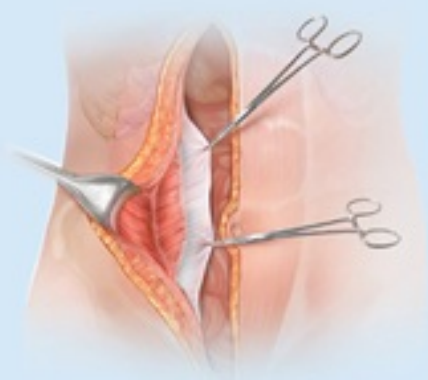


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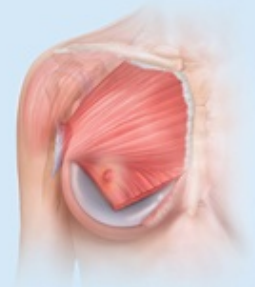
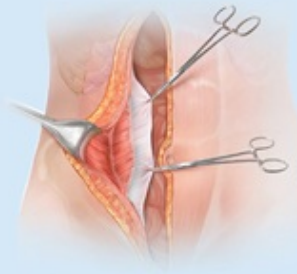
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VOLUME I

Kevin C. Chung, MD, MS

EDITOR-IN-CHIEF

Chief of Hand Surgery, Michigan Medicine
Director, University of Michigan Comprehensive Hand Center
Charles B. G. de Nancrede Professor of Surgery
Professor of Plastic Surgery and Orthopaedic Surgery
Assistant Dean for Faculty Affairs
Associate Director of Global REACH
University of Michigan Medical School
Ann Arbor, Michigan



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Executive Editor: Brian Brown

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To Chin-Yin and William.

—KCC

Dedicated to my daughter, Wells Thorne—my standard for beauty, harmony, and ethics.

—CHT

To my wonderful and patient wife, Rosa—without her support this book would not be possible, I love you. To Genoa and Giovanni—thank you for being the best kids I could ask for and completing my life. To my parents for their lifetime of support and love and being the best role models. To my great plastic surgery mentors who have inspired me, including Charlie Thorne, whom working with on this book with has been a tremendous joy.

—SS

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—JVA

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To Julie, Michael, and Nicholas. Thank you for never-ending love and support.

—JJD

To my wife, Yun-Ting, and my sons, Jordan and Kyle, for their love, patience, and understanding of me as a busy husband, father, and surgeon. And to my mother, Helen, and my father, Leyton, who taught me to never give up.

—GKL

To my teachers for giving me the background to contribute to this text and to my family for allowing me the time to do so.

—AKG

EDITOR-IN-CHIEF

Kevin C. Chung, MD, MS

Chief of Hand Surgery, Michigan Medicine
Director, University of Michigan Comprehensive Hand Center
Charles B. G. de Nancrede Professor of Surgery
Professor of Plastic Surgery and Orthopaedic Surgery
Assistant Dean for Faculty Affairs
Associate Director of Global REACH
University of Michigan Medical School
Ann Arbor, Michigan

EDITORS

FACIAL AESTHETIC

Charles H. Thorne, MD

Chairman
Department of Plastic Surgery
Lenox Hill Hospital
New York, New York

Sammy Sinno, MD

Private Practice
Chicago, Illinois

CRANIOFACIAL

John van Aalst, MD, MA, FACS, FAAP

Professor and Director
Division of Pediatric and Craniofacial Plastic Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

HEAD AND NECK RECONSTRUCTION

Babak J. Mehrara, MD

Chief, Plastic and Reconstructive Surgery Service
Member, Memorial Sloan Kettering Cancer Center
New York, New York
William G. Cahon Chair in Surgery
Professor of Surgery
Weill Cornell Medical College
New York, New York

PLASTIC SURGERY OF THE BREAST

Joseph J. Disa, MD, FACS

Vice Chair of Clinical Activities
Department of Surgery
Attending Surgeon
Memorial Sloan Kettering Cancer Center
Professor of Surgery
Weill Medical College of Cornell University
New York, New York

TRUNK RECONSTRUCTION AND BODY CONTOURING HAND SURGERY

Kevin C. Chung, MD, MS

Chief of Hand Surgery, Michigan Medicine
Director, University of Michigan Comprehensive Hand Center
Charles B. G. de Nancrede Professor of Surgery
Professor of Plastic Surgery and Orthopaedic Surgery
Assistant Dean for Faculty Affairs
Associate Director of Global REACH
University of Michigan Medical School
Ann Arbor, Michigan

LOWER LIMB RECONSTRUCTION AND AMPUTATION

Gordon K. Lee, MD, FACS

Professor of Plastic Surgery
Associate Chief of Clinical Affairs
Residency Program Director
Director of Microsurgery
Stanford University
Palo Alto, California

PEDIATRICS

Arun K. Gosain, MD

Children's Service Board Professor and Chief, Pediatric Plastic
Surgery
Anne and Robert Lurie Children's Hospital
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Contributors

Fizan Abdullah, MD, PhD

Vice-Chair, Department of Surgery
Head, Division of Pediatric Surgery
Program Director, Fellowship in Pediatric Surgery
Orvar Swenson Founders' Board Chair in Pediatric Surgery
Ann & Robert H. Lurie Children's Hospital of Chicago
Professor of Surgery
Northwestern University
Chicago, Illinois

Samer Abouzeid, MD, DDS

Lecturer
Plastic, Reconstructive and Craniofacial Surgery Department
Faculty of Medicine of the Saint Joseph University
Lecturer
Faculty of Dental Medicine of the Saint Joseph University
Attending
Plastic, Reconstructive and Craniofacial Surgery Department
Hotel Dieu de France the Saint Joseph University Hospital
Beirut, Lebanon

Ghassan S. Abu-Sittah, MBChB, FRCS(Plast)

Assistant Professor of Surgery
Head of Division of Plastic & Reconstructive Surgery
American University of Beirut Medical Center
Beirut, Lebanon

Co-Director, Conflict Medicine Program, Global Health Institute
Honorary Senior Clinical Lecturer, Queen Mary University of London
London, United Kingdom

Nicholas S. Adams, MD

Clinical Instructor
Division of Plastic Surgery
College of Human Medicine
Spectrum Health/Michigan State University
Grand Rapids, Michigan

Oluwaseun A. Adetayo, MD, FAAP, FACS

Assistant Professor of Plastic Surgery
Section Chief of Pediatric Plastic Surgery
Bernard & Millie Duker Children's Hospital
Director, Cleft-Craniofacial Center at Albany Medical Center
Albany Medical Center
Albany, New York

Joshua M. Adkinson, MD

Chief of Hand Surgery
Assistant Professor of Surgery
Division of Plastic Surgery
Indiana University School of Medicine
Indianapolis, Indiana

N. Scott Adzick, MD

Surgeon-in-Chief
Children's Hospital of Philadelphia
C. Everett Koop Endowed Chair of Pediatric Surgery
Perelman School of Medicine at the University of Pennsylvania
Philadelphia, Pennsylvania

Mouchammed Agko, MD

Assistant Professor
Section of Plastic Surgery
Department of Surgery
Medical College of Georgia at Augusta University
Augusta, Georgia

Sonya Paisley Agnew, MD

Assistant Professor
Loyola University Medical Center
Chicago, Illinois

Jamil Ahmad, MD

Director of Research and Education
The Plastic Surgery Clinic
Mississauga, Ontario, Canada
Assistant Professor
Department of Surgery
University of Toronto
Toronto, Ontario, Canada

Nicholas J. Ahn, MD

Research Fellow
Children's Hospital of Philadelphia
Center for Fetal Research
Philadelphia, Pennsylvania
Surgical Resident
Albany Medical Center
Department of Surgery
Albany, New York

Mithat Akan, MD

Professor

Department of Plastic Surgery
Istanbul Medipol University
Istanbul, Turkey

Asim Ali, MD, FRCSC

Ophthalmologist-in-Chief and Mira Godard Chair in Vision Research
Department of Ophthalmology
The Hospital for Sick Children
University of Toronto
Toronto, Ontario, Canada

Lee W. T. Alkureishi, MBChB

Clinical Assistant Professor
Plastic and Reconstructive Surgery
University of Illinois Health
Pediatric Plastic and Craniofacial Surgeon
Plastic Surgery
Shriners Hospitals for Children
Chicago, Illinois

Amir Allak, MD, MBA

Facial Plastic/Reconstructive Surgery Fellow
Division of Facial Plastic Surgery
Department of Otolaryngology—
Head and Neck Surgery
University of California, Davis
Sacramento, California

Michael Alperovich, MD, MSc

Assistant Professor of Plastic Surgery
Department of Surgery
Yale University School of Medicine
New Haven, Connecticut

Derek F. Amanatullah, MD, PhD

Assistant Professor
Orthopedic Surgery
Stanford Hospital and Clinics
Redwood City, California

Shoshana W. Ambani, MD

Plastic Surgeon
Medical Director of Plastic Surgery
Henry Ford Allegiance Hospital
Jackson, Michigan

Jugpal S. Arneja, MD, MBA, FAAP, FACS, FRCSC

Professor (Clinical), Surgery
Division of Plastic Surgery
University of British Columbia
Associate Member
Sauder School of Business
University of British Columbia
Associate Chief, Surgery
British Columbia Children's Hospital
Attending Plastic Surgeon
British Columbia Children's Hospital
Vancouver, British Columbia, Canada

Jeffrey A. Ascherman, MD

Thomas S. Zimmer Professor of Reconstructive Surgery at CUMC
Site Chief, Division of Plastic Surgery
Columbia University Medical
New York, New York

Samer Attar, MD

Associate Professor of Orthopaedic Surgery

Northwestern Medicine
Chicago, Illinois

Raffi S. Avedian, MD

Assistant Professor of Orthopaedic Surgery
Stanford University Medical Center
Department of Orthopaedic Surgery
Charlotte and George Schultz Orthopaedic Tumor Center
Palo Alto, California

Haithem M. Elhadi Babiker, MD, DMD, FAAP, FACS

Assistant Professor, University of Cincinnati Medical Center
Division of Pediatric Plastic & Craniofacial Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Fadi Bakal, MD

Plastic Surgery Department
Brussels University Hospital
Vrije Universiteit Brussel
Brussels, Belgium

Stephen B. Baker, MD, DDS

Professor and Program Director
Director, Center for Facial
Restoration
Department of Plastic Surgery
MedStar Georgetown University Hospital
Washington, District of Columbia
Medical Director, Craniofacial
Program
Inova Children's Hospital
Falls Church, Virginia

Daniel C. Baker, MD

Clinical Professor
Department of Plastic Surgery
New York University Langone Medical Center
New York, New York

Reena Bakshi, MD

Research Fellow
Department of Surgery
University of California, Los Angeles
Los Angeles, California

Scott P. Bartlett, MD

Mary Downs Endowed Chair in Craniofacial Treatment and Research
The Children's Hospital of Philadelphia
Professor of Surgery
The Perelman School of Medicine
University of Pennsylvania
Philadelphia, Pennsylvania

Lawrence S. Bass, MD, FACS

Clinical Assistant Professor of Plastic Surgery
Zucker School of Medicine at Hofstra Northwell
New York, New York

Bruce S. Bauer, MD, FACS, FAAP

Director of Pediatric Plastic Surgery
NorthShore University HealthSystem
Clinical Professor of Surgery
University of Chicago
Pritzker School of Medicine
Highland Park Hospital
Northbrook, Illinois

Joseph Baylan, MD

Resident Physician
School of Medicine
Stanford University
Palo Alto, California

Devra B. Becker, MD, FACS

Associate Professor, Department of Plastic Surgery
Chief of Plastic Surgery, UPMC Passavant
Director of Wound Healing Services, UPMC Passavant
Department of Plastic Surgery
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Maureen Beederman, MD

Resident
Section of Plastic and Reconstructive Surgery
Department of Surgery
The University of Chicago Medicine
Chicago, Illinois

Robert Beinrauh, MD

Head of Craniofacial Surgery
Plastic and Reconstructive Surgery Department
Kaiser-Permanente Hospital
Downey, California

Daniel A. Belkin, MD

Clinical Assistant Professor
Ronald O. Perelman Department of Dermatology
NYU Langone Medical Center
Associate
Laser & Skin Surgery Center

of New York
New York, New York

Bryce R. Bell, MD

Hand and Upper Extremity Surgery
Department of Orthopaedic Surgery
Texas Children's Hospital
Conroe, Texas

Michael Bellino, MD

Assistant Professor
Department of Orthopaedic Surgery
Stanford University School of Medicine
Palo Alto, California

Mihir K. Bhayani, MD, FACS

Head and Neck Surgical Oncology
NorthShore University HealthSystem
Clinical Assistant Professor
Pritzker School of Medicine
University of Chicago
Evanston, Illinois

David A. Billmire, MD

Chief of Plastic Surgery
Cincinnati Shriners Hospital
Cincinnati, Ohio

Craig Birgfeld, MD

Associate Professor
Division of Plastic Surgery
Department of Surgery
University of Washington

Seattle Children's Hospital
Harborview Medical Center
Seattle, Washington

Julius Bishop, MD

Assistant Professor and Associate Residency Director
Department of Orthopaedic Surgery
Stanford University School of
Medicine
Palo Alto, California

Nataliya Biskup, MD

Cosmetic and Reconstructive Plastic Surgeon
Plastic Surgery Center
Wichita, Kansas

Kim A. Bjorklund, MD, MEd

Director of Brachial Plexus Program
Department of Plastic, Reconstructive & Hand Surgery
Nationwide Children's Hospital
Assistant Professor
The Ohio State University College of Medicine
Columbus, Ohio

Gregory H. Borschel, MD, FAAP, FACS

Associate Professor and Research Director
Division of Plastic and Reconstructive Surgery
University of Toronto
Associate Professor
Institute of Biomaterials and Biomedical Engineering
Associate Scientist, SickKids Research Institute
The Hospital for Sick Children
Toronto, Ontario, Canada

James P. Bradley, MD

Vice Chairman, Professor, Northwell Plastic Surgery
Zucker School of Medicine
Hofstra/Northwell
Lake Success, New York

Colin M. Brady, MD

Pediatric Plastic and Craniofacial Surgeon
Children's Healthcare of Atlanta
Atlanta, Georgia

Francisco G. Bravo, MD, PhD

Clinica Gomez Bravo
Madrid, Spain

Lawrence E. Brecht, DDS

NYC Prosthodontics
New York, New York

Derek A. Bruce, MB, ChB, FAANS, FACS, FAPP

Professor of Neurosurgery & Pediatrics
Center for Neuroscience & Behavioral Medicine
Children's National Medical Center
Washington, District of Columbia

Patrick J. Buchanan, MD

Director of Hand Surgery
Plastic and Reconstructive Surgeon
Georgia Institute for Plastic Surgery
Savannah, Georgia

Charles E. Butler, MD, FACS

Professor and Chairman

Department of Plastic Surgery
The University of Texas MD Anderson Cancer Center
Houston, Texas

Michael R. Bykowski, MD, MS

Chief Resident
Department of Plastic Surgery
University of Pittsburgh
Pittsburgh, Pennsylvania

Nicole C. Cabbad, MD, MBA

Craniofacial Plastic Surgeon
Department of Plastic and Reconstructive Surgery
Nicklaus Children's Hospital
Miami, Florida

**Richard H. Caesar, MA, MB BChir,
FRCOphth**

Consultant Surgeon
Ock Street Clinic
Abingdon, England

Bariş Çakir, MD

Plastic Reconstructive and Aesthetic Surgery Specialist
Visiting Staff of American Hospital (Sisli/İstanbul)
Istanbul, Turkey

Bradley Calobrace, MD

CaloAesthetics Plastic Surgery
Center
CaloSpa
Louisville, Kentucky

Ashley A. Campbell, MD

Assistant Professor of
Ophthalmology
Wilmer Eye Institute
Johns Hopkins University School of Medicine
Baltimore, Maryland

Chris A. Campbell, MD, FACS

Associate Professor
Department of Plastic Surgery
University of Virginia
Charlottesville, Virginia

Jennifer Capla, MD

Plastic Surgeon
Private Practice
Northwell—Lenox Hill Hospital
Department of Plastic Surgery
New York, New York

Joseph Catapano, BHSc, MD

Department of Surgery, Division of Plastic and Reconstructive
Surgery
University of Toronto
Toronto, Ontario, Canada

Paul S. Cederna, MD

Chief
Section of Plastic Surgery
Michigan Medicine
Robert Oneal Professor of Plastic Surgery
Professor, Department of Biomedical Engineering
University of Michigan

Ann Arbor, Michigan

Nuri A. Celik, MD

Private Practice

Istanbul, Turkey

Neil K. Chadha, MBChB(Hons), MPHe BSc(Hons), FRCS

Associate Clinical Professor

Division of Otolaryngology-Head and Neck Surgery

University of British Columbia

Vancouver, British Columbia, Canada

Pediatric Otolaryngology Surgeon

Division of Pediatric Otolaryngology-Head and Neck Surgery

British Columbia Children's Hospital

Vancouver, British Columbia, Canada

Rawad S. Chalhoub, MD

Post Graduate Year 1

Plastic and Reconstructive Surgery

American University of Beirut Medical Center

Beirut, Lebanon

Christopher B. Chambers, MD

Associate Professor of Ophthalmology

Associate Professor of Plastic Surgery, Department of Surgery

Oculoplastic and Orbital Surgery Fellowship Director

Associate Residency Program Director

University of Washington School of Medicine

Seattle, Washington

Bernard W. Chang, MD

Chief of Plastic Surgery

Mercy Medical Center

Baltimore, Maryland

David W. Chang, MD, FACS

Chief of Plastic and Reconstructive Surgery
Director of Microsurgery Fellowship
Professor of Surgery
The University of Chicago Medicine & Biological Sciences
Chicago, Illinois

Edward I. Chang, MD, FACS

Associate Professor
Department of Plastic Reconstructive Surgery
University of Texas MD Anderson Cancer Center
Houston, Texas

Vincent A. Chavanon, MD

Chief Resident
Division of Plastic Surgery
Department of Surgery
Mount Sinai Hospital
New York, New York

Vishwanath R. Chegireddy, MD

General Surgery Resident
Department of Surgery
Houston Methodist Hospital
Houston, Texas

Hung-Chi Chen, MD, PhD, FACS

Professor of Plastic Surgery
Department of Plastic and Reconstructive Surgery
China Medical University
China Medical University Hospital International Medical Service

Center
Taichung, Taiwan

Michael J. Chen, MD

Current Orthopaedic Resident
Department of Orthopaedic Surgery
School of Medicine
Stanford University
Stanford, California

Neal C. Chen, MD

Assistant Professor
Harvard Medical School
Interim Chief
Department of Orthopaedic Surgery
Hand and Upper Extremity Service
Massachusetts General Hospital
Boston, Massachusetts

Philip Kuo-Ting Chen, MD

Director, Craniofacial Center
Taipei Medical University Hospital
Professor of Surgery
Taipei Medical University
Taipei, Taiwan

Earl Y. Cheng, MD

Division Head of Pediatric Urology
Founder's Board Chair of Pediatric Urology
Ann and Robert H. Lurie Children's Hospital of Chicago
Professor of Urology
Feinberg School of Medicine
Northwestern University

Chicago, Illinois

Ming-Huei Cheng, MD, MBA, FACS

Professor

Division of Plastic Reconstructive Microsurgery

Department of Plastic & Reconstructive Surgery

Chang Gung Memorial Hospital

Taoyuan City, Taiwan

Pierre M. Chevray, MD, PhD

Houston Methodist, Institute for Reconstructive Surgery

Associate Professor, Weill Cornell Medical College

Adjunct Associate Professor, Baylor College of Medicine

Program Director, Houston Methodist Plastic Surgery Residency

Houston, Texas

Jessica A. Ching, MD

Co-Director, Craniofacial Clinic

Assistant Professor of Plastic
Surgery

Associate Program Director of Plastic Surgery

Department of Surgery

University of Florida

Gainesville, Florida

Michael V. Chiodo, MD

Plastic Surgery Resident

Hansjörg Wyss Department of Plastic Surgery

New York University Langone Medical Center

New York, New York

Ernest S. Chiu, MD, FACS

Associate Professor of Plastic

Surgery
Director, Kimmel Hyperbaric and Advanced Wound Healing Center
NYU Langone Health
New York, New York

Gerald J. Cho, MD

Assistant Professor, Plastic Surgery
Washington University in St. Louis
Saint Louis, Missouri

Jong-Woo Choi, MD, PhD, MMM

Professor
Department of Plastic Surgery
Asian Medical Center
Seoul, South Korea

David K. Chong, MBBS, FRACS

Cleft/Craniofacial Surgeon
Department of Plastic and Maxillofacial Surgery
Royal Children's Hospital
Melbourne, Australia

Loretta Chou, MD

Professor of Orthopaedic Surgery
Stanford University
Redwood City, California

Carrie K. Chu, MD, MS

Assistant Professor
Department of Plastic Surgery
The University of Texas MD Anderson Cancer Center
Houston, Texas

Michael W. Chu, MD

Kaiser Permanente Medical Group
Department of Plastic & Reconstructive Surgery
Los Angeles, California

Kevin C. Chung, MD, MS

Chief of Hand Surgery, Michigan Medicine
Director, University of Michigan Comprehensive Hand Center
Charles B. G. de Nancrede Professor of Surgery
Professor of Plastic Surgery and Orthopaedic Surgery
Assistant Dean for Faculty Affairs
Associate Director of Global REACH
University of Michigan Medical School
Ann Arbor, Michigan

Jeffrey R. Claiborne, MD

Private Practice Plastic Surgeon
Sieveking and Claiborne Plastic Surgery
Nashville, Tennessee

Mark W. Clemens, MD, FACS

Associate Professor
Department of Plastic Surgery
MD Anderson Cancer Center
University of Texas
Houston, Texas

C. Spencer Cochran, MD

Dallas Rhinoplasty Center
Assistant Professor
Department of Plastic Surgery
Clinical Assistant Professor
Department of Otolaryngology

UT Southwestern Medical Center
Dallas, Texas

Eric Lowry Cole, MD

Director, Craniofacial and Pediatric Plastic Surgery
Assistant Professor Plastic Surgery
University of Texas Medical
Branch
League City, Texas

Patrick Colley, MD

Assistant Professor
Otolaryngology—Head and Neck Surgery
Icahn School of Medicine—Mount Sinai Hospital
New York, New York

Zachary J. Collier, MD

Division of Plastic & Reconstructive Surgery
Department of Surgery
USC Keck School of Medicine
Los Angeles, California

Brendan Collins, MD

Attending Physician and Microsurgical Fellowship Director
Mercy Medical Center
Baltimore, Maryland

Amy S. Colwell, MD, FACS

Associate Professor Harvard Medical School
Division of Plastic Surgery
Massachusetts General Hospital
Boston, Massachusetts

J. Alejandro Conejero, MD, FACS

Assistant Professor of Surgery
Division of Plastic Surgery
Albert Einstein College of Medicine
Montefiore Medical Center
Bronx, New York

Mark B. Constantian, MD, FACS

Traveling Professor, American Society for Aesthetic Plastic Surgery
Clinical Adjunct Professor of Surgery (Plastic Surgery)
University of Wisconsin
Madison, Wisconsin
Visiting Professor
Department of Plastic Surgery
University of Virginia
Charlottesville, Virginia

Julia Corcoran, MD, FACS, FAAP

Associate (Adjunct) Professor of Surgery & Medical Education
Feinberg School of Medicine
Northwestern University
Attending Surgeon
Shriners Hospital for Children
Chicago, Illinois

Sebastian Cotofana, MD, PhD

Associate Professor
Albany Medical College
Albany, New York

Clayton Crantford, MD

Private Practice
Charleston, South Carolina

Eric J. Culbertson, MD

Body and Breast Cosmetic Surgeon
The Jacobs Center for Cosmetic Surgery
Healdsburg, California

Catherine Curtin, MD

Associate Professor
Division of Plastic Surgery
Stanford University
Palo Alto, California

Daniel A. Cuzzone, MD

Craniofacial Fellow
Children's Healthcare of Atlanta
Atlanta, Georgia

Kasandra Dassoulas, MD

Richmond Aesthetic Surgery
Midlothian, Virginia

Gehaan D'Souza, MD

Editor-in-Chief
CEO Iconic Plastic Surgery
Carlsbad, California

Rollin K. Daniel, MD

Clinical Professor
Department of Plastic Surgery
University of California
Irvine Medical Center
Orange, California
Private Practice
Newport Beach, California

Lisa R. David, MD, MBA, FACS

Chairman

Department of Plastic and Reconstructive Surgery

Professor of Plastic and Reconstructive Surgery and Pediatrics

Residency Program Director

Wake Forest University Baptist Medical Center

Winston-Salem, North Carolina

Gabrielle B. Davis, MD, MS

Resident Physician

Division of Plastic & Reconstructive Surgery

Department of Surgery

Stanford, California

Erez Dayan, MD

Plastic & Reconstructive Surgery

Massachusetts General Hospital/Harvard Medical School

Boston, Massachusetts

Joseph H. Dayan, MD

Division of Plastic & Reconstructive Surgery

Memorial Sloan Kettering Cancer Center

New York, New York

Alessandro de Alarcon, MD, MPH

Associate Professor

Director, Center for Pediatric Voice Disorders

Medical Director, Complex Airway Cincinnati Children's Hospital

Medical Center

University of Cincinnati

Cincinnati, Ohio

Sahitya K. Denduluri, MD

Resident Physician
Department of Orthopaedic Surgery
Stanford University
Stanford, California

Arlen Denny, MD, FACS, FAAP

Professor
Plastic Surgery Neurosurgery Pediatrics
Medical College of Wisconsin
Director
Craniofacial Surgery Fellowship
Retired
Children's Hospital of Wisconsin
Milwaukee, Wisconsin

Rafael J. Diaz-Garcia, MD

Attending Surgeon
Medical Operations Officer
Department of Surgery
Allegheny Health Network
Clinical Assistant Professor
Department of Plastic Surgery
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania

J. Rodrigo Diaz-Siso, MD

Postdoctoral Research Fellow
Hansjörg Wyss Department of Plastic Surgery
New York University Langone
Health
New York, New York

Claire Sanger Dillingham, DO

Associate Professor
Department of Plastic and Reconstructive Surgery
Wake Forest Baptist Medical Center
Winston-Salem, North Carolina
Cone Health
Department of Plastic and Reconstructive Surgery
Greensboro, North Carolina

Robert C. Dinsmore, MD, FACS

Staff Surgeon
Medical College of Georgia at Augusta University
Chief of Plastic Surgery at Charlie Norwood VA
Associate Professor of Surgery
Section of Plastic and Reconstructive Surgery
Department of Surgery
Augusta, Georgia

Joseph J. Disa, MD, FACS

Vice Chair of Clinical Activities
Department of Surgery
Attending Surgeon
Memorial Sloan Kettering Cancer Center
Professor of Surgery
Weill Medical College of Cornell University
New York, New York

Amir H. Dorafshar, MD, FACS, FAAP

Professor (PAR), Chief and Program Director
Division of Plastic and Reconstructive Surgery
Rush University Medical Center
Chicago, Illinois

Gaby Doumit, MD, MSc, FRCSC, FACS

Assistant Professor of Surgery
Department of Plastic and Craniofacial Surgery
University of Montreal
Montreal, Canada

Anahita Dua, MD, MS, MBA

Vascular Surgery Fellow
Division of Vascular Surgery
Department of Surgery
Stanford Hospital and Clinics
Palo Alto, California

Gregory A. Dumanian, MD

Lucille and Orion Stuteville Professor of Surgery
Chief of Plastic Surgery
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

David J. Dunaway, CBE, FDSRCS, FRCS(plast)

Professor
Craniofacial Unit
Great Ormond Street Hospital for Children
London, United Kingdom

Nguyen Phan Tu Dung, MD, PhD

Chief of Rhinoplasty and Maxillofacial Department
Director of Vietnam JW Anesthetic Hospital
Ho Chi Minh City, Vietnam

Kyle R. Eberlin, MD

Assistant Professor of Surgery
Associate Director, MGH Hand Surgery Fellowship

Division of Plastic and Reconstructive Surgery
Massachusetts General Hospital
Harvard Medical School
Boston, Massachusetts

Anthony Echo, MD

Assistant Professor of Plastic Surgery, Houston Methodist Hospital
Research Institute
Assistant Professor of Plastic Surgery, Weill Cornell Medicine
Assistant Clinical Professor of Surgery, Texas A&M University
Houston, Texas

Ahmed Elsherbiny, MSc, MD

Associate Professor of Plastic
Surgery
Director of Sohag Cleft Clinic
Sohag University Hospital
Sohag, Egypt

Dino Elyassnia, MD, FACS

Marten Clinic of Plastic Surgery
San Francisco, California

Kate Elzinga, MD, FRCSC

Plastic Surgeon
Department of Surgery
University of Calgary
Calgary, Alberta, Canada

Omri Emodi, DMD

Vice Chair Department of Oral and Maxillofacial Surgery
Rambam Health Care Campus
Clinical lecture in Oral and Maxillofacial Surgery

Ruth & Bruce Rappaport Faculty of Medicine
Technion—Israel Institute of Technology
Haifa, Israel

Barry L. Eppley, MD, DMD

Clinical Professor of Plastic Surgery
Indiana University School of Medicine
IU Health Hospitals
Indianapolis, Indiana

Detlev Erdmann, MD, PhD, MHSc

Professor of Surgery
Division of Plastic, Reconstructive, Maxillofacial and Oral Surgery
Duke University Medical Center
Chief, Section of Plastic Surgery
Durham VA Medical Center
Section Chief, Plastic & Reconstructive Surgery
Durham Veterans Administration Medical Center
Durham, North Carolina

Cherry L. Estilo, DMD

Attending Dentist
Dental Service
Department of Surgery
Memorial Sloan Kettering Cancer Center
Clinical Member
Memorial Sloan Kettering Cancer Center
Associate Professor of Surgery
Weill Cornell Medical College
Associate Attending Dentist
New York Presbyterian Weill Cornell Medical Center
New York, New York

Adel Y. Fattah, PhD, FRCS(plast)

Consultant Plastic Surgeon
Director, Facial Nerve Programme
Clinical Director
Regional Paediatric Burns and Plastic Surgery Service
Alder Hey Children's NHS Foundation Trust
Liverpool, United Kingdom

John M. Felder, MD

Assistant Professor of Surgery
Division of Plastic Surgery
Washington University in St. Louis
St. Louis, Missouri

Mark Felton, BSc, MBChB, MSc, MD, FRCS(Eng)

Consultant Paediatric Otolaryngologist
Evelina London Children's Hospital
Guy's and St. Thomas' NHS Foundation Trust
London, United Kingdom

John G. Fernandez, MD, FACS

Director of Plastic and Reconstructive Surgery
Cancer Treatment Centers of America
Philadelphia, Pennsylvania

Julius W. Few, MD

Director, The Few Institute for Aesthetic Plastic Surgery
Clinical Professor, Division of Plastic Surgery
University of Chicago Pritzker School of Medicine
Health Science Clinician
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Michael W. Findlay, MBBS, PhD, FRACS, FACS

Program Director—Plastic Surgery
The Peter MacCallum Cancer Centre
Plastic, Reconstructive and Hand Surgeon
The Canberra Hospital
Surgical Lead
Plastic, Reconstructive and Hand Surgery
Australasian Clinical Trials Network
Director
Program for Molecular and Cellular Innovation in Surgery
Senior Lecturer
The University of Melbourne Department of Surgery
Royal Melbourne Hospital
Melbourne, Australia

David Charles A. Fisher, MD

Clinical Assistant Professor of Surgery
University of North Carolina School of Medicine
Assistant Professor of Surgery
Division of Plastic Surgery
Department of Surgery
Carolinas Medical Center
Charlotte, North Carolina

Sean M. Fisher, MD

Plastic and Reconstructive Surgery Resident
University of Washington
Seattle, Washington

Roberto L. Flores, MD

Joseph G. McCarthy Associate Professor of Reconstructive Plastic
Surgery
Director of Cleft Lip and Palate

Hansjorg Wyss Department of Plastic Surgery
NYU Langone Health
New York, New York

Christopher R. Forrest, MD, MSc, FRCSC, FACS

Professor and Chair
Division of Plastic and Reconstructive Surgery
Department of Surgery
University of Toronto
Chief, Division of Plastic and Reconstructive Surgery
Medical Director, The Centre for Craniofacial Care and Research
The Hospital for Sick Children
Chair, Division of Plastic and Reconstructive Surgery
Department of Surgery
Toronto, Ontario, Canada

Jordan D. Frey, MD

Resident
Hansjörg Wyss Department of Plastic Surgery
NYU Langone Health
New York, New York

John R. Fowler, MD

Assistant Dean for Medical Student Research
Assistant Professor, Department of Orthopaedics
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania

Brad M. Gandolfi, MD

Craniofacial Plastic and Reconstructive Surgeon
Paramus, New Jersey

Benjamin C. Garden, MD

Department of Dermatology
University of Illinois at Chicago
Chicago, Illinois

Jerome M. Garden, MD

Professor of Clinical Dermatology
Northwestern University Feinberg School of Medicine
Chicago, Illinois

Evan S. Garfein, MD, FACS

Associate Professor of Surgery
Departments of Surgery and Otorhinolaryngology
Albert Einstein College of Medicine
Chief
Division of Plastic Surgery
Montefiore Medical Center
Bronx, New York

Ravi Garg, MD

Chief Resident
Plastic and Reconstructive Surgery
University of Wisconsin
Madison, Wisconsin

Catharine B. Garland, MD

Director, Cleft and Craniofacial Anomalies Clinic
American Family Children's Hospital
Assistant Professor of Surgery
Division of Plastic and Reconstructive Surgery
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin

Katherine M. Gast, MD, MS

Assistant Professor of Surgery
Plastic and Reconstructive Surgery
Medical Director, Comprehensive Gender Services Program
University of Wisconsin
Madison, Wisconsin

Brian R. Gastman, MD

Professor
Cleveland Clinic Lerner College of Medicine
Staff in Plastic Surgery/Taussig Cancer Center
Melanoma-Soft Tissue Cancer-Head and Neck Cancer
Cleveland Clinic
Cleveland, Ohio

Finny George, MD

Long Island Plastic Surgical Group
Garden City, New York

Patrick A. Gerety, MD

Assistant Professor of Surgery
Division of Plastic Surgery
Indiana University and Riley Hospital for Children
Indianapolis, Indiana

Roy G. Geronemus, MD

Director, Laser & Skin Surgery Center of New York
Clinical Professor of Dermatology
New York University Medical
Center
Attending Surgeon
Department of Plastic Surgery
New York Eye and Ear Infirmary
Mt Sinai School of Medicine

New York, New York

David Gerth, MD

Plastic Surgery

MOSA Surgery

Miami Beach, Florida

Paul A. Ghareeb, MD

Fellow

Division of Plastic and Reconstructive Surgery

Emory University School of Medicine

Atlanta, Georgia

Ashkan Ghavami, MD

Assistant Clinical Professor

David Geffen School of Medicine

UCLA

Private Practice

Beverly Hills, California

Amir M. Ghaznavi, MD

Staff, Department of Plastic & Reconstructive Surgery

Cleveland Clinic Florida

Weston, Florida

Cerrene N. Giordano, MD

Instructor, Micrographic Surgery and Dermatologic Oncology

Mount Sinai Icahn School of Medicine

New York, New York

Jesse Goldstein, MD, FAAP, FACS

Assistant Professor

Department of Plastic Surgery

Children's Hospital of Pittsburgh
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Christopher B. Gordon, MD, FACS, FAAP

Professor
Division of Plastic Surgery
Department of Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Arun K. Gosain, MD

Children's Service Board Professor and Chief, Pediatric Plastic
Surgery
Anne and Robert Lurie Children's Hospital
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Jeremy Goss, MD

Research Fellow
Department of Plastic and Oral
Surgery
Boston Children's Hospital
Harvard Medical School
Boston, Massachusetts

Lawrence J. Gottlieb, MD, FACS

Professor of Surgery
Director of Burn & Complex Wound Center
Section of Plastic and Reconstructive Surgery
The University of Chicago Medicine & Biological Sciences
Chicago, Illinois

Alexander Govshievich, MDCM

Senior Resident
Plastic and Reconstructive Surgery
University of Montreal
Montreal, Canada

Samita Sally Goyal, MD

Medical College of Wisconsin
Milwaukee, Wisconsin

**Frank R. Graewe, MBChB,
MMed, FCS**

Extraordinary Associate Professor
Division of Plastic Surgery
Stellenbosch University
Stellenbosch, South Africa

John H. Grant III, MD

James C. Lee Chair in Pediatric Plastic Surgery
Director UAB Cleft and Craniofacial Center
Chief of Pediatric Plastic Surgery
Professor of Surgery Division of Plastic Surgery
Children's of Alabama
University of Alabama, Birmingham
Birmingham, Alabama

Arin K. Greene, MD, MMSc

Boston Children's Hospital
Department of Plastic and Oral
Surgery
Professor of Surgery
Harvard Medical School
Boston, Massachusetts

Jacob Nathaniel Grow, MD

Integrated Plastic Surgery Resident
University of Kansas Medical
Center
Kansas City, Missouri

**Lorelei Grunwaldt, MD, FACS,
FAAP**

Associate Professor of Plastic Surgery
Children's Hospital of Pittsburgh
Pittsburgh, Pennsylvania

Joseph Gruss, MD, FRCS

Marlys C. Larson Professor and Chair in Craniofacial Surgery
Professor
Division of Plastic Surgery
Department of Surgery
Attending Plastic Craniofacial Surgery
University of Washington
Seattle, Washington

Pierre Guerreschi, MD, PhD

Plastic Reconstructive and Aesthetic Surgery
University Hospital of Lille
Chief of Competence
Center for Clefts and Craniofacial Malformations
Lille, France

Deepak M. Gupta, MD

Clinical Assistant Professor of Plastic Surgery
Santa Clara Valley Medical Center and Stanford University School of
Medicine
San Jose, California

Bahman Guyuron, MD, FACS

Editor-In-Chief, Aesthetic Plastic Surgery Journal
Emeritus Professor, Department of Plastic Surgery
Case Western Reserve University School of Medicine
Cleveland, Ohio

Larissa Habib, MD

Clinical Fellow in Ophthalmic Plastic and Reconstructive Surgery
Department of Ophthalmology
Harvard Medical School
Massachusetts Eye and Ear Infirmary
Boston, Massachusetts

Nicholas Haddock, MD

Associate Professor
Department of Plastic Surgery
University of Texas Southwestern
Dallas, Texas

Martin Halle, MD, PhD

Karolinska Institutet
Department of Reconstructive Plastic Surgery
Karolinska University Hospital
Stockholm, Sweden

Eric G. Halvorson, MD

Halvorson Plastic Surgery
Asheville, North Carolina

Moustapha Hamdi, MD, PhD

Professor and Chairman of Plastic Surgery Department
Brussels University Hospital—Vrij Universiteit Brussel
Brussels, Belgium

Dennis C. Hammond, MD

Clinical Assistant Professor
Department of Surgery
Michigan State University College of Human Medicine
East Lansing, Michigan
Associate Program Director
Plastic and Reconstructive Surgery
Grand Rapids Medical Education Partners
Private Practice
Partners in Plastic Surgery of West Michigan
Grand Rapids, Michigan

Jeffrey A. Hammoudeh, MD, DDS

Associate Professor of Surgery
University of Southern California
Associate Professor
Division of Plastic and Maxillofacial Surgery
Department of Surgery
Children's Hospital Los Angeles
Los Angeles, California

Scott L. Hansen, MD

Associate Professor of Surgery
Division of Plastic and Reconstructive Surgery
University of California, San Francisco
Chief, Hand and Microvascular Surgery
University of California, San Francisco
Chief, Plastic and Reconstructive Surgery
Zuckerberg San Francisco General Hospital
San Francisco, California

Matthew M. Hanasono, MD

Professor and Fellowship Program Director

Department of Plastic Surgery
The University of Texas MD Anderson Cancer Center
Houston, Texas

Jamie C. Harris, MD

General Surgery Resident
Rush University Medical Center
Chicago, Illinois

Raymond J. Harshbarger, MD

Chief of Plastic Surgery
Dell Children's Medical Center
Associate Professor of Surgery
Dell Medical School
UT Austin
Austin, Texas

Ahmed M. Hashem, MD

Professor of Plastic Surgery
Division of Plastic Surgery
Department of General Surgery
Kasr Al-Ainy, Faculty of Medicine
Cairo University
Cairo, Egypt

Mahmoud Hassouba, MD

Craniofacial and Pediatric Plastic Surgery Fellow
Plastic Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Robert J. Havlik, MD

Chairman and George Korkos Professor

Department of Plastic Surgery
Medical College of Wisconsin
Milwaukee, Wisconsin

Alexes Hazen, MD, FACS

Associate Professor
NYU Langone Health
New York, New York

Rachel Hein, MD

Resident
Department of Plastic Surgery
Duke University Medical Center
Durham, North Carolina

Peter Henderson, MD, MBA

Assistant Professor of Surgery
Division of Plastic and Reconstructive Surgery
Icahn School of Medicine at Mount Sinai
New York, New York

Gregory G. Heuer, MD, PhD

Assistant Professor of Neurosurgery
Department of Neurosurgery
University of Pennsylvania
Division of Neurosurgery
Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

David A. Hidalgo, MD

Clinical Professor of Surgery
Weill-Cornell Medical College
New York-Presbyterian Hospital

New York, New York

Matthew A. Hiersche, MD

Division of Plastic Surgery
Valley Children's Hospital
Madera, California

David L. Hirsch, MD, DDS, FACS

Chief, Oral-Maxillofacial Surgery
Department of Otolaryngology—Head & Neck Surgery
Lenox Hill Hospital
New York, New York

Michael C. Holland, MD

Resident Physician
Division of Plastic and Reconstructive Surgery
University of California, San Francisco
San Francisco, California

Scott T. Hollenbeck, MD, FACS

Associate Professor, Plastic and Reconstructive Surgery
Director of Microsurgery Training
Medical Student and Physician Assistant Clerkship Director – Plastic
Surgery
Duke University Medical Center
Durham, North Carolina

Richard A. Hopper, MD, MS

Marlys C. Larson Chair of Pediatric Craniofacial Surgery
Professor, Division of Plastic Surgery
University of Washington
Chief, Division of Craniofacial and Plastic Surgery
Surgical Director, Craniofacial Center

Seattle Children's Hospital
Seattle, Washington

Jean-Louis Horn, MD, PhD

Professor, Anesthesiology, Regional Anesthesia and Acute Pain
Medicine
Stanford University
Stanford, California

Patrick Horrigan, MD

Assistant Professor, University of Minnesota
Department of Orthopaedic Surgery
Regions Hospital
Saint Paul, Minnesota

Michael A. Howard, MD

Clinical Associate Professor of Surgery
Section of Plastic Surgery
Pritzker School of Medicine
University of Chicago
Northbrook, Illinois

Jung-Ju Huang, MD

Associate Professor
Plastic and Reconstructive Surgery
Chang Gung Memorial Hospital
Chang Gung University
Linkou, Taiwan

James I. Huddleston, III, MD

Associate Professor of Orthopaedic Surgery
Adult Reconstruction Service Chief
Department of Orthopaedic Surgery

Stanford University Medical Center
Stanford, California

Thomas B. Hughes, MD

Clinical Associate Professor of Orthopaedic Surgery
Orthopaedic Specialists, UPMC
School of Medicine
University of Pittsburgh
Pittsburgh, Pennsylvania

C. Scott Hultman, MD, MBA, FACS

Director of Johns Hopkins Burn
Center
Professor of Plastic Surgery (PAR)
Johns Hopkins University School of Medicine
Vice Chair for Strategic Development
Department of Plastic and Reconstructive Surgery
Vice President of Academic Affairs
American Society of Plastic Surgeons
Member, ACGME Review Committee for Plastic Surgery
Associate Editor
Annals of Plastic Surgery
Baltimore, Maryland

John Hulsen, MD

Clinical Fellow, Aesthetic and Reconstructive Breast Surgery
Division of Plastic and Reconstructive Surgery
Massachusetts General Hospital/Harvard Medical School
Boston, Massachusetts

Kenneth Hunt, MD

Associate Professor and Chief, Foot and Ankle Surgery
Department of Orthopaedic Surgery

School of Medicine
University of Colorado
Aurora, Colorado

Dennis J. Hurwitz, BS, MD

Clinical Professor of Plastic Surgery
Plastic Surgery
University of Pittsburgh Medical
Center
Attending Plastic Surgeon UPMC Magee-Womens Hospital
Surgery
University of Pittsburgh Medical
Center
Pittsburgh, Pennsylvania

Amir Inbal, MD

Section of Plastic and Reconstructive Surgery
Department of Surgery
University of Chicago Medical
Center
Chicago, Illinois

Matthew L. Iorio, MD

Associate Professor
Co-Director of Hand Surgery, & Extremity Microsurgery
Associate Program Director
Division of Plastic Surgery
University of Colorado Hospital
Aurora, Colorado

Kathryn V. Isaac, MD, FRCSC

Clinical Fellow
Department of Plastic and Oral

Surgery
Boston Children's Hospital
Boston, Massachusetts

Clyde H. Ishii, MD

Immediate Past President, American Society for Aesthetic Plastic
Surgery
Assistant Clinical Professor of Surgery, John Burns School of
Medicine
University of Hawaii
Chief of Plastic Surgery, Shriners
Hospital
Honolulu, Hawaii

Sarah M. Jacobs, MD, Med

Assistant Professor
Department of Ophthalmology
University of Alabama
Ophthalmic Plastic and Reconstructive Surgeon
Department of Ophthalmology
Callahan Eye Hospital
Birmingham, Alabama

Deborah L. Jacobson, MD

Fellow of Pediatric Urology
Department of Urology, Northwestern University
Division of Pediatric Urology, Lurie Children's Hospital
Chicago, Illinois

Adam Jacoby, MD

NYU Langone Health
New York, New York

Jeffrey E. Janis, MD, FACS

Professor of Plastic Surgery, Neurosurgery, Neurology,
and Surgery
Chief of Plastic Surgery
University Hospitals
Ohio State University Wexner Medical Center
Columbus, Ohio

Reza Jarrahy, MD, FACS, FAAP

Associate Clinical Professor
Division of Plastic and Reconstructive Surgery
Department of Pediatrics
UCLA Medical Center
Los Angeles, California

**Noor ul Owase Jeelani, MBA, MPhil (Medical Law), FRCS
(Neuro.Surg.)**

Head of Clinical Services—Neurosurgery
Consultant Paediatric Neurosurgeon
Great Ormond Street Hospital
London, United Kingdom

Elizabeth B. Jelks, MD

Adjunct Staff
Department of Plastic Surgery
Lenox Hill Hospital
New York, New York

Glenn W. Jelks, MD, FACS

Associate Professor Hansjorg Wyss Department of Plastic Surgery
Associate Professor Department of Ophthalmology
New York University School of Medicine
New York, New York

John N. Jensen, MD

Associate Professor
Department of Plastic Surgery
Medical College of Wisconsin
Milwaukee, Wisconsin

Woo Shik Jeong, MD

Clinical Assistant Professor
Department of Plastic Surgery
Asan Medical Center
University of Ulsan College of Medicine
Seoul, South Korea

Peter Johannet, MD

Chief of Plastic Surgery
Veterans Affairs Palo Alto
Palo Alto, California
Associate Clinical Professor of Plastic & Reconstructive Surgery
Division of Plastic & Reconstructive Surgery
Stanford University
Stanford, California

Dana Johns, MD

Assistant Professor
Division of Plastic and Reconstructive Surgery
University of Utah Hospital
Salt Lake City, Utah

Yumiko Kadota, BSc, MBBS

Surgical Assistant
Private Practice
Chatswood, New South Wales,
Australia

George N. Kamel, MD

Albert Einstein College of Medicine
Montefiore Medical Center
Division of Plastic Surgery
Department of Surgery
Bronx, New York

Sahil K. Kapur, MD

Assistant Professor
Department of Plastic Surgery
The University of Texas MD Anderson Cancer Center
Houston, Texas

Yvonne L. Karanas, MD

Chief of Plastic Surgery and Director, Burn Center
Santa Clara Valley Medical Center
Associate Clinical Professor
School of Medicine
Stanford University
San Jose, California

Nolan Karp, MD

Professor of Plastic Surgery
New York University School of Medicine
New York, New York

Robert A. Kaufmann, MD

Associate Professor, Orthopaedics
University of Pittsburgh
Pittsburgh, Pennsylvania

Jeffrey M. Kenkel, MD, FACS

Professor and Chairman

Betty and Warren Woodward

Chair in Plastic and Reconstructive Surgery
Director, Clinical Center for Cosmetic Laser Treatment
Department of Plastic Surgery
Dallas, Texas

Ibrahim Khansa, MD

Division of Plastic and Maxillofacial Surgery
Children's Hospital Los Angeles
Los Angeles, California

Matthew S. Kilgo, MD

Plastic Surgeon
Long Island Plastic Surgical Group
Garden City, New York

**Hana Farhang Khoei, MD, MSc,
FRCSC**

Adjunct Professor
Department of Surgery
Schulich School of Medicine & Dentistry
Western University
London, Ontario, Canada
Plastic, Reconstructive, and Aesthetic Surgeon
Department of Surgery
Windsor Regional Hospital
Windsor, Ontario, Canada

Rohit Khosla, MD

Assistant Professor of Plastic Surgery
Division of Plastic Surgery
Stanford University Medical Center
Palo Alto, California

Jeff J. Kim, MD

Resident Physician, PGY6
Section of Plastic and Reconstructive Surgery
Department of Surgery
The University of Chicago Medical Center
Chicago, Illinois

So Young Kim, MD, PhD

Assistant Professor
Department of Plastic and Reconstructive Surgery
Inje University Sanggye Paik
Hospital
Inje University School of Medicine
Seoul, South Korea

Gabriel M. Kind, M.D.

Attending Staff
Division of Microsurgery
Department of Plastic Surgery
California-Pacific Medical Center
Associate Clinical Professor
Division of Plastic and Reconstructive Surgery
Department of Surgery
University of California—San
Francisco
San Francisco, California
Clinical Instructor
Department of Surgery (Plastic & Reconstructive Surgery)
Stanford School of Medicine
Stanford University Medical Center
Palo Alto, California

Richard E. Kirschner, MD

Robert F. and Edgar T. Wolfe Foundation Endowed Chair in Plastic
and Reconstructive Surgery
Chief, Section of Plastic and Reconstructive Surgery
Nationwide Children's Hospital
Professor of Surgery and Pediatrics
Senior Vice Chair, Department of Plastic Surgery
The Ohio State University College of Medicine
Columbus, Ohio

Michael J. A. Klebuc, MD

Associate Clinical Professor of Plastic and Neurosurgery
Weill Medical College
Cornell University
Director Center for Facial Reanimation and Functional Restoration
Houston Methodist Hospital
Houston, Texas

Grant M. Kleiber, MD

Assistant Professor
Department of Plastic Surgery
MedStar Georgetown University Hospital
Washington, District of Columbia

Kristen Klement, MD

Craniofacial Fellow
Department of Plastic Surgery
Medical College of Wisconsin
Milwaukee, Wisconsin

Jennifer A. Klok, MD, MSc

Associate Staff
Division of Plastic Surgery
Department of Surgery

Peterborough Regional Health
Centre
Peterborough, Ontario, Canada

Ulrich Kneser, MD

Professor of Plastic and Hand
Surgery
University of Heidelberg Medical School
Director, Department of Hand, Plastic and Reconstructive Surgery,
Burn Unit
BG Trauma Center Ludwigshafen
Ludwigshafen, Germany

Jason H. Ko, MD

Associate Professor
Division of Plastic and Reconstructive Surgery
Department of Orthopedic Surgery
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Petro Konofaos, MD, PhD

Assistant Professor of Plastic Surgery and Neurology, Director of
Microsurgery and Research
Department of Plastic Surgery
University of Tennessee Health Science Center
Memphis, Tennessee

Bill Kortesis, MD, FACS

Co-Owner and Partner
Hunstad/Kortesis/Bharti Cosmetic Surgery
Huntersville, North Carolina

Aaron M. Kosins, MD

Clinical Assistant Professor
Department of Plastic Surgery
University of California, Irvine Medical Center
Orange, California
Private Practice
Newport Beach, California

Jeffrey H. Kozlow, MD, MS

Associate Professor (Clinical Track)
Section of Plastic Surgery
University of Michigan
Ann Arbor, Michigan

Emily Krauss, MD, MSc, FRCSC

Clinical Instructor
University of British Columbia and the University of Victoria
Victoria, British Columbia, Canada

Thomas Kremer, MD

Professor of Plastic and Aesthetic Surgery, Hand Surgeon
Department of Plastic and Hand Surgery
Burn Center
Leipzig, Germany

Deepak G. Krishnan, DDS, FACS

Associate Professor of Surgery & Residency Program Director
Oral & Maxillofacial Surgery
University of Cincinnati Medical Center
Cincinnati, Ohio

Edward W. Kubek, MD

The Carolinas Cleft and Craniofacial Clinic at David Matthews Plastic

Surgery
Charlotte, North Carolina

Anand R. Kumar, MD, FACS, FAAP

Chairman, Department of Plastic and Reconstructive Surgery
Residency Program Director, Department of Plastic and
Reconstructive Surgery
Director, Cleft and Craniofacial Center, Vascular Anomalies Center
Division Chief, Pediatric Plastic and Craniomaxillofacial Surgery
Dewayne Greenwood Richey II Endowed Professor of Plastic and
Reconstructive Surgery and Pediatrics
Department of Plastic and Reconstructive Surgery
Case Western Reserve University School of Medicine
Cleveland, Ohio

Theodore A. Kung, MD

Assistant Professor of Surgery
Section of Plastic and Reconstructive Surgery
University of Michigan
Michigan Medicine
Ann Arbor, Michigan

T. Jonathan Kurkjian, MD

Clinical Assistant Professor
Department of Plastic Surgery
University of Texas Southwestern Medical Center
Dallas, Texas

William M. Kuzon, Jr., MD, PhD

Reed O. Dingman Collegiate Professor of Plastic Surgery
Section of Plastic Surgery
University of Michigan
Chief of Surgery

VA Ann Arbor Healthcare
Ann Arbor, Michigan

Daniel Labbé, MD

Plastic Reconstructive and Aesthetic Surgery
Private Hospital Saint Martin
Caen, France

Brian I. Labow, MD, FACS, FAAP

Associate Professor of Surgery
Harvard Medical School
Boston Children's Hospital
Boston, Massachusetts

Nicholas Lahar, MD

Sherman Oaks, California

Val Lambros, MD

Clinical Professor of Plastic
Surgery
University of California, Irvine
Irvine, California

Brock Lanier, MD

Clinical Instructor in Microsurgery
Division of Plastic and Reconstructive Surgery
Stanford University
Stanford, California

David L. Larson, MD

Professor Emeritus
Department of Plastic Surgery
Medical College of Wisconsin

Milwaukee, Wisconsin
Accreditation Field Representative
Accreditation Council for Graduate Medical Education
Chicago, Illinois

Kedar S. Lavingia, MD

Fellow
Division of Vascular Surgery
Stanford University
Menlo Park, California

Amy Lee, MD, FAANS

Attending Pediatric Neurosurgery
Associate Professor, University of Washington
Associate Residency Program
Director
Seattle Children's Hospital
Seattle, Washington

Gordon K. Lee, MD, FACS

Professor of Plastic Surgery
Associate Chief of Clinical Affairs
Residency Program Director
Director of Microsurgery
Stanford University
Palo Alto, California

Jason T. Lee, MD

Professor of Vascular Surgery
Director of Endovascular Surgery
Program Director, Vascular Surgery Residency/Fellowship
Stanford University Medical Center
Stanford, California

Johnson C. Lee, MD

Private Practice
Beverly Hills, California

Michael R. Lee, MD, FACS

Assistant Professor
Department of Plastic Surgery
University of Texas Southwestern
Dallas, Texas

Jean-Francois Lefaivre, MD

Clinical Associate Professor of Surgery
University of North Carolina School of Medicine
Associate Professor of Surgery
Carolinas Medical Center
Division of Plastic Surgery
Department of Surgery
Charlotte, North Carolina

Amber R. Leis, MD

Assistant Clinical Professor
Director of Hand Surgery
Assistant Program Director
University of California—Irvine
Orange, California

Benjamin T. Lemelman, MD

Section of Plastic Surgery
Department of Surgery
University of Chicago Medical Center
Chicago, Illinois

L. Scott Levin, MD, FACS

Paul B. Magnuson Professor of Bone and Joint Surgery
Chairman, Department of Orthopaedic Surgery
Professor of Surgery
Division of Plastic Surgery
University of Pennsylvania
Philadelphia, Pennsylvania

Jamie P. Levine, MD

Associate Professor of Plastic Surgery
Hansjörg Wyss Department of Plastic Surgery
Chief of Microsurgery
Microsurgery Fellowship Director
NYU Langone Medical Center
New York, New York

Steven M. Levine, MD

Aesthetic and Reconstructive Plastic Surgeon
Private Practice
New York, New York

Sean S. Li, MD

Resident
Division of Plastic and Reconstructive Surgery
University of California, San Diego
San Diego, California

Eric Yu Kit Li, MD

Private Practice
Plastic and Reconstructive Surgery Associates
San Jose, California

James Y. Liao, MD, FACS

Associate Professor

Division Plastic Surgery
University of Kentucky
Lexington, Kentucky

John R. Lien, MD

Assistant Professor
Department of Orthopaedic Surgery and Section of Plastic Surgery
University of Michigan Health
System
Ann Arbor, Michigan

Shelby R. Lies, MD

Assistant Professor
Department of Plastic
Surgery
University of Texas Southwestern
Medical Center
Dallas, Texas

Jan Lilja, MD, PhD, DDS

Associate Professor
Department of Plastic Surgery
Sahlgrenska University Hospital
Gothenburg, Sweden

Alexander Y. Lin, MD, FACS

Alan A. and Edith L. Wolff Endowed Chair in Craniofacial,
Maxillofacial, and Pediatric Plastic Surgery
Associate Professor of Surgery and Orthodontics
Division of Plastic Surgery
Saint Louis University School of Medicine
Director, St. Louis Cleft-Craniofacial Center
Section Chief of Pediatric Plastic Surgery

SSM Health Cardinal Glennon Children's Hospital at SLU
St. Louis, Missouri

Angelo B. Lipira, MD, MA

Assistant Professor of Plastic and Reconstructive Surgery
Oregon Health & Science University
Portland, Oregon

Richard D. Lisman, MD, FACS

Professor
Department of Ophthalmology
New York University School of Medicine
Director of Ophthalmic Plastic Surgery—Hans Wyss
Department of Plastic Surgery
NYU Medical Center
Manhattan Eye and Ear Hospital
New York, New York

Xiangxia Liu, MD, PhD

Associate Professor and Associate
Chief
Division of Plastic Surgery
First Affiliated Hospital
Sun Yat-sen University
Guangzhou, Guangdong, China

Yuen-Jong Liu, MD

Plastic and Hand Surgeon
Aesthetic Surgery Center
Darien, Connecticut

Christopher C. Lo, MD

Fellow

Division of Orbital and Ophthalmic Plastic Surgery
Stein and Doheny Eye Institutes
University of California, Los Angeles
Los Angeles, California

Joseph Lopez, MD, MBA

Plastic Surgery Resident
Department of Plastic & Reconstructive Surgery
Johns Hopkins Hospital
Baltimore, Maryland

Z. Paul Lorenc, MD, FACS

Lorenc Aesthetic Plastic Surgery
Center
Department of Plastic Surgery
Lenox Hill Hospital
New York, New York

H. Peter Lorenz, MD

Chief of Pediatric Plastic
Surgery
Stanford Children's Health
Director, Craniofacial Surgery
Fellowship
Professor of Surgery (Plastic and Reconstructive)
Department of Surgery
Stanford University School
of Medicine
Palo Alto, California

Joseph E. Losee, MD, FACS, FAAP

Dr. Ross H. Musgrave Endowed Chair in Pediatric Plastic Surgery
Associate Dean for Faculty Affairs

University of Pittsburgh School of Medicine
Professor and Executive
Vice Chair
Department of Plastic Surgery
Division Chief
Pediatric Plastic Surgery
Children's Hospital of Pittsburgh of UPMC
Pittsburgh, Pennsylvania

Albert Losken, MD, FACS

William G. Hamm Professor of Plastic Surgery, Program Director
Emory Division of Plastic and Reconstructive Surgery
Atlanta, Georgia

Ryan P. Ter Louw, MD

Plastic & Reconstructive Surgeon
Muskegon Surgical Associates
Muskegon, Michigan

David W. Lowenberg, MD

Clinical Professor
Department of Orthopaedic
Surgery
School of Medicine
Stanford University
Palo Alto, California

Andrew Lyons, MD

Clinical Instructor and Fellow
Regional Anesthesia Division
Department of Anesthesiology, Perioperative and Pain
Medicine
Stanford University Medical

Center
Palo Alto, California

Michael Lypka, MD, DMD, FACS, FAAP, FRCD(C)

Associate Professor of Surgery
School of Medicine
University of Missouri—Kansas City
Adjunct Associate Professor
School of Dentistry
University of Missouri—Kansas City
Division of Orthodontics Attending Physician
Children's Mercy Hospital
Division of Plastic and Craniofacial Surgery
Kansas City, Missouri

Jacques A. Machol IV, MD

Plastic, Hand, and Microsurgery
Department of Plastic Surgery
Southern California Permanente Medical Group
West Los Angeles & Los Angeles Medical Centers
Clinical Assistant Professor
Division of Plastic Surgery
University of Southern California
Los Angeles, California

Sarah Madison, MD

Anesthesiologist
Veterans Affairs Long Beach Healthcare System
Long Beach, California

Mary Claire Manske, MD

Pediatric Hand and Upper Extremity Surgery
Department of Orthopaedic Surgery

Shriners Hospital for Children Northern California
University of California
Davis Sacramento, California

Jeffrey R. Marcus, MD, FAAP, FACS

Professor and Chief
Director, Duke Cleft and Craniofacial Center
Division of Plastic, Reconstructive, Maxillofacial and Oral Surgery
Duke University
Durham, North Carolina

Brian P. Marr, MD

Director Ophthalmic Oncology Service
Professor
Columbia University College of Physicians and Surgeons
New York-Presbyterian Hospital/Columbia University Medical Center
Department of Ophthalmology
Edward S. Harkness Eye Institute
Columbia University Medical Center
Department of Oncology
Herbert Irving Comprehensive Cancer Center
New York, New York

Andre P. Marshall, MD, MPH

Plastic Surgeon
Aesthetic Plastic Surgical Institute
Laguna Beach, California

Timothy Marten, MD, FACS

Marten Clinic of Plastic Surgery
San Francisco, California

Mark C. Martin, MD, DMD, FRCSC

Professor of Plastic Surgery
Associate Program Director
Department of Plastic Surgery
Loma Linda University Medical Center
Loma Linda, California

Mohamad Masoumy, MD, MS

Resident
Section of Plastic and Reconstructive Surgery
Department of Surgery
Medical College of Georgia
Augusta University
Augusta, Georgia

Hani Matloub, MD

Professor, Department of Plastic Surgery
Program Director, Hand Surgery Fellowship
Department of Plastic Surgery
Medical College of Wisconsin
Milwaukee, Wisconsin

Alan Matarasso, MD, FACS

Clinical Professor of Surgery
Hofstra University/Northwell School of Medicine
President-Elect
American Society of Plastic Surgeons, Executive Committee & Board
of Directors
Past President, the Rhinoplasty Society & Chair Board of Trustees, &
2016-2017 Traveling Professor
Past President, New York Regional Society of Plastic Surgeons &
Chair Board of Trustees

Evan Matros, MD, MMSc, MPH

Associate Member
Memorial Sloan Kettering Cancer Center
Associate Professor
Weill Cornell Medical College
New York, New York

David Matthews, MD

The Carolinas Cleft and Craniofacial Clinic at David Matthews Plastic
Surgery
Charlotte, North Carolina

Chet Mays, MD

Private Practice
CaloAesthetics Plastic Surgery Center
Louisville, Kentucky

Graeme E. McFarland, MD

Assistant Professor
Division of Vascular Surgery and Endovascular Therapy
Department of Surgery
University of Alabama at Birmingham
Birmingham, Alabama

Colleen McCarthy, MD, MSc, FRCSC

Associate Attending Surgeon
Department of Surgery
Memorial Sloan Kettering Cancer Center
New York, New York

Jennifer L. McGrath, MD

Division of Plastic and Reconstructive Surgery
Feinberg School of Medicine
Northwestern University

Ann and Robert H. Lurie Children's Hospital of Chicago
Chicago, Illinois

Kibwei A. McKinney, MD

Assistant Professor
Department of Otolaryngology—Head and Neck Surgery
University of Oklahoma Health Sciences Center
Oklahoma City, Oklahoma

McKay Mckinnon, MD

Attending Plastic Surgeon
Ann and Robert Lurie Children's Hospital
Chicago, Illinois

Babak J. Mehrara, MD

Chief, Plastic and Reconstructive Surgery Service
Member, Memorial Sloan Kettering Cancer Center
New York, New York

Alexander F. Mericli, MD

Assistant Professor
Department of Plastic Surgery
MD Anderson Cancer Center
University of Texas
Houston, Texas

Joseph Michaels, MD

Private Practice
North Bethesda, Maryland
Assistant Professor of Plastic Surgery
Department of Plastic Surgery
John Hopkins Medicine
Baltimore, Maryland

Fred G. Mihm, MD

Professor
Division Chief, Critical Care Medicine
Department of Anesthesiology, Perioperative and Pain Medicine
Stanford University School of
Medicine
Associate Medical Director, Intensive Care Units
Department of Anesthesiology, Perioperative and Pain Medicine
Stanford University Medical Center
Stanford, California

Lauren M. Mioton, MD

Resident Physician
Division of Plastic and Reconstructive Surgery
Northwestern University
Chicago, Illinois

Arash Momeni, MD

Assistant Professor of Surgery
Director, Clinical Outcomes Research
Ryan-Upson Scholar in Plastic and Reconstructive Surgery
Division of Plastic & Reconstructive Surgery
Stanford University Medical Center
Palo Alto, California

Adeyiza O. Momoh, MD

Associate Professor of Plastic Surgery
Program Director, Integrated Plastic Surgery Residency
University of Michigan
Ann Arbor, Michigan

Amy M. Moore, MD

Assistant Professor of Surgery

Chief, Section of Hand Surgery
Program Director, Hand, Nerve and Microsurgery Fellowship
Washington University School of Medicine
St. Louis, Missouri

Mark Morris, MD

Joseph H. Boyes Hand Surgery Fellow
University of Southern California
Los Angeles, California

Christopher D. Morrison, MD

Chief Resident
Department of Urology
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Brad Morrow, MD

Pediatric Plastic Surgery Fellow
Division of Plastic and Reconstructive Surgery
The Hospital for Sick Children
Toronto, Ontario, Canada

**Afshin Mosahebi, MBBS(Lon), FRCS, FRCS(Plast),
PhD(Lon), MBA(Warwick)**

Professor of Plastic Surgery
Royal Free Hospital
University College London
London, United Kingdom

Shawn Moshrefi, MD

Plastic Surgery Resident
Stanford University Medical Center

Palo Alto, California

Goo-Hyun Mun, MD, PhD

Professor

Department of Plastic Surgery

Samsung Medical Center

Sungkyunkwan University

Seoul, South Korea

Ananth S. Murthy, MD

Associate Professor of Surgery

Northeastern Ohio Medical University

Rootstown, Ohio

Chief, Division of Plastic Surgery

Director, Craniofacial Clinic

Akron Children's Hospital

Akron, Ohio

Thomas A. Mustoe, MD

Stuteville Professor of Plastic Surgery

Chief of Plastic Surgery

Division of Plastic Surgery

Feinberg School of Medicine

Northwestern University

Chicago, Illinois

Raja A. Naddaf, DMD, OMFS

Attending Surgeon

Department of Oral and Maxillofacial Surgery

Rambam Medical Center

Haifa, Israel

Foad Nahai, MD, FACS

The Maurice J. Jurkiewicz Chair in Plastic Surgery and Professor of
Surgery
Department of Surgery
Emory University
Atlanta, Georgia

Arthur J. Nam, MD, MS

Assistant Professor
Division of Plastic, Reconstructive, and Maxillofacial Surgery
R Adams Cowley Shock Trauma Center
University of Maryland School of Medicine
Baltimore, Maryland

Rahim Nazerali, MD, MHS, FACS

Clinical Assistant Professor of Surgery
Division of Plastic & Reconstructive Surgery
Stanford Healthcare
Palo Alto, California

Peter Neligan, MB, FRCS(I), FRCSC, FACS

Professor of Surgery
Director, Center for Reconstructive Surgery
University of Washington Medical
Center
Seattle, Washington

Warwick J. S. Nettle, MBBS, FRACS

Private Practice
Sydney, Australia

Rogerio I. Neves, MD, PhD, FACS

Professor of Surgery, Pharmacology and Medicine
Deputy Director, Penn State Melanoma and Skin Cancer Center

Melanoma and Cutaneous Malignancies Disease Team

Leader

Director, Cutaneous Oncology

Program

Penn State Cancer Institute

Division of Plastic Surgery

Department of Surgery

College of Medicine

Pennsylvania State University

Hershey, Pennsylvania

Dung Nguyen, MD, PharmD

Clinical Associate Professor

Stanford University

Palo Alto, California

Shelley S. Noland, MD

Hand & Peripheral Nerve Surgery, Division of Plastic Surgery

Assistant Professor, Plastic & Orthopedic Surgery

Associate Program Director, Division of Plastic Surgery

Mayo Clinic College of Medicine

Phoenix, Arizona

Ajani G. Nugent, MD

Assistant Professor

Division of Plastic and Reconstructive Surgery

Department of Surgery

Miller School of Medicine

University of Miami

Miami, Florida

Hunter S. Oliver-Allen, MD

Resident Physician

Division of Plastic and Reconstructive Surgery
Department of Surgery
University of California,
San Francisco
San Francisco, California

**Adrian S. H. Ooi, MBBS, MMed
(Surgery), MRCS, FAMS (Plastic Surgery)**

Consultant Plastic Surgeon
Department of Plastic, Reconstructive and Aesthetic Surgery
Singapore General Hospital
SingHealth Head & Neck Disease Center
SingHealth
Singapore, Singapore

Mustafa Özgön, MD

Staff Anaesthesiologist
Amerikan Hospital
Istanbul, Turkey

Eugenia K. Page, MD

Fellow
Division of Plastic Surgery
Emory University
Division of Plastic and Maxillofacial Surgery
Department of Surgery
Emory University/Children's Healthcare of Atlanta
Atlanta, Georgia

Peter Palhazi, MD

Clinical Anatomist at the Department of Anatomy,
Histology and Embryology
Semmelweis University

Budapest, Hungary
Plastic Surgery Resident at the Department of Plastic and
Reconstructive Surgery
University of Pecs
Pecs, Hungary

Brian S. Pan, MD

Associate Professor of Surgery—Clinical
Division of Craniofacial and Pediatric Plastic Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Vikram S. Pandit, MDS

Oral and Maxillofacial
Surgeon
Consultant Oral and Maxillofacial Surgeon
Pandit Clinic
Pune, India

Andre Panossian, MD

Plastic Surgeon
Private Practice
Los Angeles, California
Staff Surgeon, Division of Plastic Surgery
Shriners Hospital for Children
Pasadena, California

Julie E. Park, MD

Assistant Professor
Section of Plastic & Reconstructive Surgery
University of Chicago Medical Centre
Department of Surgery
The University of Chicago Medicine & Biological Sciences

Chicago, Illinois

Christina Marie Pasick, MD

Resident

Division of Plastic Surgery

Department of Surgery

Icahn School of Medicine at Mount Sinai

New York, New York

Prasanth Patcha, MD, MEng

Resident

Section of Plastic and Reconstructive Surgery

Department of Surgery

Medical College of Georgia

Augusta University

Augusta, Georgia

Parit A. Patel, MD, MBA

Private Practice

Plastic Surgery Clinic of Chicago

Chicago, Illinois

Parit A. Patel, MD

Assistant Professor of Surgery

Division of Plastic and Reconstructive Surgery

Loyola University Chicago Stritch School of Medicine

Maywood, Illinois

Terrance Peabody, MD

Edwin Ryerson

Professor and Chair

Department of Orthopaedic Surgery

Feinberg School of Medicine

Northwestern University
Chicago, Illinois

Gregory D. Pearson, MD

Associate Professor Clinical
Director, Center for Complex Craniofacial Disorders
Nationwide Children's Hospital
Columbus, Ohio

William H. Peranteau, MD

Assistant Professor of Surgery
Division of General, Thoracic, and Fetal Surgery
Department of Surgery
The Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

John A. Persing, MD

Irving and Silik Polayes Professor and Chief of Plastic Surgery
Professor of Neurosurgery
Yale University School of Medicine
New Haven, Connecticut

Donato Perretta, MD

Orthopedic Surgery
Hand Surgery
Private Practice
New York Presbyterian—Hudson Valley Hospital
Cortlandt, New York

Michael Robert Pharaon, MD

Department of Plastic & Reconstruction Surgery
Craniofacial Surgeon
Straub & Kapiolani Medical

Centers
Honolulu, Hawaii

Paulo Piccolo, MD

Microsurgery Fellow
Division of Plastic Surgery
Department of Surgery
University of Pennsylvania
Philadelphia, Pennsylvania

Ximena A. Pinell-White, MD

Emory University Division of Plastic Surgery
Atlanta, Georgia

Joseph Pirolo, MD

Orthopaedic Surgeon
Seattle, Washington

Navid Pourtaheri, MD, PhD

Chief Resident
Department of Plastic Surgery
Case Western Reserve University School of Medicine
Cleveland, Ohio

John W. Polley, MD

Clinical Professor
Department of Surgery
Michigan State University College of Human Medicine
Plastic Surgeon
Pediatric Plastic and Craniofacial Surgery
Helen DeVos Children's Hospital
Grand Rapids, Michigan

Kathlyn Kruger Powell, DMD, MD

Assistant Professor
Department of Oral and Maxillofacial Surgery
School of Dentistry
University of Alabama at
Birmingham
Birmingham, Alabama

David B. Powers, MD, DMD, FACS, FRCS (Ed)

Director, Duke Craniomaxillofacial Trauma Program
Associate Professor of Surgery
Division of Plastic, Reconstructive, Maxillofacial & Oral Surgery
Director, Craniomaxillofacial Trauma and Reconstruction Fellowship
Duke University Medical Center
Durham, North Carolina

Julian J. Pribaz, MD, FRCS(Edin), FRACS(Plastics)

Professor of Surgery
Morsani College of Medicine
University of South Florida
Plastic Surgeon Moffitt Cancer Center
Plastic Surgeon
Tampa General Hospital
Tampa, Florida

Lee L. Q. Pu, MD, PhD, FACS

Professor of Surgery
Division of Plastic Surgery
University of California Davis Medical Center
Sacramento, California

Chad A. Purnell, MD

Resident Physician

Division of Plastic Surgery
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Allen Putterman, MD

Professor of Ophthalmology
Co-director of Oculofacial Plastic Surgery
College of Medicine
Chicago, Illinois

Whitney Laurel Quong, MD

Resident Physician
Division of Plastic & Reconstructive Surgery
University of Toronto
Burnaby, British of Columbia, Canada

Adi Rachmiel, DMD, PhD

Chair, Department of Oral and Maxillofacial Surgery
Rambam Health Care Campus
Clinical Professor
The Rappaport Faculty of Medicine
Technion—Israel Institute of Technology
Haifa, Israel

Paymon Rahgozar, MD

Assistant Professor
Division of Plastic and Reconstructive Surgery
University of California San Francisco
San Francisco, California

Charalambos “Babis” Rammos, MD, FACS

Assistant Professor of Surgery

Division of Plastic Surgery
Department of Surgery
Vice Chairman of Research
Department of Surgery
College of Medicine
University of Illinois
Peoria, Illinois

Joseph D. Randazzo, DDS, FACP

Assistant Attending Dental Service
Department of Surgery
Memorial Sloan Kettering Cancer Center
New York, New York

Scott J. Rapp, MD, FACS

Pediatric Cleft and Craniofacial Plastic Surgeon
Senior Research Investigator
Department of Surgery
Shriners Burn Hospital Cincinnati
Cincinnati, Ohio
Staff Surgeon
Division of Plastic Surgery
Department of Surgery
Norton Health Care
Louisville, Kentucky

Imran Ratanshi, MD, MSc, FRCSC

Microsurgery Fellow
Memorial Sloan Kettering Cancer Center
New York, New York

Edward C. Ray, MD, FACS

Assistant Professor of Surgery

Chair, Microsurgery Advisory Committee
Division of Plastic & Reconstructive Surgery
Cedars-Sinai Medical Center
Los Angeles, California

Patrick Reavey, MD, MS

Assistant Professor
Section of Plastic and Reconstructive Surgery
Department of Surgery
Department of Orthopedic Surgery and Rehabilitation
University of Chicago Medicine
Chicago, Illinois

Brenton R. Robinson, MD

Resident Physician
Department of Surgery
Presence Saint Joseph Hospital—Chicago
Chicago, Illinois

Eduardo D. Rodriguez, MD

Chair, Hansjorg Wyss Department of Plastic Surgery
Helen L. Kimmel Professor of Reconstructive Plastic Surgery
NYU Langone Medical Center
New York, New York

Rod J. Rohrich, MD

Clinical Professor and Founding Chair
Department of Plastic Surgery
Distinguished Teaching Professor
UT Southwestern Medical Center
Founding Partner
Dallas Plastic Surgery Institute
Dallas, Texas

Jason Roostaeian, MD

Assistant Clinical Professor
Division of Plastic Surgery
David Geffen School of Medicine at UCLA
Los Angeles, California

Anthony M. Rossi, MD, FAAD

Assistant Attending
Memorial Sloan Kettering Cancer Center
Assistant Professor
Weill Cornell Medical College
Assistant Attending
New York Presbyterian Hospital
Memorial Sloan Kettering
Cancer Center
New York, New York

David J. Rowe, MD, FACS

Assistant Professor, Plastic Surgery
MetroHealth Medical Center
Cleveland, Ohio

J. Peter Rubin, MD

Endowed Professor and Chair
Department of Plastic Surgery
University of Pittsburgh
Pittsburgh, Pennsylvania

Pierre Saadeh, MD

Vice Chair of Education
Residency Program Director
Chief of Plastic and Hand Surgery
Bellevue Hospital

Department of Plastic Surgery
School of Medicine
New York University
New York, New York

Christopher J. Salgado, MD

Professor and Interim Chief of Plastic Surgery
Division of Plastic Surgery
Medical Director of the LGBTQ Center for Wellness
Gender and Sexual Health
Department of Surgery
University of Miami Miller School of Medicine/Jackson Memorial
Hospital System
Miami, Florida

Saoussen Salhi, MD, CM, FRCSC

Attending Pediatric Plastic, Reconstructive and Craniofacial Surgeon
Nicklaus Children's Hospital
Miami, Florida

Kenneth E. Salyer, MD, FACS, FAAP

Founder and Chairman of the Board
World Craniofacial Foundation
Clinical Professor
Department of Biomedical Sciences
Baylor College of Dentistry
Texas A&M University Dallas
Dallas, Texas

James T. W. Saunders, BSc, MD, FRCSC

Division Head of Plastic and Reconstructive Surgery
Lions Gate Hospital, North Vancouver
Clinical Professor at the University of British Columbia

North Vancouver, British Columbia, Canada

Rajendra Sawh-Martinez, MD, MHS

Craniofacial Surgery Fellow
Section of Plastic and Reconstructive Surgery
Department of Surgery
Yale University School of Medicine
New Haven, Connecticut

Hani Sbitany, MD, FACS

Associate Professor of Surgery
Division of Plastic and Reconstructive Surgery
University of California, San Francisco
San Francisco, California

Jillian Schreiber, MD

Plastic Surgery Resident
Division of Plastic and Reconstructive Surgery
Montefiore Medical Center
New York, New York

Ann R. Schwentker, MD

Associate Professor of Pediatric Plastic and Craniofacial Surgery
Cincinnati Children's Hospital Medical Center
Program Director, Plastic Surgery
University of Cincinnati
Cincinnati, Ohio

Michelle Scott, DDS, MBA

Craniofacial Orthodontist
Department of Plastic Surgery
Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

Warren Schubert, MD, FACS

Chair, Department of Plastic & Hand Surgery
Regions Hospital
Professor of Surgery and Orthopaedics
University of Minnesota
St. Paul, Minnesota

Rosemary Seelaus, MAMS

Senior Anaplastologist
Division of Plastic & Reconstructive Surgery
University of Illinois at Chicago
Chicago, Illinois

Subhro K. Sen, MD

Clinical Associate Professor
Plastic and Reconstructive Surgery
Stanford University
Palo Alto, California

Brent A. Senior, MD, FACS, FARS

Nathaniel and Sheila Harris Distinguished Professor of
Otolaryngology/Head and Neck Surgery
Professor of Neurosurgery
Vice Chair of Clinical Affairs, Otolaryngology/Head and Neck
Surgery
Chief, Division of Rhinology, Allergy, and Endoscopic Skull Base
Surgery
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina

Michael D. Sgroi, MD

Assistant Professor of Vascular Surgery
Assistant Program Director of Vascular Surgery

Stanford University
Stanford, California

Ketan Sharma, MD, MPH

Resident Physician
Barnes-Jewish Hospital
Washington University St. Louis
St. Louis, Missouri

Ashkaun Shaterian, MD

Plastic Surgery Resident
Department of Plastic Surgery
University of California, Irvine
Orange, California

Farooq Shahzad, MBBS, FACS, FAAP

Assistant Professor of Plastic Surgery
Ann & Robert H Lurie Children's Hospital of Chicago
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Clifford C. Sheckter, MD

Chief Resident
Division of Plastic and Reconstructive Surgery
Department of Surgery
Stanford University
Stanford, California

Deana Shenaq, MD

Resident
Section of Plastic & Reconstructive Surgery
Department of Surgery

University of Chicago Medical Centre
Section of Plastic and Reconstructive Surgery
The University of Chicago Medicine & Biological Sciences
Chicago, Illinois

Michele A. Shermak, MD, FACS

Associate Professor of Plastic Surgery
Johns Hopkins Department of Plastic Surgery
Baltimore, Maryland
Private Practice Plastic Surgery
Lutherville, Maryland

Dekel Shilo, DMD, PhD

Department of Oral & Maxillofacial Surgery
Rambam Health Care Campus
Haifa, Israel

David A. Sieber, MD

Private Practice
Sieber Plastic Surgery
San Francisco, California

John W. Siebert, MD

Professor
Division of Plastic and Reconstructive Surgery
University of Wisconsin Hospital and Clinics
Madison, Wisconsin

Sammy Sinno, MD

Private Practice
Chicago, Illinois

Mark Sisco, MD

Clinical Associate Professor of Surgery
University of Chicago Pritzker School of Medicine
Chicago, Illinois
Chief of Plastic Surgery
NorthShore University HealthSystem
Evanston, Illinois

Wesley N. Sivak, MD, PhD

Fellow
Department of Plastic Surgery
University of Pittsburgh
Pittsburgh, Pennsylvania

Ann-Charlott Docherty Skogh, MD, PhD

Senior Consultant in Plastic Surgery
Breast Cancer Center
Department of Surgery
Stockholm South General Hospital and Karolinska Institute
Stockholm, Sweden

Darren M. Smith, MD

Plastic Surgeon, Aesthetic Surgeon
New York, New York

Matthew M. Smith, MD

Director of Hand and Upper Extremity Surgery
Grandview Medical Center
Birmingham, Alabama

Michael Smith, MD

Director of Hand and Upper Extremity Surgery
Grandview Medical Center
Birmingham, Alabama

Ji H. Son, MD, MS

Resident Physician
Department of Plastic and Reconstructive Surgery
Case Western School of Medicine
Cleveland, Ohio

David H. Song, MD, MBA, FACS

Physician Executive Director
MedStar Health
Plastic & Reconstructive Surgery
Professor and Chairman
Department of Plastic Surgery
Georgetown University
Washington, District of Columbia

Scott Spear, MD[†]

Georgetown University Hospital Department of Plastic Surgery
Founding Chair
Washington, District of Columbia

Dhivya R. Srinivasa, MD

Resident
Plastic and Reconstructive Surgery
University of Michigan
Ann Arbor, Michigan

David A. Staffenberg, MD, DSc, FACS

Vice Chair, Hansjörg Wyss Department of Plastic Surgery
Chief, Pediatric Plastic Surgery
Adult & Pediatric Craniofacial
Surgery
Professor, Plastic Surgery, Neurosurgery & Pediatrics
NYU Langone Medical Center

New York, New York

Rachel C. Steckelberg, MD, MPH

Clinical Instructor

Regional Anesthesia Fellow

Department of Anesthesiology, Perioperative, and Pain
Medicine

Stanford University Hospital

Palo Alto, California

Robert J. Steffner, MD

Assistant Clinical Professor

Musculoskeletal Tumor Surgery

Department of Orthopaedic Surgery

School of Medicine

Stanford University

Redwood City, California

Derek M. Steinbacher, MD, DMD, FACS

Director of Craniofacial

Craniomaxillofacial Surgery

Yale Plastic Surgery

New Haven, Connecticut

Jeffrey T. Steitz, MD

Division of Facial Plastic and Reconstructive Surgery

Department of Otolaryngology—Head & Neck Surgery

University of Illinois at Chicago

Chicago, Illinois

John T. Stranix, MD

Chief Resident

Hansjörg Wyss Department of Plastic Surgery

NYU Langone Health
New York, New York

Louis L. Strock, MD

Assistant Clinical Professor
Department of Plastic Surgery
University of Texas Southwestern Medical Center
Dallas, Texas
Private Practice
Fort Worth, Texas

James M. Stuzin, MD

Division of Plastic Surgery
Leonard M. Miller School of Medicine
University of Miami
Miami, Florida
Department of Plastic Surgery
Cleveland Clinic Florida
Weston, Florida

Man-Koon Suh, MD

Director
JW Plastic Surgery Center
Seoul, Korea

Ahmed Suliman, MD

Associate Professor, University of California San Diego, California
Section Chief, Veterans Healthcare Administration
Division of Plastic & Reconstructive Surgery
University of California San Diego
Section of Plastic & Reconstructive Surgery
Veterans Healthcare Administration
University of California, San Diego Medical Center

Veterans Healthcare Administration, San Diego
San Diego, California

Christopher C. Surek, DO

Plastic Surgeon
Private Practice
Overland Park, Kansas
Clinical Assistant Professor of Plastic Surgery
Department of Plastic Surgery
University of Kansas Health System
Assistant Professor of Anatomy
Department of Anatomy
Kansas City University of Medicine and Biosciences
Kansas City, Missouri

Srinivas M. Susarla, DMD, MD

Assistant Professor
Division of Plastic Surgery
Department of Surgery
Assistant Professor
Department of Oral and Maxillofacial Surgery
University of Washington
Seattle, Washington

Adam R. Sweeney, MD

Fellow, Oculoplastic and Facial Reconstructive Surgery
Department of Ophthalmology
Baylor College of Medicine
Houston, Texas

Jonathan Sykes, MD

Professor Emeritus
UC Davis Medical Center

Granite Bay, California

Geo N. Tabbal, MD

Assistant Professor
Department of Plastic Surgery
UT Southwestern Medical Center
Dallas, Texas

Nicolas Tabbal, MD

Clinical Associate Professor
Plastic Surgery
New York University
New York, New York

Amir H. Taghinia, MD, MPH, MBA

Assistant Professor of Surgery
Harvard Medical School
Staff Surgeon
Department of Plastic and Oral
Surgery
Boston Children's Hospital
Boston, Massachusetts

Simon Talbot, MD

Attending Plastic Surgeon
Brigham and Women's Hospital
Associate Professor
Harvard Medical School
Boston, Massachusetts

Shruti C. Tannan, MD

Plastic Surgeon
Tannan Plastic Surgery

Raleigh, North Carolina

Peter J. Taub, MD, FACS, FAAP

Professor, Surgery, Pediatrics, Dentistry, and Neurosurgery
Professor, Medical Education
Division of Plastic and Reconstructive Surgery
Residency Program Director
Chief, Craniomaxillofacial Surgery
Icahn School of Medicine at Mount Sinai
Chief, Pediatric Plastic Surgery
Director, Mount Sinai Cleft and Craniofacial Center
Director, Mount Sinai Vascular Anomalies Program
Kravis Children's Hospital at Mount Sinai
New York, New York

Jesse A. Taylor, MD, FACS, FAAP

Peter Randall Endowed Chair and Chief
Division of Plastic Surgery
Children's Hospital of Philadelphia
The University of Pennsylvania
Philadelphia, Pennsylvania

Ali Teoman Telliog˘lu, MD

Dıřkapı Yıldırım Beyazıt Eđitim ve Arařtırma Hastanesi
İrfan Bařtuđ Cad
Dıřkapı/Ankara
Turkey

Oren M. Tepper, MD

Director of Craniofacial Surgery
Director of Aesthetic Surgery
Co-Director 3D Printing & Innovation Laboratory
Assistant Professor of Surgery

Montefiore Medical Center
Albert Einstein College of Medicine
Bronx, New York

Ryan Ter Louw, MD

Plastic Surgeon
Muskegon Surgical Associates
Muskegon, Michigan

Vishal Thanik, MD

Assistant Professor, Plastic Surgery
Associate Program Director, Residency Program
Chief of Microsurgery, Bellevue Hospital
Hansjörg Wyss Department of Plastic Surgery
New York University Langone Medical Center
New York, New York

Yeshaswini Thelekkat, MDS

Senior Lecturer; Consultant Oral and Maxillofacial Surgeon
Oral Diagnostics and Surgical Sciences Division
School of Dentistry
International Medical University
Kuala Lumpur, Malaysiaa

Sunil Tholpady, MD, PhD, FACS, FAAP

Assistant Professor of Plastic Surgery
Indiana University School of Medicine
Indianapolis, Indiana

T. Guy Thorburn, BMBS, BMedSci, MA, FRCS(Plastic Surgery)

Consultant Cleft and Plastic Surgeon
Spires Regional Cleft Centre

Oxford University Hospitals NHSFT
Oxford, United Kingdom

Charles H. Thorne, MD

Chairman
Department of Plastic Surgery
Lenox Hill Hospital
New York, New York

Dean M. Toriumi, MD

Professor
Division of Facial Plastic and Reconstructive Surgery
Department of Otolaryngology—
Head & Neck Surgery
University of Illinois at Chicago
Chicago, Illinois

Richard Tosti, MD

Hand, Wrist, Elbow, and Microvascular Surgeon
Philadelphia Hand to Shoulder Center
Assistant Professor of Orthopaedic Surgery
Thomas Jefferson University
King of Prussia, Pennsylvania

Ali Totonchi, MD

Associate Professor, Case Western Reserve University
Associate Director of the Plastic Surgery Residency Program
MetroHealth Medical Center
Cleveland, Ohio

Anthony P. Tufaro, DDS, MD, FACS

Chief of Plastic Surgery
Professor of Surgery, Plastic Surgery and Surgical Oncology

University of Oklahoma Health Sciences Center
Oklahoma City, Oklahoma

Gökhan Tunçbilek, MD, PhD

Faculty of Medicine
Department of Plastic Reconstructive and Aesthetic Surgery
Hacettepe University
Ankara, Turkey

Sergey Y. Turin, MD

Resident Physician
Division of Plastic and Reconstructive Surgery
Feinberg School of Medicine
Northwestern University
Chicago, Illinois

Jacob G. Unger, MD

Assistant Clinical Professor of Plastic Surgery
Vanderbilt University
Private Practice
Maxwell Aesthetics Suite
Nashville, Tennessee

Robin Unger, MD

Assistant Professor
Department of Dermatology
Mount Sinai Hospital
New York, New York

Walter Unger, MD

Clinical Professor
Department of Dermatology
Mt. Sinai Hospital

New York, New York

Joseph Upton, MD

Clinical Professor for Surgery
Harvard Medical School
Chestnut Hill, Massachusetts

Leo J. Urbinelli, MD, MA

Associate Director, Cleft & Craniofacial Unit
Assistant Professor, Plastic & Reconstructive Surgery
Oregon Health & Sciences University
Doernbecher Children's Hospital
Portland, Oregon

John van Aalst, MD, MA, FACS, FAAP

Professor and Director
Division of Pediatric and Craniofacial Plastic Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

**Henry C. Vasconez, MD, FACS,
FAAP**

William S. Farish Endowed Chair of Plastic Surgery
Professor of Surgery and Pediatrics
Chief of Plastic Surgery at the
Veterans Administration MC, Lexington
Associate Program Director, UK Plastic Surgery Residency Program
University of Kentucky College of Medicine
Lexington, Kentucky

Dev Vibhakar, DO

Fellow, Adult Reconstructive & Aesthetic Craniomaxillofacial
Surgery

Division of Plastic & Reconstructive Surgery
Massachusetts General Hospital
Boston, Massachusetts

Mark A. Vitale, MD, MPH

ONS Foundation for Clinical Research and Education, ONS, P.C.
Greenwich, Connecticut

Timothy W. Vogel, MD

North Jersey Brain and Spine Center
Pediatric Neurosurgery and Craniofacial Surgery
Hackensack University Medical
Hackensack, New Jersey

Robert D. Wallace, MD

Professor and Chair
Residency Program Director
Department of Plastic Surgery
University of Tennessee Health Sciences Center
Memphis, Tennessee

Mark E. Walker, MD, MBA

Section of Plastic and Reconstructive Surgery
Department of Surgery
Yale University School of Medicine
Yale New Haven Hospital
New Haven, Connecticut

Robert L. Walton, MD, FACS

Professor of Surgery
Division of Plastic & Reconstructive Surgery
Feinberg School of Medicine
Northwestern University

Chief of Plastic Surgery
Department of Surgery
Saint Joseph Hospital
Chicago, Illinois

Howard D. Wang, MD

Resident
Department of Plastic and Reconstructive Surgery
Johns Hopkins/University of Maryland
Baltimore, Maryland

Richard J. Warren, MD, FRCSC

Clinical Professor of Surgery
University of British Columbia
Medical Director
Vancouver Plastic Surgery Center
Vancouver, British Columbia, Canada

Nezar Watted, DMD

Clinic and Policlinics of Dental, Oral and Maxillofacial Disease of
Bavarian Julius-Maximillian
University Hospital of Wuerzburg
University Wuerzburg
Wuerzburg, Germany

David Wei, MD

Attending Orthopaedic Surgeon
Department of Orthopaedic Surgery
Greenwich Hospital, Yale-New Haven Health
ONS Foundation for Clinical Research and Education, ONS, P.C.
Greenwich, Connecticut

Katie E. Weichman, MD

Assistant Professor of Surgery
Department of Surgery
Albert Einstein School of Medicine/Montefiore Medical Center
Bronx, New York

Joseph K. Williams, MD

Chief of Plastic Surgery
Children's Healthcare of Atlanta
Clinical Professor
Division of Plastic Surgery
Emory University
Adjunct Professor
Department of Pediatrics
Emory University
Atlanta, Georgia

S. Anthony Wolfe, MD, FACS, FAAP

Chief of Plastic Surgery
Nicklaus Children's Hospital
Miami, Florida

Alex Wong, MD, FACS

Associate Professor of Surgery
Director, Basic, Translational, and Clinical Research
Director, Microsurgery Fellowship and Medical Student Education
Division of Plastic and Reconstructive Surgery
Keck School of Medicine of USC
Los Angeles, California

Terence Kwan-Wong, MD FRCSC

Staff Surgeon
Pediatric Plastic Surgery
The Hospital for Sick Children

Toronto, Ontario, Canada

Kyong-Je Woo, MD, PhD

Assistant Professor
Department of Plastic Surgery
College of Medicine
Ewha Womans University
Ewha Womans University Medical Center
Seoul, Korea

Benjamin C. Wood, MD, MBA

Adjunct Associate Professor
Plastic and Reconstructive Surgery
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina

Jeyhan S. Wood, MD

Assistant Professor
Director of Craniofacial and Pediatric Plastic Surgery
Department of Surgery
University of North Carolina Chapel Hill
Chapel Hill, North Carolina

Eric J. Wright, MD

Reconstructive and Aesthetic Breast Fellow
Division of Plastic Surgery
Harvard Medical School
Massachusetts General Hospital
Boston, Massachusetts

Liza C. Wu, MD, FACS

Chief of Microsurgery
PENN Plastic Surgery

Professor of Surgery
University of Pennsylvania
Philadelphia, Pennsylvania

George Xipoleas, MD, FACS

The Long Island Plastic Surgical Group, PC
Garden City, New York

Wen Xu, MD

The Perelman School of Medicine at the University of Pennsylvania
The Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

Akira Yamada, MD, PhD

Professor of Surgery
Feinberg School of Medicine
Northwestern University
Ann & Robert H. Lurie Children's Hospital of Chicago
Department of Plastic Surgery
Chicago, Illinois

Ji-Geng Yan, MD, PhD

Department of Plastic Surgery
The Medical College of Wisconsin
Milwaukee, Wisconsin

Michael J. Yaremchuk, MD

Clinical Professor of Surgery
Director—Residency Training
Program
Harvard Medical School
Chief of Craniofacial Surgery
Massachusetts General Hospital

Boston, Massachusetts

Essie Kueberuwa Yates, MD

Plastic & Reconstructive Surgeon
Yates Institute of Plastic Surgery
Lauderdale, Florida

Kristen S. Yee, MD

UCSF Benioff Children's Hospital Oakland, Staff Surgeon
Chief of Facial Trauma
Santa Rosa Memorial Hospital
Santa Rosa, California

Elizabeth B. Yerkes, MD

Associate Professor
Department of Urology
Feinberg School of Medicine at Northwestern University
Attending Pediatric Urologist
Division of Pediatric Urology
Department of Surgery
Ann and Robert H. Lurie Children's Hospital of Chicago
Chicago, Illinois

SaeHee Yom, DDS, MPH

Assistant Attending—Dental Service
Department of Surgery
Memorial Sloan Kettering Cancer Center
New York, New York

Peirong Yu, MD, FACS

Professor
Division of Surgery
Department of Plastic Surgery

The University of Texas MD Anderson Cancer Center
Bellaire, Texas

Jack C. Yu, DMD, MD, MS, ED

Director of Craniofacial Center
Children's Hospital of Georgia
Milford B. Hatcher Professor of Surgery
Section of Plastic Surgery
Augusta University
Augusta, Georgia

Michael R. Zenn, MD, MBA, FACS

Zenn Plastic Surgery
Raleigh, North Carolina
Adjunct Professor of Plastic Surgery
University of North Carolina
at Chapel Hill
Chapel Hill, North Carolina

Emily M. Zepeda, MD

Pediatric Ophthalmology and Adult Strabismus Fellow
Kellogg Eye Center
University of Michigan School of Medicine
Ann Arbor, Michigan

Ming Zhuo-Stine, MD

Clinical Instructor and Fellow
Department of Anesthesiology
Stanford University Hospitals
Stanford, California

Barry M. Zide, MD, DMD

Professor of Plastic Surgery

Hansjorg Wyss Department of Plastic Surgery
NYU Langone Health
New York, New York

James E. Zins, MD, FACS

Chair, Department of Plastic Surgery
Head, Section of Cosmetic Surgery
Professor of Surgery
Cleveland Clinic Lerner College of Medicine at Case Western Reserve
Cleveland Clinic
Cleveland, Ohio

Terri A. Zomerlei, MD

Clinical Instructor House Staff
Columbus, Ohio

Yasmina Zoghbi, MD

Resident
Division of Plastic Surgery
Department of Surgery
Icahn School of Medicine at Mount Sinai
New York, New York

Toni Zhong, MD, MHS, FRCS(C)

Associate Professor
Departments of Surgery and Surgical Oncology
University of Toronto
Fellowship Director
Division of Plastic and Reconstructive Surgery
University of Toronto
Plastic Surgeon—Scientist
Belinda Stronach Chair of UHN Breast Cancer Reconstructive
Surgery

Director of the UHN Breast Reconstruction Program
University Health Network
Mount Sinai Hospital
Toronto, Ontario, Canada

Ronald Zuker MD, FRCSC, FACS, FRCSEd(Hon)

Staff Surgeon
Division of Plastic and Reconstructive Surgery
The Hospital for Sick Children
University of Toronto
Toronto, Ontario, Canada

[†]Deceased

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Contents

Contributors

Preface

Volume I

PART 1 FACIAL AESTHETIC

SECTION I TECHNIQUES FOR BOTULINUM TOXINS IN THE FACE

- 1 Injection of Botulinum Toxin to the Glabellar Region
Jonathan Sykes, Peter Palhazi, and Amir Allak
- 2 Injection of Botulinum Toxin to the Forehead
David A. Sieber and Jeffrey M. Kenkel
- 3 Injection of Botulinum Toxin to Soften Crow's Feet
Sammy Sinno
- 4 Injection of Botulinum Toxin for Treatment of the Gummy Smile
David A. Sieber and Jeffrey M. Kenkel
- 5 Injection of Botulinum Toxin for Treatment of Perioral Rhytids

Z. Paul Lorenc and Johnson C. Lee

- 6 Injection of Botulinum Toxin to the Depressor Anguli Oris
Amir Allak, Sebastian Cotofana, and Jonathan Sykes
- 7 Injection of Botulinum Toxin to Platysma Bands
Z. Paul Lorenc and Johnson C. Lee

SECTION II TECHNIQUE FOR INJECTION OF FILLERS IN THE FACE

- 8 Injection of Fillers in the Glabella, Forehead, and Brow
David A. Sieber and Jeffrey M. Kenkel
- 9 Filler Injection Into the Upper Periorbital Area
Val Lambros
- 10 Tear Trough and the Lid-Cheek Junction
Z. Paul Lorenc and Johnson C. Lee
- 11 Injection of Fillers in the Malar Region
Benjamin T. Lemelman and Julius W. Few
- 12 Nasolabial Fold With Hyaluronic Acid Filler Injection
Christopher C. Surek and Jacob N. Grow
- 13 Injection of Fillers to the Lips, Oral Commissures, Marionette Lines, Prejowl Area, and Temporal Region
David A. Sieber and Jeffrey M. Kenkel
- 14 Injection of Filler to the Nose
T. Jonathan Kurkjian, Jamil Ahmad, and Rod J. Rohrich

SECTION III **FAT GRAFTING OF THE FACE**

- 15 Fat Grafting at the Time of Facelifting
Sammy Sinno and James M. Stuzin
-

SECTION IV **LASER RESURFACING OF THE FACE**

- 16 Techniques for Laser Resurfacing of the Face
Daniel A. Belkin and Roy G. Geronemus
-

SECTION V **CHEMICAL PEEL OF THE FACE**

- 17 TCA Peel to Face
Steven M. Levine and Daniel C. Baker
- 18 Indications and Technique for Phenol-Croton Oil Peels
Gehan D'Souza and James Zins
-

SECTION VI **DERMABRASION**

- 19 Techniques for Dermabrasion to the Face
Steven M. Levine and Daniel C. Baker
-

SECTION VII **BROW LIFTING**

- 20 Indications and Techniques for Coronal Brow Lifting
Richard J. Warren
- 21 Indications and Technique for Endoscopic Brow Lifting
Navid Pourtaheri, Ali Totonchi, and Bahman Guyuron

- 22 Indications and Techniques for Subcutaneous Lateral Brow Lifting
Richard J. Warren
- 23 Lowering the Overelevated Brow
Michael J. Yaremchuk, Erez Dayan, and Dev Vibhakar
- 24 Indications and Techniques for Transpalpebral Corrugator Resection
Ximena A. Pinell-White and Foad Nahai
- 25 Indications and Techniques for Hairline Lowering
Warwick J. S. Nettle and Yumiko Kadota
-

SECTION VIII **UPPER BLEPHAROPLASTY**

- 26 Techniques for Upper Blepharoplasty
Steven M. Levine
- 27 Transpalpebral Corrugator Resection
Ji H. Son, Ali Totonchi, and Bahman Guyuron
- 28 Technique for Ptosis Correction
Ashley A. Campbell, Christopher C. Lo, and Richard D. Lisman
- 29 Technique for Ptosis Correction
Nuri A. Celik
- 30 Asian Blepharoplasty (“Double Eyelid” Surgery)
Clyde H. Ishii
-

SECTION IX **LOWER BLEPHAROPLASTY**

- 31 Transconjunctival Approach to Resection and/or Repositioning of Lower Eyelid Herniated Orbital Fat
Allen Putterman
- 32 Indications and Technique for Skin Pinch Skin Excision in the Lower Eyelids
Charles H. Thorne and Sammy Sinno
- 33 Indications and Technique for Transconjunctival Fat Removal and Redraping in the Lower Eyelids
Francisco G. Bravo
- 34 Indications and Technique for Lower Blepharoplasty via Subciliary Incision
Francisco G. Bravo
- 35 Lateral Canthal Manipulation With Canthopexy or Canthoplasty
George N. Kamel, Glenn W. Jelks and Oren M. Tepper
- 36 Indications and Techniques for Fat Grafting for Periorbital Rejuvenation
Oren M. Tepper, Jillian Schreiber, Elizabeth B. Jelks, and Glenn W. Jelks
- 37 Indications and Techniques for Upper and Lower Blepharoplasty with Microfat Injections
Nuri A. Celik
- 38 Indications and Technique for Fat Grafting for Periorbital Rejuvenation
Dino Elyassnia and Timothy Marten
- 39 Indications and Techniques for Bridge of Bone

Canthopexy

Dev Vibhakar, Erez Dayan, and Michael J. Yaremchuk

- 40 Indications and Techniques for Palatal Spacer Grafts
Dev Vibhakar, Erez Dayan, and Michael J. Yaremchuk
-

SECTION X **FACELIFTING AND NECKLIFTING**

- 41 Indication and Technique for Skin-Only Face and Neck Lifting
James Zins and Gehan D'Souza
- 42 Indications and Techniques for Face-Lifting and Neck Lifting
David A. Hidalgo and Sammy Sinno
- 43 Indications and Technique for Extended SMAS Facelift and Necklift
James M. Stuzin and Sammy Sinno
- 44 Lamellar High SMAS Face-Lift
Dino Elyassnia and Timothy Marten
- 45 SMASectomy Face-Lift
Steven M. Levine and Daniel C. Baker
- 46 Indications and Technique for Deep Plane Face-Lift
Thomas A. Mustoe
- 47 Isolated Neck Lift
Alan Matarasso and Sammy Sinno
- 48 Subplatysmal Neck Lifting
Dino Elyassnia and Timothy Marten

- 49 Indications and Techniques for Short-Scar Face-Lift
Steven M. Levine and Daniel C. Baker
 - 50 Indications and Techniques for Buccal Fat Pad Excision
Alan Matarasso and Sammy Sinno
 - 51 Nonsurgical Neck Contouring using Deoxycholic Acid or Microfocused Ultrasound
Lawrence S. Bass
-

SECTION XI **RHINOPLASTY**

- 52 Indications and Technique for Closed Rhinoplasty in Patients With Dorsal Hump and Wide Tip
Barış Çakır and Ali Teoman Tellioğlu
- 53 Indications and Technique for Treating the Narrow Midvault in Closed Rhinoplasty
Shruti C. Tannan, Jeffrey R. Claiborne, and Mark B. Constantian
- 54 Indications and Techniques for Increasing and Decreasing Tip Projection in Closed Rhinoplasty
Barış Çakır and Mithat Akan
- 55 Techniques for Controlling Tip Rotation in Closed Rhinoplasty and Rhinoplasty Anesthesia
Barış Çakır and Mustafa Özgön
- 56 Technique for Ethnic Rhinoplasty by the Closed Technique
Shruti C. Tannan, J. Clayton Crantford, and Mark B. Constantian

- 57 Indications and Technique for Open Rhinoplasty in Patients With Dorsal Hump and Wide Tip
Charles H. Thorne and Sammy Sinno

- 58 Treating the Narrow Midvault
Eric J. Culbertson and Jason Roostaeian

- 59 Indications and Technique for Increasing and Decreasing Tip Projection in Open Rhinoplasty
David A. Sieber and C. Spencer Cochran

- 60 Techniques for Controlling Tip Rotation in Open Rhinoplasty
Nicolas G. Tabbal and Geo N. Tabbal

- 61 Technique for Ethnic Rhinoplasty Using the Open Approach
Dean M. Toriumi and Jeffrey T. Steitz

- 62 Technique for Treating the Crooked Nose
Ali Totonchi, Navid Pourtaheri, and Bahman Guyuron

- 63 Technique for Treating the Long Nose
Michael R. Lee and Rod J. Rohrich

- 64 Technique for Treating the Short Nose
Nicholas Lahar and Jason Roostaeian

- 65 Technique for Dorsal Augmentation Using Costal Cartilage Graft
Dean M. Toriumi

- 66 Technique for Dorsal Augmentation Using Alloplastic Material

Man-Koon Suh and Nguyen Phan Tu Dung

- 67 Diced Cartilage in Fascia Graft for Dorsal Augmentation in Rhinoplasty
Aaron M. Kosins and Rollin K. Daniel
- 68 Indication and Technique for Diced Cartilage and Fascia Grafting in Rhinoplasty
Ashkan Ghavami
- 69 Technique for Surgical Management of the Depressor Septi Nasi Muscle
Michael R. Lee, Sammy Sinno, and Rod J. Rohrich
- 70 Alar Contour Grafts
Jacob Unger and Rod J. Rohrich
- 71 Techniques for Treating Nasal Airway Obstruction
Michael R. Lee

SECTION XII FACIAL SKELETAL AUGMENTATION WITH IMPLANTS

- 72 Chin Augmentation With Implant
Daniel A. Cuzzone and Barry M. Zide
- 73 Techniques for Placing Malar Implants
Erez Dayan, Dev Vibhakar, and Michael J. Yaremchuk
- 74 Mandible Implants
Michael J. Yaremchuk, Dev Vibhakar, and Erez Dayan

SECTION XIII SKELETAL REDUCTION

- 75 Technique for Chin Reduction
Jong-Woo Choi and Woo-Shik Jeong
-

SECTION XIV **OSSEOUS GENIOPLASTY**

- 76 An Osseous Approach to Chin Deformities
S. Anthony Wolfe and Saoussen Salhi
-

SECTION XV **HAIR TRANSPLANTATION**

- 77 Indications and Techniques for Hair Transplantation
Walter Unger and Robin Unger

PART 2 CRANIOFACIAL

SECTION I **CRANIOSYNOSTOSIS**

- 1 Fronto-Orbital Advancement
Rajendra Sawh-Martinez and John A. Persing
- 2 Fronto-Orbital Distraction
Jesse A. Taylor and Wen Xu
- 3 Posterior Cranial Vault Expansion
Alexander Y. Lin
- 4 Posterior Cranial Vault Distraction Osteogenesis
Richard A. Hopper and Amy Lee
- 5 Total Cranial Vault Remodeling
Akira Yamada, Kenneth E. Salyer, Derek A. Bruce,

and Frank R. Graewe

- 6 Spring-Assisted Surgery for Sagittal Synostosis
Lisa R. David and Claire Sanger Dillingham
- 7 Transparietal/Transtemporal Distraction for Sagittal Craniosynostosis
Kristen Klement and Arlen Denny
- 8 Monobloc Frontofacial Advancement
S. Anthony Wolfe and Nicole C. Cabbad
- 9 Monobloc Distraction
Peter J. Taub and Vincent Chavanon
- 10 Split Calvarial Bone Graft Harvest
Peter J. Taub
- 11 Cranioplasty Reconstruction with Autogenous Rib Graft
Scott J. Rapp
- 12 Three-Dimensional Implant Reconstruction for the Cranial Vault
Barry L. Eppley and Sunil Tholpady
- 13 Alloplastic Reconstruction of the Calvarium
Peter J. Taub
- 14 Craniopagus Twins
David J. Dunaway and Noor Ul Owase Jeelani
- 15 Endoscopically Assisted Approaches for Craniosynostosis
Timothy W. Vogel and Brian S. Pan

SECTION II **ORBITAL DYSTOPIAS**

-
- 16 Box and U-Shaped Osteotomies
Sunil Tholpady, Robert J. Havlik, and Barry L. Eppley
 - 17 Facial Bipartition
Jessica Ching and Christopher R. Forrest
 - 18 Orbital Expansion for Anophthalmia and Microphthalmia
Brad Morrow and Rogerio I. Neves
-

SECTION III **MAXILLARY SURGERY**

- 19 Surgically Assisted Rapid Palatal Expansion (SARPE)
Omri Emodi, Nezar Watted, and Adi Rachmiel
- 20 Premaxillary Segment Setback
Omri Emodi
- 21 Le Fort I Osteotomy and Advancement
Kathlyn K. Powell, Ahmed Elsherbiny, and John H. Grant III
- 22 Le Fort I Distraction Osteogenesis
Nicholas S. Adams and John W. Polley
- 23 Segmental Le Fort I Advancement: Two and Three Piece
Leo J. Urbinelli and Jeffrey A. Hammoudeh
- 24 Le Fort II Osteotomy and Advancement
Adi Rachmiel, Dekel Shilo, and Omri Emodi
- 25 Le Fort II Advancement With Distraction Osteogenesis
Eugenia K. Page, Colin M. Brady, and Joseph K.

Williams

- 26 Le Fort III Advancement
Ghassan S. Abu-Sittah and Rawad S. Chalhoub
- 27 Le Fort III Osteotomy With External Distraction
Gökhan Tunçbilek
- 28 Minimal Access Le Fort III Osteotomy for Midface Hypoplasia
Scott J. Rapp and Christopher B. Gordon
- 29 Secondary Alveolar Bone Grafting of the Cleft Alveolar Defect in Cleft Palate
Richard E. Kirschner, Michelle A. Scott, and Matthew A. Hiersche
- 30 Surgical Management of Facial Clefts
David C. Matthews, Samer Abouzeid, and Edward W. Kubek
- 31 Gingivoperiosteoplasty
Mark C. Martin
- 32 BMP Use in the Craniofacial Skeleton
James P. Bradley and Kristen S. Yee

SECTION IV MANDIBULAR SURGERY

- 33 Costochondral Reconstruction for Absent Temporomandibular Joint
Patrick A. Gerety and Scott P. Bartlett
- 34 Prosthetic Reconstruction of the Temporomandibular Joint

Anthony P. Tufaro and Srinivas M. Susarla

- 35** Osteocutaneous Parascapular Flap for Mandibular Reconstruction
Ravi K. Garg and John W. Siebert
- 36** Reverse Distraction to Create a Temporomandibular Joint
Joseph Lopez and Anand R. Kumar
- 37** Bilateral Sagittal Split Osteotomy for Mandibular Deficiency
Stephen B. Baker
- 38** Inverted L Osteotomy for Mandibular Surgery
Raymond J. Harshbarger
- 39** Intraoral Vertical Ramus Osteotomy of the Mandible
Deepak G. Krishnan and Haithem M. Elhadi Babiker
- 40** Internal Mandibular Distraction
Michael Alperovich and Roberto L. Flores
- 41** External Mandibular Distraction for Micrognathia
Haithem M. Elhadi Babiker
- 42** External Transfacial Mandibular Distraction
Brian S. Pan
- 43** Mandibular Setback
Haithem M. Elhadi Babiker and Deepak G. Krishnan
- 44** Osseous Genioplasty
Mark E. Walker and Derek M. Steinbacher
- 45** Alloplastic Chin Augmentation

Barry L. Eppley and Sunil Tholpady

- 46** Surgical Removal of Fibrous Dysplasia From the Craniofacial Skeleton
Alexander Govshievich and Gaby G. Doumit
-

SECTION V SKULL DEFECTS

- 47** Autologous Bone Harvest to Correct Open Skull Defects
Michael R. Pharaon
-

SECTION VI FRONTAL SINUS

- 48** Frontal Sinus Cranialization
Mohamad Masoumy, Prasanth Patcha, Robert C. Dinsmore, and Jack C. Yu
- 49** Frontal Sinus Obliteration with Fat
Matthew M. Smith and Alessandro de Alarcon
- 50** Pericranial Flap Harvest for Frontal Sinus Obliteration
Mahmoud Hassouba and John A. van Aalst
- 51** Endoscopic Correction of Frontal Sinus Fractures
Patrick M. Colley, Kibwei A. McKinney, and Brent A. Senior
- 52** Operative Management of a Late Presentation of Frontal Sinus Mucocele
Kibwei A. McKinney and Brent A. Senior
-

SECTION VII ORBITAL TRAUMA

- 53 Correction of Orbital Floor Blow-Out Fractures: Variation 1
Jean-Francois Lefaivre and David Charles A. Fisher
- 54 Correction of Orbital Floor Blow-Out Fractures: Variation 2
Henry C. Vasconez
- 55 Correction of Lateral Orbital Wall Fractures
Parit A. Patel
- 56 Medial Orbital Wall Fractures
Brad M. Gandolfi, Reena Bakshi, and Reza Jarrahy
- 57 Correction of Orbital Roof Fractures
Samita S. Goyal and James Jensen
- 58 Secondary Correction of Enophthalmos
David C. Matthews, Samer Abouzeid, and Edward W. Kubek

SECTION VIII **NASAL FRACTURES**

- 59 Closed Nasal Fracture Correction
Benjamin C. Wood
- 60 Open Treatment of Nasal Fractures
Jeyhan Wood

SECTION IX **NOE FRACTURES**

- 61 Naso-Orbital-Ethmoid (NOE) Fractures
Craig Birgfeld and Joseph Gruss

SECTION X **MAXILLARY TRAUMA**

-
- 62 Closed Reduction of Zygomatic Arch Fractures
Oluwaseun A. Adetayo
- 63 Open Correction of Zygomatic Fractures
Warren Schubert and Yeshaswini Thelekkat
- 64 Addressing Late Malpositioning of the
Zygomaticomaxillary Complex
Warren Schubert and Yeshaswini Thelekkat
- 65 Correction of Le Fort I Fracture
Ananth S. Murthy
- 66 Correction of Le Fort II Fracture
Nataliya Biskup and John van Aalst
- 67 Correction of Le Fort III Fractures
Joseph Lopez and Amir H. Dorafshar
-

SECTION XI **MANDIBULAR TRAUMA**

- 68 Maxillomandibular Fixation of Mandible Fractures
Joseph Baylan and Dana Johns
- 69 Open Treatment of Mandible Fractures
Joseph Baylan and H. Peter Lorenz
- 70 Open Treatment of Condyle Fractures
Michael A. Lypka
- 71 Management of Mandibular Coronoid Fractures
Raja Naddaf

- 72 Surgical Correction of Nonunion of Mandible Fracture
Howard D. Wang, Arthur J. Nam, and Amir H. Dorafshar
-

SECTION XII **PANFACIAL TRAUMA**

- 73 Surgical Correction of Panfacial Fractures
Detlev Erdmann and David Powers
-

SECTION XIII **PEDIATRIC TRAUMA**

- 74 Pediatric Orbital Fractures
James Y. Liao
- 75 Surgical Correction of Pediatric Midface Fractures
Eric Lowry Cole and Shelby R. Lies
- 76 Management of Pediatric Mandible Fractures
Nataliya I. Biskup and Brian S. Pan

PART 3 HEAD AND NECK RECONSTRUCTION

SECTION I **ANESTHESIA**

- 1 Local Anesthesia of the Face
Cerrene N. Giordano and Anthony M. Rossi
-

SECTION II **FACIAL LACERATIONS**

- 2 Management of Facial Lacerations

John G. Fernandez

SECTION III SCALP AND CALVARIUM

- 3** Scalp Reconstruction With Rotation Flaps
Finny George and Evan Matros
 - 4** Scalp Reconstruction With Free Flaps
Finny George and Evan Matros
 - 5** Scalp Reconstruction With Tissue Expansion
Finny George and Evan Matros
 - 6** Calvarial Reconstruction With Split Rib Grafts
David A. Staffenberg and Gerald J. Cho
 - 7** Calvarial Reconstruction With Split Calvarial Grafts
David A. Staffenberg and Gerald J. Cho
-

SECTION IV SKULL BASE AND MIDFACE

- 8** Free Fibula Flap for Midface Reconstruction
J. Rodrigo Diaz-Siso and Eduardo D. Rodriguez
 - 9** Soft Tissue Flaps for Maxillary Reconstruction
Ahmed M. Hashem and Brian R. Gastman
-

SECTION V MANDIBLE

- 10** Mandible Reconstruction with Fibula Free Flap Using CAD/CAM Techniques
Jamie Levine, David Hirsch, and Lawrence Brecht

- 11 Mandible Reconstruction with Fibula Flap with Templates
Eric G. Halvorson
 - 12 Mandible Reconstruction With Scapula Flap
Mouchammed Agko and Hung-Chi Chen
 - 13 Lateral Mandible Reconstruction With Soft Tissue Flaps
Afshin Mosahebi, Evan Matros, and Babak J. Mehrara
 - 14 Maxillomandibular Fixation
Cherry L. Estilo, SaeHee Kim Yom, and Joseph Randazzo
-

SECTION VI **LIP**

- 15 Repair of Lip Commissure Defects with Estlander Flaps
Simon G. Talbot and Julian J. Pribaz
 - 16 Repair of Lip Defects With Karapandzic Flaps
Simon G. Talbot and Julian J. Pribaz
 - 17 Repair of Lip Defects With the Abbe Flap
Robert Beinrauh and Joseph H. Dayan
 - 18 Lower Lip Reconstruction With the Nasolabial Flap
George D. Xipoleas and Matthew S. Kilgo
 - 19 Lip Reconstruction With Radial Forearm Free Flap
Vishal Thanik
-

SECTION VII **EYELID**

- 20 Direct Closure and Lateral Cantholysis

Aaron Fay and John Nguyen

- 21 Tenzel Semicircular Rotational Flap
John Nguyen and Aaron Fay
 - 22 Eyelid Reconstruction With the Hughes Flap or Cutler-Beard Flap
Larissa Habib and Brian Marr
 - 23 Lower Eyelid Reconstruction With Palatal Grafts
Farooq Shahzad, Babak J. Mehrara, and Aaron Fay
 - 24 Lateral Tarsal Strip Canthoplasty
Richard H. Caesar
-

SECTION VIII CHEEK

- 25 Cheek Reconstruction With Laterally or Medially Based Cervicofacial Flap
Sammy Sinno and Barry M. Zide
 - 26 Cheek Reconstruction With Tissue Expanders
John T. Stranix and Barry M. Zide
 - 27 Cheek Reconstruction With Free Radial Forearm Flap
John G. Fernandez
 - 28 Cheek Reconstruction With Skin Grafts
Farooq Shahzad and Babak J. Mehrara
-

SECTION IX EAR

- 29 Antia-Buch Flaps for Ear Reconstruction

Amir M. Ghaznavi and Brian R. Gastman

- 30** Postauricular Flap for Ear Reconstruction
Matthew M. Hanasono
 - 31** Reconstruction of the Ear Lobe
Matthew M. Hanasono
 - 32** Wedge Reconstruction of Partial Auriclectomy Defects
Edward I. Chang and Matthew M. Hanasono
-

SECTION X NOSE

- 33** Nasal Reconstruction With Banner Flaps, Bilobed Flaps, and Nasolabial Flaps
Michael V. Chiodo and Pierre Saadeh
 - 34** Nasal Reconstruction With Paramedian Forehead Flap
Robert D. Wallace and Petros Konofaos
 - 35** Septal Flaps for Nasal Lining
Jordan D. Frey, John T. Stranix, and Pierre Saadeh
 - 36** Radial Forearm Flap for Nasal Lining Reconstruction
Robert L. Walton and Brent Robinson
 - 37** Nasal Reconstruction With Skin Grafts and Composite Grafts
Steven M. Levine and Daniel C. Baker
 - 38** V-Y Advancement Flaps for Nasal Reconstruction
Julian J. Pribaz and Simon G. Talbot
-

SECTION XI CAVITY AND PHARYNX

-
- 39 Facial Artery Perforator Flap
 Julian J. Pribaz and Simon G. Talbot
 - 40 Facial Artery Musculo-Mucosal (FAMM) Flap
 Julian J. Pribaz and Simon G. Talbot
 - 41 Free Flap for Hemi-Tongue Reconstruction
 Carrie K. Chu and Periong Yu
 - 42 Floor of Mouth Reconstruction
 George N. Kamel, J. Alejandro Conejero, and Evan Garfein
 - 43 Reconstruction of Total Glossectomy Defects
 Mark Sisco and Mihir Bhayani
 - 44 Reconstruction of Buccal Mucosal Defects
 Imran Ratanshi and Colleen M. McCarthy
 - 45 Jejunum Flap for Pharyngeal Reconstruction
 Farooq Shahzad and Babak J. Mehrara
 - 46 Anterolateral Thigh Flap for Pharyngoesophageal Reconstruction
 Edward I. Chang and Matthew M. Hanasono
 - 47 Pectoralis Major Flap for Pharyngeal Reconstruction
 Michael A. Howard and Babak J. Mehrara
 - 48 Supraclavicular Island Flap for Oropharyngeal Reconstruction
 Michael W. Chu and Ernest S. Chiu

SECTION XII **FACIAL NERVES**

- 49 Facial Reanimation in the Oncologic Patient Using Nerve Grafts and Nerve Transfers
Joseph H. Dayan
- 50 Temporalis Flap and Lengthening Temporalis Myoplasty for Facial Paralysis
Andre Panossian
- 51 Labbé Procedure: Lengthening Temporalis Myoplasty
Daniel Labbé and Pierre Guerreschi
- 52 Babysitter Nerves for Facial Reanimation
Adel Y. Fattah
- 53 Gold Weight Insertion for Upper Eyelid Reanimation
Larissa A. Habib and Brian Marr

Volume II

PART 4 PLASTIC SURGERY OF THE BREAST

SECTION I **AUGMENTATION MAMMOPLASTY**

- 1 Transaxillary Breast Augmentation
Louis L. Strock
- 2 Breast Augmentation: Subglandular, Subfascial, and Submuscular Implant Placement
Chet Mays and Bradley Calobrace

- 3 Breast Augmentation Plane: Dual Plane
Bill Kortesis and Charalambos “Babis” Rammos
 - 4 Breast Augmentation with Round and Anatomic Implants
Bill Kortesis and Charalambos “Babis” Rammos
 - 5 Female to Male Transgender Breast Surgery
Ann R. Schwentker
-

SECTION II **MASTOPEXY**

- 6 Mastopexy: Periareolar, Vertical, and Wise Pattern
R. Ter Louw and Scott Spear[†]
-

SECTION III **REDUCTION MAMMAPLASTY**

- 7 Reduction Mammoplasty
Peter Henderson and Joseph J. Disa
 - 8 Inferior Pedicle
Paul A. Ghareeb and Albert Losken
 - 9 Breast Reduction with Free Nipple Graft
Paul A. Ghareeb and Albert Losken
 - 10 Gynecomastia
John T. Stranix and Alexes Hazen
-

SECTION IV **BREAST RECONSTRUCTION FOR PARTIAL MASTECTOMY DEFECTS**

- 11 Partial Breast Reconstruction With Local Tissue

Rearrangement
Moustapha Hamdi

- 12** Local Flaps in Partial Breast Reconstruction
Moustapha Hamdi and Fadi Bakal

SECTION V PROSTHETIC BREAST RECONSTRUCTION

- 13** Delayed Tissue Expansion
Hana Farhang Khoee, Edward C. Ray, and Joseph J. Disa
- 14** Tissue Expander with Acellular Dermal Matrix
Gabriel M. Kind
- 15** Immediate Tissue Expander
Eric G. Halvorson and Joseph J. Disa
- 16** Replacement of Expander with Permanent Implant
Eric G. Halvorson and Joseph J. Disa
- 17** Direct-to-Implant Breast Reconstruction
Amy S. Colwell and Eric J. Wright

SECTION VI LATISSIMUS FLAP BREAST RECONSTRUCTION

- 18** Latissimus Flap
Peter Henderson and Joseph Disa

SECTION VII ABDOMINAL FLAP BREAST RECONSTRUCTION

- 19 TRAM
Peter Henderson, Jeffrey A. Ascherman, and Joseph J. Disa
- 20 Free TRAM
Jennifer A. Klok and Toni Zhong
- 21 Muscle-Sparing Free Transverse Rectus Abdominis Myocutaneous (TRAM) Flap
Arash Momeni and Liza C. Wu
- 22 DIEP Flap Breast Reconstruction
Pierre M. Chevray
- 23 Abdominal Breast Reconstruction Using a SIEA Flap Approach
Adrian S. H. Ooi, Deana Shenaq, Julie E. Park, and David H. Song
- 24 Recipient Vessel Exposure—Internal Mammary and Thoracodorsal
Theodore A. Kung and Adeyiza O. Momoh
- 25 Inferior Gluteal Artery Perforator Flap Breast Reconstruction
Katie E. Weichman
- 26 Superior Gluteal Artery Perforator Flap Breast Reconstruction
Katie E. Weichman

SECTION VIII OTHER FREE FLAPS

- 27 Profunda Artery Perforator Flap for Breast Reconstruction
Katie E. Weichman and Nicholas Haddock
 - 28 Transverse Upper Gracilis Flap for Breast Reconstruction
Adeyiza O. Momoh
 - 29 Skate Flap for Nipple Reconstruction
Katie E. Weichman
 - 30 C-V Flap for Nipple Reconstruction
Katie E. Weichman
 - 31 Nipple Reconstruction
Kassandra Dassoulas, Brendan Collins, and Bernard W. Chang
 - 32 Low-Volume Fat Grafting for Contour Correction
Nolan Karp and Jordan Frey
 - 33 Large-Volume Fat Grafting for the Breast
Wesley N. Sivak and J. Peter Rubin
-

SECTION IX **LYPHEDEMA**

- 34 Lymphedema Microsurgery for Breast Cancer–Related Upper Limb Lymphedema
Ming-Huei Cheng and Jung-Ju Huang

PART 5 TRUNK RECONSTRUCTION AND BODY CONTOURING

SECTION I **RECONSTRUCTION OF THE CHEST WALL**

-
- 1 Pectoralis Flap for Chest Wall Reconstruction
Jeff Kim and David H. Song
 - 2 Sternal Debridement and Application of Muscle Flaps
Sean M. Fisher, Jeff J. Kim, and David H. Song
 - 3 Rectus Abdominis Flap for Thoracic Reconstruction
Maureen Beederman and David H. Song
 - 4 Omental Flap for Thoracic Reconstruction
Amir Inbal and David H. Song
 - 5 Latissimus Dorsi Flap for Chest Wall Defects
Essie Kueberuwa Yates and David H. Song
 - 6 Serratus Anterior Flap for Chest Wall Reconstruction
Zachary J. Collier and David H. Song

SECTION II **RECONSTRUCTION OF THE ABDOMINAL WALL**

- 7 Hernia Repair With Open Component Separation
Ibrahim Khansa and Jeffrey E. Janis
- 8 Ventral Hernia: Component Separation Technique
Mark W. Clemens and Charles E. Butler
- 9 Abdominal Hernia Reconstruction With Synthetic and Biologic Mesh
Sergey Y. Turin and Gregory A. Dumanian
- 10 Rectus Femoris Flap for Abdominal Wall Reconstruction

Alexander F. Mericli and Charles E. Butler

- 11** Lower Abdominal Wall Reconstruction With Lateral Thigh-Based Flaps
Dhivya R. Srinivasa and Jeffrey H. Kozlow
-

SECTION III BODY COUNTOURING

- 12** Abdominoplasty
Alan Matarasso and Darren M. Smith
- 13** Abdominal Panniculectomy
Devra B. Becker
- 14** Abdominal Panniculectomy in Super Obese Patients
David J. Rowe
- 15** Buttock Lift
Michele Shermak
- 16** Circumferential Body Lift
Joseph Michaels and Jennifer Capla
- 17** Lower Posterior Torso and Buttock Sculpting
Dennis J. Hurwitz
- 18** Gynecomastia Procedures after Massive Weight Loss
Michele Shermak
- 19** Mons Pubis Reduction
Michele Shermak
- 20** Upper Arm Lift (Brachioplasty)
Jennifer Capla and Joseph Michaels

- 21 Upper Thigh Lift
Michele Shermak
-

SECTION IV RECONSTRUCTION OF PERINEAL DEFECTS

- 22 Vertical Rectus Abdominis Myocutaneous Flap for Perineal Reconstruction
Sahil K. Kapur and Charles E. Butler
- 23 Gluteal Thigh Flap for Perineal Reconstruction
David Gerth and Christopher J. Salgado
- 24 Omental Flap for Pelvic Floor Reconstruction
Carrie K. Chu and Charles E. Butler
- 25 Posterior Labial Artery Flap for Vulvar and Vaginal Reconstruction
Chris A. Campbell
- 26 Vertical Rectus Abdominis Flap for Perineal Reconstruction
Dhivya R. Srinivasa and Jeffrey H. Kozlow
- 27 Gracilis Flap for Perineal and Vaginal Reconstruction
Ajani Nugent, Yasmina Zoghbi, and Christopher J. Salgado
- 28 Gender-Affirming Surgery
Katherine M. Gast and William M. Kuzon
-

SECTION V RECONSTRUCTION OF PRESSURE INJURIES

- 29 Gluteal Flaps for Sacral Pressure Injuries

Terri A. Zomerlei and Jeffrey E. Janis

30 Posterior Thigh and Hamstring Flaps for Ischial Ulcers
John Hulsen and Jeffrey E. Janis

31 Tensor Fascia Lata Flaps for Trochanteric Ulcers
Terri A. Zomerlei and Jeffrey E. Janis

32 Repair of Flank and Lumbar Defects
Sergey Y. Turin, Chad A. Purnell, and Gregory A. Dumanian

SECTION VI POSTERIOR TRUNK RECONSTRUCTION

33 Erector Spinae (Paraspinous) Muscle Flap
Lauren M. Mioton and Gregory A. Dumanian

34 Trapezius Muscle Flap
Lauren M. Mioton and Gregory A. Dumanian

35 Superior Gluteal Artery Perforator Flap
Lauren M. Mioton and Gregory A. Dumanian

36 Tissue Expansion for Trunk Defects
Ibrahim Khansa and Jeffrey E. Janis

37 Keystone Flaps
Theodore A. Kung and Peter C. Neligan

38 Treatment of Axillary Hyperhidrosis
David L. Larson

PART 6 HAND SURGERY

SECTION I **ANESTHESIA AND EMERGENCY PROCEDURES**

- 1 Anesthesia and Emergency Procedures
John R. Lien and Kevin C. Chung
- 2 Fasciotomy for Compartment Syndrome of the Hand and Forearm
John R. Lien and Kevin C. Chung
- 3 Revision Amputation and Shortening of the Digit
John R. Lien and Kevin C. Chung
- 4 Drainage of Septic Flexor Tenosynovitis
John R. Lien and Kevin C. Chung

SECTION II **HAND FRACTURES AND DISLOCATIONS**

- 5 Distal Phalanx Fractures
John R. Fowler and Thomas B. Hughes
- 6 Proximal Phalanx Fractures
John R. Fowler
- 7 Metacarpal Shaft Fractures
John R. Fowler and Thomas B. Hughes
- 8 Open Reduction for Carpometacarpal Joint Dislocation
John R. Fowler and Robert A. Kaufmann
- 9 Reconstruction of Acute and Chronic Ulnar Collateral Ligament Injuries of the Thumb
John R. Fowler and Robert A. Kaufmann

- 10 Closed Reduction and Fixation of Bennett and Rolando Fractures
John R. Fowler and Thomas B. Hughes
-

SECTION III **JOINTS**

- 11 Volar Plate Arthroplasty of the Proximal Interphalangeal Joint
James T. W. Saunders and Amy M. Moore
- 12 Hemihamate Arthroplasty for the Proximal Interphalangeal Joint Fracture Dislocation
David Wei, Mark A. Vitale, and Amy M. Moore
- 13 Thumb Carpometacarpal Joint Fusion With Locking Plates
John M. Felder and Amy M. Moore
-

SECTION IV **WRIST FRACTURES AND CARPAL INSTABILITY**

- 14 Arthroscopic Examination of the Wrist
Emily Krauss and Amy M. Moore
- 15 Ligament Reconstruction for Chronic Scapholunate Dissociation
Mark Morris and Kevin C. Chung
- 16 Lunotriquetral Ligament Reconstruction Using a Slip of the Extensor Carpi Ulnaris Tendon
Mark Morris and Kevin C. Chung
- 17 Fixation of Acute Scaphoid Fractures

Ketan Sharma, James T. W. Saunders, and Amy M. Moore

- 18** Scaphoid Nonunion: Nonvascularized Bone Reconstruction

Matthew L. Iorio and Jason H. Ko

- 19** Scaphoid Fracture Nonunion: Vascularized Bone Reconstruction

Matthew L. Iorio and Jason H. Ko

- 20** Open Reduction and Fixation of Acute Perilunate Fracture Dislocation

Grant M. Kleiber and Amy M. Moore

- 21** Dorsal Capsulodesis for Scapholunate Stabilization with Extensor Carpi Radialis Longus Tenodesis

Mark Morris and Kevin C. Chung

- 22** Proximal Row Carpectomy

Patrick Reavey and Amy M. Moore

SECTION V DISTAL RADIUS FRACTURES

- 23** Distal Radius Fractures

Shoshana W. Ambani and Kevin C. Chung

SECTION VI RHEUMATOID ARTHRITIS

- 24** Rheumatoid Arthritis of the Hand and Wrist

Shoshana W. Ambani and Kevin C. Chung

SECTION VII DEGENERATIVE DISEASE

-
- 25 Degenerative Disease of the Hand and Wrist
Shoshana W. Ambani and Kevin C. Chung
-

SECTION VIII NERVE CONDITIONS

- 26 Carpal Tunnel Release
Angelo B. Lipira and Jason H. Ko
- 27 Ulnar Tunnel Syndrome
Mary Claire Manske and Jason H. Ko
- 28 Cubital Tunnel Syndrome
Mary Claire Manske and Jason H. Ko
- 29 Radial Tunnel Decompression
Joseph Pirolo and Jason H. Ko
- 30 Primary Nerve Repair and Nerve Graft for Traumatic Nerve Injuries
Sonya paisley Agnew and Jason H. Ko
- 31 Tendon Transfers for Median Nerve Injury
Rafael J. Diaz-Garcia and Kevin C. Chung
- 32 Tendon Transfers for Ulnar Nerve Injury
Rafael J. Diaz-Garcia and Kevin C. Chung
- 33 Tendon Transfers for Radial Nerve Injury
Rafael J. Diaz-Garcia and Kevin C. Chung
- 34 Tendon Transfers for Combined Median and Ulnar Nerve Injury
Kate Elzinga and Kevin C. Chung

35 Distal Anterior Interosseous Nerve Transfer to Motor Branch of Ulnar Nerve
Shelley S. Noland and Jason H. Ko

36 Nerve Transfers for High Radial Nerve Palsy
Shelley S. Noland and Jason H. Ko

SECTION IX **TENDON CONDITIONS**

37 Acute Repair of Flexor Tendon Injuries
Jacques A. Machol IV, Neal Chen, and Kyle R. Eberlin

38 Repair of Multiple Flexor Tendon Injury at Wrist Zone V (Spaghetti Wrist)
Jacques A. Machol IV, Neal Chen, and Kyle R. Eberlin

39 Staged Flexor Tendon Grafting and Pulley Reconstruction
Richard Tosti, Jacques A. Machol IV, and Neal Chen

40 Tenolysis of Flexor Tendons
Richard Tosti, Jacques A. Machol IV, and Neal Chen

41 Acute Repair of Extensor Tendon Injuries in Zones I to VI
Michael Smith, Jacques A. Machol IV, and Neal Chen

42 Stabilization of Extensor Carpi Ulnaris Tendon Subluxation With Extensor Retinaculum
Michael Smith, Jacques A. Machol IV, and Neal Chen

43 Trigger Finger Release
Donato Perretta, Jacques A. Machol IV, and Neal Chen

44 First Dorsal Compartment (de Quervain) Release

SECTION X **FLAPS AND MICROSURGERY**

- 45 Flap Coverage of Fingertip Injuries
 Kate Elzinga and Kevin C. Chung
- 46 Flap Coverage of Thumb Defects
 Kate Elzinga and Kevin C. Chung
- 47 Reverse Flow Radial Forearm Flap
 Kate Elzinga and Kevin C. Chung
- 48 Ulnar Artery Perforator Flap
 Kate Elzinga and Kevin C. Chung
- 49 Posterior Interosseous Artery Flap
 Kate Elzinga and Kevin C. Chung
- 50 Free Lateral Arm Flap
 John R. Lien and Kevin C. Chung
- 51 Pedicled and Free Groin Flap
 Mark Morris and Kevin C. Chung
- 52 Free Anterolateral Thigh Flap
 John R. Lien and Kevin C. Chung
- 53 Revascularization and Replantation of Digits
 Mark Morris and Kevin C. Chung
- 54 Digital Artery Sympathectomy
 John R. Lien and Kevin C. Chung

- 55 Ulnar Artery to Superficial Arch Bypass With a Vein Graft
for Ulnar Artery Thrombosis
Mark Morris and Kevin C. Chung
- 56 Second Toe to Thumb Transfer
John R. Lien and Kevin C. Chung
-

SECTION XI **DUPUYTREN DISEASE**

- 57 Dupuytren Contracture
John R. Lien and Kevin C. Chung
-

SECTION XII **SPASTIC CONDITIONS**

- 58 Elbow Extension Procedures
Paymon Rahgozar and Kevin C. Chung
- 59 Wrist Extension Procedures
Paymon Rahgozar and Kevin C. Chung
- 60 Finger Extension Procedures
Paymon Rahgozar and Kevin C. Chung
- 61 Lateral Key Pinch Reconstruction
Paymon Rahgozar and Kevin C. Chung
- 62 Grasp Improvement Procedures
Paymon Rahgozar and Kevin C. Chung
-

SECTION XIII **CONGENITAL HAND DISORDERS**

- 63 Release of Finger Syndactyly Using Dorsal Rectangular

Flap
Amir H. Taghinia

- 64 Hypoplastic Thumb Reconstruction
Amir H. Taghinia
- 65 Reconstruction of Radial Polydactyly
Amir H. Taghinia
- 66 Index Finger Pollicization for Hypoplastic Thumb
Amir H. Taghinia, Brian I. Labow, and Joseph Upton
- 67 Second Toe-to-Thumb Transfer for Hypoplastic Thumb
Amir H. Taghinia, Brian I. Labow, and Joseph Upton
- 68 Reconstruction of Amniotic Constriction Bands
Amir H. Taghinia
- 69 Centralization for Radial Longitudinal Deficiency
Amir H. Taghinia, Brian I. Labow, and Joseph Upton
- 70 Excision of Vascular Malformation of the Hand
Amir H. Taghinia

SECTION XIV **TUMORS**

- 71 Lumps and Bumps of the Hand and Wrist
Paymon Rahgozar and Kevin C. Chung
- 72 Excision of Glomus Tumors
Paymon Rahgozar and Kevin C. Chung
- 73 Excision of Hemangioma of the Hand
Paymon Rahgozar and Kevin C. Chung

- 74 Excision of Metacarpal Enchondroma
 Paymon Rahgozar and Kevin C. Chung
- 75 Excision of Peripheral Nerve Schwannoma
 Paymon Rahgozar and Kevin C. Chung
- 76 Excision of Malignant Skin Tumors
 Paymon Rahgozar and Kevin C. Chung

Volume III

PART 7 LOWER LIMB RECONSTRUCTION AND AMPUTATION

SECTION I ANESTHESIA AND EMERGENCY PROCEDURES

- 1 Femoral and Adductor Canal Blocks
 Sarah Madison and Jean-Louis Horn
- 2 Popliteal Nerve Blocks
 Ming Zhuo-Stine and Sarah Madison
- 3 Ankle Block
 Andrew Lyons and Fred Mihm
- 4 Epidural Anesthesia
 Rachel C. Steckelberg, Jean-Louis Horn, and Sarah Madison

SECTION II FOOT, ANKLE, AND LOWER LEG

- 5 Fasciotomy of the Thigh, Lower Leg, and Foot
Graeme E. McFarland and Jason T. Lee
- 6 Drainage of Abscesses of Lower Leg and Foot
Michael Holland and Scott L. Hansen
- 7 Excision of Soft Tissue Tumors of the Foot and Ankle
Raffi S. Avedian, Robert J. Steffner, and Subhro K. Sen
- 8 Ankle and Foot Bone Tumors
Robert J. Steffner, Raffi S. Avedian, and Sahitya K. Denduluri
- 9 Debridement of Soft Tissue Infections of the Foot and Ankle
Hunter S. Oliver-Allen, Michael Holland, and Scott L. Hansen
- 10 Debridement of Infected Bone of the Foot and Ankle
Michael Holland and Scott L. Hansen
- 11 Bony Reconstruction of Foot and Ankle (Bone Grafts)
Kenneth J. Hunt and Loretta Chou
- 12 Reconstruction of the Forefoot
Rachel E. Hein and Scott T. Hollenbeck
- 13 The Medial Plantar Flap
Arash Momeni and Subhro K. Sen
- 14 Reconstruction of Heel and Plantar Defects: Free Flap
Goo-Hyun Mun and Kyong-Je Woo

- 15 The Reverse Sural Artery Flap for Lower Extremity Reconstruction
 Ashkaun Shaterian and Amber Leis
- 16 Ankle Reconstruction With Free Flap
 Sean S. Li, Ahmed Suliman, and Deepak M. Gupta
- 17 Vascular Reconstruction of Lower Extremity, Foot, and Ankle
 Michael Sgroi and Jason T. Lee
- 18 Management of Diabetic Foot Ulcers
 Rahim Nazerali
- 19 Nerve Repair and Reconstruction—Peroneal Nerve
 Shawn Moshrefi and Catherine Curtin
- 20 Achilles Tendon Reconstruction
 Hani Sbitany
- 21 Excision of Soft Tissue Tumors of the Lower Leg
 Raffi S. Avedian and Robert J. Steffner
- 22 Excision of Bone Tumors of the Lower Leg
 Raffi S. Avedian and Rohit K. Khosla
- 23 Debridement of Soft Tissue Infections of the Lower Leg
 L. Scott Levin, Paul Magnuson, and Paulo Piccolo
- 24 Tibial Reconstruction
 Vishwanath R. Chegireddy, Michael J. A. Klebuc, and Anthony Echo
- 25 Soft Tissue Coverage of Lower Leg—Free Flap

Goo-Hyun Mun and Kyong-Je Woo

- 26** Soft Tissue Coverage of Lower Leg—Soleus Flap
Rahim Nazerali and Lee L. Q. Pu
-

SECTION III **KNEE**

- 27** Nerve Repair and Reconstruction—Tibial Nerve
Shawn Moshrefi and Catherine Curtin
- 28** Excision of Soft Tissue Tumors of the Knee
Raffi S. Avedian
- 29** Excision of Bone Tumors of the Knee
Raffi S. Avedian
- 30** Bony and Soft Tissue Debridement Around the Knee
Derek F. Amanatullah, Michael J. Chen, Sahitya K. Denduluri, and James I. Huddleston
- 31** Bone Reconstruction of the Knee
Robert J. Steffner and Raffi S. Avedian
- 32** Soft Tissue Coverage of the Knee: Gastrocnemius Muscle Flap
Hani Sbitany
- 33** Soft Tissue Coverage of the Knee: Free Flaps
Goo-Hyun Mun and So Young Kim
- 34** Repair of Patella Tendon
Patrick Horrigan, Michael Bellino, and Julius Bishop
-

SECTION IV **THIGH**

-
- 35 Excision of Soft Tissue Tumors of the Thigh
 Raffi S. Avedian
- 36 Excision of Bone Tumors of the Femur
 Raffi S. Avedian
- 37 Femoral Bone Debridement
 Robert J. Steffner, David W. Lowenberg, and Sahitya K. Denduluri
- 38 Reconstruction of Femur
 Vishwanath R. Chegireddy, Michael J. A. Klebuc, and Anthony Echo
- 39 Soft Tissue Coverage of the Thigh—Pedicled Rectus Flap
 Brock Lanier and Alex Wong
- 40 Soft Tissue Coverage of Thigh-Free Flaps
 Ulrich Kneser and Thomas Kremer
- 41 Nerve Repair and Reconstruction—Sciatic Nerve and Femoral Nerve
 Gabrielle B. Davis and Catherine Curtin
- 42 Keystone and Related Perforator Flaps
 Michael W. Findlay

SECTION V **AMPUTATION AND REPLANTATION**

- 43 Amputation of the Lower Extremity: Toes, Foot, Ankle
 Kedar S. Lavingia and Jason T. Lee
- 44 Amputation of the Lower Extremity: Above-Knee

Amputation, Below-Knee Amputation, Through-Knee Amputation
Anahita Dua and Jason T. Lee

SECTION VI **LYMPHEDEMA**

- 45 Lymphaticovenous Anastomosis
Ann-Charlott Docherty Skogh and Martin Halle
 - 46 Lymphedema: Lymph Node Transfer
Adrian S. H. Ooi and David W. Chang
 - 47 Fasciocutaneous Debulking of Extremity Lymphedema: The Charles Procedure
Clifford C. Sheckter and Peter Johannet
 - 48 Liposuction for Treatment of Lymphedema
Dung Nguyen and Joseph Baylan
-

SECTION VII **BURNS**

- 49 Acute Management: Tangential Excision and Skin Grafting
Yvonne Karanas
- 50 Reconstruction of Contractures: Z-Plasty, Skin Grafting, and Flaps
Xiangxia Liu
- 51 Soft Tissue Reconstruction with Propeller Flaps
Adam Jacoby, John T. Stranix, and Pierre Saadeh

PART 8 **PEDIATRICS**

SECTION I **CLEFT LIP**

- 1 Anatomical Subunit Repair of Unilateral Cleft Lip
David K. Chong and Kathryn V. Isaac
- 2 Unilateral Cleft Lip Repair: Millard/Mohler Modifications
Roberto L. Flores and Gerald J. Cho
- 3 Salyer Unilateral Cleft Lip/Nose Repair
Kenneth E. Salyer

SECTION II **CLEFT PALATE REPAIR**

- 4 Lip Adhesion
Catharine B. Garland, Jesse A. Goldstein, and Joseph E. Losee
- 5 Bilateral Cleft Lip Repair
John A. van Aalst
- 6 Secondary Deformities
Catharine B. Garland, Jesse A. Goldstein, and Joseph E. Losee
- 7 Delayed Hard Palate Repair in UCLP Patients
Jan Lilja
- 8 Furlow Palatoplasty
T. Guy Thorburn
- 9 von Langenbeck Palatoplasty
Kathryn V. Isaac and David K. Chong

- 10 Sommerlad Palatoplasty
T. Guy Thorburn
 - 11 Two-Flap Palatoplasty
David K. Chong, Kathryn V. Isaac, and Kenneth E. Salyer
 - 12 Tongue-Lip Adhesion/Floor of Mouth Muscle Release for Pierre Robin Sequence
Chad A. Purnell and Arun K. Gosain
 - 13 Palatal Fistula
Gregory D. Pearson
 - 14 Velopharyngeal Insufficiency
Jennifer L. McGrath and Arun K. Gosain
-

SECTION III **CLEFT RHINOPLASTY**

- 15 Secondary Cleft Rhinoplasty
Ali Totonchi and Ji H. Son
-

SECTION IV **ATYPICAL CLEFTS-SOFT TISSUE COMPONENT**

- 16 Tessier 3 and 4 Clefts (Nasal-Cheek Region)
Philip Kuo-Ting Chen and Vikram S. Pandit
 - 17 Tessier 7—Macrostomia Repair
Patrick A. Gerety and Scott P. Bartlett
-

SECTION V **CUTANEOUS LESIONS**

- 18 Tissue Expansion for Congenital Nevi
Lee W. T. Alkureishi and Bruce S. Bauer
 - 19 Surgical Treatment of Congenital Midline Nasal Mass
Patrick A. Gerety and Scott P. Bartlett
-

SECTION VI **SOFT TISSUE MASSES**

- 20 Surgery of Neurofibromatosis in the Pediatric Patient
McKay McKinnon
 - 21 Vascular Anomalies
Arin K. Greene and Jeremy A. Goss
-

SECTION VII **PEDIATRIC BURNS AND WOUNDS**

- 22 Functional Burn Reconstruction
David A. Billmire and Kim A. Bjorklund
- 23 Harvesting a Skin Graft
David A. Billmire and Kim A. Bjorklund
- 24 Burned Hand Reconstruction
David A. Billmire and Kim A. Bjorklund
- 25 Reconstruction of Burned Eyelids
David A. Billmire and Kim A. Bjorklund
- 26 Burn Neck Contracture Release
David A. Billmire and Kim A. Bjorklund
- 27 Adolescent Burned Breast Reconstruction
David A. Billmire and Kim A. Bjorklund

- 28 Pressure Injuries (Sacral and Pelvic Region, Columella—
From CPAP)
David A. Billmire and Kim A. Bjorklund
 - 29 Pressure Injuries
Lawrence J. Gottlieb and Maureen Beederman
 - 30 Vascular Lesions
Benjamin C. Garden and Jerome M. Garden
 - 31 Laser Burn Scar Revision
C. Scott Hultman and Yuen-Jong Liu
 - 32 Fat Grafting for Nerve Entrapment Within Burn Scars
C. Scott Hultman and Yuen-Jong Liu
-

SECTION VIII **EAR RECONSTRUCTION**

- 33 Auricular Reconstruction for Microtia and Post-Traumatic
Deformities
Charles H. Thorne
 - 34 Stahl Ear
Akira Yamada and Arun K. Gosain
 - 35 Constricted Ear
Akira Yamada and Julia Corcoran
 - 36 Cryptotia
Akira Yamada and Arun K. Gosain
 - 37 Prominent Ear
Akira Yamada and Arun K. Gosain
-

SECTION IX EYELID RECONSTRUCTION

- 38 Eyelid Coloboma
Adam R. Sweeney and Christopher B. Chambers
 - 39 Congenital Ptosis
Adam R. Sweeney and Christopher B. Chambers
 - 40 Epiblepharon
Adam R. Sweeney and Christopher B. Chambers
 - 41 Canthopexy
Adam R. Sweeney and Christopher B. Chambers
 - 42 Nasolacrimal Duct Obstruction
Emily M. Zepeda, Sarah M. Jacobs, and Christopher B. Chambers
 - 43 Management of the Microphthalmic or Anophthalmic Orbit
Sarah M. Jacobs and Christopher B. Chambers
-

SECTION X NASAL RECONSTRUCTION

- 44 Nasal Tip Hemangioma
T. Kwan-Wong and Jugpal S. Arneja
 - 45 Nasal Septal Hematoma
Whitney L. Quong and Jugpal S. Arneja
-

SECTION XI PEDIATRIC NECK MASSES

- 46 Branchial Cleft Sinuses and Cysts
Mark Felton, Jugpal S. Arneja, and Neil K. Chadha

- 47 Thyroglossal Duct Cysts
Mark Felton, Jugpal S. Arneja, and Neil K. Chadha
-

SECTION XII **FACIAL REANIMATION**

- 48 Sural Nerve Harvest
Andre P. Marshall, Jeffrey R. Marcus, and Michael R. Zenn
- 49 Cross Face Nerve Graft
Michael J. A. Klebuc
- 50 Motor Branch of Masseter for Innervation of Free Muscle Flap
Michael J. A. Klebuc
- 51 Masseter-to-Facial Nerve Transfer
Michael J. A. Klebuc
- 52 Pediatric Facial Reanimation Using a Functional Gracilis Muscle Transfer
Brad M. Gandolfi, Jeffrey R. Marcus, and Michael R. Zenn
- 53 Corneal Neurotization
Joseph Catapano, Ronald Zuker, Asim Ali, and Gregory H. Borschel
-

SECTION XIII **BRACHIAL PLEXUS (OBSTETRICAL INJURY)**

- 54 Primary Treatment of Neonatal Brachial Plexus Palsy
Bryce R. Bell, Ji-Geng Yan, and Hani Matloub

- 55 Secondary Neonatal Brachial Plexus Palsy Reconstruction
Joshua M. Adkinson
-

SECTION XIV **LOWER EXTREMITY**

- 56 Rotationplasty of the Lower Extremity
Samer Attar, Robert J. Steffner, and Terrance D. Peabody
-

SECTION XV **BREAST**

- 57 Poland Syndrome
Patrick J. Buchanan and Paul S. Cederna
- 58 Gynecomastia
Dennis Hammond and Eric Yu Kit Li
- 59 Juvenile Hypertrophy
Dennis Hammond and Eric Yu Kit Li
- 60 Pectus Excavatum and Pectus Carinatum
Jamie C. Harris and Fizan Abdullah
-

SECTION XVI **THORAX AND BACK**

- 61 Myelomeningocele: Postnatal Repair
Gregory G. Heuer and Jesse A. Taylor
- 62 Myelomeningocele, Prenatal (Fetal) Repair
Gregory G. Heuer and Scott N. Adzick
- 63 Sacrococcygeal Teratoma

SECTION XVII **ABDOMEN**

- 64 Prune Belly
Jamie C. Harris and Fizan Abdullah
 - 65 Gastroschisis and Omphalocele
Jamie C. Harris and Fizan Abdullah
 - 66 Management of the Open Abdomen
Alexander F. Mericli and Charles E. Butler
 - 67 Umbilicoplasty
Sergey Y. Turin, Chad A. Purnell, and Gregory A. Dumanian
-

SECTION XVIII **PERINEUM**

- 68 Hypospadias Repair
Christopher D. Morrison and Earl Y. Cheng
 - 69 Vaginal and Vulvar Reconstruction
Elizabeth B. Yerkes and Julia Corcoran
 - 70 Ambiguous Genitalia
Deborah L. Jacobson and Elizabeth B. Yerkes
-

SECTION XIX **EMERGENCY DEPARTMENT LACERATIONS**

- 71 Facial Laceration Emergency Room Closure Techniques
Christina Pasick and Peter J. Taub

SECTION XX **CRANIOFACIAL PROSTHETICS**

- 72** Craniofacial Anaplastology: Prosthetic Osseointegration
Chad A. Purnell, Rosemary Seelaus, and Pravin K. Patel
-

SECTION XXI **CONJOINED TWINS**

- 73** Conjoined Twin Separation
Michael R. Bykowski, Joseph E. Losee, and Lorelei J. Grunwaldt

Index I-1

[†]Deceased

Video Clips

PART 1

- Chapter 1 Injection of Botulinum Toxin into the Glabellar Region
- Chapter 3 Injection of Botulinum Toxin into Crow's Feet
- Chapter 6 Injection of Botulinum Toxin into the DAO
- Chapter 12 Nasolabial Fold Filler Injection
- Chapter 14 Soft Tissue Injection 1
Soft Tissue Injection 2
Soft Tissue Injection 3
Soft Tissue Injection 4
Soft Tissue Injection 5
- Chapter 31 Transconjunctival Approach to Resection and/or Repositioning of Lower Eyelid Herniated Orbital Fat
- Chapter 33 Transconjunctival Redraping
- Chapter 70 Alar Contour Grafts
- Chapter 76 Genioplasty 1
Genioplasty 2

PART 2

- Chapter 2 Cranial Vault Expansion
- Chapter 9 Monobloc Distraction
- Chapter 23 Segmental Le Fort I Advancement: Two and Three

- Piece
- Chapter 29 Secondary Alveolar Bone Grafting of the Cleft Alveolar Defect in Cleft Palate
- Chapter 37 Right-Side Osteotomy
Splitting Right Side Nerve
Verifying Split
Left-Side Osteotomy and ST Dissection
Left-Side Osteotome and Split
Applying Wire Loops
Verification
- Chapter 53 Correction of Orbital Floor Blowout Fractures: Variation 1
- Chapter 54 Correction of Orbital Floor Blowout Fractures: Variation 2
- Chapter 60 Open Reduction for Nasal Fracture
- Chapter 73 Midface Exposure
Zygomaticofacial Repair, Part 1
Zygomaticofacial Repair, Part 2
Zygomaticofacial Repair, Part 3

PART 3

- Chapter 1 Infraorbital Nerve Block
- Chapter 6 Calvarial Graft Harvest
- Chapter 7 Rib Graft Harvest
- Chapter 12 Osteocutaneous Scapular Flap
- Chapter 24 Tarsal Strip Canthoplasty
- Chapter 43 Glossectomy
- Chapter 46 Anterolateral Thigh Flap
- Chapter 51 Labbé Procedure

PART 4

- Chapter 5 Transgender Breast
- Chapter 13 Delayed Tissue Expander
- Chapter 17 Direct to Implant Breast Reconstruction
- Chapter 20 Free TRAM Flap: Fascial and Intramuscular Dissection

PART 5

- Chapter 7 Minimally Invasive Anterior Components Separation
- Chapter 9 Anterior Components Release Technique
Ventral Hernia Repair
- Chapter 15 Buttock Lift, Part 1
Buttock Lift, Part 2
- Chapter 17 VASERlipo Buttock Augmentation
Lipoabdominoplasty/Flankplasty/Lipoaugmentation of the Buttocks
Silicone Elastomer Buttock Augmentation
- Chapter 32 Flank Hernia Repair Technique
- Chapter 33 Erector Spinae Muscle Flap

PART 7

- Chapter 14 Reconstruction of Heel and Plantar Defects: Free Flap
- Chapter 25 Soft Tissue Coverage of Lower Leg (Free-Flap)
- Chapter 31 Bony Reconstruction of the Knee

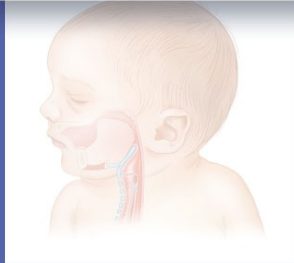
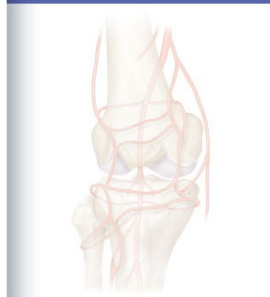
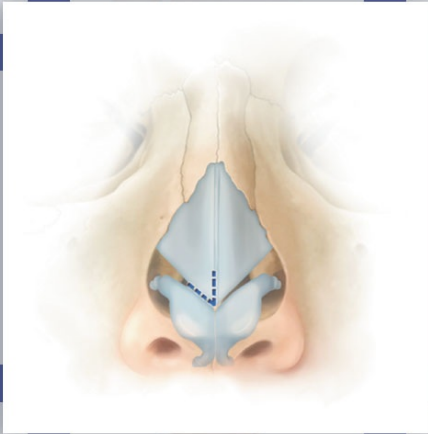
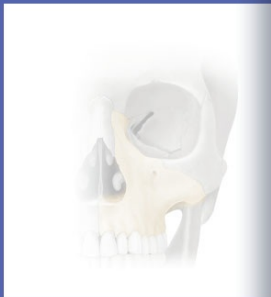
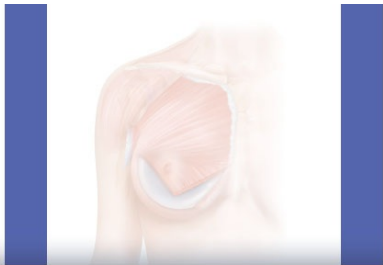
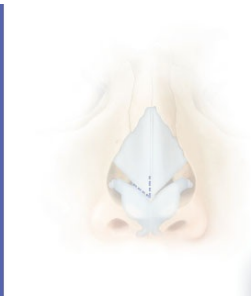
- Chapter 40 Soft Tissue Coverage of Thigh—
Free Flaps
- Chapter 45 ICG Lymphography
- Chapter 48 Liposuction for Lymphedema
- Chapter 49 Tangential Excision, Part 1
Tangential Excision, Part 2
Tangential Excision, Part 3

PART 8

- Chapter 12 Tongue-Lip Adhesion
- Chapter 21 Vascular Anomalies
- Chapter 31 Fractional Carbon Dioxide Laser
Pulsed Dye Laser
- Chapter 32 Puregraft
Lipovage
- Chapter 48 Sural Nerve Harvest
- Chapter 51 Masseter-to-Facial Nerve Transfer
- Chapter 52 Facial Reanimation
- Chapter 55 PT Release
FCU to ERCB Tendon Transfer for Wrist Extension
- Chapter 67 Umbilicoplasty

PART 1

Facial Aesthetic



Section I: Techniques for Botulinum Toxins in the Face

1 **Injection of Botulinum Toxin to the Glabellar Region**

CHAPTER

Jonathan Sykes, Peter Palhazi, and Amir Allak

DEFINITION

- Hyperfunctioning of muscles in the periorbital region results in a tired, aged appearance and increased rhytids.
- Hyperdynamic glabellar musculature can create an angry appearance, whereas overuse of the lateral eyelid muscles can narrow the eyelid aperture.
- The position and orientation of the eyebrow is related to the relative strength and contraction of the brow depressors vs the brow elevators.
- The only elevators of the eyebrow are the paired frontalis muscles, whereas depression of the eyebrow is accomplished by contraction of the midline procerus muscles, the paired corrugator, and orbicularis oculi muscles.
- Treatment with botulinum toxin can lessen the contraction of hyperdynamic periorbital muscles and can improve the eyelid aperture, improve brow position, and decrease periorbital rhytids.¹

ANATOMY

- The corrugator supercilii (CS) are paired, obliquely oriented muscles located in the inferomedial brow deep to the inferior portion of the frontalis muscles.
- The CS muscle originates from the bony superomedial orbital rim and passes in a superior and lateral direction to insert onto the fascia of the frontalis muscle and into the overlying skin (**FIG 1**).

- In addition to coursing superiorly and laterally from its insertion, the CS becomes more superficial as it travels laterally.

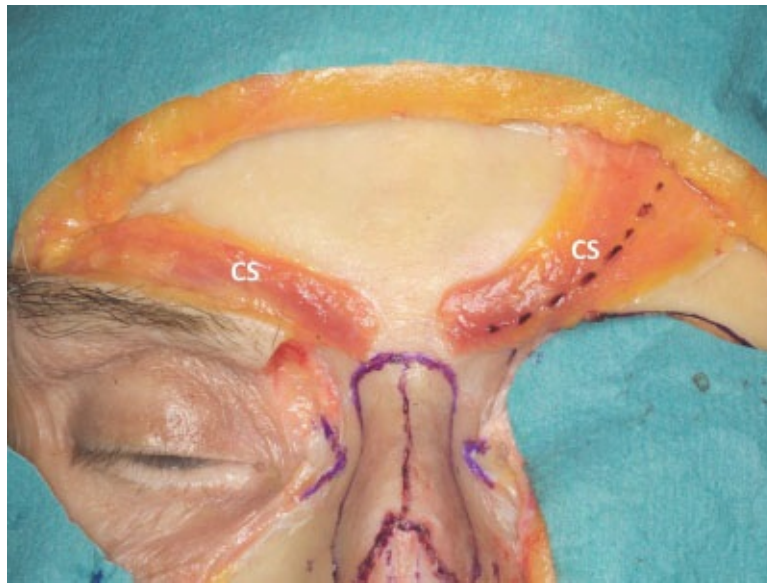


FIG 1 • Cadaveric dissection of the relationship of the corrugator muscle to the nasal root and frontalis. CS, corrugator supercilii.

- The CS muscle body is pierced by the supraorbital and supratrochlear neurovascular bundles carrying sensory input to the trigeminal nerve (V1). The nerves then pierce the frontalis muscles approximately 2 to 3 cm above the supraorbital rim to travel subcutaneously to the forehead and scalp (**FIG 2**).
- The medial head of the CS has motor innervation from the zygomatic branch of the facial nerve, whereas the lateral portion is supplied by the temporal branch of the nerve.
- Contraction of the muscle causes vertical grooves in the glabellar skin and imparts an angry expression. Contraction also causes an inferomedial descent of the medial clubhead of the brow.
- The procerus is a midline flat and pyramidally shaped muscle located at the root of the nose contributing to upper nasal contour.
- The procerus originates from the periosteum and perichondrium of the nasal bones and upper lateral cartilages and from the fascia of the nasal superficial musculoaponeurotic system (SMAS) (see **FIG 2**).
- Procerus inserts into the midline skin overlying the nasal root and

interdigitates superiorly with the frontalis muscle (see **FIG 2**).

- The motor innervation to the procerus is supplied by the zygomatic branch of the facial nerve.
- Contraction of the midline muscle is responsible for horizontal glabellar rhytids, transverse rhytids on the nasal dorsum, and descent of the medial brow.

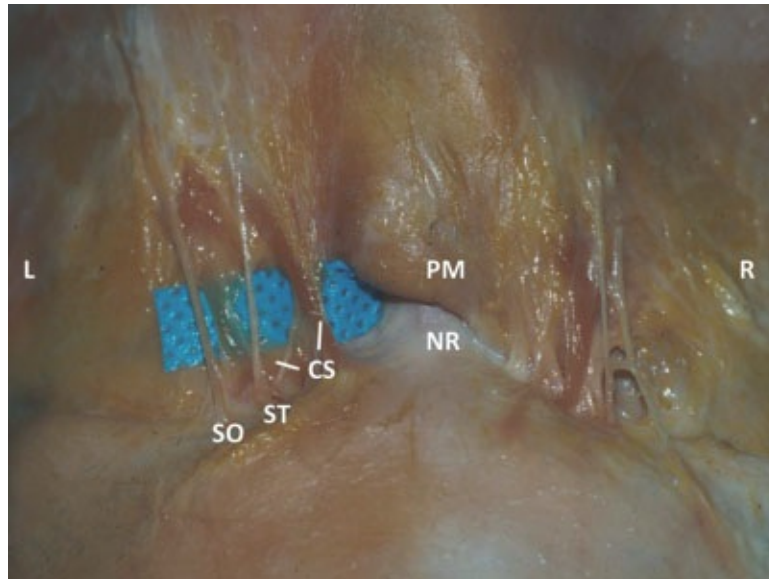


FIG 2 • Cadaveric dissection with coronal forehead flap elevated viewed from the superior aspect of the head. L, patient's left; R, patient's right; SO, supraorbital neurovascular bundle; ST, supratrochlear neurovascular bundle; NR, nasal root (indicating midline); PM, procerus muscle.

PATIENT HISTORY AND PHYSICAL FINDINGS

- It is important to evaluate the eyebrow and eyelid margin position prior to any injection of botulinum toxin in the periorbital region.
- The position of the eyebrow is related to the relative contraction of the brow elevator (the frontalis muscle) vs the brow depressors (the CS and procerus muscles medially and the orbicularis oculi muscle laterally).
- In patients who are brow depressor dominant, the brow will assume a relatively inferior position and appear ptotic; chemodenervation will elevate

the brow and enhance periorbital appearance.

- The position of the upper eyelid margin in relation to the globe is also important to evaluate prior to any botulinum toxin injection in the periorbital region. The amount of ptosis is related to the amount of globe coverage by the upper eyelid.
- The distance from the superior to the inferior limbus of the globe is 11 mm in most adults with the upper eyelid typically covering the superior limbus by 1 mm. If the upper eyelid position is inferior to this level, the lid is considered ptotic.
- It is important to diagnose any upper eyelid ptosis preinjection as any injection into the periorbital musculature will affect brow position and injection into the frontalis muscle in patients with eyelid ptosis may cause a decrease in the visual field.
- Any asymmetries in eyebrow and/or upper eyelid position should be noted, documented, and discussed with the patient before injection of botulinum toxin.
- Hypercontraction of the corrugator muscles produces an angry, scowling appearance. Muscular contraction depresses the medial clubhead of the brow and causes a vertical fold that appears at right angles to the muscular axis.
- The brow clubhead is moved both medially and inferiorly with contraction of the corrugator. This is important in patients who have cosmetically removed medial brow hairs, as injection of botulinum toxin will cause elevation and lateralization of the brow clubhead.
- Hypercontraction of the procerus muscle draws the medial brow inferiorly and causes a horizontal furrow at the root of the nose.
- Injection of botulinum toxin of the procerus causes elevation of the medial brow and lessens the horizontal deep rhytid at the nasal root.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients should be screened for neuromuscular disorders including amyotrophic lateral sclerosis, myasthenia gravis, and Eaton-Lambert syndrome because these are contraindications for the use of the product.
- Use in pregnant or nursing mothers is not advised, though no studies have shown teratogenic damage to fetus or adverse effects to breast-feeding infants.
- Patient medications should be screened for aminoglycoside antibiotics because

these affect the pharmacokinetics of the toxin and can potentiate the effects.

Positioning

- The patient is examined in an upright position along with full facial analysis. The treatment position is surgeon preference, upright, slightly recumbent, or supine.

Approach

- Delivery of the product is performed uniformly with percutaneous injection.

TECHNIQUES



Video p1-c001

■ Injection of Botulinum Toxin Into the Glabellar Region

- Topical anesthetic cream, commonly containing lidocaine, is applied and left in place for a minimum of 15 to 20 minutes and sometimes longer for maximal anesthetic effect.
- Botox is reconstituted into sterile injectable saline to the concentration of 2.5 to 4 units/0.1 mL. This is drawn up into a 1-cc syringe, and a 30-gauge short Luer Lock needle is prepared for injection.
- To avoid any spread of toxin into the extraocular muscles, or the upper

eyelid retractors (levator aponeurosis and Müller muscle), the needle is usually directed away from the globe.

- Injection of the glabellar muscles should be performed with a no. 30- to no. 32-gauge needle.
- Approximately 20 to 25 units of botulinum toxin (or equivalent) are typically sufficient to treat the glabellar musculature including both the CS and procerus. This is usually distributed in a V-shaped pattern with the apex at the nasal root.
- The medial corrugator/depressor (clubhead) injection should be deep (just superficial to bone), and the tail of the muscle should be injected closer to the skin with the needle tangential to the skin.
- Injection of toxin into the procerus should be at moderate depth over the midline of the nasal root, with the needle being placed perpendicular to the skin at the nasion.

PEARLS AND PITFALLS

Avoidance of denervation and ptosis of eyelid and brow

- To avoid diffusion of toxin into eyelid elevator muscles and ptosis, injection should be directed superiorly and obliquely.
- If injection is performed too far superiorly above the region of the corrugator, the medial inferior frontalis muscle can be affected causing medial brow ptosis.

Dosing

- A total of 20–25 units of Botox (or equivalent) is typically used for treatment of the glabellar muscles.
- A higher dosage may be necessary in males for optimal results.

POSTOPERATIVE CARE

- Ice packs should be provided to the patient and placed immediately after injection.
- Some patients may bruise post procedure, especially if anticoagulated. This can be expected to resolve in several days.
- Avoidance of topical massage for 24 hours postinjection is suggested. Although some injectors suggest exercising injected facial muscles for 24

hours after a botulinum toxin injection, there is no evidence to prove that this affects outcomes.

OUTCOMES

- Onset of effect usually become apparent in 1 week.
- The neuromodulation is commonly effective for 12 to 20 weeks wherein it would need to be redosed for continued effect. This can vary from patient to patient.
- The outcome of botulinum toxin injection into the glabellar musculature is to decrease or alleviate the glabellar frown lines and elevate the medial brow. The cumulative effect is to eliminate the frowning or scowling appearance.²
- Satisfaction after injection of glabellar botulinum toxin is usually high. The procedure is simple, is fast, and causes no to very minimal downtime.
- If all of the musculature is not denervated after an injection and the patient requests additional toxin, it is simple to add toxin during a follow-up office visit.

COMPLICATIONS

- Inadvertent spread of the toxin into the upper eyelid retractor muscles can cause ptosis of the upper eyelid via diminished contraction of the levator aponeurosis/Müller muscle complex, allowing the eyelid protractors (orbicularis oculi muscles) to dominate the eyelid position.³
- If upper eyelid ptosis occurs, treatments exist to elevate the ptotic upper eyelid. These treatments are designed to strengthen the eyelid retractors or to slightly weaken the upper lid protractors. Either of these treatments changes the protractor/retractor muscle balance, thereby elevating the ptotic eyelid.
- Initial treatment in patients with toxin-induced ptosis is to instill topical sympathomimetic eye drops. Topical drops, such as apraclonidine, stimulate the sympathetic nervous system causing contraction of Müller muscle, resulting in 1 to 3 mm of upper eyelid elevation. The drops are placed every 6 to 8 hours as needed to alleviate the ptosis.
- The other means to treat inadvertent upper eyelid ptosis is to inject small amounts of additional botulinum toxin into the pretarsal fibers of the orbicularis oculi muscles. Diminishing the tone and contraction of the upper eyelid protractor (orbicularis oculi muscle) also can result in upper eyelid elevation and treatment of the ptotic eyelid.

ACKNOWLEDGMENT

The authors thank Sebastian Cotofana, MD, PhD, for his contribution to the preparation of this chapter.

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2 Injection of Botulinum Toxin to the Forehead

CHAPTER

David A. Sieber and Jeffrey M. Kenkel

DEFINITION

- *Static rhytids*: wrinkles in the skin present at rest
- *Dynamic rhytids*: wrinkles in the skin present with muscle activation/animation

ANATOMY

- Frontalis muscle: broad, fan-shaped muscle originating from the galea aponeurotica below the coronal suture with insertions interdigitating into the procerus, corrugator supercilii, depressor supercilii, and orbicularis oculi^{1,2} (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients will present complaining of static and/or dynamic rhytids on their forehead.
- Have the patients contract their frontalis muscles by asking them to raise their brows and assess:
 - Muscle length and width
 - Strength of muscle (with stronger muscles having a few coarse rhytids and weaker muscles with many fine rhytids)
 - Whether muscle has a decussation in the midline
 - Activity beyond temporal fusion line
- Notice any superficial blood vessels, as injury of these during injection will cause unnecessary post-treatment bruising.
- Take note of brow position, depth, and strength of frontalis muscle as weakening the frontalis muscle may worsen an already low brow or one that is

held in position with activation.

NONOPERATIVE MANAGEMENT

- Nonoperative management using any form of the currently available botulinum toxins (onabotulinumtoxinA, abobotulinumtoxinA, and incobotulinumtoxinA) is able to successfully treat forehead rhytids.

Positioning

- The patient should be comfortably seated in an upright position.

Approach

- The forehead may be injected either from the side of the patient or behind the patient's head.
- It is the author's preferred approach to inject standing to the side of the patient.
- When injecting from one side of the patient only, it is important to be cognizant that the contralateral side is treated as desired and directed by assessments done from the front of the patient.

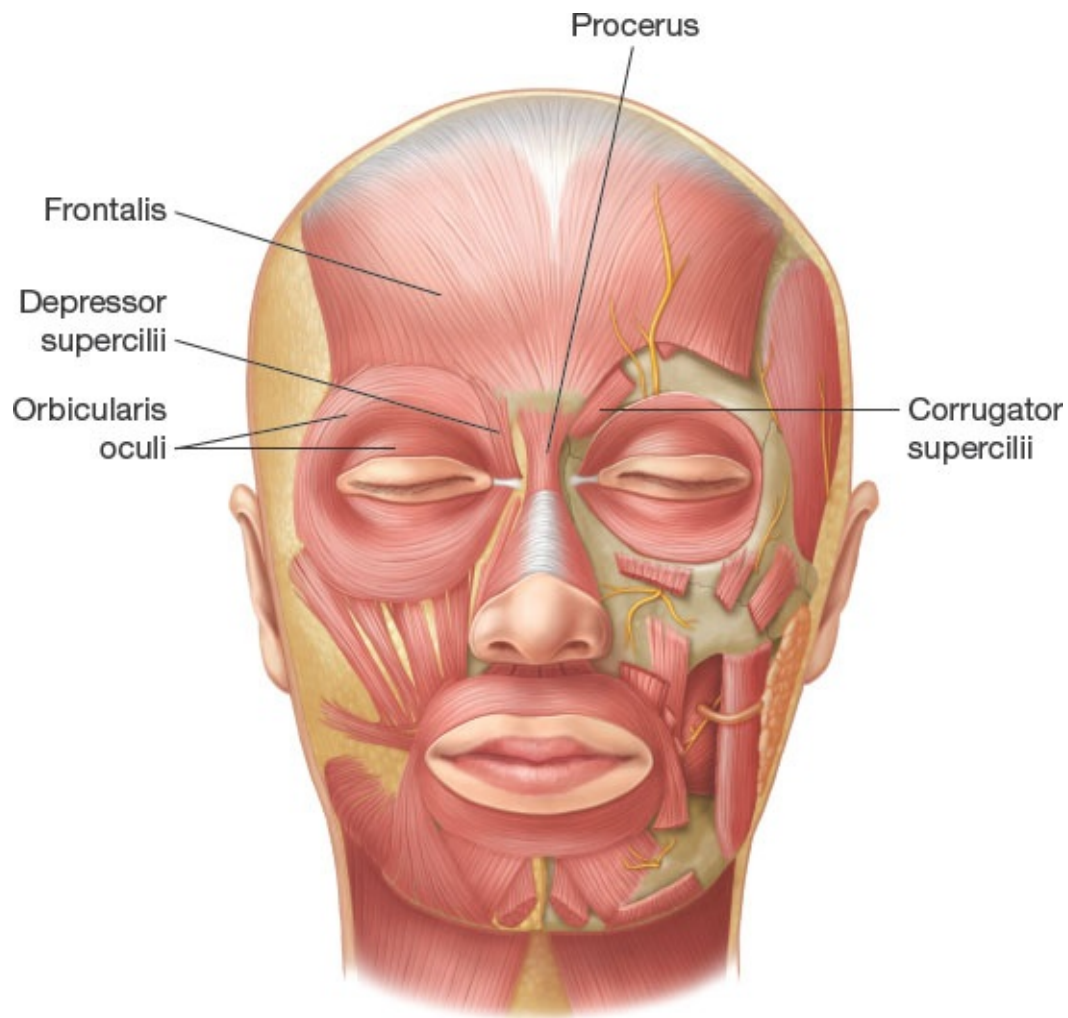


FIG 1 • Shape of the frontalis muscle with insertions in the orbicularis oculi, corrugator supercillii, depressor supercillii, and procerus muscles.

TECHNIQUES

■ Injection of Botulinum Toxin in the Forehead

- The botulinum is mixed according to manufacturer recommendations or physician preference.
- Skin is prepped using alcohol and ice may be applied for anesthetic and as a distractor.

- The patient is asked to animate to demonstrate muscular boundaries (see above).
- Injections start medially and proceed across the patient's forehead. The neurotoxin is placed superficially beneath the dermis and raises a small skin wheal. Additional rows of neurotoxin are placed above or below as needed.
- Care should be taken when injecting around the brows as diffusion of the product into the levator palpebrae superioris may cause the patient to have temporary upper lid ptosis.
- To prevent this, injections should not be performed beneath the lowest brow crease or less than 2 cm above the orbital rim.

PEARLS AND PITFALLS

Technique	■ To avoid upper lid ptosis, neurotoxin should not be placed below the lowest dynamic rhytid or less than 2 cm above the orbital rim.
Technique	■ Dosing and placement are determined by pretreatment assessment and often may include a dose of toxin lateral to the temporal crest and in the midline (in contrast to classic definitions of the frontalis).
Patient selection	■ Patients with severe brow ptosis and strong dynamic lines may need to be declined treatment with neurotoxins to avoid exacerbation of brow ptosis.

POSTOPERATIVE CARE

- Patients are sent home with small pack of ice and may apply as needed for swelling and/or bruising.

OUTCOME

- Excellent outcomes are achievable as demonstrated in **FIG 2** with preservation of natural brow position and shape (see **FIG 2**).



FIG 2 • A 44-year-old female before **(A)** and after **(B)** having 38 units of onabotulinumtoxinA placed into her forehead, glabella, and crow's feet. Note the preservation of brow shape and position after treatment as well as slight opening of orbital aperture.

COMPLICATIONS

- Patients should be counseled on possible risks of procedure including bleeding, bruising, brow and upper eyelid ptosis, and facial asymmetry.

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3 Injection of Botulinum Toxin to Soften Crow's Feet

CHAPTER

Sammy Sinno

DEFINITION

- *Lateral canthal lines*, or “crow’s feet,” are one or more radial lines extending laterally from the lateral canthus (**FIG 1**).

ANATOMY

- The orbicularis oculi muscle is responsible for the appearance of crow’s feet. Chronic contraction of this muscle (during squinting and smiling) as well as thinning of the dermis with age accentuates these lines.



FIG 1 • Lateral canthal lines, or “crow’s feet.”

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with crow's feet at rest commonly present initially in their 40s and 50s, though younger patients who desire softening of their crow's feet during animation may present earlier.

IMAGING

- No imaging is required for this procedure.

MANAGEMENT

Preoperative Planning

- The patient is asked to smile and squint repeatedly. The crow's feet radiating from the lateral canthus are noted.

Positioning

- The patient is seated in an upright position.

TECHNIQUES

- After allowing 30 to 45 minutes for topical anesthetic to take effect, a cooling device is used to further desensitize the area of injection.
- 12 units of botulinum toxin are then injected on each side:
 - 4 units at 1 cm lateral to the lateral canthus
 - 4 units directly above
 - 4 units directly below (**TECH FIG 1**)
- Care is taken on the inferior injection to avoid the zygomaticus major muscle, which would cause unwanted smile abnormalities.



TECH FIG 1 • Target areas marked for injection into the orbicularis oculi muscle.

PEARLS AND PITFALLS

Anesthesia	■ Allow adequate time for topical anesthesia to take effect.
Injection	■ Inject 1 cm lateral to the lateral canthus. ■ 12 units of botulinum toxin should be injected per side. ■ Avoid injection into the zygomaticus major muscle.
Postoperative care	■ Avoid strenuous exercise for 1–2 d. ■ No tight goggles for 3 d. ■ Sleep on back for 1–2 d postprocedure.

POSTOPERATIVE CARE

- Cold compresses are given following injection to minimize postprocedure bruising and edema.
- Patients are instructed to sleep on their backs for 1 to 2 days postprocedure and avoid wearing goggles for 3 days to avoid migration of toxin and unwanted

effects.

- Strenuous exercise is permitted after 1 to 2 days.

OUTCOMES

- See pre- and postprocedure photos.

COMPLICATIONS

- Inadvertent injection into the zygomaticus major muscle can cause unwanted smile deformity.
- Migration of toxin postprocedure can also have unwanted effects including brow ptosis.

4 Injection of Botulinum Toxin for Treatment of the Gummy Smile

CHAPTER

David A. Sieber and Jeffrey M. Kenkel

DEFINITION

- Gummy smile is the hyperactivity of the levator labii superioris alaeque nasi with animation causing excess upper lip elevation and exposure of the gums.

ANATOMY

- The levator labii superioris alaeque nasi originates on the medial wall of the maxilla and then divides into two heads that insert into the nasal ala and medial orbicularis oris (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients may present complaining of “too much teeth or gums showing while smiling” or may also state that their “upper lip is too short” with animation.

NONOPERATIVE MANAGEMENT

- Nonoperative management using any form of the currently available botulinum toxins (onabotulinumtoxinA, abobotulinumtoxinA, and incobotulinumtoxinA) can successfully treat a gummy smile. Typically, 2 to 4 units per side are selected as a starting dose, depending on degree of deformity and prior patient injection history.

Positioning

- The patient should be comfortably seated in an upright position.

Approach

- It is the authors’ preferred approach to inject standing to the side of the patient.

- When injecting from one side of the patient only, it is important to ensure that both sides are treated in the same anatomical locations.

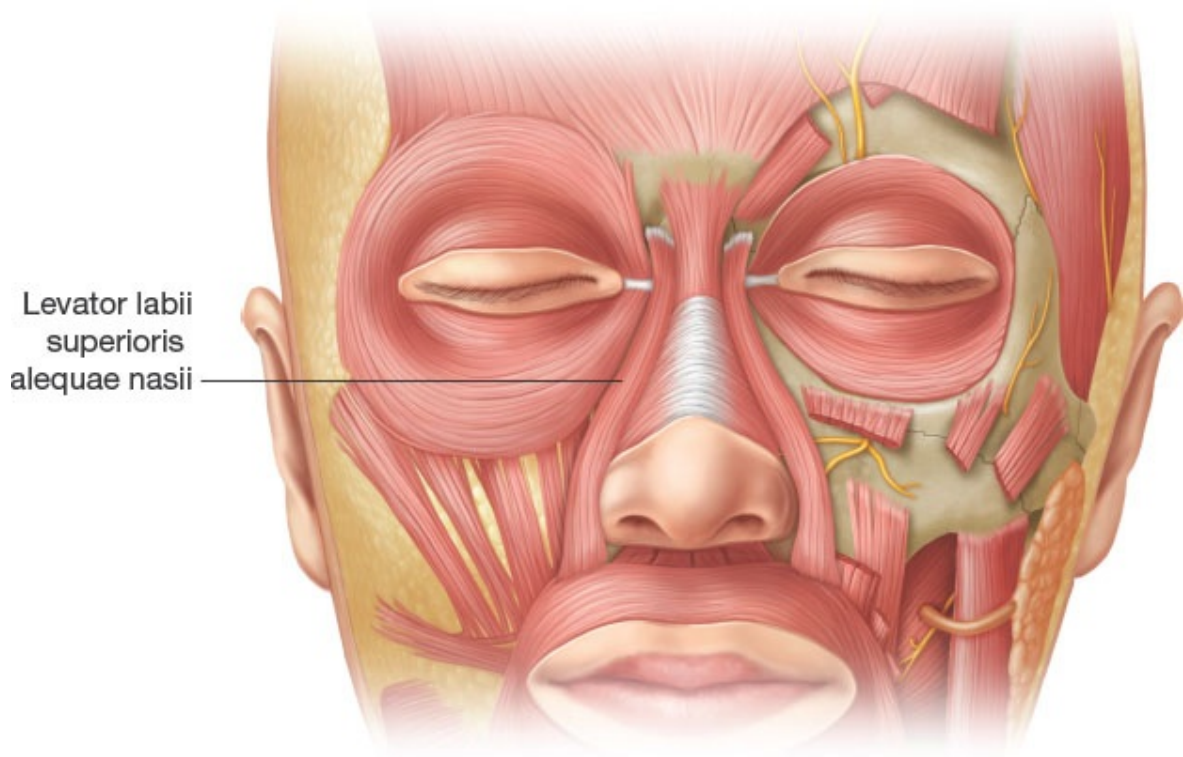


FIG 1 • Diagram illustrating orientation and length of levator labii superioris alaeque nasi muscle.

TECHNIQUES

■ Injection of Botulinum Toxin for Treatment of the Gummy Smile

- The botulinum is mixed according to manufacturer recommendations or physician preference.
- Skin is prepped using alcohol, and ice may be applied for anesthetic and as a distractor.
- The needle should be inserted 1 cm above the lateral extent of the ala down to the supraperiosteal plane at the piriform aperture (**TECH FIG 1**).¹



TECH FIG 1 • Location of injection site 1 cm above the lateral extent of the ala.

PEARLS AND PITFALLS

Patient selection

- It is best to start with a low dose and have the patient come back for more. Overtreating initially can cause central lip ptosis on smiling.

Technique

- Using a very dilute concentration may cause more neurotoxin to diffuse into the muscle of the orbicularis, causing muscular weakness. Start with 2–4 units per side.



FIG 2 • Patient photo before **(A)** and after **(B)** Botox treatment for gummy smile.

POSTOPERATIVE CARE

- Patients are sent home with small pack of ice and may apply as needed for swelling and/or bruising.

OUTCOME

- Excellent outcomes are achievable as demonstrated in **FIG 2** with improvement in the gummy smile with animation.

COMPLICATIONS

- Patients should be counseled on possible risks of procedure including bleeding, bruising, lip ptosis, facial asymmetry, and weakness of the orbicularis oris.

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5 Injection of Botulinum Toxin for Treatment of Perioral Rhytids

CHAPTER

Z. Paul Lorenc and Johnson C. Lee

DEFINITION

- The orbicularis oris (OO) and depressor anguli oris (DAO) muscles produce raylike perioral lines and pull downward on the angle of the mouth, respectively.
- Small doses of botulinum toxin type A injection directly into the OO prevent perioral rhytids.
- Botulinum toxin injections into the DAO soften marionette lines and raise the corners of the mouth.

ANATOMY

- The OO muscles originate from both the maxilla and mandible, creating a ring with insertions into the upper lip, lower lip, and modiolus.
- The OO is innervated by both the buccal and the marginal mandibular branches of the facial nerve.
- Contraction of this ring of muscles closes the lips and creates a competent seal against intraoral pressure.
- The DAO is the most superficial muscle in the chin originating from the lower edge of the mandible and inserting into the modiolus at the angle of the mouth.
- The DAO is innervated by the marginal mandibular branch of the facial nerve and contraction pulls the corners of the mouth downward with assistance from the platysma, accentuating the marionette lines (**FIG 1**).

PATHOGENESIS

- Dermal atrophy due to aging, bony resorption, and environmental factors

reveals vertical lines around the lips from OO contraction.

- Marionette lines start from the corners of the mouth to the chin and are a combination of tissue descent, age-related volume loss, and DAO activity.

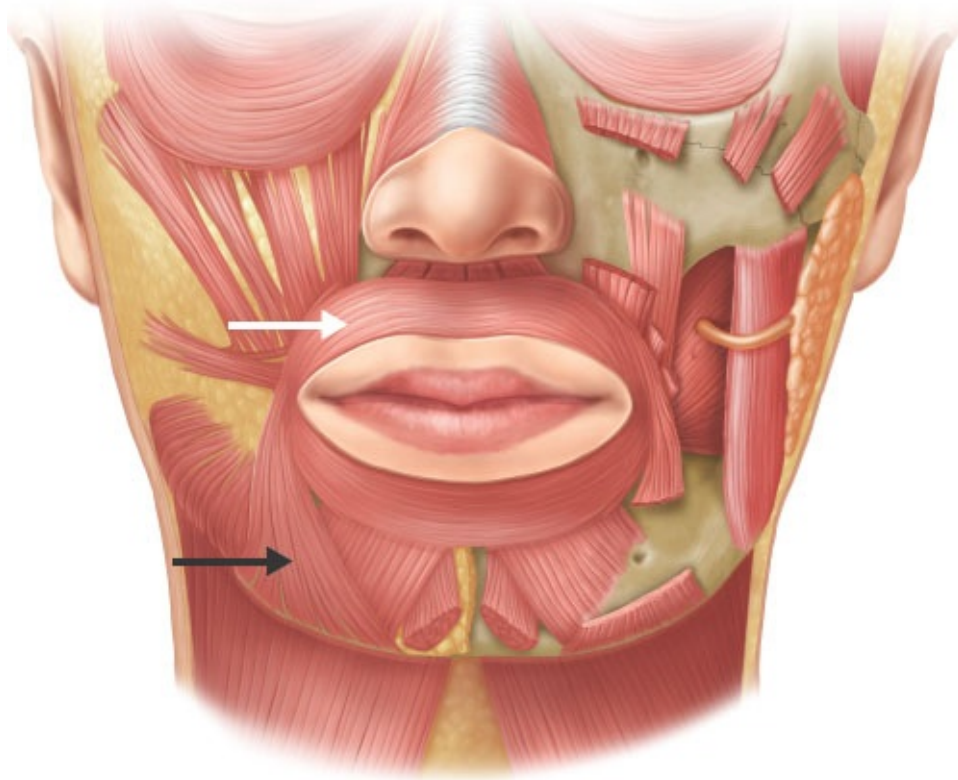


FIG 1 • The orbicularis oris (*white arrow*) creates a ring around the lips and contraction of this muscle creates a competent seal against intraoral pressure while producing vertical rhytids around the mouth. The depressor anguli oris (*black arrow*) inserts into the angle of the mouth, creating a downward pull, and accentuating the marionette lines.

PATIENT HISTORY AND PHYSICAL FINDINGS

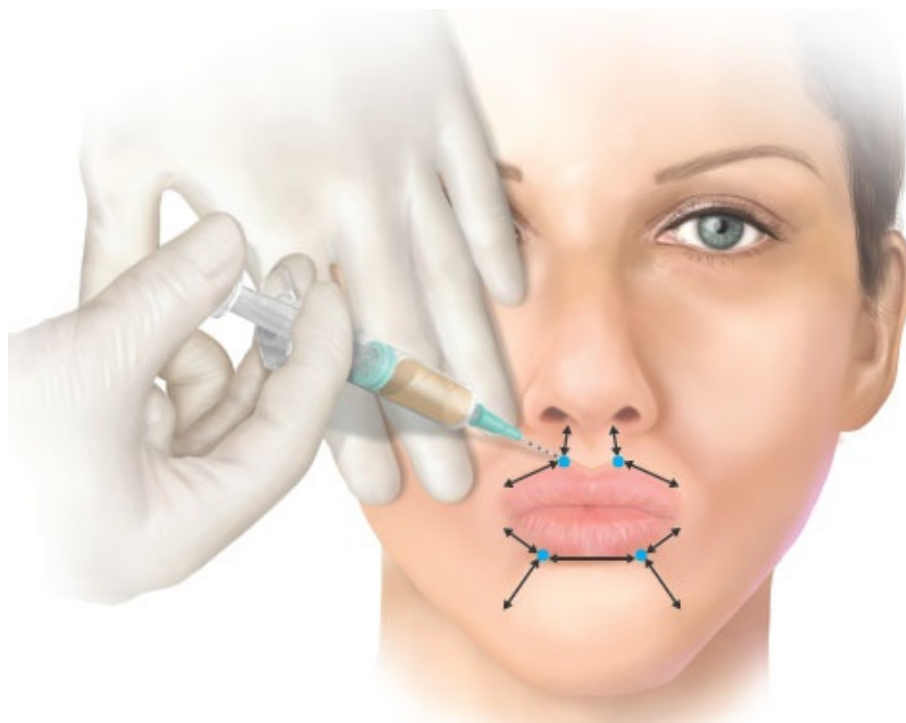
- Patients may report static or dynamic rhytids around the lips as well as prominent marionette lines or a “frownlike” appearance.

TECHNIQUES

- The perioral and chin area is sterilely prepped with an alcohol pad.

■ Vertical Rhytids

- The patient is instructed to purse or tightly pucker the lips.
- Visible rhytids are injected along the base of each line at the vermillion border in the subcutaneous plane (**TECH FIG 1**).
- Inject 0.5 to 1 unit of Botox per site. A total of 2 units maximum are placed onto each side in the upper lip and 2 units into the lower lip for a total dose of 6 units (100 units/4 cc NaCl).
- For patients with significant dermal atrophy, a combination of hyaluronic acid filler can be combined with botulinum toxin type A for maximal effect.
 - After extruding 0.2 cc of material from a 1.0-cc syringe (Restylane Refyne), 0.2-cc solution of botulinum toxin type A containing 5 units(100 u/4 cc NaCl) is mixed using an accessory kit.
 - This homogenous HA/BTX material is then injected along the vermillion border in the potential space using a 27G 25-mm blunt tip cannula.
- For deep static rhytids, additional hyaluronic acid filler such as Restylane Refyne, Belotero, or Juvederm Volbella XC can be injected vertically or horizontally along each line for direct increase in volume.

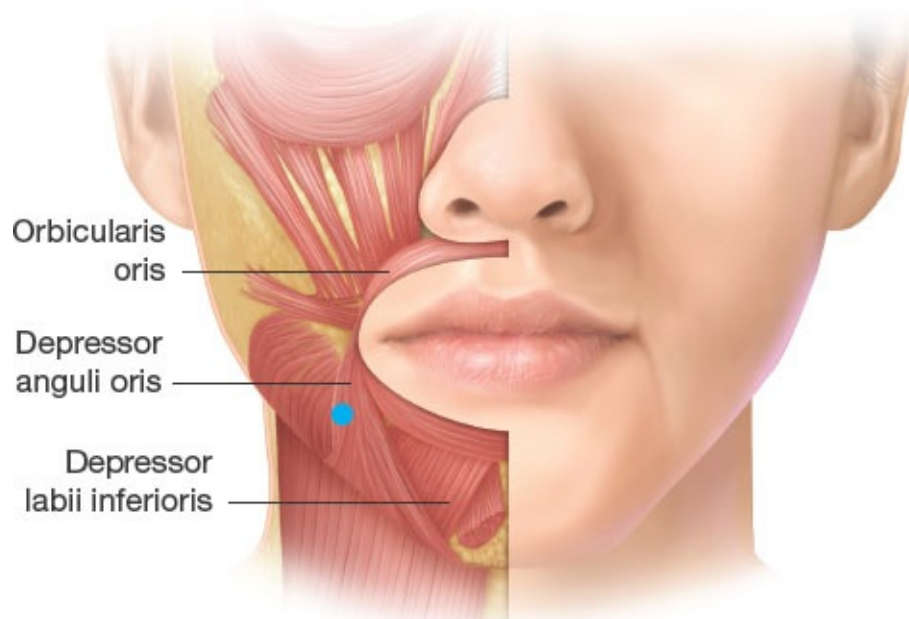


TECH FIG 1 • While the patient is pursing the lips, botulinum toxin is injected along at vermilion border in the subcutaneous plane (*dots*). For severe rhytids, this can be combined with hyaluronic acid filler injection (*arrows*) injected alone or perpendicular to the rhytids' direction.

■ **Marionette Lines**

- The patient is instructed to frown and pull the corners of the mouth downward.
- The injection point is marked with the patient animating and in the upright position.
 - The marking is halfway between the oral commissure and the jawline.
 - Because the DAO is a vertically oriented pyramidal muscle, injection in its midportion, where the DAO muscle mass is minimal, will have a more pronounced and longer lasting effect.
 - The marking is made lateral to the Marionette line.
- Inject 2.5 units of Botox into each DAO to elevate the corners of the mouth and reduce the shadowing of the Marionette lines (**TECH FIG 2**).

- Pronounced Marionette lines should also undergo concurrent augmentation with a hyaluronic acid filler such as Restylane Lyft, Juvederm Ultra Plus, or Juvederm VOLUMA or a CaHA agent such as Radiesse.



TECH FIG 2 • The DAO should be injected with 2.5 units of Botox, halfway between the oral commissure and the jawline where the DAO muscle mass is thinnest. Injection should be performed laterally to the marionette line to avoid weakening of the depressor labii inferioris muscle.

PEARLS AND PITFALLS

- | | |
|----------------------------------|--|
| Equipment | ■ Use a 27G 25-mm cannula, 32G ½ in. needle. |
| Choice of botulinum toxin | ■ Botox and Xeomin—4–5 units the upper lip, 2 units the lower lip.
■ Dysport—10–20 units the upper lip, 10 units the lower lip. |
| Technique | ■ Injection of the OO should occur closer to the midline/philtrum to |

reduce risk of oral incompetence from laterally placed injections.

- Maximum limit of 4 units of Botox each in the upper and lower lip to minimize risk of incompetence.
- Injection into the thinnest area of the DAO will allow for maximal effect with the lowest dose.
- Care must be taken to inject the lateral aspect of the DAO to avoid injection into the depressor labii inferioris.
- Marionette lines should also undergo concurrent augmentation, when appropriate, with a hyaluronic acid filler such as Restylane Lyft, Juvederm Ultra Plus, or Juvederm VOLUMA or CaHA agent such as Radiesse.

POSTPROCEDURAL CARE

- Patients ice the area immediately after the procedure (15 minutes).
- Avoid pressure, sweating, and alcohol for the remainder of the day to minimize swelling.

OUTCOMES

- Patient should expect additional treatments every 3 to 4 months (**FIG 2**).
- Because of use of conservative dosages to avoid oral incompetence, perioral retreatments may be needed even sooner.

COMPLICATIONS

- Slight bleeding, discomfort, or ecchymosis can occur after injection.
- Excessive injection of botulinum (8 units or greater) into the OO can result in oral incompetence, which can last for several weeks.
- Incorrect injection medial to the DAO will result in weakening or paralysis of the depressor labii inferioris and an asymmetric smile.

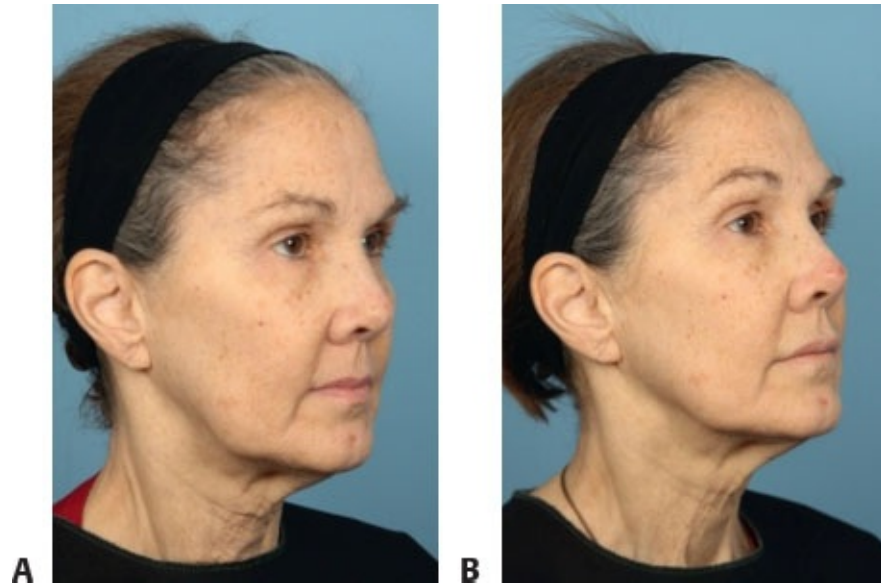


FIG 2 • Before **(A)** and after **(B)** botulinum toxin injection in the perioral area.

6 Injection of Botulinum Toxin to the Depressor Anguli Oris

CHAPTER

Amir Allak, Sebastian Cotofana, and Jonathan Sykes

DEFINITION

- Hyperfunction of the muscular depressor anguli oris (DAO) results in a scowling, aged appearance, and marionette lines.
- The position and orientation of the oral commissure is related to the relative strength and contraction of the DAO (and to a lesser extent the depressor labii inferioris [DLI]) vs the elevators of the oral commissure (levator anguli oris, levator labii superioris).
- Treatment with botulinum toxin can lessen the contraction of hyperdynamic DAO muscles and can elevate the downturned oral commissure, resulting in a more rejuvenated appearance.¹

ANATOMY

- The depressor DAO is a paired bilateral muscle that originates from the soft tissue overlying the oblique line and the inferior border of the anterior body and parasymphysis of the mandible. DAO inserts onto the lateral aspect of the lower lip and oral modiolus (**FIG 1**).
- The DAO is innervated by the marginal mandibular branch of the facial nerve, and its activation moves the oral commissure inferolaterally.
- The shape of the DAO is roughly a triangle with its base inferiorly at its origin and its apex superiorly near the modiolus of the oral commissure.
- At its origin, the DAO muscular body is continuous with the platysma muscle inferiorly within the superficial musculoaponeurotic system.

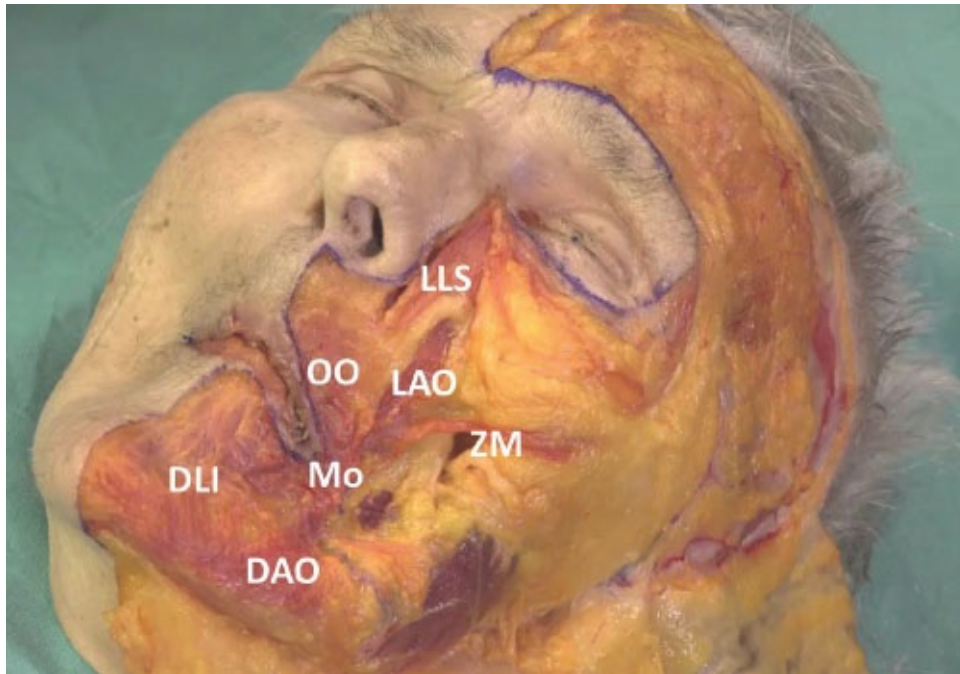


FIG 1 • Cadaveric dissection of muscles acting at the angle of the mouth. Mo, modiolus; DLI, depressor labii inferioris; DAO, depressor anguli oris; OO, orbicularis oculi; LAO, levator anguli oris; ZM, zygomaticus major; LLS, levator labii superioris.

- The DLI is a paired bilateral muscle that is directly medial to the DAO, which also originates from the inferior border of the parasymphysis of the mandible but inserts mostly on the body of the lower lip (see **FIG 1**). Its action, as its name implies, depresses one side of the lower lip.
- In the areas where the DAO and DLI overlap, the DLI lies deep to the DAO (see **FIG 1**).
- The facial artery runs superomedial from the mandibular notch, and the inferior labial artery arises inferior to the modiolus. The inferior labial artery, a branch of the facial artery, runs deep to the DAO fibers (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Overactivation of the DAO contributes to an aged-appearing downturn of overall lip shape and rhytids that follow from the oral commissure inferolaterally (paralleling the course of the muscle), known commonly as marionette lines.²

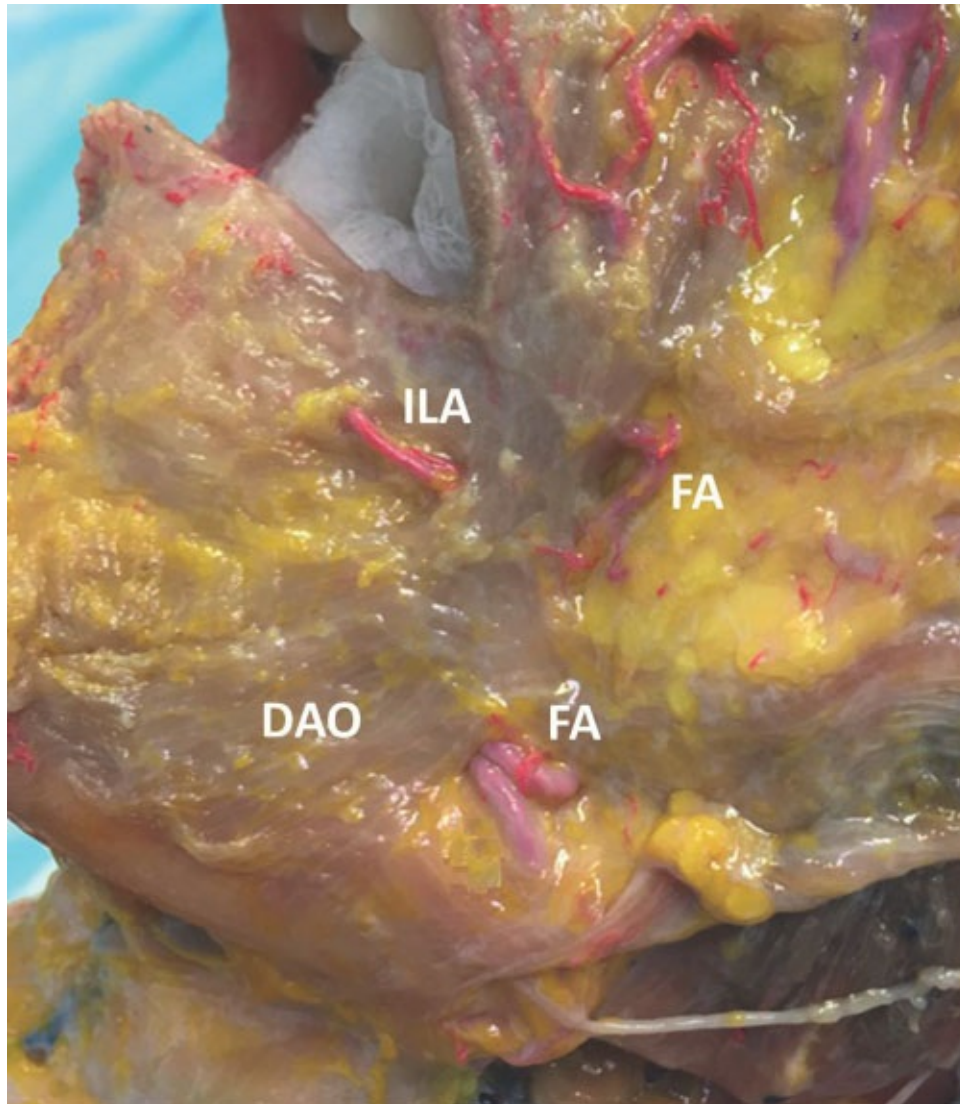


FIG 2 • Cadaveric dissection demonstrating the relationship of the facial vasculature to the depressor anguli oris. FA, facial artery; DAO, depressor anguli oris; ILA, inferior labial artery.

- There is often an associated soft tissue depression just inferior to the oral commissure that is partially related to muscular activity and partially attributed to descent of the cheek fat pad relative to the lower lip subunit.

IMAGING

- No imaging is required for this procedure.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients should be screened for neuromuscular disorders including amyotrophic lateral sclerosis, myasthenia gravis, and Eaton-Lambert syndrome because these are contraindications for the use of the product.
- Use in pregnant or nursing mothers is not advised, though no studies have shown teratogenic damage to fetus or adverse affects to breast-feeding infants.
- Patient medications should be screened for aminoglycoside antibiotics because these affect the pharmacokinetics of the toxin and can potentiate the effects.

Positioning

- The patient is examined in an upright position along with full facial analysis. The treatment position is surgeon preference, upright, slightly recumbent, or supine.

Approach

- Delivery of the product is performed uniformly with percutaneous injection.

TECHNIQUES



Video p1-c006

■ Injection of Botulinum Toxin Into the DAO

- Topical anesthetic cream, commonly containing lidocaine, is applied and left in place for a minimum of 15 to 20 minutes (and sometimes longer) for

maximal anesthetic effect.

- Botox is reconstituted into sterile injectable saline to the concentration of 2.5 to 4 units/0.1 mL. This is drawn up into a 1-cc syringe, and a 30-gauge short Luer Lock needle is prepared for injection.
- The patient is asked to grimace to reveal the area of maximal activation of the DAO and its distribution along the marionette line.
- The mandibular groove is palpated at the junction of the posterior body and angle on the inferior border of the mandible.
 - This is the area where the facial artery and vein course from the deep neck to supply and drain the facial soft tissue.
 - Injection in this area should be avoided.
- The product is typically injected in two to three locations, following the shape of the inverted triangle of the DAO: two at the inferior aspect and one superiorly for a total of 3 to 6 units per side.
- Injection should be posterior to the oral commissure to avoid the DLI and anterior to the mandibular groove to avoid the facial vascular structures.
- Injection should be delivered in a relatively superficial plane to avoid the DLI and the inferior labial artery running deep to the DAO.

PEARLS AND PITFALLS

Location of injection	■ Injection should be anterior to the mandibular notch to avoid vascular structures and posterior to the oral commissure to avoid injection of the DLI and subsequent smile asymmetry. ■ The plane of injection should be relatively superficial because the DAO fibers run superficial to the DLI and inferior labial artery.
Dosing	■ 3–6 units are divided in 2–3 doses in a line or triangular orientation. ■ More product may be required in men.

POSTOPERATIVE CARE

- Ice packs should be provided to the patient and placed immediately after injection.
- Some patients may bruise post procedure, especially if anticoagulated. This can be expected to resolve in several days.

OUTCOMES

- Onset of effect usually become apparent in 1 week.
- Inactivation of the DAO should lead to less downturn of the oral commissures and some relief and softening of marionette lines.³
- The neuromodulation is commonly effective for 12 to 20 weeks wherein it would need to be redosed for continued effect. This can vary from patient to patient.

COMPLICATIONS

- Injection of the DLI or migration of product so as to chemically denervate this muscle will lead to asymmetry when smiling because the ipsilateral muscle will not activate the lower lip to depress. The effect of the product should wane over the normal metabolic period.
- Intravascular injection, though exceedingly rare, can cause systemic effect similar to botulism (generalized weakness, visual disturbance, dysarthria, etc.)

ACKNOWLEDGMENT

The authors thank Peter Palhazi, MBBS, for his contribution to the preparation of this chapter.

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7 Injection of Botulinum Toxin to Platysma Bands

CHAPTER

Z. Paul Lorenc and Johnson C. Lee

DEFINITION

- Platysma bands become more pronounced with age and activity.
- Botulinum toxin injection directly into the muscular cords relaxes the muscle, efface the vertical bands, and define the mandibular border.
- Treatment of the platysma muscle is routinely combined with treatment of the depressor anguli oris (DAO) to lessen the downward forces of the muscles of the neck and face.

ANATOMY

- The platysma originates along the fascia of the superior portions of the pectoralis major and deltoid muscles. The muscle fibers run superiorly and obliquely before inserting into the perioral muscles, dermis of the cheek and chin, and inferior mandibular symphysis posterior to the DAO origin (**FIG 1**).
- The platysma is innervated by the cervical branch of the cervicofacial trunk of the facial nerve with some superior coinnervation by the mandibular branch.
- Activation causes depression of the corners of the mouth and mandible, tightening the anterior neck skin, and blunting of the mandibular border.

PATHOGENESIS

- Contraction of the free anterior and posterior fibers in the submental and neck regions creates both vertical platysma bands and horizontal neck lines.
- Excess or lax skin can compound the appearance of platysma bands even at rest.
- With aging, loss of submental fat contributes to platysma bands prominence.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients may report the appearance of bands when speaking or making facial expressions, which become more pronounced with age.
- Patients with significant skin laxity component may have suboptimal results.

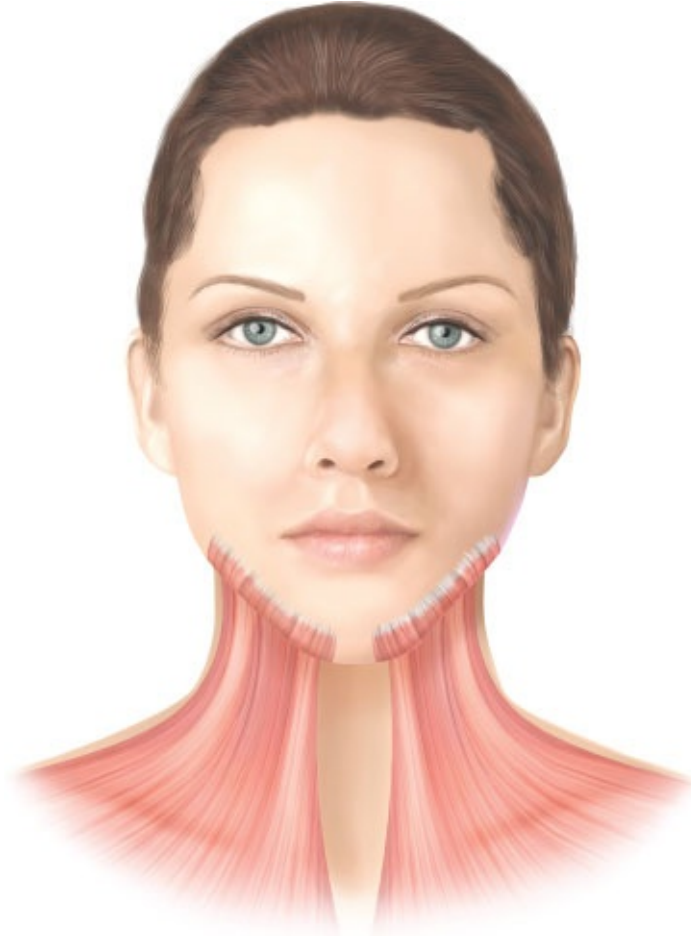


FIG 1 • The platysma originates along the pectoralis major and deltoid muscles and inserts into the anterior mandible and skin of the lower face. Activation causes the formation of vertical bands.

TECHNIQUES

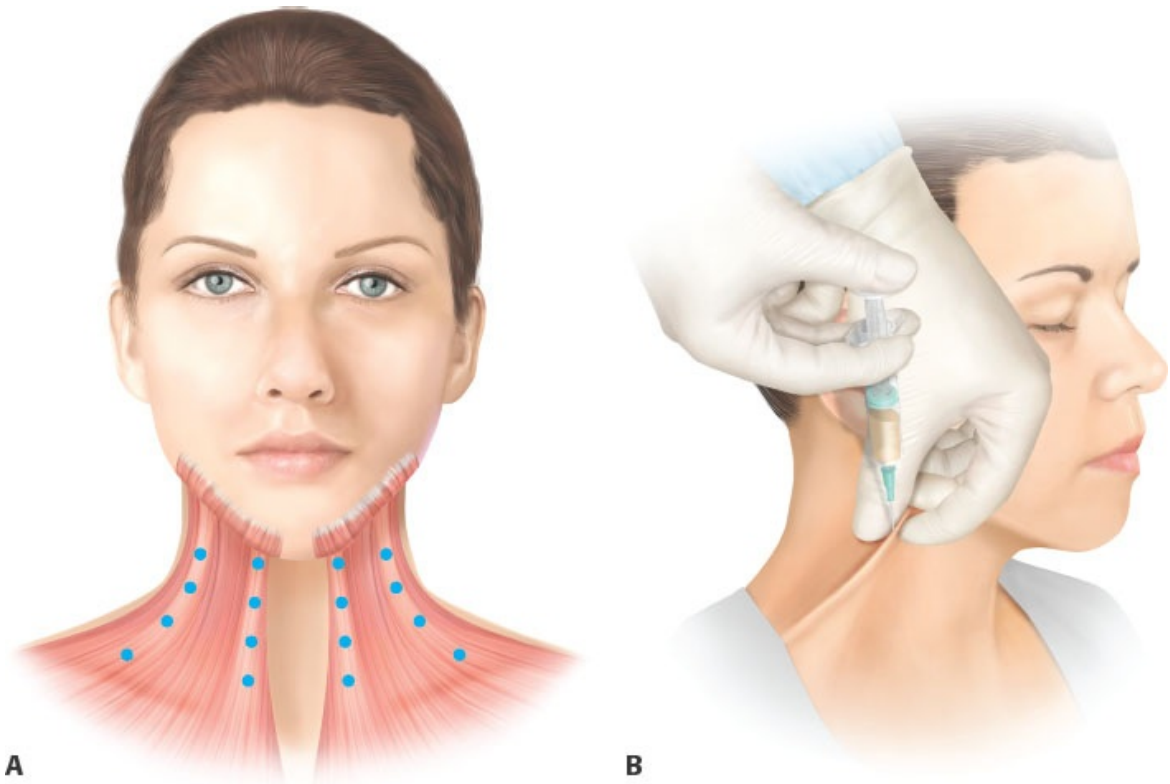
■ Preparation

- Choice of botulinum toxin

- Botox (onabotulinum toxin type A)
 - Xeomin (incobotulinum toxin type A)
 - Dysport (abobotulinum toxin type A)
 - Suggested dilution
 - Onabotulinum toxin type A—100 units/2.5 cc NaCl
 - Incobotulinum toxin type A—100 units/2.5 cc NaCl
 - Abobotulinum toxin type A—300 units/1.5 cc NaCl
 - The neck area is sterilely prepped with an alcohol pad.
 - The patient is in an upright sitting position.
-

■ Botulinum Toxin Injection

- The patient is instructed to voluntarily contract the platysma by grimacing or pulling the corners of the mouth and lower lip downward and laterally while tightening the skin of the neck.
- Visible anterior and lateral platysma bands are marked using a marking pen with 1-cm spacing.
 - Platysma injection points at the mandibular border as well as the depressor anguli oris (DAO) injection sites are marked, if clinically necessary.
- Visible cords are held between the thumb and index finger during the injection (**TECH FIG 1**).
- Injections are given directly into the vertical muscular cords with a 32-gauge needle using a 1.0-cc Luer-Lok tip syringe.
- Dosage total depends on the choice of botulinum toxin:
 - 25 to 50 units of onabotulinum toxin type A
 - 25 to 50 units of incobotulinum toxin type A
 - 100 to 150 units of abobotulinum toxin type A
- Additional injections can be performed along the mandibular border, at the posterior platysma bands, and the DAO injection points for improved jawline.



TECH FIG 1 • Visible cords **(A)** are held between the thumb and index finger **(B)**, and botulinum toxin is injected evenly spaced approximately 1 cm apart at the level of the deep dermis.

PEARLS AND PITFALLS

Equipment ■ Use a 32-gauge needle, 1.0-cc Luer-Lok tip syringe.

Technique ■ Retract the individual cord away from the deeper muscles.
■ Inject into the deep dermal layer to avoid deeper structures or the hypoglossal nerve.



FIG 2 • Before (A–C) and 60 days (D–F) after treatment. Full animation, $\frac{3}{4}$ view, side view. A 62-year-old female, total dose: 80 units incobotulinum toxin type A (100 units/2.5 cc NaCl). Muscles injected: platysma, medial, lateral, mandibular border, depressor anguli oris.

POSTPROCEDURAL CARE

- Patients place ice over the area immediately after the procedure.
- Avoid pressure, sweating, alcohol for the remainder of the day to minimize postinjection sequelae.

OUTCOMES (FIG 2)

- Resolution of platysma banding may not occur for up to 3 to 5 days after treatment.
- Patient is seen 1 week post injection for additional therapy if necessary.
- Patient should expect additional treatments every 3 to 4 months.
- Horizontal banding, if necessary, may be addressed with injectable hyaluronic acid filler with low G' characteristics.

COMPLICATIONS

- Slight bleeding, discomfort, or ecchymosis can occur after injection.
- Accidental botulinum toxin injection into the strap muscles, deeper muscles of the neck, or hypoglossal nerve injury can cause dysarthria, dysphagia, dysphonia, or breathing difficulties.

Section II: Technique for Injection of Fillers in the Face

8

Injection of Fillers in the Glabella, Forehead, and Brow

CHAPTER

David A. Sieber and Jeffrey M. Kenkel

DEFINITION

- Hyaluronic acid: a naturally found glucosaminoglycan polymer found in human tissue, which is reversible with hyaluronidase
- Tyndall effect: bluish hue created in the skin from light scattering off superficially injected particles of filler

ANATOMY

- The supratrochlear artery lies approximately 2 cm lateral to midline between the corrugator and frontalis/orbicularis, traversing the frontalis/orbicularis 1.5 to 2.5 cm above the orbital rim transitioning into the subcutaneous plane¹ (**FIG 1**).
- The supraorbital artery runs approximately 3 cm lateral to midline, piercing the frontalis between 2 and 4 cm above the orbital rim also transitioning to a subcutaneous plane.^{1,2}
- The supraorbital nerve originates 2.1 to 3.5 cm from midline and divides into superficial and deep branches. The deep branch courses deep to the corrugator supercilii and frontalis muscles, traveling between the periosteum and galea superiorly and laterally toward the temporal fusion line.^{3,4}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients will often present complaining of static rhytids in the glabella and forehead that persist after adequate treatment with neurotoxins.
- Other patients will have hollowing of the inferior brow, complaining of an aged and gaunt appearance of the eyes.

NONOPERATIVE MANAGEMENT

- The senior author's preference is to use hyaluronic acid fillers due to their temporary nature and ability to be reversed through the use of hyaluronidase.

Positioning

- The patient should be comfortably seated in an upright position.

Approach

- The glabella, forehead, and brow may be injected from either side of the patient.
- It is the author's preferred approach to inject standing to the side of the patient.

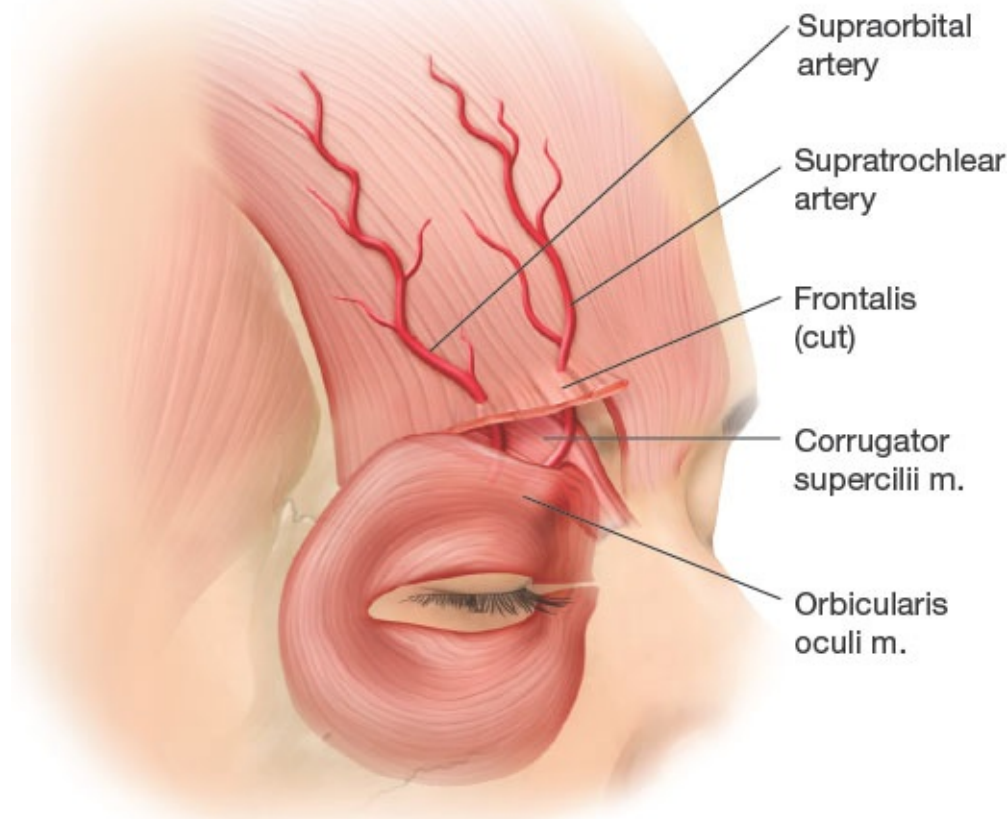


FIG 1 • Location of the supratrochlear and supraorbital arteries. Notice the transition to a more superficial plane as they ascend in the forehead.

TECHNIQUES

- For most hyaluronic acid products, the authors add 0.2 cc of 0.5% lidocaine with epinephrine using a Luer-lock to Luer-lock connector to help constrict local blood vessels, reducing the risk of postprocedural ecchymosis.
- When superficial/dermal injections are performed, the authors follow Dr. Fagien's recommendations regarding dilution, which reconstitutes the product 1:1 with 1% lidocaine.⁵
- Although injections may be performed with a 30-gauge needle, 27-gauge needle, 25-gauge cannula, or 27-gauge cannula, the authors' preference is to

use a cannula for injections of the inferior brow along the orbital rim and a 30-gauge needle for treatment of superficial rhytids of the forehead.

- Skin is always prepped using a swab containing 4% chlorhexidine gluconate prior to injection.

■ Injection of Fillers in the Glabella and Forehead

- A 30-gauge needle is advanced into an intradermal plane parallel to the rhytids being treated.
- The filler is then deposited in a serial retrograde fashion along the course of the rhytid.
- This area is slightly overcorrected and then massaged to produce an even result.
- Additional cross-hatching may be necessary for complete correction of the rhytid, especially in treating deep vertical lines of the glabella.
- Care is taken to stay very superficial (intradermal) so as to not cannulate or injure the supratrochlear or supraorbital vessels.

■ Injection of Fillers in the Brow

- A common portal is made in the lateral tail of the brow with a needle.
- The cannula is advanced medially along the brow periosteum to just past the area needing correction. This is below the inferior border of the brow.
- Filler is gently injected along the inferior border of the superior orbital rim as the cannula is withdrawn laterally.
- Multiple passes may be necessary to achieve the desired effect.
- An additional portal may be needed medially to reach the more medial aspects of the orbital rim.
- After placement, the product is massaged into place along the orbital rim to produce an even, natural result.

PEARLS AND PITFALLS

Technique

- The supratrochlear and supraorbital arteries lie in the subcutaneous plane starting 2 cm above the orbital rim; care must be taken to not cannulate or injure these during injection.
- When injecting the glabella and upper forehead, filler should be placed into a superficial/dermal plane to avoid injury to the supratrochlear and supraorbital vessels.
- Filler placed along the superior orbital rim can produce a subtle brow lift in patients with pre-existing brow ptosis.
- Filler placed along the superior orbital rim helps with orbital hollowing and correction of “A” frame deformities.

POSTOPERATIVE CARE

- Patients are sent home with small packs of ice and may apply as needed for swelling and/or bruising.
- Patients should keep their heads elevated for a few hours after injection and should abstain from exercise for 4 hours.

OUTCOMES

- Excellent outcomes are achievable as demonstrated in **FIG 2** with correction of the brow hollowing (see **FIG 2**) and superficial rhytids of the forehead (**FIG 3**).

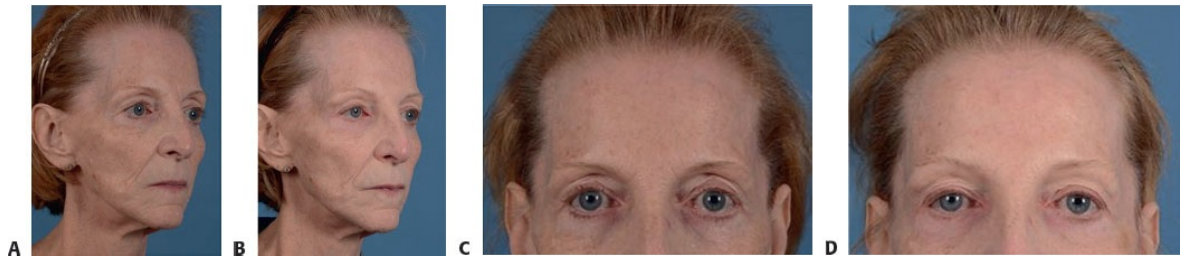


FIG 2 • A 66-year-old female pre (**A**) and post (**B**) injection of 0.5 cc Restylane Lyft into each temporal region/lateral brow, 1 cc total of Restylane Silk into the lips/perioral region, and 0.4 cc Restylane Lyft into each sub-brow region. Notice the more youthful appearance of the brow/periorcular region (**C,D**).

COMPLICATIONS

- Patients should be counseled on possible risks of procedure including

bleeding, bruising, facial asymmetry, and intravascular injection leading to skin necrosis and/or blindness.



FIG 3 • A 50-year-old female pre **(A)** and post **(B)** treatment with a total of 2 cc Restylane Silk placed into static forehead rhytids as well as perioral lines.

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9 Filler Injection Into the Upper Periorbital Area

CHAPTER

Val Lambros

DEFINITION

- The upper periorbital area refers to the superior orbital rim inferiorly to roughly the height of the eyebrow, from the medial temple to medial-most orbit.
- The reason to fill the brows is that a certain population of patients looks better with fuller upper periorbital than hollow.

ANATOMY

- The anatomy of the brow is well known. The pertinent anatomy is aesthetic and vascular.
- The supraorbital and supratrochlear arteries arise from the bone and rise to the level of the frontalis muscle.
- The superior orbital rim in most young persons is characterized by skin that most clinicians characterize as “tight” as well as generalized fullness of subcutaneous fat. The overall look in many of these eyes is a full orbital rim and upper lid, which describes a low and horizontal path across the orbit. These young eyes tend to look longer from medial to lateral than the does old eye. Part of this phenomenon is secondary to the stretch of the lateral canthal tendon, and part is from the height versus width ratio: the visual height of the orbit is low in relation to its length.

PATIENT HISTORY AND PHYSICAL FINDINGS

- In patients whose faces age by thinning, it is very common for the orbit to hollow. Therefore, eyes that fit the description above become eyes that look larger vertically (less fat volume) and round (greater height for width, as well

as a shorter lid aperture). This look when extreme is sometimes descriptively called a nursing home eye (**FIG 1**).

- Older eyes tend to have greater eyelid show and room for makeup. Some patients like this look. In young eyes that have had surgery with a great deal of fat removal, the loss of fat can in time accelerate the natural aging of the eyelid.
- The thesis of this chapter is simply that some upper lids and superior orbital rims look better when fuller than not.

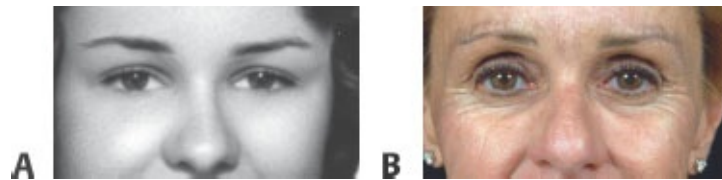


FIG 1 • Contrast of youthful (**A**) versus aged (**B**) periorbital.

Preoperative Planning

- Though the criteria above give a hint as to who may be good candidates for filling the supraorbital area, some patients with configurations described above may look better with fill and some not.
- Though most patients would understand the effect of filling in a wrinkle, filling certain areas of the face is not intuitive, for example, the temples, brows, and anterior jawline, where a small amount of filler may make a huge change visually.
- Because cosmetic alterations of the face are visual by definition, there is an easy way to show patients the visual alternatives before the final injections and get their understanding and approval of the procedure before it is actually done. Though one may use preoperative computer imaging, I prefer the use of a small amount of local anesthesia to duplicate the effect of the filler.

Positioning

- Injections are performed with the patient seated upright.

Approach

- I prefer to block all filler injection with local anesthesia with epinephrine before placing the filler. The primary reasons are for pain control and

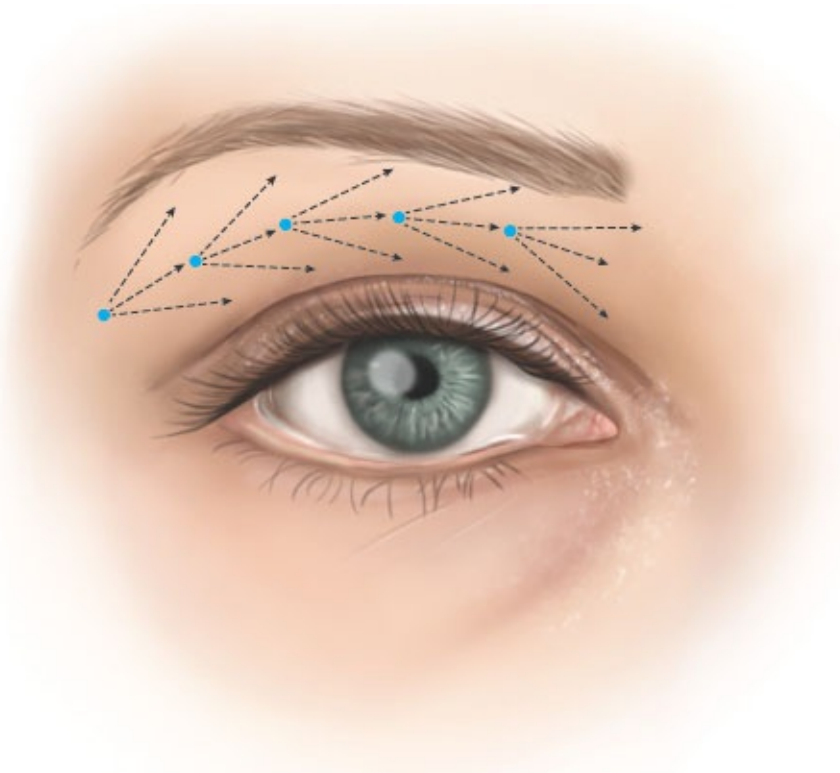
vasoconstriction. The least common but most feared complication of filler injections is intra-arterial injection of product. Injecting into a vasoconstricted environment would logically be expected to reduce its incidence. If one is going to inject local anesthetic anyway, one may as well get additional benefit from doing so, and that is to show the patient the intended outcome of the final result.

TECHNIQUES

■ Filler Injection Into the Upper Periorbital Area

- In my experience, patients uniformly like the idea of visualizing the result before committing to the injection; it tilts the balance of power from the doctor to the patients, and all patients are familiar with the idea of trying on clothes before buying them.
- Most patients like the preview with local anesthesia, and the filler injection is performed immediately afterward.
 - The patients who do not like the preview do not have to find out after spending money and experiencing a result that they do not like.
 - The extra 5 minutes that this takes is well worth the effort in my opinion. No one has told me that they did not like an injection that was previewed and approved.
- Placing the local anesthetic is more difficult than doing the final injection. It is all too easy to place a blob of fluid in the tissues that demonstrates nothing but lack of injection ability; with some practice, one learns to place the local anesthetic in even threads, which are quite convincing.
 - The local is massaged and the patient is shown the result, and the area is now numb and vasoconstricted.
 - The presence of the local does not complicate the injection at all as one knows both the dose and distribution already and the smoothness is confirmed by feel.
- Either a cannula or a needle is used for the final injection.
 - From long experience, I use a 30 G ½ in. needle.
 - The presence of the local helps with the distribution of the product.
 - Most commonly, the dose is ½ cc per side.

- The injection of product itself begins laterally at about the tail of the brow. It is in the middle level, below the orbicularis oculi, but not subdermal or adjacent to the bone. There are two reasons not to be deep here:
 - In some patients, the globe is immediately adjacent to the bone, increasing the possibility of injury.
 - The supraorbital and supratrochlear as well as other forehead arteries arise from the bone or adjacent to it and may be more easily injured with the needle (**TECH FIG 1**).



TECH FIG 1 • Injection into the upper periorbital.

- The injection is done in a fanning manner with an injection headed superiorly straight ahead and inferiorly to the injection path.
 - Usually about 5 needle placements are necessary, making a total of about 15 passes.
 - As the dose is typically $\frac{1}{2}$ cc per side, that makes about 0.03 cc per pass.

Patient selection

- The first and most important criterion for patient and doctor satisfaction is patient selection.
- In the currently popular volume-centric approach to facial cosmetic surgery, patients may be treated by rote or by principle that faces should be made fuller regardless of the face. Though some faces may deflate with age, many do not in the American population. Volume treatments across the face and specifically around the eye may look ridiculous and be permanent.
- When one is changing as visually important a part of the face as the periorbital area, one wants to know that the patient will like it and that complications can be treated.

Filler selection

- I invariably use HA fillers around the eyes. Fillers in this class, which, at the time of this writing, include Restylane and Juvederm, have unique properties that make them invaluable in the periorbital area.
- The longevity in the periorbital area (as well as the temple and tip of the nose) is much greater than in the lips and nasolabial fold. I tell patients that it will last 2 years, but it is common to see 3 or 4 years of persistence. In addition, HA fillers can be dissolved with hyaluronidase, thus making it easy to erase lumps and most complications. These luxuries are simply not available when using calcium- or lactic acid-based fillers.



FIG 2 • Pre (A) and post (B) injection.

POSTOPERATIVE CARE

- Postprocedure care is minimal. Ice usually suffices. Using a needle has a higher incidence of bruising, which takes the usual course. Cannulas have less bruising but are less maneuverable and precise.

OUTCOMES

- **FIGS 2 to 5** show before and after photos in four patients.

COMPLICATIONS

- Complications specific to the periorbital area are similar to other parts of the

face. Occasional irregularities may be supplemented with more product or sometimes dissolved with a low dose of hyaluronidase.

- Arterial injection injuries are rare but most serious. It is thought that some lesions from arterial injection are embolic by virtue of distal arterial flow, whereas some occur from flow proximal to the injection point.
 - Severe injuries include duskiness of the skin to full-thickness necrosis of the skin or even blindness. Suggestions for prevention include using a cannula, vasoconstriction, and low-pressure injection with a moving needle.
 - Cannulas would be expected to generate less arterial perforations than needles though arterial injections have been generated with cannulas as well.
- Aspiration of the syringe before injection, though traditionally recommended, does not seem to be reliable, as HA fillers injected through a small needle are too viscous to allow product to backflow into the syringe. The only article that characterized the incidence of “severe complications” gave an incidence of close to 1 in 1 000 000,¹ though the incidence is probably higher than that.

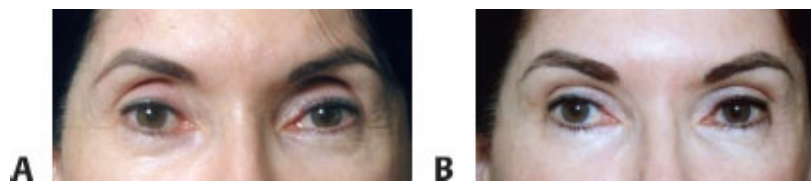


FIG 3 • Pre (A) and post (B) injection.



FIG 4 • Pre (A) and post (B) injection.

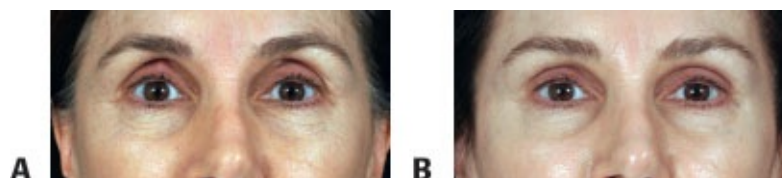


FIG 5 • Pre (A) and post (B) injection.

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10 Tear Trough and the Lid-Cheek Junction

CHAPTER

Z. Paul Lorenc and Johnson C. Lee

DEFINITION

- The tear trough and lid-cheek junction are natural anatomical structures that become accentuated with time due to changes in the skin and periorbital structures.
- Proper placement of injectable fillers restores volume and support to these structures for periorbital rejuvenation.

ANATOMY^{1,2}

- The tear trough or nasojugal groove is the natural depression 4 to 6 mm caudal to the arcus marginalis at the orbital rim and extends inferolaterally from the medial canthus to the midpupillary line.
- The lid-cheek junction extends from the tear trough at the midpupillary line and lies below and parallel to the infraorbital rim.
- In the subcutaneous plane, both the tear trough and the lid-cheek junction correlate with a junctional cleft between the palpebral and orbital portions of the orbicularis muscle.

The lid-cheek junction has an additional deep submuscular plane at the orbitomalar ligament (**FIGS 1 and 2**).

PATHOGENESIS

- The tear trough and lid-cheek junction are normal anatomic features that can be seen in many youthful individuals.

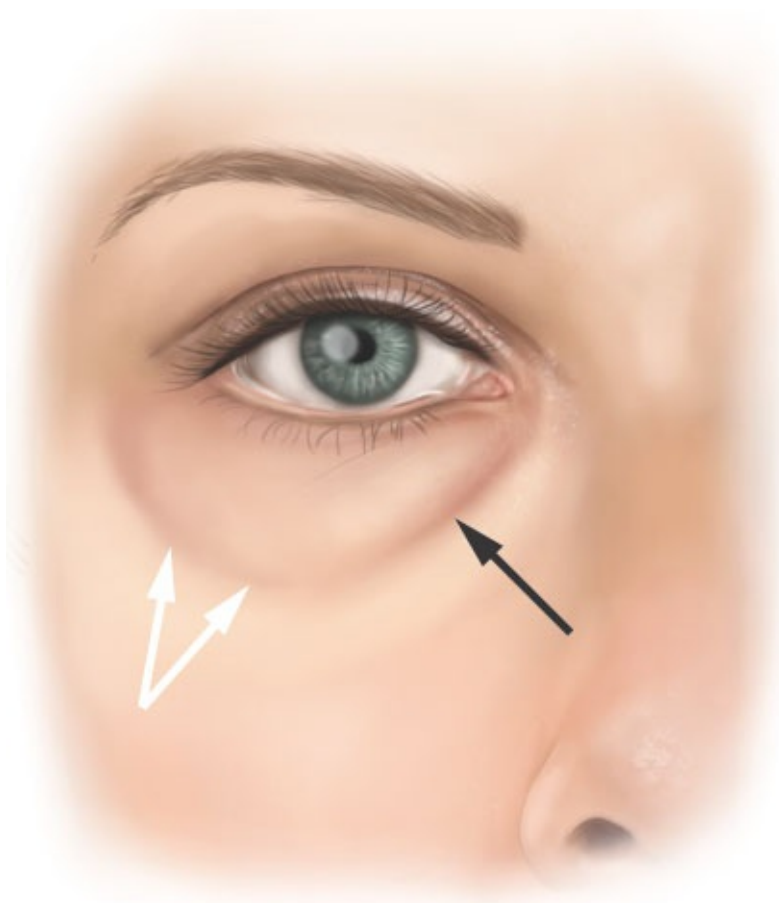


FIG 1 • The tear trough deformity (*arrow*) is the natural groove extending inferolaterally from the medial canthus to the midpupillary line. The lid-cheek junction (*white arrow*) extends laterally.

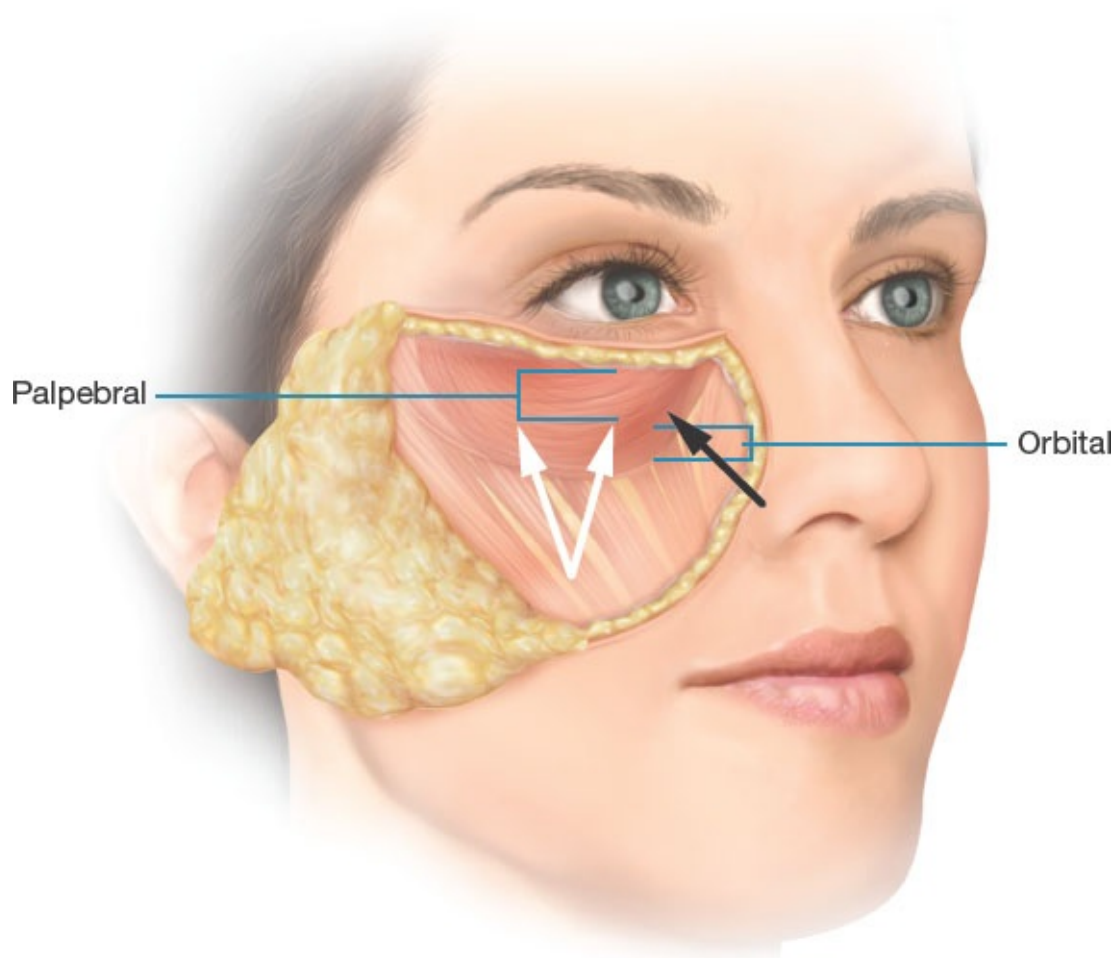


FIG 2 • The underlying anatomy is shown with the malar fat pad reflected. The tear trough deformity (*black arrow*) lies at the junction of the palpebral and orbital components of the orbicularis oculi muscle. This continues laterally with the lid-cheek deformity (*white arrows*).

- With age, there is skin and fat atrophy and attenuation of the periorbital structures allowing orbital fat herniation and increasing shadows.
- The tear trough and lid-cheek junction become more visible and accentuated by overlying pigment, texture, and shadow changes.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients may report a “tired” or “aged” under-eye appearance which is not relieved with rest, hydration, or topical therapies.

- A depression can be seen starting at the medial canthus and parallel to the orbital rim.

The tear trough and lid-cheek junction deformity can be accentuated by actively increasing orbital fat herniation with upward gaze or globe pressure (**FIG 3A**).

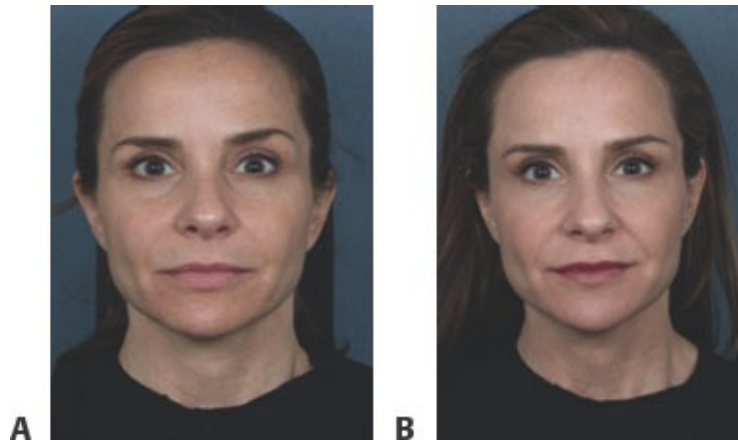


FIG 3 • Patient photos before (**A**) and after (**B**) injection.

TECHNIQUES

■ Preparation

- The area is cleansed and sterilized with a sterile alcohol pad.
- Marking of the areas for filler injection of the tear trough and the lid-cheek junction is made with the patient in an upright position with the orbicularis oculi muscle in a completely relaxed state. Cannula access port is marked in the midpupillary line 0.5 cm inferior to the border of the orbital rim.
- Topical anesthetic (benzocaine 20%, lidocaine 6%, tetracaine 4%) is carefully applied to the area with cotton-tipped applicators for 30 to 45 minutes prior to injection.
- Cannula access port is injected with 0.1 cc of 1% lidocaine solution and epinephrine 1:100 000.
- Just prior to cannula insertion, a 25G 5/8" needle is used to puncture the skin and create the cannula access port.

Tear Trough

- Restylane-L (Galderma Laboratories, L.P.) is diluted with 2% lidocaine 1:1 (off-label use). When reconstituting an agent, make sure there is a homogenous distribution of the material throughout the syringe.
- After insertion of the cannula, injections begin medially to laterally with a 27G 25-mm cannula in a retrograde fashion at the suprapariosteal level.
- Using the free hand, the orbital rim is palpated.
- Care is made to inject below the orbital rim, deep to the muscle, and onto the periosteum between the palpebral and orbital portions of the orbicularis oculi muscle.
- Injection of small aliquots (0.01–0.05 cc) is made in a retrograde fashion.
- Average reconstituted volume delivered is 0.6 cc.
- Minimal massage, if any, can be used to blend (**TECH FIG 1**).

Lid-Cheek Junction

- The 27G 25-mm cannula is advanced from the access port laterally at the suprapariosteal plane toward the lateral canthus.
- Injections are made directly onto the periosteum with a 27G 25-mm cannula in a retrograde fashion similar to the tear trough but now laterally to medially stopping short of the access port.



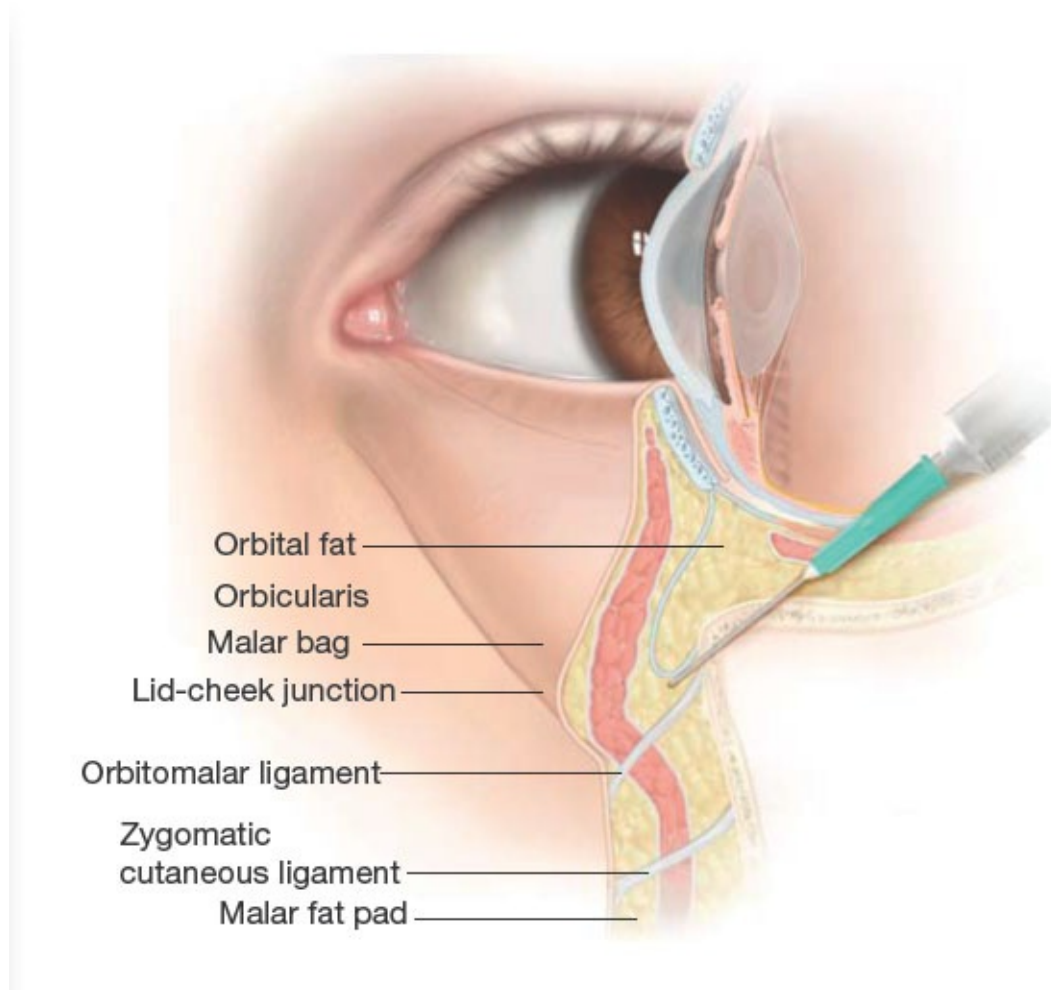
TECH FIG 1 • Injection technique—The orbital rim is palpated, and the cannula is inserted between the two portions of orbicularis muscle of the tear trough and onto the supraperiosteal plane. Filler is then injected in a medial to lateral and retrograde fashion.

- Average reconstituted volume delivered is 0.4 cc.
- Minimal massage, if any, can be used to blend (**TECH FIG 2**).

Additional Agents

- Belotero Balance (Merz, Inc. Frankfurt, Germany)—short-lived HA filler (6 months or more) can also be placed intra- or subdermally.
- Juvederm Ultra XC (Allergan, Inc., Santa Barbara, Calif.)—hydrophilic HA filler if used, should be injected conservatively.
- Restylane Refyne (Galderma Laboratories, L.P.)—a flexible HA recently

cleared in the United States, as all agents, is recommended to be injected in the supraperiosteal plane.



TECH FIG 2 • Injection technique—The lid-cheek junction is injected in a similar fashion to the tear trough in the supraperiosteal plane below the orbicularis oculi muscle at the level of the orbitomalar ligament from lateral to medial toward the cannula insertion point located at the midpupillary line.

PEARLS AND PITFALLS

Equipment	■ A 30G 13-mm needle may be used. Multiple punctures routinely result in increased ecchymosis. Injections are performed at 90 degrees to the skin surface at the supraperiosteal plane.
Choice of injectable filler	■ Hydrophilic or fillers with higher lifting capacity should be used conservatively and injected in the deepest plane possible to minimize complications. ■ Fillers with a high elastic modulus (G') and lifting capacity can be more safely placed laterally along the lid-cheek junction with caution.
Technique	■ Be aware of the orbital rim at all times. ■ Inject conservative amounts in a retroactive manner, and avoid overcorrection. ■ Slow injection should be performed at all times.

POSTPROCEDURAL CARE

- Makeup and other under-eye products should not be used until the following day.
- Patients may ice the area immediately after the procedure and should remain with their head elevated for the next 24 hours to minimize swelling.
- Gentle digital pressure can be used to blend areas of edema or irregularity. Massage is not recommended.

OUTCOMES

- Patients may expect edema, ecchymosis, and injection site tenderness for the first 24 to 48 hours lasting up to 7 to 10 days.
- Patient should expect additional treatments every 6 to 12 months depending on the filler used and or associated use of botulinum toxin type A in the periorbital area.
- See **FIG 3** for before and after patient photos.

COMPLICATIONS

- Irregularities and nodules occur rarely and are secondary to poor technique and/or overcorrection.
- A gray-bluish hue of the skin caused by the Tyndall effect can be seen if a hyaluronic acid (HA) product is placed too superficially or undiluted.
- Injection of material above the rim or posterior to the orbital septum can cause prolonged edema or contour abnormalities.
- Excessive volume, malposition of filler material, or contour abnormalities can

be resolved with hyaluronidase (10 units of hyaluronidase/0.1 cc of HA filler) for HA products. Allow swelling to subside for evaluation prior to attempting reversal.

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11 Injection of Fillers in the Malar Region

CHAPTER

Benjamin T. Lemelman and Julius W. Few

DEFINITION

- Injection of filler in the malar region addresses the aesthetic concerns of the aging patient without the need for surgery.
- The primary filler is hyaluronic acid (HA) gel due to its many properties and U.S. Food and Drug Administration approval.¹
 - Replaces lost midfacial soft tissue volume due to aging.
 - Increases tissue's capacity to bind water.
- The authors use a combination of U.S. Food and Drug Administration (FDA)–approved fillers including Juvéderm Voluma XC (Allergan, Inc., Irvine, CA) and Restylane Lyft (Galderma Laboratories, Fort Worth, TX).
- Various rheologic properties contribute to the ability of the HA filler to enhance volume and lift the midface:
 - One of these factors is the G' (G-prime). This describes the firmness or elasticity of the HA product. A product with higher G' has an increased firmness or density.
 - Restylane Lyft has a reported higher G' than that of Voluma.
 - Despite the differences in G' , both are considered “high density” and have shown success in midface rejuvenation.^{1–3}
 - Cross-linking of the HA particles during production also contributes to the product characteristics.

ANATOMY

- The midface extends from the lower eyelid-cheek junction to the nasolabial fold.
- The three target regions for midface enhancement include (**FIG 1A**)¹:

- Zygomaticomalar region
- Anteromedial cheek region
- Submalar region



FIG 1 • A–D. Before and after results following a total of 3 mL of HA filler to the three regions of bilateral midface of a 65-year-old woman with history of a facelift 5 years prior to presentation. The results shown are after 12 months.

- Additionally, the midface can be divided into four regions V1 to V4 (**FIG 1B**)⁴:
 - V1—zygomatic arch
 - V2—zygomatic eminence
 - V3—anteromedial cheek
 - V4—submalar
- In the V3 region, knowledge of the location of the infraorbital nerve and neuromuscular bundle is essential. The authors use a blunt cannula technique to minimize risk of intravascular injection of HA, when injection is anywhere other than on the periosteum.

PATHOGENESIS

- Midface aging is a result of many contributing factors including volume loss and tissue descent.
- Changes in underlying bony anatomy, soft tissue volume, and skin thinning all contribute to the aging mid face.^{1–3}

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed history and physical examination is required prior to any intervention.
- The main reasons for patients to seek aesthetic procedures are to appear younger and more attractive, and feel more confident.¹
- History of allergies, tobacco use, autoimmune disorders, connective tissue diseases, anticoagulation therapy, and herbal therapies are important issues to discuss with patients.
- Note any prior surgeries on the midface or history of filler use; discuss the type of filler and the number of previous treatments.
- Examination of the face must be performed with the patient in the upright position, as gravity is a major component of tissue descent.
- Examine for facial symmetry, midface firmness, function, sensation and presence of rhytids, skin lesions, or masses.
- A standardized informed consent is obtained from each patient, ensuring they understand the risks, benefits, and alternatives.

IMAGING

- Use of photographic documentation is essential for both the patient and surgeon to examine the effectiveness of the procedures.
- Many computer programs and imaging modalities have the ability to create 3D images to allow the surgeon to digitally modify the patient's midface features, showing the desired outcomes prior to injection.
- Surgeons must obtain standardized before and after photographs for each patient undergoing midface rejuvenation.

NONOPERATIVE MANAGEMENT

- Injection of HA gel is a good option for patients desiring midface rejuvenation. The technique is detailed in this chapter.
- Off-label use of calcium hydroxyapatite is an effective filler substance for the midface but lacks the reversibility seen with HA injection and is not currently approved by the U.S. Food and Drug Administration.

SURGICAL MANAGEMENT

- Autologous fat transfer to augment the aging midface is one surgical option.
- One disadvantage of fat transfer is the requirement for a surgical procedure and the associated donor-site morbidity.
- Other surgical interventions to address the midface include the

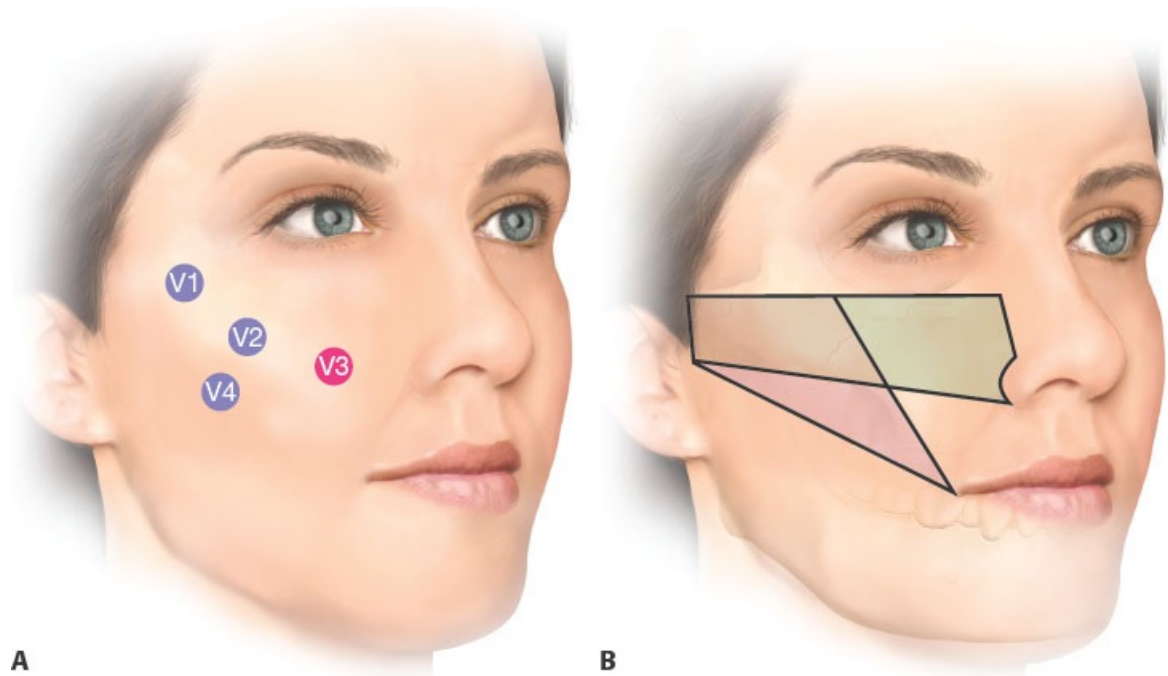
transconjunctival midface lift or standard facelift.

TECHNIQUES

- Following informed consent, the patient is positioned in the upright position to mark the midface zones and highlight the areas of concern (**TECH FIG 1A**).
- No anesthesia is required for midface injections with Voluma XC or Restylane Lyft, as each product contains lidocaine.
 - Optional topical lidocaine or related anesthetic gel may be used prior to injection.
- Clean the entry site on the midface with betadine or chlorhexidine prep.
- Using a 25 (for a 27G cannula) gauge needle, make a hole in the skin at the desired entry point.
- Focus on targeting the three main regions of the midface: zygomaticomalar, anteromedial cheek, and submalar regions (**TECH FIG 1B**).
- Target the injection in the subcutaneous space.
- The periosteal plane may also be targeted, and we prefer the use of included 27- or 30-gauge needles for the injection of Juvederm Voluma and Restylane Lyft, respectively.
- Thread the product in retrograde fashion to create the desired effect when using the cannula technique; 0.2- to 0.3-mL sequential bolus injections are preferred for needle-based periosteal placement.
- Fanning or cross-hatching of the product may also be employed.
- Take note to avoid the V2 neurovascular bundle in the anteromedial cheek region.
- Cross-hatching, with or without fanning, may be employed.
- Massage of the injection sites can help manipulate the tissues to the desired result.
- Each therapy should be tailored to the patient's desired effect.
- When finished, reassess the patient in the upright position to evaluate any areas needing further therapy.
- On average, approximately 2.5 mL of HA filler is used per side during the initial procedure for Voluma.¹
- About 1 month later, patients may undergo reinjection with an average of

approximately 1 mL per side, to achieve optimal correction.¹

- Patients with a history of oral herpes simplex virus are placed on prophylactic antiviral therapy 2 days before and 5 days after injection.



TECH FIG 1 • A. Midface zones. **B.** Midface regions.

PEARLS AND PITFALLS

Techniques

- The authors prefer a blunt cannula technique to avoid intravascular injection.
- Moderate manual massage by the surgeon helps to mold the filler.
- Layering of the product in microaliquots can help achieve the desired aesthetic result.

Complications

- Hyaluronidase must be immediately available.

POSTOPERATIVE CARE

- There are no activity restrictions for patients following the procedure.
- Ice packs are provided for pain relief and/or edema.

- Patients with history of bruising are provided Arnica Montana, a natural remedy, and/or vascular-based nonablative laser.



FIG 2 • A–D. This 63-year-old woman underwent injection of three syringes of HA filler to the three regions of the midface.

OUTCOMES

- Studies reveal results can last up to 2 years.
- Most patients require an initial touch-up (approximately 1 mL per side) 1

month after the initial injection.

- **FIGS 1** and **2** are examples of patient results.

COMPLICATIONS

- Potential complications are listed on all consent forms and must be discussed prior to injection.
- The most common complications include tenderness, swelling, firmness, lumps, or bumps. Most issues resolve at 2 weeks.
- Other complications include bruising, pain, redness, discoloration, and itching. Most of these symptoms also resolve within 2 weeks.¹
- The most devastating complication is intravascular injection of HA filler, which can result in tissue damage.
- Hyaluronidase must be readily available in any office of clinical setting providing HA fillers.
- A standardized clinical protocol must exist for treatment of accidental intra-arterial injection.
- Idiopathic HA-based nodules have been reported and appear to respond to anti-inflammatory agents combined with strategic hyaluronidase injection.

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Nasolabial Fold With Hyaluronic Acid Filler Injection

12

CHAPTER

Christopher C. Surek and Jacob N. Grow

DEFINITION

Deepening of nasolabial fold is one of the most common complaints in patients with an aging face. A deep nasolabial shadow is the result of bony and soft tissue changes that occur with aging and can be addressed with both operative and nonoperative techniques. The purpose of this chapter is to discuss augmentation of the nasolabial fold with filler injection.^{1–17}

ANATOMY

- The nasolabial fold represents a musculofibrous septation supporting the malar soft tissues superiorly.
- The intimate relationship of the facial artery to the nasolabial fold *must* be respected, although the course is highly variable (**FIGS 1 and 2**).
- The facial artery most commonly travels medial to the fold, starting 1.7 mm inferomedially and crossing beneath the fold at a depth of 5 mm at the superior third, eventually reaching a point 3.2 cm lateral to the nasal ala.¹⁷
- The levator labii superioris, levator labii superioris alaeque nasi, and zygomaticus minor muscle fibers encase the facial artery as it traverses the fold and also distribute select muscle fibers that insert into the fold.
- The deep pyriform space is a concavity just adjacent to the pyriform aperture. As the bony pyriform recesses, there is decreased support of the lateral nasal ala and increased prominence of peripyriform shadowing. Adding volume to the deep pyriform space can help restore support and shape in the peripyriform region (**FIG 3**).

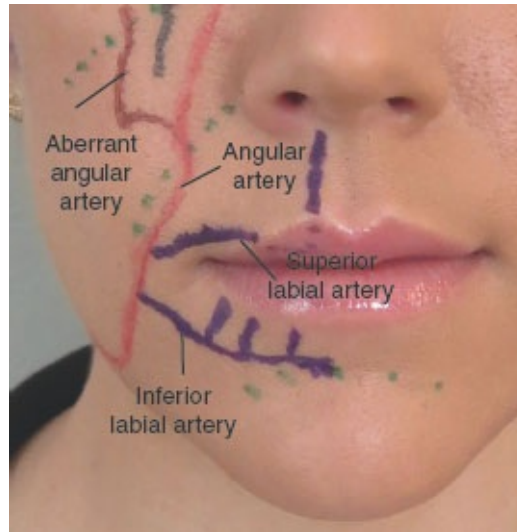


FIG 1 • Demonstration of vasculature location and pathways relative to the nasolabial fold.

NATURAL HISTORY

- In the aging face, bony recession in the anterior maxilla and pyriform aperture coupled with deflation and descent of the midface soft tissue leads to deepening of the nasolabial fold.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical findings often include midfacial soft tissue descent, shadowing in the pyriform region adjacent to the lateral nasal base, deepening of the nasolabial fold, and evidence of associated perioral aging.

IMAGING

- We recommend obtaining standardized 2D or 3D photography for preinjection planning and to assess postinjection results.

MANAGEMENT

Nonoperative management of the nasolabial fold is performed through volume augmentation with various fillers and in some cases autologous fat. The most common material used is hyaluronic acid filler through needle or blunt cannula injection technique.

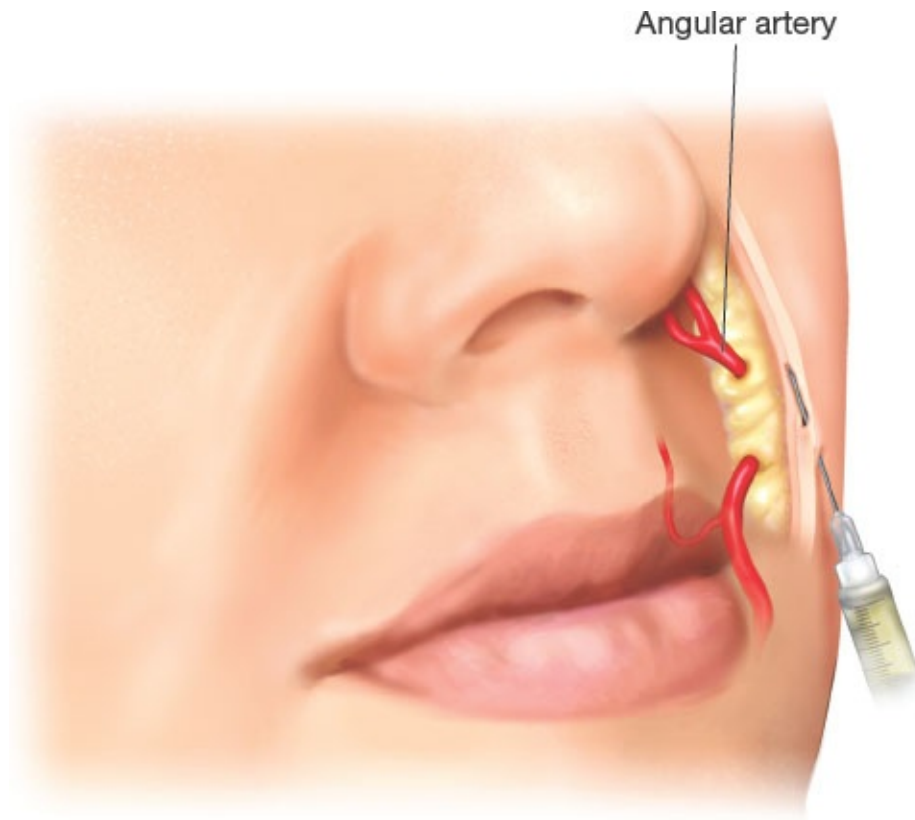


FIG 2 • The depth relationship between the angular artery and the targeted depth for needle placement in nasolabial fold injection.

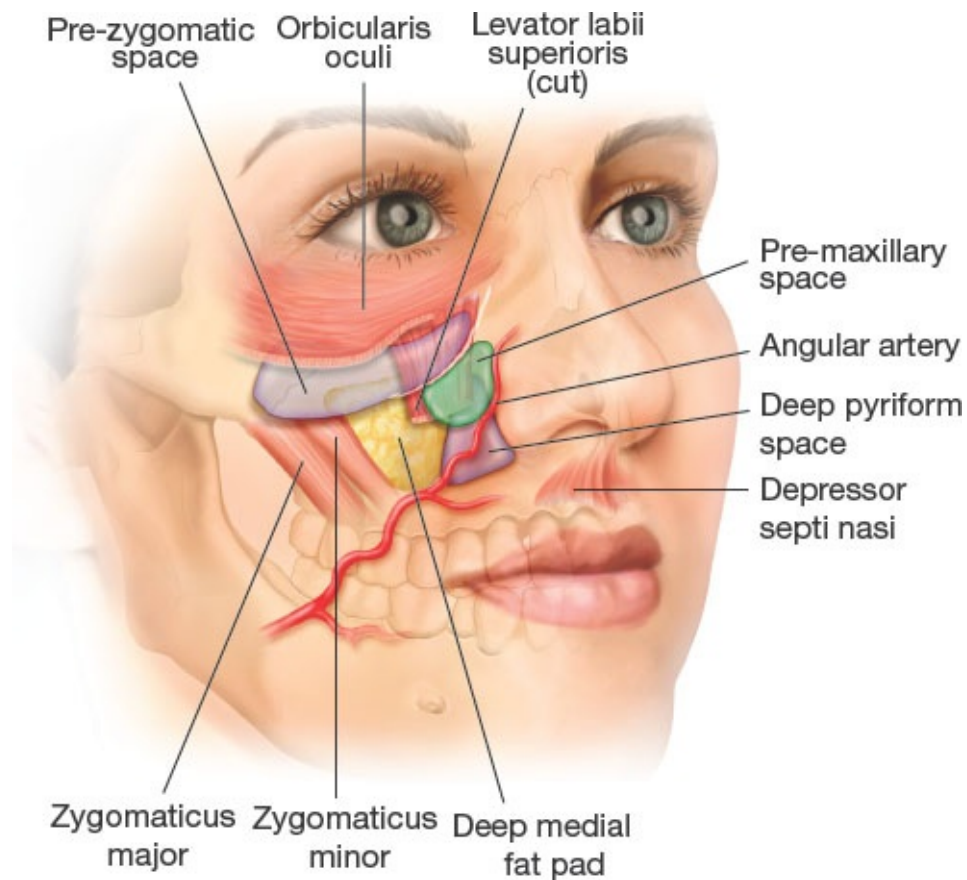


FIG 3 • The deep pyriform space and surrounding adjacent structures.

Preoperative Planning

- Preprocedure photographs should be obtained.
- Complete history and physical exam along with documentation of drug allergies and current medications should be recorded.
- Written informed consent should be obtained to document discussing the indications, risks, and benefits of the injection. Most importantly, patients should be educated on the risk of intravascular injections and counseled on the potential sequelae and treatment following vascular compromise during filler injection.
- The skin involved in the area of injection should be cleaned with an alcohol wipe or antiseptic prep swab.
- Topical anesthetic can be applied to the nasolabial fold skin and allowed to sit for 15 to 20 minutes for the anesthetic to take effect.
- We do not routinely perform infraorbital nerve blocks in our patients.

However, it is certainly a reasonable option in select cases if the injector deems necessary.

Positioning

- The patient should be marked sitting up in the chair at 90 degrees.
- For the injection procedure, we recommend reclining the chair to 45 degrees at a height comfortable for the injector.

Approach

- For needle injection, specific entry points along the nasolabial fold are selected. Typically, we use three needle insertion sites for our linear injections. The distance between each insertion point often depends on the length of the needle being used. When using a cross-hatching method, additional needle sites may be required.
- For blunt cannula injection, one or two port sites are selected for skin insertion. The distance between the ports often depends on the length of cannula being used (**FIG 4**).



FIG 4 • Needle and blunt cannula insertions sites for nasolabial fold enhancement.

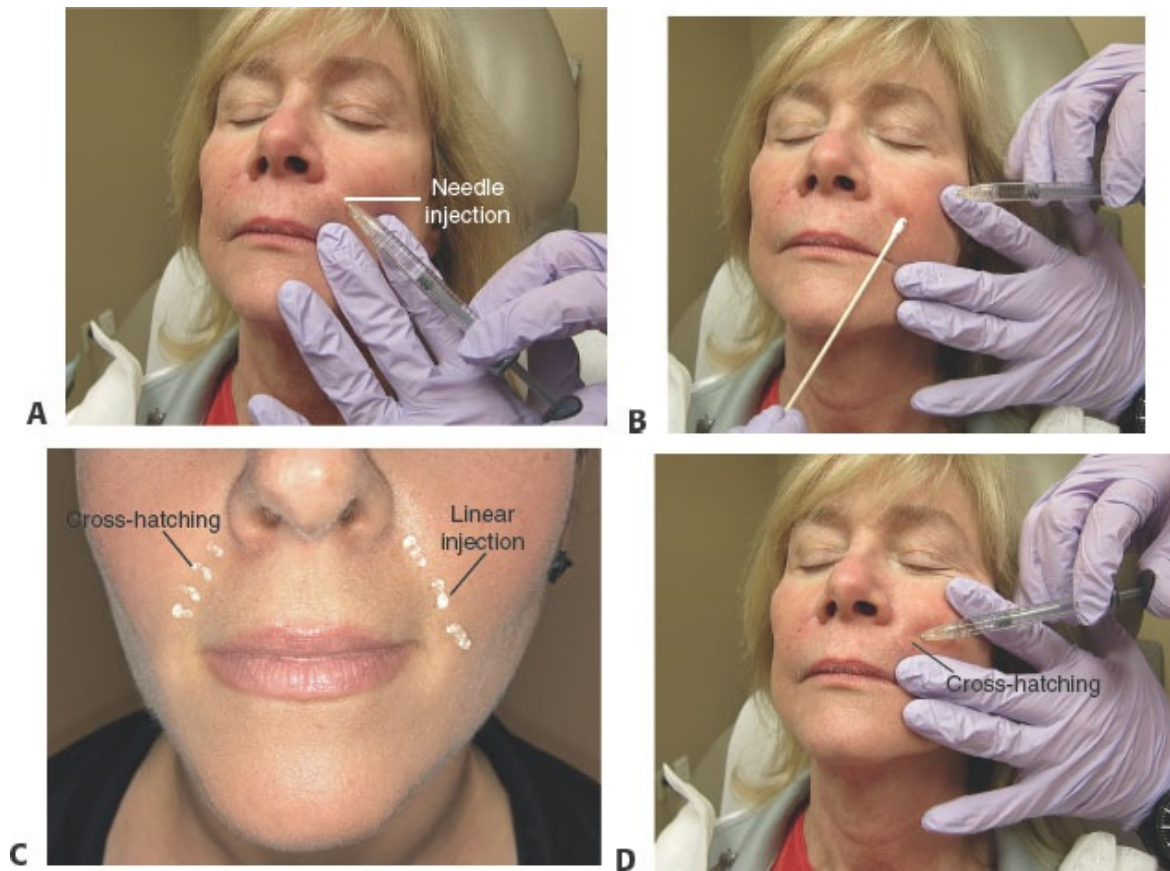
TECHNIQUES

■ Traditional Needle Injection



Video p1-c012

- Needle insertion sites at the upper one-third, middle one-third, and inferior one-third are selected.
- Once the needle is inserted into the skin at the desired location, the injector can elevate the needle against the overlying tissues and should see a gentle “white” blanching of the skin (**TECH FIG 1A**). If the gray color of the needle is visible through the skin, then the needle is too superficial and the injector is at risk of creating a Tyndall effect if the filler is deposited at this level.
- The injector will perform a gentle subcision release with the needle and then perform retrograde injection with the bevel facing down (**TECH FIG 1B**).
- Sequential linear injections in the reticular dermis or immediate subcutis are performed in a cranial to caudal direction (**TECH FIG 1C**).
- Once the liner injections are completed, the injector can perform cross-hatching injections horizontally across the fold to smooth out any contour irregularities. These are performed in a cranial to caudal direction (**TECH FIG 1D**).
- To guide proper depth placement with the needle during the cross-hatching injections, the injector can use their noninjecting hand to spread the cheek tissue. This provides tension and creates a taut fold.



TECH FIG 1 • A. Needle injection into the nasolabial fold. Note the gentle blanching of the skin underneath the needle during subcision. The injector wants to see a slight white blanching of the skin but does not want to see the gray color of the needle, which would indicate a too superficial of a plane. **B.** The injector's assistant can clean blood spotting with a cotton tip applicator. **C.** Demonstration of preferred location of filler placement during nasolabial fold enhancement with needle injection. **D.** Demonstration of cross-hatching technique for nasolabial fold enhancement.

■ Blunt Cannula Injection

- A common alternative to the traditional needle injection technique is to thread a blunt cannula immediately subcutaneous in the nasolabial crease.
- Insertion ports are created with a needle stick, then the blunt cannula is inserted and passed deep to the reticular dermis in line with desired area of volume augmentation.
- Retrograde injection is performed with the blunt cannula until desired result is achieved.

■ Adding Volume to the Peripyrimform Region

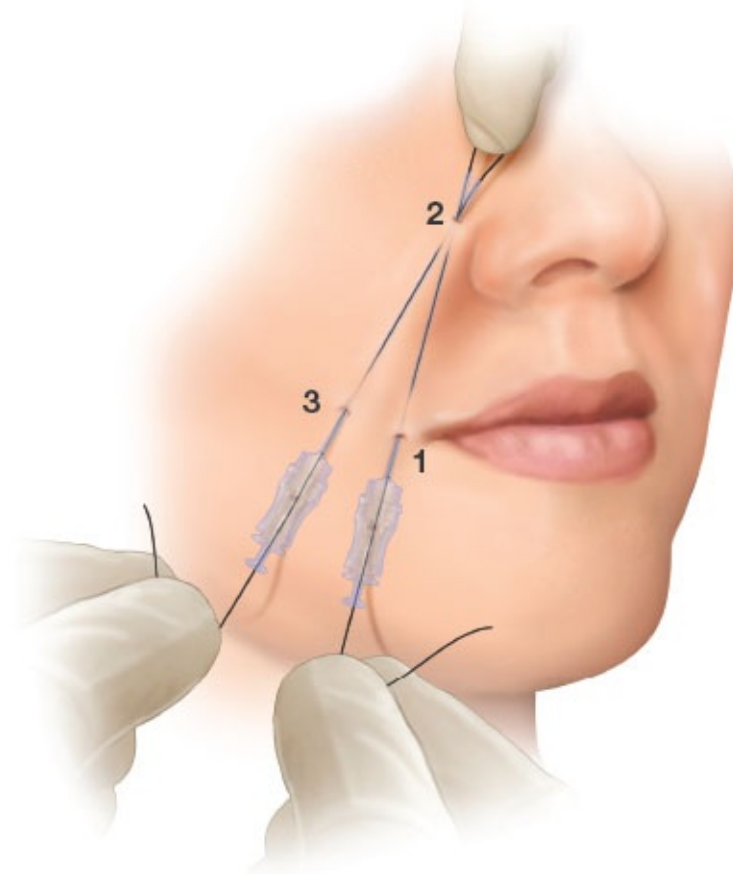
- Recession of the bony pyrimform coupled with changes in peripyrimform soft tissues results in a deep pyrimform shadow at the superior apex of the nasolabial fold. A augmentation bolus on the bone within the deep pyrimform space re-establishes support to the peripyrimform region and can soften the skin shadowing.
- Upon completion of deep pyrimform volume augmentation, the injector can inject intradermal in the peripyrimform shadow. We recommend injecting either intradermally or on the deep bone as the angular artery will travel in a tissue plane between the dermis and the sub-SMAS (**TECH FIG 2**).



TECH FIG 2 • A. Demonstration of deep injection into the deep pyrimform space for re-establishing support of the peripyrimform region. **B.** Demonstration of superficial injection into the peripyrimform shadow for softening the pyrimform shadow.

■ Threading Subcision of the Nasolabial Fold

- Various methods have been described to perform a threading subcision of the fold attachments using a wire scalpel or suture threading technique (**TECH FIG 3**).



TECH FIG 3 • Medical illustration of the suture threading technique for nasolabial fold treatment.

■ Additional Methods of Nasolabial Fold Treatment

- Some surgeons advocate for botulinum toxin injections into the nasolabial fold as alternative means for fold effacement.
 - Release of the dermal attachments of the mimetic muscles in the nasolabial fold is also a well-established tenant in rhytidectomy.
-
-

PEARLS AND PITFALLS

Needle placement

- Needle placement should be within the reticular dermis or immediate subcutis.
- The injector can perform a linear retrograde injection technique along the vertical axis of the fold or “cross-hatch” with small horizontal injections across the fold.
- Blunt cannula injection should occur in the subcutaneous plane just beneath the reticular dermis.

Depth of injection

- Be cognizant of the depth of the angular artery (approximately 5 mm deep to the skin).
- Be aware of the level at which the angular artery crosses underneath the nasolabial fold (junction of the proximal third) in a medial to lateral direction.
- To confirm depth, the injector should see the white color of blanching skin but not the gray color of the needle when placing the needle in the skin. If the injector sees the gray of the needle, the needle location is too superficial and should be readjusted.
- We recommend a gentle needle subcision of the fold followed by retrograde injection of medium-sized hyaluronic acid filler.

POSTOPERATIVE CARE

- We recommend placing a ice pack on the injected areas following injection and monitoring the patient in the clinic for 10 to 15 minutes to ensure that there is no evidence of vascular injury.
- If performing perioral injections in conjunction with nasolabial fold filler, we recommend a short course of postinjection antiherpetic prophylaxis.

OUTCOMES

- The primary goal is softening of the nasolabial fold to improve the shadows and contour reflections along the fold. The objective is not to completely efface the fold because this will distort the natural transition between the cheek and perioral aperture (**FIG 5**).

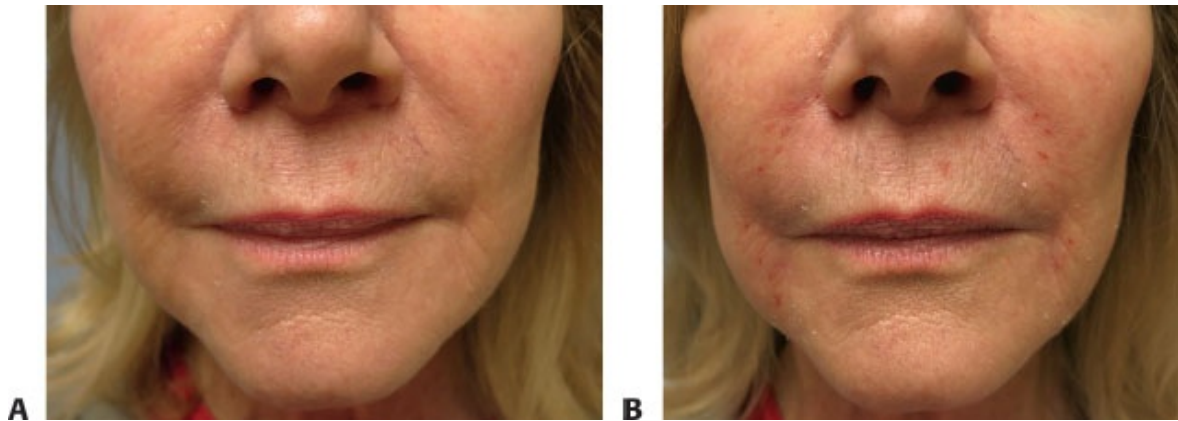


FIG 5 • A. Preprocedure photograph in nasolabial fold enhancement with needle injection technique. **B.** Postprocedure photograph in nasolabial fold enhancement with needle injection technique. The patient also underwent injections of the marionette lines.

COMPLICATIONS

- Postinjection bruising is not an uncommon occurrence. Anecdotally we have found adjuncts such as Arnica and ice packs help expedite the resolution of the bruising. Most bruising should resolve within 3 to 5 days.
- Tyndall effect is a bluish hue within dermis following an injection that was too superficial. This is the result of light reflection off the deposited hyaluronic acid filler. The injector can attempt massage to soften the area or dissolve the filler with a hyaluronidase injection.
- If you suspect vascular compromise following injection, immediate hyaluronidase injection is recommended. Doses ranging from 40 to 200 units are recommended depending on the amount of filler injected and the particle size of the filler. Inject immediately and repeat as many times as needed until manifested skin changes improve. Watch the patient very carefully and monitor them in your office until you feel the problem is resolved.

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13 CHAPTER Injection of Fillers to the Lips, Oral Commissures, Marionette Lines, Prejowl Area, and Temporal Region

David A. Sieber and Jeffrey M. Kenkel

DEFINITION

- Hyaluronic acid is a naturally found glycosaminoglycan polymer found in human tissue that is reversible with hyaluronidase.

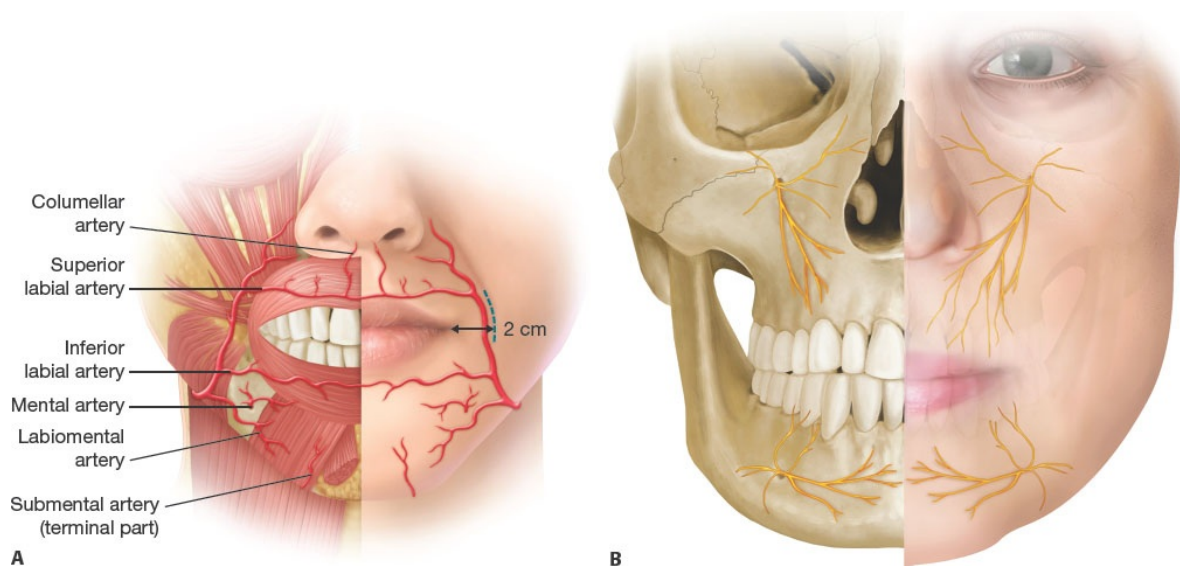
ANATOMY

- The takeoff of the superior labial artery (SLA) from the facial artery is approximately 1 to 1.2 cm lateral to the superior corner of the mouth (**FIG 1A**).^{1,2}
- The SLA then runs superior to the vermilion border, coursing inferiorly across the border just before reaching the Cupid's bow.
- In the upper lip, the SLA is 3 to 8 mm deep to the skin, running in a plane between the oral mucosa and the orbicularis oris at the junction between the dry and wet vermilion.
- The course and location of the inferior labial artery (ILA) are more varied than those of the SLA; however, the depth of the ILA remains greater than 3 mm beneath the skin.^{3,4}
- The mental foramen is most commonly situated inferior to the second premolar and gives way to the mental nerve and artery (**FIG 1B**).⁵
- The frontal branch of the superficial temporal artery (STA) runs within the temporoparietal fascia (TPF) 2 cm above the zygomatic arch, transitioning to a completely subcutaneous plane just superior to the brow and lateral to the lateral border of the frontalis (**FIG 1C**).^{6,7}

- The middle temporal vein runs 2 cm above and parallel to the zygomatic arch within the superficial temporal fat pad.⁸

PATIENT HISTORY AND PHYSICAL FINDINGS

- There are three components that define attractive and youthful lip aesthetics⁹:
 - Shape and definition of the white roll
 - Shape and projection of vermilion
 - Shape and volume of red roll
- Younger patients typically present desiring enhancement (volume and/or projection) of their existing lip shape.
- Older patients often have lost definition of their white roll and Cupid's bow as they age. There is also significant volume loss in the lips, contributing to the appearance of perioral rhytids.
- Patients also present complaining of down-turned commissures saying they have a “sad” or “angry” appearance to their mouth.



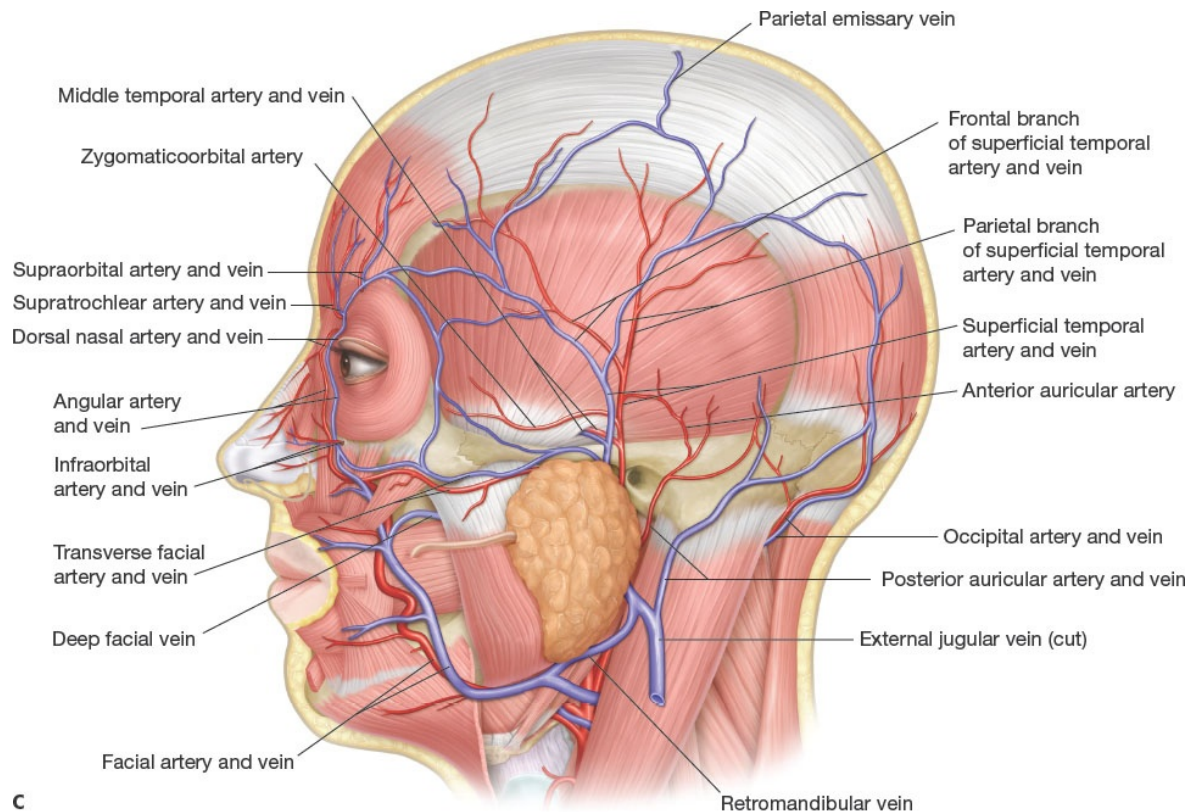


FIG 1 • A. Location of the facial, superficial labial, and inferior labial arteries as they relate to anatomical landmarks. **B.** Location of the mental foramen along the mandibular border. **C.** Location of the superficial temporal artery, transverse branch of superficial temporal artery, and middle temporal vein.

- Other common patient complaints are jowling or excess skin and soft tissue hanging from their mandibular border and temporal hollowing with aging.

NONOPERATIVE MANAGEMENT

- The senior author's preference is to use hyaluronic acid fillers owing to their temporary nature and ability to be reversed through the use of hyaluronidase.
- A topical anesthetic may be used along with ice prior to injection to make the patient more comfortable.
- The skin is always prepped using a swab containing 4% chlorhexidine gluconate prior to injection.
- Injections can be performed with a 30-gauge needle, 27-gauge needle, 25-

gauge cannula, or 27-gauge cannula.

- The patient should be comfortably seated in an upright position.
- Injections are made from a standing position beside the patient.

TECHNIQUES

■ Injection of Filler Into the Lips, Oral Commissures, or Marionette Lines

Preparation

- For most hyaluronic acid products, the authors add 0.2 cc of 0.5% lidocaine with epinephrine using a Luer-lok-to-Luer-Lok connector to constrict local blood vessels, reducing the incidence of postprocedural ecchymosis.
- The authors' preference is to use a 30-gauge needle for injections of the lips and marionette lines, which allows for better control in their hands.

Lips

- If the patient needs further enhancement of the white roll, injections are typically started at the lateral border of the lip.
 - The needle is advanced into a precise location beneath the white roll, filling the area using an antegrade or retrograde linear threading technique.
 - Serial injections are continued until the midline portion of the white roll has been treated, reestablishing an aesthetically pleasing lip shape.
 - Very small amounts are needed and seldom greater than 0.2 mL per side.
- Next, lip volume and projection are addressed again using a linear threading technique.
 - For lip volume, the product is placed at or just posterior to the red line.
 - For lip projection, the product is placed 2 mm beneath the white roll, at the dry vermilion.
- A single vertical injection is done in the center of Cupid's bow for better definition of the tubercle.
- Dermal injections along the lateral borders of Cupid's bow may help better delineate the lateral borders of Cupid's bow.

Oral Commissures

- A triangle-shaped injection is performed at the inferior commissure to help lift the corners of the mouth and refill areas of soft tissue deflation.
 - Cross-hatching of the product is often necessary and may be more efficacious when placed in the deeper dermis.
- A retrograde serial puncture technique is used to place a small amount of product within the fine radial, vertical lines around the lips in an intradermal plane.
- Care is taken to manually massage product in the lips, and the commissures as this area can be palpable to the patient.
- Overly aggressive massage in the perioral region may lead to exaggerated and prolonged lip edema.

Marionette Lines

- Marionette lines are approached starting near the oral commissure.
- Using a linear technique, the needle is inserted into the deep dermis or subdermal location parallel to the marionette line, and filler is placed fairly superficially until the desired result is achieved.
- Additional cross-hatching may be necessary depending on the degree of reinflation required.
- The deformity may extend down to the mandibular border in some patients requiring more volume.
- Some areas may need to be gently massaged to ensure there are no palpable nodules.

■ Injection of Fillers in the Prejowl Area

- For most hyaluronic acid injections in the prejowl region, the authors add 0.2 cc of 0.5% lidocaine with epinephrine using a Luer-Lok-to-Luer-Lok connector to constrict local blood vessels, reducing the incidence of postprocedural ecchymosis.
- A serial puncture technique may be done with a needle, but it is the authors' preference to treat the prejowl area with a cannula.
- A filler with a higher G' is preferred for use in this area
- The index finger or thumb of the nondominant hand is placed below the inferior border of the mandible to ensure no product is placed below this point, which would give the illusion of lengthening the mandible in the

vertical plane.

- A common portal is created using a needle just lateral to the jawl area needing correction.
- The cannula is then used to place product in a subcutaneous plane along the mandible.
- At all times, the index finger or thumb of the nondominant hand is checking to ensure the cannula remains superior to the inferior border of the mandible.
- After correction, product is very gently massaged to ensure there are no palpable areas.

■ Injection of Fillers in the Temporal Region

- For temporal injections, the hyaluronic acid being injected is diluted with 0.5 cc of 0.5% lidocaine with epinephrine 1:100 000 using a Luer-Lok-to-Luer-Lok connector.
- The addition of epinephrine to the filler helps to constrict local blood vessels and prevent postprocedural ecchymosis.
- Injections can be performed with a 27-gauge needle, 25-gauge cannula, or 27-gauge cannula. The authors' preference is to use a 27-gauge needle for injection of the temporal area.
- A superficial or deep injection may be used in this area. It is the authors' preferred approach to perform a deep injection for correction.
- The needle should be inserted 1 cm above and 1 cm lateral to the temporal crest.
- The needle is inserted directly down to the bone, and product is injected onto the periosteum until desired correction is achieved.
- Slight compression at the hairline may help keep the product more anterior, where its impact is seen.
- The product can be gently massaged to create an even appearance.

PEARLS AND PITFALLS

Lips, oral commissures,

- Knowledge of the location of the labial artery between the oral mucosa and orbicularis oris helps to prevent ecchymosis and

and marionette lines

intravascular injections.

- The superior labial artery commonly crosses the white roll at the lateral third of the upper lip. Injections should be very superficial at this location to avoid injury.
- Proper product placement can effectively improve projection, volume, and definition of the lips.
- Volume loss at the commissures is common and benefits from correction with product.
- The patients should be reassured that the product may be palpable for up to 7–10 days.

Prejowl area

- This area can be fibrous and difficult to pass a cannula. If serial puncture is performed, the product must be massaged so a homogenous result may be achieved.
- Care must be taken to avoid inadvertent injury to the mental nerve, which lies in this area.

Temporal region

- Be cautious of any superficial veins while injecting as these may lead to unnecessary bleeding and bruising.

POSTOPERATIVE CARE

- Patients are sent home with small packs of ice and may apply as needed for swelling and/or bruising.
- Patients should keep their heads elevated for a few hours after injection and should abstain from exercise for 24 hours.

OUTCOMES

- Excellent outcomes are achievable through replacement of lost lip volume, enhancement of lip shape, improvement in the appearance of radial perioral rhytids, restoration of lost volume around the oral commissures, and correction of the prejowl area and temporal hollowing (**FIGS 2 to 5**).
- Restoration of lost lip/perioral volume also reduces the prominence of the nasolabial folds and marionette lines (see **FIG 3**).

COMPLICATIONS

- Patients should be counseled on possible risks of procedure, including bleeding, bruising, facial asymmetry, and intravascular injection leading to skin necrosis and/or blindness.

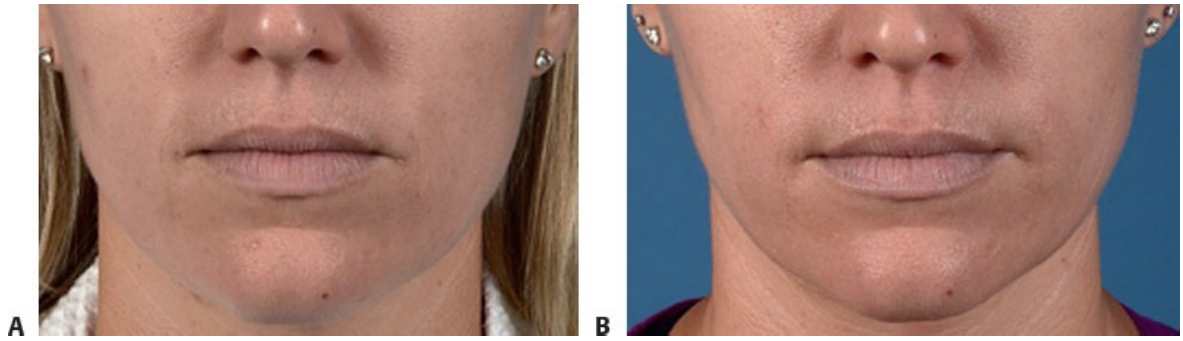


FIG 2 • A 34-year-old woman before **(A)** and after **(B)** injection of 1 cc Juvaderm Ultra Plus into her perioral lip lines.

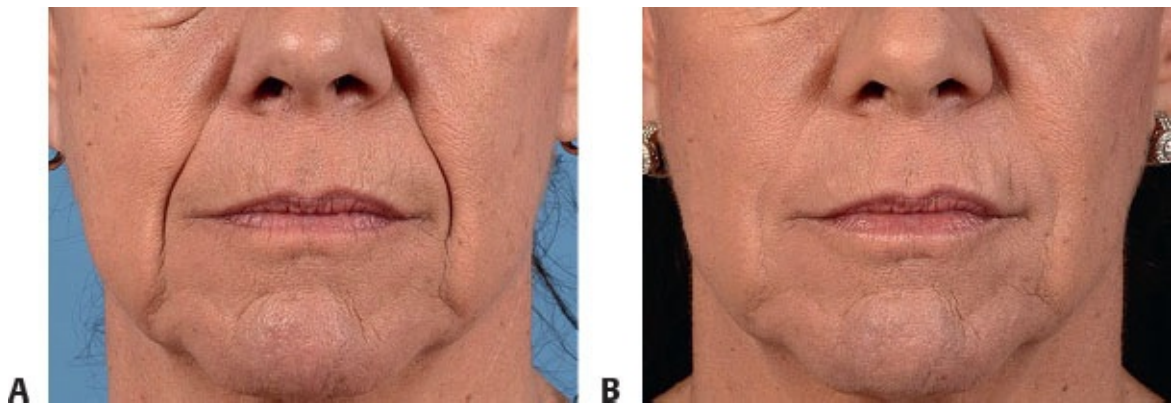
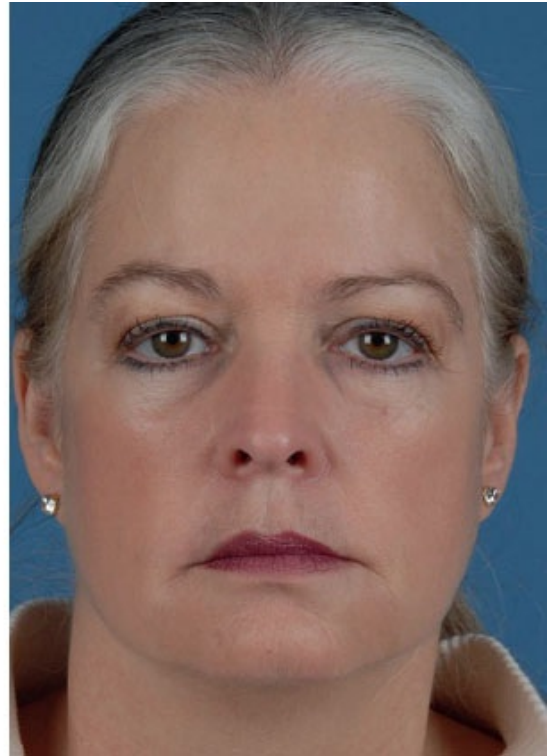


FIG 3 • A 50-year-old woman before **(A)** and after **(B)** treatment with a total of 2 cc Restylane Silk placed into her lips, nasolabial folds, and marionette lines.



A

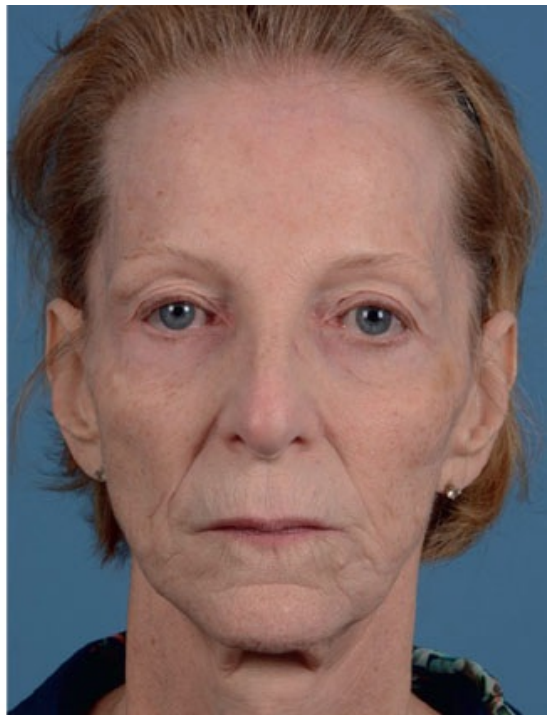


B

FIG 4 • A 62-year-old woman before **(A)** and after **(B)** treatment with 0.5 cc Restylane placed into each prejowl region.



A



B

FIG 5 • A 66-year-old woman before **(A)** and after **(B)** injection of 0.5 cc Restylane Lyft into each temporal region/lateral brow, 1 cc total of Restylane Silk into the lips/perioral region, and 0.4 cc Restylane Lyft into each prejowl region.

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CHAPTER Injection of Filler to the Nose

T. Jonathan Kurkjian, Jamil Ahmad, and Rod J. Rohrich

DEFINITION

- Volume deficiencies of the nose including both congenital and postoperative deformities
- Contour irregularities of the postoperative nose

ANATOMY

- The nose is constituted of multiple layers. From deep to superficial, these layers consist of the mucosal lining, osteocartilaginous framework, musculoaponeurotic tissue, subcutaneous fat, and skin.
- The aesthetic subunits of the external nose include the nasal tip, dorsum, sidewalls, columella, soft tissue triangles, and paired alae (**FIG 1**).¹
- The vasculature of the nose has contributions from both the internal and external carotid systems by way of the ophthalmic and facial artery, respectively. The arterial arcades are located superficial to the musculoaponeurotic layer. The subdermal plexus is located in a more superficial location deep to the dermis.

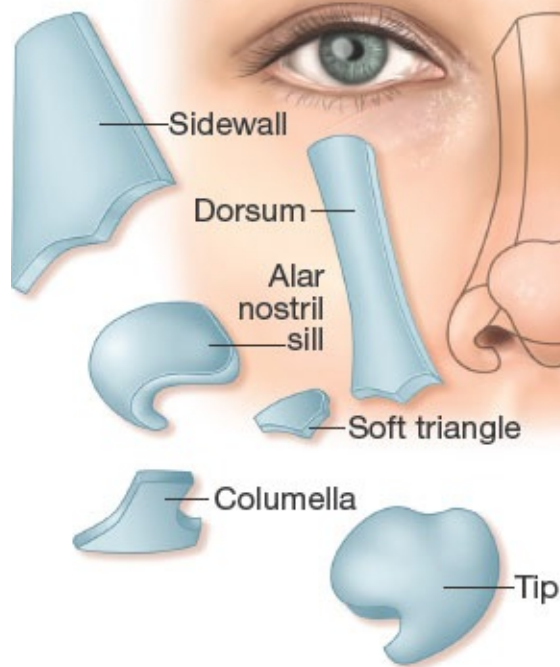


FIG 1 • Aesthetic subunits of the nose include the nasal dorsum, sidewall, tip, soft tissue triangle, ala, and columella.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient history and physical findings are fundamental components to determine if soft tissue filler injection to the nose is an appropriate option.
- Careful understanding of the patient's aesthetic complaints is critical to formulating the treatment plan.
- Physical examination must include a detailed nasal aesthetic analysis to determine the specific nasal deformities. An internal nasal examination should always be a part of the complete nasal examination.
- The patient's history of previous nasal trauma, surgery, and soft tissue filler injections should be documented. Careful examination for surgical scars is also warranted to confirm the provided history.
- Assessment of skin thickness and cicatrix is absolutely critical to planning safe soft tissue filler injections.

IMAGING

- High-resolution digital photography should be used to obtain standard nasal views. These views include frontal, lateral (left and right), oblique (left and right), and basal views.
- Preinjection computer imaging can be used to simulate results prior to injection.
 - Preinjection imaging is particularly useful for the patient who has a preconceived treatment plan.
 - Although computer imaging enables involvement of the patient in the planning process, great care should be taken to communicate that there is no implied guarantee of results.

SURGICAL MANAGEMENT

Preoperative Planning

- Review of the patient's history is important to ensure that patients do not take any medications that may make them more prone to bleeding as this may increase the propensity for postinjection bruising.
- Photographs should be available for preinjection planning and reassessment during treatment.
- Only hyaluronic acid gel fillers are used (ie, Restylane [Medicis, Scottsdale, AZ], Juvederm [Allergan, Irvine, CA]). Particulate-based fillers (ie, Sculptra [Valeant, Bridgewater, NJ], Radiesse [Merz, San Mateo, CA]), are not used to avoid long-term palpability.²
- Soft tissue filler choice is determined by the aesthetic subunit that is to be injected.
 - Restylane has a higher level of cross-linking and lower hydrophilicity; thus, it is used for the nasal dorsum and sidewalls.
 - Juvederm Ultra or Juvederm Ultra Plus tends to be more malleable several days after injection. This ability to mold Juvederm proves to be helpful for the aesthetically sensitive nasal tip and ala.²

Positioning

- The patient should be positioned in an exam chair so that he or she is comfortable and thus less likely to require a change of position during the procedure. Typically, the patient is positioned with the feet slightly elevated and the chair back slightly reclined.

Approach

- Transcutaneous syringe injection approach is preferred as a more sterile route than a transmucosal injection.

TECHNIQUES

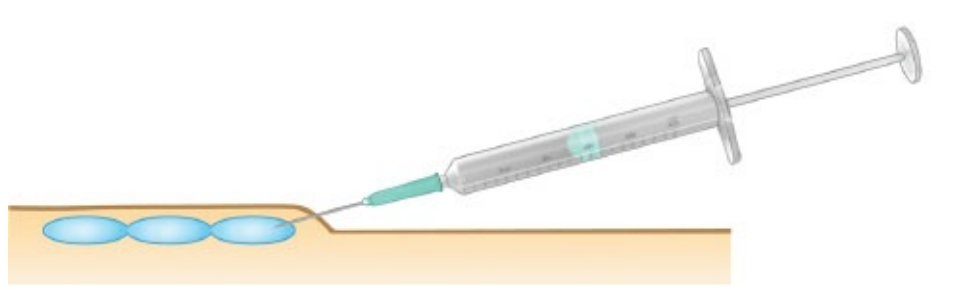
- Some patients may require the skin to be anesthetized with topical anesthetic. The injector may also use 1% lidocaine with epinephrine to perform a nerve block to bilateral maxillary divisions of the trigeminal nerve. The resulting vasoconstriction can theoretically help minimize the risk for intravascular injection. However, vasoconstriction may prevent recognition of vascular compromise of the skin.
- Proper cleansing of the skin prior to injection can help avoid infectious complications. All makeup should be removed, and the skin should be cleansed with chlorhexidine.
- Aspiration prior to each injection is critical to help prevent intravascular injection and associated sequelae including tissue necrosis and blindness.
- All injections should be completed with small volumes and with minimal pressure to avoid contour deformities and intravascular injection. It is critical that all injections are deep to avoid palpability and intravascular injection.
- Gentle massage of the hyaluronic acid can assist with even distribution of the product.
- The injector should allow 15 minutes to pass prior to assessing the final contour. This gives sufficient time for the product to diffuse fully.
- Skin color and turgor should be assessed continuously throughout the procedure as an indication of proper soft tissue perfusion.
- Injection volumes must be monitored closely to help avoid pressure necrosis.
- The technique of nasal injection depends significantly on the aesthetic subunit that is being injected.

■ Injection of the Nasal Dorsum



Video p1-c014_01

- The threading injection technique is preferred to maintain the linear conformation of the dorsum. The needle is inserted along the long axis of the nose, thus respecting the dorsal aesthetic lines while pursuing a more pleasing profile. Careful injection deep along the nasal bone and midvault cartilages will help prevent visibility and palpability of product (**TECH FIG 1**).²

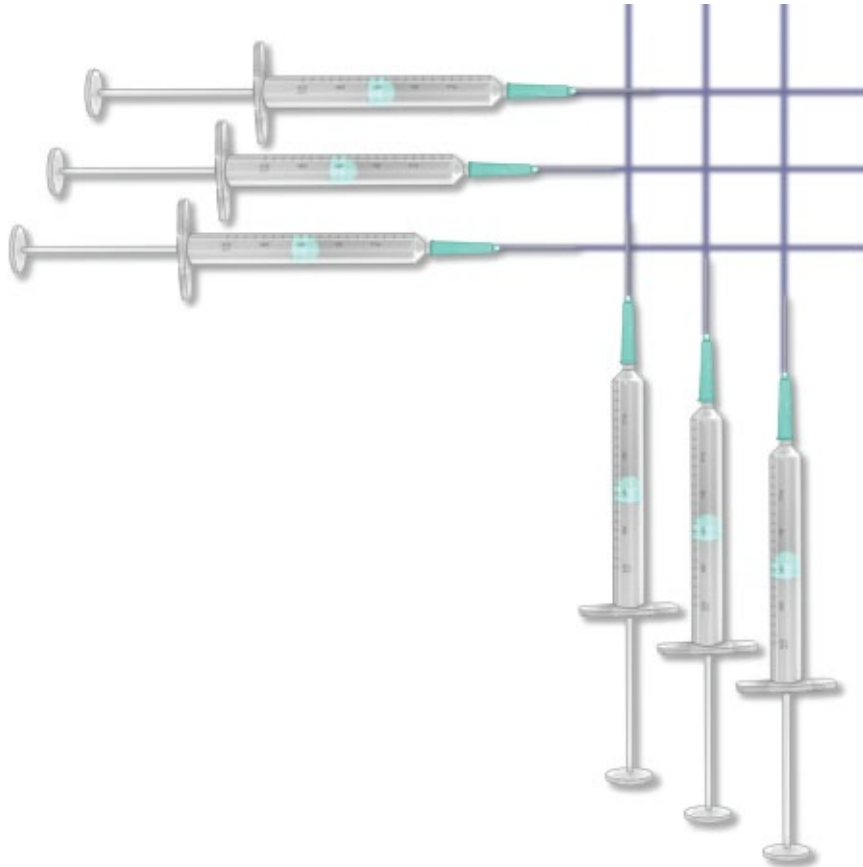


TECH FIG 1 • Linear threading injection technique. The needle is inserted to its full length along a distance and the filler is then injected uniformly with removal of the needle.

■ Injection of the Nasal Sidewall

- Injection of the nasal sidewall should be avoided due to the inherent risk of intravascular injection. If sidewall injection is necessary, a cross-hatching

technique is the preferred method of injection to assist with uniform volume augmentation of the relatively flat nasal sidewall. The needle is inserted parallel to the sidewall thus maintaining a deep supraperiosteal plane during injection (**TECH FIG 2**).^{1,2}



TECH FIG 2 • Cross-hatching injection technique. The needle is inserted in a grid pattern to achieve a smooth contour over a flat plane.

■ Injection of the Nasal Tip/ala

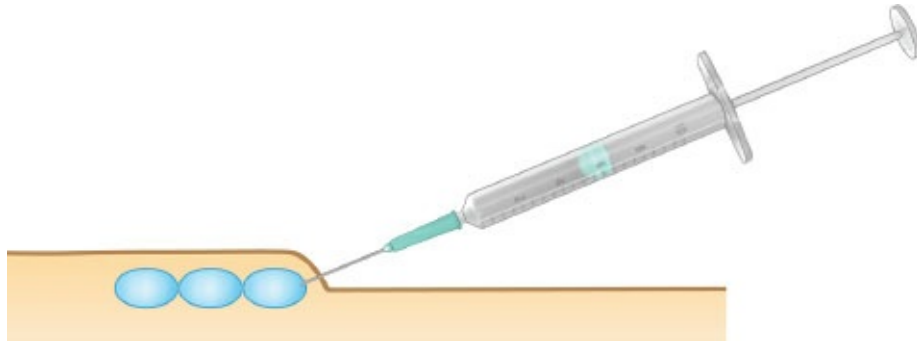


Video p1-c001_02



Video p1-c001_03

- The nasal tip and ala are injected with a serial injection technique using small aliquots of hyaluronic acid. It is particularly important to continuously monitor the skin of the nasal tip during injection for any blanching, which may indicate hypoperfusion due to excessive pressure (**TECH FIG 3**).²
- Soft tissue filler should never be injected along the alar groove to avoid intravascular injection into the lateral nasal artery.
- In order to avoid contour deformities, the filler should be injected deep and never along the alar rim.



TECH FIG 3 • Serial puncture injection technique. The needle is inserted to a shallow depth, and a small aliquot of filler is injected to maximize accuracy and precision.

PEARLS AND PITFALLS

Clinical assessment

- Accurate clinical assessment is absolutely necessary to achieve optimal aesthetic results.

Filler choice

- Hyaluronic acids are the safest and most forgiving products to use for soft tissue filler injection of the nose.
- Restylane is the preferred soft tissue filler for the nasal dorsum and sidewalls.
- Juvederm is preferred for the nasal tip and ala.

Technique

- Each anatomic subunit of the nose is best treated with a specific injection technique, thus enabling accurate and reproducible volume augmentation.
- Aspiration is recommended prior to each injection to minimize the risk for intravascular injection.

Necrosis

- The skin should be continuously monitored for any signs of hypoperfusion that may occur as a result of intravascular injection or pressure necrosis.
- Injection into the previously operated nose should be performed by those with significant injection experience and understanding of the altered blood supply.

POSTOPERATIVE CARE

- Patients are advised to avoid pressure to the injected areas for 2 weeks because it may impact the aesthetic outcome.
- For 24 hours after injection, patients are instructed to avoid exercise, alcohol, and aspirin to minimize the risk of bruising.

OUTCOMES

- The aesthetic outcomes depend greatly on the clinical analysis of the nose prior to injection.
- Clinical experience indicates that Juvederm Ultra/Ultra Plus or Restylane can persist in the nose for 2 to 3 years as opposed to the shorter durations seen with injection to other locations in the face (**FIGS 2 and 3**).³



FIG 2 • Low radix and inadequate dorsal and tip projection. Preprocedure (*left*) and postprocedure (*right*) views of a 19-year-old woman with a low radix and inadequate dorsal projection. She was treated with 0.8 mL of Restylane to the dorsum and radix and 0.1 mL of Juvederm to the nasal tip.



FIG 3 • Asymmetric dorsal aesthetic lines and low radix. Preprocedure (*left*) and postprocedure (*right*) views of a 26-year-old woman with asymmetric dorsal aesthetic lines, narrow midvault, and low radix. She was treated with 0.3 mL of Restylane to the left nasal sidewall and 0.2 mL of Restylane to the right nasal sidewall and 0.5 mL of Restylane to the radix and nasal dorsum.

COMPLICATIONS

- Intravascular injection of hyaluronic acid may cause local tissue necrosis and even blindness. To avoid this complication, aspiration should always be attempted prior to each injection. Small needles (27 g or smaller) are preferred with careful attention to minimize pressure of injection.
- Pressure necrosis can result from volume injected in excess to the compliance of the overlying soft tissue and skin. This complication is more common in the previously operated nose where cicatrix can greatly reduce the pliability of the skin.
- If skin blanching is observed, the injection should be stopped immediately. If the blanching does not improve, hyaluronidase should be injected into the area. If the skin still appears to be hypoperfused, the patient should be started on oral aspirin and topical nitropaste. If a wound results, hyperbaric oxygen may assist with wound healing (**FIG 4**).²

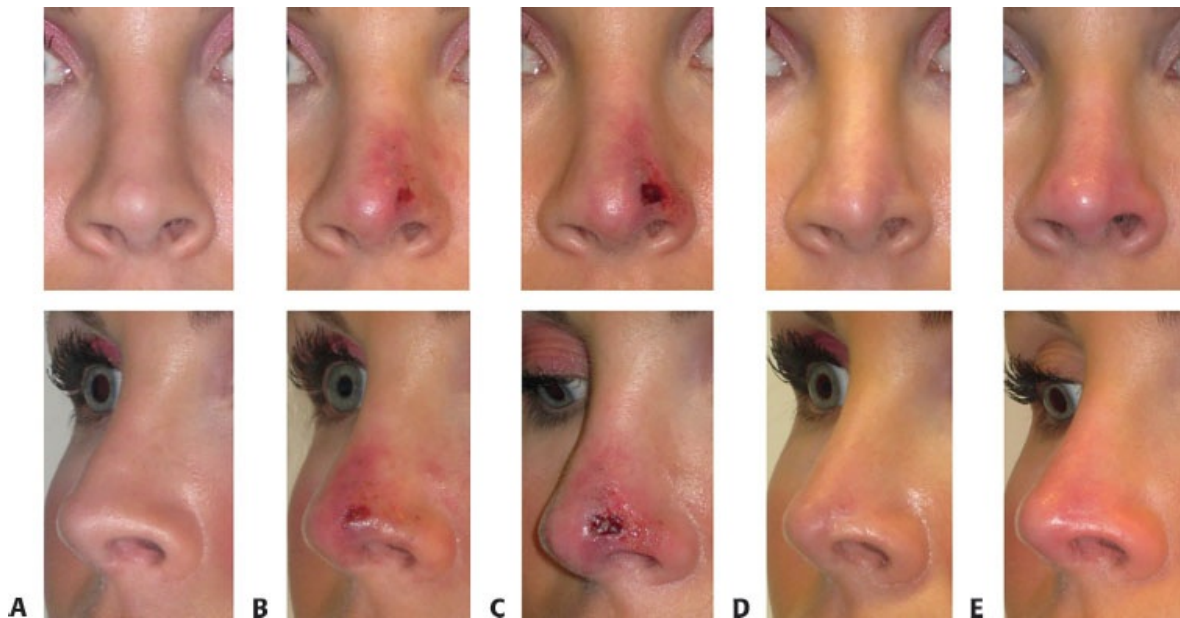


FIG 4 • Management of tissue necrosis. **A.**

Preprocedure view of a 36-year-old woman with asymmetry of the nasal tip including an irregularity of right tip-alar junction and an over-reduced nasal tip after eight previous rhinoplasty surgeries. She was injected with 0.1 mL of Juvederm Voluma to the right tip-alar junction and 0.2 mL to the supratip and left tip-alar

junction. **B.** At 6 days postprocedure, she began to show signs of tissue necrosis. Three separate injections at 10-minute intervals delivering a total of 30 units of hyaluronidase in 1.5 mL of 2% lidocaine were injected to the nasal tip, alae, dorsum, and sidewalls. The patient was started on 81 mg aspirin daily, and nitropaste was applied topically every 8 hours. Hyperbaric oxygen treatment was started and she had a total of 12 sessions. **C.** At 8 days postprocedure with the maximum amount of tissue necrosis that she experienced. **D.** At 6 months after the initial injection. **E.** After injection of 0.1 mL of Juvederm Refine to the right tip-alar junction and 0.05 mL to the left tip-alar junction over two treatment sessions at 4-week intervals. Both the type of product and the volume injected during the session may have contributed to this complication. (From Kurkjian TJ, Ahmad J, Rohrich RJ. Soft-tissue fillers in rhinoplasty. *Plast Reconstr Surg*. 2014;133:121e-126e, with permission.)

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Section III: Fat Grafting of the Face

15 Fat Grafting at the Time of Facelifting

CHAPTER

Sammy Sinno and James M. Stuzin

DEFINITION

- The aging face is characterized by complex problems that evolve over time.
- Fat descent, deflation, and radial expansion of fat away from the central face contribute to some of the changes seen with aging.
- The goal of a facelift is to surgically reposition fat to create a more youthful facial contour. Surgery alone, however, cannot treat deflation of fat that occurs with age.
- Autologous fat grafting has become a common technique utilized by most surgeons today performing facial rejuvenation.¹ In addition to treating volume deflation, fat can make smooth the noticeable demarcations between aesthetic regions in the face that occur with aging.

ANATOMY

- Studies have identified precise anatomic compartments of the face where fat should ideally be placed.^{2,3}
- The anatomy of the deep malar compartment has only been recently elucidated, clarifying that there is deep volumetric support that exists in the plane deep to the mimetic muscles and superficial to the periosteum of the orbit and anterior cheek.⁴ This deep fat system provides volumetric support between the lower eyelid and anterior cheek in youth.
- The medial deep malar compartment is situated along the pyriform aperture

and blends the anterior cheek with the perioral region in youth. Similarly, the central aspect of the deep malar fat pad abuts the buccal extension of the buccal fat pad, allowing for a smooth blending of contour between the lateral cheek and the anterior cheek. Augmenting this compartment is critical to correct the deep deflation that occurs with aging.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- In aging, typically both deep and superficial malar compartment deflation develops, leading to demarcation lines between aesthetic subunits of the midface. Visually, the lower lid sinks into the cheek, developing the infraorbital V deformity.
- Similarly, the nasolabial fold deepens, and, in many patients, an abrupt transition is noted between the lateral cheek and the anterior cheek over time. All of these characteristics are hallmarks of deep malar deflation.¹
- Other areas that should be assessed for potential volume augmentation include the perioral region, temples, tear trough, and prejowl sulcus.

IMAGING

- No imaging is needed for this procedure other than routine preoperative testing.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients are asked to bring pictures from their youth. Patients who have sustained volume loss with age in various compartments of the face are candidates for fat grafting.
- Particular attention is paid to patients who have deep compartment deflation.
- The amount of fat needed for facial fat grafting is estimated.
- A donor site (abdomen, thighs, or hips) is selected with adequate fat for harvesting.
- Importantly, patients should be counseled that not all fat survives, and repeat fat grafting procedures may be necessary 6 to 12 months postoperatively to adequately augment the areas of interest.

Positioning

- The patient is in a supine position for this procedure.

Approach

- Fat grafting can be performed immediately prior to the facelift or immediately after. Advantages to fat grafting before the facelift include minimized tissue trauma and swelling prior to placement. Advantages to fat grafting after facelift include the ability to visualize the effect of surgical repositioning prior to grafting and also avoid displacing the grafted fat during surgical dissection.

TECHNIQUES

■ Fat Grafting at the Time of Facelifting

Fat Harvest

- The goal of fat harvest is to acquire fat as gently as possible.
- The Coleman technique is utilized for fat grafting procedures.⁵
- Possible donor sites include the abdomen, thighs, or hip area.
- The area is infiltrated with a solution of dilute lidocaine and 1:200 000 epinephrine.
- Stab incisions are made with an 11-blade scalpel.
- Fat is collected using a harvesting cannula attached to a 10-cc syringe (**TECH FIG 1**).

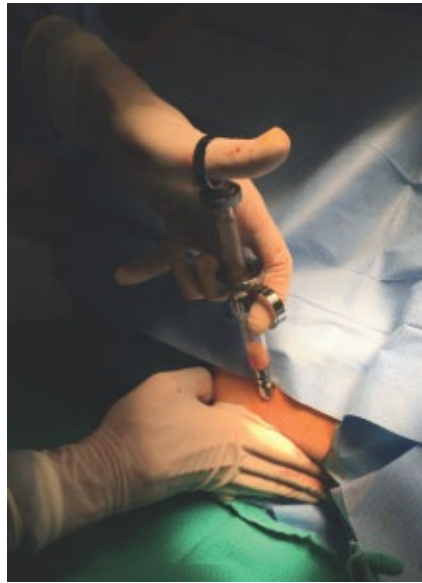
Fat Processing

- A Luer Lock plug is attached to the end of the syringe and the syringe spun in a balanced centrifuge for 3 minutes at 3000 rpm (**TECH FIG 2A**).
- The oil layer (ruptured adipocytes) is removed with a neuropad whereas the aqueous layer (blood and local anesthesia) is evacuated, leaving intact adipocytes (**TECH FIG 2B**).
- Fat is transferred to a 1-cc syringe in preparation for grafting (**TECH FIG 2C**).

Fat Placement

- An 18-gauge needle is used for access.
- Fat is injected using a 1-cc syringe and a 27-gauge Tulip blunt tip side-port cannula (**TECH FIG 3**).

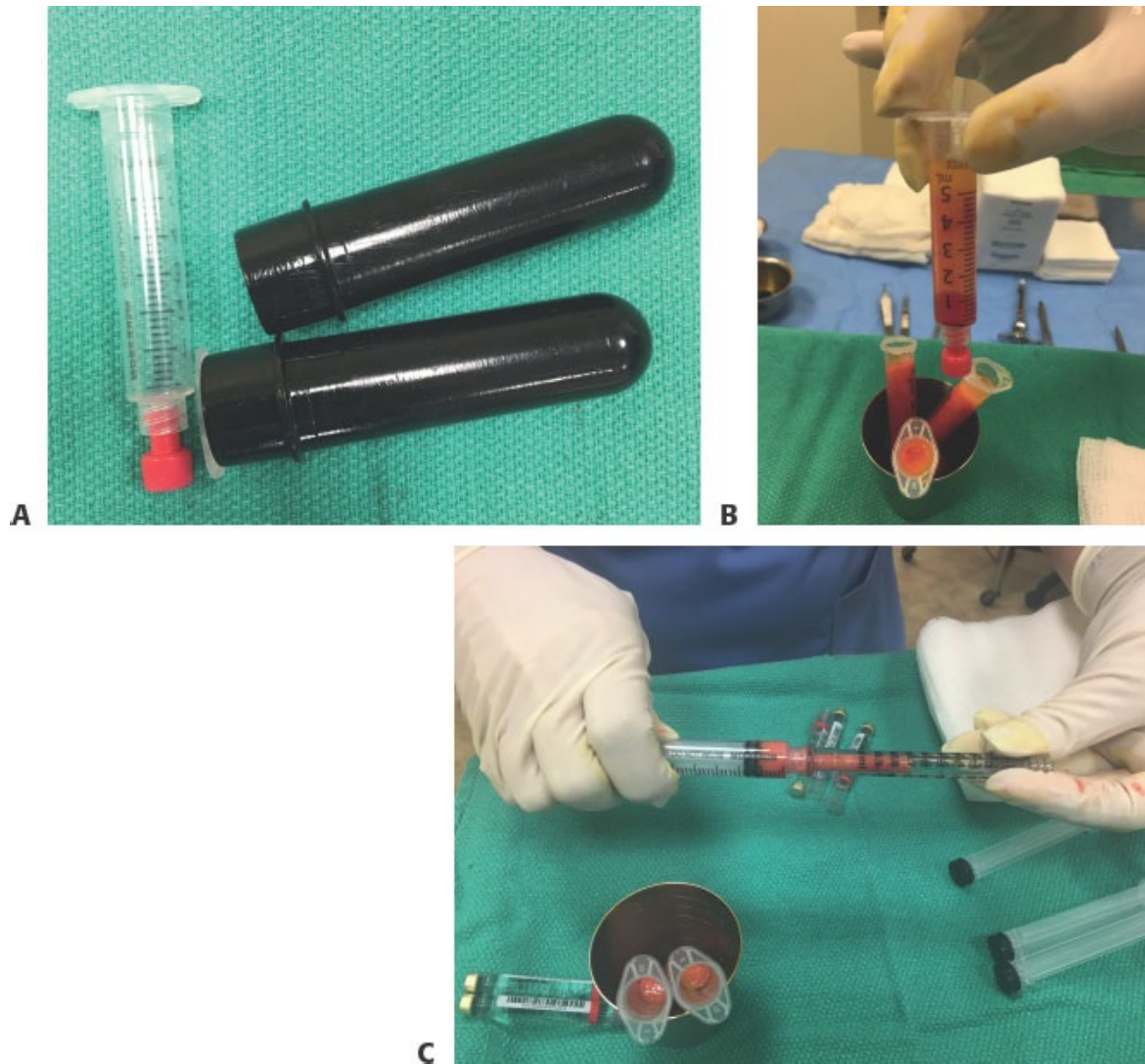
- All fat should be placed in small aliquots in multiple passes with the cannula in constant motion under low pressure.



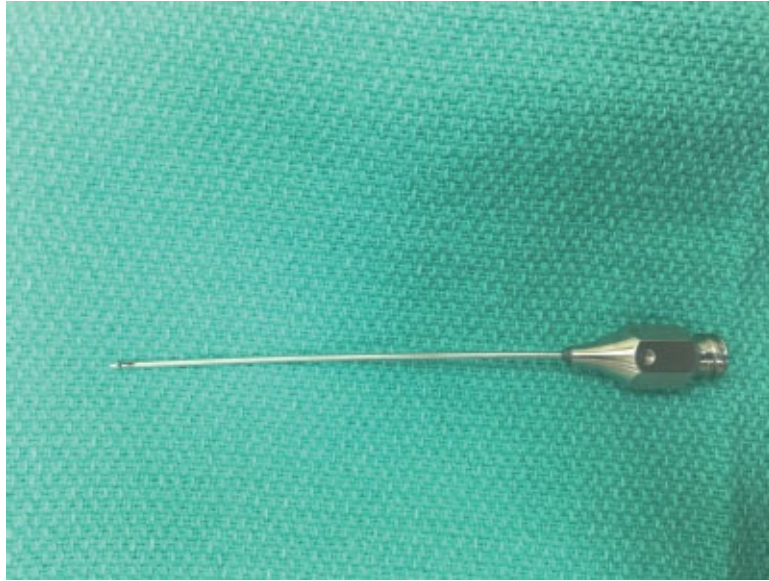
TECH FIG 1 • Fat harvest.

Injection by Anatomic Location

- Deep malar compartment
 - Although facelift techniques can be successful in repositioning superficial malar facial fat into areas of deflation, it is technically difficult to reposition fat into the deep compartment.
 - For this reason, deep compartment augmentation requires volumetric addition for correction. Volumetric addition to the deeper compartments is technically straightforward,⁶ and our preference is to approach this injection via the alar base.
 - Approximately 1 to 3 cc is placed depending on the severity of deflation deep onto the periosteum (**TECH FIG 4**).



TECH FIG 2 • **A.** Luer Lock plugged syringe and centrifuge carriers. **B.** Centrifuged syringes with ruptured adipocytes in the top layer and an aqueous layer at the bottom; fat to be injected is in the middle and then **(C)** transferred to 1-cc syringes.



TECH FIG 3 • Injection cannula.

- Superficial and lateral malar compartments
 - Though typically addressed with surgical repositioning, 1 to 3 cc of fat can be injected directly into these compartments to accentuate malar convexity.
- Nasolabial folds
 - The nasolabial folds are injected directly with 1 to 2 cc of fat depending on fold depth in the subcutaneous and preperiosteal layers.
 - Care is taken to avoid injection into the angular vessels.
- Temples
 - Significant temporal hollowing can result with aging.



TECH FIG 4 • Fat injection into the deep malar compartment.

- Often a significant amount of fat, 3 to 5 cc or more, injected onto the periosteum is required for correction.
- Tear trough and eyelid-cheek junction
 - The tear trough is anatomically a very challenging area to inject.
 - Aesthetic goals in this area are to restore smooth transitions between topographic compartments in the face, overcoming sharp demarcations that become evident with aging.
 - If injected, less than 0.5 cc of fat should be injected cautiously directly into the tear trough with care to avoid causing any irregularities.
 - 1 cc of fat can be injected to blend the eyelid-cheek junction.
- Prejowl sulcus
 - To create a well-defined mandibular border, 1 to 2 cc of fat can be injected preperiosteally into the prejowl sulcus (**TECH FIG 5**).
- Lips
 - Significant perioral rejuvenation can be achieved with fat injection into the lips.
 - 1 or 2 cc of fat is injected with access from the commissure.

Completion

- Following injection, all access sites are closed with a 4-0 plain gut suture.



TECH FIG 5 • Fat injection into the prejowl sulcus.

PEARLS AND PITFALLS

Aesthetic considerations

- Surgery alone cannot correct deep compartment deflation that occurs with age.
- Fat augmentation at the time of facelifting should be considered into areas of volume deflation (ie, deep malar compartment) and into areas where volume will help blend demarcations between anatomic regions that occur with age.

Harvest

- Fat can be harvested from the abdomen, thighs, or hip area.

Processing

- Fat is prepared using the Coleman technique of centrifugation followed by removal of the oil and aqueous layers.

Injection

- All fat should be placed in small aliquots in multiple passes with the cannula in constant motion under low pressure.
- Avoid superficial injections that can cause contour irregularities.
- Exercise extreme caution when injecting into the tear trough.
- Pay close attention to the anatomy of vasculature in the areas of injection to avoid intravascular complications.

Revisions

- Typically, 5%–60% of the injected fat is viable at 1 year.
- Augmentation with additional fat can be performed at 3 months,

but it is advisable to wait 6–12 months if possible.



FIG 1 • A–D. A 54-year-old female seen prior to and following an extended SMAS facelift. Autologous fat (3 cc) was injected into the central deep malar compartment, and 2 cc of autologous fat were injected into the lateral aspect of the deep malar compartment. Note the blending between the lower eyelid, anterior cheek, and lateral cheek as superficial fat repositioning is combined with deep compartment augmentation.

POSTOPERATIVE CARE

- Head of bed elevation is encouraged to minimize swelling.
- Patients will also follow instructions for postoperative facelift care.
- Deep massage is discouraged to avoid displacing injected fat.

OUTCOMES

- The combination of facial fat repositioning, which alters shape by shifting volumetric highlights, in conjunction with volume addition, which further corrects deflation, provides greater aesthetic control in surgical outcome (**FIG 1**).
- Additional fat grafting, or supplementation with off the shelf fillers, can be performed at 3 to 6 months.
- Additional fat grafting is typically performed under sedation.

COMPLICATIONS

- Contour deformity (most common)

- Fat necrosis
- Infection
- Unnatural growth of fat
- Tissue necrosis (rare)
- Intravascular injection

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Section IV: Laser Resurfacing of the Face

16 Techniques for Laser Resurfacing of the Face

CHAPTER

Daniel A. Belkin and Roy G. Geronemus

DEFINITION

- With age, there is a loss of the supporting frame of the skin: collagen, elastin, and hyaluronic acid. Skin laxity results, with increased redundancy, accentuated skin folds, and uneven texture. Skin aging is expedited by exogenous factors, most importantly chronic sun exposure and cigarette smoking, resulting in further wrinkling and dyspigmentation.
- Resurfacing of the skin of the face can be achieved with dermabrasion, chemical peels, energy devices (radiofrequency and plasma energy), and laser surgery, which is the focus of this chapter. Laser resurfacing stimulates collagen synthesis and improves rhytides, dyspigmentation, and the overall quality of the skin.

ANATOMY

- The histology of skin treated with laser resurfacing has been well studied and varies based on the specific laser or device used.
- Resurfacing lasers are either ablative or nonablative and either fractionated or nonfractionated.
 - Ablative lasers vaporize treated zones of skin with surrounding heat injury and coagulation, whereas nonablative lasers produce heat injury without vaporization.
 - Fractionated lasers create small columns of injury within treated areas,

leaving large zones of unaffected skin between them, rather than injuring the entire treated area at once (**FIG 1**).

PATHOGENESIS

- Resurfacing lasers tend to use wavelengths in the near- and mid-infrared range and target water as their chromophore. Destruction can therefore be achieved to any thickness through the skin. The depth and extent of injury are determined by the wavelength of the laser source (nm) and the power delivered, known as fluence (J/cm^2).
- Once injury is produced, new collagen is formed via the wound healing response of dermal fibroblasts, and the epidermis is repopulated from stem cells found in skin appendages.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient expectation, skin quality including Fitzpatrick skin type, and relevant medical history should be assessed before treatment.
- Patient history
 - An appropriate patient has reasonable expectations for cosmetic outcome, and the primary concern is related to the indications described above. Patients should understand the side effect profile and be able to manage the necessary downtime following treatment (depends on modality—see Table 1).
 - Topical and oral medications and medication allergies should be reviewed.
 - History of herpes simplex virus, connective tissue disease, local inflammatory skin disease, and other conditions that may affect wound healing should be elicited.
- Physical examination
 - For most laser resurfacing techniques, it is best if the patient is Fitzpatrick skin types I to IV. Caution is advised in patients of skin types V and VI as they are at risk for dyspigmentation.
 - The aesthetic issue to be addressed will determine the type of resurfacing. Subtle fine lines, sun damage, mottled pigmentation, and hypopigmented scars are some conditions that will respond to noninvasive fractional nonablative resurfacing. Moderate to severe rhytides and atrophic scars will respond to more invasive fractional ablative resurfacing. Elevated lesions, such as fibrous papules or papular scars, may require the localized use of a nonfractionated ablative laser (see Table 1).

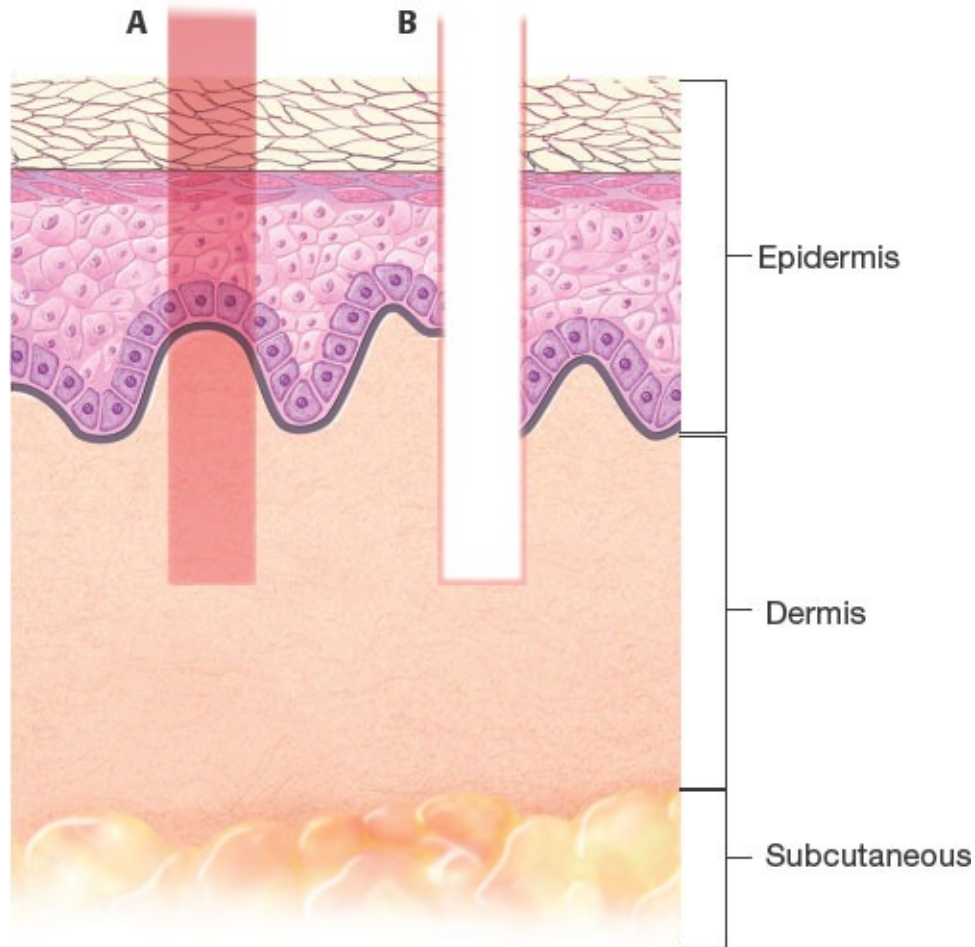


FIG 1 • A schematic of fractional treatment. Healing occurs via stem cells within zones of viable tissue amidst columns of injury, either coagulation **(A)** or ablation **(B)**.

Table 1 Representative Resurfacing Devices and Our Protocols for Their Us

Selected Representative Devices	Category	Medium	Wavelength (nm)	FST	Preoperative Preparation
Fraxel dual (Solta)	Fractional nonablative	Thulium/erbium glass	1927/1550	I–III	1 hour topical lidocaine/pri
Clear and	Fractional	Diode	1927	I–	1 hour topical

brilliant Perméa (Solta)	nonablative (low energy)			VI	lidocaine/pri (optional)
Fraxel repair (Solta) Halo profractional (Sciton)	Fractional ablative	Carbon dioxide Erbium-YAG	10 600 2940	I– III I– IV	1 hour topical lidocaine/pri nerve blocks (mental, infraorbital, supraorbital, lidocaine inf)
Burane (Alma)	Nonfractional ablative	Erbium-YAG	2940	I– VI	Local lidocaine infiltration, n blocks (men infraorbital, supraorbital)

IMAGING

- No radiologic or diagnostic studies are necessary prior to routine laser resurfacing.

SURGICAL MANAGEMENT

Preoperative Planning

- Topical retinoids should generally be stopped a week before treatment and only restarted after complete healing has occurred.
- There is controversy over how long to wait to resurface after a course of oral isotretinoin; to be safe, it is reasonable to wait six months for ablative procedures until there is further data.
- Pre- and postoperative medication depends on provider preference, patient medical history, and device used.
 - Full-face nonablative fractional resurfacing, except for low-energy low-density treatment, may warrant immediate preoperative and postoperative treatment with corticosteroids (eg, prednisone 40 mg prior to procedure and then daily for 2 more days) and antiviral prophylaxis (eg, valacyclovir 500 mg prior to procedure and then BID for 3 more days).
 - Full-face ablative fractional resurfacing often warrants corticosteroids as above, antiviral prophylaxis extended to 7 days, and antibiotic prophylaxis for 7 days (eg, dicloxacillin 500 mg prior to procedure and then BID × 7 days).

- Localized treatment areas often need no pre- or postoperative treatment, including localized treatment with nonfractional ablative devices. Localized ablative fractional treatment around the eyes or mouth is an exception, and prophylaxis above should be considered.

Positioning

- Laser resurfacing requires the patient to recline on an exam table in the supine position with protective eyewear in place.
 - Eyewear may generally be opaque tanning goggles or sticky pads.
 - For ablative resurfacing (fractional or nonfractional) within the orbital rim, protective stainless steel corneal shields should be employed.

Approach

- Some devices require a stamping motion, whereas others require a scanning motion.
 - Fractional nonablative treatments and some fractional ablative devices employ the scanning technique whereby the practitioner paints the skin with a rolling handpiece.
 - The laser should be applied in multiple passes in different directions with attention paid to the total amount of energy (kJ) applied to each subunit of the face.
 - Nonfractional ablative devices and some fractional ablative devices employ the stamping technique whereby the practitioner applies a certain spot size to targeted areas.

TECHNIQUES

- Please refer to Table 1 for further details of selected representative devices.

■ Nonablative Fractional Resurfacing

- These devices include the Fraxel Dual, Palomar LUX 1540, Affirm Multiplex, Clear + Brilliant, Clear + Brilliant Perm  a, and Palomar Emerge.
- They have near-infrared wavelengths in the range of 1410 to 1927 nm and penetrate from 100   m to 1.1 mm.
- They create columns of coagulation and leave zones of spared tissue

between (**FIG 1A**).

■ Ablative Fractional Resurfacing

- These devices include the Fraxel Repair, Lumenis Active FX and Deep FX, Sciton Pro-Fractional, Sciton Core, Deka SmartXide, Alma Pixel, and MiXto SX.
- They have mid-infrared wavelengths of either 2940 nm or 10 600 nm and penetrate up to 1.6 mm.
- They create columns of ablation surrounded by coagulation and leave zones of spared tissue between (**FIG 1B**).
- In some cases, the zone of coagulation can be controlled; in general, coagulation improves skin tightening effect but may be counterproductive in darker skin types and hypertrophic scars.

■ Ablative Nonfractional Resurfacing

- Nonfractional resurfacing can often be done by setting the density on fractional devices to 100%.
- At our practice, we use the erbium-doped yttrium aluminum garnet (Er:YAG) laser for the purpose of localized full ablation. Fully ablative resurfacing of the entire face carries a higher risk of scarring and permanent pigmentary loss than does fractional treatment.

PEARLS AND PITFALLS

- Fractional ablative resurfacing produces much faster healing times and a lower rate of scarring and hypopigmentation than full-field ablative resurfacing
- In general, lower densities (of both ablative and nonablative resurfacing) should be used in darker skin types
- Ablative resurfacing off the face, including on the neck, must be done with caution (and generally with much lower energy and density) as fewer sebaceous glands increase likelihood of scarring
- Acneiform eruptions after nonablative resurfacing can be treated with a course of oral tetracyclines such as doxycycline and/or topical antibiotics such as clindamycin

- Postoperative healing should be largely painless; pain should prompt investigation and possible empiric treatment for herpetic or bacterial infection

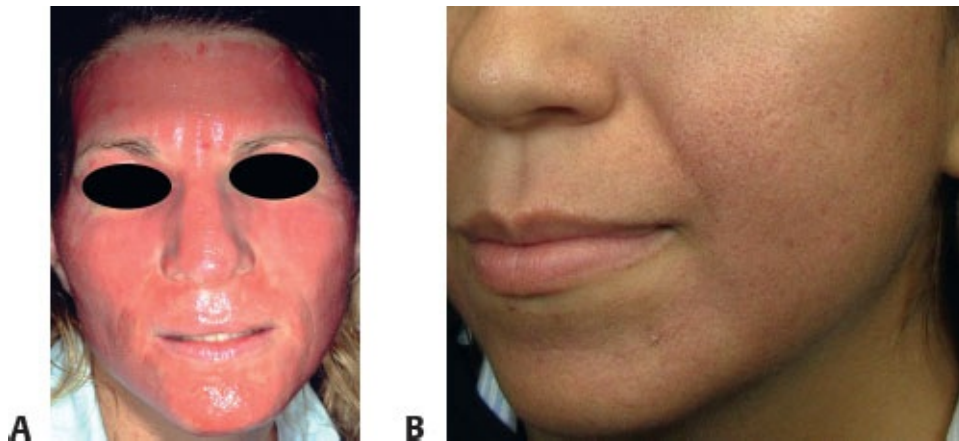


FIG 2 • One day post-treatment. Fractional ablative (**A**) and fractional nonablative (**B**).

POSTOPERATIVE CARE

- Postoperative care differs among treatments, which produce different degrees of injury (**FIG 2**; Table 1).
- For all modalities, strict sun avoidance and generous emollients are important until healing is complete.

OUTCOMES

- Outcomes depend on indication, patient, and device (see Table 1). Some possible outcomes include
 - Improvement in fine lines (**FIG 3**)
 - Improvement of hypopigmentation (**FIG 4**)
 - Improvement of dyschromia (**FIG 5**)
 - Improvement of under-eye festooning (**FIG 6**)
 - Smoothing of moderate to severe rhytides (**FIG 7**)
 - Improvement in acne scarring (**FIG 8**)
 - Improvement in atrophic surgical scarring (**FIG 9**)

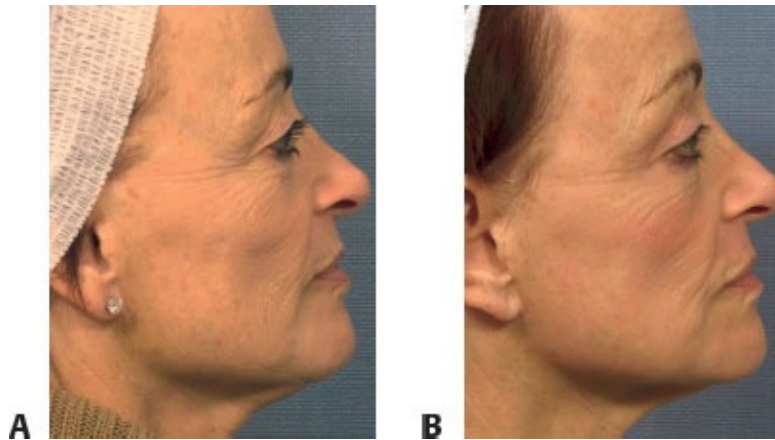


FIG 3 • Improvement in texture, dyschromia, and fine lines. Fractional nonablative therapy with 1550 nm was used with 70 mJ fluence at 40% density. **A.** pretreatment and **(B)** post-treatment.

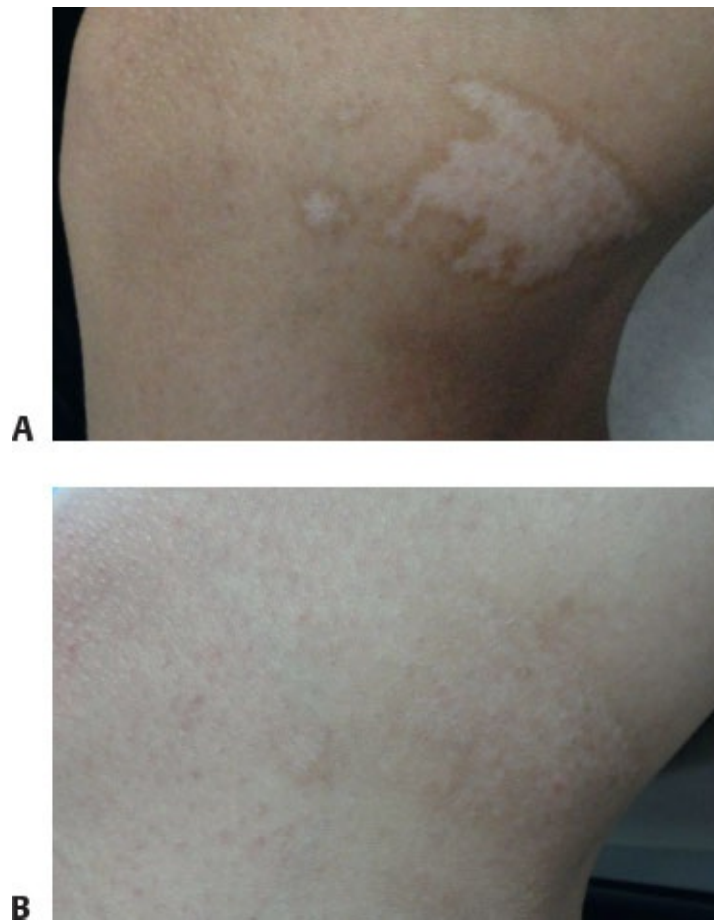


FIG 4 • Improvement of hypopigmentation. Fractional

nonablative therapy with 1927 nm was used with 10 mJ fluence at 65% density. **A.** pretreatment and **(B)** post-treatment.

- Eyelid lift¹
- Clearance of actinic damage²

COMPLICATIONS

- Complications are outlined in Table 1 for each modality.



FIG 5 • Improvement of dyschromia. Fractional nonablative therapy with low energy low density 1927 nm was used with 7 mJ fluence at 10% density. **A.** pretreatment and **(B)** post-treatment.



FIG 6 • Treatment of under-eye festoons. Fractional

ablative therapy with 10 600 nm carbon dioxide laser was used with 70 mJ at 50% density. **A.** pretreatment and **(B)** post-treatment.

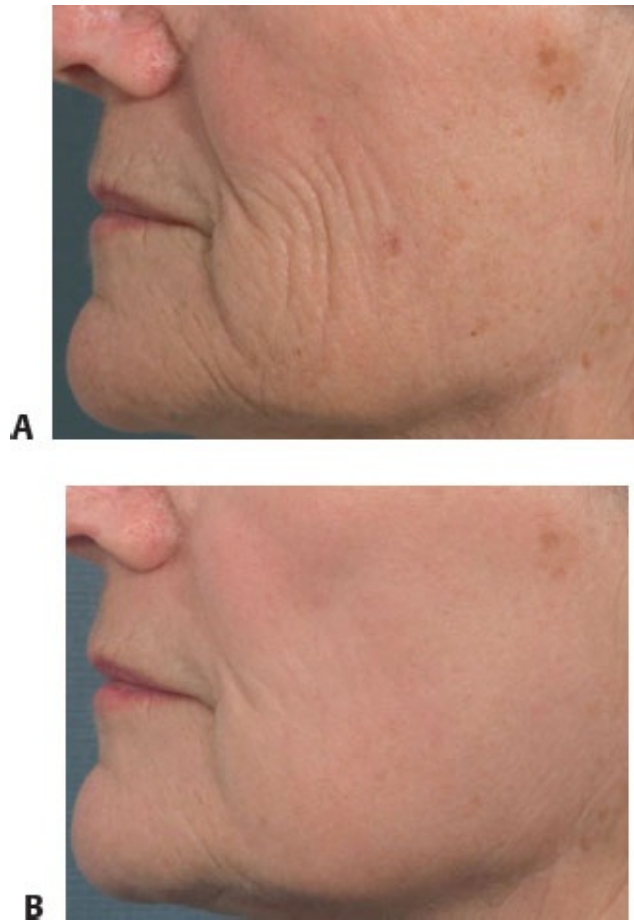


FIG 7 • Smoothing of moderate to severe rhytides. Fractional ablative therapy with 10 600 nm carbon dioxide laser was used with 70 mJ at 50% density. **A.** pretreatment and **(B)** post-treatment.

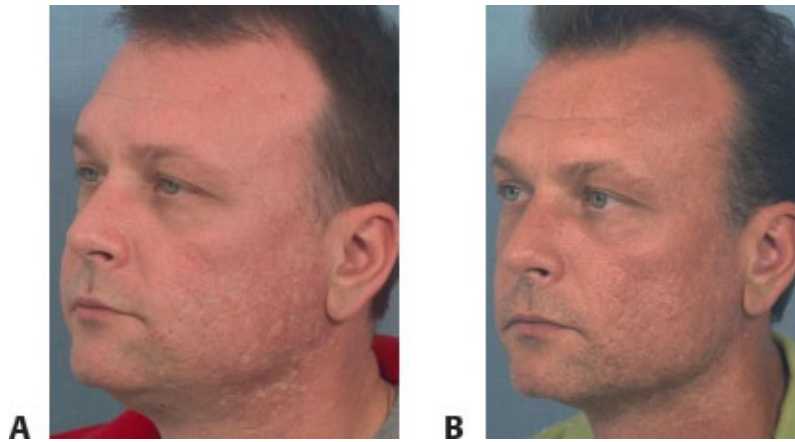


FIG 8 • Improvement in acne scars. Fractional ablative therapy with 10 600-nm carbon dioxide laser was used with 70 mJ fluence at 50% density. Some neck retraction was also achieved. **A.** pretreatment and **(B)** post-treatment.



FIG 9 • Improvement in atrophic surgical scar. Fractional ablative therapy with 10 600-nm carbon dioxide laser was used with 70 mJ fluence at 60% density. **A.** pretreatment and **(B)** post-treatment.

- Feared complications of ablative laser include permanent hypopigmentation and scarring; these are much less likely when energy is fractionated.
- Postinflammatory hyperpigmentation is an important complication and is avoided by careful sun protection post-treatment and caution with darker skin types.
- Acneiform reactions can occur following nonablative treatment and can be treated like acne vulgaris with oral tetracyclines and topical antibiotics.
- Wounding of the skin may predispose to herpes simplex reactivation and bacterial soft tissue infection warranting antiviral and antibacterial prophylaxis in certain cases.

ACKNOWLEDGMENT

We thank Julia Pettersen Neckman, MD, for her significant contributions to this chapter.

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Section V: Chemical Peel of the Face

17

CHAPTER TCA Peel to Face

Steven M. Levine and Daniel C. Baker

DEFINITION

- The aging face changes in multiple facets.
- Surgery is the standard to address descent and laxity.
- Resurfacing is important to treat textural and other surface changes related to aging and environmental damage.
- Trichloro acetic acid (TCA) peel is one highly effective, reliable, and low-cost method to facial resurfacing.

ANATOMY

- Facial peeling can be performed on the entire face and neck or can be isolated to specific aesthetic units such as the lower lids or perioral region.
- The perimeter of any area being treated should be “feathered” to minimize the creation of a transition between peeled and nonpeeled tissue.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Indications for peeling are broad and can include desire to improve skin texture, reduce visible fine lines, or ameliorate age spots (such as solar keratosis).
- It is important to elicit a history of oral herpes so that these patients can be pretreated with antiviral medication.
- Skin type is important to note.

SURGICAL MANAGEMENT

- TCA peeling can be performed as a stand-alone procedure or in combination with a face and necklift.

Preoperative Planning

- The primary consideration for preoperative planning is the patient's skin tone. The more pigmentation in the skin, the higher the chance for postpeel complications such as postinflammatory hyperpigmentation or areas of hypopigmentation.
- Some providers choose to pretreat patients with a retinol or bleaching agent for 4 to 6 weeks prior to TCA peel. Neither of the authors use pretreatment.
- TCA can be used in a variety of strengths. The authors prefer to keep only two strengths of TCA—25% and 35%.
 - 25% TCA is used for lighter peels and darker complexions (Fitzpatrick grade III).¹
 - 35% TCA is used for heavier or more aggressive peels and lighter complexions (Fitzpatrick grades I and II).¹

Positioning

- The patient is either supine if under sedation or full anesthesia or sitting upright in an exam chair while holding a fan if performing a peel on an awake patient.

Approach

- The approach to the peel can be accomplished using a variety of application techniques that yield a controlled, reproducible distribution of chemical to the skin.

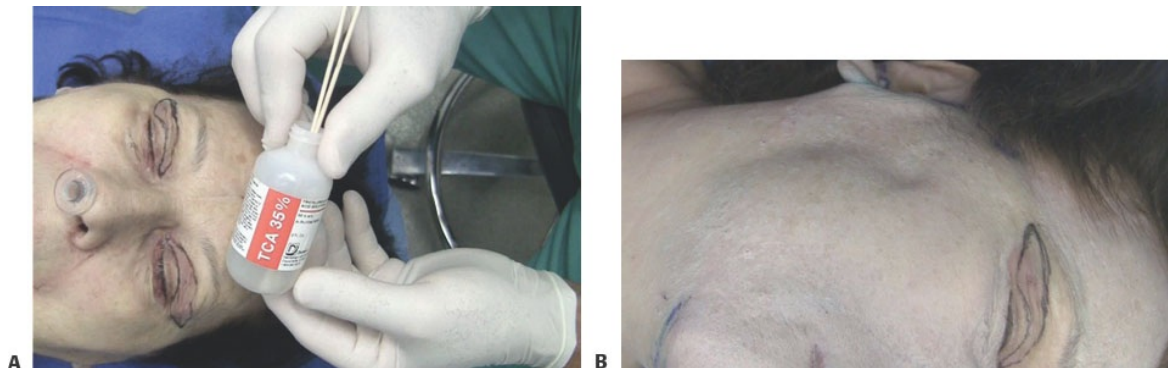
TECHNIQUES

■ Cotton Tip Applicator on Sedated Patient

- The patient is laid supine on the operating room table.
- The face is cleaned with alcohol to remove as much oil from the skin.
- A small amount of eye ointment is placed on the sclera to protect the eyes.
- An assistant should stand adjacent to the procedure table holding the TCA or

the TCA should be kept on a Mayo stand away from the patient. An open bottle of TCA is NEVER placed over the patient or in any position where it can spill on the patient.

- For the majority of the face, two cotton tip applicator sticks are used to spread the TCA (**TECH FIG 1A**).
- Usually the forehead and nose are more keratinized and require a heavier coat of TCA.
- For the lower eyes, a single cotton tip applicator is used to apply the TCA. The skin beneath the lower lid is stretched with the nondominant hand for complete placement of the TCA to just before the lash line.
- Care is taken to “feather” the borders of any anatomic area that means lightening the amount of TCA applied to reduce the appearance of a transition zone.
- The skin will usually frost within 60 seconds (**TECH FIG 1B**).
- An area that does not frost or is not uniform can be retreated in the same manner.



TECH FIG 1 • **A.** TCA peel is applied using cotton applicator sticks. **B.** TCA frost.

■ Cotton Tip Applicator on Awake Patient

- An identical technique is used on the awake patient with the addition of patient-held fan to increase comfort during the procedure.
 - Usually, any burning or discomfort lasts less than 60 seconds as the TCA is neutralized by the skin.
-

PEARLS AND PITFALLS

Start low and light

- Use 25% TCA and apply a thin coat until you get use to correlating the amount of frosting with the level of skin peel.

Avoid TCA spills

- Never hold the bottle of TCA yourself while applying.

Safely combine procedures

- TCA is a an excellent adjunct to a facial surgery procedure

Feathering

- Always extend the treatment beyond the zone being treated (ie, beneath the jaw line if treating the full face).

POSTOPERATIVE CARE

- This procedure is often combined with a facelift in which traditional surgical preparation of the skin is not required in the setting of the TCA peel.
- If combined surgery is not planned, a petroleum-based ointment is applied to the patient's face immediately after the procedure.
- Cool packs are also used to reduce swelling.
- Patients are instructed to remain away from the sun during the acute peeling period (7–10 days postop).
- Sun avoidance should ideally be carried out for several months after TCA peel.
- Patients are instructed to use cool compressed at home for the first 24 to 48 hours.
- After 48 hours, patients are instructed to use warm compressed to speed the peeling process.
- Patients are instructed not to remove any peeled skin themselves (though if they are in the office, I will often do this for them). The concern is the patient could be too aggressive and remove skin prematurely.
- Patients should apply a thin layer of petroleum-based ointment 3 times daily until the skin is re-epithelialized.

OUTCOMES

- TCA peel will predictably improve certain fine lines and reduce the appearance of certain superficial pigmentation issues.

- The provider needs to start using this technique in a metered fashion to gain comfort with expectations and limitations.

COMPLICATIONS

- The most feared complication is TCA entering the eye. If this happens, the eye should be irrigated with saline or water continuously and an ophthalmologist should be consulted immediately.
- Caution must be taken near hair-bearing areas such as the brow because they can trap TCA in the hair causing a deeper burn in that region than intended.
- Hyperpigmentation can occur which usually resolves on its own.
 - Sun avoidance is paramount.
 - Lightening agents such as hydroquinone 4% topical can be used if necessary.
 - Hypopigmentation should not occur with 25% or 35% TCA peel in the patients who do not have dark skin.

REFERENCE

1. Reference to Fitzpatrick classification.

18 Indications and Technique for Phenol-Croton Oil Peels

CHAPTER

Gehan D'Souza and James Zins

DEFINITION

- Intermediate and deep chemical peeling imparts injury to the epidermis and varying depths of the dermis in a controlled manner in efforts to stimulate epidermal regrowth. Peeling has been shown to rejuvenate facial skin and has been used to treat acne, rhytides, and photodamage.¹
- Chemical peels are available in a variety of formulas, which produce superficial, medium, and deep wounds.
 - Superficial peeling techniques are limited to epidermal injury only.^{1,2} Intermediate and deep chemical peels most commonly involve trichloroacetic acid (TCA) and phenol-croton oil. Both TCA and phenol-croton oil depth can be varied by changing the concentration, number of applications, and the amount of peeling agent applied.
 - Deeper peels, such as the conventional phenol-croton oil formula, are the most effective in resurfacing skin but are also associated with more severe complications and may not be appropriate for certain patients.
- The use of phenol-based chemical peels declined with the advent of laser technologies.
 - There has been renewed interest in the use of this technique in recent years with the realization that reducing the concentration and application methods can reduce complications while maintaining results.^{3,4}
 - The phenol-croton oil formulas use varying concentrations of phenol, croton oil, Septisol, and water.³
- Full facial phenol peels require deep sedation or general anesthesia and cardiac monitoring. Because of the potential for cardiac arrhythmias, full facial chemical peeling should be done based on anatomic units over a relatively

prolonged period of time (1–1.5 hours).

- Additionally, these peels pose risk for renal failure and hepatotoxicity.^{3,5}
- Adjusting croton oil concentration allows for variation in phenol-croton oil peel depth and achievement of more uniform results on different thicknesses of skin.³
- Phenol-croton oil peels are increasingly being used as a medium-depth peeling modality and can be performed on a spectrum of ages and skin conditions.⁴

ANATOMY

- Phenol-croton oil, while most commonly recognized as a deep peeling technique, can also be used as a superficial or medium-depth peeling modality (**FIG 1**).⁶
- Chemical peels are divided into three categories based on the degree of injury caused by the treatment⁷:
 - Superficial peels—cause epidermal injury and do not penetrate below the basal layer
 - Medium-depth peels—ablate the epidermis and varying degrees of the dermis
 - Deep peels—remove the epidermis, papillary dermis, and generally extend to the midreticular dermis
- Indications for phenol-croton oil peels include^{4,6,8}
 - Rhytides
 - Melasma
 - Acne

PATHOGENESIS

- Factors such as environmental damage, actinic damage, smoking, and radiation.^{9–11}
- Rhytides form for a variety of reasons. The contraction of the musculature and attachments of the retinaculum cutis that attaches to the skin acts on the skin to create a wrinkle with animation.
- Strategies for preventing rhytides include sun avoidance, smoking cessation, and treatment of skin with retinoids.¹¹
 - Once rhytides are present in the perioral area at rest, they are difficult to treat.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Medical and surgical history, as well as physical examination should address

general health or risks from current medications (eg, isotretinoin, birth control pills, or immunosuppressants), possibility of pregnancy, liver disease, history of herpes simplex virus, history of hypertrophic or keloid scars, history or risk of hepatitis or HIV, history of radiation exposure, and history of cutaneous disease at the peel site (eg, rosacea, seborrheic dermatitis, atopic dermatitis, psoriasis, and vitiligo).

- Previous injury to the reticular dermis including previous peeling, laser, or even electrolysis will affect how aggressive one is with peeling depth.
- Gender differences in perioral wrinkling have been described.
 - Women have a lower ratio of blood vessels to connective tissue than do men.¹² This can also be explained by the differences of follicles, sebaceous glands, and androgen-dependent hair.¹³
- The patient's skin type using a Fitzpatrick classification is important in determining the need for suppression of melanin and prevention of hyperpigmentation.
- The Glogau photoaging scale determines the depth of the peel.^{14,15}
- Indications for chemical resurfacing:
 - Photoaging of the skin and rhytides
 - Preneoplastic or neoplastic lesions such as actinic keratosis and lentigines

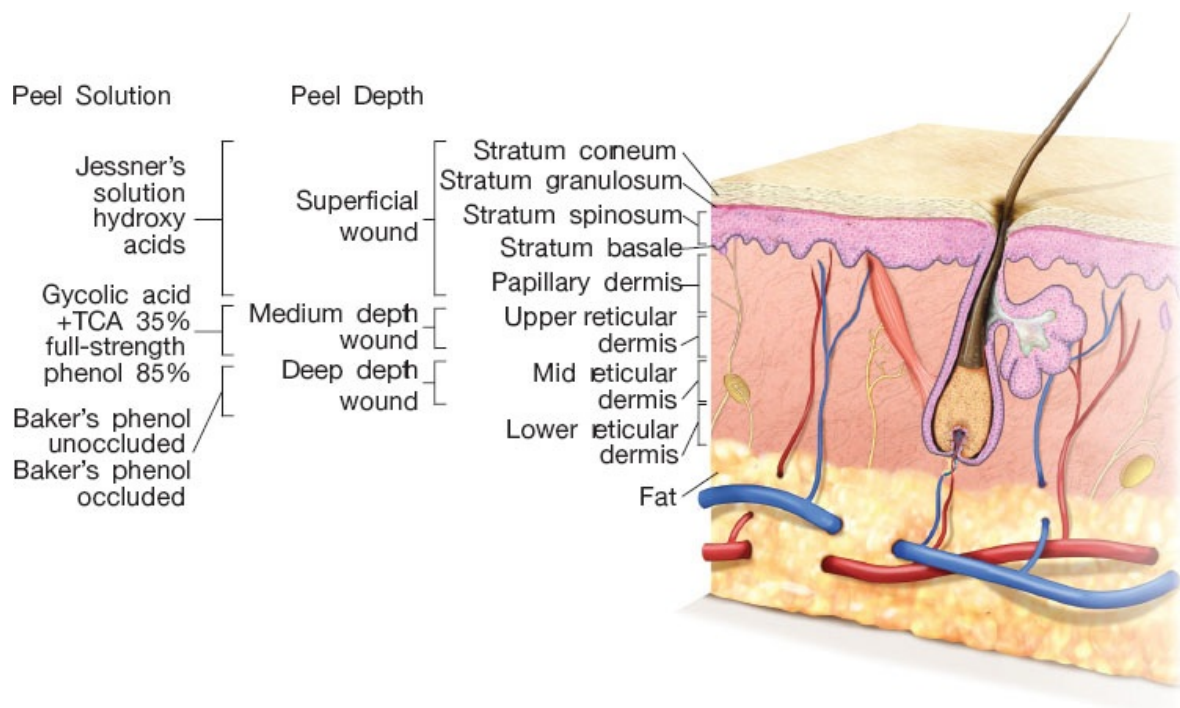


FIG 1 • Review of basic skin anatomy as it relates to peel depth.

- Acne or other underlying skin diseases
- Pigmentary dyschromias
- Demarcation lines secondary to other resurfacing procedures
- Contraindications to chemical resurfacing:
 - Absolute:
 - Isotretinoin therapy within the last 6 months or until pilosebaceous units begin functioning
 - Active infection or open wounds (eg, herpes, excoriations, or open acne cysts)
 - Lack of psychological stability and mental preparedness
 - Unrealistic expectations
 - Poor general health and nutritional status
 - Poor physician-patient relationship
 - History of abnormal scar formation or delayed wound healing and therapeutic radiation exposure
 - History of certain skin diseases (such as rosacea, seborrheic dermatitis, atopic dermatitis, psoriasis, and vitiligo) or active retinoid dermatitis; Fitzpatrick skin types IV, V, and VI are contraindications for medium and deep-depth peels.
 - Relative:
 - Need to proceed with caution with a history of medium-depth or deep resurfacing procedures within the previous 3 to 12 months
 - Chemical peeling at the time of rhytidectomy is practiced by some. This should not be done with phenol peels. Areas not undermined can be peeled with phenol peel. Patients must wait 3 months to peel undermined areas.

SURGICAL MANAGEMENT

- The goal of a phenol peel is to produce controlled partial-thickness skin injury. This leads to improving skin quality, reduction of fine lines, and coarse rhytides.
- Pretreatment (priming) with Retin-A and 4% hydroquinone is helpful to minimize post-treatment hyperpigmentation. In those with darker Fitzpatrick

skin types, there should be a minimum of 6 weeks of treatment.

- Hypopigmentation and incidence of hypertrophic scarring are directly correlated with the depth of injury.
- In a phenol peel much like a TCA peel, the depth of injury can be controlled leading to peels from papillary dermis to midreticular dermis depending on the amount of facial aging. The depth of injury can be altered by changing the concentration and the number of applications of the peeling agent. The critical factor is the degree of frosting.
- Time to healing can vary from 5 days (superficial peel) to 10 to 14 days when a deep peeling technique is used.
- Hypopigmentation and hyperpigmentation are the most common complications.
- Damage to the melanocytes at the epidermal-dermal junction leads to hypopigmentation.
- Hypopigmentation is more noticeable in dark skin patients, so segmental applications should not be done in these patients.
- Hyperpigmentation usually results from peeling-induced inflammation with melanocyte overstimulation. Darker skin patients are more prone to this complication. This is exacerbated with premature sun exposure.

Preoperative Planning

- Consultation should be held with the patient to establish realistic goals and expectations.
- Peel depth should be determined by assessing and documenting patient's Fitzpatrick skin type and photoaging grouping, degree of actinic damage, sebaceous gland density, dyschromias, suspicious lesions, and scarring.
- The hands and neck have very few progenitor cells in the reticular dermis. The scarcity of these cells makes peeling in these areas risky.
- Gravitational changes can best be treated with facelift.
- Standard preoperative photographs should be taken for preoperative planning.
- Informed consent should be obtained and should include an overview of the healing process and phases, additional surgeries or procedures that may be necessary, complications, explanations of what can and cannot be accomplished with the phenol-croton oil peel, and a description of financial responsibilities, including for revisions.
- Important considerations for ethnic skin¹⁴:

- Ethnic skin, including that of Latino and Hispanics, may respond unpredictably to chemical peels and are more prone to melasma and postinflammatory hyperpigmentation than nonethnic skin types.

Preparation and Positioning

- Patient is pretreated with tretinoin and hydroquinone for 4 to 6 weeks to suppress melanin production.
- Patient is instructed to use acyclovir 400 mg TID 2 days before the procedure and continued until complete healing observed.
- Varying concentrations of phenol and croton oil have been used.⁴
 - Phenol-croton oil can be used as a superficial or medium to deep depth peel.
 - Technique is extremely important. By altering concentration and application technique (number of swipes or amount of solution applied), different depths can be achieved at different regions of the face. For example, a light peel, which uses a lower concentration of croton oil, can be used to peel the lower eyelids, while a higher concentration of croton oil may be used to peel more deeply wrinkled areas of the face, such as the perioral region.⁶
- Safety checks before peeling:
 - Mark the mandibular ramus, so that peel is not applied caudal to this line.
 - Begin an IV and run fluid.
 - Phenol is metabolized in the liver and excreted by the kidneys. Therefore, patients with liver disease should be treated with increased caution.
 - Monitor with cardiac monitoring equipment, pulse oximeter, and blood pressure monitoring.
 - Cardiac arrhythmias during chemical peeling have been reported; however, cause and effect relationship is controversial.
 - Ensure applicator and peeling agent never pass over the patient's eyes.

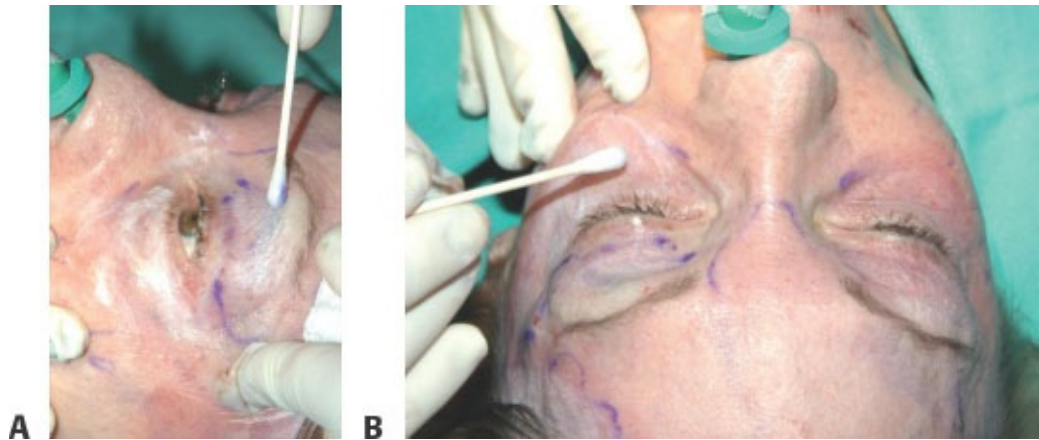


FIG 2 • Preoperative markings.

- Anesthesia:
 - Administer sedation and analgesia by performing facial nerve block and direct infiltration using a longer acting anesthetic.
 - Epinephrine should be avoided, as it can exacerbate cardiac arrhythmias.
 - Decadron (8–10 mg) or betamethasone (6 mg) may also be administered.
- Skin preparation:
 - Peel area should have been thoroughly washed the night before and morning of the surgery, with no residual makeup.
 - Clean peel area using Septisol (hexachlorophene with alcohol) to adequately degrease the skin. This step is essential for optimal results.
 - The patient's face is marked (**FIG 2**).
- Positioning:
 - The patient should be lying supine.

TECHNIQUES

■ General Region Peel

- The phenol-croton oil wound agent should be applied using a moistened, wrung out cotton-tipped applicator, tending to the deep rhytides first.
- The peeling agent should be applied to aesthetic units over an extended period of time (1–1.5 hours).
- Because phenol does not affect hair growth, the agent should be spread into

hair-containing areas.

- Apply swipes until a proper depth of injury is attained. Pink-white frost signifies a papillary dermal injury, and dense white frost denotes a reticular dermal injury. Brown-white frost signifies a deep dermal injury.
- Allow 10 to 15 minutes between cosmetic units before applying a new coat to reduce renal and cardiovascular risk. The full procedure may last between 60 and 10 minutes.
- A thick layer of Vaseline and viscous Xylocaine solution should be applied to each region of the face as soon as it has been treated with the peeling agent, to prevent peeled areas from drying out. This acts as an occlusive dressing and as a pain reliever.

■ Periorbital Peel Technique

- Ensure that no agent drips into the patient's eye. Do not pass vials over the patient in case of spillage.
- Elevate the patient's head 30 to 45 degrees.
- Patient's tears should be wiped away using a cotton-tipped applicator at the medial and lateral canthus while holding the patient's eye open to prevent the peeling agent from entering the eye.
- For the lower eyelid, have the patient look up and apply the agent within millimeters of the eyelash margin by moving from the lateral crow's feet to the medial canthal area. For the upper eyelid, have the patient close her eyes and apply the agent from the lateral to inner canthal area. Avoid applying product below the superior tarsal plate, as it may lead to prolonged edema. Be certain to peel the orbital rims to avoid lines of demarcation.
- Apply an ice pack over the eyes for 6 to 8 hours after the peel to reduce swelling.

■ Perioral Peel⁸

- Applying peeling agent onto the vermilion border to avoid missing lipstick lines.
- Manually stretch the skin to create deeper and more even penetration.
- Use the wooden end of a cotton-tip applicator to apply peeling agent to

individual rhytides (**TECH FIG 1**).

- Degreasing the skin by aggressive rubbing with alcohol swab until skin erythema has proven to be an effective method in treating especially perioral skin damage.
- If peeling the perioral area only, make sure to use to proper technique to avoid lines of demarcation. Apply the peeling agent just beyond the nasolabial fold, and then brush out the remaining regions of the face.



TECH FIG 1 • Intraoperative photos. **A.** Upper lid. Application of agent within millimeters of eyelash margin by moving from lateral crow's feet to the medial canthal area. **B.** Lower lid. The agent is applied with the patient looking upward.

■ Taping (for Occluded Peel)

- Taping increases the depth of injury.
 - Apply precut, 1.5 to 4 cm strips of tape to each cosmetic unit after the completing the peel.
 - Begin by applying the tape along the inferior border of the mandible in a saw tooth pattern, which produces a less discrete line. Continue taping outward, by placing strips 1 to 2 cm parallel to the inferior border of the mandible.
 - The tape mask should be removed as a single unit, approximately 48 hours after the procedure, when the exudate has elevated the tape.
-

PEARLS AND PITFALLS

Intraoperative complications

- Intraoperative complications may be the result of technical errors. Monitor for cardiac arrhythmias.

Pretreatment

- Pretreatment with tretinoin and hydroquinone is helpful to minimize pigmentation problems in darker-skinned individuals.

Depth

- Depth of peel is varied by pathology. Frosting is the key element to getting a good result.

Pigmentation

- Secondary alteration of skin pigmentation is the most common complication and should be discussed with the patient.

POSTOPERATIVE CARE

- Wound care: areas should be kept constantly moist with ointment. Discomfort is relieved with the use of Vaseline/Xylocaine mixture. This acts as a pain reliever and occlusive dressing. Expect considerable swelling and drainage. Erythema duration varies with the depth of injection and Fitzpatrick skin type. Patients are quite allergic in the early postoperative period. General pruritus can be decreased by steroid cream. Contact dermatitis should be similarly treated. Sign of infection is the development of significant pain in patients otherwise healing well. Infection can be bacterial, fungal, and viral.
- Retouching of specific areas or repeeling may be necessary after 3 to 6 months for deeper wrinkles.

- Sleeping: While sleeping, head should be kept elevated using multiple pillows.
- Bathing/washing: Clean in the shower with unscented liquid soap. Perform a splashing action, and use fingers only. Do not use any type of exfoliating aide, such as a washcloth or sponge. Apply a thick coat of moisturizing ointment after each wash. Wash in the shower after 48 hours if no tape is present.
- Lifestyle: Avoid the sun completely. Sun exposure can lead to postoperative skin pigmentation. In addition to sun exposure, becoming pregnant or taking birth control pills before redness has subsided may cause blotching. Avoid contact of caps, shower caps, eyeglasses, or visors on peeled areas until the underlying skin has healed. Patients may return to work as early as 14 days postprocedure. Makeup and sunscreen may be applied on healed areas. Exercise should be avoided for 30 days postprocedure, as increased blood flow could cause microhemorrhaging or red blotching.

OUTCOMES

- The use of perioral phenol peel combined with facelifting has been found to add 5.3 years of reduction in apparent age after the combined facelift and peel¹⁶ (**FIGS 3 to 6**).



FIG 3 • A–C. Two years after phenol-croton oil peel of the perioral, periorcular area, and temples. Phenol peel used 27.5% phenol, 0.105% croton oil for the periorcular area, and 33% phenol and 1.1% croton oil for the perioral area. (Preoperative photos of the patient are shown in **FIG 2**.)

- Using validated questionnaires, patient satisfaction was found to be high with the use of a combined phenol peel and facelift.
- Perioral phenol-croton oil peel resulted in a significant and objective wrinkle shown by the reduction in Glogau score.¹⁶
- When carefully assessed, some degree of hypopigmentation occurs with most patients, and hypopigmentation is subtly progressive. When peeling is confined to lower Fitzpatrick skin types, it is not disabling.



FIG 4 • A,B. Preoperative patient photos. **C,D.** Six months after bilateral rhytidectomy with extended SMAS and perioral phenol-croton oil peel and fat injections to the cheeks and nasolabial folds. Phenol peel to perioral area using 33% phenol and 1.1% croton oil.

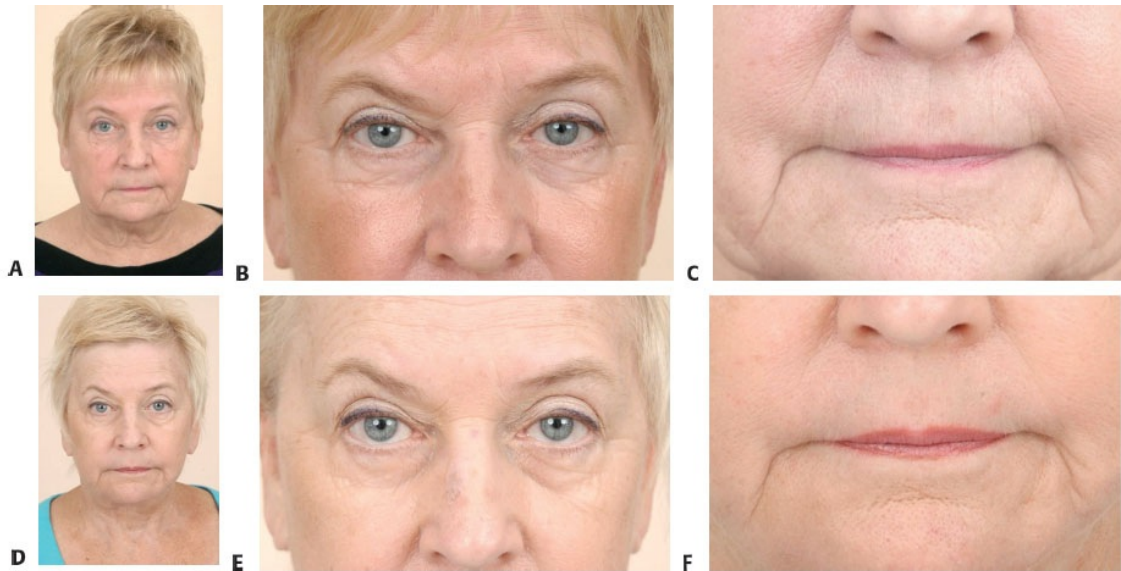


FIG 5 • A–C. Preoperative patient photos. **D–F.** Six months after bilateral rhytidectomy with extended SMAS and perioral phenol-croton oil peel and fat injections to the cheeks and nasolabial folds. Phenol peel to perioral area using 33% phenol and 1.1% croton oil.

COMPLICATIONS

- Complications following intermediate depth phenol-croton oil peeling are primarily of four types: preoperative, intraoperative, early postoperative, and late postoperative.¹⁶
- Preoperative:
 - Poor history—patients on Accutane, electrolysis, or previous peels
 - Lack of pretreatment of dark-skinned individuals
- Intraoperative:
 - Cardiac arrhythmias have been reported, but no cause and effect relationship has been established. Patient's cardiac status should be monitored during the procedure, and the peel duration needs to be extended over 1 to 1.5 hours.
 - Peeling too deeply—failing to recognize the signs of the depth of peel.
 - Segmental peeling in the area of the face results in splotchy appearance.
- Early postoperative:
 - Infection—bacterial, fungal, and viral: While bacterial infections from

Staphylococcus and *Streptococcus* species are more common, infections from *Pseudomonas* species, mycobacteria, and fungi are rare. There has been no literature detailing the need for prophylaxis antibiotics. The characteristic of an infection is significant pain in the postoperative period.



FIG 6 • A,B. Preoperative patient photos. **C,D.** Six months after bilateral rhytidectomy with extended SMAS and perioral phenol-croton oil peel and fat injections to the cheeks and nasolabial folds. Phenol peel to perioral area used 33% phenol and 1.1% croton oil.

■ Late postoperative:

- Milia, or benign, keratin-filled cysts that tend to occur around the periorbital area may occur 3 weeks after the peel. Milia can be physically extracted but also respond well to topical vitamin A derivatives, which also help to prevent

future outbreaks.

- Acneform eruptions, or tender, erythematous follicular papules, may occur as a result of the emollients or ointments being used for postoperative care. These can be treated with a topical antibiotic (eg, clindamycin, erythromycin, or systemic tetracycline and erythromycin therapy) and take approximately 5 to 10 days to clear.
- Hyperpigmentation develops 4 weeks after the procedure. Hypopigmentation is a late complication and gets progressively worse. While hyperpigmentation can be treated with topical bleaching agents (eg, 4% hydroquinone) or topical steroids, there is no effective treatment for hypopigmentation.
- Prolonged erythema may take between 3 to 6 months to resolve completely. This occurs most frequently in Fitzpatrick I patients.
- Hypertrophic scars may result from delayed wound healing. Early postoperative redness, induration delineates an incipient hypertrophic scar. This is treated with dilute intralesional triamcinolone injections (5 mg/cc).

ACKNOWLEDGMENT

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Section VI: Dermabrasion

19 Techniques for Dermabrasion to the Face

CHAPTER

Steven M. Levine and Daniel C. Baker

DEFINITION

- Surgery is the standard to address descent and laxity in the aging face.
- Resurfacing is important to treat textural and other surface changes related to aging and environmental damage.
- Dermabrasion is a highly effective, reliable, and low-cost method to facial resurfacing.
- It is particularly useful for vertical perioral rhytides.

ANATOMY

- Dermabrasion can be performed on the entire face and neck or can be isolated to specific aesthetic units such as the glabella or perioral region.
- The perimeter of any area being treated should be “feathered” to minimize the creation of a transition between dermabraded and nondermabraded tissue.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Indications for dermabrasion are broad and can include desire to improve skin texture, reduce visible fine lines, or reduction in age spots (such as solar keratosis).
- It is important to elicit a history of oral herpes so that these patients can be pretreated with antiviral medication.
- Skin type is important to note.

SURGICAL MANAGEMENT

- Dermabrasion can be performed as a stand-alone procedure or in combination with a face and necklift.

Preoperative Planning

- The primary consideration for preoperative planning is the patient's skin tone. The more pigmentation in the skin, the higher the chance for postdermabrasion complications such as postinflammatory hyperpigmentation or areas of hypopigmentation.
- Some providers choose to pretreat patients with a retinol or bleaching agent for 4 to 6 weeks prior to dermabrasion.
 - The authors do not use pretreatment.
- A marker is used preoperatively to stain the fine lines for which the dermabrasion is targeting.

Positioning

- The patient is supine on the procedure table.
- Usually the head of bed is slightly elevated.
- The provider should be sitting for maximum stability.

Approach

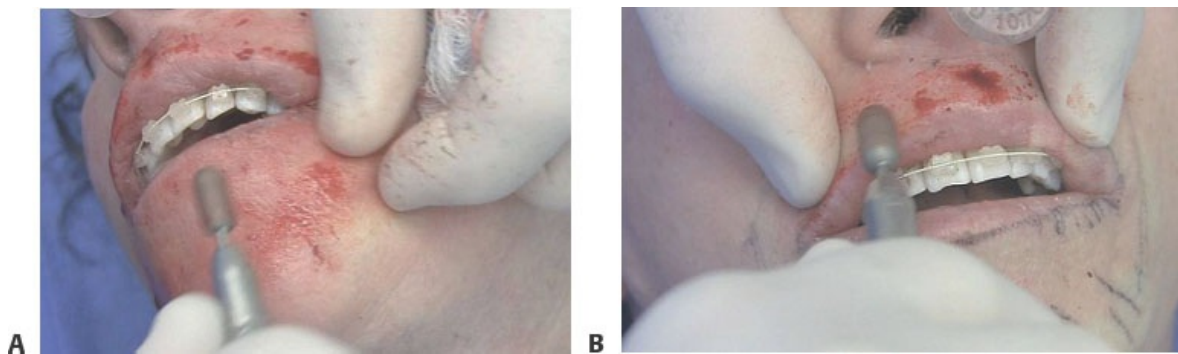
- The approach can be accomplished using a variety of techniques that yield a controlled, reproducible distribution of mechanical resurfacing to the skin.

TECHNIQUES

■ Mechanical Dermabrasion

- The patient's face is cleaned with alcohol.
- Marker was used to reinforce any marks that were removed during the prep. All rhytides to be addressed should be colored in marker.
- A small amount (0.1 cc for entire upper lip) of 1% lidocaine with epinephrine is injected into the dermis of the areas to be dermabraded.
- Eight minutes is allowed to pass to obtain full effect of the epinephrine.
- Choose the dermabrasion tip that you feel most comfortable within a specific area.

- The authors use the bullet tip for areas above the lip and the barrel for larger areas like below the lip (**TECH FIG 1**).
- You can effectively dermabrade at a variety of speeds.
 - Start slow (5000–10 000 rpm and advance to 25 000 rpm).
- The key to dermabrasion is to keep the skin on tension and is accomplished with the nondominant hand.
 - Do not attempt to dermabrade an area that is not under tension.
- The end point is a combination of pinpoint bleeding and visualization of the rhytide effacement. The ideal goal is to completely efface the targeted rhytide before dermabrading too deep and damaging the melanocytes.
- Care is taken to “feather” the borders of any anatomic area that means reducing the depth of the dermabrasion to reduce the appearance of a transition zone.



TECH FIG 1 • **A.** Dermabrasion tips include a barrel for larger areas. **B.** Note the nondominant hand applying tension to the skin under the dermabrasion tip.

PEARLS AND PITFALLS

Skin tension is paramount	■ Always place skin on tension prior to dermabrasion. This may include place a hand intraoral to accommodate tension around the mouth.
Keep moving	■ Keep the dermabrader moving to avoid getting too deep in any area.
Safely	■ Dermabrasion is a an excellent adjunct to a facial surgery

combine procedures

procedure.

Feathering

- Always extend the treatment beyond the zone being treated (ie, beneath the jaw line if treating the full face).

Practice

- Consider using an orange or grapefruit to practice your technique.

POSTOPERATIVE CARE

- This procedure is often combined with a facelift. In this case, the dermabrasion should be performed after the facelift.
- A petroleum impregnated gauze is applied to the dermabraded areas immediately after the procedure.
- Cool packs are also used to reduce swelling.
- Patients are instructed to remain away from the sun during the acute peeling period (7–10 days postop).
- Sun avoidance should ideally be carried out for several months after dermabrasion.
- Patients are instructed to use cool compressed air at home for the first 24 hours.
- Patients should keep the gauze in place for several days. As the skin re-epithelializes, the gauze will fall off. When it does, patients should apply a thin layer of petroleum-based ointment 3 times daily until the skin is re-epithelialized.

OUTCOMES

- Dermabrasion will predictably improve certain fine lines and reduce the appearance of certain superficial pigmentation issues.
- The provider needs to start using this technique in a metered fashion to gain comfort with expectations and limitations.

COMPLICATIONS

- It is important to be aware of the entire surgical field.
 - Often a gauze is near the field to aid the provider in wiping blood from the operative field. This gauze can easily get caught in the dermabrader and whip around and hit the patient's face or eye.
- Overly aggressive dermabrasion can damage melanocytes and lead to areas of hyperpigmentation. Sometimes, this can reverse, but often it is permanent.

- Hyperpigmentation can occur which usually resolves on its own. Sun avoidance is paramount. Lightening agents such as hydroquinone 4% topical can be used if necessary.

Section VII: Brow Lifting

20 Indications and Techniques CHAPTER for Coronal Brow Lifting

Richard J. Warren

DEFINITION

- Brow ptosis describes an abnormally low position of the eyebrow complex, either in whole or in part.
- Low lying or malpositioned eyebrows may be congenital or acquired through aging.
- Brow position and shape convey an impression of emotion. When the entire brow is low, the patient looks tired. When only the medial brow is low, the patient appears to be angry, and when only the lateral brow is low, the patient appears to be sad.¹
- Brow ptosis encroaches on the upper lid sulcus, changing the dynamics of the upper lid/brow junction. Thus, brow ptosis will affect the assessment of patients presenting for blepharoplasty, periorbital fat grafting, or senile eyelid ptosis repair.

ANATOMY

- Underlying the forehead is the frontal bone. Laterally, the frontal bone is crossed by a curved ridge called the temporal crest (temporal ridge or temporal fusion line). This palpable landmark separates the forehead from the temporal fossa laterally (**FIG 1**). The temporalis muscle takes its origin from the temporal fossa.
- The surgical significance of the temporal crest line is that overlying fascial layers are tethered to bone in a band immediately medial to the palpable ridge. This has been called the zone of fixation or the zone of adhesion.^{2,3} Inferiorly,

where the ridge approaches the orbital rim, the fixation becomes broader and denser, forming the orbital ligament, also known as the temporal ligamentous adhesion. Regardless of the surgical technique used, when a full-thickness forehead flap is mobilized, all fascial attachments to bone must be released, including the zone of adhesion and the orbital ligament, plus attachments to the supraorbital rim and lateral orbital rim.⁴

- The temporal crest also marks a change in nomenclature as tissue planes transition from lateral to medial. The deep temporal fascia covers the temporalis muscle and is attached to bone along the temporal crest. It then continues medially as the periosteum of the frontal bone. Similarly, the superficial temporal fascia (also known as the temporal-parietal fascia) continues medially as the galea aponeurotica.
- The galea aponeurotica splits into a superficial and a deep layer to encompass the frontalis muscle. Inferiorly, the deep galea layer separates further into three separate layers: two layers encompass the galeal fat pad, and a third layer is adherent to periosteum.² Superficial to the deepest galeal layer is the so-called glide plane space, which allows the scalp flap to shift superiorly.

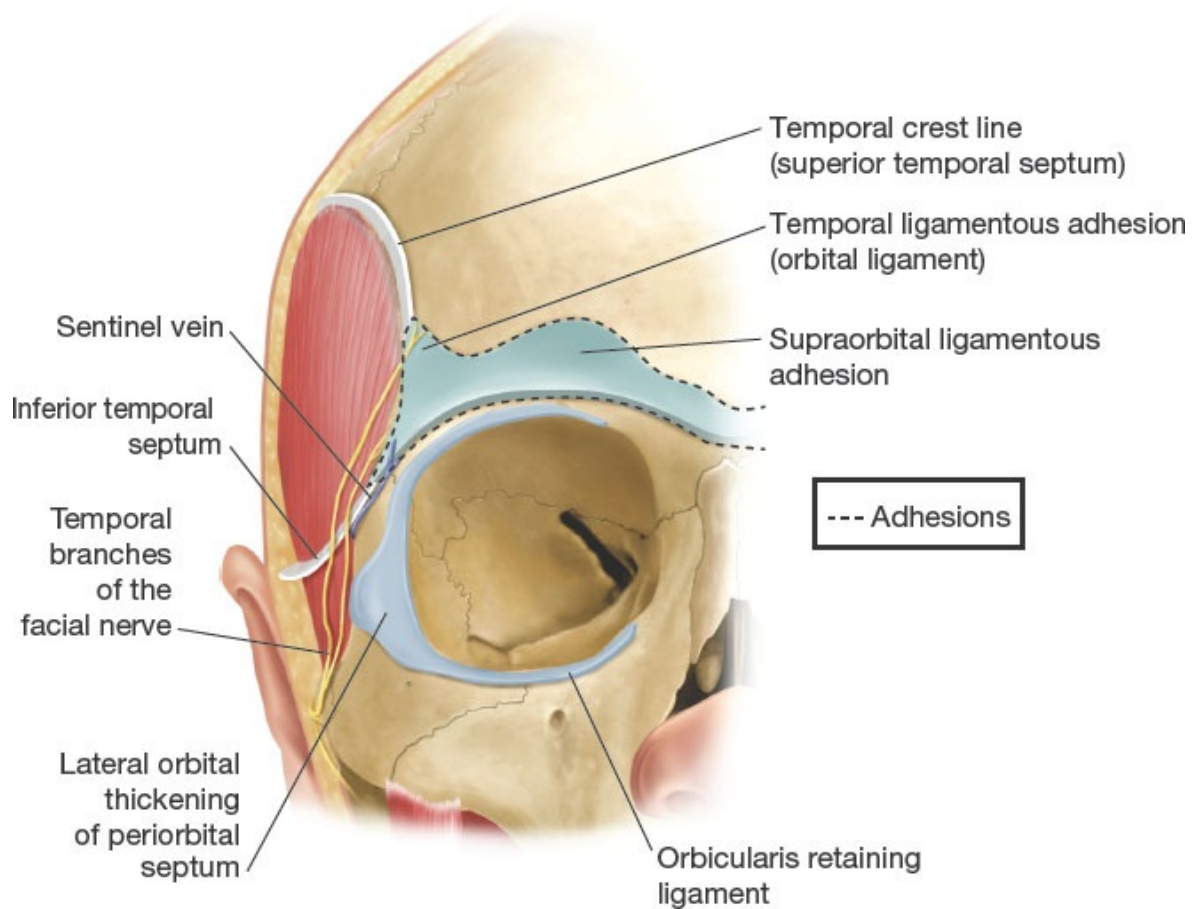


FIG 1 • Galeal attachments must be completely released to allow a forehead flap to move superiorly. The firmest attachment is at the temporal ligamentous adhesion (orbital ligament) but is also present along the supraorbital rim (supraorbital ligamentous adhesion), down the lateral orbital rim (lateral orbital thickening) and along the temporal crest line. In raising the flap, the temporal branches of the facial nerve will be in the roof of the dissection immediately above the medial zygomatic vein (sentinel vein).

- The galeal fat pad extends across the entire width of the lower 2 cm of the forehead; medially it encompasses the supratrochlear nerves and much of the corrugator musculature. The galeal fat pad is separated from the preseptal fat (retro-orbicularis oculi fat or ROOF) by one of the layers of galea (see above).

Laterally, this galeal layer is thought to be inconsistent, with some individuals having continuity between the galeal fat pad and the preseptal fat (ROOF). Within the eyelid, the septum orbitale divides the preseptal fat (ROOF) from orbital fat.

- Muscle anatomy plays a significant role in determining eyebrow shape and position. In addition to the soft tissue attachments, the level of the eyebrow is the result of a balance between the muscular forces that elevate the brow, the muscular forces that depress the brow, and gravity.
- Brow depressors in the glabella originate from bone and insert into soft tissue. The procerus runs vertically near the midline, the depressor supercilii and supramedial orbicularis run obliquely, and the corrugator supercilii runs mostly transversely.
- The transverse corrugator supercilii is the largest and most significant of these muscles. Useful landmarks to locate the corrugator are as follows: the corrugator originates from the orbital rim at its most superomedial corner, right at the entrance to the orbit. The transverse head passes through galeal fat becoming more superficial until it interdigitates with the orbicularis and frontalis under a skin dimple that is visible when the patient frowns.
- The orbicularis encircles the orbit acting like a sphincter. Medially and laterally, the orbicularis fibers run vertically and act to depress brow level. Laterally, orbicularis is the only muscle that depresses brow position.
- The frontalis is the only elevator of the brow. It originates from the galea aponeurotica superiorly and interdigitates inferiorly with the orbicularis. Contraction raises this muscle mass and the overlying eyebrow, which is a cutaneous structure. The muscle is deficient laterally, so its primary lifting effect is on the medial and central portions of the eyebrow.

Sensory Nerves

- Innervation to the upper periorbital area is supplied by the supraorbital and supratrochlear nerves, as well as two lesser nerves, the infratrochlear and zygomaticotemporal.
- The zygomaticotemporal nerve exits posterior to the lateral orbital rim piercing the deep temporal fascia just inferior to the sentinel vein. In coronal brow lifting, with complete release of the lateral orbital rim, it is often avulsed. Consequences of this are minimal and temporary.
- The supratrochlear nerve usually exits the orbit superomedially, although the exact location is variable. It immediately divides into four to six branches that

usually pass through the substance of the corrugator. These branches then travel superiorly, on the superficial surface of the frontalis, innervating the central forehead and first few centimeters of the scalp.

- The supraorbital nerve exits the superior orbit through a notch in the rim, or about 10% of the time, through a foramen that is superior to the rim.
- The supraorbital nerve divides into two segments: superficial and deep. The superficial branch pierces orbicularis and frontalis, traveling as several small branches on the superficial surface of the frontalis to innervate the central forehead as far posteriorly as the first 2 cm of hair. The rest of the scalp, as far back as the vertex, is innervated by the deep branch that runs between the periosteum and the deepest layer of galea and then pierces the frontalis near the hairline to innervate scalp skin.⁵

Motor Nerves

- The temporal branch of the facial nerve is the only motor nerve of surgical concern in this area. The temporal branch enters the temporal fossa as several (2–4) fine branches that lie on the periosteum of the zygomatic arch in its middle third. Between 1.5 and 3.0 cm above the arch, these branches become more superficial, traveling within the superficial temporal fascia (temporoparietal fascia) to innervate the frontalis, superior orbicularis, and glabellar muscles.⁶ A number of different landmarks can be used to predict the course of the temporal branches. These include
 - The middle third of the palpable zygomatic arch
 - 1.5 cm lateral to the tail of the eyebrow
 - Parallel and adjacent to the inferior temporal septum
 - Immediately superior to the medial zygomaticotemporal vein (sentinel vein)
- In the coronal brow lift procedure, the dissection should be entirely deep to the temporal branches of the facial nerve.

PATHOGENESIS

- The periorbital region is the most expressive part of the human face. Subtle changes in eyebrow shape can profoundly affect facial appearance.¹
- Because of the importance of periorbital expression, humans have historically resorted to any means at their disposal to alter their eyebrows. These have included eyebrow plucking and shaving, makeup, and tattoos.
- Aesthetically, the eyebrow is only one part of the puzzle in the periorbital zone. Other variables include the presence of senile eyelid ptosis, the loss of

upper sulcus orbital fat, and the accumulation excess of upper eyelid soft tissue (skin, orbicularis muscle, and orbital fat).

- The preferred forehead will be devoid of vertical or transverse lines. It will be framed superiorly by a well-positioned aesthetically shaped hairline and inferiorly by well-positioned, attractively shaped eyebrows.
- The “ideal” eyebrow shape is affected by ethnicity, gender, and the era in which we live (**FIG 2**). There are certain themes that define aesthetically pleasing eyebrow in the 21st century:⁷
 - The medial eyebrow level should lie over the medial orbital rim.
 - The medial border of the eyebrow should be vertically in line with the medial canthus.
 - The eyebrow should rise gently, peaking slightly at least two-thirds of the way to its lateral end; typically, this peak lies vertically above or lateral to the lateral limbus.
 - The lateral tail of the brow should be higher than the medial end.
 - The male brow should be lower and less peaked.
- Abnormally low eyebrows can be congenital or acquired over time through aging.
- Age-related brow ptosis causes the forehead/eyebrow complex to encroach on the upper orbit, resulting in a pseudoexcess of upper eyelid skin. In response, patients subconsciously contract the frontalis to raise the eyebrows, leading to transverse forehead lines. This is accentuated with the presence of mild senile eyelid ptosis. Such patients will often present with a request for upper lid blepharoplasty.



FIG 2 • The attractive eye exhibits a modest amount of

visible upper lid (“tarsal show”); this dimension is about one-third of the distance from the lash line to the lower border of the eyebrow. The brow itself starts medially over the supraorbital rim and vertically in line with the medial canthus. It angles gently upward, peaking about two-thirds of the way along the brow toward its lateral extent. In females, this peak is at or lateral to the lateral limbus of the eye. In men, this peak is minimal or absent. Laterally, the “tail” of the brow should end at a higher point than the medial end of the brow.

- Other lines in the forehead are caused by the glabellar frown muscles. Vertical lines are caused by the transversely oriented corrugator, horizontal lines are caused by the vertically running procerus, and oblique lines are caused by the depressor supercilii and orbicularis.
- Age-related brow ptosis is not universal. Up to 40% of people have relatively stable eyebrow position throughout life and are generally not candidates for brow lift surgery.⁸
- Frontalis is the only lifting force to counter balance the various muscles and gravity that depress the brow level. The lateral portion of the eyebrow is particularly sensitive to this interplay because frontalis action is attenuated laterally and also because the security of lateral brow fixation to bone is inconsistent.^{9,10} Poor soft tissue attachment with no muscular lift will inevitably lead to ptosis of the lateral third of the eyebrow.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most patients will not be aware of the many factors involved in periorbital aging, and they may not want the multiple procedures required to treat all of these components. For that reason, identifying the main component of every patient’s periorbital aging is important. Old photographs are very helpful in helping the surgeon determine which age-related changes predominate.
- Assessment is done with the patient awake and upright in the sitting or standing position. The following issues are evaluated: visual acuity, eyebrow and orbital symmetry, position of anterior hairline, thickness of scalp hair, transverse forehead lines, glabellar frown lines, thickness of eyebrow hair, eyebrow height, axis of the eyebrow (downward or upward lateral tilt), shape

of the eyebrow (flat or peaked), passive and active eyebrow mobility, and the presence of old scars or tattoos. The upper eyelids should also be assessed for soft tissue redundancy, for upper sulcus hollowing, and for eyelid level (ptosis or lid retraction).

- To identify patients with chronic frontalis contraction, examination should be done with eyes open and eyes closed. When the eyes are closed, the frontalis can be made to relax, revealing the true position and shape of the eyebrows. If the eyebrows are forcibly held in this position when the patient opens their eyes, the eyebrow-eyelid relationship without frontalis effect will be revealed.
- A patient may be a candidate to have the entire brow complex lifted or more commonly to have only part of the eyebrow raised, thus improving eyebrow shape. Occasionally, in a patient who chronically looks angry, this may involve raising the medial brow only, but most commonly, it is the lateral third to one-half of the eyebrow that requires repositioning with little or no lift of the medial portion.
- Weakening or eliminating the glabellar frown musculature is a useful parallel objective.
- If brow lifting is contemplated, the effect on the upper eyelid complex must be considered. Previous upper lid blepharoplasty may have left a patient tissue deficient, so that brow lifting could impair eyelid closure. Also, brow lifting may reveal the previously unappreciated hollowing of the upper lid sulcus.

NONOPERATIVE MANAGEMENT

- Numerous nonoperative strategies are available to change eyebrow shape and/or position.
- Nonmedical: eyebrow plucking, cosmetic makeup, tattooing
- Medical, nonsurgical: botulinum toxin injection, synthetic filler injection, thread lifting
- Surgical, non-brow lift: transpalpebral frown muscle ablation

SURGICAL MANAGEMENT

Preoperative Planning

- There are many surgical techniques available to elevate or to reshape the eyebrow. The coronal approach is a traditional method with a long track record of proven results.^{11,12}
- The preoperative discussion is an excellent time for the surgeon to teach the

patient about periorbital aging. To achieve the patient's objectives, some concepts that are new to the patient may be introduced. A patient requesting brow rejuvenation surgery may also be a candidate for blepharoplasty, upper sulcus fat grafting, or eyelid ptosis repair.

- This procedure provides maximum visibility and flexibility. Therefore, during the planning process, the surgeon should develop a mental image of what portion of the eyebrows are to be lifted, how much lift is required, and if there is any brow asymmetry to be corrected.
- With the patient awake and in the upright position, with the forehead in repose, the desired amount and direction of eyebrow elevation are assessed by manually elevating the brow complex (**FIG 3**). Specific vectors have been described, but more artistic decision-making is preferred.



FIG 3 • With the frontalis muscle in repose, the desired amount and direction of eyebrow elevation are estimated by manually elevating the brow complex. The desired vector of lift can also be determined using this method.

- Essential preoperative markings include the incision and the vectors for flap mobilization.
- Ancillary markings that are useful include the expected course of the temporal branch of the facial nerve, the expected location of the supraorbital and supratrochlear nerves, and the location of the frown muscles (determined with the patient awake and frowning).

Positioning

- The patient is placed on the operating table in the supine position with the head on a small pillow or soft donut.
- The head of the head is raised slightly to help reduce venous engorgement in the surgical area.
- Intermittent compression devices are applied to the legs, and a heating device covers the patient.

Approach

- Possible approaches for an open brow lift are
 - Coronal incision
 - Anterior hairline incision
 - Combination of these two (modified coronal) (**FIG 4**)
- Possible planes of dissection are
 - Subcutaneous
 - Subgaleal
 - Subperiosteal
- The coronal incision is well hidden in the hair of the scalp. There are two options for the dissection plane: subgaleal or subperiosteal. Of the two, the subgaleal approach is most often used because it provides a rapid bloodless plane of dissection with excellent exposure of the frown musculature.
- The anterior hairline incision puts the surgeon closer to the eyebrows and also provides excellent visibility. The main disadvantage of the anterior hairline incision is a potentially visible scar along the anterior hairline. Thoughtful incision techniques and careful suture techniques will mitigate this problem. There are three potential planes of dissection: subcutaneous, subgaleal, and subperiosteal. The subcutaneous plane offers some unique advantages: no transection of sensory nerves, the separation of skin from underlying frontalis, thus effacing transverse forehead lines and the direct shifting of the eyebrow, which is a cutaneous structure.¹³

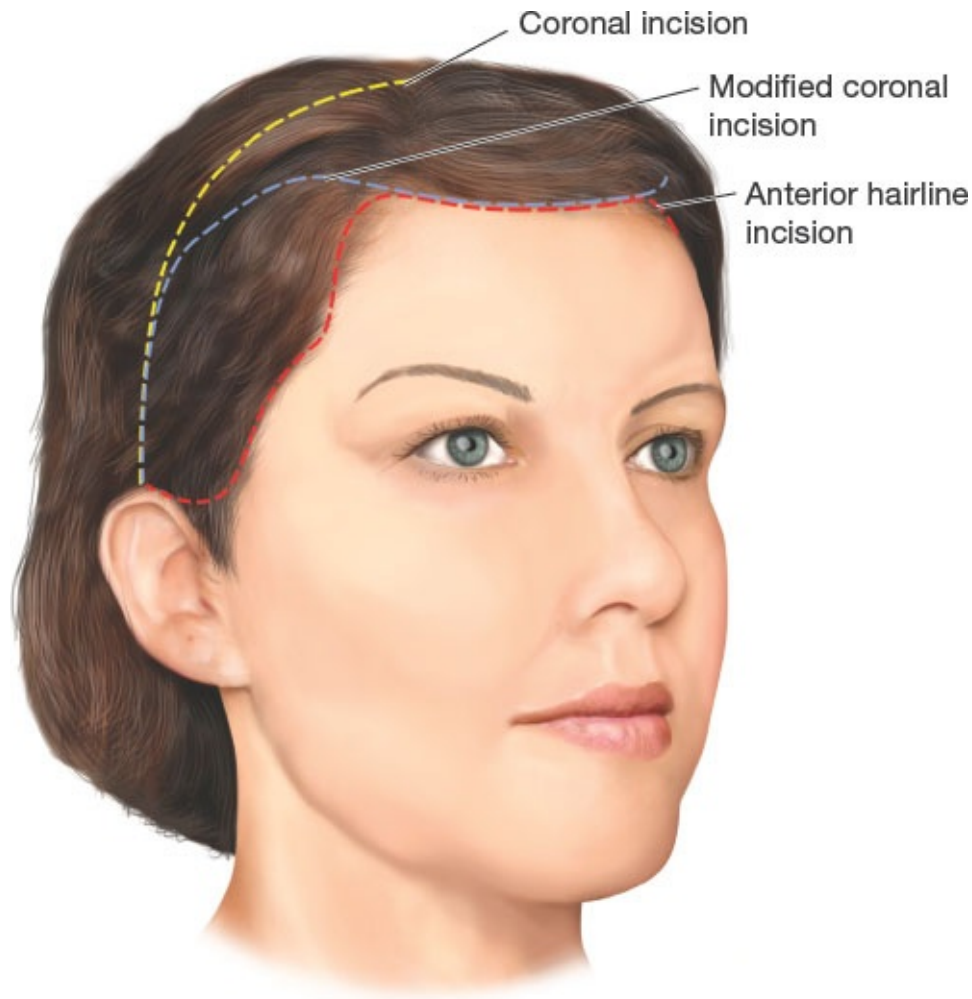


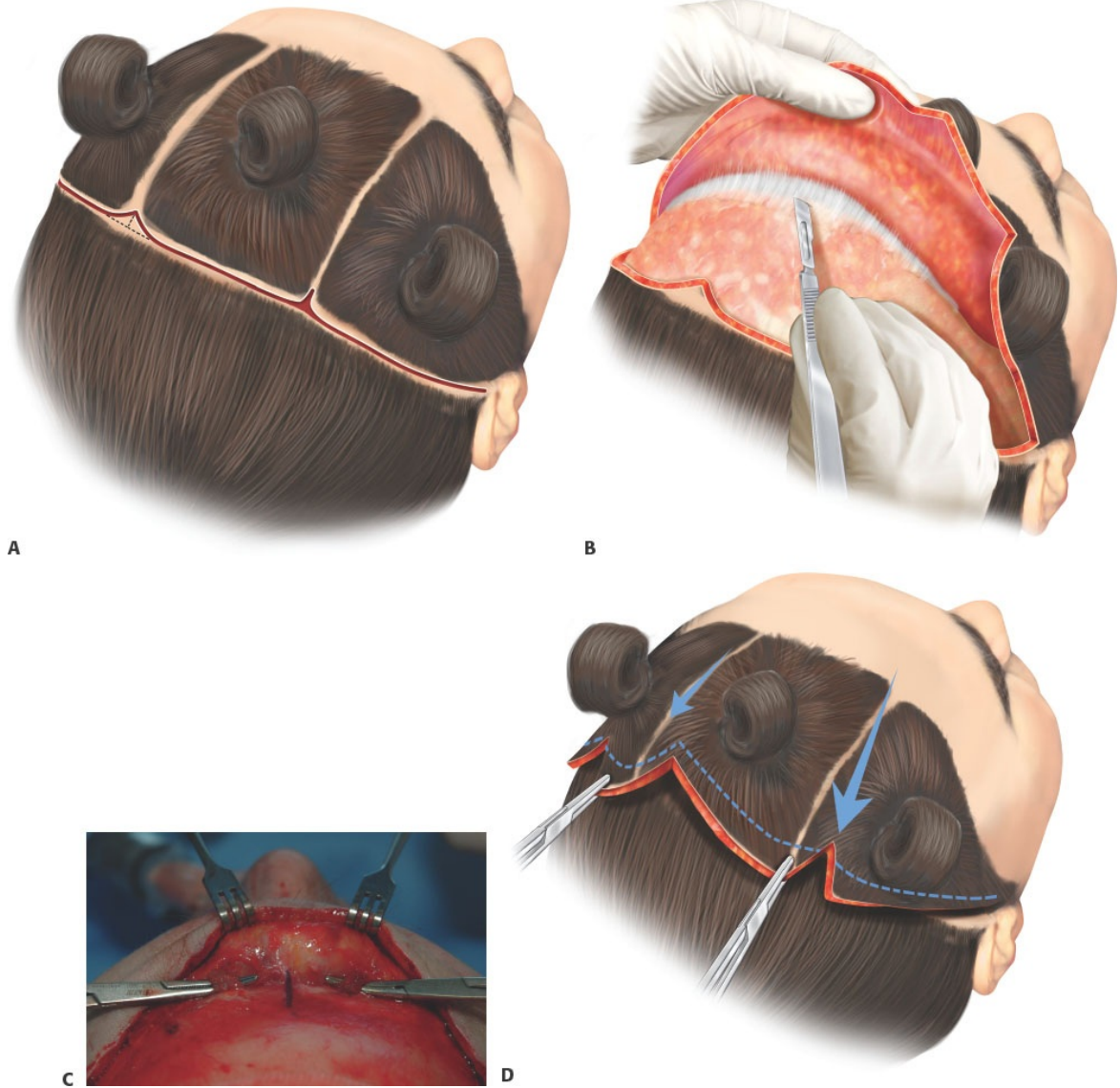
FIG 4 • Approaches for an open brow lift include the classic coronal incision, made about 6 cm behind the hairline, the anterior hairline incision, and a combination of the two—a modified version with an anterior hairline incision combined with a coronal-type approach laterally.

- The modified coronal approach (anterior hairline approach with lateral incision placement like a coronal incision) is much like a coronal procedure but with a hairline incision used to avoid elevating the anterior hairline in patients with a high forehead. Like the coronal, this approach lends itself to the subgaleal plane, although it is technically straightforward to change planes at the anterior hairline, creating a subcutaneous plane deep to the forehead skin and a subgaleal plane laterally.

TECHNIQUES

■ Coronal Brow Lift (Subgaleal Plane)

- Preoperative surgical marking will have been done (see above).
- The procedure is done under general anesthetic or local anesthetic with sedation.
- The head and neck area is prepped and draped with exposure of the entire face.
- A local anesthetic mixture composed of 1% lidocaine with 1:100 000 epinephrine and 0.25% bupivacaine with 1:200 000 epinephrine is infiltrated into the incision line, along the supra- and lateral orbital rims plus some injection under the scalp flap.
- After waiting for the epinephrine effect, the incision is made full thickness through the scalp down to periosteum over the skull centrally and laterally down to the deep temporal fascia. The scalpel is beveled parallel to the hair follicles. If an anterior hairline incision is planned, the scalpel is beveled in such a way that the hair follicles will be partially transected, utilizing the Camirand principle¹⁴ (**TECH FIG 1A**).
- The standard coronal incision is designed to be about 6 cm behind the hairline although this is variable, depending on the height of the forehead. Laterally, the marking extends to the ear and, in some cases, may be made in continuity with a facelift incision. The incision can be taken across the top of the head in a gentle curve, or it can peak slightly in the midline to allow for some flap rotation.
- With all coronal brow lift approaches, the superficial and deep branches of the supraorbital nerve will be transected, as will the anterior branch of the temporal artery, which will require hemostasis.
- The flap is easily raised in the subgaleal plane. This can be done with blunt dissection or with a scalpel blade beveled away from the periosteum (**TECH FIG 1B**). Lateral to the temporal crest, the superficial temporal fascia (temporoparietal fascia) is separated from the deep temporal fascia. Along the zone of adhesion, just medial to the temporal crest line, soft tissue attachment to bone is released.



TECH FIG 1 • A. The standard coronal incision extends across the top of the head from ear to ear, approximately 6 cm behind the anterior hairline. Laterally, on either side, it can be curved forward to allow for greater flap mobility. It can also be designed to be contiguous with a facelift incision. **B.** The coronal flap is raised in the avascular subgaleal plane down to the orbital rim. Temporal facial nerve branches course within the flap laterally; cautery and traction in that area should be done cautiously. **C.** The corrugator

muscles are demonstrated, taking their origin from the edge of the supramedial orbital rim. They can be seen coursing obliquely through galeal fat and become more superficial until they insert into the orbicularis/frontalis muscle mass at a skin dimple that can be seen when a patient frowns. The *purple line* marks the midline. The two procerus muscles can be seen coursing vertically from the origin on the nasal bones. Behind the tips of the clamps are vertically running fibers—the depressor supercillii muscles. **D.** Once the flap has been released from its deep attachments, it is mobilized along preplanned vectors. Normally, most of the flap advancement is done laterally, with typically 2 to 3 cm of scalp being excised. Centrally, the excision will be less than half that. After ablation of frown musculature, in the presence of an intact frontalis muscle, the medial brow will rise naturally without the need for tension on the scalp flap.

- In approaching the supraorbital rim, care is taken to look for the supraorbital nerve, which in 10% of cases will exit the skull through a foramen above (superior to) the supraorbital rim. Traction on the flap with skin hooks and elevation with L-shaped retractors are useful maneuvers, but care should be taken to avoid traction damage to the temporal branches of the facial nerve that travel laterally within the flap.
- Complete release of the galeal attachment to the supraorbital and lateral orbital rims is necessary to achieve enough flap mobilization to create lasting brow elevation. The most adherent zone is the region of the orbital ligament (temporal ligamentous adhesion). Adequate galeal release along the supraorbital rim is confirmed when retro-orbicularis fat (ROOF) is observed.
- Release of attachments to the lateral orbital rim should continue inferiorly as far as the level of the lateral canthus. When this dissection is done as an extension of the subgaleal plane, the periosteum will remain intact. The

medial zygomaticotemporal vein (sentinel vein) is routinely encountered and can either be preserved or, to ensure better access, cauterized. Cautery should be done carefully due to the presence of the temporal facial nerve branches running in the flap above this vein.

- In the midline, in most cases, it is prudent to leave some attachment of the deepest galea to the periosteum. This will guard against excessive medial brow elevation. Conversely, in those cases where medial brow elevation is desired, this area should be released.
- Once the flap has been freed from the orbital rims, the corrugator supercilii is identified within the galeal fat (**TECH FIG 1C**). The muscle is removed in a piecemeal fashion from its medial origin to the supraorbital nerve laterally. In removing this muscle, branches of the supratrochlear nerve are encountered coursing through the substance of the corrugator. These are small branches accompanied by small vessels that may require cauterization; loupe magnification is therefore helpful.
- Depending on the preoperative findings, the paired procerus muscles and the vertically running depressor supercilii can also be removed, although this will be a partial, not a complete, removal.
- Removal of a large corrugator muscle can create a soft tissue deficiency; if so, a small fat graft is harvested elsewhere and sutured into the soft tissue defect.
- After muscle modification and flap mobilization are complete, the flap is then drawn superiorly along the preplanned vectors. In most cases, the primary objective is to elevate the lateral half of the eyebrow with less (or no) elevation of the medial half. The desired flap overlap is normally maximal in a vector along the temporal crest line. Every case is individualized. Internal fixation may be done by suturing the advancing superficial temporal fascia down to the underlying deep temporal fascia at a higher level than it previously had been. This suturing should be done superior to the expected course of the temporal facial nerve branches. Typically, 3-0 PDS suture is used for this fixation.
- The scalp flap is advanced superiorly over the cut edge of the original scalp incision. To line up the flap, three short radial incisions made, and temporary key sutures are placed—centrally and along the temporal crest line bilaterally. Excess full-thickness flap is removed: typically about 2 cm of scalp flap laterally and 1 cm or less centrally (**TECH FIG 1D**).

- Repair of the scalp incision is done with absorbing stitches (3-0 Vicryl) in the galea and staples or interrupted sutures in the scalp. In the coronal brow lift technique, brow elevation depends on flap advancement and scalp removal. Consequently, some tension on the closure is inevitable, and the galeal sutures should bear the brunt of this. If scalp sutures or staples are excessively tight, hair follicles will be permanently damaged.
- In more vascular cases, a suction drain is put in place prior to suturing of the flap.
- A bupicaine block is done across the supraorbital rim, targeting the supratrochlear and supraorbital nerves.
- The head may be treated by exposing it with ointment along the suture line or be wrapping the head with a light head dressing.

■ Anterior Hairline Brow Lift (Subcutaneous Plane)

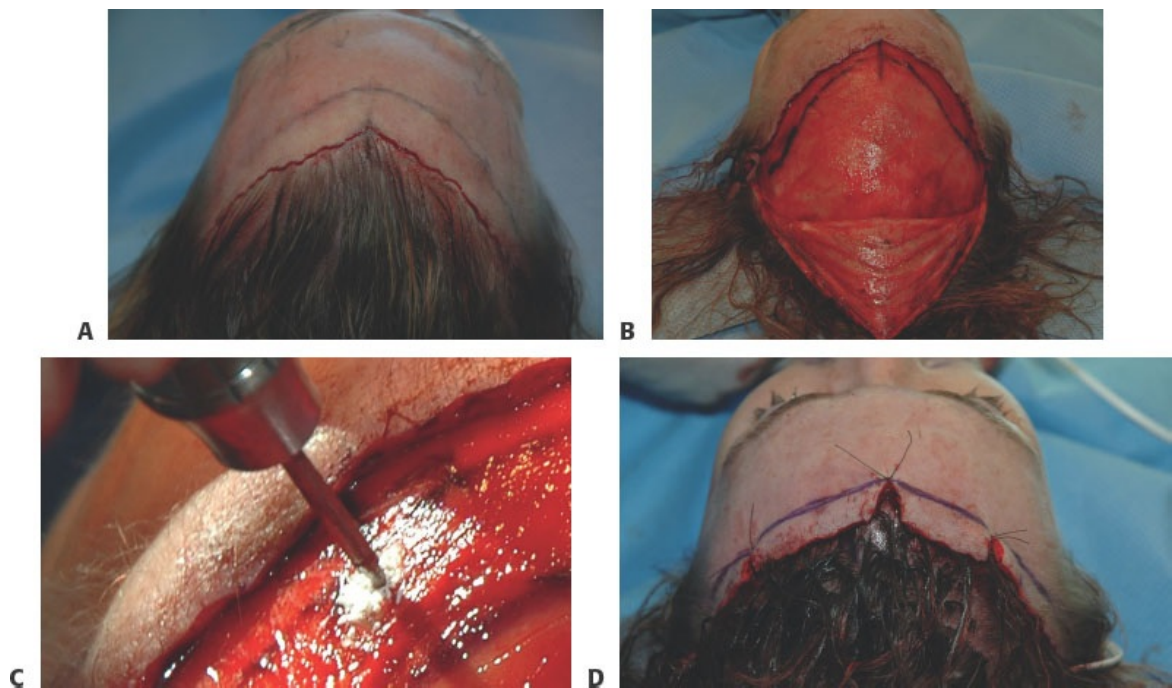
- Preoperative surgical marking will have been done (see above).
- The procedure is done under general anesthetic or local anesthetic with sedation.
- The head and neck area is prepped and draped with exposure of the entire face.
- A local anesthetic mixture composed of 1% lidocaine with 1:100 000 epinephrine and 0.25% bupivacaine with 1:200 000 epinephrine is infiltrated along the anterior hairline, and in an effort to hydro dissect the skin flap, the skin is infiltrated over the entire forehead in the subcutaneous plane, down to the eyebrows.
- After waiting for the epinephrine effect, the incision is made through the scalp skin, down to the frontalis muscle, taking care to preserve the sensory nerves, which will be seen running on the superficial surface of the frontalis.
- In making the anterior hairline incision, the scalpel is beveled in such a way that the hair follicles will be partially transected.¹⁴
- The skin flap is raised off the underlying frontalis muscle as far as the eyebrows and one-third of the way down the lateral orbital rim. Hemostasis is an important aspect of dealing with this somewhat vascular plane of dissection.
- When the eyebrow is approached, under direct vision, the transverse running fibers of the orbicularis are identified.

- A 5-0 Vicryl or similar suture can be used to pexy the orbicularis to a higher point on the frontalis muscle, using two or three sutures for this purpose. Others have described progressive tension sutures from the underside of the flap down to the frontalis muscle.¹⁵
- The subcutaneous scalp flap is then advanced superiorly over cut edge of the original scalp incision. This is done with minimal tension but still with enough tension to cause the undermined flap to advance superiorly over cut edge of the scalp incision.
- The degree of overlap is marked, and excess forehead skin is removed from the inferior (undermined) side of the incision.
- Repair of the scalp incision is meticulously done with 5-0 nylon sutures.
- A bupivacaine block is done across the supraorbital rim, targeting the supratrochlear and supraorbital nerves.
- A light forehead dressing can be applied, or alternatively the incision is open with ointment applied along the suture line.

■ Brow Lowering Procedure (Subgaleal Plane)

- The high hairline in conjunction with a long forehead can be a congenital condition, or it may be acquired through hair loss in the frontal hairline.
- The high hairline can be lowered and the long forehead shortened by advancing the hair-baring scalp and excising a portion of the upper forehead skin.¹⁶
- Preoperative markings delineate an incision at the anterior hairline and then coursing laterally into the temple and then into the temple (see **FIG 4** above).
- Anterior hairline incisions create less visible scars if the incision is wavy, not linear (**TECH FIG 2A**). Also, when very thin hair is present at the hairline, it is preferable to place the incision a few millimeters behind, into the zone of denser hair to hide the ultimate scar.
- The incision is made with a scalpel beveled in such a way as to transect some hair follicles, causing new hairs to grow through the resulting scar.
- Like the open coronal, the incision is carried down full thickness through scalp down to periosteum.
- Using blunt dissection or with a scalpel beveled away from the periosteum, a posterior dissection is done, raising the scalp flap as far posteriorly as the occiput.

- In order to advance the scalp flap anteriorly, shallow transverse releasing incisions are made into the galea, taking great care to not cut further into the flap. Clinical experience is that for every galeal releasing incision, expect about 1 mm of additional scalp advancement (**TECH FIG 2B**).
- Once the flap has been mobilized, gentle traction is applied for several minutes to allow for soft tissue creep.
- The anterior forehead flap is raised far enough to allow for the advancement of the posterior flap.
- After anterior advancement of the posterior scalp flap, it is fixed to bone, using 3-0 PDS (or equivalent) to some form of bony fixation such as LactoSorb bone tacks (**TECH FIG 2C**).
- The excess portion of the anterior forehead flap is excised (**TECH FIG 2D**).
- The incision is closed with absorbing sutures in the galea/frontalis plane (3-0 Vicryl) and fine sutures in the skin (running 5-0 nylon).
- Occasionally a patient may present with a high hairline in conjunction with low eyebrows. In such a case, through the anterior hairline incision, two procedures can be done at once: posterior scalp advancement (to lower the hairline) and an open brow lift (to raise and reshape the eyebrows).



TECH FIG 2 • A. A slightly wavy line is used for the anterior hairline incision. It is placed a few hairs

behind the hairline, and hair follicles are transected to encourage new hair growth through the scar. **B.** The scalp has been raised posteriorly to the occiput, and to improve its anterior mobility, multiple transverse releasing incisions have been made in the galea. **C.** To hold the advancing flap as far forward as possible, two points of bony fixation are used on either side of the midline at the leading edge of the flap. In this case, a dissolving bone tack is being used and is placed just posterior to the anticipated new location of the new hairline in order that the device will be hidden under hair-bearing scalp. **D.** After the scalp flap has been advanced anteriorly and fixed to bone, the excess forehead skin is excised.

PEARLS AND PITFALLS

Diagnosis	■ A preoperative aesthetic diagnosis is a vital step embarking on brow lift surgery. Variables that affect aesthetic decision-making include eyelid ptosis, excess upper lid soft tissue, or, conversely, deficient upper sulcus fat.
Eyebrow shape and height	■ Many patients have stable brow position throughout their lives and never develop brow ptosis. In patients whose brows become ptotic, it is lateral brow ptosis that usually predominates.
Technique	■ The elevated forehead through the coronal approach provides maximum visibility. Frown muscle ablation is easily accomplished, and the results of brow elevation are relatively predictable. ■ Sensory nerve transection during the coronal approach is inevitable. Patients should be warned of this in advance.
Closure	■ Excess suture tension on the scalp skin along the incision line can cause scar alopecia. Tension should be taken by the galeal sutures. ■ In most cases lateral brow elevation should exceed medial brow elevation.

POSTOPERATIVE CARE

- Cold packs are applied to the upper third of the face, as required for comfort.
- The patient is encouraged to keep the head elevated for the first week to decrease swelling.
- A light dressing consisting of a head wrap is put in place.
- Sutures are removed at 1 week postop.

OUTCOMES

- An open coronal brow lift is relatively predictable. Complete relapse is uncommon, and the surgical result is long lasting.
- This procedure affords unparalleled access for modification of frown musculature.
- Unavoidable side effects are a long scar in the scalp, sensory nerve transection, and a posterior shift of the anterior hairline that lengthens the height of the forehead.
- Unaesthetic overlifting of the central brow has historically been a problem, but with improved knowledge of forehead anatomy and the physiology of aging, this issue can be avoided.
- In the end, after assessment at 18 to 24 months, patient satisfaction is reported as being very high.¹¹

COMPLICATIONS

- Unsatisfactory scar formation with scar alopecia can occur due to suture tension along the incision line. A systematic review identified this problem in 3.6% of cases.¹⁷ Scar revision is usually successful.
- Sensory nerve damage routinely occurs leading to dense scalp numbness initially. This recovers over time, but on testing, there is almost always some permanent paresthesia to part of the scalp. This is generally not a concern to patients after 18 to 24 months have passed.¹²
- Hematoma is an uncommon complication at 0.5%.
- Infection is uncommon at 0.2%.
- Motor nerve damage (temporal branch of the facial nerve) has rarely been reported with subgaleal coronal dissections.
- The anterior hairline subcutaneous approach, when done in smokers, has led to a small incidence of partial skin necrosis in the forehead flap.¹⁸

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21 Indications and Technique for Endoscopic Brow Lifting

CHAPTER

Navid Pourtaheri, Ali Totonchi, and Bahman Guyuron

DEFINITION

- Age-related changes of the forehead include elongation of the forehead from a receding hairline and eyebrow ptosis, static and dynamic rhytides or frown lines, frontal bossing, glabellar flattening, and a misshapen eyebrow arch.
- An elongated forehead is defined as having an upper third of the face, hairline down to the glabella that is greater than approximately one-third of the vertical height of the face.

ANATOMY

- The forehead is the continuation of the scalp from the hairline to the eyebrows.
- The glabella, frontal sinuses, and frontal bone give the forehead its underlying contour.
- Overlying the bone, the soft tissue layers of the forehead, from deep to superficial, include the pericranium, loose areolar tissue, muscular layer (ie, frontalis muscle and galea aponeurosis), subcutaneous connective tissue and fat, dermis, and epidermis.
- Sensory nerves are supplied from supratrochlear and supraorbital nerves, emerging from the supraorbital rim at 1.7 and 2.5 cm from the midline, respectively, via a foramen or notch along with associated arteries.
- The paired frontalis muscles are brow elevators with vertically oriented fibers, and their attachments with the dermis give rise to horizontal rhytides of the forehead.
- Medial, intermediate, and lateral fibers of the frontalis are continuous with the procerus muscle, corrugator supercilii, and orbicularis oculi muscles, respectively.

- The procerus muscle is a brow depressor vertically oriented, originates from the periosteum over the nasal bones, and inserts into the frontalis muscle and the glabellar dermis which is responsible for rhytides at the root of the nose.
- The corrugator supercilii muscles are brow depressors obliquely oriented originating from the medial superciliary arch and passing through the orbicularis oculi muscle superolaterally inserting into the dermis of the brow and are responsible for vertical frown lines in the glabella.
- The paired depressor supercilii muscles are brow depressors originating from the medial orbital rim and inserting into the glabellar dermis and are responsible for oblique rhytides in the medial eyebrow area.
- The orbital portion of the orbicularis oculi muscle is a brow depressor (**FIG 1**).

PATHOGENESIS

- Recession of the upper hairline and temporal hairline increases the length and width of the forehead, respectively.
- Eyebrow ptosis occurs with age secondary to involutional changes of the facial soft tissues from thinning fat and dermis, collagen laxity, and aging. It is usually first seen in the lateral forehead and eyebrows because the frontalis muscle may compensate by elevating the medial two-thirds of the eyebrows. Brow ptosis may also occur due to blepharospasm from hyperactivity of the orbicularis oculi muscle or weakness of the facial nerve and frontalis muscle.
- Frontal bossing is typically due to hyperaeration of the frontal sinuses and less commonly due to soft tissue excess.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A comprehensive analysis is recommended of the face, hairline, brow position and arch, forehead length, width, contour, soft tissue quality, and rhytides. A significantly elongated forehead is best rejuvenated with an open approach via a pretrichial incision to remove excess skin (discussed in another chapter). A useful method to analyze the brow position is to eliminate the compensation from the frontalis muscle by asking the patient to smile or close their eyes tightly and then open them just enough to see the examiner. The uncompensated position of the eyebrows is at the supraorbital rim in males or slightly above in females, with its apex at the lateral limbus of the eye.
- Then, rhytide evaluation is recommended in repose, smiling, and frowning. Deep static forehead rhytides are best treated with a subcutaneous approach rather than the endoscopic approach, whereas the fine rhytides are treated with

laser resurfacing after endoscopic brow lift.

IMAGING

- Imaging is only warranted if there are contour abnormalities due to a soft tissue mass or underlying bony defect that must be evaluated and addressed prior to forehead rejuvenation.

NONOPERATIVE MANAGEMENT

- A combination of botulinum toxin injection, fillers, and fat grafting may be used to perform forehead rejuvenation nonoperatively.

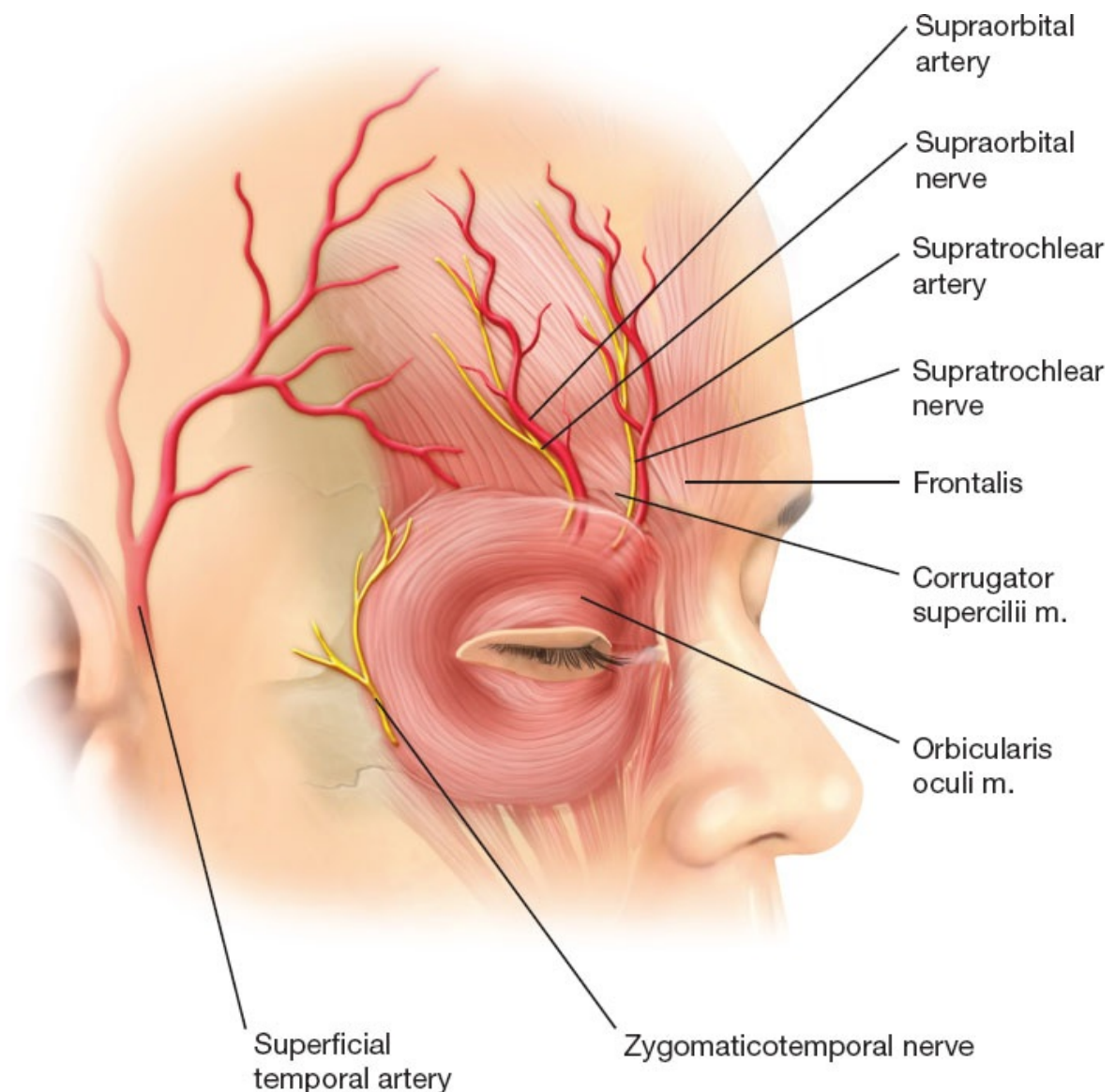


FIG 1 • Forehead anatomy. (Reprinted from Guyuron B.

Forehead rejuvenation. In: Guyuron B, Eriksson E, Persing J, eds. *Plastic Surgery: Indications and Practice*. Philadelphia, PA: Saunders Elsevier, 2009:1409-1426, with permission from Elsevier.)

SURGICAL MANAGEMENT

- Endoscopic brow lift is indicated in patients with eyebrow ptosis and hyperactive forehead muscles without static deep horizontal forehead wrinkles or excess forehead length. This is done on an outpatient basis under intravenous sedation or general anesthesia. Compared to open technique, there is a smaller chance of hair loss or forehead elongation (commonly observed after a coronal incision), as well as improved visualization with magnification.
- Disadvantages of endoscopic rejuvenation include the need for specialized instruments and a learning curve due to operating while looking at a monitor with a two-dimensional view.

Preoperative Planning

- An AP photograph of the patient's forehead in repose and while furrowing the brow in a standardized fashion is recommended for analysis and postoperative comparison; any eyebrow asymmetry needs to be noted and addressed using differential eyebrow suspension during surgery.
- General medical conditions including hypertension and hyperglycemia, as well as smoking cessation, are best addressed prior to surgery to minimize wound-healing complications.

Positioning

- Surgery is done in supine position. After anesthesia/sedation and prepping and draping the patient, the marking is started by marking a 1.2- to 1.5-cm incision on the midline from the hairline going posteriorly, followed by pairs of lateral incisions in the temple approximately 7 and 10 cm from the midline and 1.5 to 2 cm behind the hairline on either side. Each marking should be made vertically approximately 1.2 cm in length or 1.5 cm if the scalp is thick (**FIG 2**).

Approach

- This chapter explains the endoscopic approach of the brow lift. Open

approaches are discussed in another chapter.



FIG 2 • Markings and hair braiding for endoscopic brow lift. (Reprinted from Guyuron B. Forehead rejuvenation. In: Guyuron B, Eriksson E, Persing J, eds. *Plastic Surgery: Indications and Practice*. Philadelphia, PA: Saunders Elsevier, 2009:1409-1426, with permission from Elsevier.)

TECHNIQUES

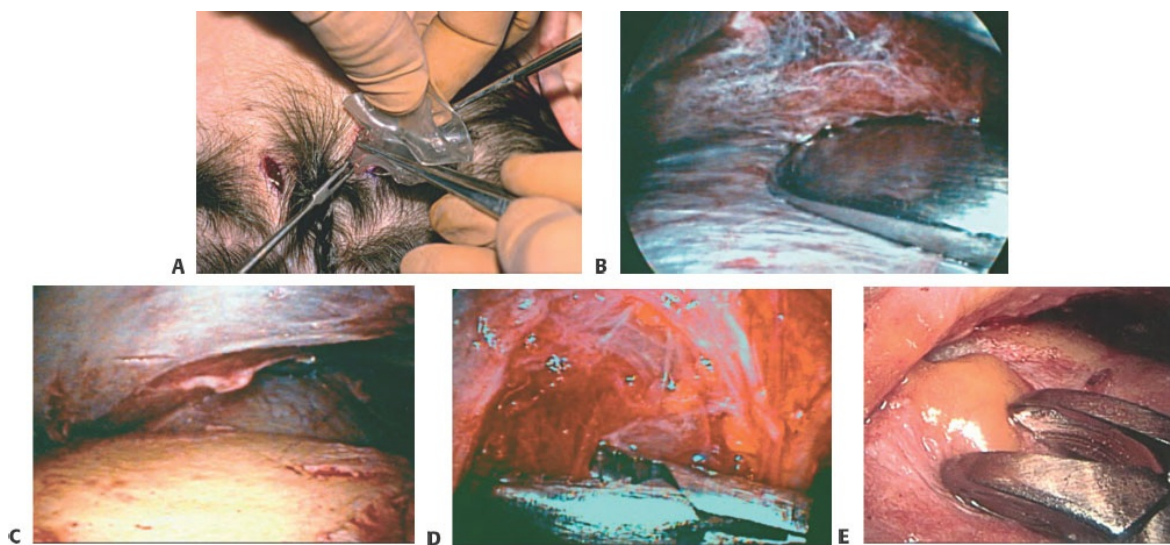
■ Endoscopic Brow Dissection

- Following the positioning of the patient, the hair next to the incision line is either braided or clamped to prevent it from entering the incision.
- The non-hair-bearing forehead is injected with approximately 10 cc of 1% lidocaine with 1:100 000 units of epinephrine using a 27-gauge needle, and the hair-bearing scalp is injected caudally up to 7.5 cm behind the incision with approximately 10 cc of 1% lidocaine with only 1:200 000 units of epinephrine to minimize hair loss due to vasoconstriction.
- Five minutes after the injection, incisions are made using a no. 15 blade scalpel on the most lateral marking and then using a pair of baby Metzenbaum scissors, and the tissue is spread bluntly down to the deep temporal fascia.

- At this point, Obwegeser periosteal elevator is used to make a pocket above the deep and superficial temporal fascia to insert an endoscopic access device. To insert the access device, the inner shield is folded using a pair of large multitooth Adson forceps and with an assistant separating the wound margins using skin hooks, introducing the inner shield into the incision (**TECH FIG 1A**).
- A periosteal elevator is passed through the most lateral incision and advanced toward the adjacent temporal incision to dissect the tissues at the plane immediately superficial to the deep temporal fascia and frontal periosteum.
- Endoscopic access devices are inserted in the same fashion described before.
- Using a periosteal elevator, subperiosteal dissection is performed posterior to the incision in the hair-bearing area and lateral to the incision over the deep temporal fascia. Unlike posterior and lateral dissection that is performed blindly, the anterior dissection is performed with the assistance of an endoscope.
- A 30-degree 4-mm endoscope is used through the second access device on the right side, whereas the most lateral access device is used to control the dissector.
- Under endoscopic visualization, a periosteal elevator is introduced through the lateral temporal access device on the right, and dissection is continued inferiorly toward the supraorbital rim (**TECH FIG 1B**).
- To preserve the temporal branch of the facial nerve, it is important not to leave the plane of dissection from deep temporal fascia to more superficial layers. One practical point is to ensure that all fat cells over the deep temporal fascia are dissected off the deep temporal fascia and elevated with skin, subcutaneous, and deep layer of the deep temporal fascia until dissection reaches the zygomatic arch.
- At this point, using a longer periosteal elevator, soft tissue is separated from lateral orbital rim and zygomatic arch at subperiosteal plane (**TECH FIG 1C**).
- Medial to the zone of adhesion of the temporal muscle, dissection is carried subperiosteally to the supraorbital rim where the supraorbital and supratrochlear nerves and vessels are identified after making a cut over the periosteum of the supraorbital rim.
- The corrugator supercilii muscle is grasped and carefully avulsed using

Daniel grasper or punch biopsy forceps.

- Muscles need to be removed as thoroughly as possible to minimize the dynamic asymmetry and deformity of the area postoperatively. The corrugator muscle lies superficial to a communicating vein between the supratrochlear and supraorbital veins—this vein is cauterized using suction Bovie cautery. Bovie nerve hooks can be used to retract and prevent injury to the supraorbital and supratrochlear nerves during corrugator myectomy. The depressor supercilii can be mistaken for the corrugator supercilii—it can be distinguished as the darker, more pliable muscle that lies deeper and more medial in its location (**TECH FIG 1D**).



TECH FIG 1 • **A.** Endoscopic access device insertion into the temple. **B.** Endoscopic dissection is performed using a periosteal elevator in a plane superficial to the deep temporalis fascia in the temple and subperiosteal over the medial forehead. **C.** Release of the arcus marginalis and fibrous attachments of the eyebrow using a periosteal elevator. **D.** Resection of the corrugator supercilii using a grasper. **E.** A fat graft is harvested to replace the volume of the removed corrugator supercilii by making a small opening in the deep temporal fascia cephalad to the medial zygoma and then harvesting fat with biopsy forceps.

(Reprinted from Guyuron B. Forehead rejuvenation. In: Guyuron B, Eriksson E, Persing J, eds. *Plastic Surgery: Indications and Practice*. Philadelphia, PA: Saunders Elsevier, 2009:1409-1426, with permission from Elsevier).

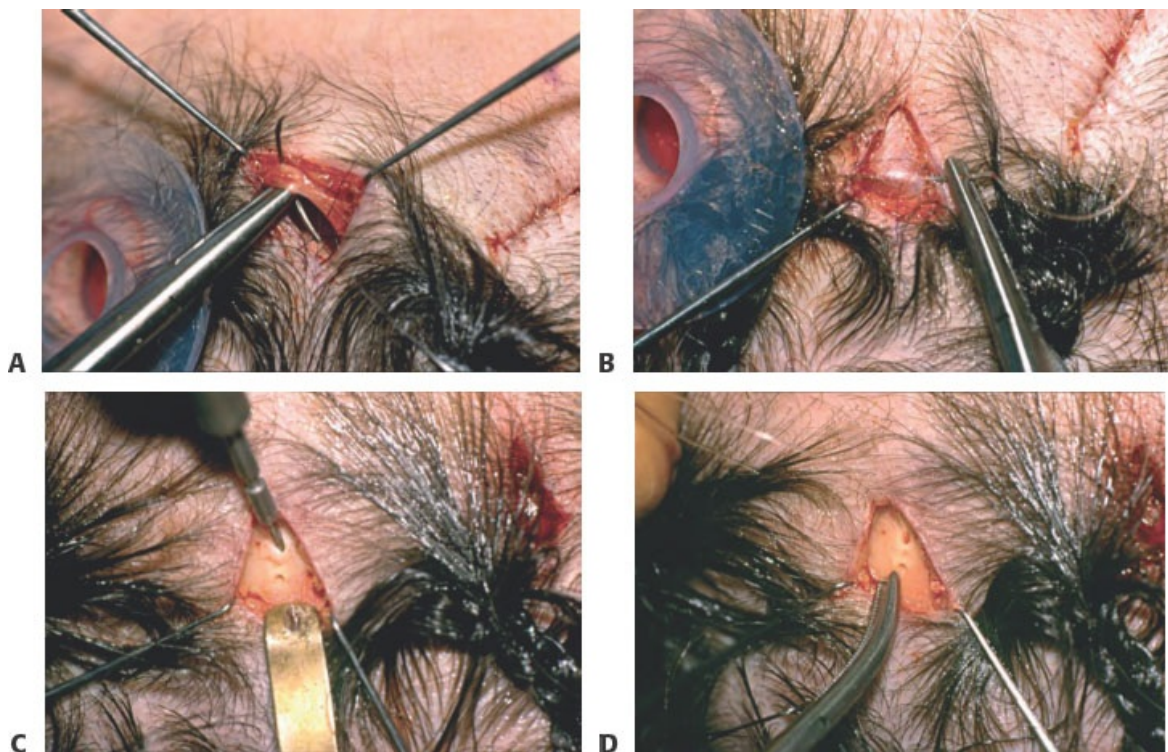
- Elevation of the periosteum over the glabella and the central portion of the periosteum will cause the undesirable medial eyebrow elevation. Uncommonly, there may be significant medial eyebrow ptosis with skin folding over the radix. If so, dissection of the medial part is necessary. At this point, the process is repeated on the other side, and hemostasis is achieved with suction Bovie cautery.
- To prevent contour deformity, the removed corrugator muscle pieces are eyeballed to harvest and replace the similar-sized piece of fat at the corrugator site.
 - Fat is usually harvested from deep temporal fat pad deep to the deep temporal fascia just above the zygomatic arch using the sharp end of the curved endoscopic periosteal elevator and grasper.
 - If there is a second procedure to be performed in which there is access to fat for harvest, this alternate site may be used.
 - Using a curved iris scissors, the harvested fat graft is trimmed to the size of the removed corrugator muscle. Then, using a periosteal elevator, the graft is delivered to the corrugator supercilii removal site (**TECH FIG 1E**).

■ Brow Resuspension

- Fascial suspension of the forehead is performed next. Usually, one lateral fascial suspension suture per side is sufficient.
 - Medial suspensions are avoided to prevent the elevation of the medial site.
 - Suspension is usually performed in the most lateral incision after removing the endoscopic access device, after placement of two single skin hooks at the junction of the caudal one-third and the cephalad two-thirds of the incision. While an assistant retracts the wound edges, a 3-0 polydioxanone suspension (PDS) suture is passed through the galea on two sides of the incision, and the forehead is suspended from deep temporal fascia after applying necessary tension. This is done while watching the eyebrow, and

the suture is tied down incrementally until the desired eyebrow position is reached (**TECH FIG 2A,B**).

- If additional fixation is needed to reposition the eyebrow or to correct asymmetry, a second suspension suture may be placed on the second port site.
- A 3-0 PDS suspension suture is passed through the galea on two side of the incision, and the suture is pulled along the desired vector to confirm the position where it will be suspended cephalically from the frontal bone after making a bone tunnel.
- Skin hooks are placed in the cranial half of the incision by retracting the scalp laterally and cephalically along the intended vector.
- A narrow malleable retractor is placed at the posterior edge of the wound to protect the soft tissue.
- A 1.1-mm drill bur with a safety guard length of 5 mm is connected to an office dermabrader.



TECH FIG 2 • A. A 3-0 PDS suture being passed through the anterocaudal third of the lateral-most incision. **B.** The suspension suture passed through the

anterior superficial temporal fascia of the incision is passed through the deep temporal fascia and then tied down incrementally to achieve the proper eyebrow position. **C.** A bone tunnel is made for suspension suture anchoring by drilling two 1.1-mm bur holes 3 to 4 mm apart opposing one another drilled at 45 degrees to the bone to meet at a depth of 3 to 4 mm. **D.** The suspension suture is bent to facilitate its passing through the bone tunnel. (Reprinted from Guyuron B. Forehead rejuvenation. In: Guyuron B, Eriksson E, Persing J, eds. *Plastic Surgery: Indications and Practice*. Philadelphia, PA: Saunders Elsevier, 2009:1409-1426, with permission from Elsevier).

- A Zimmer-Hall drill may be used to bur two opposing holes. Each hole should be drilled in at a 45-degree angle to the bone approximately 3 to 4 mm apart to meet at a depth of 3 to 4 mm (**TECH FIG 2C**).
- During drilling, the bone is irrigated with saline to minimize thermal damage. The free end of the PDS needle is bent using a pair of fine hemostat clamps. The needle is passed through the bony tunnel (**TECH FIG 2D**). The suture is tied down incrementally while watching the eyebrow to achieve the desired eyebrow position. The distance from the cranial border of the eyebrow to the eyelashes is measured while the eyes are closed—this distance should be approximately 2.5 cm. These steps are repeated for suspension on the contralateral side using one or two suspension sutures, beginning with the lateral most temporal incision.
- Screws or absorbable fixation devices such as the Endotine Forehead device can be used for fixation. Disadvantages of screw fixation over the proposed technique include the short length of the screws limiting penetration into the skull, the need for extraction of the screw, cost, short duration of fixation, and potential alopecia around the screw site.
- Drains are usually not necessary in this procedure. Skin closure is done by repairing the galea at each incision with buried 5-0 Monocryl suture and skin with simple interrupted 5-0 plain catgut sutures.

PEARLS AND PITFALLS

Periorbital release and corrugator resection

- Complete release of the periorbital and adequate removal of the corrugator muscles is the most important factor in guaranteeing a smooth lift and aesthetically pleasing result.

Preserving the periosteum and fascia of the central glabella

- Transection of the central glabellar attachments can result in excessive medial eyebrow elevation and a displeasing eyebrow curvature.

Pre-existing eyebrow asymmetry requires differential eyebrow elevation

- Pre-existing eyebrow asymmetry will persist postoperatively and be a source of patient discontent.
- This can be addressed by intraoperative differential eyebrow elevation with one to two suspension sutures per side.
- Medial forehead suspension sutures are not recommended.

Hemostasis

- Meticulous hemostasis with a suction Bovie is performed while the patient is at baseline preoperative blood pressure to prevent postoperative bleeding.

POSTOPERATIVE CARE

- Patients are typically allowed to shower on postoperative day 1 but instructed not to scrub their forehead or anterior hair-bearing scalp or submerge their head under water for 2 weeks.
- Patients are instructed to avoid strenuous activity and manage their blood pressure at home.

OUTCOMES

- With proper postoperative care, patients are usually pleased with the results of their forehead rejuvenation.
- Pre- and postoperative photographs of the patient's forehead in repose and while furrowing their brow can be used to highlight the outcomes of surgery to the patient at their postoperative visit.

COMPLICATIONS

- Inadequate, excessive, or asymmetric elevation of the eyebrows (may require corrective procedures)
- Dimpling upon animation
- Alopecia around the incision sites (usually temporary)
- Persistent paresthesia or temporary weakness due to injury to the temporal branch of the facial nerve (usually temporary)
- Persistent and intense itching of the forehead
 - No universally accepted treatment; antihistamines or antiserotonin-type compounds such as cyproheptadine, may provide some relief
- Infection
- Hematoma

Indications and Techniques for Subcutaneous Lateral Brow Lifting

22

CHAPTER

Richard J. Warren

DEFINITION

- Lateral brow ptosis describes an abnormally low position of the lateral third to one-half of the eyebrow complex.
- Brow position and shape convey an impression of emotion. When the lateral portion of the brow turns down, the patient appears sad or melancholy. It is also associated with aging.¹
- Ptosis of the lateral eyebrow encroaches on the upper lid sulcus, changing the dynamics of the upper lid/brow junction. Thus, lateral brow ptosis will affect the assessment of patients who present for blepharoplasty, periorbital fat grafting, or senile eyelid ptosis repair.

ANATOMY

- Please refer to the anatomy section of the coronal brow lift chapter.
- The position of the lateral brow depends on two main issues: muscle anatomy and the firmness of soft tissue attachment.
- The level of the lateral eyebrow is the result of a balancing act between the muscular forces that elevate the brow and the muscular forces that depress the brow, along with the universal depressor, gravity (**FIG 1**).
- The frontalis is the only elevator of the eyebrow. It originates from the galea aponeurotica superiorly and interdigitates inferiorly with the upper orbicularis. Contraction raises this muscle mass and the overlying eyebrow, which is a cutaneous structure. The muscle is deficient laterally and nonexistent lateral to the temporal crest line, so its primary lifting effect is exerted on the medial and central portions of the eyebrow.

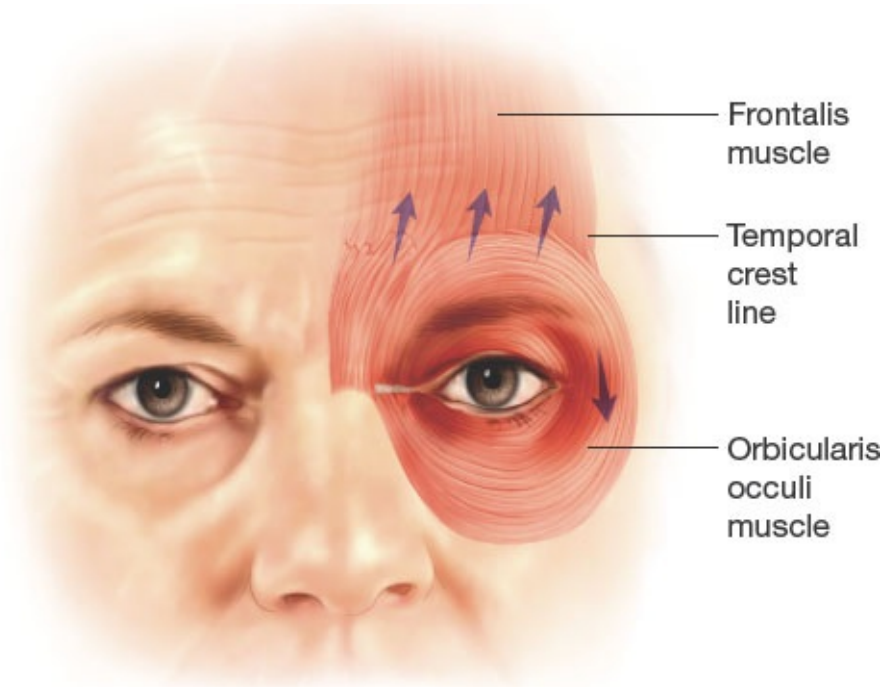


FIG 1 • The frontalis is the only muscle which lifts the eyebrow complex. On contraction, most of the movement occurs in the lower third of the muscle, and this action is strongest in the medial and central eyebrow. Laterally, frontalis action is weaker and is completely absent lateral to the temporal crest line. The orbicularis oculi acts like a sphincter surrounding the orbit. Laterally, it pulls the tail of the brow inferiorly.

- The primary muscular depressor of the lateral eyebrow is the orbicularis that encircles the orbit acting like a sphincter. Its action on the lateral brow can be temporarily reversed with botulinum toxin.

Sensory Nerves

- Innervation to the lateral brow and forehead is supplied by the supraorbital nerve that divides into two segments after it exits the orbit: the superficial and the deep branches.
- The superficial branches of the supraorbital nerve run on the superficial surface of the frontalis muscle and are visible when a subcutaneous flap is raised. These nerves innervate the forehead and the first 2 cm of the hair-

bearing scalp. The rest of the scalp, back to the vertex, is innervated by the deep branch that courses laterally and is deep to the frontalis muscle.

Motor Nerves

- The temporal branch of the facial nerve crosses the middle third of the zygomatic arch as two or three branches. These branches are entirely deep to the frontalis muscle and are on the underside of the superficial temporal fascia. Therefore, they are completely safe during the raising of a subcutaneous forehead skin flap.

Vessels

- The anterior branch of the temporal artery and accompanying veins coursing superficial to the frontalis muscle and the superficial temporal fascia. These may require cauterization during the raising of a subcutaneous forehead flap.

PATHOGENESIS

- Please refer to the pathogenesis of eyebrow ptosis in the coronal brow chapter.
- The desired eyebrow shape and position vary with ethnicity, gender, and the era in which we live. In this era, the elevated lateral eyebrow is the preferred configuration with the lateral end of the eyebrow ideally being higher than the medial end.
- As mentioned, the lateral portion of the eyebrow has two causes for inferior displacement (lateral orbicularis contraction and gravity) balanced against the only force that can lift: the frontalis. Despite this apparent imbalance, many patients (40% in one study) do not develop lateral brow ptosis over time.² The likely explanation for their brow stability is the strength of the underlying soft tissue attachments.
- Soft tissue fixation to bone is inconsistent in the lateral eyebrow. Laterally along the supraorbital rim, the galeal fat pad is separated from the preseptal fat (ROOF, retro orbicularis oculi fat) by one of the layers of galea. However, in the lateral brow, this galeal layer is thought to be variable, with some individuals having limited soft tissue attachment to bone. As a result, the galeal fat pad is contiguous with the preseptal fat (ROOF), and the lateral brow is relatively free to descend over time.³
- Many patients who develop lateral brow ptosis do so as a relatively early sign of facial aging.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Please refer to the patient history and physical examination in the coronal brow chapter (Chapter 20).
- Patients with lateral brow ptosis may present with a request for upper eyelid blepharoplasty, or they may request a facelift procedure, hoping it will improve their brow position. Both scenarios provide the surgeon with an opportunity to teach the patient about the dynamics of eyebrow aging.
- The laxity of the lateral forehead skin is assessed by manually manipulating the tail of the brow. Patients best suited for a subcutaneous lateral brow lift are those with loose skin and a relatively lax attachment between their lateral forehead skin and the underlying frontalis and superficial temporal fascia.
- The eyebrow itself is a cutaneous structure, and shifting the deep plane tissues with a deeper procedure may not translate well to the overlying skin if that skin is loose. Conversely, a successful procedure to shift the skin will directly shift the eyebrow.
- The ptotic lateral eyebrow is a common physical finding in the patient demographic who seek facial rejuvenation surgery. Consequently, a subcutaneous lateral brow lift can be an excellent adjunctive procedure for the patient who is a candidate for a facelift or blepharoplasty (**FIG 2**).



FIG 2 • This 56-year-old woman presents for blepharoplasty and facelift surgery. She has downturned lateral eyebrows that were not present in youth. The position of her medial and central brow is well maintained. In conjunction with the procedures she is requesting, a repositioning of the lateral eyebrows will be a useful adjunctive procedure.

- An examination of the temporal hairline will often demonstrate a triangular widow's peak where the hair is thin; this can be an ideal area to extend a hairline incision into the peak laterally.

NONOPERATIVE MANAGEMENT

- Nonoperative strategies to elevate the lateral eyebrow include the following:
 - Nonmedical: eyebrow plucking, cosmetic makeup, tattooing
 - Medical: botulinum toxin injection to the lateral orbicularis and the medial brow depressors, thread lifting

SURGICAL MANAGEMENT

Preoperative Planning

- The planned repositioning and degree of eyebrow elevation are reviewed with the patient who may have specific requests regarding eyebrow position and shape.
- The location of the hairline will affect the incision planning. The normal hairline will lend itself to an incision along the anterior hairline in the widow's peak area. Patients with a low hairline may benefit from an incision behind the hairline, which will shift the anterior hairline posteriorly. Patients in whom the temple hairline is positioned above (superior to) the lateral eyebrow may benefit from an incision placed in the temple hair.
- The presence of transverse forehead lines and the quality of forehead skin is assessed. The patient with thick corrugated skin may benefit from an incision made in a transverse forehead crease. This is often the case with middle age or older men.
- With the patient awake in the upright position and the forehead in repose, the desired amount and direction of lateral eyebrow elevation are assessed by manually elevating the lateral eyebrow. A mark is made on the skin, and the eyebrow is allowed to drop, thus determining the degree of elevation required.
- The most effective vector for eyebrow advancement is determined when the examiner manually repositions the brow. Most commonly, the desired vector runs along the axis of the temporal crest line.

Positioning

- The patient is placed on the operating table in the supine position with the head on a small pillow or soft donut.

- The head of the bead is raised slightly to help reduce venous engorgement.

Approach

- As described for preoperative planning, possible locations for subcutaneous lateral brow lifting are
 - At the hairline
 - Just behind the hairline
 - Lateral extension of a transverse forehead line
 - Directly adjacent to the eyebrow (**FIG 3**)
- All of these approaches are “skin deep” with varying degrees of subcutaneous dissection. For the first three incisions (hairline, behind the hairline, transverse forehead line), the dissection plane is subcutaneous, immediately superficial to the frontalis muscle. In the fourth option (adjacent to eyebrow), there is no skin undermining.

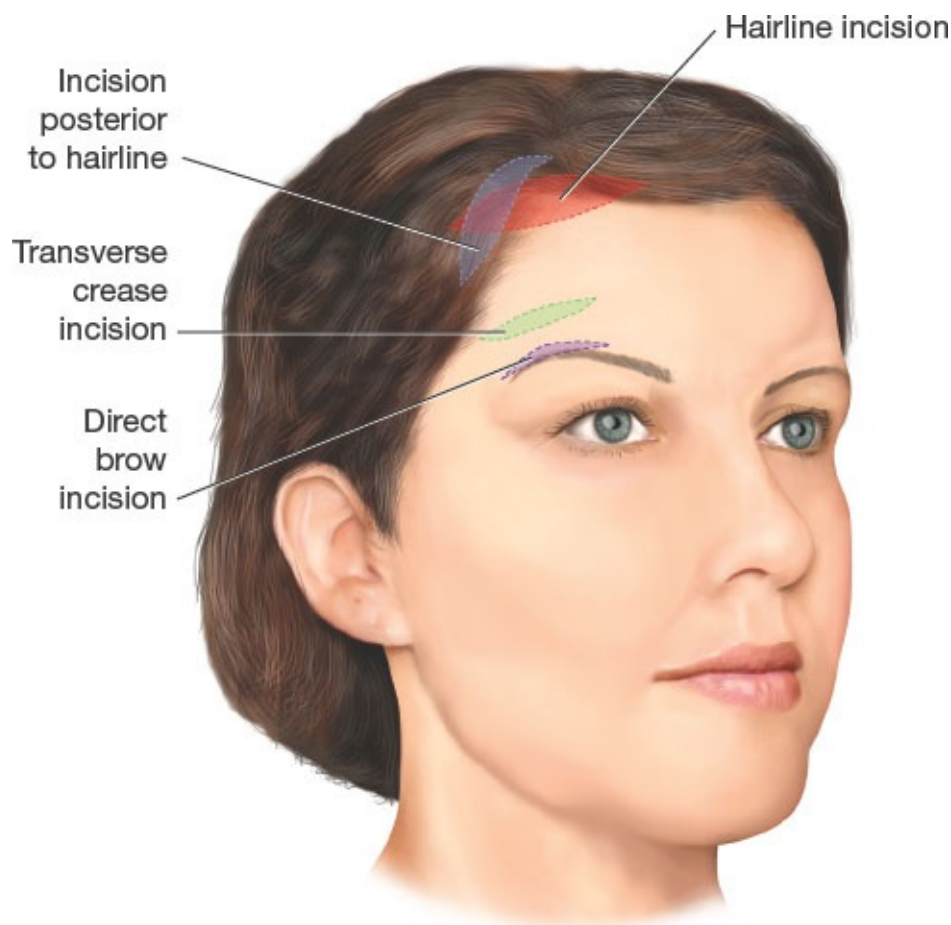


FIG 3 • Incision options for subcutaneous brow lifting

are shown. An incision posterior to the hairline involves the removal of hair-bearing skin posterior to the incision. An incision at the hairline involves the removal of forehead skin inferior to the incision. The transverse crease incision involves subcutaneous dissection on the eyebrow side of the incision, with skin excision on the inferior side of the crease. The direct brow incision does not involve undermining. The ideal vector for lateral eyebrow lifting is shown. This will be slightly different in every case but typically will follow the temporal crest line.

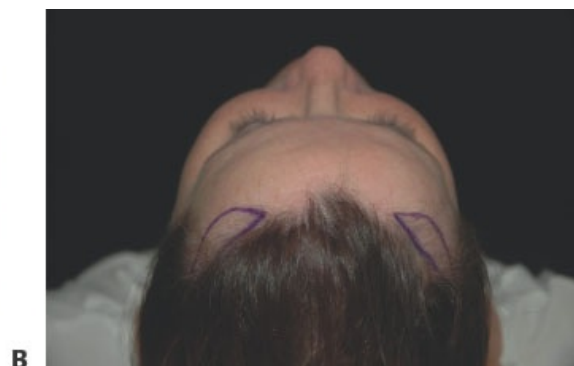
- The farther away from the eyebrow the incision is made, the less effective a subcutaneous lift will be.
- In planning the skin resection, the author's clinical experience has determined a "rule of thumb": at the time of surgery, an incision directly adjacent to the eyebrow will initially raise the eyebrow in a 1:1 ratio to the width of skin excised. An incision in the mid forehead will raise it in a 1:2 ratio, and an incision at the hairline will raise the eyebrow in a 1:3 ratio, or even 1:4, depending on the height of the forehead and the elasticity of the skin. In addition, over the first few months, there is always some relapse of lateral brow height that in some cases approaches 50% of the lift achieved at the time of surgery. Firm, thick forehead skin provides a more durable result than thin aged skin.
- Incisions posterior to the hairline are potentially the least visible but introduce the possibility of damaging hair follicles. Also, they will result in a slightly raised hairline.
- Incisions at the hairline are potentially visible but will not shift the hairline.
- Incisions in deep forehead lines provide a powerful lift and are potentially very well hidden, depending on the depth of the existing fold.
- Incisions adjacent to the eyebrow provide the most powerful lift of the various subcutaneous options. The scar can be well hidden when eyebrows are full or when there is an adjacent transverse fold in which to hide the scar.

TECHNIQUES

■ Anterior Hairline Approach

Markings and Anesthesia

- The preoperative markings are done prior to surgery with the patient awake and in the upright position.
- The essential preoperative markings include the planned incisions and the desired vector for flap movement (**TECH FIG 1**).
- The incision length is determined by the length of the eyebrow and the amount of eyebrow to be lifted. This may be just the tail or, possibly, the entire lateral half of the brow.
- Because of variability in desired lifting vectors as well as hairline variability, there is variability in the incision location. Every case is customized. Normally, the incision starts medially at the mid pupillary line and extends laterally from there over a distance of 3 to 6 cm in length, entering the temporal scalp. If a widow's peak is present, the incision follows the hairline into the peak.
- The procedure is done under local anesthetic with or without sedation.
- The head and neck area is prepped and draped with exposure of the entire face.
- A local anesthetic mixture composed of 1% lidocaine with 1:100 000 epinephrine and 0.25% bupivacaine with 1:200 000 epinephrine is infiltrated into the superior incision line, along the supralateral orbital rim and in a hydrodissection manner, into the subcutaneous space between these two zones.



TECH FIG 1 • A. Preoperative marking is done with the patient upright and with the frontalis in repose. The planned incision is marked. In this case, the incision location is the anterior hairline, with a planned skin ellipse inferior to that. The vector for the lateral brow lift is marked. As in this case, the preferred vector is often along the temporal crest line. **B.** The planned incisions and skin removal as seen from above.

Incision and Dissection

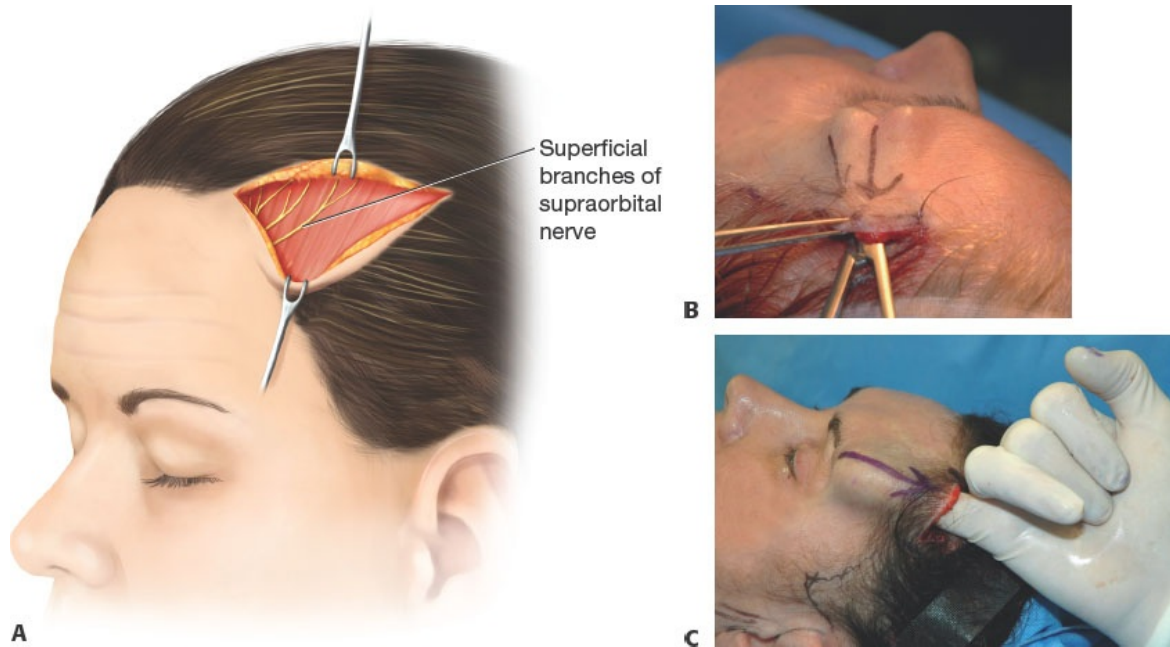
- After waiting for the epinephrine effect, the incision is made a few hairs posterior to the hairline. The scalpel is beveled in such a way that the hair follicles will be partially transected, utilizing the Camirand principle.⁴
- The incision stops when the frontalis is visualized. Dissection then turns inferiorly, following the superficial surface of the frontalis (**TECH FIG 2A**).
- Initially, dissection is sharp, using fine scissors, but after 1 to 2 cm, Metzenbaum scissors can be used with a gentle spreading motion, with tips up toward the skin (**TECH FIG 2B**). Blunt finger dissection deeper in the dissection pocket is a useful adjunct (**TECH FIG 2C**).
- Care is taken to identify and protect the superficial branches of the supraorbital nerve that will be running on the superficial surface of the frontalis muscle.
- Subcutaneous veins may require cauterization, and the anterior branch of the temporal artery may be protected or, if necessary, cauterized.
- Laterally, dissection is taken down the upper third of the lateral orbital rim.

Suturing and Completion

- The transverse running fibers of the orbicularis oculi will normally be visualized. A 5-0 or 4-0 Vicryl or similar suture is then used to pexy the orbicularis to a higher point on the frontalis muscle, using two or three sutures (**TECH FIG 3**).
- Another option is to place similar sutures from the underside of the skin flap to the frontalis muscle, shifting the skin flap superiorly with progressive tension sutures.⁵
- Once internal suturing is done, the undermined flap is advanced superiorly

over the cut edge of the scalp incision.

- The degree of overlap is marked and excess skin is removed from the inferior (undermined) side of the incision. Normally, the width of skin excision is in the range of 1.5 to 2.5 cm, depending on the age of the patient and the laxity of their skin.
- Repair of the scalp incision is done with 5-0 nylon sutures.
- A bupivacaine block is done across the supraorbital rim, targeting the supratrochlear and supraorbital nerves.
- The incision is left open with ointment applied along the suture line.
- In vascular cases, a light pressure dressing can be placed over the forehead, and an elastic head wrap can be put in place for 1 hour.



TECH FIG 2 • A. After carefully beginning the dissection, branches of the supraorbital nerve will be seen lying on the surface of the frontalis muscle. Dissection continues inferiorly as far as the eyebrow. **B.** Metzenbaum scissor dissection. **C.** Finger dissection.



TECH FIG 3 • The placement of internal pexy sutures is an optional maneuver, especially in those cases where the eyebrow is very mobile. Two sutures (5-0 Vicryl, 4-0 Vicryl or equivalent) are placed from the transverse running fibers of the orbicularis to a higher level on the frontalis. Similar sutures can be used from the underside of the skin flap in a progressive tension fashion.

■ Posterior to the Hairline Approach

Incisions and Dissection

- This procedure is identical to the hairline approach, except that the incision is placed in hair-bearing scalp, 1 cm posterior to the anterior hairline.
 - Consequently, the incision will follow the hairline and will usually be a gentle S-shaped incision following the hairline (**TECH FIG 4**).
- This incision is well suited for the patient with a hairline close to the tail of the eyebrow, where a modest shift of the hairline is not a problem and where a scar within the hair will be less visible than one at the leading edge of a low

hairline.

- This incision is also helpful when the natural nap of hair lies in such a way that the anterior hairline incision scar would not be well hidden by the hair.
- The incision is made with the scalpel blade kept parallel to the hair follicles in order to preserve the hairs in the flap.
- Flap dissection toward the eyebrow is done on the superficial surface of the frontalis (or if the incision is lateral, on the superficial temporal fascia).



TECH FIG 4 • Markings designate an incision within the hairs of the temple behind the hairline. Following the hairline down into the temple, the inferior dissection will be done deep to the hair follicles and will then proceed subcutaneously the short distance to the eyebrow. After flap advancement along the planned vector, hair-bearing skin will be removed posterior to the planned incision. This marking designates the desired vector of lift and the planned incision. In this case, the incision is being placed within the fine hairs of the temple and skin excision will be done posterior to the incision.

- For the first 1 cm of dissection, care is taken to stay deep, directly on the frontalis and/or superficial fascia, to protect the hair follicles. Dissection is done with a scalpel or fine dissecting scissors
- After the first 1 cm, the hair follicles are no longer at risk, and dissection can

continue inferiorly in the subcutaneous plane, in the same fashion as with the anterior hairline approach.

Suturing and Completion

- As with the anterior hairline approach, deep sutures may be placed to help with flap advancement superiorly.
- At the incision line, the overlapping flap is placed against the scalp, and the amount of overlap is marked.
- Excess scalp skin is then removed from the posterior (cranial) side of the incision.
- Scalp resection is done with the blade beveled to partially transect hair follicles. On closing the incision, the anterior hairline will be preserved but will be shifted slightly posteriorly.
- Occasionally, because of variations in a patient's hairline, this incision can be broken up into two separate incisions behind different parts of the hairline.
 - This provides excellent exposure and two different lifting vectors for the lateral brow (**TECH FIG 5**).



TECH FIG 5 • In this case, due to the shape of the hairline, two shorter incisions placed behind the hairline, each 2.5 cm in length, have been used for access. The subcutaneous flap has been raised, and the skin will be advanced superiorly and obliquely along two different vectors. Skin excision will be superior to the incision.

■ Transverse Forehead Line Approach

- Preoperative surgical markings are done in the upright position (**TECH FIG 6**).
- The procedure is done under local anesthetic with or without sedation.
- The head and neck area is prepped and draped with exposure of the entire face.
- A local anesthetic mixture composed of 1% lidocaine with 1:100 000 epinephrine and 0.25% bupivacaine with 1:200 000 epinephrine is infiltrated into the planned incision site and 1 to 2 cm inferior to that.
- After waiting for the epinephrine effect, the initial incision is made and the planned ellipse of skin is removed.



TECH FIG 6 • This 68-year-old man has deep transverse forehead lines. Preoperative markings designate three locations for transverse crease incisions with elliptical skin excisions inferior to the crease incisions.

- The inferior skin is then undermined for several millimeters, using a scalpel in the subcutaneous plane, freeing it from its attachment to the underlying frontalis.
- This incision is closed meticulously, using interrupted 6-0 or 5-0 permanent sutures.
- The incision is left open with ointment applied along the suture line.

■ Direct Eyebrow Incision

- Preoperative surgical markings are done.
- There are two possible incision locations for a direct eyebrow lift.
 - Directly adjacent to the eyebrow, cutting parallel to the hairs, and excising an ellipse of skin above (superior) to that
 - Within the lowest transverse fold which is near the eyebrow, excising an ellipse of skin below (inferior) to that
- The procedure is done under local anesthetic with or without sedation.
- The head and neck area is prepped and draped.
- A local anesthetic mixture composed of 1% lidocaine with 1:100 000 epinephrine and 0.25% bupivacaine with 1:200 000 epinephrine is infiltrated into the planned incision site.
- After waiting for the epinephrine effect, the inferior incision is made directly adjacent to eyebrow hair follicles, taking care to bevel the blade accurately along the axis of these hairs.
- No flap undermining is done.
- The planned ellipse of full-thickness skin is excised.
- The incision is closed meticulously, using 5-0 Vicryl (or similar) in the deep dermal layer and a fine suture in the skin, either a running subcuticular 5-0 nylon or interrupted 6-0 Prolene sutures.
- The incision is left open with ointment applied along the suture line.

PEARLS AND PITFALLS

Incision choice

- Choose the anterior hairline approach when the forehead skin is mobile and the anterior hairline is high.
- Choose an incision behind the hairline when the hairline is low and the patient is averse to a potentially visible scar.
- Choose the transverse fold incision when forehead skin is thick and deep transverse folds are present.
- Choose the direct brow lift when there is a bushy eyebrow or when there is a deep nearby fold in which to hide the scar.

Suturing

- All these procedures require very careful suture closure to

minimize the chance of a visible scar.

Tension

- For an incision in the vicinity of the anterior hairline, excess tension can create a widened scar and can lead to skin necrosis, especially in smokers.

Predictability

- The longevity of a subcutaneous brow lift is somewhat unpredictable due to the inherent elasticity of skin.

POSTOPERATIVE CARE

- The patient is encouraged to keep the head elevated for the first week to decrease swelling.
- Sutures are removed 5 to 6 days postoperatively.
- At 7 to 10 days postoperatively, botulinum toxin can be injected into the lateral orbicularis to reduce the brow depressing effect of the lateral orbicularis during the healing phase.

OUTCOMES

- These subcutaneous procedures are all relatively simple. The operative time is short, and they can be done under local anesthetic in the day surgery setting. In appropriately selected cases, they accomplish the same objective as much more involved procedures such as open brow lifts or endoscopic brow lifts.
- Overall patient satisfaction is very high, and serious complications are rare.^{6–10}
- Clinical experience does demonstrate a degree of unpredictability with respect to the magnitude of brow lift achieved and longevity of the surgical result. However, this issue is common to all brow elevation procedures.

COMPLICATIONS

- Subcutaneous procedures are truly “skin deep, and therefore they avoid potential damage to deeper anatomic structures. The biggest concern with subcutaneous brow lift procedures is the potential of visible scarring, but multiple series have demonstrated that this is not a problem reported by patients.^{6,7}
- A recent series of subcutaneous lateral brow lifts report no cases with seromas, hematomas, infection, or nerve damage, either sensory or motor.⁵
- Accurately predicting the amount of relapse is a problem with subcutaneous brow lifting as it is with all brow lift procedures. Relapse is more likely to occur in patients with lax tissues and when the incision is relatively far removed from the eyebrow.

- Scar alopecia can occur along the incision line when sutures are placed in hair-bearing skin with excessive tightness.

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23 Lowering the Overelevated Brow

CHAPTER

Michael J. Yaremchuk, Erez Dayan, and Dev Vibhakar

DEFINITION

- Brow lift procedures can create brows with positions much higher and configurations much different than those seen in youth. This results in an older appearance, with hollowed upper lids and a raised hairline (**FIG 1**).^{1,2}
- Brow lifts that preferentially elevate the medial brow and increase the distance between the medial brows create an unnatural, surprised, and unintelligent look.¹⁻³

ANATOMY

- The ideal youthful eyebrow in women has been described as an arch where the brow apex terminates above the lateral limbus of the iris. The medial and lateral ends of the brow should be at the same horizontal, located at or below the supraorbital rim, not above it.
- Men have a flatter-shaped, lower-placed brow.⁴
- With aging, the gravitational descent of the medial two-thirds of the brow is often camouflaged by the reflexive action of the frontalis muscle to counteract upper lid descent. This lid descent results from the senile dehiscence of the levator muscle. Because the lateral aspect of the brow extends beyond the frontalis territory, it descends. As a result, brows often elevate with aging. As described by Garcia and Matros, brow shape may change from an apex lateral slant to an apex neutral position¹ (**FIG 2**).

PATHOGENESIS

- Brow lift procedures can raise the brow to positions higher than they existed in youth. Because the medial brow often elevates with aging, exaggerated brow

lifts often have an aging effect due to this brow position.^{1,2}



FIG 1 • Patient after brow lift with overelevated, flattened, and widened brow. Also, note elevated hairline and hollow upper lids.

- Over elevation of the brows also tends to decrease upper lid redundancy by exaggerating the hollow eyes of senility and accentuating lid ptosis.²
- Removal of the corrugator muscles in an attempt to eliminate glabellar frown lines allows the medial brows to separate and elevate.
- Overelevation of the brows may result in an unacceptably high hairline. This may disrupt the proportional balance of the horizontal zones of the face. Hairline elevation can also reflect senility.^{1,2}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination should focus on the forehead and periorbital area and its relation to the balance of the face. Analysis should document the height of the forehead, shape and position of the brows, depth of the upper lid sulcus, upper lid position, and levator function.
- History should focus on elements related to the periorbital area, including method and date of the brow lift surgery; periorbital surgeries or procedures including neurotoxins, fillers, and fat injections; and ocular health.

IMAGING

- Photographs documenting pre-brow lift appearance should be obtained.

SURGICAL MANAGEMENT

Preoperative Planning

- Informed consent should include intrinsic risks related to brow and hairline repositioning. These include infection, asymmetry, alopecia, and motor/sensory nerve injury.
- Preoperatively, with the patient both in the upright and supine position, the distance of the medial brow and the central hairline is measured in relation to the intercanthal line. The distance change to accomplish the desired locations is recorded.
- The authors' preference is to use general endotracheal or nasotracheal anesthesia. This allows optimal preparation of the operative site and control of the airway.²

Positioning

- Patients are placed supine on the operating room table at a 90-degree perpendicular position relative to the anesthesiologist for maximal exposure.

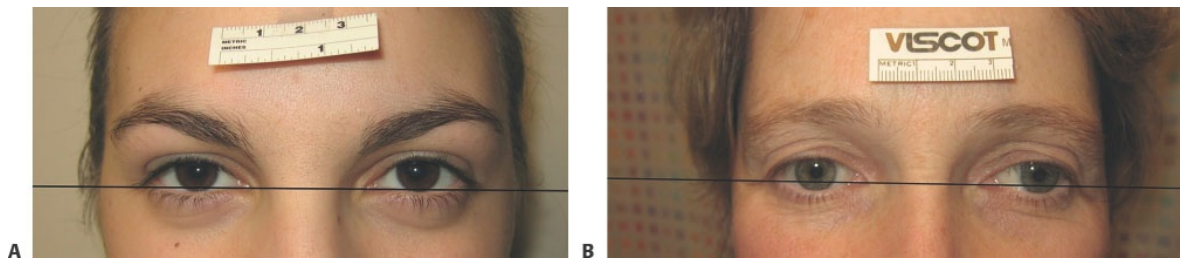


FIG 2 • A. In young patients, the medial brow is the lowest point or apex lateral slant. **B.** In older patients, the medial brow elevates, creating an apex neutral brow. This levels the brow in older patients, generating a flat appearance compared to the peaked brow of younger patients.

TECHNIQUES

■ Preparation

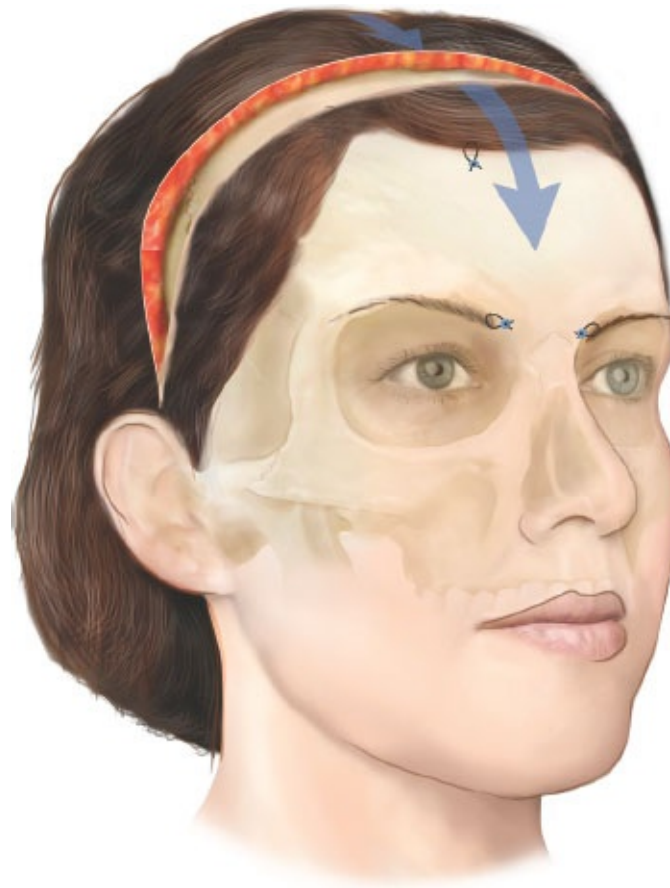
- Prior to antiseptic preparation and draping, a dilute solution of lidocaine and

epinephrine (1:200 000) is infiltrated into the operative site for postoperative pain control and intraoperative hemostasis.

- Intravenous cephalosporin or ciprofloxacin antibiotic prophylaxis is administered approximately 30 minutes preoperatively.

■ Incisions

- Bicoronal incisions are used for both previously performed open or closed (endoscopic) brow lift procedures. The incision is made to re-elevate the anterior scalp flap in a subperiosteal plane down to the supraorbital rim and just beyond the nasofrontal suture.
- If in the preoperative evaluation it was determined that the frontal hairline was high prior to the brow lift, a hairline incision may be used.
- After scalp incision and before flap elevation, the skull is scored with a drill directly beneath the scalp incision. The position of the anterior hairline is similarly marked. These marks serve as reference points during hairline and scalp repositioning (**TECH FIG 1**).

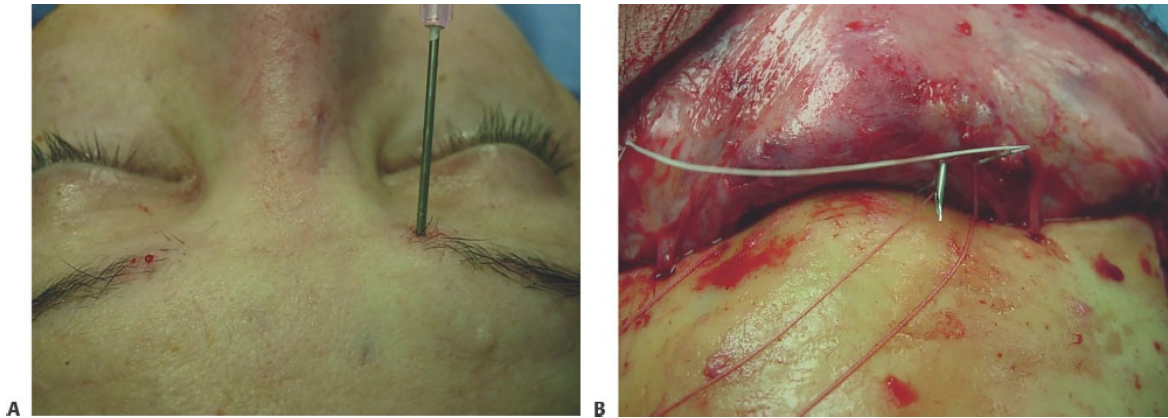


TECH FIG 1 • Coronal incision with register for hairline and Mitek anchors for medial brow positioning.

■ Brow Repositioning

- The anterior scalp flap is freed by subperiosteal dissection well onto the nasal root medially and the supraorbital rims laterally.
- The brow is repositioned relative to the medial canthus with Mitek anchoring system.
- The Mitek anchor is secured in the frontal bone at the desired distance (usually 15–18 mm) directly above each medial canthus. This places the anchors near the level of the nasofrontal suture. The inevitable penetration of the frontal sinus by this anchor is of no clinical significance.
- The nasofrontal suture is easily palpable through the skin and clearly visible when the scalp flap is reflected, and it is a useful reference when positioning the Mitek anchor.

- A 19-gauge needle is positioned at the most inferomedial aspect of the brow and passed through the scalp flap. This marks the area for Mitek anchor suture purchase (**TECH FIG 2**).
- The sutures are then tied, securing the posterior aspect of the flap and, hence, the medial aspect of the brow on its anterior surface to the desired position.
- Depending on the plan, this technique repositions the medial brow 3 to 8 mm inferiorly and 1 to 3 mm medially.



TECH FIG 2 • Anchoring the medial brow using transcutaneous needle (**A**) and Mitek anchor (**B**).

- The midbrow and lateral brows are repositioned as determined by patient preference. Most often, an “apex lateral slant” appearance is created through manipulation of the lateral aspect of the scalp flap. This position is secured by suturing the galea beneath the hair-bearing skin over the tail of the brow to the deep temporal fascia.
- With the incision and hairline registration marks placed earlier as a reference, the anterior hairline is repositioned. This position is secured with Mitek anchor scalp fixation to the skull positioned just off the midline to avoid possible sagittal sinus penetration. Cortical tunnels are an alternative to anchors in providing a stable fixation point for suturing to the skull.

■ Posterior Scalp Flap Advancement

- Brow and hairline lowering inevitably leaves a gap between the anterior and posterior scalp flaps.

- In patients who have had their brow lift surgery performed endoscopically, no scalp is removed and the gap reflects tissue repositioned posteriorly.
- Sufficient tissue can be recruited from the posterior flap by widely undermining it back to the occiput and advancing it anteriorly.
- In patients who have had their brow lift surgery performed through an open approach, the gap reflects scalp that has been excised. Filling this defect requires serial scoring of the galea to expand the scalp surface area, as well as wide undermining and posterior scalp advancement.
- It is sometimes necessary to elevate the posterior scalp flap beyond the occiput to obtain sufficient posterior scalp flap length and forward movement.

■ Closure

- Prior to closure, a thin suction drain is placed immediately above the supraorbital rim.
- Closure is achieved in two layers with inverted dermal sutures and nylon skin sutures.
- Using the nasal dorsum as a point of fixation, the medial brow is taped in the desired position prior to initiating the suction apparatus. These measures are intended to control scalp flap adherence and, hence, desired brow position.

PEARLS AND PITFALLS

Apex lateral vs apex neutral slant

- Younger patients have a medial brow that is low with the apex of the brow positioned lateral (at the lateral limbus). Older patients have an elevated medial and middle brow, which contributes to a flattened or apex neutral appearance.

Hairline repositioning

- Scoring the calvarium at the scalp incision and hairline provides useful landmarks for subsequent hairline repositioning.

Medial brow positioning

- The nasofrontal suture is a useful landmark for medial brow repositioning.

Brow and

- Mitek anchoring sutures and cortical tunnels are valuable fixation



FIG 3 • **A,B.** Brow lift reversal was performed using a hairline incision in this patient who preoperatively had a high forehead. The patient also underwent infraorbital rim augmentation, subperiosteal midface lift, and lateral canthopexy. **C,D.** This patient underwent brow lift reversal and subperiosteal midface lift. **E,F.** This patient underwent brow lift reversal.

POSTOPERATIVE CARE

- The drain is removed the morning after surgery.
- Oral antibiotics are prescribed for 3 to 5 days after surgery.
- Patients are instructed to refrain from strenuous exercise for 2 to 3 weeks postoperatively.
- Sutures are removed at 7 to 10 days after surgery.

OUTCOMES

- In the senior author's experience of reversing brow lifts, the medial brow is typically lowered 4 to 10 mm (average 5 mm) relative to the intercanthal line and the anterior hairline is lowered 5 to 18 mm (average 10 mm). Repositioning of the brow has remained clinically stable during follow-up, and no revisional surgery to reposition the brow or hairline has been requested (**FIG 3**).

COMPLICATIONS

- Postoperative complications are rare following lowering of the over elevated

brow and tend to involve concerns over asymmetry and temporary sensory nerve dysfunction.

- Areas of temporary and rarely permanent alopecia in the posterior scalp flap after galeal scoring are a potential complication after using this technique. Rogaine may be helpful in stimulating regrowth in these instances.
- Soft tissue redundancy may develop in the glabellar area after flap lowering, particularly in those patients who have had extensive corrugator resection during their brow lift surgery.
- Brow asymmetry may result with animation when corrugator resection was uneven during the initial brow lift surgery.

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24 Indications and Techniques for Transpalpebral Corrugator Resection

CHAPTER

Ximena A. Pinell-White and Foad Nahai

DEFINITION

- Horizontal glabellar frown lines result from contraction and hypertrophy of the corrugator supercilii and transverse lines from procerus muscle activity. Commonly, these central glabellar changes are also associated with lateral brow ptosis.

ANATOMY

- The paired corrugator supercilii muscles originate from the superomedial brow, traverse the galeal fat pad, and insert on the skin of the central brow. The corrugator muscles lie deep to the procerus and frontalis muscles. Contraction depresses the central brow, creating vertical and oblique glabellar rhytids (**FIG 1**).
- The procerus muscle takes its origin in the lower nasal bone and inserts into the skin overlying the nasal root. Contraction depresses the central brow and creates a transverse line at the nasal bridge.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The procerus and corrugator muscles can be identified by asking the patient to frown.
- It is important to distinguish between dynamic lines, which are evident only on animation, and static rhytids, which are uniformly present and are more challenging to correct. The Glogau classification of photoaging describes the severity of actinic changes based on the degree of skin wrinkling.
 - Dynamic lines represent early to moderate photoaging (Glogau class II) and

generally respond to less invasive procedures such as injection of neurotoxins.

- Static wrinkles, on the other hand, indicate more advanced photodamage (Glogau class III) that will often require surgery.

NONOPERATIVE MANAGEMENT

- Injection of neurotoxins is most effective in relaxing the muscles to temporarily eliminate glabellar rhytids. Etched or deep lines may also be improved with resurfacing or injections of fillers.

SURGICAL MANAGEMENT

- Glabellar frown lines can be addressed through an upper eyelid blepharoplasty incision in patients with little or no medial brow ptosis and no excess skin above the nasal radix. In patients with significant lateral brow ptosis, the procedure can be paired with a lateral temporal brow lift.

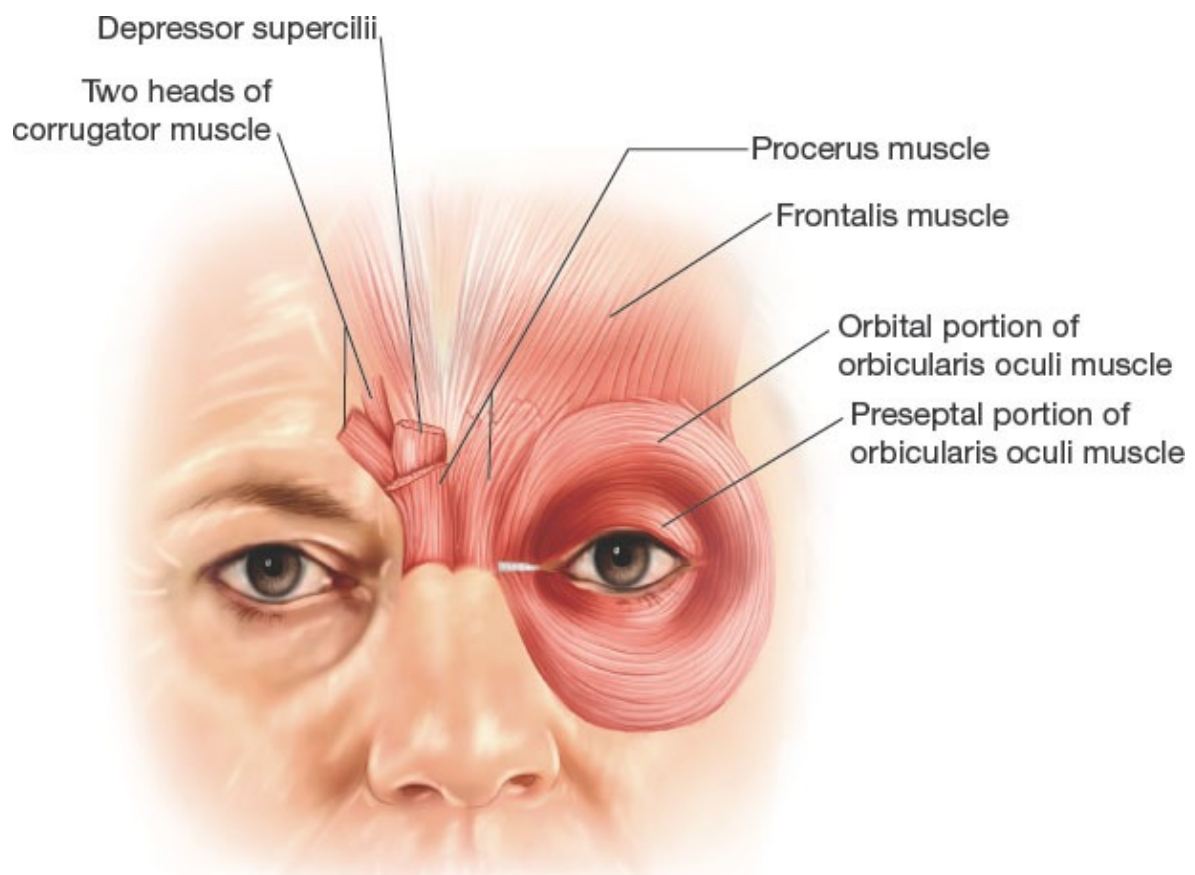


FIG 1 • Anatomy of the glabellar muscles.

Preoperative Planning

- The patient is marked preoperatively for an upper lid blepharoplasty. He or she is asked to frown to identify and mark the glabellar muscles. Note is made if the procerus should be divided.

Positioning

- The patient is positioned supine with slight elevation of the head.

Approach

- A transpalpebral approach to the glabellar muscles is employed at the time of upper lid blepharoplasty.

TECHNIQUES

■ Transblepharoplasty Excision of Corrugator and Procerus Muscles

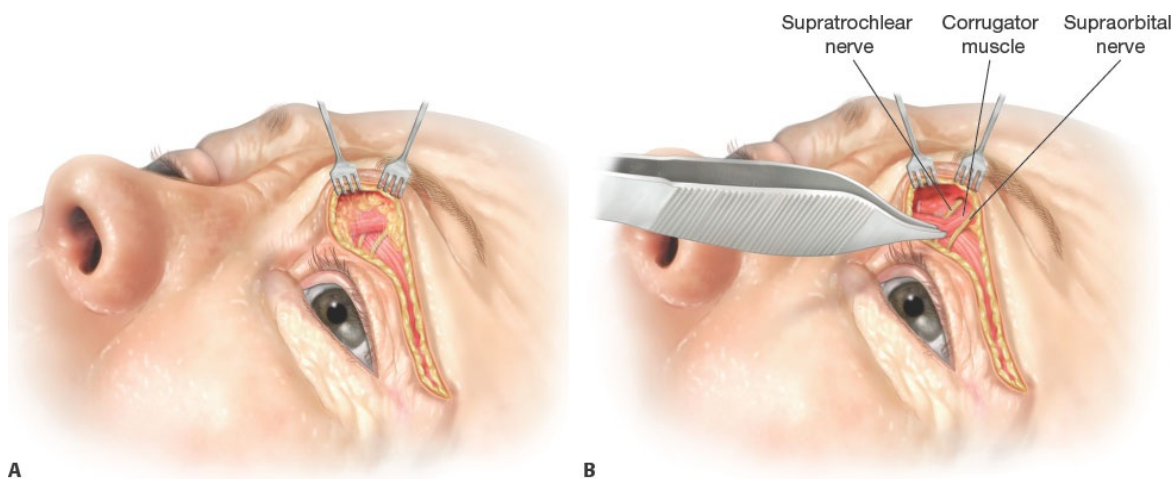
Incision and Dissection

- Upper lid blepharoplasty incisions are made, and the upper eyelid skin and, when indicated, muscle are excised.
- Any planned fat removal is deferred until after the glabellar muscles are excised so as to facilitate dissection of the orbicularis off of the orbital septum.
- The dissection is then continued superiorly, deep to the orbicularis muscle.
- The depressor supercilii portion of the orbicularis is divided to expose the diagonal and more deeply colored fibers of the corrugator muscle at the superior orbital rim (**TECH FIG 1A**).
- Our preference is to dissect with the cutting current of a Colorado tip needle.
- The supraorbital and supratrochlear nerves are visualized at this stage (**TECH FIG 1B**). The supraorbital nerve is more lateral and tends to be singular, larger, and in front of the muscle, whereas the supratrochlear nerve arborizes early and interdigitates with the fibers of the corrugator medially.

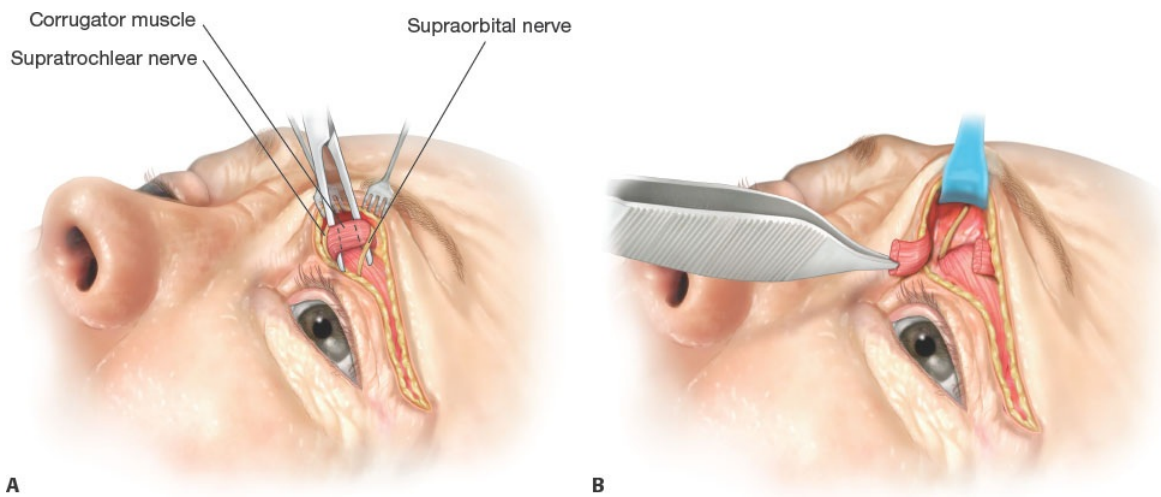
Muscle and Fat Excision

- After the nerves are identified and protected, a mosquito clamp is passed around the corrugator muscle to elevate it centrally (**TECH FIG 2A**).

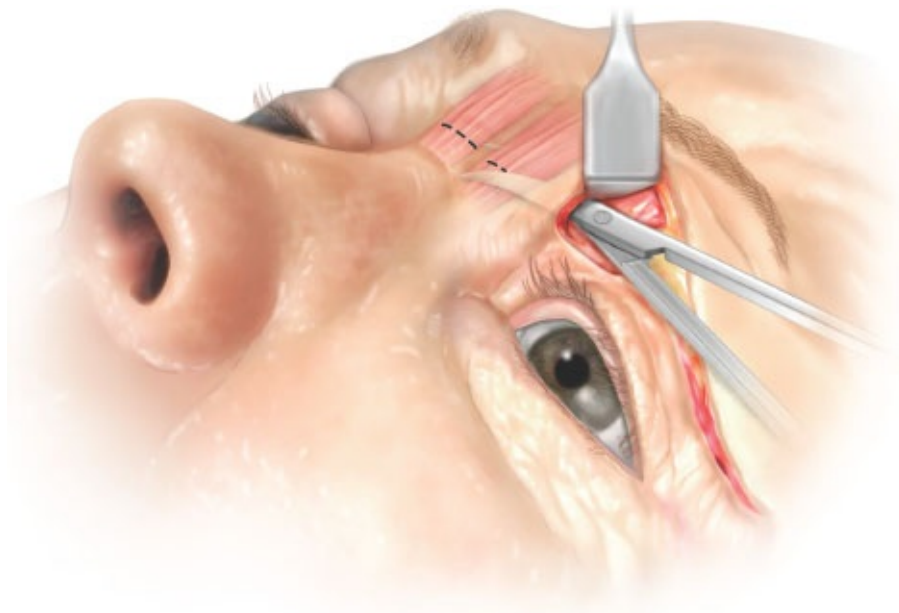
- A portion of the muscle is resected using electrocautery so as to leave a central gap. More muscle is taken from the lateral cut edge when the corrugators are particularly hypertrophied (**TECH FIG 2B**).
- There are often veins coursing with the nerves that should be avoided but when necessary can be cauterized with bipolar forceps. The trochlea of the superior oblique muscle tendon can theoretically be injured during dissection in the superomedial corner of the orbit, but this is rare and can be avoided by limiting dissection behind the origin of the corrugator.
- Patients with transverse dorsal nasal lines benefit from division of the procerus muscle.
 - This is accomplished by elevating the orbicularis muscle medially, directing a pair of scissors toward the nasal radix, and cutting the procerus muscle fibers just beneath the skin (**TECH FIG 3**).
 - This is a blind procedure and is often accompanied by some bleeding, which can easily be controlled with pressure.
- Fat removal from the upper lid can be performed if desired at this point, and the incision closed.
 - On occasion, I may place a small 5×5 mm piece of fat, harvested from the nasal fat pocket, in between the remaining edges of the corrugator. This would be to avoid a depression following removal of sections of the muscle.



TECH FIG 1 • A. Identification of the corrugator supercilii muscle. **B.** Location of the supraorbital and supratrochlear nerves.



TECH FIG 2 • **A.** Division of the corrugator muscle. **B.** Appearance of corrugator after resection of central segment.



TECH FIG 3 • Division of the procerus muscle.

PEARLS AND PITFALLS

Incomplete ■ It is important that full-thickness portions of the muscle are removed.

muscle excision	The muscle is wider than it may seem, and incomplete removal results in suboptimal results.
Bleeding	■ We infiltrate with vasoconstrictors so the dissection is performed in a relatively bloodless field.
Nerve injuries	■ The branches of the supratrochlear nerve are intertwined with the muscle and are at risk. The supraorbital nerve is much larger and lateral to the area of dissection and is therefore less at risk.

POSTOPERATIVE CARE

- Postoperative swelling after this procedure may be prolonged and more noticeable than following a standard blepharoplasty. This can be minimized by keeping the head elevated, applying ice packs to the eyelids, and in some cases, administering diuretics and a short course of steroids.

OUTCOMES

- This technique has proved very effective for treatment of glabellar frown lines (**FIG 2**).



FIG 2 • Patient before and after transpalpebral corrugator resection.

COMPLICATIONS

- Injury to the supraorbital or supratrochlear nerves can produce anesthesia or paresthesias of the forehead and, in the case of the supraorbital nerve, the scalp behind the hairline.
- Contour defects following corrugator excision or procerus division are rare,

but these can be filled with periorbital fat when necessary.

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25 Indications and Techniques for Hairline Lowering

CHAPTER

Warwick J. S. Nettle and Yumiko Kadota

DEFINITION

- The ideal length of the female forehead should be approximately one-third of the length of the face (**FIG 1**).¹⁻⁴
 - Forehead length should typically be 5.5 to 6 cm from the eyebrows to the anterior hairline.^{2,4,5} This varies depending on eyebrow position and overall facial size.
- The forehead may be elongated congenitally, due to hairline recession with aging or iatrogenic causes, such as coronal incision brow lift.^{1,4}
- A high hairline, or large forehead, causes the upper third of the face to be disproportionately larger than the middle and lower thirds.
- Young women find that a high hairline masculinizes their faces.⁴
- Hairline lowering utilizes a posterior scalp advancement flap.^{1,3-6}

ANATOMY

- The hairline is an extended area consisting of various zones and borders that frame the face.⁷
- The frontal hairline has an irregular border that extends from temple to temple.
 - The transition zone is the anterior border of the frontal hairline where soft, small hairs are found.⁷
 - The defined zone is immediately behind the transition zone, where the hairs become coarser and denser.⁷
 - The midfrontal point is the midline, most anterior point of the hairline. This is where the “widow’s peak” is, if it exists in the patient.
- The frontotemporal angle is the point where the frontal hairline meets the

temporal hairline.⁷ This angle is the angle of temporal hair recession, routinely found in males and sometimes found in females.

- The layers of the scalp from superficial to deep are
 - Skin: the thickest in the body and most hair-bearing
 - Dense connective tissue where the blood vessels run
 - Occipitofrontalis muscle
 - Galea aponeurotica between occipitalis and frontalis muscles. This aponeurosis blends with the temporalis fascia laterally, just above the zygomatic arch.
 - The subgaleal space of loose areolar tissue provides a plane for scalp mobility.
- Scalp blood supply
 - Blood supply to the scalp derives from external and internal carotid artery branches, which anastomose freely with each other.
 - Scalping does not cause necrosis of the underlying skull, which receives blood supply from the middle meningeal artery.
 - The external carotid artery gives rise to the occipital, posterior auricular, and superficial temporal arteries.
 - The occipital artery runs from the apex of the posterior triangle of the neck to supply the posterior scalp to the vertex.
 - The posterior auricular artery supplies the scalp behind the ear.
 - The superficial temporal artery is a terminal branch of the external carotid artery and supplies the skin over the temporalis fascia and scalp.
 - The supraorbital and supratrochlear arteries derive from the internal carotid artery and supply the forehead and anterior scalp to the vertex.
- Scalp sensation
 - The greater occipital nerve (posterior ramus of C2) runs with the occipital artery and supplies the posterior scalp to the vertex.
 - The posterior scalp is also supplied by the third occipital nerve (posterior ramus of C3).
 - The lesser occipital nerve (anterior ramus of C2) runs with the posterior auricular artery and supplies sensation to the skin behind the ear.
 - The skin of the temple is supplied by the auriculotemporal and zygomaticotemporal nerves.
 - The forehead and anterior scalp are supplied by the supratrochlear and supraorbital nerves, which run with the corresponding arteries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Suitable candidates³⁻⁵ have
 - High hairline
 - Good, healthy hair
 - Lack of cowlicks (posterior exiting hairs)
 - Good scalp mobility (measured by the ability of the scalp to rock back and forth on the skull)
 - Absence of scalp disease and previous scalp surgery
 - No history of stress-induced or unexplained hair loss
 - No family history of progressive hair loss

SURGICAL MANAGEMENT

- Hairline lowering is a day procedure, of about 2-hour duration.
- The major steps are as follows:

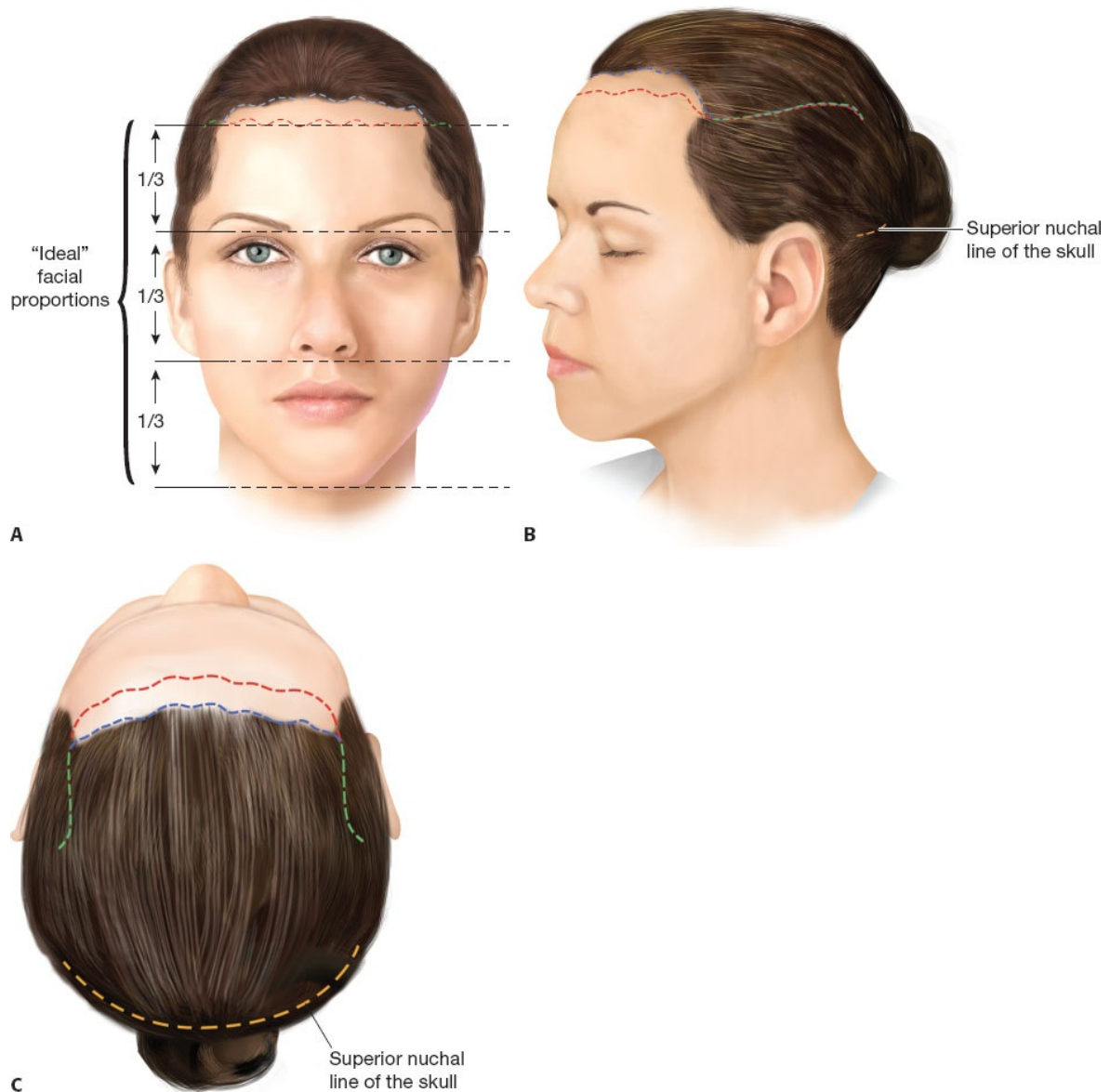


FIG 1 • A. Frontal view showing ideal facial proportions, undulating incision along current hairline (*blue*), posterior incision extensions (*green*), and proposed incision for inferior and anterior advancement of new hairline (*red*). **B.** Oblique view showing the same markings as (**A**), plus the superior nuchal line, a very minor ridge or crest on the posterior skull bone (occipital bone) that provides attachment for the sternocleidomastoid and trapezius muscles, as well as the occipital belly of the occipitofrontalis muscle. **C.**

Overhead view.

- The hairline is surgically advanced anteriorly using a posterior scalp advancement flap, to meet the proposed new hairline (**FIG 2A–D**).
 - It is easier to advance the central anterior hairline (narrow flap) than the whole frontal hairline (broad flap).
- The ellipse of the forehead skin between the pre-existing and new lower hairline is excised (**FIG 2C**).
- The scalp is secured in its advanced position to the underlying bone with sutures through converging outer cortical bone tunnels, Endotines, or other fixation devices (**FIG 2C**).

Preoperative Planning and Positioning

- Marking of the existing and new proposed hairlines is made preoperatively with the patient standing or sitting up.
- The marking of the frontal hairline should be in an irregularly undulating fashion, which resembles the natural hairline and helps with camouflage of the incision (**FIG 3A**).^{3–5}
 - This marking is just posterior to the fine hairs of the anterior hairline but before the coarse hairs of the defined zone become denser.^{3–5}
- If needed, the incision is made as lateral as possible, to allow for lateral as well as central advancement, and to avoid recession at the frontotemporal angle (temporal recession).
- The proposed new, lower hairline traces the superior marking (**FIG 3B**).
- The level is marked according to the patient's desires while taking into consideration the pre-existing scalp mobility.
- Usually 2.5 cm of scalp advancement is not difficult with a moderately mobile scalp.⁵
- The incision continues posteriorly bilaterally, in a shape similar to the arms of a pair of spectacles (**FIG 3C**).
- The patient is positioned supine, on a head ring at the superior most end of the table.
- Surgery is performed under general anesthesia or local anesthesia with sedation.^{3–5}

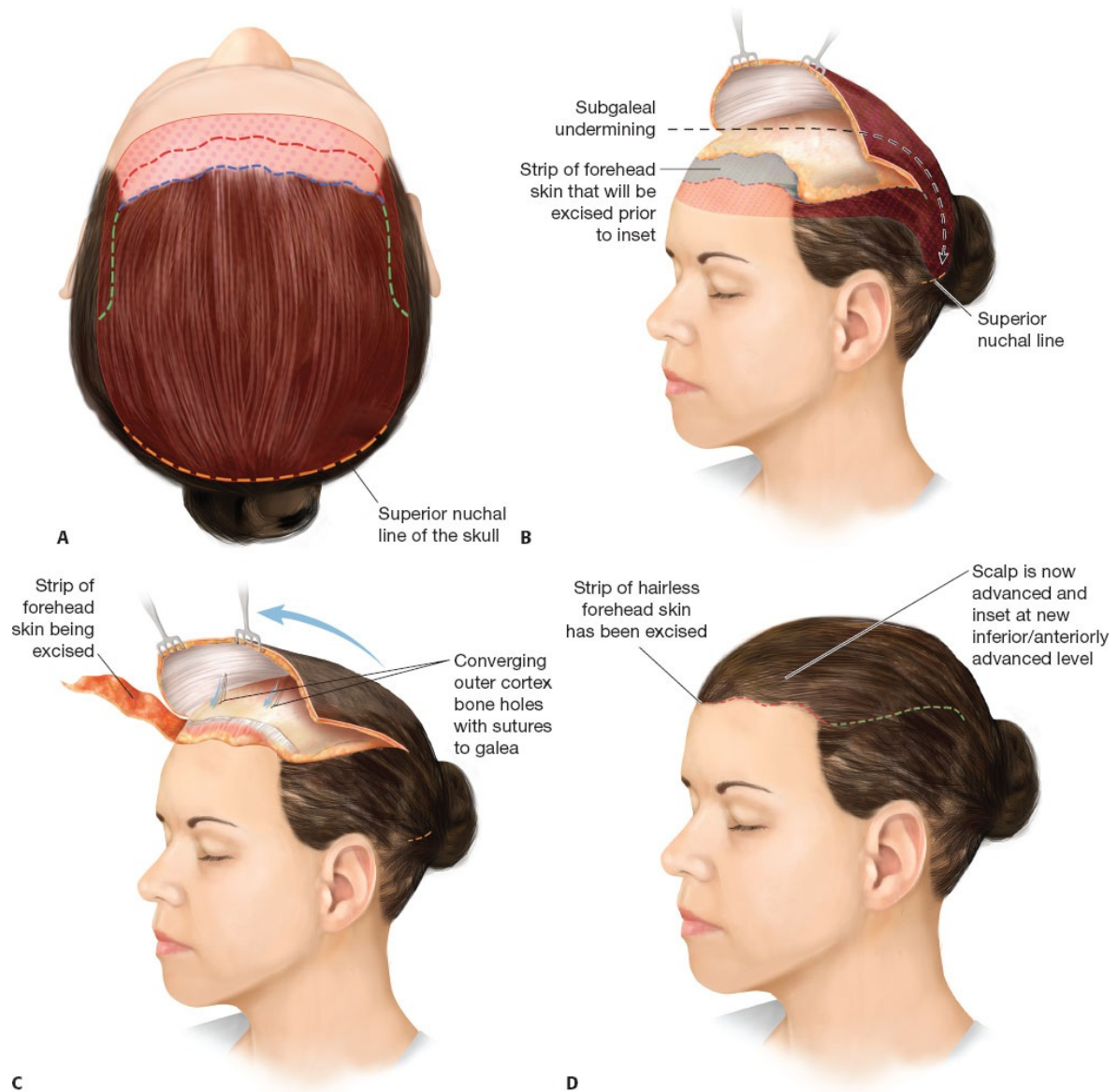


FIG 2 • A. The extent of subgaleal undermining, not only of the proposed scalp flap but also of the scalp and forehead 2 to 3 cm in addition to the scalp flap. The *blue line* is the undulating incision along the current hairline; the *green lines* are posterior incision extensions; the *red line* is the proposed new hairline, and the *pink area* is the limit of subgaleal scalp elevation. **B.** Elevation of the scalp away from the underlying skull. This occurs as far posteriorly as the superior nuchal line. Rake retractors are used to

elevate the scalp flap. The scalp and forehead are undermined 2 to 3 cm lateral to the lateral incisions and anterior to the proposed new hairline. The strip of forehead skin to be excised remains in situ until the flap is advanced anteriorly. **C.** The undermined scalp is advanced anteriorly with the help of rake retractors. Bilateral bone holes (converging external cortical bone holes) that have been drilled are used with sutures to keep the scalp flap advanced. The undersurface of the scalp flap has galeotomies (incisions in the galea), which help it to stretch and reach further anteriorly. The strip of hairless forehead skin is excised and discarded prior to inset of the advanced flap. **D.** End result with hairline lowered by scalp flap. Insetting is accomplished with deep dissolvable sutures with staples laterally and sutures anteriorly. The undulating hairline is preserved.

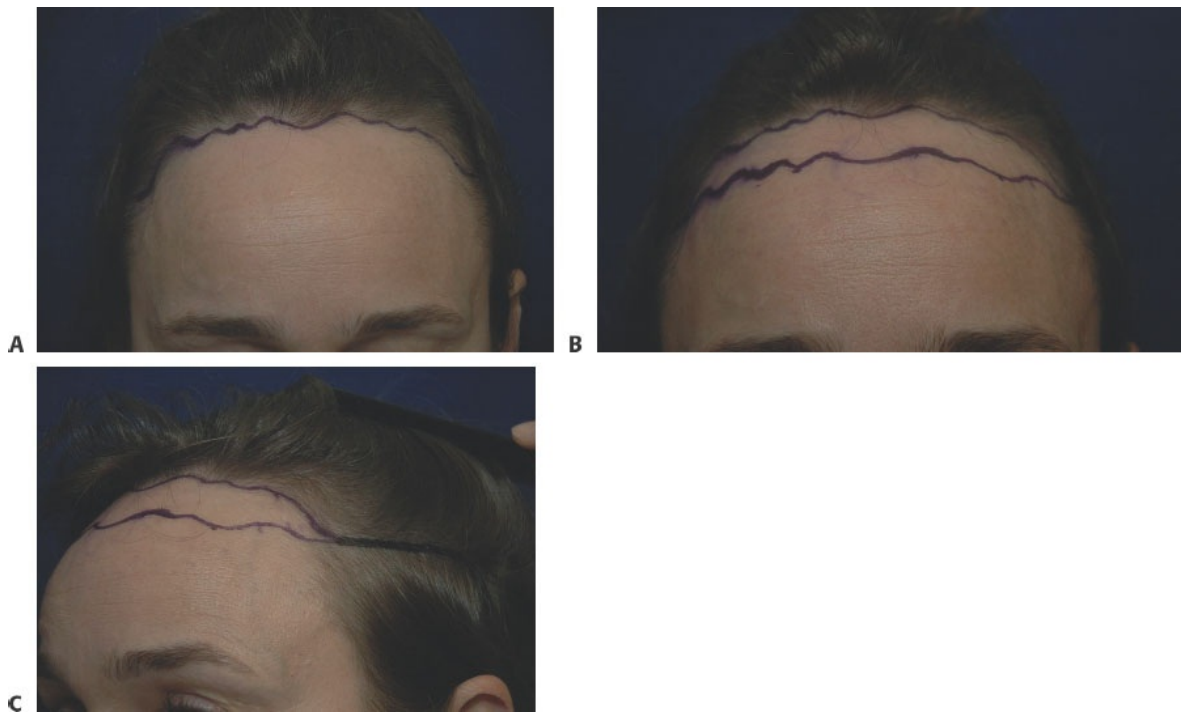


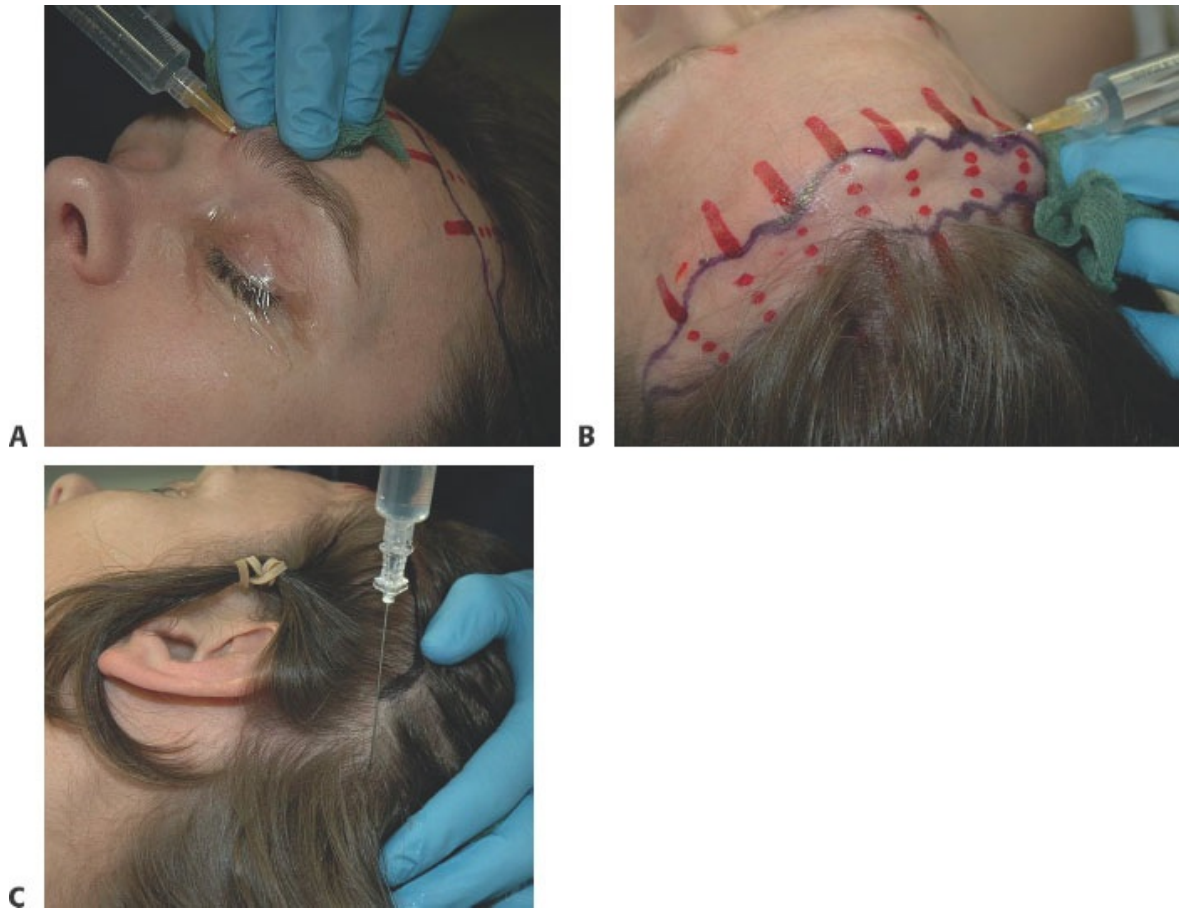
FIG 3 • A. Undulating irregularly irregular incision line marking at the existing hairline. The incision will be just

posterior to this. **B.** Markings for the new proposed hairline are drawn on the forehead to match the undulating existing hairline marking. The two lines meet laterally to outline the ellipse of skin to be excised. **C.** Marking for the incision is extended posteriorly, in a shape similar to the arms of a pair of spectacles.

TECHNIQUES

■ Local Anesthesia

- Local anesthesia (ropivacaine/marcaine/lignocaine) with epinephrine is used for both hemostatic and intraoperative and postoperative analgesic effects.
- The local anesthesia is injected at the brow to anesthetize the supraorbital and supratrochlear nerves (**TECH FIG 1A**).³
- Then it is injected along the existing and proposed new hairlines (**TECH FIG 1B**) and posteriorly in a circumferential manner, which produces a vasoconstrictive, pseudotourniquet effect (**TECH FIG 1C**).^{3–6}

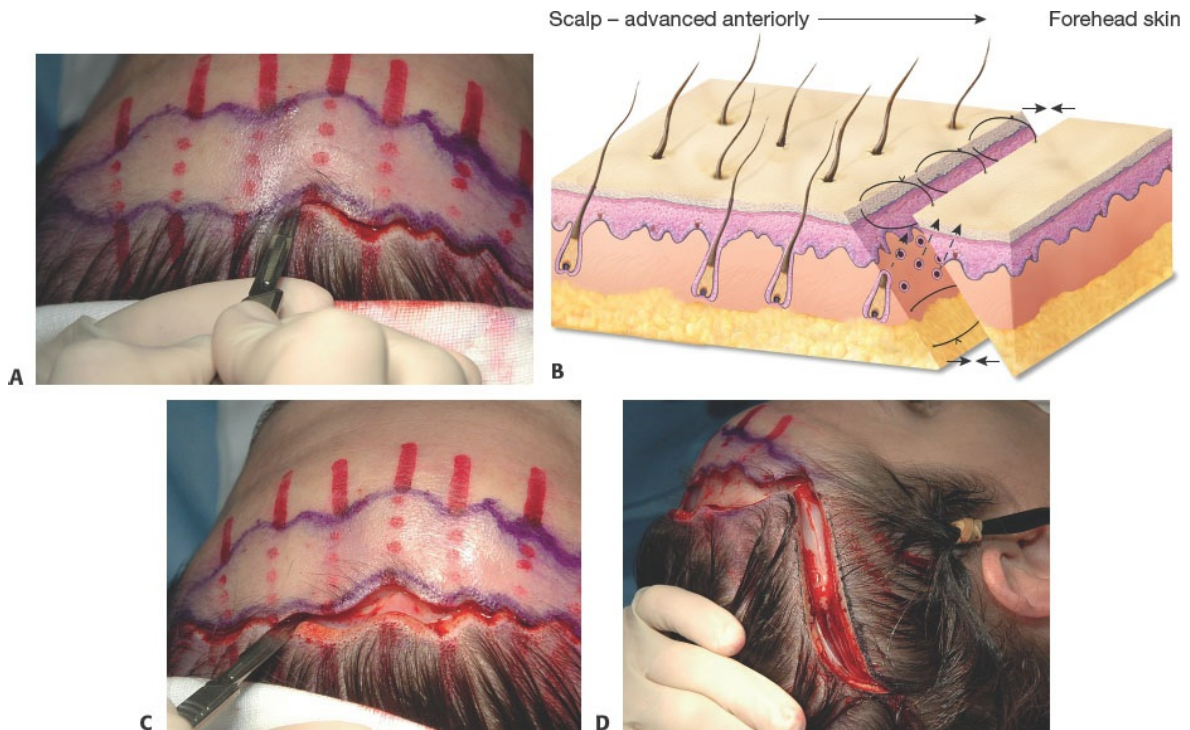


TECH FIG 1 • **A.** Local anesthetic is injected to block the supratrochlear and supraorbital nerves. **B.** Local anesthetic with epinephrine is injected along the incision lines. **C.** Local anesthetic with epinephrine is injected along the posterior incision line in a circumferential pattern toward the superior nuchal line using a spinal needle. Meeting the local anesthetic from the contralateral side produces a pseudotourniquet effect.

■ Incision and Dissection

- The incision anteriorly is made in a trichophytic beveled manner using a no. 15 blade.^{1,3,4} This denudes or de-epithelializes hair follicles along the length of the anterior incision (**TECH FIG 2A,B**).

- It is just posterior to the forehead-scalp junction, posterior to the transition zone, just anterior to where the thicker hair of the defined zone starts.
- The incision is deepened to the subgaleal level with a no. 10 blade, in the same beveled manner (**TECH FIG 2C**), and transitions to become parallel to the hair follicles for the posterior extensions.³
- The incision is extended posteriorly parallel to the hair follicles (**TECH FIG 2D**).

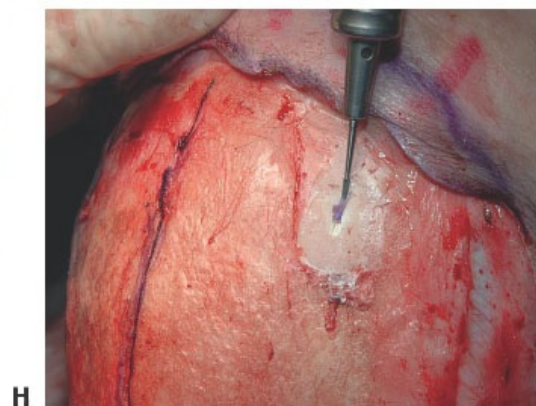
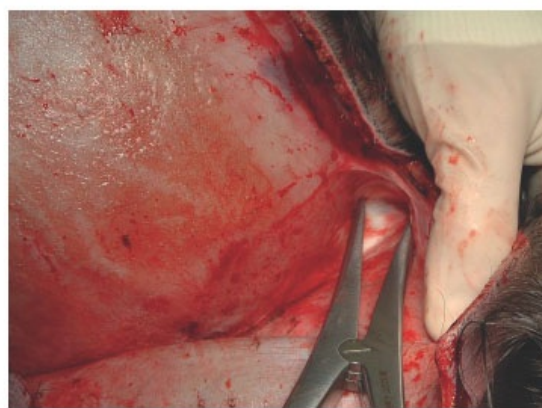
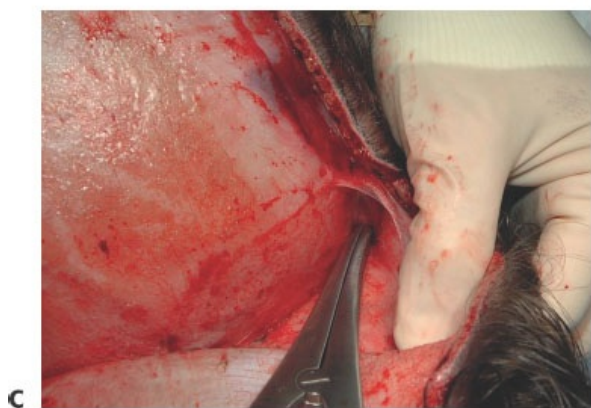


TECH FIG 2 • A. The undulating existing hairline incision is made posterior to the markings, just posterior to the fine hairs of the transition zone. The incision is made in a beveled, trichophytic manner denuding follicles of the anterior scalp. **B.** Beveled incision causes the hairless forehead skin to overlap the denuded hair follicles of the anteriorly advanced scalp flap. Some of the denuded follicle hairs will exit the forehead skin anterior to the incision line, helping to camouflage the incision line. **C.** The initial incision is made with a no. 15 blade but deepened with the same

bevel using a no. 10 blade. **D.** The incision is extended posteriorly parallel to the hair follicles.

■ Flap Elevation

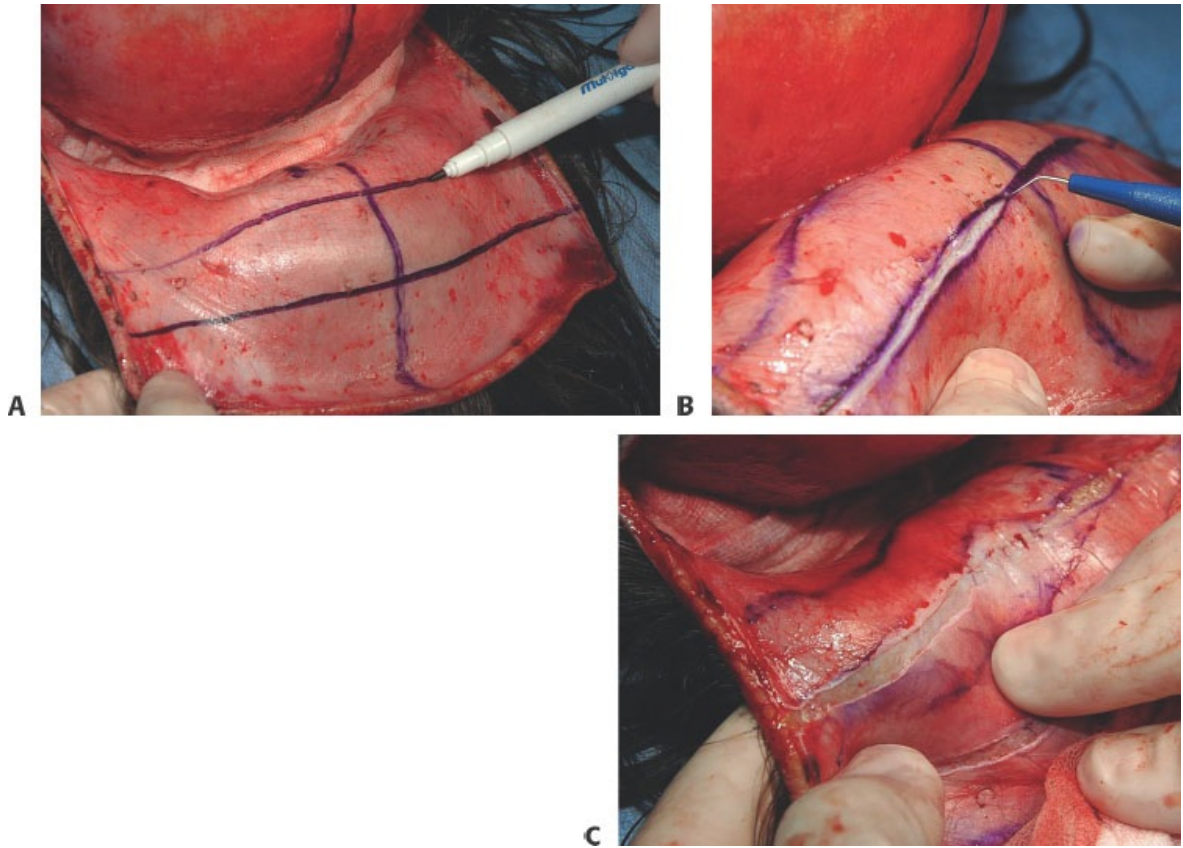
- The scalp is raised posteriorly in a subgaleal plane using a no. 10 blade with the aid of multipronged rake retractors (**TECH FIG 3A**).
- Digital dissection is then used to further dissect this flap posteriorly (**TECH FIG 3B**).
- The Iconoclast helps to elevate this flap in the subgaleal plane in the difficult to reach portion, as far posteriorly as the superior nuchal line (**TECH FIG 3C,D**).
- The scalp laterally and forehead anteriorly are undermined in the subgaleal plane to facilitate tension-free closure.
- A sponge is placed in the recess between the skull and the raised flap for hemostasis (**TECH FIG 3E**).
 - Subgaleal undermining continues for 2 to 3 cm lateral to the posterior extension incisions and 4 to 5 cm anterior to the anterior incision line.
- The midline of both the skull and galea of the scalp flap is marked with a marking pen to ensure symmetry when the flap is advanced later (**TECH FIG 3F**).
- Outer cortical converging bone tunnels are made in the anterior skull, 4 to 5 cm from the midline, to attach the scalp once it has been advanced (**TECH FIG 3G,H**).^{1,3,6}
 - Endotines or other fixation devices can be used if desired.^{4,5}



TECH FIG 3 • **A.** Initially the scalp is elevated in the subgaleal plane using a 10 blade with traction from rake retractors. **B.** Digital dissection in the subgaleal plane is used as the skull curves toward the neck. **C,D.** The Iconoclast is a spreading instrument used for subgaleal dissection posteriorly to the superior nuchal line. The instrument facilitates scalp flap elevation in the hard to reach posterior sections of the scalp. **E.** A sponge is placed in the scalp-skull recess to aid hemostasis. **F.** A marking pen is used to mark the midline of the skull and the scalp flap. This facilitates even and accurate scalp flap advancement. **G.** The periosteum of the scalp is elevated to expose the bone of the underlying skull, and markings for outer cortical bone holes are made on the anterior skull, equidistant from the midline. **H.** Converging external cortical bone holes are drilled.

■ Galeotomies

- To achieve further advancement, galeotomies are made in the anterior to midscalp using an angled ophthalmic blade (**TECH FIG 4A,B**).^{4,5}
- Galeotomies must be made superficial to the underlying scalp vessels to preserve the scalp blood supply (**TECH FIG 4C**).^{4,5}
- Four or five galeotomies may be made, each of which generally advances the scalp a further 2 to 3 mm. They are generally made 1.5 to 2 cm apart.³



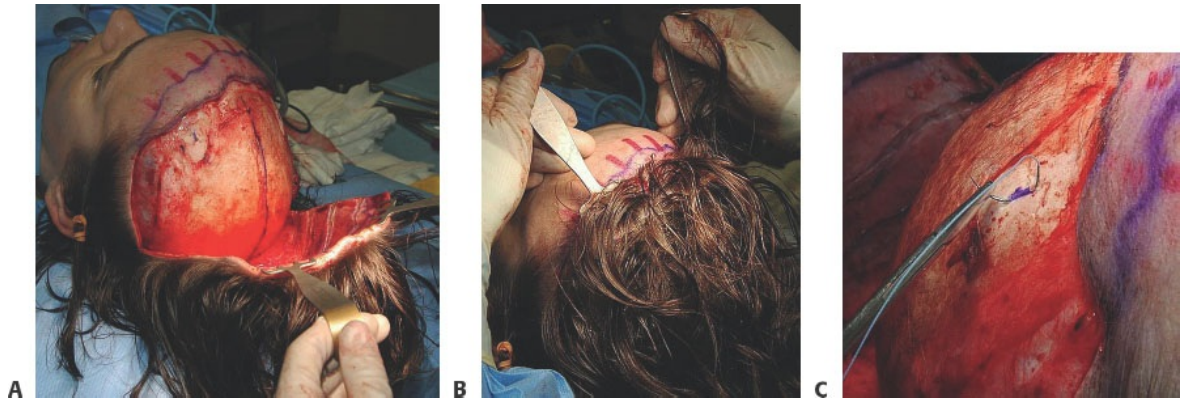
TECH FIG 4 • A. Markings are made for galeotomies, which allow further scalp advancement. **B.** An angulated fine ophthalmic blade is used to perform the galeotomies. Care is taken to avoid going too deep which could damage hair follicles and scalp blood supply. **C.** Stretching of the scalp separates the galeotomies, facilitating scalp lengthening and advancement.

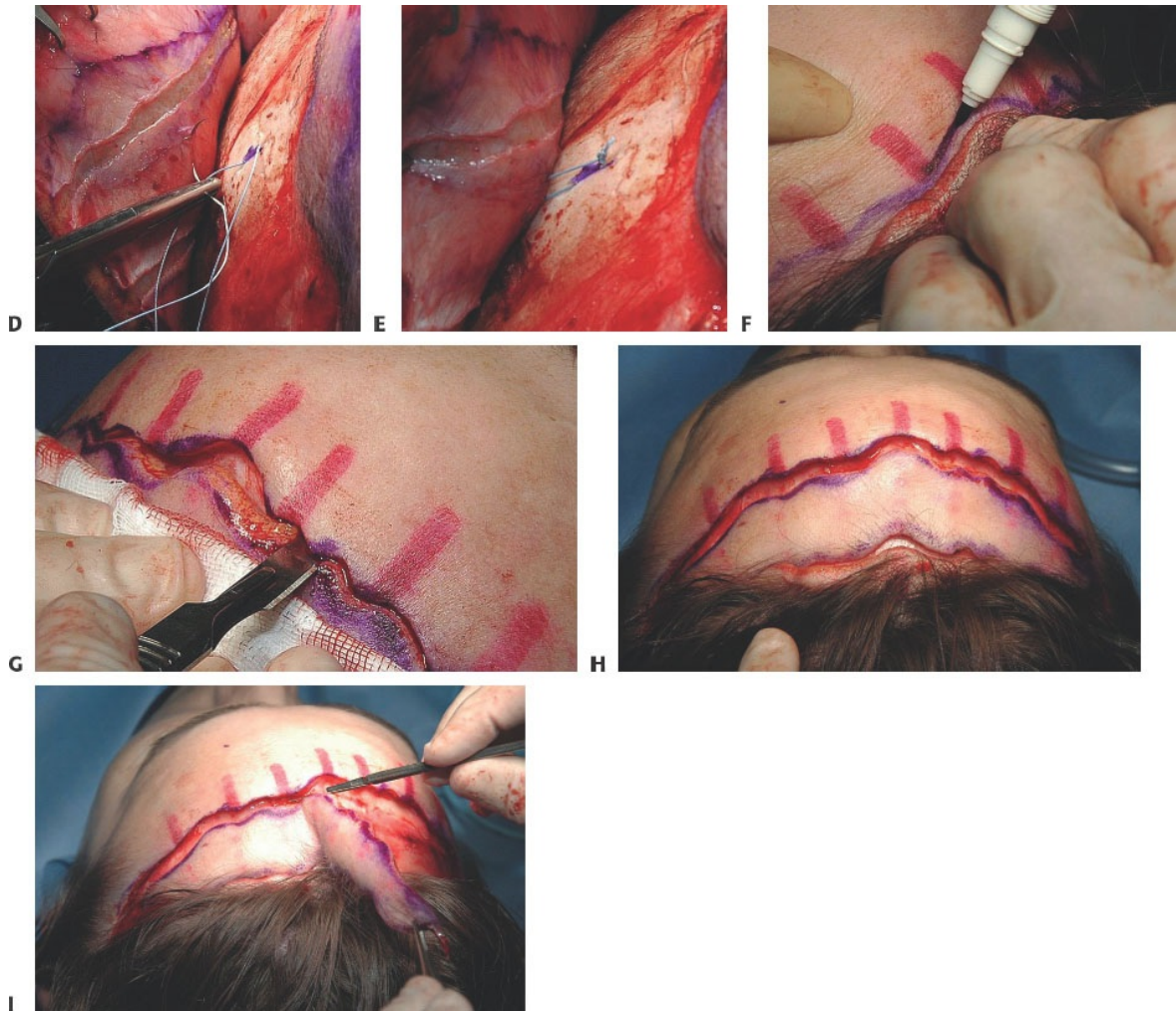
■ Scalp Advancement

- The sponge is removed, and the scalp is advanced (**TECH FIG 5A,B**).
- The scalp is maintained in the advanced position by a suture through the bone tunnels, attached gently to the galea (**TECH FIG 5C–E**).
- With the posterior scalp flap stabilized in the advanced position, excessive tension on the resulting incision closure is avoided.
- Adjustments may now be made in the markings of the proposed new hairline

(**TECH FIG 5F**).

- The new hairline is incised in a similar beveled fashion to the original incision (**TECH FIG 5G**).
 - This beveled incision allows the forehead skin to slightly overlap the advanced scalp.
 - This facilitates growth of some hairs from the denuded scalp follicles through the forehead skin anterior to the incision line.^{1,3,4,5}
- The hairless forehead skin is removed (**TECH FIG 5H,I**).





TECH FIG 5 • A,B. After the sponge is removed from the scalp-skull recess, rake retractors are used to advance the posteriorly based scalp flap. **C.** A suture is placed through the external cortical bone holes of the anterior skull. **D,E.** This suture attaches to the galea of the scalp flap and anchors the advanced scalp flap under limited tension. **F.** The proposed new hairline is checked against the leading edge of the advanced scalp flap. Any adjustments to the proposed hairline markings can be made at this time. **G.** The new hairline incision is made in a similarly beveled manner to the existing hairline incision. **H,I.** The ellipse of hairless forehead skin is removed.

■ Scalp Fixation and Wound Closure

- The remainder of the procedure requires accurate inset of the advanced scalp flap with dissolvable deep sutures (3-0 and 4-0 Monocryl). Tension is avoided (**TECH FIG 6A,C**).
- Interrupted or running 6-0 Prolene sutures are used anteriorly (**TECH FIG 6B**).
- Staples are used laterally (**TECH FIG 6D**).
- The patient's hair is washed with hydrogen peroxide and then saline or water (**TECH FIG 6E**).
- The hairline is covered with a light foam dressing, using a 10-cm conforming stretch bandage under minimal tension (**TECH FIG 6F**).



TECH FIG 6 • A. Dissolvable deep sutures under minimal tension are used to inset the advanced flap. **B.** The bevel used allows the denuded follicles of the scalp flap to slip deep to the hairless forehead skin. **C.** Interrupted or continuous Prolene sutures are used anteriorly. These will be removed between postoperative days 5 and 7.



PEARLS AND PITFALLS

Indications	■ Follicular unit grafts are better for deep temporal recession. ■ Cow licks (posterior exiting hairs) make incision camouflage more difficult. ■ A two-stage procedure utilizing a scalp tissue expander may be necessary for patients with tight scalps or very high hairlines or where the desired anterior hairline advancement is more than 3 cm.
Flap elevation	■ The Iconoclast is an instrument that allows subgaleal scalp elevation in the difficult to reach posterior scalp recesses.
Scalp advancement	■ A narrow central scalp flap is easier to advance than a broad flap of the whole frontal hairline. However, most female patients desire a rounded hairline without temporal hairline recession. ■ Broad flaps have a higher incidence of lateral incision line tension and minor incision line hair loss.
Scalp fixation	■ Outer cortical converging bone holes allow stabilization and fixation of the scalp flap in an anterior position. ■ Excessive tension must be avoided.
Wound closure	■ Dissolving deep sutures allow tension-free closure of the incision lines. ■ Overlap of the incision line denuded scalp follicles by hairless forehead skin is desired.

POSTOPERATIVE CARE

- The dressing is removed on postoperative day 1.
- Patients are able to shower and wash their hair from day 1 with warm water and a mild soap/shampoo.
- Patients are instructed not to blow-dry or brush their hair.
- Alternate staples and Prolene sutures may be removed at day 5 or 6.
- Remaining staples and Prolene sutures are removed on day 7 or 8.
- Most patients are back at work within a week or so.
- Patients are instructed to avoid the following:
 - Tasks that cause a Valsalva maneuver, such as heavy lifting or straining
 - Trips to the hairdresser/coloring hair for 6 weeks
 - Hot hairdryers/scalding hot showers

- Tight caps and constricting helmets

OUTCOMES

- Reliable hairline advancement with immediate results⁴
- Good alternative to hair grafting—mobilizes many thousand follicular units⁴

COMPLICATIONS

- Visible scars
- Hyperpigmented or hypopigmented scars
- Scalp numbness and dysesthesia
- Hair loss
 - Telogen effluvium (“stress” or “shock” hair loss)^{2,4,5}
 - Incision line alopecia (especially with broad scalp advancement)
 - Patchy scalp alopecia²⁻⁶
- Hairline aesthetic/shape issues
- Need for scar revision/need for hair grafts to finesse scars⁴
- Scalp necrosis⁵
- Future hair loss with progressive scar visibility

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Section VIII: Upper Blepharoplasty

26 Techniques for Upper CHAPTER Blepharoplasty

Steven M. Levine

DEFINITION

- Surgery is the standard treatment to address the aging upper eye.
- The aging upper eye can be broken down into excess skin and excess fat.

ANATOMY

- Relevant anatomy pertains to the layers of the upper eyelid: notably, the skin, the orbicularis oculi muscle, and the preaponeurotic fat (central fat pad and medial/nasal fat pad).
- The lacrimal gland is located laterally and deep to the preaponeurotic fat pad. This gland can become ptotic and be confused as redundant fat.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Beyond the usual history, to make sure a patient is an acceptable candidate for facial plastic surgery, certain physical findings should be noted.
- Ptosis should always be noted. Ptosis repair is not being addressed in this chapter.
- The eyes should be studied carefully to note the exact location of the excess or “hooded” skin.
- Ask for photographs of the patient when younger to note whether the upper lids were always “full.”
 - This will avoid hollowing out a patient who is used to having full lids.

- The lateral extent of the excess should be noted and care taken to include that tissue in the resection (even if it falls beyond the lateral orbital rim).
- The tarsal insertion should be marked to represent, approximately, the inferior aspect of the surgical excision.

SURGICAL MANAGEMENT

- Surgery should be performed in an accredited operating room.
- An upper blepharoplasty can be performed under local anesthesia with or without sedation or general anesthesia.

Preoperative Planning

- The author requires all patients to be seen by an ophthalmologist and have a Schirmer tear test preoperatively.
- Consideration should be given as to whether the surgeon believes the patient will require fat to be removed.
 - If the operation is “skin only,” it is easier to perform under local anesthesia.
- The patient should be marked while sitting upright.
- It is important to end the medial extent of resection prior to the medial canthus to avoid creation of a web.
- A “pinch test” should be performed on the estimated skin resection to ensure the surgery will not create a lagophthalmos.
- Use a ruler to ensure the markings are roughly equal on both sides.
 - Measure the distance from the lash line to the inferior aspect of resection and the distance from the lateral canthus to the lateral extent of the resection (**FIG 1**).
- The author rarely removes fat from the upper lid.
 - That said, the medial or nasal fat compartment is more commonly full and can benefit from fat removal.
- The globe is balloted to accentuate the excess fat, and a decision is made preoperatively as to where fat will be removed and how much.
 - Fat is not removed indiscriminately. The surgeon should know roughly how much fat he or she plans to excise.

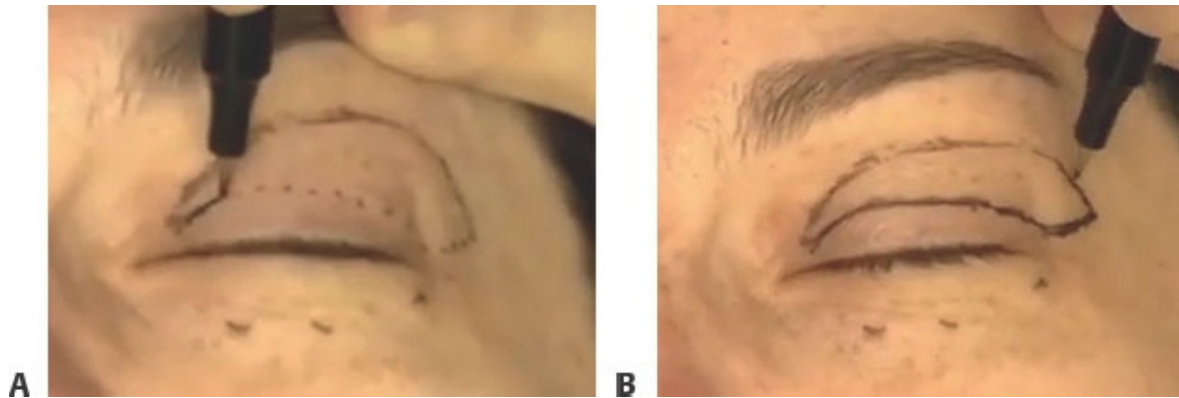


FIG 1 • A and B. The planned resection is marked in the standing position and then checked again on the operating table ensuring the accuracy of the markings.

- Discussion of scar placement, complications, and expected healing time should be reviewed with the patient.

Positioning

- The patient is supine on the procedure table.
- Usually, the head of bed is slightly elevated.
- The authors prefer to sit for maximum stability.

Approach

- Approach is dictated by the decision to remove skin, muscle, and/or fat.
 - If only fat is being removed, a small stab incision is made to access the fat. No further incision is required.
 - If skin is being removed, a small stab incision through the muscle and septum is made. The author does not favor an “open sky” technique.

TECHNIQUES

■ Upper Blepharoplasty

- After 1% lidocaine with epinephrine 1:100 000 is infiltrated into a predesigned excision pattern, at least 8 minutes is allowed to pass to allow for vasoconstriction (**TECH FIG 1A**).

- The skin is excised using a no. 15 blade and the muscle is kept intact (**TECH FIG 1B**).
- If fat is to be removed, the globe is balloted to accentuate the excess fat, and sharp scissors are used to penetrate the muscle septum. The fat is then exposed through the small stab incision.
- Care is taken to remove only fat considered excess. Often, this is the size of an eraser head. (Note: this is where the surgeon's personal aesthetic sense comes into play. The key is to know how much fat you intent to remove before you do so.)
- A Bovie electrocautery is use to obtain hemostasis (**TECH FIG 1C**).
- The skin is closed from medial to lateral with a running 5-0 subcuticular nylon (**TECH FIG 1D**).
- If necessary, the closure is reinforced with either running or interrupted 6-0 nylon on the skin.



TECH FIG 1 • **A.** Administration of local anesthesia. **B.** Skin excision. **C.** Meticulous hemostasis is essential. **D.** Closure.

PEARLS AND PITFALLS

Markings

- Mark the patient's tarsal crease preoperatively. This is more challenging when the patient is supine.

Lateral tissue removal

- Do not leave excess lateral tissue. There is often a fear of extending the upper blepharoplasty incision beyond the orbital rim; however, this scar heals very well. This is also the area where patients are likely to complain of residual excess.

Fat removal	■ Do not over-resect fat. A surgeon can adversely change a person's appearance by converting the person from an individual with full upper lids to one with hollow upper lids.
Maintaining symmetry	■ Measure both eye markings to ensure symmetry. Scars at different heights on the lid need to be avoided.
Eye exam	■ A preoperative ophthalmologist exam may seem overly cautious, but in the event of a problem, it is very useful to have a consultation performed prior to surgery.

POSTOPERATIVE CARE

- Steri-Strips are placed over the incisions.
- Cool packs are also used to reduce swelling.
- Strict blood pressure control is enforced postoperatively.
- Patients are instructed no lifting or bending for 2 weeks.
- At 48 hours, the medial end of the running suture is trimmed to below the level of the skin to prevent inclusion cyst formation.
- If skin sutures were used, they are removed within 4 days.
- The author prefers to keep the running subcuticular suture in for 7 to 9 days.
- All patients are seen by the surgeon 48 hours after surgery.

OUTCOMES

- An upper blepharoplasty is a highly reliable and predictable operation.
- Scars are usually well concealed (including the extent beyond the lateral orbital rim).

COMPLICATIONS

- Bruising and bleeding are the most common complications.
- The surgeon must be cognizant of the creation of a retrobulbar hematoma. This is exceedingly rare if fat is not removed.
- On occasion, a second surgery is required to trim excess skin, but this is favored over removing too much tissue.

27 Transpalpebral Corrugator Resection

CHAPTER

Ji H. Son, Ali Totonchi, and Bahman Guyuron

DEFINITION

- Glabellar frown lines develop as a result of the contraction of the corrugator supercilii muscles and thinning of the overlying skin.
- Resection of these muscles corrects the deep furrowing and is usually accomplished through upper blepharoplasty incisions.

ANATOMY

- Frontalis muscle: elevates the eyebrows and causes transverse wrinkling of the forehead. Its contraction provides a constant, cranially directed force vector on the eyebrows.
- Orbicularis oculi muscle: depresses the eyebrows. The two main portions of this muscle are orbital and palpebral.
- Corrugator supercilii muscle: thin, long, hexagon-shaped muscle located at the medial end of the eyebrow, deep to frontalis and orbicularis oculi muscles. Corrugators pass between the orbicularis oculi and insert into the deep surface of the forehead skin.
- Depressor supercilii: a thin muscle that extends from the medial canthus area to the subcutaneous plane above the eyebrows.
- Procerus muscle: pulls the glabella area skin caudally. The procerus originates from the caudal portion of the nasal bones and inserts into the dermis between the eyebrows, which makes it a major stabilizer of the eyebrows. Hyperactivity of this muscle causes transverse lines in the glabellar area and the nasal root.
- Supraorbital nerve: exits the supraorbital notch or foramen 2.7 cm from the midline and runs with an associated artery.
- Supratrochlear nerve: located 1.7 cm from the midline and 0.8 cm anterior to

the supraorbital nerve and runs with associated artery.

PATHOGENESIS

- Glabellar frown lines (vertical or oblique) develop due to the contraction/hyperactivity of the corrugator and depressor supercilii muscles and the thinning of the overlying skin.
- The overactive procerus muscle can result in horizontal lines in the radix area.

HISTORY

- Corrugator supercilii muscle resection is traditionally done using open or endoscopic forehead lift approaches. The senior author first introduced the transpalpebral approach in 1993.¹
- This chapter will focus on the transpalpebral resection only. Other techniques are discussed in different chapters in this textbook.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A comprehensive analysis of the face, hairline position, brow position and arch, forehead length, width, contour, soft tissue quality, and rhytids will aid in selection of the procedure that will best serve the patient.
- The upper face length is approximately one-third of the entire face.
 - Frontalis compensation is extremely common, and it is crucial to eliminate it for a more accurate judgment about the eyebrow position by asking the patient to smile or close the eyes tightly and then open them just enough to see the examiner, making every effort to avoid upward motion of the eyebrows.
 - The uncompensated position of the eyebrows is at the supraorbital rim in males and slightly above it in females, with its apex at the lateral limbus of the eye.
 - The evaluation of the forehead rhytids is recommended in repose, smiling, and frowning.
- The best candidates for transpalpebral corrugator resection are:
 - Patients who have proper lateral eyebrow position with hyperactive corrugator muscles²⁻⁴
 - Patients who are undergoing endoscopic forehead rejuvenation and blepharoplasty concomitantly
 - Patients with male pattern baldness, on whom incisions must be limited further laterally to avoid visible scars in the forehead area

- Patients with long foreheads, who would not wish to have a forehead shortening procedure
- Patients with proptosis and overactive glabellar muscle where elevation of the eyebrows needs to be avoided, which would otherwise expose the proptosis more and have an adverse effect on the patient's face
- Similarly, patients with eyelid ptosis who decline eyelid ptosis correction whereby elevation of the eyebrows would enhance the ill effects of existing ptosis on the periorbital congruity^{3,4}
- Patients with documented frontal migraine headaches without the temporal component⁵

IMAGING

- Imaging is not indicated for transpalpebral corrugator resection, unless there is a clear reason such as mass or lesion in the area or frontal migraine headaches with the retrobulbar component.

NONOPERATIVE MANAGEMENT

- Botulinum toxin A or fillers injection: These would be appropriate for temporary reduction of corrugator hyperactivity or contour deformity for those who are not ready to undergo surgery.⁶
- Fat injection: Limited indication for the patient with permanent and static wrinkles, where the results are long lasting but less predictable than injectable fillers. Fat injection is indicated on patients who are not ready to undergo more invasive procedures.

SURGICAL MANAGEMENT

- The main objective of transpalpebral corrugator resection is to resect the hyperactive corrugator and depressor supercilii muscles through the upper blepharoplasty incisions as thoroughly as possible to correct the deep furrowing lines in a lasting manner.

Preoperative Planning

- An AP photograph of the patient's forehead in repose and while frowning in a standardized fashion is recommended for analysis and postoperative comparison. Any asymmetry needs to be noted and discussed with the patient.
- General medical conditions including hypertension and hyperglycemia, as well as smoking cessation, are imperative to be addressed prior to surgery to minimize wound healing complications.

- Risks, benefits, and expectations need to be clearly discussed with the patient prior to surgery, with specific attention to risk of anesthesia, asymmetry, incomplete resolution of glabellar frown lines, and paresthesia in the supraorbital and supratrochlear regions.

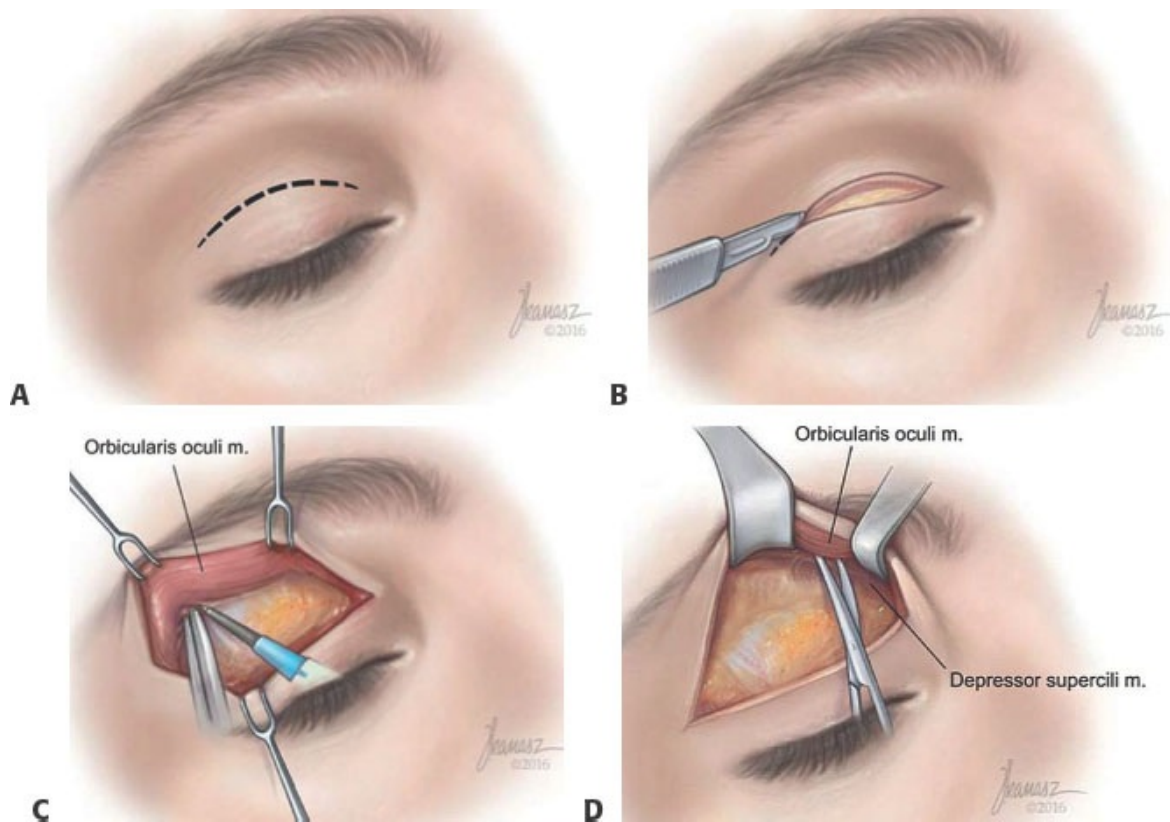
Approach

- The surgery can be done under general or monitored anesthesia care (MAC).
- After positioning the patient supine and prior to anesthesia, the supratarsal crease is marked as the incision line.
 - If a concomitant blepharoplasty is intended, the entire blepharoplasty incision is designed.
 - Otherwise, the medial half or third of a blepharoplasty incision is used.

TECHNIQUES

■ Incision and Dissection

- The upper eyelids and the lower forehead area as well as glabellar area are injected with mixture of 1% lidocaine with 1:100 000 epinephrine mixed with 0.5% of Naropin using a 30-gauge needle generously.
- Incision is made on the upper eyelid in supratarsal crease (**TECH FIG 1A**) and taken through the orbicularis muscle (**TECH FIG 1B**).
- Skin hooks are placed at the skin edges to retract the skin and orbicularis muscle cephalically.
- Dissection is started in the plane between the orbicularis muscle and the orbital septum while staying immediately under the orbicularis muscle and aiming toward the supraorbital rim. Initially, the dissection is done with a cautery for an extent of 5 to 10 mm (**TECH FIG 1C**) and is then continued using Metzenbaum scissors (**TECH FIG 1D**).



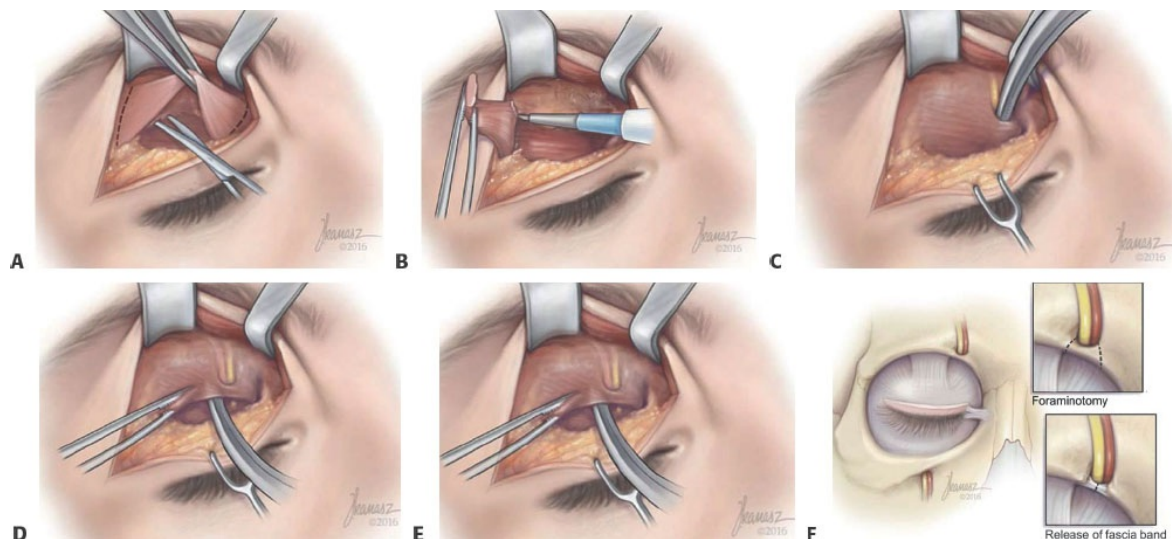
TECH FIG 1 • **A.** Upper eyelid incision using conventional blepharoplasty incision. **B.** Incision down to the orbicularis muscle. **C.** Dissection between the orbicularis muscle and the orbital septum. **D.** Continuation of dissection between the orbicularis muscle and the orbital septum until depressor supercili is visualized. (From Guyuron B. Transpalpebral corrugator resection: 25-year experience, refinements and additional indications. *Aesth Plast Surg.* 2017;41:339-345.)

■ Removal of the Corrugator and Depressor Supercilii Muscle

- After elevation of the skin and the orbicularis muscle, a thin layer of the depressor supercilli muscle overlying the darker and more friable corrugator supercilli muscle comes into view; it is dissected (**TECH FIG 2A**) and

removed (**TECH FIG 2B**).

- Upon removal of the depressor supercilii muscle, a branch of the supraorbital nerve piercing the corrugator supercilii muscle is identified and followed deep into the muscle using a mosquito hemostat (**TECH FIG 2C**).
- The supraorbital nerve is deeper and bigger than the supratrochlear nerve.
- The corrugator muscle is lifted to identify and protect the main nerve branches above the periosteum (**TECH FIG 2D**).
- The caudal portion of the muscle is isolated and removed first using coagulating cautery (**TECH FIG 2E**), followed by the cephalic segment.
- The remaining portion of a muscle is removed in a piecemeal fashion using the cautery as thoroughly as possible, including a lateral segment of the procerus muscle, the end point being the exposure of the fat in the subcutaneous plane.
- If the intention of the surgery is to treat frontal migraine headaches, the supratrochlear and supraorbital arteries are removed as well. If the nerve and vessels pass through a foramen, a foraminotomy is carried out using a 2-mm osteotome or a rongeur while protecting the orbital content (**TECH FIG 2F**).

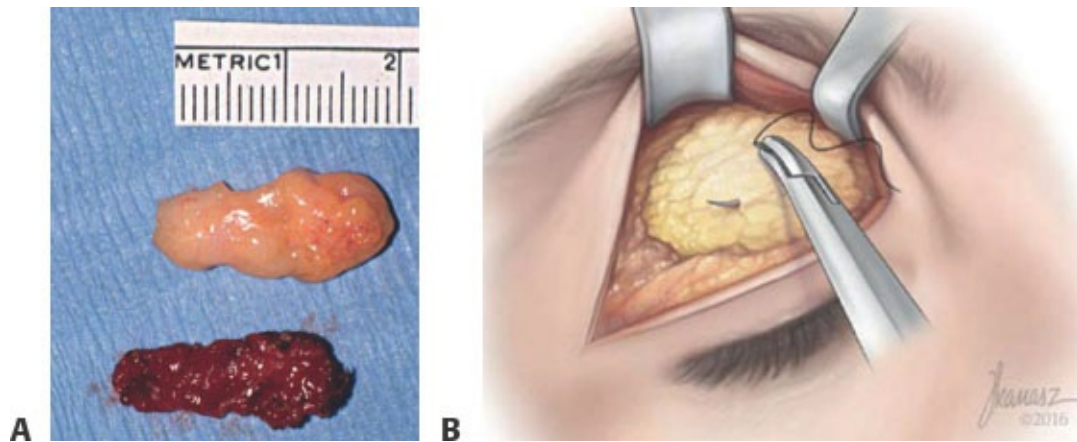


TECH FIG 2 • **A.** Corrugator supercilii is dissected. **B.** Corrugator supercilii is removed. **C.** Branch of the supraorbital nerve is identified and followed deep in the muscle using a hemostat. **D.** The same nerve branch is identified above the periosteum and protected. **E.** Corrugator supercilii caudal to the nerve

is lifted and removed using cautery, medially and then laterally. **F.** If the intention of the surgery is to treat frontal migraine headaches, the supratrochlear and supraorbital arteries are removed due to their roles in compressing the nerve, and if the nerve and vessels pass through a foramen, a foraminotomy is carried out. (From Guyuron B. Transpalpebral corrugator resection: 25-year experience, refinements and additional indications. *Aesth Plast Surg.* 2017;41:339-345.)

■ Fat Grafting and Closure

- The upper eyelid nasal (medial) fat pad is gently isolated and injected with small amount of lidocaine with 1:100 000 epinephrine and removed with cautery (**TECH FIG 3A**).
- For the patient without protruding medial fat pads, 1 to 2 cc of fat is harvested from the abdomen and injected in the area.
- Fat graft or injection will prevent the depression resulting from a thorough removal of the muscles, minimize the potential for the recurrence of the frown lines by avoiding the reattachment of the muscle to the skin, and rejuvenate the glabellar area by restoring the naturally lost volume because of aging.
- After fat harvest, it is flattened and placed in the corrugator site and fixed to the underlying periosteum using a 6-0 Vicryl suture to avoid any depression and to restore the lost glabellar volume to the site (**TECH FIG 3B**).
- The skin incision is closed using a 6-0 plain gut in a subcuticular fashion.



TECH FIG 3 • **A.** Isolated fat graft. **B.** The fat is flattened and placed in the corrugator site and fixed to the underlying periosteum using a 6-0 Vicryl suture. (From Guyuron B. Transpalpebral corrugator resection: 25-year experience, refinements and additional indications. *Aesth Plast Surg.* 2017;41:339-345.)

PEARLS AND PITFALLS

- Inadequate removal of the muscle will result in irregularities and flaws mostly during animation.
- Only the lateral fibers of the procerus muscle are removed because complete or almost complete removal of the procerus muscle can cause excessive elevation of the medial eyebrows, resulting in an aesthetically displeasing outcome.
- The depressor supercilii muscle is commonly mistaken for the corrugator muscle. The latter is darker, more pliable, and located deeper and medial to the former. The goal of the surgery is complete or near complete removal of the muscles between the orbicularis muscle/skin and the periosteum.
- Some patients with established skin wrinkles may require fat injection or graft to the central portion of the glabella and laser surfacing to obtain optimal results.

POSTOPERATIVE CARE

- Head elevation for the first few days along with the use of a cold compress

during the first 24 hours of surgery will help with edema and ecchymosis.

- Patients are instructed not to apply pressure on the glabellar area for a few days.
- Ophthalmic ointments help prevent dryness of the incisions, corneal abrasion, and exposure keratitis.

OUTCOMES

- Long-term satisfaction is usually very gratifying as long as the muscle is removed thoroughly (**FIG 1A,B**).



FIG 1 • Before (*left*) and 1 year after (*right*) transpalpebral corrugator resection. **A.** In repose. **B.** animated expression. (From Guyuron B. Transpalpebral corrugator resection: 25-year experience, refinements and additional indications. *Aesth Plast Surg.* 2017;41:339-345.)

COMPLICATIONS

- The most common complication of transpalpebral corrugator resection is anesthesia/paresthesia of the forehead, which is often temporary.
- Early recurrence of glabellar furrowing may occur if the corrugator muscle is not adequately resected or is not replaced with fat graft. If the fat graft is not secured in place, it can migrate caudally causing excessive upper eyelid fullness.
- Patients who undergo transpalpebral corrugator resection with blepharoplasty experience more ecchymosis, compared with those who have blepharoplasty alone.

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Technique for Ptosis Correction

CHAPTER

Ashley A. Campbell, Christopher C. Lo, and Richard D. Lisman

DEFINITION

- Blepharoptosis, or ptosis, is the abnormally low position of the upper eyelid in primary gaze. Ptosis is classified by its etiology as congenital, involutional, neurogenic, myogenic, and mechanical.

ANATOMY (FIG 1)

- In normal eyelid anatomy, the upper eyelid retractors are the levator muscle (innervated by cranial nerve III) and the Mueller muscle (innervated by the sympathetic system).
- The levator muscle extends from the lesser wing of the sphenoid just above the annulus of Zinn to Whitnall ligament; at this point, it transitions to become the levator aponeurosis.
- The lid height is determined by the attachment of fine strands from the levator aponeurosis to the pretarsal skin and orbicularis muscle.
- The upper eyelid fold is subsequently created by the overhanging skin, fat, and orbicularis muscle superior to the crease.
- Mueller muscle originates from the undersurface of the levator aponeurosis to the superior tarsal margin. It provides about 2 mm of elevation to the upper lid.
- The upper eyelid tarsus is a dense plate of connective tissue that acts as structural support to the eyelids. It measures 10 to 12 mm in the vertical dimension.

PATHOGENESIS

- The most common type of ptosis is involutional (also referred to as aponeurotic).

- This occurs gradually with age and is thought to be related to dehiscence of the levator from its attachment to tarsus.
- Involutional ptosis may be related to contact lens use, prior eye or periocular surgery, eye rubbing, and chronic ocular allergy. These all produce a levator dehiscence.

NATURAL HISTORY

- Involutional ptosis typically presents as a gradual decrease in lid height over time.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient's primary complaint is often eyelid height or crease asymmetry and/or a gradual decrease in the size of the palpebral aperture.
- This often produces the complaint of a tired appearance in patients presenting for aesthetic correction.
- Visual symptoms include superior visual field loss and even central loss of vision in severe cases.
- This often presents with highly elevated/arched eyebrows with deep frontalis contraction in an involuntary attempt to open each aperture. Less commonly, the patient may present with a chin-up posture in an involuntary attempt to look out from under the resultant "canopy effect." If long standing, neck pain or postural problems can result.

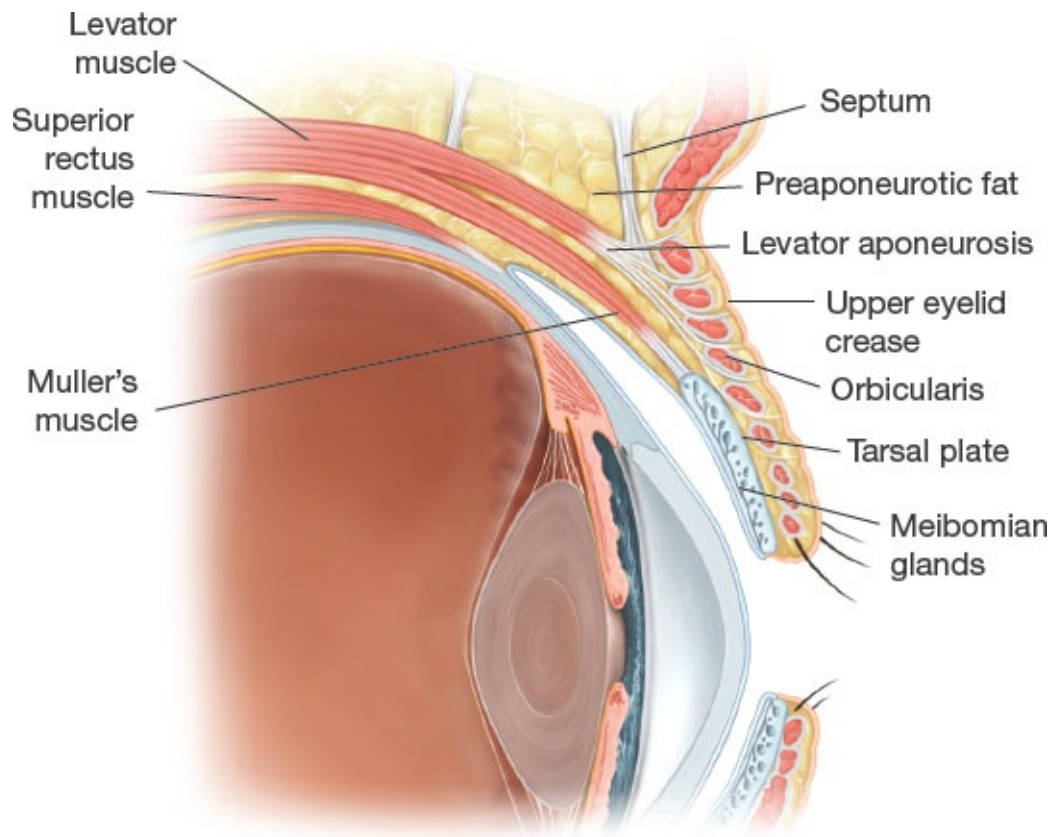


FIG 1 • Normal anatomy of the upper eyelids.



FIG 2 • Marginal reflex distance is measured from the central corneal light reflex to the upper eyelid while the patient sustains a neutral gaze in primary position.

- Pertinent questions to ask in the patient's history include onset of ptosis, a history of trauma, a history of contact lens wear, prior surgery or botulinum toxin injections, fluctuations in the eyelid height, diplopia, and any associated systemic manifestations.

- Ocular history, especially including the history of dry eyes, should be obtained.
- Old photographs are useful in determining onset and degree of prior ptosis.
- Important aspects of the physical examination include the following:
 - Margin reflex distance (MRD): measured from the central corneal light reflex (usually the center of the pupil) to the upper eyelid margin. Normal measurement is 3 to 4 mm. In ptosis patients, this is reduced (**FIG 2**).
 - Palpebral fissure (PF): measured from the lower to upper eyelid margin in the midpupillary axis. Normal measurement is 8 to 10 mm. In ptosis patients, this is reduced.
 - Levator function (LF): measures the upper eyelid excursion from extreme downgaze to extreme upgaze while the brow is neutralized (**FIG 3**). This is critical in determining what ptosis repair technique is most appropriate. Normal measurement is 14 to 16 mm, and a value less than 5 mm indicates that either congenital blepharoptosis or acquired neurogenic etiologies need to be investigated prior to ptosis correction.
 - Lid crease height (LC): should evaluate shape and height. In the case of involutional ptosis, the LC is often elevated as the levator muscle is disinserted from its attachment to the tarsus.
 - Bell phenomenon: the involuntary upward movement of the eye on lid closure. This needs to be assessed to determine the degree of corneal exposure should there be any lagophthalmos postoperatively.
- In asymmetric ptosis, Hering law should be evaluated by mechanically lifting one ptotic eyelid and observing the contralateral eyelid positional change.
- Pupillary examination should be performed to assess symmetry and reactivity in light and dark to rule out a Horner syndrome.
- Humphrey visual field testing performed with and without taping of the upper eyelid can be performed to demonstrate a superior visual field defect that is often present in patients with severe ptosis.

IMAGING

- Imaging is not typically required in the ptosis workup, unless there is any indication of a myogenic or neurologic etiology for ptosis.
- If the patient describes any variation in the amount of ptosis throughout the day or any double vision, a myogenic cause of ptosis (such as myasthenia gravis, chronic progressive external ophthalmoplegia, and myotonic dystrophy) should be considered. In this case, a referral to neuro-ophthalmology for

further lab testing is indicated.

- If there is any evidence of unilateral ptosis in the context of a meiotic pupil (suggesting a Horner syndrome) or abnormal eye movements (suggesting a cranial nerve III palsy), a referral to neuro-ophthalmology for further workup is also indicated.

DIFFERENTIAL DIAGNOSIS

- Congenital ptosis
- Myogenic
 - Myasthenia gravis
 - Chronic progressive external ophthalmoplegia
 - Myotonic dystrophy
- Neurogenic
 - Horner syndrome
 - Cranial nerve III palsy
- Mechanical
 - Traumatic
 - Dermatochalasis/blepharochalasis

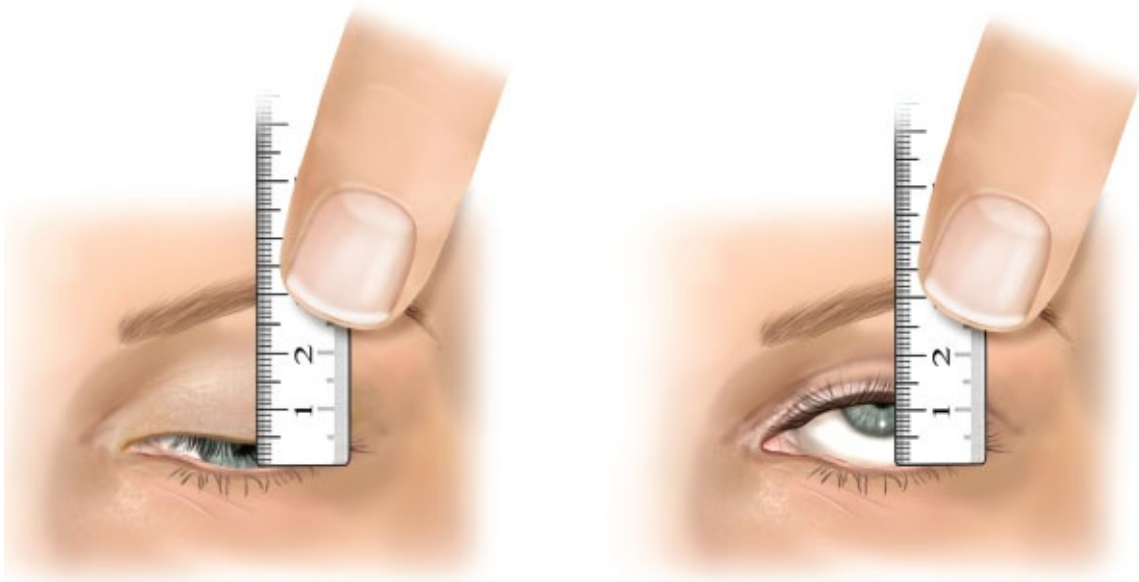


FIG 3 • To clinically evaluate levator function, measure the upper eyelid excursion in millimeters from extreme downgaze to upgaze with the brow relaxed or

neutralized by the examiner's hand.

SURGICAL MANAGEMENT

- Many operative techniques have been described for the correction of involutional ptosis associated with moderate or good levator function. These include levator reinsertion, mullerectomy, and the Fasanella-Servat procedure.
- Here, we describe the modified Fasanella-Servat procedure, which is our procedure of choice out of many for aesthetic patients who obviously demand the most symmetry and have a good tear film and tear production. It is also possible to perform this ptosis correction in conjunction with other aesthetic procedures, and it does not require the patient's cooperation.

Preoperative Planning

- Prior to surgery, a careful ophthalmic examination should be performed particularly to assess for any evidence of dry eye disease, as there is a risk of increased early postoperative dry eye.
- If there is evidence of dry eye, history of laser in situ keratomileusis (LASIK), or a poor Bell phenomenon, a conservative ptosis correction should be considered. This is usually a conservative levator reattachment procedure.
- If there is asymmetric ptosis, Hering law of central and equal innervation to the levator muscles should be considered, as unilateral ptosis correction on the more ptotic-appearing side could then unmask ptosis on the normal-appearing eyelid.

Positioning

- A typical blepharoplasty incision site is marked in the preoperative holding area with the patient seated or in a semireclined position.
- Upon arrival to the operating room, the patient is placed in the supine position, and either monitored sedation or general anesthesia is used.
- Tetracaine ophthalmic drops are placed in each eye.
- Protective corneal shields covered with ophthalmic ointment are placed over both eyes.
- 2% lidocaine with 1:100 000 epinephrine is injected into both upper eyelids to achieve local anesthesia.

Approach

- The various approaches to consider in mild-moderate ptosis repair include levator reinsertion, mullerectomy, and the modified Fasanella-Servat. In this text, the modified Fasanella-Servat procedure will be further elaborated.

TECHNIQUES

■ Modified Fasanella-Servat Procedure

- A no. 15 blade is used to incise the skin in the previously made blepharoplasty mark.
- The skin and orbicular oculi muscle are removed with curved Steven scissors.
- Hemostasis is obtained with unipolar cautery and epinephrine-soaked pledgets.
- The orbital septum is incised along the extent of the incision.
- Any excess central or medial fat is judiciously resected with the Colorado needle tip.
- The orbicularis muscle is contoured with the same device.
- Two symmetrically sized and shaped curved hemostat clamps are chosen for the tarsoconjunctival resection. The pair should be matched with care, as these will ultimately create the eyelid contour (**TECH FIG 1A,B**).
- The upper eyelid is everted, and a small (2 mm), medium (4 mm), or large (6 mm) tarsoconjunctival resection is delineated with the clamps. It is anticipated that 1 mm of lift is achieved with a small resection, 2 mm for a medium resection, and 3 mm for a large resection.
- The clamps are placed so that the largest resection occurs over the medial aspect of the pupil in primary gaze.
- At least 4 mm of residual tarsus and conjunctiva on the upper eyelid is required to avoid lid destabilization and potential entropion.
- A 5-0 nylon suture on a P-3 needle is loaded backhand and passed from inside the upper eyelid wound centrally and directed laterally to exit at the posterior aspect of the clamp (**TECH FIG 1C**).
- The suture is passed in a running, buried fashion, just posterior to the clamps, medially to laterally (**TECH FIG 1D,E**). It is important that each suture pass begins in the previous suture hole, thereby burying the suture. If

exposure of the suture occurs, the patient will experience foreign body sensation and may develop a corneal abrasion or ulcer.



TECH FIG 1 • A. Symmetrically sized and shaped hemostat clamps with a smooth contour will result in a smooth upper eyelid contour. **B.** Poor clamp selection and positioning may result in eyelid peaking and contour abnormalities. **C.** A 5-0 nylon placed on a P-3 needle loaded backhand is passed from inside the upper eyelid wound centrally and directed laterally to exit at the posterior aspect of the clamp. **D,E.** The running 5-0 nylon suture is passed posterior to the hemostat clamps medially to laterally in a buried fashion. **F.** A tarsoconjunctival resection is performed

with a no. 15 blade using the clamps as a guide to ensure a smooth contour. **G**. The ends of the 5-0 nylon suture are tied with multiple knots and left long for easy retrieval postoperatively. This suture is externalized through the upper eyelid blepharoplasty wound.

- The tarsoconjunctival resection is performed with a no. 15 blade using the clamps as a guide, ensuring a smooth contour (**TECH FIG 1F**).
- The lateral clamp is removed, and the suture is passed from the posterior aspect of the eyelid to exit in the upper eyelid wound just adjacent to the opposite arm of the suture. The medial clamp is then removed. Careful attention is given to ensure that the needle with its first and last pass traverse the entire eyelid thickness and pass through the levator as the procedure actually reattaches a levator disinsertion to a foreshortened tarsus. The release of the clamp adhesions with separation allows for later readjustment, if needed, just prior to the dense scarring after postoperative days 8 to 10.
- The suture is tied with multiple knots and left long for easy retrieval at the time of suture removal. This suture is externalized through the upper eyelid wound (**TECH FIG G**).
- The contour of the upper eyelid should be smooth at this point. The eyelid height, however, should not be evaluated.
- The upper eyelid wound can be closed using whatever technique the surgeon prefers, as long as the 5-0 nylon Fasanella-Servat suture is externalized.

PEARLS AND PITFALLS

Curved clamp selection

- Make sure each curved clamp is symmetric given that the curve of the clamp will ultimately determine the curvature of the eyelid.
- Choice of two asymmetric clamps may result in significant lid peaking and contour abnormality.

Closure

- Ensure that the knot is externalized through the blepharoplasty incision to facilitate suture removal at postoperative week 1.

Burying the

- Failure to bury the suture through the previous suture hole when

suture

running nylon suture through the palpebral conjunctiva can result in foreign body sensation and a corneal abrasion.

- If a corneal abrasion should develop, it is recommended to place a bandage contact lens until the suture is removed.
- The antibiotic/steroid drop should be changed to an antibiotic drop alone if a bandage contact lens is placed.

Postoperative adjustment

- At postoperative days 5 to 7, an adjustment can be made in the office if there is eyelid peaking, overcorrection on the surgical site, or undercorrection on the opposite side. This involves gentle downward tugging in the desired area of adjustment from the lashes or eyelid margin.

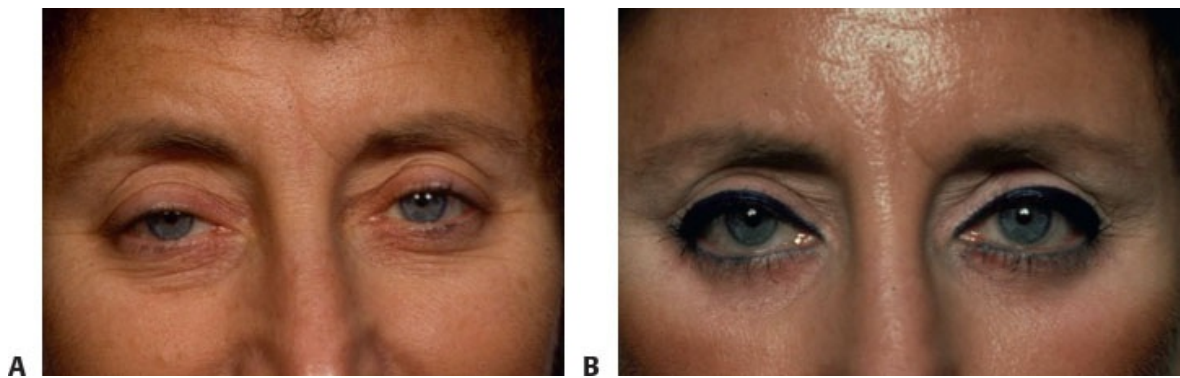


FIG 4 • Female with moderate, asymmetric, right-worse-than-left involutional ptosis, and dermatochalasis. **A.** Preoperative photos. **B.** A 2-month status post bilateral modified Fasanella-Servat procedure and quad blepharoplasty with symmetric eyelid height and contour.

POSTOPERATIVE CARE

- Postoperatively, a topical antibiotic/steroid eye drop is recommended four times a day for 1 week.
- For the first 72 hours postoperatively, patients should sleep with their head elevated and apply cold compresses.
- Patients should be instructed to avoid heavy lifting, bending, and straining for at least 2 weeks after surgery.
- If the patient should develop any foreign body sensation or evidence of a corneal abrasion, this could mean exposure of the nylon suture along the

palpebral conjunctiva. This can be managed with placement of a bandage contact lens, which is removed at the time of suture removal. At this point, the antibiotic/steroid drop should be changed to an antibiotic drop alone.

- At postoperative week 1, the Fasanella suture can be removed. At this time, adjustments can be made as necessary (**FIG 4**).

OUTCOMES

- The Fasanella-Servat procedure is unique in that subtle correction of lid contour and height asymmetries can be made in the early postoperative period. Given that tarsus does not adhere until postoperative day 8 or 9, early adhesions can be broken around postoperative days 5 to 7 at the time of suture removal (**FIG 5**).
- Indications for adjustment include eyelid peaking, overcorrection on the surgical side, or undercorrection on the opposite side (**FIG 6**).
- Adjustment requires a gentle downward tugging in the desired area from the lashes or lid margins (**FIG 7**). Use of a cotton-tipped applicator to apply pressure at the superior border of the tarsus separates early tarsal adhesions. Local anesthesia or sedation is not needed.
- In the case of bilateral surgery, readjustment is aimed at lowering the higher lid given that the lower eyelid will secondarily elevate due to the phenomenon of Hering law.

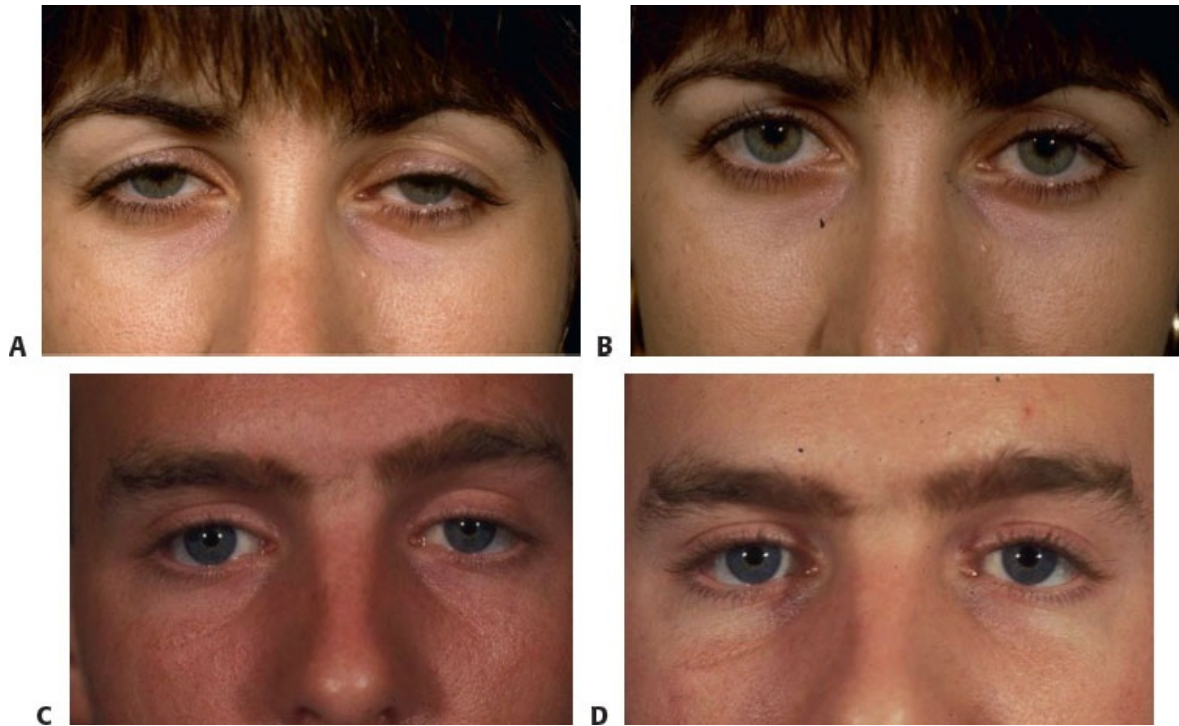


FIG 5 • A. Preoperative photo of a young female with bilateral upper eyelid aponeurotic ptosis. **B.** Two months after bilateral upper eyelid modified Fasanella-Servat procedure showing improved MRD, symmetry, and contour restoring a youthful appearance. **C.** Preoperative photo of a male with unilateral aponeurotic ptosis and compensatory left brow elevation. **D.** Postoperative photo 2 months after left modified Fasanella-Servat surgery with deviation of the left upper eyelid. Left brow drop further contributes to overall symmetry and balance of periorbital features.

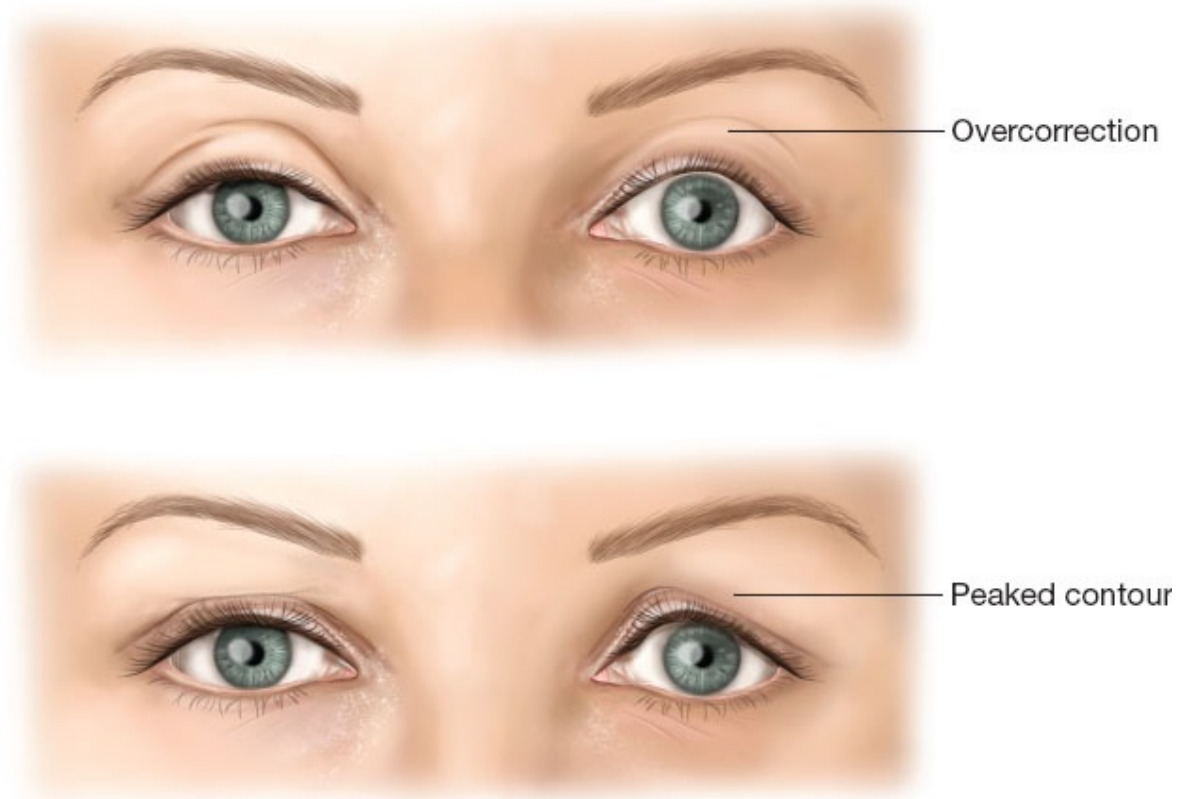


FIG 6 • Aberrant contour and eyelid height are complications of all methods of eyelid ptosis repair. With the modified Fasanella-Servat procedure, these pitfalls can be easily reversed with postoperative in-office adjustments.

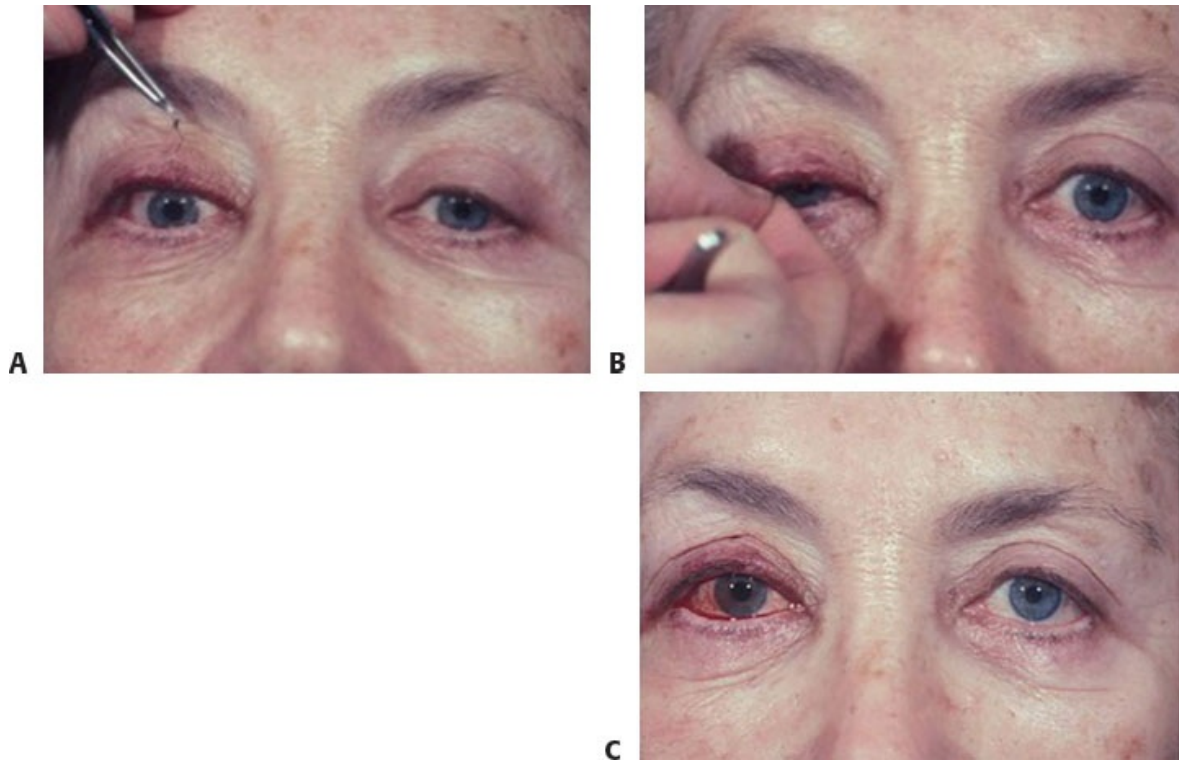


FIG 7 • A. A. Postoperative adjustments can be performed prior to tarsal adhesion 5 to 7 days postoperatively when sutures are removed and edema subsides. **B.** Adjustments entail a gentle downward tugging in the desired area from the lashes or lid margins. **C.** It is common to see some blood in the tear film after a successful adjustment.

- In general, approximately 20% of patients require a small postoperative adjustment. Once adjusted, nearly 100% of patients can attain a satisfactory result.¹
- Final lid height is determined at about 14 to 21 days postoperatively or when all the edema has fully cleared.
- Although it is rare to need a reoperation, if an additional surgery is necessary, it is recommended to wait at least 3 months postoperatively.²

COMPLICATIONS

- Foreign body sensation or a corneal abrasion can occur immediately postoperatively if there is exposure of the nylon suture through the palpebral

conjunctiva. This can be addressed by placement of a bandage contact lens that is kept in place until suture removal at postoperative days 5 to 7.

- Dry eye is a known complication after any ptosis surgery, especially if dry eye is a pre-existing condition. This can be treated with increased lubrication including antibiotic acutely and artificial tears chronically.
- Asymmetry between lids is a risk factor in ptosis surgery. In the Fasanella-Servat procedure, mild asymmetry can be consistently corrected postoperatively with a minor in-office adjustment (**FIG 7**).

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29 Technique for Ptosis Correction

CHAPTER

Nuri A. Celik

DEFINITION

- There have been many procedures advocated for the treatment of the upper eyelid ptosis. Some of the techniques in the literature use incisional/excisional methods to deal with the levator mechanism failures.¹
- The technique described in this chapter relies solely on the preservation of the anatomical integrity of the levator system that is either stretched or detached because of various reasons. The key to using this technique is the presence of a good levator function. This is easily calculated by measuring the excursion of the upper eyelid during extreme upper and downward gaze (**FIG 1**).
- Practically, any measurement above 10 mm is proper to use this technique efficiently. Iatrogenic or senile levator detachment patients are a different group, because they present with decreased levator function; however, in most cases, the system is intact to perform this type of correction. Fatty degeneration of the levator muscle is also a possibility with aging.

ANATOMY

- The upper eyelid is a complex structure that consists of multiple tissue layers that seem to adhere to each other around the upper anterior tarsal surface. When the skin and muscle layers are incised and a skin muscle flap is elevated as a superiorly based flap, one notices a thin layer of adipose tissue on top of the upper orbital septum that is more defined medially and somewhat less laterally (**FIG 2**). The increased convexity of the globe is possibly responsible from this uneven distribution of the fat layer. The underlying septum should always be incised laterally and higher than the upper tarsal border in order not to injure the levator mechanism inadvertently. There usually is a

preaponeurotic fat pad present, if not previously excised or developmentally absent. Under the fat pad, toward the upper orbital rim, one can find the vertically oriented fibers of the levator muscle. The surgeon should always keep in mind that immediately under the levator aponeurosis, there is the vertically oriented arterial loop of the supratarsal arch that might resemble the fibers of the levator muscle, for untrained eyes, that might be difficult to differentiate.

PATHOGENESIS

- Periorbital aging is a very complex phenomenon. Twelve percent of the patients in Dr. Lambros' series had upper eyelid ptosis; however, there is no reference to frontalis activity in his patient population.² Increased frontal muscle activity is a common finding in the elderly population and usually is a compensation for a ptotic upper eyelid. The original percentages of upper eyelid ptosis should be higher in the aging population due to the weakening of the levator attachments or stretching of the aponeurosis.

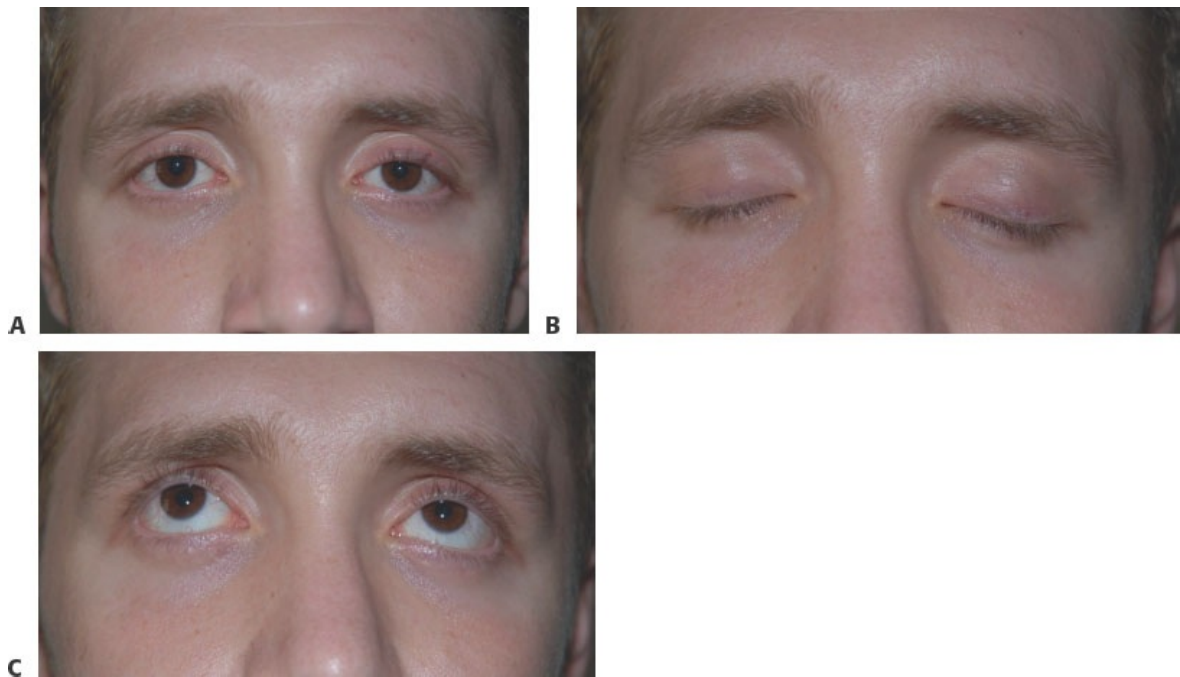


FIG 1 • This young patient presents with bilateral ptotic upper eyelids. **A.** He has empty upper sulci and an increased supratarsal fold distance. **B,C.** The upper eyelid excursion during the upper and lower gazes is 12

mm, and he has good levator function.

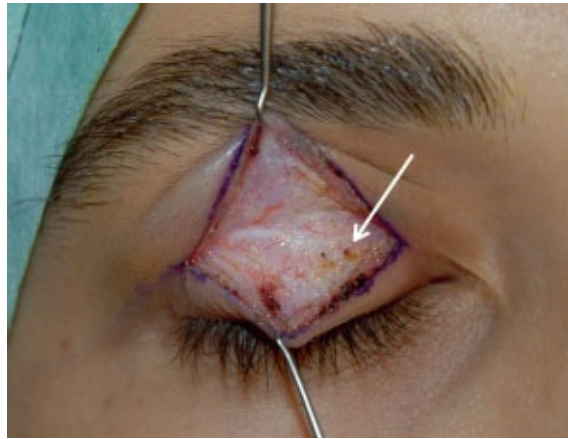


FIG 2 • Skin muscle flap elevated following upper blepharoplasty incision. There is a thin layer of adipose tissue medially and less laterally. This fatty layer is a landmark to be able to distinguish the upper orbital septum.

- There are still some centers that use incisional and excisional surgical methods on the levator mechanism. It is very important not to distort the anatomy of the levator system.
- The most frequent complications happen with resection of the levator aponeurosis, because failure of the suture correction results in recurrence of ptosis and loss of levator function (**FIG 3**).
- Another possible mechanism is inadvertent surgical damage to the aponeurosis (**FIG 4**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- In younger patients, when present, ptosis is a significant complaint because a higher upper eyelid arch is the norm in early decades of life.
- In severe cases, there might be significant visual field obstruction (**FIGS 5 and 6**).
- Asymmetric cases are easily diagnosed.
- In senile ptosis, most of the time, the patient is not aware of the problem if it is bilateral. Senile ptosis takes a long time to advance, and by that time, compensatory mechanisms such as frontalis hyperactivity develop (**FIG 7**).



FIG 3 • This 28-year-old patient underwent two unsuccessful left ptosis repair attempts in the previous 2 years. The second surgery consisted of resection and shortening of the levator aponeurosis. The ptosis recurred a week after surgery. He has the typical symptoms of levator detachment with an increased supratarsal distance, upper eyelid ptosis, and slight elevation of the left eyebrow. The loss of the levator aponeurosis contribution to the lateral canthus resulted in relaxation of the lower eyelid on the left side causing a scleral show and distortion of the proper cant of the eye. Even the vertical orientation of the eyelashes is affected due to loss of the levator aponeurosis pull on the skin.

- An occasional patient might complain about transverse wrinkles as a result of the long-standing frontalis muscle contraction.
- The anatomy of the brow-upper eyelid interface changes in ptosis patients. If there is no skin excess to camouflage the superior sulcus, this area appears hollow (**FIG 8**). The supratarsal crease-eyelash margin distance is increased, and the upper eyelid covers more than 2 mm of the upper limbus. In elderly cases, brow ptosis and skin excess disguise the deformity, and supratarsal crease might appear to be of proper dimension. In these cases, elevating the eyebrows will reveal the underlying pathology (**FIG 9**). A meticulous preoperative assessment and planning ensure symmetric eyelid levels and

supratarsal crease distances.³ The superior sulcus fullness should also be evaluated separately on both sides, and upper eyelid fat manipulation should be taken into account in order to achieve a satisfactory outcome (**FIG 10**).

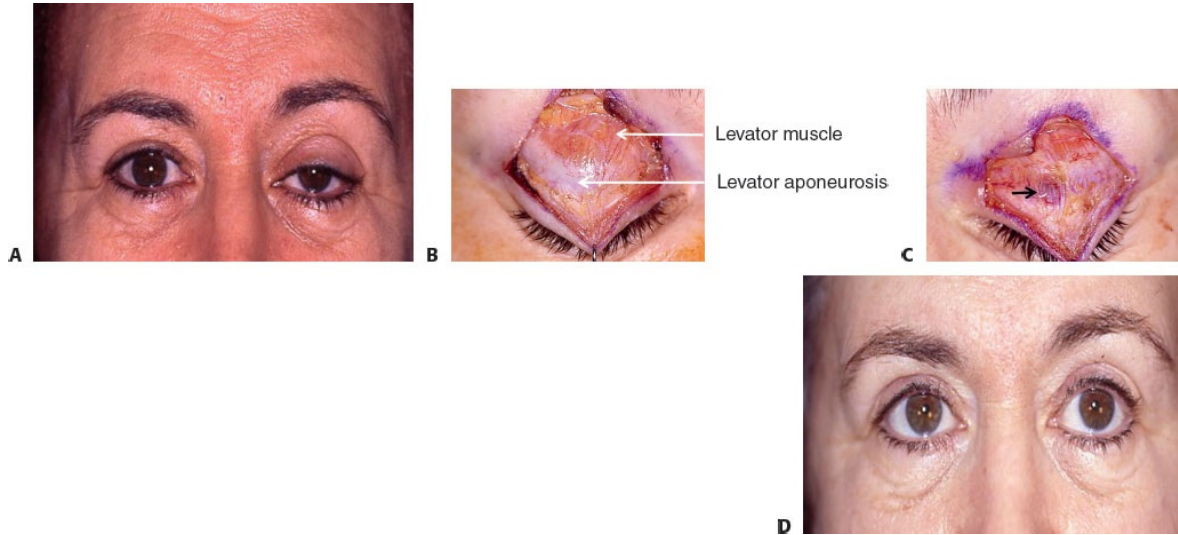


FIG 4 • A. A 64-year-old patient seen following a cyst removal from the left upper eyelid. She has left frontalis muscle hyperactivity due to left eyelid ptosis, an increased supratarsal distance. **B.** Intraoperative findings of the patient. The upper orbital septum is opened, and the preaponeurotic fat pad is retracted to expose the levator system. The right upper eyelid shows a normal anatomy of levator muscle and mechanism. **C.** The left upper eyelid levator aponeurosis has a significant injury medially, which possibly caused complete detachment of the system resulting in upper eyelid ptosis. **D.** One year after treatment with a levator advancement technique, she had bilateral blepharoplasty to equalize the supratarsal fold and correct the left ptosis. However, the frontalis muscle hyperactivity is not completely resolved.



FIG 5 • A. A 52-year-old male patient with asymmetric ptosis—right side more droopy than the left. He has more frontalis muscle compensation on the right side due to obliteration of the pupil. The laxity of the lateral canthal tendon and the scleral show are possible signs for the levator system detachment from its insertion on the tarsus. The ptotic brows mask the supratarsal fold deformity. **B,C.** The patient demonstrates good levator muscle function that makes him an excellent candidate for levator advancement correction.



FIG 6 • A 39-year-old patient with unilateral right ptosis and the lack of frontalis muscle compensation. The superior orbital sulcus fat volume is significantly decreased. The left upper eyelid fat and excess skin are camouflaging the real location of the supratarsal fold. In these patients, skin excision should always be accompanied with upper sulcus fat grafting.



FIG 7 • A 73-year-old female patient with a long-standing upper eyelid ptosis due to complete detachment of the levator aponeurosis from the upper tarsus attachments. She has bilateral frontalis muscle hyperactivity. Even this compensation has failed; she has to hold her upper eyelids with her fingers in a higher position to be able to see properly. The detached edge of the levator mechanism is still pulling the skin forming an unusually high supratarsal fold (*arrows*).

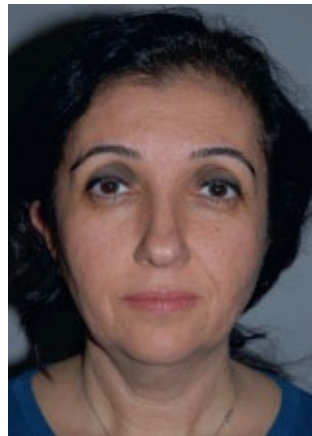


FIG 8 • A 49-year-old female with unusually high supratarsal fold distance. She almost has no preaponeurotic fat to fill the upper sulcus. Notice that the upper orbital rim is clearly visible throughout its course. The medial two-thirds of the brow is elevated to

compensate for the upper lid ptosis.

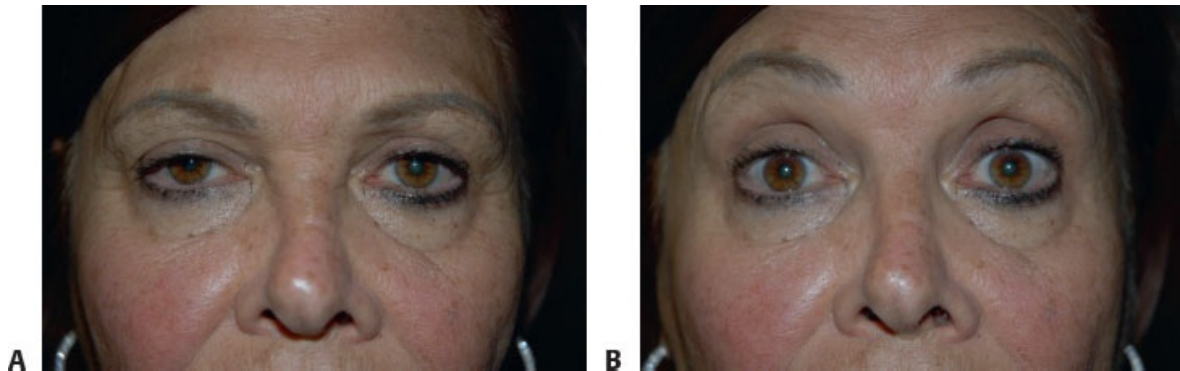


FIG 9 • A. A 60-year-old female presents with asymmetric upper eyelid levels and levator function. The supratarsal fold height is surprisingly symmetric due to the presence of excess upper eyelid skin. Brow ptosis masks the levator-upper tarsal border interface. **B.** When the patient is asked to elevate the brows, the deformity becomes visible. She has almost no upper eyelid fat, and the levator is detached, pulling the skin at a much higher level than normal. The normal level of the supratarsal folds is completely deceiving. Skin resection type of upper blepharoplasty will give her a sunken eye appearance.



FIG 10 • A,B. A 39-year-old patient who had Fasanella-Servat procedure for the treatment of her ptosis. She also had resection of her upper eyelid medial fat pads through a stab incision. She still has compensatory frontalis muscle hyperactivity and residual ptosis. Notice the high skin attachment of the levator system, more on the left. Upper orbital sulcus appears relatively empty.

- The unilateral ptosis cases are more difficult to assess preoperatively (**FIG 11**). The ptotic upper eyelid should be elevated to a normal position with the finger, and the contralateral side should be watched carefully. If the normal upper eyelid level drops as a result of this maneuver, this is a sure sign of an occult ptosis. In this case, the surgical approach should involve both upper eyelids to achieve symmetry postoperatively.

IMAGING

- The assessment of the levator function is of utmost importance in surgical candidates. The measurement of the upper eyelid excursion between extreme upward and downward gaze gives the levator function, and a measurement above 10 mm guarantees successful outcomes with levator advancement technique.

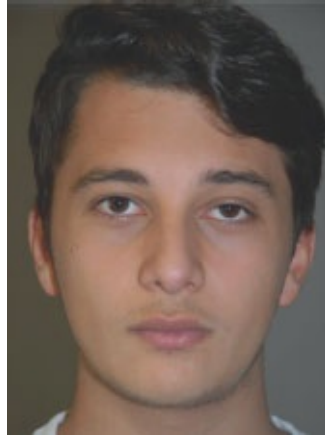


FIG 11 • A 17-year-old male patient presents with left upper eyelid ptosis. He has slight elevation of the left medial eyebrow.

DIFFERENTIAL DIAGNOSIS

- Congenital ptosis
- Muscle disease
- Fatty infiltration of the levator muscle

SURGICAL MANAGEMENT

Preoperative Planning

- The patient should not take any blood thinning agents for 3 weeks preoperatively. A bloodless field and loupe magnification are much needed for proper dissection and recognition of the pertinent anatomy.

Positioning

- The patient is placed on the surgical table in the supine position. A reverse Trendelenburg positioning of the patient is best for a bloodless surgical field.

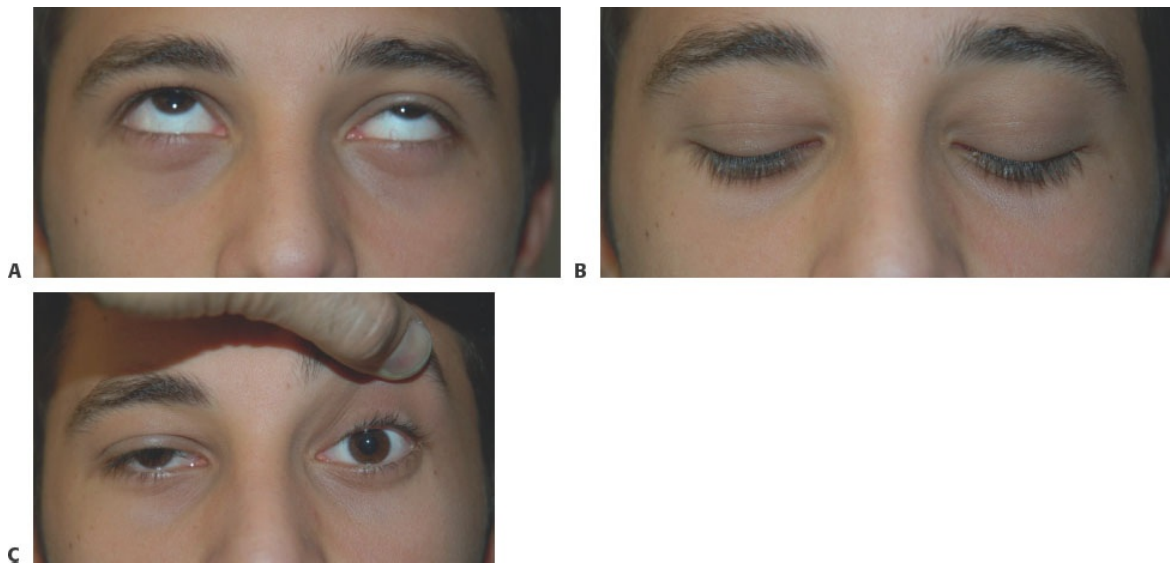
Approach

- The supratarsal crease incision is used. It is not preferable to use the original crease of the patient because it might be displaced higher due to the pull of the levator muscle on the skin. I prefer to place my incision 8 mm from the upper eyelid lash border. This unfortunately coincides with the junction of the levator aponeurosis with the upper orbital septum and is a difficult area to delineate the anatomy. This requires surgical expertise and the use of loupe magnification.

TECHNIQUES

■ Levator Advancement Technique for the Treatment of Upper Eyelid Ptosis

- The patient is a 17-year-old who presents with left upper eyelid ptosis and slight left eyebrow asymmetry. He has quite equal skin folds on both sides and this ensures a good outcome. He has asymmetric levator function, 14 mm on the right and 11 mm on the left (**TECH FIG 1A,B**). A surgical simulation is performed by elevating the ptotic lid to a higher level with the index finger while watching the normal side to detect a positional change. In his case, the upper lid level drops on the normal side; hence, the surgery is performed on both sides (**TECH FIG 1C**).

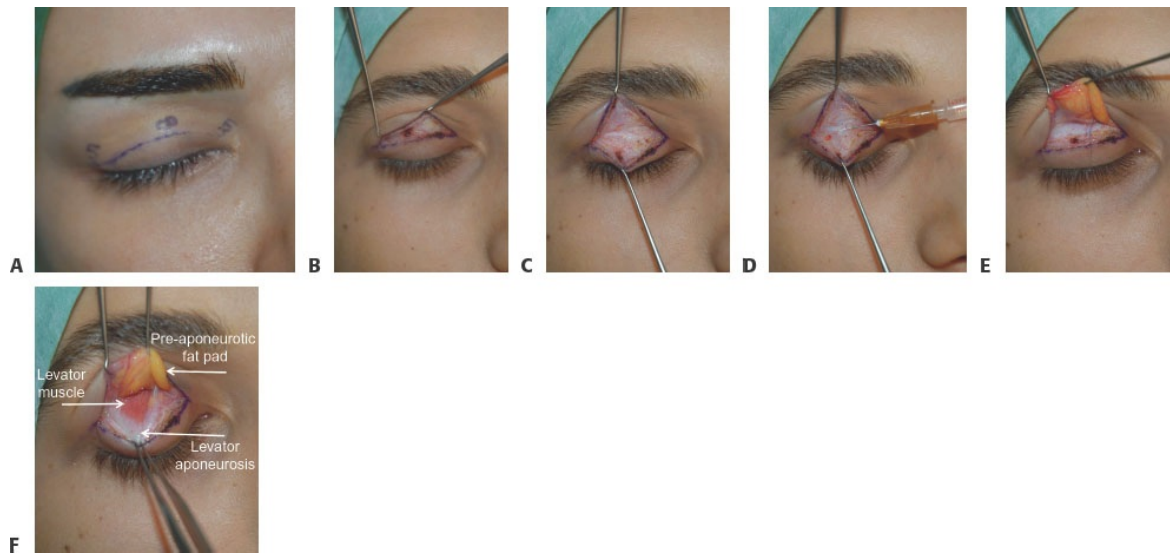


TECH FIG 1 • **A,B.** The patient has asymmetric

levator function, 14 mm on the right and 11 mm on the left. **C.** Hering law in effect: if the left upper eyelid is pulled to a higher level to simulate surgery, the right lid drops. This shows the occult ptosis of the contralateral side. In this case, a bilateral approach is mandatory.

■ Incision and Dissection

- The upper eyelid incision is injected with local anesthetic and adrenaline solution, and 7 to 10 minutes are allowed to pass before skin incision. The surgical incision is placed at 8 mm from the eyelash margin in the middle and both ends at 5 mm. Laterally, the lateral canthus is the outer limit, and medially, the limit is the punctum (**TECH FIG 2A**).
- The upper eyelid incision is performed very superficially, and then the dermis is cut with the cautery to prevent bleeding. The dissection continues with the muscle layer. There is uneven thickness of the orbicularis muscle in the upper eyelid due to the convexity of the eye globe; the muscle is thicker laterally and medially. It is advisable to advance along the medial incision first, because there is a more significant adipose layer in between the muscle and the upper orbital septum in this area. Once the dissection reaches this layer, it is easier to extend toward the middle and then laterally, staying on top of the orbital septum (**TECH FIG 2B**). Under loupe magnification, the upper flap is dissected toward the upper orbital rim for another 10 mm, staying immediately adjacent to the muscle layer (**TECH FIG 2C**). This facilitates the closure at the end of the surgery.
- The upper orbital septum is punctured, and 1 cc of saline is injected staying close to the undersurface of the septum (**TECH FIG 2D**). This type of hydrodissection facilitates the separation of the septum from the levator aponeurosis. In most of the ptosis cases, there is not much of a tissue space in between these layers, and this increases the risk for inadvertent levator system surgical damage. If the patient has well-developed preaponeurotic fat pads, these lie immediately under the septum (**TECH FIG 2E**). There are fibrous connections in between the levator system and the fat pads; they are released and the fat pad is retracted to visualize the levator muscle (**TECH FIG 2F**).



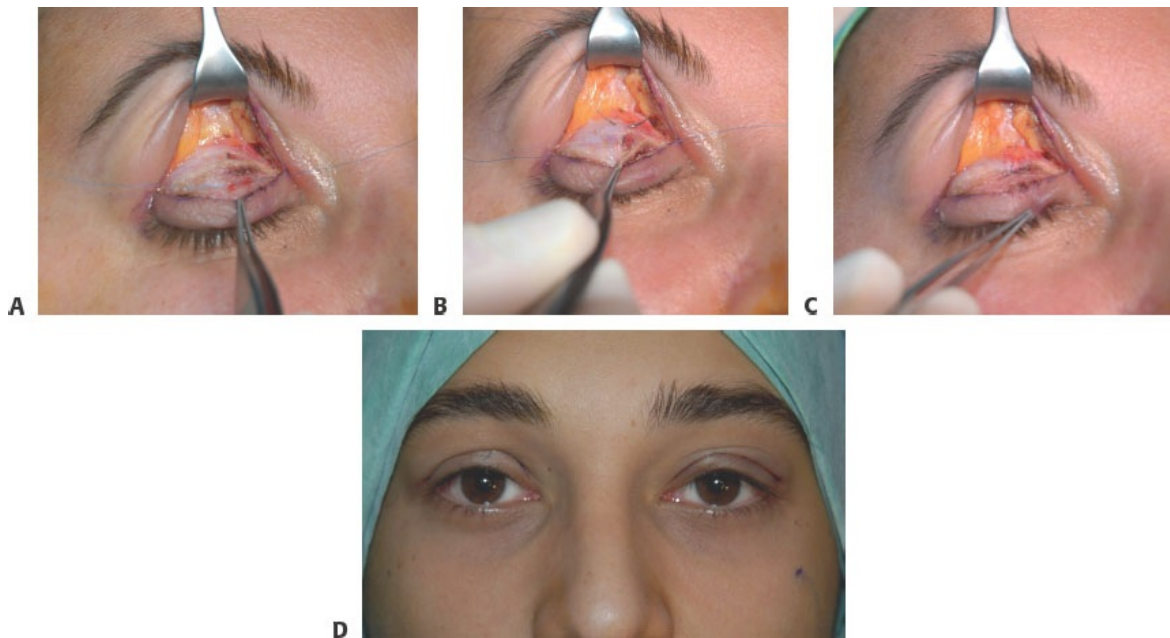
TECH FIG 2 • A. The surgical incision is planned 8 mm from the lash margin, and the corners have 5 mm distance to maintain the natural curve of the supratarsal crease. **B,C.** The upper eyelid skin and muscle are incised, and the upper edge of the flap is elevated off of the orbital septum. **D,E.** The injection of saline into the upper orbital space helps with the separation of the levator system from the septum. The elevation of the upper orbital fat pad helps to visualize the levator muscle. **F.** The levator muscle and the aponeurosis are clearly visible immediately under the preaponeurotic fat pad.

■ Suturing

- There is a strong fibrous tissue layer along the anterior surface of the upper tarsal plate immediately deep to the orbicularis muscle layer. A 6-0 nylon suture is passed through this strong layer without penetrating the cartilaginous tarsal plate. This prevents the unnecessary manipulation of the upper eyelid tarsal plate (**TECH FIG 3A**).
- The second suture is then passed through the aponeurosis close to the distal edge of the levator muscle (**TECH FIG 3B**). The decision-making process for the amount of aponeurosis shortening depends on the severity of the

ptosis and experience. The suture is then tied, which will effectively pull the levator muscle closer to the upper tarsal edge (**TECH FIG 3C**).

- The aponeurosis shortening sutures are placed on both eyes, and the patient is asked to open the eyes and look forward (**TECH FIG 3D**). There should be perfect symmetry of the upper eyelid levels. If not, the sutures are removed and arranged accordingly. When equal upper eyelid levels are maintained, two more additional sutures are placed on both sides of the midline suture to reinforce the attachment of the system to the anterior tarsal plate.
- The septum is closed with 6-0 poliglecaprone sutures, the upper flap is pulled down, and the skin excess is measured. The orbicularis muscle is never excised as the muscle fibers are more condensed close to the incision. The skin is injected with a local anesthetic solution and de-epithelialized with a surgical blade. Then the muscle is folded on itself and the skin is closed with a 6-0 nylon continuous suture.



TECH FIG 3 • **A.** The 6-0 nylon suture is passed through the strong fibrous tissues of the anterior surface of the upper tarsal plate. The suture is then grasped and pulled up to see if it will hold the repair. **B.** The suture is then passed through the levator aponeurosis at a level closer to the muscle. The decision process for the placement of this suture is

obtained with practice and time. **C.** The suture is then tied to pull the muscle closer to the upper tarsal border, hence the name levator advancement repair. **D.** After the levator is advanced on both sides, the patient is asked to open the eyes to check for symmetry. If this is not achieved, the levator system suture is removed, and a new level is obtained to provide equal upper eyelid levels.

PEARLS AND PITFALLS

Hemostasis	■ Instruct patient to stay away from blood thinning agents for at least 2 weeks. ■ Use freshly prepared local anesthetic and adrenaline solution. ■ Elevate the head of the bed. ■ Dissect with a Colorado tip cautery and obtain meticulous hemostasis.
Orbital septum incision	■ Inject saline for hydrodissection to prevent injury to the levator.
Levator muscle	■ The muscle is very fragile, and once it bleeds, its function is temporarily lost—no touch technique is mandatory.
Symmetry	■ The patient is asked to open the eyes and look up and down to check for function after placement of the aponeurosis shortening sutures.

POSTOPERATIVE CARE

- Apply ice for 5 days.
- Elevate the head of the bed.
- Suture removal in 3 to 5 days
- Ophthalmic antibiotic ointment application for the first 3 days
- If the patient has compensatory frontalis muscle hyperactivity, he/she should be informed that it would take up to 3 to 6 months for the muscle to relax. In

the early postoperative period, frontalis muscle activity might cause asymmetry and overelevation.

- The patient should understand that there is a period of 1 to 3 months of refractory changes in the postoperative phase.

OUTCOMES

- See **FIG 12**.



FIG 12 • The patient is seen 6 months after surgery with symmetric upper eyelid levels. There is better match of the left eyebrow position.

- The most common complication is a slight asymmetry in the postoperative period. This possibly is due to suture displacement in the healing phase. It is more frequent in asymmetric ptosis cases, and a proper consent should be obtained prior to initial surgery (**FIG 13**).

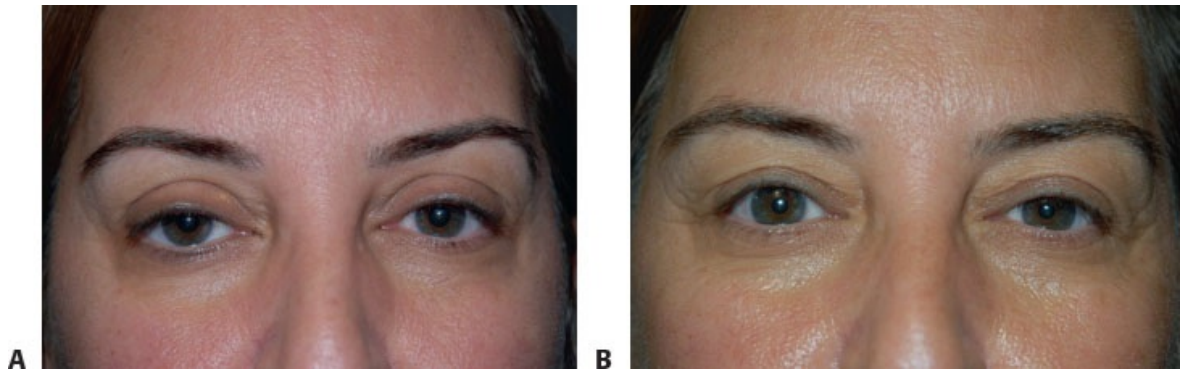


FIG 13 • **A.** A 37-year-old female presenting with right upper eyelid ptosis and an occult ptosis on the left side. She had levator advancement procedure on both sides with medial fat pad excision and grafting of the middle upper sulcus and 15-mm skin-only resection preserving the orbicularis muscle mass. **B.** The patient has asymmetric levels of the upper eyelids 4 months later. There is inadequate correction of her occult ptosis on

the left side, even though the eyelid levels looked perfectly symmetric on the operative table at the end of the procedure.

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30 Asian Blepharoplasty CHAPTER (“Double Eyelid” Surgery)

Clyde H. Ishii

DEFINITION

- Asian blepharoplasty or “double eyelid” surgery is a procedure to create a supratarsal fold.
- The fusion level of the orbital septum–levator aponeurosis and dermal insertions result in naturally occurring supratarsal folds.
- The incision height, amount of remaining upper eyelid skin, height of fixation, and levator function affect pretarsal exposure or “show.”
- The shape of the desired fold varies according to patient preference.

ANATOMY

- Tissue connections between the levator aponeurosis and pretarsal skin result in the formation of the supratarsal fold^{1,2} (**FIG 1**).
- Caucasians and Asians with naturally occurring supratarsal folds have a relatively higher fusion level of the orbital septum and levator aponeurosis.³ In contrast, these structures fuse at a lower level in Asians with low or absent folds⁴ (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Ethnic differences must be considered when performing Asian blepharoplasty. Asian blepharoplasty is not simply Caucasian blepharoplasty applied to Asians. Asians undergoing this procedure want to enhance their appearance while maintaining their ethnicity. Most Asians do not want to end up with deep-set eyelids and tall supratarsal folds as seen in Caucasians.
- Physical examination:
 - The upper eyelid is examined for asymmetry, ptosis, abundance of skin/fat,

and scarring or previous incision sites. The presence of brow ptosis should also be noted because this will affect the final appearance.

- The chosen height of the supratarsal fold is key to the final result and must be discussed in detail with the patient. Patients are interested in the final amount of pretarsal exposure or “show.” Most Asians prefer to end up with a pretarsal exposure of 3 mm or slightly less. Older patients and males tend to prefer a smaller amount of pretarsal exposure. Pressing a lacrimal probe or bent paper clip against the eyelid may simulate the desired pretarsal exposure (**FIG 3**).
- The shape of the desired fold is also very important and must be discussed with the patient.
 - Medially, the fold may taper toward the medial canthus resulting in an “inside” fold⁵ (**FIG 4**).
 - Folds that run outside the epicanthus (“outside” fold) will result in more of a Western appearance⁵ (**FIG 4**). Some Asians prefer such an “outside” fold because it gives the illusion of a narrower intercanthal distance.
 - Most Asians prefer that the central third of the fold runs parallel to the lid margin.

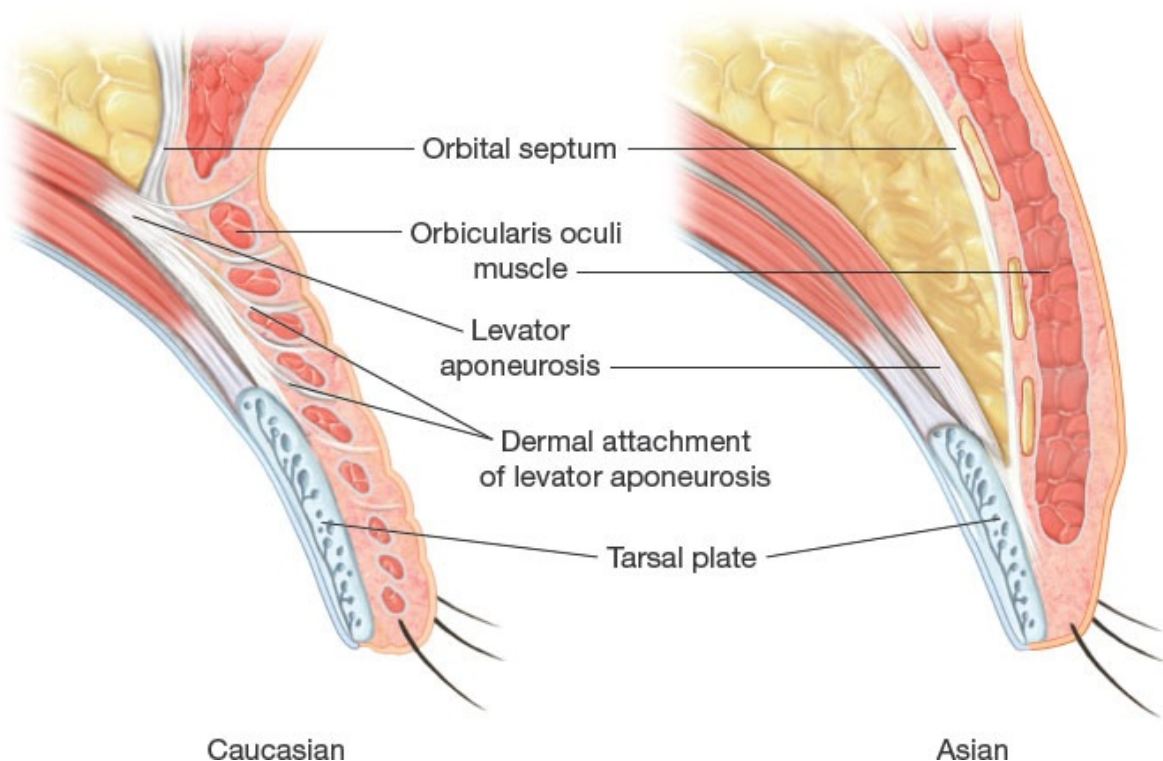


FIG 1 • Dermal attachments from the levator

aponeurosis result in the formation of the supratarsal fold.

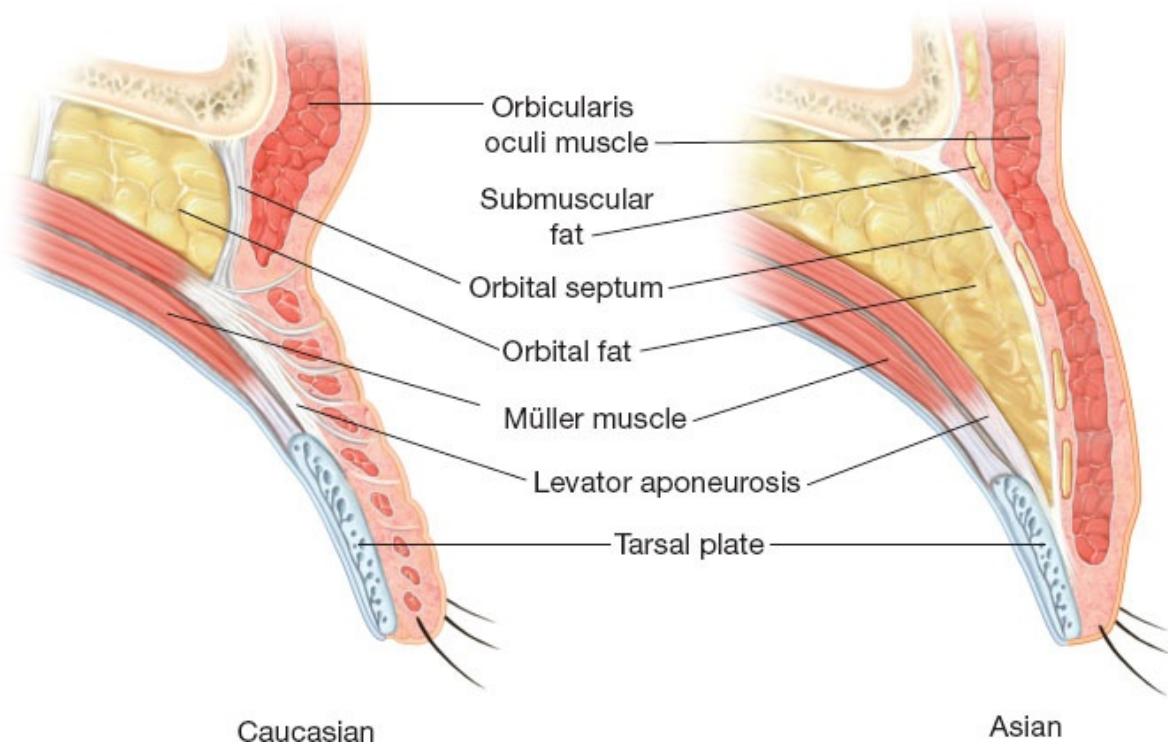


FIG 2 • Asians with short or absent folds have a lower fusion level of the orbital septum and levator aponeurosis.

- Laterally, the fold may run parallel to the lid margin or have a slight lateral flare. This lateral flare produces an uplifted appearance and tends to mitigate the natural bunching of skin in this area that occurs with aging.

SURGICAL MANAGEMENT

- Surgical techniques to create a supratarsal fold include nonincisional methods (sutures alone), partial incisional methods (one or more small incisions combined with sutures), and incisional methods.
- Nonincisional methods are mainly used for young patients who do not need excision of skin or fat. Although these methods are associated with less postoperative edema than partial incision or incisional methods, the fixation is not as durable and loss of the fold is well-documented.
- Partial incisional methods allow for excision of excess fat and better fixation

than nonincisional methods but any excess skin cannot be addressed.

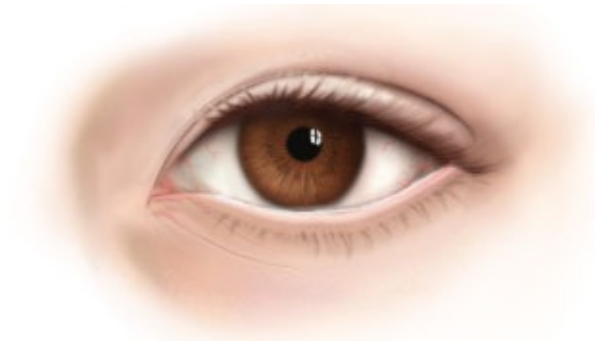
- My preferred technique is the incisional method because it allows the surgeon to address redundancy of skin/fat and correct any accompanying blepharoptosis while providing secure fixation. These incisions heal well, and unsightly scars are rare. In my experience, the advantages of this technique far outweigh any disadvantages.



FIG 3 • Simulation of a supratarsal fold using a lacrimal probe or bent paper clip.

Preoperative Planning

- The desired height and shape of the fold are once again discussed with the patient.
- Marking of the eyelid is performed with the patient in the supine or semirecumbent position. Needed materials include vernier caliper, toothed forceps, and marking pen (**FIG 5**). An alcohol swab is used to clean the eyelid of makeup or oil film.
- The caliper is set to the desired fold height, and ink is applied to the distal tip of the caliper. With the eyelids closed, the surgeon gently lifts the superior lid/brow skin until slight eversion of the upper lid lashes is noted. The proximal tip of the caliper is placed at the lid margin and a marking is laid down in line with the midpupil. A similar marking is made laterally if a slight lateral flare of the fold shape is desired. If an “inside” fold is desired, the markings can taper toward the medial canthus. For an “outside” fold, the medial markings run several millimeters above the epicanthus.



“Inside” fold



“Outside” fold

FIG 4 • Medially, the fold may taper toward the medial canthus (“inside” fold) or run outside the epicanthus (“outside” fold).



FIG 5 • Vernier caliper, toothed forceps, and marking pen.

- Markings for skin excision depend on the amount of skin excess in a given patient. Younger patients usually need only 0 to 2 mm skin excision. In older patients, the amount of skin excess is determined by gently grasping the eyelid

skin with toothed forceps. One tip of the forceps is placed on the fold height marking above while gathering the excess skin with the other tip. Mild eversion of the lid lashes is used as an end point. A third to half of the measured skin excess is marked centrally, and the markings taper medially and laterally to complete the elliptical marking. One should err on the more conservative side of skin excision in patients who desire a more subtle pretarsal exposure.

Positioning

- The patient is positioned supine on the operating table.

Anesthesia

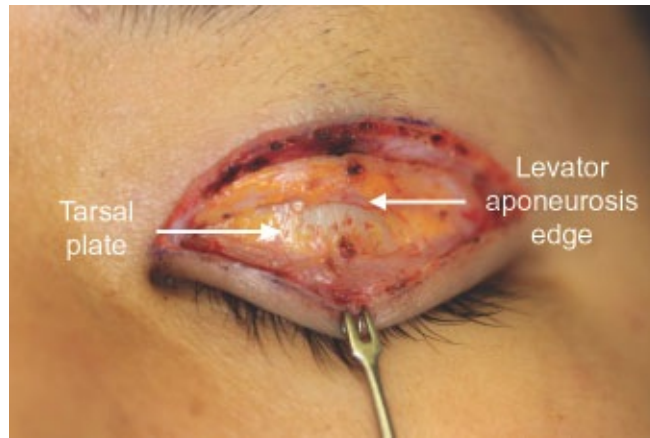
- The procedure is performed under local anesthesia with mild sedation.
- The sedation must be mild so patients can open/close their eyelids on command after the fixation sutures are placed. This allows the surgeon to check for symmetry regarding fold height and shape.

Approach

- An incisional approach is used because of its versatility while providing very secure fixation.

TECHNIQUES

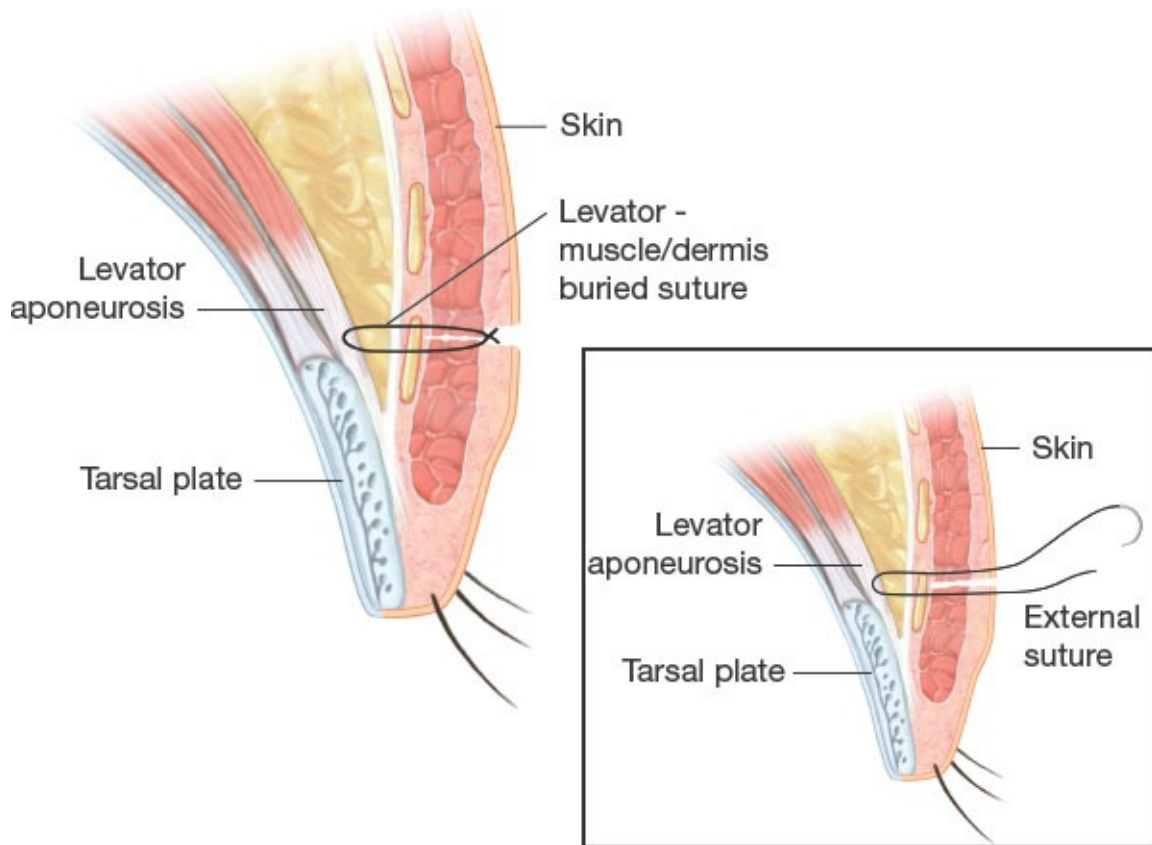
- With the eyelid under stretch, the elliptical skin incisions are made and a strip of skin is excised. A strip of orbicularis is also removed along with any excess submuscular fat. The fusion of the orbital septum and levator aponeurosis is thus exposed as it approaches the tarsal plate (**TECH FIG 1**). The orbital septum may be entered to address any excess retroseptal fat. Care should be taken to leave some fat behind to avoid unnatural accessory folds from forming above the fixation line.



TECH FIG 1 • Exposure of fusion involving orbital the septum and levator aponeurosis.

■ Skin-Aponeurosis Fixation Technique

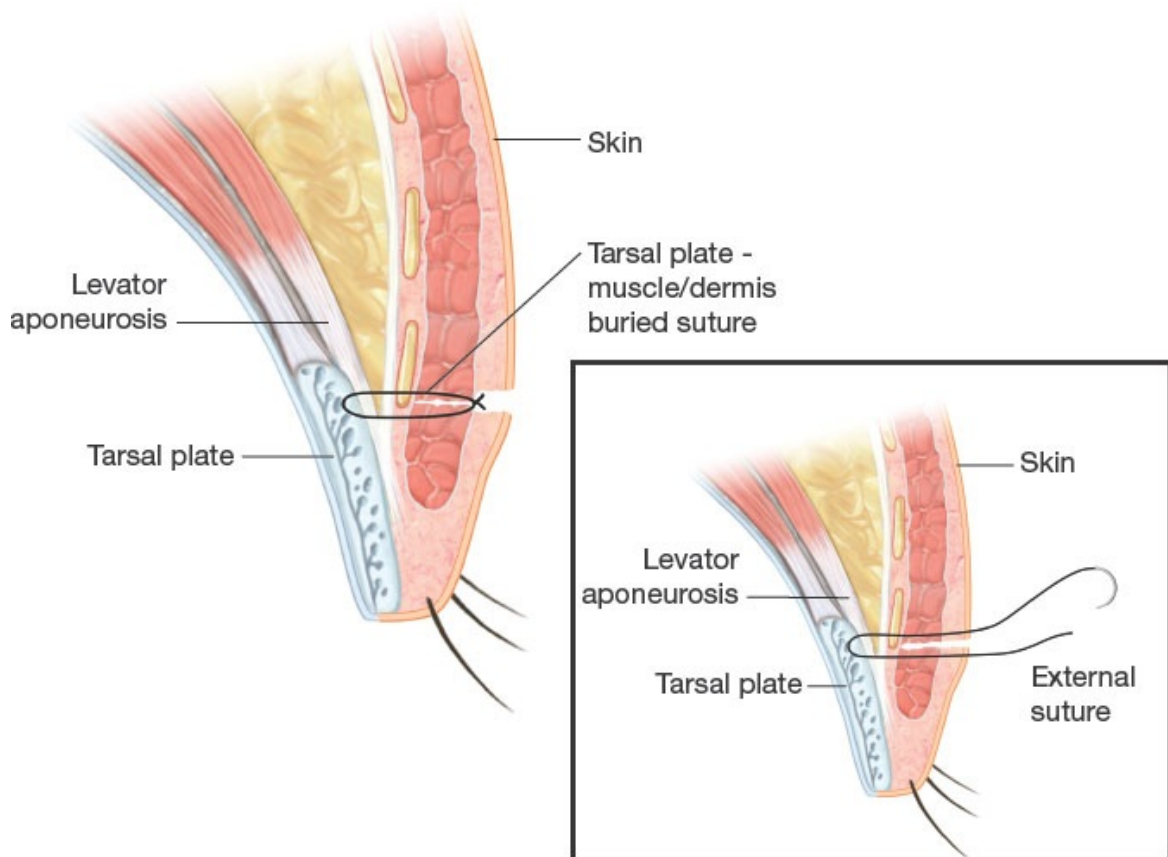
- Three or four 7-0 nylon sutures are placed to secure the levator aponeurosis to the muscle-dermis of the pretarsal skin edge (**TECH FIG 2**).
- The sutures may be either of the buried internal variety or external in nature.
- I prefer buried internal sutures because I like to remove all external sutures on postoperative days 4 to 5.



TECH FIG 2 • Skin fixation to the levator aponeurosis.

■ Skin-Tarsus Fixation Technique

- The caliper is used to place markings on the tarsus in the mid pupil line and laterally according to the patient's desired fold height. Medially, the markings parallel the pretarsal skin edge.
- 7-0 nylon sutures are placed to secure the markings on the tarsus to the muscle-dermis of the pretarsal skin edge (**TECH FIG 3**).
- At the medial and lateral extremes where the tarsus tapers narrowly, the sutures fix the aponeurosis to the muscle-dermis of the skin edge. As noted above, the sutures in this technique may be of the buried internal variety or external in nature.
- The skin-tarsus fixation technique results in a more static and well-defined fold when compared to the skin-aponeurosis fixation technique described above.
- **Closure:** Skin closure is performed using a 7-0 nylon running suture for both techniques.



TECH FIG 3 • Skin fixation to the tarsal plate.

PEARLS AND PITFALLS

Planning

- Most Asians prefer only a modest amount of pretarsal exposure (3 mm or less) compared to their Western counterparts.
- Creating an “outside” fold or eyelids with significant pretarsal exposure will tend to Westernize the eye, and many patients will find this distressing.
- The desired fold height, shape, and pretarsal exposure should be carefully discussed with the patient preoperatively.
- Reviewing preoperative and postoperative images of other patients or models may be helpful.

Technique

- The leading edge of the levator aponeurosis must be carefully identified when using the skin-aponeurosis fixation technique. Failure to identify and secure the proper anatomic structures will

lead to incomplete/lack of folds.

Postoperative care

- Patients desiring a taller supratarsal fold with more pretarsal exposure will show more pretarsal edema postoperatively, and this will persist for several months. Accordingly, patients should be informed of this preoperatively.

POSTOPERATIVE CARE

- Apply cold compresses during the first 24 hours.
- Cleanse the suture line with water and apply a light coat of antibiotic ointment two to three times a day.
- Avoid use of cosmetics to the upper eyelid for 10 days.
- Avoid bending, straining, or strenuous activities for 1 week.

OUTCOMES

- A highly satisfactory outcome is likely if the patient's desired final appearance is properly understood and the procedure is performed with the above guidelines in mind.
- Pre-existing asymmetry involving a patient's brow or lid level may affect the final result. Such asymmetry must be discussed with the patient prior to surgery.

COMPLICATIONS

- Bleeding/hematoma
- Excessive swelling
- Asymmetry in fold height/shape
- Dehiscence
- Infection
- Incomplete/loss of folds
- Multiple folds
- Milia
- Suture granuloma
- Hypertrophic scarring

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Section IX: Lower Blepharoplasty

Transconjunctival Approach to Resection and/or Repositioning of Lower Eyelid Herniated Orbital Fat

31
CHAPTER

Allen Putterman

DEFINITION

- This procedure is undertaken to treat baggy lower eyelids and inferior orbital rim hollowing.

ANATOMY

- Pertinent anatomic structures are the lower eyelid conjunctiva, Müller muscle, capsulopalpebral fascia, orbital fat, and orbital septum (**FIG 1**).
- There are three distinct lower eyelid orbital fat pads (nasally, centrally, and temporally).
 - The nasal and central fat pads are divided by the inferior oblique muscle, and the central and temporal fat pads are separated by the temporozygomatic ligament.
 - There may be a second temporal fat pad.¹

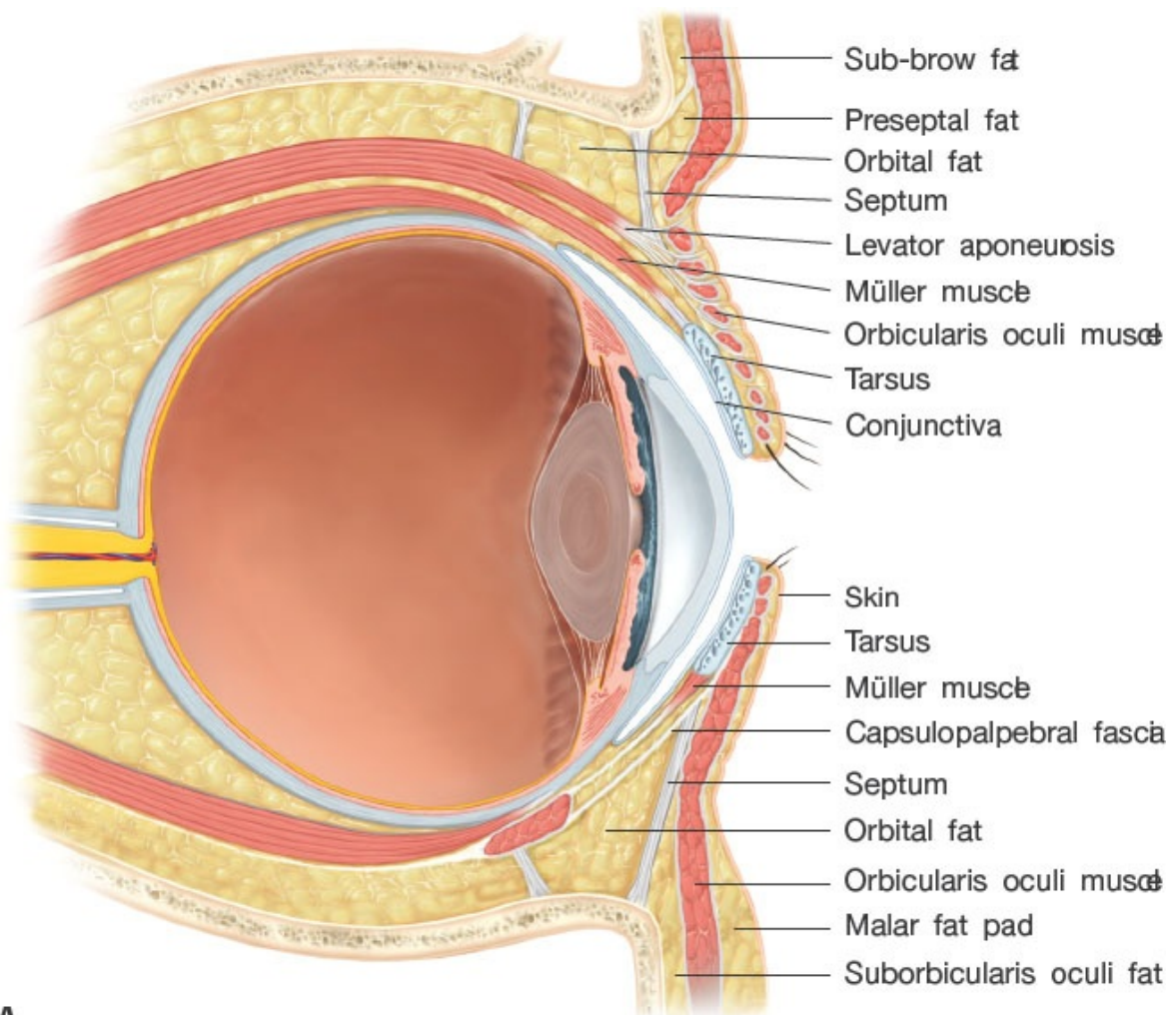
PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients note fullness and bagginess of their lower eyelids. Some patients also notice a hollowing appearance in the inferior orbital rim area.
- This technique is also especially advantageous for:

- Younger patients with large amounts of herniated orbital fat
- Patients who have had previous blepharoplasties and for whom an external approach might lead to eyelid retraction or ectropion
- Fat repositioning is advocated for patients with inferior orbital rim hollowness.

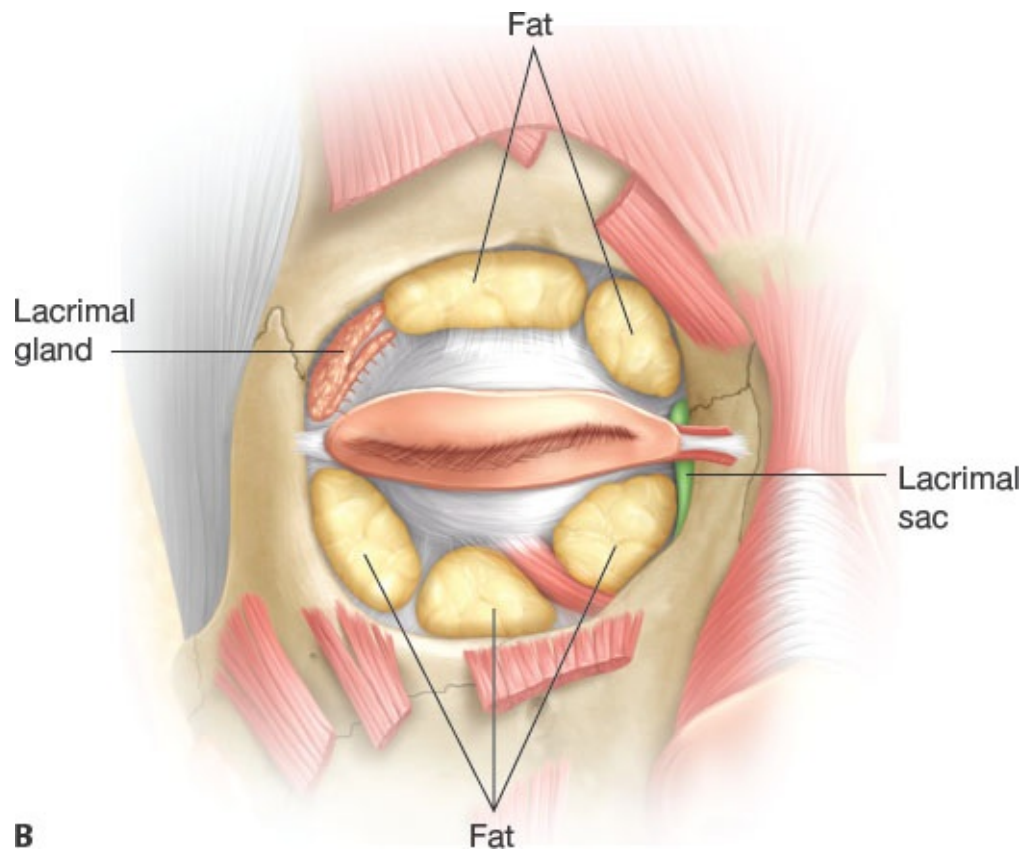
SURGICAL MANAGEMENT

- The transconjunctival approach to removal of herniated orbital fat is the preferred method of treatment in patients who have only herniated orbital fat with minimal or no evidence of dermatochalasis (excess skin) and no hypertrophic orbicularis oculi muscle.



A

FIG 1 • Eyelid anatomy.



TECHNIQUES



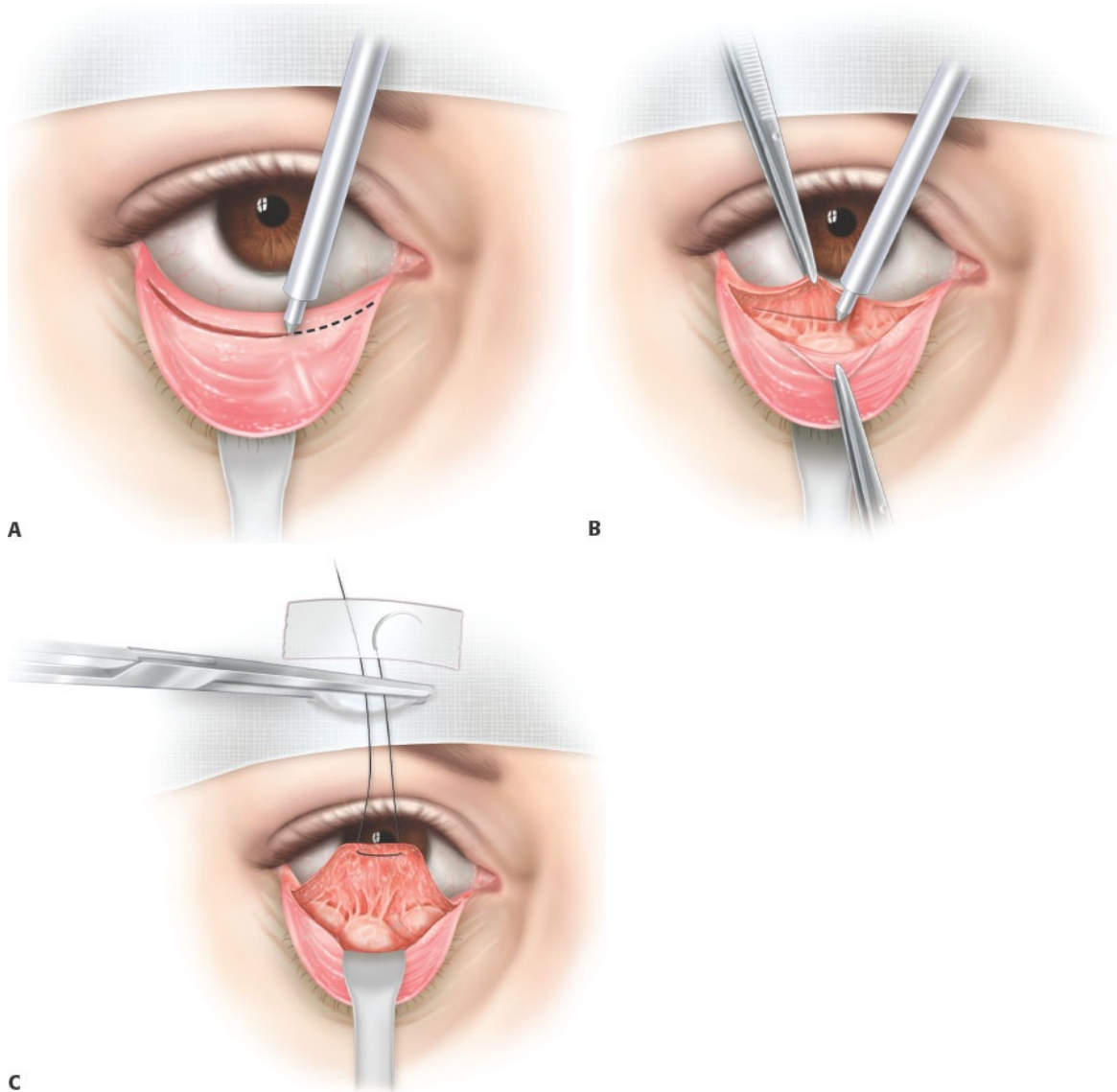
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■ Anesthesia and Eye Preparation

- Two percent lidocaine (Xylocaine) with 1:100 000 epinephrine is injected subcutaneously at the center of the lower eyelid just beneath the lashes.
 - An additional anesthetic agent is injected into each fat pad.
 - To inject the anesthetic into the nasal, central, or temporal fat pad, the surgeon inserts a 25-gauge, 0.8-cm needle just above the inferior orbital rim and directs it downward slightly until it penetrates its entire length (0.8 cm).
 - The barrel of the syringe is withdrawn to make sure that no blood vessel has been entered and approximately 0.5 mL of the agent is injected into each of the three fat pads.
 - Topical tetracaine is instilled over the eye, and a scleral lens is placed over the eye to protect it.
 - A 4-0 black silk traction suture is placed through the skin, orbicularis muscle, and superficial fascia at the center of the eyelid. The surgeon pulls the eyelid downward with a traction suture as the assistant everts the lower eyelid over a small Desmarres retractor to expose the inferior palpebral conjunctiva.
 - Additional anesthetic is injected subconjunctivally over the inferior palpebral conjunctiva across the eyelid.
-

■ Isolating the Eyelid Retractors

- A Colorado needle is used to cut the conjunctiva from the medial to temporal end of the eyelid halfway between the inferior palpebral fornix and the inferior tarsal border (**TECH FIG 1A**).
- The surgeon grasps the inferior edge of the severed palpebral conjunctiva, while the assistant grasps the adjacent, more superior edge with forceps, and the assistant pulls the Desmarres retractors downward (**TECH FIG 1B**).
 - The two forceps are pulled apart.
 - Further dissection with the Colorado needle is carried out through the Müller muscle, and capsulopalpebral fascia until fat is seen.
- A 4-0 black silk double-armed suture is passed through the inferior edge of the conjunctiva, the Müller muscle, and the capsulopalpebral fascia, and the suture arms are pulled upward and clamped to the drape (**TECH FIG 1C**).

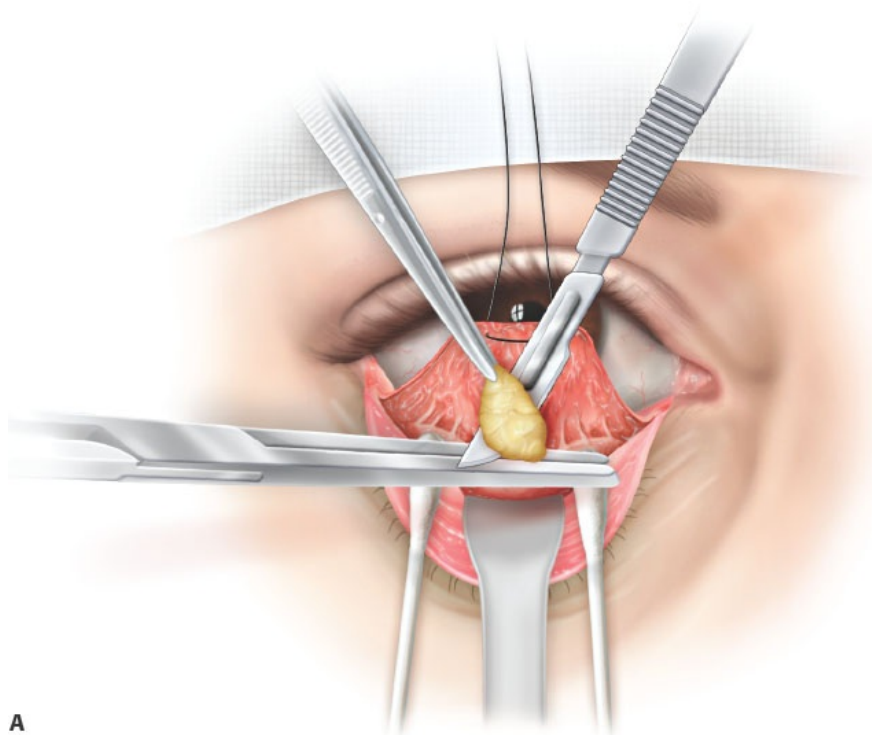


TECH FIG 1 • A. A Colorado needle is applied to the inferior palpebral conjunctiva halfway between the fornix and the inferior tarsal border and is used to sever the conjunctiva from medial to temporal end of the eyelid. **B.** With forceps, the surgeon and surgeon's assistant grasp the inferior and superior edges, respectively, of the severed palpebral conjunctiva to facilitate dissection of the Müller muscle and capsulopalpebral fascia with the Colorado needle. **C.** A 4-0 double-armed black silk suture is placed through

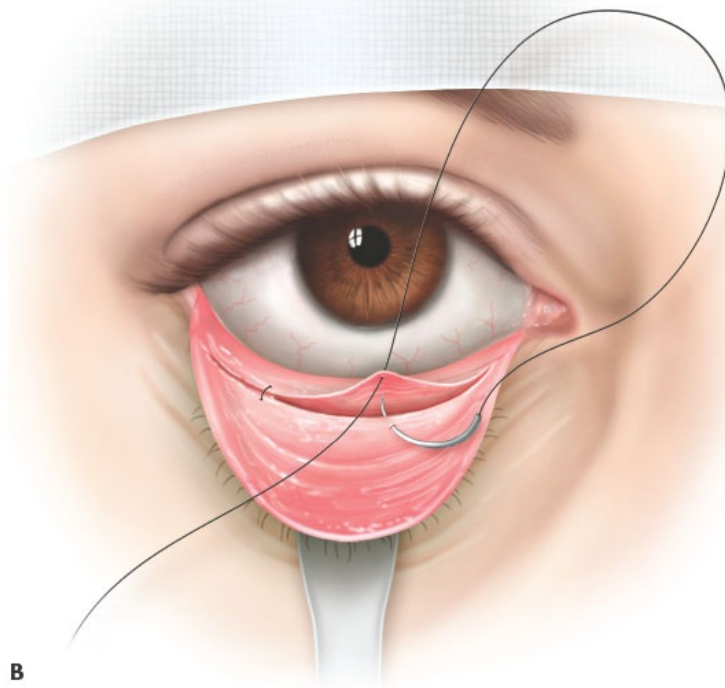
the inferior edge of the conjunctiva, Müller muscle, and capsulopalpebral fascia and is pulled upward and clamped and taped to the drapes.

■ Excision of Orbital Fat

- A small Desmarres retractor is placed over the lower eyelid and is pulled downward and outward to expose the orbital fat.
- With the use of a disposable cautery and Westcott scissors, blunt dissection is carried out to isolate the three orbital fat pads.
- The temporal herniated orbital fat is isolated, and the fat that prolapses with gentle pressure on the eye is clamped with a hemostat and cut along the hemostat blade with a no. 15 Bard-Parker blade (**TECH FIG 2A**).
- Cotton-tip applicators are placed underneath the hemostat as a Bovie cautery is applied over the fat stump.
- The surgeon grasps the fat with forceps before it is allowed to slide back into the orbit to make sure that there is no residual bleeding that might cause a retrobulbar hemorrhage.²
- After the first temporal fat pad is removed, the surgeon applies additional pressure to the eye to determine whether there is a second temporal fat pad:¹
- If a second temporal fat pad is found, it is also removed. The central and nasal fat pads are then removed in a similar manner.
- The retractor suture is removed, and then the conjunctiva is reapproximated with three 6-0 plain catgut buried sutures (**TECH FIG 2B**).



A



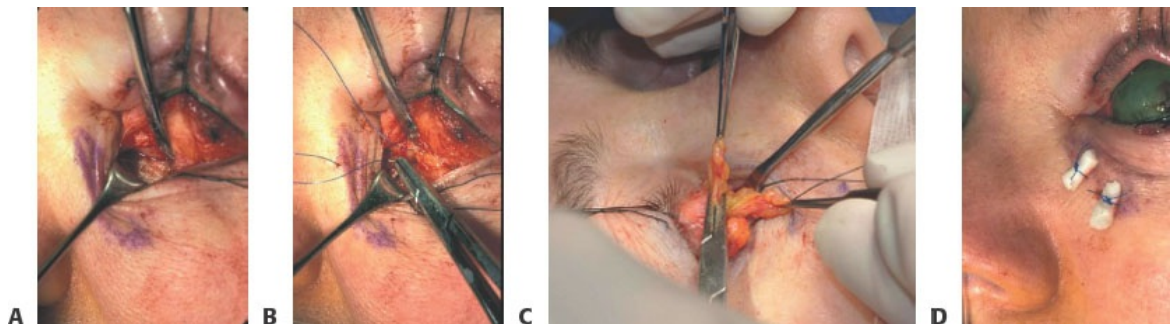
B

TECH FIG 2 • A. The surgeon removes the temporal, central, and nasal fat orbital fat pads by cutting along the hemostat blade with a no. 15 Bard-Parker blade and then applying a Bovie cautery to the fat stump. **B.**

The conjunctiva is reapproximated with three 6-0 plain catgut buried sutures.

■ Orbital Fat Repositioning

- If there is both herniated orbital fat and inferior orbital rim hollowing, fat repositioning is performed.
- After the isolation of the orbital fat pads, an incision is made over the nasal inferior orbital rim, and periosteum is dissected for approximately 1 cm inferior to the orbital rim from the orbital bone (**TECH FIG 3A**).
- A 4-0 Prolene double-armed suture is threaded through the distal end of the nasal orbital fat pad, and then each arm of the suture passes subperiosteally 1 cm beneath the inferior orbital rim and exits through the skin (**TECH FIG 3B**).
- The central fat pad at times will also be repositioned in a similar manner.



TECH FIG 3 • A. Orbital fat repositioning. Periosteum is dissected from orbital bone over the nasal half of the lower eyelid for approximately 1 cm. **B.** A 4-0 Prolene double-armed suture is threaded through the nasal lower eyelid distal fat stump. Each arm of the suture is passed subperiosteally approximately 1 cm beneath the inferior orbital rim and exits through skin inferior to the hollowed areas. **C.** If there is excessive lower eyelid fat, the nasal and or central fat pads are divided into pedicles and parts of the fat pads are excised and parts repositioned. **D.** The 4-0 Prolene

sutures are tied over cotton pledgets to allow the nasal and central fat to be repositioned into the nasal inferior orbital rim hollowed areas.

- The arms of the suture are tied over cotton pledgets to allow the nasal and central fat pads to be repositioned into the inferior orbital rim hollowed area and to fill this area as well as to decrease the bagginess of the lower lid.
- At times, if there is too much nasal or central fat, pedicles are used to divide the nasal and/or central fat, parts of the nasal and central fat pads are excised, and parts are repositioned (**TECH FIG 3C**).³
- The cotton pledgets and 4-0 Prolene sutures are removed approximately 1 week postoperatively (**TECH FIG 3D**).

PEARLS AND PITFALLS

Inferior oblique muscle	■ Identify inferior oblique muscle to avoid injury with secondary diplopia.
Temporal fat	■ Check for the second or deeper temporal fat pad after initial temporal fat pad is removed to avoid residual temporal lower lid postoperative fullness. ¹
Fat transposition	■ Perform fat pedicles with fat repositioning if there is a large amount of fat to avoid inferior orbital rim overfill and bulging. ³
Selective fat removal	■ Only remove the fat that flows forward when gentle pressure is applied to the eye through the eyelids to avoid overcorrection with secondary inferior orbital rim hollowing.
Excess swelling	■ Apply pressure to closed eyelids over areas of postoperative conjunctival chalasis to speed resolution of conjunctival chalasis.⁴ ■ If there is a retrobulbar hemorrhage, remove the conjunctival sutures and do a lateral canthotomy.²

POSTOPERATIVE CARE

- No dressings are used after surgery.

- The patient is instructed to apply ice cold compresses on the eyelids, and pads (4 × 4 in.) soaked in a bucket of saline and ice are applied with slight general pressure to the eyelids:
 - When the pads become warm, they are dipped again into the saline and ice and reapplied.
 - This process is repeated for 24 hours but is not necessary during sleep.
 - The application should be fairly constant, especially for the first postoperative hours. After that, the compresses are applied for about 15 minutes with a 15-minute rest period in between until bedtime. The applications are resumed on awakening.
- To reduce edema postoperatively, the patient lies in a bed with the head approximately 45 degrees higher than the rest of the body:
 - Nurses should check for bleeding associated with proptosis, pain, or loss of vision every 15 minutes for the first 2 to 3 hours postoperatively or until the patient leaves the surgical facility.
 - Every hour thereafter until bedtime, the family or patient should monitor the patient's ability to count fingers and should check the residual proptosis and pain.
 - If the patient cannot count fingers or has marked proptosis or pain, the family should take him or her to the emergency room.
 - If loss of vision occurs secondary to retrobulbar hemorrhage, it could be treated by opening the incision involved and doing a lateral canthotomy.²
- Neomycin ointment is applied to the eyes twice a day for the first 2 weeks.

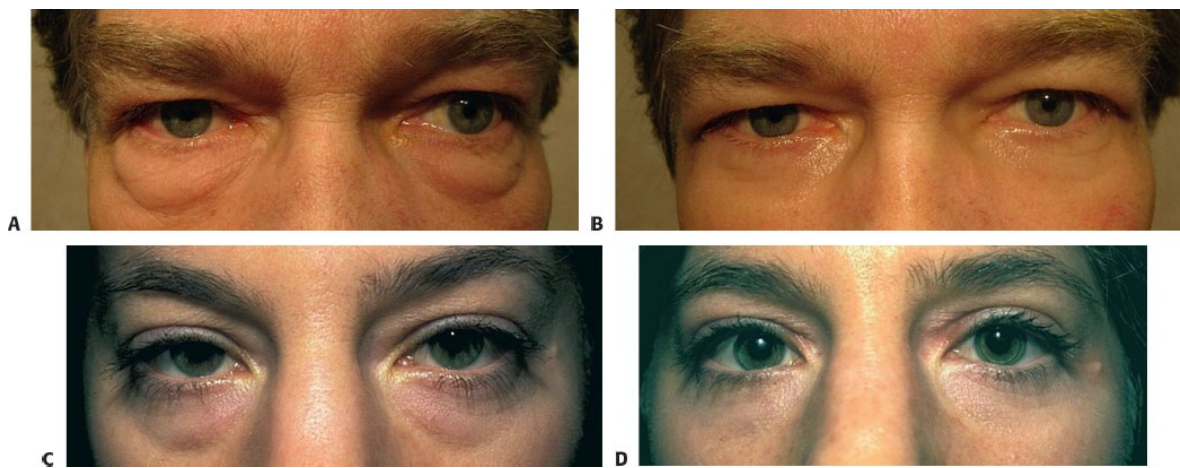


FIG 2 • A. A patient with lower eyelid herniated orbital fat preoperatively. **B.** Postoperative appearance after

removal of herniated fat with a transconjunctival approach. **C.** A patient with lower eyelid herniated orbital fat and inferior orbital rim hollowing areas. **D.** Postoperative photograph showing resolution of the baggy lower lids and filling in of the inferior orbital rim hollowed areas.

OUTCOMES

- I have performed the transconjunctival approach in more than 1000 patients (**FIG 2A–D**).
- The procedure has the advantages of causing less eyelid retraction and ectropion than with the skin flap or skin muscle flap approaches because the external lamellae are not manipulated.
- I believe there is less ecchymosis because the orbicularis muscle and skin are not severed.
- There tends to be more conjunctival chemosis immediately postoperatively with this procedure than with the external technique. If it occurs, it is treated with pressure applied over the closed eyelids.⁴
- With the fat repositioning, there is always the concern of overfill of the inferior orbital rim hollowed areas. I have performed fat repositioning for the last 25 years and so far have not had to repeat the procedure or to remove overfill of herniated orbital fat. Titrating the amount of fat reposition, I believe, has been the secret to that success.³
- I have had several patients who initially postoperatively had diplopia, but this has resolved in all patients, and I have not had any permanent diplopia from fat repositioning.

COMPLICATIONS

- Several patients in whom I have performed a transconjunctival approach had postoperative residual dermatochalasis, which needed to be removed through an external approach.
- Better patient selection or combined initial procedure with a skin flap excision or orbicularis muscle plication could have presented this problem.

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Indications and Technique for Skin Pinch Skin Excision in the Lower Eyelids

32

CHAPTER

Charles H. Thorne and Sammy Sinno

DEFINITION

- *Skin pinch skin excision* is a technique in which excess lower eyelid skin is simply grasped and excised without performing any subcutaneous dissection.
- *Dermatochalasis* is the condition of excess and loose eyelid skin. It is important to distinguish this condition from blepharochalasis.
- *Blepharochalasis* is a syndrome of recurrent eyelid edema that causes thinning and fine wrinkling of eyelid skin.

ANATOMY

- The skin of the eyelid is the thinnest of the body at less than 1 mm and has a high concentration of sebaceous glands.

PATIENT HISTORY AND PHYSICAL FINDINGS

- All patient undergoing eyelid surgery should have a detailed ophthalmologic history. History of previous periorbital surgery, visual disturbances, and relevant medications are noted.
- Patients who are candidates for skin pinch lower eyelid blepharoplasty have redundant and lax skin and often complain of a “tired” look. The stimulated effect of surgery can be reproduced preoperatively by providing gentle lateral traction on the lower eyelids.
- Patients who undergo this procedure may undergo additional procedures to correct other periorbital deformities, ie, transconjunctival lower eyelid fat removal for “puffy eyelids.”

IMAGING

- No imaging is needed for this procedure.

SURGICAL MANAGEMENT

- The procedure is relatively simple and straightforward if carefully planned.

Preoperative Planning

- Skin pinch lower blepharoplasty can be performed under general anesthesia or local anesthesia. If local infiltration is used, the surgeon must be aware that skin excision may be less precise because the field has been distorted.

Positioning

- The patient is positioned supine. Corneal protectors can be used but are associated with increased risk of corneal abrasion.

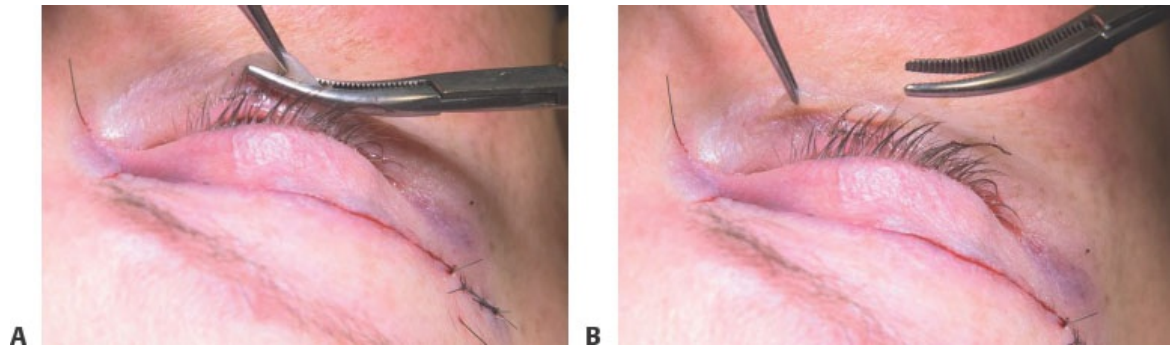
Approach

- The removal is performed just under the ciliary margin.

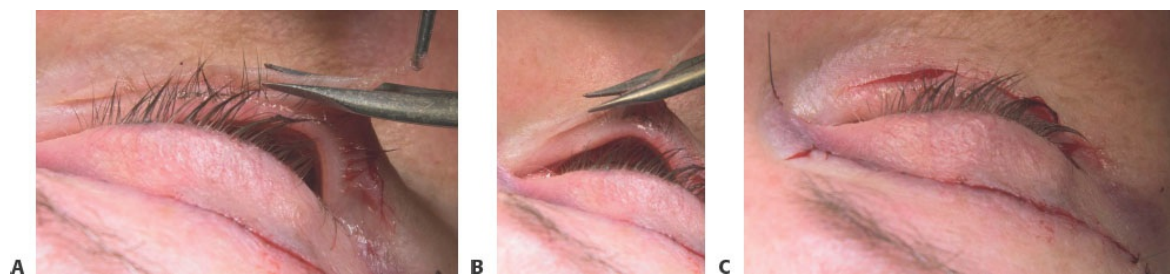
TECHNIQUE

■ Excess Eyelid Skin Removal

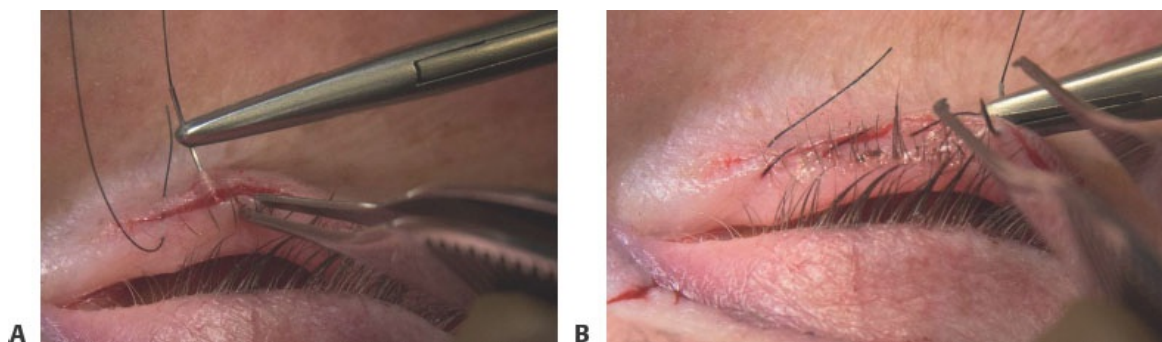
- Using two Adson-Brown forceps, the skin of the lower eyelid near the ciliary margin is grasped and moved cephalically.
- The skin is then tented up sequentially from lateral to medial and crushed with a fine hemostat for hemostasis and to precisely outline the amount of skin to be removed (**TECH FIG 1A–C**).
- Using a Stevens scissors, the tented skin only is excised. The skin is trimmed from medial to most commonly just lateral to the lateral canthus (**TECH FIG 2A–C**).
- Closure is performed using a running 6-0 silk suture (**TECH FIG 3A,B**).



TECH FIG 1 • A–C. A hemostat is used to precisely and sequentially outline the planned skin resection.



TECH FIG 2 • A–C. The skin is excised using Steven scissors.



TECH FIG 3 • A,B. Closure with 6-0 silk suture.

PEARLS AND PITFALLS

Preoperative counseling

- Patients must be counseled that all lower eyelid laxity cannot be removed to avoid lower eyelid malposition.
- This procedure should be avoided with patients who exhibit lower eyelid malposition and/or poor lower eyelid tone.

Local anesthesia

- Injected volume can reduce precision of the procedure.

Lateral extension of excision

- If excision is not carried out lateral to the lateral canthus, bunching and incomplete correction can result.

POSTOPERATIVE CARE

- Patients are instructed to apply cold compresses to the eyes continuously for 12 hours after surgery.
- Sutures are removed at 3 days.
- Alcohol should be avoided for 2 to 3 days and heavy exercise avoided for 2 weeks.
- Patients are encouraged to sleep on their backs.

OUTCOMES

- Excellent contour is restored to the lower periorbital area following excess skin excision.

- This technique does not require any dissection, so complications such as excess bruising, swelling, and eyelid malposition are nonexistent.

COMPLICATIONS

- If too much skin is excised, there is a possibility for excess tension on the incision at closure. Typically, delayed healing will occur spontaneously.

Indications and Technique for Transconjunctival Fat Removal and Redraping in the Lower Eyelids

33

CHAPTER

Francisco G. Bravo

DEFINITION

- Patients with good skin quality who present with prominent lower eyelid bags and evident nasojugal and palpebromalar grooves may benefit from transconjunctival fat removal and redraping of excess fat over the inferior orbital rim.^{1–4}
- This procedure avoids the need for external incisions, which may be visible in younger patients and may be associated with a higher incidence of complications such as lower lid retraction, scleral show, and prolonged swelling.
- The need for routine use of canthal support techniques is also generally avoided through this approach.
- A recessed lower orbital rim and an evident tear trough deformity may be augmented and attenuated, respectively, with the patient's own prominent lower eyelid bags without the need for fat grafting or synthetic filler injections.

ANATOMY

- The lower eyelid consists of an anterior, middle, and posterior lamella⁵ (**FIG 1A**).
- Skin and the *orbicularis oculi* muscle form the anterior lamella.
- The orbital septum, orbital fat, and suborbicularis adipose tissue form the middle lamella.
- The tarsal plate, lower eyelid retractors (capsulopalpebral head and fascia),

and the conjunctiva form the posterior lamella.

- The *orbicularis oculi* muscle is subdivided into the pretarsal, preseptal, and orbital components.
- There are three postseptal fat compartments in the lower eyelid (**FIG 1B**).
- Nasal and central fat pads are separated by the inferior oblique muscle.
- Central and lateral fat pads are separated by the arcuate expansion of the Lockwood ligament (**FIG 1C**).
- The *orbicularis* retaining ligament or orbitomalar ligament attaches the palpebral *orbicularis oculi* muscle to the underlying maxilla (**FIG 2A**).
- The tear trough or nasojugal groove and the lid-cheek junction or palpebromalar groove extend below the orbital rim and are explained by anatomical features in the subcutaneous plane⁶ (**FIG 2B**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for patients seeking lower eyelid surgery includes a detailed assessment of the patient's medical history and a thorough physical examination.⁷
- Medical history
 - Special attention should be paid to risk factors that may predispose to postoperative complications.
 - Thyroid pathology, diabetes, hypertension, heart disease, coagulopathy, and any previous periorbital surgery or trauma should be documented.
 - Vision disorders such as impaired visual acuity or the need to use corrective glasses or contact lenses should be noted before surgery.
 - The use of medications such as aspirin and other nonsteroidal anti-inflammatory drugs, anticoagulants, and certain vitamins and herbal supplements such as vitamin E and ginkgo should be recorded and suspended 2 weeks prior to surgery.

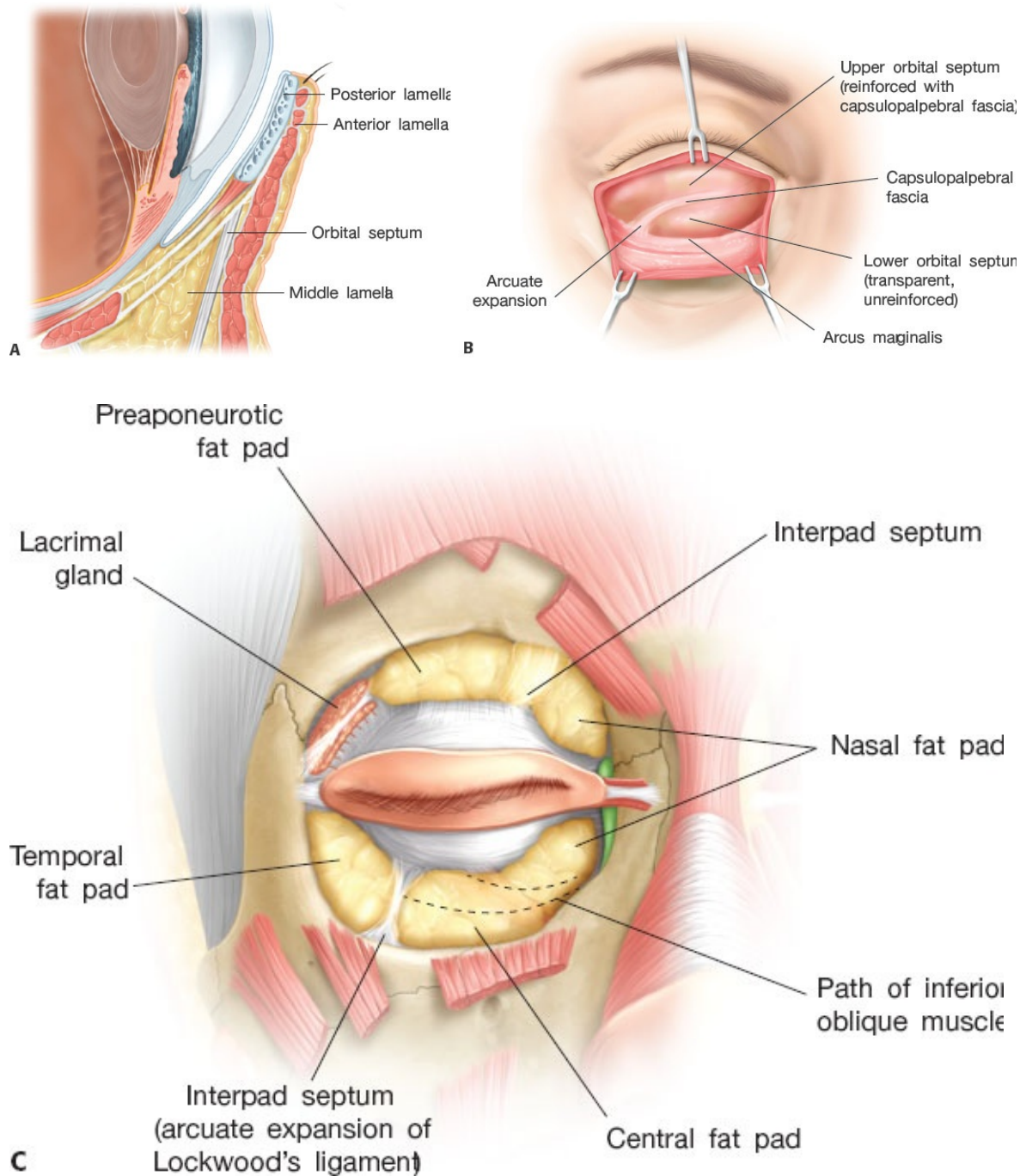


FIG 1 • A. The lower eyelid consists of an anterior, middle, and posterior lamella. **B.** There are three postseptal fat compartments in the lower eyelid. **C.** Central and lateral fat pads are separated by the arcuate expansion of the Lockwood ligament.

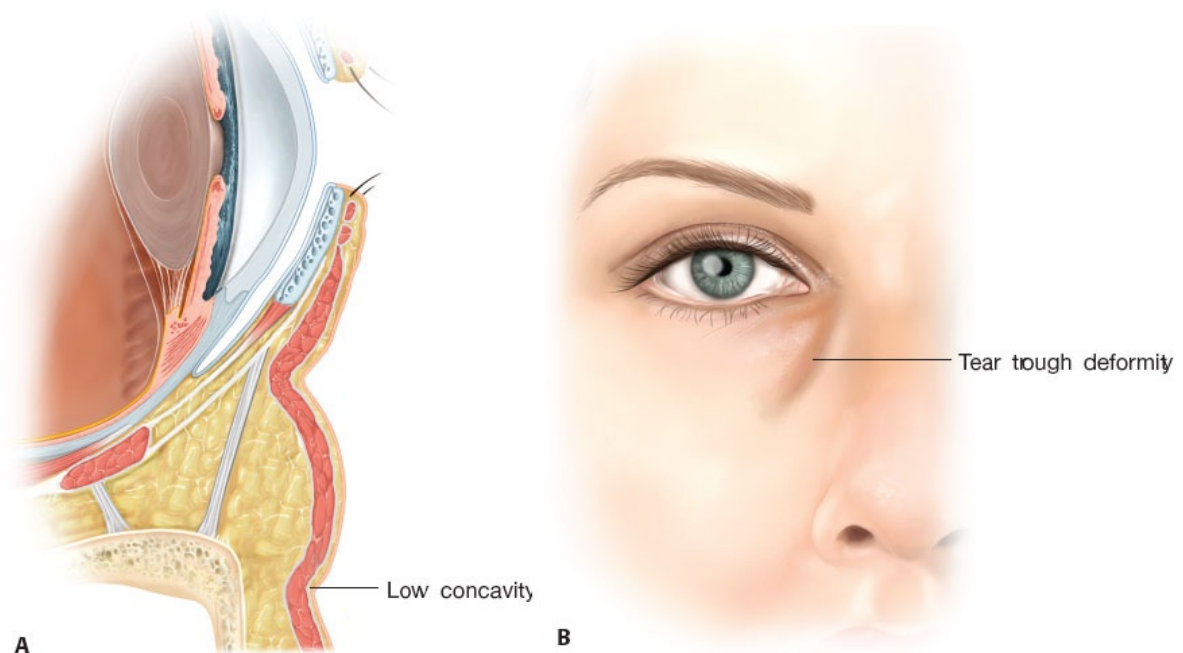


FIG 2 • A. The *orbicularis* retaining ligament or orbitomalar ligament attaches the palpebral *orbicularis oculi* muscle to the underlying maxilla. **B.** The tear trough or nasojugal groove and the lid-cheek junction or palpebromalar groove extend below the orbital rim and are explained by anatomical features in the subcutaneous plane.

- Smoking history should also be documented and interrupted preferably for 4 weeks prior and 2 weeks after surgery.
- A history suggestive of dry eye syndrome should be clarified, and if present, the decision to proceed should be discussed carefully with the patient.
- Physical examination
 - Evaluation should be performed with three goals in mind:
 - To document preoperative eye function
 - To identify anatomical features that may predispose patients to developing postoperative complications
 - To identify the specific anatomical features that are causing the patient's concern in order to customize the procedure
 - Functional evaluation should include an examination and documentation of visual acuity, extraocular muscular movements, Bell phenomenon, pupillary

response, and adequate tear production through a Schirmer or tear break-apart time test.⁷

- Anatomic features that may predispose to postoperative complications such as lower eyelid retraction, ectropion, or malposition⁸ include the following:
 - A negative vector caused by a prominent eye or a retruded maxilla, which may be measured by a Hertel exophthalmometer
 - Tarsoligamentous or horizontal lid margin laxity with a measurable lag in the snapback test and a greater than 6-mm distraction test
 - A negative canthal tilt in which the lateral canthus lies at a lower position in relationship to the medial canthus
 - Scleral show in which the lid margin rests below the corneoscleral limbus
- Specific anatomic features^{9,10} that need to be identified as possible causes of the morphological concerns the patient might wish to address are as follows:
 - Orbital fat herniation or prolapse due to fat pad hypertrophy or to excessive laxity of the orbital septum and orbicularis oculi muscle
 - Tear trough deformity and a deep lid-cheek junction
 - Dark circles due to skin pigmentation or prominent intramuscular vasculature in patients with thin, translucent skin and subcutaneous fat atrophy
 - Dermatochalasis or skin excess and rhytides
 - Orbicularis prominence or hypertrophy
 - Malar bags and festoons

IMAGING

- The use of high-quality preoperative photography is a key element to plan and carry out eyelid surgery, as well as to document and serve as reference for clinical examination.
- Standardization in patient positioning, lighting, lens focal length, and background is crucial to avoid misinterpretation and distortion of the patient's anatomic features.¹¹
- The photographic series should include frontal, oblique, and profile views (**FIG 3**), as well as frontal views while smiling, rising the eyebrows, frowning, gazing upward, closing the eyes, and also with slight posterior and anterior head tilts while looking into the lens.
- High-quality video capture should also be considered to appropriately document ocular and eyelid function preoperatively.

- Digital imaging software may be an important adjunct to precisely evaluate eyelid morphology and to detect asymmetries, which are common in the lower eyelid.¹²

NONOPERATIVE MANAGEMENT

- With the popularity and appeal of noninvasive procedures among cosmetic surgery patients, a thorough and earnest discussion should be maintained regarding the advantages and disadvantages of such techniques versus surgical options by attending to the patient's particular anatomic features and concerns.
- Botulinum toxin may be employed to reduce skin wrinkles and expression lines along the lateral portion of the lower eyelid, as well as to soften *orbicularis* hypertrophy or protrusion.
- Skin resurfacing techniques with either lasers or chemical peels such as trichloroacetic acid or phenol/croton oil may be performed to improve skin quality and dermatochalasis.
- The use of fillers such as hyaluronic acid, collagen, or the patient's own fat may be infiltrated around the lower eyelid to correct an evident tear trough or deep lid-cheek junction or to augment the inferior orbital rim and malar area to provide better support and contour in a negative vector patient.
- The use of nonsurgical procedures should not be discarded even if surgery is indicated as they may be valuable adjuncts to improve and enhance the results after lower blepharoplasty.

SURGICAL MANAGEMENT

- The decision to proceed with surgery depends on the specific anatomic concerns of the patient as well as on the degree and duration of the result sought.¹³
- Indications for surgery include herniated and prolapsed bags appearing together with an evident tear trough deformity or deep lid-cheek junction.
- Patients with poor skin quality or noticeable dermatochalasis are not good candidates for transconjunctival fat removal and redraping in the lower eyelid. They must be informed that this procedure alone will not improve and may even worsen this specific condition.
- Risks to the patient include hematoma, infection, and scarring
- Determining the correct amount of fat to resect directly impacts the result of the procedure. Excessive resection may result in insufficient tear trough correction, whereas inadequate resection may leave a bulge that could require

revision.¹⁴

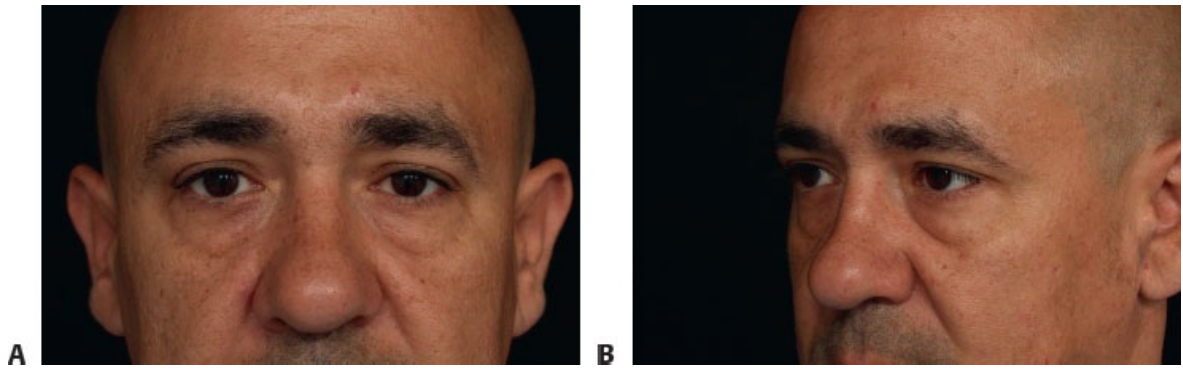


FIG 3 • **A.** Preoperative frontal. **B.** Preoperative three-quarters views of a male patient with protruding eyelid bags and marked nasojugal and palpebromalar grooves.



FIG 4 • Preoperative markings.

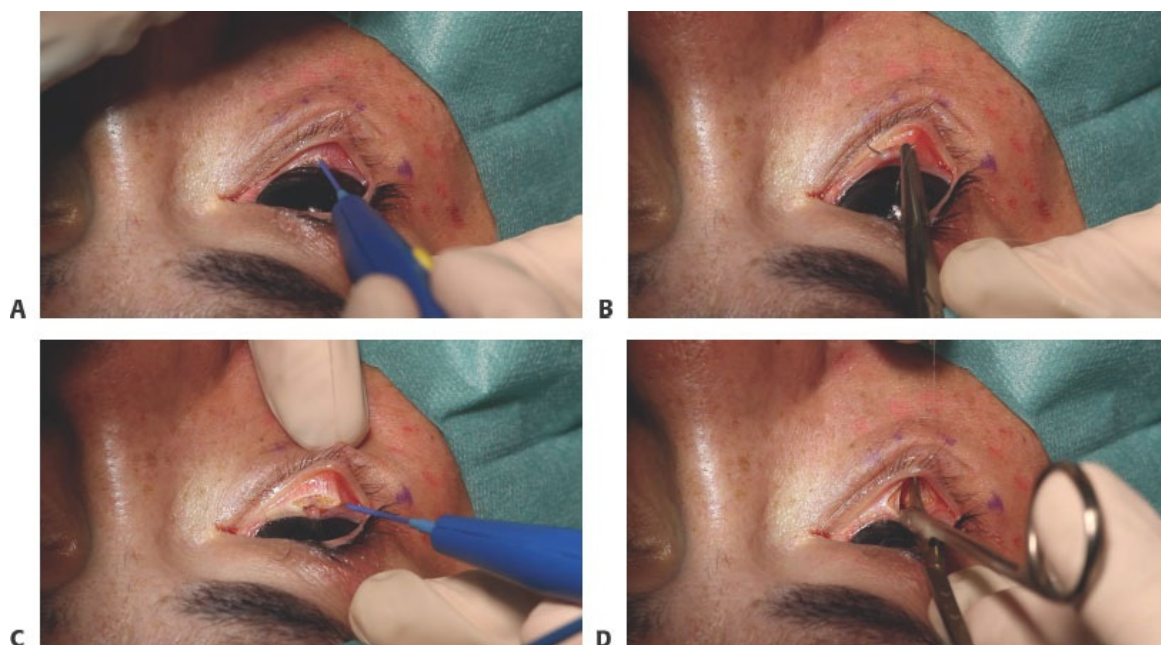
TECHNIQUES



Video p1-c033

■ Exposure

- A 5/0 silk traction suture with a noncutting needle is placed through the lower eyelid to expose the conjunctiva.
- An incision with needle-tip electrocautery is performed just above the fornix through the conjunctiva (**TECH FIG 1A**).
- A traction suture is placed through the posterior conjunctival flap and held with a mosquito clamp over the corneal protector (**TECH FIG 1B**). The incision through the conjunctiva is then completed (**TECH FIG 1C**).
- Vertical dissection with Stevens scissors divides the capsulopalpebral fascia, and an insulated Desmarres retractor is used to elevate caudally the palpebral edge of the divided conjunctiva (**TECH FIG 1D**).



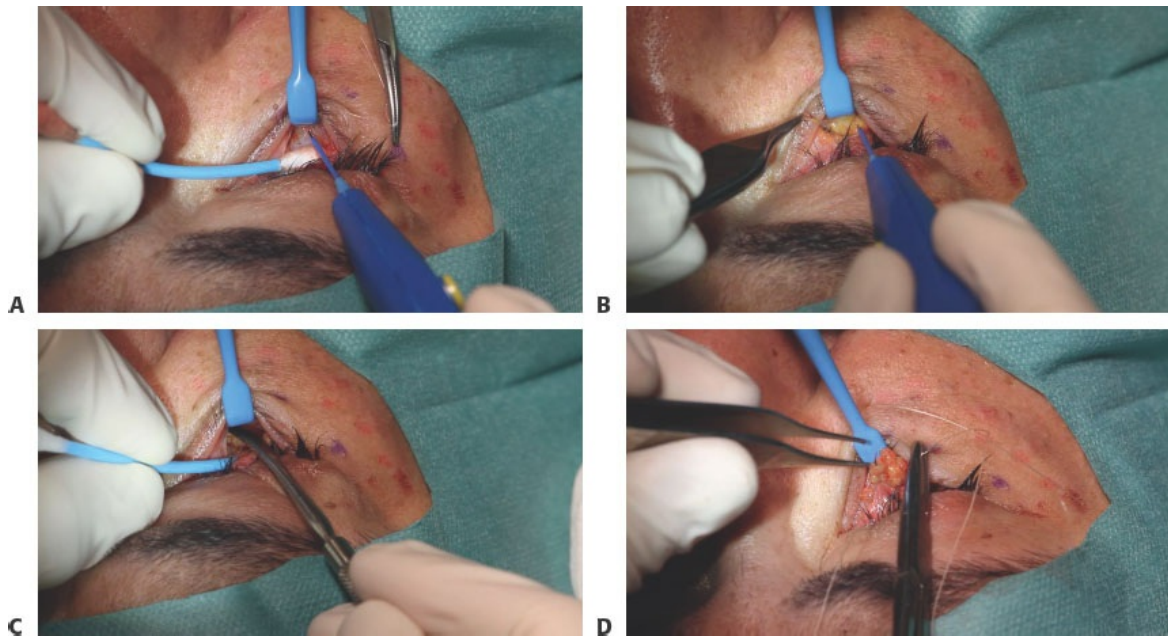
TECH FIG 1 • **A.** An incision with needle-tip electrocautery is performed just above the fornix through the conjunctiva. **B.** A traction suture is placed through the posterior conjunctival flap and held with a mosquito clamp over the corneal protector. **C.** The incision through the conjunctiva is then completed. **D.** Vertical dissection with Stevens scissors divides the capsulopalpebral fascia, and an insulated Desmarres retractor is used to elevate caudally the palpebral edge of divided conjunctiva.

■ Fat Pad Resection

- The orbital septum is visualized and the fat compartments identified with the help of sterile cotton tips (**TECH FIG 2A**).
- The septum is incised and gentle, continuous pressure is applied to the globe to allow the fat to herniate.
- Fat is conservatively excised with electrocautery according to the preoperative plan from the medial, central, and lateral fat compartments (**TECH FIG 2B**).
- The *arcus marginalis* is released and a 7- to 15-mm subperiosteal dissection

over the inferior orbital rim is performed and extended laterally by releasing the *orbicularis* retaining ligament with cautery and a periosteal elevator³ (**TECH FIG 2C**).

- Alternatively, the dissection can be carried out in the suborbicularis plane suprapariostally, although more bleeding may be encountered.
- Fat transposition is performed with the aid of two to three percutaneous sutures by securing the medial and central fat pads over the inferior orbital rim to ablate the tear trough deformity and blending the lid-cheek junction¹⁴ (**TECH FIG 2D**).
- Transposition of the lateral fat pad is seldom indicated although it may be performed after releasing the lateral orbital thickening.



TECH FIG 2 • A. The orbital septum is visualized and the fat compartments identified with the help of sterile cotton tips. **B.** Fat is conservatively excised with electrocautery according to the preoperative plan from the medial, central, and lateral fat compartments. **C.** The *arcus marginalis* is released and a 7- to 15-mm subperiosteal dissection over the inferior orbital rim is performed and extended laterally by releasing the *orbicularis* retaining ligament with cautery and a

periosteal elevator. **D.** Fat transposition is performed with the aid of two to three percutaneous sutures securing the medial and central fat pads over the inferior orbital rim ablating the tear trough deformity and blending the lid-cheek junction.

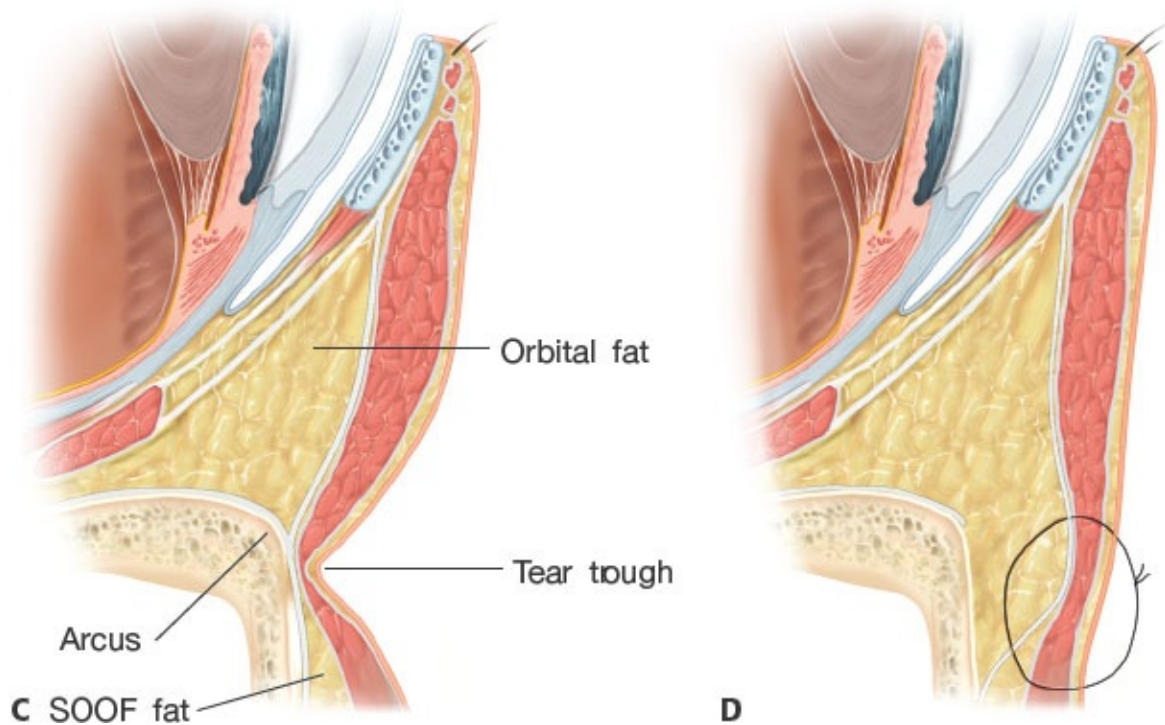
■ Completion

- A 4/0 fast resorbing suture on a noncutting needle is passed percutaneously deep to the *orbicularis*, through the fat pads twice and back out through the skin (**TECH FIG 3A**).
- The sutures are secured over a Xeroform or cotton bolster or simply held in place using Steri-Strips² (**TECH FIG 3B–D**).
- Hemostasis is revised and the wound is thoroughly cleansed with saline. The traction suture and corneal protector are removed. It is not necessary to suture the conjunctiva.
- Secondary procedures such as a lower eyelid skin excision/resurfacing or canthopexy may be performed at this stage.





B



TECH FIG 3 • A. A 4/0 fast resorbing suture on a noncutting needle is passed percutaneously deep to the *orbicularis*, through the fat pads twice and back out through the skin. **B.** The sutures are secured over a Xeroform or cotton bolster or simply held in place using Steri-Strips. **C,D.** Illustration showing the lower eyelid fat pads before being secured over the inferior orbital rim through percutaneous sutures.

PEARLS AND PITFALLS

Patient evaluation	■ Failure to identify adequate candidates for the procedure will inevitably lead to suboptimal results. ■ A tear trough deformity caused by a sagging <i>orbicularis</i> muscle or excessive skin will not be corrected by transconjunctival fat pad redraping alone.
Hemostasis	■ Bleeding should be avoided from beginning to end of the procedure through adequate infiltration and use of needle-tip cautery for dissection and fat excision.
Exposure	■ Inadequate exposure of the surgical field should be avoided. The length of the transconjunctival incision should be long enough to ensure correct visualization. ■ Alternatively, the lateral fat pad may be approached through the upper eyelid incision if an upper blepharoplasty is planned concomitantly.
Fat resection	■ Fat pad resection should be performed cautiously on the medial and central compartments to avoid ending up with too little fat to transpose. ■ Excision of the lateral fat pad is often more ample because correction of a deep lid-cheek junction laterally is usually insufficient through transposition alone.
Orbital rim dissection	■ Dissection over the inferior orbital rim should be generous to accommodate for the transposed fat pads and allow them to adequately redrape caudally. Care should be taken to avoid injury to the inferior orbital nerve.
Percutaneous sutures	■ Placement of the percutaneous sutures should be performed far enough caudally to provide sufficient tension to the transposed fat pads to avoid their retraction back to their original position. ■ A de la Plaza retractor or a small Langenbeck-type retractor may be employed instead of a Desmarres to aid in the placement of the sutures. ■ A blunt tip needle should be employed and passed twice through the fat pads to avoid cheese wiring of the sutures. ■ Caution should be taken not to tie the sutures excessively tight over the bolsters to avoid dents or injury to the skin over the inferior orbital rim due to postoperative facial swelling. ■ Alternatively, Steri-Strips may be employed to hold the sutures in place.

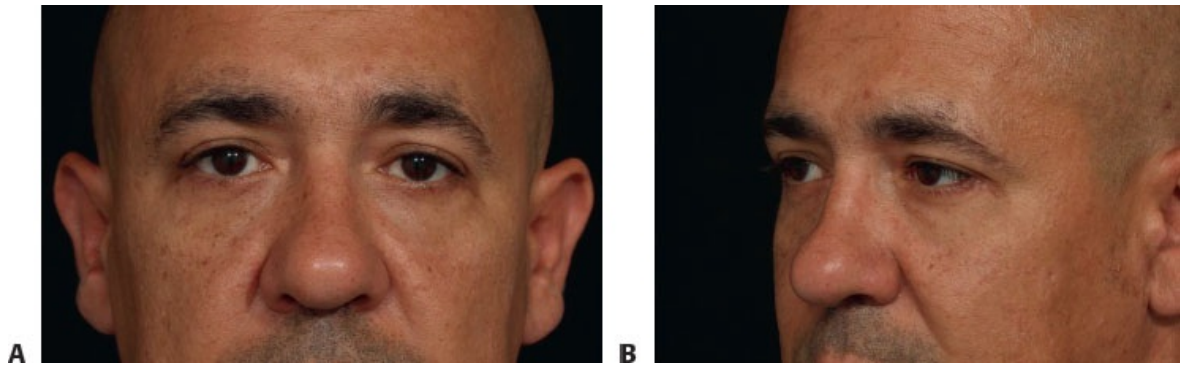


FIG 5 • A. Postoperative frontal. **B.** Postoperative three-quarters views of the patient.

Preoperative Planning

- The complete eyelid photographic series of the patient should be carefully reviewed before surgery and should be available in the operating room.
- Markings on the patient should be performed in the upright position. The tear trough and lid-cheek junction should be outlined, as well as the areas of maximal protrusion of the fat pads (**FIG 4**).
- The patient should be inquired as to whether having taken aspirin in the days prior to surgery and the procedure suspended if aspirin is still taken.
- The surgeon must be familiar with techniques for canthal support and tarsorrhaphy should they be necessary at the end of the procedure.

Positioning

- The patient is positioned supine on the operating table.
- Prepping is performed with a low concentration chlorhexidine solution without alcohol, avoiding penetration into the eyes.
- Intravenous sedation is started and corneal protectors are placed.
- Oxygen is administered through a nasal catheter at a low flow and concentration. Instructions should be given to the anesthetist to momentarily interrupt flow when using electrocautery to avoid accidental fires in the operating room.
- The conjunctiva, lower eyelid, and tear trough are infiltrated with a 1% lidocaine with 1:100,000 epinephrine solution.

Approach

- Approach to the lower eyelid bags and tear trough is achieved preseptally

through a transconjunctival incision made midway between the tarsal plate and fornix.

- Alternatively, the transconjunctival incision may be shortened and the lateral bag may be approached through an upper blepharoplasty incision if performed concomitantly.¹⁵
- Dissection over the orbital rim to create a pocket for the fat pads to be transposed may be performed in a supra- or subperiosteal plane.

POSTOPERATIVE CARE

- The bolsters or Steri-strips are removed after 6 days.
- Patients are instructed to apply cold packs and slight compression for 48 hours.
- Artificial tear drops are prescribed as well as oral antibiotics and pain medication.
- Patients should be carefully followed the evening and day after surgery. Any suspicion of retrobulbar hematoma such as excessive pain, pressure, or nausea and vomiting should be managed urgently through canthotomy with cantholysis and hematoma drainage.
- Patients should start early with massage if lower lid retraction or hardness appears.
- Patients are advised to sleep for 5 days with their head elevated and to avoid activity, medication, or food, which may increase blood pressure or swelling.

OUTCOMES

- Patients with protruding fat pads and an evident tear trough deformity should expect good outcomes when no skin excess is present preoperatively (**FIGS 5–7**).
- Hidalgo performed transconjunctival fat transposition in 61% of 248 consecutive lower blepharoplasties in which an integrated approach was employed. Only 2.4% required revision to remove excess fat or skin.¹⁴
- Goldberg reviewed the results of 24 consecutive patients who underwent subperiosteal transconjunctival fat repositioning and noted hardening of the transposed fat that resolved by 6 months. Four patients required revision for undercorrection of the tear trough deformity.³
- A recurrence of the initial deformity may appear if fixation of the extruded fat pads over the inferior orbital rim is insufficient or if excess fat was not adequately removed.

COMPLICATIONS

- Apart from prolonging postoperative downtime, a hematoma may constitute a true surgical emergency if the bleeding accumulates in the retrobulbar space, which may lead to optic nerve compression and blindness.¹⁶
- Although an infrequent complication, an infection should be treated promptly with topical or systemic antibiotics if necessary.
- Patients should be informed of the possibility of lid margin malposition or retraction despite avoiding an external incision. Excessive or inadequate scarring in the middle or posterior lamella may be responsible for this complication. Surgical revision may be required to correct it, although early management with vertical massage and taping may be sufficient to avoid surgery.

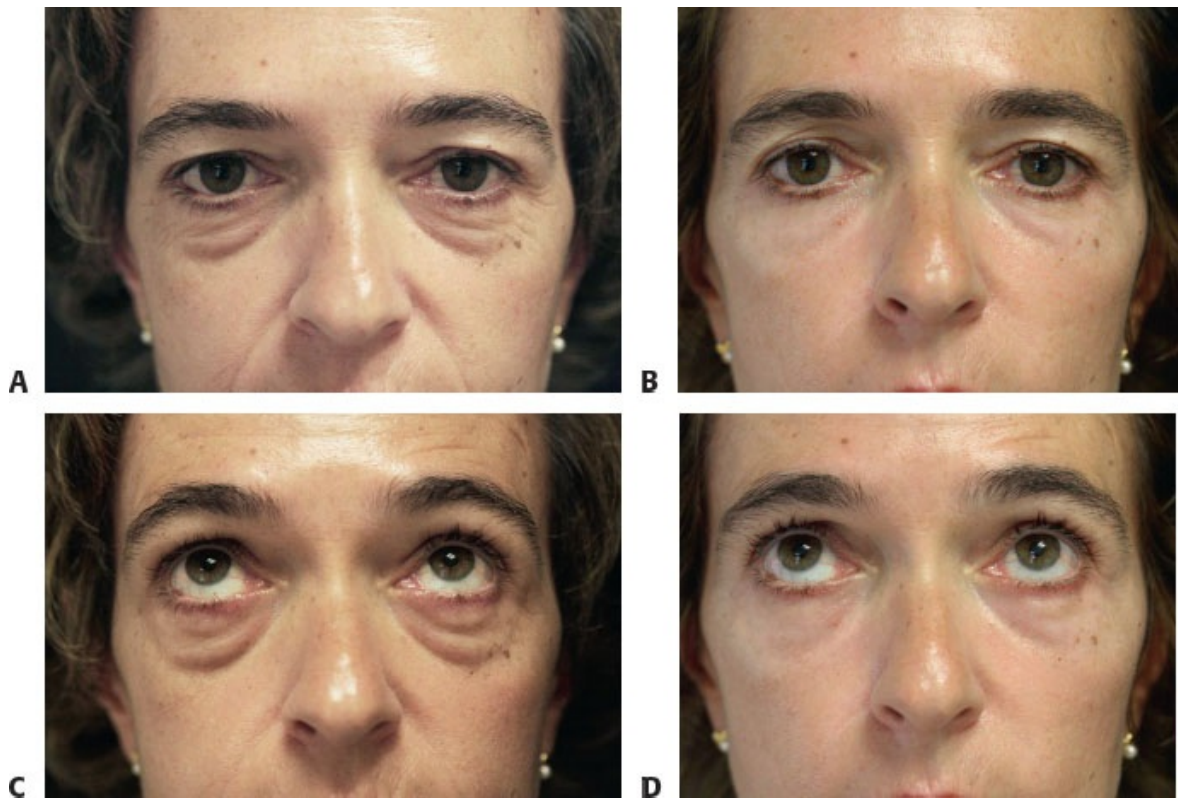


FIG 6 • Female patient with protruding eyelid bags and marked nasojugal and palpebromalar grooves. **A.** Preoperative frontal view. **B.** Postoperative frontal view. **C.** Preoperative view in upward gaze. **D.** Postoperative view in upward gaze.

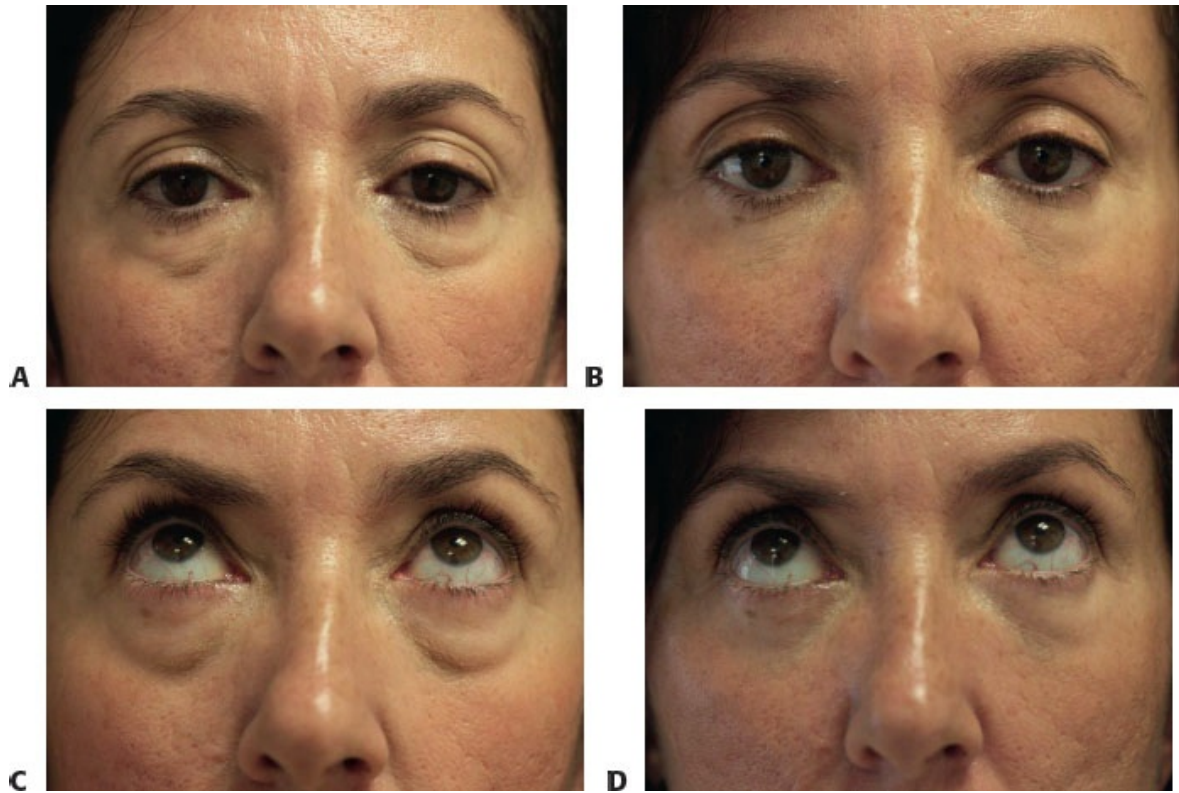


FIG 7 • Female patient with protruding eyelid bags and marked nasojugal and palpebromalar grooves. **A.** Preoperative frontal view. **B.** Postoperative frontal view. **C.** Preoperative view in upward gaze. **D.** Postoperative view in upward gaze.

- Prolonged edema may be seen more frequently when fat transposition is performed, due to the more extensive infraorbital dissection required, which produces more disruption of lymphatic channels draining the orbit.
- Patients may also experience various degrees of hardening and fibrosis around the infraorbital rim where the fat is transposed, especially in the first 3 months.³
- Inclusion cysts or granulomas may occur after a transconjunctival approach, especially if a long incision was employed and topical ointment was prescribed postoperatively.
- Chemosia is less common through the transconjunctival approach but may occur more frequently if canthal support techniques were added to the procedure.

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Indications and Technique for Lower Blepharoplasty via Subciliary Incision

34

CHAPTER

Francisco G. Bravo

DEFINITION

- Patients concerned with the aesthetic appearance of their lower eyelids may be managed surgically through a direct external approach bellow the lid margin.
- Patients with poor skin quality or dermatochalasis associated with prominent bags and orbicularis laxity are good candidates for this approach.
- Canthal support techniques as well as orbicularis suspension maneuvers are usually required and are frequently performed routinely to avoid postoperative lid malposition.

ANATOMY

- The lower eyelid consists of an anterior, middle, and posterior lamella¹ (**FIG 1A**).
- The skin and the orbicularis oculi muscle form the anterior lamella.
- The orbital septum, orbital fat, and suborbicularis adipose tissue form the middle lamella.
- The tarsal plate, lower eyelid retractors (capsulopalpebral head and fascia), and the conjunctiva form the posterior lamella.
- The orbicularis oculi muscle is subdivided into the pretarsal, preseptal, and orbital components.
- There are three postseptal fat compartments in the lower eyelid (**FIG 1B**).
- Nasal and central fat pads are separated by the inferior oblique muscle.
- Central and lateral fat pads are separated by the arcuate expansion of the Lockwood ligament (**FIG 1C**).
- The orbicularis retaining ligament or orbitomalar ligament attaches the

palpebral orbicularis oculi muscle to the underlying maxilla (**FIG 2A**).

- The tear trough or nasojugal groove and the lid-cheek junction or palpebromalar groove extend below the orbital rim and are explained by anatomical features in the subcutaneous plane² (**FIG 2B**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for patients seeking lower eyelid surgery includes a detailed assessment of the patient's medical history and a thorough physical examination.³
- Medical history
 - Special attention should be paid to risk factors that may predispose to postoperative complications.
 - Thyroid pathology, diabetes, hypertension, heart disease, coagulopathy, and any previous periorbital surgery or trauma should be documented.
 - Vision disorders such as impaired visual acuity or the need to use corrective glasses or contact lenses should be noted before surgery.
 - The use of medications such as aspirin and other nonsteroidal anti-inflammatory drugs, anticoagulants, and certain vitamins and herbal supplements such as vitamin E and ginkgo should be recorded and suspended 2 weeks prior to surgery.
 - Smoking history should also be documented and interrupted preferably for 4 weeks prior and 2 weeks after surgery.
 - A history suggestive of dry eye syndrome should be clarified, and if present, the decision to proceed should be discussed carefully with the patient.
- Physical examination
- Evaluation should be performed with three goals in mind:
 - Document preoperative eye function
 - Identify anatomic features that may predispose patients to developing postoperative complications.
 - Identify the specific anatomical features that are causing the patient's concern in order to customize the procedure.
- Functional evaluation should include an examination and documentation of visual acuity, extraocular muscular movements, Bell phenomenon, pupillary response, and adequate tear production through a Schirmer or tear break-apart time test.³
- Anatomic features that may predispose to postoperative complications such as lower eyelid retraction, ectropion, or malposition include the following:

- A negative vector caused by a prominent eye or a retruded maxilla, which may be measured by a Hertel exophthalmometer.
- Tarsoligamentous or horizontal lid margin laxity with a measurable lag in the snap-back test and a greater than 6 mm distraction test.
- A negative canthal tilt in which the lateral canthus lies at a lower position in relationship to the medial canthus.
- Scleral show in which the lid margin rests below the corneoscleral limbus.
- Specific anatomic features that need to be identified as possible causes of the morphological concerns the patient might wish to address include^{4,5}

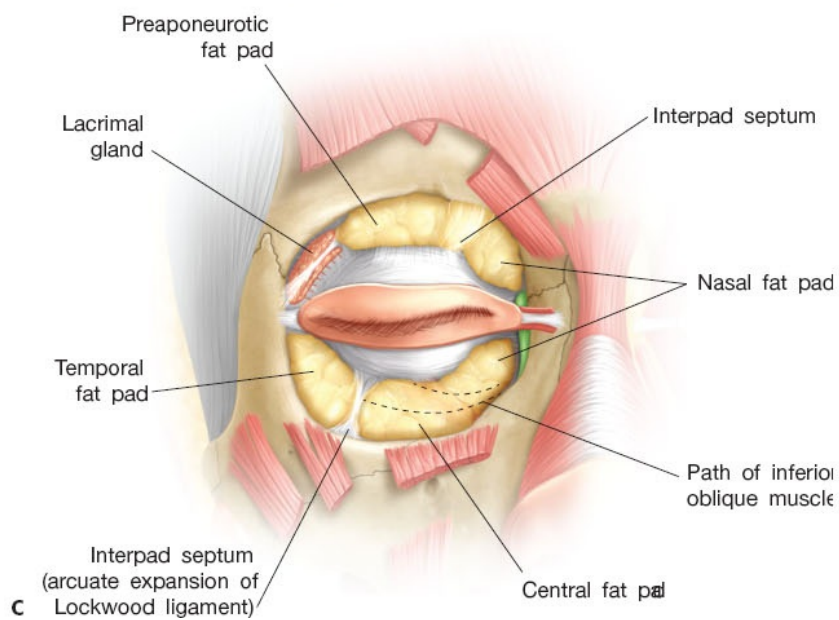
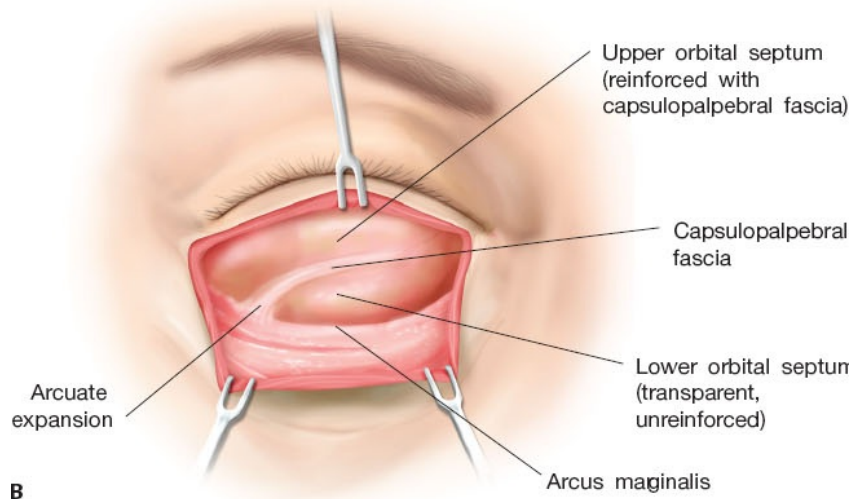
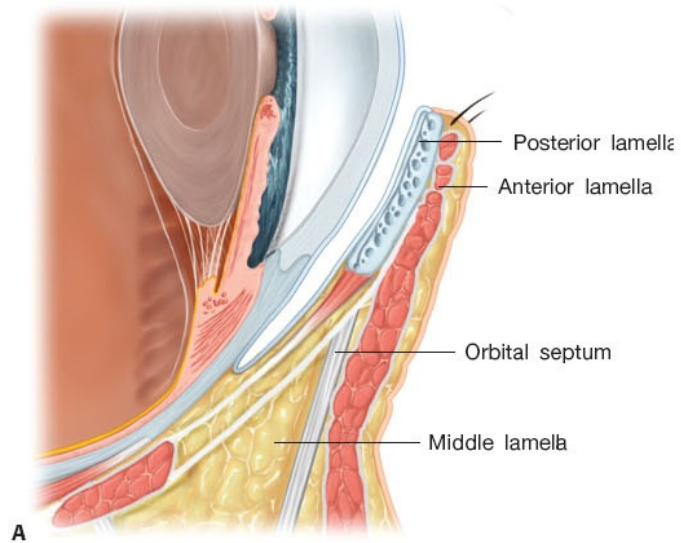


FIG 1 • A. The lower eyelid consists of an anterior, middle, and posterior lamella. **B.** There are three postseptal fat compartments in the lower eyelid. **C.** Central and lateral fat pads are separated by the arcuate expansion of the Lockwood ligament.

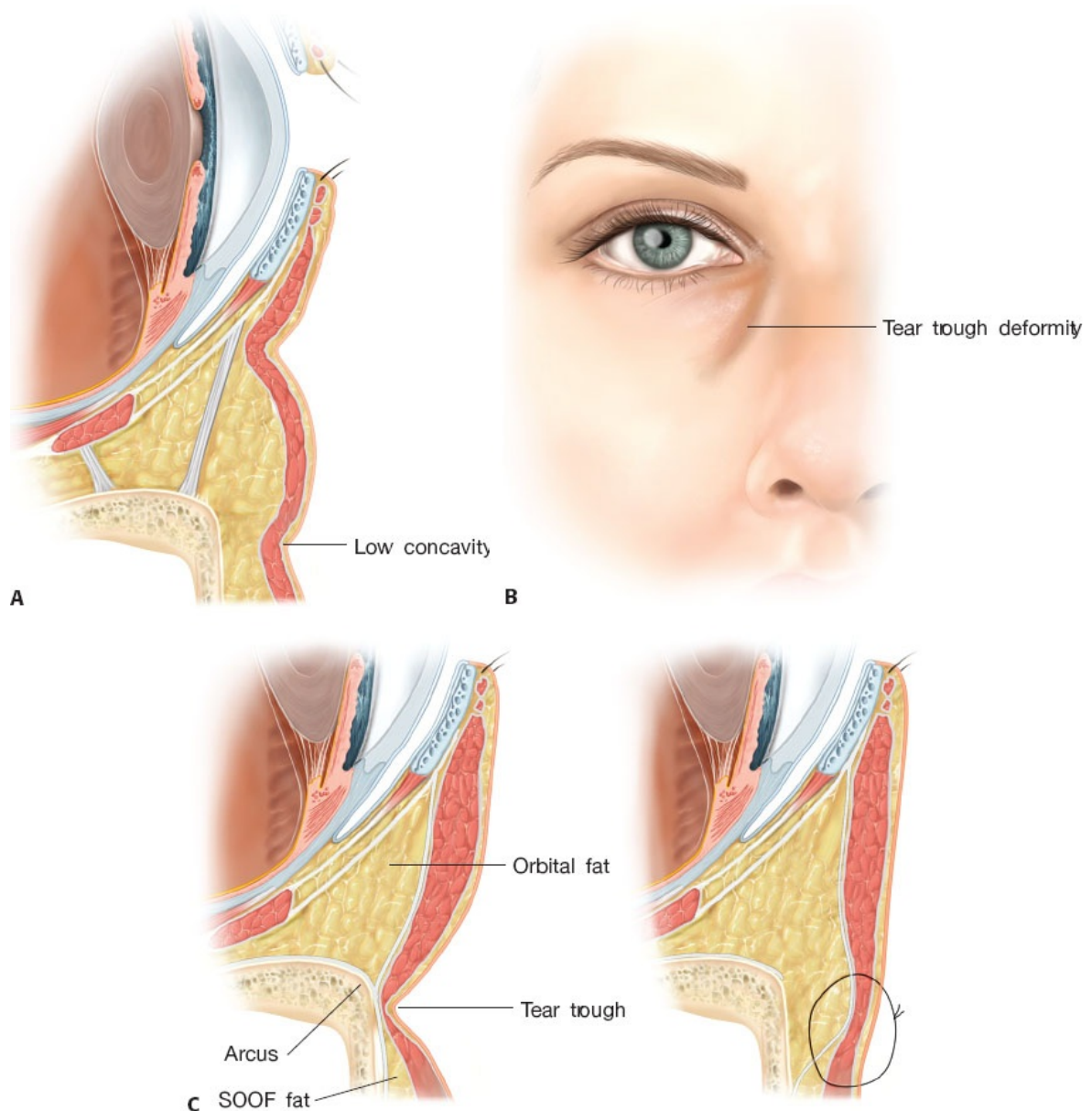


FIG 2 • A. The orbicularis retaining ligament or orbitomalar ligament attaches the palpebral orbicularis

oculi muscle to the underlying maxilla. **B,C.** The tear trough or nasojugal groove and the lid-cheek junction or palpebromalar groove extend below the orbital rim and are explained by anatomical features in the subcutaneous plane.

- Orbital fat herniation or prolapse due to fat pad hypertrophy or caused by excessive laxity of the orbital septum and orbicularis oculi muscle
- Tear trough deformity and a deep lid-cheek junction
- Dark circles due to skin pigmentation or prominent intramuscular vasculature in patients with thin, translucent skin and subcutaneous fat atrophy
- Dermatochalasis or skin excess and rhytides
- Orbicularis prominence or hypertrophy
- Malar bags and festoons

IMAGING

- The use of high-quality preoperative photography is a key element to plan and carry out eyelid surgery, as well as to document and serve as reference for clinical examination.
- Standardization in patient positioning, lighting, lens focal length, and background is crucial to avoid misinterpretation and distortion of the patient's anatomic features.⁶
- The photographic series should include frontal, oblique, and profile views, as well as frontal views while smiling, rising the eyebrows, frowning, gazing upward, and closing the eyes, and also with slight posterior and anterior head tilts while looking into the lens.
- High-quality video capture should also be considered to appropriately document ocular and eyelid function preoperatively.
- Digital imaging software may be an important adjunct to precisely evaluate eyelid morphology and to detect asymmetries, which are common in the lower eyelid.⁷

NONOPERATIVE MANAGEMENT

- With the popularity and appeal of noninvasive procedures among cosmetic surgery patients, a thorough and earnest discussion should be maintained regarding the advantages and disadvantages of such techniques vs surgical

options attending to the patient's particular anatomic features and concerns.

- Botulinum toxin may be employed to reduce skin wrinkles and expression lines along the lateral portion of the lower eyelid, as well as to soften orbicularis hypertrophy or protrusion.
- Skin resurfacing techniques with either lasers or chemical peels such as trichloroacetic acid or phenol-croton oil may be performed to improve skin quality and dermatochalasis.
- The use of fillers such as hyaluronic acid, collagen, or the patient's own fat may be infiltrated around the lower eyelid to correct an evident tear trough or deep lid-cheek junction or to augment the inferior orbital rim and malar area to provide better support and contour in a negative vector patient.
- The use of nonsurgical procedures should not be discarded even if surgery is indicated as they may be valuable adjuncts to improve and enhance the results after lower blepharoplasty.

SURGICAL MANAGEMENT

- The decision to proceed with surgery depends on the specific anatomic concerns of the patient as well as on the degree and duration of the result sought.⁸
- Indications for surgery include herniated and prolapsed bags, an evident tear trough deformity or deep lid-cheek junction and orbicularis muscle laxity or excess skin.
- Patients with good skin quality might be better candidates for a transconjunctival approach.
- Risks to the patient include hematoma, infection, and lower eyelid retraction or malposition.
- The main steps include access to the eyelid bags through a subciliary incision, release of the arcus marginalis and orbitomalar ligament, removal of lower eyelid fat, lateral canthopexy, and resuspension or tightening of the orbicularis muscle.
- The skin should be excised conservatively in most cases, and canthal support techniques should be employed routinely to decrease the incidence of lower lid retraction or scleral show.

Preoperative Planning

- The complete eyelid photographic series of the patient should be carefully reviewed before surgery and should be available in the operating room.

- Markings on the patient should be performed in the upright position. The tear trough and lid-cheek junction should be outlined, as well as the areas of maximal protrusion of the fat pads.
- The patient should be inquired as to whether having taken aspirin in the days prior to surgery and the procedure suspended if a positive response was given.
- The surgeon must be familiar with techniques for canthal support and tarsorrhaphy as they are often necessary at the end of the procedure.

Positioning

- The patient is positioned supine on the operating table.
- Prepping is performed with a low concentration chlorhexidine solution without alcohol, avoiding penetration into the eyes.
- Intravenous sedation is started, and corneal protectors are placed.
- Oxygen is administered through a nasal catheter at a low flow and concentration. Instructions should be given to the anesthetist to momentarily interrupt flow when using electrocautery to avoid accidental fires in the operating room.
- The lower eyelid and inferior orbital rim are infiltrated with a 1% lidocaine with 1:100 000 epinephrine solution.

Approach

- Skin-muscle flap approach with orbicularis oculi resuspension:
 - Exposure to the lower eyelid bags and orbital septum is achieved through the subciliary incision, dividing the muscle in a stair-step fashion to preserve the pretarsal segment.
 - Undermining of the skin-muscle flap is performed to achieve adequate exposure of the orbital septum and inferior orbital rim for fat reduction.
 - A strong resuspension of the orbicularis to the periosteum is required after skin excision, so as to avoid lid malposition or retraction postoperatively.
- Skin-only flap approach with reverse orbicularis oculi tightening (ROOT):
 - Exposure of the pretarsal and preseptal segments of the orbicularis is achieved through the subciliary incision by undermining a skin-only flap extending to the infraorbital rim.
 - The orbital septum and fat pads are exposed through an incision in the caudal aspect of the preseptal orbicularis taking care to avoid the medial portion that provides innervation through buccal branches to the pretarsal segment.

- After fat reduction is performed, tightening of the lax orbicularis muscle is performed in a reverse fashion by excising a segment of the muscle caudally and repairing the orbicularis without tension.
- Skin excision and muscle tightening are performed independently through this approach, which may be useful in patients with evident muscular laxity and excess skin.

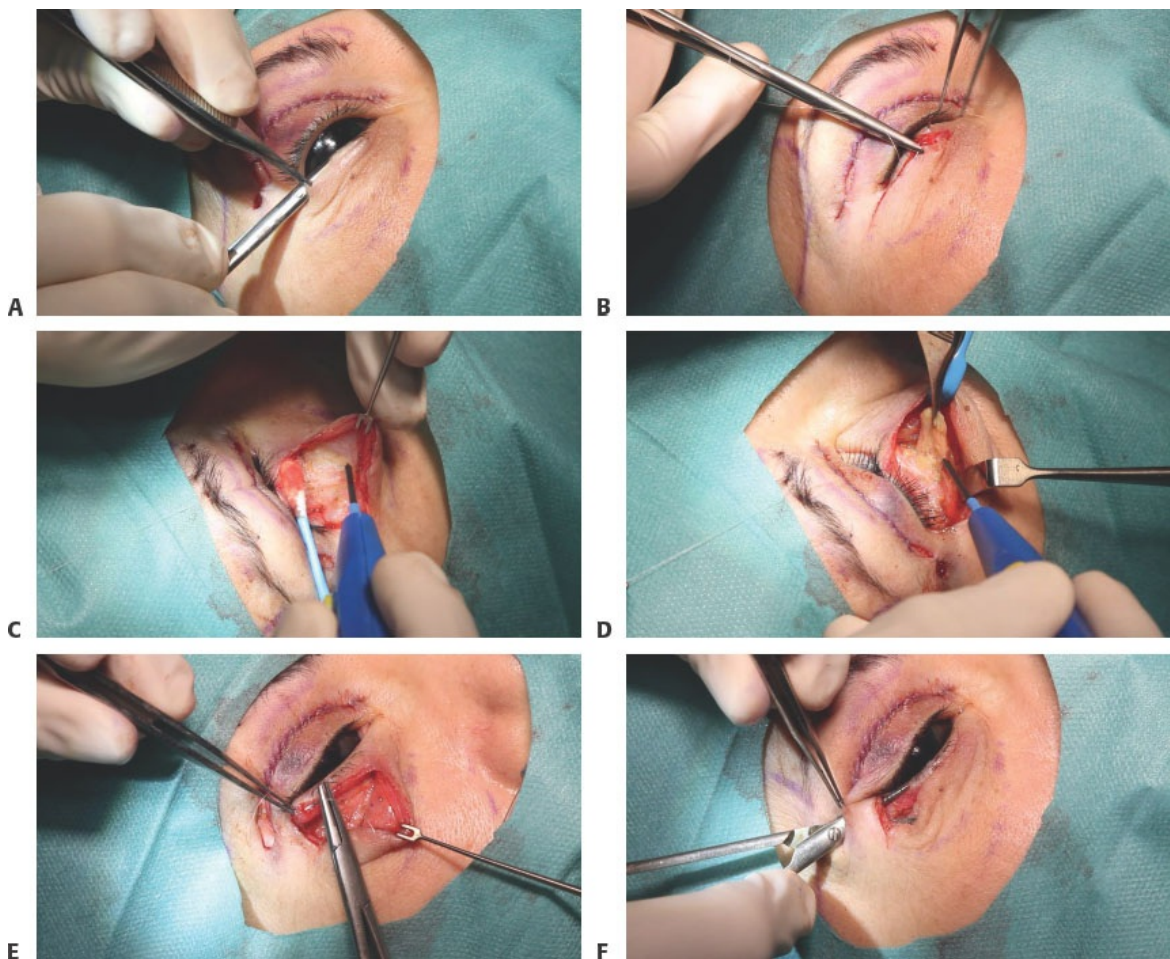
TECHNIQUES

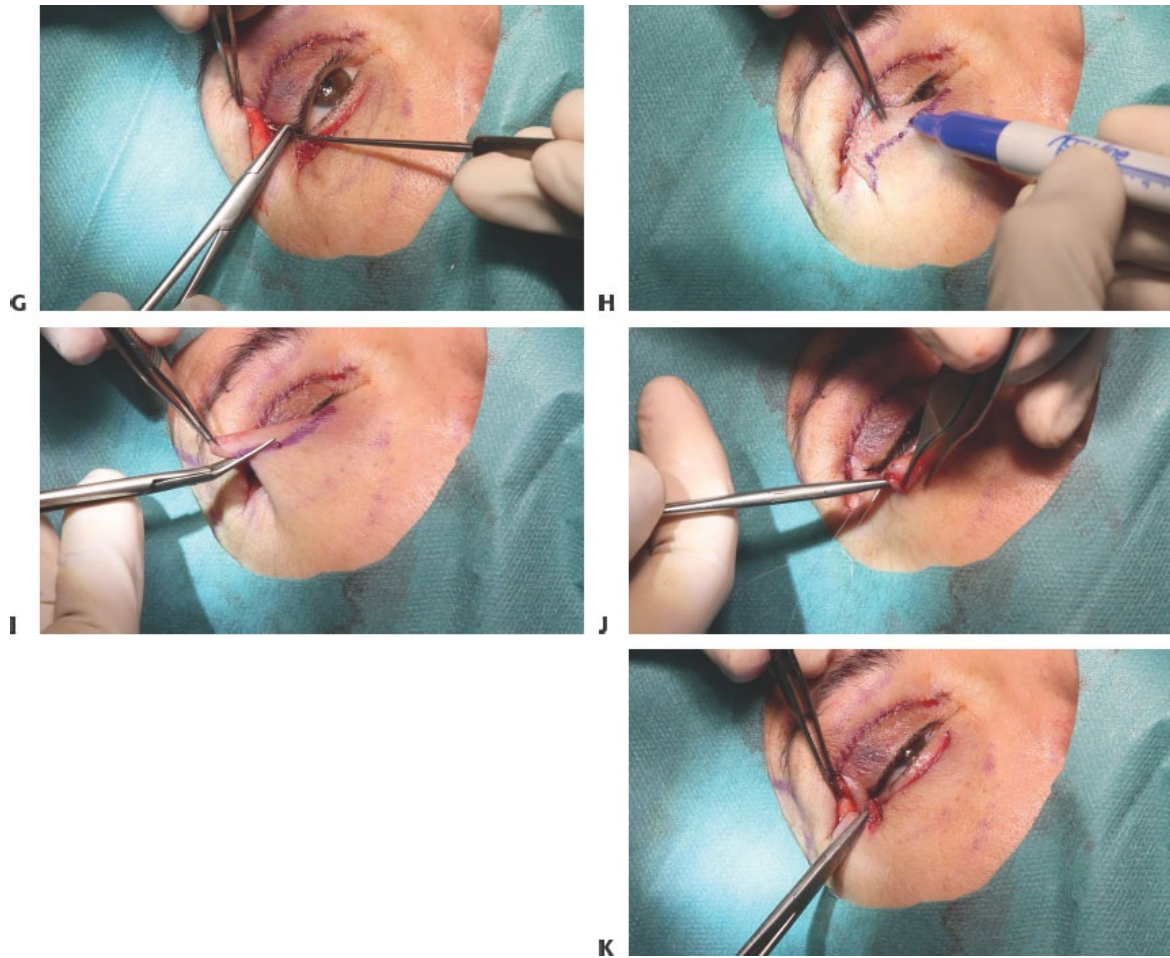
■ Skin-Muscle Flap Approach With Orbicularis Oculi Resuspension

- The skin is incised 5 mm from the canthal angle with a slight downward slant to run parallel or within an existing crow's foot.
- Straight scissors are employed to undermine the skin from the pretarsal muscle through careful spreading, pointing the tips of the scissors to the medial canthus (**TECH FIG 1A**).
- A 5-0 silk traction suture with a noncutting needle is placed through the lower eyelid, and the lid margin is retracted upward covering the eye (**TECH FIG 1B**).
 - The subciliary incision is performed through skin only with straight scissors, 2 to 3 mm below the lid margin.
- The muscle is divided in a stair-step fashion⁹ 2 to 3 mm below the skin incision to preserve at least 5 mm of pretarsal orbicularis muscle (**TECH FIG 1C**).
- The skin-muscle flap is elevated inferiorly in a preseptal plane to the inferior orbital rim.
- The orbital septum is visualized and the fat compartments identified with the help of sterile cotton tips.
- The septum is incised and gentle, continuous pressure is applied to the globe to allow the fat to herniate.
- Fat is conservatively excised with electrocautery according to the preoperative plan (**TECH FIG 1D**).
- The arcus marginalis is released, and dissection over the inferior orbital rim is performed and extended laterally by releasing the orbicularis retaining

ligament with cautery and a periosteal elevator.

- Alternatively, the dissection can be carried out in the suborbicularis plane suprapariostally, although more bleeding may be encountered.
- Excess fat may be transposed or grafted over the inferior orbital rim to blend the lid-cheek junction or improve a tear trough deformity.
- Canthopexy is performed to correct lid laxity and prevent scleral show postoperatively. Care is taken to maintain the lid margin against the globe at the lateral canthus and to remove the corneal protector before tightening the canthopexy suture⁹ (**TECH FIG 1E–G**).
- Hemostasis is revised, and the wound is thoroughly cleansed with saline.
- The skin-muscle flap is redraped in a superior lateral vector, and excess skin and muscle are excised conservatively (**TECH FIG 1H,I**).
- Remaining excess muscle is excised with cautery.





TECH FIG 1 • **A.** After the skin is incised, straight scissors are used to undermine the skin from the pretarsal muscle. **B.** A 5-0 Silk traction suture with a noncutting needle is placed through the lower eyelid, and the lid margin is retracted upward covering the eye. **C.** The muscle is divided in a stair-step fashion⁹ 2 to 3 mm below the skin incision to preserve at least 5 mm of pretarsal orbicularis muscle. **D.** Fat is conservatively excised with electrocautery according to the preoperative plan from the lateral, central (shown), and medial fat compartments. **E.** A 4-0 white Ethibond or Mersilene suture is placed on the tarsal plate and lateral retinaculum. **F.** Right angle scissors are employed to connect the lateral orbital rim to the

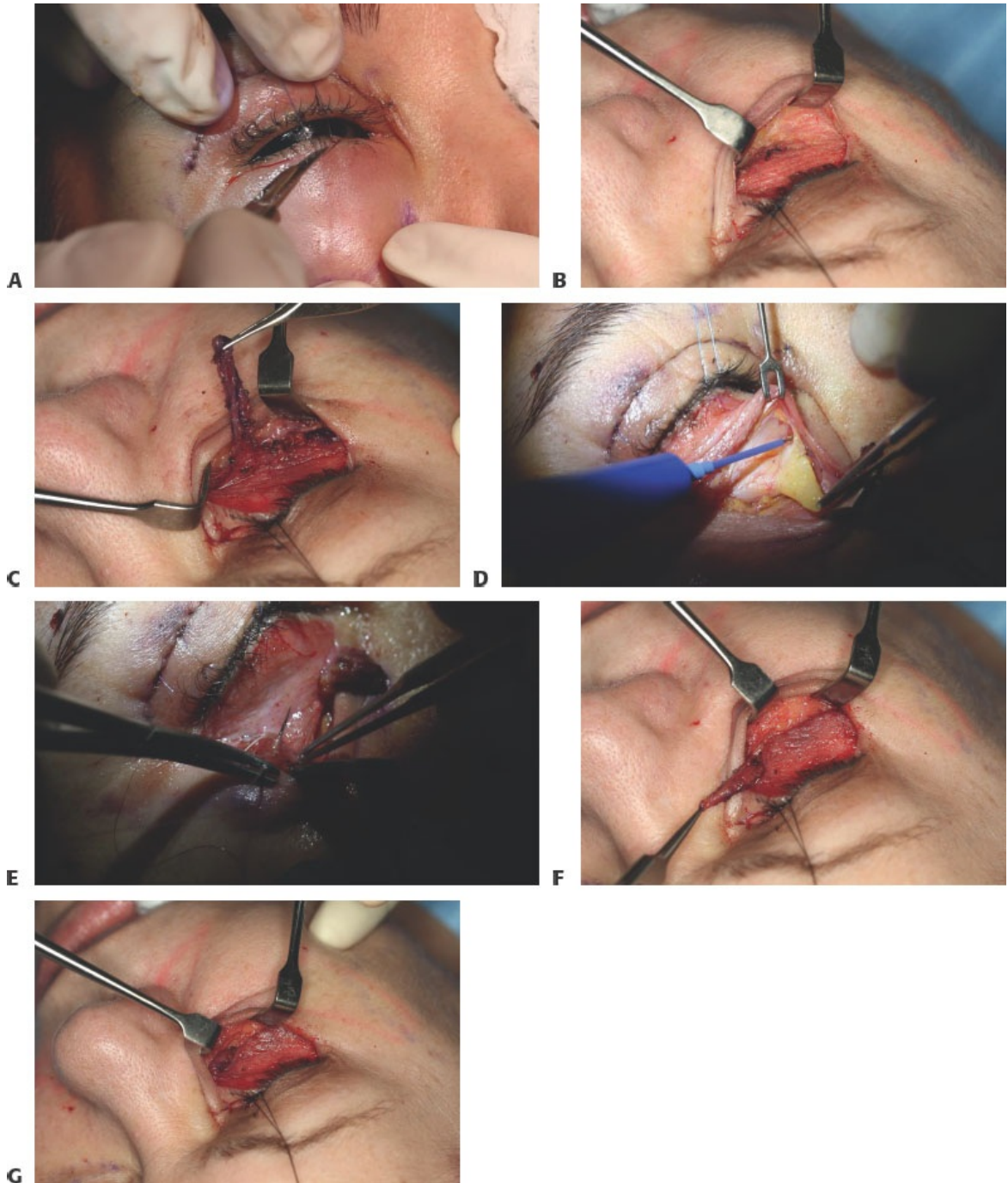
inferior incision. **G.** The needle is passed through the periosteum in the lateral orbital rim. **H.** The skin-muscle flap is redraped, and excess skin is marked for removal. **I.** Excess skin and muscle are excised. **J.** Resuspension of the orbicularis muscle: the needle is passed through the orbicularis muscle. **K.** The needle is passed through the periosteum of the lateral orbital rim.

- Resuspension of the orbicularis muscle is performed with direct periosteal fixation of the muscle to the lateral orbital rim using a 4-0 resorbable suture (**TECH FIG 1J,K**).
- A 6-0 fast resorbing or a 7-0 Prolene suture is employed to close the subciliary incision.
- The initial traction suture may be employed as a temporary Frost suture in patients who might be prone to lower lid retraction or scleral show and left in place for 24 to 72 hours.
- A temporary lateral tarsorrhaphy using a 5-0 Prolene suture is performed in patients who develop chemosis intraoperatively or in those that required more extensive canthal support and left in place for 3 days.

■ Skin-Only Flap Approach With Reverse Orbicularis Oculi Tightening (ROOT)

- A 5-0 silk traction suture with a noncutting needle is placed through the lower eyelid, and the lid margin is retracted upward to cover the eye.
- The skin is incised 5 mm from the canthal angle with a slight downward slant to run parallel or within and existing crow's foot and continued medially toward the medial canthus 2 to 3 mm below the lid margin (**TECH FIG 2A**).
- A skin-only flap is elevated to the level of the orbital rim exposing the pretarsal and preseptal portions of the orbicularis muscle. Countertraction with sterile cotton tips and transillumination are helpful in this dissection (**TECH FIG 2B**).
- Orbicularis muscle laxity is assessed, and a small strip of muscle is marked for removal near the inferior orbital rim.

- The muscle is incised along the markings, and a small strip of orbicularis is elevated as a flap from lateral to medial (**TECH FIG 2C**).
- Care is taken to avoid extending the incision too far medially in order to preserve buccal branches that provide innervation to the pretarsal orbicularis.
- Through the resulting gap in the muscle, the orbicularis is undermined in a preseptal plane cranially to expose the fat compartments and caudally to access the inferior orbital rim.
- The orbital septum is visualized, and the fat compartments are identified with the help of sterile cotton tips.
- The septum is incised, and gentle, continuous pressure is applied to the globe to allow the fat to herniate.
- Fat is conservatively excised with electrocautery according to the preoperative plan from the medial, central, and lateral fat compartments (**TECH FIG 2D**).



TECH FIG 2 • **A.** The skin is incised. **B.** A skin-only flap is elevated. **C.** The muscle is incised where it has been marked for removal, and a small strip of orbicularis is elevated as a flap from lateral to medial. **D.** Fat is excised with electrocautery. **E,F.** The orbicularis muscle is tightened by directly suturing the

edges of excised preseptal orbicularis with a running 6-0 Vicryl suture. **G.** Excess muscle is excised, but a portion is maintained and turned over medially to provide volume in order to improve a tear trough deformity if present.

- The arcus marginalis is released, and dissection over the inferior orbital rim is performed and extended laterally by releasing the orbicularis retaining ligament with cautery and a periosteal elevator.
 - Alternatively, the dissection may be carried out in the suborbicularis plane supraperiostally, although more bleeding may be encountered.
 - Excess fat may be transposed or grafted over the inferior orbital rim to blend the lid-cheek junction or improve a tear trough deformity.
 - Canthopexy is performed to correct lid laxity and prevent scleral show postoperatively. A white Ethibond or Mersilene suture is employed to fix the tarsal plate and lateral retinaculum to the periosteum in the lateral orbital rim. Care is taken to maintain the lid margin against the globe at the lateral canthus and to remove the corneal protector before tightening the canthopexy suture.
 - Hemostasis is achieved, and the wound is thoroughly cleansed with saline.
 - The orbicularis muscle is tightened by directly suturing the edges of excised preseptal orbicularis with a running 6-0 Vicryl suture. Excess muscle is excised, and a portion is maintained and turned over medially to provide volume to improve a tear trough deformity if present (**TECH FIG 2E-G**).
 - The skin-only flap is redraped in a superior lateral vector, and excess skin is excised conservatively.
 - A 6-0 fast resorbing or a 7-0 Prolene suture is employed to close the subciliary incision.
 - The initial traction suture may be employed as a temporary Frost suture in patients who may be prone to lower lid retraction or scleral show.
 - A temporary lateral tarsorrhaphy using a 5-0 Prolene suture is performed in patients who develop chemosis intraoperatively or in those who required more extensive canthal support. The suture is left in place for 3 days.
-

PEARLS AND PITFALLS

Patient evaluation	■ Failure to identify adequate candidates for the procedure will inevitably lead to suboptimal results. ■ Patients with good skin quality and minimal orbicularis laxity may benefit more from a transconjunctival approach.
Hemostasis	■ Bleeding should be avoided from the beginning to the end of the procedure through adequate infiltration and use of needle-tip cautery for dissection and fat excision.
Canthopexy	■ Although the standard position of the lateral canthopexy suture is at the lower level of the pupil, patients with prominent eyes or negative vectors require a higher fixation at the upper level of the pupil, whereas patients with deep set eyes will require positioning at a lower level. ■ Patients with asymmetric lower eyelids, as is often the case, will also require a higher fixation on the side in which the lateral canthus is initially lower. ■ Special attention must be paid to maintaining the lid margin against the globe when tightening the canthopexy suture. The anchoring point in the periosteum should be well inside the lateral orbit at the depth of Whitnall tubercle.
Orbicularis muscle incision	■ Care must be taken to leave a segment of at least 5 mm of pretarsal orbicularis when incising the muscle through the subciliary skin-muscle approach. ■ The incision should not extend excessively past the medial corneal limbus to avoid injury to the buccal nerve branches that are responsible for pretarsal orbicularis innervation.
Orbicularis muscle tightening	■ A strong canthal support and a secure orbicularis resuspension to periosteum are imperative to avoid lower lid malposition and retraction when the skin-muscle flap approach is employed. ■ Muscle resection must be conservative and not extended medially when performing a reverse orbicularis oculi tightening procedure through a skin-only flap.
Skin excision	■ The skin should be removed very conservatively. ■ A slight upward pull should be applied on the lid margin until it lies above the inferior corneal limbus before assessing the skin that should be excised.
Postoperative care	■ Frost and tarsorrhaphy sutures must be employed readily in patients morphologically prone to develop postoperative lid

- malposition or retraction.
- Slight compression with a loose elastic head band applied over the eyes may prove useful to control swelling during the initial postoperative period. Adequate padding over the eyelids and midface is essential.

POSTOPERATIVE CARE

- Patients are instructed to apply cold packs and slight compression for 48 hours.
- Artificial tear drops are prescribed as well as oral antibiotics and pain medication.
- Patients are advised to sleep for 5 days with their head elevated and to avoid activity, medication, or food that may increase blood pressure or swelling.
- Sutures are removed at the 6th postoperative day.

OUTCOMES

- Patients with protruding fat pads and an evident tear trough deformity, who also have excess skin in the lower eyelid and a lax orbicularis muscle, should expect good outcomes (**FIG 3A–D**).
- Although excellent results may be obtained, patients should be well informed of the risks associated with the procedure that may require surgical revision as well as of the prolonged swelling that may occur.
- Codner reviewed the results of 264 patients who underwent transcutaneous lower lid blepharoplasty.⁹
 - Chemosis was the most common complication occurring in over 12% of the patients.
 - Blepharitis developed in 10 patients (3.8%) and required antimicrobial eye ointment in combination with steroids.
 - Temporary lid malposition was encountered in 16 patients (6.1%) and resolved completely with conservative lid massage.
 - Lower lid retraction requiring surgical correction occurred seven patients (2.7%), whereas frank bilateral ectropion with symptoms of corneal exposure occurred in two patients (0.8%) who also required revision of the lateral canthoplasty.
 - Another 11.7% of the patients required revision for minor complications such as cysts or granulomas developing from the incision line, inadequate scars, canthal suture palpability, or inflammation and canthal webbing.

COMPLICATIONS

- Apart from prolonging postoperative downtime, a hematoma may constitute a true surgical emergency if the bleeding accumulates in the retrobulbar space, which may lead to optic nerve compression and blindness.
- Although an infrequent complication, an infection should be treated promptly with topical or systemic antibiotics if necessary.
- Patients should be informed of the possibility of lid margin malposition. Surgical revision may be required to correct this complication, although early management with vertical massage and taping may be sufficient to avoid surgery.¹⁰
- Prolonged edema may be seen more frequently when the transcutaneous approach is performed, due to the more extensive dissection required that produces more disruption of lymphatic channels draining the orbit.

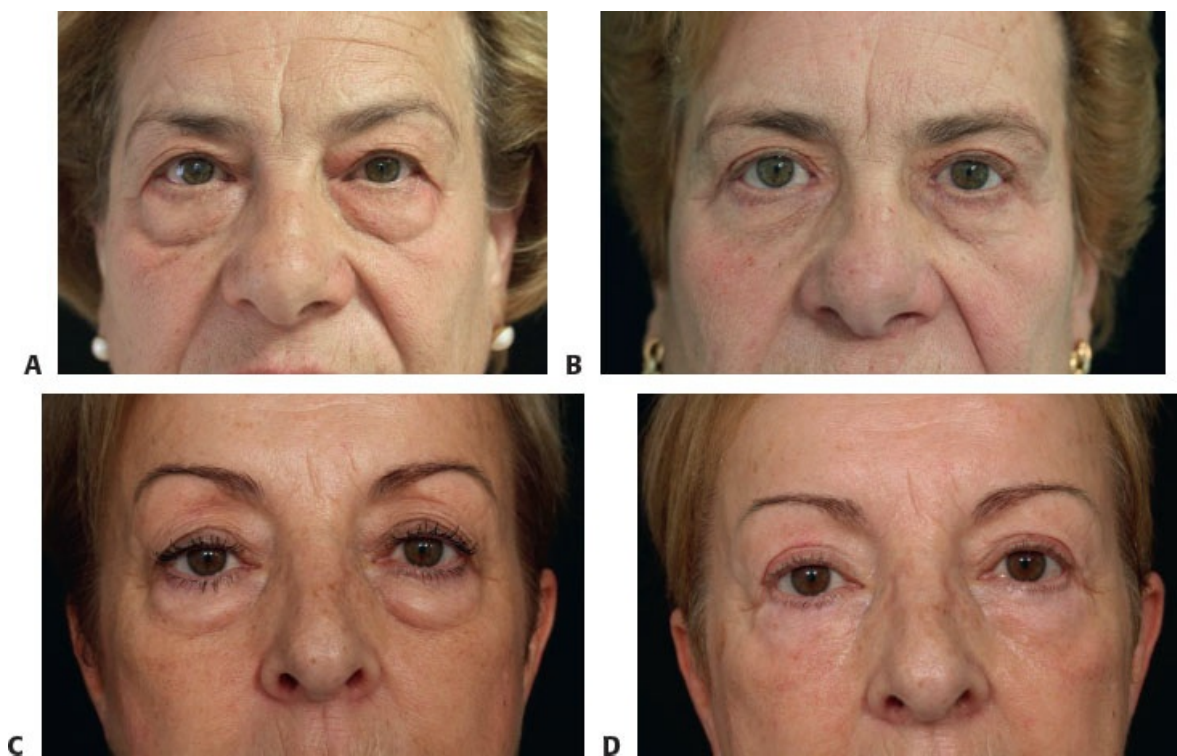


FIG 3 • **A.** Patient shown preoperatively and postoperatively (**B**) after lower blepharoplasty through a subciliary incision with a skin-muscle flap and orbicularis resuspension. **C.** Patient shown preoperatively and postoperatively (**D**) after lower

blepharoplasty through a subciliary incision with a skin-only flap and reverse orbicularis oculi tightening (ROOT).

- Patients may also experience various degrees of hardening and fibrosis around the infraorbital rim if fat was transposed or grafted, which normally resolves by 3 months.
- Chemosis may occur frequently when canthal support techniques are used, due to postoperative edema with poor lymphatic drainage. Treatment includes prescription of mild topical steroid eye drops or short-term eye patching. A temporal lateral tarsorrhaphy may prevent corneal exposure and avoid chemosis in selected patients. Conjunctival incision and drainage may be required in recalcitrant cases.⁹

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Lateral Canthal Manipulation With Canthopexy or Canthoplasty

35

CHAPTER

George N. Kamel, Glenn W. Jelks, and Oren M. Tepper

DEFINITION

- The lateral canthus or lateral retinaculum is a continuation of the preseptal and pretarsal orbicularis muscle and receives contributions from the following anatomic structures: the lateral horn of the levator aponeurosis, the lateral extension of the preseptal and pretarsal orbicularis oculi muscle (lateral canthal tendon), the Lockwood ligament, and the check ligament of the lateral rectus muscle.
- The inferior retinaculum refers to the lower eyelid's contribution to the lateral retinaculum.
- Lateral canthopexy refers to repositioning of the lateral canthus without disinsertion from the orbital tubercle, whereas in a lateral canthoplasty, the lateral canthus is disinserted and repositioned.

ANATOMY

- A thorough understanding of the periorbital anatomy is necessary to achieve optimal aesthetic surgical results while avoiding potential complications.
- The eyelids and surrounding structures can be divided into five anatomical zones (**FIG 1**).^{1,2} Zone I and zone II represent the upper and lower eyelid, respectively. Zone III represents the medial canthus and lacrimal drainage system. Zone IV includes the lateral canthal region and lateral retinaculum. Zone V represents the surrounding periorbital structures and includes the forehead, brow, glabellar, temple, malar, and nasal regions.
- Lower eyelid procedures including lower eyelid blepharoplasty and lateral canthopexy or canthoplasty focus on zones II and IV. The lower eyelid or zone

II can be thought of as a trilamellar structure that consists of an anterior, middle, and posterior lamella. The anterior lamella consists of skin and orbicularis oculi muscle that is further divided into pretarsal, preseptal, and orbital components. The pretarsal and preseptal components are often referred to as palpebral portions. The middle lamella includes the tarsus, orbital septum, and retroseptal fat, while the posterior lamella denotes the capsulopalpebral fascia and conjunctiva.

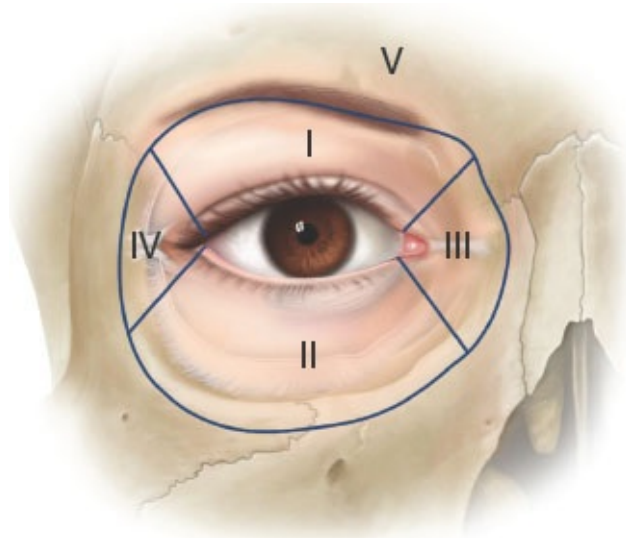


FIG 1 • The five zones of the periorbital region.

- The tarsal plate of the lower eyelid on average measures 25 mm wide, 4 mm in height, and 1 mm in thickness and provides structural integrity to the eyelid.
- The lateral canthus or lateral retinaculum (zone IV) is a three-dimensional fibrous structure that connects the upper and lower tarsal plates to the Whitnall tubercle, located 8 mm posterior to the lateral orbital rim (**FIG 2**). These structures converge at the lateral canthal angle, typically approximately 1.5 to 2.0 mm above the medial canthal angle. This aesthetically pleasing and favorable relationship of the lateral canthus above the medial canthus is often referred to as a positive canthal tilt. When the lateral canthus is at the level of or below the medial canthus, this is referred to as neutral or negative canthal tilt, respectively. It is the lower eyelid portion of the lateral retinaculum or the “inferior retinaculum” that is the focus of the lateral canthopexy or canthoplasty techniques that will be described in this chapter.

PATHOGENESIS

- Despite distinct ethnic and cultural differences, the youthful eye resembles an almond shape, which has a long and narrow palpebral fissure and an upward inclination of approximately four degrees laterally. In patients with loss of lateral canthal support, the lateral palpebral fissure takes on a more rounded appearance with concomitant laxity of the lower eyelid margin. The pathophysiology of lateral canthal disorders is attributed to the loss of canthal support from gravitational, mechanical, or involutional factors.

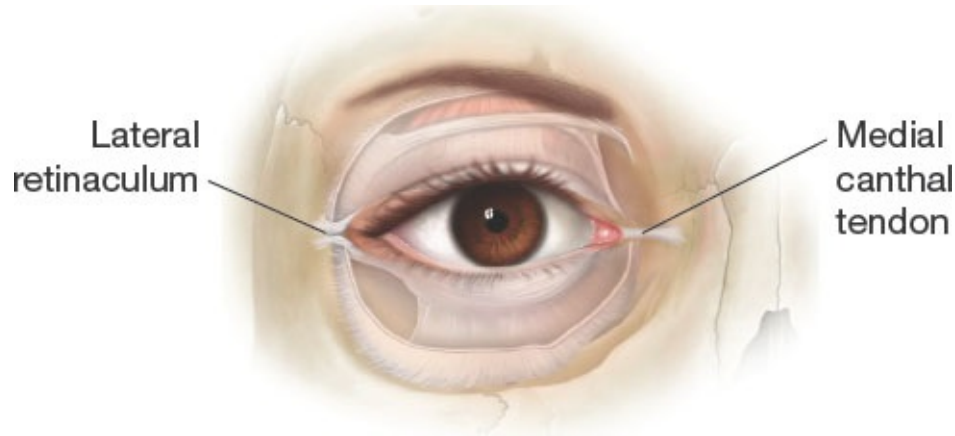


FIG 2 • Supporting structures of the upper and lower eyelid. Note the lateral retinaculum receives contributions from both the upper and lower eyelids.

7 Step Preoperative Checklist		
1. Vector analysis	☐ Positive	☐ Neutral ☐ Negative
2. Snap distraction	☐ Brisk	☐ Delayed
3. Scleral show	☐ <4 mm	☐ >4 mm
4. Canthal tilt	☐ Positive	☐ Neutral ☐ Negative
5. Lateral canthal-orbital rim distance	☐ <1 cm	☐ >1 cm
6. Midface position	☐ Normal	☐ Descended
7. Vertical restriction	☐ Absent	☐ Present

FIG 3 • Key seven-step preoperative checklist.

- A subset of patients are at increased risk for lower eyelid malposition resulting from lower blepharoplasty. In such patients, lateral canthal tightening may be indicated to help prevent these sequelae.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative assessment begins with a detailed medical history with emphasis on risk factors that may lead to postoperative complications. A past medical history of hypertension, diabetes, thyroid disease, bleeding diathesis, glaucoma, dry eyes, trauma, and periorbital and facial operations, including refractive surgery, is of particular significance and should be documented. Furthermore, the use of medications that include nonsteroidal anti-inflammatory, anticoagulants, and aspirin should be recorded and held for a minimum of 2 weeks prior to surgery.
- The physical exam should be performed with the patient sitting in an upright, relaxed position and should begin with an assessment of visual acuity, pupillary reflexes, extraocular muscle movement, and an intact Bell phenomenon.³ A focused lower eyelid exam should document the presence of malar bags, fat herniation, dermatochalasis, tear trough deformities, and skin pigmentation. In addition, the senior authors have previously identified seven key features that should be assessed in patients undergoing lower eyelid procedures and include the following: canthal tilt, vector analysis, scleral show, tarsoligamentous integrity, lateral canthal-orbital rim distance, midface position, and vertical restriction.² This standard preoperative checklist is provided in **FIG 3**.
- Canthal tilt assesses the relationship of the medial and lateral canthus (**FIG 4**). The average position of the lateral canthus is approximately 1.5 to 2 mm cephalad to the medial canthus thus resulting in a positive tilt. Canthal tilt can be described as positive, negative, or neutral.

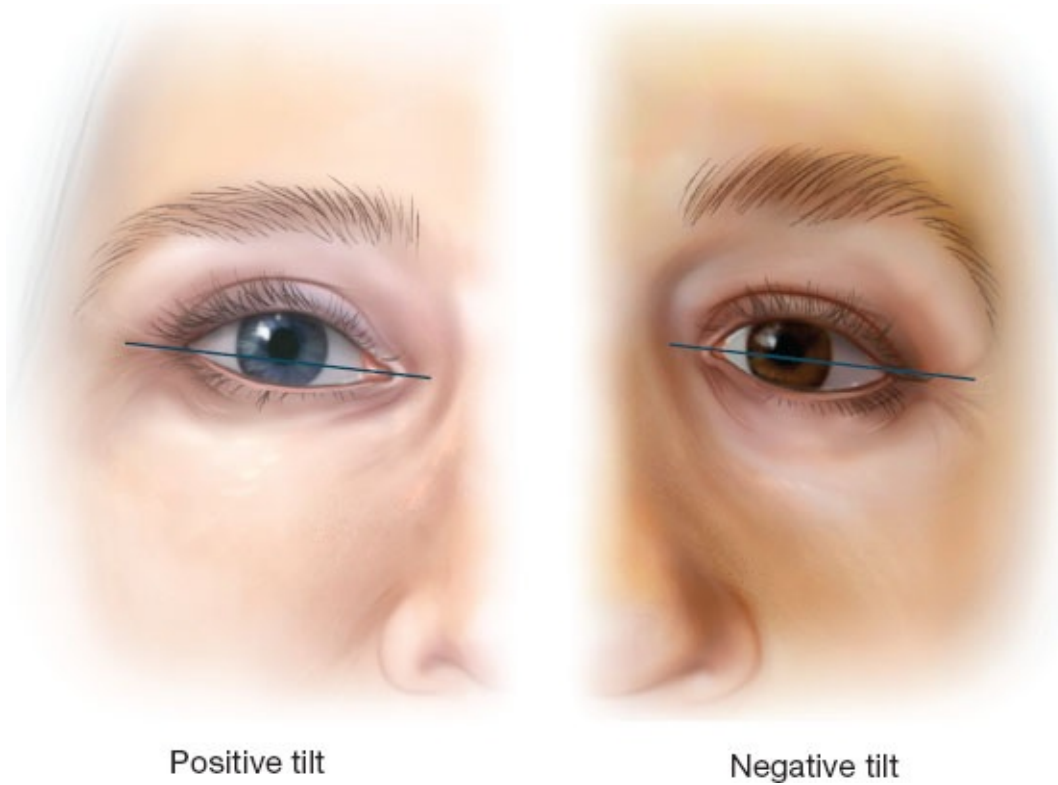


FIG 4 • Canthal tilt: The canthal tilt defines the relationship between the medial and lateral canthus.



FIG 5 • A comparison of normal malar position as

shown on the reader's right to descent.

- Vector analysis describes the relationship of the anterior cornea of the globe to the malar eminence and can be neutral, positive, or negative. A positive vector is defined by a posterior relationship of the anterior cornea to the malar eminence, whereas in a negative vector, the anterior cornea projects in front of the malar eminence. It is negative vector anatomy that is associated with prominent fat pads, midface descent, and greater risk of lower eyelid malposition post blepharoplasty.
- Scleral show defines the relationship between the lower eyelid margin and the inferior limbus of the cornea, which is normally present at the same level precluding visualization of the sclera. Scleral show below the level of the inferior limbus suggests tarsoligamentous laxity.
- Tarsoligamentous integrity defines the tone of the lower eyelid and is examined with a snapback test and lid distraction test. The snapback test is performed by having the patient in primary gaze without blinking, displacing the lower eyelid inferiorly, and measuring the time required for the lower eyelid to return to its normal position. Measurements greater than 1 second are considered abnormal and can be associated with loss of orbicularis oculi muscle tone. The lid distraction test involves anterior traction on the lower eyelid away from the globe and measuring the distance between the globe and lower eyelid. Measurements less than 4 mm are considered normal, whereas distraction greater than 8 mm indicates tarsoligamentous laxity and the possible need for horizontal lower eyelid shortening.
- Lateral canthal-orbital rim distance (LC-OR) is a clinically valuable measurement and can be categorized as either being greater than or less than 1 cm. This measurement becomes important when determining which procedure to use for patients requiring correction of significant lower eyelid malposition.
- Midface position is an important consideration of the lower eyelid-cheek junction. Patients with midface descent may benefit from a cheek suspension to support the lower eyelid and relieve tension on the lateral canthus (**FIG 5**).
- This 7-step analysis helps to determine the proper procedures for the patient undergoing primary blepharoplasty or correcting pre-existing lower eyelid malposition. As shown (see **FIG 3**), patients with anatomic features on the left side have favorable conditions as compared to those with findings that line up on the right side.

- During the preoperative exam, one must assess for vertical restriction, which is measured by elevating the lower eyelid and ensuring that the eyelid margin reaches a level above the pupil. In cases of vertical restriction, one must decipher the origin as resulting from the anterior, middle, or posterior lamella. When restriction is present, additional corrective procedures may include release of cicatrix, placement of spacer graft, cheek suspension, or Mitek anchor fixation.

IMAGING

- Radiographic imaging is generally not indicated in the preoperative workup in patients undergoing procedures that include lower eyelid rejuvenation with lateral canthopexy or canthoplasty.

SURGICAL MANAGEMENT

- The inferior retinacular canthopexy was designed to improve eyelid aesthetics and prevent lower eyelid malposition in patients undergoing a primary blepharoplasty without separating the lower eyelid from the lateral palpebral commissure. Furthermore, its utility can be seen in correcting lower eyelid malposition in patients with a negative vector relationship. The lateral tension and pull achieved from the inferior retinacular canthopexy may provide significant improvement to lower eyelid aesthetics by smoothing the lower eyelid skin and diminishing or obviating the need for lower eyelid skin resection. Patients with more severe laxity or retraction may require canthoplasty in place of canthopexy.

Preoperative Planning

- The 7-step checklist previously described can aid the surgeon in stratifying patients into an appropriate surgical treatment plan.

Positioning

- Lower eyelid blepharoplasty with or without canthal manipulation is performed with the surgeon standing at the head of the patient looking toward the feet. Loupe magnification as well as a focused headlight is recommended to aid with visualization of key structures.

Approach

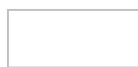
- Numerous surgical techniques have been described to address lateral canthal position and to correct lower eyelid malposition. These include dermal

orbicular pennant lateral canthoplasty, tarsal strip lateral canthoplasty cheek suspension with Mitek anchor fixation, and bride of bone canthopexy.^{1,4} The specifics of these is beyond the scope of this chapter; we will focus on inferior retinacular lateral canthopexy and canthoplasty techniques.

TECHNIQUES

■ Inferior Retinacular Lateral Canthopexy/Canthoplasty

- The inferior retinacular lateral canthopexy/canthoplasty can be performed through a horizontal canthal incision or an upper lateral eyelid incision.⁵
- The advantage of an upper eyelid incision is that this incision is already being applied to patients undergoing concomitant upper blepharoplasty.
- The inferior edge of the lateral upper eyelid incision is grasped, and a submuscular dissection is performed in a suprapariosteal plane heading in an inferomedial direction.
- The skin and muscle flap is then elevated 2 cm around the lateral canthus and lower eyelid using a combination of blunt scissor dissection and fine-point electrosurgical dissection.
- An insulated Desmarres retractor is used to retract the skin and muscle flap and help expose the lateral retinaculum, which is located just superior to the lower eyelid lateral fat.
- One additional advantage of this approach is that lower eyelid fat can also be removed at this stage, which creates an open space (Jelks cave) and allows visualization of the lateral retinaculum as it inserts on Whitnall tubercle (**TECH FIG 1A**).
- In a canthopexy, forceps are then used to grasp the inferior retinaculum (**TECH FIG 1B**), and U-stitch is placed through with two passes of permanent or semipermanent suture (Mersilene 4-0, Polydek Silky II-ME2).



TECH FIG 1 • A. The inferior retinacular lateral canthopexy is performed through the lateral aspect of

an upper eyelid blepharoplasty incision. **B.** The inferior retinaculum is grasped with forceps and fixated to the inner periosteum of lateral orbital rim.

- In a canthoplasty, the inferior retinaculum is divided from its insertion so that repositioning is possible.
- The lower eyelid is then everted to confirm that the suture has not violated the conjunctiva.
- In a canthoplasty, the inferior retinaculum is cut, thereby detaching the lower lid from the lateral orbital wall, before the suspension suture is placed.
- Fixation of the suture is then performed to the inner periosteum at the lateral orbital rim at the level of the superior aspect of the pupil in primary gaze. Placement of this stitch should be performed with great care, as this sets the new height of the lateral canthal tendon. Of note, corneal shields may limit one's ability to assess the level of the pupil. In the orbit, this represents the portion of the lateral orbital rim that starts to take an inward curve.
- The wound is closed as a single layer.
- The same principles and surgical technique apply when using a horizontal canthal incision. If an upper blepharoplasty incision is not being used, one may also perform a transcanthal canthopexy. In this case, the lateral retinaculum is approached directly and grasped from below, but similar principles apply.

PEARLS AND PITFALLS

Indications	■ Inferior retinacular lateral canthopexy was developed to help prevent lower eyelid malposition in primary blepharoplasty patients. ■ A canthoplasty can be used for correction of secondary lower eyelid malposition associated with a negative vector. ■ Lateral canthal tightening can address redundant lower eyelid skin, thus diminishing or obviating the need for more skin excision.
Advantage	■ Inferior retinacular lateral canthopexy does not separate the lower eyelid from the lateral palpebral commissure.
Approach	■ The lower eyelid should appear overcorrected and cover

approximately 1–2 mm of the inferior limbus as it settles into position in 2 to 6 weeks.

POSTOPERATIVE CARE

- Minimal activity for 24 hours and head of bed elevation to at least 45 degrees should be maintained.
- Cool compresses may be applied for the first 24 hours.
- Ophthalmic antibiotic ointment is used two to three times per day for the eyelid suture lines. Steroid ophthalmic solutions are prescribed for 3 to 5 days.
- Tear supplements may be used for the 1st week, but are usually not necessary.
- Patients should sleep at 30 to 45 degrees elevation for 2 to 3 weeks.
- Patients may resume preoperative physical activity by 3 to 4 weeks postoperatively.
- Patients follow up 5 days postoperatively for suture removal and are followed 4 weeks, 3 months, 6 months, 9 months, and 1 year postoperatively.
- Photographs are taken at 1-year follow-up.

OUTCOMES

- See **FIG 6**.

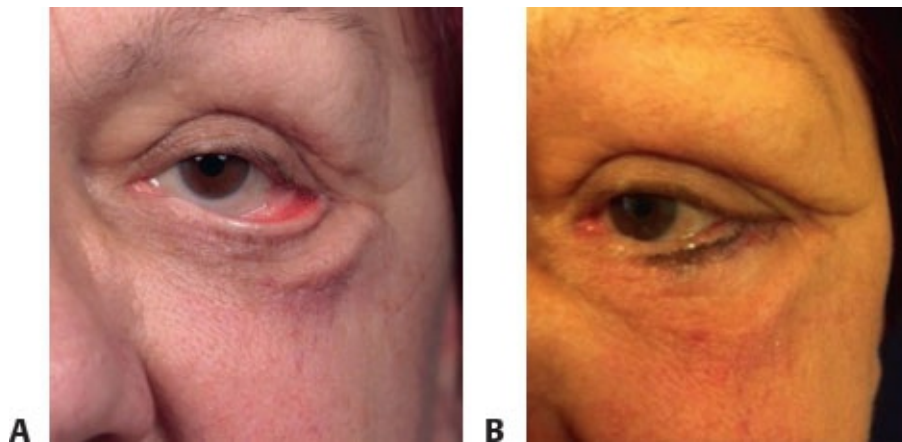


FIG 6 • **A.** A preoperative photograph of a patient with lower eyelid malposition. **B.** The inferior retinacular lateral canthopexy allows for proper lower eyelid positioning as well as improving canthal tilt.

COMPLICATIONS

■ Postoperative complications from proper lateral canthal support are uncommon but may include the following:

- Bleeding
- Infection
- Lower lid malposition
- Scar formation
- Chemosis

ACKNOWLEDGMENTS

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Indications and Techniques for Fat Grafting for Periorbital Rejuvenation

CHAPTER

Oren M. Tepper, Jillian Schreiber, Elizabeth B. Jelks, and
Glenn W. Jelks

DEFINITION

- The periorbital region is an essential component of a youthful appearing face. Aesthetic rejuvenation of the eyelids is a frequently requested and challenging procedure offered by most plastic surgery practices. Although soft tissue descent and cutaneous changes have long been recognized as a sign of periorbital aging, volume loss or deflation has more recently been appreciated as an important contributing factor as well.^{1,2}
- Traditional blepharoplasty is subtractive in nature. Conventional approaches to upper and lower blepharoplasty include excision of excess skin and fat, with potential risk of creating a hollowed or “operated” appearance.^{2–4} In light of the importance of periorbital fat to provide support and contour in the youthful eyelid, there has been a shift in blepharoplasty techniques away from excision alone toward preservation and restoration of periorbital volume.^{2,5–7} The goals of this chapter are to provide an updated approach to fat grafting in the periorbital region as a primary means of achieving upper and lower eyelid rejuvenation and/or correction of secondary deformities.
- Autologous fat grafting has gained widespread popularity as an effective means of volume augmentation for various facial procedures due to its ease of harvest, longevity, rapid execution, and relative safety.^{8–10} Autologous fat grafting is used to address changes due to aging in the upper and lower eyelid, the brow, and the eyelid-cheek junction.¹

Upper Eyelid

- Atrophy of fat and skin in the upper eyelid and surrounding regions can result in skeletonization of the bony orbit, protuberance of remaining periorbital fat, poor soft tissue support, and eyebrow descent.
- In general, fat grafting of the upper eyelid is most commonly performed for correction of a hollowed appearance to the upper eyelid sulcus. This may be the result from aging or secondary to over-resection of retroseptal fat during an upper blepharoplasty procedure.

Lower Eyelid

- A prominent nasojugal groove, often described as the “tear trough,” is a common finding in patients seeking periorbital rejuvenation. The anatomical junction of the lower eyelid and cheek (palpebral malar interface) extends from the medial canthus inferolaterally above cheek tissue to form a depression (nasojugal groove). This is distinct from colloquial terms such as “dark circles” and “puffiness” of the lower eyelid that are commonly used interchangeably.
- Fat grafting to the eyelid-cheek junction, with or without skin and fat excision, is an effective means to treat a tear trough deformity and camouflage the prominence of fat in the lower eyelid compartments.

ANATOMY

- The periorbital region is composed of the bony orbital rim, orbicularis oculi muscle, orbital fat compartments, and the upper and lower eyelids. The upper and lower eyelids are layered structures composed of an anterior and posterior lamella divided by the orbital septum (**FIG 1**).
- The thin eyelid skin and orbicularis oculi muscle constitute the anterior lamella of the upper and lower eyelids. The orbicularis oculi muscle is divided into pretarsal, preseptal, and orbital components. The pretarsal and preseptal portions make up the palpebral segment and provide involuntary blink, whereas the orbital portion provides voluntary eyelid closing.
- The posterior lamella is composed of different but analogous structures between the upper and lower eyelids. The upper eyelid posterior lamella includes the palpebral conjunctiva and tarsal plate. Above the tarsal plate, it is composed of the palpebral conjunctiva and Müller muscle. The posterior lamella of the lower eyelid is similarly made up of the palpebral conjunctiva and tarsal plate and inferior to the tarsal plate the conjunctiva and capsulopalpebral fascia and inferior tarsal muscle.

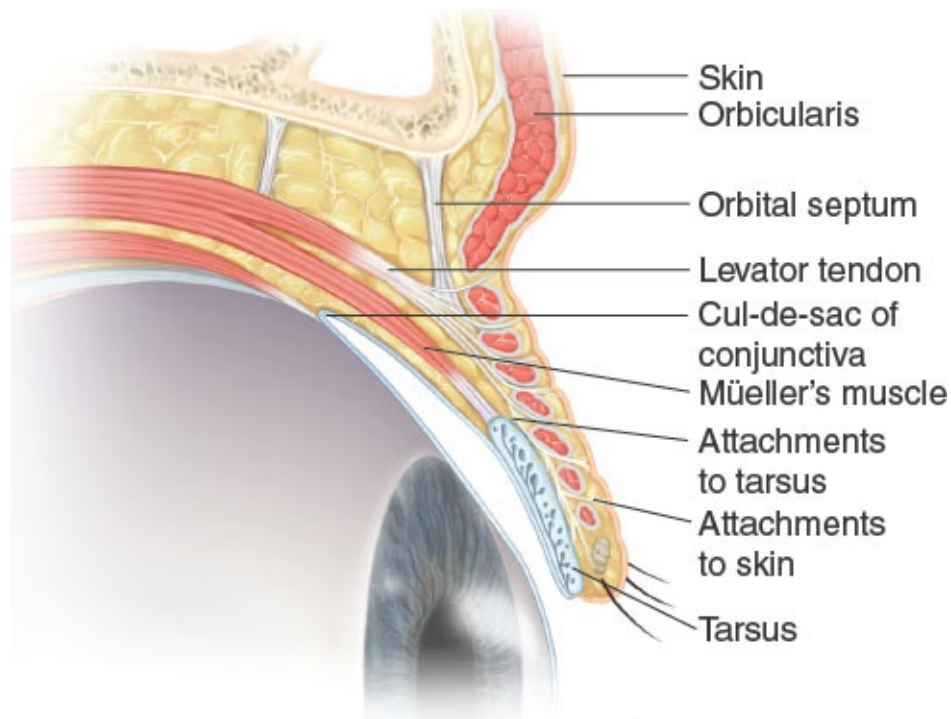


FIG 1 • Upper eyelid anatomy. Sagittal section through the upper eyelid demonstrating the anterior and posterior lamella and the relationship with the orbital septum.

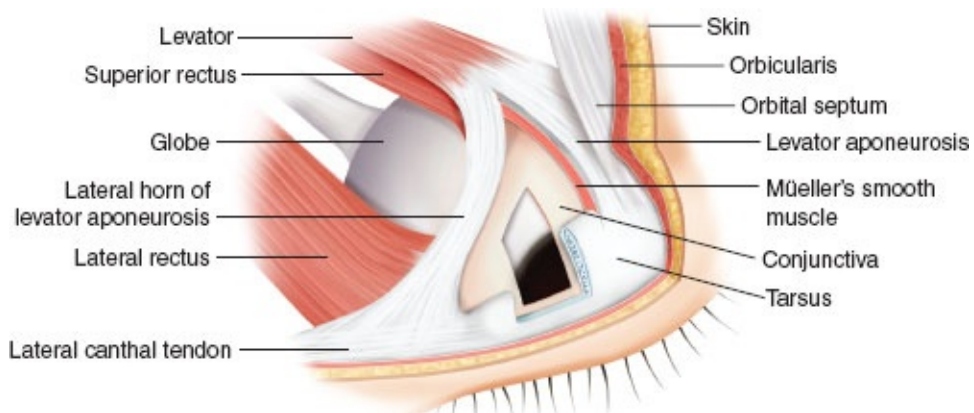


FIG 2 • Upper eyelid anatomy highlighting the relationship between the levator muscle, the tarsus, and lateral canthal tendon.

- The upper eyelid retractors are the levator palpebrae superioris innervated by

the oculomotor nerve and the sympathetically innervated Müller muscle (**FIG 2**). The lower eyelid retractors include the capsulopalpebral fascia and inferior tarsal muscle.

- The prominent tear trough is often addressed in periorbital rejuvenation. Factors that contribute to a prominent palpebral malar interface include alterations in the quality and elasticity of the overlying skin, subcutaneous tissue, orbicularis oculi muscle, orbital septum, capsulopalpebral fascia, and retroseptal orbital fat.² The anatomical position of the arcus marginalis on the zygomatic and maxillary bones determines the location of the palpebral malar interface^{2,3} (**FIG 4**).
- The arcus marginalis is defined by the bony origin of the orbital septum, orbital periosteum, and the maxillary periosteum. The origins of the preseptal and orbital orbicularis oculi muscle, the orbital retaining ligaments, malar septum, prezygomatic space, and arcuate bands are related to the arcus marginalis.
- The upper eyelid fat is composed of the medial and lateral fat compartments. In the lower eyelid, three distinct fat compartments of retroseptal fat exist: lateral, central, and nasal. The nasal and central compartments are divided by the inferior oblique muscle tendon. The medial (nasal) compartment is derived from the white orbital fat and the lateral (central) fat compartment from the less dense, yellow preaponeurotic fat.¹



FIG 3 • Periorbital fat compartments of the lower eyelid and cheek. **A.** The medial suborbicularis oculi fat compartment (MSOOF). **B.** The deep medial cheek fat compartment. **C.** Addition of the MSOOF, DMC, and the lateral suborbicularis oculi fat compartment (LSOOF).

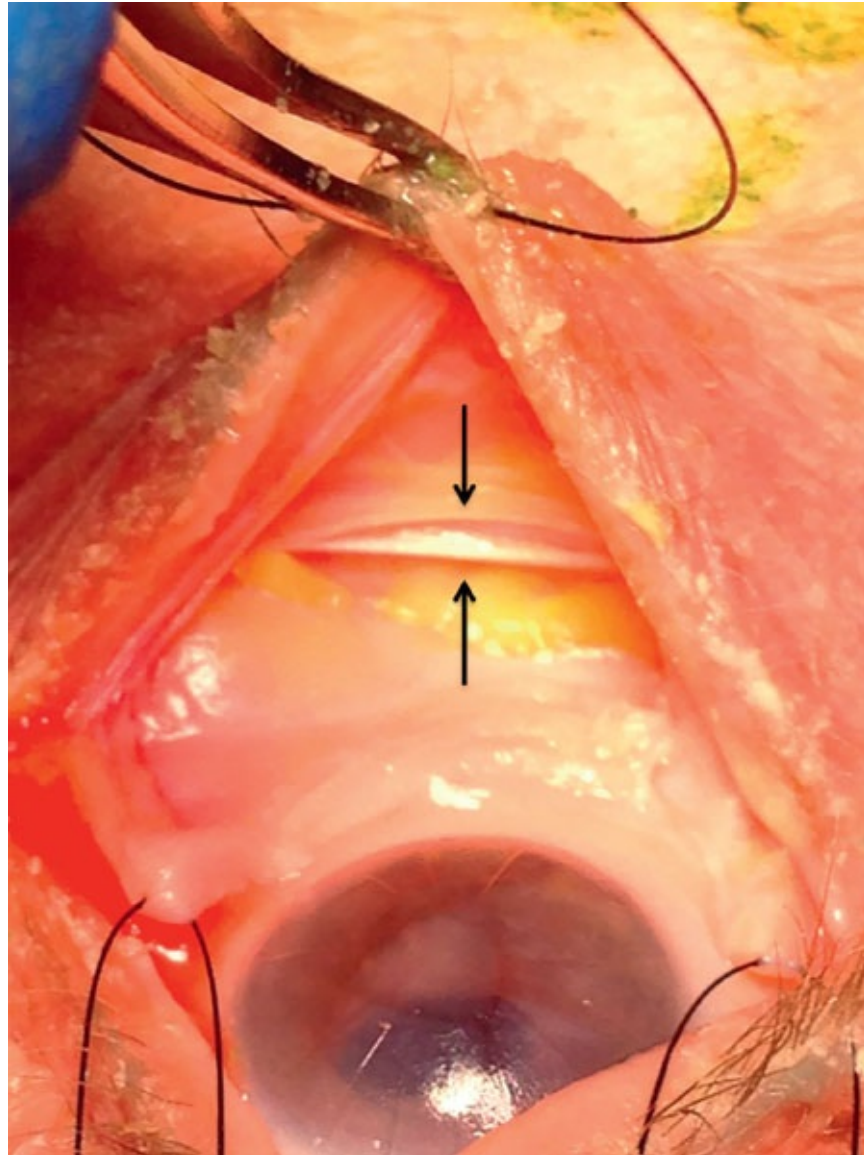


FIG 4 • The arcus marginalis is shown on cadaveric dissection. It is the bony origin of the orbital septum, orbital periosteum, and the maxillary periosteum.

- Emerging research demonstrates facial fat is divided into discrete fat compartments.^{11–13} However, the exact anatomy of the periorbital fat compartments somewhat varies within the literature. Recent cadaveric studies by Rohrich et al. describe two suborbicularis fat compartments: the medial suborbicularis oculi compartment extending from the medial limbus to the lateral canthus along the infraorbital rim and the lateral orbicularis oculi compartment from the lateral canthus to the temporal fat pad.¹¹ Regardless of

the exact nomenclature and anatomic boundaries of these compartments, eyelid aesthetics needs to go well beyond the traditional retroseptal compartments and consider the periorbital fat compartments as well (**FIG 3**).

- The temporal hollows are an underappreciated yet important region when approaching the aged face. Temporal wasting leads to an “hourglass” appearance to the upper face that can be corrected with autologous fat grafting. A smooth transition may be achieved between the forehead and malar region when volume is replaced in the temporal hollow.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical examination is vital to effectively approach rejuvenation of the periorbital region. This includes a general history and physical examination, as well as a complete ophthalmologic examination. Anticoagulant and antiplatelet medications should be documented and stopped prior to surgery to avoid complications due to bleeding. Assessment of all periorbital and adjacent structures, including malar, temporal, and glabellar regions, are vital to achieving a harmonious and balanced result.
- The periorbital region is evaluated in detail. Upper and lower eyelid skin quality, excess skin, and pseudoherniation of orbital fat are documented.
- A functional examination of the orbital region is performed. Lateral canthal descent, lid laxity, scleral show, and ectropion are all evaluated. Symmetry is appreciated.
- The vector between the globe and malar region is characterized as positive or negative. This relationship aids the surgeon in assessing malar descent and selecting patients who would benefit from malar augmentation to provide support to the lower lid as well as restore a positive vector. When assessing patients for correction of lower eyelid aging, it is essential to consider not only the lower eyelid but also the cheek and the interface of the two. Midfacial volume loss and descent lead to loss of anterior projection and contour and decreased support to the lower eyelid.
- The seven-step preoperative checklist, developed by the senior authors of this chapter, is used for preoperative planning for blepharoplasty patients.¹⁴ This examination included seven key findings: vector analysis, snap, distraction, scleral show, canthal tilt, lateral canthal-orbital rim distance, midface position, and vertical restriction. This standardized physical examination characterizes the severity of hollowing, skin quality, and descent of the periorbital region to guide treatment (**FIG 5**).

- Periorbital aging is a combination of volume loss, soft tissue descent, and cutaneous changes.^{1,2} Brow descent with atrophy of superior orbital fat and hollowing lead to a tired, aged appearance. The extent of these changes needs to be considered when evaluating patients.

NONOPERATIVE MANAGEMENT

- Hyaluronic acid fillers are an effective temporary alternative to autologous fat grafting for periorbital rejuvenation. This approach is a nonpermanent option for patients who wish to achieve added volume of the periorbital region and wish to avoid surgical intervention. The best candidates for hyaluronic acid injection are those with good skin tone and minimal skin laxity with minimal to moderate volume loss in the periorbital region.¹⁵ These characteristics help minimize the injection volume required and risk of palpable or visible deformities that are associated with fillers in this region.

SURGICAL MANAGEMENT

Positioning

- The patient is positioned supine.

7-step Lower Eyelid Checklist

		RIGHT	LEFT
1	Vector analysis 	☒ + ☐ Neutral ☐ -	☒ + ☐ Neutral ☐ -
2	SNAP DISTRACTION 	☐ Brisk ☐ Delayed ☐ ≤8mm ☐ >8mm	☐ Brisk ☐ Delayed ☐ ≤8mm ☐ >8mm
3	Scleral show 	☐ 0 ☐ 1 ☐ 2 ☐ 3	☐ 0 ☐ 1 ☐ 2 ☐ 3
4	Canthal tilt 	☒ + ☐ Neutral ☐ -	☒ + ☐ Neutral ☐ -
5	Lateral canthal – orbital rim 	☐ <1cm ☐ ≥1cm	☐ <1cm ☐ ≥1cm
6	Midface position 	☐ Normal ☐ Descended	☐ Normal ☐ Descended
7	Vertical restriction 	☐ Absent ☐ Present	☐ Absent ☐ Present

FIG 5 • The 7-step checklist for blepharoplasty planning. This examination included seven key findings: vector analysis, snap, distraction, scleral show, canthal tilt, lateral canthal-orbital rim distance, midface position, and vertical restriction.

TECHNIQUES

■ Fat Harvest and Injection Technique

- Autologous fat is most commonly harvested from the anterior abdomen or the medial or lateral thigh or anterior abdomen. The patient is positioned supine, and these locations are easily accessed for fat harvest.

- Autologous fat may be processed according to surgeon preference. The authors of this paper prefer harvesting with 10-cc syringes under negative suction, allowing for gravitational sedimentation. Fat is then transferred to 1-cc syringes for injection with 0.9-mm blunt cannulas. Fat is deposited deep at the level superficial to the periosteum. Fat may be injected in multiple passes of small aliquots into the individual compartments.¹
-

■ Eye Brow and Temporal Region

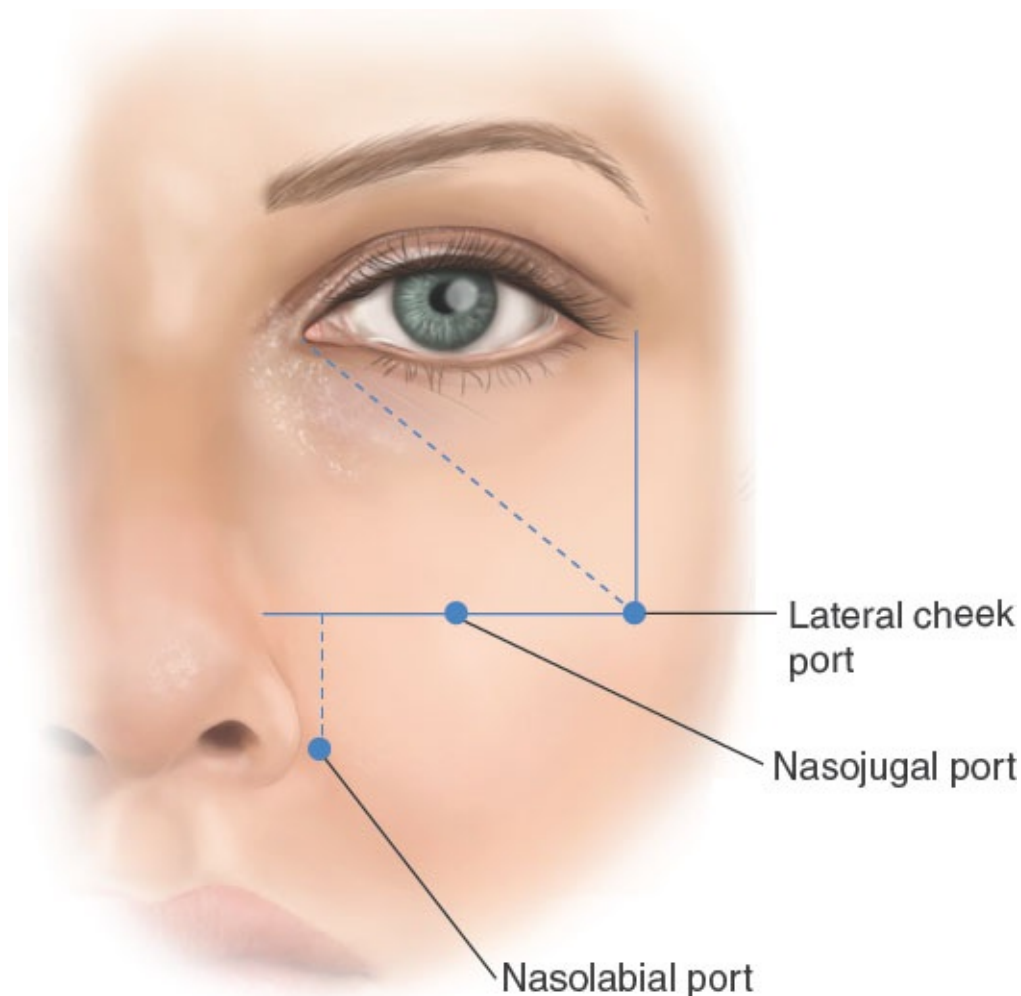
- Fat grafting of the eyebrow and temporal is routinely performed in our practice to achieve facial rejuvenation.
 - The upper brow and temporal region may be accessed approximately 15 to 20 mm above the central brow. For treatment of the eyebrow region, fat is injected deep in the supraperiosteal plane into the central and lateral brow. This not only provides volume but also has a “lifting” effect on the brow. Typical volumes are approximately 1 to 3 mL in this region, depending on the overall aesthetic goals.
 - Lipostructural fat grafting to the temporal region can also be achieved through this port site or accesses via a separate point along the lateral forehead hairline. The layer of injection is targeted between the superficial and deep temporal fascia to minimize risk of visible deformity while still achieving an added volume effect on the surface.
-

■ Upper Eyelid

- Fat grafting in the upper eyelid corrects hollowing due to aging, however more commonly treats secondary deformity due to over-resection during prior blepharoplasty.
 - The upper eyelid fat compartments are accessed by a port site located 10 to 15 mm lateral to the lateral canthus.¹ Fat is injected into the preseptal space, directly beneath the orbicularis muscle, as to avoid obvious irregularities of superficial injection beneath the thin eyelid skin. This injection is placed at the edge of the orbital rim.
-

■ Lower Eyelid/Malar Fat Grafting

- Fat grafting to the malar compartments is performed using a technique modified from Surek et al.¹⁶ The deep medial cheek compartment is accessed via the “nasolabial insertion port” located 1.5 to 2 cm inferolateral to the ipsilateral alar base within the nasolabial fold and the lateral cheek compartment via the “lateral cheek insertion port” located 1.5 to 2 cm inferolaterally to the lateral canthus, as described (**TECH FIG 1**).
- An alternative approach practiced by the authors of this paper is the use of a single port (nasolabial insertion port) to access the malar and lower eyelid fat compartments. Adding volume of the deep medial cheek provides anterior projection to the midface as well as effacement of the nasojugal groove. Via the nasolabial port, a blunt cannula is used to inject 1 to 2 cc of autologous fat. The lateral cheek compartment is accessed, and a 1 to 2 cc of autologous fat is injected.

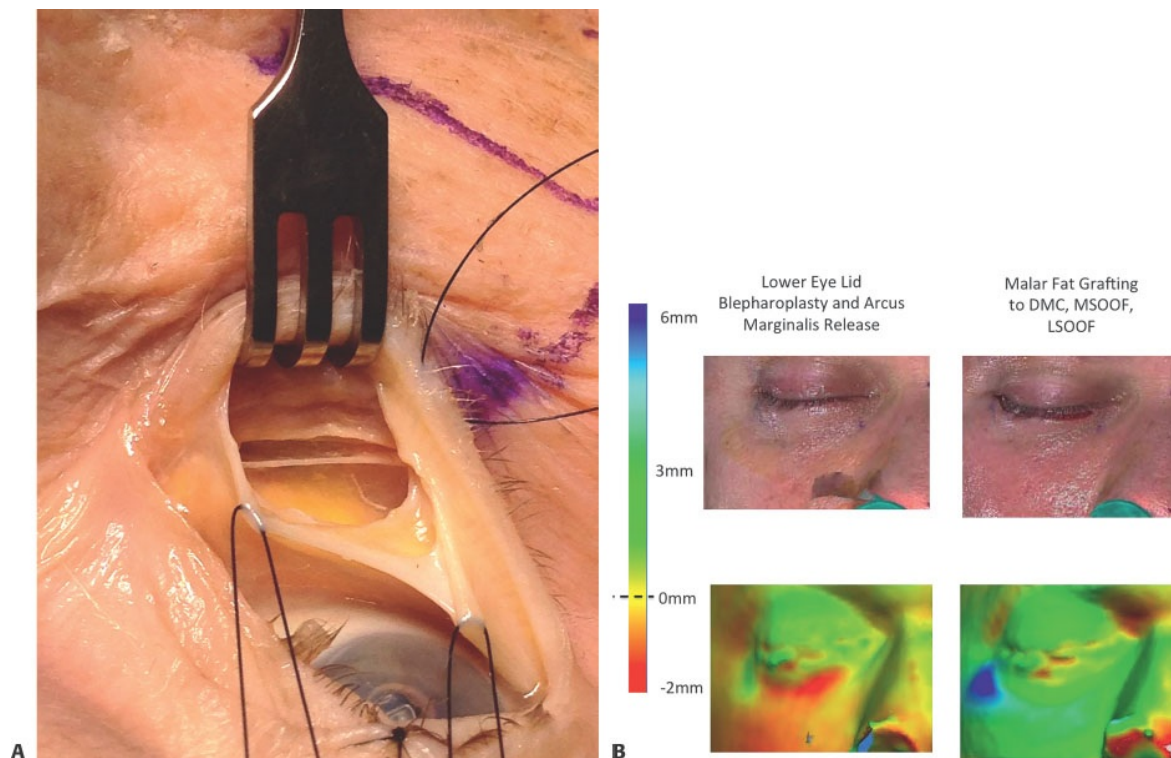


TECH FIG 1 • Malar fat grafting port sites for injection.

The nasolabial, nasojugal, and lateral cheek port sites are shown. Alternatively, all three cheek compartments may be accessed via a single port (lateral cheek port site).

■ Arcus Marginalis Release

- Arcus marginalis release in conjunction with fat grafting may be an effective means of treating a severe tear trough deformity. This is performed with a horizontal incision 8 mm from the posterior lower eyelid margin through the conjunctiva and capsulopalpebral fascia to access the retroseptal space (**TECH FIG 2A**).
- Retroseptal fat is retracted to visualize the arcus marginalis, which is sharply released from the medial canthus along the infraorbital rim to the level of the mid-pupil.¹⁷ The origin of the preseptal and orbital orbicularis oculi muscle is also released with this maneuver (**TECH FIG 2B**).



TECH FIG 2 • A. Arcus marginalis on cadaveric specimen is shown after release from the medial

canthus along the infraorbital rim to the level of the mid-pupil. **B.** Color map analysis of clinical patient following lower blepharoplasty with fat excision followed by arcus marginalis release. Color spectrum shows change in surface projection as compared to the baseline surface. Color spectrum ranges from no change (*green*) to most significant volume loss (*red*) and volume gain (*blue*). Note volume loss during fat excision (*red*) and a volume gain following arcus marginalis release (less red medially) and maximum volume following malar fat grafting (*blue*).

PEARLS AND PITFALLS

Indications

- Periorbital volume loss contributes to aging in the upper face.
- Brow descent, upper eyelid hollowing, temporal hollowing, malar descent, and a prominent nasojugal groove (or “tear trough deformity”) may be addressed by way of autologous fat grafting to various facial fat compartments.

Advantage

- Volume addition of the periorbital restores youthful contour and may provide support to the lower eyelid and brow.
- Hyaluronic acid fillers are an effective yet temporary option for patients to be reserved for patients with good skin quality and minimal to moderate volume loss.
- Patients with moderate to severe periorbital atrophy and descent of the upper and midface benefit for autologous fat grafting.
- Arcus marginalis release in conjunction with fat grafting may be an effective means of treating a severe tear trough deformity.
- A single port (nasolabial insertion port) may be used to access the malar and lower eyelid fat compartments.

Pitfalls

- A thorough history and physical examination, including ophthalmologic examination, are vital to successful patient selection and outcomes in periorbital rejuvenation.
- Anatomical knowledge of facial fat compartments permits precise placement of fat and reproducible results.

POSTOPERATIVE CARE

- Patients should maintain head of bed elevation of at least 45 degrees for the first 24 hours postoperatively.
- Cool compresses may be applied for comfort.
- Patients may resume preoperative physical activity by 3 to 4 weeks postoperatively.
- Postoperative photographs are taken at 3 and 6 months and at 1 year follow-up.

OUTCOMES

- See **FIGS 6** and **7**.

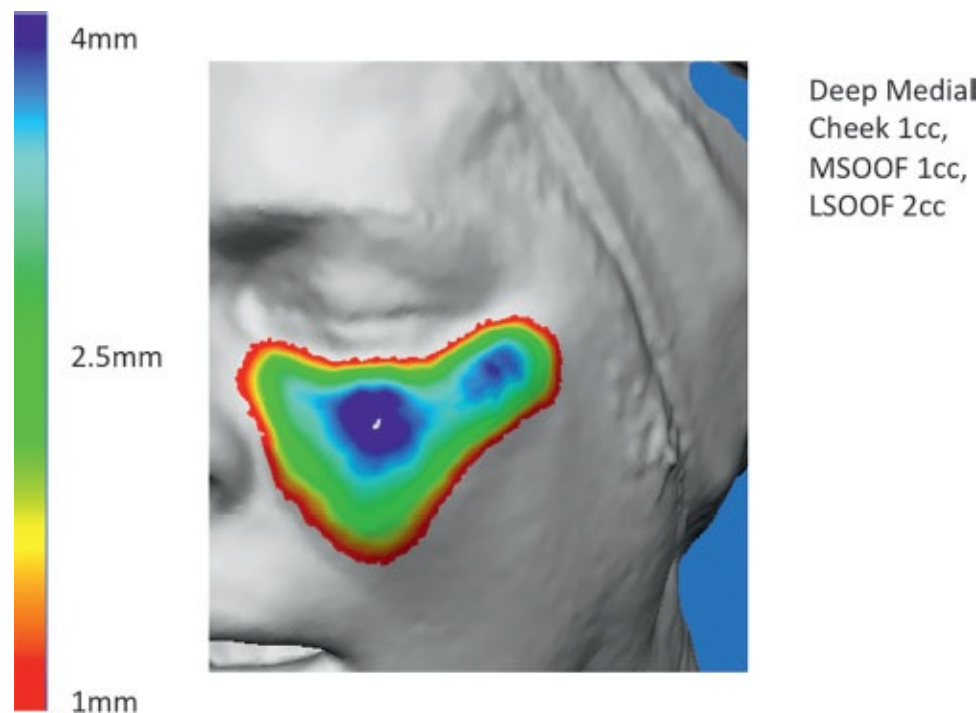


FIG 6 • 3D color map of clinical patient following malar augmentation to the deep medial cheek, medial SOOF, and lateral SOOF. Note the characteristic “boomerang” shape with the gradient of projection from the boundary in *red* (1 mm) to maximal projection in *blue* (4 mm).¹⁸

COMPLICATIONS

- Complications from autologous fat grafting to the periorbital region are rare but may be significant.
- Contour irregularities, particularly in areas of thin eyelid skin, may arise.
- Complications during fat harvest include pain, ecchymosis, and perforation of the abdominal wall and intra-abdominal viscera.



FIG 7 • Representative patient example following periorbital rejuvenation. This patient underwent autologous fat grafting to the MSOOF, LSOOF, DMC, and temporal hollows.

- Periocular complications following hyaluronic acid filler injections are exceedingly rare and due to retrograde displacement of product into the central retinal artery. Ptosis, ophthalmoplegia, enophthalmos, and blindness have been reported.¹⁹

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Indications and Techniques for Upper and Lower Blepharoplasty with Microfat Injections

37

CHAPTER

Nuri A. Celik

DEFINITION

Upper Blepharoplasty

- Upper blepharoplasty is considered an easy operation; however, depending on your level of expertise and ability to systematically analyze the inherent problems, it might be considered one of the most complex operations of aesthetic surgery practice.
- The complex component is the patient evaluation. There is more to a periorbital rejuvenation than just excision of fat, muscle, and skin. We should be able to answer the question: what makes an eye beautiful?
- The upper blepharoplasty evaluation should always involve the brow level and shape considerations. Although a high and arched eyebrow is a common feature in female beauty, transverse and low eyebrows are a masculine characteristic in the majority of the male models.
- One should always keep in mind that the facial skeleton also plays a major role in the perception of beauty.
- A convex area beneath the middle and lateral brow:
 - A surgeon should always examine the lateral brow mobility before performing an upper blepharoplasty. There are conflicting reports about the brow positional changes following an upper blepharoplasty.^{1,2} The author has two main criteria for this assessment.
 - The lateral brow response to a downward pull. This is a sure sign that the

skin resection at the end of the upper blepharoplasty procedure will easily displace the lateral brow tissues to a lower position.

- Any skin excess lateral to the lateral canthus. This is an indication for a brow lift by the author who never extends the upper blepharoplasty incision beyond the lateral orbital rim, because in thick skin individuals, scars lateral to the rim are visible.
- The fullness beneath the lateral brow area is a beauty feature in women³ and can also be a positive factor of masculinity in a low running male eyebrow. The fullness in this area is related to the fullness over the lateral orbital rim, and this can be surgically achieved with fat injection into the area (**FIG 1**) and also dermofat grafting (**FIG 2**).
- A short supratarsal distance is a significant feature of youth. It is directly associated with the periorbital soft tissue volume and an indicator of the upper sulcus fat content and the levator function.
- The skeletonized upper sulcus becomes prominent in the elderly (**FIG 3**), and the majority of these patients have an increased supratarsal distance. This shows the necessity of the addition of the intraseptal fat management and the levator procedures in our upper blepharoplasty practices.

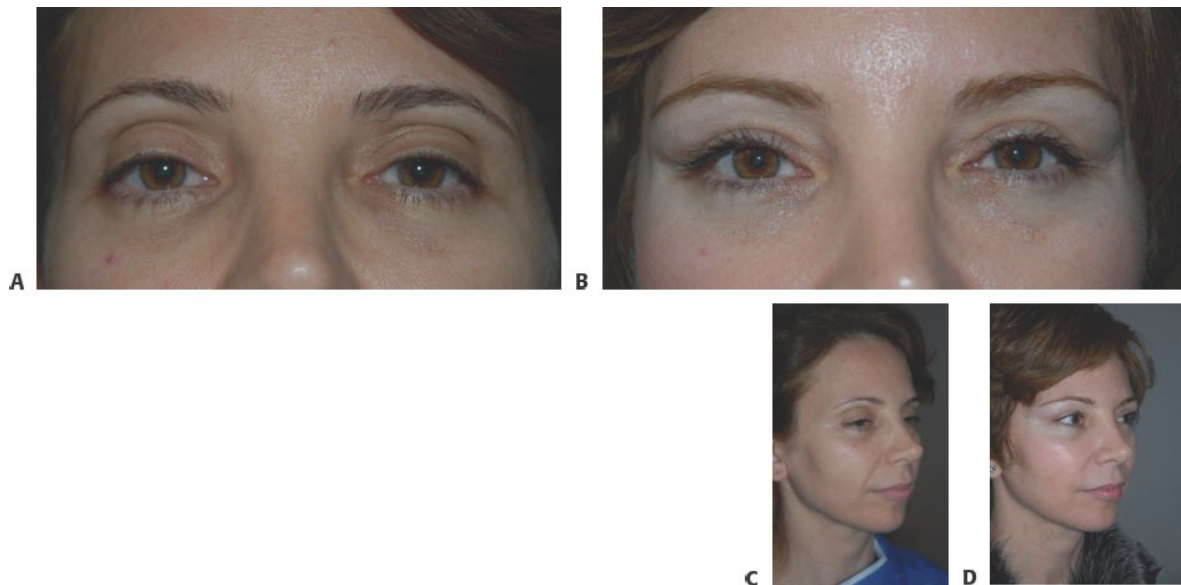


FIG 1 • **A,B.** A 45-year-old female who underwent upper blepharoplasty and lateral brow lift with fat injection. The levator advancement technique was used to correct the ptosis. **C,D.** The 2-year postoperative brow

contour is achieved with the help of lateral subperiosteal brow lift and fat injection of lateral infrabrow area.

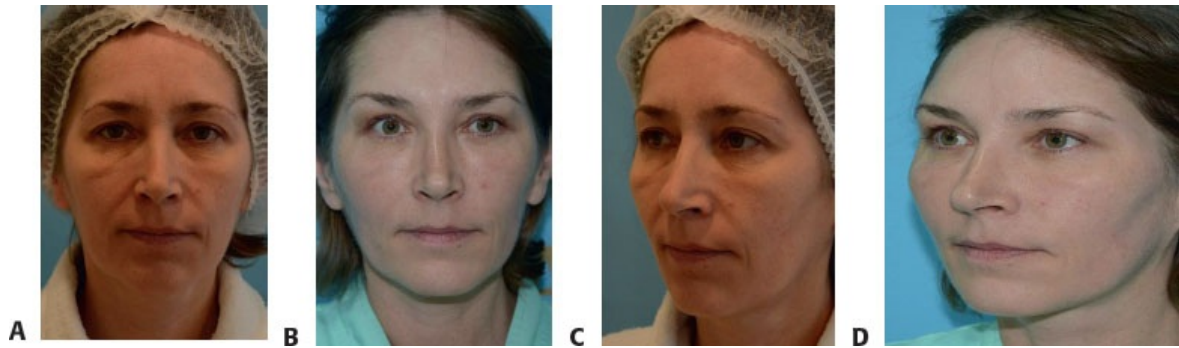


FIG 2 • A,B. A 42-year-old female patient before-after pictures. Upper eyelid ptosis corrected with levator advancement. Notice the raised lateral brow and the fullness of the infrabrow area. **C,D.** She had lateral brow lift through the upper blepharoplasty incision and dermofat grafting of the upper lateral orbital rim and the upper sulcus. The periorbital contours were obtained with 42-cc fat injection.

- The almond shape of the eye aperture:
 - In young individuals, the medial portion of the eye aperture has a higher measurement vertically than the lateral half.
 - The better support offered by the lateral canthus during early decades of life provides a higher lateral lower eyelid topography. This decreases the angle of convergence at the lateral corner of the eye and narrows the aperture in the lateral half.
 - The aging changes of the inferolateral orbital rim bone and dimension are mainly responsible for the sagging of the lateral part of the lower eyelid resulting in the change in shape of the eye to oval.^{4,5}
- An upper eyelid covering 1 to 2 mm of the limbus:
 - This is maintained with intact levator function and proper attachment of the aponeurosis on the anterior surface of the upper tarsus.
 - The upper eyelid level should be evaluated in conjunction with the frontalis

muscle activity because the frequent transverse horizontal wrinkles of the elderly show involvement of this muscle as a compensation for the failure of the levator system.

- Lateral and medial canthal position and stability:
 - The effect of the lateral canthal placement and resistance on the position of the lower eyelid is well documented in the literature.
 - The lateral canthal laxity is not age specific; it might be present in the young (**FIG 4A**), and surprisingly, the lateral canthus might have good stability in the elderly (**FIG 4B**).
 - The medial canthal position and symmetry are also significant factors in the lower eyelid stability because the lower tarsus is attached to both canthi.



FIG 3 • A 64-year-old female presenting with the typical superior sulcus fat deficiency, ptosis of the upper eyelids, and asymmetrically elevated eyebrows due to frontalis muscle compensation further accentuating the upper eyelid deformity.

- Slight asymmetries of the medial canthal origin will alter the hammock-type support of the lower eyelid, interfering with the postoperative results.
- The occasional patient who has slight displacement of the medial canthal attachment should be informed preoperatively that the possibility of obtaining perfectly symmetric lower eyelids is compromised (**FIG 5**).
- Medial and lateral canthal laxity is responsible for the majority of postoperative complications and should be taken into account to achieve good results with lower eyelid surgery.

■ Nasojugal fold:

- It is important to obtain a smooth pass from the lower eyelid to the cheek to decrease the shadows that increase with age.
- The transformation of the orbital cavity with the aging process decreases the support to the lower lateral orbital rim and the lateral canthus with increased fat herniation and degree of negative factor.⁶

Lower Blepharoplasty

- Lower blepharoplasty is a challenging operation because there are many factors that affect the outcome of surgery. The most important factors are medial and lateral canthal stability, presence of negative vector of the lower orbital rim, and orbital prominence or a shallow orbit.
- The need for a concomitant lateral canthal procedure during lower blepharoplasty procedure is not debatable in the author's opinion.⁷ It is the author's experience that patients with a medial canthal attachment at or below the level of the inferior limbus are at increased risk for lower eyelid retraction, no matter what type of maneuver is used for the lateral canthal support.⁸

Fat Injection

- As mentioned before, the telltale sign of periorbital aging is skeletonization; decreased subcutaneous fat fails to camouflage the upper and lower orbital rim bony contours.
- With the concomitant brow lift procedures, the relatively thin eyelid skin is pulled superiorly, leaving a depression over the superolateral orbital bony rim.
- This area needs augmentation in conjunction with the sub-brow area, and the relative prominence of this fill creates a need for temporal hollow, glabellar, and frontal regions and, in select cases, zygomatic arch and midface to be augmented with fat injections.⁹



FIG 4 • A. A surprisingly slack lower eyelid in a 24-year-old male patient. Notice the curved contour of the lower eyelid and excessive scleral show for his age. **B.** A 67-year-old male with good lateral canthal support.

ANATOMY

- The upper eyelid is a complex structure that consists of multiple tissue layers that seem to adhere to each other around the upper anterior tarsal surface.
- When the skin and muscle layers are incised and a skin muscle flap is elevated as a superiorly based flap, one notices a thin layer of adipose tissue on top of the upper orbital septum that is more defined medially and somewhat less laterally.
- The increased convexity of the globe is possibly responsible for this uneven distribution of the fat layer. The underlying septum should always be incised laterally and higher than the upper tarsal border in order not to injure the levator mechanism inadvertently.
- There usually is a preaponeurotic fat pad present, if not previously excised or developmentally absent.
- Under the fat pad, toward the upper orbital rim, one can find the vertically oriented fibers of the levator muscle. The surgeon should always keep in mind that, immediately below the levator aponeurosis, there is the vertically oriented arterial loop of the supratarsal arch that might resemble the fibers of the levator muscle.
- The lower eyelid has similar tissue layers converging and attaching to the lower end of the lower tarsus, mainly the septum under the muscle and, in deeper layers, the lower lid retractors and the conjunctiva.
- The lower half of the orbital septum is almost always attenuated and the lower eyelid fat pads are herniated in individuals with protruding fat pockets.
- One important surgical landmark is the periosteal attachment of the orbicularis oculi muscle that extends around 1 cm along the medial part of the lower orbital rim.⁹
- The middle and lateral portions of the surface of the bony rim periosteum are covered by the SOOF to a variable degree in every individual. This creates two separate surgical dissection layers: around the midportion of the lower orbital rim, the medial part elevation should always be subperiosteal, whereas the

more lateral portions allow a suprapariosteal dissection.

PATHOGENESIS

- Many complex mechanisms are involved in the aging process with various contributions from different tissue layers presenting as the individual aging patterns seen in different races and skin types.



FIG 5 • A,B. A 44-year-old male seeking correction for his asymmetric ptosis, scleral show, and premature facial aging. Notice the low insertion of the medial canthi in relation to the lower limbus. This puts the patient in a “surgical risk” category. **C,D.** The patient was informed of the asymmetry of his medial canthal insertion and possibility of lower eyelid level and shape mismatch. The postoperative level of the right lower eyelid is slightly lower than the left due to lower insertion of the medial canthus on that side.

- Camirand’s paper¹⁰ deals with mainly the soft tissue changes, whereas recent

investigations⁴⁻⁶ point to concomitant bony topographical alterations.

- With time, the ligaments attenuate and the subcutaneous thinning ensues, whereas the compensatory powerful muscle contractions create furrows and lines.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The variable pattern of the individual aging process makes it impossible to specifically organize the deformities that the patients present with.
 - There are patients who present mainly with tissue loss as well as the ones who complain of increased fat pockets around the eyes (**FIG 6**).
 - Although the thin-skinned patients mainly complain of wrinkles, the thick-skinned individuals would like more of a “lift” because of the higher incidence of sagging of the periorbital tissues.
- It is advisable to obtain pictures of patients from their early decades of life. This gives the surgeon the ability to assess the aging changes and the pattern and shed light to a sound surgical planning.

DIFFERENTIAL DIAGNOSIS

- Myasthenia gravis
- Thyroid disease

NONOPERATIVE MANAGEMENT

- There are many different treatment options for this area, including lasers, ultrasonic devices, peels, and fillers.

SURGICAL MANAGEMENT

Preoperative Planning

- Consider
 - Skin thickness
 - Brow ptosis: horizontal frontal wrinkles



FIG 6 • A,B. A 72-year-old female before and after face-lift with upper and lower blepharoplasty 7 years ago. She was treated with 200-cc single-stage periorbital and perioral fat grafting and upper lip shortening of 7 mm.

- Upper eyelid ptosis
- Loss of upper eyelid curve
- Asymmetric or high supratarsal fold
- Upper eyelid fat and skin
- Lateral canthal ligament laxity
- Medial canthal ligament laxity
- Medial canthal ligament insertion variations
- Any asymmetry
- Lower eyelid fat pads, pretarsal muscle activity, and tone
- Nasojugal fold

Positioning

- Patient is operated supine and in a reverse Trendelenburg position.

Approach

- The upper blepharoplasty incision follows the natural curve of the supratarsal crease and is situated at 8 mm from the eyelash border in the middle, closing to a 5-mm distance at both corners. The lateral extension should not go beyond the lateral orbital rim.
- The lower blepharoplasty incision is a subciliary incision and does not cross

the level of the lateral corner of the eye.

TECHNIQUES

■ Upper Blepharoplasty

Preparation

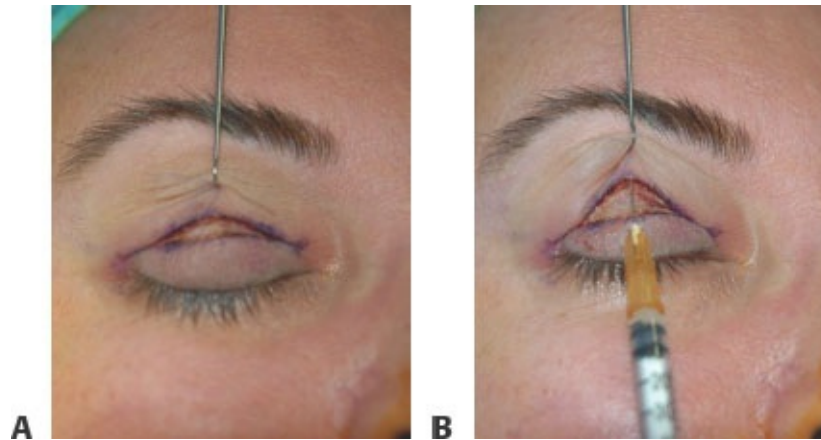
- The surgery starts with the upper blepharoplasty markings (**TECH FIG 1**) and the injection of a freshly prepared local anesthetic and adrenalin mixture.



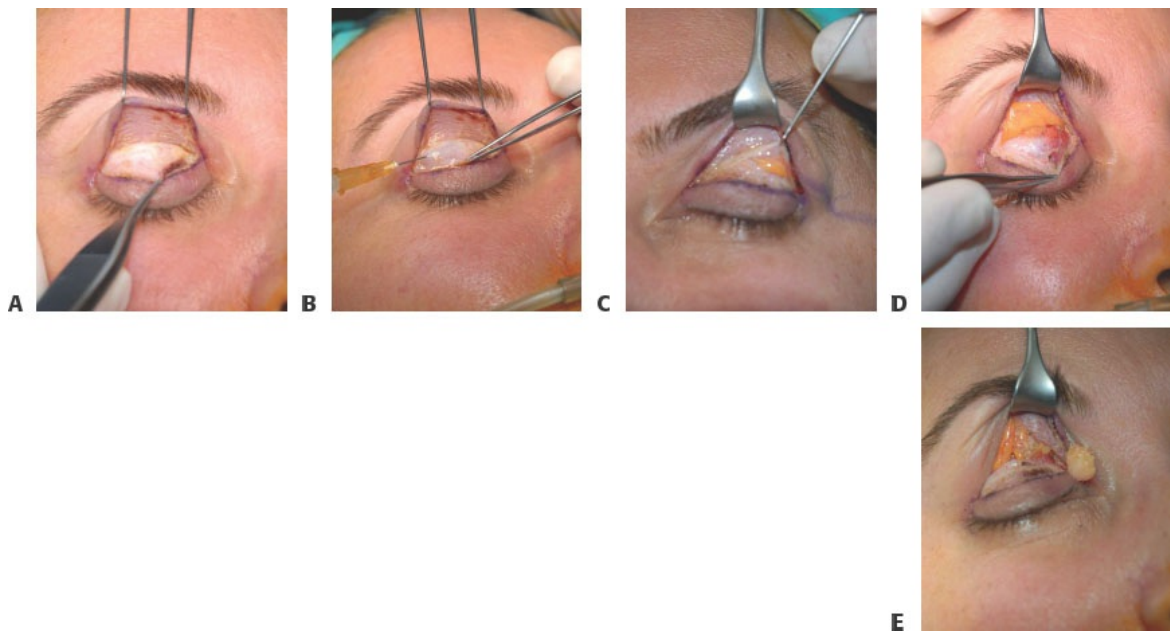
TECH FIG 1 • Upper blepharoplasty marking.

Incision

- It is important to wait for at least 7 minutes for vasoconstriction, and then a superficial skin incision is performed with the surgical blade (**TECH FIG 2A**). A Colorado tip cautery is used to incise the dermis and the muscle to prevent bleeding.



TECH FIG 2 • **A.** Dermal incision performed with Colorado tip cautery to prevent bleeding. **B.** Injection of local anesthetic into the muscle.



TECH FIG 3 • **A.** Orbicularis oculi muscle preseptal portion elevated off of the upper orbital septum. **B.** Injection of saline into the preaponeurotic cavity. **C.** Upper orbital septum opened medially to reveal preaponeurotic fat pad. **D.** Upper orbital septum opened at its full width. **E.** Medial fat pad resected.

- After incision of the full thickness of the muscle, the local anesthetic is

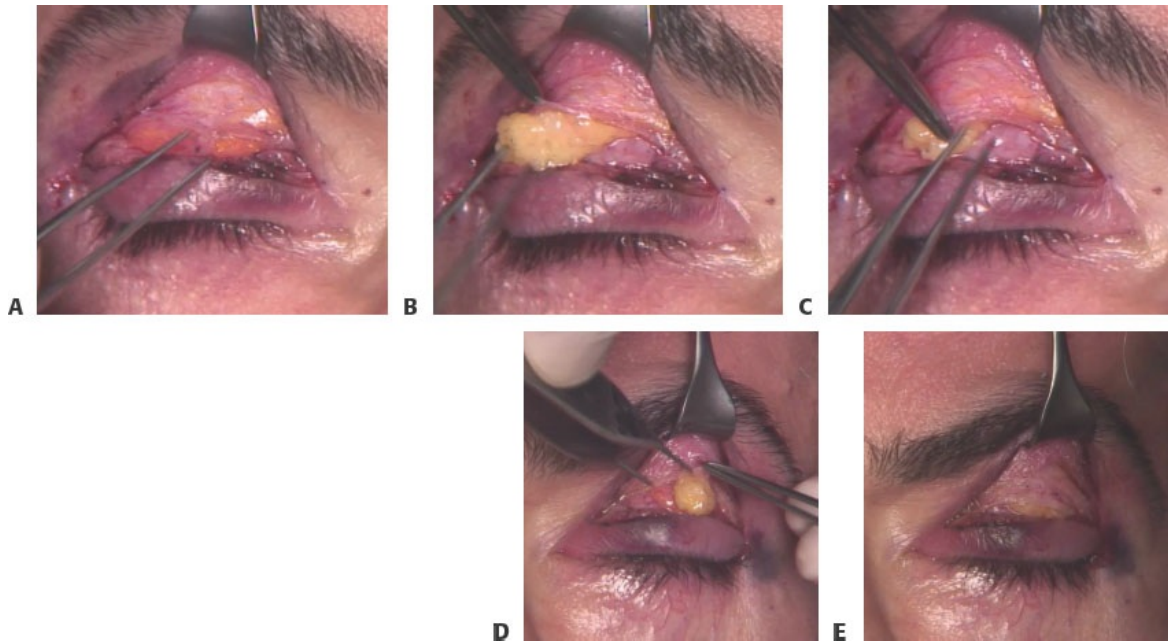
injected into the superior flap superficially (**TECH FIG 2B**).

Dissection

- Then, the dissection continues immediately adjacent to the undersurface of the orbicularis muscle layer on top of the upper orbital septum (**TECH FIG 3A**).
- With time, one recognizes a very thin layer of fatty tissue on top of the septum, more pronounced medially and laterally. It is advisable to use loupe magnification and start the submuscular dissection either medially or laterally to be able to distinguish the tissue layers.
- The elevation of the muscle flap also allows easy access to the plane of the corrugator for resection and the brow region for brow fixation.
- The upper orbital septum and levator aponeurosis layers lie almost adjacent to each other in the area of our incisions, so it is advisable to inject 1 cc of saline into the subseptal space for hydrodissection (**TECH FIG 3B**).
- This facilitates the separation of the layers, and a laterally placed incision of the septum is then advanced to completely open the preaponeurotic space. The fat pads lie in this layer (**TECH FIG 3C**).
- The preaponeurotic fat pad is gently dissected free from the underlying levator muscle (**TECH FIG 3D**), and if necessary, levator procedure is performed.
- The medial fat pad, almost always excessive, is dissected and excised (**TECH FIG 3E**).
- There is no need for preaponeurotic fat pad resection except in very rare cases. Instead, the upper sulcus needs to be augmented in the majority of the aging patients.

Suturing

- The resected medial fat pad is used to graft the middle upper sulcus, and for a better take, the fat graft is placed under the existing fat pad (**TECH FIG 4A–C**).



TECH FIG 4 • **A.** Upper orbital septum opened. **B.** Resected medial fat pad brought on site. **C.** The medial fat pad is grafted to the upper middle sulcus to treat the superior sulcus fat deficiency. **D.** Intraseptal fat graft in place. **E.** Septum is closed over the graft.

- The upper edge of the septum is then found and pulled down with a forceps to cover over the upper orbital fat pad, and the fullness and convexity are checked to obtain a smooth pass from the brow to the upper eyelid (**TECH FIG 4D**).
- The upper orbital septum is then sutured with a 6-0 poliglecaprone suture (**TECH FIG 4E**).

Closure

- The skin muscle flap is pulled down and skin excess is marked.
- The muscle fibers of the orbicularis muscle of the upper eyelid are more condensed around the supratarsal area (**TECH FIG 5**), and unfortunately, this is the region where we resect the skin and muscle at the end of our blepharoplasty procedures.
- This may interfere with proper eye closure in the early postoperative period. This is the reason why the author prefers to de-epithelialize the skin and leave the muscle intact to turn in during closure, also helping with the

upper orbital sulcus fullness.



TECH FIG 5 • The skin is de-epithelialized and the orbicularis muscle left intact. The orbicularis oculi fibers are more condensed in the area of resection in conventional blepharoplasty.

- The closure of the skin is done with 6-0 nylon sutures.

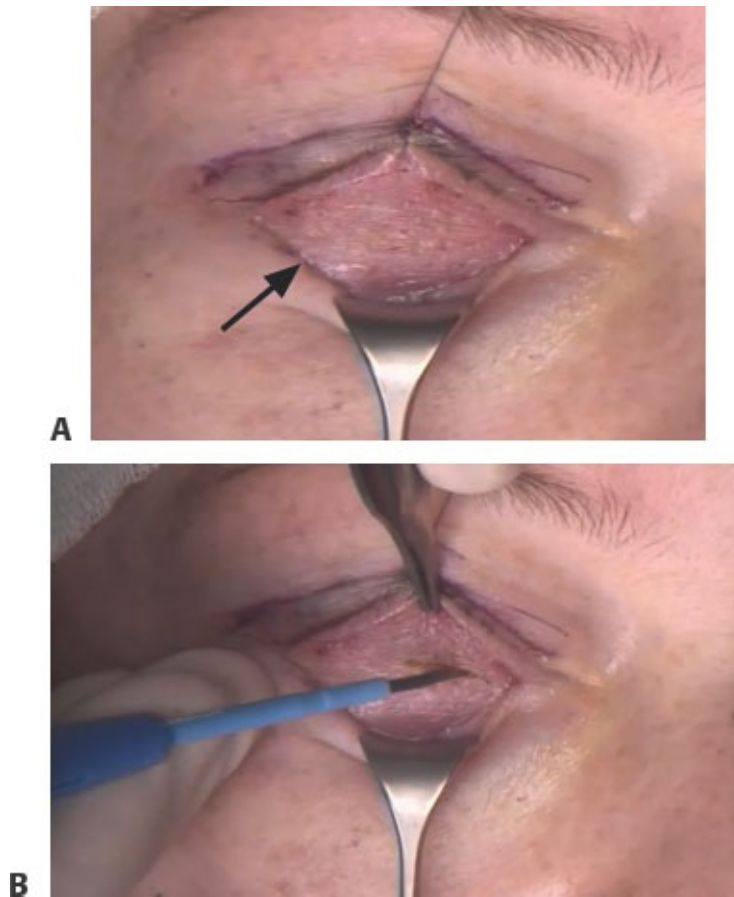
■ Lower Blepharoplasty

Preparation

- The upper and lower eyelids are sutured together at the start of the lower blepharoplasty procedure, and this suture is used for traction.
- Similar to the upper blepharoplasty technique described above, the injection of the local anesthetic and epinephrine solution is followed by the subciliary incision.

Incision

- The thin skin of the lower eyelid is then separated from the underlying orbicularis muscle fibers with the help of the Colorado needle tip cautery for 10 to 15 mm to facilitate muscle and skin excision at the time of the closure (**TECH FIG 6A**).



TECH FIG 6 • A. The skin is elevated off of the orbicularis fibers through a subciliary incision at the start of the lower blepharoplasty. **B.** The pretarsal portion of the orbicularis is protected, and the muscle is cut below the level of the lower rim of the tarsal plate.

- The lower pretarsal muscle is marked, and an incision is performed with the cautery to reach the preseptal space of the lower eyelid (**TECH FIG 6B**).

Dissection

- The dissection is continued to reach the lower orbital rim. The lower eyelid septum is most often attenuated in this region, so it is better to stay close to the fibers of the orbicularis muscle during the dissection.
- Once the surgeon reaches the lower orbital rim, the attention is focused on the most medial portion of the rim first.

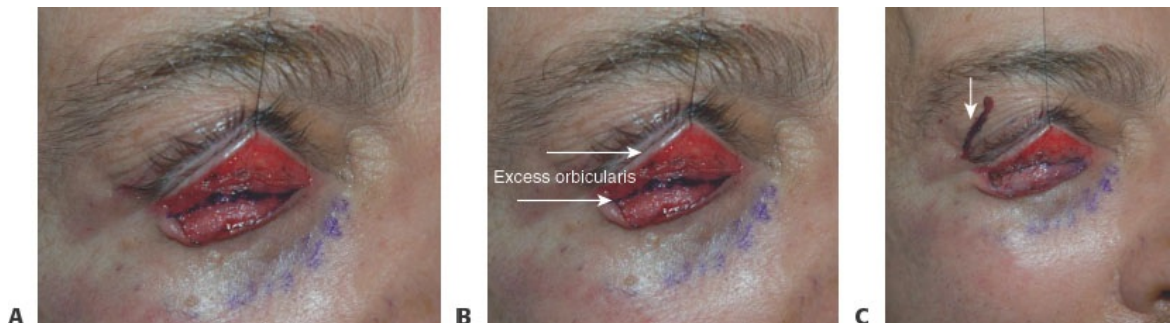
- The insertion of the orbicularis muscle on the periosteum of the medial orbital rim forms the nasojugal fold (**TECH FIG 7**), and therefore, the dissection continues in a subperiosteal plane medially to reach the level of the nasal bone suture line, creating a pocket.

Suturing

- A fat flap is formed with the already herniated medial fat pad, and it is then advanced to this space to prevent the attachment of the muscle again.
- The fat flap is sutured to the periosteum medially with 5-0 nylon sutures. The suture should be strong enough to hold the fat flap in position to cover the medial lower orbital rim.



TECH FIG 7 • The dissection reveals the anatomy of the medial lower orbital rim. The *arrow* points the orbicularis muscle insertion on the periosteum.



TECH FIG 8 • **A.** At the time of closure, the lower eyelid muscle layer is pulled up and the excess

orbicularis is marked. **B.** The excess orbicularis muscle. **C.** The excess muscle is elevated as a laterally based Anderson flap, and the edges of the lower orbicularis muscle are sutured together.

- This effective fat transposition fills the nasojugal fold depression that is caused by the orbicularis attachments on the rim periosteum.¹²
- The lateral fat pad is almost always excessive and is excised.
- The lower eyelid is then pulled up with the help of the traction suture. The decision of skin and muscle excision should be done in this position to prevent complications.

Closure

- The muscle is pulled up gently and excess muscle is marked, if there is any (**TECH FIG 8A**).
- It is advisable not to resect the muscle (**TECH FIG 8B**) and, instead, prepare it as a laterally based Adamson flap (**TECH FIG 8C**) to suture to the lateral rim periosteum to act as an efficient canthopexy in individuals with a proper canthal tilt.
 - If the patient does not have a proper canthal tilt to start with preoperatively, then a transpositional type of canthal surgery should be undertaken.
- The cut edges of the muscle are then sutured with 6-0 inverted polydioxanone suture to prevent muscle retraction in the early postoperative period. With the help of this measure, it is possible to see early intact pretarsal muscle activity in the lower blepharoplasty patients (**TECH FIG 9**).
- There usually is no need for skin excision other than a marginal correction.
- The subciliary incision is then closed with 6-0 nylon sutures.



TECH FIG 9 • A,B. The patient force closes the eyes on the 5th postoperative day. Notice the upward movement of the lower eyelid. This is due to the early intact function of the lower eyelid orbicularis muscle, possibly due to the atraumatic technique and suturing of the muscle edges together to prevent avulsion.

■ Periorbital Fat Injection

- Injecting fat in the periorbital area is a sculpting measure to help with the surgical fat preservation and reorganization principle observed during the upper and lower blepharoplasty.
 - Midfacial, frontal, glabellar, root of the nose, zygomatic, and brow fat injections are done at deeper tissue layers, over the periosteum.
 - The temporal area injections are superficial in the subcutaneous plane.
- The microfat grafts pass through tuberculin syringes and are used to directly inject into the wrinkles (**TECH FIG 10**).
- It is advisable to use an average of 45 to 60 cc of fat grafting in the periorbital area.



TECH FIG 10 • A,B. A 47-year-old female underwent a periorbital lift with upper and lower blepharoplasty with fat preservation and additional fat injection. **C,D.** The profile view of the patient. Notice the change in the periorbital and perioral profile as a result of the brow and midface lift, upper lip shortening, and 60 cc

of facial fat grafting.

PEARLS AND PITFALLS

Hemostasis	■ Hemostasis is the key to the success of the surgical dissection and tissue healing. ■ Stop any coagulants 3 weeks before surgery. ■ Postoperatively, use only opioids for pain.
Incisions	■ Never extend incisions beyond the level of the lateral canthus; estimate skin excess at the end of the procedure.
Technique	■ Use loupe magnification and Colorado tip cautery. ■ Do not aim excision; plan to preserve fat and muscle. ■ Assess lateral and medial canthal stability before surgery and plan necessary measures to increase lower eyelid support. ■ Skin and muscle excision of the lower eyelid is performed with the lid pulled up.

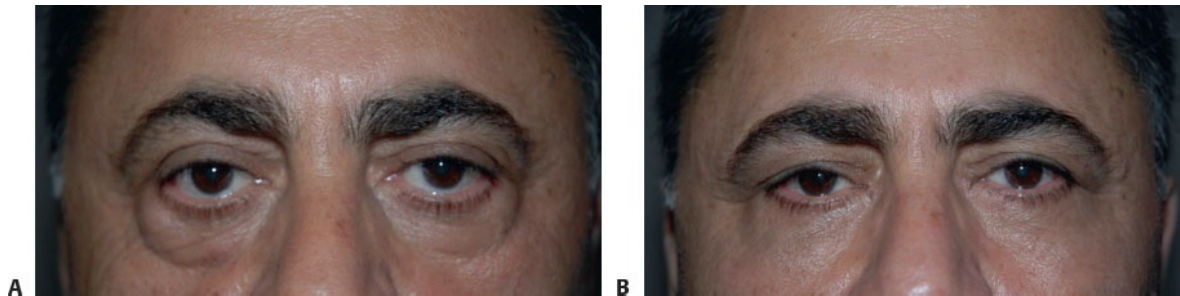


FIG 7 • A,B. A 62-year-old male presented with medial fat pad herniation of the ptotic upper eyelids, periorbital skeletonization, lower eyelid medial and lateral fat pad herniation, midfacial atrophy R greater than L, lower eyelid laxity, and rather low medial canthal attachment. He was treated with resection of only the medial fat pad of the upper eyelid and the lateral from the lower. The medial fat pad of the lower eyelid was maintained and advanced subperiosteally to efface the nasojugal fold.

Periorbital and midfacial fat injection helped achieve better contours. Levator advancement procedure corrects his upper eyelid senile ptosis, and a tensor fascia lata suspension of the lower eyelid overcomes the possible complications.

POSTOPERATIVE CARE

- The head of the bed is elevated.
- No NSAID at any time, intra- or postoperatively.
- Constant application of ice for 5 days over a wet sponge.
- Suture removal 3 to 5 days.

OUTCOMES

- The principles of fat and muscle preservation, judicious fat grafting help accomplish good results with upper and lower blepharoplasty surgery.
- The surgeon's awareness before surgery about the inherent problems of the medial and lateral canthal position and stability will help prevent the possible complications of lower eyelid surgery (**FIGS 7 and 8**).

COMPLICATIONS

- The most common complication of the upper eyelid surgery is caused by excessive removal of the fat pads. This causes superior sulcus fat deficiency and increased supratarsal fold distance and is a telltale sign of poor surgical evaluation (see **FIG 8**).
- The fibrosis associated with the poor technique when performing a lower blepharoplasty will increase the fibrous tissue (**FIG 9**) and exert a pull and cause shortening of the lower eyelid causing scleral show.

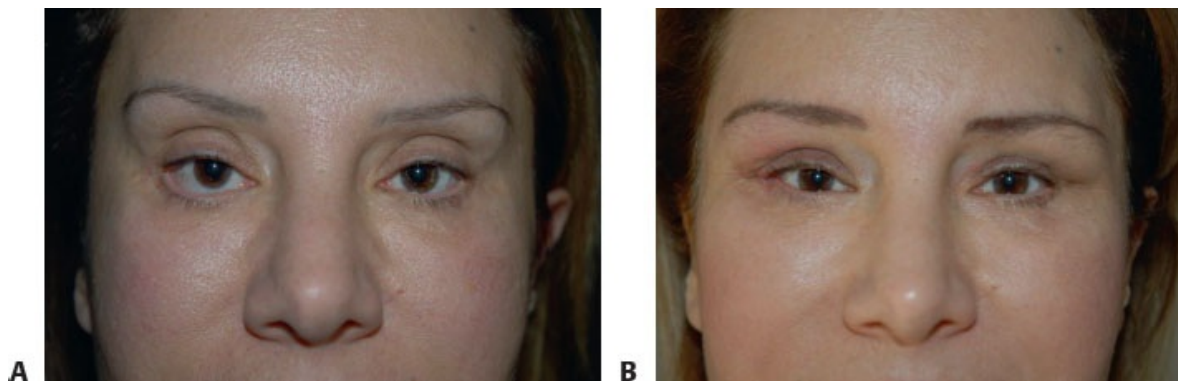


FIG 8 • A. A 44-year-old female S/P upper and lower blepharoplasty and brow lift and six consecutive revisions. Notice the fat deficiency of the upper eyelid sulcus. She also has sagging of the right lower eyelid. **B.** The patient 2 years after dermofat grafting of the upper eyelids, tensor fascia lata suspension reconstruction of the lower eyelid, and periorbital fat grafting. The right upper eyelid still needs more fatty tissue support.

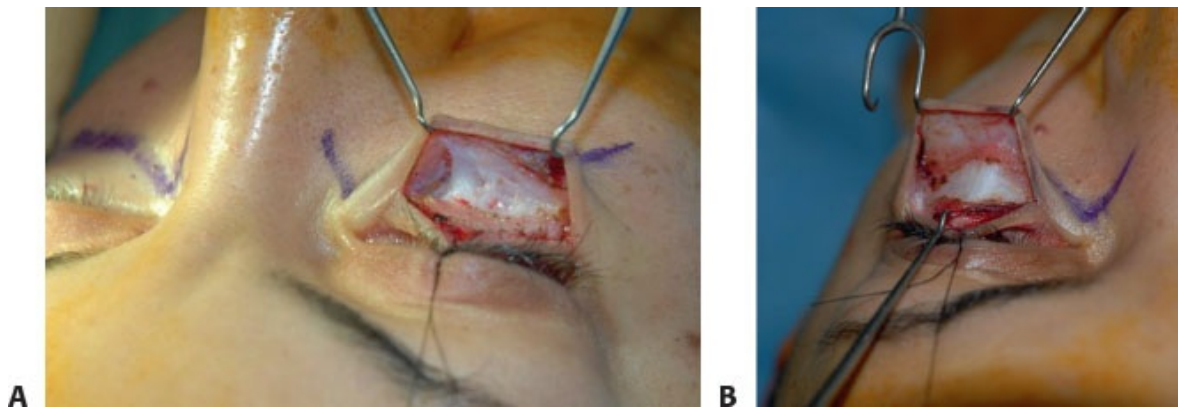


FIG 9 • A,B. The surgical dissection findings of a lower blepharoplasty complication. Notice the significant fibrous thickening of the orbital septum, shortening the lower eyelid.

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Indications and Technique for Fat Grafting for Periorbital Rejuvenation

38

CHAPTER

Dino Elyassnia and Timothy Marten

DEFINITION

- The hallmark of a youthful, attractive orbit is fullness. It has become clear that fat atrophy is a significant component of periorbital aging that results in volume loss and a hollow appearance around the eyes.
- Traditional blepharoplasty procedures have focused on treating skin laxity, fat herniation, canthal laxity, and levator dehiscence but have largely ignored fat atrophy. Often, blepharoplasty procedures aggressively remove fat from the eyelids, further compounding the problem of volume loss.
- Periorbital fat grafting represents a new paradigm in eyelid aesthetics that focuses on volumetric rejuvenation of the upper and lower eyelids. This approach produces a full, healthy appearance to the eyes that has not been possible with traditional blepharoplasty techniques.

ANATOMY

- In recent years, a great amount of work has been done to beautifully elucidate the detailed fat compartments of the face.¹
- Although this work has been a great contribution to further understanding of facial anatomy, it plays a smaller role in technically carrying out periorbital fat grafting because the goal is not to inject fat in such a way that we aim to “refill” each deflated fat compartment.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A focused history should include any ophthalmologic conditions, previous blepharoplasties, or other aesthetic treatments including filler use. As

hyaluronic acid filler tends to last especially long in the upper and lower eyelids, knowledge of its use must be obtained so a decision can be made whether to dissolve the material prior to fat grafting.

- Physical exam of the eyelids should include looking for the presence of ptosis, dermatochalasis, lower lid fat herniation, canthal laxity, orbital vector, and degree of fat atrophy of the eyelids, midface, and cheek. If problems other than fat atrophy are present such as significant lower lid fat herniation or excess skin, traditional blepharoplasty techniques may need to be combined with fat grafting.
- A significant advantage of periorbital fat grafting over traditional lower lid blepharoplasty is that fat grafting is very safe in the setting of dry eye or the presence of canthal laxity, whereas these problems represent relative contraindications for lower blepharoplasty.
- Regarding fat harvest, thin patients should be examined at the time of their consultation because patients with limited fat stores often present significant challenges. Extra time and effort will be required to obtain fat from them. Anesthesia and OR times must be calculated accordingly.
- Although the abdomen is often cited as the “best” and most convenient site for fat harvest, in our practice, the hip, waist, and outer thigh are the harvest sites of choice. The abdomen typically has thinner, less forgiving skin than the hip, waist, and outer thigh (especially in the face-lift age group) and is readily open to detailed inspection by the patient after the procedure. As such, it can be problematic as a sole donor site in many cases if more than a small amount of fat is needed. The hip, waist, and outer thigh taken together by contrast typically provide more volume and are less subject to surface irregularities, and fat harvest from these areas generally provides more overall improvement in the patient’s silhouette.

IMAGING

- Typically, radiographs are not necessary for periorbital fat grafting.
- All patients should have standardized photographs taken preoperatively, and any markings made preoperatively on patients should be photographed as well.
- These photos should be used intraoperatively to help guide precise placement of fat injections.

NONOPERATIVE MANAGEMENT

- Fillers to the periorbital area are a viable alternative to fat grafting and have

helped patients understand how volume loss contributes to the periorbital and facial aging process.

- Advantages of fillers are they have minimal downtime, they are easily adjustable, they can be reversed (if hyaluronic acid is used), and they last particularly long in the periorbital area compared to other regions of the face.
- Disadvantages are they require ongoing maintenance; they are time-consuming, painful, and expensive; and they can look unnatural requiring a high level of precision during injection.

SURGICAL MANAGEMENT

- Whether the result of illness, aging, or previous overzealous surgical treatment, filling the hollow upper orbit can produce a remarkable rejuvenation of the upper eyelid and eliminate an unnaturally hollow and elderly appearance sometimes referred to by patients as “nursing home” or “owl” eyes (**FIG 1**).
- Like the upper orbit, fat grafting the infraorbital area allows comprehensive correction of age-associated hollowness that lends the face an ill or haggard appearance, “shortens” the apparent length of the lower eyelid, and produces a youthful, attractive, and highly desirable smooth transition from the lower eyelid to the cheek. This effect is generally unobtainable by traditional lower eyelid surgery, fat transpositions, “septal resets,” midface lifts, free fat grafts, and other like means (**FIG 2**).

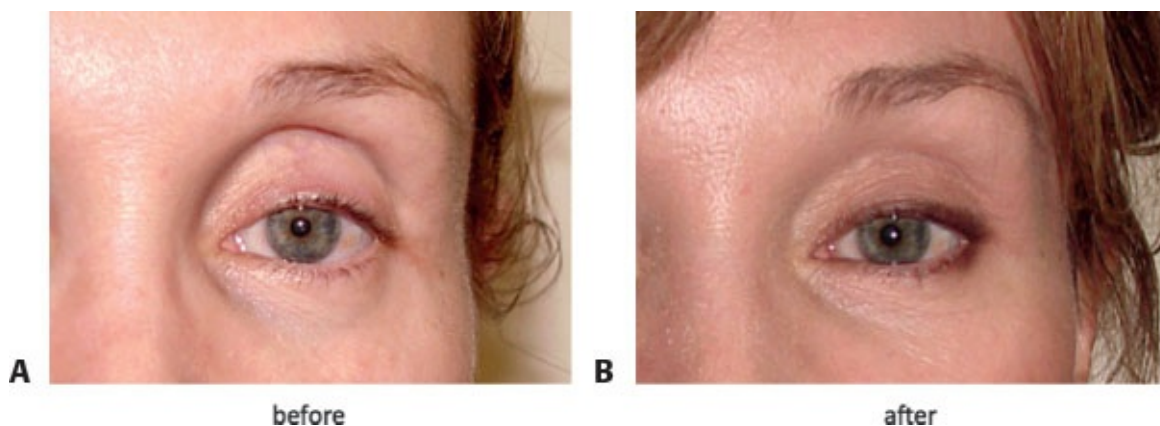


FIG 1 • Correcting upper orbital hollowing. **A.** Patient with an unnaturally hollow upper eyelid appearance (“owl eyes”) following blepharoplasty performed by an unknown surgeon. **B.** Same patient seen after fat injections to the upper orbit. A healthier, more youthful

appearance can be seen (procedure performed by Timothy Marten, MD, FACS—Courtesy of Marten Clinic of Plastic Surgery).

- Although the primary goal of fat harvest is to obtain the “best” tissue for the fat grafting procedure, fat harvesting should be thought of as an opportunity to improve the patient’s figure. Thus, harvest must be undertaken in a thoughtful and artistic manner and generally in a bilateral and symmetrical fashion. Although any area can theoretically be used for a donor site, the hip, waist, and outer thigh are our primary choice for the reasons detailed above.

Preoperative Planning

- Fat grafting cannot be performed casually, and deficient areas and key landmarks must be marked preoperatively with the patient in an upright position. Marking will require concentration and focus and is best carried out in an area that is free from distractions.
- Creating a proposed plan on a full-page laser print of the patient’s face is helpful in organizing the treatment plan and facilitates confirming with the patient the areas that will be treated.
- If the patient wishes, marks can be made while she or he holds a hand mirror. Once markings are complete, a new series of photographs are taken and printed up for use during the procedure. These photographs typically provide the best information to the surgeon intraoperatively.

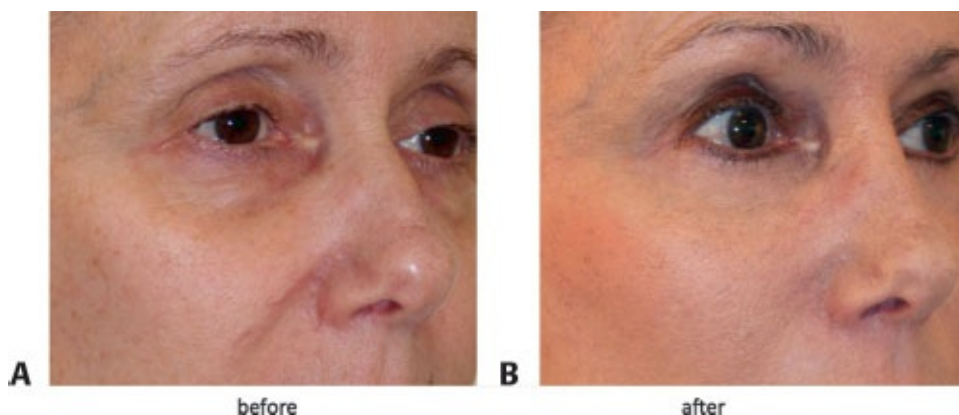


FIG 2 • Filling the hollow lower orbit with fat. **A.** Patient with an unnaturally hollow and elderly infraorbital appearance. The lower eyelid appears “long,” and there

is a distinct line of demarcation between the lower eyelid and the cheek. **B.** Same patient seen after face-lift and fat injections to the infraorbital area. There is a smooth transition from the lower eyelid to the cheek, and the patient has a healthier, youthful, and attractive appearance (note: the upper orbit, radix, cheek, and nasolabial crease have also been treated with fat injections, and the patient has undergone ptosis correction) (procedure performed by Timothy Marten, MD, FACS—Courtesy of Marten Clinic of Plastic Surgery).

- Regarding fat harvest, an estimate should be made as to the amount of fat that will be used and thus the amount that needs to be harvested. In estimating the amount that one needs to harvest, a helpful guideline is that after centrifugation, approximately 50% of what was harvested will be obtained as usable processed fat.
- If one wishes to perform the fat grafting procedure predominantly with “stem cell”-rich fat (the bottom 2 cc of fat in the centrifuged 10-cc syringe consisting of high-density adipocytes), only 20% of what is harvested fat will be available for injection, and the total amount harvested will have to be adjusted accordingly.
- As in the case of formal liposuction, the patient’s torso must be marked preoperatively while she or he is standing if optimal contours are to be created and if irregularities are to be avoided at the harvest sites. Once markings are complete, marked areas should be photographed and the photos printed up for use during the harvesting part of the procedure.

Positioning

- Fat is harvested after anesthesia is initiated but before prep and drape of the face. A complete prep of the torso is not necessary, and in all but the unusual case, a limited prep of the marked area is made and a sterile field is established.
- If fat is to be harvested from the hip or lateral thigh, the patient is turned into a semilateral decubitus position; prep, drape and harvest is performed; and the patient then is turned to the opposite side where a similar procedure is

performed.

- This position can be used to simultaneously harvest fat from multiple sites including the hip, waist, flank, upper buttocks, outer and inner thigh, and knees (**FIG 3**). With practice, a well-organized OR team can complete this process expeditiously without undue delay of the procedure.



FIG 3 • Positioning patient for fat harvest. If the patient is carefully positioned in a semilateral decubitus position, fat can be simultaneously harvested from multiple sites including the hip waist, flank, inner knee, outer and inner thighs, buttocks, and inner knee. Obtaining fat from multiple sites is particularly important in thin patients with minimal fat stores or when multiple site fat grafting is being performed. Following harvest from one side, the patient is turned to the other where a similar harvest is performed.

- The patient is then returned to the supine position for fat grafting the periorbital area.

Approach

- For upper orbit fat grafting, small stab incisions are made in the brow with a no. 11 blade scalpel or a 20-gauge needle. These incisions are so small that they will not require suturing upon completion of the procedure.
- Injecting from two separate injection sites at the medial and lateral ends of the

brow allows “crisscrossing” of cannula passes during graft placement parallel to the superior orbital rim.

- This “crisscrossing” provides smoother fat infiltration and helps avert a “row of corn” effect that may result if injection is made from only one site.
- Unlike the upper orbit, however, experience has shown that for the lower orbit, fat is best and most easily injected *perpendicular* to the infraorbital rim from stab incisions in the midcheek or perioral area. When this is done, lumps and irregularities are far less common. *Fat should not be injected parallel to the lid-cheek junction in the infraorbital area.*

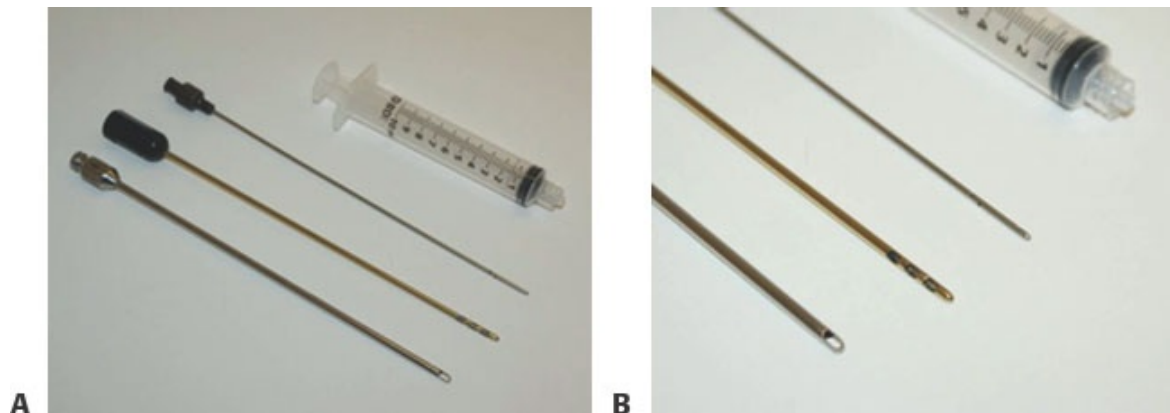
TECHNIQUES

■ Fat Harvest

- Areas from which fat is to be harvested are infiltrated with a dilute 0.1% lidocaine with 1:1 000 000 epinephrine solution using a multiholed infiltration cannula (**TECH FIG 1**), and an adequate time is allowed for a proper anesthetic and hemostatic effect.
- Approximately 1 cc of this solution is injected for every 3 cc of anticipated fat removal. It is not necessary or desirable to infiltrate in a “tumescent” fashion as overwetting the tissue will result in an overdilute harvest and more time spent in the harvesting process.
- Local anesthetic should be injected even if general anesthesia is used to limit stimulation of the patient and the overall amount of general anesthetic needed.
- Fat is harvested with a special harvesting cannula (see **TECH FIG 1**) ranging in size from 2.1 to 2.4 mm and 15 to 25 cm long attached to a 10-cc syringe using gently applied syringe suction to minimize vacuum barotrauma to the tissue.
- Sharp hypodermic needles should not be used to harvest fat.
- In general, and as mentioned previously, at least twice as much fat is harvested as is anticipated will be used to ensure an adequate amount of processed fat will be available for use on the face.

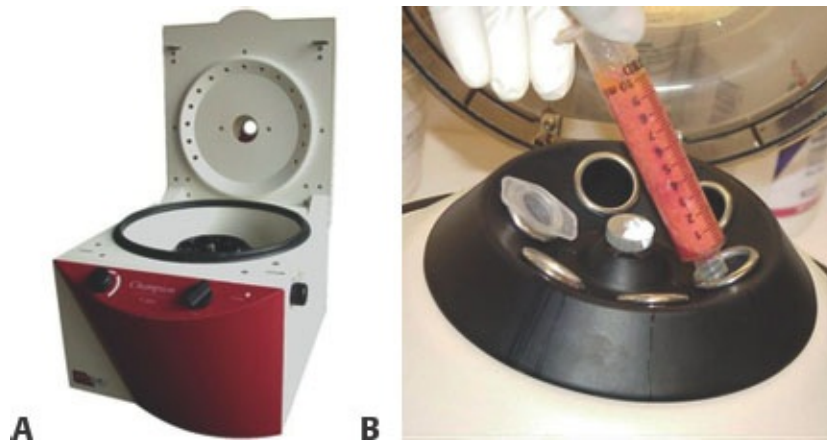
Processing Harvested Fat

- Our preferred method of processing fat is centrifugation.
- Before centrifugation is commenced, a sterile disposable plastic cap is placed on the end of the syringe to keep its contents inside it, and the syringe plunger is removed from the syringe barrel.
- Capped syringe barrels containing unprocessed fat are then loaded into the centrifuge in a balanced fashion and spun for 1 to 3 minutes at 1000 RPM.
- Many centrifuges available for this purpose have variable speed adjustments and rotors that can be sterilized so that the syringes the fat is in remain sterile and can be handled by the scrubbed surgical team. Other centrifuges have sterile tubes that fit into the rotor for this purpose (**TECH FIG 2**). The typical spin speeds of approximately 3500 RPM used by most single-speed desktop centrifuges sold for fat processing are said to not cause injury to fat or compromise its “take.”
- Once centrifuged, syringe barrels containing spun fat are removed, centrifuged fat will be seen to contain an upper oil (ruptured fat cells), central fat, and lower “water” (blood, lidocaine) components (**TECH FIG 3**).
- The often blood-tinged “water” (local anesthetic) component is discarded by simply removing the syringe tip cap and allowing it to run out. The oil fraction is then poured off out of the top of the syringe. Telfa sponges can also be placed inside the syringe barrel to wick up the small amount of residual oil present after the majority of it has been poured off.
- A laboratory “test tube”–type rack to hold and organize the syringes containing fat greatly facilitates fat processing activities (**TECH FIG 4**).



TECH FIG 1 • Fat harvesting instruments. **A.** Specially designed harvesting cannulas ranging in size from 2.1 to 2.4 mm are attached to 10-cc Luer-Lok syringes

and are used to extract fat from donor sites using gentle syringe suction. Fat harvested with these cannulas easily passes through injection cannulas as small as 0.7 mm. Shown from top to down: (a) 10-cc Leur-Lok syringe, (b) 1.6-mm Coleman local anesthetic infiltration cannula, (c) 2.4-mm Tulip “Tri-Port” harvesting cannula, and (d) Coleman harvesting cannula. **B.** Close-up of instrument tips. Shown from top to down: (a) 10-cc Leur-Lok syringe, (b) Coleman infiltration cannula, (c) Tulip harvesting cannula, and (d) Coleman harvesting cannula.



TECH FIG 2 • Centrifuging fat. Harvested fat is generally not uniform in character as extracted from donor sites as each syringe will contain a variable amount of fat, blood, local anesthetic, and ruptured fat cells (“oil”), and some type of processing is necessary to obtain uniform material for injection. Centrifugation allows separation of the “oil” and “water” fractions from the fat cells and concentrates high-density adipocytes (“stem cells”). **A.** Small portable countertop centrifuge (www.tulipmedical.com). **B.** Close-up view of centrifuge rotor being loaded with unprocessed fat in 10-cc syringes. Note that the syringe tip has been

sealed with a disposable plastic cap. The removable and sterilizable metal sleeves shown to fit into rotor to keep syringe barrels containing fat sterile and allow them to be handled on the sterile field after spinning. Some centrifuges are designed to allow the entire rotor to be sterilized.

- After centrifugation and the separation and discarding of the resulting oil and water components have been accomplished, the resultant fat is transferred into 1-cc Luer-Lok syringes using a transfer coupler (**TECH FIG 5**). Proper infiltration of fat requires injection in very small amounts that cannot be reliably made with a 10-cc, 5-cc, or even 3-cc syringes.
- The bottom 2 cc of fat in the syringe containing the highest concentrations of high-density adipocytes (or adipose-derived regenerative cells [ADRC]) is segregated and is used preferentially in the procedure.

Upper Orbit Fat Grafting

- First, nerve blocks are performed with 0.25% bupivacaine with epinephrine 1:200 000 local anesthetic solution. It is typically not necessary to directly infiltrate areas to be treated with local anesthetic, if nerve blocks are properly performed and adequate sedation has been administered.



TECH FIG 3 • Centrifuged fat. Harvested fat seen after centrifugation. Three layers can be seen in the centrifuged material: an upper “oil” layer (ruptured fat

cells), a middle layer of intact fat cells, and a bottom layer of blood and local anesthetic. Unlike straining of fat through a sieve, centrifugation may allow separation of the “oil” and “water” fractions from the fat cells with minimal loss of “stem cells,” “growth factors,” and “cellular messengers.”

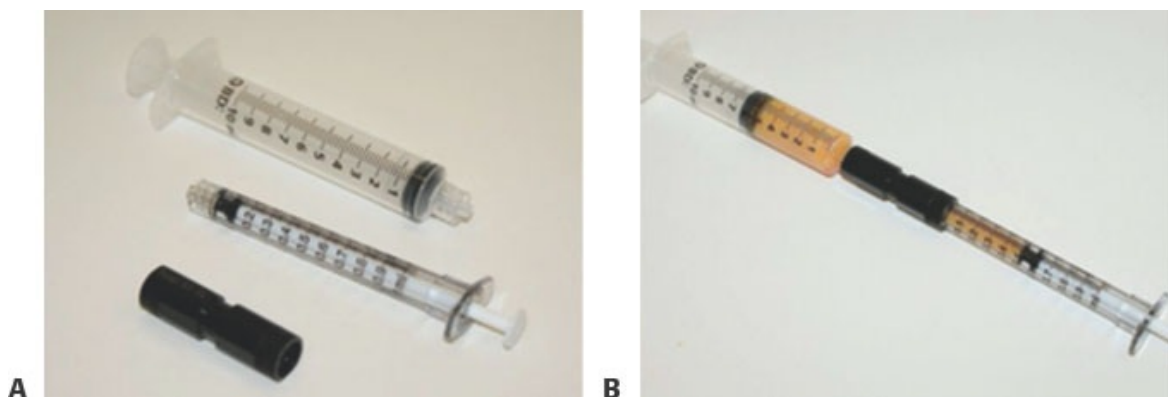


TECH FIG 4 • Syringe rack. A “test tube” rack to hold the syringes containing fat greatly facilitates fat processing activities. On the *left*, syringes containing unprocessed fat are present. In the *center*, syringes containing centrifuged fat can be seen. The rack also conveniently holds 1-cc syringes, syringe components, and other equipment used in the fat grafting procedure.

- Once nerve blocks have been administered, small stab incisions are made in the medial and lateral extent of the eyebrow.
- Infiltration is made in multiple passes injecting on both the in and out strokes. Approximately 0.05 cc or less should be injected per pass. This corresponds to 20 to 40 back and forth passes or more for each 1-cc syringe of processed fat.
- The goal is to inject the fat in a way that optimizes its chance of developing a blood supply and surviving, and the mental model should be one of scattering tiny particles of fat into the recipient site in multiple crisscrossing

fine trails in such a way that each particle sits in its own compartment and has maximal surface contact with perfused tissue.

- Advancement and withdrawal of the injection cannula will typically be made slowly by the beginning injector, but as familiarity with the technique is acquired, the movements can and should be made faster. Ultimately, all other things being equal, faster movements are desirable in that if the injection cannula is constantly in motion, intravascular injection is less likely, and the likelihood that an accidental bolus injection into one area will be made is reduced.
- How the syringe is held is also important in avoiding overinjection and controlling the volume injected with each pass. If the syringe is held in the manner one would traditionally use to give an injection with the thumb on the end of the syringe plunger, it is easy to inject too much fat if tissue resistance changes or injection cannula resistance suddenly decreases. More control can generally be maintained, and overinjection more easily avoided, if the syringe is held with the end of the plunger in the palm of the hand (**TECH FIG 6**). Held in this manner, a slight closing of the hand results in a small amount of fat only being expressed from the cannula, and overinjection into any one area can more readily be avoided.
- To allow for the deposition of tiny aliquots of fat per pass, very fine cannulas must be used when fat grafting around the eyes. Currently, a 4-cm-long 0.7-mm (22-gauge) cannula is preferred. These newer fine cannulas have made injecting the upper orbit easier and more predictable than in the past as they can be advanced more smoothly and accurately through tissues.



TECH FIG 5 • Transferring centrifuged fat to 1-cc syringes. Fat is transferred from 10-cc Luer-Lok

syringes into 1-cc Luer-Lok syringes after centrifugation, and the oil and water fractions have been discarded using a transfer coupling. Proper injection in the very small quantities that are needed in the face cannot be made with larger syringes. **A.** 10-cc Luer-Lok syringe, 1-cc Luer-Lok syringe, and Luer to Luer transfer coupling. **B.** Transfer coupling in use.

- A common misconception in treating the hollow upper orbit is that fat is needed and should be grafted into the preseptal portion of the eyelid itself. The hollow upper eyelid is however more properly and practically restored by placing fat in a deep submuscular/preperiosteal position along the inferior margins of the supraorbital rim. The process is best conceptualized as one of *lowering the supraorbital rim* and filling the upper orbital area to push skin that has retracted up into the orbit down onto the preseptal eyelid to create a full and appropriately creased upper eyelid (**TECH FIG 7**).
- Once one accepts that improvement is obtained by grafting of the orbit, and not the eyelid itself, it becomes apparent that larger volumes than might otherwise be expected are required. In general, 2 to 3 cc of fat must be placed in each upper orbit to achieve the improvement typically sought.
- When grafting the upper orbit, it must always be remembered that when one is working in very close proximity to the eye, and although the injection cannulas are blunt tipped, they are easily capable of perforating the ocular globe.
- Fat grafting the upper orbit and “eyelid” is advanced in difficulty, and treatment of this area should be made only after experience has been gained treating more forgiving areas.



TECH FIG 6 • Method of holding syringe to control volume expressed during injection. If the syringe is held in the way one would traditionally use to give an injection, it is easy to inject too much fat if tissue or injection cannula resistance suddenly decreases. More control can be maintained, and overinjection better avoided, if the syringe is held with the end of the plunger in the palm of the hand. Held in this manner, a slight closing of the hand results in a small amount of fat only being expressed.

- Once that experience is obtained, fat grafting the upper orbit can be one of the most artistically rewarding uses of autologous fat and one that is likely to become a routine part of rejuvenating the upper eyelid in the future.

Lower Orbit Fat Grafting

- First, nerve blocks are performed as is done in the upper orbit.
- Unlike the upper orbit, for the lower orbit, fat is best and most easily injected *perpendicular* to the infraorbital rim through stab incisions placed in the midcheek or perioral area (**TECH FIG 8**). When this is done, lumps and irregularities are far less common.
- Like the upper orbit, fat grafting of the infraorbital area is typically performed with a 4-cm-long 0.7-mm (22-gauge) injection cannula with a focus on placing very small aliquots of fat per pass using the same basic injection technique described above.

- Also like the upper orbit, fat need not and should not be grafted in the pretarsal lower eyelid. Fat should be injected deep in a submuscular/preperiosteal plane, and the technical goal of the procedure should be thought of as raising up and anteriorly projecting the infraorbital rim rather than filling the lid itself.
- It is wise to avoid any subcutaneous injection in the infraorbital area due to the extremely thin skin present and the likelihood of creating visible lumps and irregularities. Thus, it is best to limit injections to a preperiosteal/suborbicularis oculi plane. The purported benefit of superficial injections—improving skin texture and color—is too small an improvement in most cases for all but the expert injector to offset the all too likely occurrence that visible and difficult-to-correct irregularities will result.



TECH FIG 7 • Incision sites and plan for injecting fat into the upper orbital (“upper eyelid”) area. Fat grafting of the upper orbital area is typically performed with a 4-cm 0.7-mm (22-gauge) cannula, and fat is placed deep in a suborbicularis oculi/preperiosteal plane. Typically, 2 to 3 cc of fat is placed in each upper orbit. Level of difficulty: advanced.



TECH FIG 8 • Incision sites and plan for injecting fat into the infraorbital (“lower eyelid”) area. Fat grafting of the infraorbital area is typically performed with a 4-cm 0.7-mm (22-gauge) cannula, and fat is placed deep in a suborbicularis oculi/preperiosteal plane. Typically, 2 to 3 cc of fat is placed on each side although occasionally more will be needed. Level of difficulty: advanced.

- When injecting the lower orbit, the surgeon should place her or his index finger of the nondominant (noninjecting) hand firmly on the infraorbital rim to protect the ocular globe while injections are made.
- Volumes required to obtain corrections in the lower orbit are typically more than one might initially expect, and 2 to 3 cc per side is necessary to produce the desired effect in most cases.

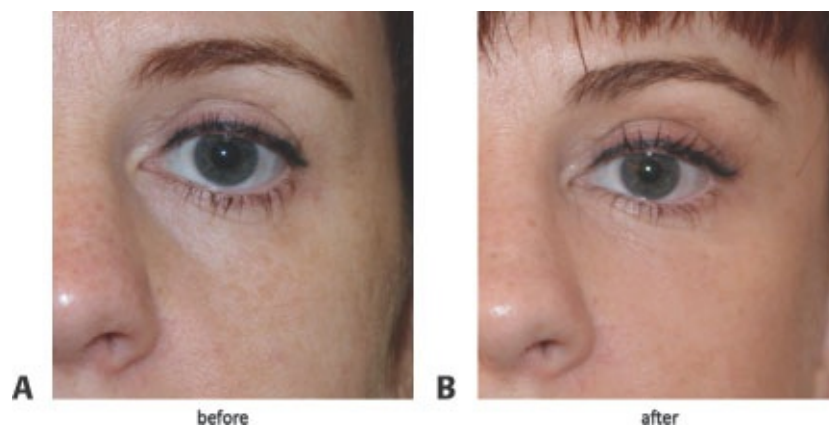
“Tear Trough” Fat Grafting

- Where the infraorbital area ends and the “tear trough” and cheek areas begin is hard to precisely define, and in reality, the treatment of the infraorbital, cheek, and “tear trough” areas must be undertaken concurrently in most patients, and the treated areas will overlap each other to a certain extent.
- Treatment of the “tear tough” is most easily and best performed using incisions situated inferior to the medial orbit and placing fat predominantly perpendicularly as in the infraorbital areas (**TECH FIG 9**).



TECH FIG 9 • Incision sites and plan for injecting fat into the nasojugal (“tear trough”) areas. Fat grafting of the nasojugal “tear trough” area is typically performed with a 4-cm 0.7-mm (22-gauge) injection cannula, and fat is placed deep in a preperiosteal/suborbicularis oculi plane. Typically, 0.5 to 1.5 cc of fat is placed on each side depending on how far inferiorly and laterally the “tear trough” extends onto the cheek. Level of difficulty: advanced.

- A 4-cm-long 0.7-mm (22-gauge) cannula is typically used, and fat is placed deep in a preperiosteal/suborbicularis oculi plane—especially superiorly and medially—where the skin is the thinnest. As experience is gained, and if care is taken, fat can be placed safely more superficially, especially in the lower more lateral part of the tear trough that is frequently seen to run down into and onto the cheek.



TECH FIG 10 • Filling the “tear trough” with Fat. **A.** Patient with hollow nasojugal groove (“tear trough”) and an unnaturally hollow and elderly infra-orbital appearance. **B.** Same patient seen after fat injections. A healthier and youthful ocular appearance is noted (procedure performed by Timothy Marten, MD, FACS —Courtesy of Marten Clinic of Plastic Surgery).

- Typically, 0.5 to 1.5 cc of fat is placed in the “tear trough” area, depending on how far inferiorly and laterally it extends onto the cheek (**TECH FIG 10**). Although ostensibly seeming simple to do, fat grafting the tear trough is advanced in difficulty.

PEARLS AND PITFALLS

Fat harvest	■ The hip, waist, and outer thigh are the primary choice for fat harvest sites in our practice. ■ They provide for abundant volume of fat, have less risk of surface irregularities, and produce the best improvement in the patient’s silhouette.
Fat processing	■ The bottom 2 cc of fat in the centrifuged 10-cc syringe consists of “stem cell”-rich fat. ■ This fat should be isolated and used for more critical areas like the upper and lower orbits.
Instruments	■ Special fine blunt cannulas are required to safely perform periorbital fat grafting. ■ Sharp needle injection increases the risk of embolization and should be avoided.
Technique	■ Fat should be placed in very tiny aliquots with each pass in a preperiosteal plane to produce optimal results and minimize complications.
Ocular injury	■ For both the upper and lower orbit, the surgeon must always keep the nondominant index finger between the globe and the end of the cannula to protect the globe at all times.

POSTOPERATIVE CARE

- Regional fat grafting to the periorbital or more comprehensive facial fat grafting is performed on an outpatient basis. Patients having a combined face-lift with fat grafting are typically discharged to an aftercare specialist for the first night after surgery.
- Patients are asked to rest quietly and apply cool (but not ice or ice-cold) compresses to their face for 15 to 20 minutes of every hour that they are awake for the first 3 days after surgery.
- Patients are advised to take a soft diet that is easy to chew and digest for 2 weeks after surgery and are encouraged to avoid salty foods.
- When patients return to work or their social lives depends on how much fat is injected, their individual swelling response, their occupation, and need for secrecy. Patients are asked to set aside 2 to 3 weeks for recovery and 2 to 3 months prior to any major business presentation or important social function.
- Most of the change in facial contour seen at 4 to 6 months is likely to consist of living fat and represent a persistent improvement. Patients can be informed that most of what they see is what they get at that point because swelling has completely resolved.

OUTCOMES

- See before and after examples (**FIGS 4 to 6**).

COMPLICATIONS

- No major complications attributable to fat grafting, including infection, embolization, tissue infarction, or blindness, have been encountered in our clinic over the last 20 years.
- Embolization leading to tissue infarction or blindness has been reported and largely attributed to sharp needle injection.
- Other complications are largely minor aesthetic problems and include lumps, oil cysts, asymmetries, undercorrection, overcorrection, and donor-site irregularities.
- Though lumps or areas of overcorrection around the eyes have been exceedingly rare in our practice, they are best treated by opening the eyelid and removing the excess fat under direct vision.



FIG 4 • Periorbital fat grafting case example. **A.** Patient with no previous surgery and hollow appearance around the eyes. **B.** Same patient seen after facial fat injections including the upper and lower orbit. A healthier, more youthful appearance can be seen (procedure performed by Timothy Marten, MD, FACS—Courtesy of Marten Clinic of Plastic Surgery).

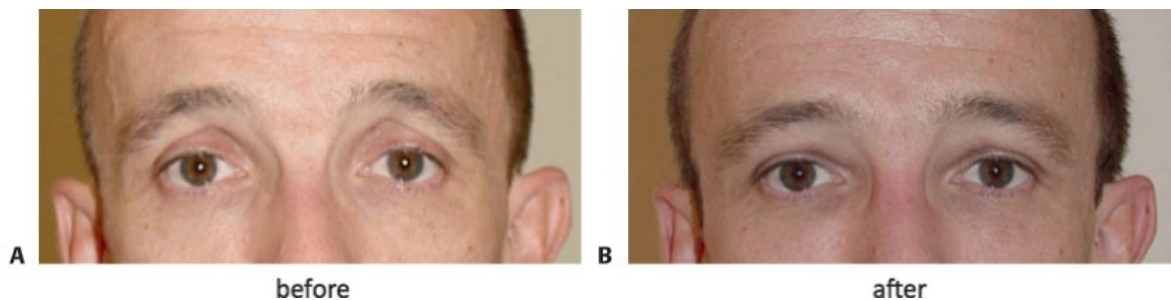


FIG 5 • Periorbital fat grafting case example. **A.** Patient with no previous surgery and hollow appearance around the eyes. **B.** Same patient seen after facial fat injections including to the upper and lower orbit. A healthier, more youthful appearance can be seen (procedure performed by Timothy Marten, MD, FACS—Courtesy of Marten Clinic of Plastic Surgery).

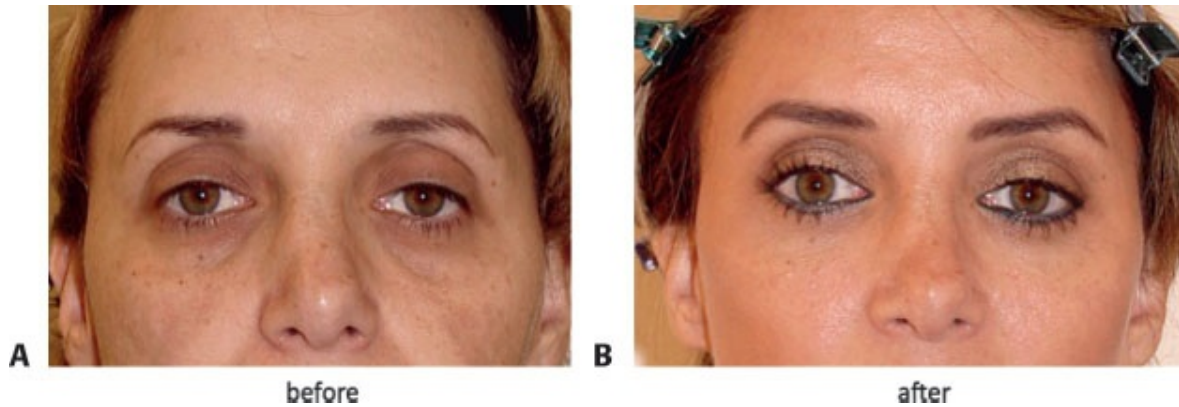


FIG 6 • Periorbital fat grafting case example. **A.** Patient with previous upper and lower blepharoplasty and hollow appearance around the eyes. **B.** Same patient seen after facial fat injections including to the upper and lower orbit along with face-lift and forehead lift. A healthier, more youthful appearance can be seen (procedure performed by Timothy Marten, MD, FACS—Courtesy of Marten Clinic of Plastic Surgery).

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Indications and Techniques for Bridge of Bone Canthopexy

39

CHAPTER

Dev Vibhakar, Erez Dayan, and Michael J. Yaremchuk

DEFINITION

- The positions of the lateral canthi are important functional and aesthetic facial landmarks. Their position is a fundamental determinant of the shape of the palpebral fissure.¹
- The terminology of lateral canthal surgery may be confusing. A lateral canthopexy repositions the lateral canthal mechanism without violating the commissure. Canthoplasty procedures, by design, alter the shape of the palpebral fissure, because they disassemble and reassemble the lateral commissure while often shortening the lower lid margin.^{2,3}
- Bridge of bone lateral canthopexy requires exposure of the lateral orbit and mobilization of the lateral canthus soft tissue mechanism. Its efficacy is based on the stable suture fixation point provided by drill holes placed relative to the zygomaticofrontal suture in the bone of the lateral orbit. It is our preferred technique for most surgical indications.

ANATOMY

- The lateral canthus is more correctly termed a lateral retinaculum. The retinaculum receives contributions from the lateral horn of the levator aponeurosis, the lateral extension of the preseptal and pretarsal orbicularis oculi muscle (lateral canthal tendon), the inferior suspensory ligament of the globe (Lockwood ligament), and the check ligament of the lateral rectus muscle. It has a broad attachment to the periosteum over the Whitnall tubercle (**FIG 1**).⁴
- Variations of the point of attachment or length of the retinaculum will alter eyelid shape, tension, and contour.⁵

- The lateral canthal angle is normally superior to the medial canthal angle, lying 4 ± 2 degrees or approximately 1.2 mm higher. This relationship is important for effective tear film distribution, and lacrimal drainage and for an aesthetically pleasing contour (**FIG 2**).¹

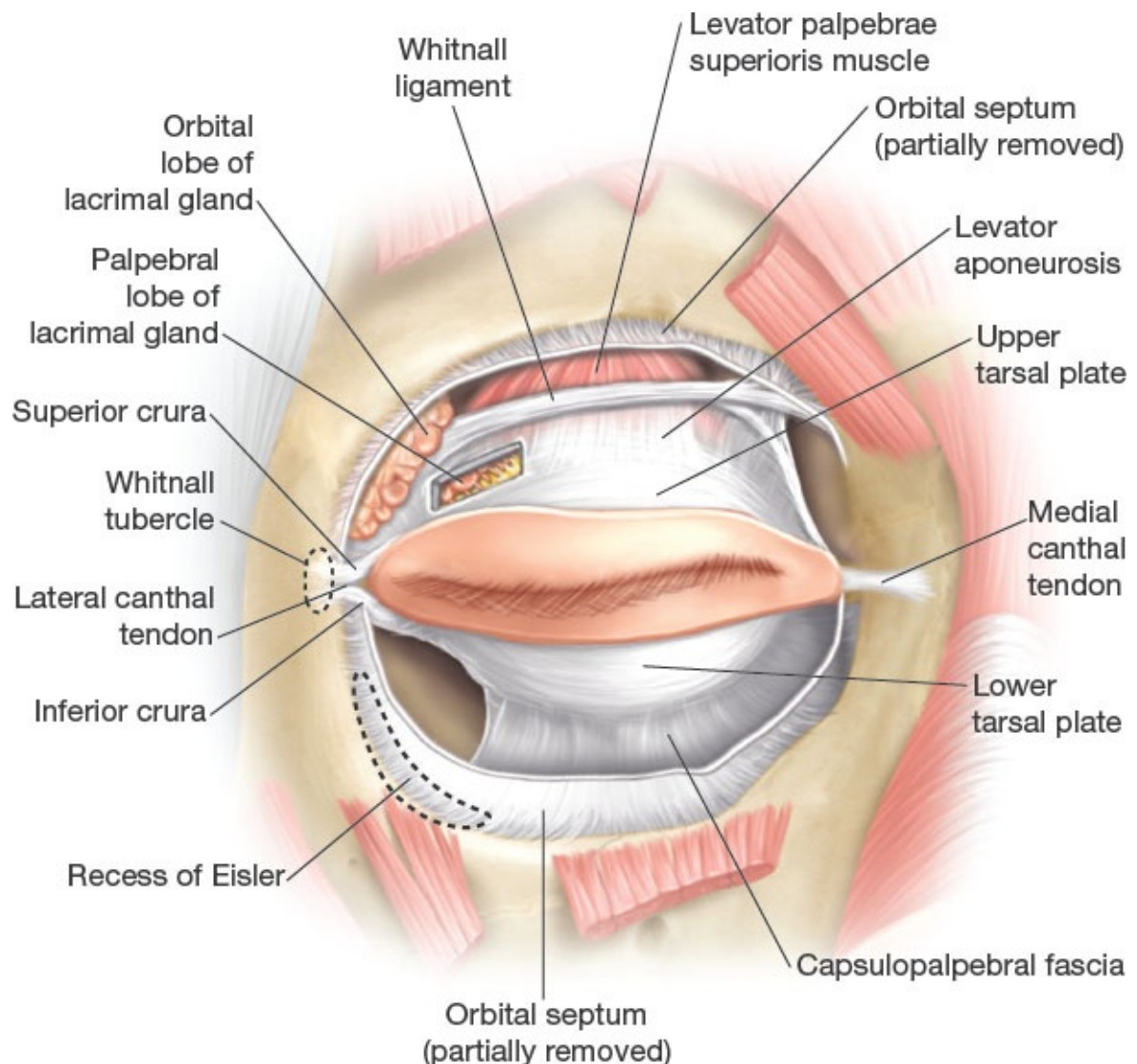


FIG 1 • Position of the medial and lateral canthal ligaments with respect to the bony orbit, tarsal plates, and underlying ligamentous structures

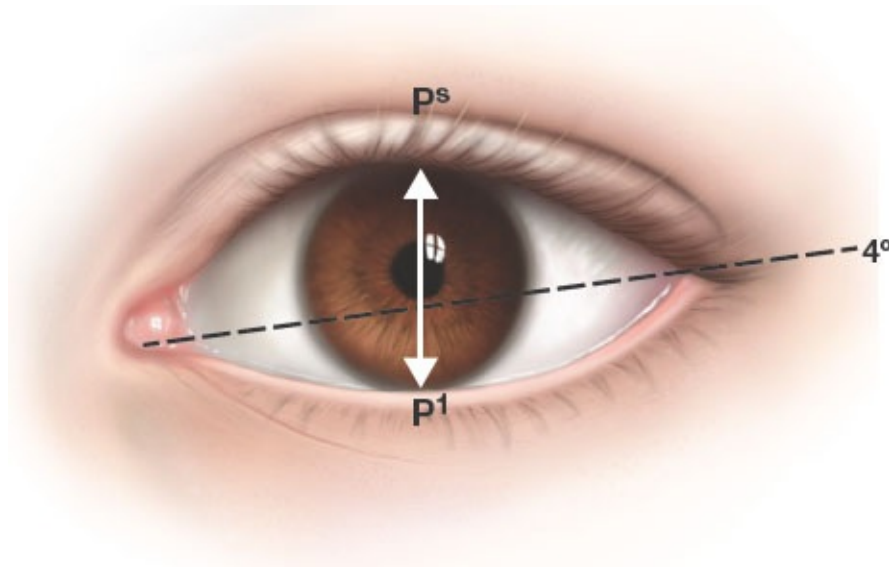


FIG 2 • Dimensions of the palpebral fissure measured in young Caucasian women. The mean height of the palpebral fissure measured from the upper lid (P^s) to lower lid (P^i) margin at the midpupil was 10.8 ± 1.2 mm ($n = 200$). The mean length of the eye fissure measured from medial commissure to lateral commissure was 30.7 ± 1.2 mm ($n = 200$). The mean inclination of the eye fissure was 4.1 ± 2.2 degrees.

PATHOGENESIS

- Medial and inferior canthal malposition changes the width and shape of the palpebral fissure as well as the position of lower eyelid resulting in the round eye deformity.¹
- Inferior displacement of the lower eyelid may cause lagophthalmos leading to inadequate globe protection and exposure keratitis. Epiphora secondary to a displaced lower punctum and impaired tear drainage may also occur.
- The etiology of canthal malposition may be hereditary, senile, paralytic, traumatic, or iatrogenic.⁴
- Malposition of the lateral canthus most often occurs secondary to surgical access to the orbit and lower lid structures.^{2,3}

PATIENT HISTORY AND PHYSICAL FINDINGS

- History and physical examination are the most important elements of

preoperative assessment and planning for both reconstructive and cosmetic procedures. Standard preoperative photographs are taken and reviewed with the patient.

- History of recent eye surgery, dry eye, or visual acuity changes should be specifically elicited.
- Physical examination findings for lower eyelid malposition include canthal tilt, lid snapback test, lid distraction test, vector analysis, scleral show, and the presence of chemosis or keratoconjunctivitis. Other patient-directed examination includes visual acuity testing, Schirmer test for lacrimation, and slit-lamp evaluation.

IMAGING

- Whereas preoperative radiologic examination is uncommon for purely aesthetic surgery, computerized tomographic (CT) evaluation is almost routine for reconstructive procedures. CT scans provide the ability to view anatomic features in different planes and in three dimensions.

SURGICAL MANAGEMENT

Preoperative Planning

- Informed consent should include intrinsic risk of canthal malposition and potential for temporary postoperative chemosis.
- The patient's desired canthal position should be determined in aesthetic-focused procedures.
- This procedure may be performed under local or general anesthesia.

Positioning

- The patient is placed supine on the operating room table at a 90-degree perpendicular position relative to the anesthesiologist for maximal exposure.

TECHNIQUES

■ Preoperative Preparation

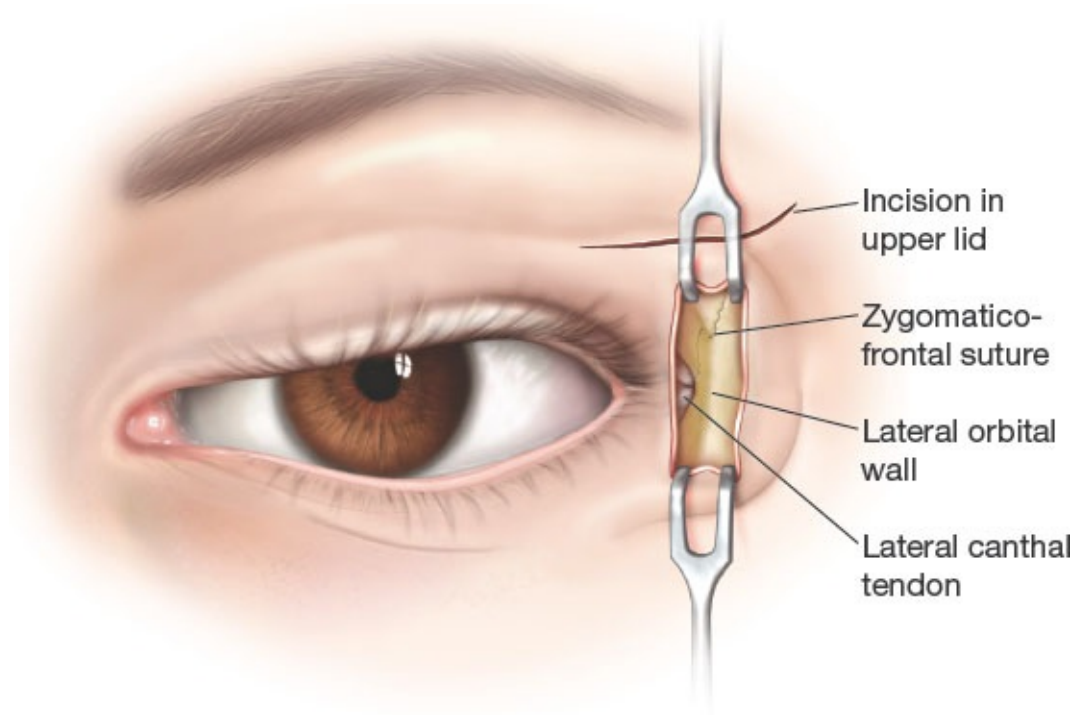
- Prior to antiseptic preparation and draping, a dilute solution of Marcaine and epinephrine (1:200 000) is infiltrated into the operative site for postoperative

pain control and intraoperative hemostasis.

- Intravenous antibiotic prophylaxis is administered approximately 30 minutes preoperatively.

■ Operative Approach

- Bridge of bone lateral canthopexy requires access to the lateral orbital rim from the level of the Whitnall tubercle to the zygomaticofrontal suture. This can be accomplished through the lateral extent of an upper blepharoplasty incision. Most often, the lateral extent of both upper and lower blepharoplasty incisions is used (**TECH FIG 1**).
- The lower blepharoplasty incision provides superior visualization of the lateral canthal tissue.
- This anatomy may also be approached from the access provided by a bicoronal incision during exposure of traumatic fractures or aesthetic brow lift.

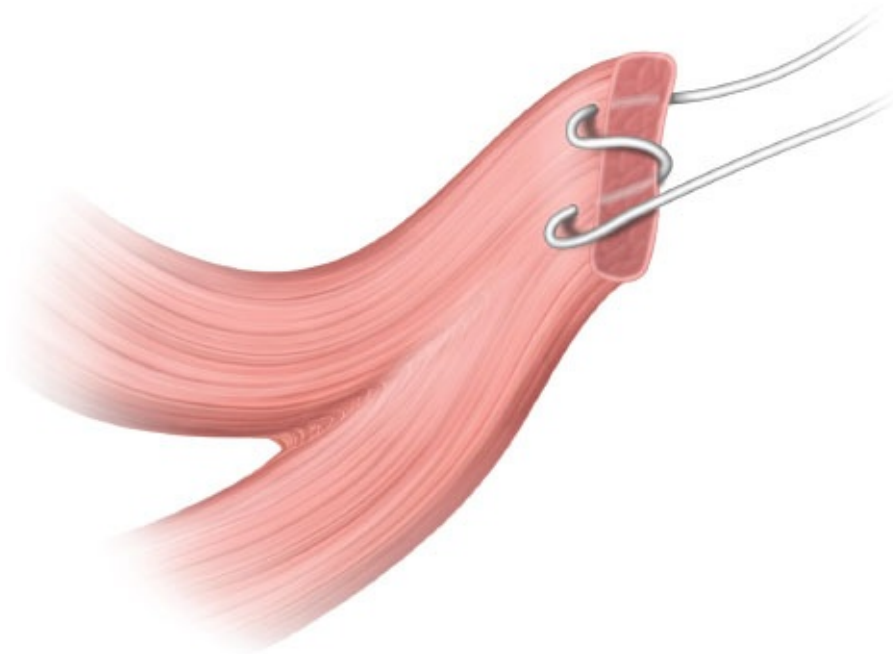


TECH FIG 1 • Through the lateral extent of the lower lid blepharoplasty incision, the lateral canthus is identified and released from the Whitnall tubercle by

subperiosteal dissection.

■ Figure-of-8 Suture Fixation of Lateral Canthus

- When only 1 or 2 mm of superior or lateral movement of the lateral canthus and adjacent lid margin are desired, one or both limbs of the lateral canthus may be purchased with a figure-of-8 suture without freeing of the lateral retinacular structures from the lateral orbit (**TECH FIG 2**). The amount of commissure movement will be limited by the length of the ligament, the point of suture purchase relative to the lateral commissure, and the position of the lateral orbit drill holes. This approach is most appropriate when there is minimal commissure malposition and no local scarring from previous lid surgery.
- When more significant movements of the lateral commissure and lid margin are desired, complete subperiosteal freeing of the lateral retinacular structures is required before figure-of-8 suture purchase of both limbs of the ligament.
- Through the lateral extent of the lower blepharoplasty incision, the lateral retinaculum is identified and dissected, and both limbs of the lateral canthus are purchased with a figure-of-8 nonabsorbable suture or 30- or 32-gauge titanium wire suture.

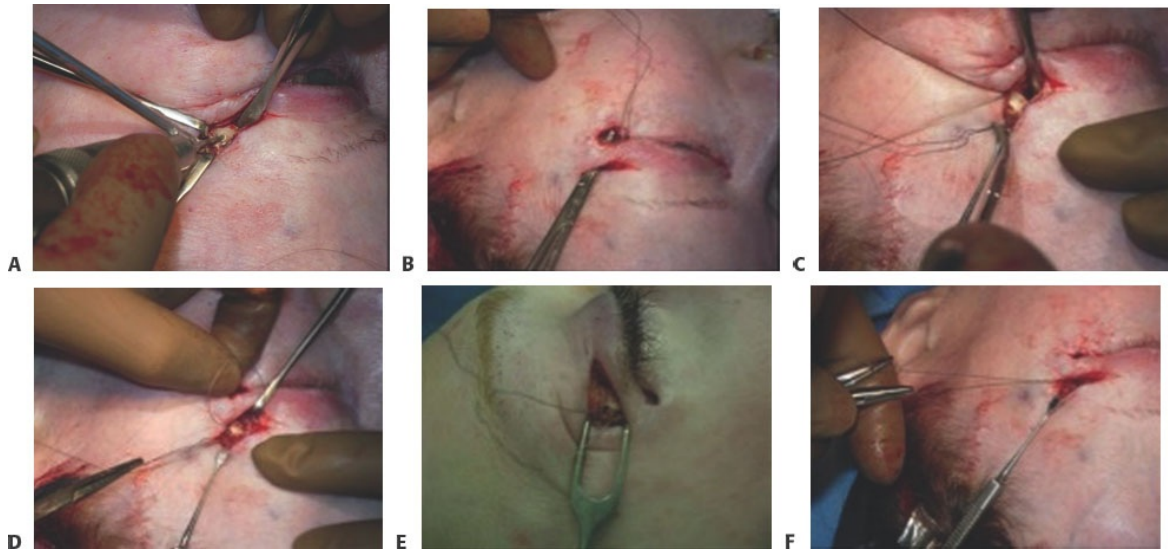


TECH FIG 2 • The lateral canthus is purchased by a figure-of-8 suture or 30-gauge titanium wire suture.

- If scarring from previous lower lid surgery restricts canthal movement, the lateral third of the middle lamellae is incised with needle-tip electrocautery to allow for sufficient mobility.

■ Drill Holes and Positioning of Lateral Canthus

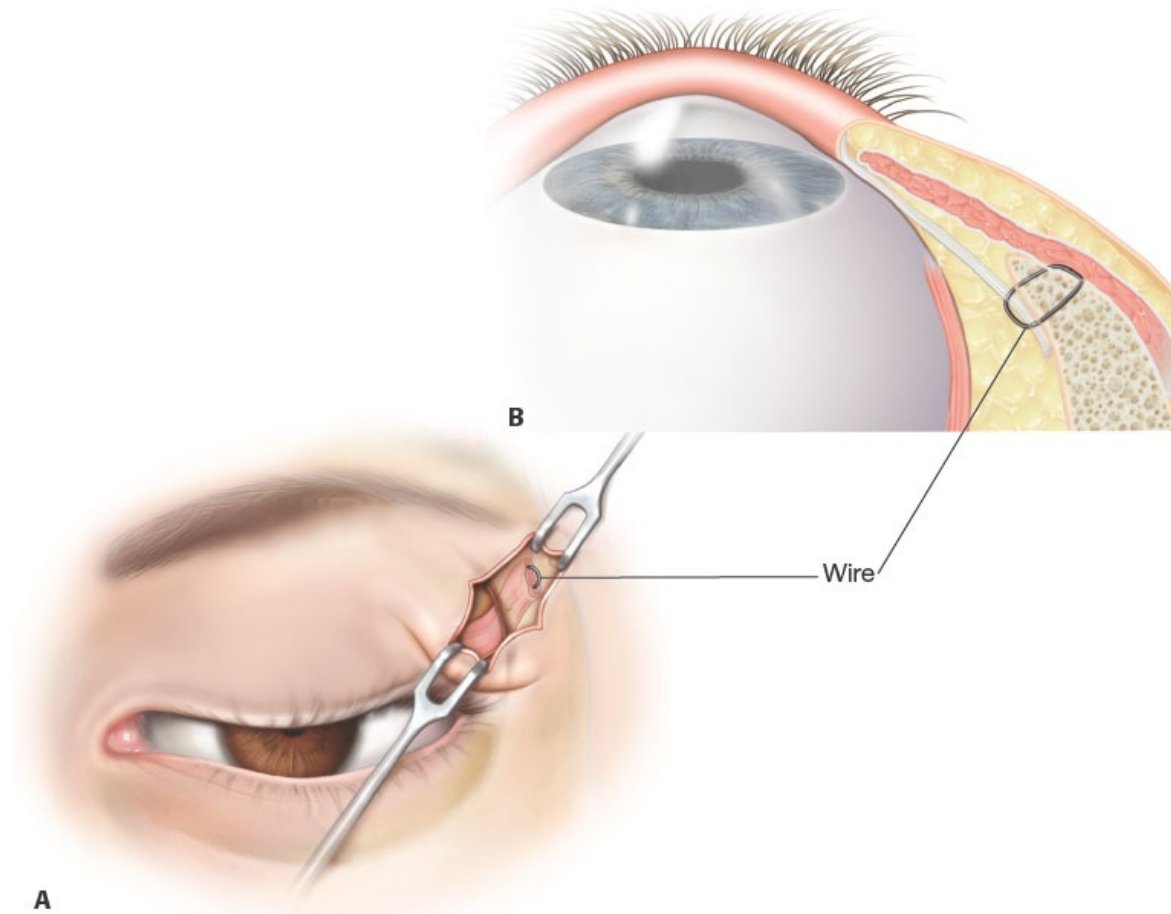
- Through the upper access approach, the zygomaticofrontal suture is identified. This suture provides a landmark to allow symmetric placement of drill holes made in the lateral orbital rim.
- Using the zygomaticofrontal suture as a landmark, two drill holes are placed in the lateral orbital rim (**TECH FIG 3A**). The position of the lower drill hole is key, because it determines the maximum upward movement of the canthus. The upper drill hole is necessary to create the “bridge of bone”—a stable fixation point.
- The lateral canthal position and aperture shape are determined by the position of the drill holes, which should be 2 to 3 mm above the medial canthal plane to give the intercanthal axis a slight upward tilt. The drill holes should also be placed in the internal orbit about 3 to 4 mm posterior to the anterior margin of the lateral orbital rim so the lateral lid will not be drawn away from the globe.
- To determine the ideal position of the drill holes, one can grasp the lateral canthus and tuck it against the lateral orbital rim until the desired canthal and lower lid position is obtained. The positions are marked and drill holes are made at that point. Most often, they are positioned just at, and 2 mm below, the zygomaticofrontal suture.
- The suture is then delivered in a subcutaneous plane from the lower to the upper incision (**TECH FIG 3B**).
- Each end of the suture is then passed from within the orbit through the drill holes to the lateral orbital rim. This is accomplished by bending a 28- or 30-gauge wire on itself and passing the bent end through the drill hole into the orbit (**TECH FIG 3C**).



TECH FIG 3 • **A.** Using the zygomaticofrontal suture as a landmark, two drill holes are placed in the lateral orbital rim. **B.** Suture is then delivered in a subcutaneous plane from the lower to the upper incision. **C.** Each end of the suture is then passed from within the orbit through the drill holes to the lateral orbital rim. **D.** One end of the canthopexy stitch is placed into the “passing wire” loop to be pulled from inside the orbit through the drill hole to outside the orbit. **E.** The suture ends are then tied over the bridge of bone between the two holes. **F.** Tension on the sutures during their tying or tension on the wires during their twisting will determine canthal movement.

- One end of the canthopexy stitch is placed into the “passing wire” loop to be pulled from inside the orbit through the drill hole to outside the orbit (**TECH FIG 3D**).
- The suture ends are then tied over the bridge of bone between the two holes (**TECH FIG 3E**).
- Tension on the sutures during their tying or tension on the wires during their twisting will determine canthal movement (**TECH FIG 3F**). The location of the lower drill hole dictates the limit of movement.
- Passage of the canthopexy sutures must occur from within the orbit to the

outside. This allows tying the sutures over the bridge of bone (**TECH FIG 4A**) and allowing the lower lid to be applied to the globe (**TECH FIG 4B**).



TECH FIG 4 • Passage of the canthopexy sutures must occur from within the orbit to the outside. This allows tying the sutures over the bridge of bone (**A**) and allowing the lower lid to be applied to the globe (**B**).

- When wire fixation is used (most often for reconstructive cases), the wire ends are left approximately 5 mm long. This length of twisted wire has two advantages. First, it allows intraoperative (or postoperative) adjustment of the canthal position by simply twisting or untwisting the wires without repeating the suturing process. In addition, this length allows the ends to be placed into one of the drill holes or into the orbit. This maneuver avoids postoperative visibility or palpability of the wire ends.

■ Closure

- If local incisions are used for access, an ellipse of skin and muscle is removed from the lateral aspect of the upper lid to remove the lid redundancy caused by the upward movement of the canthus.
- The wounds are closed in layers.
- A temporary tarsorrhaphy stitch is often placed to avoid or minimize chemosis.

■ Postoperative Care

- Postoperatively, keep the patients head in a raised position to minimize edema and pain. Ice packs are applied to counteract swelling.
- Analgesia (narcotic and/or NSAIDs) as necessary for pain control.
- A single dose of IV antibiotics is given 30 to 60 minutes prior to incision. Oral antibiotics are continued no longer than 24 hours after surgery.
- Sutures are removed at 1 week after surgery.
- When extensive dissection is performed, postoperative chemosis is common. In addition to ophthalmic lubricants, a temporary tarsorrhaphy stitch is left in place for 5 to 7 days. The tarsorrhaphy is performed by placing a single 5-0 nylon suture through the upper and lower lid margins and adjacent skin approximately 2 to 3 mm lateral to the lateral limbus.

■ Outcomes

- Appropriate patient selection and sound surgical technique provide a vast majority of patients with satisfactory aesthetic outcomes (**FIGS 3 and 4**).



FIG 4 • A. Brow lift reversal was performed using a hairline incision in this patient who preoperatively had a high forehead. **B.** The patient also underwent

infraorbital rim augmentation, subperiosteal midface lift, and bridge of bone lateral canthopexy as well as brow lift reversal.

- When canthopexy is performed in heavily scarred tissues, wound contraction and contracture usually result in some loss of long-term canthal position. When bridge of bone canthopexy is performed in a nontraumatized field, canthal reposition is stable.

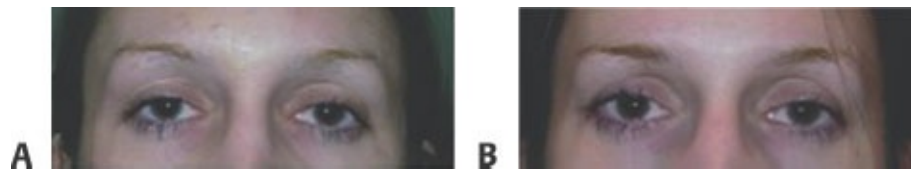


FIG 3 • A 27-year-old woman without any previous orbital surgery desired upward movement of her lateral canthus. **A.** Preoperative frontal view. **B.** Six-month postoperative view.

■ Complications

- Complications are infrequent after bridge of bone canthopexy.
 - Temporary chemosis is an anticipated short-term sequela. Some relapse may be anticipated when surgery is performed in heavily scarred fields.
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40 Indications and Techniques for Palatal Spacer Grafts

CHAPTER

Dev Vibhakar, Erez Dayan, and Michael J. Yaremchuk

DEFINITION

- Retraction of the lower eyelid is a consequence of various surgical and medical conditions affecting the periorbital and midface region.
- Craniofacial trauma, tumors, facial paralysis, thyroid eye disease, and cosmetic blepharoplasty can alter the position of the normal lower eyelid.
- The clinical manifestation of this is inferior scleral show, lagophthalmos, and exposure keratitis. This can lead to dry eye syndrome, ocular discomfort, excessive tearing, photophobia, and blurred vision, as well as a cosmetically unappealing sad-eyed appearance.¹
- Placement of a graft of palatal mucosa between the tarsal plate and lower lid retractors can elevate the lower lid margin.^{2,3}

ANATOMY

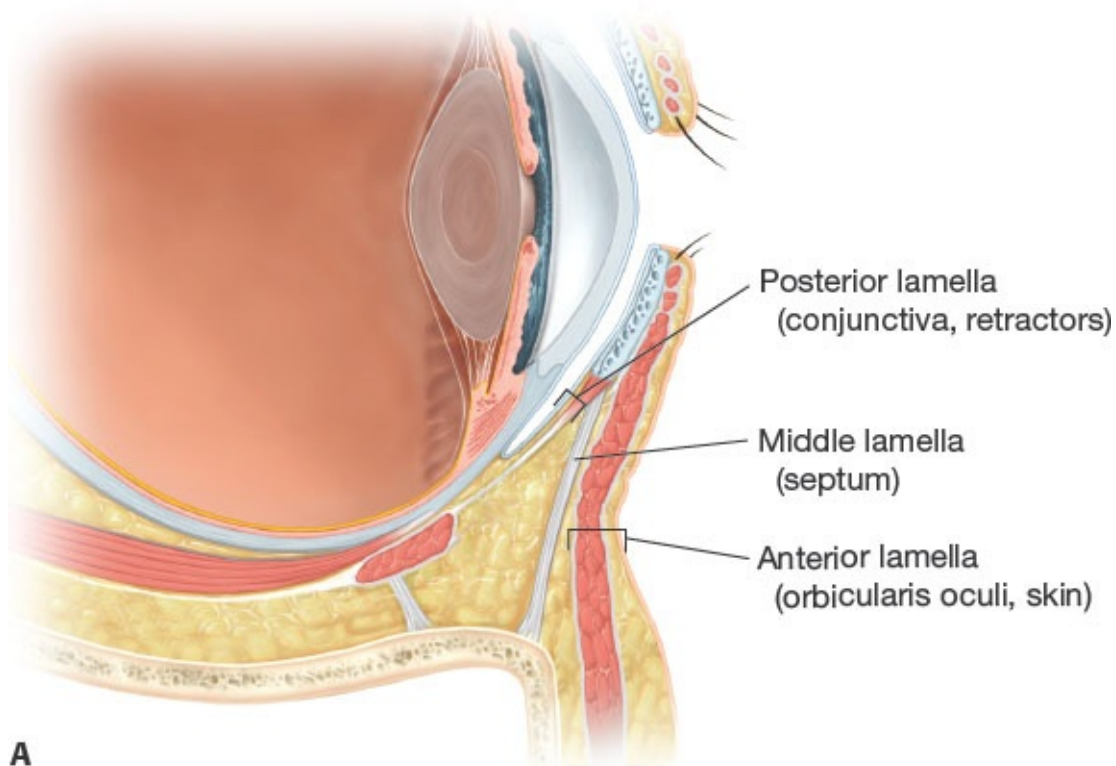
- The normal lower eyelid lies at or just above the inferior corneal limbus.
- It is tethered medially and laterally by the canthal tendons.
- The lateral canthal angle is approximately 4.1 degrees or 1.2 mm higher than the medial canthal angle.
- It is considered a trilamellar structure—the anterior lamella (skin and orbicularis oculi muscle), the middle lamella (orbital septum), and the posterior lamella (lower eyelid retractors and conjunctiva (**FIG 1A**)).
- The hard palate is composed of keratinized stratified squamous epithelium.
- There is no sex difference in mucosal thickness, and it increases with greater distance from the marginal gingiva, the mucosa being thinnest near the first molar.
- The bones of the hard palate are the palatine processes of the maxilla

anteriorly and the horizontal plates of the palatine bones posteriorly.

- The greater palatine neurovascular bundles emerge bilaterally from the greater palatine foramina most commonly found medial to the upper second molar.
- They pass anteriorly along grooves in the palate to enter the incisive foramina (**FIG 1B**).

PATHOGENESIS

- Lower lid retraction can result from shortening of any of the lower eyelid lamella.
- This results in vertical contracture of the lower lid and is most commonly seen because of trauma or aggressive lower lid blepharoplasty.
- Patients with thyroid eye disease have a relative lower eyelid deficiency due to its inferior displacement caused by globe prominence.
- When lower lid malposition is caused by middle and posterior lamella inadequacy, grafts of palatal mucosa placed beneath the tarsal plate provide increase height and stiffness to support and elevate the lower lid margin (**FIG 2**).



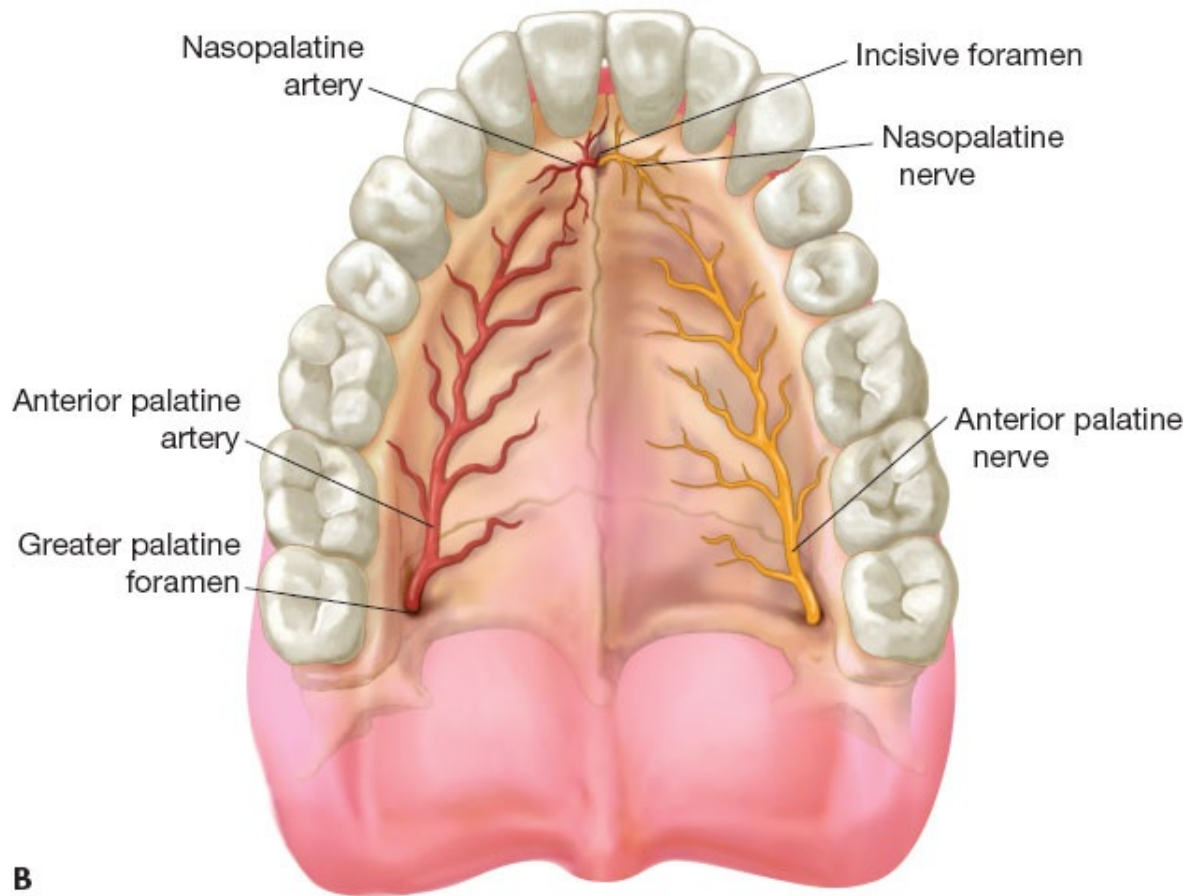


FIG 1 • A. Lower eyelid anatomy demonstrating the anterior lamella (skin and orbicularis oculi muscle), the middle lamella (orbital septum), and the posterior lamella (lower eyelid retractors and conjunctiva). **B.** Relevant palatal neurovascular anatomy for donor-site harvest.

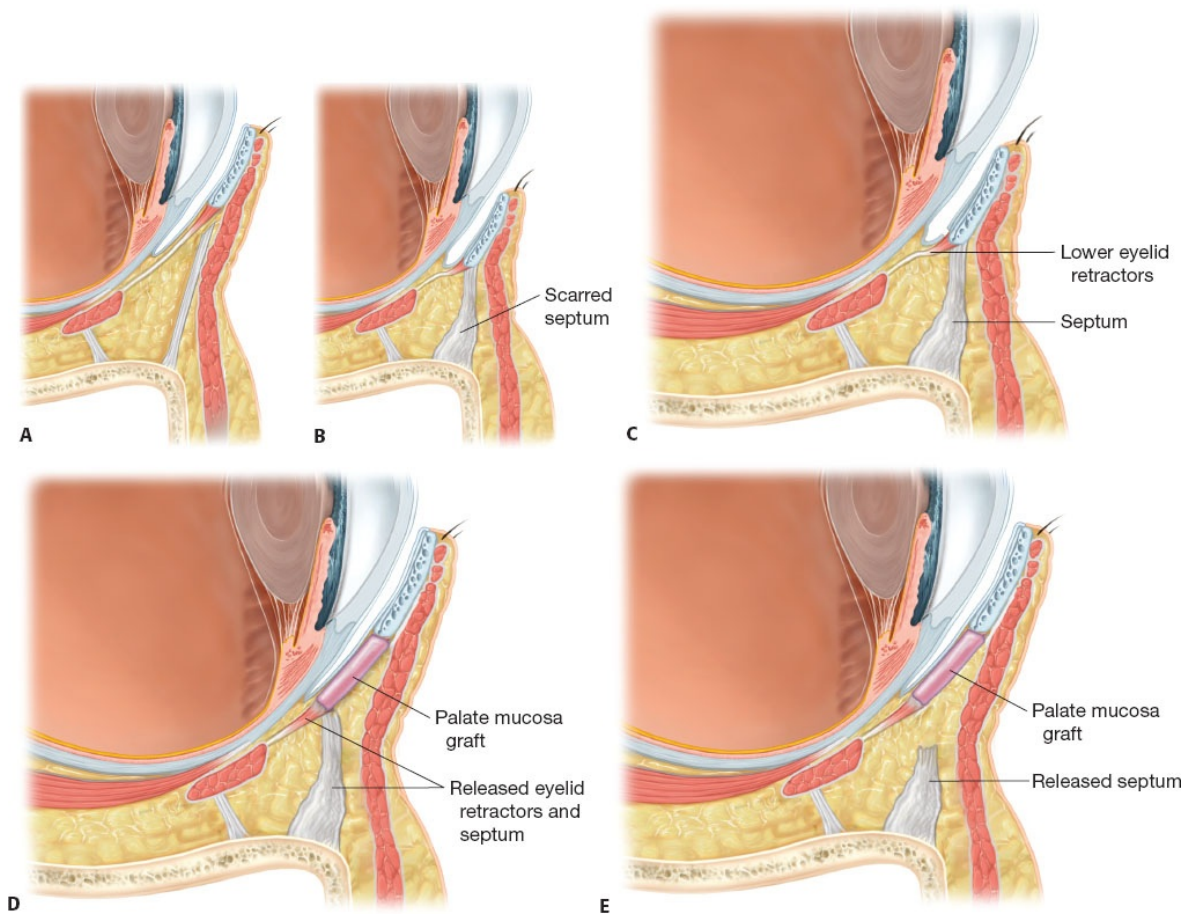


FIG 2 • A,B. Lower lid malposition secondary to vertical contracture of scarred septum. **C–E.** Hard palate mucosal graft used as a spacer between the lower tarsal plate and the recessed conjunctiva, lower eyelid retractors, and orbital septum.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The underlying cause (previous surgery, metabolic disease, trauma, skeletal morphology) of lower eyelid retraction is determined.
- A thorough ophthalmologic examination is performed.
- Measuring the inferior scleral show assesses the degree of lower lid displacement.
- The status of the lower lid lamellae, skeletal morphology, and cheek prominence is assessed.
- Deficiencies of the middle and posterior lamellae are indications for the use of

spacer grafts.

SURGICAL MANAGEMENT

Preoperative Planning

- Informed consent should include intrinsic risks and benefits of donor-site–related and lower lid complications. These include the possibility of infection, displacement, asymmetry, deformation, hematoma, seroma, motor/sensory nerve injury, donor-site discomfort, and palatal fistula.
- Prior to the induction of anesthesia, the amount of vertical height required to correct scleral show is measured medially and laterally with the patient in a sitting position.
- The authors' preference is to use general endotracheal or nasotracheal anesthesia. This allows optimal preparation of the donor site, operative site, and control of the airway.
- 0.12% chlorhexidine gluconate oral rinse is prescribed for daily use beginning 3 days preoperatively and including the day of surgery.

Positioning

- Intravenous cephalosporin or ciprofloxacin antibiotic prophylaxis is administered approximately 30 minutes preoperatively.
- Patients are placed supine on the operating room table at a 90-degree perpendicular position relative to the anesthesiologist to allow for maximal exposure.

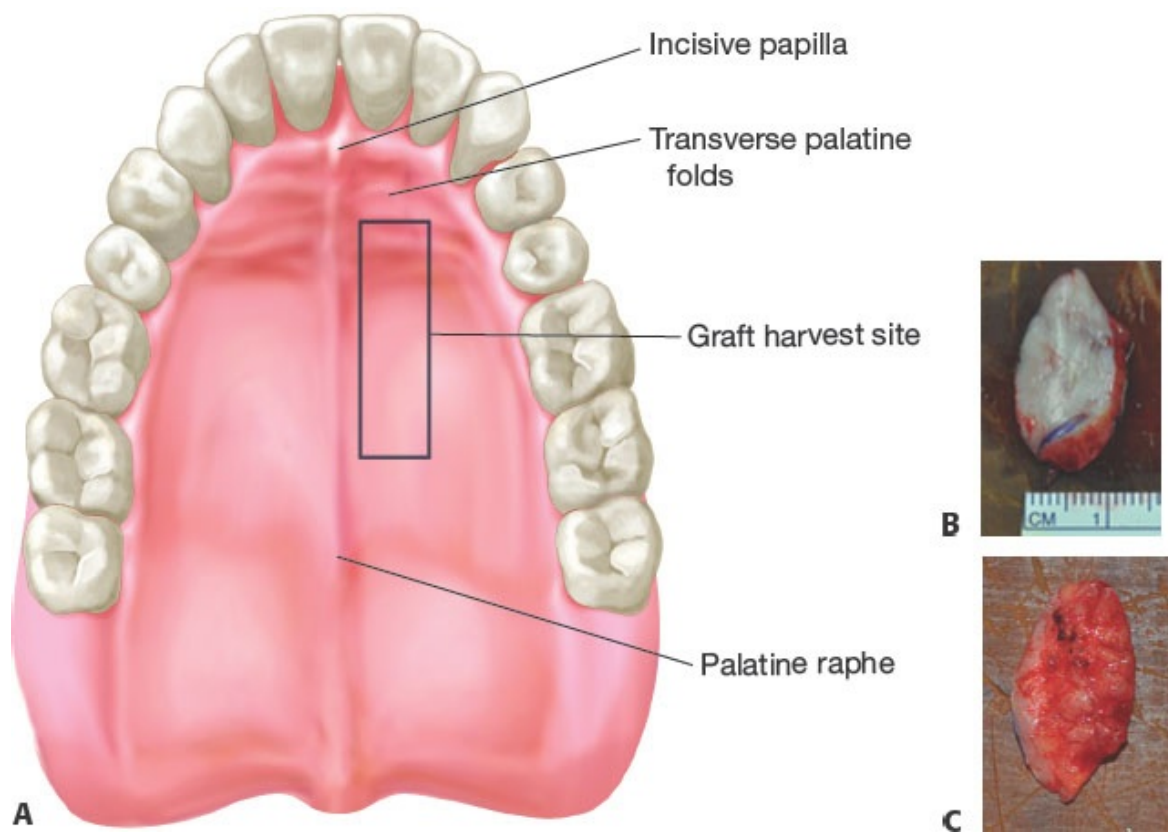
TECHNIQUES

■ Harvesting the Hard Palate Mucosa

- A side bite block is placed to facilitate exposure.
- A throat pack is placed.
- On average, a 25 × 10 mm graft is measured for harvesting. In cases of bilateral lid retraction, either one large central graft is taken and divided, or two separate grafts are taken from opposite sides of the palate.
- The junction of the hard and soft palate is identified laterally with forceps. The second molar is identified to assess the location of the greater palatine

foramen.

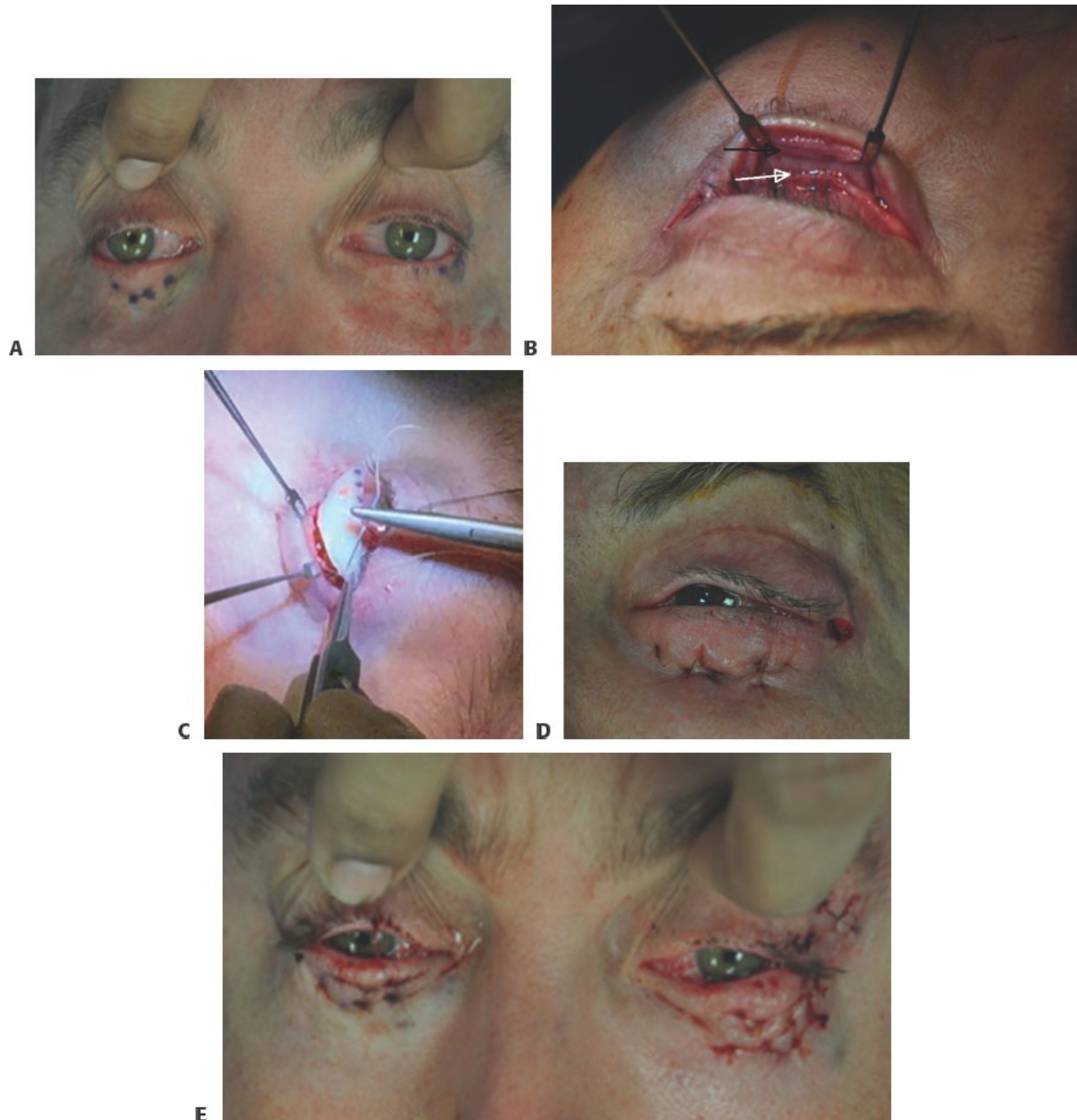
- The graft is harvested in the canine-premolar region toward midline, where the palatal mucosa is thickest (**TECH FIG 1A**).
- The palate is then infiltrated with 1% lidocaine with epinephrine 1:100 000.
- A 15-blade scalpel is used to incise the mucosa and submucosa leaving the periosteum intact. A small layer of fat is harvested with the graft.
- Once the graft is harvested (**TECH FIG 1B**), bipolar cautery is used for selective hemostasis.
- The resulting defect is then covered with Surgicel (Johnson & Johnson, New Brunswick, NJ) that is secured in place with 4-0 chromic gut sutures.
- The graft is trimmed to remove all fatty tissue, mucosal glands, and submucosa from its undersurface (**TECH FIG 1C**).
- It is stored in saline-soaked gauze until ready for transfer to the eyelid.



TECH FIG 1 • **A.** Graft harvest site. **B.** Average palatal graft is about 25 × 4 mm. **C.** Trimmed graft.

■ Lower Eyelid Surgery

- After markings are made (**TECH FIG 2A**), the lower lid is infiltrated with 1% lidocaine with epinephrine 1:100 000.
- Double skin hooks are used to expose the posterior lamella and identify the inferior border of the tarsal plate. A cotton-tipped applicator can facilitate palpating the transition.
- A 5-0 nylon suture is placed through the central portion of the lower fornix and retracted posteriorly over the eye to protect it and provide countertraction.
- A transconjunctival incision is made extending from below the punctum to the lateral canthus.
- Dissection is performed sharply to create a space between the inferior border of the tarsus and the superior edge of the recessed conjunctiva and lower lid retractors (**TECH FIG 2B**).
- The graft is placed within this space with the mucosal surface toward the globe (**TECH FIG 2C**).
- The inferior border of the graft is sutured to the recessed retractors and conjunctiva. The superior border of the graft is sutured to the inferior border of the tarsal plate.
- This is performed with double-armed 5-0 chromic sutures. The needles are passed full thickness through the lid, exiting the skin surface. Simple interrupted stitches are placed to ensure a flat transition and prevent any ridges.
- Each suture is then tied on the skin surface, ensuring that the knots are not secured tightly (**TECH FIG 2D**).
- A temporary tarsorrhaphy suture of 5-0 nylon is placed laterally if chemosis is a concern (**TECH FIG 2E**).



TECH FIG 2 • A. Patient markings. **B.** Transconjunctival exposure of the posterior lamella to identify the inferior border of the tarsal plate. **C.** Palatal graft is secured between the inferior border of the tarsus (*black arrow*) and the superior edge of the retracted conjunctiva (*white arrow*) and lower lid retractors with the mucosal surface toward the globe. **D.** The graft-securing sutures are tied on the skin surface. **E.** Immediate postoperative results.

PEARLS AND PITFALLS

Patient selection

- Many cases of lower lid retraction involve a multifactorial process requiring adjunct procedures such as a lateral canthopexy/canthoplasty, release of middle lamellar scarring, midface suspension, or infraorbital rim augmentation.

Surgical approach

- In the anterior palatal region, the neurovascular bundle runs toward the midline incisive canal and may be damaged if graft harvesting is not limited to the canine-premolar region.^{2,3}
- The donor site often oozes; it is important to not damage the periosteum or apply excessive electrocautery as this may cause necrosis of the underlying bone resulting in an oronasal fistula.
- Donor site granulates and heals completely within 2 to 3 weeks.
- The donor graft is typically trimmed medially. The majority of vertical height is required from the central lower limbus to the lateral canthus.

Donor-site selection

- Hard palate mucosa closely approximates lower lid tarsus in terms of contour, thickness, and stiffness.
- It is abundant and easily obtained.
- As an autograft, it is not at risk for rejection. It may undergo only minimal shrinkage following grafting for predictability in lid elevation.
- It has a mucosal surface and is well tolerated when grafted into the lower lid.

POSTOPERATIVE CARE

- Oral antibiotics are prescribed for 7 days after surgery (cephalexin 500 mg q8h).
- Patients are asked to eat a soft diet for 7 days postoperatively.
- Frequent mouthwashes are advised as well as careful tooth brushing.
- Ocular lubricant ointment is applied every 12 hours.
- Patients are instructed to refrain from strenuous exercise for 2 to 3 weeks postoperatively.
- The patients are instructed to apply ice for 48 to 72 hours and sleep with head of bed elevated greater than 30 degrees or with three or four pillows.
- Follow up is at 1-, 2-, and 4-week intervals. Thereafter, long-term follow-up is

at 6 months and 1 year.

- The external lower lid chromic sutures are trimmed at 1 week's time.

OUTCOMES

- Appropriate patient selection and sound surgical technique provides a vast majority of patients with satisfactory aesthetic outcomes (**FIG 3**).
- The improvement in scleral show and resolution of symptoms are noted once the swelling has resolved.

COMPLICATIONS

- Donor site
- Palatal fistula is typically self-limiting and allowed to granulate over time. A palatal splint or obturator can be made to provide symptomatic relief.
- Oral candidiasis will result in compromised healing. This resolves with oral antifungal treatment.
- Lower lid

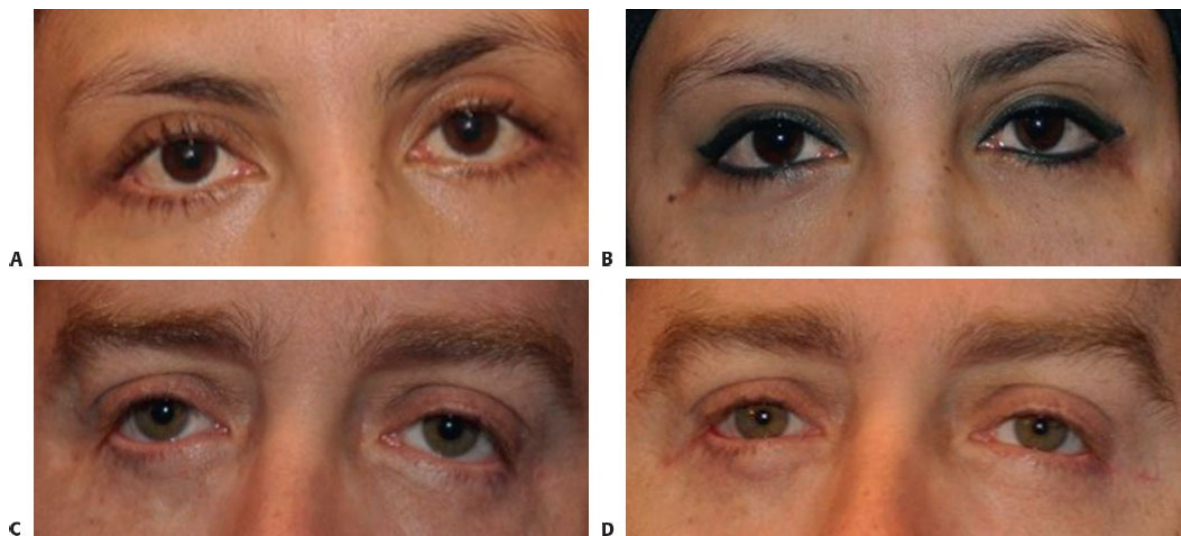


FIG 3 • **A.** A 45-year-old woman presented with lid descent after lower lid blepharoplasty with tarsal strip in negative vector patient. **B.** One year after infraorbital rim augmentation, subperiosteal midface lift, and palatal spacer graft. **C.** A 49-year-old man with lower lid descent after lower lid blepharoplasty and tarsal strip. **D.** Six months after subperiosteal midface lift and

palatal graft placement.

- Corneal irritation can occur from hard palate suture grafts, but this is limited by placing the suture knots on the external skin surface.
- Ocular discharge is not uncommon in the initial postoperative period. The keratin layer of the hard palate graft continues to accumulate. Over time metaplasia to nonkeratinized mucosa occurs.

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Section X: Facelifting and Necklifting

41 Indication and Technique for Skin-Only Face and Neck Lifting

CHAPTER

James Zins and Gehan D'Souza

DEFINITION

- Modern face and neck rejuvenation no longer focuses only on skin tightening but also may include fat contouring and volume restoration.
- Skin-only face-lift techniques avoid superficial musculoaponeurotic system (SMAS) manipulation. When combined with the release of major ligaments of the face, a skin-only face-lift may produce results equal to a more invasive technique.
- Knowledge of anatomical planes, three-dimensional relationship of the facial nerves, and location of the retaining ligaments is imperative.
- Procedures range from skin-only manipulation to alterations of the SMAS including minimal access cranial suspension (MACS) lift, lateral SMASectomy, extended SMAS, and the composite rhytidectomy.

ANATOMY

- Skin/fascial relationship
 - The facial soft tissue architecture can be described as being arranged in a series of concentric layers: skin, subcutaneous fat, superficial fascia, mimetic muscle, deep facial fascia (parotidomasseteric fascia), and the plane containing the facial nerve, parotid duct, and buccal fat pad.

- Superficial fascial system invests mimetic muscles of facial expression, whereas deep fascial system covers and protects the facial nerve branches.¹
- Ligaments and zones of adhesion
 - Retaining ligaments buttress the facial soft tissues against downward forces. These ligaments are in a constant location in relation to the facial nerve branches.^{2,3}
 - Ligaments act as sentinels to the facial nerve branches.
 - True ligaments such as zygomatic and mandibular ligaments fixate the bone to the dermis and pass through SMAS.
 - False ligaments such as parotid and masseteric ligaments fixate fascial layers to superficial soft tissue.
 - Recent writings have emphasized the concept of adhesions rather than retaining ligaments. Adhesions such as the masseteric temporal and supraorbital ligaments are fibrous or fibrofatty attachments between superficial and deep tissue.
- Neck
 - Factors that provide a youthful and aesthetically pleasing neck include distinct mandibular border, subhyoid depression, thyroid bulge, a distinct border to the sternocleidomastoid muscle, and a cervicomental angle of 105 to 120 degrees.
 - Facial nerve—five groups of branches are identified
 - Frontal (temporal) branches: Pitanguy delineated the course that extends from 0.5 cm below the tragus to 1.5 cm above the lateral eyebrow.⁴ At the level of the zygomatic arch, the branches run 1.8 cm anterior to the helical crus, and 2 cm posterior to the lateral orbital rim deep to the SMAS and parotid masseteric fascia. Superior to the arch, the nerves travel in the innominate fascia—a fusion plane between superficial and deep fascia. One should remain superficial to the superficial layer of the deep temporal fascia or deep to the layer.⁴
 - Zygomatic and buccal branches: Interconnections between these branches account for natural recovery. The most commonly injured facial nerve is the buccal ramus.
 - Mandibular branches: The mandibular branch consists of a single nerve with few interconnections with other facial nerves that results in a risk of permanent injury. Posterior to the facial vessels, the mandibular rami travel within 1 cm cephalad to the mandibular border. Anterior to the facial vessels,

the branches are always cranial to the border. The nerve travels deep to the parotid masseteric fascia and under the platysma by crossing superficial to the facial vessels.

- Cervical branches: The nerve travels in close proximity to the gonial angle at the 1.74 mm inferior to the mandibular border.

PATHOGENESIS

- There is controversy between descent of soft tissue and volume loss in relation to facial aging. One camp suggests laxity of malar soft tissues as an etiology. The other side suggests that volume loss is the key factor leading toward facial aging.^{1,5}
- Malar soft tissue migrates distal to the zygomatic cutaneous ligaments. This leads to soft tissue ptosis directly adjacent to the fixation of the nasolabial fold.
- Masseteric cutaneous ligaments support the cheek soft tissues that migrate downward inferior to the mandibular border to forming jowls.
- Jowling and loss of mandibular definition occurs by laxity of masseteric ligaments or deflation of the fat compartments of the face (submandibular).

NATURAL HISTORY

Upper third

- Aging is associated with
 - Eyebrow ptosis
 - Transverse forehead rhytides
 - Vertical glabellar lines
 - Hairline recession

Middle third

- Aging is associated with
 - Blepharochalasis
 - Ptosis of malar soft tissue
 - Laxity of lateral canthus and lid lead to rounding of palpebral fissure and ectropion
 - Lower lid fat bulge
 - Crow's feet
 - Tear trough deformity
 - Palpebromalar groove
 - Malar mound

The lower third and neck

- Aging is associated with
 - Bulge superior to the nasolabial crease
 - Nasolabial crease deepening
 - Marionette lines
 - Exaggeration of the labiomentral fold
 - Perioral wrinkles
 - Loss of the cervicomental angle secondary to skin ptosis, fat accumulation, and muscle banding
 - Platysmal bands

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with medical comorbidities including cardiac and respiratory conditions should be excluded from surgery. Screening of bleeding complications should be undertaken.
- Antiplatelet medication must be ceased 2 weeks prior to surgery.
- Smoking must be stopped at least 4 weeks prior to operation.
- Patients with body dysmorphic disorder, unrealistic expectations, or psychiatric illness should also be excluded.
- Elderly patients (older than 65 years) are not at higher risk for complications compared to those younger than 65 years old when properly screened.

IMAGING

- No imaging is necessary prior to procedure.

NONOPERATIVE MANAGEMENT

- Nonsurgical interventions include botulinum toxin and soft tissue fillers. Skin resurfacing procedures include chemical peels, Ulthera, deoxycholic acid, and light amplification by stimulated emission of radiation (LASER) therapy such as fractionated CO₂ or erbium laser. Fat grafting is used for volume augmentation.

SURGICAL MANAGEMENT

- In the cheek a skin-only dissection can lead to good or excellent results when subcutaneous dissection is extensive by freeing the zygomatic cutaneous ligament, mandibular cutaneous ligament, and masseteric cutaneous ligament.
- Operative intervention for face-lift by elevating, advancing, and redraping of the skin.

- When aging affects the neck, one must proceed with fat removal and platysma tightening.

Preoperative Planning

- Soft tissue and skeletal cephalometrics may be helpful for assessment of facial aging. One should assess symmetry and proportions of regions of the face and identify differences between soft tissue and skeletal muscle pathology that cause facial aging.
- Assessment should begin with the head in straightforward gaze with the Frankfort horizontal parallel to the ground and the lips and eyebrows in a relaxed position.
- When assessing the face, it can be divided into three horizontal thirds. The horizontal thirds are produced by lines drawn adjacent to the menton, nasal base, brows at the supraorbital notch level, and hairline.
- The lower third can be divided into the upper third and the lower two-thirds by a line drawn through the oral commissures.
- The lower third can be divided into halves by a horizontal line adjacent to the lowest point of the lower lip vermilion.

Positioning

- The endotracheal tube is secured. Stainless steel dental wire (26 gauge) is used to affix the endotracheal tube to the first bicuspid.
- Face and hair are prepped entirely.
- Reinforced endotracheal tube is used and brought over the head rather than down toward the chin. The tube is attached to the anesthesia machine using a straight connector and extension tubing, which rests on a “Christmas tree” holder (Mainline Medical, Norcross, Georgia).
- Sterile stockinet is applied over the tubing and the “Christmas tree” connector.
- When eyelids and upper face access is required, the Christmas tree is removed from under the stockinet; the tube is directly placed onto the patient’s draped torso and clipped to the drapes.

Approach

- Preauricular incision
 - Incision in the preauricular region has been shown to decrease scarring.
 - Incision should be carried out in a retrotragal or pretragal fashion (**FIG 1**).

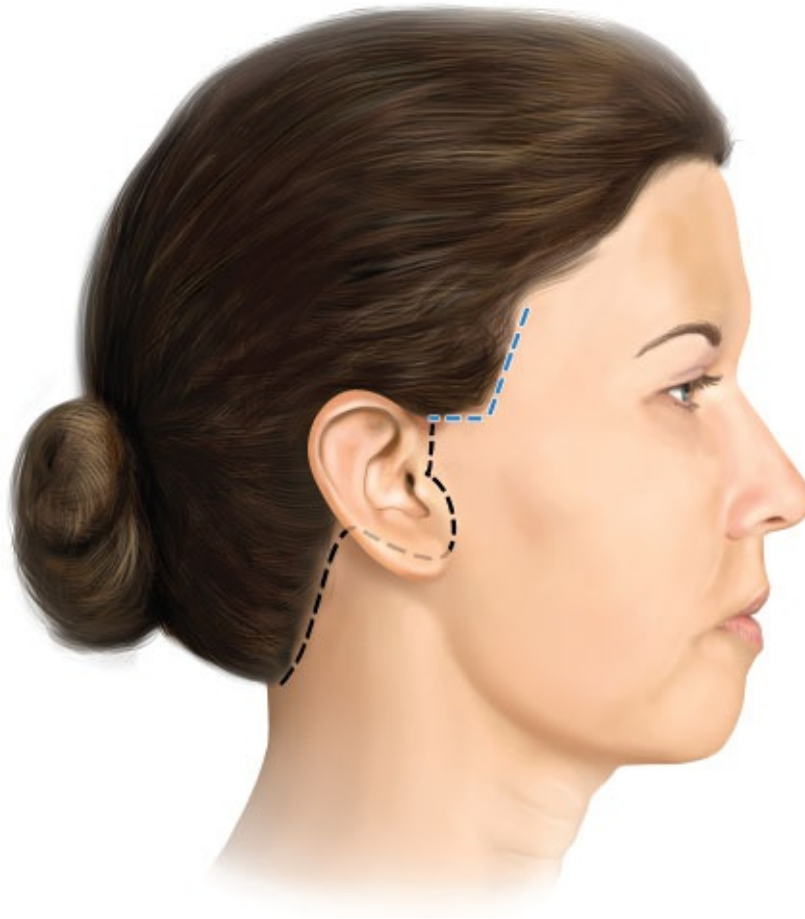


FIG 1 • The course of the preauricular and postauricular incision.

- Temporal incision
 - Temporal hairline incision is used when lateral canthus to temple distance is more than 5 cm.
 - When distance is less than 5 cm, temple scalp extension incision is made.
- Postauricular incision
 - Incision in the postauricular sulcus and crosses the region of postauricular skin where the helix and postauricular hairline join
 - This continues into the occipital scalp or follows the hairline.
- Submental incision
 - A 3 to 4 cm incision is centered over midline 5 mm caudal to the submental crease.⁵

TECHNIQUES

■ Skin-Only Face and Neck Lifting

■ Subcutaneous dissection (**TECH FIG 1**)

■ Local anesthetic

- Infiltrate incision sites with 0.5% lidocaine with epinephrine (1:200 000). Regions of subcutaneous undermining are infiltrated with 0.5% lidocaine with epinephrine (1:200 000).
- Inject each ipsilateral facial region prior to undermining to maintain tumescence and local block effect.

■ Subcutaneous undermining

■ Skin flaps should be elevated under direct vision.

■ Preauricular dissection

- Dissect anterior to the helix beginning in a superficial subcutaneous plane to avoid injury to the superficial temporal vessels. Care should be taken to avoid injury to tragal cartilage. In the area of the cheek, dissection should preserve fat on skin flap to provide for a robust flap. This plane should be consistent in the area of the upper neck and inferior mandibular border.
- Dissect anteriorly to incise platysma-cutaneous ligaments and mandibular cutaneous ligaments when indicated.

■ Postauricular dissection

- Elevate skin superficial to the sternocleidomastoid taking care to preserve fascia protecting the great auricular nerve (GAN).
- Note: GAN location has been described (GAN fall within a 30-degree angle constructed using the vertical limb perpendicular to the Frankfort horizontal and a second limb drawn posteriorly from the midlobule).

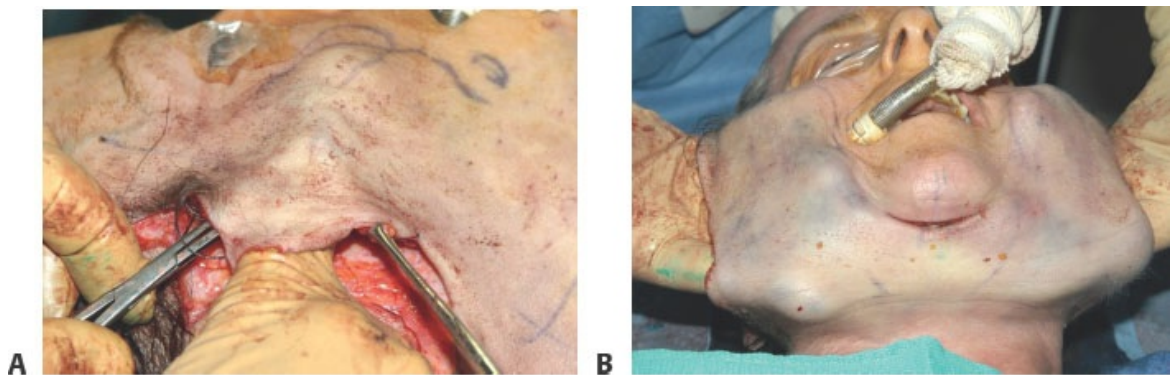
■ Temporal region

- Dissect in a plane superficial to the superficial temporal fascia and bevel blade parallel to the hair follicles.
- Identify the orbicularis oculi and remain in a superficial plane to this muscle.

■ Neck dissection

■ Local anesthetic is administered if general anesthetic is used.

- Infiltrate incision site with 0.5% lidocaine with epinephrine (1:200 000). Regions of subcutaneous undermining are infiltrated with 0.5% lidocaine with epinephrine (1:200 000).
- Incise the skin through 3.5 mm submental incision 5 mm caudal to the submental crease previously marked.
- Use Bovie cautery or scissors to begin undermining in subcutaneous tissue to connect lateral dissection subcutaneous planes with that of the lower face.
- Defat submental region above the platysma in the midline.
- Incise platysma in midline to level of the thyroid cartilage.
- Remove interplatysmal and subplatysmal fat.
- Fat is resected flush with the anterior bellies of the digastric muscles.
 - Subplatysmal fat is excised flush with the digastric muscles to avoid creation of a cavity between the muscles.
 - Digastric muscles may be plicated in the midline or partially resected if bulging prominent.
- Dissection extends inferiorly to the thyroid cartilage inferiorly and laterally to the anterior belly of the digastric. Lateral dissection is strictly in a preplatysmal plane.
- Platysmaplasty
 - 3-0 PDS suture used in running fashion to sew cut edges of platysma to midline from chin to thyroid cartilage and back to the chin (corset platysmaplasty).
- Close incision with subdermal 4-0 Monocryl suture and running 5-0 subcutaneous fast-absorbing suture.



TECH FIG 1 • A. Skin flaps elevated. **B.** Extent of

cheek and neck dissection

- Skin redraping
 - Goal: Skin shifted along vector perpendicular to the nasolabial fold. In postauricular region, skin should be shifted along vector parallel to mandibular border for optimal improvement of the anterior neck.
 - Suspend skin flap first at the cranial most aspect of the helix with vector perpendicular to nasolabial fold.
 - Use a face-lift marker and incise in a T-shaped incision in flap.
 - Suspend flap with a 4-0 Prolene suture.
 - A third suture is placed high in the postauricular region.
 - Second point of suspension is at the lobular region where 4-0 Monocryl suture suspends flap at inferior lobule.
 - Flap is divided at the lobule and exteriorized.
- Skin flap tailoring
 - Preauricular trimming/closure
 - Mark skin flap redundancy and trim skin flap. Preauricular portion of flap is trimmed to match preauricular curves.
 - Care must be taken over tragal region to avoid tragal retraction from tension on skin flap and tragus.
 - Defat pretragal portion of skin flap for pleasing contour.
 - Affix skin flap to cranial preauricular skin with 4-0 Monocryl subdermal sutures.
 - Run 6-0 fast-absorbing sutures for preauricular closure taking care to evert skin edges.
 - Postauricular trimming/closure
 - Trim anterior border of the postauricular skin flap to match curve of incision in auriculomastoid sulcus.
 - Excise skin along posterior border of the postauricular skin flap using face-lift marker as guide. Wound edges should touch one another without gaps (ie, no tension on postauricular skin flaps).
 - Run 5-0 fast-absorbing gut suture for single-layer closure.

Tension	■ Preauricular incision under moderate tension. Postauricular incision should be under no tension. Tension in the postauricular region leads to a hypertrophic scar at best or skin slough at the worst.
Release of ligaments	■ Subcutaneous dissection over the cheek over the region of the major zygomatic ligament must be done carefully as nerve injury can occur in a deep dissection.
Dissection plane	■ In the cheek, the dissection of the skin-only face-lift is more superficial than the deeper dissection over the platysma.
Excellent results	■ Excellent results in skin-only face-lift are predicated on the release of mandibular ligaments, zygomatic ligaments, and masseteric ligaments.
Neck	■ Patients with platysmal banding require an anterior neck approach platysmaplasty in addition to the skin-only face-lift.
Cautery	■ Bipolar cautery use rather than unipolar cautery use reduces both the incidence of neuropraxia and neck drainage.

POSTOPERATIVE CARE

- Patient discharged from postoperative unit after procedure.
- A head dressing is not essential, but a soft dressing prevents unsightly blood leakage and is removed the following morning.
- Patients are provided with analgesics only.
- Patients are examined 1 day after surgery with care to examine suture lines and skin flaps.
- Patient drains are removed 1 day after surgery regardless of output unless drainage is significant, ie, greater than 30 cc.
- Patients begin showering 1 day after surgery following removal of dressings.
- Residual sutures are removed 7 days after surgery.

OUTCOMES

- See **FIGS 2** and **3**.



FIG 2 • A–C. Preoperative. D–F. Postoperative 1 year—
Skin-only face-lift with neck lift



FIG 3 • A–C. Preoperative. D–F. Postoperative 1 year—
Skin-only face-lift and neck lift

COMPLICATIONS

■ Early complications

- Hematoma: The incidence of hematoma formation is variable ranging from 1% to 10%. One should maintain blood pressure at preoperative levels during closure to detect bleeding once epinephrine effect wanes. Small hematomas are dealt with in a conservative fashion. Large hematomas must be drained in the operating room and cleared through (milking out through drains or aspirated with needle).
- Seromas: Occur in the neck region and lower face. If seroma forms after drain removal, aspirations with a needle and syringe in clinic are required. Undrained seromas lead to neck irregularities that can be difficult or impossible to correct.
- Sialoma: Rarely occur, caused by parotid gland injury. This is diagnosed with high amylase levels. Leaks resolve with conservative treatment in the absence of distal obstruction.
- Facial nerve injury: Permanent injury incidence is 0.4% to 2.6%. Most common branches injured are injuries include buccal branches. Buccal branch injury is not apparent as there are many interconnections between the buccal branch and other facial nerve branches. Marginal mandibular nerve injury is the second most common but is apparent due to it being single nerve without interconnections with other branches. Early nerve defects are neuropraxic rather than axonotmesis and usually resolve. The marginal mandibular and cervical nerves are differentiated as the marginal mandibular gives innervation to the mentalis, which results in the lack of lip eversion

when injured.

■ Late complications

- Contour irregularities: Occur as a result of asymmetric fat excision
- Pixie ears: Caused by tension on the lobule during closure
- Unsatisfactory scars: Widened misplaced scars, hypertrophic scars, or skin slough
- Alopecia
- Loss of tragal definition

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Indications and Techniques for Face-Lifting and Neck Lifting

42

CHAPTER

David A. Hidalgo and Sammy Sinno

GENERAL CONCEPTS

- Facial aging is a result of progressive degenerative changes in the skin, deeper soft tissues, and underlying skeletal structures, often occurring independently and each to variable degrees.
- Although new nonsurgical techniques that attempt to restore a more youthful facial appearance continue to develop, surgical rejuvenation remains the most powerful approach.
- Face-lifting and neck lifting involves dissection and manipulation of facial skin and deeper soft tissues to create an aesthetically rejuvenated facial appearance and youthful contour in the neck.
- The superficial musculoaponeurotic system (SMAS) layer of the face can be manipulated independent of facial skin in several ways to provide more natural and long-lasting results.
- SMAS technique options include SMAS flap, SMASectomy, and SMAS plication.^{1–3} Facial contour, skin quality, soft tissue volume, and bone structure all influence the choice of technique.
- There are various strategies applicable to treating aging changes in the neck that address visible muscle banding, skin laxity, and general neck contour.
- Adjunctive procedures involving periorbital surgery, regional resurfacing, soft tissue volume augmentation, skeletal augmentation, and others enhance the results of face-lifting and neck lifting.

ANATOMY

- The face is a lamellar structure that, from superficial to deep, consists of skin,

subcutaneous fat, SMAS, deep fascia (parotidomasseteric fascia), the mimetic muscles, facial nerve branches and the parotid gland, muscles of mastication, deep fat compartments, and bone.

- The facial nerve innervates most muscles of facial expression on their deep surface and is protected in the area over the parotid by the parotidomasseteric fascia.⁴
- The SMAS is contiguous with the platysma muscle inferiorly and the galea aponeurotica superiorly.⁵ Tightening of this layer repositions ptotic facial tissues and is a key component of restoring youthful facial contour.
- The platysma muscle in the neck typically develops ligamentous laxity with aging. This commonly results in the development of visible medial muscle edges (bands) anteriorly that exhibit variable thickness, length, and spacing between them. Excess subcutaneous fat superficial to the muscle can also contribute to the appearance of an aging neck.
- Structures deep to the platysma including subplatysmal fat, submandibular glands, digastric muscles, and the hyoid bone can also contribute to contour problems independent of the aging process, as can skeletal conditions such as microgenia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present for surgical rejuvenation of the face and neck over the age of 50, but some seeking correction of minimal deformities can present in their early 40s.
- Patients presenting for the first time in their 70s are also reasonable candidates provided there are no prohibitive medical conditions.
- The best candidates for surgery are those with significant aging changes who are motivated for the right reasons; good candidates should be psychologically stable and have realistic expectations.
- Characteristic signs of facial aging include deepening of the nasolabial folds with associated midface ptosis and deflation; progressive actinic skin damage and laxity; subcutaneous atrophy; development of jowls, “marionette lines,” and adjacent prejowl hollowing; and platysma laxity leading to anterior bands and an obtuse cervicomental angle laterally.
- Smoking increases the risk of wound complications, particularly in the setting of wide skin undermining. Therefore, complete cessation of smoking is required for at least 3 weeks prior to surgery. Nicotine substitutes of all types are also prohibited.

- Strategies to minimize complications when uncertainty exists regarding compliance include avoiding retrotragal incisions, limiting the extent of the retroauricular incision design (short-scar option if appropriate), avoiding opening the anterior neck, and limiting skin undermining.
- Patients with a BMI over 30 and significant medical conditions such as obstructive sleep apnea, severe diabetes, or cardiovascular disease are unfavorable candidates for surgery in an office-based setting. Men with a history of obstructive urinary symptoms should have a urology consultation prior to surgery.

IMAGING

- Although 3D scanning is available today, it does not significantly enhance communication between the surgeon and patient beyond what high-quality facial photographs and mirror examination can achieve.

SURGICAL MANAGEMENT

Preoperative Planning

- Skin quality is assessed including thickness, elasticity, and degree of actinic damage.
- Many patients will benefit from simultaneous regional skin resurfacing with a chemical peel such as 30% trichloroacetic acid for the thinner periorbital skin or dermabrasion for the thicker perioral skin.
- Lasers are an alternative resurfacing modality, perhaps best suited to full face treatment with fractionated laser-based technology subsequent to surgery.
- Patients with high sideburns are advised that their hairline may move slightly or that a subsideburn incision may be necessary to prevent excessive movement. The latter is more common in secondary or tertiary cases.
- Pretrichial temporal incisions are another option but can cause variable scar quality and generally are not well accepted by patients.
- The choice between a pretragal and retrotragal incision is influenced by tragal anatomy, its overlying skin quality, and adjacent preauricular skin thickness and texture.
- Retrotragal incisions effectively break up the continuity of the preauricular incision but must be carefully crafted to avoid an unnatural-appearing tragus.
- Women who have a large, projecting tragus with thin, delicate overlying skin and adjacent thick cheek skin are better suited to a pretragal incision.

- Most men are also good candidates for pretragal incisions to avoid the transposition of thicker, hair-bearing skin over the tragus and to avoid a more feminized appearance in this area.
- Women under 60 years with minimal neck changes seeking improvement for early jowls and nascent lateral cheek laxity are often good candidates for a posterior incision pattern limited to the postauricular sulcus (short-scar technique).⁶ This is particularly advantageous in those who habitually expose this area due to hairstyle preferences.
- Nevertheless, well-designed and expertly executed full postauricular scar patterns are preferred to a more limited incision approach that fails to correct cervical skin laxity.
- Most women and even men with complete alopecia are best served with a complete postauricular scar pattern.
- Individual bone structure, soft tissue volume, and surgical timing (primary or secondary, tertiary) are all influential in selecting the optimal SMAS technique for each patient. Those with strong mandibular or maxillary bone contours generally require less SMAS manipulation, as do those with lighter soft tissue volumes. The opposite scenarios argue for more extensive SMAS manipulation.
- For patients with prominent facial bone structure and light or medium thickness soft tissues, a SMASectomy is indicated.
- For patients with normal or small facial bone structure who require more extensive repositioning of heavier facial soft tissues, an extended SMAS flap is more effective.
- For patients with thin, minimally ptotic soft tissues, or in secondary or tertiary cases, a SMAS plication is appropriate.
- Facial fat volume and distribution are assessed.
 - If significant hollowing in the prejowl sulcus or deflation of the malar compartment is observed, adjunctive fat grafting of these areas should be considered at the time of the primary procedure.
 - Prominent lateral cheek hollowing, seen less commonly, is best treated with a separate fat grafting procedure at a later procedure.
- The extent of cervical skin laxity and the underlying neck contour are evaluated.
 - Older patients with very loose skin of poor quality that extends to the base of the neck are always counseled that they may need a limited secondary

procedure at 1 year to obtain an optimal, durable result. This also applies to younger patients having a single strong midline submental skin band.

- It is important to discuss this preoperatively with those having either of these characteristics.
- Anterior neck surgery is indicated for platysmal bands that are prominent and generally no further apart than 2.5 cm. Patients are advised that a 2.5- to 3-cm submental incision will be necessary to accomplish this.
- Subplatysmal fat excision is a helpful adjunct for improving an obtuse cervicomental angle and can be an indication alone for opening the neck in the absence of platysmal bands.
- Partial excision of the submandibular glands and digastric muscles is a much more aggressive and controversial approach for contour improvement and is not routinely recommended.
- Patients are counseled on the option of having a chin implant placed when microgenia is present. Even in subtle cases, an extra small implant is often beneficial.
- Ptotic chin pads (witch's chin deformity) and more subtle chin/neck junction depressions should be noted and addressed in the surgical plan.
- Perioral resurfacing is often indicated in conjunction with face-lifting and neck lifting.
- Upper lip rhytides are usually the first to appear and tend to be the deepest. The oral commissures, prejowl sulcus, and chin are also affected to variable degrees but usually much less than the upper lip.
- Chemical peels, laser resurfacing, and mechanical dermabrasion are all effective at improving rhytides but also can cause depigmentation of the treated areas.
- Nevertheless, even conservative rhytide ablation significantly enhances the overall result of surgery. Dermabrasion, perhaps the least technically sophisticated and oldest tool, allows precise depth control of treatment in experienced hands.
- Simultaneous periorbital rejuvenation is frequently requested and discussed and, less commonly, a nasal tip plasty to address concerns regarding a bulbous or drooping tip.
- Earlobe reductions or repair of elongated or lacerated earlobe piercings are also sometimes requested during the preoperative evaluation.

Patient Preparation

- All patients have standardized multiview facial photographs taken, with additional views of areas where adjunctive treatment is planned.
 - These photographs are used for preoperative planning and communication, intraoperative reference, and postoperative outcome discussions.
- Medical clearance is routinely obtained in patients over 60 or in younger patients with specific medical conditions of concern.
- Patients taking blood-thinning medications for cardiac stents or arrhythmias must be evaluated by their cardiologist to determine the safety of discontinuance for a suitable interval both before and after surgery. The same applies to patients on prophylactic low-dose aspirin.
- Strict blood pressure control is necessary perioperatively to facilitate surgery and minimize the potential for a postoperative hematoma. Therefore, patients with hypertension must optimize their medical regimen for blood pressure control prior to surgery.
 - Clonidine can be administered from either an oral or transdermal route immediately prior to surgery to manage blood pressure that remains refractory to tight control.
- Hospital employees, such as anesthesiologists and nurses, or others with a prior history of MRSA should be screened with a nasal swab culture.
 - Patients who test positive should be treated with Bactroban (mupirocin) prior to surgery to eliminate their carrier status.
- The benefits of perioperative homeopathic use such as *Arnica montana* for ecchymosis and bromelain for edema are unproven but can be safely employed at the surgeon's discretion.
 - Excessive doses of *Arnica* may increase the risk of hemorrhage.
- Patients are instructed to wash their face and hair thoroughly the night before surgery, remain nothing by mouth (NPO) after midnight, and take their blood pressure medication on the morning of surgery.

Patient Positioning

- The patient is positioned supine on the operative table with the knees slightly bent to optimize lower extremity venous return.
 - The arms are carefully immobilized and a warming blanket is placed.
 - A triangular headpiece facilitates performing the procedure.
- Anesthesia is induced, either an oral airway or laryngeal mask airway (LMA) placed, and the patient typically maintained on propofol for the duration of the

procedure.

- Normotensive anesthesia is preferred throughout the procedure in order to minimize the prospect of hematoma development.
- Consideration should be given for placement of a urinary catheter for long procedures and for men with a history of obstructive symptoms.
- One preoperative dose of cephalosporin is administered.
 - If the patient is a hospital employee or has a history of MRSA, vancomycin is given instead.
- The incisions and key reference points are marked, the sites of injection prepped with Betadine swabs, and the areas of dissection infiltrated with a dilute lidocaine and epinephrine solution (100-cc normal saline, 100 cc 1% lidocaine, 1 cc of epinephrine).
 - Tumescence technique is not necessary, and typically 200-cc total is used for the face and neck.
- The face is then prepped with Zephiran Chloride (benzalkonium chloride) and a head drape applied.

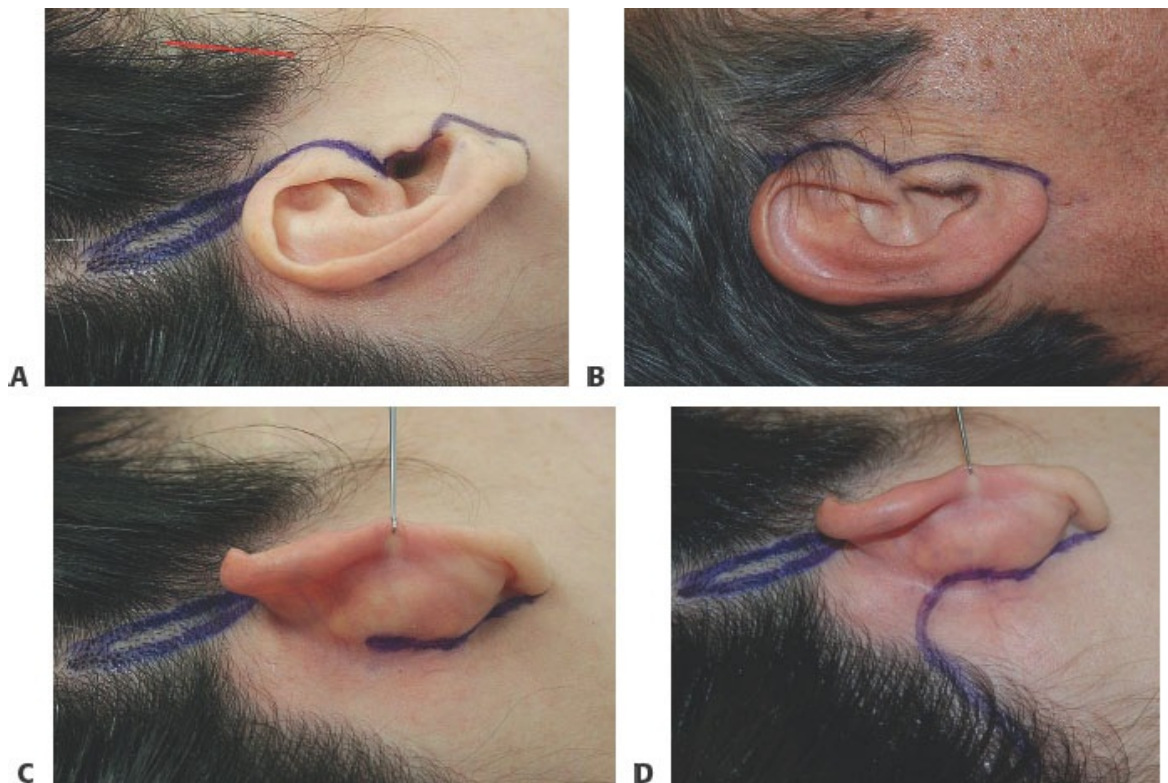
TECHNIQUES

■ Incisions

- Incisions are all made using a no. 10 blade scalpel.
- Temporal incisions within the scalp angle back approximately 20 to 30 degrees above the ear to avoid the course of the superficial temporal artery (**TECH FIG 1A**).
 - Pretrichial incisions are avoided in the temporal area due to their inconsistent healing quality.
- Subsideburn incisions are positioned at the root of the helix and extend transversely for no more than 2 cm when needed.
 - A commitment for making subsidence incisions is generally not necessary until skin redraping at the time of closure.
- The retrotragal incision is positioned slightly posterior to the free edge of the tragus and defines its superior and inferior borders. The inferior portion of the incision then extends anterior to the tragus for several millimeters before making a sharp angle to parallel the attached portion of lobule (see **TECH**

FIG 1A).

- Pretragal incisions parallel the curve of the helix to its root and then inflect downward with a short mirror image curve that then straightens to parallel the tragus down to the lobule (**TECH FIG 1B**).
- Short-scar postauricular design can use the full length of the sulcus to allow for even skin distribution when closing, thereby minimizing the potential for significant pleat formation (**TECH FIG 1C**).
- Full postauricular incisions reflect posteriorly high in the sulcus, cross the mastoid skin with a gentle upward curve, and then continue into the occipital scalp parallel to and just inside the hairline, cut on a bevel to preserve hair shafts (**TECH FIG 1D**).
- The submental incision is 2.5 to 3 cm in length and can be placed either in the natural crease or slightly posterior to it, depending on surgeon preference.
- Creation of a “mesotemporalis” by deep dissection in the temporal area is not recommended as this maneuver predisposes to late (10 to 14 days) massive superficial temporal artery hemorrhage. This complication occurs suddenly and is associated with challenging patient management issues.

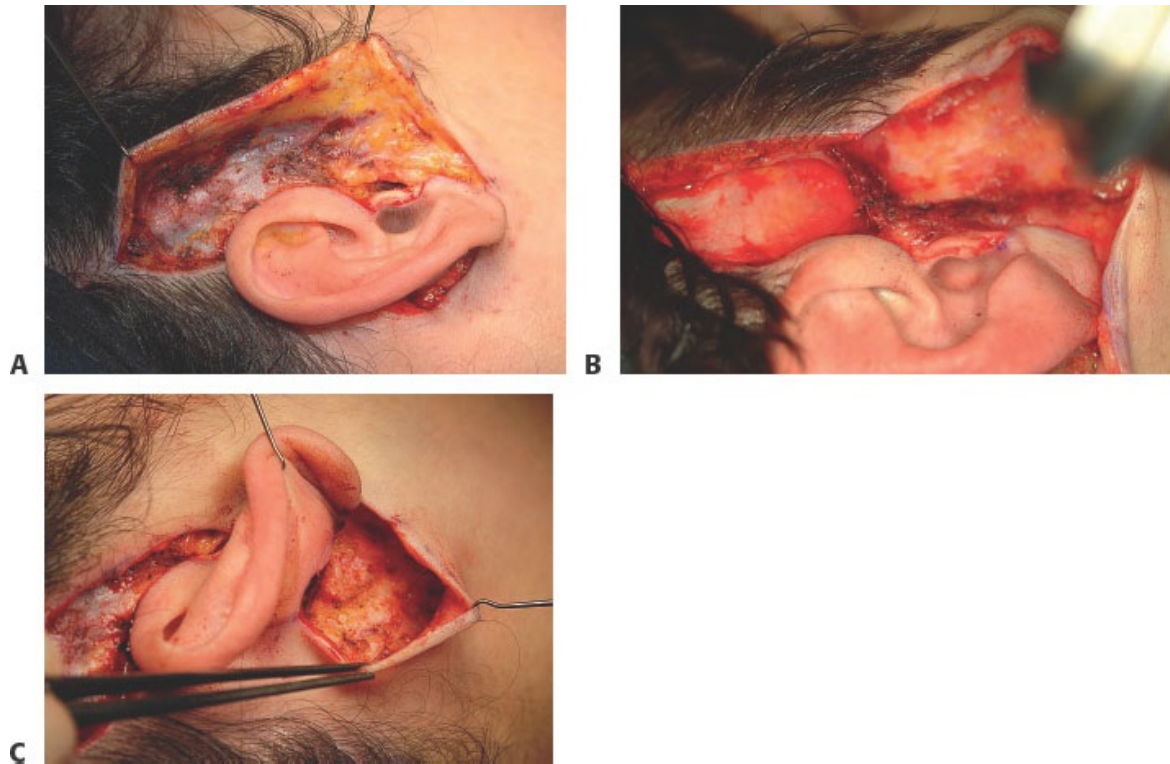


TECH FIG 1 • Incisions. A. The temporal scalp

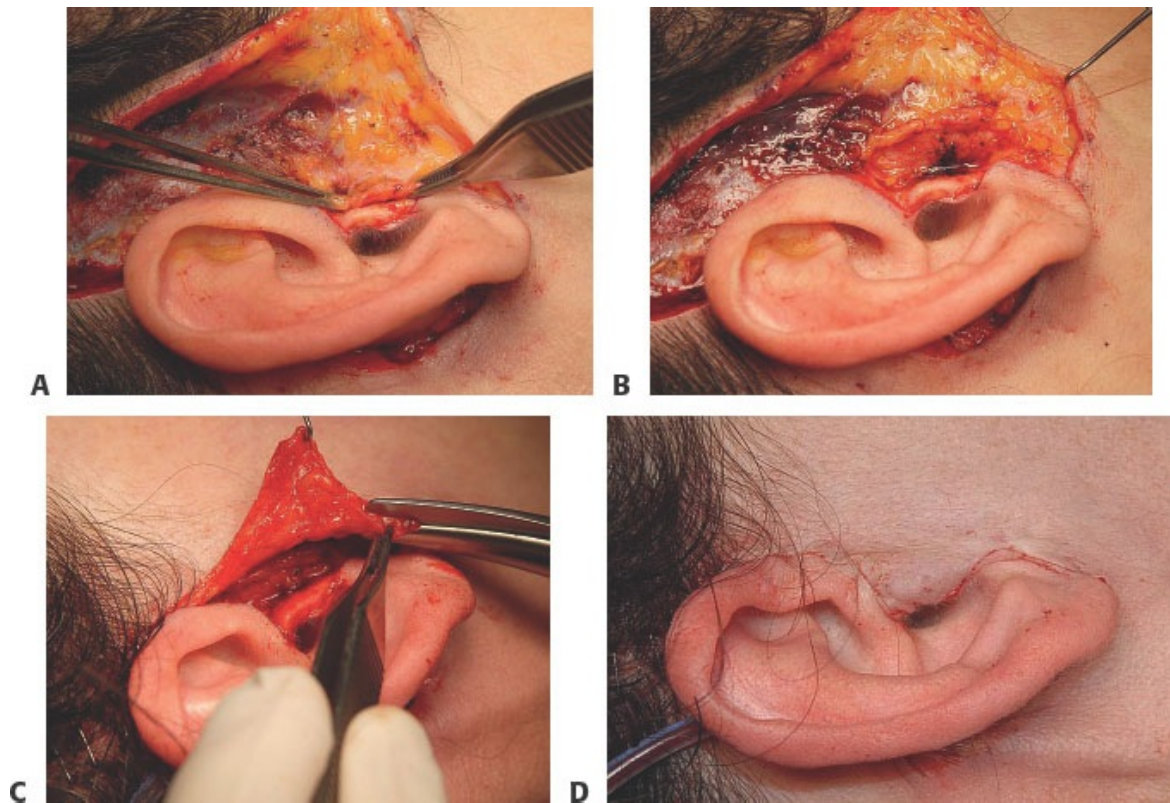
incision is angled backward approximately 30 degrees to avoid the superficial temporal artery. A small amount of scalp skin can be pre-excised as shown by the design. The retrotragal portion of the skin incision lies posterior to the free edge of the tragus. The incision then turns a right angle at the lower border of the tragus to parallel the lower ear and lobule. Avoid pretrichial incisions (*red line*) when possible. **B.** Pretragal incision design in a male. **C.** Short-scar postauricular incision design can use the whole length of the sulcus to facilitate an even distribution of skin during closure. **D.** Typical postauricular skin incision design. The incision reflects from the postauricular sulcus high on the mastoid bare skin before transitioning into the occipital scalp.

■ Skin Flap Elevation

- Once all incisions have been made, the no. 10 blade is used to begin the skin flap elevation 1.5 to 2 cm anteriorly in the preauricular area (**TECH FIG 2A,B**). Care is taken to maintain proper thickness when starting the flap with the knife.
 - The postauricular and upper neck skin is then raised sharply off the mastoid and origin of the sternomastoid muscle (**TECH FIG 2C**). Hemostasis is obtained in all areas raised so far.
- In the case of retrotragal incisions, soft tissue is sharply undermined at the base of the tragus and folded over anteriorly (**TECH FIG 3**).
 - It is sutured to the SMAS with a continuous 4-0 Vicryl suture.
 - This maneuver creates a “hill and valley” effect just anterior to the tragus. As the skin follows this contour during closure, tragal definition is enhanced.



TECH FIG 2 • A. In temporal incisions, the temporal scalp is raised in a subcutaneous plane. **B.** Raising this area in a deep plane with a transition zone to the subcutaneous plane inferiorly over the cheek should be avoided. **C.** The skin flap is shown raised over the mastoid and sternomastoid muscle origin in this short-scar example. This is a good time to obtain hemostasis of all areas prior to raising the skin flap over the cheek and neck.



TECH FIG 3 • A. In retrotragal incisions, the soft tissue over the tragus is raised as a flap. **B.** The flap is then reflected anteriorly and sutured to the preauricular SMA. The skin that will overlie the tragus at closure is thinned inferiorly where the incision pattern transitions to parallel the lower ear and also along its superior edge. **C.** The central portion is not thinned in order to avoid vascular compromise. **D.** Final closure.

- Curved Mayo or similar scissors with “tips down” are used to raise the skin flap under direct vision with transillumination, except in the region of the great auricular nerve where “tips up” aids in avoiding injury.
- The proper plane of subcutaneous elevation is most readily identified in the temporal area, which is then extended over the orbicularis oculi and the malar eminence.
 - A cobblestone appearance of the subcutaneous flap fat over the lateral zygoma verifies the correct plane.
- Dissection of the neck in a subcutaneous plane is next performed.

- The platysma should not be directly exposed until at least several centimeters below the mandibular border. Observing this principle prevents platysma denuded of fat from being repositioned above the mandibular border when the SMAS is tightened.
- The skin flap is dissected for a short distance above the mandibular border in the jowl region, tapering closer to the mandible border as the mentum is approached.
- Release of the mandibular ligaments adjacent to the mentum is not critical although some would disagree.
- The extent of medial neck dissection is variable depending on conditions and goals. It can be extended almost to the midline to anticipate dissection of the anterior neck through a submental incision if that is planned later.
- It is easiest to raise the skin flap from above to below as described and then perform the midcheek skin elevation only to the extent necessary for adequate SMAS exposure.
 - Undermining rarely proceeds within 2 cm of the nasolabial fold.
 - Excessive release of the skin flap is avoided in this area to allow maximum skin movement with SMAS tightening.

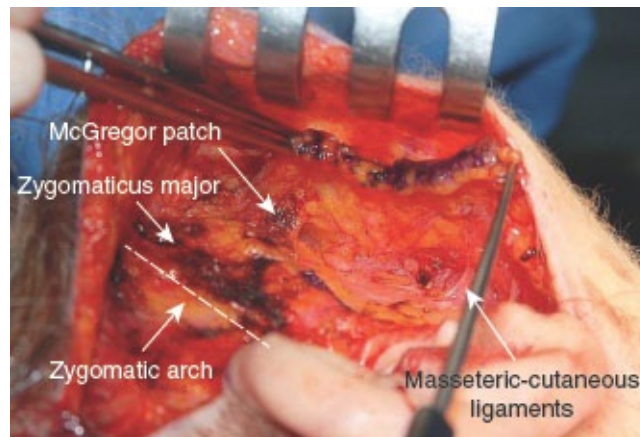
■ SMAS Treatment Options

SMAS Flap

- A line is drawn over the zygomatic arch to establish the superior border of the SMAS flap.
- The SMAS is incised with a no. 10 blade in the preauricular area. Sharp elevation continues over the surface of the parotid gland and then switches to scissors.
- The SMAS is then bluntly dissected anterior to the gland with delicate vertical spreading of the scissor tips to expose and release the masseteric-cutaneous ligaments and then the zygomatic-cutaneous ligaments superiorly (McGregor patch) (**TECH FIG 4**).
 - The latter usually includes cauterization of a small branch of the transverse facial artery.
- The medial extent of SMAS flap elevation can either cease once the border of the zygomaticus major muscle is identified or can proceed beyond it and over the zygomaticus minor muscle (extended SMAS dissection) to achieve

greater midface correction.

- The lateral border of the platysma is then elevated over the tail of the parotid gland with careful sharp and blunt dissection.
- The muscle border is mobilized inferiorly for several centimeters with care taken to identify and avoid both the great auricular nerve and external jugular vein.
- The SMAS is then elevated vertically and slightly posteriorly.



TECH FIG 4 • A SMAS flap is shown on the right side. It is initially incised along the zygomatic arch, elevated rapidly over the parotid gland, and then dissection carefully extended medially to expose the zygomaticus major and the masseteric-cutaneous ligaments. Small vessels are usually encountered anterior to the parotid gland (McGregor patch).

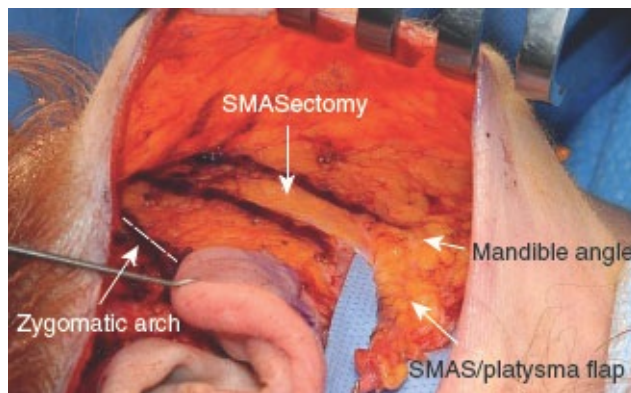
- After initial fixation in the preauricular area with a 4-0 Mersilene suture, the excess is either folded over superiorly to add volume or excised.
- The flap is then sutured at the level of the zygomatic arch with interrupted 4-0 Mersilene sutures.
- The immediate preauricular portion of the SMAS flap is incised inferiorly while pulling on the cut end in a posterolateral direction in order to transpose the split portion of the flap behind the ear.
- It is sutured to the mastoid fascia with 2-0 Maxon (polyglyconate) sutures chosen for their considerable strength, allowing maximum traction on the

platysma component to improve cervical contour.

- The SMAS flap suture line is then oversewn with a running 4-0 PDS (polydioxanone) suture along the zygomatic arch and preauricular area.
- The suture line is made smooth and isolates the parotid gland from the subcutaneous plane to help insure against fistula formation.

SMASectomy

- A line is first drawn over the zygomatic arch to properly orient SMASectomy design.



TECH FIG 5 • A SMASectomy excision is shown on the right side. The relation of the excisional design pattern to the zygomatic arch and angle of the mandible is illustrated, as is the SMAS/platysma transposition flap.

- A second line is drawn between the malar eminence and just above the angle of the mandible where the preparotid SMAS is still fixed to the gland.
- The SMAS is placed on traction below this line with Cushing forceps to assess the degree of soft tissue laxity and the amount of SMAS movement possible.
 - This is typically 1.5 to 2 cm at the angle of the mandible (less in secondary or tertiary face-lifts) with somewhat less as the malar area is approached.
 - A second parallel line is then drawn based on this maneuver to indicate the inferior border of the excision design.
- The area of SMAS between the two lines is then excised in portions, carefully observing the depth of the excision as this is done (**TECH FIG 5**).

- Medially, where distal facial nerve branches become more superficial, the excision depth is more conservative.
- The lateral platysma is then mobilized as described for the SMAS flap and sutured in the mastoid area with 2-0 Maxon sutures.
- The cut edges of the SMAS are sutured with 4-0 Mersilene in interrupted fashion.
- A 4-0 PDS continuous suture is then placed to smooth contour over the suture line.

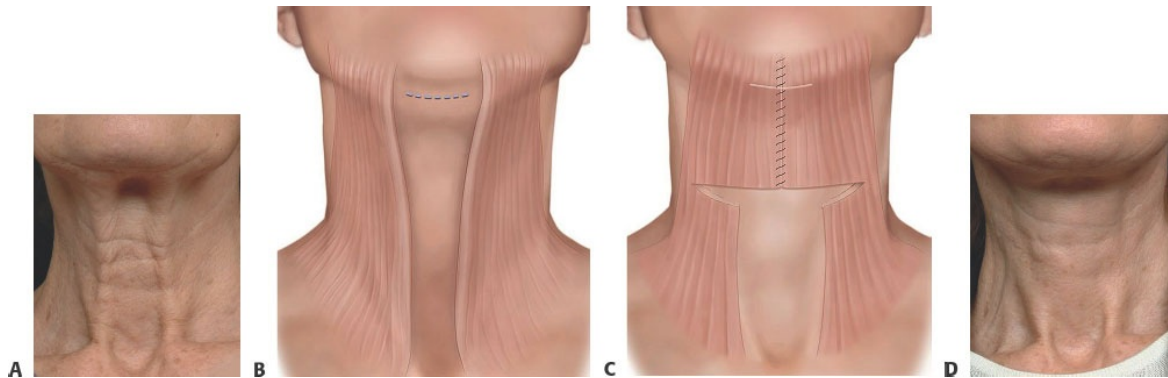
SMAS Plication

- The SMAS is marked identical to a SMASectomy design.
 - The SMAS within the marked pattern is plicated with interrupted 4-0 Mersilene sutures.
 - The lateral platysma is treated in the same fashion as described with SMASectomy.
- A 4-0 PDS continuous suture is then placed to contour smoothly over the suture line.
- After all SMAS techniques, the skin is examined to identify dimpling due to SMAS traction effects, with additional skin release performed as indicated. This is typically necessary in the midcheek but also commonly over the orbicularis oculi muscle above and in the neck below.
 - The midcheek release is done very conservatively to minimize the loss of beneficial skin movement resulting from SMAS tightening.

■ Anterior Neck Treatment

- The anterior neck dissection can be done either at the beginning of the procedure or after skin flap elevation and SMAS fixation. Expert opinion is mixed on this matter, although opening the anterior neck later seems to be more popular.
 - The theoretical concern in the debate is that tightening the SMAS first will restrict medial mobilization of the platysma for plication, whereas approximating the platysmal bands first will limit the degree of SMAS tightening possible.
 - Platysma bands less than 2.5 cm apart can usually be approximated in the midline whether or not this is done initially or after SMAS tightening.

- Platysmal plication becomes more challenging as the gap between the muscle edges increases. It should probably be deferred when bands are 3 cm apart or more, although dividing the muscle inferiorly improves medial mobilization considerably.



TECH FIG 6 • A. Example of full-length platysma bands. **B,C.** Repair includes approximating the free edges and dividing the muscle transversely. The muscle transection is performed low, where the muscle is thin and extends as far as 4 cm laterally. **D.** Result.

- The access incision for anterior neck dissection is placed in the submental crease although just posterior to this landmark is common practice.
- Liposuction is generally avoided although when done briefly with a small cannula can facilitate dissection.
- Subcutaneous skin elevation proceeds inferior to the cervicomental angle to the limits of visibility.
- Subcutaneous fat is conservatively removed by direct excision with care taken to leave adequate thickness and a smooth internal flap contour.
- Subplatysmal fat excision is performed following mobilization of the platysma edges in patients exhibiting an obtuse cervicomental angle.
- Submandibular gland resection and shave excision of the digastric muscles are considered only for extreme cases. The former requires considerable experience.
- The medial borders of the platysma are sutured together with interrupted 4-0 Mersilene sutures and can be reinforced with a second running layer of 4-0

Mersilene if desired (**TECH FIG 6**).

- A low transverse platysmal transection is performed bilaterally up to 4 cm, leaving at least a 2-cm lateral band of muscle intact over the sternomastoid muscle and external jugular vein.
- Correction of a “witch’s chin” deformity can be performed by defatting the ptotic chin pad.
 - De-epithelializing an ellipse of skin at the submental incision and burying it can also help smooth out chin-neck junction depressions.
 - Occasionally, a conservative elliptical skin excision can aid reduction of submental skin redundancy.

Skin Redraping and Closure

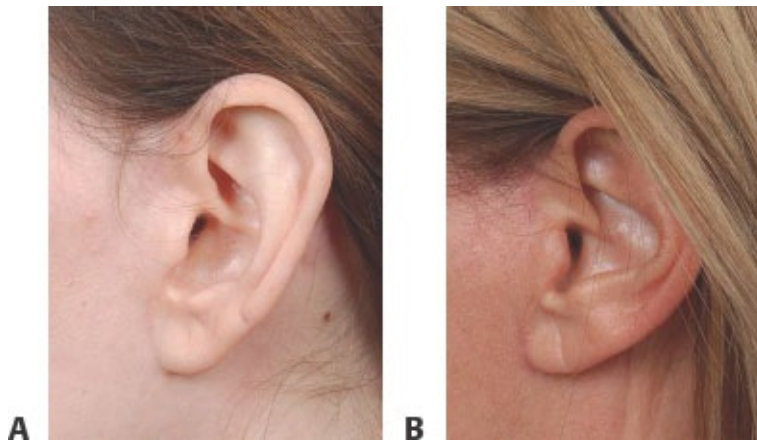
- Both sides are closed at the end of the procedure, which is preferred to sequentially closing during the procedure. This allows hemostasis to be performed once after the SMAS treatment and for the second time just prior to final closure to provide two opportunities to confirm hemostasis.
 - Additionally, venous oozing on the flap undersurface will become more apparent later as the epinephrine wears off and also because each side has been dependent while the other side is dissected. This helps prevent the development of small collections of venous blood under the flap postoperatively.
- Small-diameter closed suction drains are placed on each side if the anterior neck has not been opened. A single drain is passed all the way from one side to the opposite if the anterior neck has been opened.
- The skin is redraped in a superoposterior direction and anchored at the root of the helix with a 4-0 Vicryl suture.
 - Tension should not be excessive. Blanching of the skin flap and the appearance of traction lines should both be avoided.
- The skin is then placed on traction posteriorly and anchored with a 4-0 Vicryl suture at the highest point of the postauricular sulcus incision.
 - Excess occipital area skin is excised while maintaining the skin on tension with a hook.
 - That portion of the incision is closed with staples.
 - The remaining excess skin in the mastoid area is then conservatively trimmed so the edges appose with no gap.
- Patients with short-scar postauricular incision design do not require any of these steps but simply a minimal trim of excess skin near the lobule (**TECH**

FIG 7).

- The temporal incision is closed with clips with care taken not to raise the sideburn level. Little skin trimming is typically necessary because pre-excision has already been performed in this area.



TECH FIG 7 • Closure of a short-scar postauricular incision on the right side is shown. Using the full length of the sulcus avoids creating pleats with a shorter incision.



TECH FIG 8 • **A,B.** Examples of well-healed preauricular incisions that were properly designed and closed.

- This is the time when the need for a subsideburn incision is considered. This option prevents hairline elevation by excising a small wedge of skin.

These incisions are typically short and heal inconspicuously. They are more commonly used in secondary or tertiary cases.

- Excess skin is trimmed in the preauricular area such that the edges are closely apposed with no tension required for the final closure.
 - Tragal skin defatting for retrotragal incision closure must be done conservatively and primarily at the edges in order to avoid vascular compromise of the skin.
- A 4-0 double-armed Monderm (glycolide and e-caprolactone) barbed suture is used for intracuticular closure of the preauricular and postauricular incisions.
 - The suture starts at the lobule attachment point and runs anteriorly and posteriorly cephalad to complete closure.
 - These incisions heal extremely well if properly designed and closed (**TECH FIG 8**).
- If indicated, a subperiosteal pocket is created over the mentum and a chin implant placed.
 - It is aligned with a midline skin marking made prior to surgery with the patient in a sitting position.
 - Curvilinear implants in small and extra small sizes are suitable for most female patients.
 - The implant is secured with several 4-0 Vicryl sutures. A running 5-0 nylon is used to close the submental incision after placement of a single 4-0 Vicryl dermal suture in the middle.

Ancillary Procedures

- Ancillary procedures such as perioral dermabrasion, periorbital (**TECH FIG 9A,B**).
 - Facial fat grafting is usually done early in the procedure, soon after fat preparation is complete.
- At the conclusion of the procedure, the skin flap color is assessed. If the skin is dusky in the preauricular or postauricular area or both, nitropaste is applied prior to placement of the dressing as a one-time treatment to reduce vascular congestion (**TECH FIG 9C,D**).
- A light head dressing is placed.



TECH FIG 9 • A,B. Resurfacing of the perioral area with dermabrasion or other modalities is commonly indicated. Care must be taken regarding depth of treatment in order to avoid causing hypopigmentation. **C,D.** Nitropaste is routinely placed on the cheeks and postauricular area to speed resolution of flap congestion.

PEARLS AND PITFALLS

Patient factors

- Patients with BMI greater than 30, sleep apnea, or severe diabetes should have surgery in a hospital setting.
- Meticulous perioperative blood pressure control reduces hematoma rate.⁷
- Avoid operating on active smokers.

Incisions

- Avoid pretrichial incisions and deep temporal dissection.
- Avoid tragal blunting with meticulous inset technique.

	■ Use pretragal incisions for most men. ■ Consider short-scar technique for young patients. ■ Use subsideburn incisions to prevent hairline elevation.
Skin flap elevation	■ Avoid excessive medial cheek elevation. ■ Perform more limited flap elevation in smokers.
SMAS technique	■ Use a SMAS flap for patients needing more midface correction. ■ Use a SMASectomy in patients with prominent skeletal framework and lighter soft tissues. ■ Use SMAS plication for patients with thin tissues and secondary or tertiary cases.
Neck treatment	■ Avoid opening the anterior neck when the medial platysmal borders are very widely separated and in smokers. ■ Performing a low platysmal transection will allow the medial borders of the muscle to come together more easily. ■ Avoid excessive subplatysmal tissue resection. ■ Patients with severe cervical skin laxity should be advised initially that a secondary procedure may be necessary to achieve an optimal outcome.
Complications	■ Hematomas can be avoided with meticulous hemostasis and normotensive intraoperative blood pressure maintenance. ■ Patients at high risk for MRSA infection should be cultured by nasal swab preoperatively and treated prior to surgery if positive.

POSTOPERATIVE CARE

- Ambulation is encouraged, beginning on the day of surgery.
- Cool compresses are useful for the first 24 hours.
- The head dressing is removed on the 1st postoperative day. Drains are removed on the 1st postoperative day if the anterior neck was not opened and on the 2nd day if it was.
- Aquaphor is placed on resurfaced areas until re-epithelialization has occurred, usually by 1 week.
- Oral antibiotics can be given for up to 1 week postoperatively although proof of benefit has not been established.
- Detailed written instructions are given regarding early postoperative conduct such as talking, positioning (awake and sleeping), hygiene, and activity restrictions.
- Alcohol and excessive salt intake is discouraged for 2 weeks and smoking for

6 weeks following surgery.

- Patients are seen within 48 hours, at 6 days for suture removal, and typically at 6 weeks for further follow-up.

OUTCOMES

- Patients undergoing face-lifting and neck lifting can achieve very satisfying results when the most appropriate techniques are selected and expertly performed.
- Results in the cheek generally endure for about 10 years while ongoing aging changes in the neck become evident sooner.

COMPLICATIONS

- Massive hematomas of sudden onset require emergent evacuation.
 - Smaller or slow developing hematomas can often be managed by bedside treatment with sterile catheter aspiration and irrigation with an epinephrine-containing solution.⁸
- Nerve injury
 - Great auricular nerve injuries should be immediately repaired with fine nylon sutures and the repair buried below the platysma muscle if possible.
 - Cervical branch paresis resulting from cautery or traction injury typically resolves by 6 weeks. If afflicted patients are able to purse their lips, this confirms that the mandibular branch is intact and spontaneous resolution can be expected. Neuromodulators can be helpful to disguise the injury, but their duration of effect is typically longer than the nerve recovery period.
 - Frontal branch injury is of greater concern because overlapping innervation is not typical in this area. Neuromodulator use is more applicable in this situation. Failure of the injury to resolve may be an indication for a brow lift.
- Infection
 - Patients should be routinely seen within 24 hours after surgery and by 48 hours at the latest. Significant postoperative infections become apparent early on and require aggressive treatment.
 - Early infection is typically bilateral and presents with dusky flaps and multiple small pustules in the preauricular and postauricular areas (**FIG 1**). Intravenous antibiotics should be instituted immediately. Vancomycin is the drug of choice to cover the possibility of MRSA infection. Patients can be managed with outpatient intravenous antibiotics but must be seen daily until resolution appears certain.

- Delayed infection with *Mycobacterium fortuitum* is rare and insidious. It presents with numerous small erythematous nodules. Multiple debridements and prolonged antimicrobial therapy are typically required. Long-term outcome is generally excellent with little residual scarring evident.



FIG 1 • **A.** Early appearance of infection, which is usually bilateral. **B.** Skin slough should not be debrided until sharp demarcation is evident. Ultimately, these problems usually heal well. **C.** Parotid fistulas are heralded by cheek erythema and high output of clear drainage.

- Evolving skin slough requires frequent monitoring and treatment with topical and oral antibiotics (**FIG 1B**).
- Debridement, if necessary, is delayed until sharp demarcation is evident. Scar revision may be necessary at the appropriate time interval.
- Localized fluid masses in the cheek are usually venous collections that often not responsive to aspiration.
- Evacuation of subcutaneous fluid collection through the preauricular incision, though seemingly an aggressive approach, offers a rapid and definitive end to the problem.
- Parotid fistula is a rare complication and is heralded by persistent high drainage output, predominantly clear, and cheek erythema (**FIG 1C**). A high amylase level in the fluid confirms the diagnosis.
- A short trial of serial aspiration can be undertaken, but lack of response requires placement of a drain.

- Injecting the gland with botulinum toxin is a helpful adjunct although this can result in visible gland atrophy, presumably short term.
- Excessive scarring results from either skin loss or excessive closure tension. Both are amenable to revision provided sufficient skin laxity is present.
- Hypertrophic healing tendency is a more common problem and can usually be successfully managed with serial steroid injections.

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43 Indications and Technique for Extended SMAS Facelift and Necklift

CHAPTER

James M. Stuzin and Sammy Sinno

DEFINITION

- Facial aging is the result of many changes that occur in the skin, soft tissues, fat, and facial skeleton.
- Early attempts at surgical facial rejuvenation were skin tightening procedures.
- The works of Skoog, Mitz, and Peyronie demonstrated that soft tissue repositioning of facial fat can restore a more youthful facial contour.¹
- The primary advantage of skin and superficial musculoaponeurotic system (SMAS) flap elevation separately is greater aesthetic control in terms of repositioning facial fat independent of skin flap redraping.
- Another major advantage of an extended SMAS flap technique is the ability to restore facial shape of youth by building volumetric highlights over the anterior and lateral zygoma juxtaposed with submalar concavity.²

ANATOMY

- The layers of the face are skin, subcutaneous fat, SMAS, the muscles of facial expression, deep fascia or parotidomasseteric fascia, and the plane of the facial nerve, parotid duct, and facial vessels.
- The thickness of these layers, particularly the SMAS, varies region to region.
- The muscles of the face are all innervated on their deep surface except for the deepest muscles of facial expression, which are the mentalis, levator anguli oris, and buccinators.
- The parotidomasseteric fascia protects the facial nerve branches in the preparotid area (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient presenting with facial and neck aging demonstrates volume decent, deflation, and radial expansion of facial soft tissue from the center of the face to the periphery.
- The extended SMAS technique attempts to address these concerns by repositioning and conforming the descended facial fat to more aesthetically pleasing areas of the facial skeleton.
- On physical examination, the skin quality, elasticity, amount and location of subcutaneous fat, depth of the nasolabial fold, degree of jowling, deflation, skeletal support, malar convexity, and submalar concavity are noted.
- Platysma position and descent are similarly examined.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients are asked to bring pictures from their youth. Although patients cannot be made to look exactly like they were when younger, a similar facial shape to youth can be restored with this technique in many patients.
- Antibiotics are started 1 day before surgery and continue for 5 days afterward.
- An intertragal incision is marked along with a temporal incision and partial hairline retroauricular incision.

Positioning

- The patient is in a supine position for this procedure.
- Induction of anesthesia is achieved with midazolam and fentanyl.
- Ketamine is given for local injection, which is a mixture of lidocaine and bupivacaine.
- Propofol and valium drips are used on an as-needed basis at the discretion of the anesthesiologist.

Approach

- A submental incision just caudal to the submental crease is used for neck contouring.

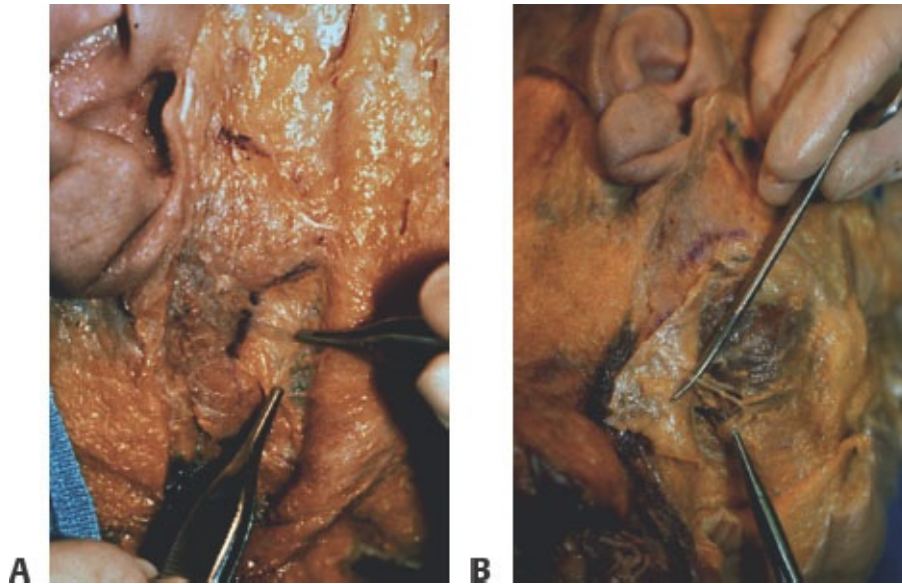


FIG 1 • A. Cadaver dissection in the parotid area showing the parotidomasseteric (or deep facial) fascia. **B.** When the parotidomasseteric fascia is reflected, the branches of the facial nerve are visualized.

TECHNIQUES

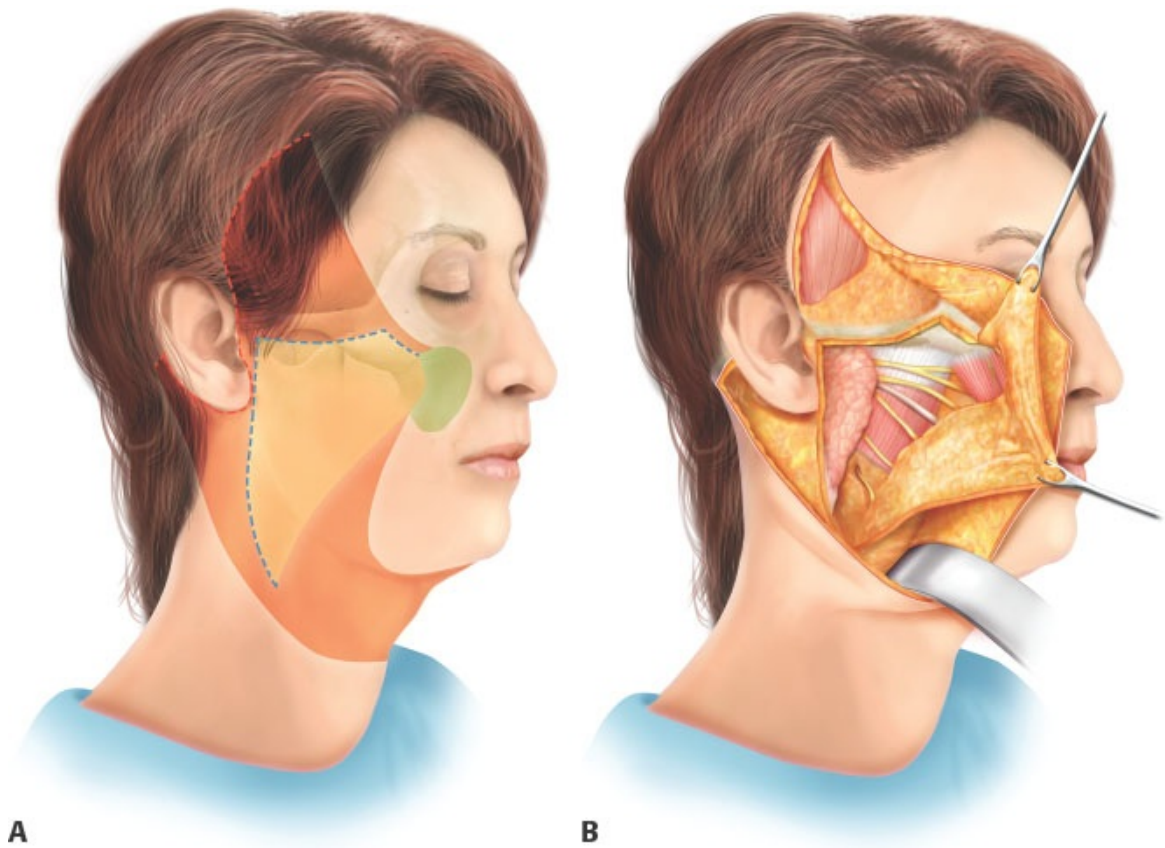
■ Extended SMAS Face and Neck Lift

Incisions and Dissection

- The partial hairline retroauricular incision is made with a no. 15 blade.
- A no. 10 blade is used in the postauricular region for the adherent fascial dissection over the adherent cervical skin ligaments overlying the sternocleidomastoid (SCM).
- The other incisions are dissected with a no. 15 blade. In the temporal area, dissection is carried deep to the temporoparietal fascia. Deep dissection here protects the hair follicles and tends to be avascular. However, the superficial temporal artery must be ligated.
- The beginning of the subcutaneous dissection over the lateral fat compartment is fascial. Using facelift scissors, the interface between the SMAS and the fat can be precisely raised with transillumination.

- When extending the subcutaneous dissection inferiorly, take care to stay superficial above the cervical fascia overlying the SCM to avoid injury to the great auricular nerve.
- As the anterior subcutaneous dissection proceeds from the lateral to middle superficial fat compartment, the dissection becomes easier as proceeding distal to the ligaments overlying the parotid.
 - Skin flaps should be dissected thinner in the region overlying where the SMAS is to be dissected to leave more fat on the SMAS for subsequent SMAS flap elevation (and avoidance of tearing).
- In the neck, the dissection is carried in the interface between the preplatysma fat and the platysma. In other words, the fat is left intact on the skin flap, whereas the platysma muscle is kept down.
- Once over the zygoma, specifically where the arch and body meet, zygomatic ligaments are encountered, and it is easy to carry dissection deep to the SMAS.
- Along the inferior lateral border of the zygomatic eminence, the zygomatic cutaneous and upper masseteric ligaments emerge, as well as perforators from the transverse facial artery.
- The zygomatic branches of the facial nerve also are superficial in this region, and inadvertent dissection deep to the SMAS in this region may produce a motor branch injury.
- Avoid dissecting thick skin flaps in this region; it may be easier to work from above and below and connect in the middle in terms of defining the proper plane of dissection when working in this region of high ligamentous density within the midcheek. This region represents the transition between the middle and malar fat compartments.
- Avoid unnecessary dissection in the area of malar bags to avoid malar edema.
- After completing the subcutaneous dissection, the SMAS is injected with local anesthetic just prior to elevation.
- The incision begins along the zygomatic arch and then extends superiorly toward the lateral malar eminence at the junction where the arch and body of the zygoma intersect (**TECH FIG 1A**).
 - It then angles up toward the lateral canthus along the lateral orbital rim, then heads inferiorly toward the anterior extent of skin undermining.
 - The lateral incision follows the lateral border of the platysma inferiorly.

- SMAS elevation begins along the lateral border of the platysma using needle tip electrocautery.



TECH FIG 1 • A. Blue dashed line shows extended SMAS flap incisions. Pink indicates the area of subcutaneous undermining. Green shows the superficial malar fat pad. **B.** The dissection is carried out past the tail of the parotid to ensure all of the retaining ligaments are released, which allows adequate SMAS mobility.

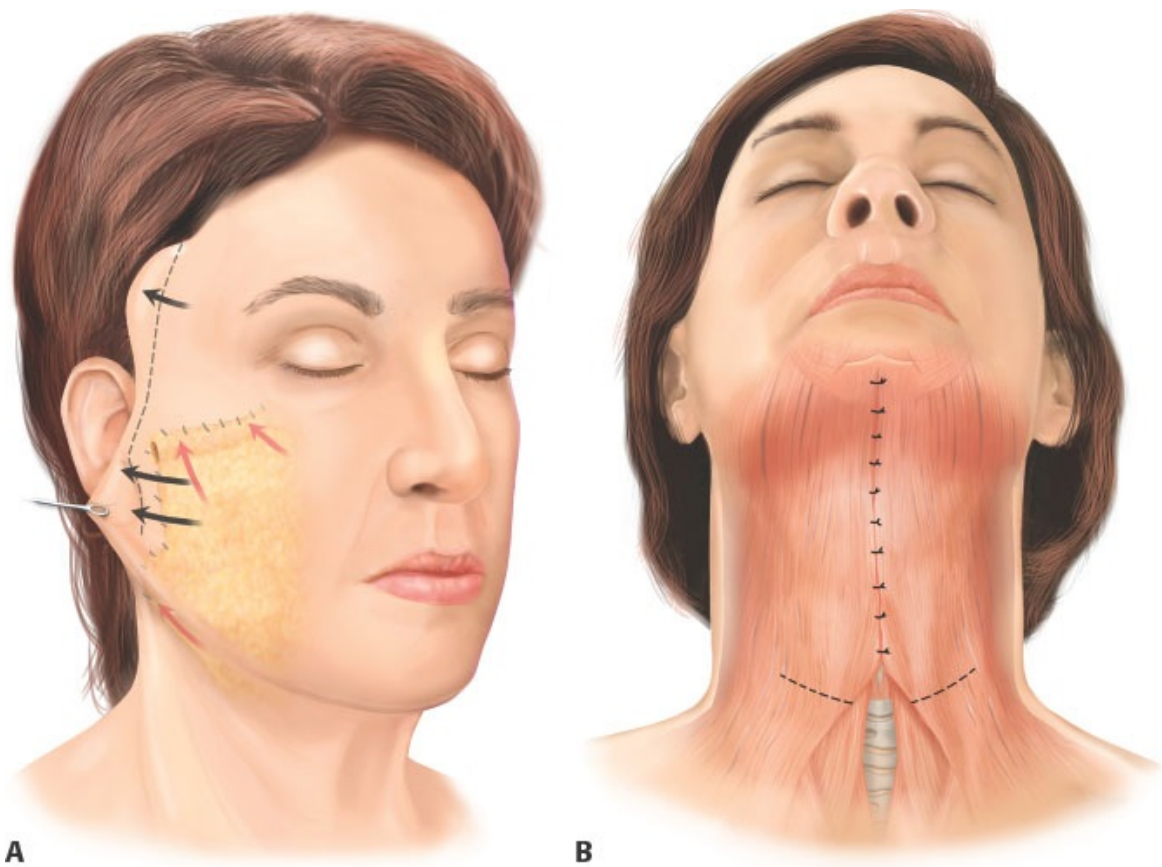
- Once sub-SMAS fat is encountered beyond the tail of the parotid, dissection can be performed bluntly, which will avoid injury to the marginal mandibular branch of the facial nerve (**TECH FIG 1B**).
- The SMAS tends to thin over the accessory lobe of the parotid, lateral to the zygoma, and in the region of the transverse facial artery perforator; care should be taken not to tear the SMAS here.

- Once the dissection has passed the retaining ligaments,³ dissection can stop, as further dissection will not provide additional benefit and can only serve to increase morbidity.

Redraping and Fixation

- A 3-0 Mersilene suture is placed vertically in the SMAS from the lateral incision along the zygomatic arch in front of the tragus to 5 to 6 cm below the earlobe. The exact vector of SMAS fixation will vary from patient to patient, but in most patients, a very vertical SMAS vector is utilized.
- Before definitive SMAS fixation, the skin is undermined a bit more anteriorly as necessary to avoid traction dimpling before the SMAS is fixated.
- The cephalic portion of the SMAS flap is rolled prior to fixation (**TECH FIG 2A**).
- 3-0 Mersilene is used for fixation in an interrupted fashion. Several sutures are placed. The endpoint is when malar convexity and submalar convexity is achieved.
- The lateral border of the platysma is fixated posteriorly to the mastoid fascia.
- Any fat irregularities on the SMAS are trimmed, particularly superiorly to avoid unsightly bulges.
- The submental incision is made 5 mm caudal to the submental crease.
- The crease is undermined, releasing the mandibular ligaments to obliterate the crease and optimize visualization.
- Subcutaneous undermining is performed.
- Preplatysmal fat is directly defatted. Subplatysmal fat in the midline is defatted on an as needed basis.
- The medial borders of the platysmal muscle are sutured with a 3-0 Mersilene suture in interrupted fashion. One or two sutures are placed caudal to the cervicomental angle and hyoid.
- The platysma is then divided inferiorly and laterally for approximately 5 cm (**TECH FIG 2B**). Care must be taken to avoid injuring the anterior jugular vein.
- After release of the platysma, additional Mersilene sutures are placed in the platysma to restore tension after platysma release and allow the platysma to conform to the floor of the mouth and thyroid cartilage.
- Meticulous hemostasis is obtained.

- Two drains are placed from the retroauricular incision extending to the base of the neck.
- The skin is carefully redraped and trimmed without any tension. The skin is usually redraped with a posterior lateral vector as opposed to the vertical vectoring of the SMAS flap.
- Skin incisions are closed with 4-0, 5-0, and 6-0 nylon sutures.
- Any fat injections are performed following the closure of the facial and submental incisions.
- A light head dressing is placed prior to arousal from anesthesia.



TECH FIG 2 • A. The SMAS flap is rolled then sutured with several 3-0 Mersilene sutures. **B.** The platysma is approximated from the mentum to the cricoid cartilage, followed by a horizontal cut on each side, which extends to the SCM.

PEARLS AND PITFALLS

Aesthetic considerations

- The major advantage of the extended SMAS flap is that it allows a building of the volumetric highlights of the upper face over the lateral zygoma, restoring the malar convexity of youth; raising the skin and SMAS as separate flaps allows a greater degree of aesthetic control in terms of vector redraping.
- Contrasting malar convexity with submalar concavity is a transition seen in youth and should be a goal in aesthetic repositioning and conforming of facial soft tissues while combating radial expansion.
- Avoid cross-cheek depression (“joker lines”); if noted intraoperatively, fat can be added to the submalar region to ameliorate. In patients with tendency to cross-cheek depressions, vertical vectors in skin flap redraping should be avoided.

Dissection

- The subcutaneous dissection is the most challenging portion of the procedure; use transillumination for precision.
- By taking advantage of knowledge of the anatomy in the cheek, one can appreciate the subcutaneous dissection as it transits from lateral to medial to superficial malar cheek compartments.
- Be careful when dissecting between the medial and malar cheek compartments; there is retaining ligamentous density, perforators from the transverse facial artery, and zygomatic facial nerve branches important for smile symmetry transiting in this area.
- If the skin flap is raised without precision, it is often impossible to raise a substantial SMAS flap.
- The SMAS flap must be raised beyond the accessory lobe of the parotid to ensure all retaining ligaments have been released.

Sequence

- Perform SMAS fixation first, followed by medial platysma suturing, then platysma release and more platysma suturing as needed

Neck

- Opening the neck offers the greatest aesthetic control in improving cervical contour.

Hematoma

- If performing dissection deep in the temporal area and exposing the superficial temporal artery, ligation is necessary to avoid postoperative hematoma.
- Always take time to ensure meticulous hemostasis.
- Perioperative blood pressure control is critical to avoid a postoperative hematoma.

Drains

- Leaving drains in longer (3–4 d) allows removal of serum that would otherwise build up and cause induration and/or bruising.
- Place drains extending to the base of the neck.

POSTOPERATIVE CARE

- The light dressing is removed in 24 hours.
- The head remains elevated at all times, but neck flexion is not permitted.
- The drains are removed at 4 days to remove as much serous fluid as possible; this reduces induration and swelling.
- Sutures in the preauricular area removed between 5 and 7 days, with remaining sutures remove on postoperative day 10.
- If patients develop induration (commonly over the platysma plication), dilute Kenalog is injected.
- Dilute Kenalog is also injected into any persistent drain sites.

OUTCOMES

- With the extended SMAS technique, natural and hopefully long-lasting results can be obtained that restore facial shaped of youth (**FIG 2**).

COMPLICATIONS

- Hematoma (most common)
- Nerve injury
- Aggressive scarring
- Edema/ecchymosis (temporary)
- Seromas
- Infection
- Contour irregularity



FIG 2 • Preoperative and postoperative views of a patient who underwent an extended SMAS facelift. Notice restoration of facial shape with malar convexity, submalar concavity, a cleaner jawline, and improvement in the appearance of the neck.

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44 Lamellar High SMAS Face-Lift

CHAPTER

Dino Elyassnia and Timothy Marten

DEFINITION

- As face-lift techniques have evolved, it has become clear that an attractive and natural appearance is not possible without diverting tension away from the skin to the superficial musculoaponeurotic system (SMAS) and platysma.
- Using the skin as the vehicle to support sagging tissue will always result in poor scars, tragal retraction, earlobe malposition, and a tight unnatural look.
- The SMAS, however, is capable of providing sustained support to facial tissues while allowing only redundant skin to be excised and wound closure under no tension. This averts a tight, “pulled” appearance and produces high-quality scars.
- A SMAS flap is a reliable and time-tested method of treating the SMAS and has been shown to provide excellent long-term outcomes. A flap is likely less destructive to the SMAS compared to various plication techniques and can be easily raised in secondary and tertiary procedures when carried out skillfully.
- The conventional “low” cheek SMAS flap elevated below the zygomatic arch suffers from the drawback that it cannot, by design, have an impact on tissues of the midface and infraorbital region. Planning the flap “higher” along the superior border of the zygomatic arch provides the biomechanical means by which a combined and simultaneous lift of the midface, lower cheek, and jawl can be obtained and avoids the need to perform a separate mid-face-lift (**FIG 1**).

ANATOMY

- The great auricular nerve is a sensory nerve derived from the cervical plexus and provides sensation to the earlobe and lateral cheek (**FIG 2**). It runs

obliquely from the posterior belly of the sternocleidomastoid muscle to the earlobe. The classic external landmark to locate the nerve is at the midbelly of the sternocleidomastoid muscle 6.5 cm inferior to bony external auditory canal.¹ The most common area of injury is where the nerve emerges from around the posterior border of sternocleidomastoid muscle.

- The facial nerve emerges through the stylomastoid foramen and is immediately protected by the parotid gland. Within the parotid, it divides into an upper and lower trunk and then into its five major branches: the frontal, zygomatic, buccal, marginal mandibular, and cervical (**FIG 3**). The branches leave the parotid gland lying on the surface of the masseter immediately deep to the parotidomasseteric fascia. Medial to the masseter, the nerve branches lie on the buccal fat pad and at the same depth as the parotid duct and facial vessels. The nerve branches then proceed to innervate the mimetic muscles on their deep surface (except for the deep layer of muscles, mentalis, levator anguli oris, and buccinator).
- The retaining ligaments of the face (**FIG 4**) are vertically oriented fibers that penetrate the concentric horizontal layers of the face and function in a supportive role.^{2,3} There seems to be two types of retaining ligaments:
 - The first type is true osteocutaneous ligaments that run from the periosteum to the dermis and are made up of the zygomatic and mandibular ligaments.
 - The second type of retaining ligaments is formed by a coalescence of superficial and deep facial fascia that form fibrous connections vertically spanning from deep structures such as the parotid gland and masseter muscle to the overlying dermis. Examples of these include parotid and masseteric cutaneous ligaments.
- The parotid cutaneous ligaments span over the entire surface of the parotid gland.
- The masseteric cutaneous ligaments are a series of fibrous bands that are found along the entire anterior border of the masseter muscle starting in the malar region down to the mandibular border.

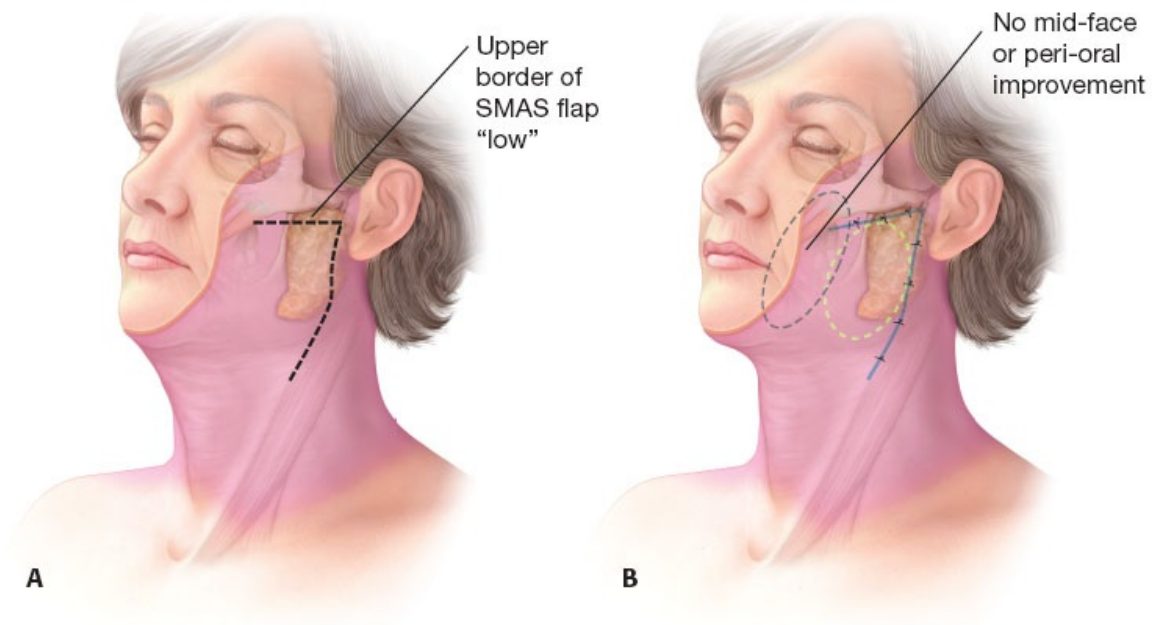
PATIENT HISTORY AND PHYSICAL FINDINGS

- A focused history should include all previous cosmetic surgery or treatments including previous face-lifts, injectables, or laser treatments.
- To determine the proper location for the temporal portion of the face-lift incision, each patient's cheek skin redundancy must be examined, and location of temple and sideburn hair noted. Assessing cheek skin redundancy requires

pinching up redundant skin over the upper cheek and measuring it. Also, the distance between the lateral orbit and anterior aspect of the temporal hairline must be measured. In youthful individuals, the distance should measure no more than 4 to 5 cm (**FIG 5**).

- If cheek skin redundancy is small and ample temple and sideburn hair is present, a temple incision can be placed within the temple scalp (**FIG 6A**).
- When the temporal hairline is predicted to shift more than 5 cm away from the lateral orbit or sideburn shifted above the junction of the ear with the scalp, a temple hairline incision should be used (**FIG 6B**). Failure to follow this plan can result in unnatural shifting or displacement of the temporal hair.

Low SMAS



High SMAS

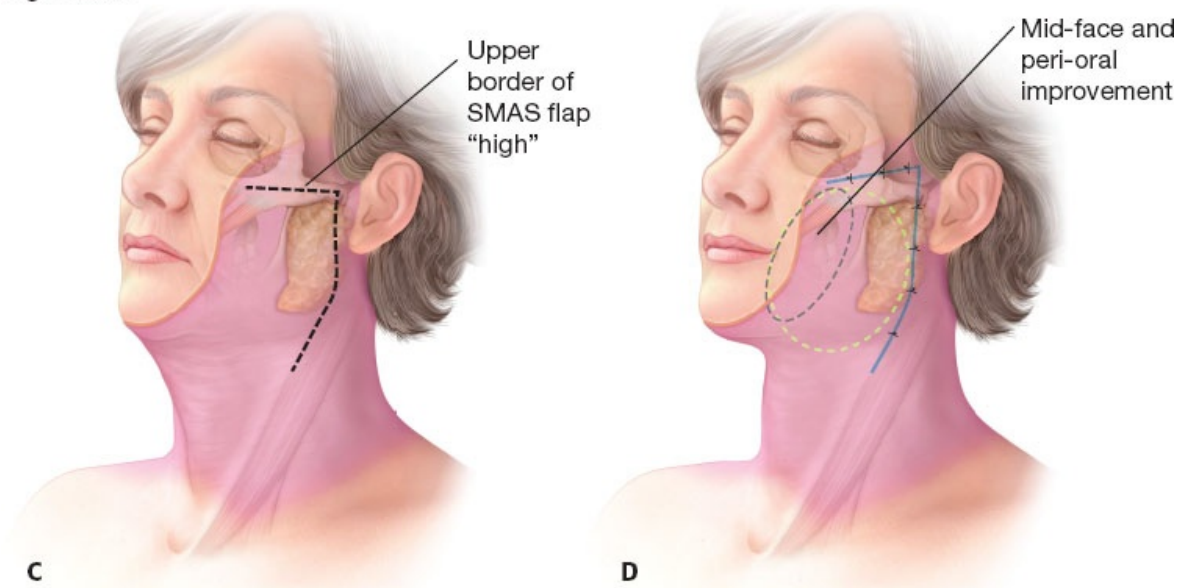


FIG 1 • "High" and "low" SMAS techniques compared. **A.** Plan for low SMAS procedure. Note that upper border of the flap lies *below* the zygomatic arch. **B.** Low SMAS flap after dissection and suspension. Area of flap effect (*green solid circle*) is limited to the lower cheek and jowl, and no improvement is obtained in the

midface, infraorbital, or perioral regions (*black dashed circle*). **C.** Plan for high SMAS procedure. Note that upper border of the flap lies over the zygomatic arch. **D.** High SMAS flap after dissection and suspension. Area of flap effect (*green solid circle*) includes not only both the cheek and jowl but the midface, infraorbital, and perioral regions (*black dashed circle*) as well.

- Like the temple, planning the appropriate location for the occipital incision requires examining each patient's neck skin redundancy. This is done like the cheek and entails pinching up tissue over the upper lateral neck and measuring it.
- If 2 cm or less of excess neck skin is present, the incision can be placed transversely, high on the occipital scalp into the hair.
- If more than 2 cm of neck skin redundancy is present, the incision should be placed along the occipital hairline but then turned into the scalp at the junction of the thick and thin hair at the nape of the neck (**FIG 7**). Failure to follow this plan can result in a visible notching of the occipital hairline.

IMAGING

- Typically, radiographs are not necessary in facial rejuvenation surgery.
- All patients should have standardized photographs taken preoperatively, and any markings made preoperatively on patients should be photographed as well.
- These photos should be used intraoperatively to help guide treatment.

SURGICAL MANAGEMENT

- A lamellar dissection for a high SMAS face-lift involves elevating the skin and SMAS as separate layers so that they can be advanced “bidirectionally” along different vectors and suspended under differential tension. Because skin and SMAS age at different rates and along somewhat different vectors, a lamellar strategy is needed to address each layer individually and to create a natural improvement.^{4,5}
- On the other hand, if a composite dissection is performed, the skin and SMAS must be advanced with the same amount in the same direction under more or less similar tension, which can result in skin overshifting, skin overtightening, and other unnatural appearances.

Preoperative Planning

- All patients undergo a preoperative physical evaluation, and patients with significant medical problems must be cleared by their internist.

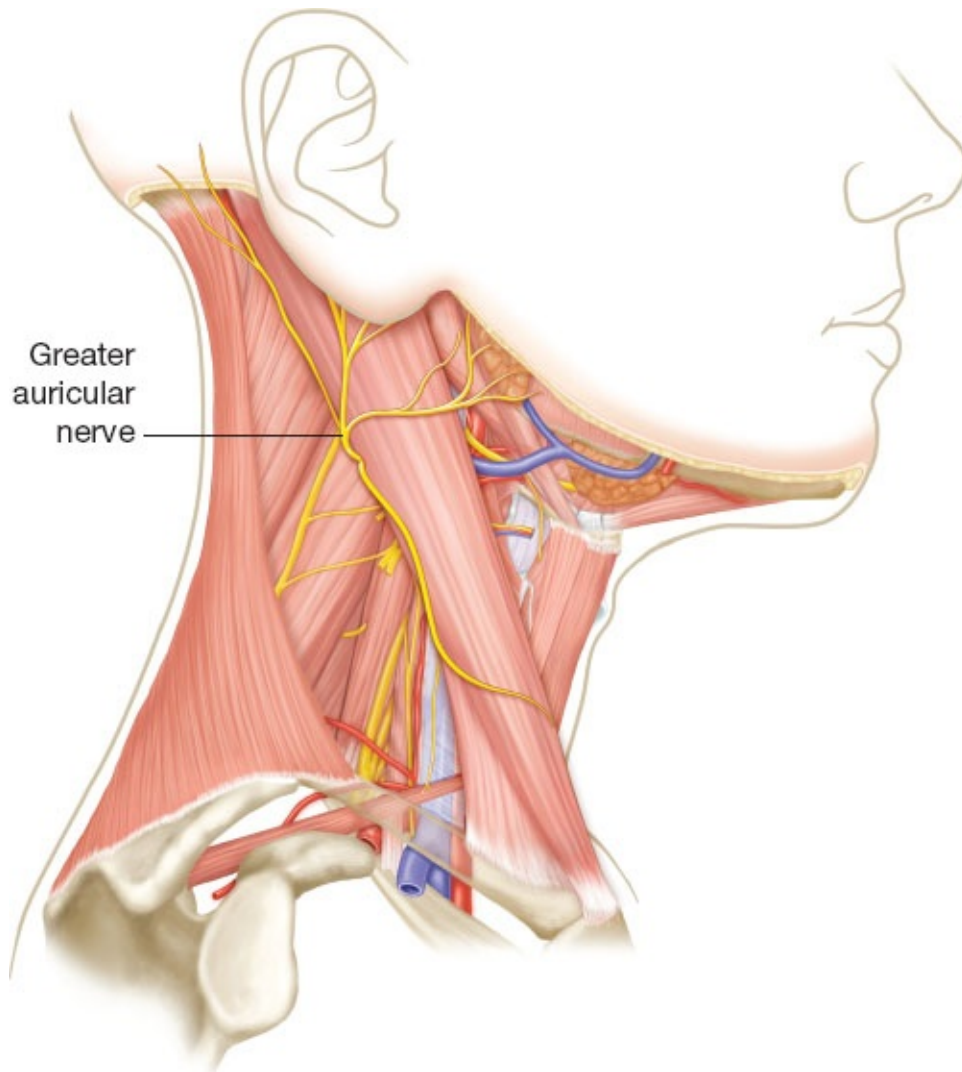


FIG 2 • The great auricular nerve can be seen lying over the midbelly of the sternocleidomastoid muscle 6.5 cm below the external auditory canal.

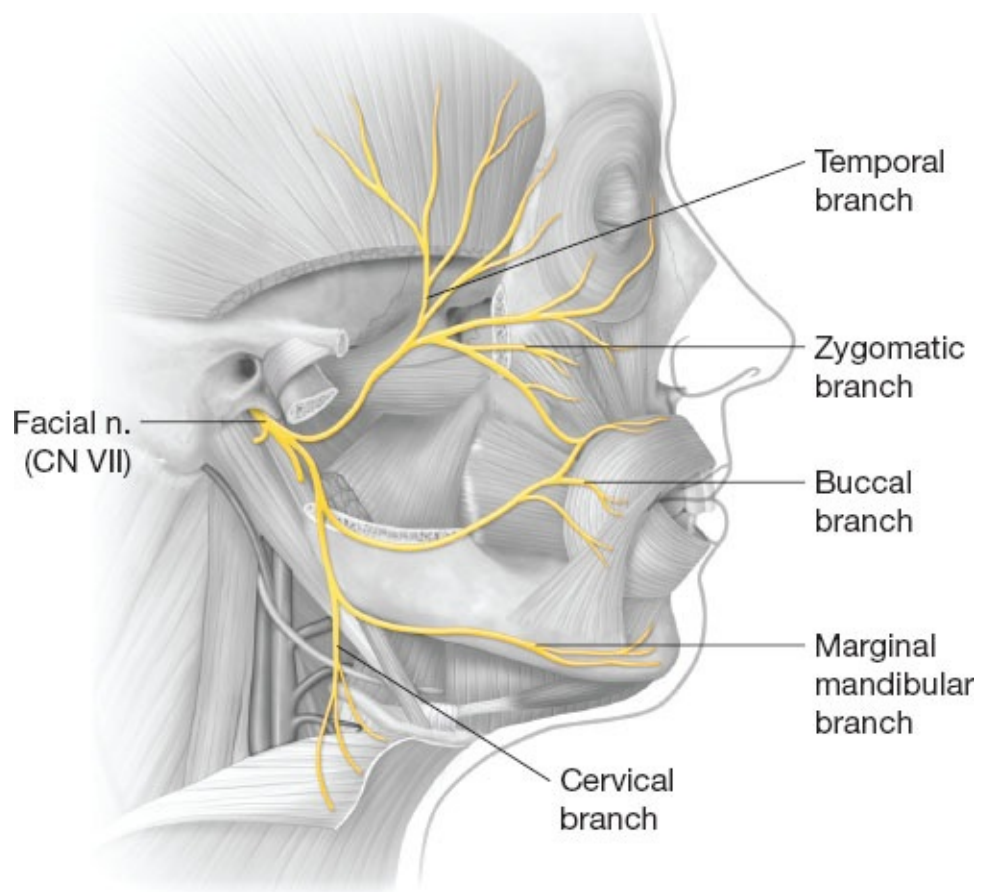


FIG 3 • The facial nerve and its branches.

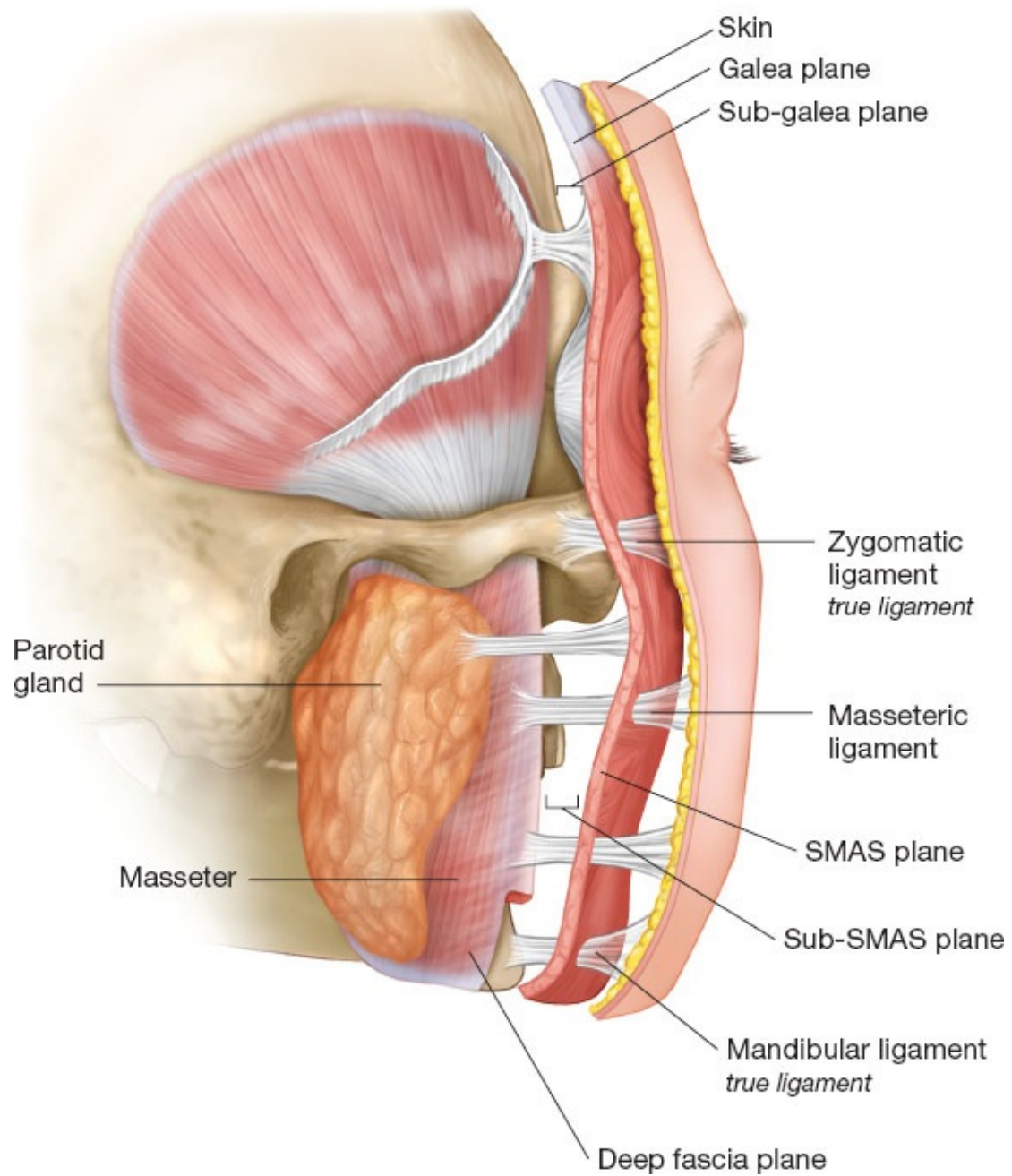


FIG 4 • The retaining ligaments of the face.

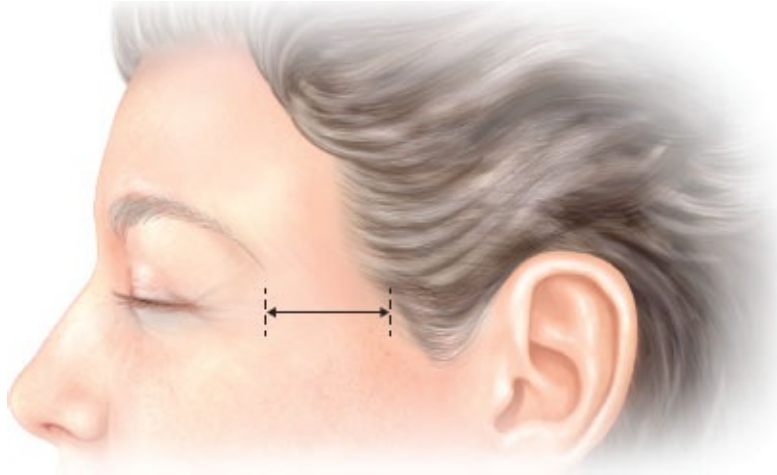


FIG 5 • Assessing “temporal skin show.” The distance between the lateral orbit and the temple hairline and how it will change with skin flap shift must be considered when planning the temple portion of the face-lift incision.

- Patients are required to avoid all medications or supplements that increase the risk of bleeding for 2 weeks prior to surgery.
- All patients who smoke are asked to quit 4 weeks before their procedure and are required to avoid smoking and all secondhand smoke for 2 weeks after. Patients who smoke or have a significant history of smoking are advised in writing that their risk of serious complications is significantly higher than is that of nonsmokers.
- Patients are instructed not to color, “perm,” or otherwise chemically treat their hair for 2 weeks before surgery and after surgery as this can result in hair breakage and hair loss.
- It is important that adequate OR time be allotted for contemporary face-lift procedures. A high SMAS face-lift, when performed in conjunction with foreheadplasty, eyelid surgery, fat injections, or other facial procedures, will often take up to 6 to 8 hours or more. It is strongly recommended that any surgeon new to these techniques consider staging a full-face rejuvenation over 2 separate days. Typically, face-lift and neck lift are performed the first day, and the patient is then kept overnight and then returned to the OR the following day or a few days later for the remainder of the procedures.

Positioning

- The majority of our face-lifts are performed under deep sedation administered by an anesthesiologist using a laryngeal mask airway (LMA).

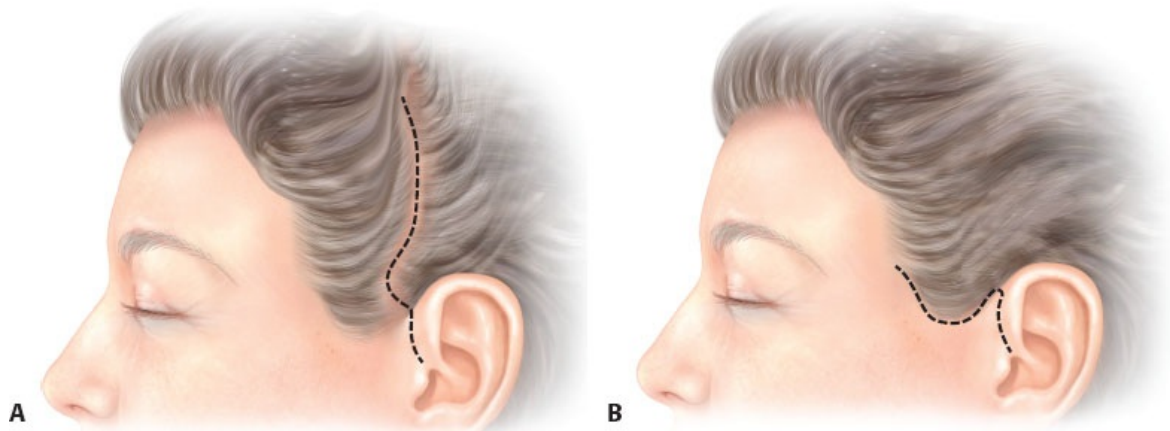


FIG 6 • A. Plan for incision on the temporal scalp. This plan is used for patients predicted to have minimal or modest shift of sideburn and temple hair after elevation of the cheek flap. It will *not* be appropriate for all patients. **B.** Plan for incision along the temporal hairline. An incision along the temporal hairline should be considered whenever objectionable displacement of the sideburn and temple hair is predicted.

- The patient is placed supine on a warmed and well-padded operating table with special effort made to ensure that all pressure points are well protected.
- The patient's lower extremities are then elevated and antiembolic pedal compression devices applied.
- Each patient receives a full surgical scrub of the entire scalp, face, ears, nose, neck, shoulders, and upper chest with full-strength (1:750) benzalkonium chloride (Zephran) solution. The head is then placed through the opening of a "split sheet" leaving the entire head and neck region including the scalp unobstructed from the clavicles up.
- The breathing circuit is draped separately from the patient by wrapping it with a sterile sheet that allows it to move during the procedure as the patient's head is turned from side to side.

- After the general prep and draping, the surface of the ear is prepped with Betadine using cotton swabs, and then Kittner “peanut” sponges are placed in each auditory meatus.

Approach

- 0.25% bupivacaine with epinephrine 1:200 000 is used for sensory nerve blocks and for infiltrating the area marked for incision. Areas of subcutaneous dissection are infiltrated with 0.1% lidocaine with epinephrine 1:1 000 000.
- All incisions on the scalp or along scalp-skin interfaces must be made precisely parallel to hair follicles to avoid injury to them that can result in pericincisional alopecia.



FIG 7 • Plan for incision along the occipital hairline. An incision along the occipital hairline should be considered whenever objectionable displacement of the occipital hairline is predicted. This incision plan protects the hairline and prevents hairline displacement.
(Courtesy of T. J. Marten, MD, FACS.)

- The prehelical portion of the preauricular incision should be made as a soft curve paralleling the curve of the anterior border of the helix. As the tragus is approached, the incision is carried into the depression superior to it.
- Next, the incision is carried precisely along the posterior margin of the tragus in a retrotragal position. This location provides for the best option for avoiding a color or texture mismatch in the preauricular skin and the best concealment of the scar.

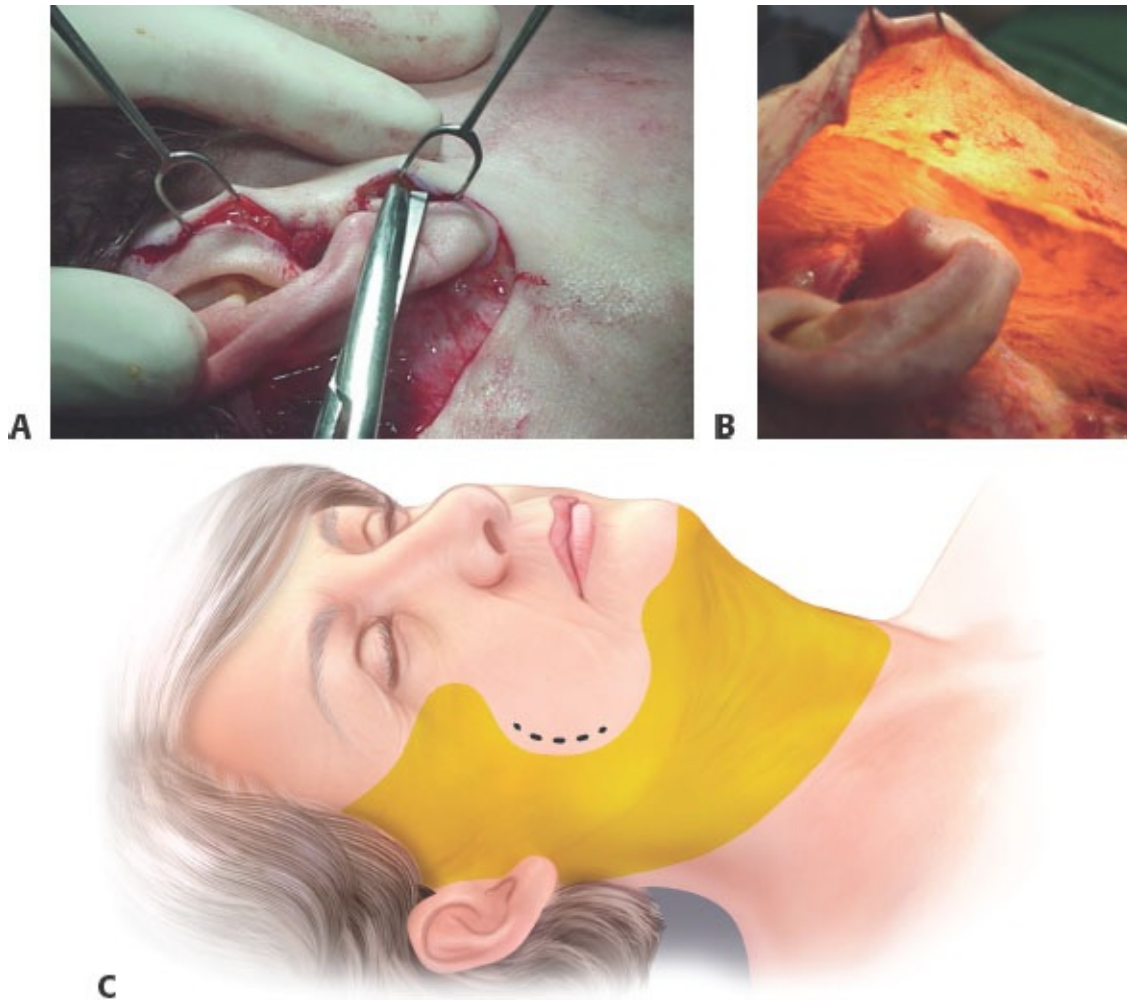
- At the inferior portion of the tragus, the incision must turn anteriorly and then again inferiorly into the crease between the anterior lobule and cheek. This creates a distinct inferior tragal border.
- The incision will then continue around the lobule and then precisely within the auriculomastoid crease. The occipital and temple portions of the incision are made according to the preoperative plan (see above).

TECHNIQUES

■ Skin Flap Elevation

- Cheek flap dissection is begun using Adson forceps and a small Kaye scissors or scalpel grasping only tissue edges that will later be excised. Once the edge is elevated, gentle traction is applied by the assistant with double-pronged skin hooks.
- Dissection is then carried out using medium Metzenbaum scissors with the surgeon and assistant working together using a “four-handed” technique (**TECH FIG 1A**):
 - The assistant applies gentle skin traction upon the skin flap directed toward the surgeon with one double-pronged skin hook in each hand, while the surgeon dissects and provides gentle countertraction toward the assistant with the fingertips of the nondominant hand.
 - As the dissection advances, one skin hook is exchanged for a small Deavor malleable-type retractor, and the remaining skin hook is used to drape the flap over the retractor.
- Proper assistance will require two team members scrubbed with the surgeon. One team member will need to be committed to providing retraction, while a second member is needed to manage all tasks related to passing of instruments.
- The assistant must be taught to not apply excessive force on delicate skin flaps, and the surgeon must avoid retracting for herself or himself as this invariably leads to rough handling of the flap.
- Skin flaps should be elevated sharply under direct vision and blind dissections avoided. This is especially important in the preauricular area and over the cheek where a deep dissection can injure the underlying superficial

musculoaponeurotic system (SMAS) and compromise its use as a flap. However, dissection too close to the posterior surface of the skin flap can result in injury to the subdermal microcirculation.



TECH FIG 1 • “Four-handed” technique. **A.** The assistant applies gentle traction upon the skin flap toward the surgeon with two large double-pronged skin hooks with one retractor held in each hand. The surgeon then dissects while providing gentle countertraction toward the assistant with the fingertips of the opposite hand. **B.** Appearance of a transilluminated skin flap in the cheek. If dissection is in the proper plane as in this case, the undersurface of

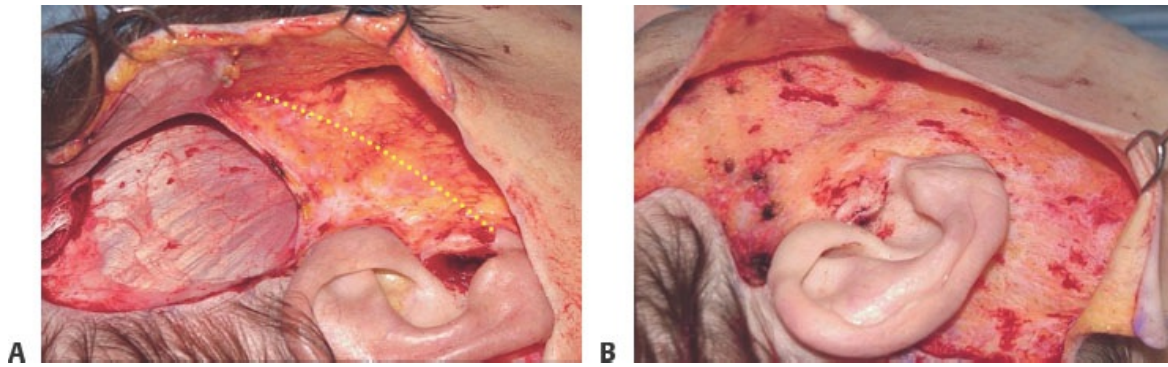
the flap will have a rough, “cobblestone” appearance to the fat. **C.** Extent of subcutaneous undermining. *Shaded area* shows area of subcutaneous undermining. Note that the platysma-cutaneous ligaments (*black dots*) are not undermined and are preserved. Preservation of platysma-cutaneous ligaments and proper elevation and fixation of the SMAS will provide support of lateral perioral tissues.

- Some visual clues can be helpful in determining the proper plane for dissection. This will require proper lighting and transillumination of skin flaps. If dissection is too deep, the underside of the flap will appear smooth and cloudy when transilluminated. If dissection is in the proper plane, however, transilluminated flaps will have a rough, “pebbled,” or “cobblestone” appearance (**TECH FIG 1B**).
- Postauricular skin flap undermining is most easily begun inferiorly if the occipital incision is made along the occipital hairline as more subcutaneous fat is usually present and the proper plane is easier to identify compared to more superiorly where less subcutaneous fat is present and the skin and fascia lie in close proximity. Once the proper plane is established, two large double-pronged skin hooks are placed by the assistant, and the dissection continues posterior to anterior rather than superior to inferior.
- As the dissection progresses toward the upper lateral neck, care must be taken to avoid injury to the greater auricular nerve.
- As dissection is continued further anteriorly into the cervical region, subcutaneous fat becomes more abundant, and the flap is easier to dissect; however, care should be taken to remain in a subcutaneous plane. Compared to the cheek skin flap that must be kept thin, a thicker layer of fat can be kept on the undersurface of the cervical flap. However, the majority of preplatysmal fat should be kept on the platysmal surface as this makes fat sculpting easier later in the procedure.
- If a submental incision is planned, completing dissection of the anterior neck skin flap will be more easily performed through it rather than the postauricular incisions. (For planning the submental incision, see “Neck Lift” chapter).

- The neck should be undermined completely in most cases, but it should not arbitrarily include the entire face (**TECH FIG 1C**). Preservation of the anterior platysma-cutaneous ligaments will create attractive and youthful appearing elevation of perioral tissue that cannot be obtained with wide undermining. If these platysma-cutaneous ligaments are divided in the perioral cheek, the SMAS effect on this area will be negated, and the benefit of SMAS elevation will be lost.
-

■ Temple Dissection

- The temple incision is made either on the temporal scalp or along the anterior hairline based on the preoperative plan.
- When on the temporal scalp, the incision is taken down to the deep temporal fascia, and the temporal hair-bearing flap is undermined in the subgaleal plane anteriorly to the lateral brow, inferiorly to the mid temple, and superiorly to the temporal line.
- The bridge of fascia (mesotemporalis) between the deep dissection in the temple and the subcutaneous dissection in the cheek can be partially divided posterior to the temporal hairline (**TECH FIG 2A**). Usually, this bridge of tissue contains the anterior branch of the superficial temporal artery and must be ligated. The frontal branch of the facial nerve lies anterior and inferior to this vessel and is safe.
- This method of dissection promotes the two planes of dissection to be joined to improve exposure.
- When an incision along the temporal portion of the anterior hairline is indicated, it is made a few millimeters within it with a slight bevel or parallel to the hair follicles.
- The incision should be made no higher than the junction of the temporal hairline with the frontotemporal hairline. If carried any higher, the scar can be visible as hair tends to grow posteriorly in this area.
- After the incision is made along the hairline, the skin flap is raised in the subcutaneous plane connecting with the cheek skin flap dissection, and no transition between planes is necessary (**TECH FIG 2B**).



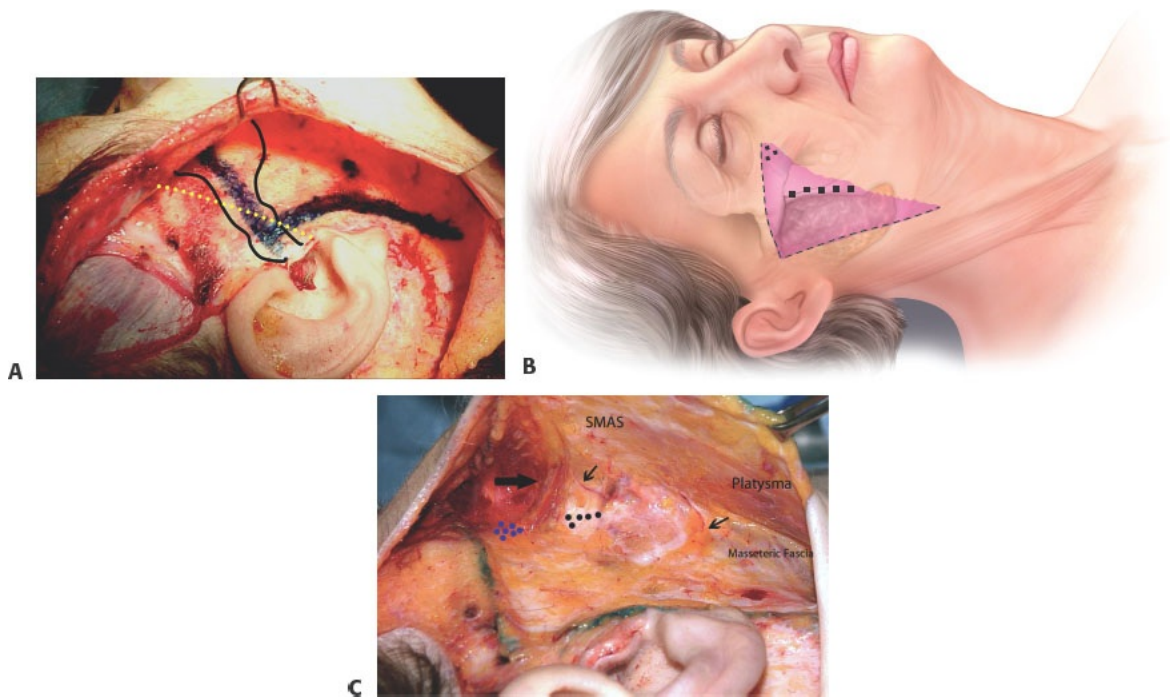
TECH FIG 2 • A. Dividing the mesotemporalis. The bridge of tissue situated between the subfascial (subgaleal) dissection in the temple and the subcutaneous dissection in the cheek can safely be divided posterior to the course of the frontal branch of the facial nerve (*white dotted line*). This bridge of tissue usually contains the anterior branch of the superficial temporal artery which must be divided and cauterized or ligated (*black arrows*). **B.** Flap dissection with hairline incision. When an incision along the temporal hairline is used, all dissection will be in a subcutaneous plane, no transition between planes will be necessary, and the superficial temporal vessels are left undisturbed, beneath the superficial temporal fascia.

■ SMAS Dissection

- To begin, markings are made for the SMAS flap. A line is marked “high” over the midportion of the zygomatic arch from the infraorbital rim to a point 1 centimeter anterior to the superior portion of the tragus. The marking is then turned inferiorly and carried over the preauricular portion of the parotid 1 to 2 cm anterior to the ear and continued inferiorly and posteriorly to the anterior border of the sternocleidomastoid (**TECH FIG 3A**).
- Flap elevation is begun by incising the SMAS over the zygomatic arch. This is done by grasping the preauricular tissue overlying the lateral arch with an Allis clamp on each side of the marked line. Metzenbaum scissors are then

used to incise along the marking medially for a few centimeters. Allis clamps are then released and reapplied incrementally as the incision proceeds medially along the marked line. A considerable amount of tissue lies over the arch, and the frontal branch will be safely beneath half a centimeter or more of fibrous fat.

- The preauricular limb of the SMAS incision is then made using the same technique, and these two incisions define the “high” SMAS flap to be elevated.
- Next, the corner of the flap is grasped with Allis clamps, and elevation is begun with scissors. Undermining should be limited in the preparotid cheek, more extensive over the zygoma and upper midface (**TECH FIG 3B**).
- Sharp scissors dissection of the flap is usually required posteriorly over the parotid where the plane between parotid fascia and SMAS is often indistinct. If a portion of the parotid fascia is incidentally raised with the SMAS flap in exposing the lobular surface of the gland, this is of no clinical significance and should be used by the surgeon as an aid in identifying the proper plane slightly more superficial.
- A distinct plane does exist, however, medial to the parotid between the SMAS-platysma and the parotidomasseteric fascia. This plane is most easily identified in the lower cheek where it can be entered by gentle blunt dissection. The parotidomasseteric fascia will be seen as a thin, shiny transparent layer covering the masseter, buccal fat, and facial nerve branches. Blunt dissection on top of this layer is safe; however, care must be taken to not violate this layer as it can result in a facial nerve injury. Sub-SMAS dissection must be carried over the anterior border of the parotid in the lower cheek to ensure the parotidomasseteric ligaments are released; otherwise, an optimal SMAS effect will not be obtained.
- As SMAS flap dissection is made medially in the upper cheek over the superior portion of the parotid and its accessory lobe, the SMAS will be seen to thin and invest the lip elevators. At this point, the dissection must be taken superficial to the superior portion of the zygomaticus major muscle. Just at the malar origin of this muscle, the zygomatic ligaments will be found. These fibrous connections between periosteum and skin must be divided, and when completely released, a dramatic liberation of the flap will be obtained.



TECH FIG 3 • Plan for “high SMAS” flap. **A.** The superior margin of flap is planned over the zygomatic arch and not below it. The frontal branch of the facial nerve (*dashed line*) lies safely posterior and deep to the majority of the dissection. **B.** Approximate extent of SMAS undermining. Complete release of the SMAS flap will require that both the parotidomasseteric ligaments (*squares*) and the zygomatic ligaments (*circles*) be released. **C.** Completed SMAS flap elevation. Inferior to the origin of the zygomaticus major muscle (*large arrow*), and superomedial to the accessory lobe of the parotid, lies the zone of transition between the zygomatic (*blue dots*) and masseteric-cutaneous ligaments (*black dots*) and the most potentially dangerous part of the SMAS dissection. Proper liberation and release of the SMAS flap usually require at least partial division of restraining attachments in this area but move the dissection into very close proximity to the zygomatic

branch of the facial nerve (*small arrow*).

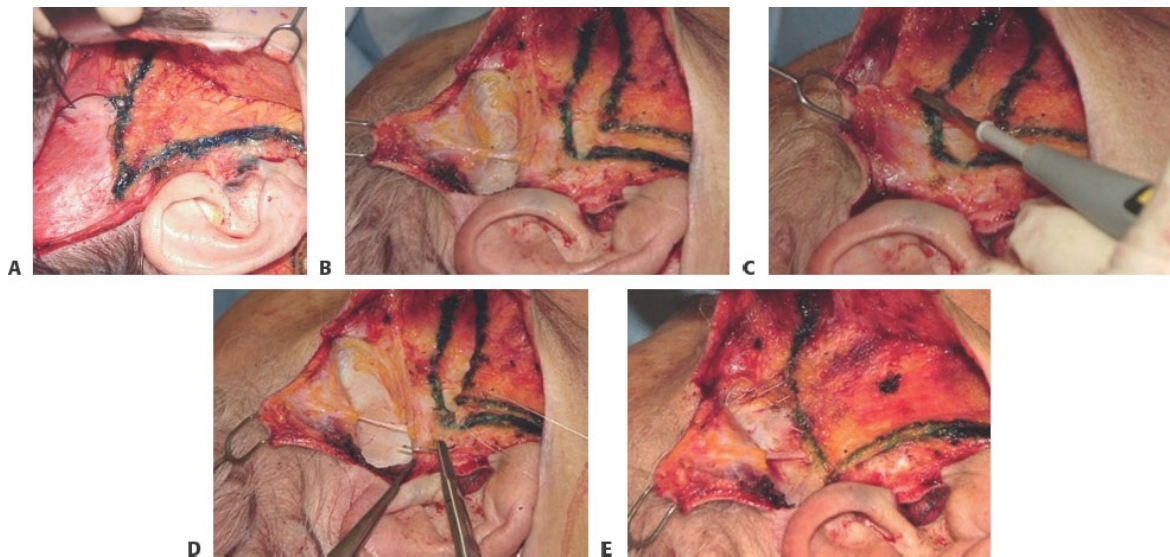
- Directly inferomedial to the origin of the zygomaticus major muscle, and superomedial to the accessory lobe of the parotid, lies the zone of transition between the zygomatic and masseteric-cutaneous ligaments and the most dangerous part of the SMAS dissection. Proper liberation of the SMAS flap usually requires at least partial division of restraining ligaments in this area but moves the dissection into very close proximity to the zygomatic branches of the facial nerve (**TECH FIG 3C**).
- In this area, it can be difficult to distinguish between nerve branches and ligamentous attachments. The inexperienced surgeon should consider using loupe magnification and the use of a disposable nerve stimulator to aid in the dissection. If confusion is encountered or the anatomy is unclear, it is better to limit dissection in this area until additional experience is gained as no amount of improvement in SMAS release is worth a facial nerve injury.
- The endpoint to the SMAS dissection is ultimately clinical and not anatomic. Gentle traction on the superior margin of the flap should produce motion at the nasal ala, philtrum and stomal angle, and elevation of infraorbital and lower eyelid tissue. If there is limited movement with this traction test, then residual tethering fibers are identified and released and the traction test repeated.

■ SMAS Suspension

- Once the SMAS flap has been properly released, it should be shifted in a posterior-superior vector parallel to the long axis of the zygomaticus major muscle. If a more vertical or posterior vector is used, the function of the zygomatic major muscle will be corrupted, and abnormal appearances during animation may result.
- The technique of flap suspension will vary depending on overall facial morphology. In most cases, no trimming of the superior margin of the flap is performed as the overlapping tissue segments of SMAS add volume to the zygomatic arch. In cases where a temporal scalp incision is used, the superior edge of the flap is anchored well over the zygomatic arch directly to the deep temporal fascia using 3-0 Vicryl or Mersilene (**TECH FIG 4A**). Suspension in this manner is greatly facilitated if the mesotemporalis is gently pushed

inferiorly as sutures are placed. No suturing is needed more medially over the zygoma or along the infraorbital rim as this can result in unnatural tissue tethering and dimpling.

- When an incision along the temporal hairline is used, the deep temporal fascia will not be exposed. In these cases, the galea can be incised just inferior to the sideburn to expose the deep temporal fascia. The SMAS can then be anchored as described above (**TECH FIG 4B–E**).
- In patients with a wide midface (ie, Asian or Slavic ancestry) or in many men, overlapping the SMAS may not be artistically appropriate. In such cases, the redundant tissue along the superior edge of the flap can be excised, and the flap margin sutured edge to edge to the superior margin of the initial incision made in the SMAS over the zygomatic arch.



TECH FIG 4 • High SMAS flap suspension with a temporal scalp incision. **A.** The SMAS flap has been advanced superiorly, the mesotemporalis pushed inferiorly, and the flap secured to the temporalis muscle fascia. **B–E.** High SMAS flap suspension with temporal hairline incision. To gain access to the temporalis muscle fascia to suspend the SMAS, the sideburn is retracted and the galea incised (**B**). Completed incision of the galea under the sideburn exposing the temporalis muscle fascia. Once incised,

a “mesotemporalis” (transition from subcutaneous plane of cheek to subgaleal plane in temple) is created (**C**). The suture has been placed through the corner of the SMAS flap. Note that the mesotemporalis is being pushed inferiorly as the suture is placed (**D**). Additional sutures have been placed between the superior margin of the SMAS flap and the temporalis muscle fascia, securely anchoring the flap. Once suspension of the SMAS is complete, the sideburn is placed back in a proper anatomic place and anchored down (**E**).

- Regardless of how the superior margin of the flap is secured, some trimming of the posterior margin of the flap is needed to facilitate edge-to-edge approximation to the posterior flap incision as overlapping here is artistically inappropriate. This should be done after the superior margin of the flap is secured.
- Unlike the superior margin of the flap, it is counterproductive to place tension on the posterior margin of the flap. Thus, the posterior margin should be trimmed conservatively to avoid a tight closure.
- To provide additional support to the anterior neck and improve contour, the excess tissue along the posterior margin of the SMAS flap can be trimmed but left attached inferiorly to the platysma and used as a postauricular transposition flap (see **FIG 1C**).
- Due to the increased length obtained with this transposition flap, it can be sutured to the immobile mastoid fascia by creating a dynamic sling that tightens the submental region when the patient looks down. This tightening is obtained because the mastoid moves superiorly with neck flexion pulling the flap up with it.
- When designing the postauricular transposition flap, the SMAS must be incised low enough so that this flap exerts its effect on the platysma below the mandibular border so as to improve submental contour.
- When using the postauricular transposition flap in conjunction with anterior platysmaplasty, the transposition flap should be secured after anterior platysmaplasty is completed or else it may not be possible to approximate the

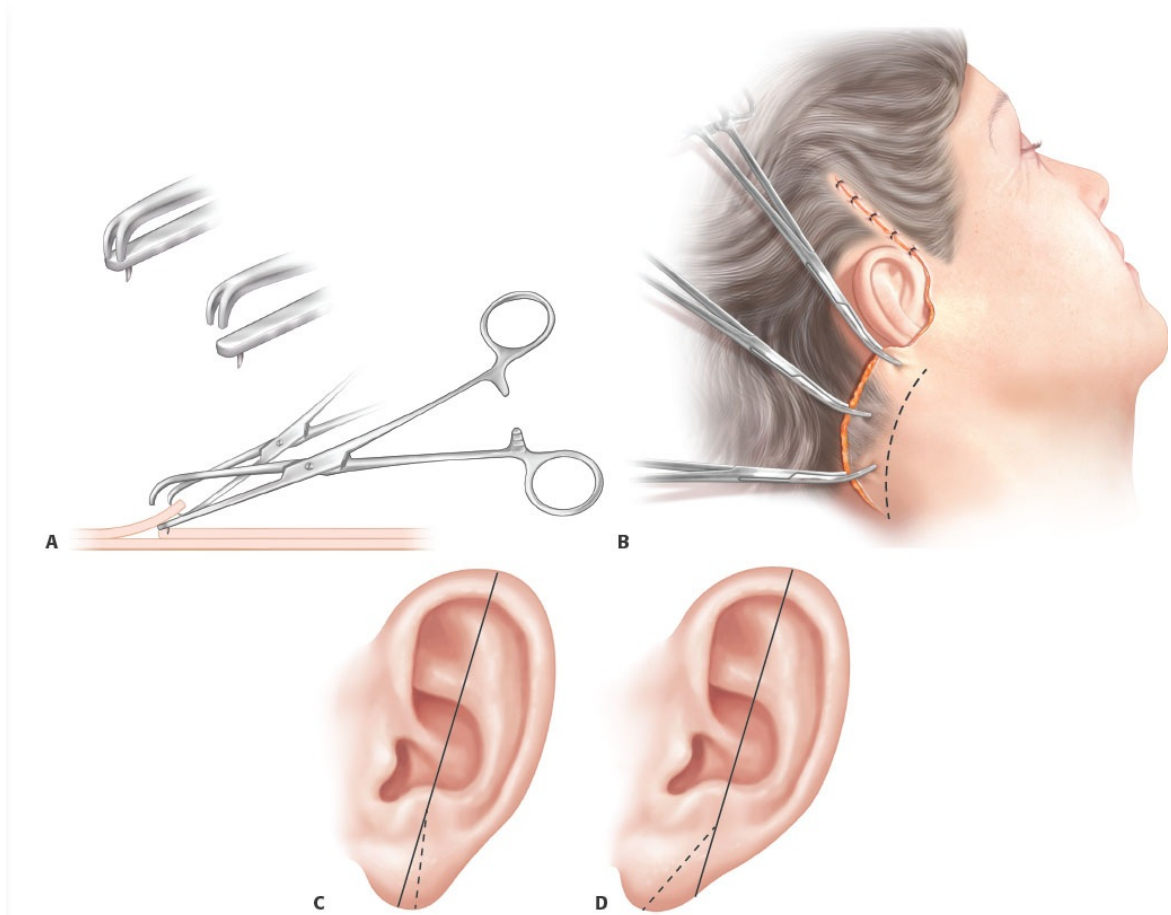
platysma anteriorly.

■ Skin Flap Repositioning, Trimming, and Closure

- Skin flap repositioning should be performed with the patient's head in a neutral position. To avoid unnatural appearances, the skin flaps must be shifted in a slightly more posterior direction than that of the SMAS. Also, it is critical to remember that the goal of skin excision is to remove redundancy and not tighten the skin flap.
- Cheek skin flaps should be shifted along a vector roughly perpendicular to the nasolabial fold, while neck skin should be shifted along a vector parallel to the mandibular border.
- There are two points of skin flap suspension that set the stage for the remainder of the closure. The first point is located just above the ear where the anterior-superior most part of the ear joins the scalp. The cheek flap is shifted and the redundancy gauged with a face-lift marker (**TECH FIG 5A**). The flap should be held under just greater than normal skin tension when the mark is made and a small "T" shaped incision made into the flap at the marked point. The flap is then anchored at this point with a half-buried vertical mattress suture of 4-0 nylon with the knot on the scalp side.
- The second key point of suspension is in the postauricular area at the superior aspect of the occipitomastoid incision. The flap is shifted roughly parallel to the mandibular border so that skin is suspended under minimal or no tension and that little or no skin needs to be trimmed from the anterior flap border that will be sutured to the postauricular incision. The flap is secured with a simple suture of 4-0 nylon; no incision into the flap is necessary.
- Once these two key sutures are placed, the flap overlying the inferior portion of the ear should be carefully divided and the lobule exteriorized. This is a key step and must be performed incrementally and with great care to avoid earlobe malposition. If this is done properly, the apex of the incision should sit snugly against the inferior most portion of the conchal cartilage.
- Skin flap trimming and incision closure should begin in the postauricular area along the auriculomastoid sulcus. Little to no skin needs to be trimmed from the anterior border of the postauricular flap, and the incision is closed with several interrupted sutures of 4-0 nylon. If it appears that a large amount of skin needs to be excised from this area, the flap has been shifted too far

anteriorly and superiorly and should be adjusted.

- Next, trimming and closure of the occipital portion of the incision are performed. If the occipital incision has been made along the occipital hairline as usually most appropriate, skin will only be excised along the posterior border of the postauricular skin flap. It is incorrect to excise any skin over the apex of the occipitomastoid incision as this will lead to a wide scar (**TECH FIG 5B**). A face-lift marker is used to gauge redundancy, and the flap is trimmed so that closure is performed under no skin tension and the wound edges about one another before sutures are placed. Closure is then performed with multiple half-buried vertical mattress sutures of 4-0 nylon and simple interrupted sutures of 6-0 nylon.
- The preauricular area is closed next. Skin flap redundancy should be carefully gauged using a face-lift marker, whereas the pretragal portion of the skin flap is held down into the pretragal hollow with an instrument by the assistant. This ensures that enough skin is present to fill the pretragal sulcus and provide natural preauricular contours. The prehelical portion of the flap is trimmed to fill in the prehelical incision without any skin tension. This is closed in one layer using interrupted 6-0 nylon or running 6-0 polypropylene.
- The prelobular (subtragal) portion of the cheek skin flap is trimmed next using a similar technique of marking excess with the face-lift marker and closed under no tension in a single layer with several interrupted 6-0 nylon sutures.
- Once the prehelical and prelobular areas have been closed, the tragal flap is trimmed. As elsewhere in the preauricular closure, the tragal flap must be trimmed with slight redundancy with the assistant holding the pretragal portion of the skin flap down into the pretragal hollow. Trimming the tragal skin flap too short is an error that will result in tragal retraction and an unnatural “chopped off” appearance. The tragal flap does not need to be thinned except at its posterior margin, and closure is done in one layer as above.



TECH FIG 5 • A. The face-lift marker. The use of a flap marker provides a reliable means for appropriate excisions of skin to be made. The pin on the lower jaw of the marker is placed near the edge of the incision. The skin flap is then draped over the lower jaw of the instrument, and the instrument is closed. On closing, the upper jaw of the instrument marks the precise position of the edge of the scalp flap beneath it. **B.** *Incorrect* trimming of postauricular skin flap. It is an error to excise any skin over (superior to) the apex of the occipitomastoid incision and shorten the postauricular flap along the long axis of the sternocleidomastoid muscle. There is no true excess of skin along this vector nor any aesthetic benefit from shifting skin in this direction. **C,D.** Proper inseting of

the earlobe. In the artistically ideal “nonsurgical” appearing ear, the long axis of the earlobe (*dotted line*) sits approximately 15 degrees *posterior* to the long axis of the ear itself (*solid line*) in the lateral view (**C**). As this angle is reduced, or the axis of the lobule shifted anterior to the long axis of the ear, an old, unnatural, and “face-lift look” is produced (**D**).

- There is nothing as telltale as an abnormal position of the earlobe, and for this reason, the lobule should be inset as the last step in the preauricular closure. The cheek flap should be trimmed and the earlobe inset so that the lobule ends up situated in a posterior and somewhat superior position even if it was in a more anterior and inferior position before surgery. This is because the long axis of a natural appearing earlobe ideally sits approximately 15 degrees posterior to the long axis of the ear itself (**TECH FIG 5C,D**). As this shifts anteriorly or too far inferiorly, an unnatural “face-lift look” is produced. Insetting the lobule in the proper position often requires the lobule be released from tethering tissue. It is then secured in two layers to protect the incision in the first few weeks from disruption when patients pull clothing, jewelry, and other items off over their heads. If the lobule is inset correctly, often skin redundancy will be present on the posterior surface of the ear. This can be easily treated by excising a triangle of skin in this area.
- If the temporal portion of the face-lift incision has been made on the temporal scalp, the incision is closed in one layer without excision of any hair-bearing temporal tissue. A small amount of cheek skin and scalp only will be excised immediately above the ear. If the temporal incision has been made along the hairline, skin only will be conservatively trimmed and closure performed in one layer without any skin tension using a combination of half-buried vertical mattress 4-0 nylon sutures and simple interrupted 6-0 nylon sutures.
- After all planned procedures have been completed, the patient’s hair is shampooed, rinsed, and detangled, and no dressings are required or applied.

Incision planning	■ Proper analysis, careful planning, and the use of an incision along the hairline when indicated can avert hairline notching and displacement without compromising the overall outcome. ■ This is particularly true of patients with marked skin redundancy and those presenting for secondary problems.
Skin tension	■ Skin was not meant to support sagging tissues, only redundant tissue is removed, and closure must be made under normal skin tension.
SMAS design	■ Planning the SMAS flap “high” over the zygomatic arch provides an improvement to the midface in addition to the jawline.
SMAS elevation	■ Key zygomatic and masseteric cutaneous ligaments must be released, but the endpoint of the dissection is clinical and not anatomic.
SMAS suspension	■ A lamellar dissection allows the SMAS to be suspended in a more superior vector compared to the skin.
Skin trimming	■ Inappropriate excision of the skin over the apex of the occipitomastoid defect is the cause of hypertrophic healing in the postauricular area.

POSTOPERATIVE CARE

- Most patients are discharged to an aftercare specialist for the first night with specific instructions. Patients are asked to rest quietly and apply ice compresses to their eyes for 15 to 20 minutes every hour they are awake for the first 3 days.
- All patients are provided oral analgesics, sleeping pills, antiemetics, ophthalmic ointment, and eye drops.
- All patients are instructed to sleep flat on their backs without a pillow or with a small cylindrical neck roll. This posture assures an open cervicomenal angle and averts folding of the neck skin flap. Patients are also shown an “elbow on knees” position to ensure an open cervicomenal angle while sitting.
- Patients begin a daily routine of showering and shampooing no later than 3 days after their procedure to help remove crusting at suture lines, keep bacteria count down, and improve overall well-being. Patients should be warned that their scalp and parts of their face may be partially numb and should be careful when showering that water is not too hot and that hairdryers are not on high settings.
- Drains are usually left in the neck until the first postoperative visit 4 to 5 days after surgery. Sutures are removed in two visits over a period of 7 days.

- Patients are asked to set aside 2 to 3 weeks to recover from surgery. If the patient is doing well, they can return to light office work and casual social activity 9 to 10 days after surgery. Patients are advised to avoid all strenuous activity during the first 2 weeks after surgery. Two to three weeks after surgery, they are allowed to begin light exercise and gradually work up their activity as tolerated by 6 weeks.
- Patients are informed that it will often take 2 to 3 months to look good in a photo or to be seen at an important social function.

OUTCOMES

- See **FIGS 8 to 10**

COMPLICATIONS

- The most common complication is a hematoma. The incidence ranges from 2% to as high as 10%. The incidence is higher in men and patients with a history of hypertension. Preoperative measures to reduce the risk include control of blood pressure and avoidance of medications and supplements that may affect bleeding. Intraoperative maneuvers include close cooperation with the anesthesiologist to rigorously control blood pressure along with meticulous hemostasis. Most hematomas will occur in the first 12 hours postoperatively so close monitoring in the recovery and over the first evening is critical. This includes proper management of pain, anxiety, blood pressure, and nausea.





FIG 8 • A. AP view. On the left, preoperative view of a woman, age 65. She has had previous upper and lower eyelifts performed by another surgeon. Note midface, cheek, and jawline laxity and poor transition from lower eyelid to malar area. On the right, same patient, 13 months after high SMAS face-lift, neck lift, hairline lowering forehead lift, upper and lower eyelifts, perioral dermabrasion, and fat transfer to the cheeks and lips. No skin resurfacing, facial implants, or other ancillary procedures were performed. The midface, cheek, and jawline have been repositioned harmoniously and in a uniform and balanced manner. Note smooth facial contours, more youthful facial shape, and absence of a pulled or a “face-lifted” appearance. **B.** AP view smiling. On the left, preoperative view of a woman, age 65. She has had previous upper and lower eyelifts performed by another surgeon. Note that but improvement along the jawline can be seen when the patient smiles, but midface ptosis and cheek laxity are accentuated. On the right, same patient, 13 months after high SMAS face-lift, neck lift, hairline lowering forehead lift, upper and lower eyelifts, perioral dermabrasion, and fat transfer to the cheeks and lips. The midface, cheek, and jawline have been repositioned harmoniously and in a uniform and balanced manner. Note soft, natural facial

contours and the absence of a tight, pulled, or “face-lifted” appearance. **C. Oblique.** On the left, preoperative view of a woman, age 65. She has had previous upper and lower eyelifts performed by another surgeon. Note sagging midface, cheeks, and jowl, and infraorbital hollowness. On the right, same patient, 13 months after high SMAS face-lift, neck lift, hairline lowering forehead lift, upper and lower eyelifts, preoral dermabrasion, and fat transfer to the cheeks and lips. The midface, cheeks, and jawline have been repositioned in a balanced and harmonious fashion. Note also the improved transition from lower eyelid to malar region. **D. Lateral view.** Preoperative view of a woman, age 65. She has had previous upper and lower eyelifts performed by another surgeon. Note sagging mid-face, cheek and jowl, and poor transition from lower eyelid to malar area. Same patient, 13 months after high SMAS face-lift, neck lift, hairline lowering forehead lift, upper and lower eyelifts, perioral dermabrasion, and fat transfer to cheeks and lips. The midface, cheek, and jowl have been repositioned harmoniously and in a balanced manner. Note also improved transition from lower eyelid to cheek.



FIG 9 • A. AP view. On the left, preoperative view of a woman, age 55. Note midface ptosis, heavy jowls, deep nasolabial lines, and poor jawline contour. She has had no prior plastic surgery. On the right, same patient, 1 year 6 months after high SMAS face-lift, neck lift, limited incision forehead lift, and upper lower eyelifts, chin augmentation, and fat transfer to the lips and cheeks. No skin resurfacing or other ancillary procedures were performed. Midface, cheek, and jowl have been repositioned harmoniously and in a uniform and balanced manner. Note smooth facial contours, more youthful facial shape and absence of a pulled or a “face-lifted” appearance. **B.** AP Frowning. On the left, preoperative view of a woman, age 55 frowning. She has had no prior plastic surgery. On the right, the same patient, 1 year 6 months after High SMAS face-lift, neck lift, limited incision forehead lift, upper and lower eye

blepharoplasties, chin augmentation, and fat transfer to the cheeks and lips. She is trying to frown in this photograph but is no longer able to do so due to muscle modification performed as part of the forehead lift procedure. **C.** Oblique view. On the left, preoperative view of a woman, age 55. Note midface ptosis, sagging cheek, and jowl, and perioral laxity. She has had no prior plastic surgery. On the right, same patient, 1 year 6 months after High SMAS face-lift, neck lift, limited incision forehead lift, upper and lower blepharoplasties, chin augmentation, and fat transfer to the cheek and lips. The midface, cheek, and jowl have been repositioned harmoniously in a balanced manner. Note smooth facial contours, more youthful facial shape. **D.** Lateral view. On the left, preoperative view of a woman, age 55. Note midface ptosis, sagging cheek, and jowl and poor transition from lower eyelid to malar area. She has had no prior plastic surgery. On the right, same patient, 1 year 6 months after High SMAS face-lift, neck lift, limited incision forehead lift, upper and lower eyelifts, chin augmentation, and fat transfer to cheeks and lips. Note restoration of attractive malar contour, improved transition from lower eyelid to cheek, elevation of perioral area, and well-defined jawline.



FIG 10 • A. AP view. On the left, preoperative view of patient, age 60. Atrophy in the infraorbital, perioral, and upper midface regions is evident. Loss of attractive facial contour due to deep tissue ptosis can be seen in the cheek, jawl and perioral regions. On the right, the same patient, 14 months after high SMAS face-lift, neck lift, closed foreheadplasty, conservative upper and lower blepharoplasty and partial facial fat injections. Fat injections have provided filling of the infra-orbital and per-oral areas. Note restoration of youthful facial shape without a tight or pulled appearance. **B.** AP smiling view. On the left, preoperative view of patient, age 60. On the right, the same patient, 14 months after high SMAS face-lift, neck lift, closed foreheadplasty, conservative upper and lower blepharoplasty, and partial facial fat injections. Note natural contour is present, even in animation. **C.** Oblique view. On the left,

preoperative view of patient age 60. Note lateral brow ptosis, mid-face ptosis and loss of youthful malar, perioral and mandibular contour. On the right, the same patient, 14 months after high SMAS face-lift, neck lift, closed foreheadplasty, conservative upper and lower blepharoplasty and partial facial fat injections. Note improved brow position, restoration of cheek fullness, improved transition from lower lid to cheek, elevation of ptotic perioral tissue, smooth jawline and improved submental contour. **D.** Lateral view. On the left, preoperative view of patient age 60. Note malar flattening, perioral laxity, ptotic jowl and cervicosubmental laxity. A prominent submandibular gland can also be seen. On the right, the same patient, 14 months after high SMAS face-lift, neck lift, closed foreheadplasty, conservative upper and lower blepharoplasty and partial facial fat injections. The protruding portion of the submandibular gland has also been excised. Note the restoration of cheek fullness, elevation of ptotic perioral tissue, smooth jawline and improved cervicosubmental contour. The face has a natural appearance, and all scars are well concealed (Courtesy of T. J. Marten, MD, FACS).

- A less common complication is skin slough which is most commonly the result of tension. Skin slough resulting from underlying circulatory problems includes smoking, acne scarring, and diabetes.
- One of the most devastating complications after a face-lift is facial nerve injury. Fortunately, the incidence is less than 1%. The facial nerve branches most at risk include the buccal, frontal, and marginal mandibular.

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CHAPTER SMASectomy Face-lift

Steven M. Levine and Daniel C. Baker

DEFINITION

- Surgery is the standard for addressing descent and laxity in the aging face.
- SMASectomy refers to the removal of a strip of superficial musculoaponeurotic system (SMAS) at the junction of the fixed and mobile SMAS.

ANATOMY

- Relevant anatomy is the recognition of the difference between fixed and mobile SMAS. The location of this intersection varies between patients but is roughly found on a diagonal line connected the earlobe to the lateral canthus (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Beyond usual history and physical findings to indicate a patient for a face and neck lift, the specific question to note is whether the patient has a full, wide face or a thinner face that could benefit from SMAS being “stacked” on itself to add volume.
- The authors refrain from providing specific guidelines or measurements as the ultimate decision is a function of the aesthetic sense of the surgeon.

SURGICAL MANAGEMENT

- Surgery should be performed in an accredited operating room.
- SMASectomy can be performed under local anesthesia with or without sedation or general anesthesia.

Preoperative Planning

- Consideration should be given as to whether the surgeon believes the patient will benefit from an SMASectomy (removal of tissue) or a plication (imbrication of tissue); however, this decision can also be made intraoperatively.
- The rest of the surgery is planned like any other biplanar face-lift.

Positioning

- The patient is supine on the procedure table.
- Usually, the head of bed is slightly elevated.
- The authors prefer to sit for maximum stability.

Approach

- An incision pattern is chosen (either preauricular or intratragal).
- The skin is elevated in the subcutaneous plane after infiltration with local anesthesia with epinephrine.
- The SMAS is identified, and a plan is created.

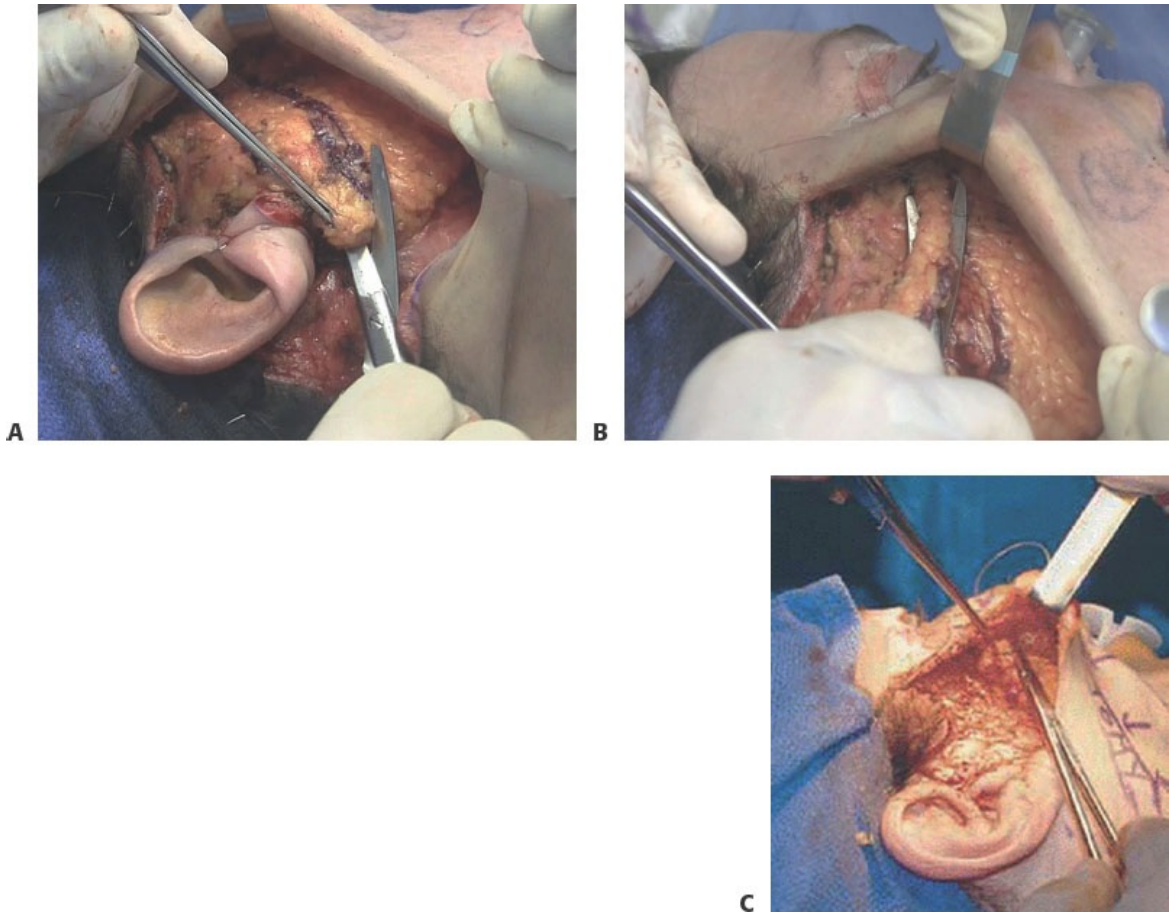


FIG 1 • Although the junction of the fixed and mobile SMAS may vary from patient to patient, it is generally found near a line from the lobule of the ear to the lateral canthus.

TECHNIQUES

■ SMASectomy

- The area of superficial musculoaponeurotic system (SMAS) to be removed is best visualized after performing a lateral platysmaplasty.¹
- A lateral platysmaplasty is performed by elevating the SMAS/platysma flap just in front of the sternocleidomastoid (SCM) muscle.
 - The author prefers to do this with a Bovie electrocautery, though any means is acceptable.
 - The flap should be elevated to allow the SMAS/platysma to freely rotate in a chosen vector cephalad and lateral to the surgeon's desires.
- The flap is then fixed to mastoid fascia with 3-0 PDS sutures and can be reinforced to the fascia of the SCM.
- Once this flap is secured, a bunching of tissue can be noted, usually near the angle of the mandible.
- This bunching is the most proximal component of the SMAS to be removed as a dog-ear, which is in effect the SMASectomy (**TECH FIG 1A**).
 - Scissors can be used to spread beneath the SMAS to safely develop the plane over the parotid fascia.
 - Care must be taken to protect the facial nerve until the distal portion of parotid fascia.
- To achieve a midface elevation, the SMASectomy must be carried out to the midface, beyond the parotid fascia (**TECH FIG 1B**).
- The edges of fixed and mobile SMAS are reapproximated using buried interrupted 3-0 PDS sutures (**TECH FIG 1C**).
- The SMAS is trimmed of irregularities.
- The skin flap is redraped, trimmed, and sewn under no tension.
- The authors prefer to leave drains, but this understandably varies between surgeons.



TECH FIG 1 • **A.** Tissue bunching near the angle of the mandible indicates a common starting point for the SMASectomy. **B.** The SMASectomy is carried anteriorly past the parotid tail to achieve midface elevation. **C.** The edges of the SMAS are reapproximated.

PEARLS AND PITFALLS

Technique	■ Doing lateral platysmaplasty prior to SMASectomy will set up the exact starting point for the SMASectomy.
Facial nerve	■ Facial nerve is protected over the parotid gland. Beyond the parotid gland, it is important to note the depth of your excision and take extra caution.

Suturing

- Always bury knots to avoid seeing or feeling bumps through the facial flap.
- Always check the facial surface after each SMAS suture. If too much or too little movement, remove suture and replace.

POSTOPERATIVE CARE

- Cool packs are also used to reduce swelling.
- Strict blood pressure control is enforced postoperatively.
- Patients are instructed to avoid lifting or bending for 2 weeks.
- The authors prefer to place patients in a face and/or neck compressive dressing for at least 4 to 6 hours after surgery but up to 24 hours.
- Drains are usually removed at 48 hours.
- All patients are seen by the surgeon the following morning and then again multiple times over the following week.
- Sutures are usually removed at 1 week.

OUTCOMES

- SMASectomy can achieve excellent jawline contour and midface elevation.
- The amount of midface elevation is dependent on how high the SMAS is operated on during the procedure.

COMPLICATIONS

- Bruising and hematoma are the most common complications.
- Hematomas in males are twice as common as they are in females.
- Facial nerve injury should be exceedingly rare with these techniques and should only be temporary when observed.

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46 Indications and Technique CHAPTER for Deep Plane Face-lift

Thomas A. Mustoe

DEFINITION

- Facial aging is caused by relaxation and descent of the deeper layers of the face, including the subcutaneous fat, and the underlying superficial fascial layer that encompasses the superficial muscles as well as the skin.
- Because these layers are closely adherent, the deep plane face-lift recognizes the principles that in order to properly correct the relaxation and descent, all layers must be addressed with complete release, even tension, and avoidance of excess tension on the skin to achieve reliably a natural appearance.

ANATOMY

- The critical anatomy to understand is the makeup of the superficial musculoaponeurotic system (SMAS) or fascia, which is a thin fascia layer just deep to the subcutaneous fat. It is contiguous with the platysma muscle and is continuous to the inferior surface of the orbicularis oculi muscle.
- There are retaining ligaments that are collagen attachments passing from the SMAS to the deeper tissues, which in the midface region are just lateral to the origin of the zygomaticus major muscle (the zygomatic retaining ligaments) and in the region of the superior most portion of the platysma muscle (masseteric retaining ligaments).
- In the neck, the retaining ligaments or deep attachments are along the posterior border of the SMAS, just anterior to the greater auricular nerve, and run obliquely down the neck where they have attachments to the sternocleidomastoid muscle. There are also attachments in the region of the anteroinferior portion of the parotid gland.
- For the SMAS to be completely mobile, all of these attachments must be

divided.¹

- Immediately underneath the SMAS are the branches to the facial nerve.
- In the neck, the cervical branch comes out from the parotid and up into the platysma anterior to the retaining ligaments at the anteroinferior edge of the platysma and can be safely preserved while fully releasing the SMAS.¹
- The marginal mandibular branch is well protected underneath the masseteric fascia.
- The major buccal branch runs just above the Stensen duct and is underneath the very thin deep fascia overlying the buccal fat pad, which is more easily penetrated, meaning that nerve is less well protected but easily seen.
- The zygomatic branch runs underneath the zygomaticus major muscle and thus is protected.
- Finally, the frontal branch becomes more superficial above the zygomatic arch. Dividing the SMAS at the level of the arch protects the frontal branch while still allowing elevation of the malar fat pad with the SMAS if the dissection extends below the inferior edge of the orbicularis oculi muscle to preserve innervation to that muscle.

NATURAL HISTORY

- The aging process with relaxation of the SMAS and fat as well as overlying skin is progressive, with loss of collagen fibers and increasing viscoelasticity of the overlying skin.^{2,3}
- However, the aging process is genetically highly variable. In patients of Asian background, for instance, the skin is somewhat thicker, and the retaining ligaments are stronger, and so development of jowls and malar descent is less pronounced with age.
- In addition, there is loss of facial fat with age particularly around the mouth, and to a variable degree in the cheeks, so that facial rejuvenation usually includes some degree of volume restoration, particularly around the mouth.
- Fat also accumulates in the submental region, and in some patients (small percentage), a true excess accumulates in the jowl region, which when combined with loss of fat in the prejowl perioral area accentuates the loss of a firm jawline.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The characteristic features of the aging face are development of jowls, malar descent, loss of facial fat, accumulation of submental fat, relaxation of the

orbicularis muscle and overlying skin, and relaxation of the platysma muscle and overlying skin.

- In many patients, the relaxation of tissues is more pronounced in one region than another.

NONOPERATIVE MANAGEMENT

- Although nonoperative management of the aging face with fillers and fat, as well as noninvasive and minimally invasive techniques using laser, focused ultrasound, and radiofrequency, has increased greatly, there are limitations.
- More advanced relaxation of the skin and deeper tissues can only be corrected with a face-lift.

SURGICAL MANAGEMENT

- The author performs a deep plane rhytidectomy in all patients who are candidates for face-lift, even those with changes limited to the neck and/or jowls, without significant changes in the midface.
- What does vary is the extent of the dissection. In patients who are mainly concerned about the neck and jowls with early aging changes, undermining and release of the SMAS in the midface can be quite limited without extending out to the masseteric and zygomatic retaining ligaments, but a deep plane dissection is still done in the neck.
- The incisions can also be limited with a postauricular incision limited to the sulcus, and the preauricular retrotragal incision also limited. With a more limited dissection, the recovery period is accelerated.
- Although the submental fat, including subplatysmal fat, and superficial release of skin attachments is always addressed with fine handheld cannulas through two or three 2-mm incisions, as the author's experience has increased, a submental incision is never done except in the occasional patient 6 months postoperatively who is bothered by persistent platysmal bands in the postoperative period.
- The main steps of the procedure are as follows:
 - Make a retrotragal incision with superior and postauricular extensions.
 - Raise a superficial skin flap, which is elevated above the zygomatic arch to the lateral border of the orbicularis oculi muscle, and below that over the lateral cheek over several centimeters.
 - Incise the SMAS at the level of the zygomatic arch, extending out to the orbicularis oculi muscle and in front of the ear. A portion of the SMAS is then

elevated lateral to the retaining ligaments.

- The postauricular dissection is carried out deep to the superficial fascia over the investing fascia of the sternocleidomastoid muscle.
- The sub-SMAS dissection is then extended in a wide arc in front of and inferior to the ear until all of the retaining ligaments are released, and the SMAS slides easily along with the overlying skin.
- Deep sutures are placed anchoring and repositioning the SMAS.
- Excess skin and SMAS are cut, and final skin suturing is complete.
- The neck is addressed as described above with blunt undermining and liposuction with the use of fine cannulas.
- The other side is performed in identical fashion.

Preoperative Planning

- The patient should be medically cleared for surgery, including a recent normal electrocardiogram.
 - If the electrocardiogram is abnormal, consideration of specific cardiac clearance may be indicated including other studies such as a stress test.
- Hypertension must be well controlled, and clonidine is routinely given as a preoperative dose of 0.1 to 0.3 mg to minimize postoperative hypertension, which is a major risk factor for postoperative hematoma.
- Smoking must be stopped at least 3 weeks prior to surgery, and if there is any concern about smoking cessation, strong consideration should be given to measuring nicotine levels.
- The risks are discussed prior to surgery including hematoma, infection, skin necrosis, facial nerve injury, and the limitations of loss of elasticity, which means that some relaxation of tissues is inevitable in the postoperative period and must be viewed as a limitation rather than a failure of the procedure.

Positioning

- Positioning is straightforward in the supine position, with the head slightly elevated (10 degrees is sufficient) to enhance venous return.
- The head should be placed on a flat surface for easy turning.

Approach

- Usually, a full-length incision as described below is used, but when aging changes are early, the incision can be limited behind the ear to the postauricular sulcus and in front of the ear to the level of the superior edge of the tragus and

to the top of the ear without extending underneath the sideburn.

TECHNIQUES

■ **Modified Deep Plane Rhytidectomy with Midface Elevation and Elimination of Submental Incision**

Markings and Incisions

- The markings are consistent whether male or female and can be shortened for short scar technique or face-lifts with more limited dissection and less tissue rearrangement.
- The essential steps are an extension above the helix into the hair directly vertically; a V-shaped extension along the sideburn, stopping at the anterior point where the hair is no longer growing down to hide the incision; a retrotragal incision, taking care to have sharp angles rather than curves at the superior edge and incision of the tragus; and a postauricular incision that curves up high on the mastoid and into the hairline at approximately the superior edge of the tragus (**TECH FIG 1A**).
- In a subcutaneous plane, the cheek skin is elevated to the lateral edge of the orbicularis oculi muscle (**TECH FIG 1B**).
- An incision is made through the SMAS at the level of the zygomatic arch (high enough to allow the midface to come up as part of the SMAS) and in front of the ear, and the SMAS elevation is begun extending to the extent of the previous subcutaneous dissection (**TECH FIG 1C**).

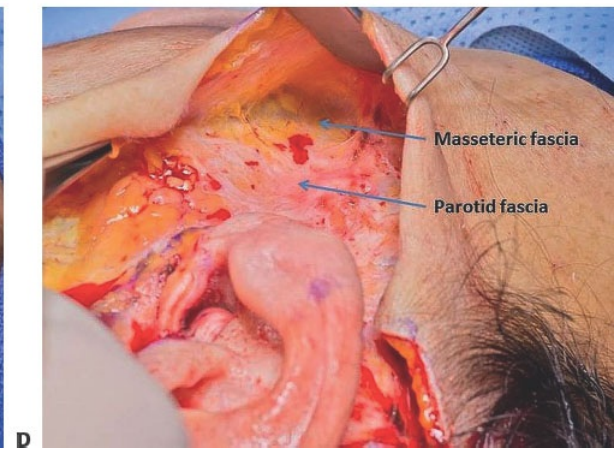
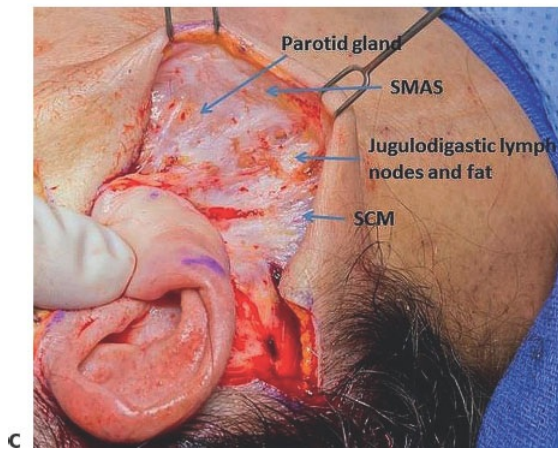
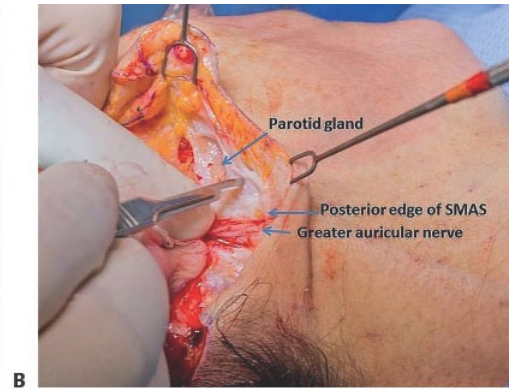
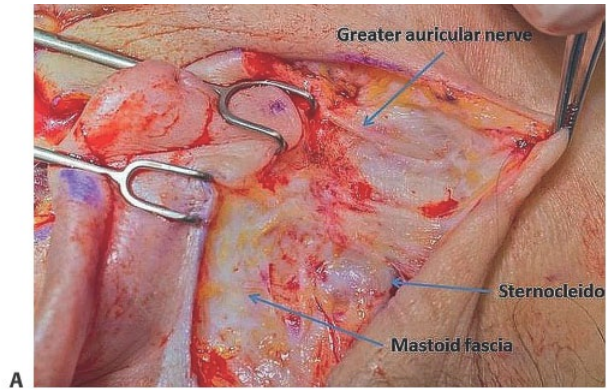
SMAS Dissection

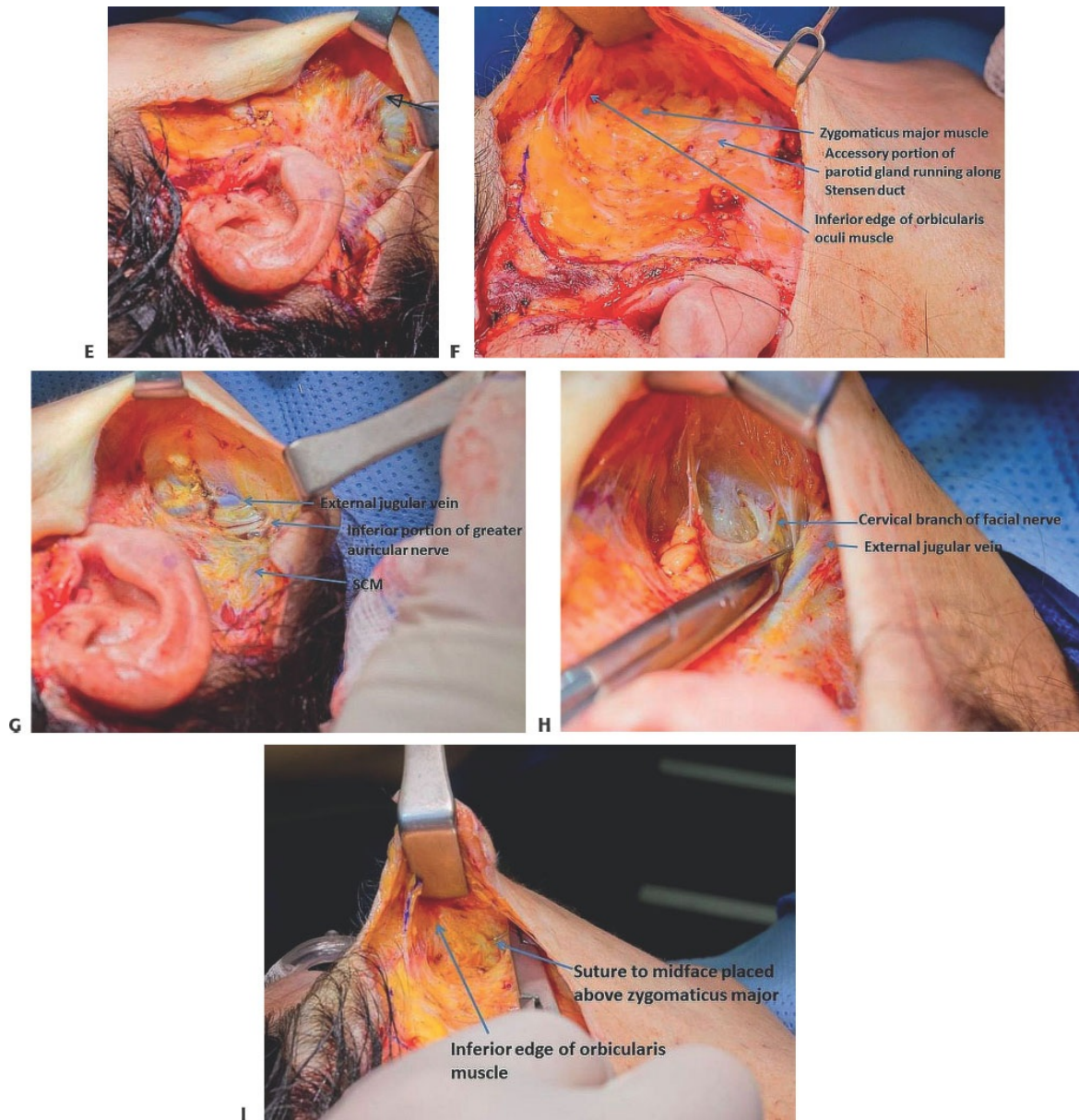
- The dissection is begun behind the ear below the level of the superficial fascia and further inferior with exposure of the vestigial postauricular muscle, the greater auricular nerve, and the investing fascia of the sternocleidomastoid muscle (**TECH FIG 2A**).
- Sharp dissection is carried around the ear lobule, connecting the anterior sub-SMAS dissection with the posterior dissection and taking care to elevate the entire SMAS, which extends to the greater auricular nerve.
 - The parotid fascia is exposed, and the SMAS is clearly demarcated by its dense collagen content (**TECH FIG 2B,C**).

- The sub-SMAS dissection is then extended beyond the parotid gland anteriorly to expose the masseteric fascia. This is easily done and is avascular except for an occasional perforating vessel (**TECH FIG 2D,E**).



TECH FIG 1 • **A.** Skin markings for face-lift. **B.** Subcutaneous dissection over the cheek. **C.** Initial SMAS elevation over the cheek.





TECH FIG 2 • A. Initial dissection in the neck with exposure of greater auricular nerve. **B.** Initial elevation of SMAS over parotid and extending posteriorly. **C.** Exposure of parotid fascia with transition zone between parotid and SCM. **D.** Completion of dissection over parotid with exposure of masseteric fascia. **E.** Inferior view of completion of dissection over parotid extending posteriorly. The *arrow* is indicating the retaining ligament at the anterior border of the

parotid gland. **F.** Extension of sub-SMAS dissection over the midface with exposure of zygomaticus major and inferior edge of orbicularis oculi. **G.** Extension of sub-SMAS dissection in the neck with inferior release of posterior edge of SMAS and exposure of external jugular vein and inferior course of greater auricular nerve. **H.** Another view of extension of sub-SMAS dissection in the neck with visible collagen attachments (retaining ligaments) at anteroinferior edge of the parotid. **I.** Exposure of cervical branch of facial nerve coming out of anteroinferior edge of parotid and coursing superficially up into deep surface of platysma.

- The dissection is carried superiorly over the midface, with release of the zygomatic and masseteric retaining ligaments, exposure of the zygomaticus major muscle, and extending under the inferior edge of the orbicularis oculi muscle so that elevation of the SMAS includes the cheek mass and tightens the orbicularis muscle (**TECH FIG 1F**).
- The dissection is then extended beyond the anteroinferior edge of the parotid with release of the neck retaining ligaments, and exposure of the external jugular vein, and inferior path of the greater auricular nerve (**TECH FIG 1G,H**).
- With release of the attachments beyond the parotid that allow full mobilization of the neck, the cervical branch of the facial nerve can sometimes be seen coursing up into the platysma (**TECH FIG 1I**).
- Inferiorly, the dissection is variable, depending on the extent of neck mobilization, but generally goes to where the greater auricular nerve crosses the posterior border of the SCM and over the investing fascia of the entire SCM posteriorly.

Closure and Completion

- The closure begins with placing two 3-0 PDS sutures from the midface area (above the zygomaticus major into inferior edge of orbicularis muscle and then back to temple) (**TECH FIG 3A**).
- Next, the corner of the SMAS is sutured in a posterosuperior direction into

deep tissues just above the anterior helical rim (**TECH FIG 3B,C**).

- The skin is rotated superiorly and, depending on skin laxity, may have a more posterior vector than the SMAS that is rotated primarily in a superior direction.
 - Excess skin is excised avoiding a dog-ear at the anterior edge of the sideburn, and closure is begun (**TECH FIG 3D**).
- Posteriorly, two or more sutures are placed from the SMAS-skin composite flap up to the mastoid (**TECH FIG 3E**).



TECH FIG 3 • A. Placement of suture above zygomaticus major into inferior edge of orbicularis and

into fatty tissues of the cheek mass. **B.** Suture placed into superolateral corner of elevated SMAS, which will be elevated in a primarily superior vector. **C.** Suture from corner of SMAS being tied down to deep tissues at superoanterior edge of the ear. **D.** Closure at sideburn after trimming of excess skin, which has been rotated in a superoposterior direction. **E.** Posterior suture behind the ear grasping SMAS as part of SMAS-skin composite layer, which will be tied posterosuperiorly to mastoid fascia. **F.** View after suturing of SMAS is complete and initiation of postauricular suture line along the hairline with separate cut into the hairline. **G.** Trimming skin anteriorly along helix and tragus. Skin is under no tension. **H.** Completed skin closure. **I.** Submental liposuction being performed after the first side of the face is closed, through stab incision.

- Skin closure is initiated posteriorly. The length of the incisions is controlled by cuts into the hair with superior rotation and an extension of variable length along the edge of the hairline (**TECH FIG 3F**).
 - In selected patients with minimal neck laxity, a short scar technique is utilized by confining the scar to the postauricular sulcus and accepting some pleating.
 - The skin is then trimmed and defatted along the tragus, and the posterior skin is excised (**TECH FIG 3G,H**).
 - Submental liposuction is carried out with a handheld fine cannula, and subplatysmal liposuction is also performed when there is significant subplatysmal fat.
 - The cannula is used to undermine the entire neck down to the sternal notch and separate skin-platysma attachments. This step is always performed even if there is no submental fat (**TECH FIG 3I**).
 - The same procedure is then carried out on the contralateral neck and face.
-

PEARLS AND PITFALLS

Skin elevation over the cheek

- When there are significant crow's-feet, extending dissection over orbicularis to orbital rim will reduce wrinkles.

SMAS dissection, midface

- In patients with minimal midface descent, the dissection can be limited to the posterior edge of the zygoma to minimize swelling and avoid more dangerous parts of the dissection.

SMAS dissection of the neck

- The extent of the dissection is dictated by the amount of neck laxity, but it is important to capture all of SMAS in the region of the ear lobule to aid in closure.

Hemostasis

- It is important to get hemostasis several times prior to closure to minimize hematoma risk.

Closure

- All tension should be borne through the SMAS. Skin closure should be absolutely tension-free.

POSTOPERATIVE CARE

- Drains can be used, though the author does not find them necessary. The area of potential concern for the accumulation of fluid is behind the ear, and this problem is minimized by the use of several sutures behind the ear from the neck flap to the mastoid area to help in fixation and minimize dead space (ie, they serve as quilting sutures).
- The head is elevated with an extra pillow or by placing a cushion underneath the mattress at the head of the bed.
- The head is wrapped overnight as a convenience to absorb fluid and blood leaking through the incision line, and then the patient is instructed to shampoo and wash the area. The incisions have ointment applied to them twice daily until the sutures are removed 7 days after surgery. The preauricular sutures are absorbable.

OUTCOMES

- The final outcome is about 3 months after surgery, when virtually all swelling is resolved and tissue relaxation has occurred. The aging process of course continues but at its normal, gradual pace.

- An estimate to patients is that the tissue relaxation that existed preoperatively in the neck and face will be corrected by 80%, which of course varies depending on the intrinsic viscoelastic properties of the individual patient's skin and SMAS.
- Some patients (5% to 10%, skewed toward older patients with more advanced tissue relaxation and greater viscoelastic properties) will not be fully satisfied with the results and elect to undergo an early second face-lift (less than 2 years after the first one).³

COMPLICATIONS

- Hematoma is the most common complication and occurs about 1% of the time, virtually always within the first 24 hours and usually due to labile blood pressure in the postoperative period that is more common in the elderly, and is minimized but not completely prevented by the use of clonidine preoperatively.
- Infection is very rare and has been localized to an area of wound breakdown. This has been minimized by postoperative wound hygiene.
- Marginal skin necrosis behind the ear has been a rare occurrence, easily treated with local wound care, due to the enhanced blood supply of the dissection deep to the superficial fascia and preservation of SMAS skin attachments (composite dissection).
- Although the facial nerve is at risk, I have had no permanent injuries. Neuropraxia of the cervical branch of the facial nerve (pseudomarginal mandibular paralysis) has occurred in 1 of 200 patients earlier in my experience but with much less frequency in the last 10 years with full understanding of the anatomy of the cervical branch. I have had one incidence of neuropraxia of the buccal branch due to thermal injury and one case of frontal branch neuropraxia in my personal series of more than 1500 cases. All cases of neuropraxia have resolved within 2 to 3 months.

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CHAPTER Isolated Neck Lift

Alan Matarasso and Sammy Sinno

DEFINITION

- The appearance of neck aging can occur as early as the late 30s.
- Differences in the quality of skin above and below the mandible can contribute to neck aging independently. The neck changes may occur prior to facial aging, which can be particularly disconcerting to patients.
- Recent advances allow the neck to be rejuvenated in a spectrum of methods that include neck lift, minimally invasive surgical procedures (submentalplasty and liposuction), and nonsurgical methods depending upon the indications and goals.
- The most comprehensive treatment of the aging neck requires an isolated neck lift.

ANATOMY

- The youthful neck is characterized by a distinct mandibular border with the relative absence of jowls, subhyoid depression, visible thyroid cartilage bulge, distinct border to the sternocleidomastoid (SCM) muscle, and a cervicomental angle between 105 and 120 degrees (**FIG 1**).¹
- The aging neck is manifested by attenuation of retaining ligaments from the medial platysma, which leads to platysma edge shortening and banding. Additionally, there can be accentuation of preplatysmal or subplatysmal fat, laxity of skin with texture changes, hypertrophy of the digastric muscles, and hypertrophied and/or ptotic submandibular glands.

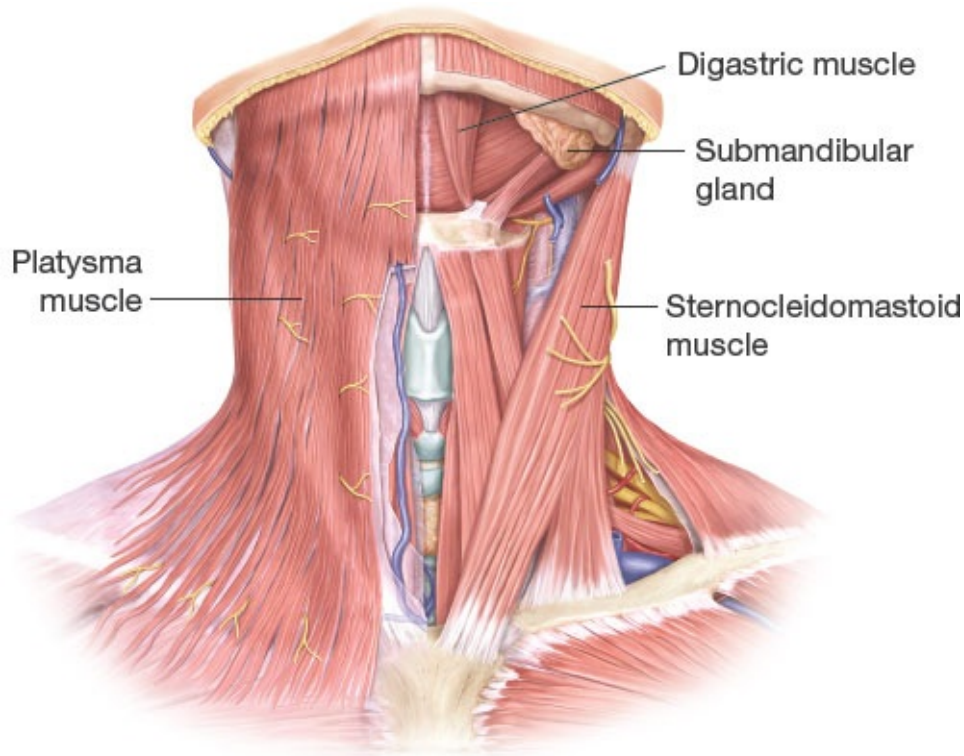


FIG 1 • Relevant neck anatomy.

- Treatment options vary based on individualized patient assessment of key anatomic landmarks and treatment goals.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Ideal candidates for an isolated neck surgery procedure are those who want to address neck rejuvenation without the need to concomitantly treat the midface with a face-lift.
- During the initial consultation, it is essential to evaluate the patient's goals and expectations and to reconcile them with the surgeon's evaluation and treatment plan. Furthermore, it is important to discuss relevant procedures that may play a role in enhancing the result of neck surgery, such as chin augmentation, buccal fat pad removal, salivary gland treatment, skin quality enhancement, or midface treatments.^{2,3}
- When evaluating the patient and discussing the surgical options, the patient should be educated on the algorithm to discuss the surgical treatments available to treat the various soft tissue components of the aging neck.
- More advanced cases of the aging neck are treated with a neck lift that encompasses liposuction as indicated and submentalplasty along with wide

skin flap undermining, elevation, and skin excision.

- Less severe cases can be treated with minimally invasive surgical procedures, including liposuction for fatty necks or submentalplasty that applies liposuction and midline platysma muscle treatment.
- Nonsurgical methods including Ultherapy (Ulthera, Mesa, AZ), among other “tightening” energy-based systems, Kybella (Allergan, Weston, FL), and Botox (Allergan, Weston, FL) can be used to improve the appearance of the neck skin, fat, and muscle, respectively, albeit with a different result than a surgical procedure.

IMAGING

- No imaging other than routine preoperative clearance imaging is needed.

SURGICAL MANAGEMENT: NECK LIFT

Preoperative Planning

- A traditional neck lift encompasses improvement in the area from the jawline down to the clavicle.
- The quality and quantity of skin are noted.
- If patients desire improvement in the jowls as well as the neck, an “extended” neck lift can be considered, which addresses the same areas as neck surgery and incorporates improvement in the jowl region. This is accomplished by extending the neck lift incision slightly cephalically toward the tragus, which allows jawline skin advancement, SMAS tightening, and jowl liposuction.

Positioning

- The patient is placed in the supine position for this procedure.

Approach

- The isolated neck lift procedure is performed under general anesthesia administered by an anesthesiologist.
- Perioperative antibiotics are used, and TED stockings or sequential compression devices are placed for the entirety of the case.
- Antibiotic ointment is placed in the nostrils and cotton soaked in Betadine is placed in each ear canal.

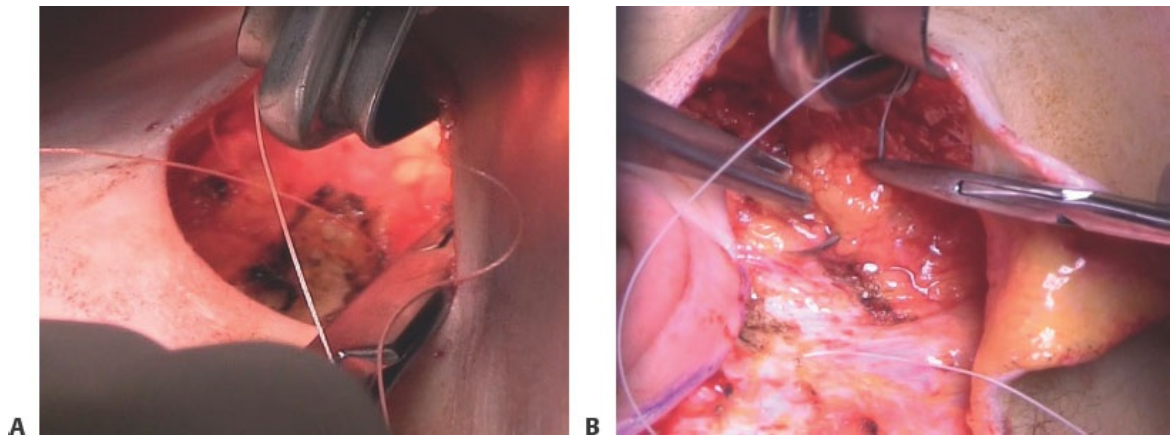
TECHNIQUES

■ Isolated Neck Lift

- The surgical field is infiltrated with local anesthetic solution containing 1 mL of 1:1000 epinephrine, 100 mL of 1% lidocaine, and 200 mL of normal saline.
- After waiting for the effect of the local anesthetic, we begin with liposuction of the subcutaneous fat as indicated. A 2.4-mm Mercedes cannula is used for the neck liposuction, and a 1-8 mm Mercedes cannula is used for the jowl area. Additional liposuction is conducted with a spatula tip cannula.
- After completion of liposuction, a submental incision is made just above or below the natural submental crease if treatment of the platysmal muscle is indicated (submentalplasty).
- Wide undermining of the neck skin is performed with the aid of a lighted fiber-optic retractor and the assistant placing countertraction on the skin.
- Medial platysmal bands are identified. In patients who have loose redundant or hypertrophic anterior platysmal bands, a strip of excess platysmal muscle is excised.
- After the platysmal band is resected, submuscular fat can be identified and treated in patients who will benefit from a reduction. This is carried out by directly excising small amounts of fat and melting the remainder with a ball tip electrocautery.
- Attention is then returned to the platysmal muscle. Various options for the repair of the midline platysmal muscle repair have been described.⁴ The muscle is approximated with interrupted 3-0 Mersilene (Ethicon, San Lorenzo, PR) sutures (**TECH FIG 1A**).
- Once the anterior neck treatment is completed, the patient's head is turned and the surgery continues on the right side of the neck where the incisions are made. The skin flaps are incised and undermined under direct vision sharply and with face-lift scissors. The neck is completely undermined from side to side by connecting the dissection with the prior submental plane.
- The lateral border of the platysma is located and evaluated.
 - If the platysma is lax or redundant, it is undermined with sharp and blunt dissection at least 3 to 4 cm below the angle of the mandible, back cut, and

sutured to the sternocleidomastoid (SCM) fascia with 3-0 Mersilene suture (Ethicon, San Lorenzo, PR) while avoiding placing excessive tension on the midline repair.

- In other cases, the platysma is plicated to the SCM at 3 to 4 points including the lower superficial musculoaponeurotic system (SMAS) for jowl improvement (**TECH FIG 1B**).



TECH FIG 1 • A. Plication of medial platysma borders.
B. Suturing of the lateral border of the platysma to sternocleidomastoid fascia.

- Final hemostasis is achieved by electrocautery, and Jackson-Pratt drains (Cardinal Health, Dublin, OH) soaked in Betadine are placed and brought out through the wound and sutured.
- Excess skin is elevated, advanced, redraped, and excised so as to optimize the result and preserve the integrity of the hairline.
- The hair-bearing region is closed with staples, and the area between the hair-bearing region and postauricular incision is closed with half-buried absorbable sutures.
- The postauricular crease is closed with 3-0 nylon sutures; the lower preauricular area, if opened for an extended neck lift, is closed with a 5-0 nylon suture.
- The submental region is the last area inspected for hemostasis after closing both sides of the neck incision. The submental incision is closed with a subcuticular 5-0 Prolene and 5-0 interrupted nylon (Ethicon, San Lorenzo, PR).

- Antibiotic ointment is placed on the wounds. A three-layer face-lift dressing consisting of gauze and SurgiNet (Won Industry, Gyeonggi-do, Korea) is placed on the patient.

PEARLS AND PITFALLS

Neck aging

- Occurs in conjunction and often more rapidly or can be more apparent than facial aging.
- It is a result of changes in the skin, platysma, and fat of the neck. Other structures such as the digastric muscle and submandibular glands can also contribute to neck aging.
- Nonsurgical treatments offer improvement when directed at the appropriate layer of tissue.
- Liposuction and submentalplasty can produce significant results in patients with appropriate skin.
- The most comprehensive treatment of the aging neck is a surgical neck lift.

Medial platysma treatment

- After any platysma redundancy is removed, it is repaired in the midline, which, when completed, resembles the Eiffel Tower.
- The platysma is back cut at the level of the cricoid cartilage.
- The hyoid fascia can be incorporated as a potential means of reducing recurrent platysma banding, which can be a formidable issue.

Lateral platysma treatment

- If the platysma is lax or redundant, it is undermined at least 3 to 4 cm below the angle of the mandible, back cut, and sutured to the SCM fascia.
- In other cases, the platysma is plicated to the SCM at three points including the lower SMAS for jowl improvement.

POSTOPERATIVE CARE

- Attempts should be made to keep the neck extended in a semisniffing position to avoid skin flap ischemia.
- Dressing and drains are removed on the first postoperative day, and suture lines are treated with antibiotic ointment. The drain tracts are “milked” of excess fluid.
- Staples and sutures are removed within the first 10 days.
- Return to normal activities usually occurs progressively from 2 to 6 weeks.

During that time, patients should avoid excessive sun exposure or nonsurgical facial treatments.

- Firm scars are treated with massage and occasionally ultrasound therapy, as these tend to resolve with time.

OUTCOMES

- Isolated surgical treatment for the aging neck is a viable option for a subset of patients who either do not require or may not wish to have a concurrent treatment of the midface. Optimal aesthetic results can be achieved by tailoring the procedure to the underlying anatomy and expectations of the patient (**FIG 2**). Ultimately, judicious patient selection and education will provide for the greatest satisfaction in patients undergoing isolated neck lift surgery.

COMPLICATIONS

- Complications can vary depending on the extent of the procedure that is performed. Most frequent complications include seroma and hematoma.
- Although skin necrosis is infrequent, it can be a significant complication when it occurs. We use dimethyl sulfoxide or nitroglycerin ointment for these issues.
- Facial nerve injuries are less common than in face-lifts but can occur. Most often, the marginal mandibular branch and the cervical branch are placed at risk during the procedure if the overlying platysma muscle is breached; this is more frequent in secondary surgery. It has a tendency to occur when defatting just lateral to the submental incision caudal to the mandible.



FIG 2 • Preoperative (**A**) and postoperative (**B**) views of patient who underwent isolated neck lift. Note the drastic improvement in cervical contour.

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CHAPTER Subplatysmal Neck Lifting

Dino Elyassnia and Timothy Marten

DEFINITION

- A well-contoured neck is an artistic imperative to an attractive appearance.
- A good neckline conveys a sense of youth, health, and vitality and lends an appearance of sensuality and beauty (**FIG 1**).
- Neck improvement is of high importance to almost every patient seeking facial rejuvenation, and the results of our face-lift procedures are largely judged by the outcome of the neck.
- Traditional neck lift techniques do not adequately address many aspects of aging in the submental region, and it is not enough in most situations to limit treatment to preplatysmal lipectomy alone or with postauricular skin excision. Subplatysmal problems will contribute significantly to aging and require treatment in most cases if optimal results are to be obtained (**FIG 2**).

ANATOMY

- It is critical to understand the distribution of fat in the cervicosubmental region. Cervical fat is present in three distinct layers—preplatysmal, subplatysmal, and deep interdigastic fat.
- Subplatysmal fat will be evident as a centrally situated triangular shaped fat pad with its base lying at the hyoid and tip near the mentum (see **TECH FIG 1A**). The two sides of the triangle will lie along each digastric muscle. Deeper interdigastic fat is situated in between and deep to the plane tangent to the anterior bellies of the digastric muscles.
- The submandibular gland (SMG) is a lobulated, pink to tan-colored structure covered by a smooth capsule. It sits in confined space with the anterior belly of the digastric muscle lying medial, the mandibular border lateral, and the

mylohyoid muscle deep (see **TECH FIG 2A**). The superficial and deep lobes are separated by the mylohyoid muscle.

- Important neurovascular structures will all lie extracapsular to the gland, so intracapsular dissection is safe. The marginal mandibular nerve will lie superior and lateral to the SMG. The facial artery and vein will lie in close proximity with the vein passing superficial and the artery deep to the gland. An intraglandular perforator artery arising from a branch of the facial artery will be found within the posterior portion of the superficial lobe in a central location.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Success or failure in treating the neck lies in the ability of the surgeon to identify the anatomic basis of patient problems and to form a sound surgical plan for their correction.
- A focused history should include all previous cosmetic treatments for the neck including previous neck lift or noninvasive treatments like Thermage, Ulthera, Kybella, etc.
- Obtain any history of dry mouth or Sjogren syndrome as this is a relative contraindication to reduction of the prominent SMG.
- The cervicosubmental region of each patient must be carefully examined both at rest and during platysmal activation to distinguish between soft adynamic cervical bands and dynamic hard bands. This is best accomplished by asking the patient to “push the jaw forward and tighten the neck.” Soft bands change little during activation and are predominantly a problem of loose skin or platysmal laxity, whereas hard bands become tight or exaggerated and indicate a problem of platysma hyperfunction (**FIG 3**).
- Evaluating the location of fat in the neck is also made easier by palpating the neck with and without platysmal activation. Fat lying predominantly in a preplatysmal position will generally feel “soft” and remain in the examiner’s grasp upon platysmal activation. However, fat in a subplatysmal location will have a firmer feel and will tend to be pulled superiorly out of the examiner’s grasp when the platysma is contracted (**FIG 4**).
- SMGs are usually palpable as firm, smooth, discrete, mobile masses in the lateral submental triangle. Large glands requiring treatment are most readily visible in the secondary face-lift patient who has had prior aggressive lipectomy; however, they can be more hidden in the primary patient with a full neck and must be palpated to ascertain their size and need for treatment (**FIG**

5).



FIG 1 • Patient seen before and after neck lift. A good neckline conveys a sense of youth, health, fitness, sensuality, and beauty. The patient has also undergone a face-lift, foreheadplasty, eyelid surgery, and fat injections.



FIG 2 • Patient seen before and after neck lift. A careful evaluation of the preoperative photo shows platysmal laxity, excess subplatysmal fat, large submandibular glands, and digastric muscle hypertrophy. Removing subcutaneous fat and tightening skin over these anatomic problems do not correct them and cannot produce the type of improvement shown here.

- A small subgroup of patients will present with large, bulky anterior bellies of their digastric muscles that are evident on visual exam as linear paramedian submental fullness. These are most often seen in the secondary face-lift patient

who has had prior aggressive lipectomy (**FIG 6**). However, in the typical primary patient, it is difficult to assess their size; thus, the decision to treat these muscles is usually made intraoperatively.

IMAGING

- Typically, radiographs are not necessary in facial rejuvenation surgery.
- All patients should have standardized photographs taken preoperatively, and any markings made preoperatively on patients should be photographed as well.
- These photos should be used intraoperatively to help guide treatment.

NONOPERATIVE MANAGEMENT

- Some limited options exist to treat isolated problems in the neck.
- Neuromodulators can be used to treat dynamic platysmal bands. Some have reported success using neuromodulators to partially reduce the size of SMGs, but results have been mixed at best.
- Deoxycholic acid (Kybella) is an injectable medication recently approved for reduction of submental fat. Also, CoolSculpting has been approved for the same treatment. At this point, it is unclear if these treatments are only affecting the subcutaneous fat or also having an impact on subplatysmal fat. Significant reduction of subcutaneous fat is likely not appropriate for most patients in the typical face and neck lift age group. Thus, like submental liposuction, use of these newer treatments should probably be limited to younger patients with discrete subcutaneous fat excess in the submental area.



FIG 3 • Dynamic assessment of the cervicosubmental region. The neck is examined in repose (**A**) and as the platysma is contracted (**B**). Dynamic platysma muscle irregularities are often referred to as “platysma bands.”

SURGICAL MANAGEMENT

- Traditional neck lift techniques that focus on preplatysmal lipectomy, skin excision, and platysmaplasty do not adequately address many aspects of aging in the submental region. For many patients, subplatysmal fat accumulation, SMG enlargement, and digastric muscle hypertrophy will contribute

significantly to the neck deformity and necessitate additional treatment.^{1,2}

- In all but the unusual or young patient, the majority of cervical fat accumulates in a subplatysmal location, and little if any will need to be removed from the preplatysmal layer. As patients age, fat stores generally shift from a preplatysmal location to a subplatysmal one. The small amount of subcutaneous fat present must be preserved to maintain a soft appearance to the neck.
- Large SMGs often contribute to the appearance of a full, “obtuse,” and “lumpy” neck. Glands protruding inferiorly to a plane tangent to the ipsilateral digastric and the mandibular border are likely to be problematic if excess cervical fat is removed, platysma is tightened, and excess skin is removed. These glands warrant reduction, and the protruding portion can be incrementally resected through the submental incision.



FIG 4 • Assessing the location of cervicosubmental fat. **A.** Submental “waddle” is grasped with the face and neck in repose. **B.** The patient is then asked to activate the platysma muscle. In this example, fat is pulled superiorly from the examiner’s grasp indicating a predominantly *sub* platysmal position. Fat lying predominantly in a subcutaneous, preplatysmal position would tend to remain within the examiner’s grasp when the platysma is activated.



FIG 5 • Prominent submandibular glands.

Submandibular glands are usually evident as protruding masses in the lateral submental triangle, lateral to the anterior belly of the ipsilateral digastric muscle. **A.**

Patient with residual prominent submandibular gland after face-lift and submental liposuction. His prior procedure has made the prominent glands more obvious. **B.** Patient with residual prominent submandibular gland after “weekend neck lift.”

Aggressive resection of subcutaneous fat has exposed the prominent gland.

- The decision to perform SMG reduction should be made in conjunction with the patient after appropriate discussion of the benefits versus risks. Patients should know that the procedure may prolong submental induration and carries a small but unlikely risk of bleeding, sialoma, salivary fistula, and dry mouth. Patients should also be informed, however, that only the protruding portion is excised and the majority of the gland is left in place.
- Once treatment of subplatysmal fat and SMGs has been performed, the anterior bellies of the digastric muscles should be evaluated. If the muscle bellies are deemed to be prominent intraoperatively, subtotal digastric myectomy should be performed. Failure to evaluate bulging of these muscles after other modifications of the submental region can lead to an unexpected and objectionable submental bulge postoperatively.



FIG 6 • Prominent anterior belly of the digastric muscle. The patient has had prior face and neck lift. The anterior belly of the digastric muscle can be seen as objectionable linear paramedian fullness in the submental region that spoils an otherwise good result. Prominent digastric muscles often go unnoticed at the time of the primary procedure due to the fact that they are frequently hidden by cervical fat and lax platysma muscle. (Courtesy of T. J. Marten, MD, FACS.)

Preoperative Planning

- All patients undergo a preoperative physical evaluation, and patients with significant medical problems must be cleared by their internist.
- Patients are required to avoid all medications or supplements that increase the risk of bleeding for 2 weeks prior to surgery.
- The majority of our neck lifts are performed under deep sedation administered by an anesthesiologist using a laryngeal mask airway (LMA). This allows the patient to be heavily sedated but still maintains spontaneous breathing without compromise of the airway.
- The flexible LMA is also particularly useful in neck surgery. When this device along with the breathing circuit is draped separately, it can be moved side to side during surgery giving unobstructed access to the submental region.

Positioning

- The patient is placed in the supine position, and a surgical scrub of the entire scalp, face, ears, nose, neck, shoulders, and upper chest is performed with full-

strength (1:750) benzalkonium chloride. The patient's head is then placed through the opening of a split sheet leaving the entire head and neck region unobstructed from the clavicles up. No "turban" or "head wrap" is used to allow total access.

- In addition, the breathing circuit is draped separately from the patient as described above.

Approach

- Whether performing a neck lift alone or in combination with a face-lift, a submental incision is used to access the subplatysmal space.
- This incision should be placed posterior to the submental crease at a point roughly half the distance between the mentum and hyoid. This is usually 1 to 2 cm posterior to the submental crease and measures 3 to 3.5 cm in length (**FIG 7**). It can be longer as long as it remains concealed under the mandible after skin flaps are shifted superiorly.
- Placing the incision posterior to the submental crease provides better access to the submental region, prevents accentuating a "witch's chin," and still heals in an inconspicuous scar.

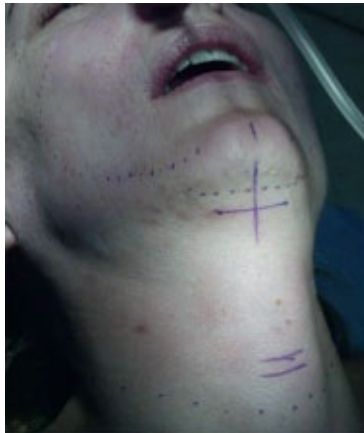


FIG 7 • Plan for the submental incision. The submental portion of the face-lift incision (*solid line*) should be placed posterior to the submental crease (*dotted line*), approximately one-half the distance between the mentum and hyoid (*arrows*). Usually, this corresponds to a point about 1.5 cm posterior to the submental crease.

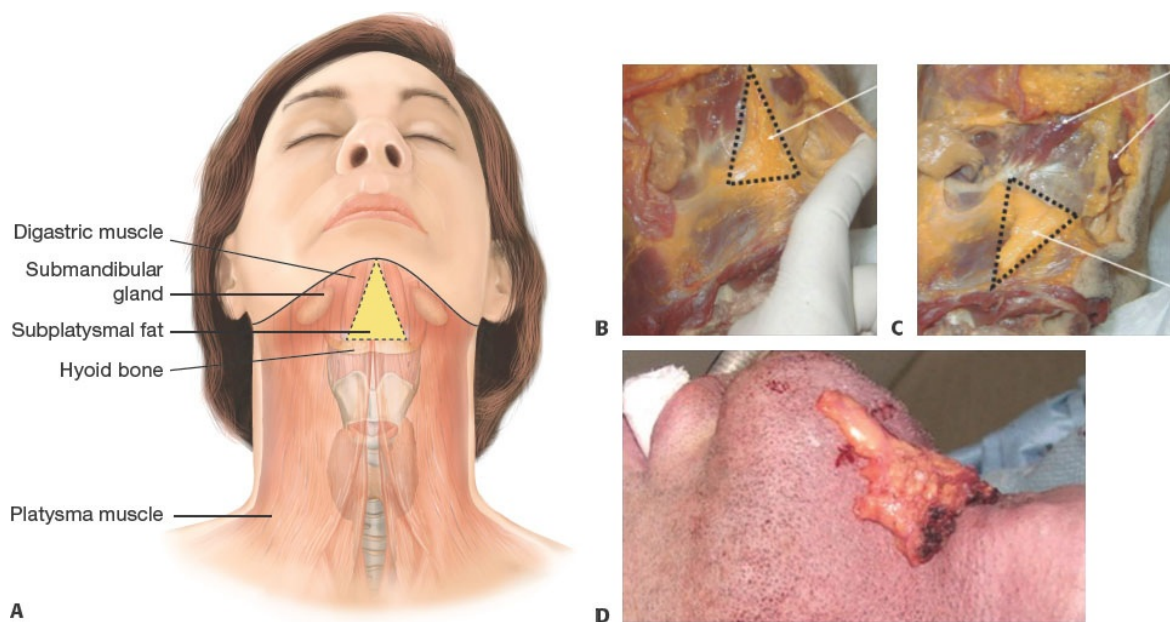
TECHNIQUES

■ Skin Flap Elevation

- First, sensory nerve blocks are performed using 0.25% bupivacaine with epinephrine 1:200 000. This allows the neck to be injected with a reduced degree of stimulation. This same solution is used to infiltrate the submental incision.
- Next, areas of subcutaneous dissection are generously infiltrated with 0.1% lidocaine with epinephrine 1:1 000 000. Infiltration of the neck and submental region is carried out with a 1.6-mm multihole blunt-tipped infiltration cannula via a stab incision at the earlobe or jawline. No direct infiltration is needed beneath the platysma if the subcutaneous tissues are infiltrated generously.
- The submental incision is made as described above (see Approach). The surgeon should stand at the head of the table, and with the assistant retracting the skin edges with a pair of 10-mm double-pronged skin hooks, skin undermining is done using Metzenbaum scissors.
- Subcutaneous dissection is carried out leaving the majority of preplatysmal fat on the platysma surface so that fat excision and sculpting will be easier to perform if needed at the end of the procedure. However, in contrast to the face-lift skin flap, a slightly thicker layer of fat should be preserved on the cervical skin flap to help avoid a hard or over-resected appearance to the submental area.
- A retrograde dissection should be made subcutaneously up onto the inferior chin to ensure release of the submental crease and mandibular retaining ligaments. Some bleeding should be expected with this necessary maneuver. Subcutaneous dissection is continued inferiorly and laterally, and if an “extended neck lift” or face lift is being performed, the submental dissection will join the lateral skin flap dissection from a postauricular incision. If this lateral dissection is being performed, care must be taken to avoid injury to the greater auricular nerve.

■ Cervical Lipectomy

- The focus of cervical lipectomy in most cases should be subplatysmal fat (**TECH FIG 1**). The subplatysmal space is entered by incising the superficially situated fascia between the medial platysma muscle borders using a Metzenbaum scissors. A combination of blunt and sharp scissors technique is used to isolate each muscle edge. The muscle edge is then grasped and retracted by the assistant using a skin hook or Allis forceps.
- The dissection is then carried laterally over the anterior belly of the digastric muscle hugging the undersurface of the platysma in a relatively avascular plane. Subplatysmal fat should be left on the deep surface of the neck and not raised with the platysma flap to facilitate fat removal as it is technically more difficult to resect fat from the undersurface of the platysma muscle.
- The plane tangent to the anterior bellies of the digastric muscles with the neck neutral or slightly flexed should be used as the landmark for subplatysmal fat removal. All fat lying superficial to this plane should be removed theoretically. If fat excision is made with the neck extended, inadvertent overexcision can occur. Any fat situated deep to this plane (interdigastric fat) should not be removed and the temptation to totally “clean out” the deep cervical space resisted, or else a significant submental depression will result.



TECH FIG 1 • Subplatysmal fat. **A.** Illustration of the triangular shaped subplatysmal fat located in the

submental space with its tip near the mentum and base at the hyoid bone. **B.** Cadaveric demonstration of subplatysmal fat. The *arrow* is pointing to the subplatysmal fat. The right and left borders of the platysma have been elevated clearly displaying the submental space. The subplatysmal fat pad can be seen overlying the digastric muscles to the upper right and left of the triangle with the hyoid bone at the base of the triangle. **C.** Cadaveric demonstration of subplatysmal fat. The two *upper arrows* point to the anterior bellies of the right and left digastric muscles and the *lower arrow* points to the subplatysmal fat pad. In this photo, the fat pad has been reflected downward but still attached at its base. The hyoid is now visible along with the interdigastric space. There is a small amount of deep cervical fat visible between the two *upper arrows*. **D.** Intraoperative demonstration of the subplatysmal fat specimen lying over the submental space from which it was removed. The patient's chin is pointing superiorly with the neck to the right of the photo.

- If large SMGs or anterior bellies of the digastric muscles are present and it is elected that they not be treated, subplatysmal fat removal should be more conservative if accentuation of these problems is to be avoided. Also, fibrous fat in the prehyoid region should not be arbitrarily removed, especially in women, as accentuation and masculinization of the larynx can occur.
- Subplatysmal fat should be removed incrementally by paying close attention to the new contours created. This is typically carried out with an extended Bovie and suction to evacuate smoke.
- In almost all cases, it is best to leave the subcutaneous fat layer untouched until all other maneuvers are completed including advancement of SMAS flaps (if concomitant face-lift is being performed). Little if any subcutaneous fat will require excision in most cases for patients in the typical face or neck

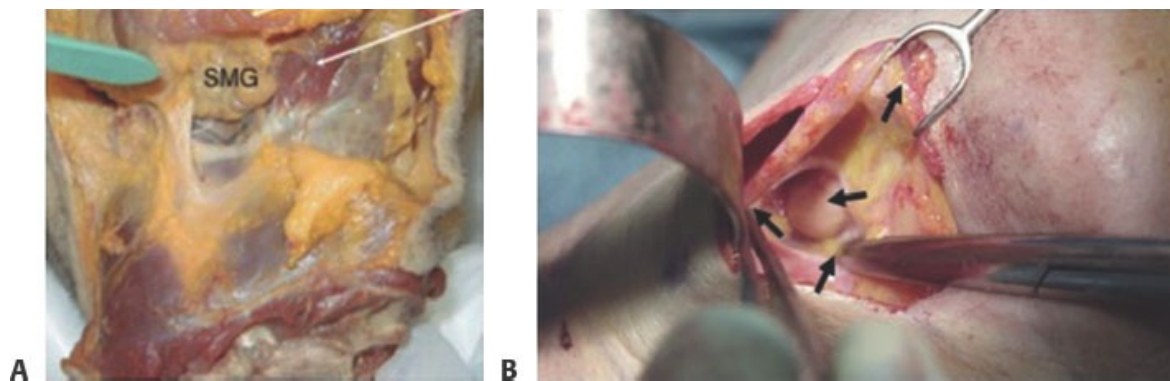
lift age group. When necessary, this can be completed under direct vision using Metzenbaum scissors or a small suction cannula (“open” liposuction) once correction of deep layer neck problems has been made and prior to closure.

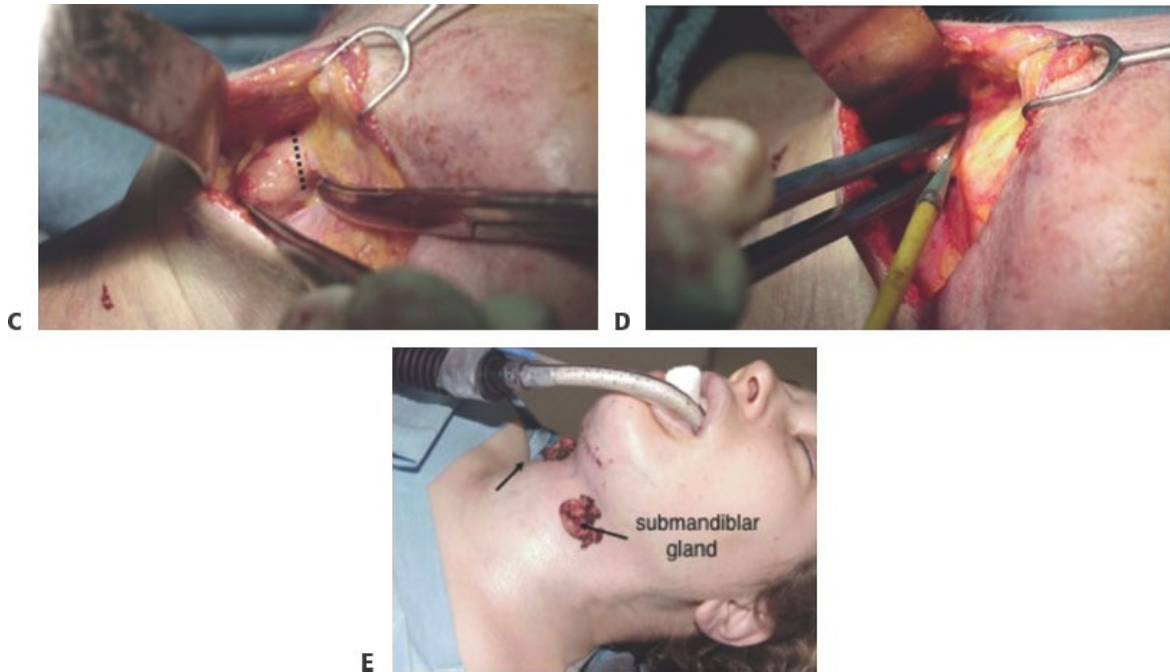
■ Submandibular Gland Reduction

- Prominent SMGs will be encountered as subplatysmal dissection is carried over the anterior belly of the digastric muscle. The prominent gland will appear as a smooth pink to tan-colored mass covered by a smooth capsule (**TECH FIG 2**).
- Reduction is begun by incising the capsule overlying the gland inferomedially just lateral to the anterior belly of the digastric muscle. The gland will be evident once exposed in this manner due to its distinctive lobulated appearance. Its inferior portion can be grasped and easily separated from adjacent tissue inside its capsule using a gentle blunt scissors spreading technique.
- A key step in the safe performance of the procedure is adequate mobilization of the gland, which will make both gland resection and the control of any intraglandular bleeding easier. Although all vital structures are outside the capsule, care should be taken when mobilizing the gland superolaterally as both the facial vein and marginal mandibular branch of the facial nerve and in close proximity.
- Once adequately mobilized, the inferior portion of the gland is grasped and pulled gently inferiorly and medially out of its fossa and away from adjacent structures. The redundant portion is subsequently incised incrementally under direct vision in a medial to lateral direction using an extended cautery. Excision of the excess part of the gland should be performed in such a manner that the portion protruding inferior to the plane tangent to the ipsilateral mandibular border and the anterior belly of the digastric muscle will be removed. It is usually best that the initial resection is conservative and that the gland is incrementally reduced as needed. Never is it necessary or appropriate to remove an entire gland, which will result in a depression or other contour deformity and could precipitate dry mouth.
- Proper instrumentation and personnel are needed to perform this procedure. An extended cautery along with long insulated forceps is necessary along

with a fiber-optic headlight (our preference) or retractor and suction. Also, two assistants will be needed for retraction, passing of instruments, etc. If a smoke evacuator is used, a second suction should be set up in the event that bleeding is encountered.

- SMG reduction must not be performed without proper preparation as mentioned above, and considerable caution as intraglandular vessels is often encountered and can produce brisk bleeding. These vessels are more commonly encountered when larger resections are made. Typically, bleeding will occur from both the gland and the specimen side, and this is usually best controlled by quickly moving the cautery back and forth between each end of the cut vessel. If bleeding is brisk and not easily controlled with simple cautery, the cut edge of the gland should be compressed with forceps and the vessel isolated and cauterized. In the unlikely event that bleeding cannot be controlled by these means, the submandibular fossae should be packed with gauze and digital pressure applied firmly for several minutes.





TECH FIG 2 • Surgical approach to submandibular gland reduction. **A.** Cadaveric demonstration of submandibular triangle. The excessive portion of the submandibular gland (SMG) is found protruding inferiorly to a plane tangent to the digastric (*lower arrow*) and the mandibular border (*small upper arrow*). **B.** Intraoperative photo demonstrating exposure of the submandibular gland. A submental incision has been made approximately 1 cm posterior to the submental crease and the neck subcutaneously undermined. The right platysma muscle has been elevated and is retracted with a double-pronged skin hook and a malleable retractor. The gland will be seen as a distinct bulge just lateral to the ipsilateral anterior belly of the digastric (scissors tips rest on digastric). The capsule has been incised inferiorly and medially and the submandibular gland isolated using blunt dissection. **C.** Intraoperative photo prior to resection of the excess portion of the gland. The gland has been mobilized and gently pulled inferiorly. The *dotted line*

represents the level at which the inferior portion of the gland will be excised. **D.** Intraoperative photo just prior to partial gland excision. This should be performed in such a manner that the portion protruding inferior to the plane tangent to the ipsilateral anterior belly of the digastric muscle and the ipsilateral mandibular border will be resected incrementally with electrocautery. **E.** Patient seen immediately after neck lift that included submandibular reduction. The excised portions of the glands are also demonstrated on both the right and left sides.

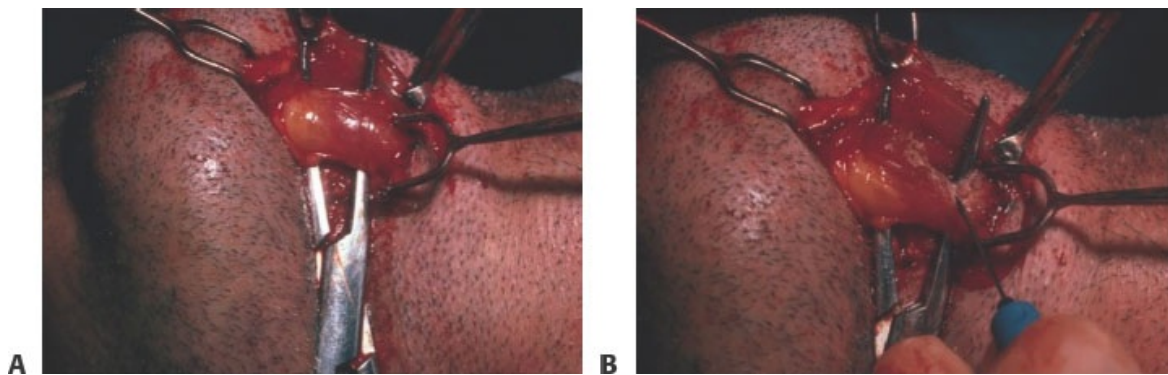
- Once the excision is complete, it is not necessary to oversee the cut edge of the gland or close the gland capsule. It is also not necessary to overcauterize the cut edge of the gland as this will result in more prolonged edema.
- A drain should be placed in the subplatysmal space with this procedure and left in place for several days. It is safest to perform the platysmaplasty before drain placement and then to perforate the platysma and thread the drain into place. This is to avoid the drain being caught with a suture during platysmaplasty.

■ Partial Digastric Myectomy

- Superficial, subtotal anterior digastric myectomy is performed under direct vision through the submental incision after the subplatysmal space has been opened, the platysma muscle has been mobilized, and subplatysmal fat and protruding portions of the SMG have been excised as needed.
- The redundant portion of the muscle can be excised by either a tangential strip excision technique or by a partial division and excision technique. Although both are reliable and effective, in most cases, tangential strip excision provides the simplest method of reducing the muscle.
- Tangential strip excision is performed by grasping the superficial redundant portion of the muscle belly with a forceps and excising a strip of muscle longitudinally with Metzenbaum scissors or cautery. Excision is begun near the muscle origin at the mentum and continues toward the lateral hyoid. The

muscle is then reassessed and the action repeated until the protruding portion is fully removed and optimal contour obtained.

- In the partial division and excision technique, the excess muscle is gauged and isolated on a tonsil forceps by pushing the tips of the instrument through the midmuscle belly at the level of optimal contour and spreading to split the muscle along the length of its fibers. The isolated muscle segment resting on the instrument consisting of the superficial, protruding portion of it is then excised with scissors or cautery by dividing it at the mentum and hyoid (**TECH FIG 3**). Usually, this entails the excision of the superficial most half or less of each muscle.

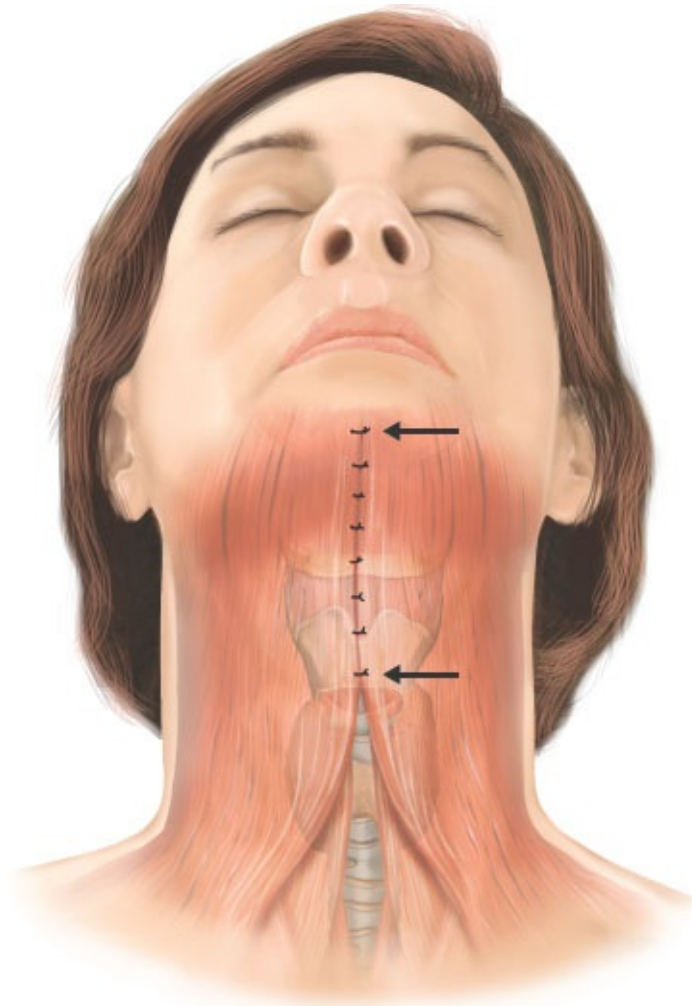


TECH FIG 3 • Partial division and excision technique of digastric muscle reduction. **A.** Excess muscle present is gauged and isolated on a tonsil forceps by pushing the tips of the instrument through the midmuscle belly at the level of optimal contour and spreading to split the muscle along the length of its fibers (view from patient's right digastric muscle through submental incision. Patient's chin is at the left upper corner of the photo and the neck is on the right). **B.** The isolated muscle segment resting on the instrument consisting of the superficial, protruding portion of it is then excised with scissors or cautery by dividing it near the mandible and the hyoid. The neck is then re-examined and the maneuver repeated if necessary until an improved contour is obtained.

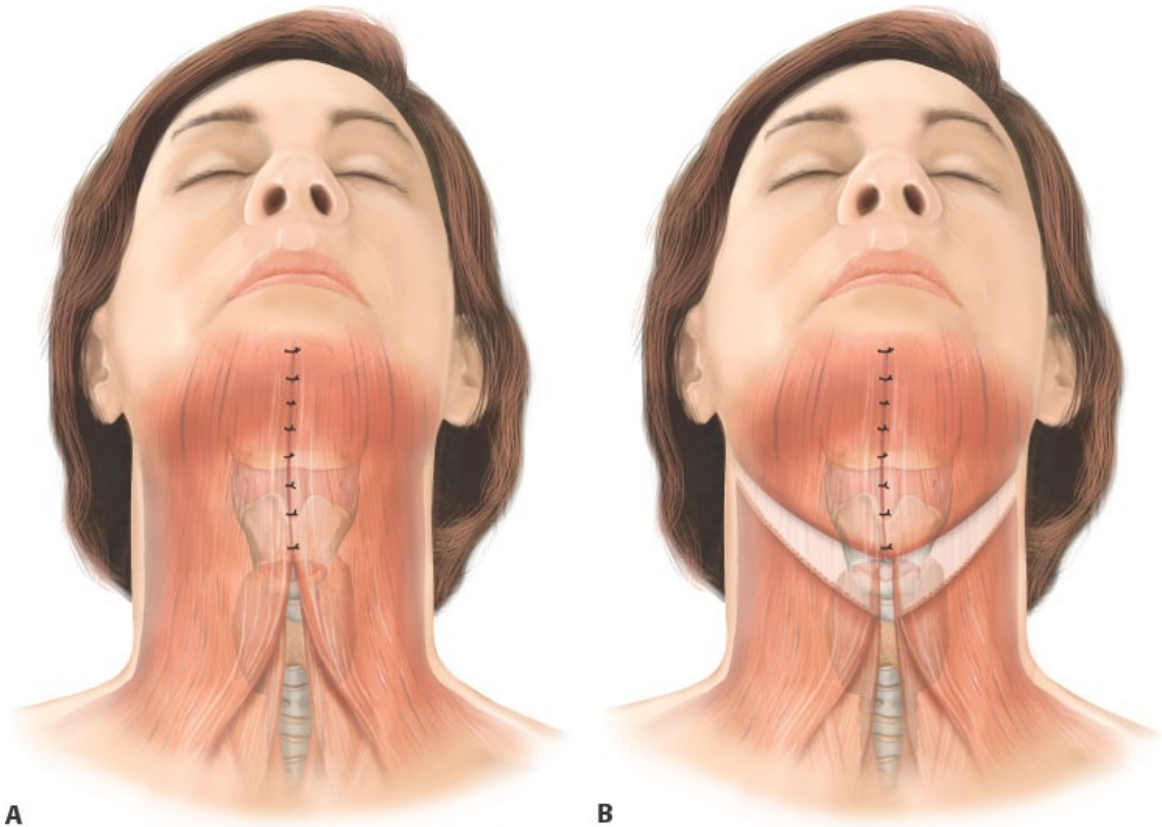
■ Anterior Platysmaplasty and Myotomy

- Platysmaplasty consists of suturing the medial muscle borders together from mentum to thyroid cartilage in one or two layers. If redundant muscle is present, it is excised medially before suturing is performed so that a smooth, edge-to-edge approximation can be made (**TECH FIG 4**).
- This is usually performed using simple interrupted sutures of 3-0 Vicryl or Mersilene on a medium tapered needle. A running suture is not recommended as this can cause a “purse string” effect potentially leading to the formation of a midline band postoperatively. Once initial approximation is made with interrupted sutures, the line of repair can be oversewn with a simple running suture if desired. The repair should be snug but not tight.
- When performing a face and neck lift together, cheek SMAS flaps should be suspended prior to anterior platysmaplasty to allow optimal treatment of the jawline. If postauricular transposition flaps are planned, this should be performed after anterior platysmaplasty to prevent difficulty in joining the medial borders of the platysma anteriorly.
- Platysma myotomy should be performed after anterior platysmaplasty if indicated (**TECH FIG 5**).
- This should be done low in the neck at the level of the cricoid cartilage. At this level, the muscle is thin and will bleed less, and the cut edges are less likely to be visible postoperatively. In addition, a smooth transition across the cervicomental angle is maintained and lower lip dysfunction is avoided.
- Platysma myotomy is best begun through the submental incision just below the inferiormost suture from the platysmaplasty. The medial muscle border is grasped and lifted away from the deep cervical fascia with forceps. Myotomy is then made by nibbling through the muscle in small increments with Metzenbaum scissors. As the muscle is divided, it usually separates a centimeter or more exposing the fascia beneath it. Gentle spreading with scissor tips before each cut is made helps separate the muscle from the underlying cervical fascia and facilitates dissection. The myotomy is continued laterally and slightly superiorly.
- If full-width division of the platysma is planned, the lateral most portion of the transection is completed through the postauricular incision. The lateral transection is complete when brought into continuity with the myotomy from the anterior approach.

- Prior to skin closure, usually one drain is placed in the subplatysmal space if deep layer problems have been treated, and a second drain is placed subcutaneously. If significant oozing is encountered at the end of the procedure or in male patients, an additional drain can be considered for the subcutaneous space.



TECH FIG 4 • Anterior platysmaplasty. Repair of platysma diastasis from mentum to thyroid cartilage (*arrows*) improves submental support and helps consolidate the neck. It is not an adequate or effective treatment of platysma bands, however.



TECH FIG 5 • Plan for “full-width” platysma transection. Full-width myotomy not only corrects anterior and lateral bands but provides improved definition over the lateral mandibular border. However, for patients with only anterior bands, a partial-width transection beginning medially may be adequate. **A.** Anterior neck after platysmaplasty but before full-width platysma myotomy. **B.** After full-width platysma myotomy (note: myotomy is most easily and effectively performed after platysmaplasty has been completed).

PEARLS AND PITFALLS

Subcutaneous fat	■ This layer of fat is essential to maintaining a soft smooth contour to the neck. In most cases, very little subcutaneous fat needs to be removed if proper attention is paid to deep layer problems.
Subplatysmal fat	■ Aggressive treatment of subplatysmal fat can make submandibular glands and digastric muscles much more visible; thus, a surgeon should be prepared to treat all three problems in such cases.
Submandibular gland reduction	■ It is critical to adequately mobilize the gland prior to resection. This will greatly simplify both resection and control of any significant bleeding.
Digastric muscle hypertrophy	■ In most cases, the decision to treat digastric muscles is made intraoperatively after treating other deep layer problems.
Anterior platysmaplasty	■ There is no need to suture the platysma under great tension when deep layer problems are adequately addressed. A snug one-layer edge-to-edge closure after excision of any redundant platysma is adequate.
Recovery	■ Subplatysmal maneuvers will lead to a longer period of swelling and induration, and surgeons using these techniques should be prepared to counsel patients.

POSTOPERATIVE CARE

- No dressings are required or used. They are arguably dangerous for tenuous skin flaps and uncomfortable for patients and preclude inspection and monitoring of the operative site.
- All patients are instructed to sleep flat on their backs without a pillow or with a small cylindrical neck roll. This posture assures an open cervicomental angle and averts dangerous folding of the neck skin flap and obstruction of regional cervical lymphatics. Patients are also shown an “elbow on knees” position that accomplishes this open cervicomental angle while sitting.
- Patients are allowed to take their usual diet after surgery but to avoid overly sweet, salty, sour, or dry foods for several weeks. This in particular is important if the SMGs have been treated.
- The neck drains are usually left in place for 4 to 5 days. This will help speed the overall resolution of edema, ecchymosis, and induration.
- Patients are asked to set aside 7 to 10 days to recover depending on the extent

of their surgery, and additional time off is recommended if a face-lift or related procedure is simultaneously performed.

OUTCOMES

- See before and after examples (**FIGS 8 to 10**).
- See case examples of before and after photos.



FIG 8 • Before and after surgery views of a woman, age 46 who has had no prior surgery. Note full neck, obtuse cervicosubmental contour and “double chin” appearance when the patient looks down in before views. Palpation of the lateral submental triangle revealed a firm mobile mass consistent with an enlarged submandibular gland. Her preoperative appearance suggests the presence of a “low hyoid.” The same patient 11 months after face-lift, neck lift, forehead lift, lower eyelift, and facial fat grafting. The neck lift procedure included excision of subplatysmal fat, submandibular gland reduction, superficial digastric myectomy, anterior platysmaplasty, and full-width platysma myotomy. Note attractive, youthful-appearing neckline even when the patient looks down. Comprehensive neck surgery has corrected problems that are commonly misinterpreted as a low hyoid position. The double chin deformity has also been

corrected. (Surgical procedures performed by Timonthy J. Marten, MD, FACS.)



FIG 9 • Before and after surgery views of a woman age 55 who has had prior eyelifts and a perioral chemical peel by another surgeon. Note full neck, obtuse cervicosubmental contour and “double chin” appearance. Palpation of the lateral submental triangle revealed a firm mobile mass consistent with an enlarged submandibular gland. Note paucity of subcutaneous neck fat. The same patient 1 year and 4 months after face-lift, neck lift, forehead lift, upper and lower eyelid lifts, perioral dermabrasion, and facial fat grafting. The neck lift included excision of a large amount of subplatysmal fat, submandibular gland reduction, superficial digastric myectomy, anterior platysmaplasty, and full-width platysma myotomy. Note the youthful neckline. The double chin deformity has been corrected by releasing the submental retaining ligaments and blending the fat of the chin and the submental area. (Surgical procedures performed by Timonthy J. Marten, MD, FACS.)

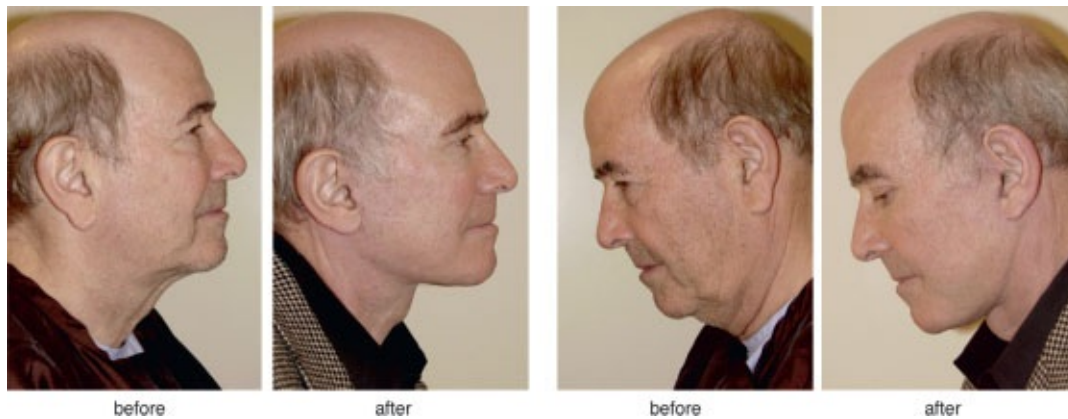


FIG 10 • Before and after surgery views of a man, age 68 who has had no prior plastic surgery. Note poor cervicosubmental contour and “double chin” appearance when the patient looks down in before views. An enlarged submandibular gland can be seen. Note paucity of subcutaneous fat that is typical for patients in older age groups. Platysmal bands are visible in the anterior neck. The same patient 1 year and 9 months after face-lift, neck lift, forehead lift, upper and lower eyelifts, facial fat grafting, and ear lobe reduction. The neck lift procedure included excision of a large amount of subplatysmal fat, submandibular gland reduction, superficial digastric myectomy, anterior platysmaplasty, and full-width platysma myotomy. Note well-defined jaw line and masculine-appearing neckline even when he looks down.

COMPLICATIONS

- Complications associated with subplatysmal neck lifting are similar to other face and neck lift techniques (see High SMAS flap chapter).
- Subplatysmal neck lifting in particular can lead to temporary platysmal dysfunction likely related to injury to cervical branches. This will manifest as asymmetric lip depressor function that should resolve within 3 months.
- No major complications attributable to SMG excision, including seroma formation, salivary fistula, or gustatory sweating, have been encountered in our

clinic over the last 20 years.

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49 Indications and Techniques for Short-Scar Face-Lift

CHAPTER

Steven M. Levine and Daniel C. Baker

DEFINITION

- Surgery is the standard treatment to address descent and laxity in the aging face.
- Short-scar face-lift is defined as an incision that remains completely preauricular.
- Most also apply that definition to face-lift incisions that extend behind the lobe and into the retroauricular sulcus, but that do not have a transverse component or cross into the hairline at any point.

ANATOMY

- Relevant anatomy is the earlobe and retroauricular sulcus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Beyond usual history and physical findings to indicate a patient for a face-lift and neck lift, the question is, “Does the patient have a significant amount of cervical laxity?”
- Short-scar face-lifts compromise on the ability to address neck laxity, specifically, inferior neck laxity. Better stated, the short-scar face-lift is ideal for a patient with minimal neck laxity who desires improvement along the jawline and midface.

SURGICAL MANAGEMENT

- Surgery should be performed in an accredited operating room.
- A short-scar face-lift can be performed under local anesthesia with or without sedation or general anesthesia.

Preoperative Planning

- Consideration should be given as to whether the surgeon believes the patient will be satisfied from the limited neck lift provided by the short-scar approach.

Positioning

- The patient is supine on the procedure table.
- Usually, the head of the bed is slightly elevated.
- The authors prefer to sit for maximum stability.

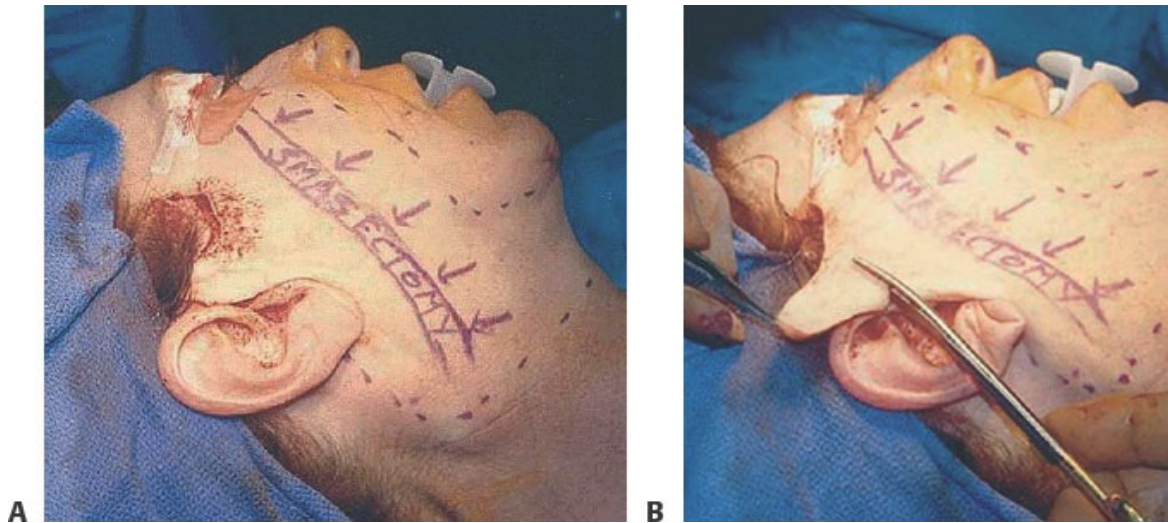
Approach

- An incision pattern is chosen, either preauricular or intratragal.
- The skin is elevated in the subcutaneous plane after infiltration with local anesthesia with epinephrine.
- The superficial musculoaponeurotic system (SMAS) is addressed by any number of acceptable means.

TECHNIQUES

■ True Short-Scar Face-Lift

- The skin incision stops at the base of the earlobe without separating the neck skin from lobe.¹
- The skin flap is undermined (**TECH FIG 1A**).
- The superficial musculoaponeurotic system (SMAS) is addressed via a flap, SMASectomy, or plication procedure.
- The skin flap is redraped, trimmed, and sewn under no tension (**TECH FIG 1B**).
- The authors prefer to leave drains, but this understandably varies between surgeons.



TECH FIG 1 • A. The pretragal incision and extent of skin undermining. The incision may extend into the retroauricular sulcus. In this patient, a SMASectomy is planned. **B.** After the SMAS has been addressed, the flap is rotated into position and excess skin is trimmed.

Extended Short-Scar Face-Lift

- The skin incision continues to the retroauricular sulcus.
- This allows the neck to be addressed more adequately than with a true short-scar procedure.
- The skin flap is undermined.
- The SMAS is addressed via a flap, SMASectomy, or plication procedure.
- The skin flap is redraped, trimmed, and sewn under no tension.
- When sewing the skin flap, a three-point stitch is placed from the lobe, the neck skin, and deep to the fascia. This suture anchors the lobe in place to prevent a pixie ear.
 - The traditional tension-bearing retroauricular suture at the cranial end of the sulcus does not exist.
- If there was neck laxity to address, the retroauricular closure will require bunching or pleating of tissue (**TECH FIG 2**).
- The wound should be closed carefully with interrupted suture.
- This pleating settles out within 6 weeks.

- The authors prefer to leave drains, but this understandably varies between surgeons.



TECH FIG 2 • In a patient with mild to moderate amounts of cervical skin laxity, there may be pleating around the incisions; this will settle with time.

PEARLS AND PITFALLS

Approach	■ Do not hesitate to convert a short scar to a traditional scar for a better result.
	■ This needs to be discussed with patients preoperatively.
Flap	■ Do not overtrim the flap beneath the lobe. There should be no tension on the skin beneath the earlobe. This is more important in a short-scar operation than a traditional scar.

POSTOPERATIVE CARE

- Cool packs are also used to reduce swelling.
- Strict blood pressure control is enforced postoperatively.
- Patients are instructed to do no lifting or bending for 2 weeks.

- The authors prefer to place patients in a face and/or neck compressive dressing for at least 4 to 6 hours after surgery, but up to 24 hours.
- Drains are usually removed at 48 hours.
- All patients are seen by the surgeon the following morning and then again multiple times over the following week.
- Sutures are usually removed at 1 week.
- If needed, a low-dose steroid injection can be delivered to the subcutaneous tissue behind the ear to help soften the pleated tissue.

OUTCOMES

- Short-scar face-lifts in carefully selected patients can achieve excellent jawline contour and midface elevation, as well as some neck tightening (**FIG 1**).



FIG 1 • Preoperative (**A,B**) and postoperative (**C,D**) views of a patient who underwent a short-scar face-lift. Note the improvement of the jowls and jawline.

COMPLICATIONS

- Bruising and hematomas are the most common complications.
- Hematomas in males are twice as common as they are in females.
- Pixie ear creation is a problem if the flap is overtrimmed or inadequately secured to the lobe and fascia.

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50 Indications and Techniques CHAPTER for Buccal Fat Pad Excision

Alan Matarasso and Sammy Sinno

DEFINITION

- The buccal fat pad is prominent in the infant face, where it contributes to the suckling function of the cheek.¹
- Typically, as the face matures, the buccal fat pad becomes less noticeable, but in some patients, it persists and serves as a primary contributor to a “round” face.
- An attractive, angular, and youthful appearing face is characterized by malar convexity juxtaposed with submalar concavity.
- Additionally, due to its intermuscular location, the buccal fat is typically spared from atrophy.²

ANATOMY

- The buccal fat pad is a stellate-shaped structure with four extensions.
- It is located deep to the masseter muscle and superficial to the buccinators in the buccopharyngeal membrane.
- The parotid duct pierces the fat pad as it courses to the papilla across the second maxillary molar (**FIG 1**).
- The fat pad extends to the anterior edge of the masseter muscle; it is at this location where the gland can protrude from overaggressive liposuction or facelift dissection among other causes, a phenomenon known as *buccal fat pad pseudoherniation*.^{3,4}

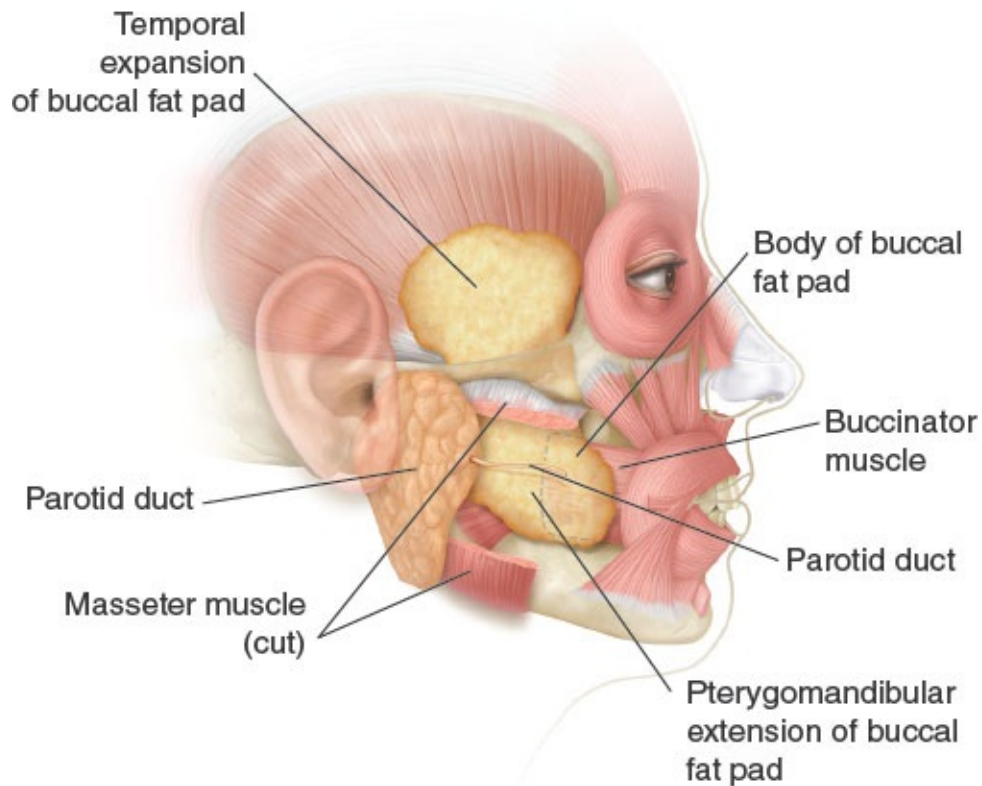


FIG 1 • Anatomy surrounding the buccal fat pad.

- Posteriorly, the fat pad extends deep to the angle of the mandible.
- Superiorly, the fat pad extends to the temporalis muscle and deep to its fascia.
- Another superior extension continues along the zygomatic bone's contribution to the lateral orbital wall.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The buccal fat pad can contribute to a “rounded” facial appearance, obliterating submalar concavity in certain patients. This feature is seen most prominently in the antero-caudal quadrant of the cheek, which is typically targeted by excision of the gland.
- The buccal fat pad is above the mandible and posterior to the nasolabial fold, an area distinct from the jowl.
- In contrast to a normally situated buccal fat pad, pseudoherniated fat can be reduced with gentle pressure.

IMAGING

- When attempting to palpate the buccal fat pad, a firm, pulsatile, or subtly

pigmented palpable mass warrants further workup with an MRI.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients undergoing buccal fat pad excision can have it as an isolated procedure or more commonly undergo other facial surgical procedures simultaneously.
- Indications for excision include patients with a full, round face.
- Excision is typically performed intraorally before other procedures (ie, facelift) under nonsterile conditions, to decrease the incidence of infection and risk of facial nerve injury.⁵

Positioning

- The patient is placed in a supine position and the head positioned to gain maximum exposure.

Approach

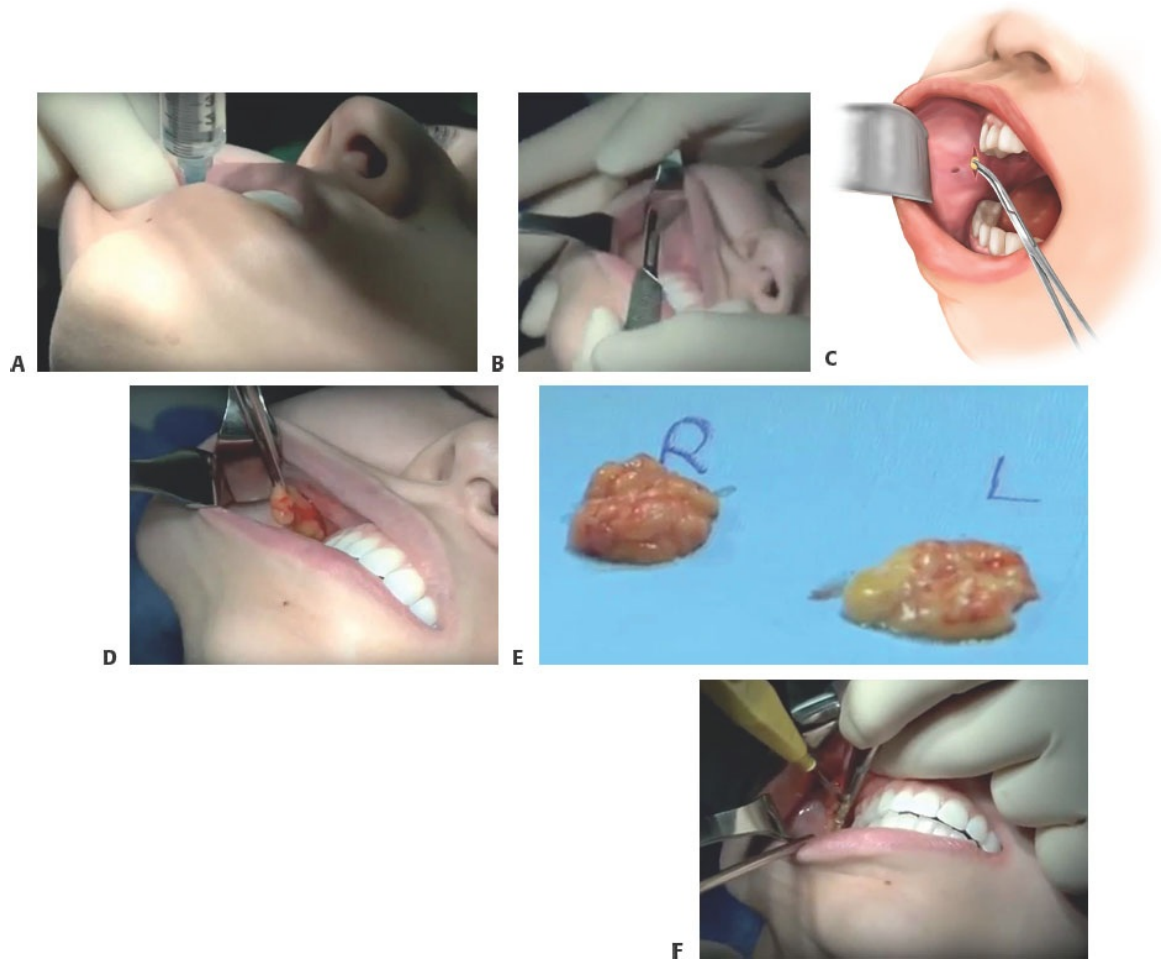
- To avoid an external incision on the face or injury to the facial nerve, the buccal fat pad is accessed through a minimal intraoral incision.

TECHNIQUES

■ Buccal Fat Pad Excision

- A total of 2 to 3 cc of 1% lidocaine with 1:100 000 epinephrine is injected into the buccal mucosa across from the first and second maxillary molars (**TECH FIG 1A**).
- The cheek is retracted with a Caldwell-Luc retractor.
- A 2.5-cm incision is made between the upper first and second maxillary molar (**TECH FIG 1B**).
- A cuff of mucosa below the gingivobuccal sulcus is maintained for adequate wound closure (**TECH FIG 1C**).
 - Care is taken to visualize the papilla to avoid injury. The papilla with the cheeks are retracted laterally.
- External pressure is applied to guide the fat pad into the wound.

- The buccopharyngeal membrane is pierced with a scalpel and then entered with scissors.
- The fat pad is grasped with Adson-Brown forceps and gently teased with a hemostat (**TECH FIG 1D**).
- The exposed portion of the fat pad is clamped with traction and the excess excised. Only fat that protrudes easily is excised; overresection can cause unattractive cheek hollowing. Extreme caution to avoid hollowing should be exercised in patients with pseudoherniation.
- Avoid excess traction that can distort the anatomy.
- Care is taken to avoid accidental cautery injury to the lips by retracting with a finger and electrocoagulating the stump.
- The incision is packed with gauze soaked with lidocaine and epinephrine while the same procedure is performed on the contralateral side.
- Resections are performed on each side to maintain symmetry (**TECH FIG 1E**).
- Electrocautery is used for hemostasis (**TECH FIG 1F**).
- The incisions are closed with one interrupted 5-0 chromic suture.



TECH FIG 1 • **A.** Injection of local anesthesia. **B.** Exposure and incision. **C.** Access for buccal fat pad excision. **D.** Buccal fat pad retrieved from incision. **E.** The specimens from each side are compared for symmetry. **F.** Meticulous hemostasis is obtained.

PEARLS AND PITFALLS

Aesthetic considerations

- The buccal fat pad can contribute to a “rounded” facial appearance, obliterating submalar concavity in certain patients.
- In contrast to normally situated buccal fat pad, pseudoherniated fat can be reduced with gentle pressure.

Operative

- Excision is typically performed before other procedures (ie,

sequence	facelift) under nonsterile conditions, to decrease the incidence of infection and risk of facial nerve injury.
Technical considerations	■ Take care to avoid injury to the papilla; always keep this landmark visualized. ■ Avoid over-resection because this will hollow the cheek area. ■ Excess traction while grasping the fat pad can distort local anatomy. Avoid excess manipulation.
Untoward sequelae	■ A small hematoma in the recess can result in an indurated cheek mass that gradually resolves over time. ■ Prolonged cheek firmness and fullness can be caused by excessive intraoperative manipulation, exploration, or hemostasis (not a fluid collection or infection); this can be managed by external massage and/or ultrasound treatments.



FIG 2 • (A,B) Preoperative and (C,D) postoperative views of a patient who underwent buccal fat pad excision.

POSTOPERATIVE CARE

- The chromic sutures will dissolve.
- Patients are encouraged to maintain adequate oral hygiene while incisions are healing by rinsing with dilute hydrogen peroxide.
- Excessive opening and closing of the mouth (“exercising”) is encouraged.

OUTCOMES

- Buccal fat pad excision is a safe and effective technique that can restore proportion to the midface (**FIG 2**).
- It can complement other surgical procedures such as facelifting to restore a more youthful aesthetic contour to the entire face.
- Even as an isolated procedure, it can produce a more angular and sculpted

facial appearance.

COMPLICATIONS

- Over-resection
- Inadequate treatment
- Injury to the papilla
- Facial nerve injury
- Wound dehiscence

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Nonsurgical Neck Contouring using Deoxycholic Acid or Microfocused Ultrasound

51 CHAPTER

Lawrence S. Bass

DEFINITION

- Submental fullness is the result of excess fat contributing to a convex surface contour.
- Skin laxity manifests as visible redundancy of skin.
- Deoxycholic acid (DOCA) is a bile salt that destabilizes cell membranes and emulsifies fat. A synthetically prepared DOCA is Food and Drug Administration (FDA) approved for the reduction of submental fat and fullness.¹
- Microfocused ultrasound (MFUS) is a technology that uses ultrasound to image the target tissues (diagnostic ultrasound) mated with therapeutic ultrasound that produces zones of coagulation. These zones are fractionated spots of coagulation at a predetermined depth under the skin. Sound energy is delivered in a beam that transits the skin at a low energy density converging at a predetermined depth under the skin by creating a high energy density zone of defined shape and size. A line of 25 fractional zones of coagulation is produced each time the device is fired.
- Ultrasound transducers of different frequencies are selected for the desired depth of treatment. Total energy in each spot in the line can be varied on the device.

ANATOMY

- The submental area is bounded by the inferior border of the mandible

(mentum) anteriorly, the hyoid bone posteriorly, and the inferior border or the mandibular bodies laterally.

- Fat in this area can be subcutaneous or subplatysmal.
- Aging changes in the neck include visible skin laxity or redundancy, prominence of visible platysmal bands, and skin surface changes.
- Laxity may manifest as a visible jowl, loss of jawline definition, and hanging festoons of skin in the neck independent of any platysmal banding.
- Transverse rhytides; crepey, rough skin texture; and solar elastosis are surface aging changes that can be treated with MFUS.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Due to the focused nature of the results obtained with DOCA and MFUS, a detailed history of aesthetic issues and goals is essential to ensure that the correct therapies are selected.
- Previous aesthetic therapies and surgeries should be carefully documented. Although these treatments are frequently performed in individuals who have previously undergone some form of treatment, safety and outcomes after extensive or multiply recurrent treatments have not been formally studied or reported at this time.
- Examination should catalogue the location and magnitude of changes in each clinically pertinent tissue layer.
- The degree and location of skin laxity in the jowl, jawline, and submental area are determined along with laxity changes inferior to the thyroid cartilage, which must be addressed separately.
- Presence of visible excesses in subcutaneous fat in the jowl and submental and lateral neck areas should be recorded.
- Platysmal diastasis is an important finding both for procedure selection and patient counseling. The distance of separation and vertical extent of separation should be noted.
- Although it is not routinely possible to determine the amount of excess fat present in the subplatysmal plane on physical examination, this may limit the amount of improvement obtained with DOCA injection that addresses the subcutaneous plane only.

IMAGING

- Radiologic and diagnostic studies are not customarily used.

DIFFERENTIAL DIAGNOSIS

- Skin laxity
- Excess subcutaneous fat
- Excess subplatysmal fat
- Platysmal diastasis
- Dermal rhytids

SURGICAL MANAGEMENT

- Excess fat in the neck, in the absence of skin redundancy, has traditionally been treated with suction-assisted lipectomy. Increasingly, energy-based devices have been mated with the liposuction procedure to amplify skin tightening or lifting in patients with mild laxity resulting from aging changes.
- For more advanced aging changes with skin laxity in the jowl and neck area, surgical lifting procedures such as facelift, neck lift, and submentalplasty are the standard for providing the most complete correction, albeit with greater incisions, recovery time, and cost.
- More recently, minimally invasive treatments utilizing sutures that suspend facial and neck tissues and stimulate neocollagenesis are occasionally utilized.

NONSURGICAL MANAGEMENT

- DOCA injection is indicated for the treatment of subcutaneous fat in the submental area. Treatment of fat in the neck inferior to the mandible and anterior to the sternocleidomastoid muscle is also commonly performed.
- Two to six treatments are required depending on the degree of excess fat. Each treatment has up to 50 injections of a fixed dose of medicine placed at a fixed distance apart.
- The amount of fat present determines the number of treatments required. Retreatment is performed at interval of at least 1 month between treatments.
- Although larger necks can be treated, the ideal patient has modest to moderate amounts of fat and is typically treated in two to three sessions of 20 injections each.
- Treatment of jowl fat is specifically contraindicated due to concerns of injury to the marginal mandibular branch of the facial nerve. Theoretically, this may not be rational on an anatomic basis given the typical submandibular location of the nerve as it courses past the jowl area and due to the subplatysmal location of the nerve. But as of this writing, there is no published clinical

experience demonstrating the safety or lack thereof for treatment of the jowl.

- MFUS has a specific FDA indication for the noninvasive lifting of skin in the jowl and neck region. Surface features such as transverse neck rhytides and laxity below the level of the thyroid cartilage can also be addressed.
- The ideal patient has good skin quality with only modest skin excess and is not substantially overweight.
- A single treatment is performed to produce neocollagenesis and skin lifting over a 3- to 6-month period, although repeat treatments may be performed for more improvement if the patient is a responder.
- The combination of DOCA injection and MFUS may provide a noninvasive means to correct many of the changes seen in the aging neck if they are mild to moderate in severity. There is currently no published literature reporting results using this combined approach.

Preoperative Planning

- The size of the treatment area for DOCA injection must be determined so the amount of medicine needed can be calculated and the patient advised of treatment cost. The patient also should be advised of the likely number of treatments to provide a complete or near-complete correction.
- Patient counseling about expected recovery after DOCA injections is essential to avoid unexpected disruption of work and social activities.
- MFUS treatment planning involves assessment of the area requiring treatment at each depth and the amount of treatment at each depth (number of lines to be placed). Although there is a theoretical standard 3-mm advancement of the transducer between lines, in practice, most providers will put a greater or fewer number of lines in a given area depending on the severity of the features being treated.

Positioning

- Patients are typically treated on a conventional examination table or chair in an examination room in the supine or partially reclining or upright position depending on provider preference. Treatment of the submental area in the upright position can be difficult with MFUS due to runoff of the fluid within the transducer when it is upside down.

Approach

- DOCA is injected in the midlevel of the subcutaneous fat with a 30-gauge

needle.

- MFUS is delivered transcutaneously using ultrasound gel to couple the energy efficiently into the skin.

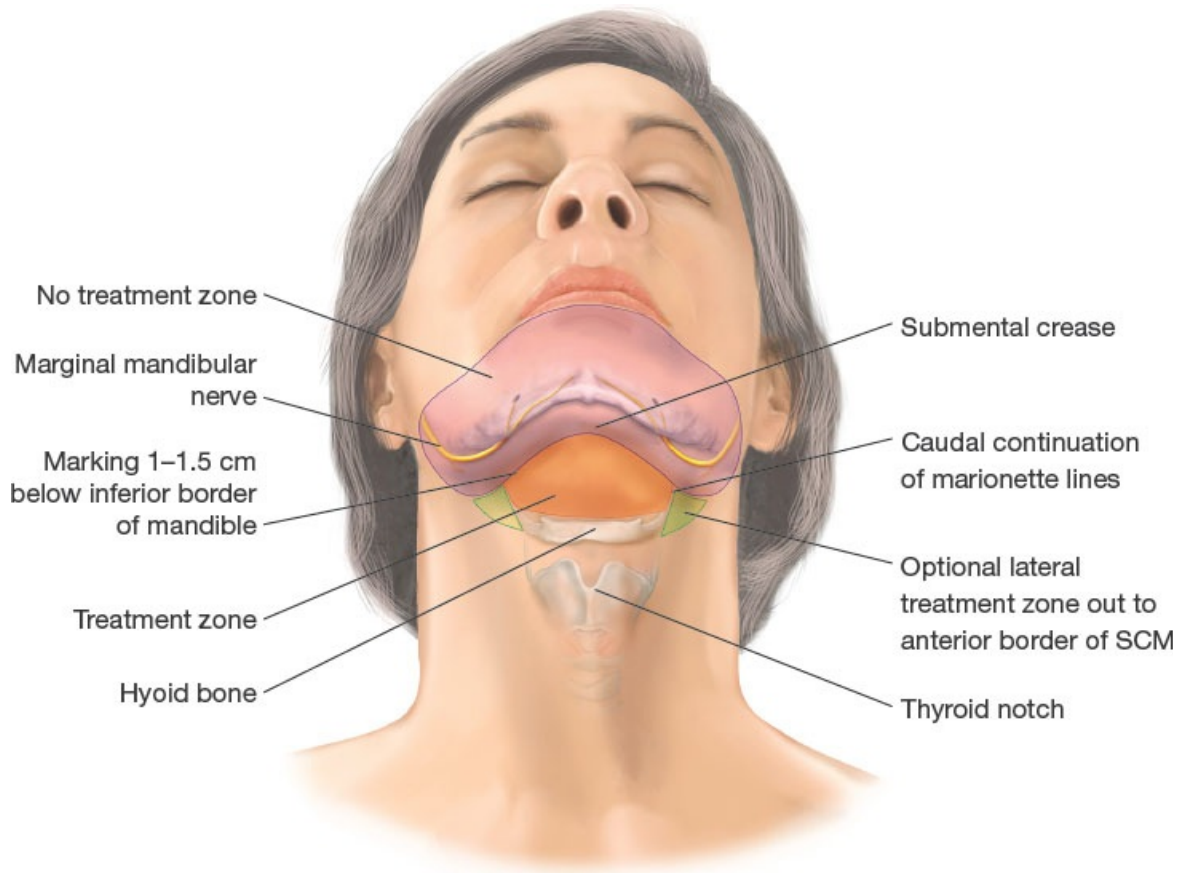
TECHNIQUES

■ Deoxycholic Acid Injection

- Marking starts with an outline of the inferior border of the mandible. A boundary marking is placed one centimeter below the inferior border of the mandible to keep the treatment away from the marginal mandibular branch of the facial nerve. The anterior border of the sternocleidomastoid muscle may be marked. Next, the thyroid cartilage is palpated and marked followed by the location of the hyoid bone. The submental crease is outlined. These are all simple anatomic landmarks (**TECH FIG 1**).
- The fat is again palpated and lateral markings are made to delimit the intended treatment zone.
- The anterosuperior border of the treatment zone will be the submental crease. The posteroinferior border will be the hyoid bone. Assessment and selection of the lateral border markings is an important judgment for the clinician, ensuring a complete treatment in an efficient fashion.
- Local anesthesia is injected into the subcutaneous fat of the treatment area to minimize patient discomfort during and immediately after the treatment. Typically, 5 mL of 1% lidocaine with epinephrine or less is required.
- A temporary marking grid is applied to guide appropriate spacing of injections. After removing the protective plastic backing, the sheet is held against the skin and moistened. Following 15 seconds of continuous gentle pressure, the application sheet is removed leaving the treatment grid markings on the skin. Use of the grid is essential to ensure appropriate dosing and density that would be difficult to produce freehand.
- Unwanted injection dots are removed with isopropyl alcohol for clarity during treatment. The remaining dots can be counted and the necessary amount of medication drawn up.
- Each 1-mL syringe holds 5 injections. Using a 30-gauge needle, 0.2 mL is injected at each point just adjacent to the grid dot to avoid tattooing the skin.

The medication is placed in the center of the subcutaneous fat, *not* intradermal or subplatysmal. Pinching up the skin at each injection site prior to insertion of the needle facilitates accurate placement of the medication.

- Once all treatment dots have been injected, the grid is removed with isopropyl alcohol and a cool compress applied.



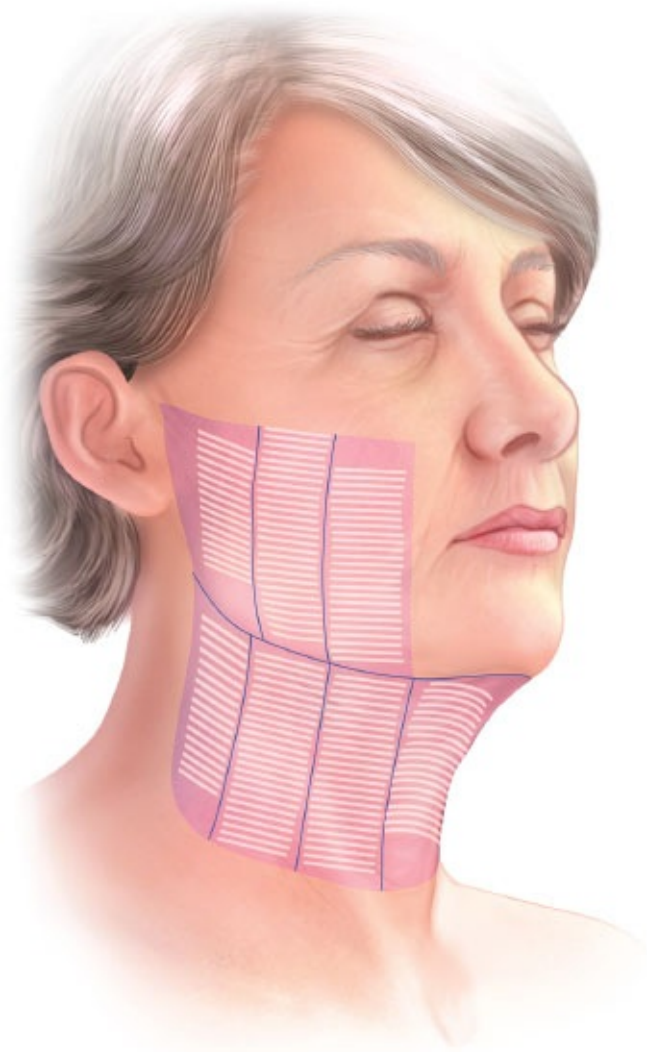
TECH FIG 1 • A diagrammatic illustration of typical pretreatment markings for DOCA injection.

■ Microfocused Ultrasound

- Columns of treatment are designed to cover the treatment area. These columns can be marked for clarity during the treatment.
- Ultrasound gel is placed on the selected treatment transducer. The deepest focal point transducer is used first, followed by successively more superficial transducers.
- The transducer is placed at one end of a treatment column and the ultrasound

image reviewed. The image must confirm adequate contact. The firing line indicates where energy will be delivered that must be aligned with appropriate target tissues such as SMAS, platysma, or deep dermis (**TECH FIG 2**).

- Once appropriate positioning and contact is confirmed, the transducer is fired, delivering the therapeutic ultrasound and placing a line of microthermal zones (MTZ) at the selected depth.
- The transducer is then advanced 3 mm or the desired distance to place the next line. This process is continued until the column of treatment is completed followed by treatment of any adjacent columns.
- After exposure of the full treatment area with the first transducer, the process is completed again with the next (more superficial) transducer. Treatments are typically bilayer and occasionally trilayer. Skin is lifted using exposures at the SMAS/platysma level with 4.5-mm focal point depth transducers and at the dermal subcutaneous junction using 3-mm focal point depth transducers. More superficial features, like transverse neck lines, can be treated using the 1.5-mm transducers.



TECH FIG 2 • Application of sound energy in a clinical MFUS treatment.

PEARLS AND PITFALLS

Injection technique

- The needle should be placed into the middle of the subcutaneous fat. This minimizes the risk of exposure of skin or deep anatomy to effects of the medication. Pinching up the skin in the fingers of the noninjection hand facilitates precision in needle placement at the appropriate depth.

Lateral jawline	■ Injection to fat in the lateral portion of the neck must avoid exposure of the marginal mandibular branch of the facial nerve. A buffer zone of 1 cm from the inferior border of the mandible is commonly used. ■ Patients who have undergone previous surgery such as facialplasty deserve extra caution due to the greater potential variation in nerve position.
Jowl	■ Although direct injection of the jowl fat is tempting, product labeling forbids injection due to concern over the marginal mandibular branch. Of course, the injection is supposed to be superficial to the platysma, and it is unclear how often the nerve even transits the jowl area en route to its muscular insertions. As of this writing, it is unknown whether this is a real or merely theoretical concern.
Injection spacing	■ DOCA should be injected using the manufacturer supplied marking grid to insure proper spacing of doses. Closer spacing can result in tissue necrosis, and wider spacing can result in loss of efficacy.²
Medication dilution	■ DOCA should be injected as supplied (10 mg/mL) without adulteration or dilution. 0.2 mL (2 mg) should be injected at each injection site. An attempt to “stretch” the medication by diluting or underdosing will result in loss of efficacy.
MFUS skin prep	■ To facilitate gliding the handpiece, avoid heavy makeup. Men should be close shaved.
Pattern planning	■ Modify standardized templates to adjust for size of the patient’s face. Select number of lines based on severity of findings.
Transducer selection	■ Transducers are selected for the anatomic structures requiring correction. Usually, this is a bilayer treatment with 3-mm and 4.5-mm depth transducers to target the dermal/subcutaneous junction and the SMAS and platysma, respectively.
Number of treatment lines	■ To create observable lifting, treatments usually deliver 400 to 700 lines to the cheek and neck areas. 200 to 300 line treatments are sometimes employed for maintenance or follow-up treatments.
Maintaining/restoring gel contact	■ Moderate pressure avoids excess thinning of the gel layer between the transducer and skin. Reapplication of gel to

	the transducer is usually more expedient than manipulation of the transducer against the skin in an effort to restore contact.
Convexities	■ Convex areas such as just medial to the sternocleidomastoid muscle are particularly prone to loss of transducer contact with the skin resulting in blistering and potential scarring.
Periocular area	■ Treatment should not be delivered within the orbital rim to avoid unintended exposure and damage to the globe.

POSTOPERATIVE CARE

- Both treatments benefit from cool compresses and nonsteroidal anti-inflammatory drugs (NSAIDs) to help minimize discomfort on the day of treatment.
- In an attempt to minimize the pronounced edema after DOCA injection, antihistamines, NSAIDs, and compression garments have been used, but formal study of this did not demonstrate any benefit.³

OUTCOMES

- Improvement in submental contour can be seen with a typical 20-injection DOCA treatment (**FIG 1**). In patients with a larger collection of submental fat, a greater number of treatments with more injections covering a larger area can be used. This provides a greater degree of improvement with durable results (**FIG 2**). Although skin laxity is generally no worse after treatment, occasional significant reduction in laxity is seen. This has not been formally studied making the degree and consistency of improvement unknown at this time (**FIG 3**).
- Fifty-five percent of subjects in one study reported a one-grade improvement in submental contour after two DOCA treatments and 75% after four treatments.⁴ Marginal mandibular paresis was reported in 4.3%, which can take several months to resolve.



FIG 1 • A 52-year-old woman who underwent a single DOCA treatment of 20 injections. **A.** Pretreatment. **B.** 2 months post treatment.



FIG 2 • A 54-year-old woman who underwent 6 DOCA treatments at monthly intervals with a total of 254 injections. **A,B.** Lateral and anteroposterior views pretreatment. **C,D.** Lateral and anteroposterior views 6 months post last treatment. **E,F.** Lateral and anteroposterior views 32 months post last treatment.

- MFUS typically reduces laxity in the neck area and sharpens the contour of the jowl/jawline area (**FIG 4**). In patients who are responders, additional treatments can be used to obtain additional improvement or to maintain the result (**FIG 5**).
- A prospective study of 93 patients treated with MFUS using the original treatment protocols (approximately 250 to 300 lines) using objective and subjective measures of response showed laxity improvement in 63.6% and 58.1% of patients at 90 days. More than half of the patients with a BMI greater than 30 did not respond.⁵

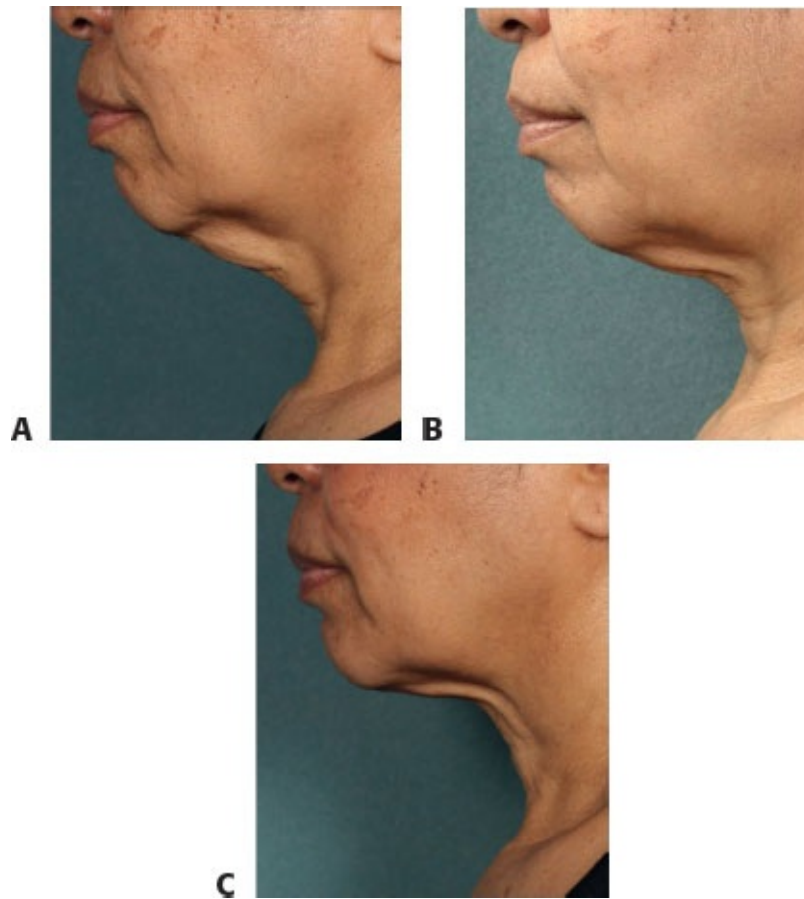


FIG 3 • A 64-year-old woman who underwent 6 DOCA treatments at monthly intervals with a total of 139 injections. **A.** Lateral view pretreatment. **B.** Lateral view 6 months post last treatment. **C.** Lateral view 32 months post last treatment.

- In another study, 67% of subjects showed improvement at 180 days post MFUS treatment. This nonresponder rate seems consistent across the available studies to date.⁶

COMPLICATIONS

DOCA

- Ecchymosis
- Edema
- Pain
- Numbness

■ Erythema

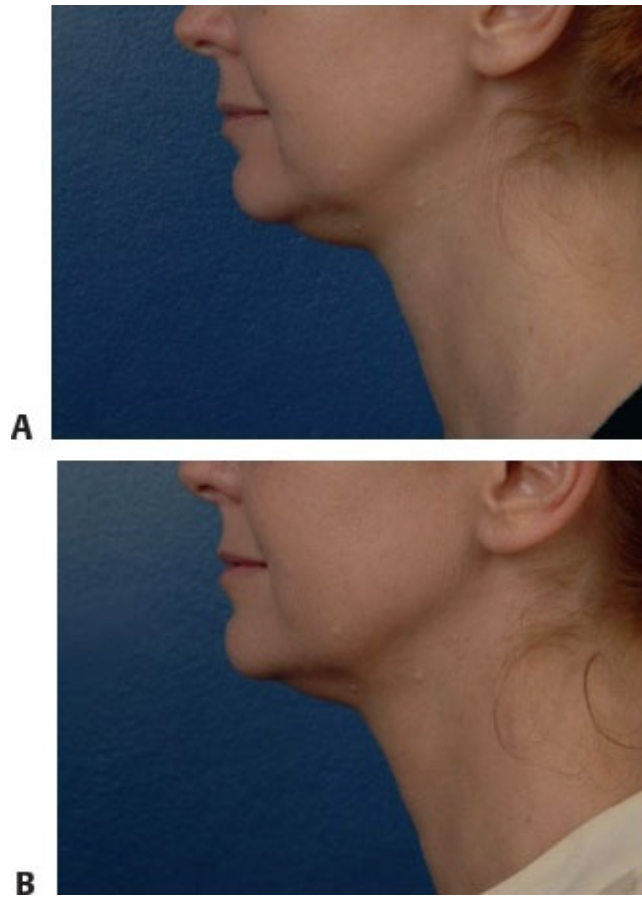


FIG 4 • A 41-year-old woman. **A.** Pretreatment. **B.** Thirteen months post a single MFUS treatment.

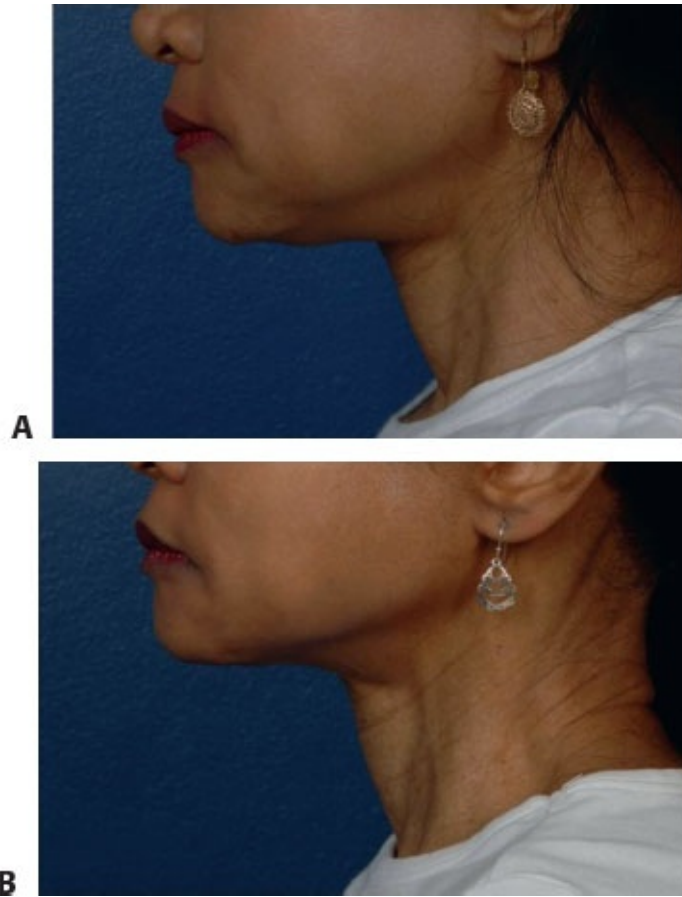


FIG 5 • A 53-year-old woman. **A.** Pretreatment age 53. **B.** Thirty months after first and 16 months after second MFUS treatment, now age 55.

- Induration
- Paresthesia
- Nodule
- Pruritus
- Dysphagia
- Facial nerve injury
- Skin loss
- Scarring
- Induration
- Nodule formation
- Facial nerve injury

MFUS

- Erythema
- Ecchymosis
- White or red wheals
- Blistering
- Scarring
- Numbness
- Facial nerve injury

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Section XI: Rhinoplasty

Indications and Technique for Closed Rhinoplasty in Patients With Dorsal Hump and Wide Tip

52

CHAPTER

Bariş Çakır and Ali Teoman Tellioğlu

DEFINITION

- The reason for a wide nasal tip is that the dome and lateral crura are wider than normal.
- The distance between the nostrils and the lateral crura is generally narrow.
- An excessively enlarged dorsal cartilage and nasal bone result in a nose with a prominent bridge that is aesthetically unacceptable.

ANATOMY

- The nose consists of mobile and immobile areas.
- The mobile part of the tip consists of the lower lateral cartilages.
- The immobile part of the nose consists of the septum, the upper lateral cartilages, the maxilla, and the nasal bones (**FIG 1**).
- The mobile nose tip is connected to the septum and the upper lateral cartilages by means of the Pitanguy and scroll ligaments. The nose tip moves up and down along these ligaments.
- The scroll and Pitanguy ligaments are formed by a thickening of the superficial musculoaponeurotic system (SMAS) at the supratip; they are functionally significant because they constitute a part of the SMAS.
- Protection and repair of these ligaments are crucial for the projection, mobility

and definition of the nose.

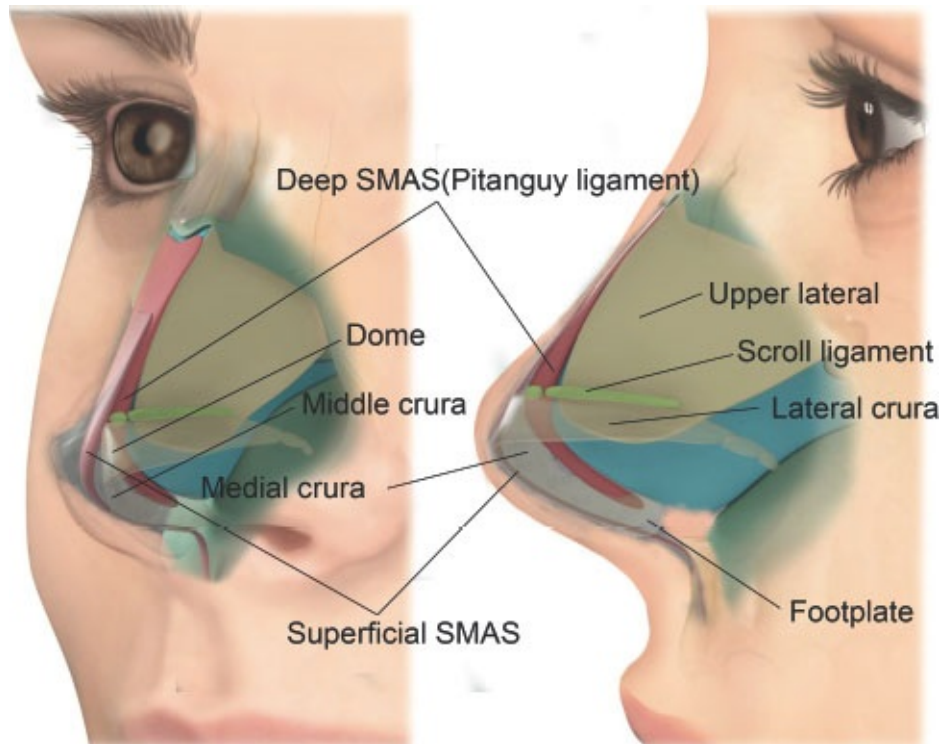


FIG 1 • The nose consists of mobile and immobile areas. The mobile part of the tip consists of the lower lateral cartilage. The immobile part of the nose consists of the septum, the upper lateral cartilages, the maxilla, and the nasal bones.

PATHOGENESIS

- The cartilages and bones that form the skeleton of the nose stand in close relation to each other.
- Many patients present with a history of trauma to the nose. Generally, one can observe a large and deviated vomer.
- Our theory is that a greatly enlarged septum pushes the upper lateral cartilages anteriorly and the medial crura caudally.
- The upper lateral cartilages pull the cephalic edge of the lateral crus anteriorly and therefore distort the resting angle of the lateral crura.
- A septal cartilage that projects antero-caudally results in the domes being formed more caudal than normal.

- The lobule is formed short, while the lateral crura are long. The nasal tip widens because the lateral crura become more dominant in the tip area.
- The convex nature of the lateral crura and the distorted reclining angle of the lateral crura result in the tip appearing wide and round (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Noses that are not in harmony with the face and have flawed internal proportions may disturb patients from an aesthetic viewpoint.
- Patients generally complain that their nasal tip is big and that they find the bridge disturbing.
- Inspection: A visual examination is most important; problems are clearly diagnosed with the help of photographs.
 - The nasal tip is wide.
 - The lobule is generally short.
 - The lateral crura are generally convex, long and wide.
 - The cephalic edge of the lateral crus is more anteriorly located than the caudal edge.
 - The dorsal septum and the nasal bones are hypertrophic.
 - Because the septum pushes the tip forward, the more than normally projecting nasal tip is likely to be pulled downward when the patient laughs.
- Palpation
 - Skin thickness directly influences the results. Strong cartilages and thin skin respond better to rhinoplasty surgery. By touching the nasal skin and examining the inside of the nasal tip with the help of a light source, we can gain valuable information about the soft tissue and cartilages.

IMAGING

- Front, base, top, lateral, and oblique photographs are standard procedure. A lateral photograph of the patient smiling gives clues about the dynamics of the nasal tip.

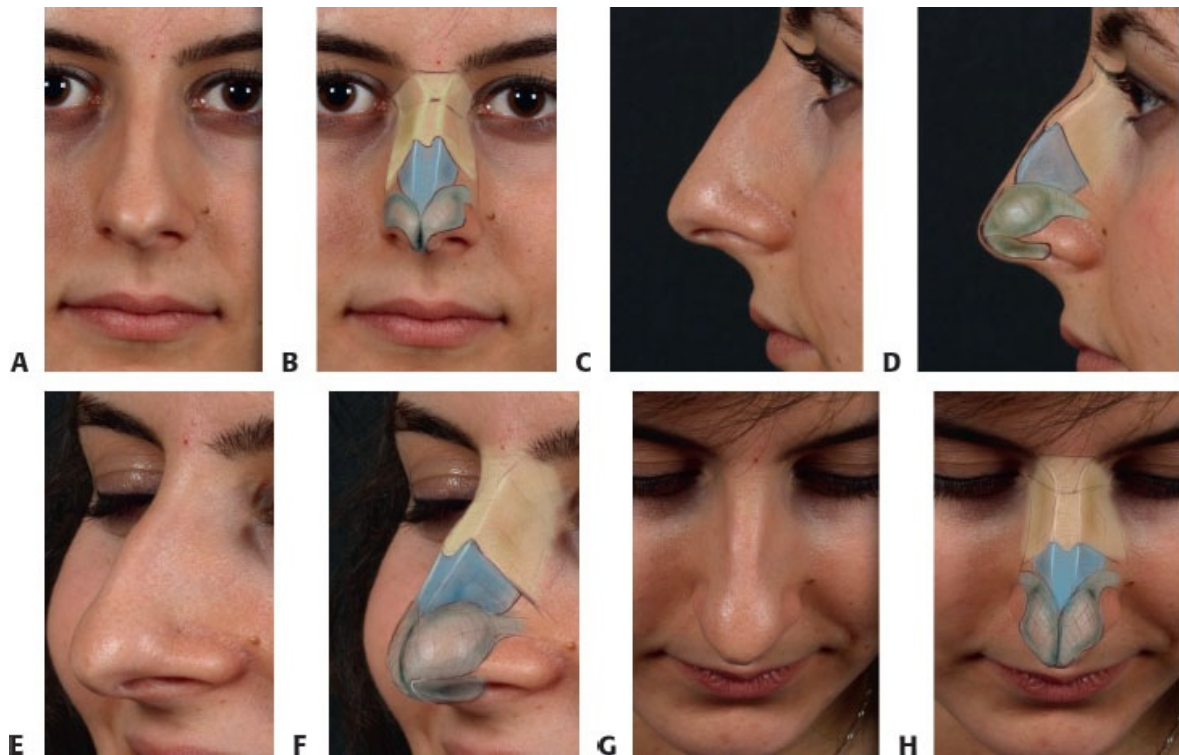


FIG 2 • A–H. The lobule is formed short, the lateral crura long. Because the lateral crura become more dominant in the tip area, the nasal tip widens. The lateral crura's convex nature and the distorted reclining angle of the lateral crura result in the tip appearing wide and round.

- An SLR camera of medium quality is sufficient. One can obtain a detailed and standard photographic archive with a 100- or 105-mm fixed macro lens.
- On close-up photographs, the nasal tip appears wider. In order to objectively depict the changes in the nasal tip, the camera's focal length has to remain the same.
- A black or blue background is preferable. A black background prevents a black shadow and looks better but may render the hair invisible. Blue is a color more appropriate for scientific purposes.
- Lighting changes the photographic results. The double softbox system is standard. To obtain standardized photographs, patient, the doctor and the lighting need to remain in the same location. It is advisable to draw a circle on the floor about 1 to 2 m in front of the background curtain.

- **Lighting:** To understand the lighting technique, one has to look at the eyes first. If the light reflection is not the same between the preoperative and postoperative photographs, it is difficult to make a comparison.
- **Fish-eye effect:** If the before photograph is taken with a fish-eye effect, the ears will not be visible. It is not possible to draw a meaningful comparison between two photographs with unequal focal distances.

SURGICAL MANAGEMENT

- Rhinoplasty surgery began in the form of closed reduction; however, a more controlled resection and reconstruction with an open rhinoplasty technique have become more popular.
- Closed surgery based on an intracartilaginous approach, where the surgeons could not see the tip cartilages, has quickly lost popularity. Because control is difficult to achieve, more inexperienced surgeons do not prefer this technique because it is difficult to achieve control.
- Because it is easy to learn and perform open rhinoplasty, this technique has gained great popularity in recent years.
- Although open rhinoplasty allows for more control, side effects such as rigidity and numbness are quite bothersome.
- In an effort to combine the control of open rhinoplasty techniques with the fast healing of the closed rhinoplasty, “open rhinoplasty with endonasal approach” has become an alternative approach. We named this philosophy as the “preservation rhinoplasty.”

Preoperative Planning

- It is important to do the imaging work on a lateral photograph before the surgery.
- By doing the imaging work together with the patient, we can learn about the patient’s expectations.

Approach

- Make a transfixion incision on one side (if the surgeon is left handed, on the left side; if right handed, on the right).
- Enter under the dorsal perichondrium from the septal angle and dissect as far as under the dorsal bone. In this area, the Daniel-Cakir blunt perichondrium elevator is particularly useful.
- Enter under the upper lateral perichondrium and dissect caudally as far as the

scroll area (**FIG 3**).

- If there exists a caudal excess of the lateral crus, make an intracartilaginous incision in such a way that 2 to 3 mm of the caudal edge of the lateral crus is left in the skin. The cartilage left in the skin is called an auto-rim flap.¹



FIG 3 • Enter under the upper lateral perichondrium and dissect caudally as far as the scroll area.

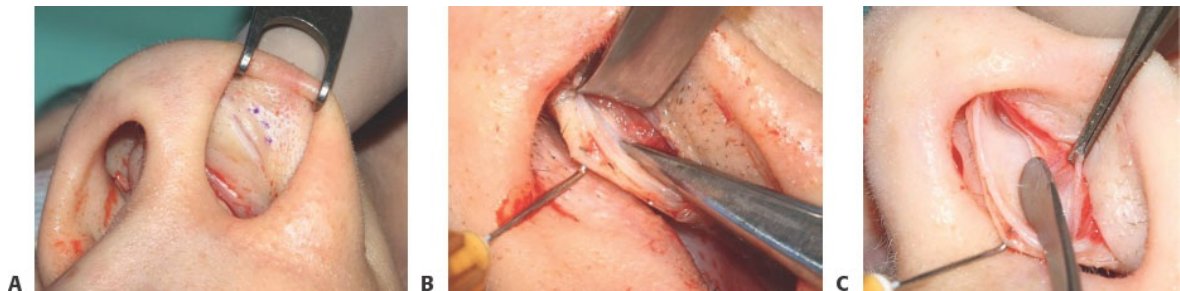


FIG 4 • **A–C**. Beginning from the turning point of the lateral crus, dissect the lower lateral cartilage by means of a subperichondrial dissection.

- Make an infracartilaginous incision to the dome and medial crus.
- Beginning from the turning point of the lateral crus, dissect the lower lateral cartilage by means of a subperichondrial dissection (**FIG 4**).
- Pulling the domes laterally with a hook, dissect the domes. Dissect the medial crura subperichondrially to the level of the footplates. In this area, the Daniel-Cakir sharp perichondrium elevator is particularly useful (**FIG 5**).
- Join the two dissections in the scroll region and expose the caudal edge of the

bones.

- Enter under the periosteum by scratching the caudal edge of the bones with an elevator.
- Dissect the nasal and maxillary bones subperiosteally. In this area, the Daniel-Cakir periosteum elevator is particularly useful.
- Carefully join the subperiosteal dissection planes in the midline.
- Beginning from the upper lateral caudal edge, dissect the internal valve mucosa subperichondrially.

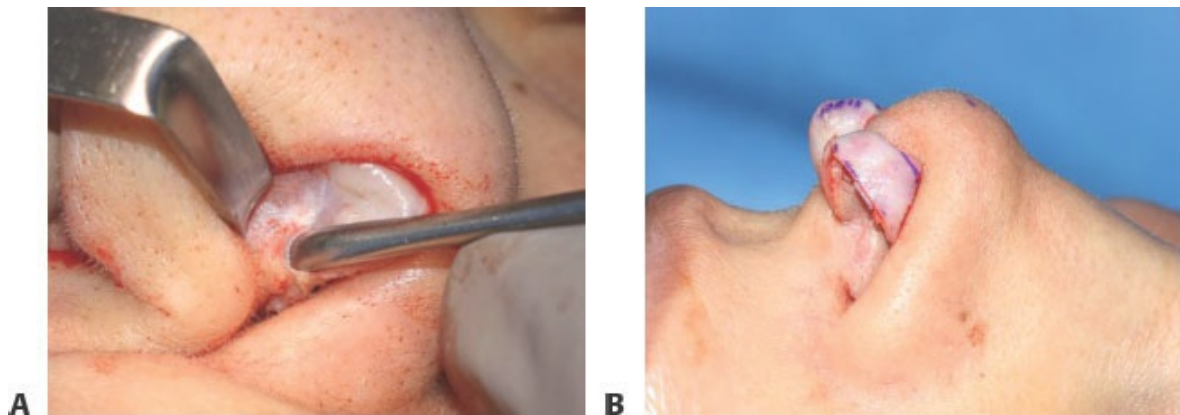


FIG 5 • A,B. Pull the domes laterally with a hook and dissect the domes. Dissect the medial crura subperichondrially until the footplate. In this area, the Daniel-Cakir sharp perichondrium elevator is particularly useful.

TECHNIQUES

■ Dorsal Resection

- Resect the cartilage hump as a composite (**TECH FIG 1A,B**).
- Resect the exposed right and left nasal bone with bone scissors (**TECH FIG 1C,D**).
- If the radix is high, rasp the radix. Reduce the radix in a controlled way without causing the glabella to swell.
- File down any asymmetries of the bony surface to create a symmetrical

appearance. A bone file, mastoid bur or rasp can be used for this purpose.

- Medialize the bone flaps with the help of lateral osteotomy, or lateral osteoectomy and median oblique and transverse osteotomies (**TECH FIG 1E,F**). Performing this procedure after tip surgery reduces swelling.

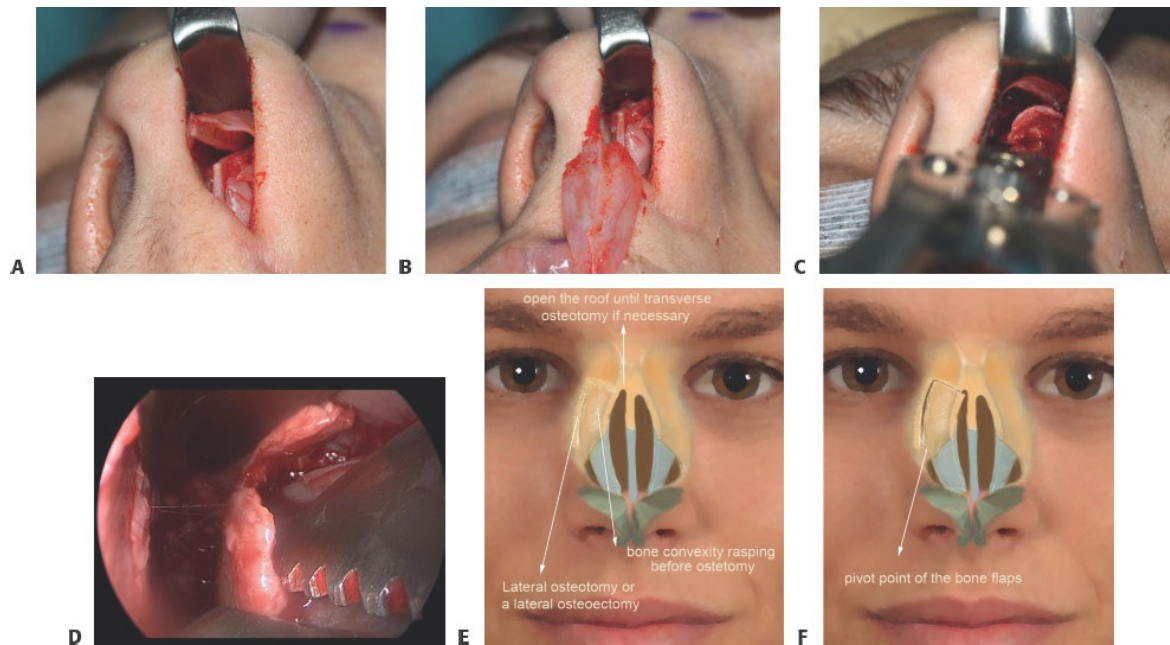
Tip Surgery

- Extract the domes from each nostril by dissecting the superficial musculoaponeurotic system (SMAS) from the deep SMAS.
- Determine the correct length of the lateral crus by stealing from the lateral crus.
- Shape the new domes with a cephalic dome suture¹ (**TECH FIG 2A,B**).
- Extract both domes through the nostril closer to you and let the assistant hold the dome farther away from you at the midline with the help of a hook.
- Join the domes by suturing the soft tissue between the domes. This suture will assist with equalizing the domes (**TECH FIG 2C,D**).
- Equalize the domes with a figure-of-8 suture.
- Place the strut graft between the medial and middle crura with sutures. Stabilize the tip of the strut cartilage graft with a U suture passing through the domes, stabilize the tip of the strut cartilage graft.
- Reconstruct the columellar break point, the lobule and the columella with a 6-0 PDS suture (**TECH FIG 2E**).
- Place the lower lateral cartilages in such a way that the superficial SMAS fits into the gap between the medial and middle crura.

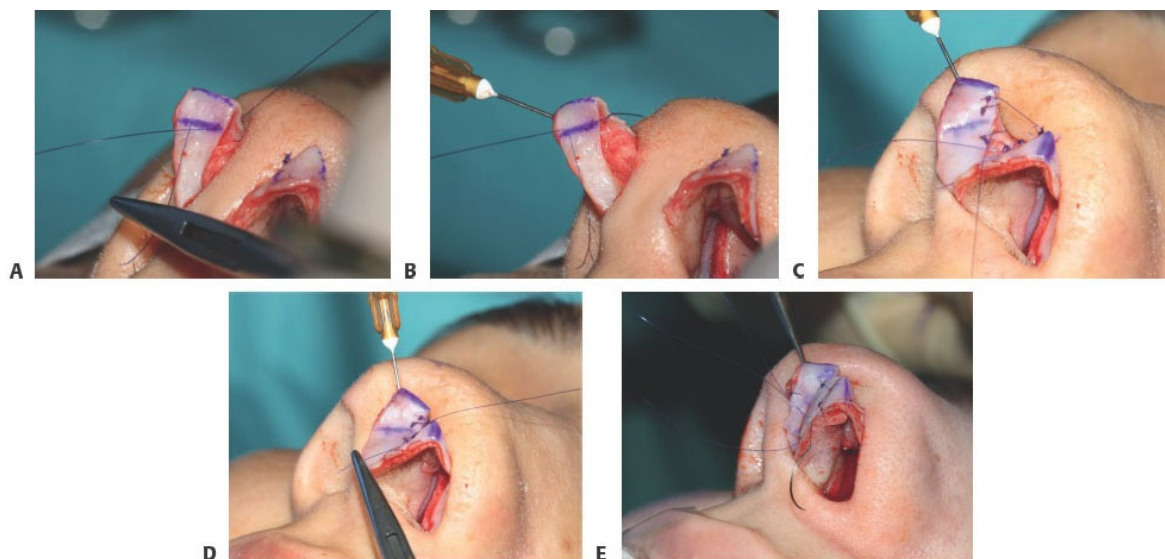
Dorsal Reconstruction

- Shape the cartilage that has been resected as a composite and place it as a spreader graft (**TECH FIG 3A–D**).
- Repair the scroll ligaments (**TECH FIG 3E,F**).
- Close the mucosa with a 6-0 Monocryl.

For more detail, see the handbook on Aesthetic Septorhinoplasty.

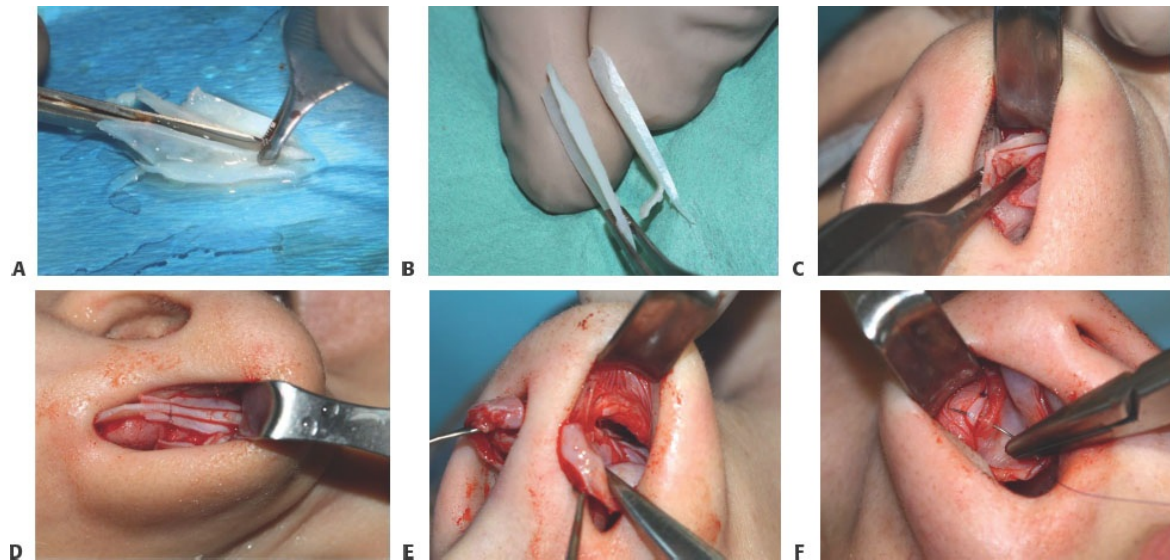


TECH FIG 1 • **A,B.** Resect the cartilage hump as a composite. **C,D.** Resect the exposed right and left nasal bone with bone scissors. **E,F.** Medialize the bone flaps with the help of lateral osteotomy, or lateral osteoectomy and median oblique and transverse osteotomies.



TECH FIG 2 • **A,B.** Shape the new domes with a cephalic dome suture. **C,D.** Join the domes by

suturing the soft tissue between the domes. This suture will assist with equalizing the domes. **E.** Reconstruct the columellar break point, the lobule and the columella with a 6-0 PDS.



TECH FIG 3 • A–D. Shape the cartilage that has been resected as a composite and place it as a spreader graft. **E,F.** Repair the scroll ligaments.

PEARLS AND PITFALLS

Osteotomy contraindications

- When performing a wide dissection to the dorsum, an osteotomy with a lateral osteotome is contraindicated. The bones may collapse. If you perform an osteotomy, do so by entering from the cut on the skin or the rim incision with a 2-mm chisel.

Dissection

- Subperichondrial dissection decreases the risk of damage and progressive thinning of the soft tissue, and it helps to protect the scroll ligament. It is easy to enter the subperichondrial plane where the cartilage is thick. A good dissection is the best camouflage.

Pitanguy midline ligament	■ A closed approach does not interfere with the Pitanguy ligament next to the columellar system. This is very beneficial to control the supratip skin.
Bruising, swelling	■ Insert an intravenous tube splinted with a scalpel next to the nasal bone to decrease swelling.
Imaging	■ We can plan rotation, projection, and resection with the help of the imaging work. Increasing the tip rotation and projection as well as filling the deep radix reduces the amount of dorsal resection. Imaging prevents us from over-resection.
Head lamp	■ For closed surgery, a headlight is absolutely necessary. In order to be able to see the deepest areas of the dissection, surgeons should align the lamp with their own radix.

POSTOPERATIVE CARE

- Carefully tape the nose without squeezing the tip. If the tape pinches the nose tip caudally, the positioning of the tip cartilages can be damaged.
- Because thermoplastic plaster is water resistant, the patient may shower every day.
- Applying tape underneath the eyes decreases swelling and bruising.
- The patient can be discharged after 3 to 4 hours.
- In case of swelling, a cold compress can be applied. Cold compresses are not routinely used after wide dissection and inserting drains.
- The patient rests in bed with the head elevated.
- Paracetamol with codeine is sufficient for pain management.
- To treat bone edema, diclofenac potassium can be prescribed from day 5 to 10.
- After the preoperative prophylaxis, there is no need for antibiotics after preoperative prophylaxis.
- Saltwater irrigation can be done for 10 days.
- Internal silicone dolly splints can be removed after 2 to 4 days.
- After 10 days, the cast is removed. Generally, no more tape is used.

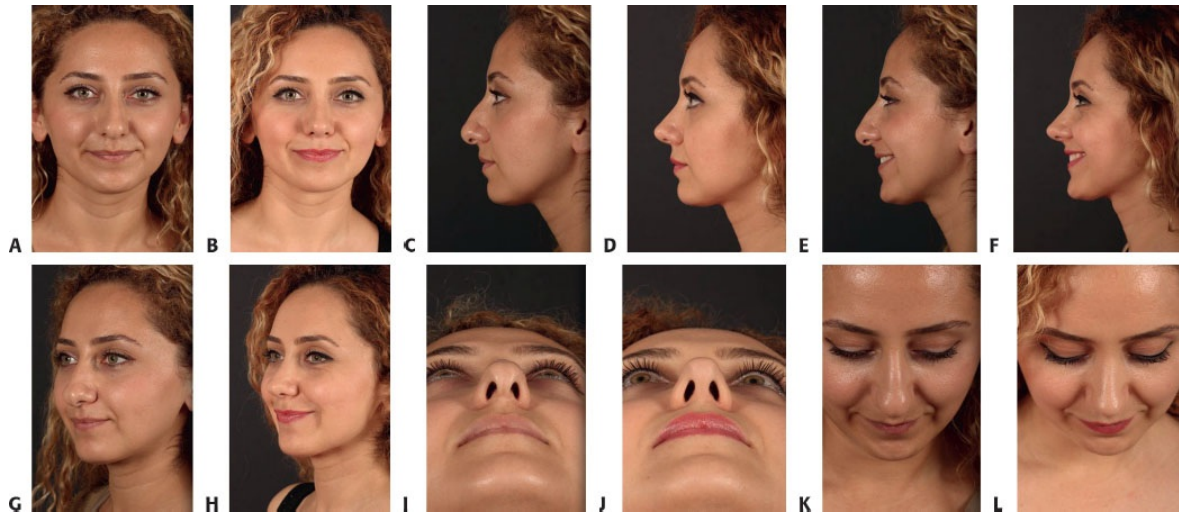


FIG 6 • A–L. Patient example. 1-year result.

OUTCOMES

- Over the past 10 years, we have performed approximately 2000 rhinoplasties.
- In 5% of the cases, a revision was necessary. As experience increases, the percentage of revisions decreases.
- Most revisions are performed due to rotation loss and dorsal residual hump and irregularities.
- For the first 3 years, we performed open rhinoplasty. During that time, we observed a more frequent occurrence of supratip deformity.
- Thereafter, we performed closed rhinoplasty for 7 years. Protecting the Pitanguy ligament increased control of the supratip skin.
- Over the past 4 years, we have been mobilizing the bone at the level of the medial canthus by performing a lateral osteoectomy rather than a lateral osteotomy. In this way, less of an infracture occurs at aperture. We receive fewer complaints concerning breathing problems.
- A case study with hump and bulbous tip (**FIG 6**).

COMPLICATIONS

- Irregularity of the dorsum
- Loss of rotation
- Loss of projection
- Tip asymmetry
- Bleeding

■ Infection

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Indications and Technique for Treating the Narrow Midvault in Closed Rhinoplasty

CHAPTER

Shruti C. Tannan, Jeffrey R. Claiborne, and Mark B. Constantian

DEFINITION

- A narrow middle vault can be defined anatomically or functionally.
- Anatomically, a narrow middle vault is defined as any part of the upper cartilaginous vault that is at least 25% narrower than the upper or lower nasal third.
- Functionally, a narrow middle vault is defined as inadequate internal nasal valve support.

ANATOMY

- The middle vault is composed of the paired upper lateral cartilages (ULCs) and the dorsal nasal septum.
- The ULCs extend superiorly beneath the paired nasal bones approximately 5 mm, in a region known as the keystone area.
- Laterally, the ULCs attach to the bony piriform aperture via the piriform ligament.
- Inferiorly, the ULCs are supported by their attachment to the lower lateral cartilages in a region called the scroll area.
- Aesthetically, the middle vault is the location of a smooth transition from the narrower nasal bones superiorly to the wider nasal base inferiorly.
- In the midline, the ULCs fuse with the septum to create a T in cross section, an intersection that creates an angle known as the internal nasal valve (**FIGS 1**

and 2).

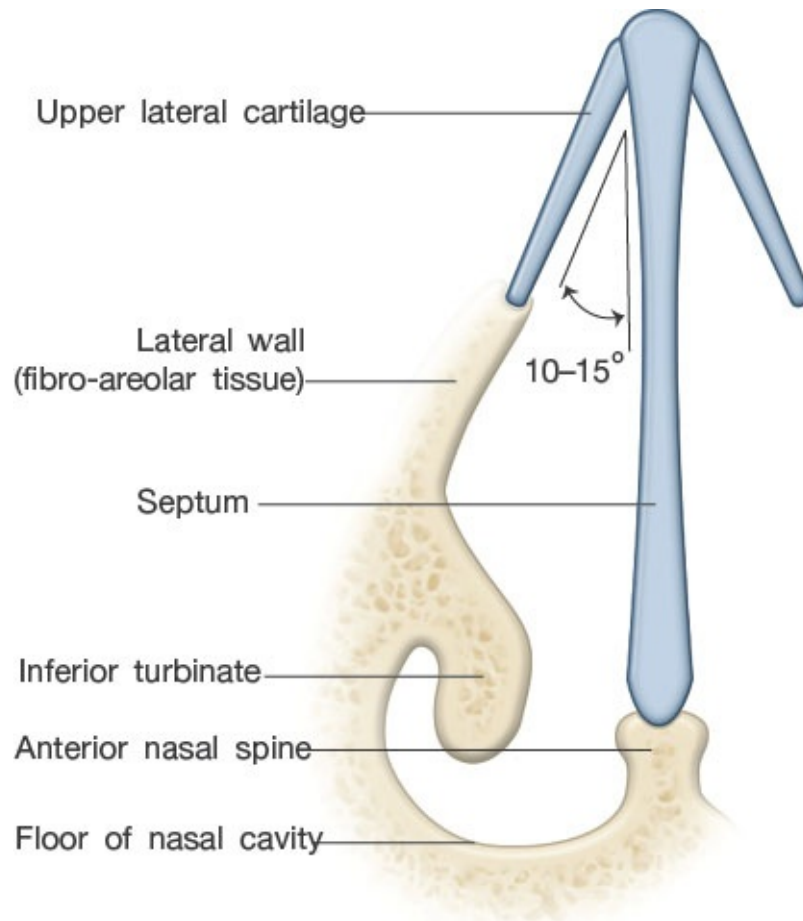


FIG 1 • Internal nasal valve.

- The internal nasal valve is bounded medially by the septum, laterally by the ULCs, and inferiorly by the inferior turbinate.
- The internal nasal valve is the narrowest portion of the nasal airway and therefore the site of highest airflow resistance.
- The width and stability of the middle vault, the critical area of the internal nasal valve, is determined by three factors:
 - Width of the nasal bony vault
 - Height and width of the middle vault roof
 - Soft tissue rigidity

PATHOGENESIS AND NATURAL HISTORY

- As air enters the region of the narrow internal nasal valve, airflow speed

increases according to the Poiseuille law and the Venturi principle: when air goes through a narrow passage, it speeds up and increases the transmural pressure on the nasal sidewall, just as water running through a brook speeds up as it passes between a narrow channel. Additionally, the Bernoulli principle dictates that with increased flow speed, the intraluminal pressure decreases, which places the valve at risk for collapse from the lower pressure.

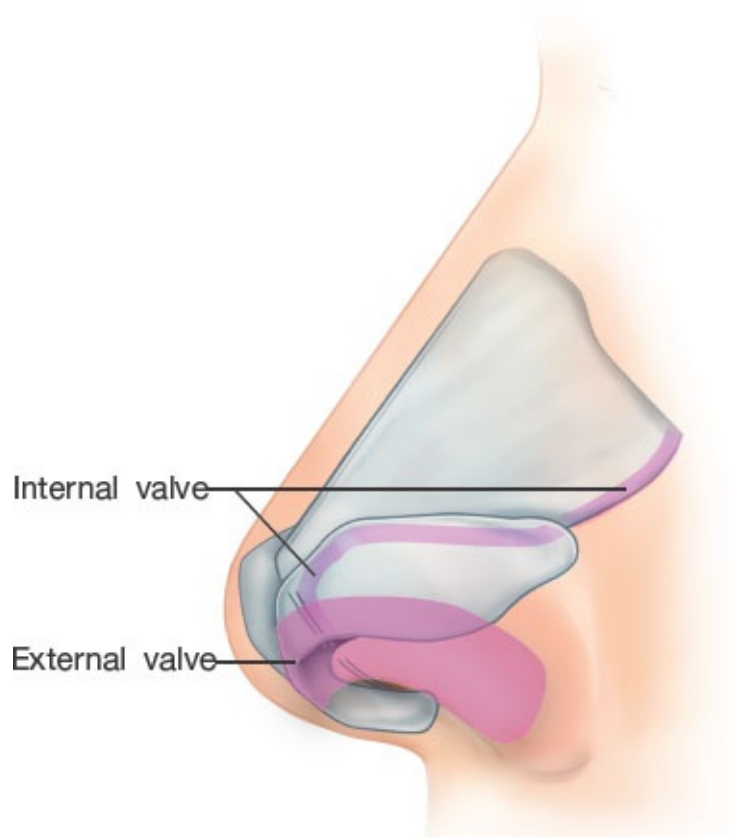


FIG 2 • Nasal valves.

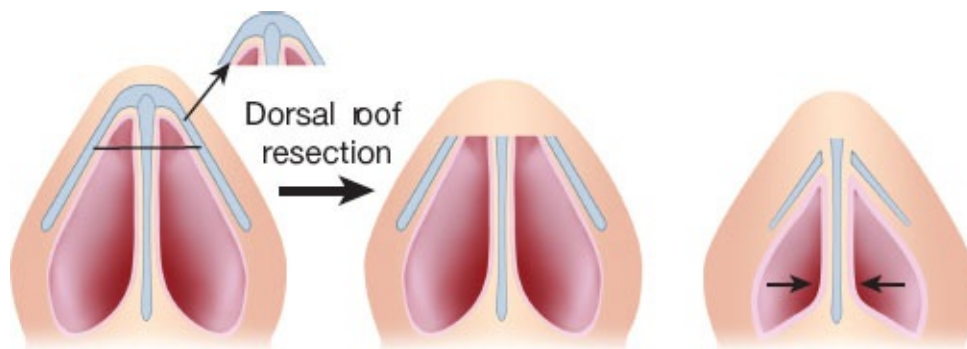


FIG 3 • Pathogenesis of iatrogenic middle vault collapse.

- Poiseuille law states that flow is proportional to the radius to the fourth power. Thus, seemingly diminutive changes in middle vault size have dramatic implications in nasal airflow.
- A decrease in middle vault size or weakening of the structural integrity of the nasal valve places the patient at risk for nasal airflow obstruction.
- Any resection of the middle vault roof greater than 2 mm during hump reduction destabilizes this most critical area, allowing the upper lateral cartilages to fall medially and produce a characteristic “inverted V” deformity and result in obstruction at the internal valves (**FIG 3**).
- Reducing the dorsum and creating an open middle vault and interval valvular incompetence will decrease the postoperative airway by 50%.
- The middle vault and internal nasal valve are at risk in three specific circumstances:
 - The midvault is congenitally narrow.
 - The nasal bones are short, therefore leaving a larger proportion of nasal sidewall supported by the ULCs (internal valves) and the lateral crura (external valves).
 - The surgeon reduces the dorsum by more than 2 mm, which in most patients will open the cartilaginous roof.
- The most common motivation for secondary rhinoplasty is an iatrogenic deformity from the previous surgery.¹
- A narrow middle vault has been shown to be present preoperatively in 38% of primary and 87% of secondary rhinoplasty patients.²
- A study of 600 consecutive patients undergoing surgery for airway obstruction between 1991 and 2008 with a mean follow-up of 27 months found the following²:
 - Septal and valvular surgery corrected the airway obstruction in more than 95% of patients in a single operation, despite the fact that two-thirds of patients were secondary rhinoplasty patients with more severe deformities.
 - Septoplasty improved airflow ipsilateral to an obstruction but made no impact on total nasal airflow.
 - Internal valvular reconstruction with dorsal or spreader grafts doubled nasal

airflow.

- Dorsal and spreader grafts were equally effective at improving nasal airflow.
- External valvular reconstruction doubled nasal airflow.
- The greatest improvement in nasal airflow was observed after both internal and external valvular reconstruction (a fourfold improvement in airflow).
- Septoplasty in addition to valvular surgery did not offer any clinical benefit compared with valvular surgery alone.
- In patients with lateralized symptoms, the septum was deviated away from the obstructed side in 45% of cases, thus emphasizing the importance of valvular obstruction in creating airway symptoms.
- Of the 384 secondary rhinoplasty patients, 94% had previously undergone adequate septoplasties but were still symptomatically obstructed. Within this group, valvular reconstruction alone corrected the airway in 97% after one operative procedure.
- When primary and secondary rhinoplasty patients were stratified, the improvement in primary patients equaled or exceeded the improvement achieved in secondary rhinoplasty patients in six of the eight obstructed sites examined.
- Valvular obstruction was 4 times more common than pure septal obstruction in primary rhinoplasty patients and 12 times more common than pure septal obstruction in secondary rhinoplasty patients.
- When the entire 600-patient group was stratified, the greatest improvement was observed in those patients observed for more than 12 months, suggesting that the airway continues to enlarge as postoperative edema resolves.
- By measuring airflow during quiet and forced inspiration, sidewall stiffness could be quantified and increased following valvular reconstruction by dorsal, spreader, or alar wall grafts.
- Based on this study indicating that reconstruction of the internal nasal valve can double airflow, iatrogenic injury to the internal nasal valve can conversely reduce airflow by 50%, and this assumption has been corroborated by recent studies.³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Four anatomic findings place patients at high risk for unfavorable results and should be identified preoperatively.⁴
 - Low radix or low dorsum
 - Inadequate tip projection

- Narrow middle vault
- Alar cartilage malposition
- Of these four, narrow middle vault and alar cartilage malposition (cephalic rotation of the lateral crus) impact the airway because they indicate preoperative threats to the internal and external nasal valves, respectively.
- The exam findings of an obstructing septum or turbinate do not often correlate well with patient symptoms.²
- Patients frequently breathe better on the apparent “obstructed” side, indicating that septal and turbinate obstruction do not explain the entire airway dysfunction.
 - Eighty percent of nasal septa in the population are deviated, yet only a small portion have clinical obstruction
- Patients with straight septa or prior successful septoplasty and turbinectomy frequently still have persistent symptoms of nasal obstruction.
- History
 - Organized approach to obtaining history: first inquire about the airway and subsequently discuss aesthetic concerns.
 - Many patients become accustomed to a poor nasal airflow and have forgotten how much better their airway used to be prior to trauma or other surgeries—thus, this part of the history requires that the physician guide the interview with direct questions.
 - It is important to inquire about a history of prior trauma because unhealed septal fracture lines may extend to the dorsal septal edge and therefore threaten dorsal strut stability.
 - Recent trauma (within 3 months) is an indication to postpone the rhinoplasty until any fractures have healed and until postoperative edema allows accurate judgment of the aesthetic contours.
 - Ask about periodic or cyclic airway obstruction including which airway is worse, any nasal trauma history, seasonal allergies, clear rhinitis and suppurative sinusitis, snoring, epistaxis, sinus headache, frequent nose blowing, and what nonsurgical remedies the patient has tried to date.
 - Often, secondary rhinoplasty patients with poor airways chronically self-medicate with steroid or vasoconstrictive sprays that must be identified and discontinued before surgery.
 - Also important are the patient’s work environment and a history of tobacco or alcohol consumption (either of which may cause nasal congestion) and

cocaine use.

- Valve examination: Watch your patients breathe!
 - Sidewall collapse with inspiration is surprisingly common. If this occurs, it is important to determine the etiology (prior surgery, intrinsic weakness, cartilage malposition).
 - Perform a modified Cottle maneuver and compare airflow between sides. This maneuver is not specific, because even with septal deviation, traction on the sidewall will open the airway. Obstruction must be localized at the valves before valvular surgery is undertaken.
 - Support the collapsing area with a cotton-tipped applicator soaked in 1% pontocaine hydrochloride for the patient's comfort. Patients with valvular incompetence will notice an obvious and gratifying increase in airway size; thus, you can guarantee that valvular reconstruction will improve the airway similarly.
 - It is important to assess whether a high septal deviation exists because hump removal will unmask the curvature: in the middle of the operation, the nose can suddenly look newly asymmetrical. When a high septal deviation exists, the surgeon needs to be prepared to place unilateral or asymmetric spreader grafts. The correction is straightforward, but the surgeon must be attentive to new intraoperative deformities.
- Turbinates
 - Obstructing turbinates are relatively low in the hierarchy of causes of nasal obstruction.
 - Given their function to warm and humidify air, turbinate reductions should be planned conservatively.
 - Because the majority of turbinate hypertrophy is due to bony (not mucosal) overgrowth, most patients should be treated with turbinate crushing and outfracture.⁵ If septal and valvular causes of airway obstruction have been corrected, the turbinates will not become enlarged again, unless the patient is atopic.

IMAGING

- Accurate photographs are imperative for consultation, formulation of an operative plan, and intraoperative guidance.
- Views should include full head and close-up frontal views, both oblique views (which often differ, particularly in patients with nasal asymmetry), both lateral views, and an inferior view.

- Photographs are best taken with a portrait focal length lens (90 to 105 mm) against a medium–dark background, lit so that symmetries and contours will be depicted accurately.
- Camera-mounted flash units are inferior to studio systems with umbrella lights or wall-mounted strobes to light the face evenly, provide backlighting, and illuminate the face and hair.

SURGICAL MANAGEMENT

- The great majority of functional nasal deformities can be corrected with only one of two operative strategies: spreader or dorsal grafts for internal valvular obstruction and alar wall grafts for external valvular obstruction. Each at least doubles airflow in most patients. Done correctly, these three procedures always work.
- For the patients presenting with nasal obstruction and/or a narrow middle vault, spreader grafts or dorsal grafts must be placed to support the lateral walls.
- Although some surgeons prefer autospreader grafts or spreader flaps where redundant ULC is turned in medially, their effectiveness at treating internal valve collapse has not shown promising results.^{6,7}
- Other options for middle vault support include spreader flaps, tension suturing techniques,⁸ and butterfly grafts.^{7,9,10} Long-term functional outcome studies supporting these alternative techniques are lacking at this time, and current evidence indicates that tension sutures are ineffective. There is another theoretical problem with tension sutures: creating a barrel effect in the middle vault is not physiologic. The nasal airway needs variable resistance (which means a movable sidewall) during both inspiration (so that the alveoli can open) and exhalation (so that O₂ and CO₂ transfer can occur). The constant, widely open middle vault eliminates that necessary movement. Spreader grafts, however, have a solid foundation of literature supporting their long-term efficacy in both preventing and correcting middle vault collapse.²

Preoperative Planning

- Fallacies in planning: there are two common false assumptions that underlie the logic of reduction rhinoplasty that lead to unsatisfactory results.
- False assumption number one: *The nasal soft tissue cover has the infinite ability to contract to the shape of any underlying skeleton.*
- The nasal skin sleeve contracts according to its quality, thickness, and

preoperative distribution, and not necessarily to the shape of the surgically reduced skeleton. The vectors of skin sleeve contraction are related to the volume and contour of the underlying skeleton, and the end result of reduction with a skin sleeve that cannot sufficiently contract to the reduced skeleton is the supratip deformity.

- False assumption number two: *Alterations in the nasal skeleton produce purely regional changes.*
- The classic application of this assumption is the common strategy in which the surgeon plans to resect all nasal dorsum anterior to a straight line drawn from the nasal radix to the point of the tip. Underlying this strategy is the assumption that dorsal reduction affects bridge height alone. Changes in the nasal skeleton are not independent, however, but rather have global effects outside their areas. Resection of the nasal bridge affects nasal width and length, apparent nasal base size, middle vault support, alar rim contour, and columellar position. Similarly, alar cartilage reduction can affect tip support and projection, nasal length, alar rim contour, and external valvular support. These structural interdependencies are not just regional. Recognizing this interplay is essential to effective preoperative planning, interpretation of intraoperative nasal appearance, postoperative success, and predictable correction of secondary deformities.
- One of the most important preoperative unknowns is the condition and quality of the cartilage graft material available. The appeal of alloplastic materials is their predictability on the day of surgery. However, the consistent longevity and intrinsic characteristics of autografts has not been duplicated with any alloplastic materials currently commercially available.
- The dorsum requires the straightest, smoothest graft—ideally septum, but autologous rib works as well.
- In planning graft placement, the surgeon should consider areas needing augmentation based on preoperative assessment as well as areas that may need grafts because of the surgical approach; for example, disequilibrium that the surgeon has created during reduction (ie, spreader grafts to support the internal valves after resection of the cartilaginous roof).
- The augmentation phase of any rhinoplasty re-establishes the preoperative nasal equilibrium and alters contours in ways that reduction alone cannot. The nose that is equilibrated at the conclusion of the procedure is less likely to change during healing and therefore gives the surgeon greater control over the result.

Positioning

- The operation is routinely performed under general anesthesia.
- The patient is placed supine, and the table is positioned in 10 to 15 degrees reverse Trendelenburg to minimize bleeding.
- The nose is blocked with 1% Carbocaine with epinephrine 1:100 000 (Carbocaine has a longer analgesic effect and intrinsic vasoconstrictive properties).
- Nasal vibrissae are shaved and the nose is thoroughly cleaned, inside and out, with povidone-iodine solution.
- Cotton packs soaked in 4% cocaine solution are placed in each airway.

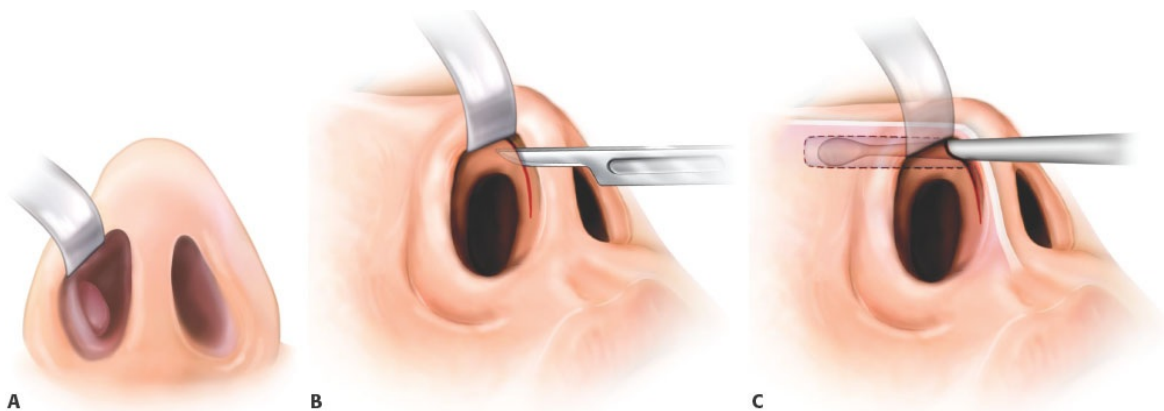
Approach

- Endonasal rhinoplasty is an operation designed around changes in the skin surface—the underlying framework is adjusted only as much as is necessary to accomplish skin surface changes and functional airway changes.
- The endonasal rhinoplasty surgeon exposes only those anatomical parts that need correction and are directly related to changes that the patient wants. This principle creates the unique advantage of not subjecting any other nasal areas to possible iatrogenic deformities. *Primum non nocere* (first, do no harm)—if you expose areas unnecessarily, you put them at risk for postoperative problems.
- Skin sleeve movement, nasal balance changes, and the effects of reduction and augmentation all depend on an ability to see the undisturbed nasal surface accurately. This is what the patient sees and what matters.
- The nasal soft tissues create half the nasal shape: without being able to assess the skin surface accurately, the surgeon forfeits half of the information that is available to make the operation a success.
- Making changes through limited incisions and judging progress by feeling the surface simplifies some maneuvers and minimizes the need for graft fixation; crushed grafts can be used in ways that would be tedious or impossible with the open approach.

TECHNIQUES

■ Endonasal Access

- Unilateral or bilateral intercartilaginous incisions are preferred—the incision runs from the lateral end of the caudal reflection of the upper lateral cartilage around the septal angle. The surgeon making only functional corrections needs a single intercartilaginous incision that exposes the septal angle (**TECH FIG 1**).
- Joseph scissors and then a broad Cottle periosteal elevator are used to elevate the soft tissues off the bony and upper cartilaginous vaults if the surgeon plans a rhinoplasty; if not, the dorsum is not skeletonized.
- If no transfixion incision is necessary, the intercartilaginous incision stops at the junction of the anterior and middle thirds of the membranous septum; if the caudal septum requires shortening, the incision can be carried toward the anterior nasal spine.



TECH FIG 1 • Endonasal access and creation of spreader graft tunnels. It is important to leave an adhesion between the mucoperichondrial edge and the anterior edge of the septum to prevent graft displacement.

■ Spreader Graft Tunnels

- When needed, spreader graft tunnels are performed before septoplasty. Spreader graft tunnels are facilitated by prior infiltration beneath the mucoperichondrium with local anesthetic.
- By identifying the septal angle, the surgeon can incise to cartilage beneath

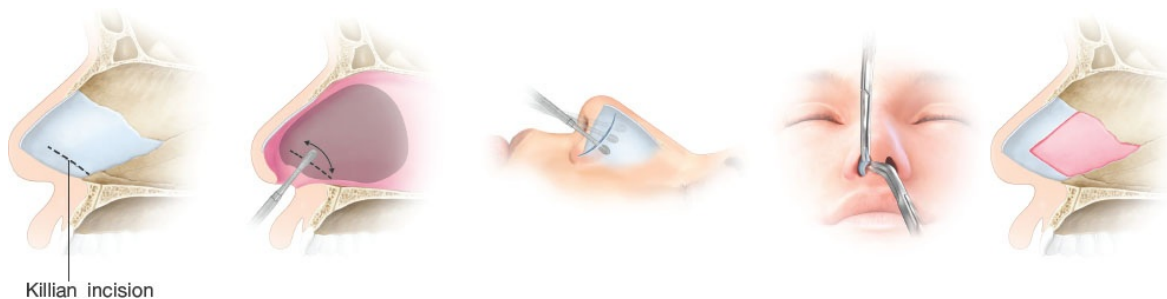
each mucoperichondrial flap and develop the tunnels with the sharp end of a Cottle perichondrial elevator (**TECH FIG 1**).

- Each tunnel must follow the dorsal septal edge and should extend beneath the caudal edge of the bony arch on each side, *leaving a narrow mucoperichondrial attachment along the anterior septal edge. This intact adhesion creates a pocket that will hold the spreader graft precisely; performed this way spreader grafts never rotate or displace. Done technically properly, they improve the airway reliably and virtually never require revision.*

■ Septoplasty

- For the septoplasty, the surgeon should perform the resection through a Killian incision, not from the dorsal edge, and leave 15 to 20 mm of intact, undissected cartilage along the nasal dorsum and 15 mm caudally to preserve stability and to facilitate spreader graft placement (**TECH FIG 2**).
- Do not perform a purely functional operation (septoplasty, crushing, and outfracture the inferior turbinates, spreader grafts, or alar wall grafts) through an open rhinoplasty approach because the risk of creating iatrogenic deformities is much too high and because it is unnecessary to take the tip apart to access the septum and internal valves. Spreader grafts are easily placed through an intercartilaginous incision; septoplasty is done through a Killian incision; and alar wall grafts are placed through short vestibular incisions to brace the anatomically unstable areas.
- Do not strip the mucoperichondrium from the dorsal or caudal struts, not only for stability but because such stripping has been experimentally shown to increase septal fibrosis and decrease chondrocytes in rabbits; we should assume that the same applies in humans.¹¹
- If significant trauma has occurred, even in the distant past, the surgeon should enter the septum very cautiously and check for old fractures, as fractures through the anterior septal edge will destabilize the dorsal strut. It is preferable to avoid simultaneous septoplasty and bilateral osteotomies or to postpone osteotomy if the surgeon is not confident of septal support.
- In practice, the need for bilateral osteotomies in the severely traumatized nose is generally uncommon because a unilateral osteotomy on the outfractured side achieves better symmetry than bilateral osteotomies.

- For septoplasty access, the initial mucoperichondrial Killian incision is made 15 mm above (cephalad to) the caudal septal edge; and using first the sharp and later the blunt end of a Freer elevator in one hand and a Frazier suction in the other, dissection proceeds under the mucoperichondrial flap onto the perpendicular plate of the ethmoid and over any posterior bony obstructions.
- Once the first flap has been developed, the sharp end of the elevator can score through the septal cartilage at the site of the opening incision; dissection then proceeds on the second side.
- Elevation of the perichondrium at the junction of septal cartilage and vomer is particularly difficult because the periosteal and perichondrial fibers are interlaced. The periosteal fibers are stronger, so mucosal tears are less likely if the surgeon begins dissection beneath the maxillary and vomerine mucoperiosteum and works cephalad.
- The first septal cut is made 15 to 20 mm below the dorsal septal edge with angled Knight septal scissors, which cut through septal cartilage and ethmoid; make sure that both blades are within the mucoperichondrial flaps before making the cut. A parallel cut is performed 8 to 10 mm inferiorly, and using Killian septal forceps, the first graft, now free on three sides, can be twisted so that the ethmoid fractures and allows removal in one piece. This maneuver often provides an initial graft 25 to 30 mm long containing the flattest, thickest, longest piece of septal cartilage, ideal for a dorsal graft.



TECH FIG 2 • Septoplasty technique.

- Dissection continues posteriorly and caudally with the sharp end of a Cottle perichondrial elevator. The septal cartilage in the vomerine groove can often be dislodged by a bit of judicious wiggling with a narrow osteotome. With an osteotome and septal forceps, additional pieces of vomer or perpendicular plate of the ethmoid can be removed if obstructing or if additional graft material is needed, always working under direct vision.

- In areas of severe deflection, tears in the mucoperichondrial flaps may be unavoidable, but the surgeon should nevertheless proceed cautiously and repair any tears.

■ Spreader Graft Placement

- Although septal cartilage provides the ideal spreader graft, strips of costal or conchal cartilage, ethmoid, or vomer may be used instead.
- Spreader grafts should provide confluence between the upper and lower nasal thirds, and they must span middle vault length from the bony arch almost to the septal angle.
- After spreader grafts are placed, caudal slippage can be avoided by a single 4-0 plain catgut transfixing suture placed at the septal angle.
- The width and contour of the middle vault should look and feel stable and symmetric once spreader grafts have been placed. In this regard, the closed approach provides significant advantages because the external surface configuration will guide the surgeon.

PEARLS AND PITFALLS

Pathogenesis

- The middle vault and internal nasal valve are at risk in three circumstances: (1) when the midvault is congenitally narrow; (2) when the nasal bones are short, therefore creating a larger portion of the cartilaginous sidewall that is supported only by cartilage; (3) when the surgeon reduces the dorsum by more than 2 mm.

Planning

- All key planning decisions can be made preoperatively from the nasal surface. Each anatomical point translates directly to a diagnosis and then to a surgical step: the entire rhinoplasty strategy can be set before surgery.
- Reconstruct anatomically, never forgetting function and considering the patient's own aesthetic.
- Reconstruction of internal valves doubles airflow in most patients.

Approach

- The surgical outcome depends on the aesthetics and function of the nose, which are determined by both the soft tissue and structural support.

- These contributions are easily assessed by the endonasal approach because the soft tissues, which determine 50% of the final result, are largely undisturbed.

POSTOPERATIVE CARE

- If septal or turbinate surgery has been performed, the nose is packed with petroleum gauze impregnated with bacitracin/mupirocin ointment.
- The packing should not overstuff the nose as it may dislodge the nasal bones or grafts.
- A no. 18 suction catheter is placed in the floor of each nasal airway to provide some airway patency and help equalize middle ear pressure.
- Oral antibiotics are prescribed for the first week while nasal packing is in place.
- A nasal splint is fashioned from layers of paper tape placed across the dorsum, tip, and cheeks, and then cloth tape is layered over it. Several layers of moistened 2-in. plaster are cut to fit and secured with another layer of cloth tape. The splint must be applied precisely but not too tightly to prevent nasal tip ischemia. Tip color should be checked frequently in the postoperative period, and the tip sling cut and nasal packs or splint removed as necessary.
- The nasal splint and any remaining packing are removed on postoperative day 6 to 7. By then, the nasal lining has healed, the nose is making mucus, and the packing slides out painlessly. Upon splint removal, the airway should instantly be excellent.
- If only septal and valvular surgery has been performed, swelling is minimal. If an entire rhinoplasty is performed, most patients are quite presentable at 7 days and may easily return to work in 10 days except in unusual circumstances. The nose will narrow after that for up to a year, but the dorsal line should be set.
- Patients should be seen as needed during the first 2 weeks to clean the nose of accumulated secretions, to ensure maintenance good alignment, and to educate the patient of expected changes over time. Patients must not exert themselves for at least 2 weeks following surgery to avoid hemorrhage and must slowly increase their activity after that to full athletic function at 6 weeks.

OUTCOMES (FIG 4)

- With good planning and technique, septal and valvular surgery can correct airway obstruction in up to 95%.²
 - That percentage reflects a combination of primary and secondary patients,

some of whom required more than one surgery because of their preoperative deformities.

- In primary patients, spreader grafts will uniformly increase airflow and, with experience, almost never require a second surgery.
- The airway will continue to improve throughout the first year, indicating that the airway enlarges as the edema resolves.²



FIG 4 • Patient before (A,B) and after (C,D) septoplasty.

COMPLICATIONS

- Iatrogenic airway obstruction
 - More common than any complication and entirely preventable is iatrogenic decrease in the postoperative airway size. That cannot occur with proper preoperative septal, valvular, and turbinate diagnosis and treatment.
 - Most new postoperative obstructions are due to increased internal valvular incompetence or an incomplete septoplasty with residual obstructions posteriorly or along the floor. A new internal valvular incompetence will cut the preoperative airway by 50%.
 - Inadequate turbinate resection, columellar widening, and nostril stenosis are rare but do occur.
- Skeletal
 - Visibility of the caudal edge of the bony vault is often mischaracterized as inadequate reduction but is usually the result of middle vault collapse—the bony arch stands out relative to the depressed and over-resected middle vault.
 - New frontal asymmetry can occur when dorsal resection uncovers a high septal deviation. When recognized preoperatively or seen intraoperatively after dorsal resection, the surgeon can correct the deviation with

asymmetrical spreader grafts and/or camouflage the deviation with a dorsal graft.

■ Grafts

- For those surgeons who augment often, graft imperfections are the most common reason for secondary revision.
- Spreader grafts may be too wide or too narrow

■ Septal perforation

- Septal perforations can be minimized with careful dissection posteriorly and inferiorly where the perichondrium is densely adherent by repairing any mucosal tears and by placing silicone splints prior to nasal packing.
- Even in the best of hands, the occasional small perforation will occur. Fortunately, many of these remain asymptomatic.
- Smaller perforations may present as whistling, while larger ones as crusting, epistaxis, obstruction, or rhinitis.
- Repair of perforations is difficult with a high recurrence rate. Repair involves debriding the exposed septal tissue and coverage with a local mucoperichondrial flap.

■ Rhinitis and empty nose syndrome

- Temporary rhinitis may occur for several weeks after an obstructed airway has been opened up.
- An overaggressive turbinectomy can cause persistent rhinitis and is not easily correctible.

■ Septal collapse

- Loss of cartilaginous support has global ramifications for nasal support and airway because the intact septal partition is necessary for normal bridge contour, nasal length, base support, internal valvular competence, and upper lip carriage.
- Septal collapse can be avoided by identifying unhealed or unstable septal fractures before surgery and by leaving a minimum 15 mm width of undissected septal cartilage and mucoperichondrium along the dorsum to avoid jeopardizing septal support if unexpected, unhealed fracture lines are encountered.
- It is safer to access the septum through a Killian incision rather than through the dorsal edge. Leaving the mucoperichondrium undissected over the L-strut protects against collapse, prevents exposure of potentially weakened cartilage, and makes placement of spreader grafts easier.

■ Infection

- Fortunately, bacterial infection with rhinoplasty is quite rare but has become more common with the emergence and increasing prevalence of methicillin-resistant *Staphylococcus aureus* as a community-acquired pathogen. Patients should be routinely cultured for MRSA preoperatively and treated with mupirocin if necessary.
- Using systemic antibiotics while nasal packing is in place may minimize the chance of maxillary sinusitis, although its necessity is unproven.

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Indications and Techniques for Increasing and Decreasing Tip Projection in Closed Rhinoplasty

54 CHAPTER

Bariş Çakır and Mithat Akan

DEFINITION

- One of the reference points in the face is the vertical line intersecting the pupil, or “midpupillary line.” The horizontal distance from the midpupillary line to the highest point of the tip is called the tip projection (TP).
- The horizontal distance from the midpupillary line to the apex of the nostril is called the nostril apex projection (NAP).
- The horizontal distance from the nostril apex to the tip’s highest point is called the lobule projection (LP).
- The NAP together with the LP constitutes the TP (**FIG 1**).
- Examining the nose in this manner, element by element, will assist with the treatment.

ANATOMY

- The lower lateral cartilages consist of the footplate, the medial crus, the middle crus, the domes and the lateral crus.
- The lower lateral cartilages rest on the lip, the septum and the upper lateral cartilages.
- With its thickness of 2 to 4 mm, the Pitanguy midline ligament, which fills the space between the septal angle and the domes, ensures an elastic projection (**FIG 2A,B**).

PATHOGENESIS

- Tip projection = nostril apex projection + lobule projection
- High NAP: Hypertrophic anterior and caudal septum, hypertrophic maxillary spine
- High LP: Long medial and middle crus
- Low NAP: Hypoplastic maxilla, footplate sitting posteriorly, hypoplastic caudal septum, previous septoplasty surgery, aggressive resection of caudal septum

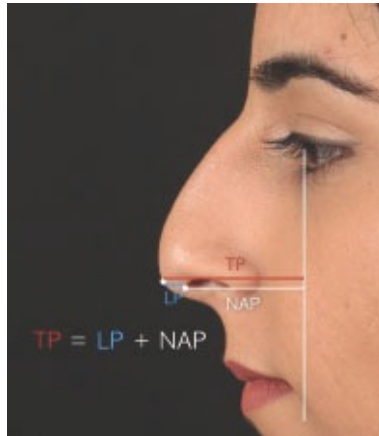


FIG 1 • Tip projection (*TP*), lobule projection (*LP*), nostril apex projection (*NAP*).

- Low LP: Short middle crus, short medial crus

PATIENT HISTORY AND PHYSICAL FINDINGS

- If the premaxillary support is weak, the nasolabial angle will be narrow, and when pulling up the lips, one can see that the maxillary mucosa is deep.
- Pressing on the nose tip will give us an idea about its support.
- In patients with posteriorly located maxilla it is difficult to obtain enough nasal projection. Patients who do not want a LeFort osteotomy may require a tongue in groove, an aggressive augmentation in premaxilla, or a long, strong columellar strut graft.

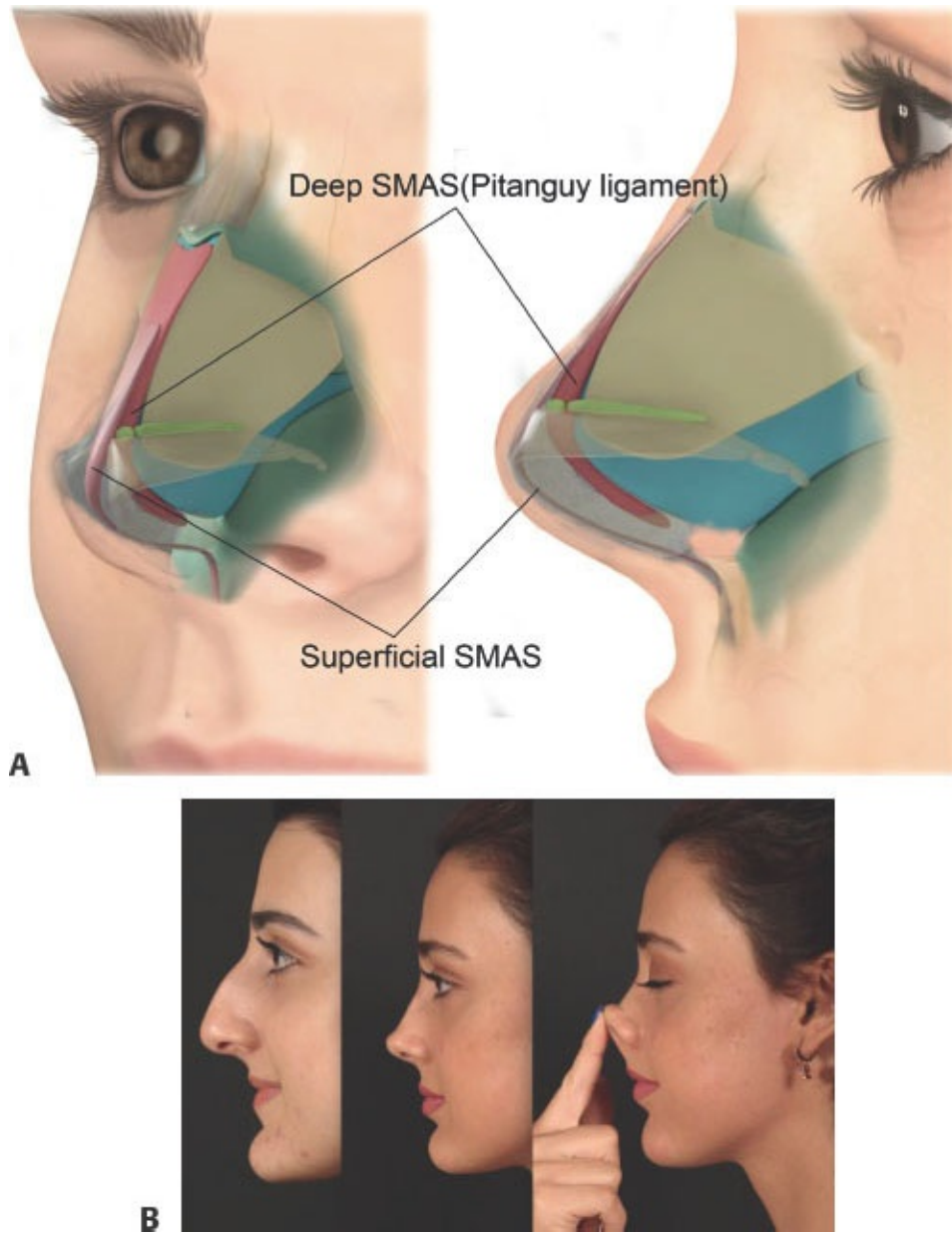


FIG 2 • A,B. With its thickness of 2 to 4 mm, the Pitanguy midline ligament, which fills the space between the septal angle and the domes, ensures an elastic projection.

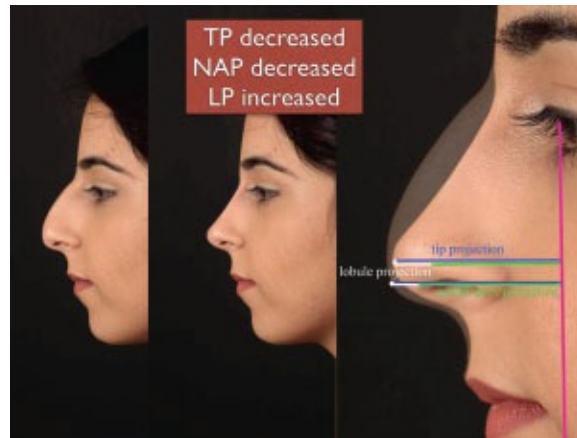


FIG 3 • One can easily plan changes to the TP, LP, and NAP by superimposing the newly planned nose over the old nose with a 50% contrast.

- It is noteworthy that in patients with high projection, the caudal and dorsal septa are hypertrophic.
- A hypertrophic septum can cause a hanging columella, tense lips and a wide footplate.
- Because the septum pushes the footplates more anterior than normal, the depressors are extremely tense. For this reason, the nasal tip may be more active when speaking.
- Skin thickness should be noted.

IMAGING

- Front, base, top, lateral, and oblique photographs are standard. A lateral smiling photograph can give clues about the dynamics of the nose tip.
- Imaging programs facilitate better analysis of the problems and planning of treatment.
- One can easily plan changes to the TP, LP, and NAP by superimposing the newly planned nose over the old nose with a 50% contrast (**FIG 3**).

SURGICAL MANAGEMENT

- The treatment needs to directly address the problem.



FIG 4 • Although a patient's LP may be normal, the high TP can be linked to a high NAP. In this case, LP did not change; TP decreased by decreasing NAP. Three months post-op photo is similar with the simulation.

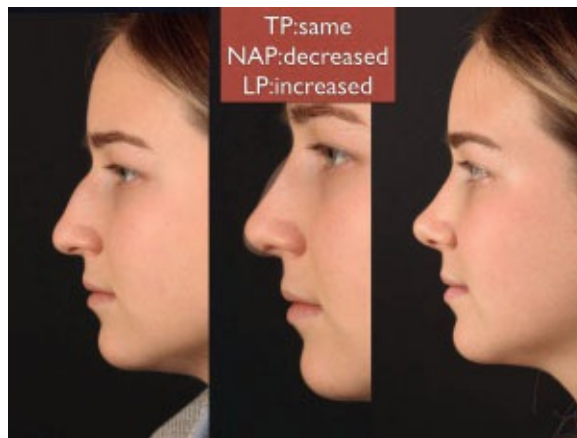


FIG 5 • A patient may have a normal TP, a high NAP, and a low LP. In order to protect the TP, one has to increase the LP in the same measure as one decreases the NAP.

Preoperative Planning

- It is important to observe how much the nasal tip contributes to the patient's facial expressions. One should observe the nose while the patient speaks. If the depressors are very active, this should be noted.
- Although a patient's LP may be normal, the high TP can be linked to a high NAP (**FIG 4**).

- A patient may have a normal TP, a high NAP and a low LP. In order to protect the TP, one has to increase the LP in the same measure as one decreases the NAP (**FIG 5**).
- A low TP may be linked to a low NAP as well as a low LP. Projection is the horizontal axis of the tip cartilage length. Rotation of the droopy tip also increases the projection (**FIG 6**).
- In thick-skinned noses, the projection needs to receive stronger support.

Approach

- A double-sided infracartilaginous incision and a single transfixion incision are sufficient.



FIG 6 • A low TP may be linked to a low NAP as well as a low LP. Projection is the horizontal axis of the tip cartilage length. Rotation of the droopy tip also increases the projection.

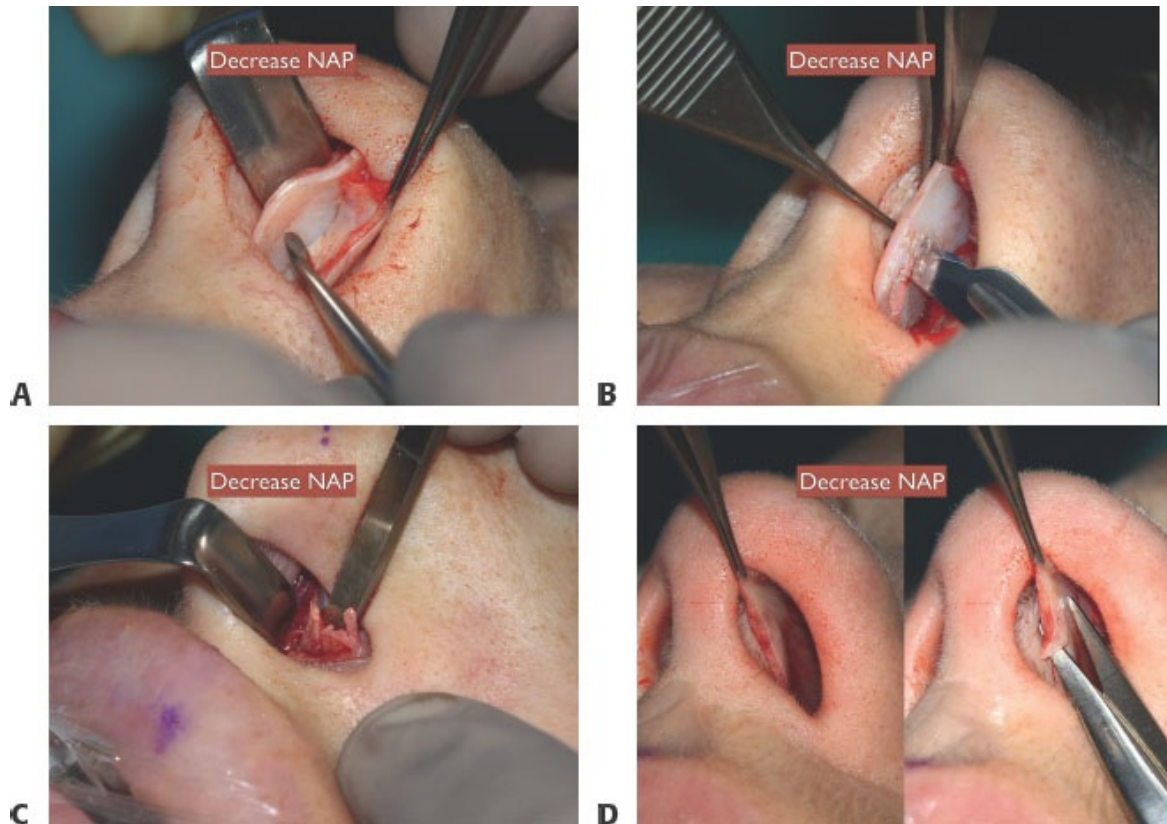
TECHNIQUES

■ Reducing the Nostril Apex Projection

- The surgical procedures outlined below all decrease the tip projection (TP). The techniques below can be applied in succession, until the desired projection is achieved.
- Dissect the caudal septum bilaterally in a subperichondrial plane (**TECH**

FIG 1A).

- If this is not sufficient, resect the excess caudal septum. This procedure is recommended if the length of the nose needs to be shortened or if more rotation is needed. Only these two procedures are enough to resolve most of the excess TP (**TECH FIG 1B**).
- If this is not sufficient, dissect the caudal periosteum of the maxillary spine.
- If this is not sufficient, widen the dissection of the spine laterally.
- If this is not sufficient, resect the maxillary spine. This resection results in a dramatic deprojection (**TECH FIG 1C**).
- In those rare cases where the above procedures are insufficient, resect more bone from the maxillary spine and the surplus of periosteum and perichondrium at the septum maxillary spine junction.
- Even a deprojection of 3 to 5 mm greatly reduces the excursion of the depressor nasi muscle. Therefore, in patients with an active depressor muscle, an additional depressor resection may not be necessary if sufficient deprojection is performed.
- To decrease the NAP, shorten the lateral crura. If the lobule is short, we can not only extend the lobule but also shorten the lateral crus by performing a lateral crural steal.
- If the lobule is beautiful, a long lateral crus can be treated with a dissection and overlap in the region of the aperture.
- In patients in whom not only the projection is decreased but also the length shortened, there may exist an excess of mucosa in the membranous septum. Here, a conservative elliptical mucosal resection can be performed (**TECH FIG 1D**).



TECH FIG 1 • **A.** Dissect the caudal septum bilaterally in a subperichondrial plane. **B.** If this is not sufficient, resect the excess in the septum's caudal. **C.** Resection of the maxillary spine results in a dramatic deprojection. **D.** In patients where not only the projection is decreased but also the length shortened, an excess of mucosa may occur in the membranous septum. Here, a conservative elliptical mucosa resection can be performed.

■ Reducing Lobule Projection

- The most effective treatment for a long lobule is a medial crus overlap (**TECH FIG 2**).
- The most suitable location for this procedure is the break point of the columella.
- An oblique cut from the columella's break point toward the caudal-posterior

direction increases the contact area.

- For an overlap, dissect the cartilage 2 to 3 mm from the mucosa.
- Tuck the medial crus underneath the middle crus, create an overlap of 2 to 3 mm, and suture it with a 6-0 PDS suture.
- Rarely is an overlap of 7 to 8 mm necessary. In this case, a resection of 2 to 4 mm can be combined with an overlap of 3 to 4 mm. In cases of long lateral crura shortened by lateral crural steal with high lobule projection (LP), an overlap of more than 4 to 5 mm may be necessary.
- A medial crus overlap is the most effective treatment for a hanging columella.



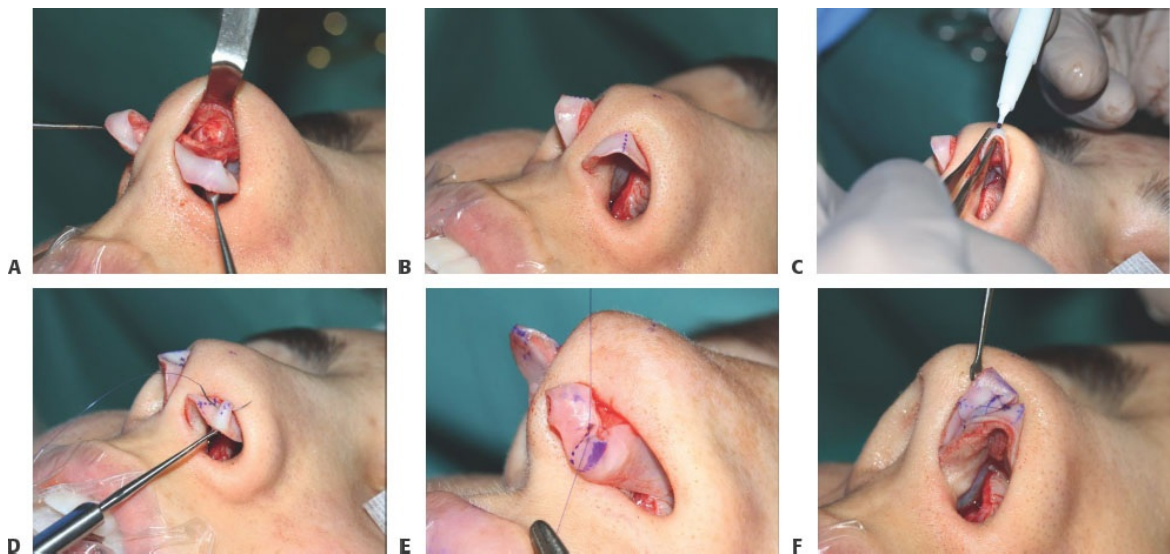
TECH FIG 2 • A–C. The most effective treatment for a long lobule is a medial crus overlap.

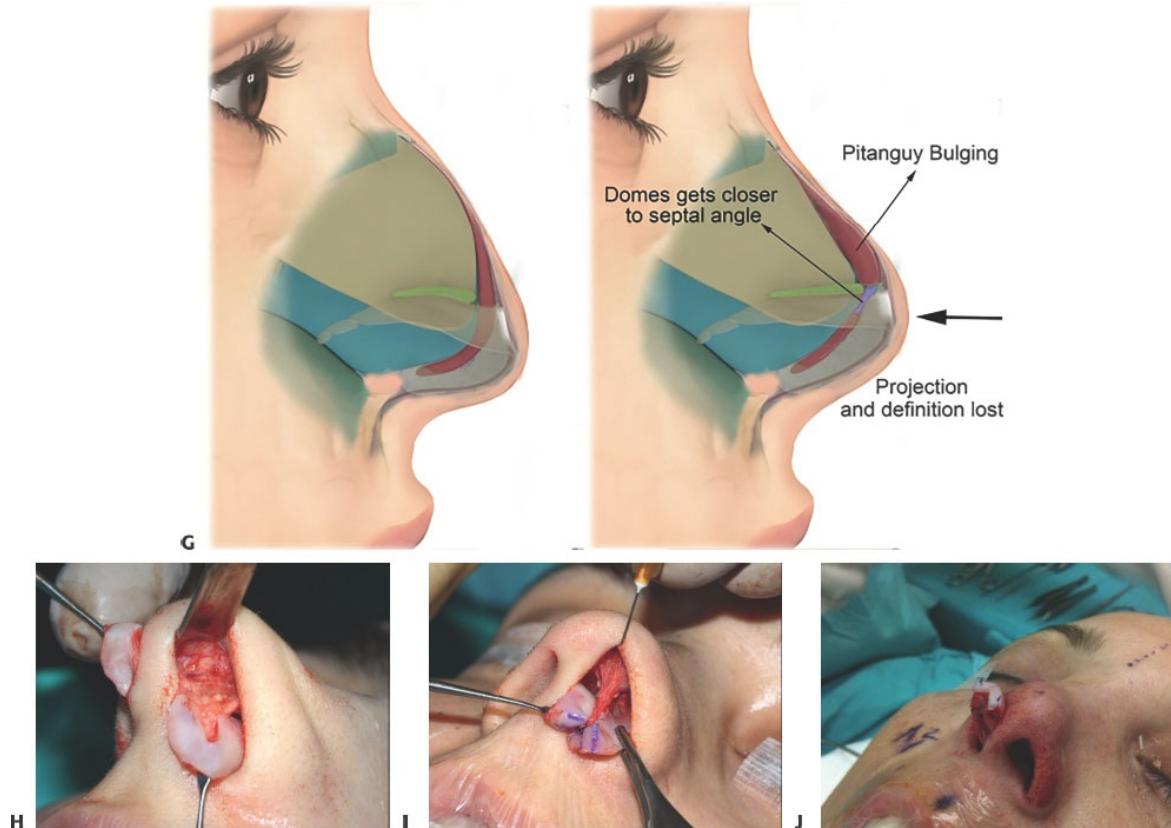
■ Increasing Lobule Projection

- The best technique for extending the lobule is a lateral crural steal (**TECH FIG 3A–F**). The LP increases at the same rate as the length of the lobular polygon.¹
- A lateral crural steal will also increase rotation. Patients with a short lobule generally tend to need greater rotation.
- In closed rhinoplasty surgery where the Pitanguy and scroll ligaments are protected, only 5% to 10% of patients require a tip graft (**TECH FIG 3A**). Even though adequate rotation can be achieved by means of a steal, this may not be sufficient for adequate LP. In this case, tip grafts are preferable.
- If the ligaments are not protected, the cushioning underneath the domes disappears and the domes collapse into the septum. The Pitanguy ligament withdraws underneath the supratip skin and fills up the supratip area. Depending on the increased height of the tip and supratip, the TP may appear

insufficient. The need for a tip graft generally occurs due to a loss of projection of 3 to 4 mm, when the Pitanguy ligament has not been protected (**TECH FIG 3G-I**).

- If the lobule extends too much due to a lateral crural steal, this can be treated with a medial crus overlap.
- A lobule extended with the help of a steal should be supported by a strut graft.
- For an LP of 1 to 2 mm, minuscule free grafts to the tip are sufficient. After the mucosa has been closed, these grafts can be placed on and in between the dome cartilages.
- An LP of 2 to 3 mm necessitates tip grafts. An onlay graft in the shape of a boomerang facilitates the correct projection for tip highlights (**TECH FIG 3J**).



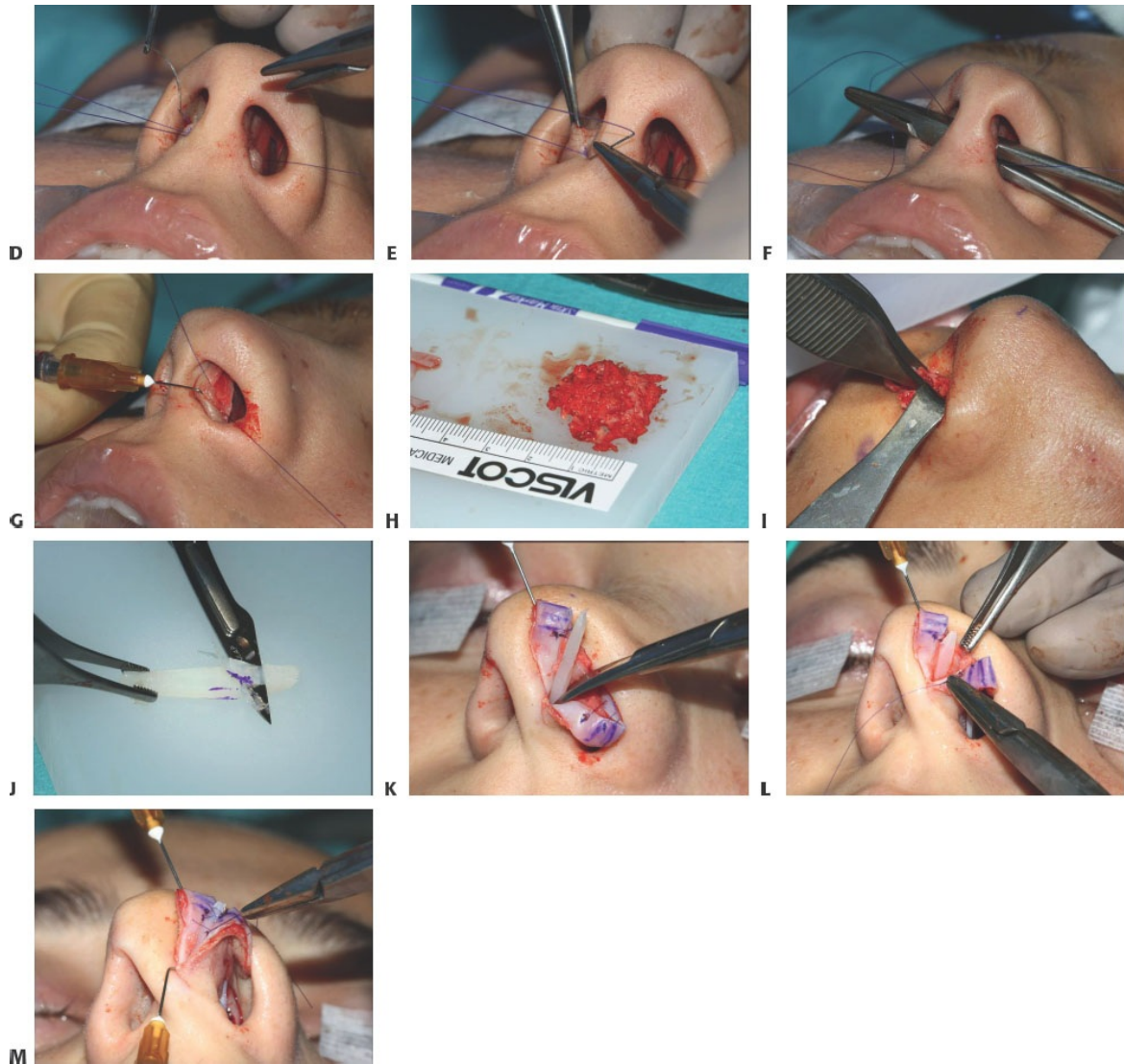


TECH FIG 3 • A–F. Lateral crural steal procedure. **G–I.** If the ligaments are not protected, the cushioning underneath the domes disappears, and the domes collapse into the septum. The Pitanguy ligament withdraws underneath the supratip skin and fills up the supratip area. Depending on the increased height of the tip and supratip, the TP may appear insufficient. The need for a tip graft generally occurs due to a loss of projection of 3 to 4 mm, when the Pitanguy ligament has not been protected. **J.** An LP of 2 to 3 mm necessitates tip grafts. An onlay graft in the shape of a boomerang facilitates the correct projection for tip highlights.

■ Increasing Nostril Apex Projection

- If the footplates are wide, narrowing them with sutures will facilitate a TP of 1 to 2 mm (**TECH FIG 4A–G**).
- If the front of the maxilla is empty, perform a subperiosteal dissection to the front of the maxilla and fill it with cartilage pieces (**TECH FIG 4H,I**).
- In patients with a recurrent droopy tip, an aggressive augmentation in front of the maxilla is an effective technique.
- A long strut graft that extends to the maxilla and fixes the interdomal gap is the most effective technique for tip projection (**TECH FIG 4J–M**).
- Fixing the strut graft while the assistant pulls the dome cartilages anteriorly makes this technique easier.
- Increasing NAP also increases the rotation.





TECH FIG 4 • A–G. If the footplates are wide, narrowing them with sutures will facilitate a tip projection of 1 to 2 mm. **H,I.** If the front of the maxilla is empty, perform a subperiosteal dissection to the front of the maxilla and fill it with cartilage pieces. **J–M.** A long columellar strut graft that extends to the maxilla and fixes the interdomal gap is the most effective technique for tip projection.

PEARLS AND PITFALLS

Lateral crural steal	■ Every steal of 1 mm results in a rotation of about 6 to 8 degrees. The amount of the rotation obtained by means of a steal decreases logarithmically.
Lower lateral cartilage division	■ In big noses, it is generally necessary to cut the lower lateral cartilage at some point. The safest region for this cut is the middle crus.
Relationship between projection and rotation	■ Deprojection techniques will also reduce tip rotation. For this reason, it is necessary to equally shorten the lateral crus.
Tip projection analysis	■ Analyzing the TP in NAP and LP makes treatment more accurate.



FIG 7 • A–D. Case examples.

POSTOPERATIVE CARE

- Carefully tape the nose without squeezing the tip. If the tape pinches the nose tip caudally, the positioning of the tip cartilages can be damaged.
- Because thermoplastic plaster is water resistant, the patient may shower every day.
- Applying tape underneath the eyes decreases swelling and bruising.
- The patient can be discharged after 3 to 4 hours.
- In case of swelling, a cold compress can be applied. Cold compresses are not routinely used after wide dissection and insertion of a drain.
- The patient rests in bed with the head elevated.
- Paracetamol with codeine is sufficient for pain management.
- Against bone edema, diclofenac potassium can be prescribed from day 5 to 10.
- After the preoperative prophylaxis, there is no need for antibiotics.
- Saltwater irrigation can be done for 10 days.
- Internal silicone dolly splints can be removed after 2 to 4 days.
- After 10 days, the cast is removed. Generally, no more tape is used.

OUTCOMES

- Sample preoperative photographs can be seen in **FIG 7**.

COMPLICATIONS

- Loss of rotation
- Loss of projection
- Tip asymmetry
- Bleeding
- Infection

REFERENCE

1. Cakır B, Oreroğlu AR, Daniel RK. Surface aesthetics in tip rhinoplasty: a step-by-step guide. *Aesthet Surg J*. 2014;34(6):941-955.

Techniques for Controlling Tip Rotation in Closed Rhinoplasty and Rhinoplasty Anesthesia

55

CHAPTER

Bariş Çakır and Mustafa Özgön

DEFINITION

- A droopy nasal tip is one of the most frequently encountered indications for rhinoplasty.

ANATOMY

- The following anatomical features impact nasal tip rotation:
 - Maxilla
 - Columella
 - Lateral crus
 - Caudal septum
 - Upper lateral caudal
 - Pitanguy, scroll and interdomal ligaments
- All these anatomical structures have to be of the right dimension in order to ensure the desired nasal tip position (**FIG 1**).

PATHOGENESIS

- The most frequent problem causing a droopy nasal tip is the “tension nasal.” Septum that extends too far caudally shapes the domes by bending the nasal tip cartilages from the middle crura.
- Septum pushes the footplates forward.
- Because the depressor and orbicularis muscles are under tension, an excessively droopy nasal occurs when laughing.

- Because the domes emerge from the middle crura, we encounter a long, wide and generally convex cartilage.
- Also, trauma or a resection of the caudal septum creates projection and loss of rotation.

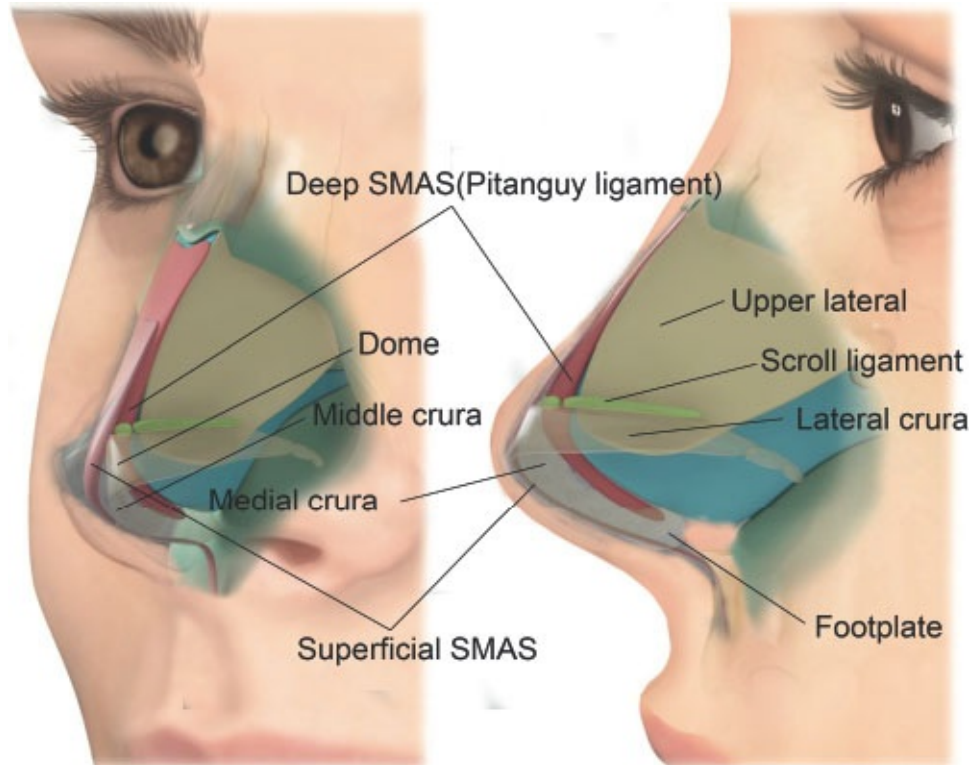


FIG 1 • Anatomy.

NATURAL HISTORY

- The nasal tip has an elastic rotation and projection.
- The nasal tip contributes to minimal facial expressions. A nasal tip that remains stiff when speaking is one of the last remaining stigmata of rhinoplasty.
- It is important for the nasal tip to be mobile, so that the patient is able to comfortably lie face down and to kiss.
- Techniques such as septal extension graft and tongue in groove are proven solutions for rotation and projection; however, the nasal tip loses its softness.
- The nasal ligaments, and most importantly the Pitanguy ligament, ensure an elastic rotation and projection (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient complains about a “droopy nasal tip.”
- The nasolabial angle is narrow.
- The patient’s skin type is of significance. Patients with thick skin and a nasal tip that droops excessively when laughing are more likely to experience loss of rotation.

IMAGING

- Front, base, top, lateral, and oblique photographs are standard. A lateral smiling photograph gives clues about the dynamics of the nasal tip. Taking a photograph of a beautiful nose, rotating it by 90 degrees, and looking at it in this way will facilitate the decision-making process concerning rotation during the surgery.

NONOPERATIVE MANAGEMENT

- Filler and Botox can be applied to the nasal base. This cannot substitute for rhinoplasty, however.

SURGICAL MANAGEMENT

- Suggested treatments for rotation control consist of different ways of attaching the medial crura to the septum.

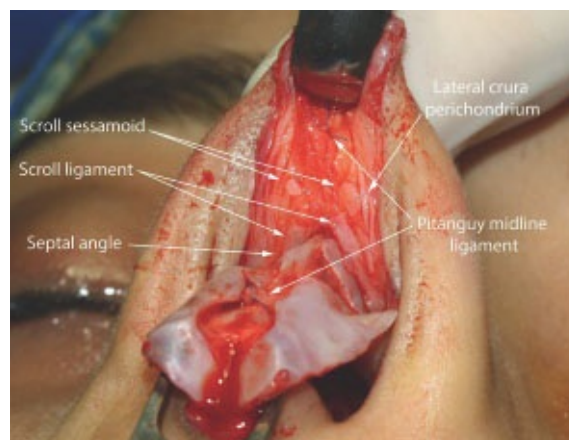


FIG 2 • Pitanguy and scroll anatomy.

- The medial crura can be sutured to the septum named tongue-in-groove technique
- Permanent sutures can be applied from the medial crura to the septum named

rotation control suture.

- The rotation can be stabilized with a septal extension graft.
- However, these techniques may lead to a stiff nasal tip.
- When deprojection is performed, the footplates, which are connected to the depressor muscles, change place posteriorly. This procedure decreases the muscle's excursion and weakens its function. For deprojection, it is generally sufficient to dissect the caudal septum in the subperichondrial plane.
- For proper rotation, it is necessary to shorten the lateral crural cartilage, the upper lateral cartilage and caudal septum.
- Shortening the lateral crus by means of the lateral crus steal technique increases lobule projection.
- Without performing deprojection, a steal does not guarantee projection. The steal procedure re-establishes the projection lost due to deprojection.¹
- The basic effect of the lateral crus steal technique is an increase in rotation.
- A strut graft is important to strengthen the support of the columella. In patients with weak columella support, 2 to 3 struts can be placed. Loss of projection causes loss of rotation.
- In patients with an insufficient maxilla support, it is difficult to obtain rotation and projection. In these patients, the front of the maxilla should be filled with cartilage and bone (**FIG 3**).
- In thick-skinned patients, it is necessary to select a strong and long cartilage as a strut graft and to use septocolumellar suture with 5-0 Prolene passing through the medial crus or the strut graft.

Positioning

- The patient is positioned in the Trendelenburg position and lumbar flexion, with the neck in an extension of 20 to 30 degrees and parallel to the floor. In this position, intracranial blood pressure and surgical bleeding decrease. Keeping the head always parallel to the floor makes it less likely for errors to occur in rotation.
- The patient is positioned on the back, with a pillow under the head, the arms on belly, and supported by a silicone cushion placed under their legs in such a way that their heels do not touch the operating table. The arms are secured by wrapping them with a sheet so that the chest is left either exposed or covered.
- In the operating room, the anesthesia device is placed at a 45-degree angle next to the patient's head, to their right side. Thus, the surgeon can access the

patient's head and check for symmetry (**FIG 4**). If the surgeon is right handed, the anesthesia device is placed to the left side.



FIG 3 • Augmentation of premaxilla with bone and cartilage grafts.



FIG 4 • Position of patient.

Anesthesia

- Goal: Anesthesia aims to ensure the patient's safety and a bloodless surgical field during rhinoplasty and to prevent pain, nausea, and shivering, especially in the postoperative phase.
- Application: On the day of the surgery, the patients, generally young adult outpatients whose anesthesia exam and workout (complete blood count, coagulation parameters, hepatitis markers, and ECG) have been completed 1 day earlier, are taken to the preop assessment room. The patient is monitored

(ECG, SpO₂, NIBP), the tympanic temperature is measured, and the baseline values are recorded. An intravenous line is started, and 250 mL 0.9% isotonic NaCl with 1 g metamizole + 100 mg tramadol + 45.5 mg pheniramine maleate is administered.

- A first-generation cephalosporin is used for surgical prophylaxis.
- Pseudoephedrine nasal spray is used for septal mucosa vasoconstriction.
- As premedication, an IV bolus of 1 mg midazolam + 10 mg metoclopramide + 50 mg ranitidine + 40 mg methylprednisolone is administered. Dexmedetomidine is administered with an infusion pump at a rate of 40 mcg/h.
- Once these preparations are completed, the patient can be taken into the operating room and will be monitored again.
- Infusions of propofol 50 mg/h and remifentanyl 250 mcg/h are administered. Over the IV—after an infusion of 60 mg 2% lidocaine + 50 mcg fentanyl—5 mg rocuronium is given for the purpose of priming, and the timer is started. Following 150 mg of propofol, another 25 mg of rocuronium is administered. Fentanyl 50 mcg and another 50 mg of propofol are administered.
- Once the eyelash reflex has disappeared, the eyes are covered with a line of polymyxin B eye cream and 1 cm of transparent tape. After 3 minutes, the patient is endotracheally intubated with a 7.0 spiral tube. The cuff is inflated with a cuff pressure of 25 cm H₂O, and during the operation, the cuff pressure is constantly measured, having been connected to a manometer with an 850 psi 120-cm extension, so that small adjustments can be made to keep it at 25 ± 5 cm H₂O.
- The endotracheal tube is fixed at 21 to 23 cm to the right side (for left-handed surgeon) of the mouth, at a distance of 1 cm and such that the upper lip is not pulled askew, with 2 cm of Hypafix tape in the shape of an omega around the tube. Then the tube is connected to the anesthesia device in a semiclosed circuit with the help of an extension tube. In the volume control mode, breathing support is secured with 44% oxygen + 50% nitrous oxide and 6% desflurane at ET CO₂: 30 mm Hg (VT 8 to 10 mL/kg, f: 10 to 12/min, rate of fresh gas flow 2 L/min).
- The mouth and stomach are checked with a 16 G orange aspirator cannula. Then the surgery is started.
- Over 30 minutes, 1 g paracetamol is given.
- After the first hour, the dexmedetomidine infusion will be adjusted to 20 mcg/h, and in each half hour thereafter, the dose will be decreased by half,

until it reaches zero after the 2nd hour.

Administering Local Anesthesia

- Local anesthesia is performed with 3-cc solution 1/80 000 (5 cc bupivacaine + 5 cc 2% lidocaine + 9 cc 0.9% NaCl + 1 cc 1/4 adrenaline) nasally, 2 cc 1/160 000 (2 cc 0.9% NaCl + 2 cc 1/80 000 lidocain-adrenaline solution. Jetokain®) solution for septal mucosa in 10 minutes. Generally, this should not lead to any significant lengthening of the QT interval or any other arrhythmia, and the increase in ETCO_2 should not exceed 10%. (Based on the adrenaline contained in the local anesthesia, the increase in ETCO_2 and the lengthening of the QT interval in the ECG are accepted as early warning signs to suspend the administration of local anesthesia, and normocapnia is ensured by increasing the minute volume on the ventilator.)
- Wait until the systolic blood pressure decreases below 90 mmHg for the local solution injection. If the local solution infiltration to nasal increases the blood pressure over 100 to 110 mm Hg, optimal adrenaline vasoconstriction cannot be achieved.
- During the surgery, generally, no further intervention is necessary. Rather than focusing on the same fixed numerical values in terms of the hemodynamic parameters for all patients during the surgical procedure, one should ensure the individual patient's regular pulse and blood pressure in such a way that they facilitate a surgical field without bleeding (**FIG 5**).



FIG 5 • Patient's parameters stabilization during the surgery.

- Based on the surgeon's feedback and the patient's hemodynamic parameters,

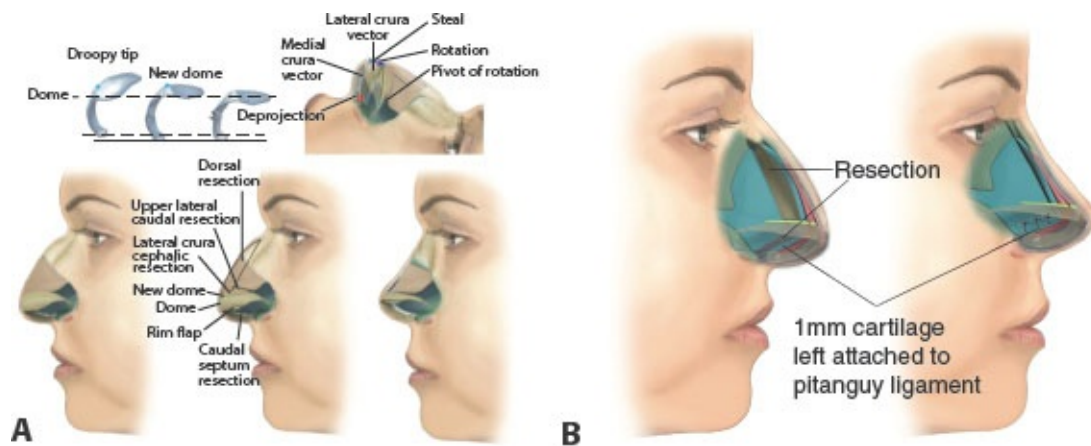
the infusion dosages can be decreased in a controlled manner after the first hour.

- Toward the end of the surgery, while the silicone doyle splints are being placed, the nitrous oxide and desflurane are turned off. After a washout with 100% oxygen, 44% oxygen and 56% air are administered.
- Dexamethasone 8 mg and 4 mg ondansetron are administered intravenously.
- Upon completion of the surgery and before applying the bandages, the mouth and stomach are aspirated with an 18 G green aspirator cannula. Infusions of propofol are discontinued.
- While applying the bandages, the patient may sometimes open the eyes when coming into contact with cold water; if the patient can follow verbal directions, he or she can be extubated and given oxygen with a simple mask at 5 to 6 L/min. If the patient has not woken up at this stage, the team waits until the patient spontaneously does so, which generally occurs within 20 minutes. A conscious patient with sufficient spontaneous breathing is kept on the operating table for 5 more minutes and then transferred to the postoperative recovery room.

TECHNIQUES

■ Securing an Elastic Rotation by Protecting the Pitanguy Ligament

- With the posterior transfixion incision, the perichondrium of the caudal septum is left attached to the Pitanguy ligament.
- Leaving 1 mm of cartilage from the caudal septum attached to the perichondrium makes it easier to suture it back.
- The surgeon delivers the caudal septum, then determines the excess caudal septum by forcing the tip rotation, and removes that excess (**TECH FIG 1A**).
- In the area of the membranous septum, the perichondrium and 1-mm cartilage flap that has been left attached to the Pitanguy ligament are fixed to the septum with 3 to 5 sutures with 5/0 PDS in the desired projection and rotation (**TECH FIG 1B**).



TECH FIG 1 • **A.** Resection for rotation. **B.** Resection of caudal septum and suturing caudal septal perichondrium and 1-mm cartilage flap to septum.

■ Shortening a Long Lateral Crus

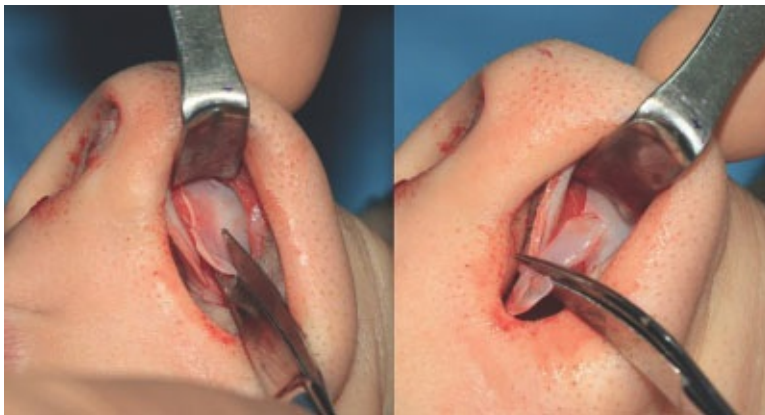
- The surgeon delivers the tip cartilages and completes the surgery on the tip.
- The lateral crus must absolutely be shortened to the correct length.
- In patients with a short lobule and weak domes, the best technique to shorten the lateral crus is the lateral crus steal (**TECH FIG 2**).
- Cephalic resection also increases rotation but not as much as shortening the lateral crura.



TECH FIG 2 • Lateral crura steal (because of long lobule after lateral crura steal, medial crura overlap performed).

■ Shortening a Long Upper Lateral

- After the desired tip position has been achieved, the caudal part of the upper lateral cartilages should be double-checked. Any kind of surplus should be resected (see **TECH FIGS 1A** and **3**).
- While repairing the scroll ligament, the surgeon can pass one suture through the upper lateral.



TECH FIG 3 • Caudal resection of upper lateral cartilage.

■ Projection is Important for the Nasal Tip Rotation

- The rigidity of the nasal tip needs to be double-checked. The nasal tip should be mobile but should still have adequate support when pressed with a finger. If support is not adequate, an additional strut should be placed.
- In secondary patients and patients with recurrent tip rotation and loss of projection, one should consider an augmentation in front of the maxilla.

PEARLS AND PITFALLS

Projection	■ Loss of projection causes loss of rotation. Therefore, the support for the tip should be double-checked at the end of the surgery.
Skin	■ Thick-skinned noses are more likely to experience loss of rotation. Projection should be well supported, and for that purpose, the surgeon

may want to perform an over-rotation of 1 to 2 mm.

Loss of rotation

- The most frequent reason for loss of rotation is a long lateral crus, a long upper lateral, and insufficient support of the nasal tip.

Impact of anesthesia

- The patient is our main priority.
- A harmonious collaboration between the anesthesia and surgical teams impacts the surgical outcome.
- Nasal spray 20 min before surgery supply bloodless septal surgery.
- We applied pre-emptive multimodal analgesia, multimodal nausea prophylaxis, combined H1 + H2 receptor blockage, and a balanced general anesthesia supported by nitrous oxide. (Noah pudding anesthesia*.)
- We supported the premedication with an alpha 2 agonist (dexmedetomidine).
- We used neither beta-blockers nor nitroglycerin.
- We administered the local anesthesia-adrenaline solution in fractions and over a span of more than 10 min. Rather than waiting for suitable conditions to occur, the surgeon should create them.
- We continuously monitored the pressure in the balloon of the intubation tube and kept it at a level that would not damage the trachea's mucosa.
- At the end of the surgery, oral and pharyngeal suction as well as gastric emptying were performed when the patient was still under general anesthesia.
- The patient was awakened at the position and the conditions that the anesthesia induction was started.
- During the surgery, easy listening type of music was listened.



FIG 6 • A,B. A case example for rotation frontal view (3 months result). **C,D.** Smiling frontal view. **E,F.** Lateral view. **G,H.** Smiling lateral view. **I,J.** Oblique view. **K,L.** Base view.

POSTOPERATIVE CARE

- The patient is on bed rest for the first hour. After 1 hour, the patient may drink water. If the patient does not complain about nausea, he or she is allowed to eat a sandwich and drink fruit juice, followed by another hour of bed rest. If the patients have no further complaints, they may sit up and be mobilized. If their general condition is satisfactory, the intravenous line can be removed. The patient should be advised not to drink alcohol or operate a vehicle in the first 24 hours. Patients should be transferred by wheelchair to the vehicle taking them home.

OUTCOMES

- A case example for nasal tip rotation can be seen in **FIG 6**.

COMPLICATIONS

- Loss of rotation
- Over-rotation

REFERENCE

1. Cakır B, Oreroğlu AR, Daniel RK. Surface aesthetics in tip rhinoplasty: a step-by-step guide. *Aesthet Surg J*. 2014;34(6):941-955.

Technique for Ethnic Rhinoplasty by the Closed Technique

CHAPTER

Shruti C. Tannan, J. Clayton Crantford, and Mark B. Constantian

DEFINITION

- Closed rhinoplasty allows the surgeon to achieve the patient's aesthetic and functional goals as accurately as possible without introducing new deformities with the surgical approach.
- Ethnic rhinoplasty refers to surgery of the non-Northern European nose that respects the aesthetics and particular challenges associated with a patient's unique ethnic background. However, in practice, the distinction is somewhat artificial because each patient, regardless of his or her ethnic background, deserves a result that matches, as much as possible, the patient's aesthetic goals and that takes into account the degree of change (or preservation) of ethnic, familial, or personal characteristics that the patient desires.
- Specifically, some patients with distinctive familial, ethnic, or personal characteristics may wish to retain them, whereas others may want a type change. *It is critical that the surgeon be aware of these expectations to prevent patient dissatisfaction with the surgical result.*
- As with all preoperative discussions, a conversation with the patient about his or her goals and expected outcomes should be a critical part of every rhinoplasty, ethnic or not.
- The principles of forming and then performing the surgical plan do not differ; thus, ethnic rhinoplasty in many ways does not differ from any other rhinoplasty.
- The surgeon must consider the technique that allows him or her to deliver what the patient wants while also maintaining his or her personal identity.

- One of the most common motivations for secondary rhinoplasty is the loss of a familial, ethnic, or personal nasal characteristic.¹ For example, the surgeon may assume the dorsal hump is to be taken down, but the patient may prefer that the dorsal hump remain as a distinctive feature; this and all areas to be addressed during rhinoplasty should be discussed together preoperatively.
- A detailed discussion of specific aesthetic goals with the patient is imperative. The closed approach offers the surgeon the ability to see the result on the table; therefore, it is possible to set goals and deliver.
- Some patients intend to maintain some of the characteristics of their noses that are a part of their shared heritage, whereas others wish to alter them; it is up to the surgeon to initiate this discussion for a thorough understanding of the operative plan.

ANATOMY

- Although there is a large spectrum of variability in the so-called ethnic nose, there are common characteristics and features. It is important to recognize these findings in advance so that a preoperative discussion is complete and so the operative plan addresses the concerns the patient wishes to alter while maintaining the characteristics the patient wishes to preserve.
- Four anatomic findings place all patients at high risk for unfavorable results and should be identified preoperatively.²
 - Low radix or low dorsum
 - Dorsal length and height, balanced against lower nasal size, determine the attractiveness of nasal proportion. A low radix or low dorsum begins caudal to the level of the upper lash margin with the patient's eyes in primary gaze.
 - When the radix begins low, nasal length is shorter and the nasal base size therefore appears larger. The surgeon must raise the dorsum segmentally or entirely to balance the patient's nasal base. In thicker-skinned patients, the strategy is particularly attractive because it requires less soft tissue contraction.
 - However, dorsal length must also be balanced against nasal base size. In patients with a very short nasal base (eg, some Asian noses), the radix should begin lower than the upper lash margin. Ethnicity and patient preference is one aspect; good nasal proportion is another.
 - Inadequate tip projection
 - Tip projection reflects cartilage strength, not skin volume, specifically the

length of the alar cartilage middle crust. Adequate tip projection, in which the tip supports itself independent of dorsal height, is necessary for a straight profile line.

- A tip with inadequate projection is any tip that does not project to the level of the anterior septal angle. Adequately projecting tips do not need increased support, whereas inadequately projecting tips do.
- A patient may have a large nasal base but still have inadequate tip projection. An oversized, unbalanced lower nose does not mean that the patient has excessive tip projection.
- Failure to recognize inadequate tip projection causes dorsal over-resection, supratip deformity, and deformity from soft tissue contraction.

■ Narrow middle vault

- A narrow middle vault signals an internal valve that is already compromised.
- The middle vault narrows following cartilaginous roof resection, so hump removal can inadvertently worsen the airway. Resection of even 2 mm of the cartilaginous roof during hump removal ablates the stabilizing confluence that braces the middle vault, which can now collapse toward the anterior septal edge, restricting airflow at the internal valves and producing a characteristic inverted “V deformity.”
- Reconstruction of incompetent internal valves by either dorsal or spreader grafts doubles mean nasal airflow in most patients.³

■ Alar cartilage malposition

- Describes cephalically rotated lateral crura whose long axes run toward the medial canthi instead of toward the lateral canthi.
- The abnormal cephalic position of the lateral crura places them at special risk if an intercartilaginous incision is made at its normal intranasal position. This will transect the entire rotated lateral crus instead of splitting the intended cephalic portion.
- The majority of malpositioned lateral crura do not provide adequate external valvular support, leading to external valvular incompetence in addition to boxy or ball tips.
- Adequate treatment of cephalic rotation of the lateral crura requires resection and replacement of these structures, relocation of the lateral crura to support the external valves, or supporting the areas of external valvular collapse with autogenous grafts.

- Correction of external valvular incompetence doubles mean nasal airflow in most patients.⁴

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history
 - Airway and aesthetic concerns
 - History of prior nasal trauma
 - Airway obstruction
- Internal nasal exam
 - Valves
 - Septum
 - Turbinates
- External nasal exam
 - Cartilage size and substance
 - Bony vault length
 - Nasal sidewall stiffness
 - Soft tissue thickness/distribution
 - Soft tissue *thickness* determines the degree of reduction possible and the character of augmenting or stabilizing grafts. Soft tissue *distribution* determines ultimate nasal size and proportion.
 - Nasal shape overall: width, length, bridge contour, tip shape, nostril size, columella and upper lip position, and any asymmetries.

IMAGING

- Software imaging systems exist that allow improved communication between surgeon and patient, although it represents a simulated, not guaranteed result. Imaging is only useful if the surgeon can simulate those structural and contour changes that the patient's anatomy and biological principles will permit.

SURGICAL MANAGEMENT

- The objectives of ethnic rhinoplasty are in keeping with the goals of as any other rhinoplasty: to achieve the patient's aesthetic and functional goals as accurately as possible without introducing new deformities.
- The closed approach to ethnic rhinoplasty offers many advantages.
- Closed rhinoplasty requires less dissection, always allowing the surgeon an undisturbed view of the nasal surface, which determines 50% of the final outcome.

- Closed rhinoplasty allows the surgeon the ability to control tip contours more accurately because there is less intraoperative soft tissue manipulation and the dorsal and tip skin never leave their preoperative positions.
- Tip grafts are easier to place in precise pockets in closed rhinoplasty because they do not have to be sutured into place. Multiple grafts of different thickness and substance can be placed to create particular aesthetic goals because the surgeon controls the soft tissue pocket. These techniques are not possible through the open approach.
- Columellar struts are never needed because the medial crura are not routinely disrupted from the adherent columellar skin and tip projection is not routinely lost through the closed approach access.
- Fewer variables are introduced by the surgical approach, and this reduces postoperative problems and greatly decreases the chance of new iatrogenic deformities.
- Closed rhinoplasty avoids problems that are almost unique to open rhinoplasty: columellar widening or notching, significant alar rim, and alar cartilage distortions.
- There are no contraindications to the closed approach to rhinoplasty, as this approach allows the surgeon to minimize morbidity in even the most difficult of cases.

Preoperative Planning

- The preoperative exam consisting of an internal and external nasal exam is critical.
- Specific attention should be paid to the valves, septum, turbinates, and basic nasal aesthetics.
- Always identify the four anatomical variants first so that their treatment can be included in the surgical plan.
- Preoperative photographs are imperative.
- Setting goals with the patient and discussing potential complications and revisions are vital.
- Three soft tissue parameters are used to form the authors' rhinoplasty plan: skin thickness, skin distribution, and tip lobular contour.⁵
- Virtually all primary and secondary nasal deformities can be solved by one of two surgical strategies that follow the necessary reduction maneuvers: (1) radix, spreader, and tip grafts or (2) dorsal grafts and tip grafts plus or minus

(3) alar wall grafts.

- This means that the surgeon need master only four graft types (because radix/dorsal grafts are the same graft in different lengths) to solve most nasal problems.
- Maxillary augmentation for retrusion, lateral wall grafts for asymmetries, composite grafts for alar retraction, and other procedures are relative details.
- The primary aesthetic and airway problems can be corrected using only the four graft types mentioned, using the two strategies outlined. This gives the surgeon much less to master.

Positioning

- The patient is placed supine with the arms and legs padded and the knees slightly flexed; the operating table is 10 to 15 degrees reverse Trendelenburg position to minimize bleeding.

Approach

- Closed rhinoplasty
- Rhinoplasty offers the possibility of individualizing a result as much as or more than any other aesthetic procedure, and the closed approach is often the key to doing so.

TECHNIQUES

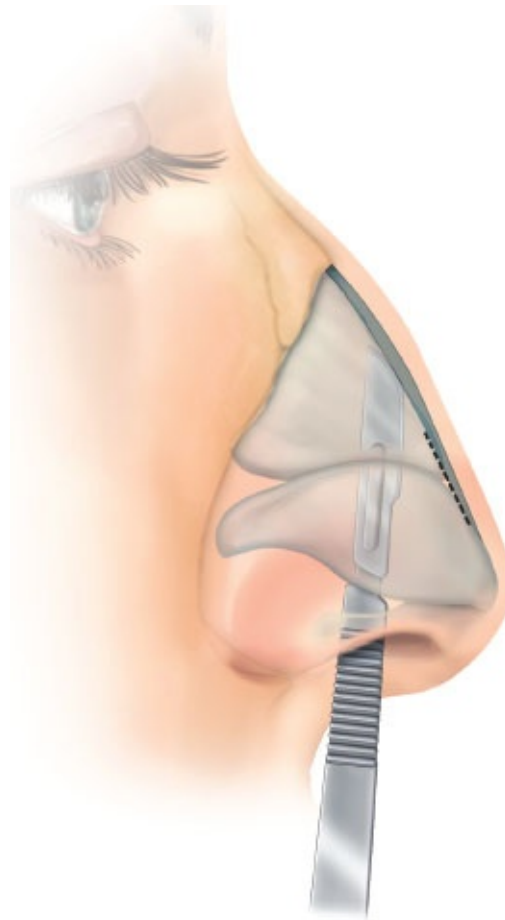
- The techniques for performing the closed approach to ethnic rhinoplasty are the same as any closed rhinoplasty.
- The key is addressing the patient's desires and goals without creating incongruity with a patient's heritage or an awkward, "operated" appearance.

■ Skeletonization

- Endonasal access via unilateral or bilateral intercartilaginous incisions is preferred.
- For details on closed rhinoplasty exposure, see Chapter 53, Indications and Technique for Treating the Narrow Middle Vault in Closed Rhinoplasty.

■ Dorsal Resection

- Bony vault reduction is performed under direct vision using a sharp rasp, judging the result by assessing surface contours.
- Next, resection of the dorsal border of the septum is accomplished with a no. 11 blade from which the tip has been broken to avoid lacerating the contralateral dorsal skin (**TECH FIG 1**).
- The dorsum should feel and appear perfectly smooth through the skin surface after dorsal resection.
 - Watch for a depressed discontinuity in the mid-dorsum; this is a “mid-dorsal notch” and signifies dorsal over-resection beyond the limits of soft tissue contraction.
 - Treatment is placement of a thin dorsal graft under the notch, not more skeletal resection.⁶

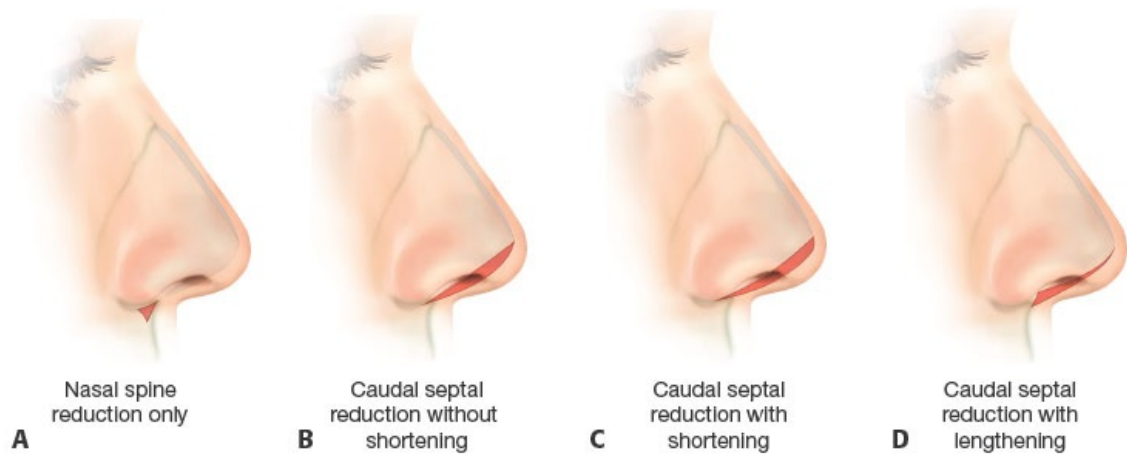


TECH FIG 1 • Resection of the dorsal border of the

septum is accomplished under direct vision with a no. 11 blade from which the tip has been broken to avoid lacerating the contralateral dorsal skin.

■ Nasal Spine–Caudal Septum

- Through a transfixion incision, the caudal septum and nasal spine can be accessed and resected as necessary to change the relationship of the columella to nostril rim, nasal length, subnasale contour, and upper lip carriage (**TECH FIG 2**).
- If the nasolabial angle and upper lip relationships are satisfactory, no transfixion incision and no caudal septal or nasal spine modifications are necessary.
- Be cautious about over-resection; 1 or 2 mm makes the difference between normal columellar position and retraction.



TECH FIG 2 • The specific maneuvers for the nasal spine and caudal septum depend on the need.

■ Alar Cartilage Resection

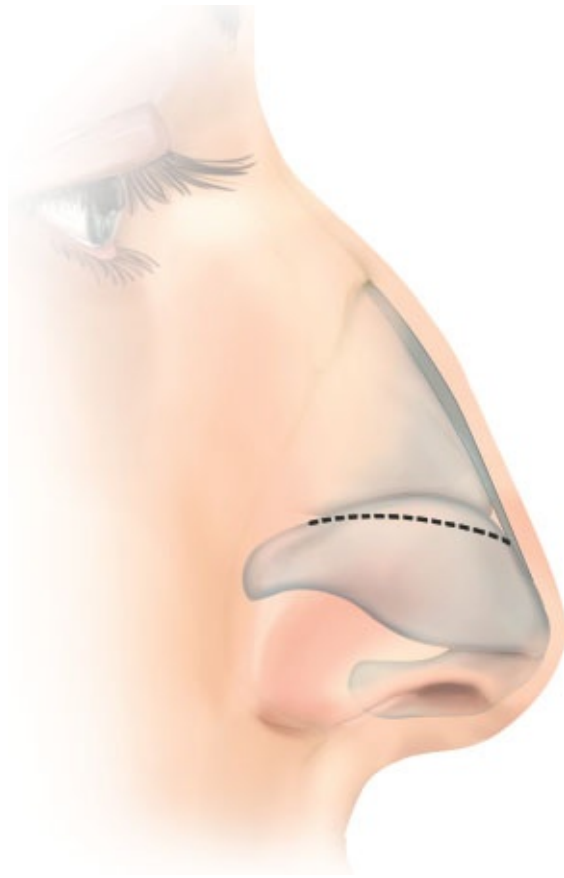
- Orthotopic or nondeforming cephalically rotated (malpositioned) lateral crural cartilages are modified retrograde through the intercartilaginous

incisions; rarely, more than 2 to 3 mm is removed, leaving lateral crura of 8 to 10 mm in width.

- The domes can be narrowed by vertical wedge resections performed at the lateral genu.
- Distorted or severely convex “boxy” or “ball” tips that must be significantly modified are dissected free from their vestibular and overlying skin and (1) resected and replaced after trimming to create the flattest segment, (2) resected and replaced by septal or ear cartilage grafts, or (3) delivered as a medially based flap and rotated into the alar rim, with care to ensure that distortion or notching at the soft triangle or lateral genua does not occur.
- Most “boxy” or “ball” tips are also malpositioned, so that a functional problem accompanies the aesthetic deformity and should be corrected simultaneously.⁷
- Freeing of the lateral crura, dome resection, or division of the alar cartilage arch reduces tip projection: thus, tip grafts are necessary to reconstruct the lobule.
- In order to avoid vestibular stenosis and iatrogenic airway obstruction, nasal lining should never be resected.

■ Upper Lateral Cartilages and Shortening the Nose

- A single hook is used to draw the caudal edge of the upper lateral cartilage downward, exposing the caudal edge for submucosal resection with Joseph scissors.
- The posterior edges of the upper lateral cartilages should be left to abut the lateral crura; mucosa should never be resected.
- A variety of interventions shorten the nose. In descending order of their effect, they are dorsal resection, caudal septal resection, resection of the cephalic edges of the alar cartilages lateral crura, and resection of the antero-caudal ends of the upper lateral cartilages (**TECH FIG 3**).
 - This final step is unnecessary unless substantial nasal shortening is required.



TECH FIG 3 • The cephalic portion of the lateral crus is resected.

■ Septoplasty and Spreader Graft Tunnels

- Spreader graft tunnels should be performed prior to septoplasty.
- For details on septoplasty and spreader grafts, see Chapter 63, Indications and Technique for Treating the Narrow Middle Vault in Closed Rhinoplasty.

■ Turbinectomy

- Turbinate crushing and outfracture suffice in most patients.
- If resection is necessary, for example, in severely atopic patients, biopsy forceps are used to trim the anterior edge sufficient to obtain 3 mm of clearance to the septum or nasal floor.
- Be conservative, as over-resection and its resulting physiologic disturbances are not correctable.

■ Graft Placement and Wound Closure

- Spreader grafts are sized to the dimensions of the tunnel and the length of the upper lateral cartilages. They may be adjusted in width or configuration to provide symmetry.
- The skin of the nasal dorsum and radix is thinnest, and slight imperfections/asymmetries may be easily noticed. Dorsal and radix grafts must fit the configuration of the defect and suit the soft tissue cover. These grafts should feel and look perfectly on the operating room table beneath the soft tissue envelope.
- Important principles of tip grafting include the following: graft length should be suited to its purpose and graft substance/contour must match the soft tissue cover.
- Multiple softened grafts work well for patients who still have their alar cartilages and only need improved definition.
- For the patient with an undefined and unsupported tip, solid cartilage or bone graft is placed to establish projection and define the angle of rotation. By itself, a single tip graft looks too artificial and pointed. Accordingly, softened cartilage grafts are placed anterior to the defining graft to re-create a normal lobule.
- As grafts are placed (in that order), 5-0 plain catgut sutures close each access incision so that graft position will be easier to maintain.

■ Osteotomy

- A single lateral osteotomy with a guarded osteotome, which begins intranasally, low at the pyriform aperture, and ends higher toward the nasal root, is sufficient to narrow the upper nasal third.
 - If the bony vault is low and broad and will be augmented, the nasal bones are short, or if the upper nasal third is already sufficiently narrow, osteotomy is not necessary (**TECH FIG 4**).
- Gentle digital pressure is used to greenstick fracture the remaining cephalic attachment and will reform the bony pyramid.



TECH FIG 4 • Intranasal osteotomies are performed with a guarded, curved 4-mm osteotome beginning at the base of the piriform and advancing toward the medial canthus.

■ Alar Wedge Resection

- When necessary, an external incision is made slightly outside the alar crease in order to not destroy this important landmark.
 - Remember that the alar wall has two surfaces, external and vestibular, and that they can be treated independently. In other words, the alar lobule can be narrowed without reducing nostril size, or both alar lobule and nostril can be reduced.
 - It is important to retain a small medial flap as the surgeon incises the nasal floor to provide a smooth closure line and avoid notching. 6-0 nylon is used for closure and sutures are removed at 5 days.
-

PEARLS AND PITFALLS

Ethnic rhinoplasty

- Ethnic rhinoplasty does not differ from any other type of rhinoplasty from a technical standpoint: treatment of a low dorsum and large nasal base under a thick soft tissue cover is the same whether the patient's ethnic background is Slavic or African American.
- It is imperative that the surgeon and patient communicate about the particular aspects of the appearance of the nose he or she wishes to preserve and which ones he or she would like to address surgically.
- Knowledge of common characteristics of each ethnic group provides a starting basis for the preoperative discussion, but it is the patient's specific nasal contour and aesthetic goals that should dominate. Individuals are too unique to make sweeping generalizations about the characteristics of any ethnic groups.

Approach

- Closed rhinoplasty does not mean blind rhinoplasty. Rather, the mental exercise that distinguishes endonasal rhinoplasty from open rhinoplasty is precisely the same thought process that distinguishes liposuction from abdominoplasty.
- The surgeon accepts limited access and makes intraoperative judgments based on the appearance and “feel” of the surface because doing so gives the surgeon more control and precision and therefore benefits the patient.
- The more difficult the deformity and the more difficult the case, the stronger the argument can be made for limiting access, limiting incisions, and minimizing morbidity by minimal disruption of the nose.

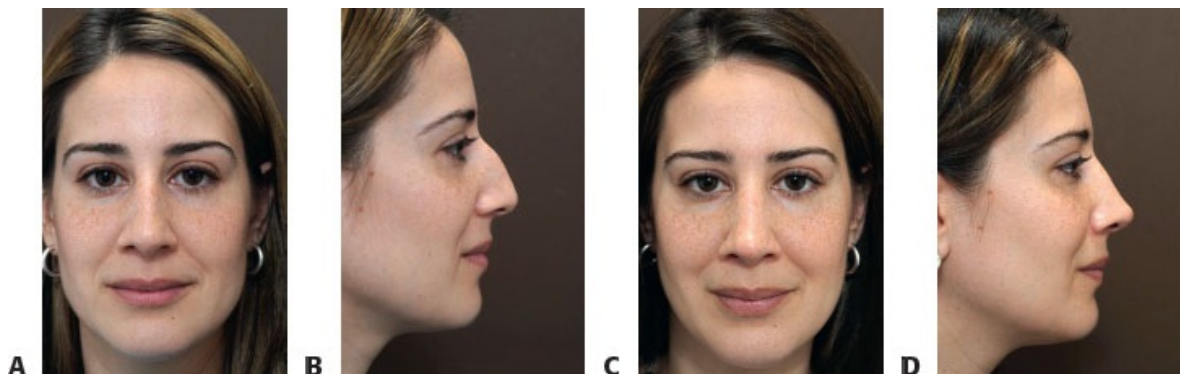


FIG 1 • A young woman of Greek ancestry for whom it was critically important to maintain ethnic identity, which

she defined as preserving her dorsal convexity. The surgical procedure involved dorsal reduction, spreader grafts to maintain valvular competence following resection of the cartilaginous roof, tip grafts to increase projection, and deliberate maintenance of dorsal height. **A,B.** Preoperative views. **C,D.** Two-year postoperative views.

POSTOPERATIVE CARE

- Nasal packs are placed in all patients who undergo septoplasty or have had grafts placed. Nasal packs, tape, and plaster splints immobilize the reconstruction for 1 week, until the grafts and modified skeleton are stable and packing can be removed without pain or bleeding.
- See each patient frequently in the early postoperative period and for at least the first postoperative year, documenting postoperative changes.

OUTCOMES

- With a thorough informed discussion preoperatively, the surgeon can achieve functional and aesthetically pleasing results that are in keeping with a patient's expectations about maintaining his or her ethnic identity (**FIG 1**).
- Because only four graft types need to be mastered, with experience, the need for revisions should not be common.

COMPLICATIONS

- Skeletal problems
- Soft tissue problems
- Graft problems
- Asymmetry
- Using the surgical planning and techniques described, the following complications virtually never occur.
 - Iatrogenic airway obstruction
 - Intraoperative and postoperative hemorrhage
 - Septal perforation
 - Rhinitis
 - Circulatory problems
 - Infection

- Septal collapse
- Red nose
- Racial incongruity
- Treatment of more common complications is straightforward. Because the underlying anatomy has not been disturbed, and no sutures or struts have been placed, not much can go wrong.
- Dorsal grafts can move out of position but can be easily adjusted in a small secondary procedure.
- Spreader grafts virtually never require revision and can be expected to double nasal airflow in most patients.
- Alar wall grafts occasionally bow or are under corrected or overcorrected but still double airflow if external valvular incompetence existed preoperatively.
- Tip grafts can be placed insufficiently, or in excess, or heal asymmetrically.
- In any of these occasions, local adjustments through limited incisions are corrective.

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Indications and Technique for Open Rhinoplasty in Patients With Dorsal Hump and Wide Tip

57

CHAPTER

Charles H. Thorne and Sammy Sinno

DEFINITION

- *Dorsal hump* refers to excess height in the upper third of the nose. When examining a patient in the lateral view, ideally the nose should be in line with a line drawn from the radix to the tip (or slightly behind this line in females); any excess projection anterior to this line is a dorsal hump.
- *Wide tip* refers to a variety of configurations of the lower lateral cartilages that create the appearance of bulbous and poorly defined nasal tip.

ANATOMY

- The anatomy of the dorsal hump is usually both cartilaginous and bony. The nasal bones and the dorsal septum can both or independently be excessive. Any of these situations can contribute to a dorsal hump.
- A wide tip is primarily related to positioning and orientation of the lower lateral cartilages. Dr. Rohrich and colleagues categorized three types of boxy tip relating to a wide intercrural angle, a wide domal arch, or both.¹ Wide or bulbous tips can also result from bifidity of the nasal tip, excess or convex lateral crura, or lower lateral cartilage malposition.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Dorsal hump and wide nasal tip are the two most commonly encountered patient complaints regarding their nose.
- On palpation of the dorsum, a dorsal hump can be bony or cartilaginous, or in some instances both.

- Palpation of the tip cartilages is important to give information regarding integrity, positioning, and recoil of the lower lateral cartilages.

IMAGING

- Although CT imaging can be useful in nasal surgery for airway abnormalities, routine scans are not obtained for patients presenting for correction of dorsal hump and wide nasal tips.

SURGICAL MANAGEMENT

- A clear surgical plan should be outlined prior to any rhinoplasty procedure.

Preoperative Planning

- The patient is counseled extensively in preoperative discussion regarding surgical outcomes and recovery. Photographs are taken and will be used intraoperatively. Currently, we do not use 3D imaging software.

Positioning

- The patient is in the supine position with the head slightly extended.

Approach

- The open approach is used for full visualization of deformities in the dorsum and tip.

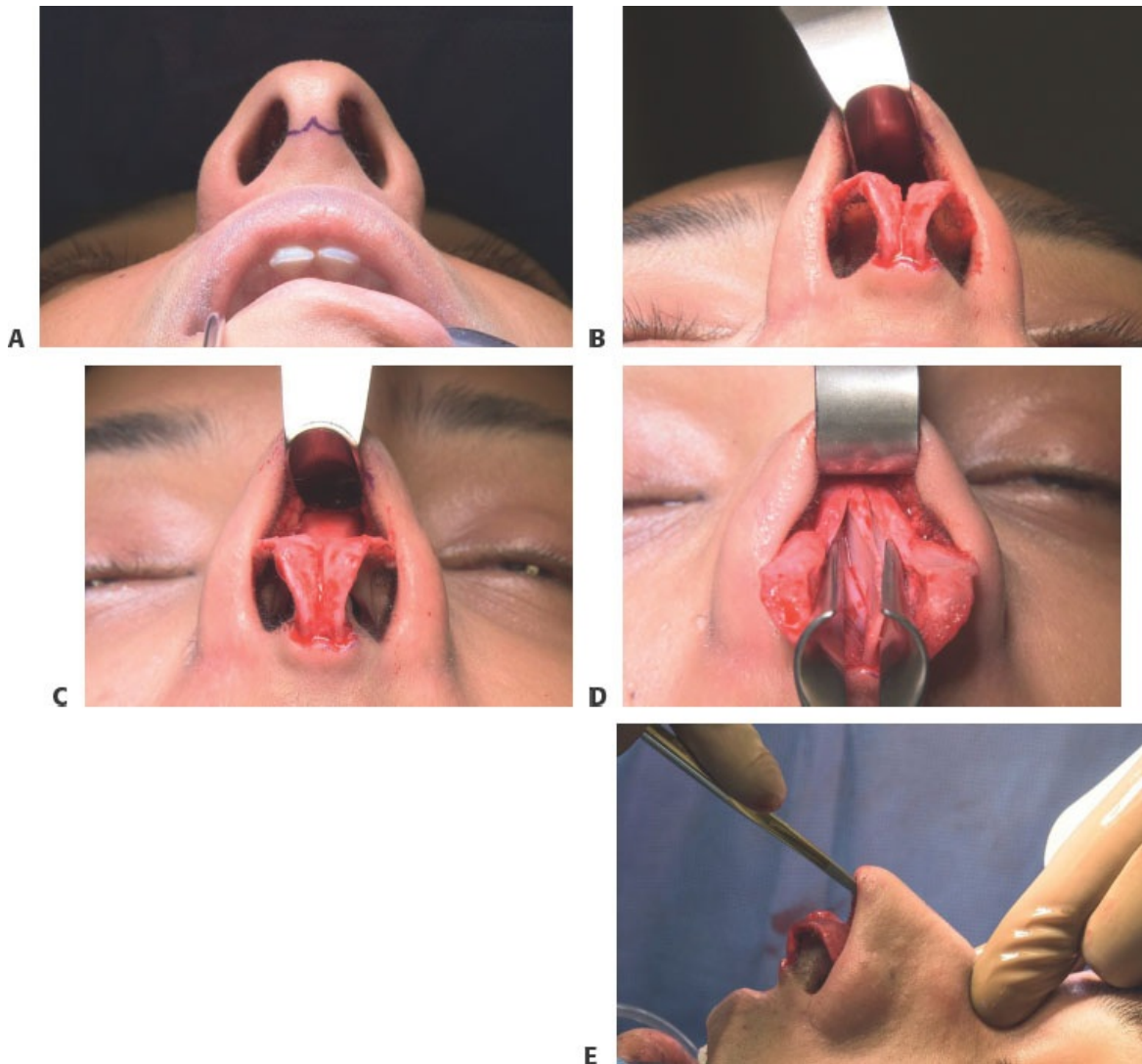
TECHNIQUES

■ Correction of the Dorsal Hump

- An inverted V or upright V incision is used to open the nose along with bilateral infracartilaginous incisions (**TECH FIG 1A**).
- Using converse tip scissors, the nasal skin and soft tissues are dissected immediately on the surface of the nasal cartilages from caudal to cranial (**TECH FIG 1B**). A Joseph periosteal elevator is used to elevate the periosteum off the nasal bones in the midline (**TECH FIG 1C**).
- Once full exposure is achieved, a no. 15 blade is used to separate the upper lateral cartilages from the septum (**TECH FIG 1D**). An assessment is then made regarding the anatomical features that contribute most to the dorsal

hump.

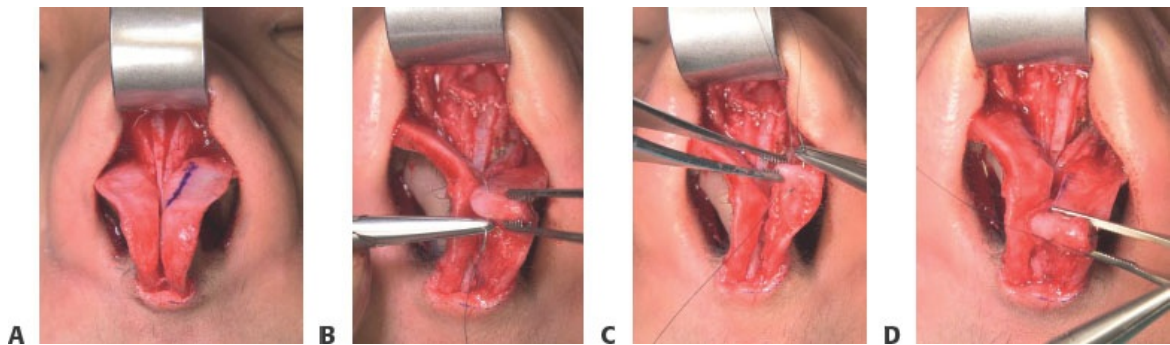
- Separation of the upper lateral cartilages from the septum:
 - If primarily cartilaginous, the dorsal septum is scored with a no. 11 blade and then excised with Swedish or Foman scissors.
 - If the hump is primarily bony, a bone rasp is used to bring down the dorsum (**TECH FIG 1E**).
- The nasal skin must be redraped and constantly reassessed by lateral visualization and palpation to determine adequacy of reduction.
- The dorsum is then restored by either suturing the upper lateral cartilages back together with 5-0 PDS sutures or spreader grafts placed and secured between the upper lateral cartilages and septum.



TECH FIG 1 • **A.** An inverted V or upright V incision can be used. **B.** Nasal cartilages dissected free. **C.** Nasal bones exposed. **D.** Separation of the upper lateral cartilages from the septum. **E.** Rasping the bony dorsum.

■ Correction of the Wide Tip

- Correction of the wide tip has several components. A cephalic trim is often performed first by marking, scoring, and then excising the cephalic aspect of the lateral crura, making sure to leave an adequate width of residual lateral crura (at least 5mm) (**TECH FIG 2A**).
- Tip sutures can also be powerful in correcting a wide tip; these are placed with 6-0 PDS:
 - Intradomal sutures can also be used to refine the tip and correctly orient malpositioned lower lateral cartilages into the correct plane (**TECH FIG 2B-D**).
 - Interdomal sutures, placed from one dome to the other and tied, also can have a drastic impact on refining the tip.



TECH FIG 2 • **A.** Marking of the cephalic aspect of the lateral crura to be excised. **B-D.** Intradomal suture placement.

Exposure	■ It is critical to expose the nasal architecture in a subperichondrial and subperiosteal plane to avoid excess bleeding and leave maximal soft tissue covering of framework modifications.
Dorsal reduction	■ Reduce the dorsum in an incremental fashion to avoid over-resection. ■ Avoid over-resection of the upper lateral cartilages. ■ If the patient has had a prior septoplasty, exercise caution in reducing the hump as an 8- to 10-mm L strut is necessary.
Osteotomies	■ Perform the infracture as low as possible to avoid a step-off deformity.
Wide tip	■ Use a graduated approach toward refining tip aesthetics: cephalic trim, then intradomal sutures, and then interdomal suture.

POSTOPERATIVE CARE

- The nose is taped, and an Aquaplast splint is applied.
- The tape, splint, and sutures are removed in 5 days.
- Patients are encouraged to sleep on their backs with head elevated for 2 weeks following surgery.
- All patients are encouraged to gently clean their nostrils with cotton swabs and a mixture of water and peroxide.

OUTCOMES

- Typically, correction of dorsal humps and wide tips yield very high patient satisfaction in rhinoplasty procedures.

COMPLICATIONS

- Undercorrection can occur and patients must be counseled extensively preoperatively.

REFERENCE

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58 Treating the Narrow Midvault

CHAPTER

Eric J. Culbertson and Jason Roostaeian

DEFINITION

- The brow-tip dorsal aesthetic lines on frontal view are paired gentle curvilinear lines starting at the medial brow curving medially along the nasal bridge before transitioning laterally to the tip. This line can be disrupted by bony irregularities of the upper third of the nose, middle vault contour deformities in the middle third, and deviations of the tip or asymmetry of the lower lateral cartilages in the lower third. Restoration of this and other nasal aesthetic contours is key to achieving an optimal result following rhinoplasty (**FIG 1A**).¹
- Narrowing of the midvault can cause both aesthetic deformity, commonly appearing as an “inverted V,” and functional airway obstruction due to narrowing of the internal nasal valve (**FIG 1B**).²

ANATOMY

- The middle vault is composed of the paired upper lateral cartilages, overlying soft tissue and skin, and underlying attached mucosa. Superiorly, the keystone area (also referred to as the K area) is the junction of the upper lateral cartilages with the nasal bones. Inferiorly in the scroll area, the upper and lower lateral cartilages are connected by loose areolar and fibrous attachments (**FIG 2**).
- The internal nasal valve is defined by the caudal border of the upper lateral cartilage, the septum, the head of the inferior turbinate, and the piriform aperture. Nasal airway resistance accounts for more than 50% of total airway resistance during nasal breathing, and the internal nasal valve has the smallest cross-sectional area of the nasal airway. The normal angle between the septum and upper lateral cartilage is 10 to 15 degrees (**FIG 3A**). An angle below this

range can contribute to nasal obstruction (**FIG 3B**).³

PATHOGENESIS

- Midvault narrowing is a common sequela of rhinoplasty, particularly following dorsal hump reduction. Reduction of the cartilaginous component frequently disrupts the relation and attachments of the septum with the upper lateral cartilages, which form a single entity. Cartilage resection can result in an open roof deformity and allow collapse of the upper lateral cartilages, narrowing the internal valve angle and resulting in an inverted-V deformity and nasal obstruction. Often, this may not become apparent for months or years after surgery.
- Patients at particular risk are those with short nasal bones, thin skin, weak cartilages, or a combination thereof.²
- Scar contracture from tumor resection or trauma involving the lower portion of the nose may distort the internal nasal valve.
- Facial paralysis may cause internal and external valve collapse through ptosis of the lateral nasal soft tissues and loss of muscle tone that normally prevents valve collapse, particularly on inspiration.
- Weakening of the attachments between the upper and lower lateral cartilages with age may lead to senile tip ptosis that can also cause internal valve narrowing.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed nasal history should be obtained, in particular to include a history of symptoms related to nasal obstruction, nasal allergies, prior nasal trauma, and nasal surgeries. Any patient aesthetic concerns and goals should be elicited and clearly defined.^{3,4}
- A complete external and internal nasal examination should be conducted in all patients.
- Evaluate symmetry of the upper lateral cartilages. An inverted-V deformity may be present as a result of collapse of the upper lateral cartilages.

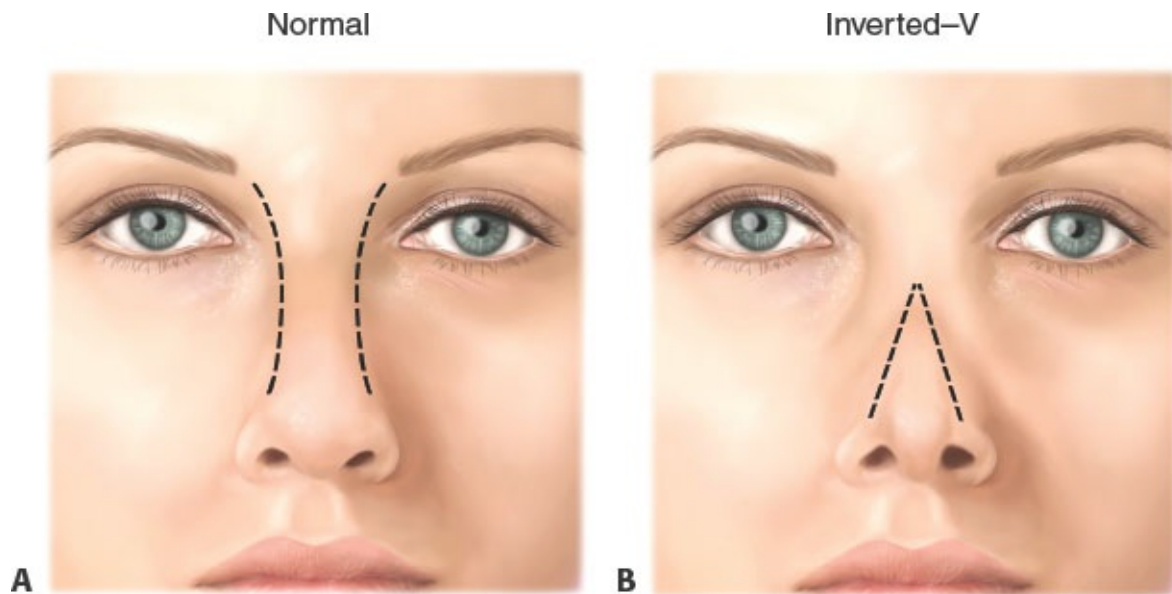


FIG 1 • Normal brow-tip aesthetics form paired curvilinear lines from the medial brow to the tip **(A)**. Midvault narrowing can disrupt these lines and distort the aesthetics of the nose, with a visible inverted-V deformity **(B)**.

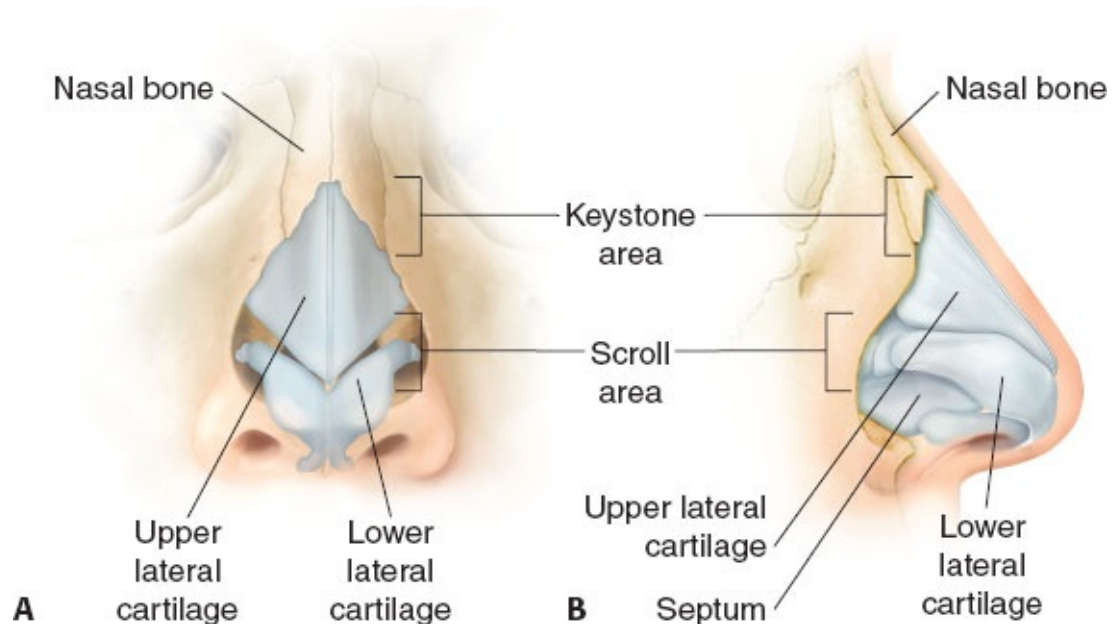


FIG 2 • **A,B.** Normal nasal anatomy.

- Perform a Cottle maneuver, where the cheek immediately adjacent to the nasal

sidewall is displaced laterally to assess for improvement in nasal airway obstruction with widening of the internal nasal valves. Gentle internal elevation of the upper lateral cartilages using a cotton-tipped applicator will also improve breathing in patients with midvault narrowing. Patency of the internal nasal valve during inspiration should also be assessed.

- A nasal speculum is used to evaluate the septum for deformities and the inferior turbinates for hypertrophy.
- Standardized photographs including frontal, lateral oblique, and basal views should be obtained in all patients.

IMAGING

- Imaging is seldom required for diagnosis or treatment; however, supplemental testing can be performed to assess airway dynamics. Rhinomanometry measures pressure and flow during inspiration and expiration and provides a measure of airflow resistance and nasal patency. Acoustic rhinometry analyzes reflected sound waves directed through the nostrils and can be used to measure cross-sectional area and nasal volume to quantify nasal obstruction.⁵

SURGICAL MANAGEMENT

- The primary objective is to correct any functional airway obstruction caused by narrowing of the internal nasal valve.
- Aesthetic concerns and goals for treatment discussed with the patient may also be addressed, particularly to restore symmetric and pleasing dorsal aesthetic lines.
- The use of spreader grafts to reconstruct the roof of the middle nasal vault and open the internal nasal valve was first described by Jack Sheen, originally through an endonasal approach.² Either an open or endonasal approach may be used for spreader graft placement. The use of the upper lateral cartilages as autospreader grafts or flaps, reducing the need to harvest cartilage grafts, was subsequently described.

Preoperative Planning

- In planning the operative approach, it is important to carefully review the preoperative photos and establish clear goals of treatment with the patient. Consideration of previous operations, extent of previous nasal trauma, and involved structures and available septal and other potential cartilage grafts (ear, rib) should be taken into account. The patient should be informed of the

possible need to harvest cartilage from these other donor sites such as the ear or rib.

Positioning

- The patient is positioned supine on the operating table with arms tucked at the side.
- An oral right angle endotracheal tube is used for intubation, and should extend inferiorly in the midline away from the nose, and secured without distorting the upper lip and nose.
- Nasal hairs may be trimmed, if desired.

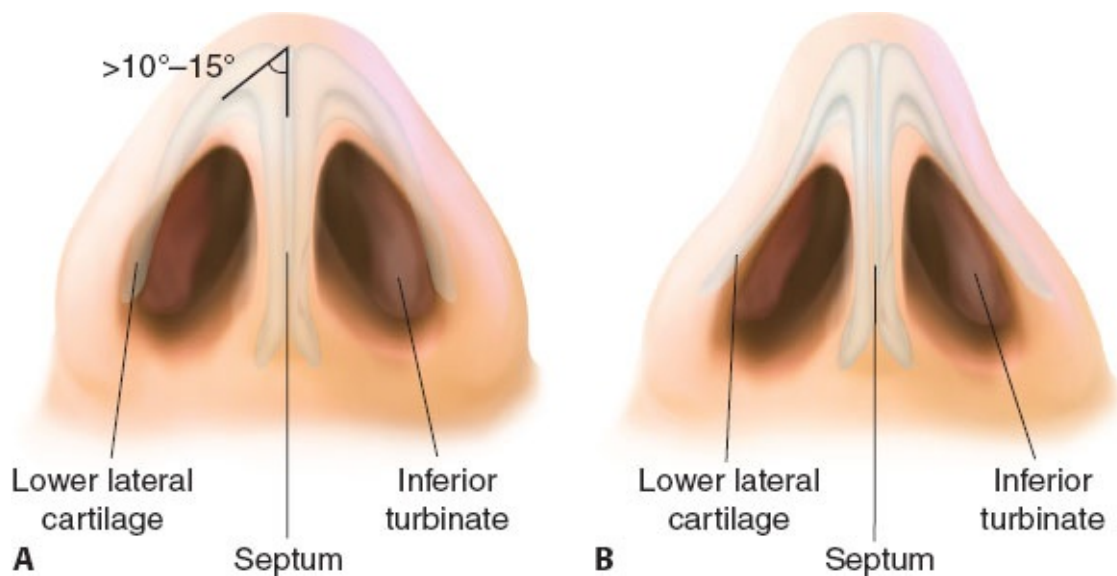


FIG 3 • Normal middle nasal vault anatomy is demonstrated. The normal angle between the septum and upper lateral cartilages is 10 to 15 degrees (**A**). A more acute angle may narrow the midvault and cause obstruction of the internal nasal valve (**B**).



FIG 4 • Local anesthetic is injected into the nasal sidewalls, columella, and inside the nostril along the lower lateral cartilages.

- Local anesthetic consisting of 1% lidocaine with 1:100 000 epinephrine is infiltrated into the nasal sidewalls and columella and inside the nostril along the lower lateral cartilages (**FIG 4**).
- Oxymetazoline or 4% cocaine-soaked pledgets are placed in each nostril.
- A throat pack is placed to prevent gastric accumulation of blood.
- The face is prepped with dilute Betadine.
- A sterile head wrap is placed followed by surgical drapes.

Approach

- The open or closed (endonasal) approach to rhinoplasty may be used to correct the narrow midvault, depending on the technique used, extent of prior surgery or trauma, and other treatment goals.
- Spreader graft placement, using either cartilage or autospreader flaps, corrects the lack of dorsal support and helps restore a normal dorsal profile. If additional cartilage is needed, this may be harvested from the rib or ear.

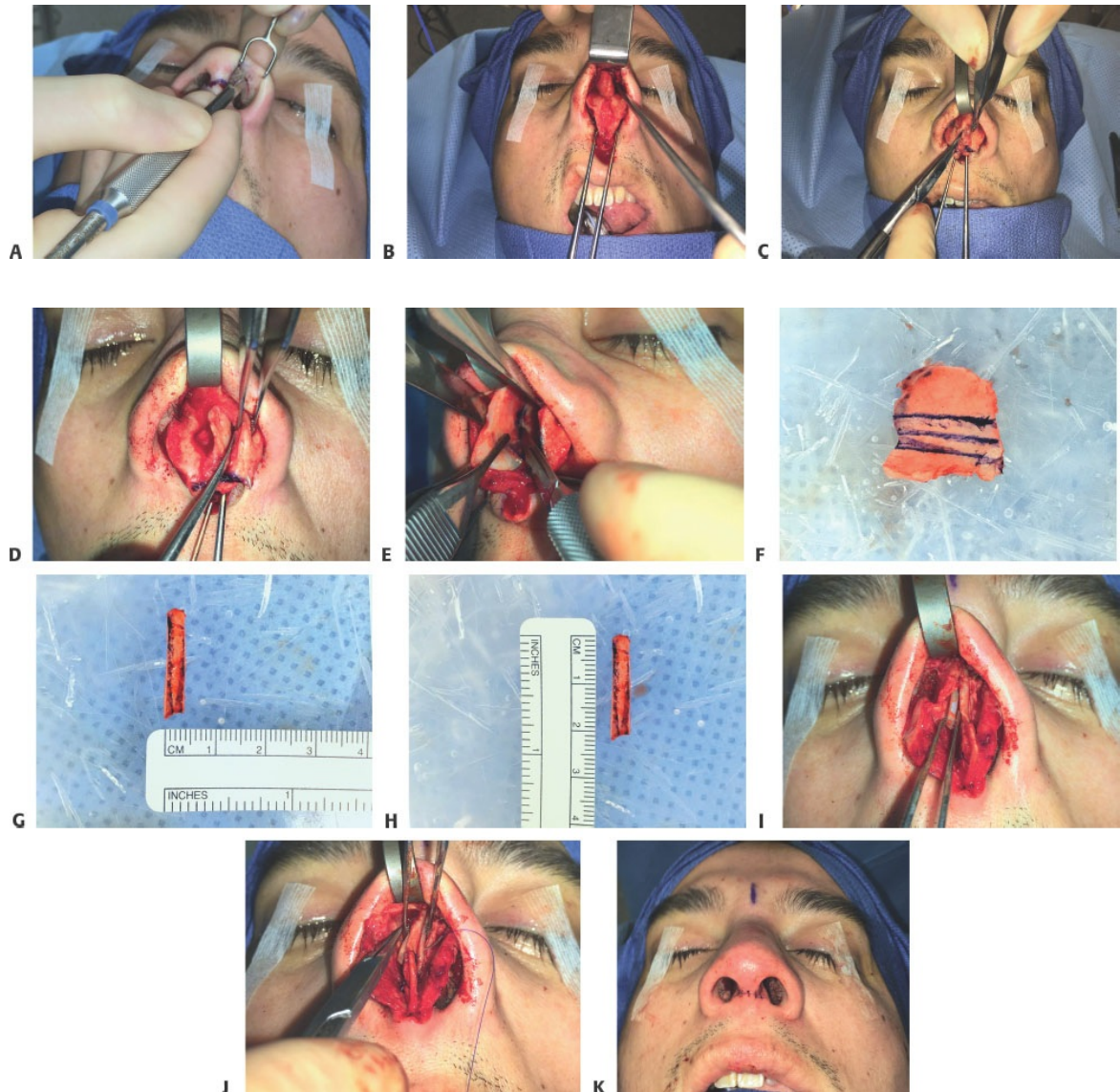
TECHNIQUES

■ Open Spreader Graft Placement

- After prepping and draping, the nasal pledgets are removed.

- A gull wing or stair-step incision is marked on the columella at the narrowest point, approximately at the midpoint, and extending along the side of the columella just into the nostril.
- This is incised with a no. 15 blade just through the dermis.
- Infracartilaginous incisions are made laterally on each side (**TECH FIG 1A**).
- The columella and alar incisions are connected.
- Fine curved iris or converse scissors are used to complete the columellar incision, with care taken to avoid injury to the medial crura.
- The nasal tip is elevated from the lower lateral cartilages with scissors, and dissection continued over the upper lateral cartilages up to the bony dorsum (**TECH FIG 1B**).
- The upper lateral cartilages are separated from the septum at the anterior septal angle using fine iris scissors or a no. 15 blade, and the mucoperichondrium on either side of the septum is incised onto the septal cartilage (**TECH FIG 1C**).
- Mucoperichondrial flaps are raised on either side of the septum using a Cottle elevator (**TECH FIG 1D**).
- The more proximal portion of the upper lateral cartilages is then separated from the septum after complete release of the mucoperichondrium using a no. 15 blade to upstroke from distal to proximal. A converse retractor should be used to protect the nasal skin.
- Adequate septal cartilage is removed for spreader and any other needed grafts as well as to correct any significant septal deviation, preserving 1 to 1.5 mm dorsal and caudal septal struts (**TECH FIG 1E**).
- Spreader grafts are designed, typically measuring 1 to 3 mm in thickness, 3 to 5 mm in width, and 15 to 30 mm in length, depending on the patient's anatomy and degree of correction needed (**TECH FIG 1F–H**).
- The spreader grafts are placed on each side of the septum, just below the level of the upper lateral cartilages, extending from above the bony-cartilaginous junction beneath the nasal bone to the caudal end of the upper lateral cartilages (**TECH FIG 1I**).
- The spreader grafts are secured in place with 2 to 3 interrupted 5-0 PDS sutures passing through the spreader graft on one side, the septum, and then the other graft (**TECH FIG 1J**).
- The upper lateral cartilages are then reapproximated to the septum at the midline over the spreader grafts using 2 to 3 interrupted 5-0 PDS sutures.

- Mattress sutures of 4-0 plain gut are placed through the mucoperichondrial flaps to close the dead space where septal cartilage was harvested.
- The nose is thoroughly irrigated, hemostasis is achieved, and the nasal skin is redraped.



TECH FIG 1 • A. The columella incision is made, followed by infracartilaginous incisions laterally on each side. The columella and alar incisions are then connected. **B.** The nasal tip is elevated from the lower lateral cartilages and dissection continued over the upper lateral cartilages up to the bony dorsum. **C.** The

upper lateral cartilages are separated from the septum, and the mucoperichondrium on either side of the septum is incised onto the septal cartilage. **D.** Mucoperichondrial flaps are raised on either side of the septum. **E.** Septal cartilage is harvested with preservation of 1 to 1.5 mm dorsal and caudal septal struts. Spreader grafts are designed (**F**), typically measuring 1 to 3 mm in thickness, 3 to 5 mm in width (**G**), and 15 to 30 mm in length (**H**). **I.** The spreader grafts are placed on each side of the septum, just below the level of the upper lateral cartilages. **J.** The spreader grafts are secured in place with interrupted sutures passing through the spreader graft on one side, the septum, and then the other graft. **K.** The columellar skin is reapproximated with interrupted 6-0 Prolene, and the infracartilaginous incisions are closed with interrupted 5-0 chromic.

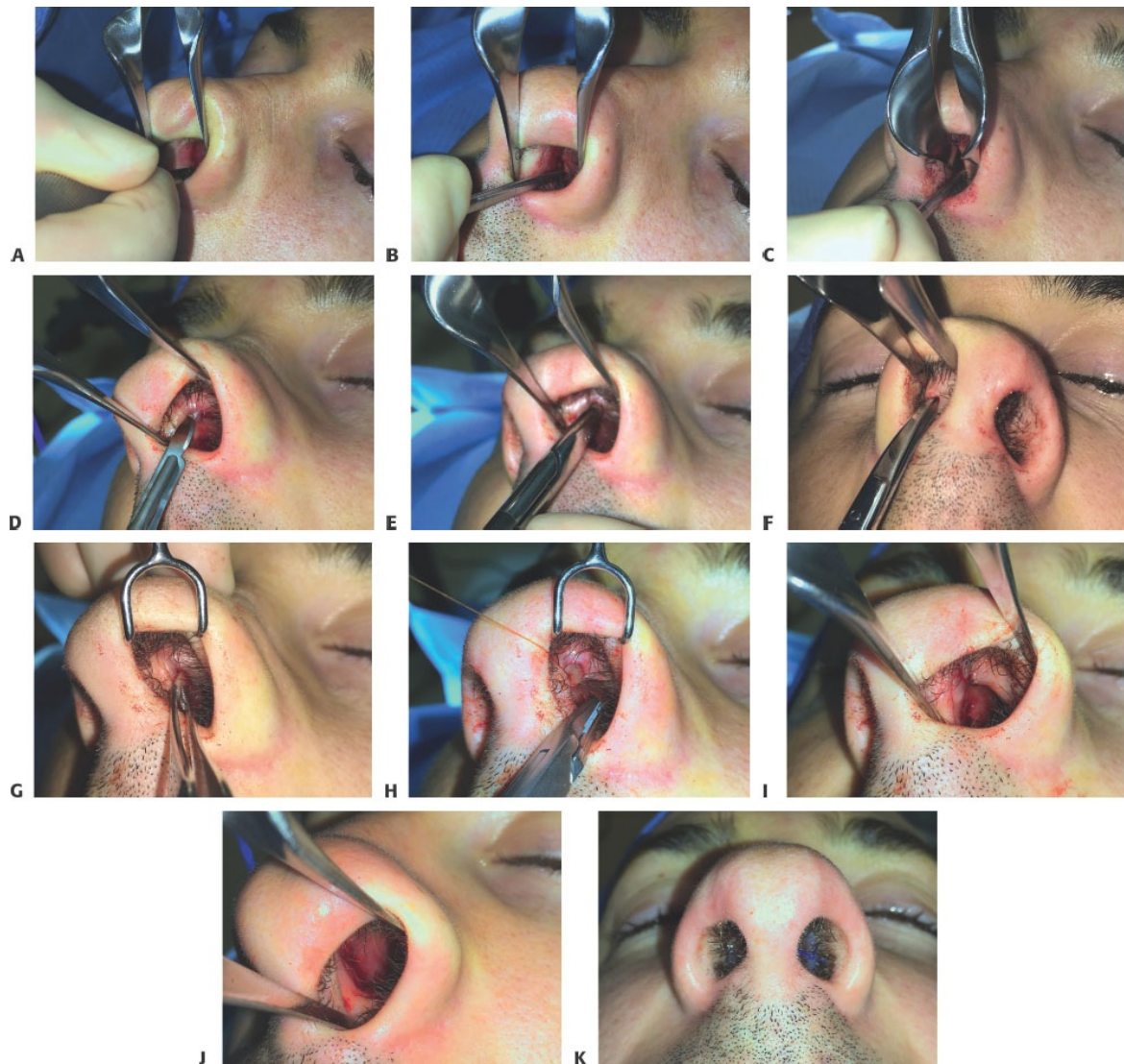
- The columellar skin is reapproximated with interrupted 6-0 Prolene, and the infracartilaginous incisions are closed with interrupted 5-0 chromic (**TECH FIG 1K**).
- Internal nasal splints are placed in each nostril and sutured through the septum with a single 3-0 Prolene mattress suture.
- Tape strips are applied to the nasal dorsum to limit postoperative swelling.
- The throat pack is removed prior to extubation. A nasogastric tube may be used to suction gastric contents to remove accumulated blood.
- A mustache gauze dressing is applied across the upper lip to absorb any nasal drainage.

■ Endonasal Spreader Graft Placement

- The patient is positioned and prepared as previously described.
- The nasal pledgets are removed after prepping and draping.
- A Killian incision, approximately 1 to 1.5 cm cranially from the caudal

septal border, or a hemitransfixion incision at the caudal septal border is performed through the mucoperichondrium using a no. 15 blade (**TECH FIG 2A**).

- Submucoperichondrial dissection is performed using a Cottle elevator, preserving the attachments to the septum dorsally for approximately 1 cm for later spreader graft pocket creation (**TECH FIG 2B**).
- The septum is incised vertically with a no. 15 blade or Freer knife with care to preserve the contralateral mucoperichondrium.
- Submucoperichondrial dissection is performed on the contralateral side, again preserving attachments dorsally (**TECH FIG 2C**).
- The septal cartilage can now be harvested using a no. 15 blade or Freer knife, preserving an L strut of at least 1 cm dorsally and caudally.



TECH FIG 2 • A. A Killian incision is made approximately 1 to 1.5 cm cranially from the caudal septal border through the mucoperichondrium. **B.** Submucoperichondrial dissection is performed, preserving the attachments to the septum dorsally for approximately 1 cm for later spreader graft pocket creation. **C.** Submucoperichondrial dissection is performed on the contralateral side, again preserving attachments dorsally for later spreader graft placement. **D.** The mucosa at the internal nasal valve is incised, and a submucoperichondrial pocket is

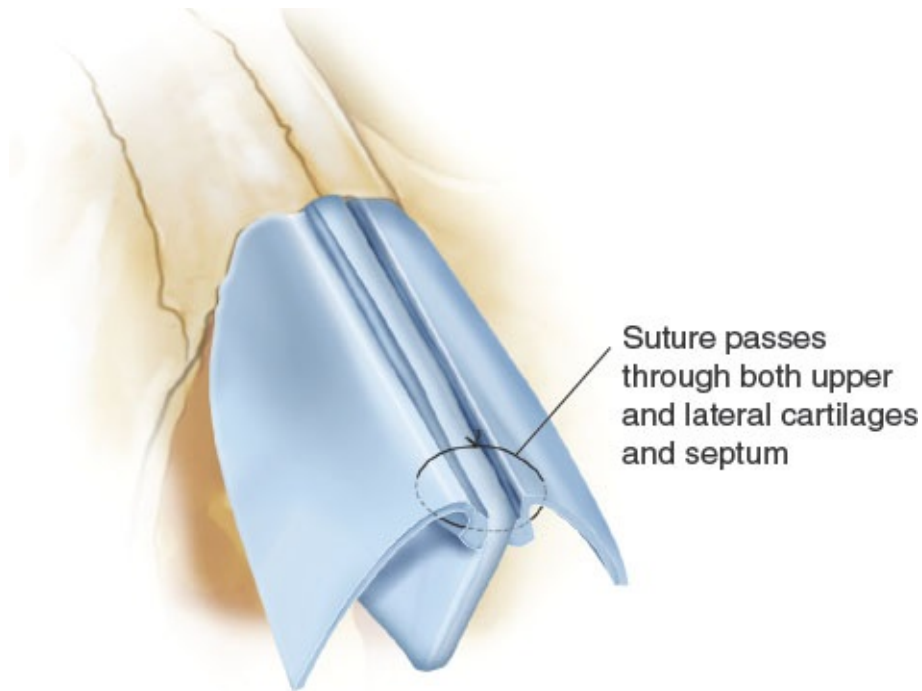
developed on each side between the septum and upper lateral cartilages. **E.** An approximately 5-mm-wide pocket for spreader graft placement is developed along the dorsal septum beneath the upper lateral cartilages to the level of the nasal bones. **F.** This is repeated on the other side. **G.** The spreader grafts are inserted into each pocket, and the caudal aspects are secured to the septum in a horizontal mattress fashion (**H**). **I.** The mucosa is closed over the spreader grafts. **J.** Mattress sutures are placed through the mucoperichondrial flaps to close the dead space where septal cartilage was harvested. **K.** Internal nasal splints are placed in each nostril and sutured through the septum.

- Spreader grafts are shaped from the harvested cartilage, one or two depending on whether unilateral or bilateral placement is desired.
- Spreader grafts typically measure 1 to 3 mm in thickness, 3 to 5 mm in width, and 15 to 30 mm in length, depending on the patient's anatomy and degree of correction needed.
- The mucosa at the internal nasal valve is incised with a no. 15 blade, and a submucoperichondrial pocket is developed on each side between the septum and upper lateral cartilages (**TECH FIG 2D**).
- Mucoperichondrial attachments to the septum between this plane and the previous septal dissection are left intact for support along the floor of the pocket.
- An approximately 3 to 5 mm wide pocket for spreader graft placement is developed along the dorsal septum beneath the upper lateral cartilages to the level of the nasal bones using fine iris scissors. This is then repeated on the other side (**TECH FIG 2E,F**).
- The spreader grafts are inserted into each pocket, and the caudal aspects are secured to the septum with a 4-0 chromic suture in a horizontal mattress fashion (**TECH FIG 2G,H**).
- The mucosa is closed over the grafts using 5-0 chromic suture (**TECH FIG 2I**).

- Mattress sutures of 4-0 plain gut are placed through the mucoperichondrial flaps to close the dead space where septal cartilage was harvested (**TECH FIG 2J**).
- Internal nasal splints are placed in each nostril and sutured through the septum with a single 3-0 Prolene mattress suture (**TECH FIG 2K**).
- The throat pack is removed prior to extubation. If necessary, a nasogastric tube may be used to suction gastric contents to remove accumulated blood.
- A moustache gauze dressing may be applied across the upper lip to absorb any nasal drainage.

■ Autospreader Flaps

- Positioning and prepping proceed as previously described.
- The open approach is used to elevate the skin of the nasal tip and dorsum and expose the upper and lower lateral cartilages and dorsal septum.
- The upper lateral cartilages are separated from the septum using a no. 15 blade, and the mucoperichondrium on either side of the septum is incised onto the septal cartilage.
- Mucoperichondrial flaps are raised on either side of the septum using a Cottle elevator.
- 5-0 PDS sutures are placed caudal to the upper edge of the upper lateral cartilages, thereby infolding the superior edge of the upper lateral cartilages, serving a spreader-type function (**TECH FIG 3**).
- The nose is thoroughly irrigated, hemostasis is achieved, and the nasal skin is redraped.
- The columellar skin is reapproximated with interrupted 6-0 Prolene, and the infracartilaginous incisions are closed with interrupted 5-0 chromic.
- Tape strips are applied to the nasal dorsum to limit postoperative swelling.
- The throat pack is removed prior to extubation. A nasogastric tube may be used to suction gastric contents to remove accumulated blood.
- A mustache gauze dressing is applied across the upper lip to absorb any nasal drainage.



TECH FIG 3 • Sutures are placed through the upper lateral cartilages caudal to their upper edges, thus infolding the superior edges against the septum and serving an autospreader flap function.

PEARLS AND PITFALLS

Preoperative

- A thorough discussion of the planned goals and risks should be conducted with the patient to ensure appropriate expectations are met.

Technique

- The open technique provides greater control of spreader graft placement and facilitates other alterations to the nasal structure, particularly tip refinement.
- The endonasal technique is especially useful in patients with long, thin noses that are straight.
- To minimize widening of the nasal dorsum and potential palpability, place the spreader grafts just below the level of the upper lateral cartilages.
- Autospreader grafts may not be adequate to straighten the deviated

dorsum, and spreader grafts are preferred.

Postoperative ■ Have the patient avoid sleeping on a side as it will worsen edema to one side and increase concern for deviation.

Prevention ■ Spreader grafts may be beneficial prophylactically following dorsal hump reduction, particularly in patients with a high bony-cartilaginous junction or weak upper lateral cartilages, in which closure of the open roof with nasal bone infracturing alone may be inadequate.

■ Preservation of the upper lateral cartilages during dorsal hump reduction and reapproximation along the dorsal septum with tension spanning sutures will frequently restore the midvault without the need for spreader grafts.⁶

POSTOPERATIVE CARE

- Surgery is performed on an outpatient basis.
- Usual postrhinoplasty precautions are followed.
- Keep the intranasal mucosa moist with frequent application of ointment and saline nasal spray.
- Any internal and/or external nasal splints are removed at 1 week.
- Prolonged edema may occur and in some cases can take up to 1 year to fully resolve.

OUTCOMES

- The goals of functional and aesthetic improvement can be accomplished with any of the described techniques.^{7,8} Optimal outcomes will be attained using the technique with which the surgeon is most comfortable and able to achieve consistent results.

COMPLICATIONS

- Spreader grafts may widen the nasal midvault and/or tip, which may or may not be desired. This is more likely with autospreader flaps.
- Other possible short-term and long-term complications include infection, hematoma, nasal asymmetry, septal perforation, worsening of nasal obstruction, scarring, nasal bleeding/crusting, empty nose syndrome, and prolonged edema that may last up to 1 year.

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Indications and Technique for Increasing and Decreasing Tip Projection in Open Rhinoplasty

59

CHAPTER

David A. Sieber and C. Spencer Cochran

DEFINITION

- Proper tip projection can be determined through multiple methods.
 - The authors' preferred method is to have a tip projection that is equal to the length of the upper lip as measured from the white roll to the base of the columella. This line should equal the distance from the base of the columella to the tip-defining point. This method assumes that the upper lip is of normal length and may not be applicable in all patients (**FIG 1A**).
 - Another method places a line from the alar crease to the tip-defining points (lines A to B). A perpendicular line is then drawn from the upper lip through lines A to B. Ideal tip projection is when A, 50% to 60% of AB (**FIG 1B**).
 - Goode method: a triangle is formed from a line drawn from the nasion through the alar crease (A). The other sides are composed of a line from the nasion to the tip-defining point (B) and another line from the alar crease to the tip-defining point (C). An ideal tip has a B:C ratio of 0.55 to 0.6 (**FIG 1C**).

ANATOMY

- Tip projection is dependent on numerous interrelated nasal structures:
 - Length and strength of lateral crura
 - Length and strength of medial crura
 - Septal angle
 - Fibrous attachments from the feet of the medial crura to the caudal septum

- Attachments between the upper lateral and lower lateral cartilages at the scroll area
- Interdomal ligaments connecting the cephalic margins of the domes
- Nasal skin and soft tissue envelope (this is the limiting factor in tip projection)

PATHOGENESIS

- Overprojection of the tip may be the result of one or many abnormalities in nasal anatomy such as a prominent septal angle or excessively long and/or strong medial or lateral crura.¹
- Likewise, underdevelopment or underprojection of the nasal tip may be due to a weak septal angle or short and weak medial or lateral crura.²
- More commonly, underprojection is the result of a poorly planned primary rhinoplasty in which proper support either through the use of a columellar strut or tip suturing was not employed, resulting in loss of tip support as the soft tissue envelope contracts.^{3,4}

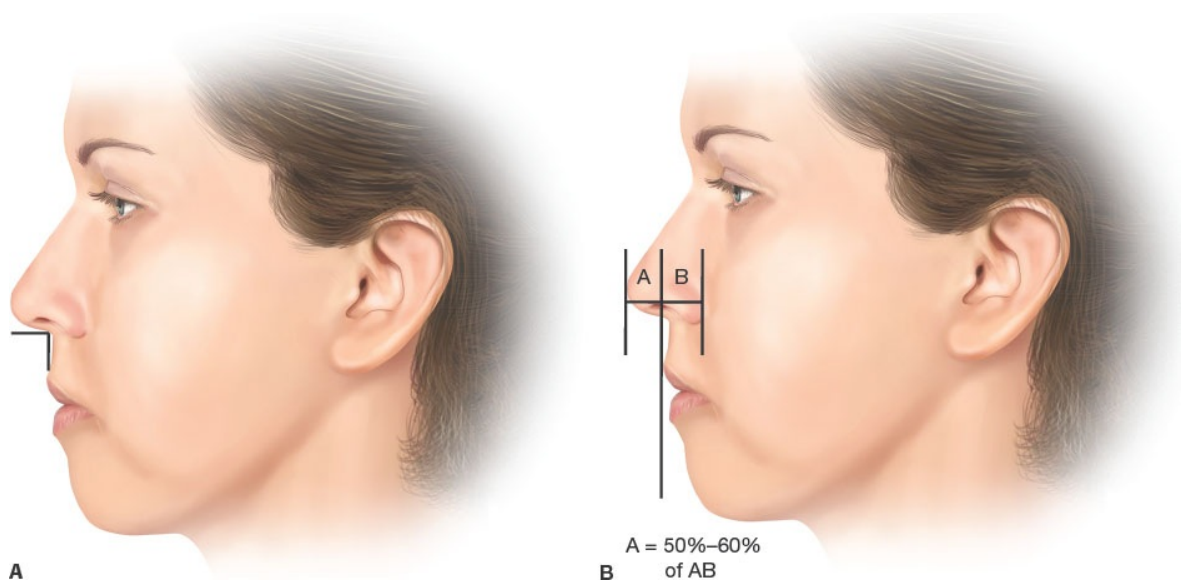


FIG 1 • A–C. Common methods for determining proper tip projection.



c

- The tripod method for understanding tip projection is both relevant and important to comprehend (**FIG 2**). As each leg of the tripod is modified to re-establish proper tip projection, there is a resulting effect on tip rotation.
- Proper support of each leg of the tripod is critical in maintaining tip projection over time through the use of:
 - Columellar strut graft: forms foundation of the tip, maintains projection, and prevents distortion
 - Extended alar contour grafts
 - Dorsal spreader grafts

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients presenting for primary rhinoplasty will complain of a nose that “sticks out too far” or will state that they do not like the appearance of their nose on profile view.

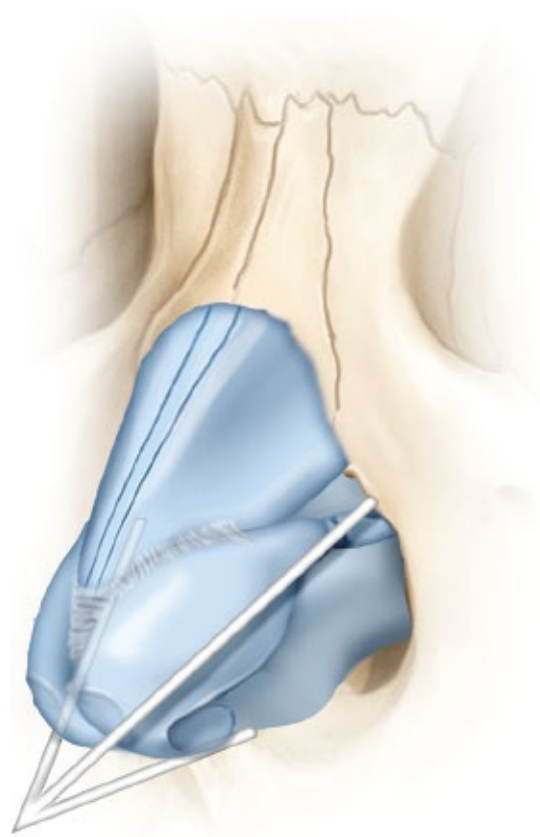


FIG 2 • Tip support is dependent on three independent structures much like the legs of a tripod. The paired lateral crura and the columella/medial crura form the three legs of support.

- Secondary rhinoplasty patients may complain of a “short” nose, stating that their nose has become smaller over time.
- Confirmation of nasal over- or underprojection should be confirmed using the aforementioned methods.

IMAGING

- Imaging may be performed using Vectra (Canfield, Parsippany, NJ) or standard photographs and should be employed to establish preoperative anatomy as well as to help determine surgical goals with the patient.

NONOPERATIVE MANAGEMENT

- Although soft tissue fillers such as hyaluronic acid are used by some surgeons as a nonsurgical option to change nasal contour, we do not advocate the use of

fillers in the tip to increase tip projection; the risk of vascular occlusion or embolization that can result in injury to the remaining nasal vascular network may lead to irreversible skin loss.

SURGICAL MANAGEMENT

- Surgical management of tip projection should follow an organized and incremental approach including the following:
 - Determine the cause of tip over- or underprojection.
 - Incrementally address each of the aforementioned factors.
 - Reset the desired tip projection based on preoperative planning and intraoperative results.
 - Re-establish proper support in each leg of the tripod.

Preoperative Planning

- Preoperative imaging should be reviewed with the patient to ensure that the patient has realistic goals for surgery and that the desired surgical result can be achieved.

Positioning

- Patient is placed in the flat supine position.
- General anesthesia and endotracheal intubation are preferred for this procedure.
- Approximately 5 cc of 1% lidocaine with 1:100 000 epinephrine is injected into the planned columellar and marginal incisions.
- The nose is packed with oxymetazoline-soaked gauze to assist with hemostasis.
- The patient is then prepped and draped in a sterile fashion.

Approach

- Any change in tip projection should be performed through an open approach for maximal control of tip positioning and support.
- Tip projection is typically a result of a combination of factors and therefore requires a stepwise approach for correction.
- After each aforementioned factor is addressed, tip projection should be reassessed by redraping the soft tissue envelope.

TECHNIQUES

■ Opening the Nose

- A transcolumellar incision is made as an inverted V or chevron shape across the narrowest portion of the columella and extends around the columellar roll to terminate on the midportion of the medial crura.
- The soft tissue envelope is elevated from the tip and nasal dorsum to expose the osteocartilaginous framework.
- The soft tissue envelope should be widely undermined from the lateral crura toward the piriform aperture. The destabilization of the nasal tip that occurs when the soft tissue envelope is elevated in the open approach establishes a modest amount of deprojection.
- Any additional dorsal refinement is then preformed at this time prior to tip modification.

■ Separation of Lower Lateral Cartilages

- Divide the ligamentous attachments between the lateral crura and the upper lateral cartilages. Also divide the suspensory ligaments traversing the septal angle connecting the cephalic margins of the domes.
 - After the suspensory ligament has been divided, patients with a prominent septal angle may require judicious trimming of the lower portion of the cartilaginous dorsal septum. This can help prevent a “polly beak” deformity resulting from excess dorsal septum in the supratip area.
 - If additional deprojection is required, the fibroelastic attachments between the feet of the medial crura and the caudal septum should be released.
 - This is accomplished by dividing the lower lateral cartilages in the midline to elevate mucoperichondrial flaps on either side of the caudal septum beginning at the septal angle and extending to the nasal spine area.
 - These maneuvers will cause a deprojection of approximately 2 to 3 mm.
 - When all other factors have been addressed and the desired decrease in tip projection still has not been achieved, the length and strength of the medial and/or lateral crura must be altered.
-

■ Isolation of Lower Lateral Cartilages

- Approximately 1.5 cc of 1% lidocaine with epinephrine is infiltrated into each dome, lateral, and medial crura to hydrodissect the vestibular mucosa off of the underside of the lower lateral cartilages.
- If indicated, a cephalic trim is then performed using a no. 15 blade to remove the cephalic excess from the lateral crura, making sure to leave at least 6 mm of cartilage in place.
- Using angled converse scissors, a spreading motion is used to separate the vestibular mucosa from the cartilage.
- Care must be taken not to tear the mucosa when developing the correct plane of dissection.
- Both the cephalic and caudal borders of the lower lateral cartilages must be completely free from mucosal attachments.
- The nasal mucosa needs to be freed from the lateral third of the lower lateral crura down to the lower third of the medial crura. The medial and lateral portions need to maintain some attachments to the mucosa so as to not avulse the cartilage completely.
- Once these maneuvers have been performed, the lower lateral cartilages should be present as a single, continuous ribbon of cartilage (**TECH FIG 1**).



TECH FIG 1 • Appearance of lower lateral cartilages with vestibular mucosa dissected off of cartilage. Lower lateral cartilage should be present as a single continuous “ribbon” of cartilage.

■ Determination of Tip Projection

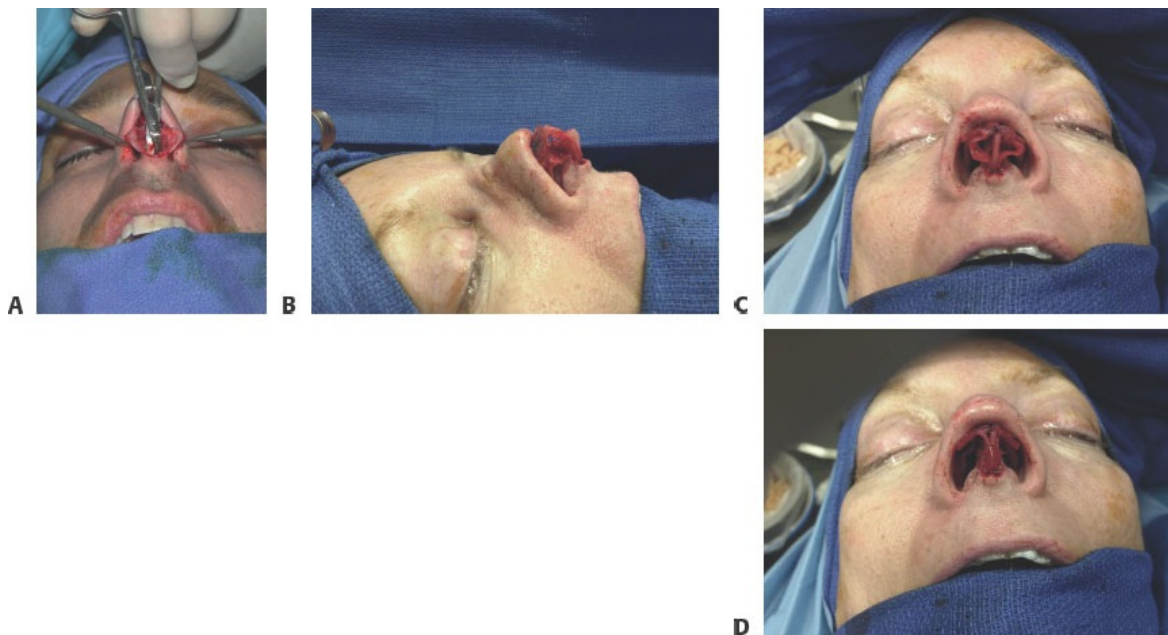
- This ribbon of lower lateral cartilage may then be reformed into the appropriate segments composed of the lateral, middle, and medial crura.
- The first step is to determine where the new dome should be located.
- The location of the new dome will determine three interrelated factors:
 - Nasal length
 - Tip rotation
 - Tip projection
- As the dome is moved from a more medial (caudal) to a lateral (cephalic) position on the lower lateral cartilage, there will be a resultant decrease in nasal length and projection with an increase in tip rotation (**TECH FIG 2**).
- The caveat is that because you are creating a new dome, increasing tip rotation, and causing tip deprojection, there will be an excess of cartilage in the new medial crura.
- Using these same concepts, additional tip projection can be created through formation of a new dome in a more medial (caudal) position along the lateral crura. This will in turn result in a decrease in tip rotation and an increase in nasal length.



TECH FIG 2 • Location of new domes has been established, causing deprojection and rotation of the tip. Excess cartilage is now present in the area of the medial crura.

■ Resupporting the Tip

- It is the senior author's (CSC) preferred technique to routinely use a columellar strut for all rhinoplasties.
- Using angled converse scissors, a pocket is created in the midline within the soft tissue caudal to the edge of the septum. Some soft tissue needs to be left between the columellar strut and septum to prevent "clicking" of the cartilage postoperatively (**TECH FIG 3A**).
- The length of the columellar strut helps to determine tip projection, and the angle at which the soft tissue pocket is created helps to determine final tip rotation (**TECH FIG 3B**).
- A horizontal mattress using 5-0 PDS is made to secure the medial crura to the columellar strut. This suture knot should be tied between the medial crura and the columellar strut so as to prevent a palpable knot from forming postoperatively.
- Once the appropriate location for the dome has been determined, a simple 5-0 PDS is passed through the new dome and into the columellar strut. The position of this suture into the caudal vs cephalic portion of the dome will also determine the degree of dome divergence. Typically, the suture is placed in the cephalic third of the dome.
- An identical suture is placed on the contralateral side.



TECH FIG 3 • A. A precise pocket is created for the columellar strut which will act to re-establish and support the new nasal tip location. **B.** The orientation and height of the columellar strut help to determine tip rotation and projection. **C.** Appearance of the lower lateral cartilages once the new domes have been secured to the columellar strut. With tip deprojection and cephalic rotation, excess lower lateral cartilage is forced into the medial crura as depicted here. **D.** Excess cartilage has been excised and is secured to the columellar strut. Cut edges of cartilage should be placed within the soft triangle so as to not create visible ridges postoperatively.

- A third simple suture is then placed through the cephalic portion of one dome, then through the cephalic portion of the columellar strut, and through the contralateral dome.
- At this point, the excess cartilage that has been forced into the medial crura must be assessed (**TECH FIG 3C**).
- A small amount of cartilaginous excess in the medial crura with a minimal convexity may be plicated to the columellar strut using a 5-0 PDS as a horizontal mattress.
- If too much excess cartilage exists in the medial crura so that it creates a visible convexity not correctable with a suture, then this excess will need to be excised.
- The segment of medial crural cartilage should be cut in a way so that the cut edges of the cartilage lie within the soft triangle. This can either be in an end-to-end fashion or with the proximal segment overlapping on top of the distal segment. Leaving the ends of the cartilage too far posteriorly will create a visible ridge on the columella postoperatively.
- Two to three horizontal mattress sutures are then used to tie down the cephalic, caudal, distal, and proximal edges of the cartilage to the columellar strut (**TECH FIG 3D**). Failure to do so will again result in a visible ridge.
- These techniques help incremental manipulation of tip projection, which

when properly supported, should provide the patient with a lasting result.

- The soft tissue is then redraped, and the vestibular and columellar incisions are closed.

PEARLS AND PITFALLS

Pitfall	■ Skin thickness is often the limiting factor in the amount of possible tip deprojection because the skin must be able shrink around the osteocartilaginous framework for the nose to have sufficient tip definition.
Pitfall	■ Changing the length of the lateral crura or medial crura can have the potential to affect rotation.
Pitfall	■ The surgeon should be cognizant of the possibility of alar base flaring and be prepared to correct the flaring with an alar base resection.
Pearl	■ Multiple factors contribute to tip projection. Incrementally eliminating these factors will allow the surgeon to decrease tip projection in a controlled manner.
Pearl	■ When the ligamentous attachments and fibroelastic attachments are eliminated, the main support to the tip comes from the length and strength of the lower lateral crura, especially in an open rhinoplasty where the support from the skin has been eliminated.

POSTOPERATIVE CARE

- Steri-Strips are applied to the dorsum with one in the infratip region to support the new tip position.
- A Denver Splint is placed onto the dorsum.
- The Denver Splint and Steri-Strips are removed 7 days postoperatively.

OUTCOMES

- **FIGS 3** and **4** demonstrate representative examples of successful tip modification using the described techniques.

COMPLICATIONS

- Because of the destructive nature of tip refinement, the most common complication requiring reoperation is a distortion or twisting of the nasal tip due to abnormal scarring. This is typically resolved by releasing the soft tissue

envelope and the cartilaginous interfaces causing the distortion. The tip must then be resupported as described.

- The strength of the lateral crura needs to be evaluated intraoperatively. If they are weak and are not resupported, then external nasal valve collapse may occur postoperative. Support is best maintained through the use of a lateral crural strut graft or extended alar contour graft.

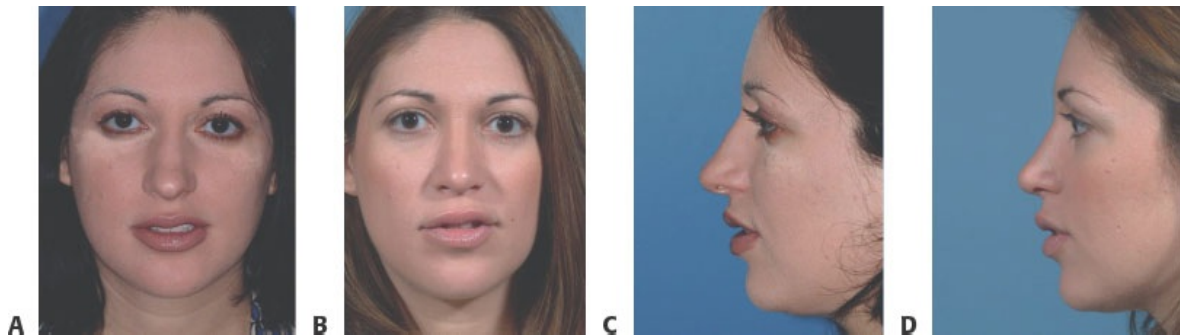


FIG 3 • **A,B.** Frontal view of a 27-year-old female pre- and 1-year postoperative from open primary rhinoplasty with tip deprojection. **C,D.** Lateral view of a 27-year-old female pre- and 1-year postoperative from open primary rhinoplasty with tip deprojection.



FIG 4 • **A,B.** Frontal view of a 48-year-old female pre- and 1-year postoperative from primary open rhinoplasty with tip deprojection. **C,D.** Lateral view of a 48-year-old female pre- and 1-year postoperative from primary open rhinoplasty with tip deprojection.

- After deprojection of the tip, the patient may have excess flaring of the alar

bases. This needs to be evaluated preoperatively with the patient as there may be a need for an alar base resection to restore proportional nasal aesthetics.

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61 Technique for Ethnic Rhinoplasty Using the Open Approach

CHAPTER

Dean M. Toriumi and Jeffrey T. Steitz

DEFINITION

- The ethnic nose is very diverse and can encompass many different nasal contours and anatomic variations. It is outside the scope of this chapter to cover all of these anatomic variations. For this chapter, I will cover the Black and Asian nose and how I use the open approach to perform structural grafting to augment the nose.
- When I use the term “ethnic” in this chapter, I will be referring to primarily Black and Asian patients. These techniques may also prove to be effective in the thick-skinned “Mestizo” nose. This is with the understanding that there are many other forms of ethnic noses that have significantly different anatomy but will not be emphasized in this chapter.
- Many ethnic patients have an underprojected nose with a wide alar base and poorly defined nasal tip. These patients also tend to have thicker skin. They can have a low wide dorsum lacking definition on frontal view. Some ethnic patients may have a dorsal hump with a low radix. All of these different configurations require different management.
- In general, most Black and Asian patients require augmenting their nose to stretch the thick skin envelope to create improved contour. This requires cartilage grafting to push out and stretch the thick skin envelope making the lateral view larger to enhance the appearance of the frontal view.

ANATOMY

- The anatomy of the Black and Asian nose can vary significantly from patient to patient. Most ethnic patients will tend to have thicker sebaceous skin that is

much thicker in the lower half of the nose. They tend to have weak lower lateral cartilages that can make controlling and preserving tip projection very difficult.

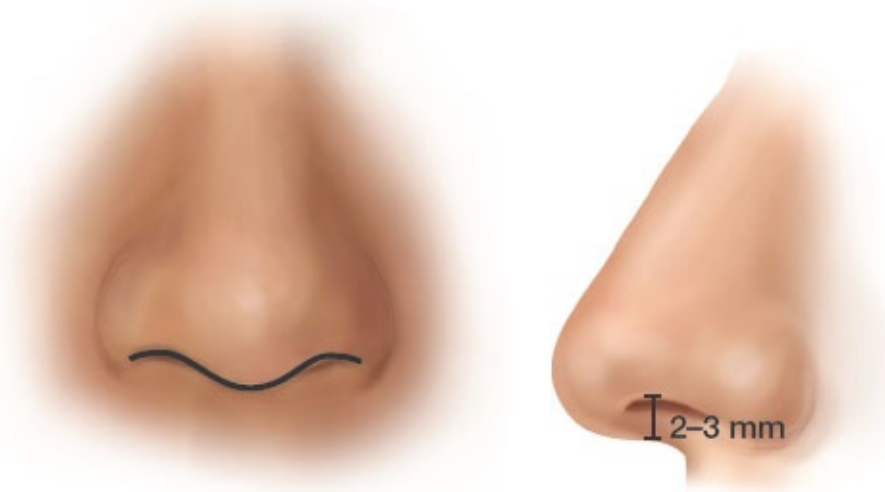


FIG 1 • The normal relationship between the infratip lobule and ala demonstrates a “gull in flight” appearance on the frontal view. This translates to a 2- to 3-mm columellar show on the lateral view.

- Ethnic patients tend to have a short weak nasal septum that lacks caudal projection leaving a deficiency in tip support. For this reason, adding structural support is critical to providing a good aesthetic and functional outcome.
- Ethnic patients may demonstrate a reversal of the normal “gull in flight” appearance of the transition from alar margin to infratip lobule (**FIG 1**).¹ Many of these patients will demonstrate a reversal of normal with retraction of the columella in relation to the hanging alar lobule (**FIG 2**). Correction of the retracted columella requires a large caudal septal extension graft that can push the columella and infratip lobule inferiorly to create a more normal “gull in flight” appearance to the alar lobular transition to the infratip lobular projection.² This graft will act to move the columella/infratip lobule or central compartment inferiorly to create a more favorable relationship between the ala and infratip lobule.
- Ethnic patients also tend to have a wide alar base that creates a discrepancy between the width of the upper third of the nose and the width of the lower third of the nose. It is preferable to avoid overnarrowing the upper third of the

nose with aggressive lateral osteotomies to create narrowing and then accentuate the imbalance between the upper third and lower third widths.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient should be examined to assess nasal tip support and caudal projection of the septum.
- Intranasal examination should be performed using a nasal speculum, appropriate lighting, and preferably examination with an endoscope. Assess the nasal septum and status of the inferior turbinates. Watch the patient breathe in to determine if there is any lateral wall weakness, which is rare in Black and Asian patients.



FIG 2 • A Black patient with retracted columella and hanging ala to create the opposite of the normal “gull in flight” orientation between the infratip lobule and ala. **A.** Frontal view showing the ala projecting inferiorly to greater extent than the columella/infratip lobule. **B.** Lateral view showing hidden columella.

- Discuss with the patient what the primary goal of the surgery should be. Determine their primary deformities they would like corrected.
- The deficiency in nasal tip support and reversal of the normal “gull in flight” orientation of the ala and columella must be pointed out to the patient.
- Preoperative computer imaging is critical in the ethnic patient and should be used in most patients. This will enhance your ability as the surgeon to determine what the patient’s goals are and to point out specific concepts to the

patient. This will help ensure your aesthetic goals align with those of the patient.

- The linkage between lack of structural support and the large thick skin envelope must be pointed out to the patient as well.
- One of the key concepts in ethnic rhinoplasty (Black and Asian) is to realize that it is usually necessary to augment the lateral view via dorsal augmentation, place a caudal septal extension graft and possibly a shield-type tip graft to stretch the thick skin, and create a narrowing effect on the lateral view. By stretching the skin on the nose, particularly in the nasal tip area, definition can be increased and narrowing can be achieved. This can be very difficult for both the surgeon and patient to understand, but thick-skinned patients rarely look better when the nose is reduced unless the skin is able to contract. Typically, the thicker skin of the lower third of the nose will not contract significantly, potentially leaving a polly beak deformity, a wider scarred nasal tip, and an underprojected tip complex.
- Expanding and augmenting the lateral view can also improve the lateral view by lifting the upper nasal dorsum to match the projection of the prominent thicker supratip skin by creating a straighter profile (**FIG 3**).



FIG 3 • By augmenting the lateral view, the upper nasal dorsum can frequently be elevated to the level of the prominent supratip skin creating a straighter dorsal line.

SURGICAL MANAGEMENT

- It is preferable to perform these surgeries under general anesthesia. With the patient intubated, the airway is protected from blood contacting the vocal cords and potentially causing laryngospasm. A protected airway is particularly important if any work is planned on the nasal septum or turbinates.
- Local anesthetic agent (1% lidocaine with 1:100 000 epinephrine) is injected into the nose to provide hemostasis. Injections are made along the septum, along the marginal incisions, over the nasal dorsum and middle vault, and in the nasal tip area. At least 10 minutes should pass before the procedure is initiated to allow the full vasoconstrictive effect to set in.

TECHNIQUES

■ Harvesting Cartilage for Grafting

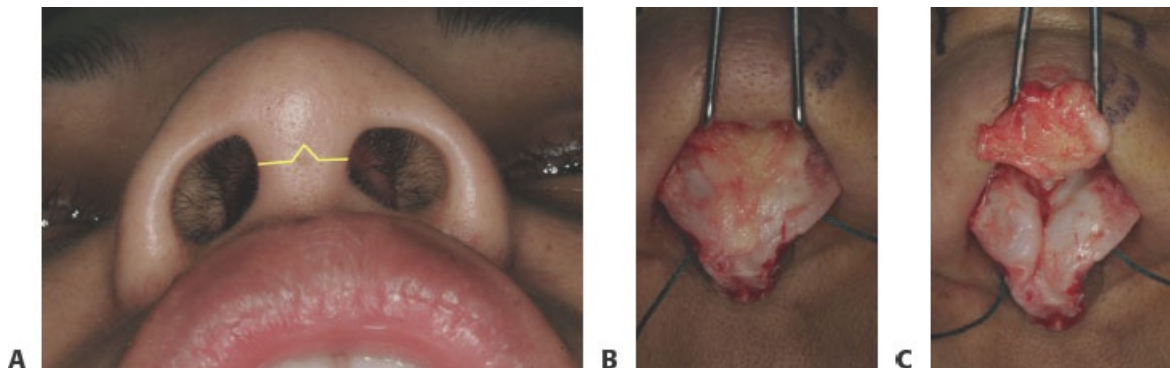
- Auricular cartilage can be harvested but is not ideal for grafting. The auricular cartilage is softer and weaker than costal cartilage and usually not adequate for augmentation cases. If auricular cartilage is harvested, the posterior approach is preferred to minimize the chance of ear deformity or change in position.
- In most ethnic patients, a larger amount of cartilage is needed for grafting. Costal cartilage is preferable and can be harvested from a smaller 11-mm incision³ (**TECH FIG 1A**). It is recommended to use a larger incision when less experienced because safety is most important when harvesting costal cartilage.
- The 6th or 7th ribs are ideal for cartilage grafting material in the ethnic patient. If a longer dorsal graft is needed, it is preferable to use the seventh rib as it is straighter and longer. The 6th rib tends to have a genu that will shorten the straight segment that could be used for dorsal augmentation. If both dorsal augmentation and premaxillary augmentation need be performed, two costal cartilage grafts may be harvested.
- Costal perichondrium should be harvested as well, because this material can be used for camouflage and to aid in fixation of the dorsal graft to the underlying dorsal nasal bone. In these cases, the costal perichondrium is placed as an interpositional graft that is sutured to the undersurface of the dorsal graft. The nasal dorsum is rasped or perforated with a 3-mm straight osteotome, and then the dorsal graft with perichondrium is placed over the nasal dorsum. The perichondrium will rigidly fix the dorsal graft to the underlying nasal dorsum.



TECH FIG 1 • A 4.5-cm segment of costal cartilage harvested through an 11-mm incision.

■ Open Approach

- An inverted-V incision is made at the level of the midcolumella (**TECH FIG 2A**). The position of the incision can be varied depending on the goals of the surgery. In most ethnic patients, the goal is to increase nasal tip projection.
- The columellar incision is connected to bilateral marginal incisions made along the caudal margin of the lateral crura.
- The columellar flap is elevated off of the medial crura. Care is taken to avoid damaging the columellar flap.
- During flap elevation, dissection can be performed just below the subdermal plexus leaving the fibrofatty tissue of the nasal tip and supratip on the cartilages to then be excised (**TECH FIG 2B,C**).



TECH FIG 2 • **A.** Position of the inverted-V midcolumellar incision marked out in yellow. **B.** A

Black patient with thick skin after flap elevated leaving fibrofatty tissue on the lower lateral cartilages. **C.** After fibrofatty tissue dissected from cartilages.

■ Exposing the Nasal Septum

- Dissection is performed between the medial crura to access the caudal septum. Typically, the caudal septum is further cranial than in most Caucasian patients (**TECH FIG 3**). After identifying the caudal septum, mucoperichondrial flaps are elevated.
- Septal deviations can be corrected, and septal cartilage can be harvested for grafting purposes. Most ethnic patients have small harvestable segments of cartilage that are available.



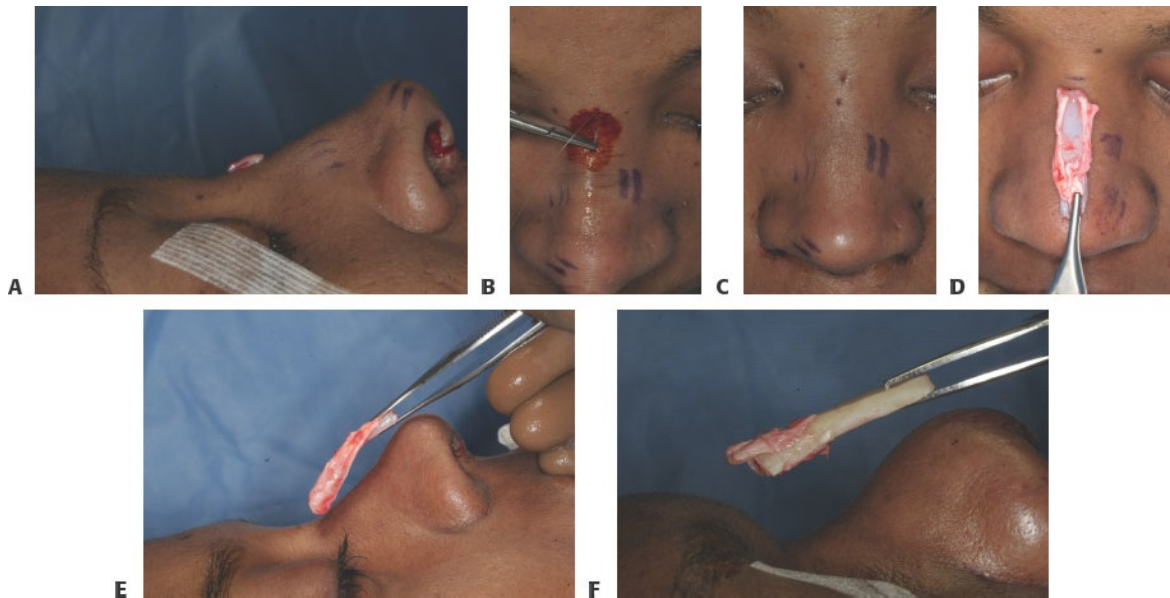
TECH FIG 3 • Caudal septum exposed and bilateral mucoperichondrial flaps elevated. Note how far cranial the caudal septum is set back.

■ Managing the Nasal Dorsum

- In most ethnic patients, the nasal dorsum needs augmentation. Major dorsal augmentation with costal cartilage will be covered in another chapter.
- Many ethnic patients will require radix augmentation to elevate a deep radix. When placing a radix graft, smaller grafts can be fixated using a transcutaneous suture (**TECH FIG 4A–C**).
- If a modest degree of dorsal augmentation is required, septal cartilage can be

used. It is helpful to camouflage the lateral margins of the dorsal graft with soft tissue (costal perichondrium, temporalis fascia, etc.) (**TECH FIG 4D,E**).

- Larger dorsal grafts will be fixated to the nasal dorsum by suturing costal perichondrium to the undersurface of the dorsal graft (**TECH FIG 4F**).^{3,4} The dorsal graft is then placed on the nasal dorsum after perforating the nasal bones with a 3-mm straight osteotome. The perichondrium ossifies, resulting in rigid fixation of the dorsal graft to the nasal dorsum. This method of fixation is covered in Chapter 76.

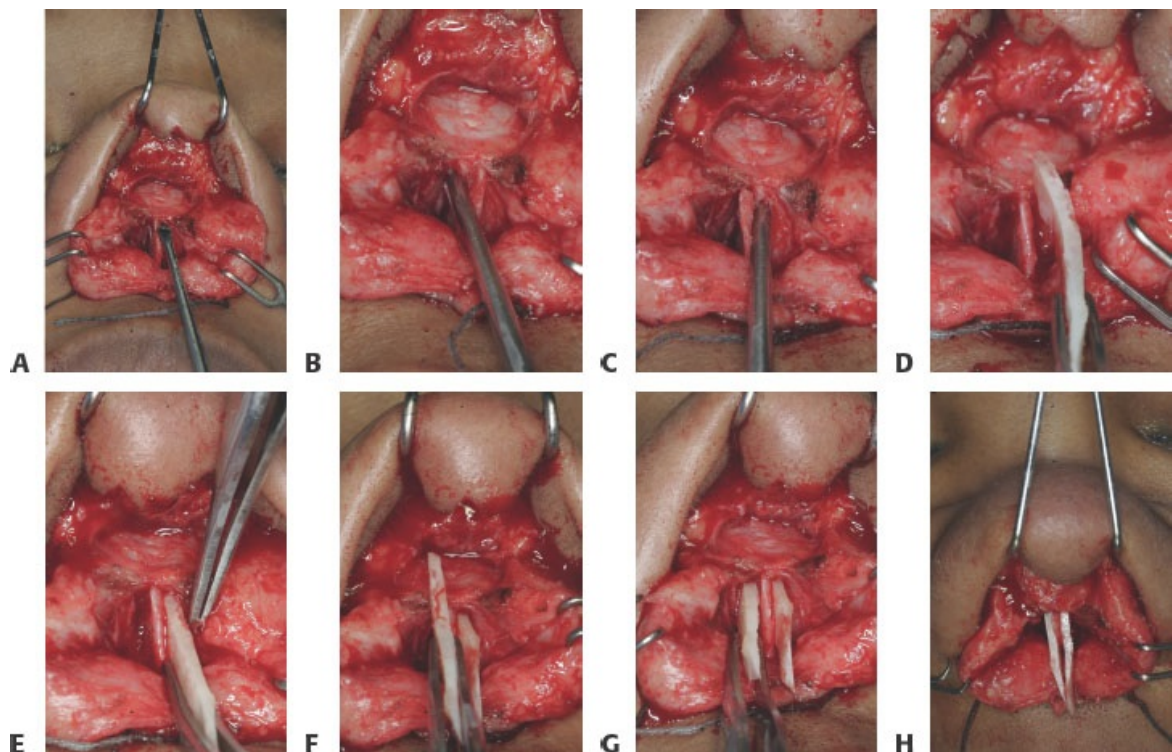


TECH FIG 4 • A. Soft cartilage radix graft over radix area. **B.** A 6-0 Monocryl suture placed transcutaneously to fix radix graft into position. **C.** Transcutaneous fixation suture in place over radix area. **D.** For lesser degrees of dorsal augmentation, septal cartilage can be used. Septal cartilage dorsal graft with costal perichondrium sutured to the lateral margins to camouflage the graft. **E.** Lateral view showing the perichondrium draped over the edges of the dorsal graft. **F.** For major dorsal augmentation, costal perichondrium is sutured to the undersurface of the dorsal graft and placed on top of the nasal bones after they have been perforated with a 3-mm straight

osteotome. The perichondrium will act to ossify the dorsal graft and fixate it to the bridge.

■ Middle Nasal Vault

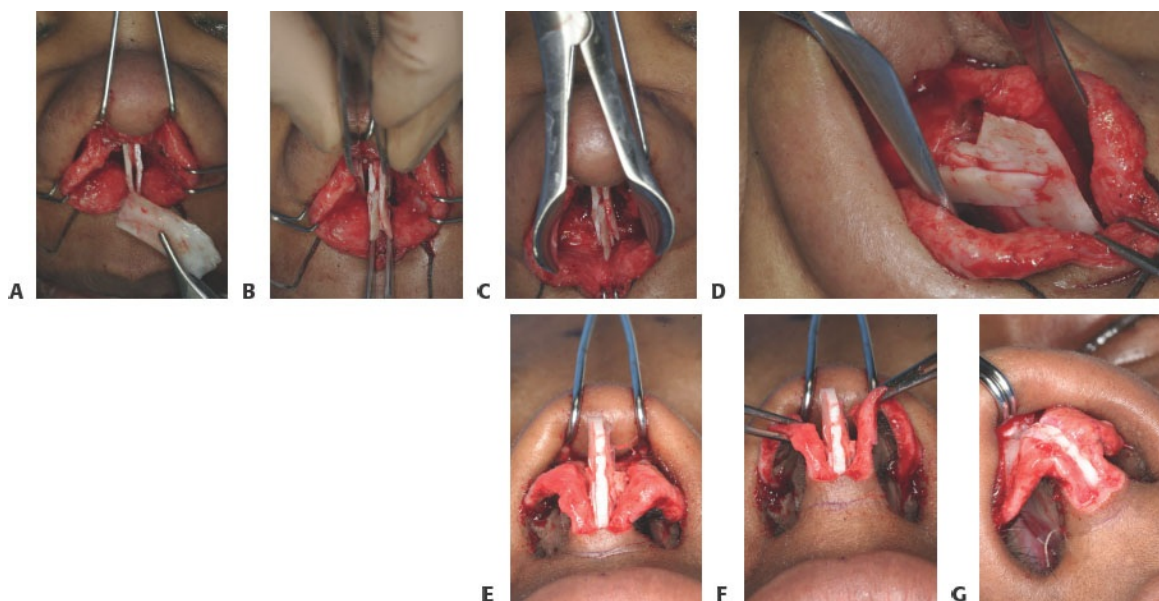
- Most ethnic patients do not require dorsal hump reduction. In this case, there is no need to open the middle nasal vault unless deviated. The spreader grafts can be placed into submucoperichondrial pockets to stabilize the dorsal septum and extended caudally to stabilize the caudal septal extension graft.
- Submucoperichondrial tunnels are dissected using a narrow Cottle elevator. The elevator is advanced superiorly in a submucoperichondrial plane up to the nasal bones (**TECH FIG 5**).
- After the tunnels are created, spreader grafts are fashioned and placed into the submucoperichondrial tunnels. The spreader grafts should fit rather snugly into the pockets. The grafts are left to extend beyond the caudal septum to stabilize the caudal septal extension graft.
- The spreader grafts are fixated using a single 5-0 PDS suture that traverses the spreader grafts and septum.



TECH FIG 5 • Spreader grafts placed into submucoperichondrial tunnels. **A.** Cottle elevator used to create the tunnels. **B.** Making the right tunnel. **C.** Making the left tunnel. **D.** Left spreader graft ready to be inserted into the tunnel. **E.** Left spreader graft being positioned. **F.** Right spreader graft. **G.** Both spreader grafts in place. **H.** Bilateral spreader grafts in place.

■ Stabilizing the Nasal Base

- The nasal base is stabilized using a caudal septal extension graft. Typically, the extension graft is slightly wider along the anterior margin (**TECH FIG 6A–D**). The extension graft is stabilized anteriorly using the extended spreader grafts and inferiorly using thin slivers of cartilage placed across the caudal septum and the extension graft.^{5,6} The grafts are sutured in place with 5-0 PDS sutures.
- After the extension graft is stabilized, the medial crura are fixed to the septal extension graft using a 4-0 plain on an SC-1 needle. It is helpful to pull the medial crura and columella anteriorly to open the nasolabial angle and increase projection (**TECH FIG 6E–G**). This suture is followed up with a 5-0 PDS suture that is placed between the medial crura catching the caudal septum as well.



TECH FIG 6 • **A.** Rectangular-shaped caudal septal extension graft ready to be sutured between the spreader grafts. **B.** Caudal septal extension graft being fixed to extended spreader grafts. **C.** Caudal septal extension graft in place. **D.** Caudal septal extension graft from the side. **E.** Caudal septal extension graft from below. Note the position of the medial crura. **F.** Medial crura are advanced anteriorly to open nasolabial angle and increase tip projection. **G.** Medial crura sutured to caudal septal extension graft.

■ Managing the Nasal Tip

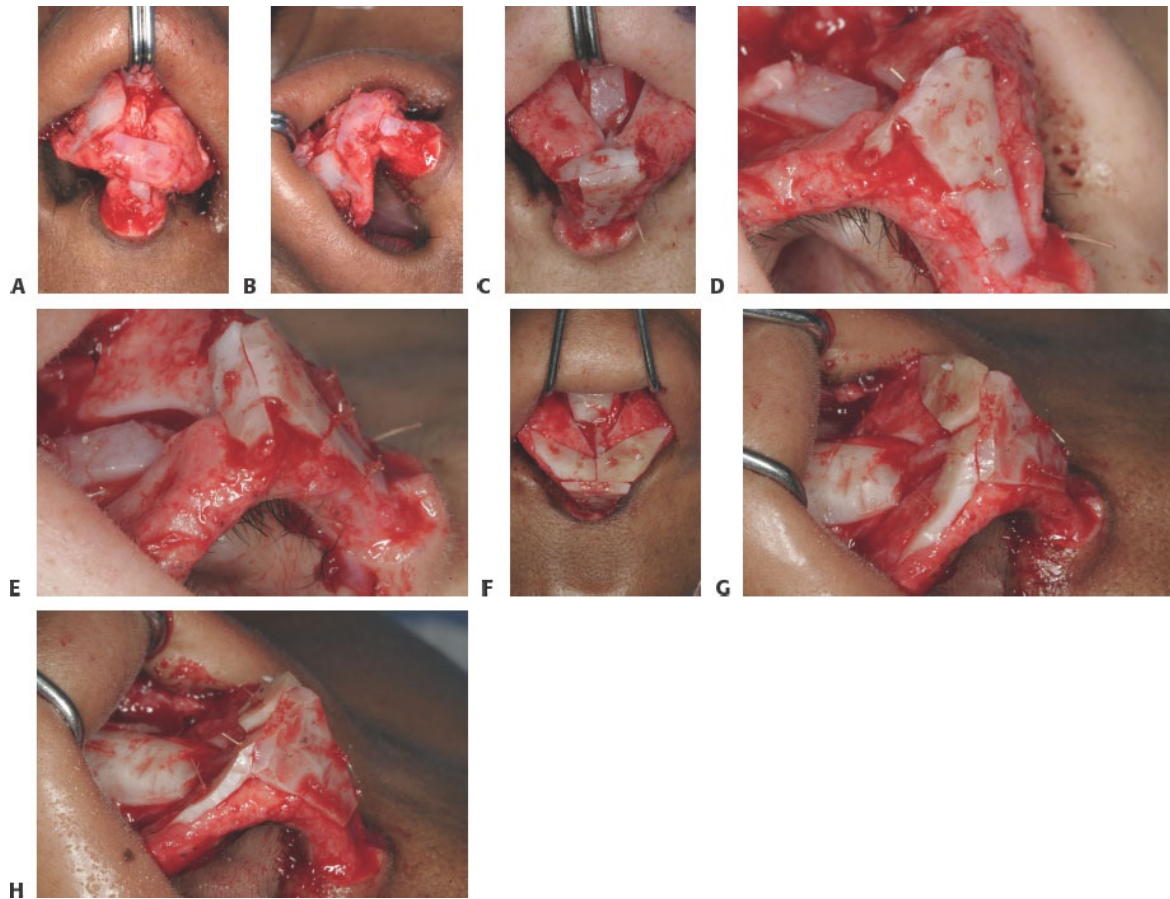
- Nasal tip contour and definition are controlled by what is done at the tip lobule. In most ethnic patients, a tip graft is placed over the domes to provide additional tip projection and tip definition.⁷ There is rarely any need to reduce the lateral crura as the tip grafting is what achieves the change in lobular contour. Furthermore, the lateral crura tend to be very weak, and any reduction can result in weakening of the tip structure.
- An onlay-type tip graft can be sutured horizontally over the domes (**TECH FIG 7A,B**). These tip grafts are typically softer cartilage and are sutured over

the domes using two 6-0 Monocryl sutures.

- In most patients with thicker skin, a shield-type tip graft is used. In these cases, if the shield-type tip graft extends more than 2 mm but less than 3 mm above the existing domes, a buttress graft is used to stabilize the posterior surface of the graft to prevent it from rotating cephalically (**TECH FIG 7C–E**).⁹ This graft prevents over-rotation of the nasal tip lobule.
- If shield-type tip graft projects more than 3 mm above the domes, lateral crural grafts are used to stabilize the shield-type tip graft. These grafts are angled at 45 degrees off of the midline and sutured to the posterior surface of the shield graft to stabilize it and prevent it from rotating cephalically (**TECH FIG 7F–H**). Lateral crural grafts are different from lateral crural strut grafts that are placed under the lateral crura between lateral crus and the underlying vestibular skin. Lateral crural grafts are placed on top of the lateral crura and are used to stabilize the shield-type tip graft.^{3,7}

Alar Rim Grafts

- In some patients after placing the shield-type tip graft and stabilizing it with a buttress graft or bilateral lateral crural grafts, additional camouflage is needed to prevent visibility. In such cases, alar rim grafts can be placed. Alar rim grafts are usually sutured to the lateral margin of the shield-type tip graft with a 6-0 Monocryl suture (**TECH FIG 8A–F**). Then, the alar rim graft is placed into pockets along the marginal incision. The alar rim graft is placed into the pockets by suturing a guide suture to the end of the alar rim graft. Then, the alar rim graft is advanced using the guide suture into the depth of the pocket, and the suture is sutured over the mucosa with a loop and left until the cast is removed. This helps to prevent the alar rim graft from becoming displaced.
- If additional camouflage is needed, soft tissue (scar tissue, fascia, or costal perichondrium) can be sutured over the domes using a 6-0 Monocryl suture (**TECH FIG 8G,H**).



TECH FIG 7 • **A.** Onlay-type tip graft sutured over the domes. **B.** Onlay-type tip graft from side view. **C.** Shield-type tip graft with buttress graft sutured to posterior surface of the shield graft to stabilize it. **D.** Side view. **E.** Note how the buttress graft extends lateral to the shield tip graft. **F.** Shield-type tip graft from above with lateral crural grafts extending off the posterior surface of the tip graft to stabilize it. **G.** Side view showing angulation of the graft. **H.** Note the shield shape of the tip graft.



TECH FIG 8 • **A.** Alar rim grafts sutured to the lateral margins of the shield-type tip graft. **B.** Guide suture sutured to the end of alar rim graft. **C.** Alar rim graft

placed into pockets along marginal incision. **D.** Guide suture pulled taught to pull alar rim graft into the depth of the pocket. **E.** Tying guide suture over the vestibular skin. **F.** Basal view at the end of the operation with *yellow arrows* pointing to knots tied over vestibular skin. **G.** Costal perichondrium sutured over leading edge of the shield-type tip graft for camouflage. **H.** Lateral view showing perichondrium over tip graft.

■ Managing the Alar Base

- If necessary, alar base reduction can be performed to decrease the size of the nostrils and to narrow the nasal base. In most ethnic patients, a lateral alar base reduction can be used to decrease alar flare (**TECH FIG 9A–C**). In patients with larger nostrils, a combination of internal and external alar base reduction is performed (**TECH FIG 9D–K**). This type of resection involves extending the excision into the nostril and onto the nostril sill. The design of the excision depends on the size of the nostril and the amount of lateral alar flare.



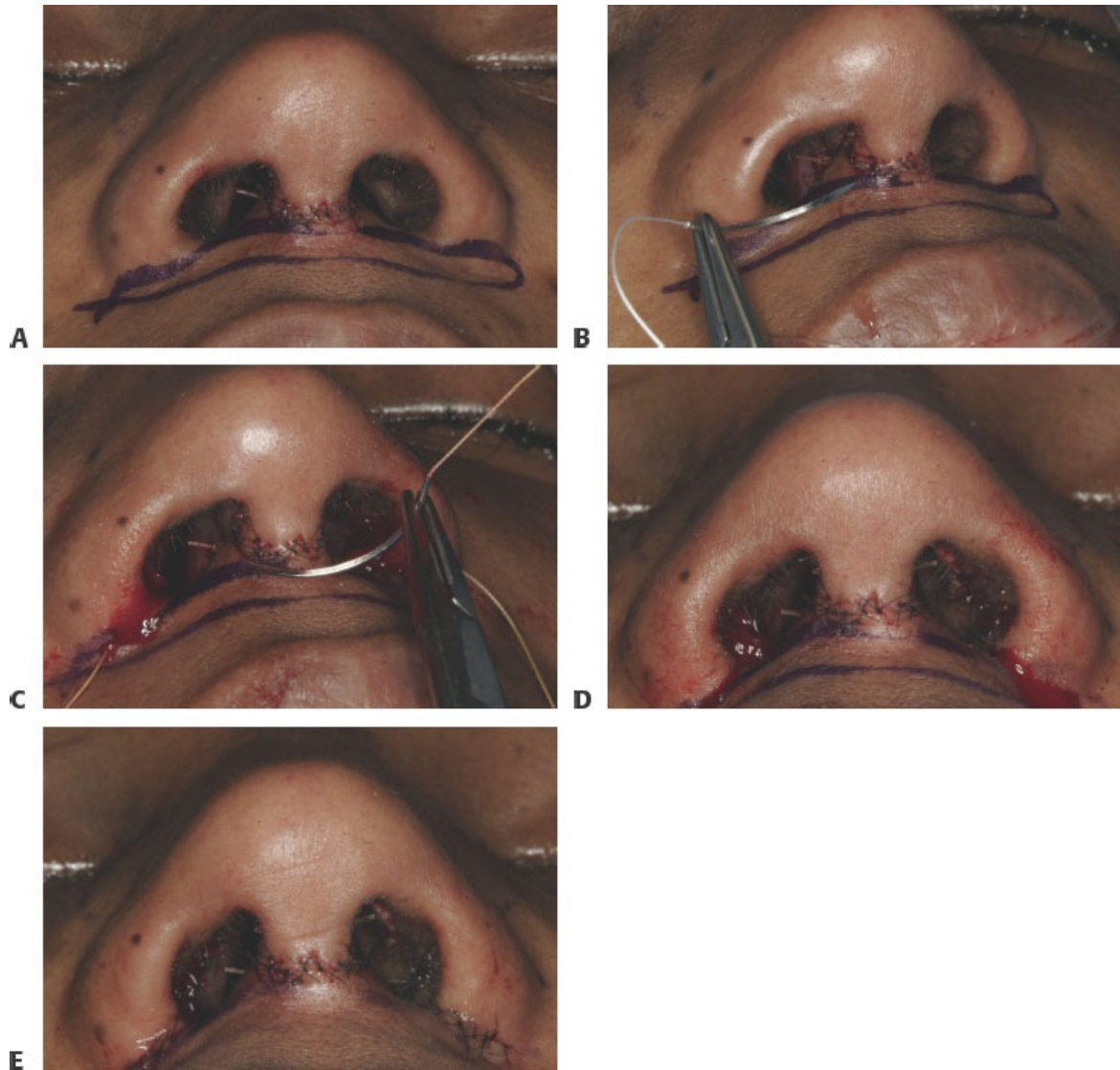
TECH FIG 9 • **A.** Planned lateral alar base reduction to decrease alar flare. **B.** Note how the excision is above the alar groove to allow some eversion of the skin edge. **C.** After lateral alar base excisions are completed. **D.** Preoperative frontal view showing wide alar base. **E.** Planned combined internal and external excisions to decrease nostril size and alar flare. **F.** Excising skin. **G.** Alar base reduction completed. **H.** Preoperative close-up frontal view. **I.** One-year

postoperative close-up frontal view (*right*). **J.**
Preoperative base view. **K.** Postoperative base view.

- After making the skin excision, a subcutaneous 6-0 Monocryl suture is placed to help with approximation of the nostrils. The skin edges are approximated using 7-0 nylon vertical mattress sutures with some interspersed 6-0 fast-absorbing gut sutures.

Nasal Base Bunching

- In some ethnic patients, excision alone is not adequate to narrow the base of the nose. In these cases, a nasal base bunching suture can be used to further narrow the base of the nose (**TECH FIG 10A**). A 3-0 Mersilene suture is passed from one alar base excision site to the other and cinched down to narrow the nasal base (**TECH FIG 10B–E**). It is helpful to place some fibrous tissue around the suture as it is passed through the skin to act a “stop” to prevent the suture from tearing through the tissues.



TECH FIG 10 • A. Alar base bunching suture. A nonresorbable multifilament suture is passed across the base of the nose to create a narrowing effect. **B.** Marked-out path of alar base bunching suture. **C.** 3-0 Mersilene suture on large needle. **D.** Suture passed to the left side via alar base reduction incisions. **E.** After alar base bunching suture placed. Note narrowing at the end of the case.

PEARLS AND PITFALLS

Approach	■ Avoid making columellar incision too high or too low. Keep incision away from the soft tissue triangle.
Grafting material	■ Harvest adequate cartilage for grafting to avoid suboptimal outcomes.
Nasal dorsum	■ Avoid excessively narrowing the nasal bones and potentially creating imbalance between upper and lower third of the nose.
Approach to managing the ethnic nose	■ Avoid reducing the Black or Asian nose as most of these patients require expansion of the skin envelope using cartilage grafts and stabilization of the nasal base.
Stabilizing nasal base	■ Make sure the nasal base is adequately stabilized. In most cases, a columellar strut may be inadequate.
Managing nasal tip	■ If a shield-type tip graft is placed, make sure it is adequately stabilized using a buttress graft, lateral crural grafts, or alar rim grafts.
Managing the alar base	■ When performing alar base reduction, avoid excessive excision.

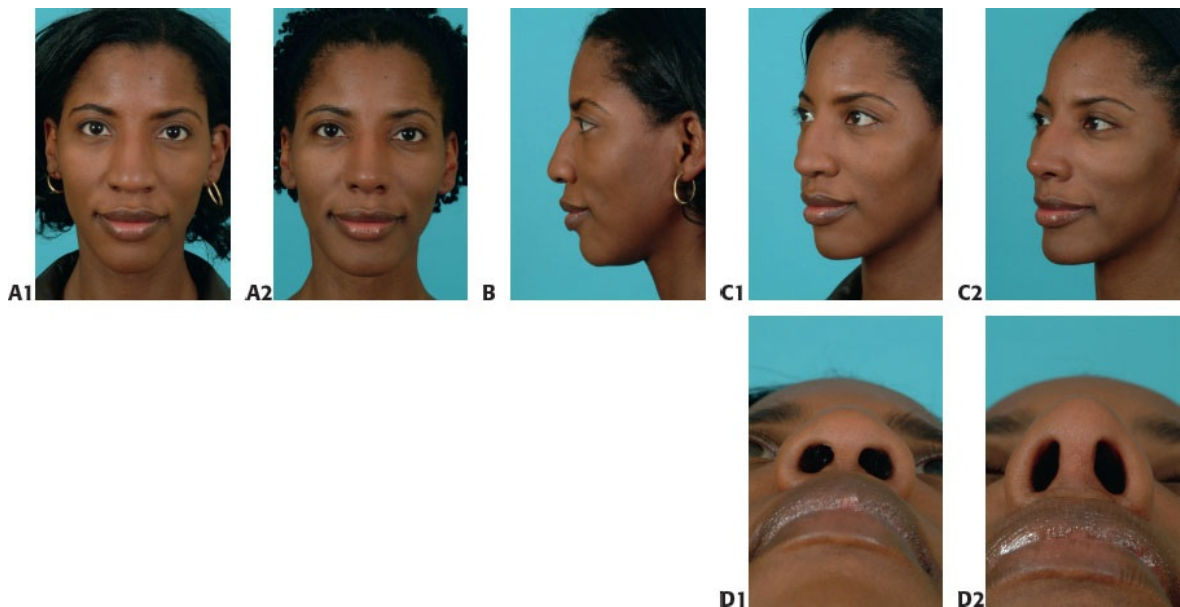


FIG 4 • A Black patient with wide nasal nose and

underprojected nasal tip. **A.** Preoperative frontal view (*left*). Two-year postoperative frontal view (*right*). **B.** Preoperative lateral view (*left*). Postoperative lateral view (*right*). **C.** Preoperative oblique view (*left*). Postoperative oblique view (*right*). **D.** Preoperative base view (*left*). Postoperative base view (*right*).

POSTOPERATIVE CARE

- No nasal packing is used in the rhinoplasty patients. A running quilting 4-0 plain gut suture is used to approximate the septal flaps.
- Cast is removed on the 7th postoperative day.
- Patients should avoid salty foods postoperatively to minimize edema.
- Kenalog (10 mg/mL) can be injected deep into the tissues of the nasal tip to decrease edema and help to prevent scarring. These injections can be started at 1 month postoperatively and repeated every 3 months.

OUTCOMES

- Improved nasal tip definition and stronger profile can be expected after augmenting the nose using structural grafting (**FIG 4**).

COMPLICATIONS

- Infection is rare but can occur when extensive cartilage grafting is performed.
- Potential complications include asymmetries, deviation, and irregularities.
- If costal cartilage is used, warping of the cartilage can occur.
- Postoperative polly beak deformity can occur if there is a loss on tip projection or if there is prolonged supratip edema.
- Postoperative loss of nasal tip projection can be seen if the nasal base is not adequately stabilized.
- Potential visibility of the shield-type tip graft over time.

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62 Technique for Treating the Crooked Nose

CHAPTER

Ali Totonchi, Navid Pourtaheri, and Bahman Guyuron

DEFINITION

- A crooked nose is a nose with a portion of its midline structures deviating away from the facial midline along any extent of its cranial to caudal or anterior to posterior dimension.

ANATOMY

- The crooked nose involves deviation or asymmetry of one or more structural components of the nose, including nasal bones, upper lateral cartilages, lower lateral cartilages, septum, and nasal spine.

PATHOGENESIS

- The crooked nose may be a result of trauma, collapse or cicatrix after surgery, cocaine abuse, infection, mass effect from tumor, congenital defects, or improper development.
- The crooked nose can affect nasal airway patency and sinus drainage in causing sinus or migraine headaches.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete patient history, including prior nasal and facial reconstructive or aesthetic procedures, should be reviewed.
- It is essential to collect a history of nasal trauma, airway complaints, allergies, sinus symptoms, and headaches.
- A crooked nose can be associated with sinus infections, sinus headaches and migraines, or nasal airway obstruction. Assessing for these factors and postoperatively tracking these symptoms aid in gauging the benefits of surgery beyond its aesthetic outcome.

- Unilateral nasal airway obstruction that is persistent or obstructive symptoms during quiet and deep inspiration is a reliable indicator of mechanical airway compromise, such as an enlarged turbinate, septal or nasal deviation, or incompetent internal or external nasal valve that should be addressed during surgery. Cyclical nose obstruction is a physiological or occasionally pathological change that may not improve with surgery.
- It is crucial to obtain a history of medications that can lead to bleeding (ie, aspirin and NSAIDs) and behaviors that may affect wound healing (ie, smoking, poor diet, steroid use). Discussion of these deleterious factors and their potential impact on postoperative outcomes with the patient may improve patient compliance.
- Patient expectations should be assessed and managed, and the patient's role in facilitating a successful outcome should be emphasized.
- Physical examination should include facial analysis to assess for overall symmetry, canting of the occlusal plane, alignment of the nose with the rest of the face, and chin position in relation to the upper and the lower incisor midlines, lips, and upper face midline.
- The nasal midline should be at the intercanthal midline rather than the intereyebrow midline, because patients often pluck their eyebrows differentially to align the midline of the deviated nose with the altered eyebrow.
- Nasal analysis should assess each structural component and their degree of deviation. This should include observation of asymmetric nasal bones, a deviated caudal dorsum (septum and upper lateral cartilages), or a deviated nasal base (septum and lower lateral cartilages).
- Midvault deviation always involves anterior septal deviation and is commonly associated with mid- and posterior septal deviation.
- By tilting the patient's head up for an examination of the basilar view, one can assess the deviation or asymmetry of the columella, tip, footplates, nostrils, and alar bases. An overhead view may detect the external nasal deviation more clearly. The most powerful view for observation of nose deviation is a full-smile frontal view.
- Palpation to assess the three-dimensional frame of the nose could prove helpful:
 - One can palpate the nasal bones, upper lateral, and lower lateral cartilages, as well as the membranous septum, tip support, the caudal cartilaginous septum, and the anterior nasal spine. The latter is done by placing this structure

between the dominant index finger and the thumb and confirming the midline positioning of this structure precisely.

- Percussion over the frontal, ethmoid, and maxillary sinuses can elicit tenderness. This may be indicative of inflammation of the underlying sinuses.
- To assess nasal valve competence or airway patency, one can occlude the patient's nostril one side at a time and ask the patient to inhale normally and then deeply.
- During the modified Cottle test, the examinee asks the patient to breathe quietly while supporting the nostril open at the level of the external and then internal nasal valve with a cotton-tip applicator or the speculum. If breathing is improved, this represents a positive test and indicates internal and/or external nasal valve incompetence.
- An internal nasal exam using a speculum can detect septal deviation, enlarged turbinates, synechiae, perforation, spurs, and contact between the turbinates and the septum:
 - Septal deformities observed may include septal tilt, C- or S-shaped deviation in the anteroposterior or cephalocaudal dimensions, or localized deviation with septal spurs. When there is a septal tilt, usually there is no curve to the septum, and the caudal septum is dislocated to one side of the vomer bone. This is the most common class of septal deviation, followed by C-shaped anteroposterior septal deviation.
 - Crusting, purulence, ulceration, or presence of polyps should also be noted.
 - It is important to observe and document the color and size of the turbinates—pale boggy turbinate mucosa may indicate allergic rhinitis, whereas erythematous mucosa may indicate infection or inflammatory rhinitis.
 - Analysis of the turbinates may reveal hypertrophy that typically occurs on the side ipsilateral to the external deviation or a paradoxical curl, which can misdirect the air and increase turbulence of airflow through the nose.
- Analysis of the nasal valves and internal nose should be repeated before and after vasoconstriction of the nasal mucosa using 0.25% phenylephrine or 1% ephedrine sulfate delivered via an aerosolized misting system or topically with cottonoid pledgets:
 - Posterior rhinoscopy is often helpful in patients with nasal airway obstructive symptoms.
 - Visualization of the posterior nasal airway is best achieved using a 0- or 30-degree nasal endoscope.

IMAGING

- Life-sized photographic and cephalometric analysis should be performed to confirm the findings of the physical examination and allow for measurements used to plan for surgical correction, particularly on patients who are expecting aesthetic improvement.
- Computed tomographic (CT) imaging of the nose and perinasal sinuses is not obtained routinely but can provide valuable information in the following cases (**FIG 1**):
 - Patients with frequent sinus headaches, sinus infections, or migraine headaches
 - Patients for whom the extent of deviated structures are not clear after physical examination
 - Imaging provides clear visualization of the nasal bones, septum, turbinates, or a mass that may have contributed to the nasal deviation.
 - The CT may reveal many conditions such as septal deviation, large posterior spur sinusitis, concha bullosa, septal bullosa, Haller cell, and contact points.



FIG 1 • Coronal CT image illustrating a deviated nasal septum and asymmetric turbinates. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:306, with permission from Elsevier.)

SURGICAL MANAGEMENT

- The crooked nose usually presents with multiple deviated substructures, and

successful surgical correction requires complete elimination of deviation from all substructures.

- Surgical techniques for correction of the crooked nose will be discussed for each substructure of the nose that may be involved.

Preoperative Planning

- Analysis of life-sized photographs and measurements of the deviation from the midline for each component of the nose can be valuable in correcting the deviation and discussing the surgical plan with the patient preoperatively. “Morphed” or simulated preoperative photos demonstrating the intended surgical changes can help the patient understand the surgical goals and manage the patient’s expectations prior to obtaining final written consent for the procedure. It is crucial to clearly indicate to the patient that there cannot be any guarantee that the simulated or intended results may not be achieved.
- If there is a need for cartilage grafts, the first choice is septal cartilage as long as there is enough cartilage present. It is important to discuss with the patient the potential need for cartilage from a second site such as a conchal or costal graft if the septal cartilage is too deformed, absent, or insufficient to correct the nasal deformities planned.

Positioning

- The patient is placed in supine position with the arms tucked by their sides.
- After induction of general anesthesia, the airway is secured with dental floss or dental wire to the first premolar.
- The table is turned 90 degrees away from anesthesia to optimize access to the face and nose.
- The internal nasal hairs are trimmed with a pair of curved iris scissors, and the internal nose is cleansed with cotton swabs.
- The entire face is prepped with Betadine solution. After 1 to 2 minutes, the Betadine is wiped away with sterile saline solution.
- A split drape is placed sterilely around the face to expose the forehead up to the hairline and down to the chin.
 - This exposure allows for continual assessment of the nasal midline with respect to the facial midline and the effect of surgery on the upper lip position.

Approach

- An open approach is the authors’ preferred method for correcting significant

deviation or if other concomitant rhinoplasty maneuvers are planned.

- Deviation of the upper nasal third or bony vault involves the nasal bones and will require osteotomies for correction.
- Deviation of the midvault involves the septum and in most cases the upper lateral cartilages, which have to be separated from the septum and differentially trimmed after septoplasty and completion of nasal bone osteotomies. Other techniques, such as spreader grafts and/or septal rotational sutures, may be indicated.
- Deviation of the lower nasal third or nasal base involves the lower lateral cartilages, and successful correction may require elongation of the short side, shortening of the long side, reshaping, and/or the use of cartilage grafts.

TECHNIQUES

■ Administration of Local Anesthesia

- It is important to achieve long-lasting and profound local anesthesia and vasoconstriction using the double-injection method:
 - Initial injection includes approximately 10 cc of 1% Xylocaine with 1:200 000 epinephrine solution.
 - If a turbinectomy is indicated, inject the turbinates using a 25-gauge spinal needle.
 - Cottonoid gauze saturated in oxymetazoline hydrochloride or phenylephrine solution is inserted deep in the nose as far cephalically and posteriorly as possible to produce vasoconstriction of the lining of areas that are difficult to reach with injection.
- The injection should be performed with precision and in an organized manner, starting from the radix into soft tissues along the lateral and medial surface of the nasal bones profusely, along the medial surface of the nasal bones, followed by injection along the nasal base and columella, the dorsal septum on either side of the nasal roof, and the lining on either side of the vomer as far posteriorly as possible.
- After a few minutes, the injection is repeated in the same order of initial injection using approximately 10 cc of 0.5% ropivacaine with 1:100 000 epinephrine.

- This double-injection method starting with 1:200 000 solution reduces systemic uptake of the higher epinephrine concentration in the second injection that may otherwise cause hypertension, tachycardia, or arrhythmia. Ropivacaine in the second injection is longer lasting, which minimizes discomfort and the need for analgesics in the early postoperative period. Additionally, the initial injection by virtue of vasoconstriction renders the effects of the second injection more intense and produces protracted anesthesia.

■ Nasal Bone Correction

Unilateral Nasal Bone Correction

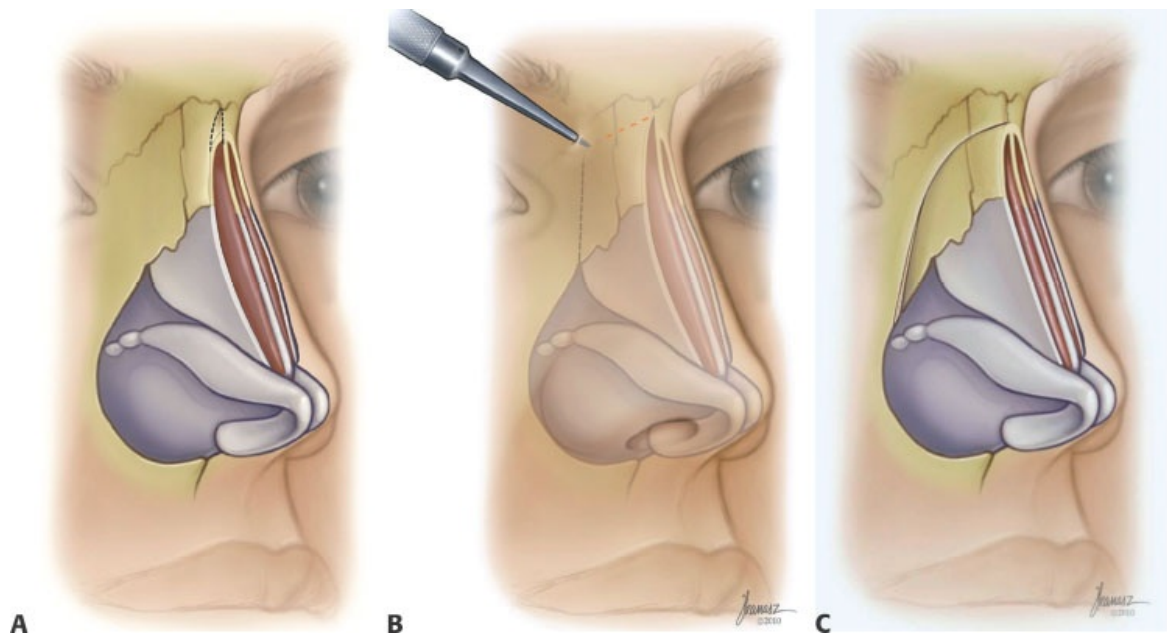
- Unilateral nasal bone deviation not affecting the internal nasal valve patency can be corrected with an onlay graft:
 - Septal cartilage (provides the most predictable outcome), conchal cartilage (gently crushed as a single or double layer), diced cartilage, soft tissue such as dermis, fascia graft, or fat injection may be used for this purpose.
 - An intercartilaginous incision is made to expose the target nasal bone.
 - A limited pocket is created by elevation of the periosteum using a Joseph periosteal elevator.
 - The graft is positioned in the subperiosteal plane and molded into place.
 - The incision is loosely approximated to allow for drainage.
- If the nasal bone shift is associated with medial transposition of the upper lateral cartilages, this may compromise ipsilateral internal valve function and requires correction by unilateral out-fracture.
 - A small vestibular incision at the pyriform aperture is made, and the periosteum is elevated using a Joseph periosteal elevator.
 - A low-to-low osteotomy and out-fracture of the nasal bone can be used to reposition the bone.
 - A spreader graft may be placed to avoid return of the nasal bone to its previous position as follows:
 - Make a 3-mm-long incision in the mucoperichondrium immediately caudal to the junction of the upper lateral cartilage and the septum as anteriorly as possible.
 - A septal elevator is used to create a pocket only large enough to accommodate the spreader graft between the septum and the upper lateral

cartilage. The dissection is extended under the nasal bone.

- A piece of folded Surgicel saturated in bacitracin ointment is placed between the nasal bone and septum and is left in position until it dissolves while the patient is maintained on oral antibiotics.

Bilateral Nasal Bone Deviation

- Bilateral nasal bone deviation is corrected with bilateral osteotomies and repositioning of the deviated nasal bones:
 - An onlay graft may be placed instead of osteotomy for mild deviation with no midvault deviation or compromise of internal nasal valve function.
 - If the nasal bone deviation also involves midvault deviation, a septoplasty is also needed, along with separation of the upper lateral cartilages from the septum.
- The bilateral independent controlled osteotomy technique begins with medial osteotomy of the nasal bones (**TECH FIG 1**):
 - A 4- or 6-mm osteotome is placed medial to the nasal bones and is driven cephalically with gentle tapping of a mallet.
 - A wedge of bone is resected medially, unilaterally, or bilaterally, to reposition the nasal bones if the bones are too widely spaced from the septum.
- Percutaneous anteroposterior vertical osteotomy of the nasal bones is performed next:
 - It is important to palpate the cephaloanterior border of the nasal bones to identify their point of divergence from the midline. This is where the osteotomy will begin.
 - A 2-mm osteotome is passed through the skin and muscle at this point, and osteotomy is performed through this small incision by sliding the osteotomy over the bone to avoid injury to the angular artery.
 - The osteotomy is advanced in the subperiosteal plane to make several interrupted puncture osteotomies in a linear fashion from anterior to posterior.



TECH FIG 1 • Nasal bone osteotomies. **A.** Medial wedge osteotomy is carried out using a 4- to 6-mm osteotome. **B.** Vertical osteotomy performed anterior to posterior percutaneously using a 2-mm osteotome. **C.** Low-to-low osteotomy is performed at the nose-face junction using a guarded osteotome to complete the nasal bone osteotomies. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:117-119, with permission from Elsevier.)

■ Finally, perform a low-to-low lateral osteotomy:

- A no. 15 blade is used to make an incision in the vestibular lining close to the piriformis aperture.
- A Joseph periosteal elevator is used to elevate the periosteum in a protected manner (it provides a barrier to reduce diffusion of blood that may otherwise cause periorbital ecchymosis).
- A guarded osteotome is placed at the nasofacial junction. A low-to-low osteotomy is completed to avoid a step deformity with gentle tapping of a mallet.

- The osteotomies are repeated on the contralateral side.
 - Reposition the nasal bones with direct pressure.
-

■ Septoplasty

- Correction of the deviated septum can be accomplished using an open approach or closed technique through a left-sided L-shaped (Killian) incision.
- Open approach
 - After separation of the upper lateral cartilages from the septum, the mucoperichondrium on the left side of the septum is elevated, starting from the caudal septal angle. A small incision in the mucoperichondrium anteriorly may be needed to facilitate opening into the correct subperichondrial plane.
 - Once in the correct plane, the glistening cartilage will be in view. The blunt end of a periosteal elevator is used to raise a mucoperichondrial flap.
 - Continue dissection posteriorly, cephalically, and caudally until the junction of the quadrangle cartilage and the vomer bone is reached. It is often easier and safer to start the dissection from the posterocaudal septum anteriorly to facilitate dissection of the firm antero-caudal fibrous attachments.
- Closed approach:
 - An L-shaped (Killian) incision is used on the left mucoperichondrium (for the right-handed surgeon) to enter the subperichondrial plane and to elevate the mucoperichondrium on the left side.
- From this point on, the septoplasty technique is the same, regardless of whether an open approach or closed Killian incision was used.
- Using the sharp end of the septal elevator, one can continue an L incision through the quadrangular cartilage, leaving an L strut at least 20 mm wide anteriorly and 10 mm wide caudally:
 - This L strut helps maintain long-term dorsal and columellar support, particularly if the operative plan includes repositioning of the nasal bones or manipulation of the upper lateral cartilages.
- Beyond the L strut, only the deviated portion of the septum that cannot be straightened with scoring needs to be resected. If more cartilage is needed to serve as a graft in other parts of the nose, then the remainder may be harvested. In other words, only the deviated portion of the posterocaudal

septum is removed.

- The mucoperichondrium is elevated posterior and cephalad to the L incision only. Gentle separation of the caudal portion of the septal cartilage from the maxillary crest of the vomer bone is performed using the sharp end of the septal elevator.
- The sharp end of the septal elevator is also used to separate the cartilage from the perpendicular plate of the ethmoid bone.
- Once the septal cartilage is freed, it is removed using cartilage forceps (Adson-Brown).
- Correction of bony septal deviation and spurs
 - Septal deviation and spurs are often corrected by posterocaudal resection of the septal cartilage. Spurs, if present, are usually at the junction of the vomer bone, quadrangle cartilage, and perpendicular plate of the ethmoid bone.
 - If the maxillary crest or any portion of the vomer bone is deviated or if there is a bony spur on one side of the septum, it is important to remove this portion of bone using a rongeur.
 - It is imperative to dissect the mucoperichondrium and the periosteum on the concave side of the septum first to prevent a tear in the mucoperichondrium. If a tear occurs, it can be addressed after septoplasty is complete (see below).
- Deviation or protrusion of the anterior nasal spine (ANS)
 - By palpating the ANS with the thumb and index finger of the dominant hand, the position of and size of the ANS is assessed. If the ANS is deviated or protruding, it can be reduced. If it is deviated, it can be repositioned with a greenstick fracture using a 2-mm osteotome.
- When the posterocaudal portion of the remaining septal cartilage is dislodged to one side of the maxillary crest, it is paramount to correct this septal tilt (see below).
- The caudal septum is affixed to the ANS spine using a figure-of-8 5-0 PDS suture placed from the septal cartilage to the periosteum of the ANS.
- The deviated portion of the vomer bone and the perpendicular plate are removed as thoroughly as possible to completely eliminate any internal septal deviation posteriorly.
- The remaining portion of the septoplasty technique depends upon the type of septal deviation observed.

- Correction of septal tilt (**TECH FIG 2**):
 - Disengaging the dislodged caudal and posterior portion of the retained L strut from the vomerine groove and ANS is accomplished using a periosteal elevator.
 - Removal of the overlapping redundant caudal portion of the septal cartilage with a no. 15 blade scalpel provides a “swinging-door”-type free movement of the cartilage.
 - Repositioning and fixation of the septum at midline to the periosteum of the anterior nasal spine are performed by placing a 5-0 PDS figure-of-8 suture.

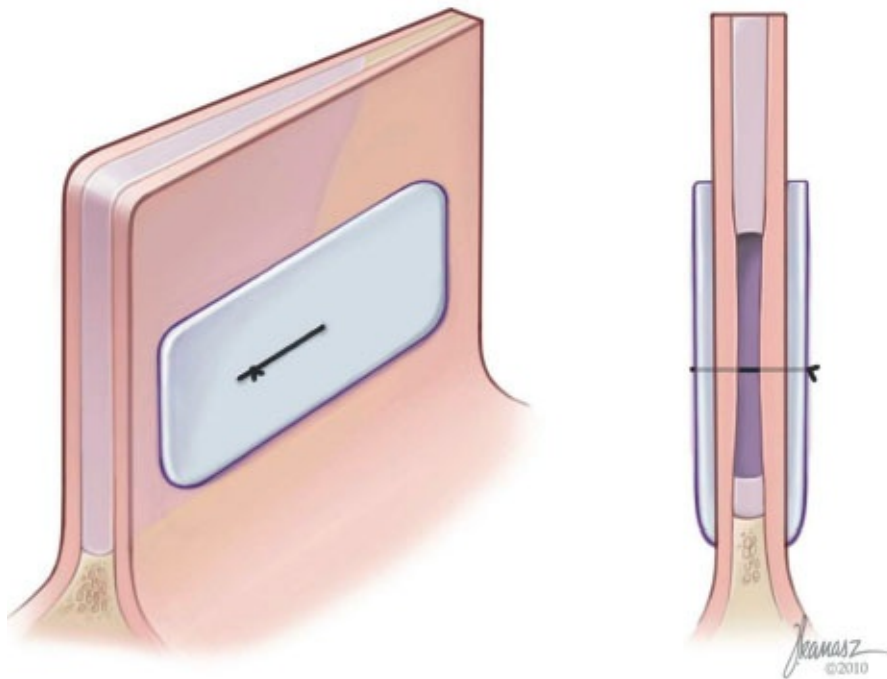


TECH FIG 2 • Septal tilt correction. The overlapping and displaced caudal portion of the deviated septal L strut is resected, moved into position at midline, and sutured into place. Deviated nasal spine correction may be needed prior to medializing the septum. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:316.)

- Prior to repositioning the septum, it is important to ensure that the ANS is in the midline or correct its position as discussed earlier.
- Correction of C- or S-shaped septal deviation
 - The posterocephalic portion of the septum is resected as described above.
 - Using a 2-mm osteotome, the ANS is greenstick fractured to reposition it in the midline as needed.
 - The perpendicular plate of the ethmoid and remaining portion of the quadrangular cartilage beyond the L strut is may be partially resected only if needed to correct deviation in the anterior and cephalic third of the septum.
 - Typically, removal of the posterior and caudal portion of the cartilage and creation of a swinging-door-type movement will release enough tension from the cartilage to eliminate the curvature.
 - If still deviated, one can score the L-shaped frame on its concave surface

using a scalpel.

- Specific differences in septal cartilage scoring based on the type of C- or S-shaped deviation are as follows:
 - Anteroposterior C-shaped deviation—the cartilage is scored in a cephalocaudal direction on the concave surface of the septal cartilage.
 - Cephalocaudal C-shaped deviation—the cartilage is scored in an anteroposterior direction on the concave surface of the septal cartilage.
 - Anteroposterior S-shaped deviation—the cartilage is scored in a cephalocaudal direction on both surfaces.
 - Cephalocaudal S-shaped deviation—the cartilage is scored in an anteroposterior direction on both surfaces.
- Because the final outcome of scoring is not predictable, it is mandatory to place bilateral extramucosal stents (Simple Stent, Supramed) which are fixed into position using a through-and-through suture (**TECH FIG 3**). This will mold the septal cartilage while it is healing to further remove the deviation.



TECH FIG 3 • Septal stents. To control the effects of the scoring and eliminate dead space, simple stents are applied on both sides and sutured in position.

(Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:322.)

- Correction of mucoperichondrial perforation
 - Inadvertent tears in the mucoperichondrium if unilateral or bilateral without apposing perforations may be managed with nasal stents (Doyle or Simple) to prevent synechiae.
 - A bilateral tear with apposing perforations should be corrected by replacing a straight piece of septal cartilage, perpendicular plate of the ethmoid bone, or a PDS synthetic plate between the mucoperichondrial flaps, spanning the full width of the perforation.
- Correction of the deviated caudal dorsum
 - Despite a thorough septoplasty, if the caudal portion of the dorsal L-shaped strut remains deviated to one side along the caudal third of the anterior septum, one has to place spreader grafts and possibly a septal rotation suture as follows.
 - The spreader grafts are cut to size from the harvested septal cartilage or secondary donor site such as rib cartilage and are sutured along the dorsum of the septum after septal scoring using 5.0 PDS horizontal mattress sutures (**TECH FIG 4**).
 - After placement of the spreader grafts, a septal rotation suture is placed (**TECH FIG 5**). On the side that the anterior septum needs to be shifted toward, a 5-0 PDS suture is passed through the caudal portion of the upper lateral cartilage and then through the spreader grafts and the septum and further caudal through the upper lateral cartilage on the side where the septum needs to be shifted away. The suture is then returned through the upper lateral cartilage, spreader grafts, septum, and upper lateral in mattress fashion.
 - As the suture is tied, the composite layers, including the spreader grafts and the septum, are pulled toward the somewhat fixed upper lateral cartilage on the side where the suture was placed more cephalically.
 - The suture is tied incrementally until the septum becomes perfectly aligned with a line bisecting the intercanthal line and the upper incisor midline (as long as these structures are positioned centrally).
 - A second suture may be required to avoid bowing of the upper lateral

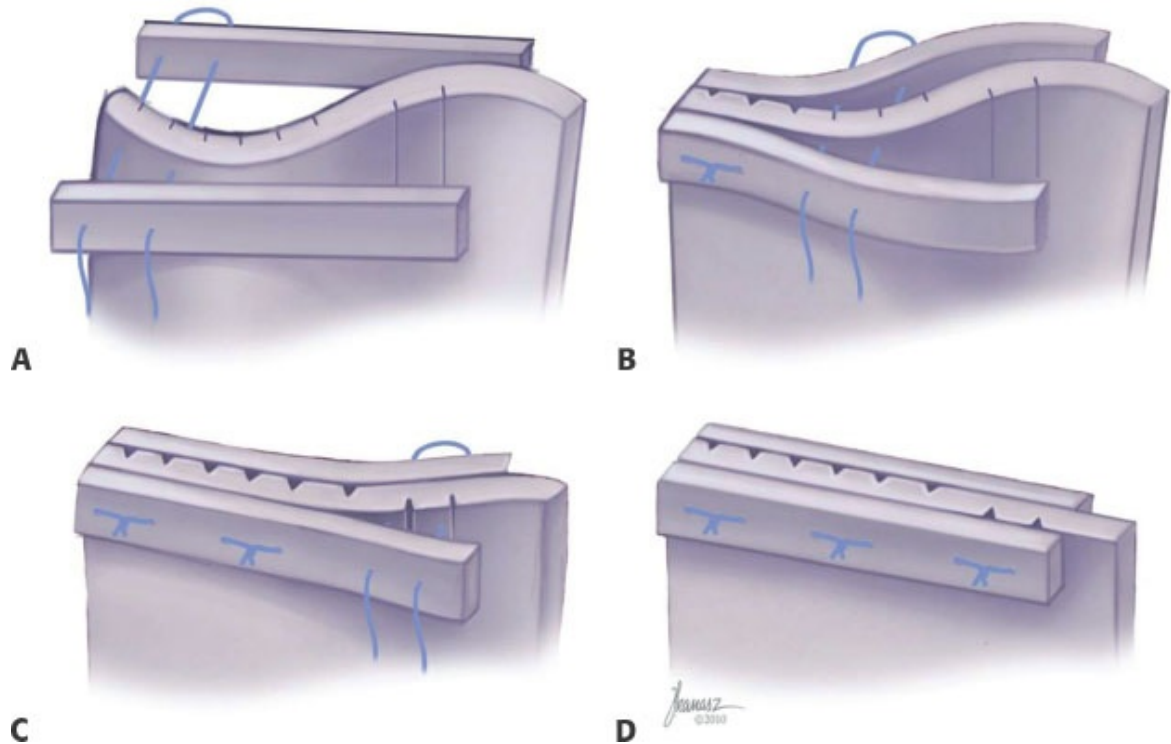
cartilage on the side toward the septum that is being rotated.

■ Turbinate reduction:

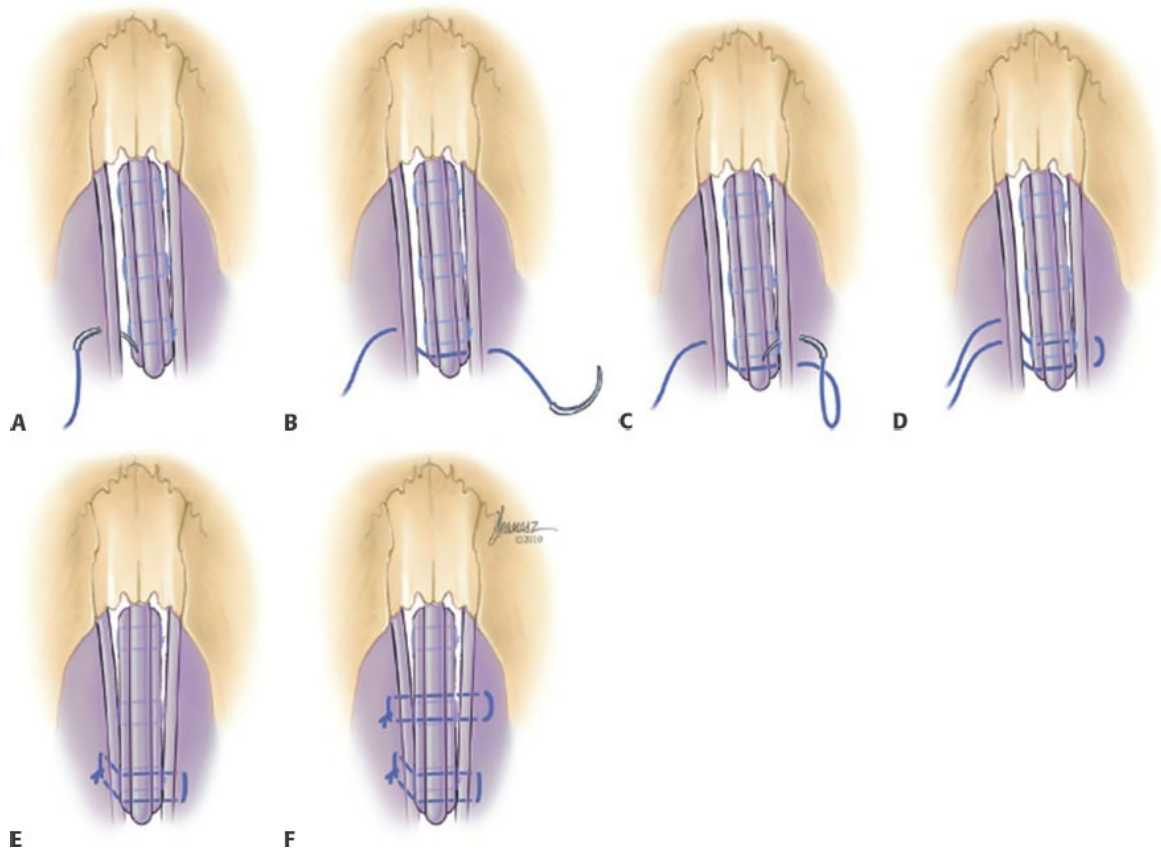
- Repositioning the septum requires reduction of the turbinates for optimal correction of the septal position and to prevent nasal airway obstruction after correction of the deviated septum.
- Partial turbinectomy is more versatile and predictable than submucous resection, because it addresses both the hypertrophic mucosa and the underlying bone while leaving a normal-sized turbinate behind, which leads to less morbidity and greater success than complete turbinectomy.
- Excising medial aspects of the turbinate evenly across the full length of the turbinate using a pair of turbinate scissors will produce a reliable outcome. Submucous resection with a microdebrider (XPS blade) combined with out-fracture of the turbinate is another reasonable option.
- One can out-fracture the middle turbinate or partially or completely remove the middle turbinate if there is hindered sinus drainage or other indications, such as migraine headaches.
- Concha bullosa can be treated by removal of the medial wall or on rare occasions, resection of most of the turbinate.

■ Use of septal stents

- After completion of septoplasty, a Doyle stent or a Simple Stent is placed on either side of the septum and fixed in position using a through-and-through 4-0 polypropylene suture (see **TECH FIG 3**).



TECH FIG 4 • A–D. Spreader graft placement. Bilateral spreader grafts are placed and sutured into position along the dorsal septum to correct septal curvature after septal scoring. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:322, with permission from Elsevier.)



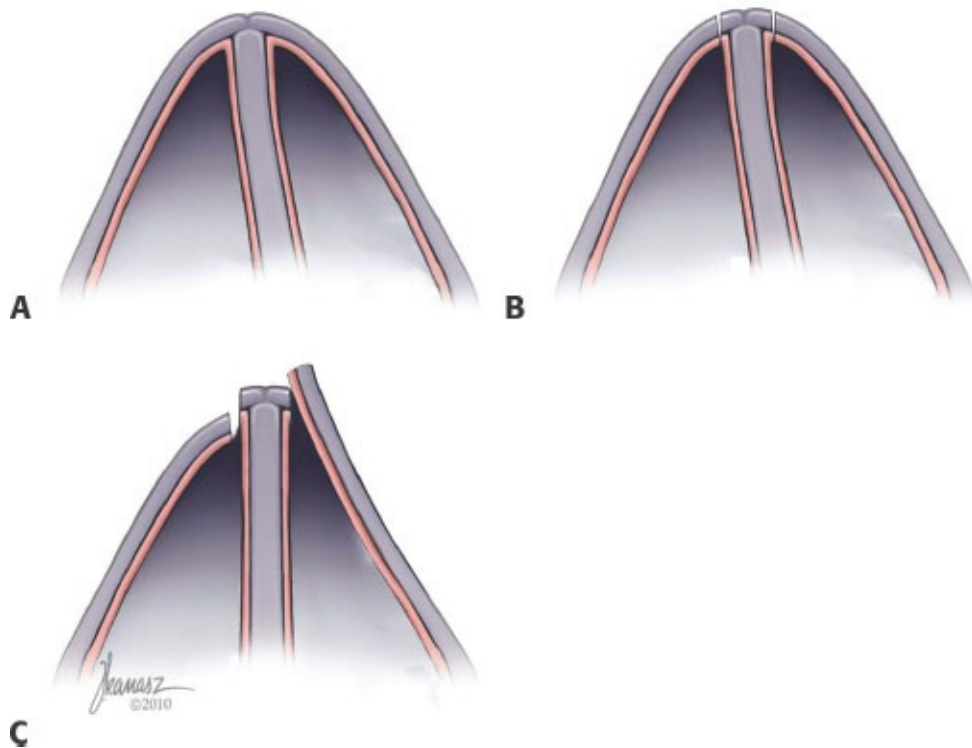
TECH FIG 5 • Septal rotation sutures. **A–D.** Technique for placement of septal rotation mattress suture. **E.** Septal rotation suture. **F.** An additional septal rotation suture may be placed cranially to control bowing of the upper lateral cartilage on the side toward which the septum is being rotated. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:336-337, with permission from Elsevier.)

■ Upper Lateral Cartilage Correction

- For a deviated midvault dorsum, an open approach is preferred.
- It is important to separate the upper lateral cartilages from the septum and assess for symmetry after the septum is pushed to midline and nasal bones

have been repositioned (**TECH FIG 6**).

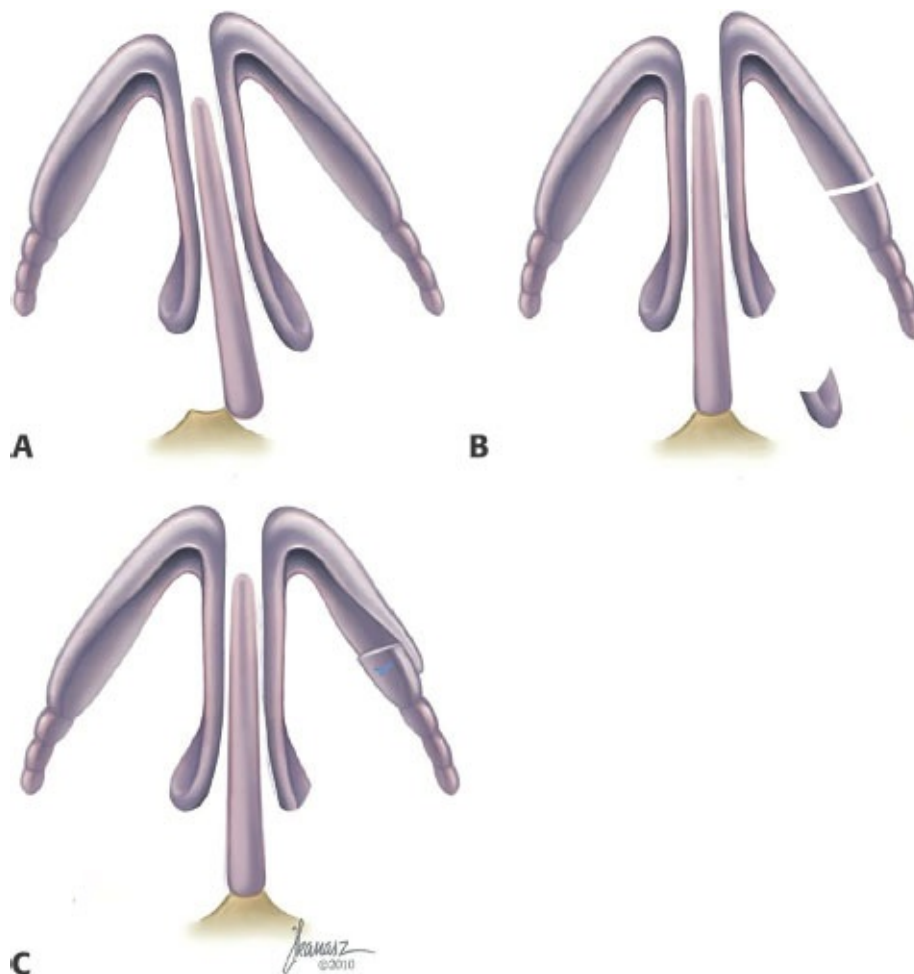
- Repositioning of the septum may require differential trimming of the upper lateral cartilages using a Joseph scalpel and then sutured along the septum with spreader grafts (see **TECH FIG 4**) if indicated using 5.0 PDS horizontal mattress sutures or a septal rotation suture (see **TECH FIG 5**) as discussed in the sections above.



TECH FIG 6 • Importance of differential trim of the upper lateral cartilages after septoplasty and nasal bone repositioning. **A.** Deviated septum and upper lateral cartilages. **B,C.** Trimmed upper lateral cartilages prior to nasal bone osteotomies and septal repositioning may result in residual excess or shortage of the upper lateral cartilages on either side. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:314, with permission from Elsevier.)

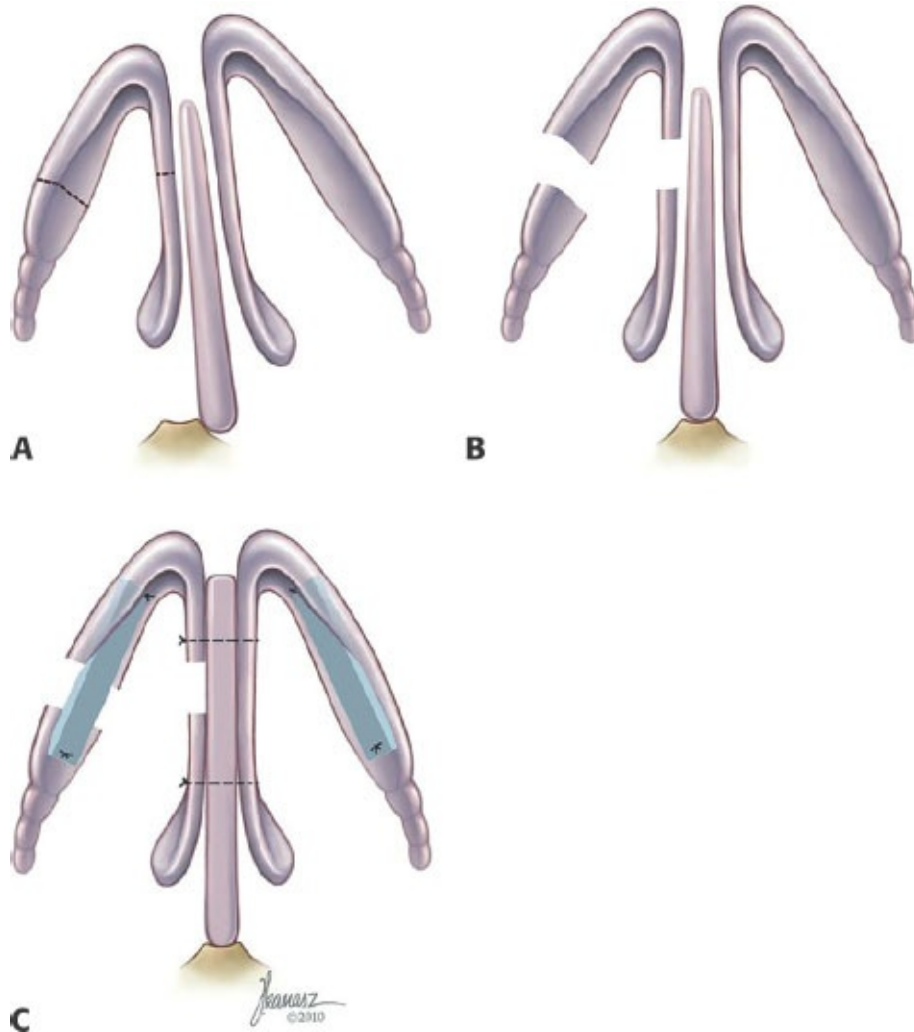
■ Lower Lateral Cartilage Correction

- The lower lateral cartilages may be accessed for correction using an open rhinoplasty approach.
- If the caudal septum is displaced, straighten it prior to adjusting the length of the lower lateral cartilages.
- The tripod concept is used to determine the appropriate length that each side of the lower lateral cartilages must be matched in order to correct the deviation and nasal projection. For example, a nasal base that is deviated to the left will require lengthening of the lateral crus of the left lower lateral cartilage or shortening of the lateral crus of the right lower lateral cartilage, depending on what the appropriate tip projection would be. In the underprojected nose, the lateral crus on the side the base is deviated toward is lengthened, whereas in the overprojected nose, the lateral crus on the side the base is deviated away from is shortened.



TECH FIG 7 • Lower lateral cartilage trim after septal tilt correction. **A,B.** Lower lateral cartilage exposed and mobilized after septal tilt correction, a portion of the medial crus portion is resected or overlapped as needed. **C.** Lateral crus is overlapped depending on the orientation of the lower lateral cartilage and taking into consideration the tripod concept. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:341, with permission from Elsevier.)

- If correction requires shortening of the lower lateral cartilage on one side, one can mobilize the lower lateral cartilage, transect and overlap it laterally and if necessary medially, and then repair it preferably after placement of a Gunter lateral crus strut with 5.0 PDS sutures (**TECH FIG 7**).
- If correction requires lengthening of the lower lateral cartilage on one side, the lateral crus is dissected, transected, and elongated, and the cut ends are secured to a Gunter lateral strut using 5.0 PDS sutures (**TECH FIG 8**). A lateral crus strut, if used, should be placed bilaterally for symmetry.
- After correction, the lower lateral cartilages are secured to a columellar strut graft to provide long-term stability.
- A perfect alignment of the nasal domes and the midline of the dorsum is checked repeatedly.



TECH FIG 8 • Lower lateral cartilage extension after septal tilt correction. **A,B.** Mobilization of the lower lateral cartilage and anterior advancement after septal tilt correction. **C.** Segments fixed in position with a columella and lateral crus strut. (Reprinted from Guyuron B. Correcting deviated noses, septoplasty, and turbinectomy. In: *Rhinoplasty*. Philadelphia, PA: Elsevier; 2012:342, with permission from Elsevier.)

Preoperative examination	■ Careful preoperative analysis of the face, nasal framework, and internal structures allows for thorough correction, including important observation of eyebrow alteration. A full-smile frontal view will best elucidate nasal deviation. ■ Failure to do so may result in residual deviation.
Mucoperichondrial tears	■ It is important to identify any mucoperichondrial tears before repair of the incisions. ■ Bilateral apposing tears can result in a persistent septal perforation if not addressed.
Turbinate reduction	■ Turbinates must be conservatively reduced intraoperatively before or after the septoplasty. ■ Failure to reduce the turbinates on the side toward which the septum was corrected may result in relapse of the septal deviation.
Trim the upper lateral cartilages last	■ Trimming these structures prior to repositioning the septum and nasal bones may result in upper lateral cartilage excess on one side and shortage on the opposite side.
Protect the periosteum during lateral osteotomy	■ The periosteum provides a barrier to limit diffusion of blood into the periorbital tissues. ■ If disrupted, this can result in significant periorbital ecchymosis.

POSTOPERATIVE CARE

■ Stents:

- If a septoplasty was performed, at the end of the procedure, Doyle stents are placed on either side of the septum and fixed to the membranous septum using a through-and-through mattress 4-0 polypropylene suture. Doyle stents allow further stabilization of the septum and eliminate dead space. These stents are removed after 3 to 8 days, depending on the condition and the amount of dissection or manipulation of the septum.
- Extramucosal internal stents (Simple Stents) that are placed for septal scoring or stents placed for bilateral apposing perforations of septal mucoperichondrium should be removed after 2 to 3 weeks.
- The patient is kept on oral antibiotics throughout the period that any internal stents are in position to prevent toxic shock syndrome. An oral first-generation cephalosporin is preferable.

■ Dressing:

- Place Steri-Strips transversely across the nasal dorsum and sidewall touching down onto the midface on either side as well as one vertically along either sidewall connecting beneath the tip to help maintain the new shape of the nose and facilitate collapse of the dead space.
- Splint:
 - If nasal bone osteotomy was performed, a dorsal nasal splint (aluminum and thermoplastic) is applied over the Steri-Strips.
 - The dorsal splint is removed after 7 to 8 days and after Doyle stent removal to prevent nasal bone shift.
 - A Medrol dose-pack may be prescribed postoperatively to minimize swelling and bruising from osteotomies. Corticosteroids are to be avoided in patients with active acne or a propensity for severe acne.
 - The patient should avoid wearing glasses for 5 weeks after nasal bone osteotomy.
- The patient can bathe on postoperative day 1 but is instructed to not get the nasal dressings wet.
- Patients are prevented from strenuous activity for 3 weeks to avoid intranasal bleeding.

OUTCOMES

- Although the goal is correction of all of the nasal deviation in a single surgery, secondary procedures may become necessary to achieve optimal results even for the most skilled surgeon.
- It is important to discuss this possibility with patients who undergo rhinoplasty for any reason, especially those with a significantly crooked nose.

COMPLICATIONS

- Hematoma
- Persistent epistaxis
- Infection
- Graft loss
- Dorsal nasal collapse—from L-strut fracture or collapse
- Synechiae—can be avoided by use of Doyle stents
- Empty nose syndrome—from over-resection of the inferior turbinate

63 Technique for Treating the Long Nose

CHAPTER

Michael R. Lee and Rod J. Rohrich

DEFINITION

- *Long nose* is a term used to describe a nose that extends beyond the ideal nasal length. Multiple subsites may be responsible for creating a long nose and will be discussed.
- *Nasal length* is measured from the root of the nose to the most projected part of the nasal tip. Ideally, nasal length should measure 0.67 of the midfacial height (eyebrow to subnasale).
- *Nasal projection* is measured from the alar groove to the most projected part of the nasal tip. Ideally, nasal projection should measure 0.67 of the ideal nasal length.¹
- *Nasal rotation* is determined by using the nasolabial angle. On lateral view, a line is drawn bisecting the long axis of the nostril, whereas a second vertical line is drawn through the anterior most aspect of the upper lip. The angle created should fall between 90 and 110 degrees in women and between 90 and 95 degrees in men. A more obtuse angle is associated with over-rotation of the tip, whereas a more acute angle is associated with a decreased tip rotation. The latter is often seen with the long nose.

ANATOMY

- Increased nasal length may result from multiple anatomic subsites including the radix and nasal bones, dorsal and caudal nasal septum, and/or excess paired nasal cartilages. These structures may be solely responsible for the long nose, but more often it is a combination of subsites (**FIG 1**).
- The nasal skin and musculature envelop the underlying bone and cartilage. Soft tissue attachments work to keep proper relationships between nasal bone

and cartilage. These attachments provide support for the nasal tip.

- Nasal tip support structures can be divided into major and minor. Major tip support structures include the fibrous attachments between the upper and lower lateral cartilages (scroll ligament), lateral crura and pyriform aperture, medial crura and caudal septum, and the interdomal tip ligament. Minor tip support structures include fibrous attachments of alar cartilage to the cartilaginous dorsum, alar cartilage attachments to overlying skin, and the membranous septum.¹

PATHOGENESIS

- A long nose may occur as the result of congenital development, traumatic injury, iatrogenic injury, and/or aging.^{2,3} Congenital overgrowth may lead to volume excess. Traumatic injury may displace or activate growth of bone or cartilage. Iatrogenic injury may create a long nose when tip support is not properly established. Aging results in loss of tip projection and midface volume loss, both of which contribute to a long nose.
- The illusion of a long nose may occur in patients with subnasale malposition, periapical hypoplasia, short midface, or inadequate chin projection.
- A true increase in nasal length may occur with a high radix, excess volume of the upper lateral cartilages, lower lateral cartilages, nasal septum, and/or loss of tip projection.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Aesthetically, patients may feel their nose is simply too large for their face. As the focal point of the face, a long nose often disrupts nasofacial balance.
- Patients may point out a large hump caused by excess bony or cartilaginous dorsum. They may complain of a prominent or hanging columella that results from excess of the caudal septum. Patients may also report a drooping tip from inadequate support.

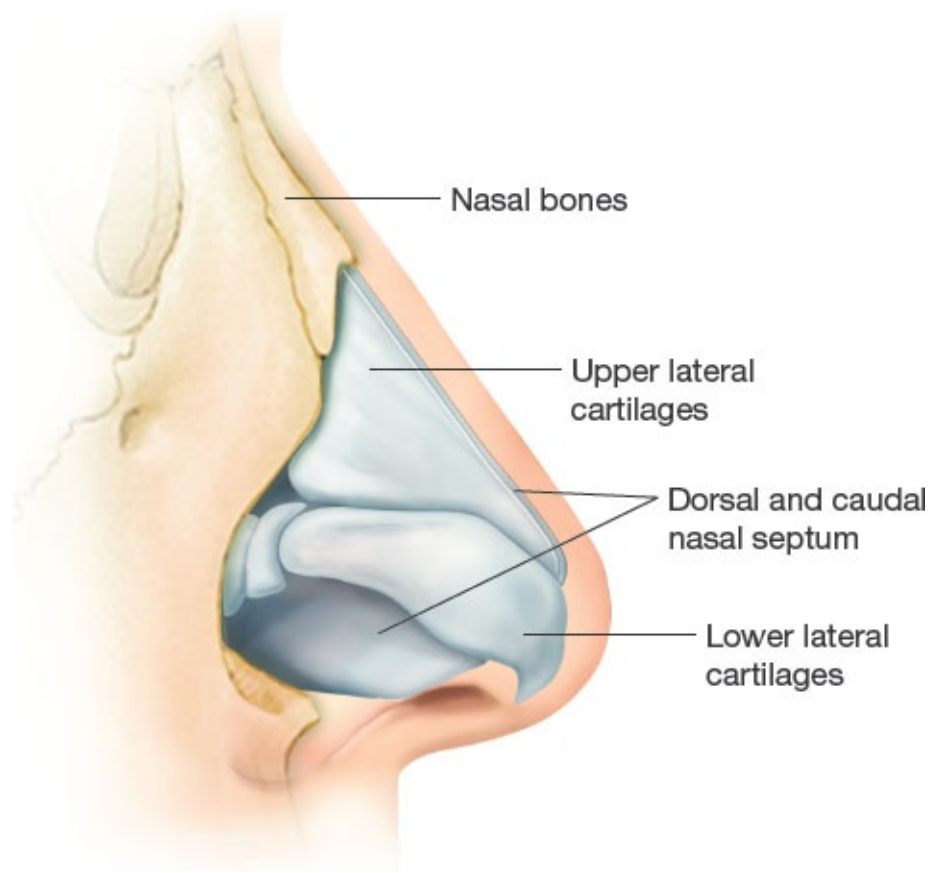


FIG 1 • Illustration depicting the nasal substructure. Increased nasal length may result from multiple anatomic subsites including the radix and nasal bones, dorsal and caudal nasal septum, and/or excess paired nasal cartilages.

- Examination begins with assessment of facial widths and vertical heights. This is important as the overall surgical goal is to create improved balance between the face and nose. If the facial proportions grossly deviate from aesthetic ideals, this is taken into consideration when creating the operative plan.
- The nose is evaluated in all classic rhinoplasty views with attention focused on areas responsible for creating a long nose. The patient is examined in repose, animation, and respiration as the nose is a dynamic structure.
- Anterior inspection is useful to determine symmetry and straightness, both of which contribute to the dorsal aesthetic lines (DALs). A large dorsal hump may distort the DALs.
- Tip definition and position are also noted.

- Lateral and oblique views are useful in the long nose. Evaluation begins with critique of the radix or nasal root. A high radix may be responsible for creating a long nose, whereas a low radix may give the nose an overprojected appearance. Next, the dorsum is inspected for the presence of a convexity (hump) or irregularities. Overgrowth of the upper lateral cartilages and/or dorsal septum is typically responsible for dorsal convexity. Distally, overgrowth of the caudal septum can downwardly displace the lower lateral cartilages. Overgrowth of the lower lateral cartilages can further contribute to caudal tip position. Caudal septal excess may also distort the alar-columellar relationship and create excess columella show.
- Basal view analysis provides additional information in the long nose patient. Excess lower lateral cartilage volume may create domal fullness and disrupt the ideal columellar:tip ratio of 2:1. The basal aesthetic lines (BALs)⁴ are studied as they may be distorted by excess lower lateral cartilage volume and malposition of the medial crura.

IMAGING

- 3D imaging is extremely helpful in the long nose and improves communication between the surgeon and patient. Modern-day imaging software can readily display the anticipated changes of hump reduction, increased nasal rotation, and decreased nasal projection.
- Imaging can also be useful to illustrate to patients the difference chin surgery or midface volume restoration can make in overall nasofacial harmony.

SURGICAL MANAGEMENT

- Surgical management is best accomplished with an open surgical approach. This provides direct visualization of the radix, upper lateral cartilages, nasal septum, and lower lateral cartilages. Direct visualization and inspection of these structures optimize the ability to correctly diagnose and treat the problem(s).⁵

Preoperative Planning

- A comprehensive consultation is required as with all patients seeking rhinoplasty. Communication is an essential component of a successful outcome. This communication allows the patients to voice their desired changes and the surgeon to determine if expectations are obtainable. Furthermore, patients may not want all aspects of their long nose addressed,

and each anticipated change should be discussed. The result of this discussion helps establish an ideal operative plan.

Positioning

- Once in the operating room, the patient is intubated and positioned on the table. The most cephalic portion of the head extends just beyond the table (**FIG 2**). The patient's head may be elevated 15 degrees to minimize venous pooling in the operative field. A throat pack is gently placed and removed at the end of the surgery. Local anesthetic with epinephrine is injected into the planned incision sites.

Approach

- Overall treatment of the long nose involves reduction of oversized nasal structures and establishment of adequate tip support. With the nasal skin envelope elevated, nasal bone and cartilages are easily inspected. Direct visualization and palpation help to determine cartilage size and integrity.
- The relationships between these structures are also studied. Excess dorsal septum may be associated with excess or normal upper lateral cartilage volume. Excess upper lateral cartilages may caudally displace excess or normal-sized lower lateral cartilages. Excess caudal septum may also caudally displace excess or normal-sized lower lateral cartilages. The open surgical approach allows an exact inspection of each structure to determine the appropriate surgical technique(s) to be implemented.



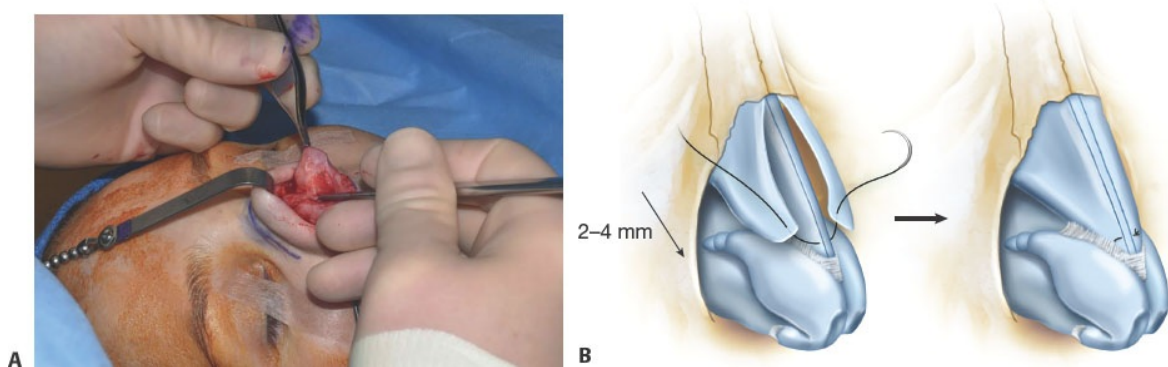
FIG 2 • Photograph depicting proper positioning of

patient undergoing rhinoplasty.

TECHNIQUES

■ Component Dorsal Hump Reduction

- The component dorsal hump reduction⁶ may be used to address multiple causes of a long nose. Such causes include a high radix, dorsal septum excess, and/or upper lateral cartilage excess.
- Dissection continues to the anterior septal angle.
 - Once identified, bilateral mucosal flaps are elevated to expose the cartilaginous septum.
 - The elevator is used to dissect away the mucosa from the medial portion of the upper lateral cartilages (**TECH FIG 1A**).
 - This move facilitates separation of the upper laterals from dorsal septum while minimizing mucosal trauma. Next, the upper lateral cartilages are separated from the dorsal septum with scalpel or scissors.
- Subsequently, short-angle scissors are used to remove excess of the cartilaginous dorsal septum.
- The rasp can be used to lower a high radix and smooth out any bony humps that exists. If excess upper lateral cartilage volume is present, it is trimmed with scissors.
- Reconstitution of the dorsum is completed with upper lateral crura tension spanning sutures⁷ (**TECH FIG 1B**).

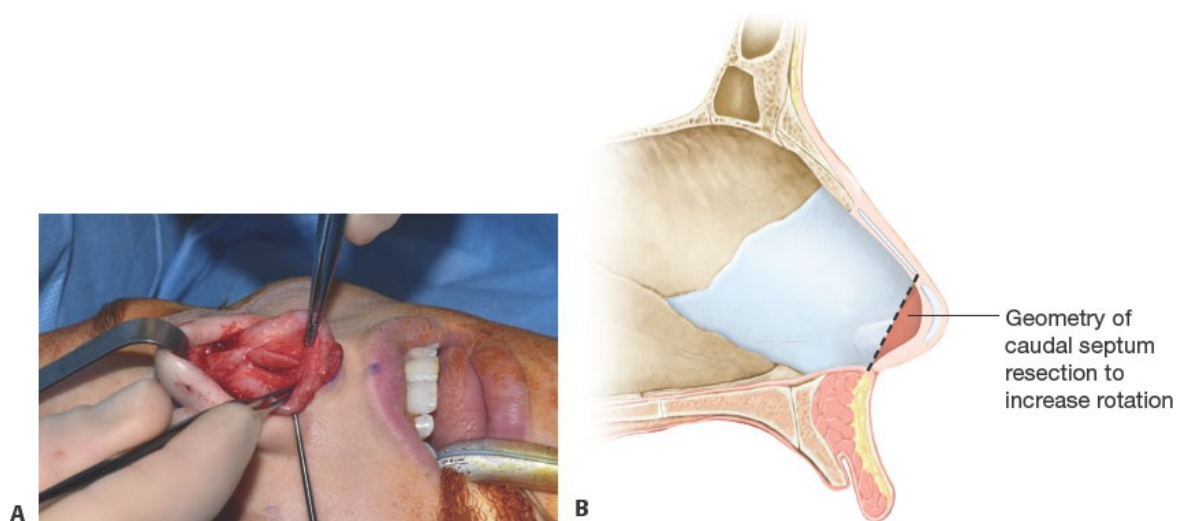


TECH FIG 1 • A. Component dorsal hump reduction.

Mucosa is freed from the medial upper lateral cartilages and nasal septum to minimize trauma during separation of these structures. **B.** Upper lateral cartilage tension spanning suture. Suture is used to advance the upper lateral cartilages anteriorly and fixate them to nasal septum. This reconstructs the middle vault and smoothens the dorsum.

■ Caudal Septal Reduction

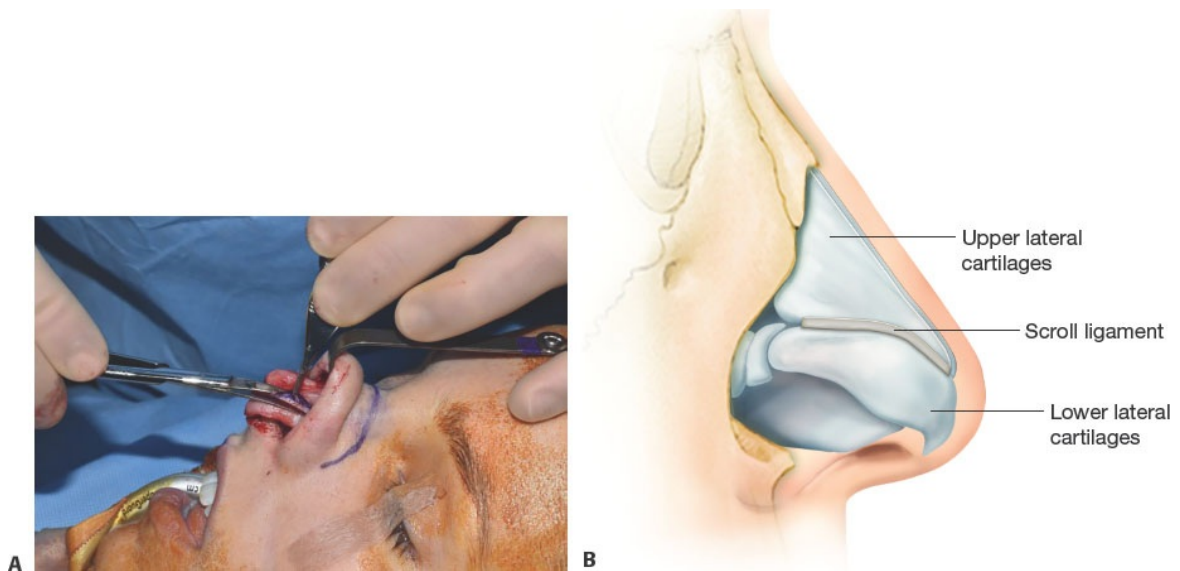
- The caudal septum is easily exposed with further dissection of the septal mucosal flaps (**TECH FIG 2A**).
- Once exposed, scissors are used to excise the excess caudal septum.
- Often in the long nose, an angulated excision is performed for increased tip rotation (**TECH FIG 2B**).



TECH FIG 2 • A. Caudal septal exposure provided with open approach rhinoplasty. **B.** Geometry of the caudal septal resection is designed to increase rotation of the nasal tip.

■ Excess Lower Lateral Cartilages

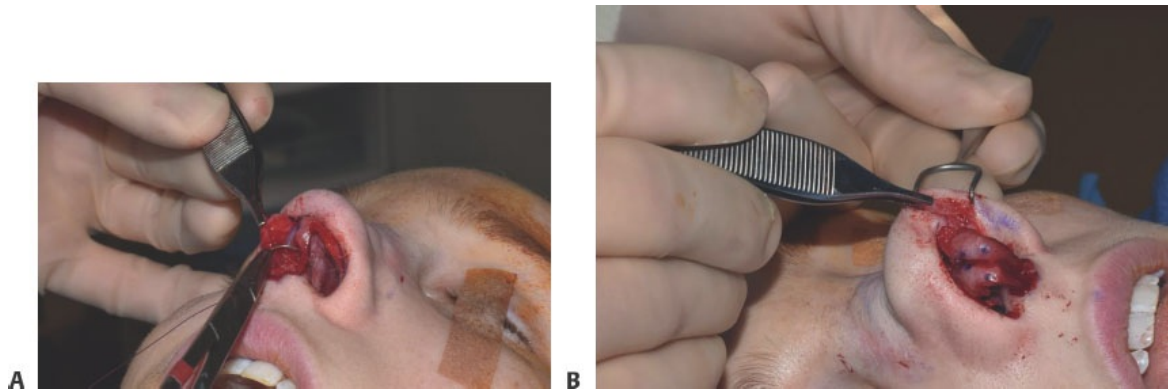
- Excess volume of lower lateral cartilages can be improved with a cephalic trim (**TECH FIG 3A**).
- This disrupts the scroll ligament (major tip support) and permits upward rotation of the nasal tip often needed in the long nose (**TECH FIG 3B**).



TECH FIG 3 • **A.** Cephalic trim to reduce lower lateral cartilage volume and increase tip rotation. **B.** Disruption of the scroll ligament is often required to allow cephalic rotation of the lower lateral cartilages.

■ Optimizing Tip Support

- Once the dorsum is established at the appropriate level, ideal tip position is determined and secured. This is most commonly accomplished with the use of a columella strut and tip sutures (**TECH FIG 4A**).
- Alar contour grafts may also be used to provide additional support to the lower third (**TECH FIG 4B**).



TECH FIG 4 • A. Placement of a columellar strut and tip sutures for stabilization. **B.** Alar contour graft placement just above the alar rim.

■ Adjuvant Procedures

- Subnasal retraction from periapical hypoplasia typically requires fat grafting or application of filler to augment. Chin augmentation and genioplasty are typically used to improve a weak chin.

PEARLS AND PITFALLS

Facial analysis	■ It is essential to analyze facial proportions and take them into account when planning for rhinoplasty. The overall goal is improved balance between the nose and face.
Relevant anatomy	■ It is important to know the structures typically responsible for creating the long nose (bone/cartilage substructure and tip support structures).
Tip support	■ Understanding major and minor tip support is key to controlling tip movement and position.
Surgical approach	■ An open surgical approach provides optimal inspection and treatment of nasal bone and cartilage.

POSTOPERATIVE CARE

- Nasal dressing is placed at the end of the surgery. Taping is done to support

and minimize swelling of the nasal tip. A nasal splint is also applied. Tape and splint are discontinued at postoperative day 7 when the trans columellar incision sutures are removed. Patients are started on saline intranasal spray and topical antibacterial ointment for the incision. Once the incision is healed, scar care is initiated and continued for 6 to 12 months.

OUTCOMES

- Reduction rhinoplasty to treat the long nose is an overall reliable operation. The aesthetic result may be limited by a thick overlying soft tissue envelope. Patients with thick skin should be made aware of this prior to surgery. Failure to thoroughly recognize all instigating factors may result in a less than desirable result.

COMPLICATIONS

- Cartilage reduction must stop short of creating a secondary deformity. Disruption of the upper lateral cartilage soft tissue connection with the nasal bones and/or dorsal septum can result in middle vault collapse. Overzealous resection of the lateral crura and failure to establish proper tip support can lead to lower nose collapse and/or problems with the nasal ala. Any number of these untoward outcomes can create aesthetic and functional problems.

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CHAPTER Treating the Short Nose

Nicholas Lahar and Jason Roostaeian

DEFINITION

The short nose is defined as a perceived excess upward tilt of the nasal tip that results in a foreshortened appearance. Common defining features include a decreased distance from nasofrontal angle to tip defining point, an over-rotated tip, and an increased nasolabial angle. Other commonly associated features can include decreased dorsal nasal length, increased nostril show, cephalic over-rotation of tip, low/deep radix, and long upper lip.¹ The perceived deficits of the nose must be evaluated with respect to the other facial features, but there are generally accepted measurements of facial harmony (see below).

ANATOMY

- The structural nose is composed of the paired nasal bones, upper lateral cartilages, and lower lateral cartilages. The midline septum also offers significant support for dorsal height and projection.

PATHOGENESIS

- Tip projection is highly dependent on support of the lower lateral cartilages. In cases of poor lower lateral cartilage support, tip support becomes more dependent on septal cartilage. Other supporting structures include intercartilaginous ligament between the upper and lower lateral cartilages, lateral crural complex extending from the piriform rim, interdomal ligaments, and medial crural attachments to the septum.
- Deformities are typically acquired or congenital.
- Acquired causes: iatrogenic, trauma, chemical (eg, cocaine), autoimmune disorders, and infections

- Scar contracture from tumor resection or trauma involving the lower portion of the nose may distort and retract the nasal tip.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed nasal history should be obtained, in particular to include a history of symptoms related to nasal obstruction, nasal allergies, prior nasal trauma, and nasal surgeries. Any patient aesthetic concerns and goals should be elicited and clearly defined.²
- A complete external and internal nasal examination should be conducted in all patients.
- Facial harmony is evaluated with particular attention to the relationships of the facial thirds on the profile view, nasofrontal angle, tip defining point, nasal length, nasolabial angle, and nostril show.
- Via palpation and examination, identify typical findings such as lack of nasal cartilage, weakened or fractured osseous/cartilaginous support, scar tissue, and contracture of soft tissue.
- Evaluate the nose with respect to the other facial features to assess facial harmony.
- There are generally accepted measurements for nasal length and nasolabial angle that can be used to assess the appearance.
 - Nasal length is typically about two-thirds the height of the midface (supraorbitale to subnasale).¹
 - Ideal nasal length: nasal length/nasal projection ratio of 5:3.¹
- Ideal nasolabial angle:
 - Caucasian women: 95 to 105 degrees
 - Caucasian men: 90 to 95 degrees¹
- The columella protrudes 3 to 4 mm below the alar rim. The ideal ala-columella relationship creates a symmetrical oval outline on profile view bisected by a line connecting the most anterior to most posterior portion of the nostril.
- Assess the nasal alae and soft tissues aesthetically and for skin quality.
- A nasal speculum is used to evaluate the septum and the inferior turbinates for abnormalities.
- Standardized photographs including frontal, lateral oblique, and basal views should be obtained in all patients.
- Assess septal cartilage and other potential donor sites (ear and/or rib), particularly if the patient has had nasal surgery previously.

- Priority should be given to strong, straight pieces of cartilage for dorsal and columellar strut grafts.

IMAGING

- No specific imaging is required if attention is being paid specifically to a shortened nose.
- A nasal x-ray can be helpful in cases of prior trauma or asymmetric nasal bones.
- Computed tomography (CT) imaging can help evaluate nasal bones, septal deviation, turbinate pathology, and the sinuses when the history warrants further investigation.

SURGICAL MANAGEMENT

- The primary objective in correction of the short nose is to increase overall radix to tip length. This often requires a concomitant increase in tip projection while reducing tip rotation and the nasolabial angle.²
- Adjunctive procedures, eg, functional modifications, should also be determined and made part of the operative plan accordingly.

Preoperative Planning

- Risks, benefits, and expectations must be discussed with the patient prior to surgery.
- Consideration of the soft tissue envelope and its overall compliance, previous operations, extent of previous nasal trauma, and involved structures and available septal and other potential cartilage grafts (ear, rib) should be taken into account. The patient should be informed of the possible need to harvest cartilage from these other donor sites such as the ear or rib. In cases of severe soft tissue contracture, preoperative discussion to set expectations accordingly and/or attempts to increase compliance via mechanical means such as frequent downward massaging should be considered.
- Principles of nasal lengthening
 - Precise assessment of length deficiency
 - Accurate identification of deficient tissues
 - Adequate release of soft tissue envelope
 - Pertinent modification of skin, mucosa, and/or skeletal deformities to restore length
 - Maintaining patency of the nasal airway

Positioning

- The patient is positioned supine with arms tucked. The head is placed at the very end of the bed.
- An oral right angle endotracheal tube is used for intubation, and should extend inferiorly in the midline away from the nose, and secured without distorting the upper lip and nose.
- Nasal hairs may be trimmed, if desired.
- Oxymetazoline or 4% cocaine-soaked pledgets are placed in each nostril.
- Local anesthetic consisting of 1% lidocaine with 1:100 000 epinephrine is infiltrated into the nasal sidewalls, into the columella, and inside the nostril along the lower lateral cartilages.
- A throat pack is placed to prevent gastric accumulation of blood.
- The face is prepped with dilute Betadine.
- A sterile head wrap is placed followed by surgical drapes.

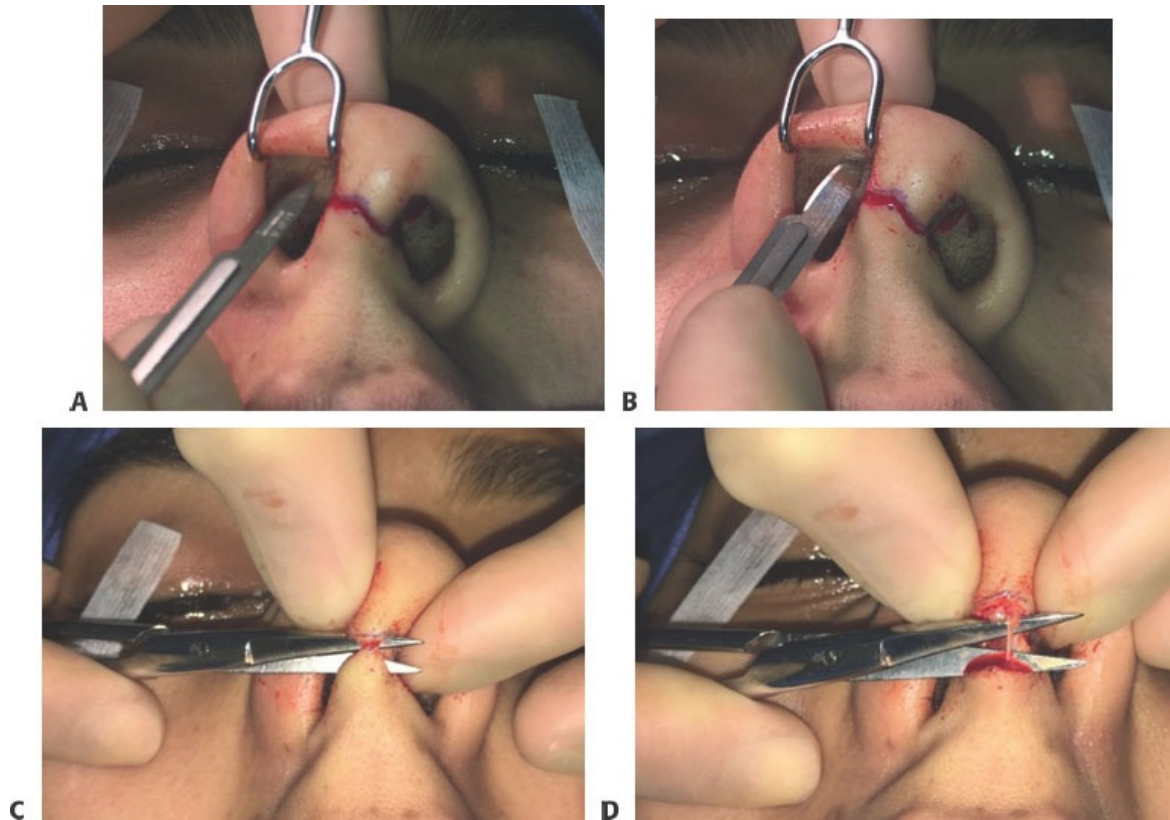
Approach

- An endonasal approach is indicated for simple refinements of the nasal tip. Otherwise, an open approach is preferred particularly when there is poor support for the nasal tip or when more complex nasal tip adjustments are necessary.

TECHNIQUES

■ Shield-Tip Graft

- Indication: Mild shortening attributed to a deficient infratip lobule or columella
- Concept: Cartilage graft is placed at the tip of the lower lateral cartilages to increase the length or manipulate contour.
- A gull wing or stair-step transcolumellar incision is made at the narrowest point of the columella (**TECH FIG 1A**).
- An incision is made in the nostril margin at the caudal margin of the lower lateral cartilages and extends to the transcolumellar incision medially (**TECH FIG 1B**).



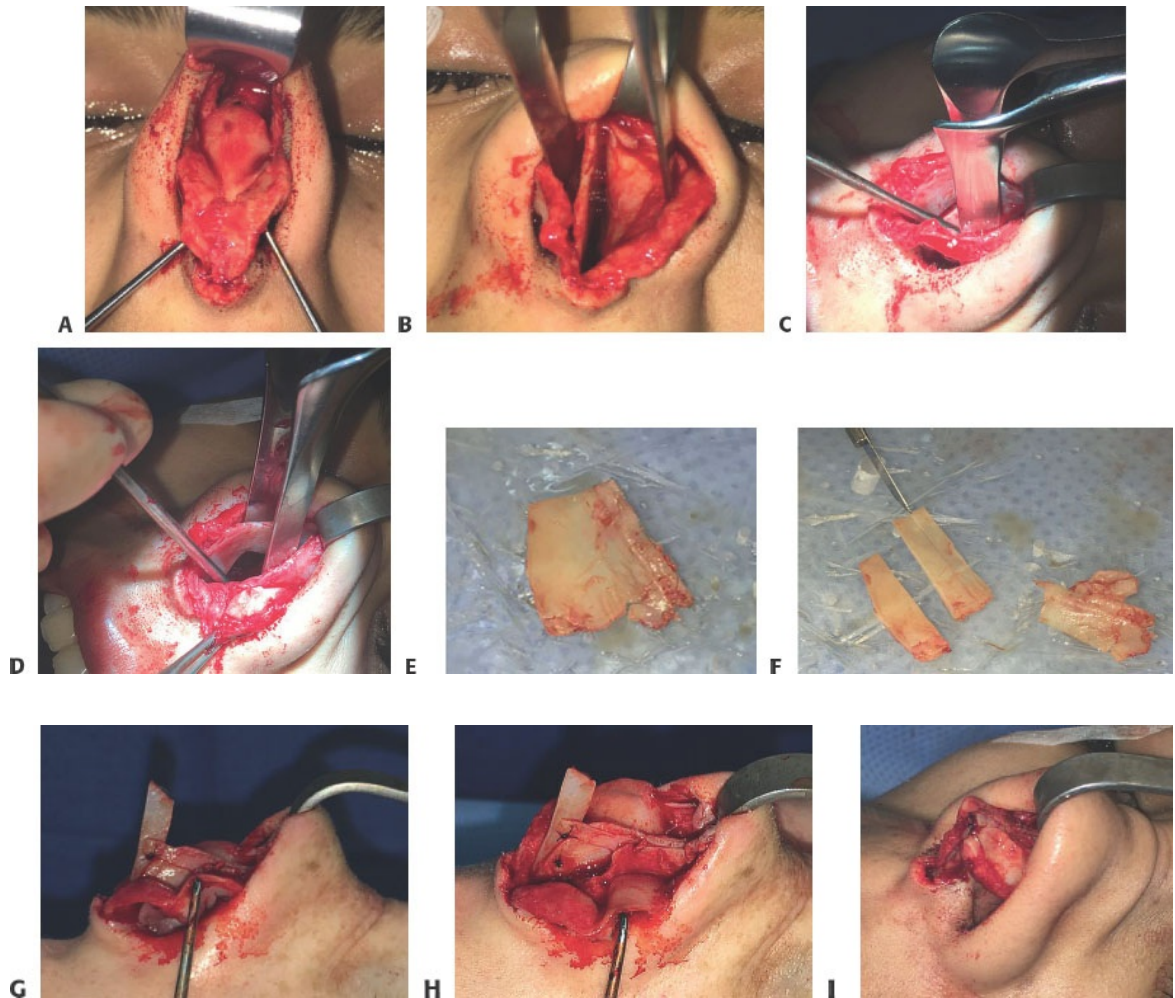
TECH FIG 1 • A. A transcolumnellar incision is made with care to avoid injuring the medial crus. **B.** An infracartilaginous incision is made at the lower margin of the lower lateral cartilages. **C,D.** The transcolumnellar incision is completed.

- Fine curved iris or Converse scissors are used to complete the columellar incision, with care taken to avoid injury to the medial crura (**TECH FIG 1C,D**).
- A nasal skin flap is elevated from the columellar incision and lower lateral cartilages using sharp double hooks for traction.
- If the relationships of the lower lateral cartilages are to be preserved, a Killian incision is performed approximately 1 to 1.5 cm cranially from the caudal septal border through the mucoperichondrium using a no. 15 blade.
- Submucoperichondrial dissection is performed using a Cottle elevator.
- The septal cartilage can now be harvested using a no. 15 blade or swivel knife, preserving an L strut of at least 1 cm dorsally and caudally.
- The shield tip graft is shaped from the harvested cartilage.

- The graft is laid in the desired location to augment tip projection and/or nasal length. It is secured in place with 6-0 polyglactin (Vicryl) suture. Graft position is adjusted to augment lengthening vs projection depending on the needs of the patient.
- Other preoperatively planned functional and aesthetic adjustments are made as needed.
- The nasal skin flap is laid back down and secured with 5-0 chromic sutures intranasally and 6-0 polypropylene in the columella.
- Tape strips are applied to the nasal dorsum to limit postoperative swelling and to help shape and refine the tip.
- The throat pack is removed prior to extubation. A nasogastric tube may be used to suction gastric contents to remove accumulated blood.
- A mustache gauze dressing is applied across the upper lip to absorb any nasal drainage.
- An ice pack may be used on the midface to minimize swelling.

■ Septal Extension Graft

- Indicated for moderate length deficiency.
- Allows for a relatively stable construct and control of the length deficiency.
- A gull wing or stair step incision is made at the narrowest point of the columella.
- An infracartilaginous incision is made in the nostril margin at the caudal margin of the lower lateral cartilages and extends to the transcolumellar incision medially.
- Fine curved iris or Converse scissors are used to complete the columellar incision, with care taken to avoid injury to the medial crura.
- A nasal skin flap is elevated from the columellar incision using sharp iris or Converse tip scissors. Care is taken to keep the perichondrium on the lower lateral cartilages (**TECH FIG 2A**).
- Intercartilaginous ligament attachments are divided sharply, allowing the lower lateral cartilages to splay and to expose the septum (**TECH FIG 2B**).
- The lower lateral cartilages are splayed open with sharp hooks, and an incision is made on the dorsal septum.
- Submucoperichondrial dissection of the septum is performed bilaterally using a Cottle elevator.



TECH FIG 2 • A. The nasal soft tissues are elevated in the subperichondrial plan, revealing the lower lateral cartilages, the upper lateral cartilages, and nasal dorsum. **B.** After separating the lower lateral cartilages via the intercartilaginous ligament, the mucoperichondrium is elevated off the nasal septum, revealing the entire cartilaginous septum. **C,D.** A 1-cm dorsal L strut is preserved while harvesting septal cartilage for various grafts. **E,F.** The septal cartilage is carefully crafted to create septal extension grafts, spreader grafts, or tip grafts. **G,H.** The crafted extension grafts are secured to the caudal septal cartilage. **I.** The lower lateral cartilages are secured to

the extension graft.

- The septum is incised anteroposteriorly with a no. 15 blade with care to preserve a 1-cm dorsal and caudal strut for nasal support (**TECH FIG 2C,D**).
- The septal extension graft is shaped from the harvested cartilage (**TECH FIG 2E,F**).
- Often two small septal grafts are needed if the septal extension graft need to be placed midline; otherwise, inherent bend in septal cartilage graft and L strut can be used to place graft on right or left side of septum to ensure the tip is in the midline.
- The septal extension graft is secured to the anterior septal angle/caudal septum with multiple 5-0 PDS sutures (**TECH FIG 2G,H**).
- The domes of the lower lateral cartilages are advanced and secured to the septal extension graft as needed to increase tip projection (**TECH FIG 2I**).
- Once structural lengthening has occurred, it must be verified that soft tissues can cover the new length. Wide undermining of the dorsal and lateral nasal soft tissues may be necessary to sufficiently advance the skin flap.
- Mattress sutures of 4-0 plain gut are placed through the mucoperichondrial flaps to close the dead space where septal cartilage was harvested.
- The columellar skin is reapproximated with interrupted 6-0 Prolene, and the infracartilaginous incisions are closed with interrupted 5-0 chromic sutures.
- Internal nasal splints are placed in each nostril and sutured through the septum with a single 3-0 Prolene mattress suture.
- The throat pack is removed prior to extubation. If necessary, a nasogastric tube may be used to suction gastric contents to remove accumulated blood.
- A mustache gauze dressing may be applied across the upper lip to absorb any nasal drainage.
- An ice pack may be used on the midface to minimize swelling.

■ Tongue-and-Groove Technique

- Indication: Moderate to severe nasal length deficiency⁵⁻⁸
- This technique allows for more stable construct and control of the length deficiency.
- A gull wing or stair-step incision is made at the narrowest point of the

columella.

- An infracartilaginous incision is made in the nostril margin at the caudal margin of the lower lateral cartilages and extends to the transcolumellar incision medially.
- Fine curved iris or Converse scissors are used to complete the columellar incision, with care taken to avoid injury to the medial crura.
- A nasal skin flap is elevated from the columellar incision using sharp iris or Converse tip scissors.
- Intercartilaginous ligament attachments are divided sharply, allowing the lower lateral cartilages to splay, exposing the septum.
- The lower lateral cartilages are splayed open with sharp hooks, and an incision is made through the perichondrium on the dorsal septum.
- Submucoperichondrial dissection of the septum is performed bilaterally using a Cottle elevator.
- The septum is incised anteroposteriorly with a no. 15 blade with care to preserve at least 1-cm dorsal and caudal strut for nasal support.
- The cartilage is wedged off the bony septum and removed from the operative field.
- The dorsal septal extension grafts and columellar strut grafts are shaped from the harvested cartilage.
- Two septal grafts are cut to length in proportion to deficiency. For instance, if the nose is deficient by 3 mm, the graft will extend beyond the septum by 3 mm.
- These septal grafts will be placed along the dorsal septum with the deficiency extending beyond the margins of the septum, projecting anteriocaudally (**TECH FIG 3**).
- The width of the septal grafts is dependent on the dorsal septum width. The septal grafts can be thinned appropriately to make the total desired dorsal width. Nasal bone osteotomies may be required to narrow the nasal dorsum depending on the needs of the patient.
- The dorsal grafts are secured to the dorsal septum bilaterally with 5-0 PDS or Vicryl sutures.



TECH FIG 3 • A columellar strut is secured between two extended spreader grafts to create a stable construct for lengthening the nose.

- A columellar strut is then prepared from the septal cartilage.
 - The width of the strut will be the width of the medial crus plus the desired additional length (the deficiency).
- The columellar strut is placed between the bilateral spreader grafts, interdigitating. The strut is secured to both the caudal septum and the extended spreader grafts into a position that helps to lengthen the nose and increase projection.
- The medial crura are advanced anteriorly and caudally on the columellar strut as needed to increase tip projection. This medial crura are sewn and secured to the columellar strut using 5-0 PDS or Vicryl suture.
- Lower lateral cartilage tip refinements (eg, interdomal, transdomal, etc.) can be made at this time.
- Once structural lengthening has occurred, it must be verified that soft tissues and lateral tissues can cover the new length. Wide undermining of the dorsal and lateral nasal soft tissues may be necessary to sufficiently advance the skin flap.
- Mattress sutures of 4-0 plain gut are placed through the septal mucoperichondrial flaps to close the dead space where septal cartilage was harvested.
- The columellar skin is reapproximated with interrupted 6-0 Prolene, and the infracartilaginous incisions are closed with interrupted 5-0 chromic sutures.
- Internal nasal splints are placed in each nostril and sutured through the septum with a single 3-0 Prolene mattress suture.

- The throat pack is removed prior to extubation. If necessary, a nasogastric tube may be used to suction gastric contents to remove accumulated blood.
- A mustache gauze dressing may be applied across the upper lip to absorb any nasal drainage.
- An ice pack may be used on the midface to minimize swelling.

PEARLS AND PITFALLS

Preoperative	■ A thorough discussion of the planned goals and risks should be conducted with the patient to ensure appropriate expectations are met.
Technique	■ Wide undermining of the nasal skin is required to redrape the skin over the cartilaginous framework. ■ Columellar strut grafts or septal extension grafts should not extend past domes/tip defining points. ■ When there is insufficient septal strut cartilage, consider septal extension graft given the minimal cartilage requirements. Lower lateral cartilages can be strengthened with lateral crural strut grafts or alar rim grafts if nasal lengthening causes excess alar retraction. ■ Be mindful of overwidening the nose with spreader grafts that are too wide and high along the dorsal strut.
Postoperative	■ Have the patient avoid sleeping on a side as it will worsen edema to one side and increase concern for deviation.

POSTOPERATIVE CARE

- Surgery is usually performed on an outpatient basis.
- Usual postrhinoplasty precautions are followed.
- Keep the intranasal mucosa moist with frequent application of ointment and saline nasal spray.
- Any internal and/or external nasal splints are removed at 1 week.
- Prolonged edema may occur and in some cases can take up to 1 year to fully resolve.

OUTCOMES

- The goals of functional and aesthetic improvement can be accomplished with

any of the described techniques.^{3,4} Optimal outcomes will be attained using the technique with which the surgeon is most comfortable and able to achieve consistent results.

COMPLICATIONS

- Possible short-term and long-term complications include infection, hematoma, nasal asymmetry, septal perforation, worsening of nasal obstruction, scarring, nasal bleeding/crusting, cartilage exposure, and prolonged edema that may last up to 1 year.

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65 Technique for Dorsal Augmentation Using Costal Cartilage Graft

CHAPTER

Dean M. Toriumi

DEFINITION

- Low nasal dorsum is when the bridge of the nose demonstrates inadequate height/projection.
- A low dorsum can appear wide and flat on frontal view with inadequate lateral wall shadowing.
- Asian patients tend to have inadequate dorsal height and frequently are in need of dorsal augmentation.
- Inadequate dorsal height may be directly related to excessive nasal tip projection. The relationship between dorsal height and tip projection frequently requires creating balance between these two parameters.

ANATOMY

- The anatomy of the low dorsum can vary from patient to patient.
- In the Asian patient, the nasal dorsum can be low and wide (**FIG 1**).
- Asian patients tend to have a low radix (low nasal starting point) as well.
- Asian patients tend to have very small and thin septal cartilage that provides insufficient stock for dorsal augmentation.
- Some patients have a congenitally low dorsum.
- Patients that suffered from trauma can present with a low dorsum or saddle nose deformity.
- Most patients with a saddle nose deformity have a deficiency in the middle nasal vault usually with a normal bony nasal vault. Many of these patients may actually have a dorsal convexity above the saddled area.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Any evidence of previous trauma or surgery should be elicited in the history.
- Any prior placement of alloplastic implants should be elicited in the history.
- Physical exam should reveal any septal deviations or fractures.
- Asian patients who have a low dorsum also tend to have an underprojected nasal tip.
- All patients should be queried as to any previous injectable fillers placed into their nose.

SURGICAL MANAGEMENT

Anesthesia

- It is preferable to perform these surgeries under general anesthesia. With the patient intubated, the airway is protected from blood contacting the vocal cords and potentially causing laryngospasm. A protected airway is particularly important if any work is planned on the nasal septum or turbinates.
- Local anesthetic agent (1% lidocaine with 1:100 000 epinephrine) is injected into the nose to provide hemostasis. Injections are made along the septum, along the marginal incisions, over the nasal dorsum and middle vault, and in the nasal tip area. At least 10 minutes should pass before the procedure is initiated to allow the full vasoconstrictive effect to set in.

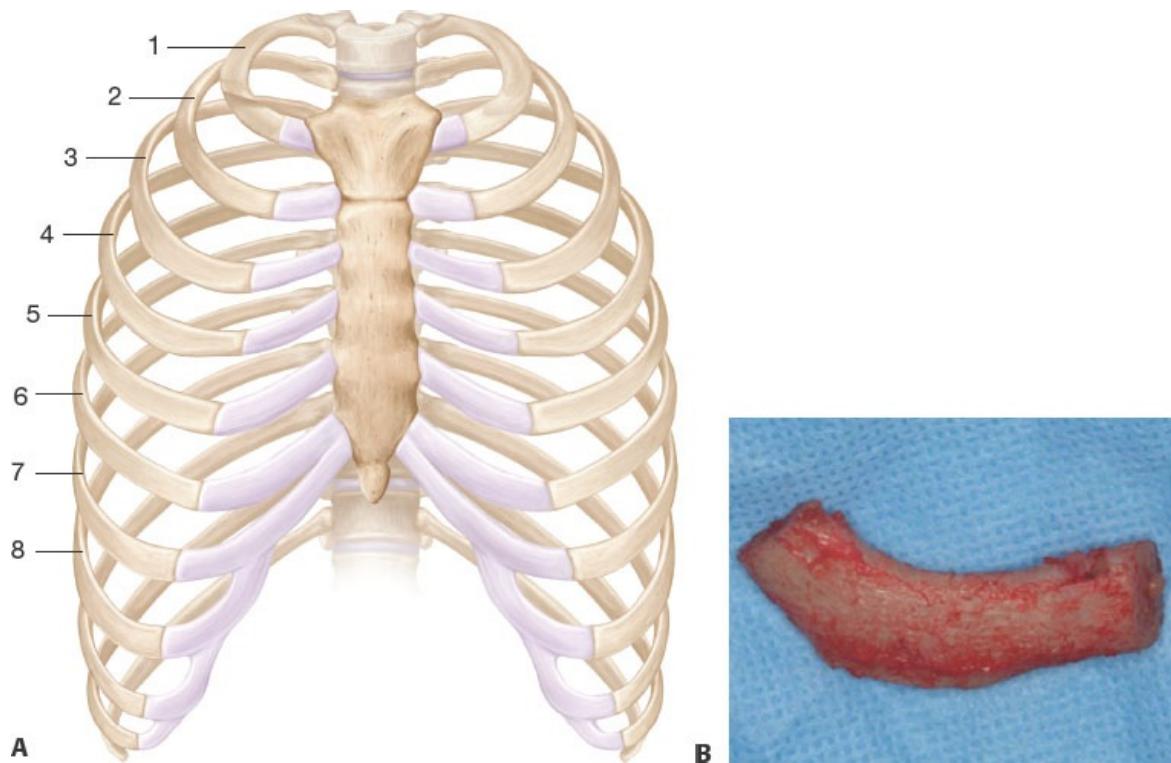


FIG 1 • Asian patient with low dorsum showing lack of lateral wall shadowing and flat appearance to nasal dorsum.

TECHNIQUES

- **Harvesting Costal Cartilage for Dorsal Augmentation**

- Costal cartilage can be harvested from relatively small incisions with low morbidity. Costal cartilage of adequate length and width can be harvested through an 11-mm chest incision.^{1,2}
 - When less experienced, a larger incision should be used to safely harvest the costal cartilage.
 - Consider using a 3-cm incision until you are comfortable with the chest wall anatomy and have significant experience harvesting costal cartilage.
- Avoid cutting the muscle layer.
 - It is preferred to separate the muscle fibers bluntly.
 - This allows the muscle layer to be tightly resutured at the end of the operation to provide good support to the area.
- Costal perichondrium should be harvested from the surface of the rib. Costal perichondrium can be used for camouflage or as a soft tissue graft.
- The best rib to harvest for dorsal augmentation is typically the 7th rib. The 7th rib is longer and straighter and provides the best cartilage stock for major dorsal augmentation^{3,4} (**TECH FIG 1A,B**).
 - The 5th rib is curved and not appropriate for large dorsal augmentations.
 - The 6th rib is relatively straight but has a genu that could shorten the straight segment that can be used for the dorsal graft.
 - The 7th rib is also more superficial than the 6th rib, so it is easier to harvest through a smaller incision.
- The 7th rib cartilage is sharply dissected away from the 6th and 8th ribs using a Freer elevator and lifted off of the underlying perichondrium.
 - Typically, a 3.5- to 4.5-cm segment of costal cartilage should be harvested.
- Perform a Valsalva maneuver after the rib is harvested to see if there is a tear in the pleura.
 - If so, a red rubber catheter can be placed during closure, and then the chest can be expanded and the catheter removed after the closure is completed.
- The 7th rib tends to lie below the level of the diaphragm and therefore lessens the likelihood of a pneumothorax. As you move medially on the 7th rib, it may move above the diaphragm.

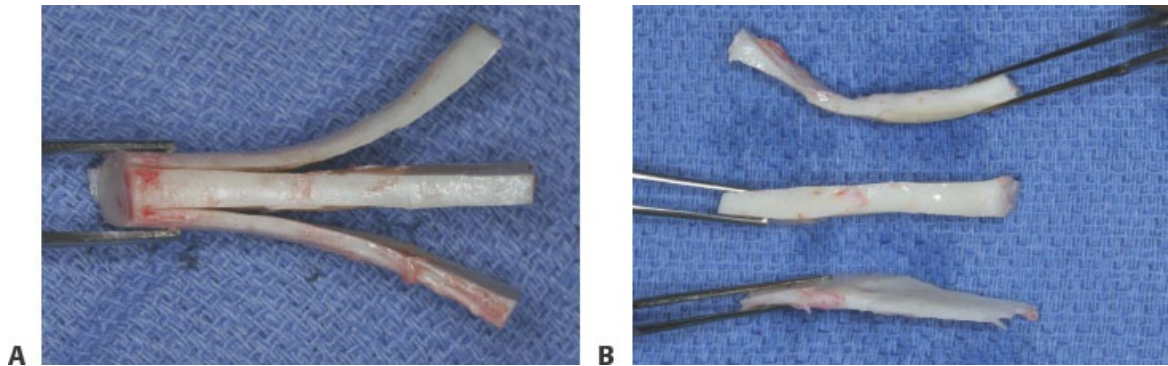


TECH FIG 1 • A. Chest wall showing rib anatomy. The 7th rib is longer and straighter than the 5th and 6th ribs. The 6th rib has a genu where the rib passes below the breast. **B.** Harvested rib.

■ Preparing and Affixing the Dorsal Graft

- The harvested costal cartilage should be initially carved into three separate segments (**TECH FIG 2A**), which are then assessed for the most ideal curvature.
 - If a very thick dorsal graft is needed, the rib should be carved differently by taking thinner peripheral segments to provide a thicker dorsal graft (**TECH FIG 2B**). In this case, the middle segment is typically used for the dorsal graft.
- If the central core of the costal cartilage has a soft (pearlike) texture, this increases the likelihood of warping of the cartilage. In this case, it is preferable to use the outer core of the rib for the dorsal graft.
 - If this cartilage must be used, it is recommended to laminate the cartilage by suturing two thinner layers of cartilage together to create one dorsal

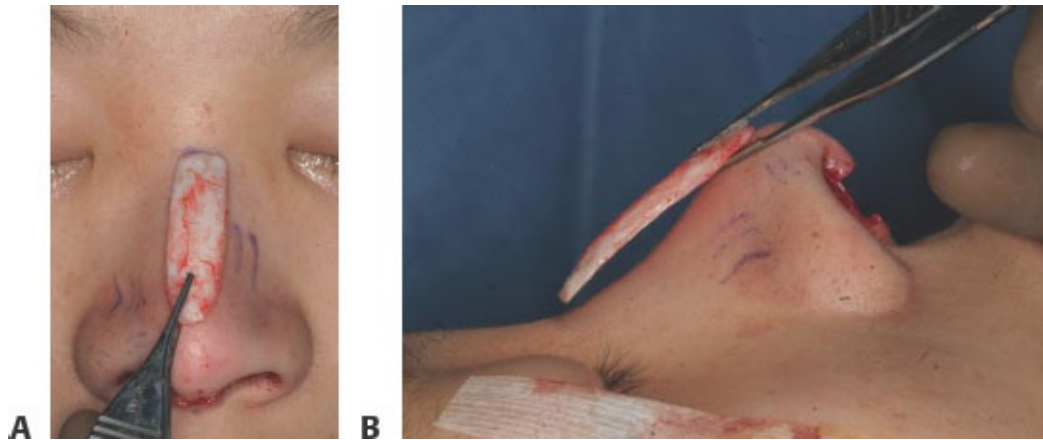
graft. The lamination acts to decrease the likelihood of warping.



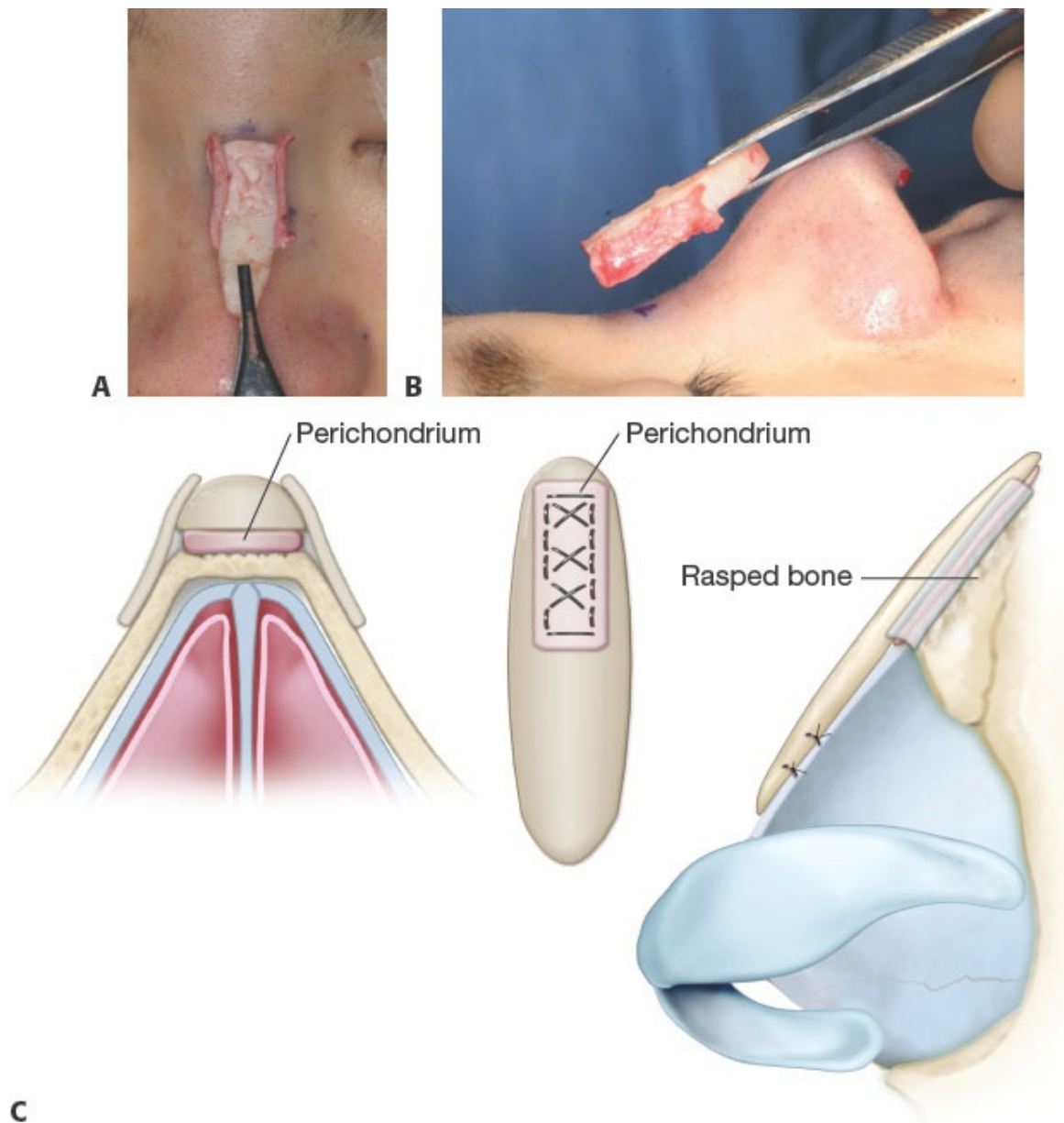
TECH FIG 2 • A. Younger patient with the rib being carved into three separate segments. Note the bending of the cartilage. **B.** For larger dorsal grafts, the central segment of the rib can be made thicker to allow for a thicker dorsal graft.

- The dorsal graft should be carved into a canoe shape that is narrower at both ends (**TECH FIG 3A**).
- It should be carved to provide appropriate dorsal height. Care should be taken to avoid making it too narrow. It is carved so it is curved anterior to posterior (**TECH FIG 3B**).
- The graft is fashioned so the concave surface is facing inferior or toward the nasal dorsum. This is critical to prevent the upward bending of the cartilage graft creating a prominent radix and supratip.
- The dorsal graft is carved slightly wider than what would be considered ideal, as contracture over time will tend to make the dorsum look narrower.
- If costal perichondrium is sutured to the sidewalls of the dorsal graft, it will look a bit wider, and this should be accounted for when carving the graft. Perichondrium that is so sutured acts to camouflage the graft and prevent visibility of its lateral margins (**TECH FIG 4A,B**).
- The perichondrium should overlap the junction between the lateral margins of the dorsal graft and the nasal dorsum (**TECH FIG 4C**).
- If the perichondrium is placed at the junction between dorsal graft and nasal dorsum, the perichondrium will form bone and create an osseous bridge between the dorsal graft and nasal dorsum.

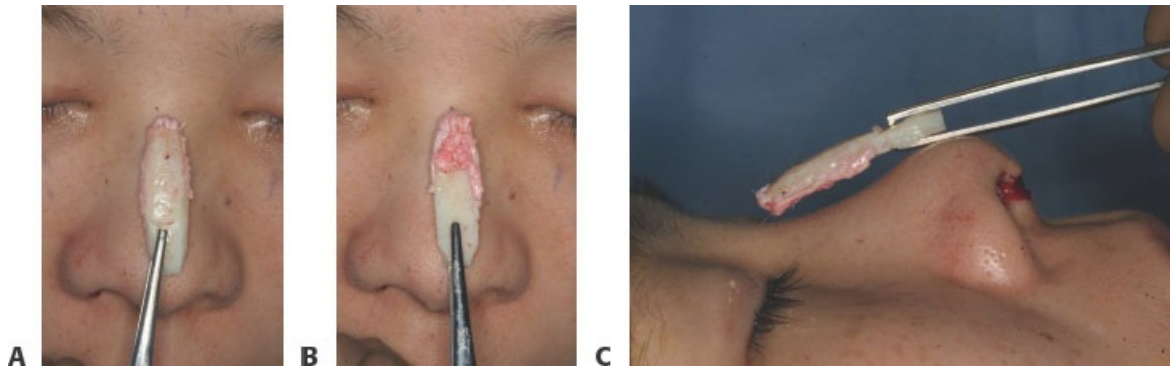
- A strip of costal perichondrium is sutured to the undersurface of the superior aspect of the dorsal graft, where it would sit on top of the nasal bones (**TECH FIGS 4C** and **5**).
- The perichondrium is sutured to the undersurface of the upper portion of the dorsal graft with a running 5-0 PDS suture. Care is taken to make sure the costal perichondrium is oriented so the surface that was initially against the cartilage is oriented so it is facing the bone.
- Costal perichondrium is at the bone/cartilage interface and will ossify, creating a bony union between the dorsal graft and nasal dorsum. This ossification and rigid fixation occur within the 1st month after surgery.
- The nasal dorsum is rasped with a narrow rasp, or multiple perforations are made in the bony nasal vault at the interface with the dorsal graft. Using a narrow rasp decreases the likelihood that the dorsal pocket will be enlarged (**TECH FIG 6**).
- Multiple perforations are made in the bone using a 2-mm straight osteotome. At least 8 to 10 perforations are made in the bone to expose cancellous bone and allow more rapid ossification of the dorsal graft with perichondrium interface to the underlying bony dorsum.
- This ossification typically occurs within the first month after surgery. Once the ossification is complete, the dorsal graft becomes immobile and cannot be moved or shifted. This rigid fixation acts to prevent bending or warping of the dorsal graft.
- For the dorsal graft with costal perichondrium interface to ossify and fix to the nasal dorsum, there must be a tight subperiosteal space that will force the dorsal graft against the bone.
- Thus, at the beginning of the operation, the surgeon should use a Joseph periosteal elevator to raise the periosteum off the bone, leaving a relatively narrow tunnel. This will ensure a tight fit when the dorsal graft is inserted into the subperiosteal space.



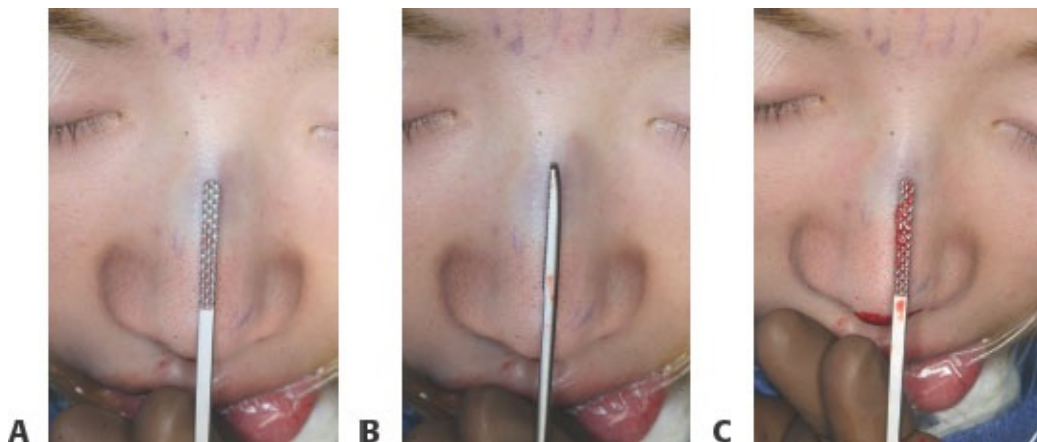
TECH FIG 3 • Shape of dorsal graft. **A.** Dorsal graft is typically canoe shaped tapering inferiorly. **B.** The dorsal graft is curved with the concave surface facing the nasal dorsum.



TECH FIG 4 • Dorsal graft with perichondrium. **A.** Dorsal graft with perichondrium sutured to the sides of the graft. **B.** Lateral view of the dorsal graft with perichondrium. **C.** Dorsal graft with perichondrium sutured to the undersurface of the dorsal graft and placed into a tight subperiosteal pocket to force the dorsal graft against the bone. Perichondrium is also placed along the sides of the dorsal graft.



TECH FIG 5 • Dorsal graft with perichondrium. **A.** Dorsal graft over the dorsum. **B.** Perichondrium sutured to the undersurface of the dorsal graft. **C.** Dorsal graft with concave surface facing the bony dorsum.

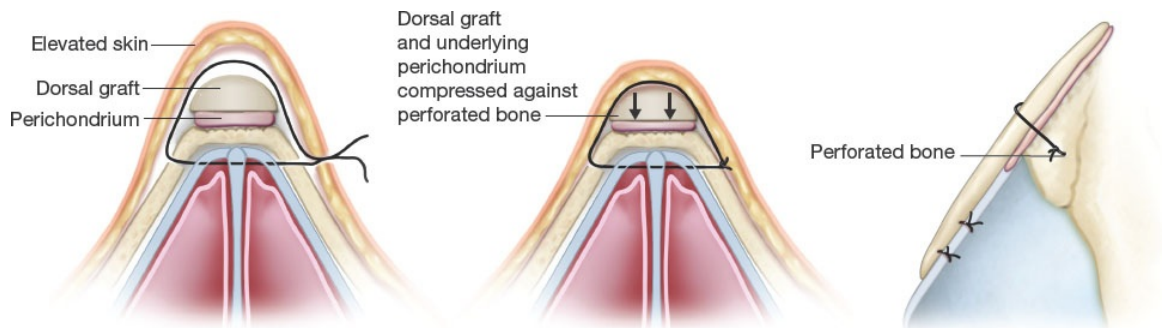


TECH FIG 6 • Rasping the nasal dorsum. **A.** Narrow rasp to roughen the nasal dorsum. **B.** Side view of the low-profile rasp. **C.** After rasping bone dust on the rasp.

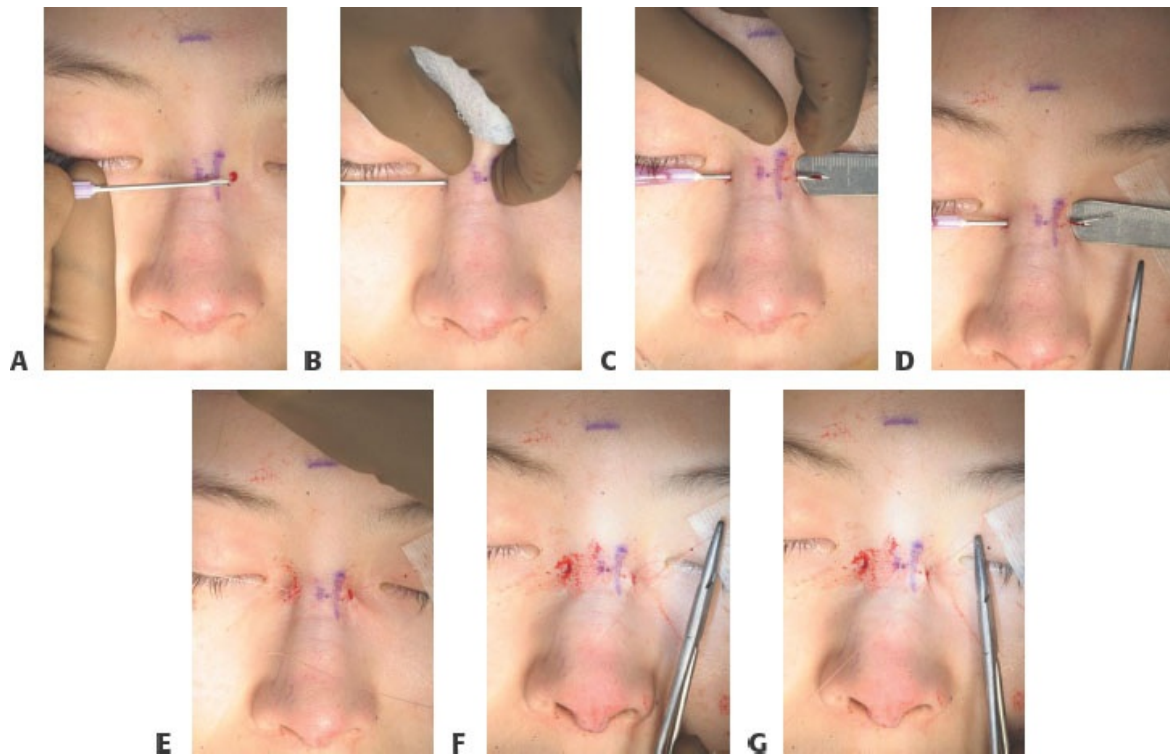
■ Use of a Transosseous Suture or K-Wire

- If a tight subperiosteal space is not possible as a result of removal of a previous implant or deformity, a transosseous suture can be used to fix the dorsal graft with interpositional costal perichondrium to the bony nasal vault (**TECH FIG 7**).

- In this case, small stab incisions are made along the side of the dorsum, and holes are created across the nasal dorsum approximately 4 to 5 mm below the leading edge of the dorsum just below the level of the medial canthus (**TECH FIG 8**). This is done using multiple 16-gauge needles. Care must be taken to make sure the holes are directly opposite each other at the same level across the bridge of the nose.
- The transdorsal path should be above the level of the intranasal mucosa. This can be ensured by dissecting the intranasal mucosa to make room for passage of the 16-gauge needle (see **TECH FIG 7**).
 - Protect the eye when drilling the hole to avoid ocular damage.
- Once the transdorsal hole is created, a 4-0 PDS suture can be passed through the needle and passed back through the dorsum. The suture is then passed back through the same skin incision and over the top of the upper part of the dorsal graft. Then, the suture is passed back through the opposite skin incision and tied tightly to force the upper segment of the dorsal graft with intervening costal perichondrium tightly against the bony nasal dorsum.
- This tight contact between costal cartilage dorsal graft, costal perichondrium, and underlying perforated bone allows rigid fixation of the dorsal graft to the bony dorsum.



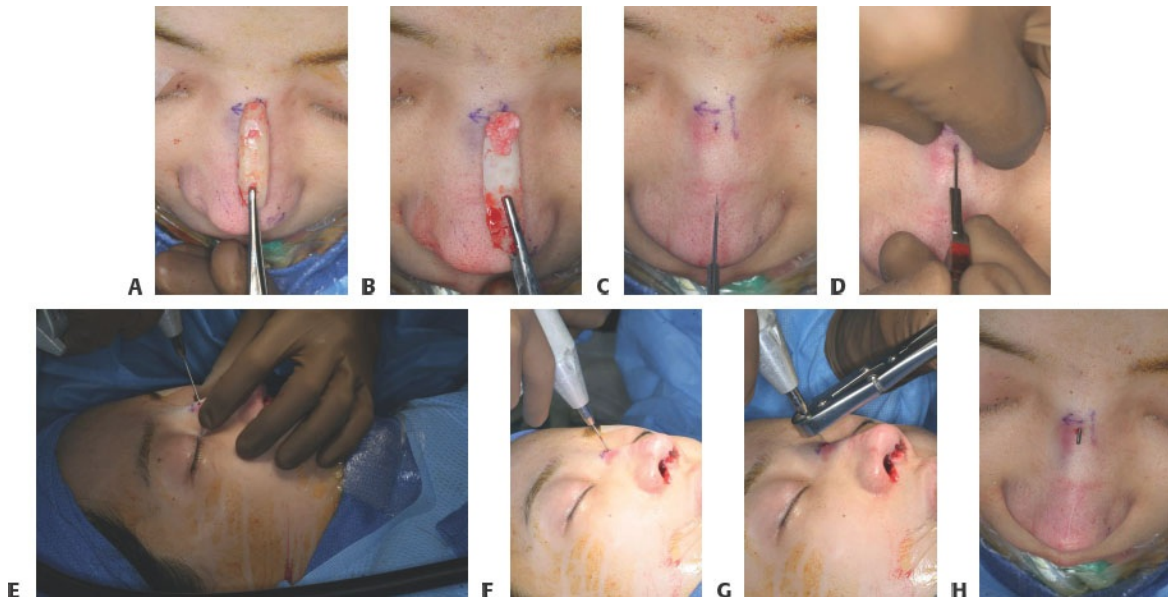
TECH FIG 7 • Transosseous hole drilled across the dorsum above the mucosa. The suture is passed across the dorsum and then over the top of the dorsal graft to hold it snugly against the bony dorsum.



TECH FIG 8 • Transosseous suture placement to hold dorsal graft in position. **A.** A 16-gauge needle used to drill hole across the dorsum. **B.** Needle is used to drill a hole across the dorsum through small stab incisions on the side of the dorsum. **C.** Needle passed across the dorsum protecting the opposite eye. **D.** A 4-0 PDS suture needle is placed into the core of the 16-gauge needle to pass back across the dorsum. **E.** Suture passed across the dorsum. **F.** Suture passed back through stab incision and over the top of the dorsal graft and through the opposite incision. **G.** Tying down suture to force dorsal graft with interpositional costal perichondrium against the perforated bony dorsum.

- In some cases, in which a large dorsal pocket is created and a transosseous suture is not possible (very low dorsum), a 0.45 threaded Kirschner wire can be passed through a small upper dorsal skin incision, through the upper dorsal graft, and into the bony dorsum (**TECH FIG 9**). The K-wire should pass only 3 to 4 mm into the underlying bony dorsum.

- It is left in place until the 7th postoperative day and then gently backed out in the office using a hemostat or needle holder. The small stab incision will close in a couple of days, leaving a small scar on the nasal dorsum.
- In most patients, the dorsal graft with costal perichondrium interface is ossified into position by the 21st day postoperative. At 1 month, the dorsal graft is difficult to move.



TECH FIG 9 • Use of a Kirschner wire to fix the dorsal graft. **A.** Canoe-shaped dorsal graft over the nasal dorsum. **B.** Costal perichondrium sutured to the undersurface of the upper aspect of the dorsal graft. **C.** Dorsal graft in position and placement of 0.45 threaded Kirschner wire planned. **D.** Making a small stab incision over the dorsal graft. **E.** Drilling the threaded Kirschner wire through the dorsal graft and then 4 mm into the underlying bony dorsum. **F.** Drilling Kirschner wire into position. **G.** Cutting the Kirschner wire with a wire cutter. **H.** Kirschner wire in place.

Choosing the grafting material for dorsal augmentation	■ Auricular cartilage is insufficient. Costal cartilage provides larger cartilage stock and allows for carving of larger dorsal grafts.
Harvesting costal cartilage	■ Chose the proper rib to insure adequate cartilage. For most larger dorsal grafts, the 7th rib is ideal as it is longer and straighter.
Harvesting costal perichondrium	■ Harvest costal perichondrium from the surface of the rib.
Managing warping of costal cartilage grafts	■ Observe for curvature as the dorsal graft is carved. Splint cartilage grafts to prevent further bending. Lamination is very effective.
Fixation of dorsal grafts	■ Suture costal perichondrium to undersurface of the dorsal graft and place on top of bony dorsum after perforated with 2-mm osteotome.
Dorsal graft pocket	■ Make a tight narrow subperiosteal dorsal pocket to force dorsal graft with interpositional costal perichondrium tightly to the perforated bone.
Contour dorsal graft	■ Dorsal graft should be canoe shaped and should be oriented with the concave surface facing the perforated bone.
Other modes of fixation of dorsal graft	■ If tight subperiosteal pocket is not possible, consider transosseous suture fixation.

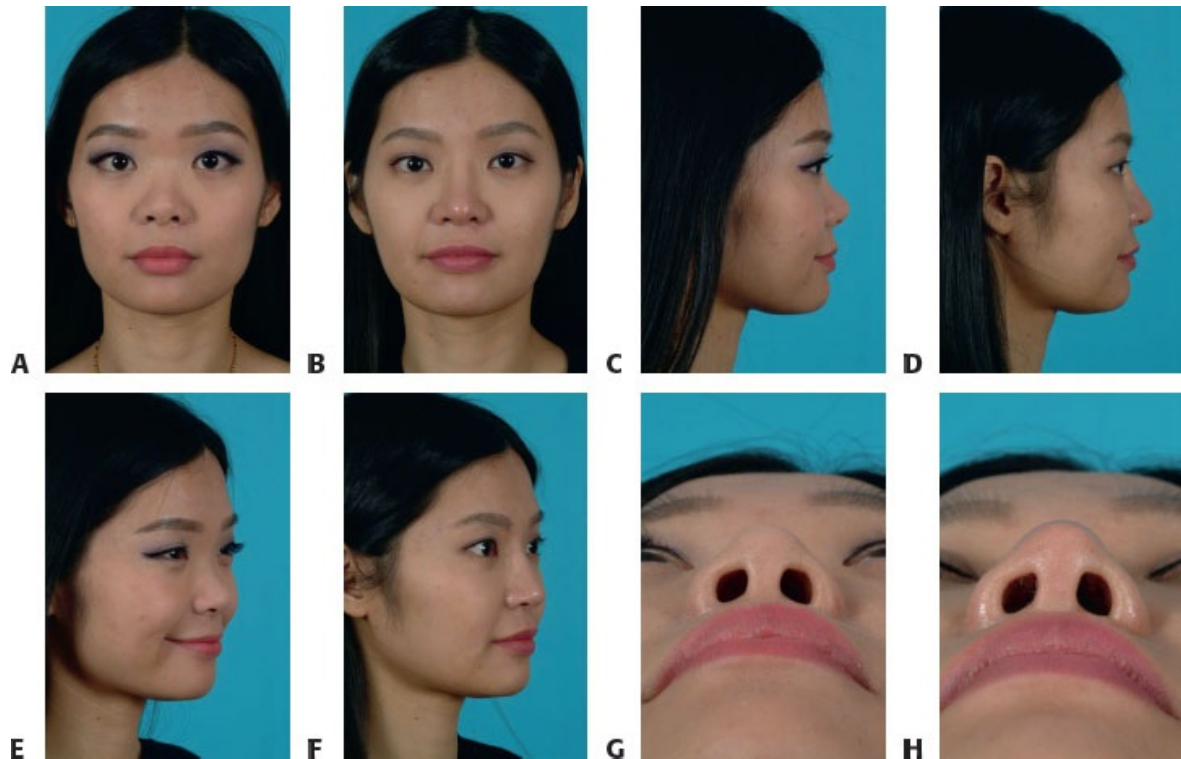


FIG 2 • Asian patient who underwent dorsal augmentation using costal cartilage. **A.** Preoperative frontal view. **B.** Postoperative frontal view. **C.** Preoperative lateral view. **D.** Postoperative lateral view. **E.** Preoperative oblique view. **F.** Postoperative oblique view. **G.** Preoperative base view. **H.** Postoperative base view.

POSTOPERATIVE CARE

- No nasal packing is used in the rhinoplasty patients. A running quilting 4-0 plain gut suture is used to approximate the septal flaps.
- Cast is removed on the 7th postoperative day.
- Patients should avoid salty foods postoperatively to minimize edema.

OUTCOMES

- Most patients that undergo dorsal augmentation using costal cartilage with dorsal graft fixation using the costal perichondrium interface do well over time. The incidence of warping is relatively low, and the nasal dorsum looks very natural (**FIG 2**).

COMPLICATIONS

- Infection is rare but occurs when extensive cartilage grafting is performed.
- Warping or displacement of the dorsal graft is possible but can be minimized if preventive measures are taken.
- Pneumothorax is a potential problem with harvesting of costal cartilage.
- Resorption of the dorsal graft is rare.
- Aesthetic problems such as undercorrection or overcorrection are possible if appropriate sizing is not accomplished.
- Potential visibility of the dorsal graft is possible as the dorsal nasal skin contracts or thins.

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66 Technique for Dorsal Augmentation Using Alloplastic Material

CHAPTER

Man-Koon Suh and Nguyen Phan Tu Dung

DEFINITION

- A low nasal dorsum is one of the main characteristics of Asian noses. Dorsal augmentation is one of the most frequently performed procedures in Asian rhinoplasty.
- There is a distinctive difference in preferences of materials used for dorsal augmentation between surgeons from Asia and other countries.
 - Autogenous tissues preferred by Western surgeons provide better safety but have several disadvantages:
 - Less satisfaction aesthetically
 - Scars on the donor site
 - Decreased height or irregularity of the nasal dorsum due to tissue resorption
 - More complex surgical procedure compared with implants
 - Thus, use of an implant is still preferred for dorsal augmentation in Asia.
- Owing to the thick and fibrotic soft tissue envelope of Asian noses, as opposed to that of Westerners' noses, implant visibility or an operated looking appearance after dorsal augmentation with implant is considerably less likely. The appropriate surgical technique complemented by a high-quality implant surely minimizes the frequency of adverse effects.¹⁻³

ANATOMY

- The structure of an Asian nose is shown in **FIG 1**.
- Use of an implant is limited to dorsal augmentation. Tip projection should be carried out by various tip-plasty techniques including suture techniques and cartilage grafting. It is safe to use an implant only from the radix to the supratip

area (**FIG 2**).

- Application of an implant extending to the tip area should be avoided, since it may cause thinning and redness of the tip skin or a rupture of the tip skin with implant exposure.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The following must be checked during the preoperative evaluation:
 - Presence of facial asymmetry
 - Presence of nasal axis deviation
 - Presence and underlying causes of tip and nostril asymmetry
 - Dorsal skin characteristics, including the texture, color, and any skin problems such as visible veins or telangiectasias
- The surgeon must decide the following during the preoperative consultation:
 - How high the nasal dorsum should be raised
 - Whether the profile should be straight or curved
 - The type of prosthesis to be used for dorsal augmentation
 - The type of cartilage to be used for tip projection

SURGICAL MANAGEMENT

- Dorsal augmentation material for Asians is chosen from either autogenous tissues or implants.
- In cases in which the dorsal skin is too thin, autogenous tissues are recommended.
- Dermofat graft or diced cartilage wrapped with the temporal fascia is preferred.



FIG 1 • A–D. Asian nose with a low and short nasal dorsum. Nasal bone is flat and low, and alar cartilage is

small and weak as well. (D. Copyright Man Koon Suh, MD.)

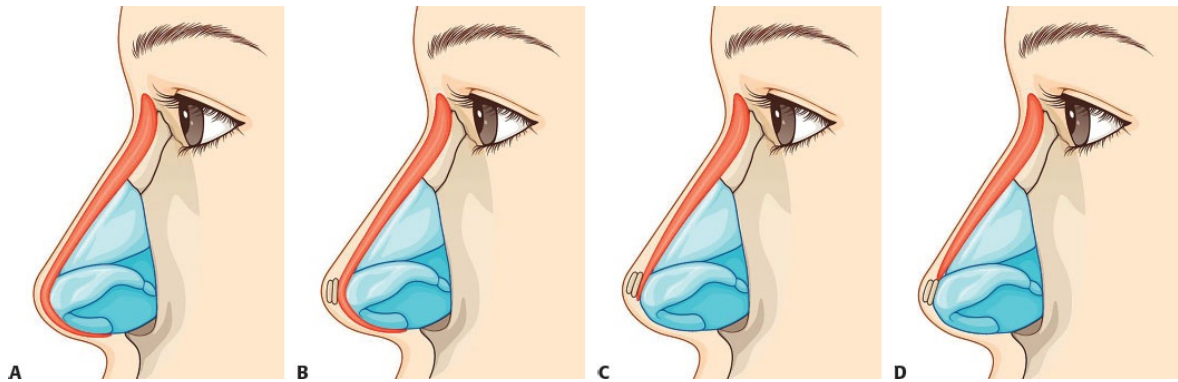


FIG 2 • Four types of dorsal and tip augmentation strategies in Asian noses. **A.** L-shaped implant only for dorsal and tip augmentation. **B.** L-shaped implant combined with cartilage graft on the tip of the implant. **C.** Long I-shaped implant combined with cartilage graft on the tip of the implant. **D.** Short I-shaped implant with cartilage graft on the alar cartilage. This is the most recommended technique for the Asian rhinoplasty. (Copyright Man Koon Suh, MD.)

- A rib cartilage block used for dorsal augmentation for a patient with thin skin may result in a visible contour of the rib cartilage graft, increasing the possibility for revision surgery.
- The implant can be relatively safe and bring aesthetically beautiful results for Asians when the skin is not thin.

Preoperative Planning

Implant Selection

- Each material has advantages and disadvantages. Silicone and e-PTFE (expanded polytetrafluoroethylene) are used most commonly for dorsal augmentation, but other products are available, such as Medpor.
- Characteristics of silicone implants
 - There is no change in the implant height as time progresses.

- Capsular formation.
- The frequency of calcification on the surface of the implant is higher than that of an e-PTFE implant over a long period.
- Characteristics of e-PTFE implants
 - Micropores are present within implant, allowing tissue ingrowth. As a result, there is less implant mobility and no capsular formation.
 - Calcification occurs less in e-PTFE implants than in silicone implants.
 - Delayed spontaneous hematoma also occurs less in e-PTFE implants.
 - The height of an e-PTFE implant decreases to about 5% to 20%.⁴

Accordingly, the height predictability decreases, and tissue ingrowth makes it difficult to remove an e-PTFE implant as opposed to a silicone implant.
- The answer to which type of implant is better between silicone and e-PTFE implant depends largely on the experience and preference of the surgeon. Silicone implants are generally used because there is no morphologic change over time and height predictability is excellent. Nevertheless, an e-PTFE implant may be considered for the following cases:
 - A contracted nose due to capsular contracture
 - Wide dorsum due to hypertrophied capsule
 - Weak periosteum (cases with fragile periosteum are prone to implant mobility; e-PTFE implants have higher adherence to the nasal bones or adjacent tissues, so that implants are less mobile)
 - Calcification on the surface of a silicone implant
 - Foreign body reaction to silicone
 - Late spontaneous hematoma inside the capsule of a silicone implant
- Thin dorsal skin is not an indication for an e-PTFE implant.
 - An e-PTFE implant inserted into a patient's nose with thin dorsal skin may force the thin skin to adhere closely to the implant without capsular formation. Thus, the implant edges may be more conspicuous.
- There are I-shaped (boat shape) and L-shaped silicone implants (**FIG 3**).
 - An I shape is mainly used for dorsal augmentation, whereas an L shape is used to simultaneously raise both the dorsum and the tip.
 - An L shape is not recommended because it has a risk of the nasal tip becoming too hard, tip skin thinning, and implant exposure through the nasal tip skin.

Implant Design

- The patient is asked to look straight ahead, and the starting and end points of an implant are marked on the nose (**FIG 4A,B**).
- The starting point of an implant would coincide with the double eyelid line for Westerners. However, it looks natural to have the implant starting point coincide with the eyelash line for Asians.

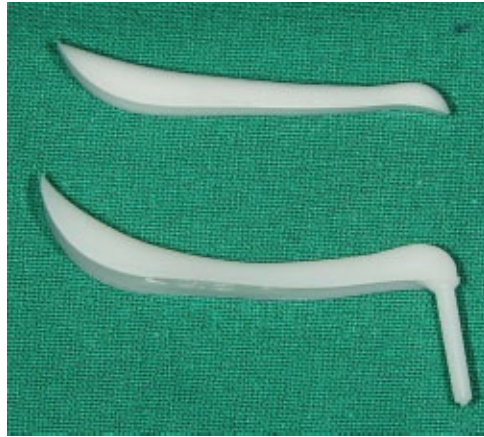


FIG 3 • I- and L-shaped silicone implants.

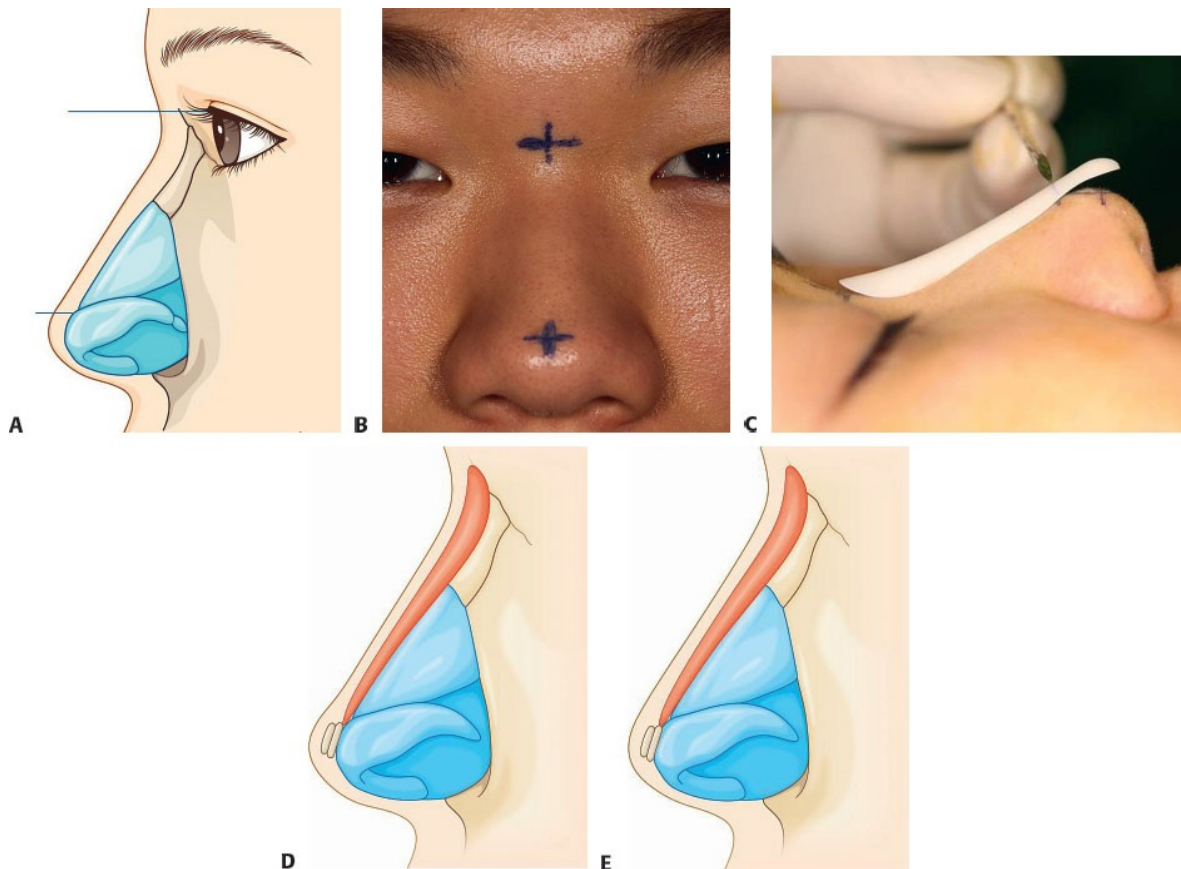


FIG 4 • A. Start and end point of the implant. **B.** Markings. **C.** The implant tip should be shortened and adjusted to fit to its ending point, which is 3 to 5 mm above the tip defining point. The dorsal line should be slightly curved and have a higher nasal tip and supratip break in women (**D**) but be straight in men (**E**). (**A,D,E.** Copyright Man Koon Suh, MD.)

- The starting point of an implant would be somewhat higher for patients with a protruding forehead. The more protruding the forehead, the higher the position of the implant starting point. The flatter the forehead of a patient, the lower the implant starting point.
- The distal end of an implant should not extend to the nasal tip but to the area just above the nasal tip. Hence, the length of an implant would be approximately 35 to 45 mm.
- No part of an implant should enter into the nasal tip under any circumstance, and the nasal tip must be projected with cartilage graft (**FIG 4C**).
- Raising the radix area high like that of the Westerner creates a fierce-looking face for Asians. It is pertinent for Asians to have the line extending from the forehead to the radix to be natural.
- The nasal tip of a female should be slightly higher than the dorsal line so as to form the natural supratip break. Accordingly, the nasal tip should also be projected by a cartilage graft. The side view line from dorsum to the nasal tip should be a straight line in males (**FIG 4D,E**).

Approach

- Dorsal augmentation can be done through an intranasal or an open approach.
- An open approach is needed in cases requiring tip plasty, whereas the intranasal approach is adequate for dorsal augmentation using a simple implant. In these cases, an inframarginal incision is recommended.

TECHNIQUES

■ Implant Carving

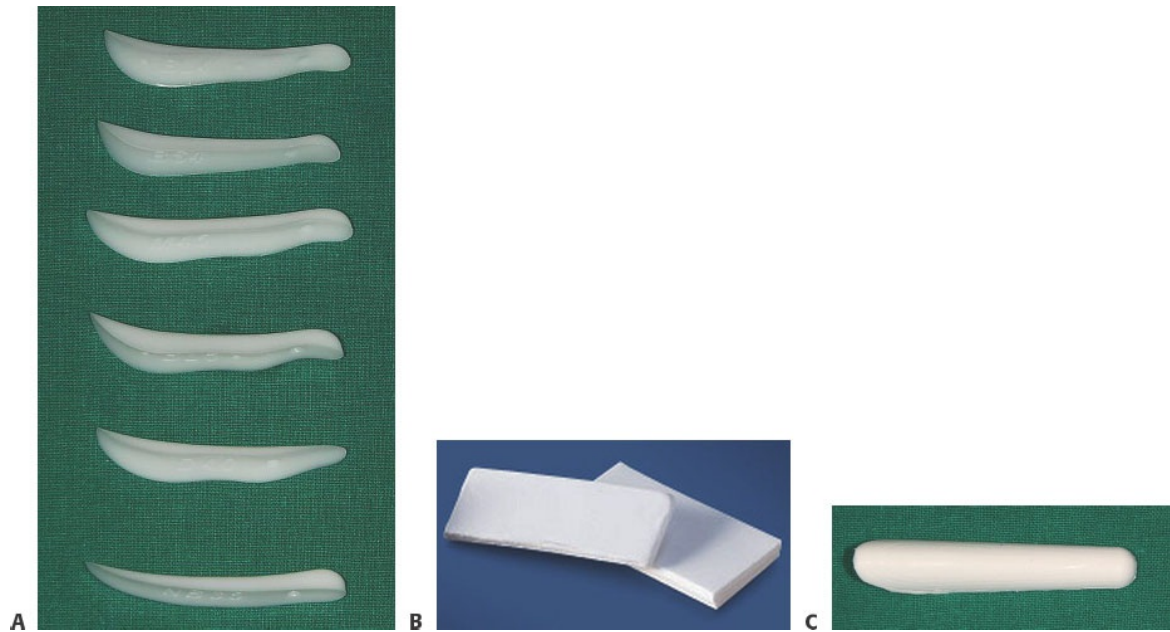
- The operator must be equipped with implants of various shapes and heights provided by the manufacturer (**TECH FIG 1A**).
- Until recently, an e-PTFE block was carved into nasal implant shape (**TECH FIG 1B**). Now, however, ready-made products that are precarved in various shapes facilitate ease of carving (**TECH FIG 1C**). The carving process for an e-PTFE prosthesis is similar to that for a silicone implant.

Carving Process

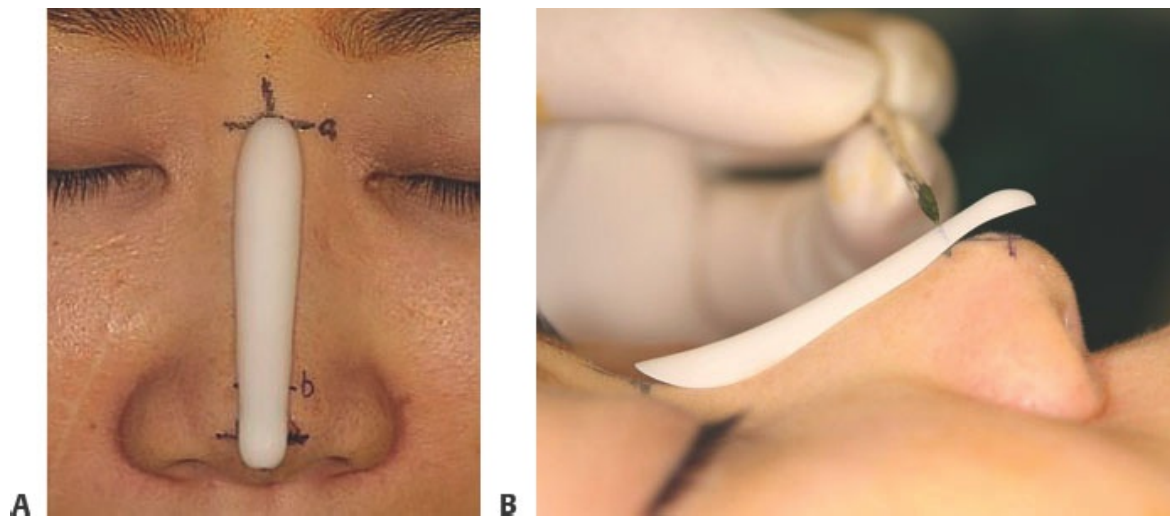
- The operator selects the most appropriate implant in consideration of nasal profile and the desired nasal shape of a patient.
- The proximal beginning part of the implant is placed on the starting point marked on the nose, and then distal ending point of the implant is marked (**TECH FIG 2A,B**).
- The marked distal end of the implant is cut, and then the thick distal end is thinly carved (**TECH FIG 2C,D**).
- The bottom of the implant is carved and trimmed to the curvature of the dorsum (**TECH FIG 2E,F**).
- With respect to carving of an implant, various techniques exist depending on the surgeon. However, it is convenient to use a no. 11 scalpel blade for a novice surgeon. A number of blades must be prepared so that a slightly dull blade can be replaced with a new one.

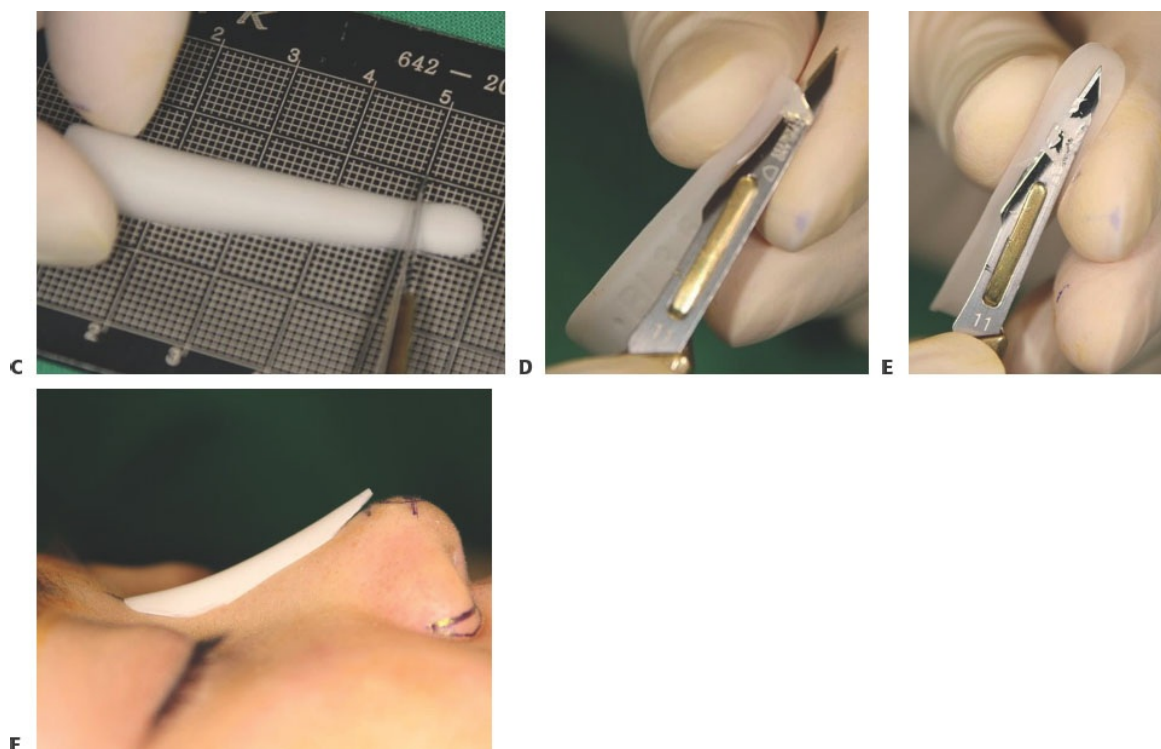
Carving Precautions

- Implants are available with a variety of width profiles, ranging from 8 to 12 mm. While the most common implant width for Asians is 10 mm, the width is individually determined depending on the width of the nasal bone.
- With respect to the hardness of the silicone implant, the soft type has advantages of better adherence to the nasal bone and less mobility as opposed to the hard type.



TECH FIG 1 • **A.** Various silicone implant shapes. **B.** e-PTFE implant block that would be carved into shape. **C.** Preshaped e-PTFE implant.





TECH FIG 2 • Silicone implant carving. **A,B.** Placing the company-supplied implant on the designed marking. **C.** Shortening the implant. **D.** Thinning the thickness of the tip. **E.** Carving the implant body according to the patient's dorsal irregularity. **F.** Final shape after carving.

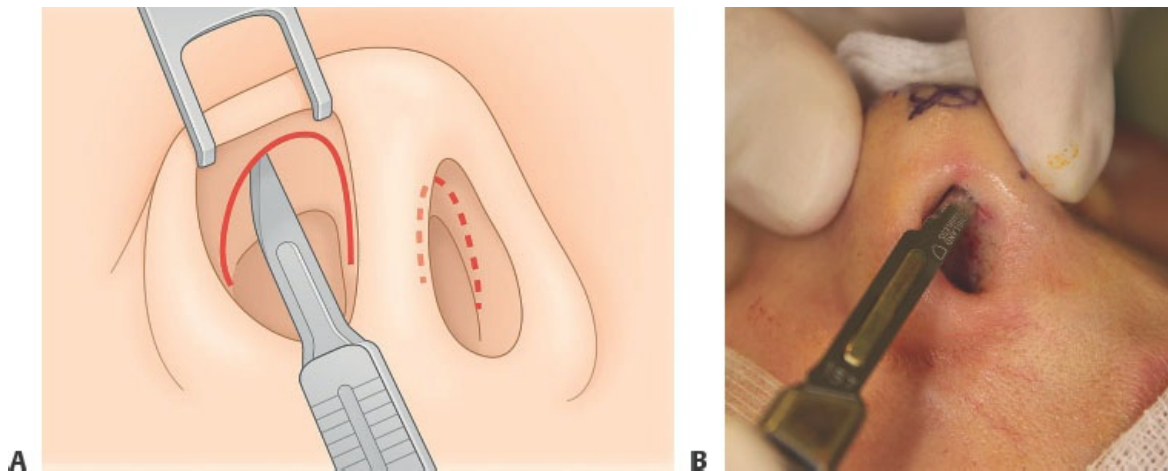
- The shape of the bottom side of an implant should be curved or concave, so that the surface adheres to the nasal skeleton. Thus, implant mobility is less likely to occur.
- The end of an implant should be carved very thin.
 - A thick terminal end of an implant may lead to capsular contracture, which can occasionally cause skin indentation.
- The author avoids both hatching and making holes in silicone implants.

■ Incision

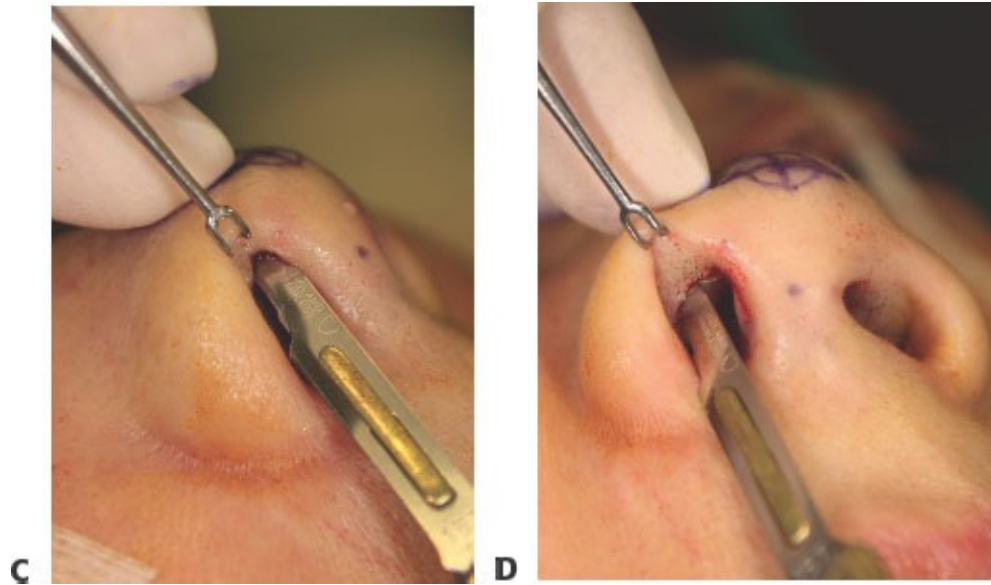
- The endonasal approach would be sufficient for cases desiring a simple augmentation of the dorsum and tip. In such a case, an infracartilaginous

incisional approach is recommended (**TECH FIG 3A**).

- An incision begins initially along the inferior margin of the medial crus, at 2 to 3 mm inward from the columella border of the midpoint of the columella (**TECH FIG 3B**).
- Once the incision is made to the dome area, it changes direction and moves laterally along the inferior border of the medial crus (**TECH FIG 3C**).
- The inferior margin of the lateral crus can be visualized by turning over the alar rim inside out.
- The incision lies deep medial to the alar rim (**TECH FIG 3D**). Incisions made along the lines of the alar rim must not be performed because they cause a nostril deformity.



TECH FIG 3 • A–D. Inframarginal incision. (Copyright Man Koon Suh, MD.)



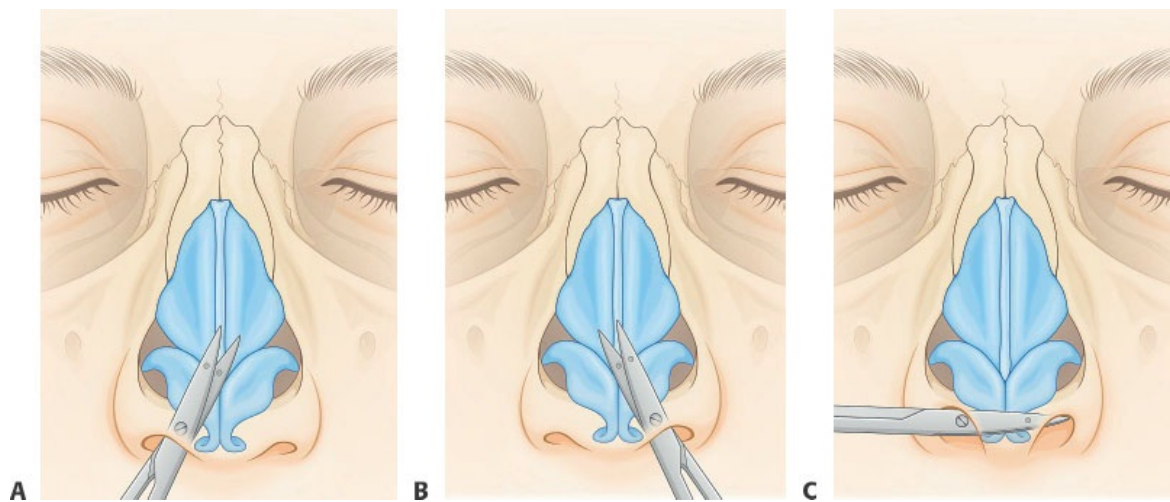
- In cases requiring an additional operation, such as tip plasty, open rhinoplasty incisions are used.
- Implant deviation occurs in the process of making a pocket for an implant. When an operation creates a pocket by making incisions in the right side, a pocket in the radix may easily deviate toward the left side. Therefore, it is safe to create a symmetrical pocket by making incisions bilaterally.

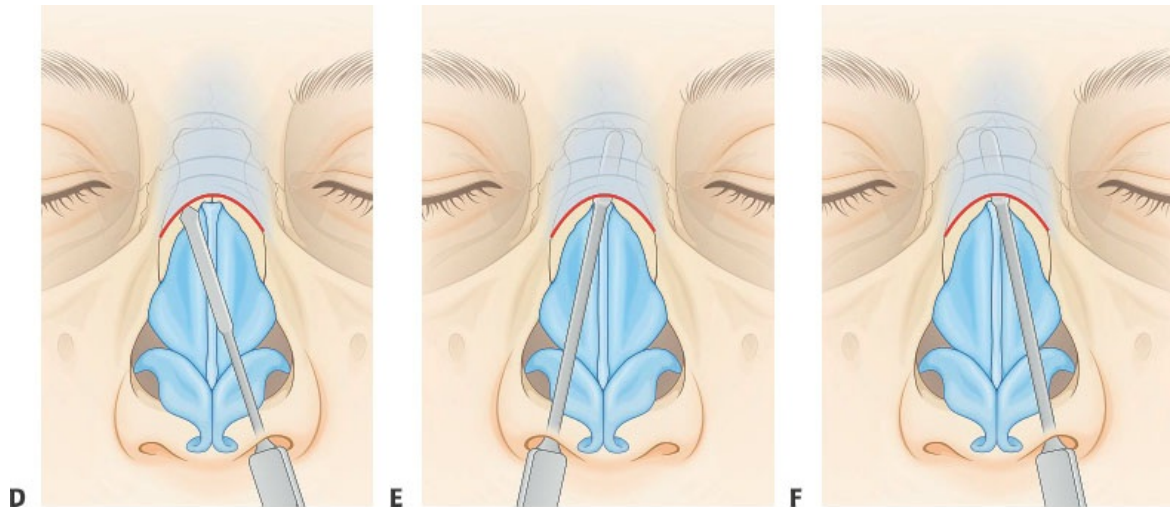
■ Dissection for the Pocket

- A space for inserting an implant is referred to as a pocket. A dissection to form a straight and symmetrical pocket is the most significant part of dorsal augmentation.
- The dissection plane is supraparichondrial and subperiosteal, which means that dissections are performed above the perichondrium in the lower lateral and upper lateral cartilages and under the periosteum in the nasal bone area.
 - Metzenbaum scissors are used for the dissections over the lower and upper lateral cartilages while making sure a maximum amount of the soft tissues is included in the skin envelope.
- Implants should be inserted into the subperiosteal pocket to prevent mobility and shifting of the implant and to reduce visibility of the implant through the skin.
 - A Joseph knife is used to cut the periosteum transversely about 1 mm above the inferior margin of the nasal bone. Then, a Joseph elevator is used

to lift the periosteum.

- At that time, lifting the periosteum a little bit at a time, step by step, can avoid periosteal damages, rather than lifting a large portion of the periosteum all at once. Once the operator is acquainted with this procedure, he or she may proceed by using only a Joseph elevator without the knife.
- Dissection and pocket formation mentioned above are performed through the opposite side incision to form a symmetric pocket (**TECH FIG 4**).
- Some surgeons prefer that the implant pocket be exactly the same size as the implant, but this author recommends a slightly larger pocket size.
- Theoretically, fitting snugly and precisely to the width of a pocket prevents shifting of an implant. In reality, there is no assurance of having accurate identical left and right dimensions of a pocket. Thus, having a pocket width slightly wider than that of the implant allows room for prompt manual correction of implant shifting externally in the event of a development of implant deviation later on.





TECH FIG 4 • A–C. Dissection around the nasal tip and over the upper lateral cartilage. **D–F.** Periosteal elevation. (Copyright Man Koon Suh, MD.)

- The time it takes for an implant in a pocket to be fixed by capsular formation is 10 to 14 days after surgery. A deviated implant may be properly positioned by moving it by hand during the time.
- In cases in which the nasal dorsum is not straight or uniform (eg, the nasal dorsum is skewed to one side of the nose), an inserted implant may easily be deviated if the gradient difference of the slope of the nasal dorsum has not been properly compensated by carving the implant properly before inserting it.

■ Pretreatment of e-PTFE Implant

- Unlike a silicone implant, an e-PTFE implant has internal pores of 25 to 40 μm in size. The size of bacterium is smaller than that of the pore. Bacteria may enter through these pores and reside within an e-PTFE implant, whereas a macrophage is larger than the pore, which makes it impossible to enter and combat these bacteria through the pores within an e-PTFE implant. Accordingly, a pretreatment is required for infection prevention.
- For the prevention of infection, a thorough aseptic technique and removal of the powders in the gloves are necessary.
- A liquid mixture of povidone-iodine and antibiotics is used for implant

washing. Simply soaking an e-PTFE implant within a bowl of antibiotic does not allow infiltration of an antiseptic solution within the pores. Thus, the antiseptic solution should be forced to flow through these pores by using negative pressure.

- The author inserts an e-PTFE implant within a syringe and draws into the syringe a 10-cc antiseptic solution, for which an antibiotic is reconstituted with a povidone-iodine solution. Then, in an attempt to fill these pores with the antiseptic solution, negative pressure is applied by pulling the syringe plunger (along with the piston in the syringe) (**TECH FIG 5**).



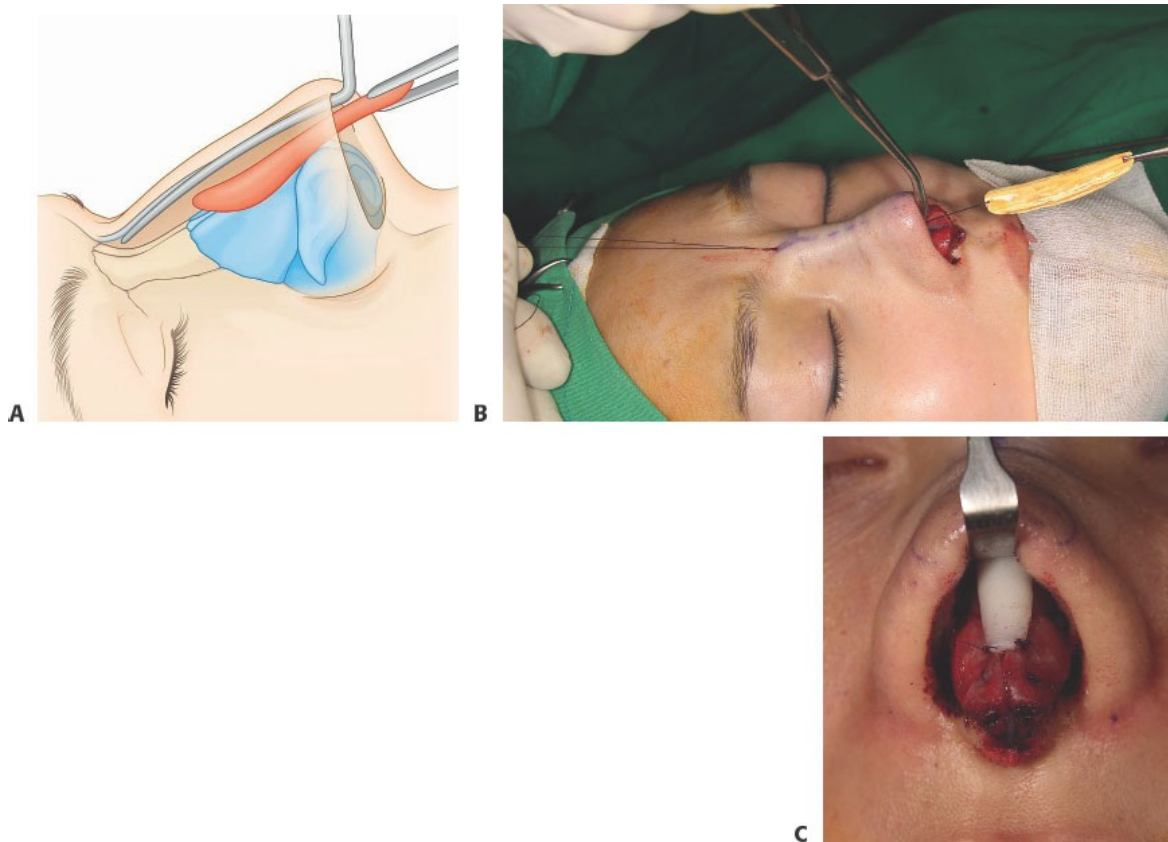
TECH FIG 5 • Pretreatment of the e-PTFE using the negative pressure.

■ Implant Insertion

- Washing the inner pocket with a povidone-iodine solution mixed with an antibiotic before implant insertion is helpful for the prevention of infection.
- When the implant is inserted into the pocket through an incisional opening, make sure it is positioned in the center of the pocket without deviation to one side (**TECH FIG 6A**).
- Insertion of a silicone implant is not that difficult, but an operator needs to

take precautions for insertion of e-PTFE implant.

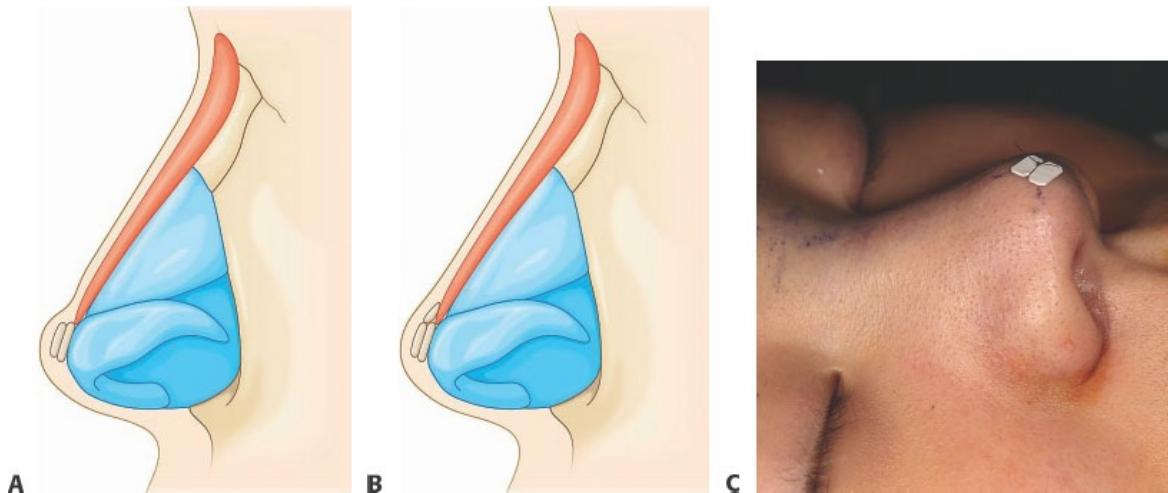
- If a soft type e-PTFE implant is being used, the implant may be pressed or wrinkled or may produce a dead space during insertion, which can increase the possibility of infection. An e-PTFE implant should not be pushed to be inserted. Rather, it is pulled into place with thread (**TECH FIG 6B**). This technique also facilitates proper positioning of the implant in the midline.
- There is no need to fix the distal end of an implant. A prospect of implant shifting may require suturing of the distal implant to the septal angle or alar cartilage (**TECH FIG 6C**).

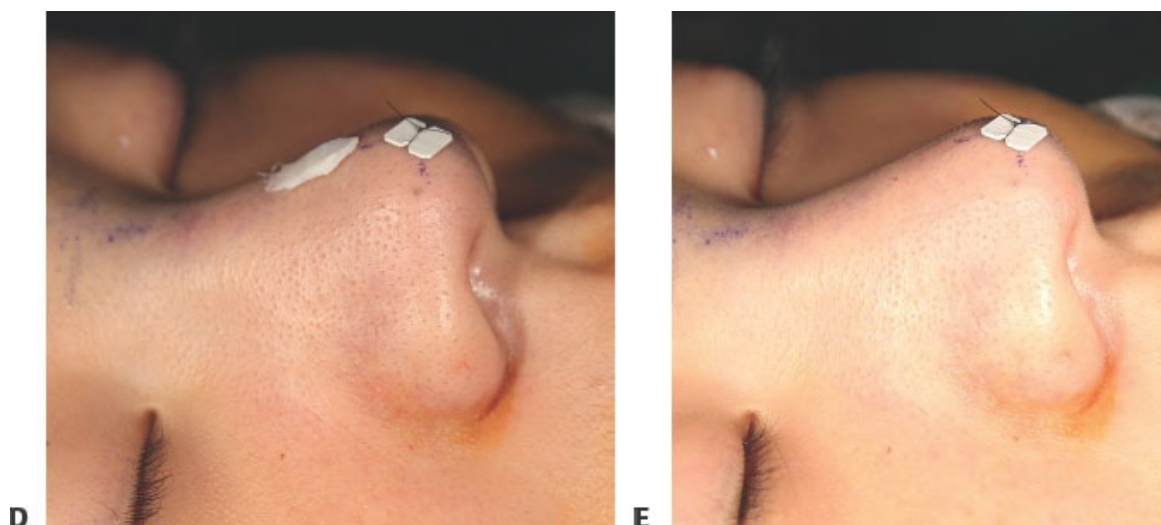


TECH FIG 6 • **A.** Silicone implant insertion. **B.** Pullout technique for the e-PTFE insertion. **C.** Fixation of the silicone implant tip to the alar cartilage. (**A.** Copyright Man Koon Suh, MD.)

■ Management of Supratip Area

- Theoretically, female patients should have a break point in the supratip area, so that there is a slight curvature, from the dorsum to the nasal tip.
- A formation of a natural-looking supratip break requires two elements:
 - Adequate tip projection
 - Prevention of supratip bulging
- The thickness of the terminal end of a prosthesis should be thinly carved for the prevention of supratip bulging.
- Supratip bulging may occur in cases where a tip projection is inadequate, thick supratip soft tissues that existed before surgery have not been corrected, or the distal end of an implant is thick. Thus, these issues need to be solved.
- A supratip groove occurs due to a height discrepancy at the area where the thinly carved distal end of an implant meets the cartilage onlay graft of the tip (**TECH FIG 7A**).
 - The groove is largely inconspicuous in cases with thick skin. Nevertheless, the existence of a groove should be verified by palpating it by hand before wound closure.
- If the surgeon is concerned with an unsightly groove on the nose, it can be resolved by using dermis or cartilage graft in the area (**TECH FIG 7B-E**). A graft should be placed between the skin envelop and the distal end of an implant.



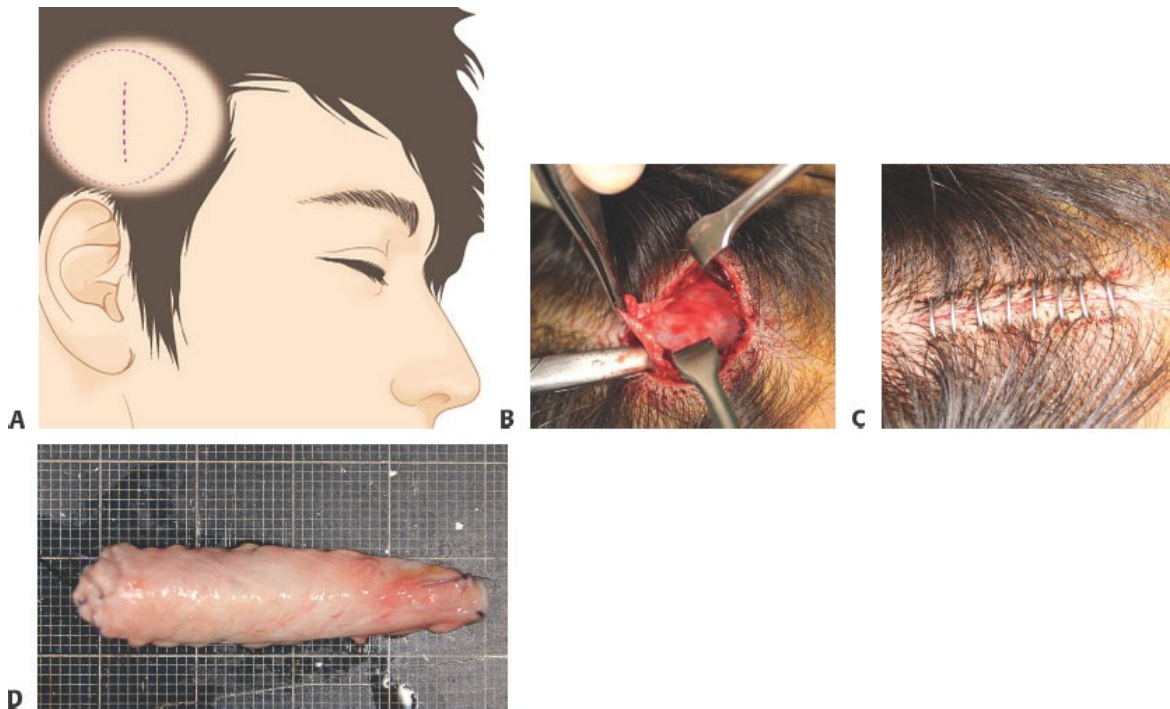


TECH FIG 7 • A. Visible groove between the implant tip and grafted cartilage on the tip. **B.** Cartilage or dermis graft is placed at the visible groove between the implant tip and cartilage onlay graft. **C.** Groove on the supratip area. **D.** Cartilage graft on the groove. **E.** Groove disappears after the cartilage graft. (A,B. Copyright Man Koon Suh, MD.)

■ Implant Wrapped With Temporal Fascia or Allograft Dermis

- If an implant is needed in patients with thin dorsal skin, covering it with temporal fascia or allograft dermis can reduce the issue of an implant visibility.
- The temporal fascia does not leave visible scar in the donor area, while donor harvesting is easy. Both superficial and deep temporal fascia may be used, but this author uses the latter.
- Temporal fascia may be easily harvested under local anesthesia and is performed from the area between the temporal crest and the superior root of the ear helix (**TECH FIG 8A**).
- An incision of a 3 cm in length is made, 1 cm anterior and 3 cm superior to the superior root of the helix. The surgeon should take precaution not to injure the superficial temporal vessels.

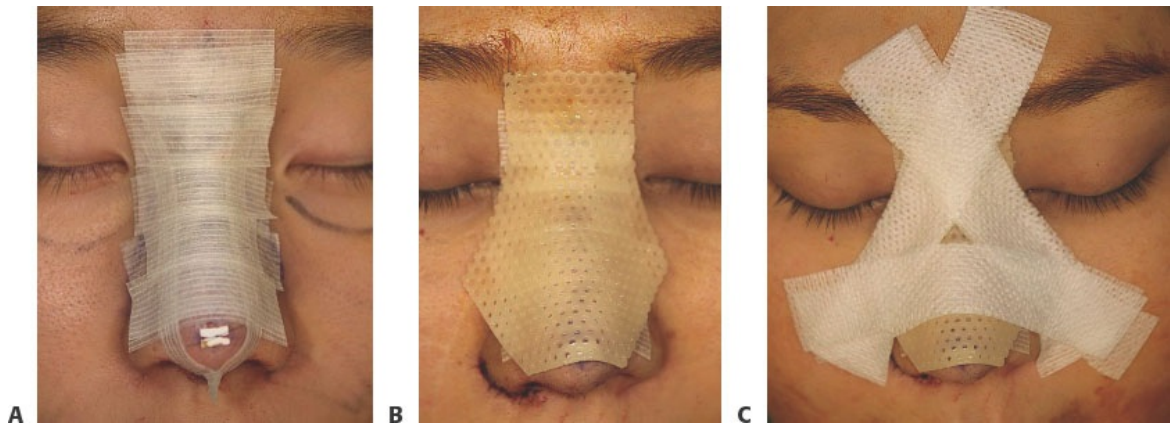
- The glittering and lustrous deep temporal fascia can be seen after retracting the superficial temporal fascia. This fascia is appropriately incised and carefully removed from the temporal muscle (**TECH FIG 8B**) and the wound is closed (**TECH FIG 8C**).
- An implant is carved to coincide with the curvature of the nasal dorsum. Then, all sides of the implant, except for the bottom, are covered with the harvested temporal fascia.
- After the fascia is trimmed along the margin of the implant, the fascia is fixed to the implant by using an absorbable suture material (**TECH FIG 8D**).
- An identical effect may be obtained from allograft acellular dermis used in place of a fascia.



TECH FIG 8 • **A.** Donor site for the harvest of temporal fascia. **B.** Harvest of the deep temporal fascia. **C.** The temporal wound is closed with glue and staples. **D.** Silicone implant covered with temporal fascia. (**A.** Copyright Man Koon Suh, MD.)

■ Completion

- An absorbable suture material is used to repair the intranasal wound.
- Joseph dressing is done using paper tape (**TECH FIG 9A**). The paper tape is applied starting from the radix and proceeding caudally.
- This author applies compression by implementing an AquaSplint as well as a Joseph dressing. They both serve to minimize postoperative swelling (**TECH FIG 9B,C**).



TECH FIG 9 • **A.** Joseph dressing. **B,C.** AquaSplint.

■ Correction of Implant Deviation

- In the event that prosthetic deviation is detected after 2 to 3 weeks of surgery, making it difficult to manipulate manually, a surgical revision is made as follows.
- Deviated silicone implant
 - A small inframarginal incision is made on the contralateral side of implant deviation.
 - Unilateral capsulotomy is performed along the lateral margin of the posterior capsule by using a D knife or a pair of scissors (**TECH FIG 10**).
 - A small additional pocket is made for movement of an implant in the area slightly lateral to the capsulotomy site.
 - After moving the implant manually, the implant is fixed by using a paper tape and AquaSplint.
- Deviated e-PTFE implant

- After incisions are made in the inner nose, an elevator is used to separate the implant from the upper lateral cartilage and nasal bone.
- The implant is moved to its proper position.



TECH FIG 10 • Design for the unilateral capsulotomy.

PEARLS AND PITFALLS

Good candidate for an implant

- Low-profile nasal dorsum with thick dorsal skin

Implant position

- Eyelash: right above the nasal tip
- Pocket: subperiosteal, supraperichondral plane
- Pocket size: slightly larger than the width of an implant

Patients with thin skin

- Autograft using patient's own dermis or diced cartilage, rather than an implant, is recommended.
- Implant wrapped up with the fascia or dermis is recommended for patient who must have an implant.
- There is no truth in the opinion that e-PTFE implants used in patients with thin skin would show less visibility through the skin.

- In patients with thin skin, both sides of the edge of the implant are sometimes more visible rather than for a non–capsule-forming e-PTFE implant.

How to manage the supratip area

- In an attempt to prevent supratip bulging, it is important to thinly carve the implant tip and provide sufficient tip projection.
- Additional cartilage or dermis graft may be necessary in some cases for the sunken groove between the implant tip and cartilage onlay graft.

Carving the silicone implant

- Some surgeons make multiple partial-thickness cuts on the bottom of an implant to improve accurate contact and adherence to the nasal bone in the nasofrontal area (**FIG 5A**). This can cause an uneven thickness of the posterior capsule and late spontaneous hematoma, however, as well as a higher probability of infection secondary to increased surface area of an implant, so this practice should be avoided as much as possible.
- Occasionally, several holes are drilled into an implant to prevent implant mobility (**FIG 5B**). This should also be avoided since it can cause dorsal dimpling, secondary to capsular contracture formed within the hole, or can lead to late spontaneous hematoma following tearing of the thread-shape capsule in the hole.

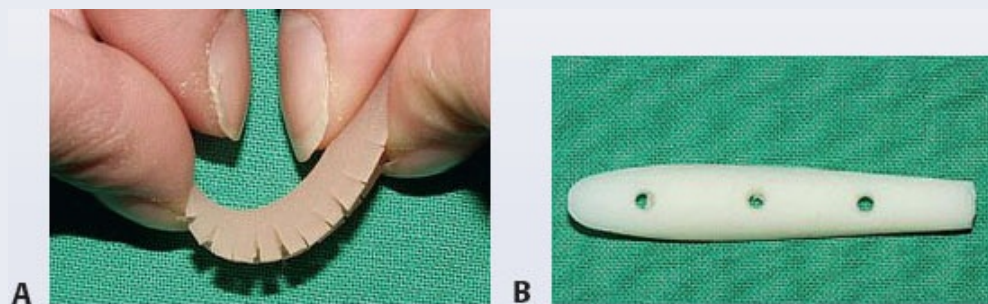


FIG 5 • **A.** Hatching on the undersurface of the silicone implant is not recommended. **B.** Making several holes in the implant is not also recommended.

POSTOPERATIVE CARE

- An AquaSplint and paper dressing are removed 4 to 5 days after surgery.
- Implant deviation should be frequently verified up to 2 weeks after surgery.
- Detected implant deviation may be corrected by manual manipulation of the implant within 2 weeks after surgery.

COMPLICATIONS

- Immediate complications
 - Implant deviation
 - Hematoma
 - Infection
- Delayed complications
 - Thinned dorsal skin with visible implant contour (**FIG 6A**)
 - Redness of the dorsal skin
 - Capsular contracture resulting in upturned nasal tip or visible implant contour on both sides (**FIG 6B**)
 - Delayed spontaneous hematoma (**FIG 6C**)
 - Calcification on the surface of the implant or on the inner surface of capsule
 - Implant extrusion through the tip skin or vestibular mucosa (**FIG 6D–I**)

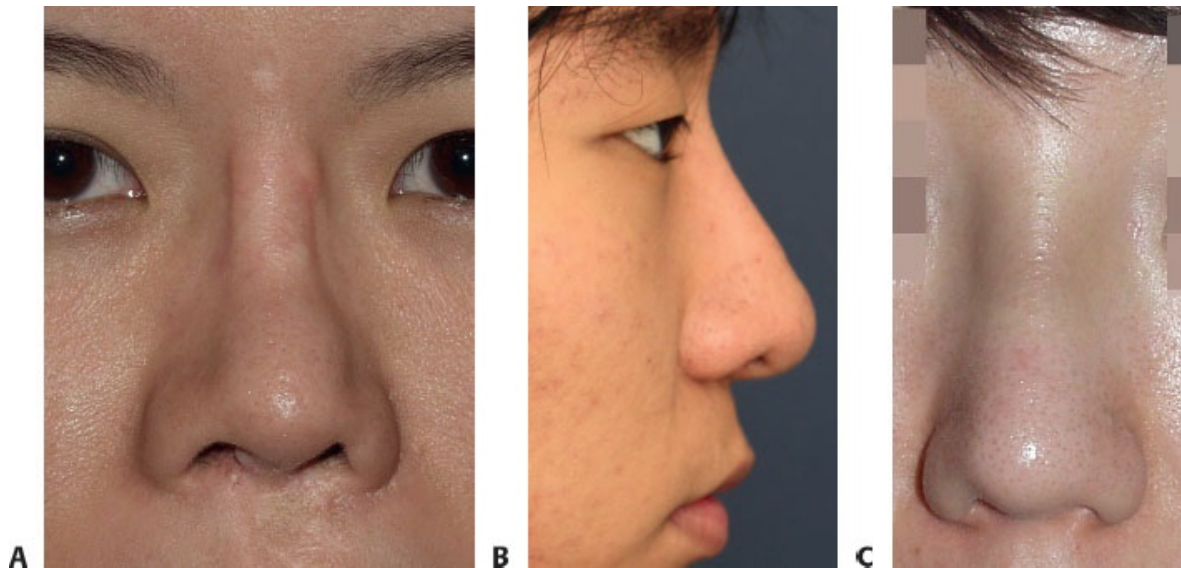
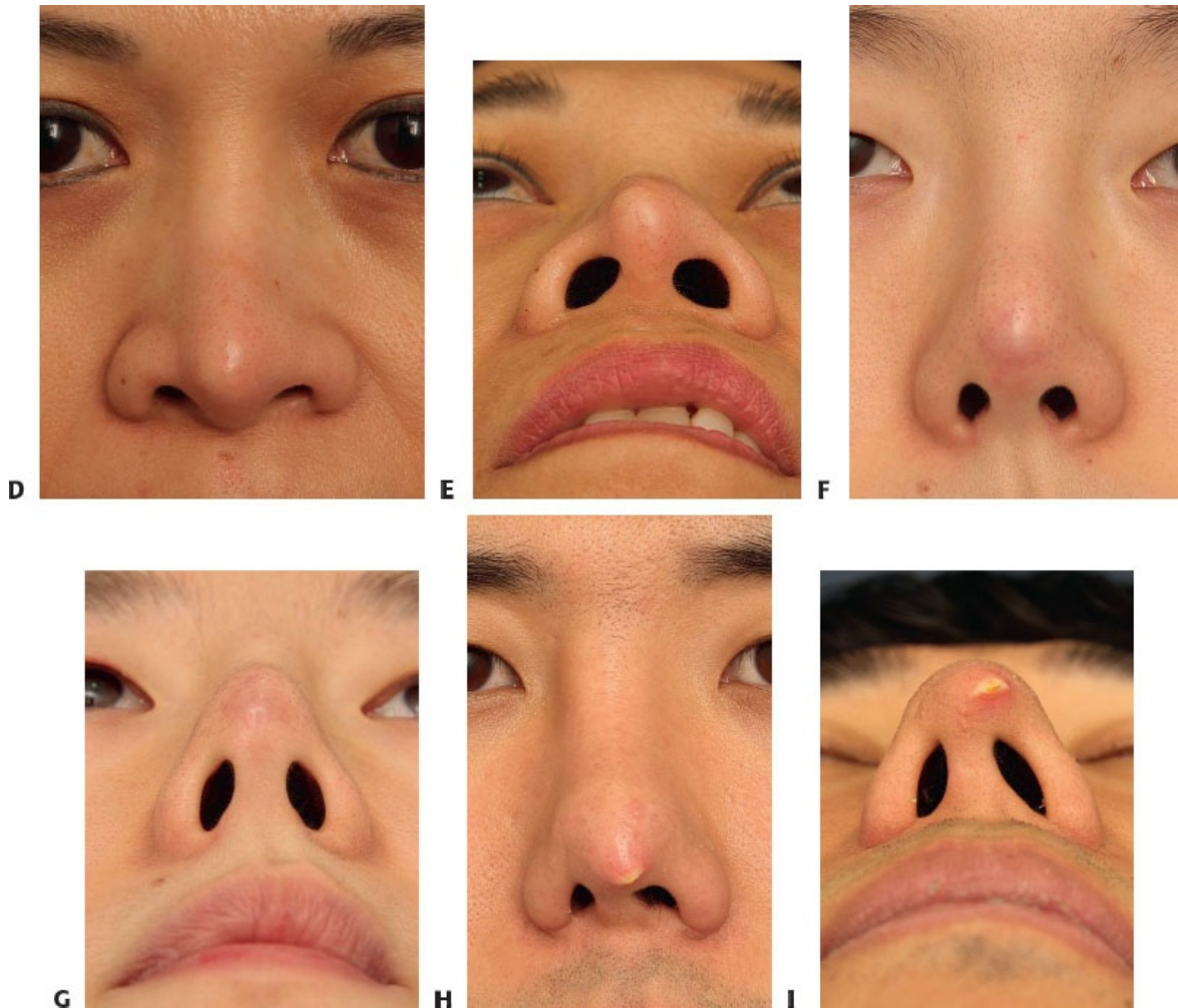


FIG 6 • **A.** Rib cartilage contour is visible through the thinned skin, and there is dorsal irregularity because of the focal partial resorption of the graft. **B.** Capsular contracture at the thick implant tip results in a supratip groove. **C.** Delayed spontaneous hematoma developed 3 years after dorsal augmentation with a silicone implant that had been hatched. Complications of L-shaped or long nasal implant include nasal tip skin thinning (**D,E**), contracted nose with redness of the tip skin (**F,G**), and exposure of the implant through the tip

skin (H,I).



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Diced Cartilage in Fascia Graft for Dorsal Augmentation in Rhinoplasty

67

CHAPTER

Aaron M. Kosins and Rollin K. Daniel

DEFINITION

- Dorsal augmentation refers to augmentation of the nasal dorsum, which can be done with alloplastic or autogenous materials.
- Dorsal augmentation with a diced cartilage in fascia graft refers to augmentation of the nasal dorsum using autogenous tissues—the patient’s cartilage from the nasal septum, ear, and/or rib that is diced into small pieces and wrapped in deep temporal fascia. The methods outlined herein include refinements to the techniques initially proposed by Daniel and Calvert.^{1–3}

ANATOMY

- The normal or “ideal” dorsum exhibits a smooth transition from the nasal radix to the nasal tip. In a male, this relationship is classically identified as a smooth line, whereas in a Caucasian female, the ideal dorsum lies 2 mm behind this line. Patients with deficiency of the nasal dorsum (low dorsum) lie behind this line.
- In non-Caucasian patients, the ideal dorsum may be different, and patient preferences must be identified.

PATHOGENESIS

- Dorsal deficiency can be congenital, genetic, traumatic, or a consequence of previous surgery. Some patients are born with a low dorsum, and many ethnicities have a naturally occurring low dorsum (eg, Asian ancestry).
- Trauma to the nose can cause septal collapse resulting in a low dorsum or

“saddle deformity.”

- Previous over-resection of the nasal dorsum and aggressive septal surgery are the most common reasons for dorsal deficiency after rhinoplasty.

PATIENT HISTORY AND PHYSICAL FINDINGS

- In cases where no prior surgery has been performed, the diagnosis is clear and based on physical examination. The patient is viewed on profile, and the ideal radix and tip are visualized. The dorsum is designed to fit these ideals.
- If previous surgery has been performed, the rhinoplasty surgeon should be aware of the causes of a dorsal deficiency. Along with physical examination, photographs should always be taken and, again, the ideal radix and tip overlaid on the profile photograph. A complete internal speculum examination should be done to assess the presence and integrity of the nasal septum. Previous operative reports are desirable in diagnosis and should help guide the surgical plan.

IMAGING

- CT scans are rarely indicated except in the presence of severe trauma or asymmetric developmental deviation of the nose (ADDN). CT scans are useful to assess the nasal bones, nasal septum, heights of the maxillae, and the presence of concha bullosa.

DIFFERENTIAL DIAGNOSIS

- Differentiate the causes of dorsal height deficiency with physical examination, speculum assessment, and previous operative reports.

NONOPERATIVE MANAGEMENT

- Theoretically hyaluronic acid fillers can be used as a temporary solution; however, the authors do not advocate this type of treatment. Results are marginal at best, and injections require a high level of accuracy and experience. Follow-up (repeat) treatments must be done at least twice per year.

SURGICAL MANAGEMENT

- The authors perform diced cartilage in fascia as the mainstay for dorsal augmentation whenever dorsal deficiency exists. Timing is dependent on patient age (patients should be older than 14 years old) and timing of previous operations. We advocate waiting *at least* 1 year from any prior nasal surgeries to perform secondary surgery.

Preoperative Planning

- Discuss again risks, benefits, and expectations with patient at both the preoperative visit and on the day of surgery. Risks include bleeding, infection, septal perforation, dorsal asymmetry, prolonged swelling of the graft (6 weeks), and cosmetic deformity. Harvest of the deep temporal fascia involves a temporal incision, and risks include alopecia and poor scarring. Finally, if auricular or rib cartilage must be taken, then these risks must be discussed as well.

Positioning

- The patient is positioned supine, and the hair, head, and neck are prepped and draped in sterile fashion.

Approach

- The temporal incision is planned. A line is drawn up from the most anterior point of the tragus into the temporal hair. A V-shaped incision is drawn so that the superficial temporal artery is avoided (**FIG 1**).



FIG 1 • A temporal V-shaped incision is used for access to the deep temporal fascia.

TECHNIQUES

■ Deep Temporal Fascia Harvest

- The V-shaped incision is carefully planned and infiltrated subdermally with 5 cc of 1% lidocaine with epinephrine.
- The incision is made clearly through the dermis, and careful cauterization is used to avoid trauma to the hair follicles.
- Dissection is carried down to the superficial temporal fascia, which is identified and divided.
- Scissors are used to spread the loose areolar layer until the glistening white deep temporal fascia (superficial leaflet) is identified (**TECH FIG 1**).
- Retractors are used to expose the operative site, and a 4 × 3 cm graft is taken using a 15-blade scalpel. Care is taken to avoid trauma to the temporalis muscle below. A distinct vessel is always present below the fascia at the 4 or 5 o'clock position.
- The superficial temporal fascia is reapproximated as well as the skin with staples.



TECH FIG 1 • After incision through the skin, the superficial temporal fascia is divided, and scissor dissection is carried out to the glistening layer of the deep temporal fascia.

■ Diced Cartilage in Fascia Graft

- The fascia graft is measured in length to approximate the dorsal augmentation and 20 mm wide. The fascia is folded over on itself to fasten a 10-mm wide fascial sleeve. This is sewed on one side with a running 4-0 chromic suture. Two 4-0 plain gut sutures on straight needles are placed in

the proximal portion so that the graft may be guided up to the radix.

- Cartilage from any donor site is prepared and diced into fine, less than 1 mm cubes with 10-blade scalpels or dermatome blades.
 - The diced cartilage is placed in a tuberculin syringe for injection into the fascial sleeve. It is important that the cartilage is finely diced so that the cartilage is injected with minimal resistance. Excess fluid is removed before injection.
 - Diced cartilage is injected into the fascial sleeve into the distal end. Once injected, it is molded on the back table to the predetermined height.
 - Using the 4-0 plain gut sutures, the graft is guided into position up to the nasal radix and secured distally with a 4-0 plain gut suture. If cartilage needs to be removed, it can be done from the distal free end. Molding is then done on the table.
 - After all incisions are closed, a Denver splint is placed for 6 to 7 days. The graft can be molded postoperatively for up to 2 weeks. At times, a percutaneous stitch is placed after graft insertion to prevent mobility.
 - See **FIG 2** for a patient example.
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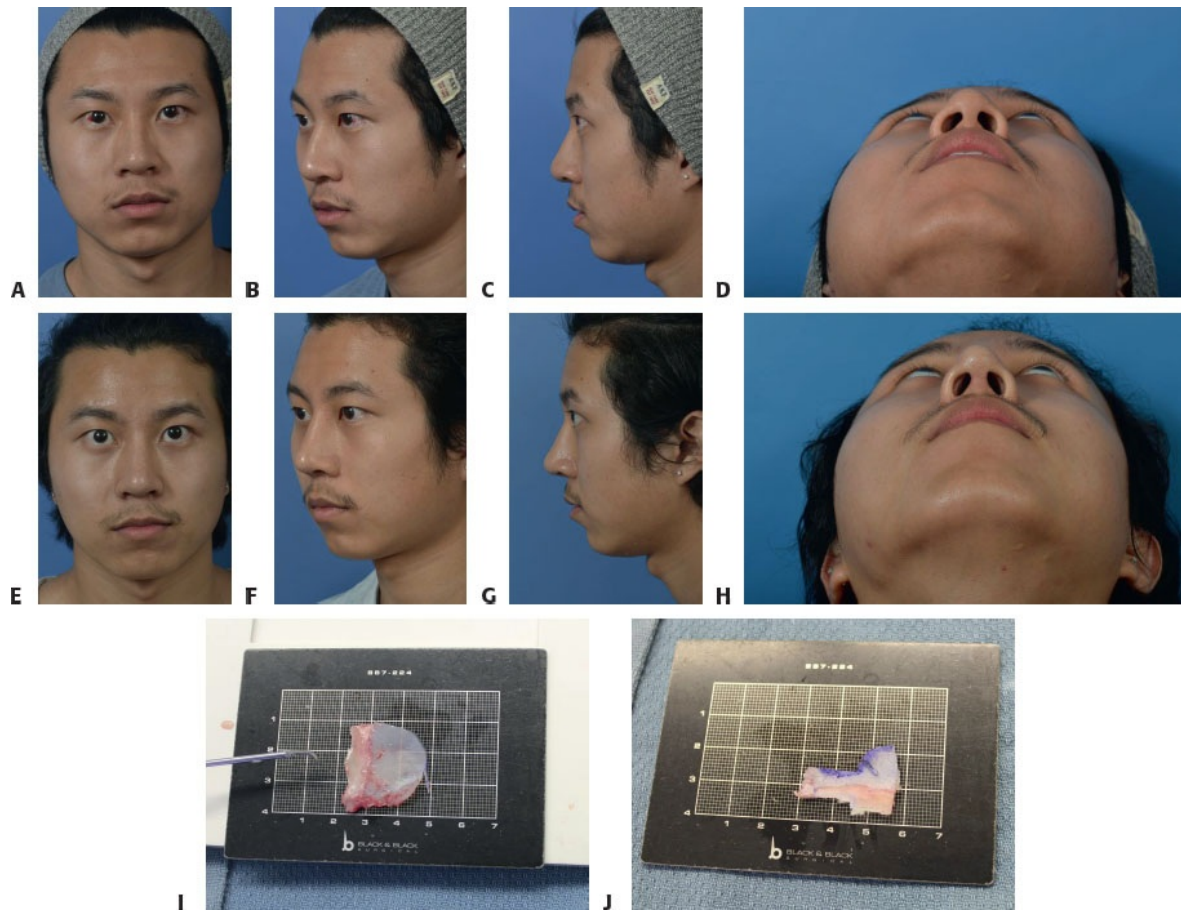


FIG 2 • Frontal, oblique, lateral, and basal views of a patient (**A–D**) preoperatively and 13 months postoperatively (**E–H**). The patient requested dorsal augmentation and required a diced cartilage in fascia graft for dorsal augmentation. 0.6 cc of diced cartilage was placed inside the fascial sleeve. **I**. A large piece of septum and perpendicular plate of ethmoid bone were harvested using Piezo instrumentation. After making the cuts in the cartilage with a 15-blade scalpel, a Piezo saw was used under direct vision to cut the bony ethmoid. **J**. Tip projection was achieved by creating a septocolumellar “tomahawk” graft that was placed on the right side of the caudal septum for increased length and projection as well as derotation. 15 cc of fat grafting was also done to the forehead.

PEARLS AND PITFALLS

Do not overfill the graft. The designer dorsum is created to size.

- Grafts made too high will maintain height postoperatively.

Tapering grafts is very difficult to do. Create a flat platform, and place a uniform graft.

- Trying to change the thickness of the graft from proximal to distal does not work well and results in dorsal irregularities.

Avoid excessive molding on the table.

Make the fascial sleeve wider than you think.

Create a narrow tunnel to place the graft.

- Excessive dissection allows for graft migration. If it moves, hyaluronidase can be used to help mobilize it versus revision rhinoplasty.

POSTOPERATIVE CARE

- Typically, the nose stays swollen for 3 weeks after open rhinoplasty, but the full remodeling process takes 1 year. When a diced cartilage in fascia graft is used, this swelling persists for 6 to 8 weeks.
- Once the Denver splint is removed, taping is done at night for 3 weeks to help with swelling.
- No glasses are to be worn for 6 weeks.
- Patients must be told not to mold his/her graft or massage it.

COMPLICATIONS

- Infection occurs in less than 1% of patients and is treated with doxycycline 100 mg twice daily for 1 week. Any infection that appears to be getting worse warrants an infectious disease consultation.
- Displacement of the graft. Hyaluronidase can be attempted to mobilize the graft, but operative intervention is often warranted.
- Undercorrection
- Overcorrection

- Palpable, diced cartilage can occur if the cubes are not made as small as possible.

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Indication and Technique for Diced Cartilage and Fascia Grafting in Rhinoplasty

68

CHAPTER

Ashkan Ghavami

DEFINITION

- Augmentation of the nasal bridge and radix has historically been a highly debated topic in rhinoplasty.
- Techniques include alloplastic materials such as silicone implants, Gore-Tex, and PTFE. Although these techniques continue to be popular worldwide, particularly in Asian countries, there has been a paradigm shift toward autogenous sources. Preferred cartilage grafts include septal, costal, and conchal cartilage. Each of these in isolation is fraught with problems in stability of shape and long-term contour.
- Erol's description of the "Turkish Delight," which is diced cartilage wrapped in Surgicel, provided a simple, less complicated option for dorsal augmentation.¹ Not long after, Daniel^{2,3} described wrapping with autogenous temporal fascia (DCFG: diced cartilage fascia graft) as an alternative; this has become many surgeons' primary technique today. It should be noted that temporoparietal grafting to the nose in isolation was described long ago by Guerrerosantos in 1985.⁴
- The author's preferred material is conchal cartilage, but costal cartilage and/or septal remnants can be used.
- Fascial wrapping and/or overlay of the cartilage construct allows for incorporation of the graft and smooth contour in surgical outcomes. Contour irregularities from warping with other autogenous techniques have been a long-standing problem that is avoided with DCFG when properly executed.
- This technique can be particularly useful in secondary rhinoplasty.²

ANATOMY

- Anatomical landmarks and technical execution of harvesting the cartilage grafts to be diced/crushed are imperative to avoid injury or deformation of donor sites at the expense of obtaining cartilage source.
- Standard techniques for harvest of rib, septal, and conchal elements can be used based on the surgeon's personal preference.
- For conchal grafts, a postauricular approach is performed. Rib graft typically is taken from the sixth or seventh rib, and it is important to not harvest calcified portions that are difficult to dice and/or morselize sufficiently. The inframammary crease is used in both men and women.
- Temporal, mastoid, and rectus fascia can all be used.
- Goals are based on the desired contour and degree of augmentation/camouflaging required. This begins at the radix and proceeds caudally to the supratip and anterior septal angle region.
- Blending with the osteotomy lines and the ascending process of the maxilla as it transitions to the nasal bones is important to create a smooth nasal sidewall contour and soft contour shadow/highlight.
- "Spot" augmentation with DCFG can be done in radix alone or to fill specific contour irregularities (particularly in secondary revision cases).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Particularly in the modern era of social media and a "selfie-obsessed" culture, it is absolutely critical to communicate the magnitude of augmentation desired by the patient while setting realistic expectations.
- Accounting for the somewhat unpredictable long-term absorption rates is also important to communicate with the patient.
- The author believes that the trade-off of minor to moderate long-term absorbability of DCFG for complications associated with traditional augmentation techniques (warping, extrusion, unnatural dorsal contour lines, need for removal, and replacement/reconstruction) is highly acceptable in favor of DCFG.
- After the standard workup for rhinoplasty with imaging and planning, desired dorsal contour is obtained during the consultation. Attention is given to the width and height of desired dorsal augmentation. If specific camouflaging or contour correction is planned, then these regions should be pointed out to the patient with the end points described or shown via imaging, drawings, or

demonstration with saline (in-office).

IMAGING

- Three-dimensional imaging software as well as 2D imaging or drawings are helpful in communicating the amount of dorsal height and narrowing/widening with patients.
- The author currently prefers to demonstrate with description and reference to other surgical case examples during consultation. Hand drawings on printed out photographs are helpful, and only when necessary during repeat consultation(s) or during the preoperative office visit is 3D imaging utilized.
- X-rays or CT scans are not necessary unless there is history of recent or remote trauma or if concomitant nasal airway correction or sinus surgery is planned.
- When costal cartilage is used, assessment of possible excess calcification of the ribs should be done. This can include needle testing in the exam room using minimal local anesthesia and/or CT scan evaluation when truly necessary.

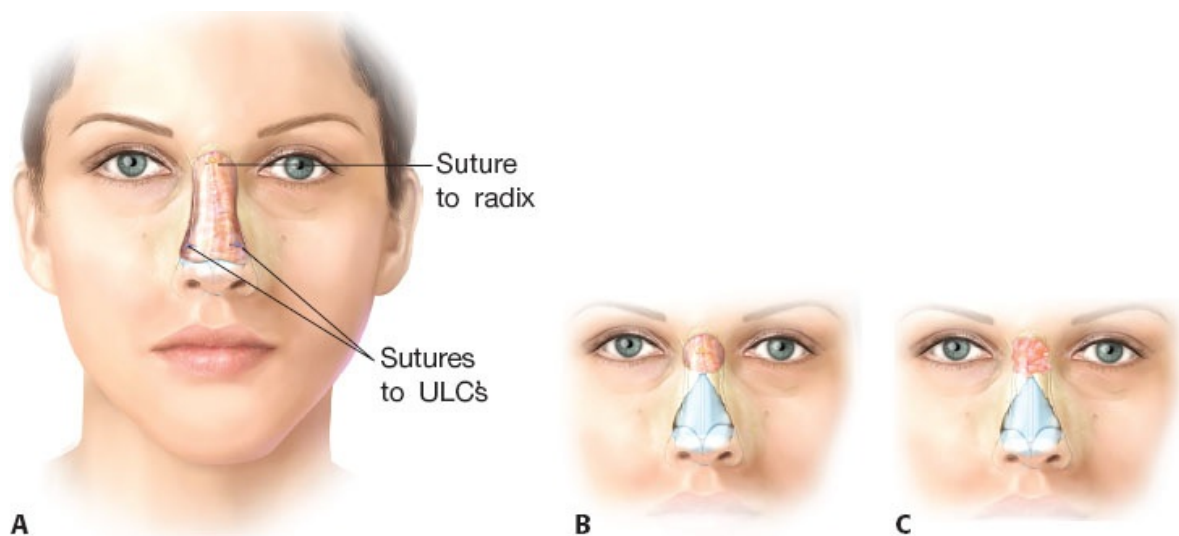


FIG 1 • **A.** Anteroposterior view of proper DCFG positioning on dorsum. **B.** Variation: radix-only DCFG. **C.** Variation: radix-only DCG. No fascia necessary due to thick nasal skin.

NONOPERATIVE MANAGEMENT

- There is no substitution for DCFG that is nonoperative and long term that is

justified in the author's opinion. However, as an adjunct to planning and only when a patient is not ready for surgery for a year or more, temporary injectable fillers can be a useful tool and "buys time." Hyaluronic acid gel fillers are preferred, and any other filler material is not recommended.

- A major limitation of nonsurgical filler augmentation is that dorsal aesthetic lines in the anteroposterior view are difficult to optimize because narrowing of the nasal pyramid is not being simultaneously performed.
- The one region that may warrant dorsal augmentation with temporary fillers instead of DCFG is in the radix when all other aspects of the nasal shape are accepted by the patient. Consultation should include surgical options and informed consent of the temporary nature of injectable fillers for the radix or for minor contour correction.
- One of the best indications for injectable (nonoperative) dorsal augmentation is for minor/subtle contour correction of dorsal and other irregularities (primary and secondary rhinoplasty). Small molecule, highly cross-linked hyaluronic acid gel is best and must be injected with respect of vascular dermal capacitance.

SURGICAL MANAGEMENT

Preoperative Planning

- Planning DCFG augmentation in rhinoplasty involves many of the methods listed above:
 - Detailed consultation with the patient with regard to the desired goals in dorsal augmentation is paramount. This includes dorsal height, dorsal aesthetic contour width, and supratip/other tip transition points to the dorsum.
 - Imaging as discussed above can aid in this process.
 - Saline solution can be injected in the office to show an approximate effect of dorsal augmentation on profile view if the surgeon and patient agree that this step is necessary to finalize the decision-making process.
- Standard rhinoplasty preoperative planning is performed including attention to internal and external valve sufficiency, airway assessment, Cottle maneuver, nasal endoscopy (when indicated), and evaluation of cartilage donor sites.
 - Note: augmentation of the dorsal height and/or narrowing of the bony pyramid and midvault can worsen airway functional issues. Dorsal height augmentation can mask these issues visually, while untreated the underlying insufficiency and patency of the airway. Dorsal width changes with DCFG

must be reconciled with the need for spreader graft/flap techniques.

- DCFG is not a substitute for proper osteotomies and correction of sidewall irregularities and asymmetries. The platform for the DCFG construct must be stable, symmetric, and structurally sound prior to using DCFG for augmentation and/or contouring.
- Marking of the topographical dimensions can be done both on the patient in the holding area on day of surgery and on photographs.
- **FIGS 1 and 2** demonstrate typical positioning of the DCFG construct.

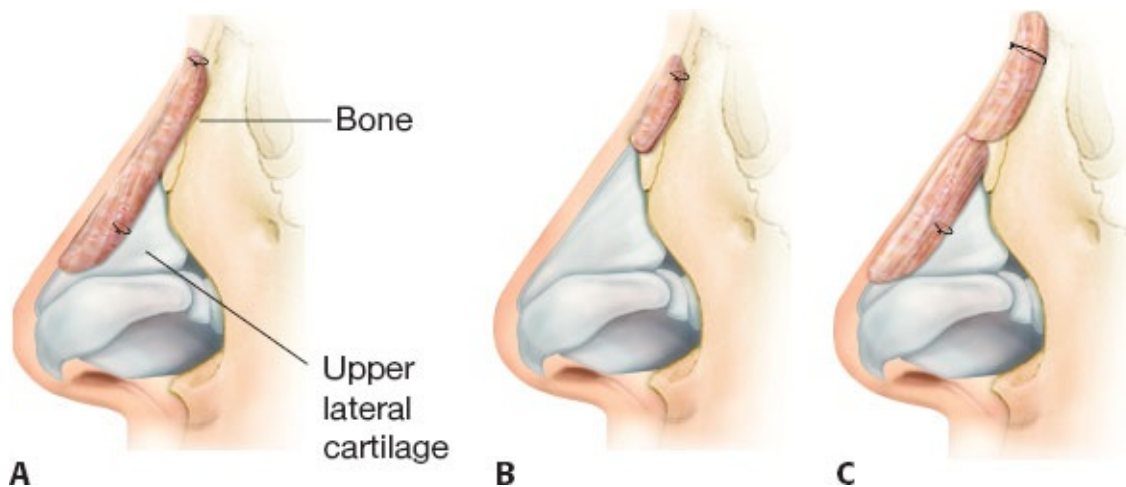


FIG 2 • A. Lateral view of typical DCFG seating and suturing for dorsal augmentation. **B.** Lateral view showing DCFG for radix-only augmentation. **C.** Lateral view: variation of using two DCFG constructs. Note: Cephalad fixation is done performed using sutures through the dorsal skin. Caudal DCFG is to cartilages.

■ Donor sites:

- Ear: The preferred sleeping side is avoided, and the contralateral ear is used when possible. Concomitant correction of prominent ears allows for more graft material, and discussion with the patient is indicated. If the patient has a small conchal area, then the larger concha is used, or bilateral conchal graft is planned.
- Rib: The inframammary crease is marked in both men and women, and the rib is accessed through the smallest incision the surgeon is comfortable with. This is typically the sixth or seventh rib. Incision placement should be shown

to the patient preoperatively.

- Fascia: The temporal, mastoid, or rectal fasciae are all options. When using costal graft, the author prefers rectus fascia because it is thick and in the same donor site. When this would be too thick and not indicated for a particular nasal envelope, temporal fascia is then harvested. When using ear cartilage, mastoid fascia is taken. If mastoid fascia is not large enough and true wrapping is required, then ipsilateral temporal fascia is obtained through a prehairline approach.

Positioning

- Standard head positioning for rhinoplasty is used with the patient in the supine position and the head of bed in reverse-Trendelenburg, as well as head elevation, approximating a 30 to 45 degree angle.
- Bilateral conchal cartilage grafts are typically consented for and prepped, so access must be available with draping.
- If rib graft is to be used, this harvest site is prepped and accessible during the rhinoplasty.

Approach

- The donor cartilage that is planned for harvest will determine the approach taken to obtain it.
- Incisions should be designed to be as small as possible and as inconspicuous as possible.
 - Ear: retroauricular sulcus
 - Rib: inframammary crease
 - Septal: preferred septal approach (open vs Killian or transfixion incision)
 - Fascia: mastoid (posterior sulcus), temporal (posterior hairline), and rectus abdominis (inframammary crease)

TECHNIQUES

■ Cartilage Harvest (TECH FIG 1)

EAR

- Prior to infiltration with local anesthesia, 7 mm of conchal height is marked

on the conchal surface anteriorly in multiple points using a caliper.

- After infiltration, prepping, and draping, a posterior sulcus incision is made. Cautery guided and sharp scissor dissection is performed to expose the conchal donor in its entirety subperichondrially.
- Two 25-gauge needles are then passed through the anterior marked points to penetrate posteriorly. A line is marked connecting the two on the posterior surface of the conchal cartilage. This avoids the sometimes messy tattooing with methylene blue dye.
- If mastoid fascia is to be used, then posterior exposure of the fascia is accomplished by undermining in a posterosuperior direction to acquire both the periosteum and mastoid fascia. Mastoid fascia often requires thinning and can be placed as an onlay without wrapping. Care is taken to not injure and transect posterior nerves. Meticulous hemostasis is necessary.



TECH FIG 1 • Components of DCFG: septal cartilage, cephalic trim cartilage, deep temporal fascia (4 × 6 cm), and diced conchal cartilage.

- Conchal harvest is then completed by excising all conchal cartilage posterior to a line from needle to needle. This line should be curvilinear to avoid deforming the superior crura. The graft and fascia are placed in saline.
- Any rents in the skin should be repaired.
- A layered closure should be performed, and Xeroform/antibiotic ointment bolster is secured with a silk or nylon suture. This should be molded to compress the conchal space.

RIB

- The inframammary crease is marked at approximately 4 cm. Surgeons should not hesitate to make this incision as big as they need based on experience and comfort. Visualization is necessary for preventing complications.
- An incision is made and dissection carried down to the perichondrium of the rib. The rib is palpated and needle prick examination performed to assess for softness and suitability. The fascial and rectus abdominis fibers are vertically spread bluntly to expose the rib. If rectus fascia is to be used, see below for details regarding harvest.
- A midline incision is made through the perichondrium parallel to the orientation of the costal cartilage. Gentle elevation is performed to preserve a perichondrial sleeve around the removed rib segment that is later closed along with fascia and muscle forming a functionally rigid construct and prevents postoperative pain from any sensation of instability during deep respiration.
- Using direct visualization and staying subperichondrial, the posterior aspect of the rib is freed from the perichondrium with a blunt elevator. Curved endoscopic brow elevators and Cottle elevators are an excellent combination for this technique.
- Once the rib is removed using a 10 blade, it is placed in saline. If strut grafts and other grafts are needed, it is allowed to sit for at least 10 minutes after symmetrical carving; the remaining cartilage will be used to dice/crush.
- Long-acting local anesthetic is infiltrated into the deep subcutaneous tissues and in the rib dead space. The author prefers to place an angiocath in this space, followed by reinjection and removal of the angiocath prior to extubation. Some surgeons prefer a pain pump, which I have found to be unnecessary. The site is then closed in a layered fashion with absorbable sutures, from deep to skin: perichondrium, rectus fascia (if fascia is harvested, then closure is still possible, or spanning sutures can be used, and remaining muscle fibers and fascia can be approximated), Scarpa fascia, deep dermal, and subcuticular closure.
- Commonly, if the rib is used for DCFG, the costal cartilage is needed for other elements such as strut grafts, spreader grafts, etc. Rib cartilage simply for DCFG is sufficient without obtaining the conchal cartilage. However, there are circumstances when rib cartilage and ear are both required for different purposes particularly in very deficient dorsum or in complex revision rhinoplasty.

■ Dicing of Cartilage

- The cartilage to be diced or crushed is placed on a silicone block. A 10 or 11 blade is used to dice the pieces as small as possible so that they can pass through a “slip tip” (non-Luer locking) tuberculin syringe. Alternatively, sterilized razor blade can also be used. The size of the pieces is determined by the augmentative goals, the rigidity/memory of the cartilage donor, and the thickness of the dorsal skin envelope (**TECH FIG 2**).
- For radix augmentation in thicker-skinned patients, finely diced cartilage can be used without fascial onlay or wrapping. Excessive crushing is not necessary and may increase absorption. However, fascial onlay or wrapping will help reduce the chance of untoward cartilage edge visibility long term and can also have a subtle augmentative benefit too, depending on the thickness of the fascia (rectus or mastoid vs temporal).



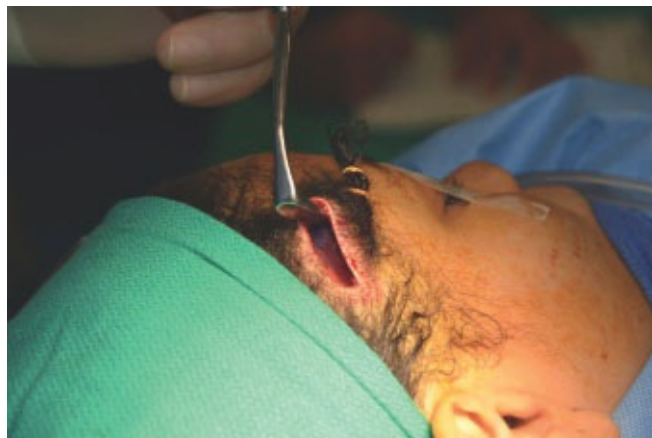
TECH FIG 2 • Dicing of cartilage graft.

- If finer pieces are needed, a handheld (Ruben) morselizer is very useful and preferred over the classic morselizer which requires a mallet and is less refined in giving the exact degree of softening or morselizing of diced pieces. Once again, excessive morselization is not indicated.

■ Temporal Fascia Harvest

- If ear cartilage is harvested, the ipsilateral temporal region is approached.

- A 3-cm incision is made several centimeters posterior to the temporal hairline. If the hair is thin, the incision is placed further posteriorly (**TECH FIG 3**).
- Respect of hair follicles and the anterior beveled approach is used to limit injury and transection of hair roots.
- If proper preinfiltration of local anesthetic with epinephrine is used, then cautery can be minimized, which also aids in prevention of iatrogenic alopecia.
- After the incision is made, the subgaleal, supratemporal bloodless plane is entered. Blunt undermining superficial to the white fibers of the deep temporal fascia is visualized and exposure from the temporal crest cephalad from the supraorbital ridge toward the sentinel vein, and 3 to 5 cm posterior to the incision point is performed.
- Marking pen can be used to delineate the rectangular piece for harvest. Typically a 5 × 7 cm piece can be obtained. Using an 11 or 15 blade, the temporal fascia is scored, muscle is exposed along the marked lines, and then fascia is grasped and pulled off the muscle with the aid of angled scissors.



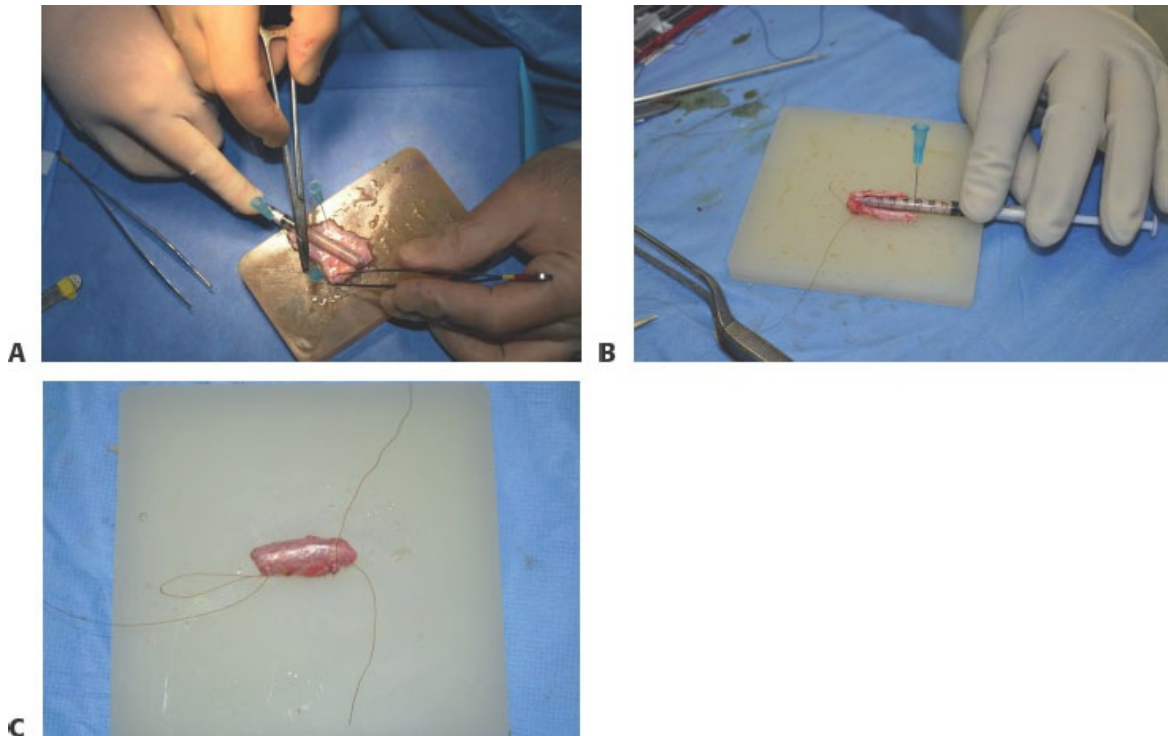
TECH FIG 3 • Temporal fascial harvest.

- Inadvertent muscle fibers and any fatty tissue carried over should be trimmed off the fascia.
- Occasionally vessels deep to the fascia are injured, especially in the inferoposterior region and temporal crest caudally. These should be cauterized precisely without inadvertent heat injury of the fascial harvest.
- The incision is closed after irrigation of the pocket and confirmation of

hemostasis. Three-point layered closure helps close the dead space. Staples or a running small caliber quick absorbing suture of the skin layer can be used. A drain is rarely used, but if it is, a round 7-French drain to bulb suction is preferred. No compressive wraps are necessary.

■ Fascial Wrapping

- There are two methods for wrapping:
 - Syringe method (**TECH FIG 4**):
 - Diced/crushed pieces are placed into a non-Luer-Lok (“slip tip”) 1 cc tuberculin syringe. The plunger is used to squeeze pieces into a confluent mass within the syringe without gaps or air. The syringe is placed on top of the fascia, and the fascia is needle-fixed at two corners to the silicone block.
 - A running absorbable suture is used from proximal to distal and needles removed for circumferential closure of the fascial sleeve around the syringe. The contents are injected into the sleeve, and final suture is placed to close the proximal open end of the sleeve. This suture can be cut with needle attached for placement and securing to the radix skin.
 - Onlay technique:
 - No syringe is required, and the diced cartilage is placed onto the fascia directly in the middle (similar to how a burrito is made), and the fascia is then wrapped around it and sutured in similar fashion as above. This technique is best for when the DCFG does not need to be as rigid and is best for lesser degree of augmentation, radix augmentation, and/or contour/camouflage grafting purposes.



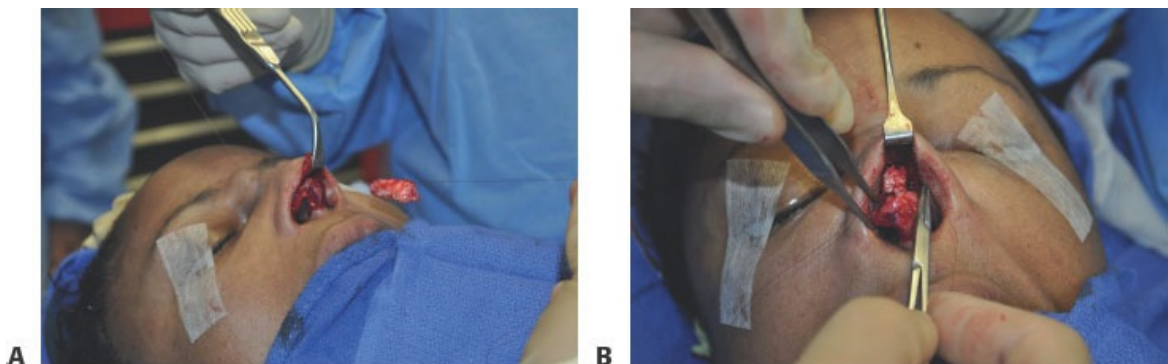
TECH FIG 4 • A. Syringe fascial sleeve wrapping. **B.** Syringe and sleeve near complete. Cartilage will now be pushed into fascial tubular sleeve and final sutures placed at open end to close the DCFG construct. It is important to not leave openings so that diced cartilage cannot extrude and create irregular contours. **C.** DCFG construct completed. Sutures left long on either end to allow for immediate fixation.

■ Placement of DCFG

- DCFG can be placed through an open or “closed” endonasal approach. A closed approach requires passing through an infra or intra-cartilaginous access incision.
- The needle that is left attached to the DCFG construct is used to pass through the radix region at the cephalad end point of the desired augmentative footprint. This is done after osteotomies to narrow the nasal bony vault (if indicated). The DCFG is slid into a pocket that was previously undermined from the tip complex to the takeoff of the frontal bone in the

nasofrontal angle/radix region. The needle is brought through the skin and grasped, and after the DCFG is positioned, it is tied to the skin and to itself as a loop. This can be removed upon splint removal on day 6 or 7 (**TECH FIG 5**).

- The lateral dimensions of the DCFG tunnel should not be overly released and undermined because this can result in inadvertent excessive blunting of the lateral dorsal aesthetic contour lines. In addition, if more height is needed, a tighter “wrap” of the DCFG and narrower tunnel will aid in driving the volumizing effect of the DCFG dorsally rather than laterally.
- If only radix augmentation is indicated, then the DCFG will be shorter, but skin securing with suture is still recommended.
- It is imperative that the caudal aspect of the DCFG is secured with at least two sutures to the anterior septal angle region. Typically the upper lateral cartilage and septum are great anchor points.
- The DCFG should be massaged in place to desired contour, width, and height.
- Note: After the remaining sequence of the primary or revision rhinoplasty is complete, it is important to create a balance between the dorsal augmentation and tip height as well as supratip transition. The caudal aspect of the fascial (DCFG) can extend to the lower lateral cartilages and/or domes depending on the desired aesthetic goals in this region.
- Splinting should take into account precise molding effects of the splint on the height and width of the DCFG. The author prefers an elastic splint (Aquaplast), but any splinting choice is acceptable as long as excessive narrowing is not created. Lastly, it is important to not have any irregularity or deviation in the splinting process because this may alter the shape and centralization of the DCFG.



TECH FIG 5 • A. Passing DCFG with 5-0 chromic suture to secure at radix skin and **B.** two sutures placed to caudal upper lateral cartilage (approximately 7 o'clock and 5 o'clock positions).

■ Combined Techniques

- Case no. 1 demonstrates the benefits of combining DCFG with traditional costal cartilage dorsal augmentation (see **FIG 3**).
- It is important to secure the cephalad portion of the costal graft to the nasal bones and to adhere to classic carving and shaping principles. This avoids lateral migration and cantilevering of the costal graft.
- The DCFG is sutured on top of the rib graft. Skin securing as described above is also necessary, as is passing the threaded K-wire through the DCFG and costal graft chimera construct. The wire is trimmed at skin level and removed during splint removal (**TECH FIG 6**).
- This combination gives a large degree of augmentation and utilizes the benefits of lateral contour and camouflage.



TECH FIG 6 • Variation of rib graft to the dorsum (wired to radix bone) and DCFG on top for warping prevention, contour blending, and further augmentation. K-wire has already been placed through the DCFG and Rib graft. Caudal suture left long and will be on two sutures to secure DCFG to the

upper lateral cartilages. A third suture can also be placed if necessary so that the DCFG can drape and contour properly over the caudal dorsal structures. Patient is Case 1.

PEARLS AND PITFALLS

Obtaining proper dorsal height	■ Preoperative photographs and/or 3D imaging ■ Thorough discussion with the patient preoperatively on setting realistic goals with dorsal height ■ Saline test if necessary
Optimizing DCFG dimensions	■ Tighter wrapping and maximal filling provide more rigid and larger construct ■ Avoid overdissection of lateral dorsal tunnel dissection ■ Larger pieces can be used in thicker skin envelopes
Fixation	■ Cephalic DCFG suturing at radix skin ■ Three-point caudal fixation (one central and two lateral)
Early contour irregularity	■ Can be molded up to 3 wk in office ■ If necessary, no earlier than 9 mo, minor dorsal ridges if present or spicules can be rasped under local anesthesia in office
Radix-only augmentation	■ May not require fascia, but pieces should be small enough for camouflage

POSTOPERATIVE CARE

- Postoperatively, the DCFG has the great advantage of being malleable and able to be further shaped/molded for 3 weeks.
- If deviations or irregularities are seen, they can be softened and improved with gentle steady yet firm pressure much like clay. Occasionally local anesthesia may be required for patient comfort.
- The splint is removed at day 6 or 7.
- Retaping is preferred to help with edema and is a routine technique of the author in all primary and secondary rhinoplasties. The patient is instructed on

how to tape and is encouraged to tape as shown nightly for 7 to 21 days, depending on the amount of edema present at splint removal.



FIG 3 • Case 1: primary Asian rhinoplasty. Rib graft augmentation of the dorsum with overlying DCFG. Note: DCFG and rib graft are both K-wire fixed to the radix bone. Wire removed at 7 days with splint. **A.** Lateral view shows preop, 1.5 years postoperatively (**B**), and 5 years postoperatively (**C**). Notice the integrity of dorsal volume. Rib graft was relatively small in height. **D.** AP view. **E.** 5-year result. **F.** Oblique view. **G.** 5-year result.

- The DCFG effects and solidification occur at approximately week 3 and continue to be complete by 3 months where its effects can be seen.
- In the author's experience, desired outcomes can be assessed accurately as with most rhinoplasty aesthetic endpoints at 1 year postoperatively.
- Much like all rhinoplasty outcomes, aesthetic results will still continue to evolve even past a year, and patients should be informed about the process.

OUTCOMES

- Patient satisfaction is high and is likely dependent on thorough preoperative assessment, and proper informed consent of dorsal dimension end goals.
- Realistic expectations are important in the preoperative discussion and planning. It should be stressed to the patient that absorption and dorsal height long term have been shown to be acceptable and revision rates are low.
- Discussion of alternative techniques and their limitations should also be done preoperatively.
- Typical dorsal aesthetic contour lines and height are shown a year or more in these case examples (**FIG 3**).

COMPLICATIONS

- In general, the adverse events that can occur from the DCFG technique are rare and when present can be addressed via closed surgical approach.
- Loss of unacceptable DCFG volume has not been in issue in the author's practice and, if present to a small degree, has not driven any patient to seek revision.
- Excess dorsal height can be present and is addressed through a closed approach with sharp trimming or rasping. If other revisions are indicated and opening of the nose is indicated, then direct excision of regions of the DCFG can be accomplished.
- Irregular contour is managed by simple rasping via a closed approach.
- DCFG contour can appear edematous and irregular for a few months, and patience from both surgeon and patient is required. Once the subtle height and width dimensions plateau and no longer change after a few months, discussion of any undesirable contours and/or dimensions can proceed, and possible revision is planned.
- Infection is rare and has not been experienced by the author but should be addressed early with oral antibiotics, irrigation (if indicated), and removal if necessary. There are no reports of DCFG removal for infection. However, meticulous sterility of grafted cartilage during acquisition and creation of the DCFG construct is important.
- "Redness" of the skin overlying the DCFG has been witnessed by the author and has typically subsided without intervention.

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Technique for Surgical Management of the Depressor Septi Nasi Muscle

69 CHAPTER

Michael R. Lee, Sammy Sinno, and Rod J. Rohrich

DEFINITION

- *Depressor septi nasi* (DSN) muscle is a paired structure occasionally responsible for deformity of the nasal tip and/or columella.¹
- *Animation deformity* of the nasal tip and/or columella may result from action of the DSN. Such deformities typically include drooping of the nasal tip and/or columella on animation.
- *Basal aesthetic lines* (BALs) are created by the lateral borders of the columella. Excess soft tissue of the columella which includes the DSN muscle may cause distortion of the BALs.²
- *Medial crura footplate approximation* is a described multistep process designed to improve symmetry and architecture of the medial nasal base, thereby improving the BALs.³

ANATOMY

- Variations of DSN anatomy have been reported in the literature, particularly with ethnicity.⁴
- Muscular fibers of the DSN may originate from the maxillary periosteum and/or orbicularis oris muscle. Fibers may be diminutive in some patients.
- Muscle fibers of the DSN course through the columella and insert on the medial crura and nasal septum.
- Columella composition includes cartilage (caudal nasal septum and medial crura) and soft tissue (muscle fibers, fibroblast, collagen fibers, elastin fibers,

adipocytes, and neurovascular structures).⁵ Muscle fibers traversing the columella are from the DSN and orbicularis oris muscle.

- The caudal septum is firmly seated on the maxillary crest and does not move with contraction of the DSN. Flanking the caudal septum is the medial crura. These more mobile medial crura may descend with contraction of the DSN.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients may report (1) tip descent on animation, (2) short upper lip on animation, (3) transverse crease in the mid-philtral area, (4) infratip/columellar decent on animation, and (5) columellar fullness and nostril deformity on basal view.
- Exam includes inspection of the nose in all classic rhinoplasty views. Inspection is initially performed in repose and then again with animation. Animation includes smiling and speaking.
- Frontal view is used to evaluate tip position both in repose and with animation. The tip is inspected to determine if descent is occurring or if the misconception of tip descent is occurring. Tip position in relation to the ala and cheek during animation helps to differentiate between the two deformities. The tip is inspected both in isolation and in comparison to the nasal ala and cheek mound. It is important to determine if the tip is truly descending or if elevation of the ala/cheek mound with subnasale repositioning are responsible for the deformity. The latter is an illusion of tip descent.⁶ The infratip lobule is also studied to identify fullness and/or asymmetry.⁷ Inspection of the upper lip for shortening and/or a transverse crease is also done.
- The lateral view is studied in repose and animation to study tip position, infratip architecture, and the alar-columellar relationship. Inspection of the nasal ala and cheek mound in relation to tip position is studied on animation. This lateral view allows a more focused inspection on the tip alone with animation. The alar-columella relationship is also assessed to identify the presence of alar retraction or a hanging columella. Fibers of the DSN attach to the mobile medial crura, and animation may distort the columella on animation.
- Basal view evaluation focuses on identifying and classifying columellar deformity. Four types of deformity exist all based on the underlying anatomy.² Excess or malpositioned cartilage and/or soft tissue can create a deformity in this area and distort the BALs.² Comprehensive evaluation of the nasal base and in particular the medial nasal base (columella) is important when treating

the DSN.

IMAGING

- Imaging is typically not utilized for diagnosis of animation deformities.
- 3D imaging is used to discuss existing static deformities and illustrate anticipated surgical results. Many patients with the aforementioned complaints will receive increased tip rotation and placement of a columella strut to stabilize the nasal tip. These potential changes can be illustrated using an imaging system.
- Changes in alar-columellar relationships are also illustrated using the imaging system.

SURGICAL MANAGEMENT

- Proper diagnosis is essential for effective surgical treatment. Treatment of the DSN can be perceived as a static problem, dynamic problem, or both.^{2,4}
- Excess muscle volume can disrupt aesthetic ideals of the medial nasal base creating a static lateralization of the BALs. Surgical management focuses on reduction of the DSN and adjacent soft tissue.
- Treatment of dynamic problems is deformity specific. Tip descent is managed with disruption of the DSN and stabilization. Illusion of tip descent is treated with increased rotation and stabilization. A shortened upper lip and/or transverse crease is addressed with treatment of the muscle and mucosal rearrangement.¹

Preoperative Planning

- A focused discussion is undertaken with the patient to determine concerns. Patients should be educated in regard to limitations of deformity correction. Although all maneuvers are executed to maximize the aesthetic and functional outcome, the face and nose are dynamic, and perfection is rarely achievable.
- Examination of the nose under anesthesia is performed prior to local injection and prepping of the patient. Both visual and tactile examinations of the tip and columella are completed. Palpation of the tip helps to determine support and cartilage integrity. Gentle manipulation of the columella from side to side can help determine caudal septal position and soft tissue volume. The BALs are also inspected (**FIG 1**).



FIG 1 • Illustration of ideal basal aesthetic lines (BALs; *dashed lines*). The BALs should be smooth and exhibit a slight convexity, harmoniously transitioning the upper lip to the nasal tip. Excess soft tissue or cartilage malposition can disrupt this nasal harmony.

Positioning

- Once in the operating room, the patient is intubated and positioned on the table. The most cephalic portion of the head extends just beyond the table. The stretcher may be placed head up to 15 degrees to minimize venous pooling in the operative field. A throat pack is gently placed and removed at surgery end. Local anesthetic with epinephrine is injected into the planned incision sites (**FIG 2**).

Approach

- Though treatment of the DSN can be accomplished through intranasal incisions, the authors prefer an open surgical approach. The transcolumellar incision allows direct visualization and access to the tip and columella tissue. When the operative plan includes lengthening the upper lip and or treating a transverse crease, a transoral incision is also used. Techniques are dependent on the problem being treated as outlined below.



FIG 2 • Photographic example of patient position and exam under anesthesia.

TECHNIQUES

■ Tip Descent

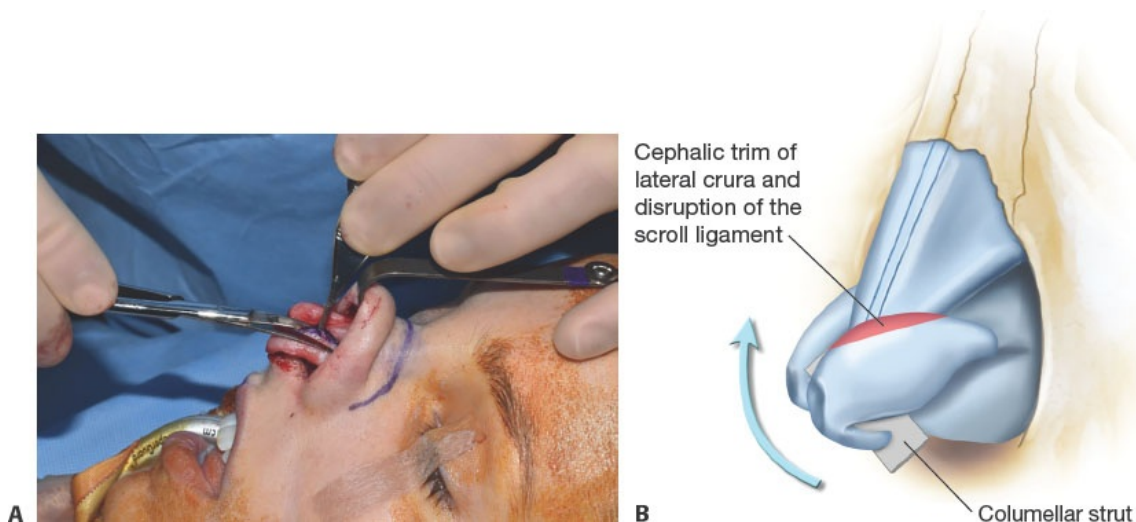
- A transcolumellar incision is made and connected to bilateral infracartilaginous incisions. As the nasal envelope is elevated, soft tissue is detached from the underlying cartilage of the lower lateral cartilages (**TECH FIG 1**). Muscle fibers are directly resected to release any attachment to the medial or domal crura.⁵ The tip is well supported with columella strut and tip suturing. Collectively, these maneuvers stabilize the tip and correct the animation deformity. Patients with short upper lip or philtral crease may undergo treatment with transoral incision. When a transoral incision is used, the muscle may be transposed and sutured together with a 4-0 chromic. Alar contour grafts are also commonly used to provide additional support to the ala.



TECH FIG 1 • Demonstration of the transcolumnellar incision with direct exposure of the medial crura cartilage.

■ Tip Descent Illusion

- An open surgical approach is performed as described above. Surgical maneuvers to increase tip rotation are often needed in these patients. Release of the scroll ligament and possible cephalic trim is used with placement of a columella strut to reposition and strengthen the nasal tip (**TECH FIG 2A,B**).

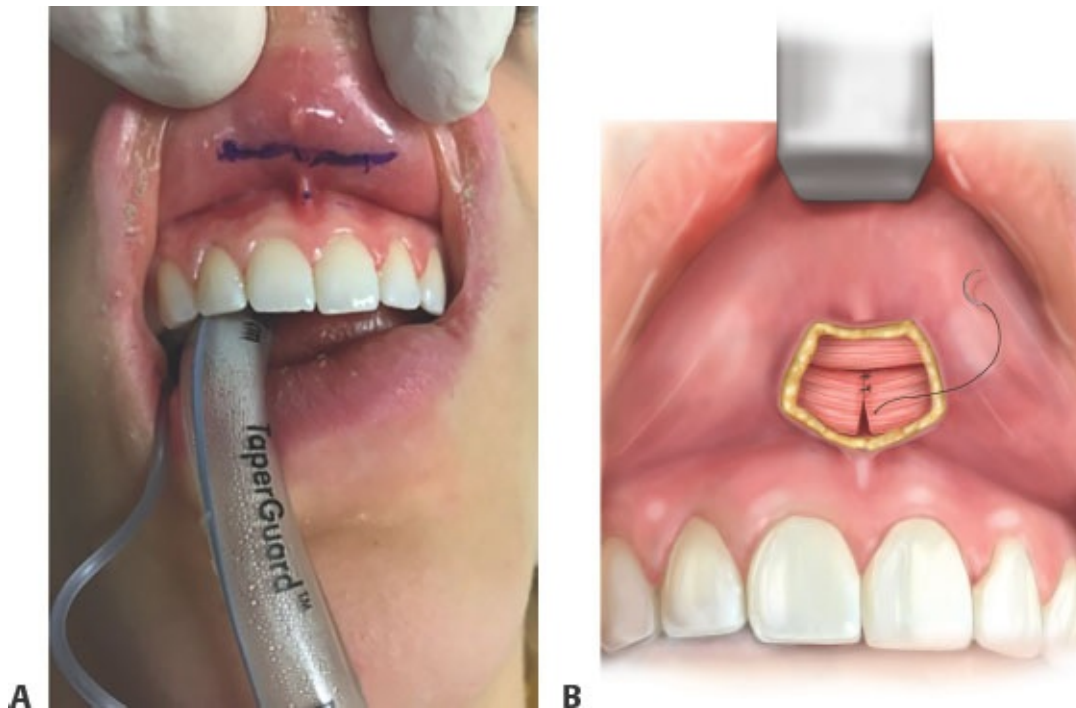


TECH FIG 2 • **A.** Photograph showing release of the scroll ligament. Release of the scroll ligament allows for upward rotation of the nasal tip. **B.** Illustration of

nasal tip mechanics. With disruption of the scroll ligament (in isolation or with cephalic trim), the nasal tip can be rotated upward and stabilized with a columellar strut.

■ Short Upper Lip/Transverse Crease

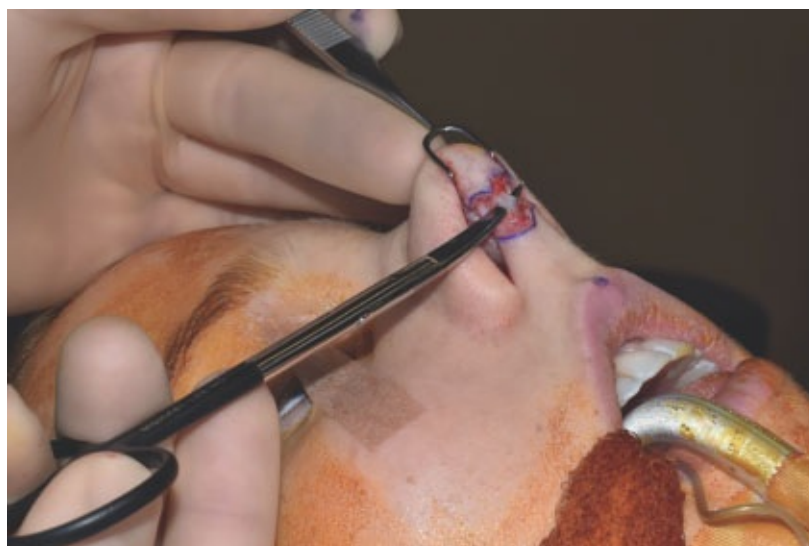
- A 1-cm horizontal incision is made in the upper labial sulcus centered on the frenulum (**TECH FIG 3A**). Incision is made with pinpoint electrocautery, and dissection is continued until the DSN is identified. The DSN is released near the point of origin (either orbicularis or periosteum). The fibers are then transposed and sutured¹ together with 4-0 chromic (**TECH FIG 3B**).



TECH FIG 3 • A. Transoral horizontal incision centered on the frenulum. This incision allows access to the DSN and orbicularis fibers. **B.** Illustration of release of the depressor septi nasi muscle and suture fixation.

■ Animation Deformity of the Columella

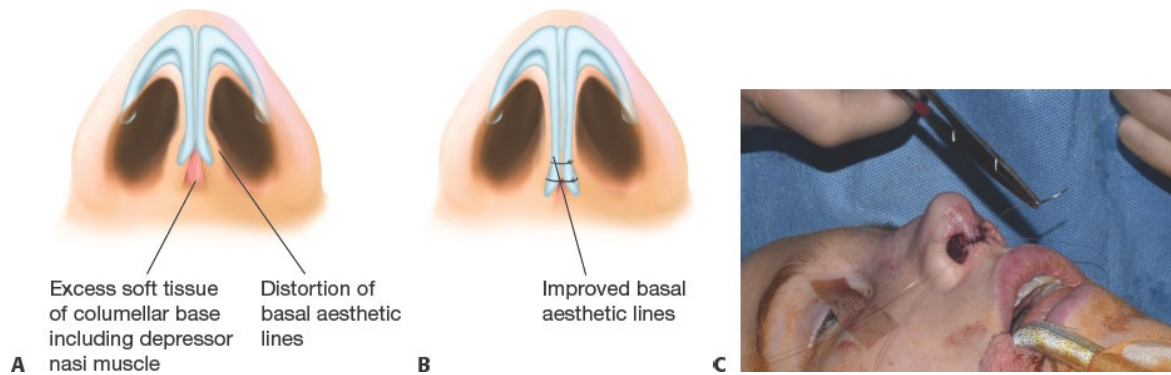
- An open surgical approach is performed as described above. The DSN fibers (both superficial to and between the medial crura) are resected away from the medial crura (**TECH FIG 4**). It is important to resect at least 2 to 3 mm so that the muscle does not scar back together. If posterior columella animation deformity is present, then any fibers inserting on the footplates are also removed. A columella strut is often placed to fortify tip position and stabilize the columella.



TECH FIG 4 • Photograph illustrating soft tissue that includes DSN fibers traversing the columella. At least 2 to 3 mm of muscle resection is needed to avoid recurrent animation deformity.

■ Columellar Base Deformity

- Excess DSN volume requires resection to recreate the ideal medial nostril and BALs. Through an open approach, this tissue is easily reduced as needed. If footplate flare is abnormal, then a MCFA³ is also performed (**TECH FIG 5**). This may displace excess soft tissue inferiorly subsequently distorting the alar-columellar relationship. Resection of excess soft tissue avoids this complication.



TECH FIG 5 • A. Premature flare of the medial crura footplates causes distortion of the basal aesthetic lines. **B.** Any excess soft tissue should be resected to prevent inferior displacement during the medial crura footplate approximation. **C.** A combination of gut and PDS sutures is used to approximate the tissue.

PEARLS AND PITFALLS

Patient communication	■ Of utmost importance is communication between the patient and surgeon. An understanding of patient goals is essential for successful rhinoplasty.
Proper diagnosis	■ Proper diagnosis provides the basis for operative planning. This requires a comprehensive evaluation of the face and nose during repose and animation.
Knowledge of relevant anatomy	■ An understanding of the anatomy responsible for existing deformities is crucial. Anatomically based classification systems are particularly useful.
Technique	■ Once the problem has been identified and diagnosed, surgical correction is planned. Understanding the problem is fundamental to correction as all DSN deformities are not treated the same.

POSTOPERATIVE CARE

- Nasal dressing is placed at surgery end. Taping is done to support and

minimize swelling of the nasal tip. A nasal splint is also applied. Tape and splint are discontinued at postoperative day 7 when the transcolumellar incision sutures are removed. Patients are started on saline intranasal spray and topical antibacterial ointment for the incision. Once the incision is healed, scar care is initiated and continued for 6 to 12 months.

OUTCOMES

- Resolution of tip deformity with DSN treatment has been well documented in the existing literature.⁴ Outcomes regarding nasal base aesthetics are limited. Composite outcomes reported included increased nasolabial angle, lengthened upper lip, improvement of lip crease, narrowed wide nasal base, and improvement in perceived tip descent/animation deformity.

COMPLICATIONS

- Described complications of DSN treatment are uncommon but include transient central upper lip paresthesia and upper lip asymmetry.⁴ These typically resolve in 2 to 3 months.^{1,4} One might also expect recurrence of deformity if the muscle is not adequately treated.

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CHAPTER Alar Contour Grafts

Jacob Unger and Rod J. Rohrich

DEFINITION

- The alar contour graft (ACG) is a cartilaginous strut utilized in rhinoplasty to strengthen and reinforce the alar rim placed along the alar margin¹ (**FIG 1**).
- ACG is synonymous with alar rim graft.
- Alar retraction is excessive elevation of the alar rim as evidenced from an AP or lateral view with >2 mm of elevation from the long axis of the nostril.²
- Alar collapse is a malformation of the rim on basal view that can occur when the lower lateral cartilage (LLC) is congenitally cephalically oriented, resulting in a loss of support along the anterior portion of the alar rim with a subsequent concavity. This deformity may be static, dynamic, or both.
- Alar notching is defined as a sharp angle within the ovular lateral contour. This can extend cephalically and sometimes be referred to as a “parenthesis deformity” or “ball tip.”^{3,4}

ANATOMY

- ACGs are intimately related to the aesthetics of the alar rim. The ideal alar rim is defined on lateral view by a smooth contour with a slight arch, peaking vertically between the level of the tip defining points and the columellar-lobular angle. Further, the height of the alae should be no higher than 2 mm above or 2 mm below the long axis of the nostril.
- The alar rim is largely composed of thick, lower nasal skin superficially and mucosa internally.
- The lateral crus of the LLC normally runs parallel to the alar rim. The LLC may be cephalically oriented, which predisposes to alar deformity. The orientation of the LLC helps determine the shape of the ala anteriorly in the

area of the soft triangle.

- The posterior half of the alar rim encompasses the alar lobule and is composed entirely of fibrofatty tissue and thick skin.^{1,2}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Visual inspection and manual palpation of the nose will indicate if any alar rim deformities are present in the preoperative state. Standard rhinoplasty imaging should be undertaken with AP, lateral, basal, and $\frac{3}{4}$ views of the nose. Visualization of the lateral crura of the LLC through the skin envelope can help diagnose a more vertical orientation, which may portend a higher risk of future alar deformities.
- Forced inspiration through the nares will uncover any dynamic external nasal valve collapse or evidence of alar collapse.

IMAGING

- No imaging is necessary or indicated to prepare for alar rim deformity correction with ACG.
- Three-dimensional imaging may be useful as a preoperative planning and patient communication tool. Caution is advised not to “lower” the alar position with a computer program if one does not feel that this is a consistently reproducible surgical outcome in his or her hands. However, this imaging may help educate patients how reinforcement of alar retraction or collapse with ACG may be very useful, as well as indicating changes in alar-columellar relationships.

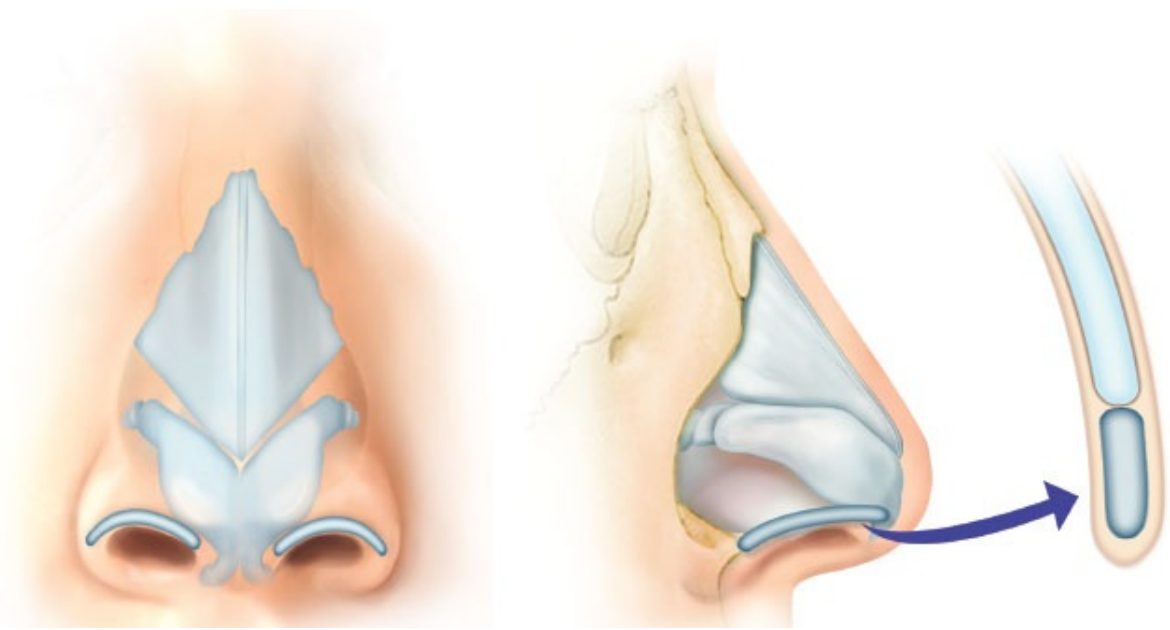


FIG 1 • Alar contour grafts.

SURGICAL MANAGEMENT

- It is crucial that the correct diagnosis is made to ensure the most accurate surgical treatment. Most crucially, if the patient has had severe mucosal loss and shortening due to previous surgery, this must be disseminated to the patient. This is a much more difficult problem to correct and may require mucosal grafts or other interventions beyond placing ACGs.
- In a virgin nose, alar retraction, notching, and collapse, both static and dynamic, can be treated with operative placement of ACGs. It is important to note the position of the LLCs as well. If they are cephalically oriented, some inferior repositioning may be indicated as well using lateral crural strut grafts or other techniques.

PREOPERATIVE PLANNING

- A discussion regarding the patients' concerns of lower nasal shape and alar position should be undertaken. The patient must understand that although this maneuver has a powerful impact on alar position and deformity correction, there is a definite possibility of only partial correction or asymmetry.
- Examination under anesthesia is performed prior to local injection and intranasal oxymetazoline-soaked pledget placement. This examination will help ensure that there is no internal mucosal shortage or scarring that can add to any alar deformity.

Positioning

- The patient is intubated and positioned on the table supine. The most cephalic portion of the head extends just beyond the table. One may choose to place the patient slightly asymmetrically on the table with the head and body closer to the edge of the bed to the surgeon's dominant hand side. If needed or desired, one may utilize a "head-up" position to 15 degrees to minimize venous pooling in the operative field.

Approach

- Although placement of ACG can be accomplished through medial or lateral approach, the authors prefer an open, medial approach. The transcolumellar, infracartilaginous incisions allow direct visualization and access to the desired location of the grafts. A laterally based approach through a radial incision within the base of the lobule on the mucosal side can be utilized but has the added difficulty of challenging angles of dissection and placement, as well as confirmation of the depth of placement.

TECHNIQUES

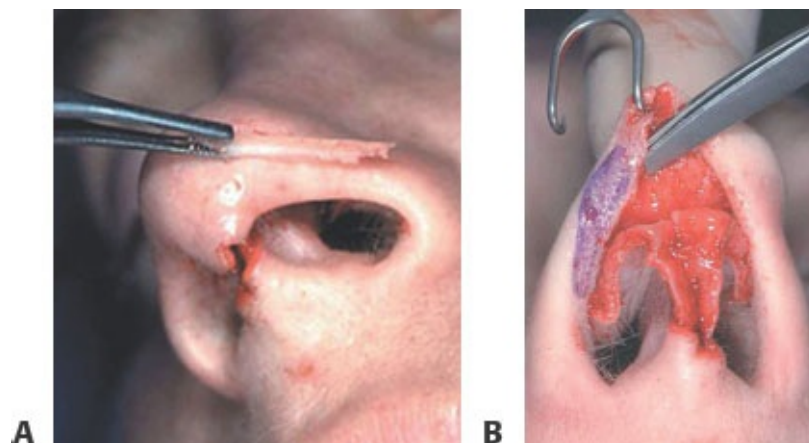
■ Open, Medial Placement (Preferred Technique)

- A stair-step transcolumellar incision with bilateral infracartilaginous incisions is used to open the soft tissue envelope.
- The placement of the ACGs is performed at the end of the procedure, immediately prior to closing, because these grafts are delicate and can tend to become misplaced or fracture during soft tissue envelope manipulation.
- First choice cartilage is septal cartilage because it can be harvested within the primary surgical field, but an ear or rib cartilage graft may be used if septum is unavailable. A double hook is utilized to place traction on the soft triangle/columellar region to create tension for accurate dissection.
- The ACG pocket is carefully dissected between the vestibular and nasal skin below the infracartilaginous incision by using long, sharp Stevens scissors.
- The pocket should be carried down into the alar lobule and ideally to the level of the alar base.
- This dissection will secure the pocket for graft placement.

- Once the grafts are placed into their pockets, the nasal skin is redraped for closure.
- Any excess cartilage extruding medially from the pocket is resected^{1,2} (**TECH FIG 1**; Video 1).



Video p1-c070



TECH FIG 1 • **A.** Planned location for placement of ACG. **B.** Dissection of pocket for ACG placement.

■ Lateral Placement—Open Approach

- This technique helps placing the ACG via a radial incision within the alar base/alar lobule.
- A no. 15 blade is used to create a 0.5-cm incision in the base mucosa.

- Use a double hook to extend the alar rim laterally and create tension for dissection of a pocket.
- Carefully place Stevens scissors into the incision and spread, aiming toward the soft triangle until the tips are visible within the space at the edge of the infracartilaginous incision at the level of the soft triangle.
- Place the grafts from lateral to medial and excise the excess cartilage at the lateral margin of the incision.

■ Closed Approach

- This is a blind technique that requires extensive experience in rhinoplasty prior to attempt and has high risk for misplacement or asymmetric placement.
- Once the domes of the LLC have been delivered and there is a medial pocket rostral to the soft triangle, careful dissection with Stevens or Converse scissors is used to create a pocket along the alar margin between the mucosal and skin envelope.
 - This requires bimanual palpation and constant checking to ensure accurate pocket dissection.
- Ensure dissection laterally to the same position bilaterally with palpation of scissor tips at the same position on each side.
- Place the grafts in the same manner and excise the excess medially.

PEARLS AND PITFALLS

Asymmetry	■ It is important to note that although alar contour grafts are not large (measuring on average 2 to 3 mm in width and 1.5 cm in length), they must be of equivalent size, strength, and design. If the grafts are not nearly identical in both dimension and strength, these powerful grafts can cause tip deviation toward the weak side or asymmetric alar contour upon healing.
Avoid nasal skin buttonhole	■ Use curved Stevens scissors with tips pointing toward the mucosal side at all times. This provides an anatomic dissection and ensures that if a rent is created in the soft tissue envelope, it is on the more forgiving mucosal side.
Difficulty	■ Cut the leading edge of the graft on an angle of 30 to 45 degrees for

of placement

an atraumatic advancement of the graft into the pocket. Undue force on the graft upon placement can result in fracture of this delicate graft.

POSTOPERATIVE CARE

- Nasal dressing is placed at surgery end.
 - Bacitracin-soaked 1 × 1 cm surgical squares are used to support the soft triangle where no suture is placed to avoid a teardrop nostril apex.
 - Taping is done to support and minimize swelling of the nasal tip.
 - A Denver nasal splint is also applied. Doyle splints are also commonly applied after septoplasty.
- Tape and splints are removed at postoperative day 7 when the transcolumellar incision sutures are removed.
 - Patients are started on saline intranasal spray and topical antibacterial ointment for the incision.
- Patients are encouraged to keep head of bed elevated while sleeping for the first 2 weeks to improve edema.
- No nose blowing for 2 weeks postoperatively
- Exercise is reintroduced on a graduated scale, beginning with light exercise at 2 weeks, heavy exercise (ie, jogging) at 4 weeks, and heavy lifting allowed and inverted maneuvers (ie, yoga head stands, etc.) at 6 weeks.

OUTCOMES

- Outcomes are well documented in the literature showing improvement in alar position, external nasal valve function, as well as prevention of postoperative alar complications such as collapse, notching, and retraction.^{2,5,6}

COMPLICATIONS

- Complications related to ACG are minimal. It is a low-risk maneuver used to improve alar aesthetics and prevent complications. One must be cautious to avoid placing asymmetric grafts because this could influence tip position and cause asymmetry of tip position.

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71 Techniques for Treating Nasal Airway Obstruction

CHAPTER

Michael R. Lee

DEFINITION

- Nasal airway obstruction (NAO) is a clinical diagnosis established through a focused history and physical examination. All patients undergoing rhinoplasty should be assessed for NAO.
- The external nasal valve is located at the nostril. Nasal ala forms the lateral aspect of the valve, whereas the columella makes up the medial portion. Collectively, these structures with the soft triangle create the external valve.
- The internal nasal valve is formed by the junction of the caudal portion of the upper lateral cartilage with the dorsal nasal septum.
- Nasal septum is the anatomic structure that divides the nasal cavity. Made of bone and cartilage, the septum provides support for the nasal dorsum and tip.
- Inferior turbinates are paired bones that extend medial into that nasal cavity from the lateral nasal wall. Turbinates regulate nasal airflow characteristics and provide mucociliary clearance.

ANATOMY

- NAO typically occurs at one of four areas:
 - External nasal valves
 - Internal nasal valves
 - Nasal septum
 - Inferior turbinates
- Understanding the anatomy of these structures is fundamental to treating NAO in rhinoplasty.
- The external nasal valve relies on structural support of the lower lateral cartilages and adjacent soft tissue.

- Lateral support is provided by fibrofatty tissue of the nasal ala and structural integrity of the lateral crura.
- Medial support is provided by the caudal septum, medial crura, and soft tissue of the columella.¹
- The term basal aesthetic lines (BALs) is used to describe this lateral border of the columella. BALs should exhibit a smooth slightly concave slope with no protrusion into the nostril (**FIG 1A**).
- Each upper lateral cartilage is supported cephalically by the nasal bone, laterally by the frontal process of the maxilla, and medially by the dorsal nasal septum.
- As form and function are closely related in rhinoplasty, structurally sound middle nose anatomy is usually associated with ideal dorsal aesthetic lines (DALs).²
- Confluence of the caudal upper lateral cartilage and dorsal nasal septum is most often a site of NAO as it forms the internal nasal valve.
- The internal nasal valve is the area of greatest restriction in terms of nasal airflow (**FIG 1B**).
- The nasal septum provides crucial support for the external nose.
- Seated firmly on the maxillary nasal spine, the septum provides support for the overlying upper and lower lateral nasal cartilages.
- The dorsal septum is responsible for creation of the internal nasal valve.
- The caudal septum extends beyond the maxillary nasal spine and provides structural support for the medial nasal base.
- It is flanked by medial crura and intimately related to soft tissue structures of the columella.¹
- The inferior turbinate extends from the lateral nasal wall into the lower nasal cavity.
- Its proximity to the internal nasal valve makes hypertrophy problematic when present.
- Although turbinate architecture is primarily a function of the bone, the overlying erectile tissue and surface mucosa contribute greatly to nasal function.
- Erectile tissue fluctuates, thereby altering nasal resistance, and directly influences nasal airflow.
- The respiratory mucosa provides immunologic benefit and mucociliary clearance.

DIFFERENTIAL DIAGNOSIS

- Stenosis/collapse of the external nasal valve
- Stenosis/collapse of the internal nasal valve
- Septal deviation
- Septal spur formation
- Inferior turbinate hypertrophy
- Nasal mass or polyp

PATHOGENESIS

- Intranasal deformity may result from congenital development, traumatic injury, or iatrogenic insult. Changes in nasal support and physiology may occur with aging resulting in NAO.
- Traumatic injury to the nasal septum may be classified by fracture patterns.³
 - High-impact trauma is associated with multiple septal fractures and displacement from the maxillary nasal spine.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Relevant history in the obstructed patient includes laterality, timing and duration, worsening or alleviating factors, perennial or seasonal response, prior nasal surgery or trauma, and associated symptoms.

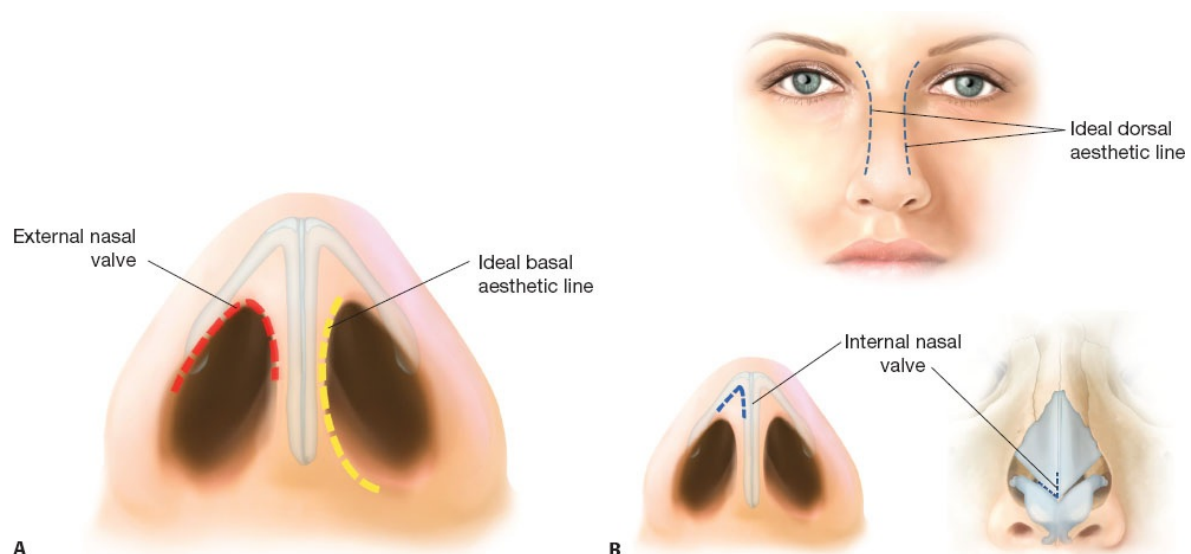


FIG 1 • A. Diagram of the external nasal valve. Nasal ala constitutes the lateral valve, whereas the columella creates the medial aspect. Note the ideal basal

aesthetic line. **B.** Diagram of the internal nasal valve. Amalgamation of the caudal edge of the upper lateral cartilage to the dorsal septum creates the valve. Note the ideal dorsal aesthetic line.

- Progressively worsening symptoms and associated epistaxis should raise concern for neoplasm.
- Inspection of the nasal airway begins with study of the nasal base at rest and during respiration.
- The external valve is assessed initially.
 - Inspection should reveal a patent nostril, free of obstruction.
 - At rest, the lateral nostril (nasal ala) should demonstrate a stable, convex architecture.
 - The medial nostril (lateral columella) should exhibit ideal BALs.
 - External valve stenosis may be the result of obstruction from either of these directions.
 - Assessment during respiration is also performed to determine if collapse of the external valve is responsible for symptoms.
- Inspection of the internal nasal valve is accomplished with a nasal speculum. Care must be used to avoid widening of the valve on speculum insertion.
 - The upper lateral cartilage caudal margin can be readily appreciated through the nasal mucosa.
 - The angle created by the junction of this caudal margin and the dorsal septum is assessed.
 - A narrow angle at baseline suggests stenosis of the valve.
 - Collapse of the internal valve on respiration may also be identified as a cause for NAO. The Cottle test can confirm internal valve insufficiency.
- Evaluation of the septum also begins at the nasal base.
 - Deviation of the caudal septum to either side can obstruct the external valve.
 - Palpation and manipulation of the columella will clearly identify caudal septum position.
 - Examining the dorsal septum and septal body is performed with nasal speculum.
 - Deviation of the dorsal septum is determined as this may cause stenosis of the internal nasal valve.
 - The body of the nasal septum is surveyed for deviation and spur formation,

either of which may cause NAO.

- The inferior turbinate is next examined also with use of a speculum.
 - Turbinate size, position, and tissue characteristics should be noted.
 - A large, boggy inferior turbinate with a bluish hue is associated with allergic response. These patients will likely have some degree of refractory symptom despite surgical reduction.
 - The location of turbinate hypertrophy guides surgical reduction and should be noted.
- Topical oxymetazoline is applied to determine the response to medical decongestant.
 - If topical treatment results in symptom resolution, a medical management trial is warranted. This often includes topical steroids and routine nasal toilet.
- Intranasal examination should also rule out less common etiologies of nasal obstruction such as nasal polyps and neoplasms.

IMAGING

- Although plain radiographs and computed tomography can be used to evaluate nasal septum and turbinate position, they are not routinely required. NAO is a clinical diagnosis that results primarily from a focused history and physical examination.
- If concerns arise of other NAO causes, such as neoplasms or polyps, proper consultation and imaging are warranted.

NONOPERATIVE MANAGEMENT

- Patients who display any suggestion of an allergic component to their NAO should undergo a medical trial.
- Patients with allergic rhinitis are typically treated with reduced exposure to allergens, nasal irrigation with saline sprays, nasal steroids, and occasionally oral antihistamines.
 - Severe cases may benefit from immunotherapy.
 - Otolaryngology consult should be considered.

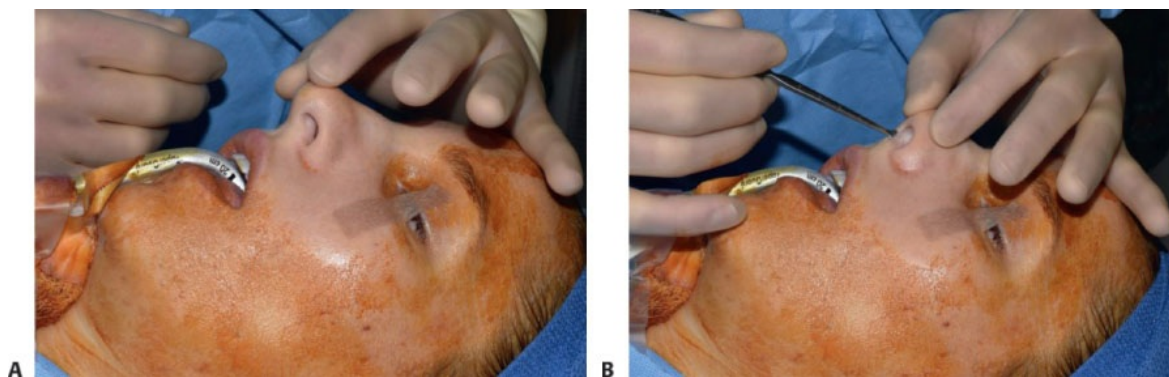


FIG 2 • A. Palpation and inspection of the nose can provide information on tip support. **B.** Help determine caudal septal position.

- Reassessment of these patients after 6 weeks of medical treatment should then be performed.
- If symptoms persist in the presence of obvious physical obstruction(s), surgical correction of the airway should be considered.

SURGICAL MANAGEMENT

- Surgeons should approach the nasal airway in a methodical manner.
- Preoperative assessment identifies the areas of concern as listed above.
- A detailed operative plan should be outlined to correct each of these problematic sites.
- Surgeons should be cognizant of the potential to create iatrogenic obstruction and avoid such sequelae.

Preoperative Planning

- Following proper diagnosis, patients are to be educated on anticipated outcomes.
 - Structural deformities of the nasal valves, septum, and turbinates are easily corrected with septorhinoplasty.
 - However, patients with any physiologic component to their NAO should be counseled about potentially persistent symptoms.
- Examination of the nose under anesthesia is performed prior to local injection and prepping of the patient.
 - Both visual and tactile examination of the tip and columella is completed (**FIG 2A**).

- Palpation of the tip helps to determine support and cartilage integrity.
- Gentle manipulation of the columella from side to side can help determine caudal septal position and soft tissue volume (**FIG 2B**).

Positioning

- Once in the operating room, the patient is intubated and positioned on the table.
- The most cephalic portion of the head extends just beyond the table.
- The stretcher may be placed head up to 15 degrees to minimize venous pooling in the operative field (**FIG 3**).
- A throat pack is gently placed and removed at surgery conclusion.
- Local anesthetic with epinephrine is injected into the planned incision sites.

Approach

- Treatment of the nasal airway can be accomplished through an open or closed rhinoplasty.
- A closed approach is often used to improve alar support with grafts,⁴ correct deviation of the septal body, and treat inferior turbinate hypertrophy.
- The open approach rhinoplasty provides better visualization to the dorsal septum and internal nasal valve.
- The following techniques will be described as if all areas of the nasal airway are being corrected during an open approach septorhinoplasty.

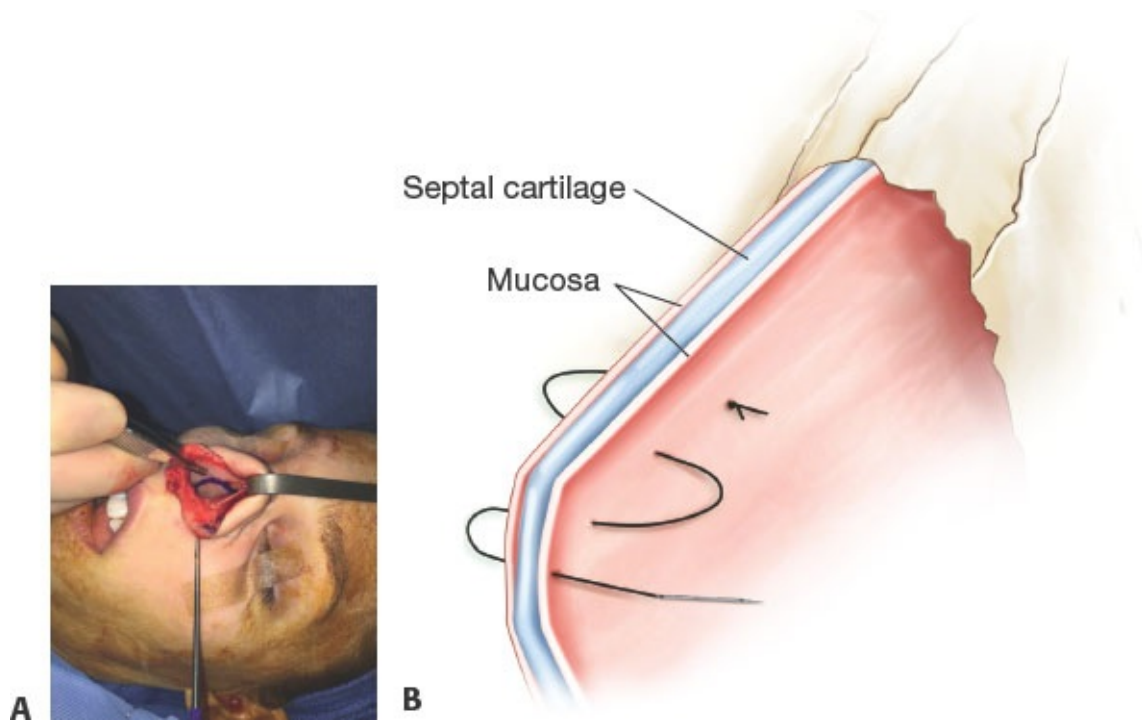


FIG 3 • Positioning of the patient for septorhinoplasty.

TECHNIQUES

■ Septoplasty

- A transcolumellar incision is connected to bilateral infracartilaginous incisions to open the nasal envelope, exposing the nasal bones and cartilages.
- Dissection is continued to the anterior septal angle.
- Bilateral mucosal flaps are elevated away from septal cartilage and bone.
 - It is of the utmost importance to dissect directly on the surface of the septum as it is a bloodless plane.
- Once there is broad exposure of the septum, the upper lateral cartilages are separated from the dorsal septum.
- Prior to resecting the septal body, it is necessary to perform any planned reduction of dorsal or caudal septum.
 - This sequence ensures that at least 1 to 1.5 cm of L strut can be preserved for nasal support.
 - With preservation of adequate L strut, the deviated septum or spur can be resected (**TECH FIG 1A**).
- A Cottle elevator is used not only to elevate the septal flaps but to disarticulate the bony cartilaginous junction.
 - There is significant variation in bony cartilaginous junction patterns.³
- Using scalpel, the marked septum is resected.
 - This cartilage can be used to create spreader grafts and alar contour grafts.
- At the end of surgery, the mucosal flaps are placed together using a weaving transmural septal suture (**TECH FIG 1B**).

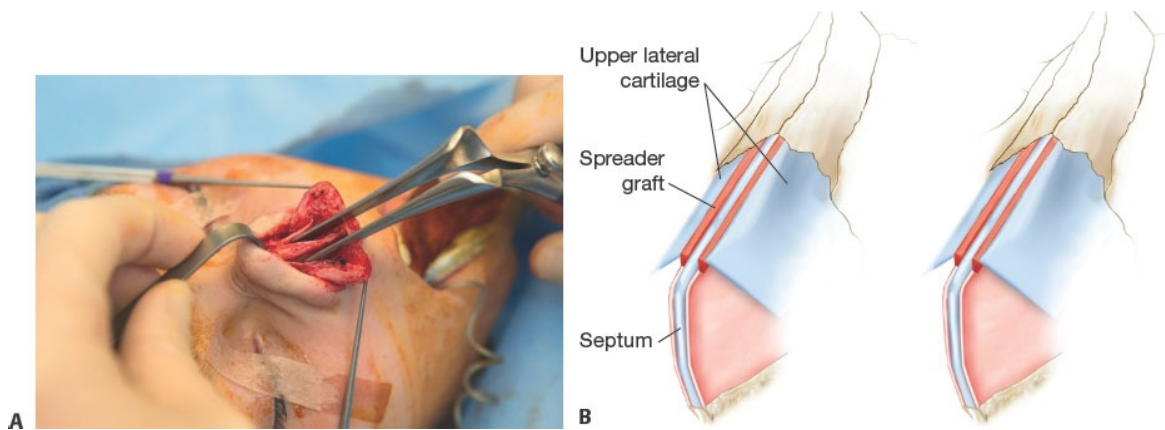


TECH FIG 1 • A. Preservation of adequate septal support is crucial. It is equally important to ensure preserved caudal septum rest sufficiently on the maxillary spine. **B.** Illustration of a weaving septal suture to approximate the septal mucosal flaps. Most commonly, a gut suture on a straight needle is used.

■ Internal Nasal Valve Repair

- Spreader grafts are an effective method of repair for internal nasal valve stenosis or collapse.
- Once the upper lateral cartilages are separated from the dorsal septum (**TECH FIG 2A**), grafts can be readily placed and secured.
- Graft length requires that they extend from underneath the nasal bones to the level of the internal valve. This can easily be measured when creating the grafts.
- Graft width is often 2 to 3 mm but may be balanced with aesthetic goals.
- If widening of the middle nose is to be avoided, grafts may be placed lower, thus allowing the upper lateral cartilages to advance over the grafts and join the dorsal septum (**TECH FIG 2B**).

- Once in position, the grafts are sutured with 6-0 polydioxanone suture.



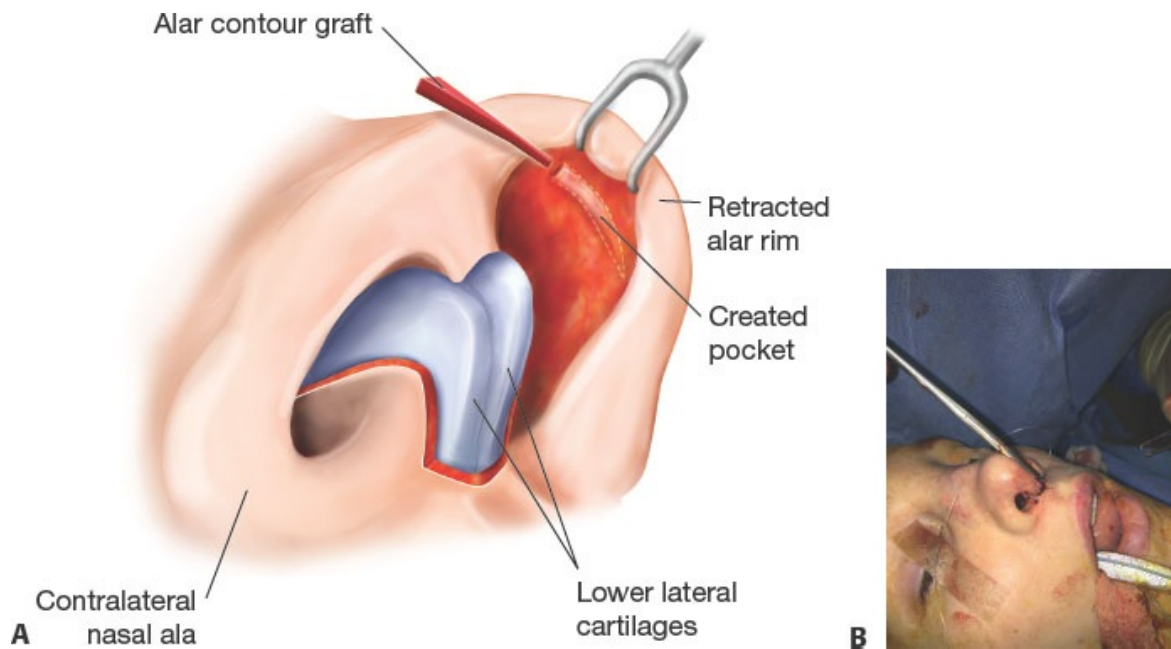
TECH FIG 2 • A. Separation of the upper lateral cartilages from the dorsal septum is required to place an internal nasal valve spreader graft. The overall goal is to widen the valve angle and increase support during respiration. **B.** Spreader grafts should extend from underneath the nasal bones to the internal nasal valve. They may be positioned lower if widening of the middle nose is of great concern.

■ External Nasal Valve Repair

- Repair of the lateral external valve involves fortification of the nasal ala.
 - Several different cartilage grafts have been described, but the alar contour graft⁴ is suitable for most situations.
 - These grafts are typically created 2 mm wide and 8 to 10 mm in length.
- The ala is then carefully retracted with a double-prong skin hook.
 - Fine scissors are used to create a pocket just cephalic to the alar rim margin (**TECH FIG 3A**).
- Repair of the medial external nasal valve involves classifying the existing deformity.⁵
 - These deformities may be abnormal volume and/or position of the caudal septum, medial crura, and columellar soft tissue.¹
 - The caudal septum can be freed from adjacent soft tissue and inspected.
- Straightening of a deviated caudal septum may be accomplished with

excision when appropriate.

- If excision is not a viable option, scoring and repositioning to the midline with suture fixation are performed.
- Abnormal or premature medial crura footplate flare is corrected using the medical crura footplate approximation (MCFA).⁶
 - The MCFA includes making stab incisions at the site of footplate flare.
 - Then, the footplates are weaved together with polydioxanone suture, after which the incisions are closed (**TECH FIG 3B**).
- Understanding tissue dynamics of the lower lateral cartilages is important when influencing medial crura shape and position.⁷



TECH FIG 3 • A. Alar contour grafts are a reliable way to improve structural support of the lateral external nasal valve. **B.** Treating a base deformity of the columella with the MCFA can help widen the nasal valve and create ideal BALs.

■ Turbinoplasty

- When treating hypertrophy of the inferior turbinate, the goals are tissue reduction and preservation of function.

- A scalpel is used to make an incision on the anterior surface of the inferior turbinate.
- The incision is carried posterior to the extent that allows introduction of bone-removing forceps.
- An elevator is used to dissect the overlying soft tissue away from turbinate bone.
- Bone and possibly erectile tissue in the location of obstruction are then removed.
- The wound is irrigated and the mucosa laid back into native position.
- The flap can be sutured back into place when needed.
- Submucosal resection (turbinoplasty) allows for bulk reduction to increase nasal airflow while preserving crucial mucosal function.
- An elevator is then used to lateralize both inferior turbinates (**TECH FIG 4**). This move should be highly controlled.



TECH FIG 4 • Following resection of excess bone and erectile tissue, the turbinate is outfractured in a controlled manner.

Relevant anatomy	■ Understand the four common sites responsible for nasal obstruction: (1) external nasal valves, (2) internal nasal valves, (3) nasal septum, and (4) inferior turbinates.
Proper diagnosis	■ Perform a focused history and physical to determine if NAO is a structural problem, physiologic problem, or combination.
Nasal valve physiology	■ Repair of nasal valves (internal and internal) often involves structural strengthening with cartilage grafts.
Comprehensive septal assessment	■ Evaluation of the septum requires attention to the (1) dorsal septum, (2) caudal septum, and (3) septal body.
Principles of turbinate technique	■ Goals of turbinate hypertrophy treatment include reduction of tissue bulk with preservation of mucosal function.

POSTOPERATIVE CARE

- Functional reconstruction of the nasal airway typically requires placement of intranasal splints in addition to external splint.
- Splinting of the nasal airway provides additional support for the internal nasal valves and nasal septum. Moreover, the splints stabilize the lateralized turbinate and may circumvent adhesion formation between raw surfaces.
- The splints are removed at 1 week, and saline nasal sprays are continued for the next 4 weeks.

OUTCOMES

- Nasal valve reconstruction with spreader and alar grafts has been shown to be highly effective in treating nasal obstruction.
- Septoplasty, while effective for treatment of deviation in most patients, has been shown to be less satisfactory in those patients who also have allergic rhinitis.
- Turbinoplasty via submucosal resection has been shown to lower nasal resistance and preserve mucosal function.

COMPLICATIONS

- Nasal valve repair may be complicated by graft malposition and associated

deformity.

- This may manifest as dorsal irregularity in the case of spreader grafts or alar/soft triangle deformity with alar contour grafts.
- Inferior malposition of spreader grafts may actually worsen nasal obstruction if they occlude the nasal valve.
- Septal surgery may be associated with perforation from injury to opposing mucosal surfaces.
- Adhesion formation may occur when two opposing raw surfaces are created.
- Epistaxis and recurrent symptoms are also potential complications of nasal airway surgery.

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Section XII: Facial Skeletal Augmentation with Implants

72 Chin Augmentation With Implant

CHAPTER

Daniel A. Cuzzone and Barry M. Zide

DEFINITION

- Chin augmentation encompasses genioplasty with the use of mandibular osteotomies as well as placement of implants in the form of grafts or alloplastic materials. Herein we do not discuss osteotomies.
- The chin is a defining feature of the lower one-third of the face that connotes a sense of strength to the face.
- Correction of microgenia is desired in about 20% to 25% of patients undergoing rhinoplasty, with the goal of balanced facial symmetry.
- Implant-based augmentation of the chin may be performed with a variety of implant-based materials, each with its own set of benefits and perceived deficiencies (TABLE 1).
- Osteotomies to advance the lower border of the symphysis may accomplish the same thing, but the risks and benefits of each are not described herein.

ANATOMY

- The chin, as an anatomical subunit, is composed of the sublabial area and the pad.
- The mental nerve is the terminal branch of the inferior alveolar nerve. It is a branch of the third division of the trigeminal nerve and is responsible for sensation of the lower lip, portions of the chin pad, and menton (**FIG 1A**, blue

area) except for a small area that is supplied by a sensory branch off the nerve to the mylohyoid (see **FIG 1A**, pink area; **FIG 1B**).

- The location of the mental foramen can be variable (**FIG 2**).
- Anatomical studies have demonstrated that the mental foramen is located inferior to the second mandibular premolar in about 50% of adults, between the first and second premolar in 25%, and posterior to the second premolar in 25% of the remaining population.
- It is located about halfway between the alveolar ridge and the inferior border of the mandible (8 to 10 mm from the inferior border) and is between 2 and 3 cm lateral to the midline.
- It may be lower in vertically short height mandibles.
- The mentalis muscles are paired mimetic muscles that elevate and compress the chin against the anterior mandible and indirectly raise the lower lip (**FIG 3**).

PATHOGENESIS

- Congenital and acquired factors may contribute the most to a hypoplastic mentum.
 - Aging
- Dentures that cause trauma to the mentalis origin may lead to soft tissue ptosis and poor projection.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A pertinent history and physical exam are instrumental in optimal operative outcomes and should include an appreciation for the patient's aesthetic goals, history of prior facial surgery, or orthodontic/orthognathic treatment, and a comprehensive facial examination.
- Point by point assessment of the lower third of the face¹⁻³
 - Lip eversion and position
 - Occlusion
 - Static chin pad thickness (normal 9 to 14 mm)
 - Labiomental fold depth and height
 - Dynamic chin pad motion while smiling (the pad may be effaced and in some cases may descend)
 - Symphyseal narrowness
- Assessment of lip position should be noted.
 - Normal interlabial gap is up to 3.5 mm.

- Normal lower incisal show at rest is 2 to 3 mm.
- Normal upper incisor show is up to 3.5 mm in males and up to 5.5 in females.
- Lower facial height should be noted. Sagittal implant projection will give the face a longer appearance; conversely, if the chin is deficient sagittally but long, an implant will not work well.
- Symmetry of the chin should be noted as well as skin irregularities.⁴

Table 1 Implant Subtypes and Characteristics

Material	Trade Name	Tissue Interface	Pros	Cons	Complications
Polydimethylsiloxane	Silastic (silicone rubber)	Fibrous capsule	Easily carved, easily placed and removed	Bone resorption (if too high), seroma, exposure	Malposition, extrusion, infection (may be salvaged)
High-density porous polyethylene	MEDPOR Su-Por	Limited tissue ingrowth	Versatile	Difficult to remove; requires hardware	Malposition, extrusion, infection (not salvageable)



FIG 1 • A. Sensory distribution of the mental nerve seen in blue and the contribution of the sensory branch of the nerve to the mylohyoid in pink. **B.** Course of the

sensory branch off the nerve to the mylohyoid (denoted by the *dotted white circle*).

- Dimpling may be seen after previous surgery, injury, or facial lesion such as Bell palsy.
- Assess in repose and during animation both from the frontal and profile view.
- When the chin symphysis is narrow, bony advancement may be inadvisable vs prosthetic augmentation.
- Dental occlusion
 - Prominent teeth may evert the lower lip, producing a more acute labiomenal fold. A vertically high implant may worsen this. Also, a skeletally deep bite may seem to shorten the face with the occlusion, allowing the upper teeth to push the lower lip forward.

IMAGING

- High-definition preoperative photography is important for photo documentation and for perioperative planning.
- Views that should be obtained include frontal and lateral, with and without smile. The smile view shows how the chin pad moves dynamically.
- Radiographic evaluation is often reserved for secondary surgical procedures, with short mandibles where the mental foramina may be low, or to evaluate prior hardware.

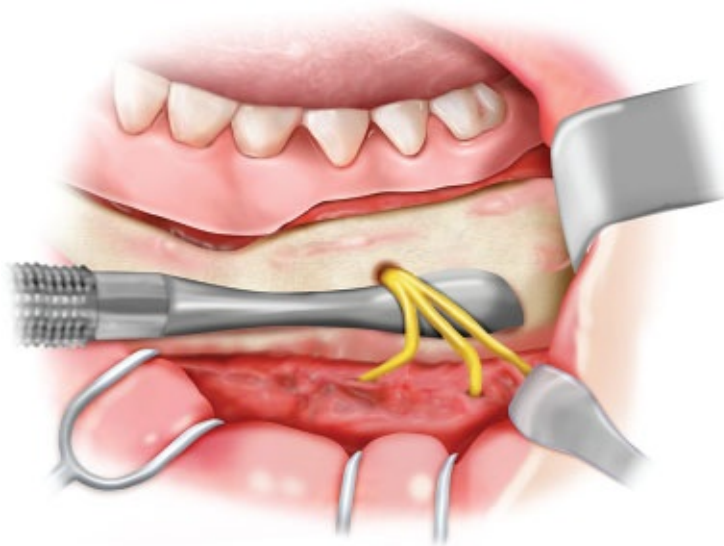


FIG 2 • Mental nerve as it exits from the mental foramen in the body of the mandible at about the level of the second premolar.

IMPLANT SELECTION

- Ideally, only small and medium silicone implants should be utilized because the larger ones tend to result in more erosion.

SURGICAL MANAGEMENT

Preoperative Planning

- Single oral or intravenous dose of antibiotic is provided as per the surgeon's preference.
- Implant-based chin augmentation can be performed under local anesthesia with oral sedation or with intravenous sedation with proper supervision.
- For intraoral placement, Peridex is prescribed starting 2 days prior to surgery, and a presurgical Betadine rinse with a few drops of peppermint oil may be helpful as a prep.

Positioning

- Supine with neck extension, which can be achieved with the use of a shoulder roll

Approach

- Chin augmentation can be performed either through an external submental incision or via an intraoral incision at the gingivolabial sulcus.
 - At least a 2.5- to 3.5-cm incision is needed for porous implants.
- External submental incisions allow more control regarding implant placement, and the incision can be used for cervical procedures.
- Intraoral incisions eliminate a visible scar, but the problem of asymmetric intraoral placement (especially with silicone) or improper placement level may lead to more resorption.
 - Implant placement is technically more difficult.
 - A 2-layered closure is required (muscle and mucosa).
 - The incision can be designed vertically or horizontally.
- Single or two-piece implants (usually porous) may be utilized. Two-piece

implants have flexibility in design and accommodates to the shape of the patients. With intraoral placement of a porous implant, the incision must be larger and intraoral rinse prep is required.

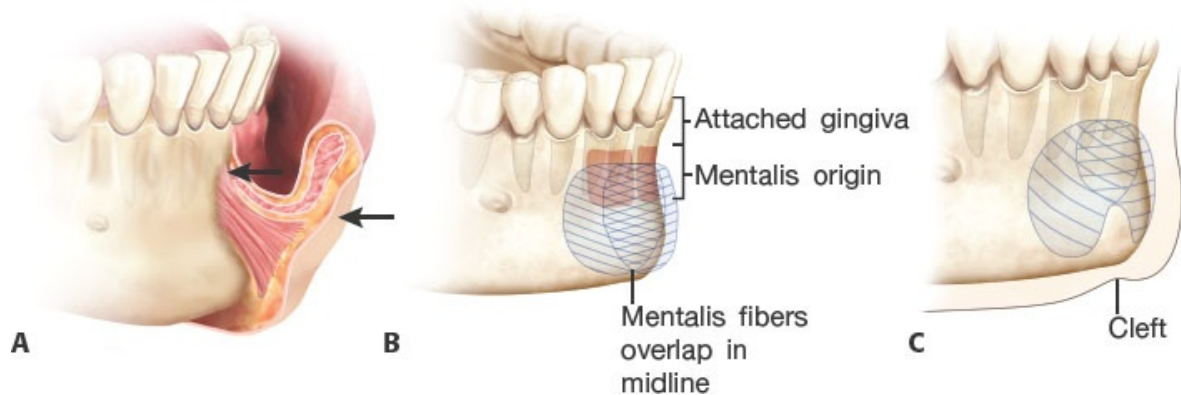


FIG 3 • A. The upper part of the mentalis muscle contains horizontally directed fibers that stabilize the lower lip (*arrow*). The oblique lower fibers allow the lip to pout. **B.** The mentalis muscle is a paired muscle that elevates and compresses the lip. **C.** It may have many configurations, ranging from complete overlap to divergence leading to a cleftlike appearance of the chin.

TECHNIQUES

■ External (Submental) Approach to Chin Augmentation

Markings

- The facial midline is marked extending from the chin pad to the submental area.
- A submental incision roughly 3.5 (for porous polyethylene) or 1.5 cm (for silicone) is marked near or in the submental crease (**TECH FIG 1**).
- Bilateral inferior alveolar nerve blocks are performed using 1% lidocaine with 1:100 000 of epinephrine, with or without bupivacaine.

- The submental incision and preperiosteal space are injected with a 50:50 mixture of 1% lidocaine and 0.5% bupivacaine with 1:100 000 epinephrine.

Porous Polyethylene Implant Precontouring

- While the local anesthetic takes effect, the implant is precontoured.
- The upper portion is pared down (30%–50%) using a bur or knife (**TECH FIG 2A,B**).
 - Note: Su-Por is softer and easier to carve.
- The lateral wings are reduced and tapered as necessary (**TECH FIG 2C**).
- The upper edge anteriorly is tapered at a 45-degree angle using a bur (**TECH FIG 2D**).
- The implant is divided in half, and a pilot hole is drilled in each side, 3 to 5 mm from midline (**TECH FIG 2E**).
 - A second hole may or may not be necessary between the first hole and the end of the implant.



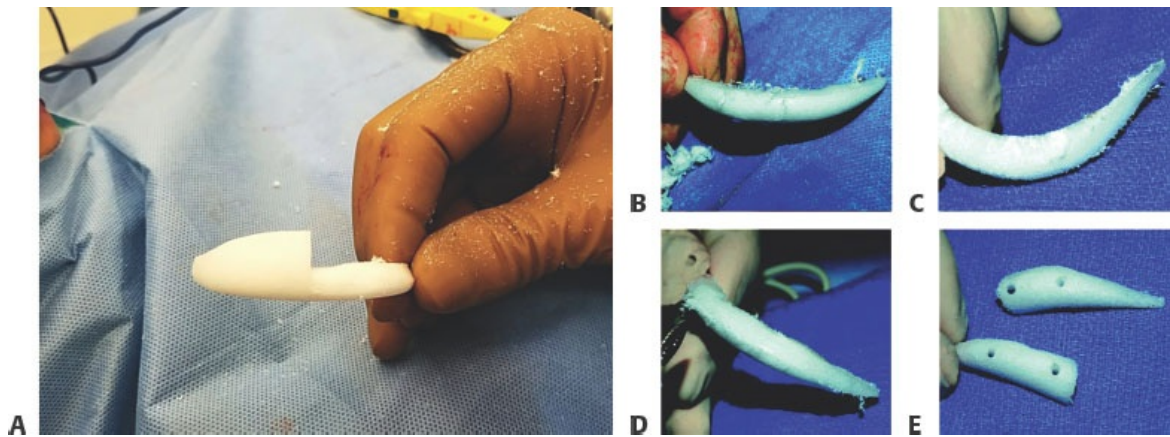
TECH FIG 1 • Marking the facial midline, from labiomental fold to hyoid, and the intended incision. (From Warren SM, Spector JA, Zide BM. Chin surgery VII: the textured secured implant—a recipe for success. *Plast Reconstr Surg.* 2007;120(5):1378-1385, with permission.)

Incision and Exposure

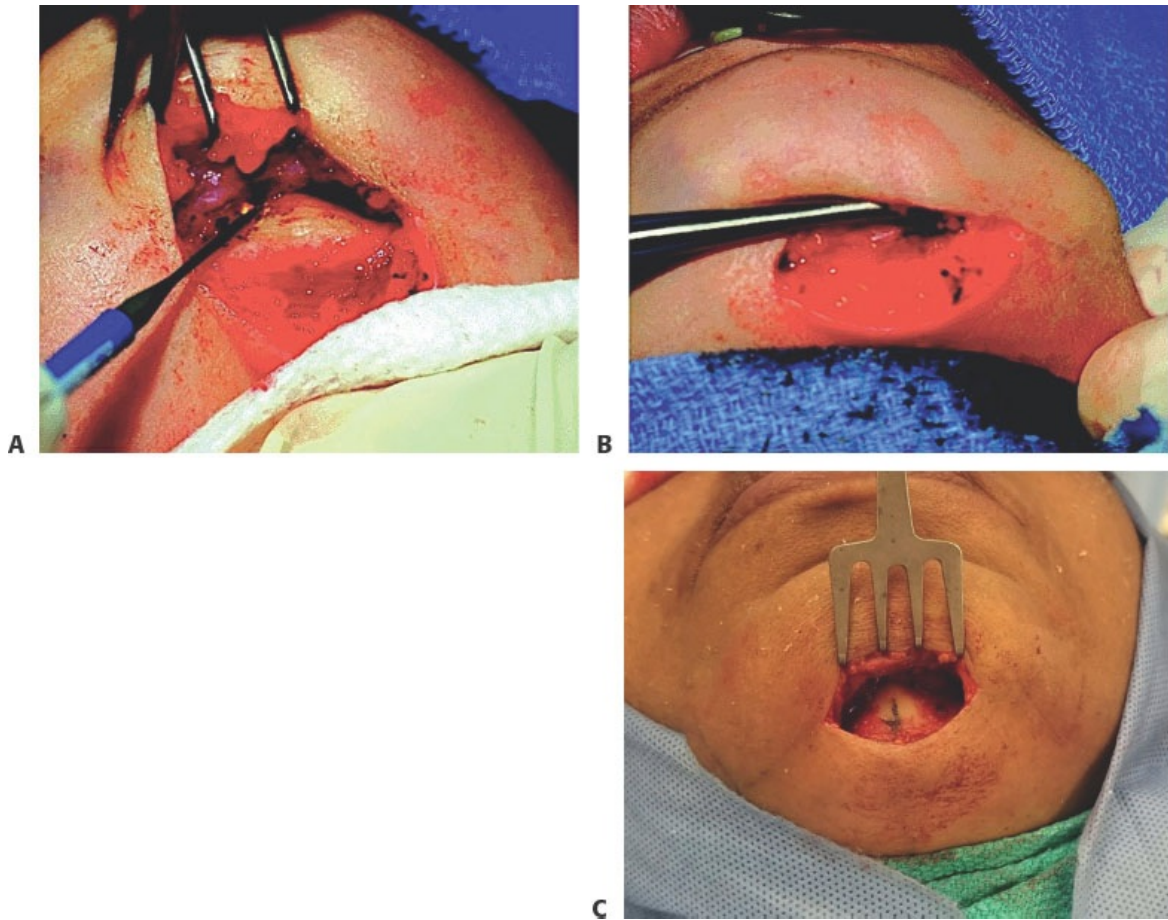
- A no. 10 or 15 blade is used to incise and deepen the submental incision to

the inferior border.

- Needle electrocautery dissection is usually employed down through the subcutaneous tissue to the periosteum. The soft tissue should be cleared from the mandibular border from canine to canine with cautery (**TECH FIG 3A**).
- A periosteal elevator is used to elevate the periosteum, and at the end of the dissection, the elevator is lifted to open the pocket farther (**TECH FIG 3B**).



TECH FIG 2 • A,B. The upper 30% to 50% of the textured implant is removed so that the implant will provide projection only at the pogonion. **C.** The lateral projection of the textured implant is trimmed and then tapered. **D.** Returning to the upper portion of the implant, a bur is used to taper the upper edge at a 45-degree angle. **E.** The implant is divided in the midline, and two drill holes are placed in each half of the implant. The first drill hole is approximately 3 mm from the midline, and the second drill hole is halfway between the first hole and the end of the implant. (**B–E:** From Warren SM, Spector JA, Zide BM. Chin surgery VII: the textured secured implant—a recipe for success. *Plast Reconstr Surg.*(2007);120(5):1378-1385, with permission.)



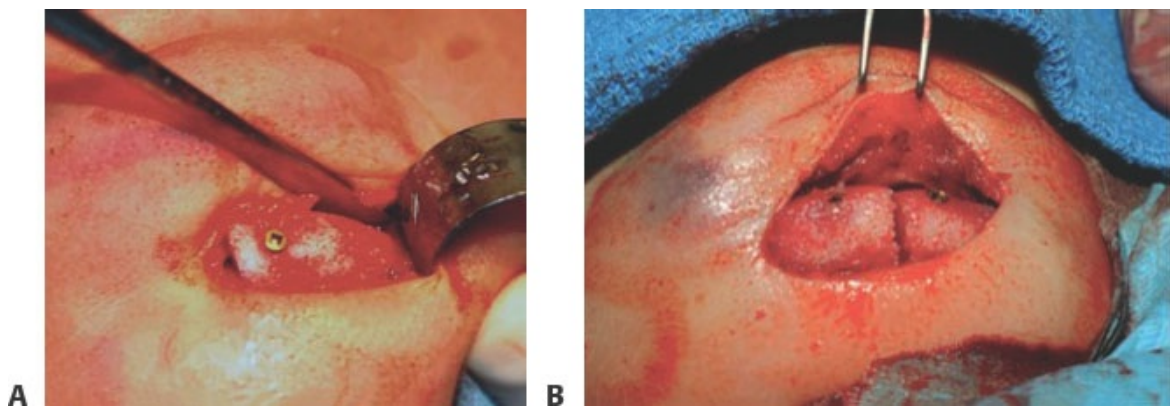
TECH FIG 3 • A. Electrocautery is used to clear the mandibular border from canine to canine, and then a periosteal elevator is used to complete the distal pocket. **B.** At the most distal extent of the dissection, the elevator is levered up to complete the pocket. **C.** A sterile no. 2 pencil is a good way to mark the midline. (**A,B:** From Warren SM, Spector JA, Zide BM. Chin surgery VII: the textured secured implant—a recipe for success. *Plast Reconstr Surg.* 2007;120(5):1378-1385, with permission.)

- Subperiosteal dissection is continued laterally with care not to injure the mental neurovascular bundle that may be viewed. Lateral dissection as required from the midline is performed.
- This dissection is repeated on the contralateral side.

- The midline is marked on the menton using electrocautery, bur, drill, or a sterile pencil (**TECH FIG 3C**).

Implant Placement

- The left or right half of the implant is inserted into its respective pocket, and the central portion is aligned with the midline of the menton.
- According to implant thickness, titanium screws are used for fixation medially.
 - The medial screw is placed through the predrilled pilot hole and partially tightened to allow the lateral part to be positioned.
 - The lateral screw placement holds the implant along the inferior border.
 - Both screws are tightened and countersunk so that the screw head is below the surface of the implant (**TECH FIG 4A**).
 - By only partially tightening the medial screw first, the implant position laterally can be decided perfectly.
- This procedure is repeated on the contralateral side (**TECH FIG 4B**).
- A dependent drain and a Canfield jaw bra are used for porous implants.
- Silicone implants can be placed as a single unit and secured to the periosteum with a suture.
 - Some operators use screws or pins for fixation, but trauma may cause the implant to split.
- The incision is closed in three layers: muscle, subcutaneous tissues, and skin.



TECH FIG 4 • A. The central portion of the implant is aligned with the midline menton mark, and a screw is drilled and sunk through the medial pilot hole. This screw is partially tightened. Then, the lateral segment

of the implant is exposed and held *exactly* along the inferior border. The second screw (lateral) is placed through the predrilled implant pilot hole. **B.** Both screws are tightened completely and countersunk so that the screw heads are below the implant surface to allow for further reduction of the anterior surface of the implant, if necessary (note that neither screw has yet to be satisfactorily countersunk in this image). (From Warren SM, Spector JA, Zide BM. Chin surgery VII: the textured secured implant—a recipe for success. *Plast Reconstr Surg.* 2007;120(5):1378-1385, with permission.)

■ Intraoral Approach to Chin Augmentation

- A midline marking is placed at the level of the pogonion.
- Further markings include the inferior margin of the mandible and the points where lateral undermining would be sufficient.
- Inferior alveolar nerve blocks are performed using 1% lidocaine with 1:100 000 epinephrine.
- Local anesthetic is instilled into the lip mucosa extending to the menton and laterally.
- A no. 15 blade or needle electrocautery is used to make a horizontal or 2 cm vertical or horizontal midline incision on the lip beyond the gingivobuccal sulcus.
 - It is paramount that at least 4 mm of a gingivomuscular cuff be left to facilitate two-layer closure.
- The incision is then carried down to the mandible ensuring that the mentalis muscle can be reattached.
- A subperiosteal pocket is developed using a periosteal elevator.
 - The pocket width is made slightly larger than the implant, but the midline should match the size of the implant correctly.
- The implant is marked in the midline to ensure central positioning.
 - The implant is then inserted into the pocket and placement is confirmed

along the inferior border.

- The incision is closed in two layers to ensure independent closure of the muscle and then mucosa.
- An external jaw bra is placed.

PEARLS AND PITFALLS

Aesthetic considerations

- The key is to bring balance to the lower one-third of the face

Assessment

- Lip eversion
- Occlusion
- Static chin pad thickness
- Labiomenal fold depth and height
- Dynamic chin pad motion while smiling

Dissection

- Avoid damage to the mental nerves by understanding their anatomic position.

External submental approach

- Minimize the length of the horizontal incision to what is needed.

Intraoral approach

- Vertical or horizontal incisions can be used.
- Resuspend the mentalis muscle.

POSTOPERATIVE CARE

- An elastic chin support is worn for 3 days.
- Drain removal (for porous implants) at day 1 or day 2 (if used).
- Soft diet, cool packs to the area, oral hygiene (eg, Peridex, for intraoral approach), and head elevation for 7 days. For an intraoral incision, liquids are continued for 36 hours postoperatively, followed by a transition to a regular diet.
- For intraoral placement, the patient continues the use of Peridex swish and spit for 5 days.
- Suture removal between 4 and 7 days postoperatively with the placement of Steri-Strips.
- Patients are seen within 1 week postoperatively and subsequently at 1, 3, 6

months, and 1 year.

- Patients should be questioned on the presence of numbness; if present, it should improve within 2 to 3 weeks of the operation.

OUTCOMES

- Improvement in chin projection and labiomental fold definition is expected following primary implant-based chin augmentation (**FIG 4**).
- The goal should be to provide lower pogonial projection and a labiomental fold that is not hyperacute.

COMPLICATIONS

- Surgical site infection has been reported between 5% and 7%.^{3,5}
 - Silicone implants may be salvaged in the setting of infection, which is usually the result of unattended bleeding or poor closure.
- Hematoma—rare.
- Capsular contracture is more common with Silastic implants after removal compared to porous polyethylene implants because of tissue integration in the latter. Management may require removal, placement of a different type of implant, or osseous genioplasty.
- Nerve injury often manifests as lower lip numbness. This is often the result of stretch, compression by implant, or transection of the mental nerve.
 - Improvement is usually seen within 2 to 3 weeks. If symptoms persist beyond 3 weeks, trimming of the implant, implant pocket check, or direct nerve evaluation should be pursued.⁶
 - Paresthesias may occur if there is malposition of the implant leading to impingement of the mental nerve. As stated, management often necessitates repositioning or trimming of the implant.

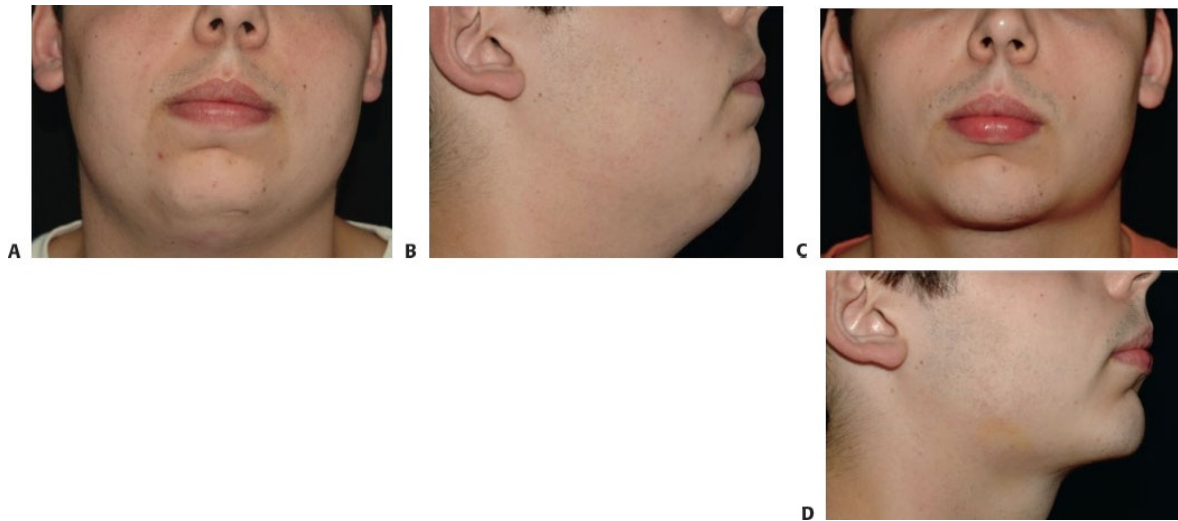


FIG 4 • A,B. Preoperative views of a 22-year-old male with deficient lip eversion, an angle I class I occlusion, and microgenia. The patient underwent primary augmentation with a Medpore implant through a submental incision. **C,D.** Postoperative views demonstrating achievement of normal chin projection and improved labiomental fold definition. It should be noted that the patient also underwent a supraplatysmal and subplatysmal lipectomy. (From Warren SM, Spector JA, Zide BM. Chin surgery VII: the textured secured implant—a recipe for success. *Plast Reconstr Surg.* 2007;120(5):1378-1385, with permission.)

- Chin ptosis may result from damage and insufficient repair of the mentalis muscle, thereby resulting in chin ptosis, lip ptosis, drooling, and increased incisor show. This is more likely with an intraoral approach. Chin pad ptosis may occur following implant removal, overly large pocket, or excessive burring. The capsule may contract and lead to a “balling” appearance. Removal of excess submental adipose and mentalis plication or repositioning may be necessary.⁷
- Mentalis dysfunction may manifest as either muscle spasm or dimpling of the skin of the chin. Botulinum toxin injections may address dimpling of the mentalis muscle.³

- Bone resorption may occur with implant placement.
 - Associated with more bone loss with implant placement above the thick inferior border
- Implant malposition

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73 Techniques for Placing Malar Implants

CHAPTER

Erez Dayan, Dev Vibhakar, and Michael J. Yaremchuk

DEFINITION

- Prominent malar bones are considered attractive and youthful in most cultures.
- The malar area is a dynamic anatomic region of the face composed of underlying skeletal support, adipose tissue, and mimetic muscles of facial expression.¹
- Characterization of the domelike shape of the malar area is largely subjective due to the lack of anthropometric and cephalometric landmarks. The inability to define “average” or “normal” for the malar area makes selection of implant shape, size, and position challenging.
- Malar augmentation using alloplastic implants yields an aesthetic benefit in select patients with relative malar hypoplasia.^{2,3}

ANATOMY

- Skeleton
 - The malar eminence is the most projecting portion of the zygoma. Its convexity extends from lateral to the infraorbital foramen to the midaspect of the zygomatic arch.
 - It is perforated in its midaspect by the zygomaticofacial foramen for the passage of the zygomaticofacial nerve and vessels.
- Muscles
 - Muscles of the midface largely provide facial expression. Those that are freed from their origins during malar augmentation elevate the upper lip and include zygomaticus major, zygomaticus minor, levator labii superioris, and levator anguli oris (**FIG 1**).
- Nerves

- The infraorbital nerve exits the maxilla through the infraorbital foramen and travels beneath the levator superioris and above the levator anguli oris. Its branches supply the skin of the lower lid, the side of the nose, most of the cheek, and the upper lip. This nerve must be identified and preserved.
- The zygomaticofacial nerve exists through a small foramen located on the lateral aspect of the malar bone. It supplies a small portion of the skin of the upper cheek. It is routinely sacrificed during malar augmentation.

PATHOGENESIS

- Most frequently, patients who present for malar augmentation are within normal range and desire more definition, angularity, or balance to their facial contour.
- Studies have demonstrated retrusion of the midface and mandibular skeleton with aging, thus supporting alloplastic augmentation of the skeleton as a component of the facial rejuvenation armamentarium.
- Malar deficiency is often part of a generalized midface deficiency requiring soft tissue evaluation and treatment. As aging occurs, the retaining ligaments of the midface attenuate and soft tissues atrophy, leading to deflation and descent of the malar soft tissue complex.^{3,4}
- Functionally, malar projection provides a platform to support overlaying the soft tissue as well as provide some protection against lower lid descent (**FIG 2**).
- Patients with craniofacial deformities often have functional and aesthetic consequences requiring more invasive osteotomy and skeletal repositioning rather than malar alloplastic augmentation. However, in skeletally deficient patients with normal occlusion, alloplastic augmentation is often a more appealing option due to its less invasive surgery.⁵

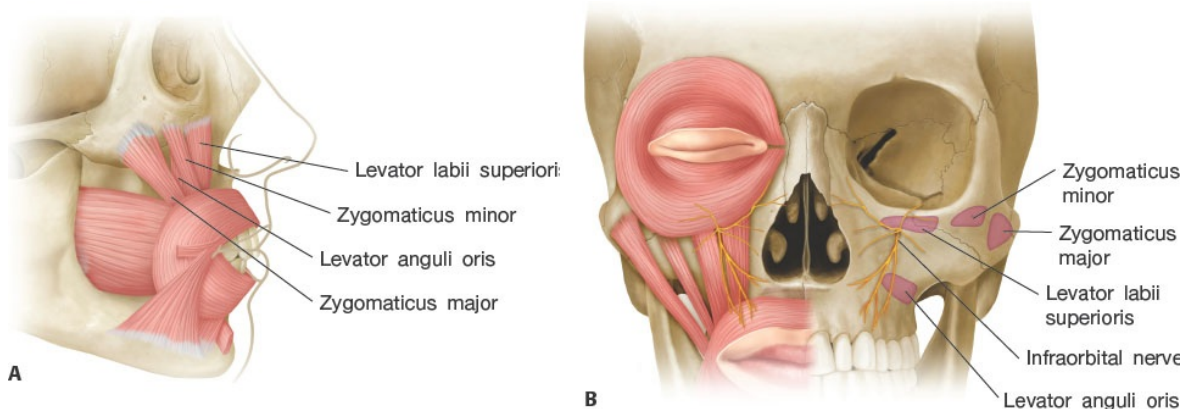


FIG 1 • A,B. Relevant facial musculature and intraorbital nerve in relation to malar implant placement.

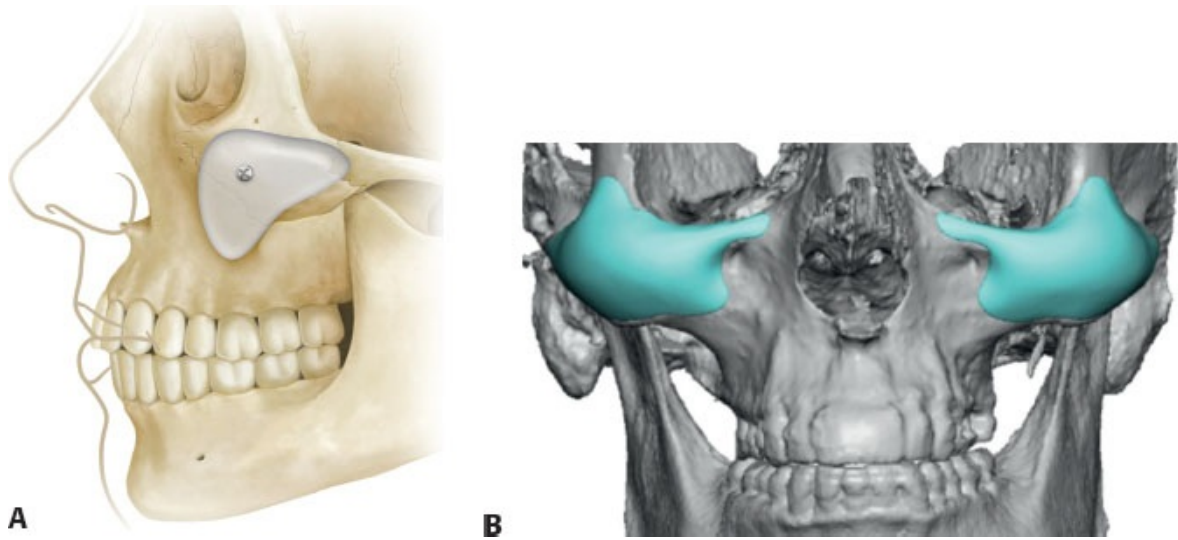


FIG 2 • A,B. Malar implant position on bony skeleton.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination should analyze both skeletal and soft tissue components, as well as overall facial balance. Asymmetries should be noted and demonstrated. It is helpful to review life-sized photos with the patient to define aesthetic concerns and goals.
- History should be obtained for any active or prior history of immunosuppression, connective tissue disorders, coagulopathy, facial trauma, and implanted facial hardware before surgery. Patients should also be asked regarding recent injections of neuromodulators or fillers (temporary or permanent).
- Patients with excessively thin skin, history of irradiation, or sinus disease are poor candidates for alloplastic malar augmentation.
- Patients may present with a desire to enhance aesthetics of other aspects of their face (ie, nose, periorbital region). The surgeon should be able to accurately diagnose malar deficiency and assess its contribution to the overall midface harmony to the patient.
- Malar skeletal augmentation is not a substitute for soft tissue augmentation or repositioning.

IMAGING

- In general, radiologic assessment is not needed. Size and position of malar implants are based on the aesthetic judgment of the surgeon.
- In patients with significant asymmetries, CT imaging may provide an advantage of multiplane views, three-dimensional reconstruction, life-sized models, and the manufacture of custom implants.

NONOPERATIVE MANAGEMENT

- Although fat grafting and synthetic filler injections are logical nonoperative techniques that may aid in restoration of soft tissue volume loss, they have a limited role in simulating the effect of increased skeletal projection.
- The aging process impacts both the soft tissue and skeletal components of the malar region. Depending on patient needs, either or both soft tissue and skeletal augmentation may be appropriate to restore youthful facial contours. It is important for the clinician to be able to differentiate the two. For example, if skeletal augmentation is performed for a patient who requires soft tissue augmentation, it will result in an overly defined appearance. On the other hand, performing fat grafting or filler injections for a patient who requires skeletal augmentation will result in a spherical shape with inadequate definition.

SURGICAL MANAGEMENT

Preoperative Planning

- Informed consent should include risks of infection, extrusion, displacement, asymmetry, deformation, hematoma, seroma, and motor/sensory nerve injury, as well as the risks of anesthesia.
- Prior to the induction of anesthesia, the area desired for augmentation is determined with the patient in a sitting position. This is marked on the surface of the skin.
- The authors' preference is to use general endotracheal or nasotracheal anesthesia. This allows optimal preparation of the operative site and control of the airway. The use of local anesthesia and sedation is an alternative.
- Silicone rubber and porous polyethylene are the predominant implant materials.
- The senior author prefers porous polyethylene implants (**FIG 3**). The implant material is semiflexible to conform to underlying bone when fixed with screws. Its porosity supports fibrovascular ingrowth, which avoids the

potentially soft tissue distorting capsule formation inherent in smooth surface implants.

- The preferred implants are designed to avoid impingement on the infraorbital nerve. Registration tabs aid in symmetric placement.

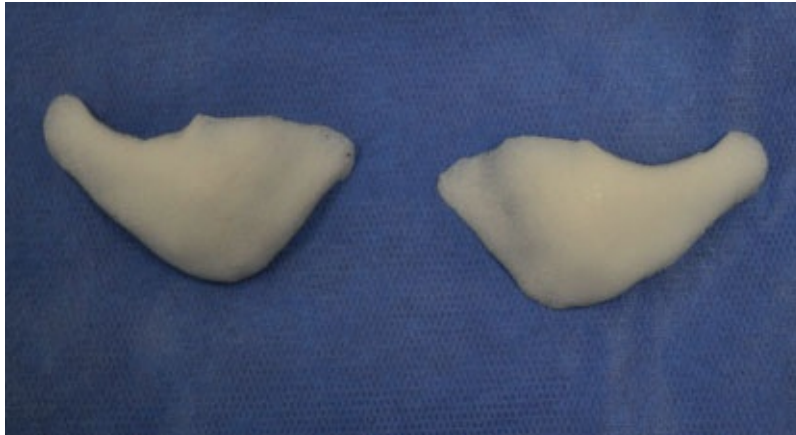


FIG 3 • Porous polyethylene malar implants.

Positioning

- Patients are placed supine on the operating room table at a 90-degree perpendicular position relative to the anesthesiologist to allow for maximal exposure.

Approach

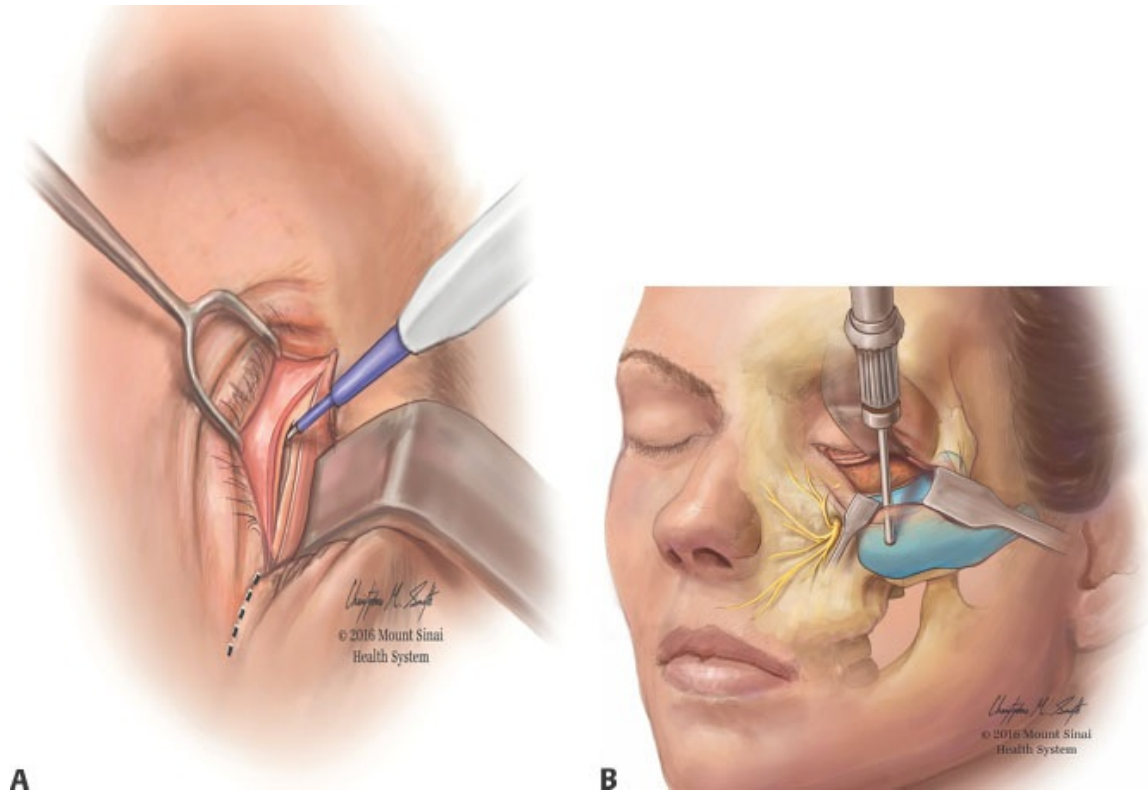
- Malar augmentation may be performed through intraoral, coronal, or eyelid approaches.
- The operative approach depends on surgical preference, implant size, implant placement, and previous facial surgeries.

TECHNIQUES

■ Preoperative Preparation

- Prior to antiseptic preparation and draping, a dilute solution of lidocaine and epinephrine (1:100,000) is infiltrated into the operative site for postoperative pain control and, most importantly, for intraoperative hemostasis.

- Intravenous cephalosporin or ciprofloxacin antibiotic prophylaxis is administered approximately 30 minutes preoperatively.
- 0.12% chlorhexidine gluconate oral rinse is prescribed for daily use beginning 3 days preoperatively and including the day of surgery.



TECH FIG 1 • A. Transconjunctival approach to placement of malar implants. **B.** Screw fixation of malar implant via lower eyelid approach with care to avoid infraorbital nerve. (Printed with permission from ©Mount Sinai Health System.)

■ Periorbital Approach

- The senior author prefers a transconjunctival retroseptal approach with lateral canthotomy (**TECH FIG 1A**).
- Wide subperiosteal dissection of the area to be augmented is performed, with identification and preservation of the infraorbital nerve.
- Implants are available with registration tabs that align with the lateral orbital

rim and proximal zygomatic arch. This allows symmetric placement.

- Screw fixation immobilizes the implant and obliterates any gaps between implant and skeleton (**TECH FIG 1B**). Gaps between the implant and skeleton result in unanticipated increase in malar projection.
- The transconjunctival incision is realigned, the lateral commissure reconstructed, and the orbicularis and skin overlying the lateral orbital wall closed in layers.
- If chemosis is a concern, a temporary tarsorrhaphy stitch of 5-0 nylon is placed until the chemosis is resolved.

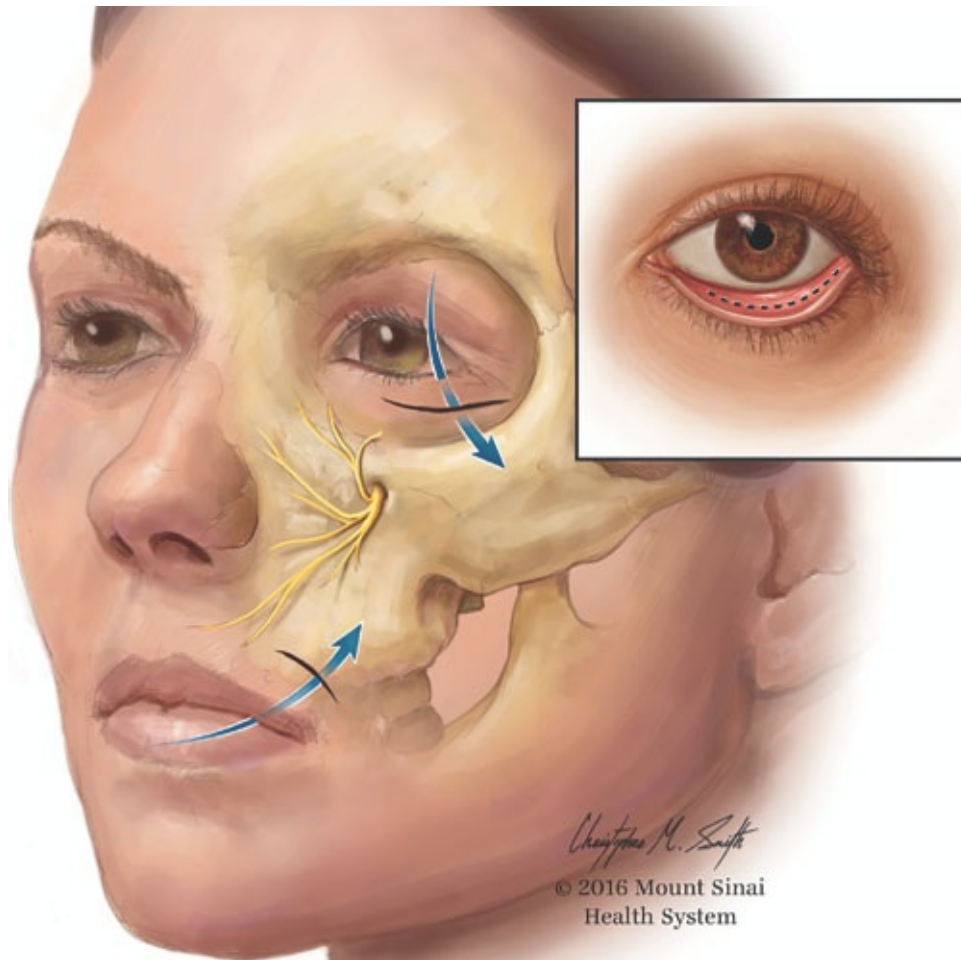
■ Intraoral Approach

Gingivobuccal Sulcus Incision and Dissection

- An upper sulcus incision is made far enough above its apex to allow sufficient tissue for a secure closure after implant placement.
- The dissection is carried to the maxillary bone where the periosteum is incised.
- With careful attention to and identification of the infraorbital nerve, subperiosteal dissection is performed over the malar eminence, up to the infraorbital rim, and onto the zygomatic arch nearly up to the zygomaticotemporal suture (**TECH FIG 2**).
- All efforts are made to avoid excessive bleeding and hematoma formation that predisposes to prolonged recovery and infection.

Pocket Formation

- Subperiosteal pocket dissection should allow for visualization of anatomic landmarks and proper placement of the implant.
- The surgeon should aim to create a pocket slightly larger than the implant itself.
- Of note, extending a malar implant onto the zygomatic arch has a significant impact on midfacial width.
- Implants can be trimmed and contoured with a scalpel or high-speed bur intraoperatively to suit the individual needs of the patient:



TECH FIG 2 • Upper gingivobuccal sulcus and lower eyelid approach to placement of malar implants.
(Printed with permission from ©Mount Sinai Health System.)

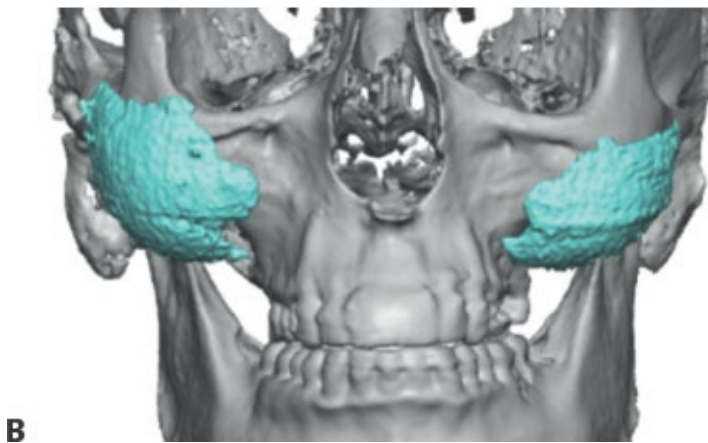
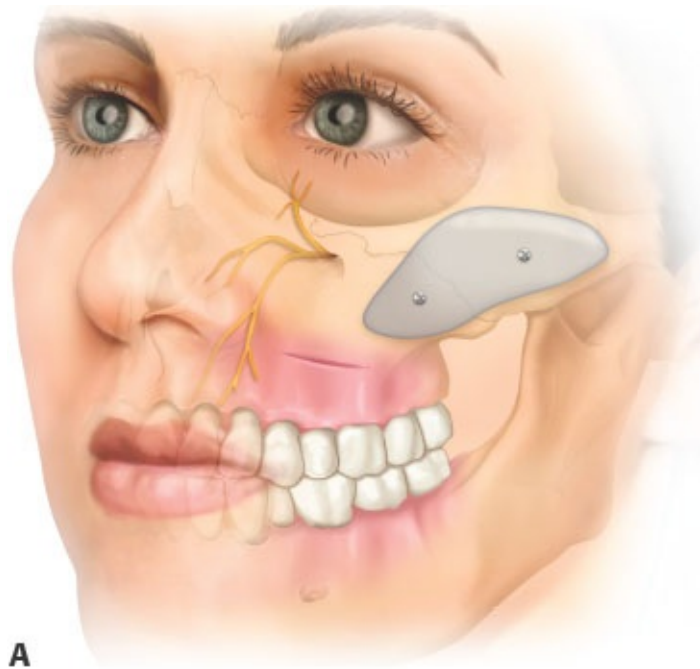
- Hot sterile saline (70°C/106°F) can be used to soften the porous polyethylene implant for further contouring.

Fixation of Implants

- Once satisfactory implant position is achieved, position is ensured with screw fixation of the implant to the skeleton (**TECH FIG 3**):
 - Penetration of the sinus with the screw is of no clinical significance.
- The position of the implant relative to the infraorbital nerve is always visualized at the end of the procedure to be confident that any sensory deficit in the postoperative period reflects retraction-related trauma to the nerve, which is temporary, rather than implant impingement on the nerve, which

will be permanent.

- The wound is irrigated with antibiotic solution prior to closure.
- The intraoral incision is closed with interrupted full-thickness resorbable sutures.



TECH FIG 3 • A. Screw fixation of malar implant via superior gingivobuccal sulcus approach. **B.** CT scan demonstrating unsatisfactory position of implant— asymmetry is not uncommon.

PEARLS AND PITFALLS

Patient selection	■ Implant augmentation best corrects malar skeletal deficiency. Its effect on surface irregularities such as lower eyelid wrinkles or secondary bags is limited. ■ Skeletal augmentation is not a substitute for soft tissue augmentation or resuspension.
Surgical approach	■ Extended eyelid approach provides direct visualization of the skeleton and therefore optimal exposure for symmetric implant placement.
Implant selection and position	■ Extension of a malar implant onto the zygomatic arch impacts midface width. ■ Inadequate exposure of the three-dimensional midface skeleton is a common error predisposing to implant malposition, implant asymmetry, and infraorbital nerve impingement. ■ Registration tabs resting on the infraorbital rim and zygomatic arch assure symmetric implant placement.
Implant fixation	■ Screw fixation assures stable implant position. ■ Screw fixation applies the posterior surface of the implant to the surface of the bone, obliterating any gaps between the implant and the skeleton. Gaps result in unanticipated increases in projection of the implant.
Asymmetry	■ Direct visualization of the area to be augmented, incorporation of registration tabs into implant design, and screw fixation limit likelihood of asymmetry. ■ Minor asymmetries are often aesthetically inconsequential due to overlaying malar soft tissue.
Hematoma	■ All efforts are made to avoid hematoma predisposing to infection.

POSTOPERATIVE CARE

- Suction drains (round no. 10 French) if used are removed the morning after surgery. A supportive tape dressing is placed postoperatively and removed the morning after surgery.
- Oral antibiotics are prescribed for 7 days after surgery (cephalexin 500 mg q8h).
- When intraoral incisions are used, patients are asked to eat a soft diet for 72 hours postoperatively.

- Frequent mouthwashes are advised as well as careful tooth brushing.
- Patients are instructed to refrain from strenuous exercise for 2 to 3 weeks postoperatively.
- Significant edema, in the known absence of hematoma, may be treated with a standard steroid taper prescribed for 6 days.
- The patient is instructed to apply iced compresses to the area for 48 to 72 hours and to sleep with the head of bed elevated greater than 30 degrees or with three or four pillows.
- Follow up is at 1-, 2-, and 4-week intervals. Thereafter, long-term follow-up is at 6 months and 1 year.

OUTCOMES

- Appropriate patient selection and sound surgical technique provide most patients with satisfactory aesthetic outcomes (**FIGS 4 and 5**).

COMPLICATIONS

- Implant malposition, implant asymmetry, and sensory nerve dysfunction are avoided with wide subperiosteal exposure, direct visualization, registration tab implant design, and screw fixation. Although it is often cited that bone resorption underlying the implant is a complication, it is rarely clinically significant with malar implants.
- Infection rates after facial implant surgery are low (less than 2%) when the techniques outlined in this chapter are employed. Acute infection is best managed by implant removal. Bacterial biofilm formation on the implant precludes antibiotic and host resistance efficacy. Antibiotic treatment will suppress the infection during treatment but will not cure it.
- Late infections (greater than 3 months post-op) have not been experienced in the senior author's experience. It is hypothesized that infections that are clinically manifested after 1 month reflect small bacterial contaminations at the time of surgery that are suppressed by host defenses and the postoperative antibiotic regimen.

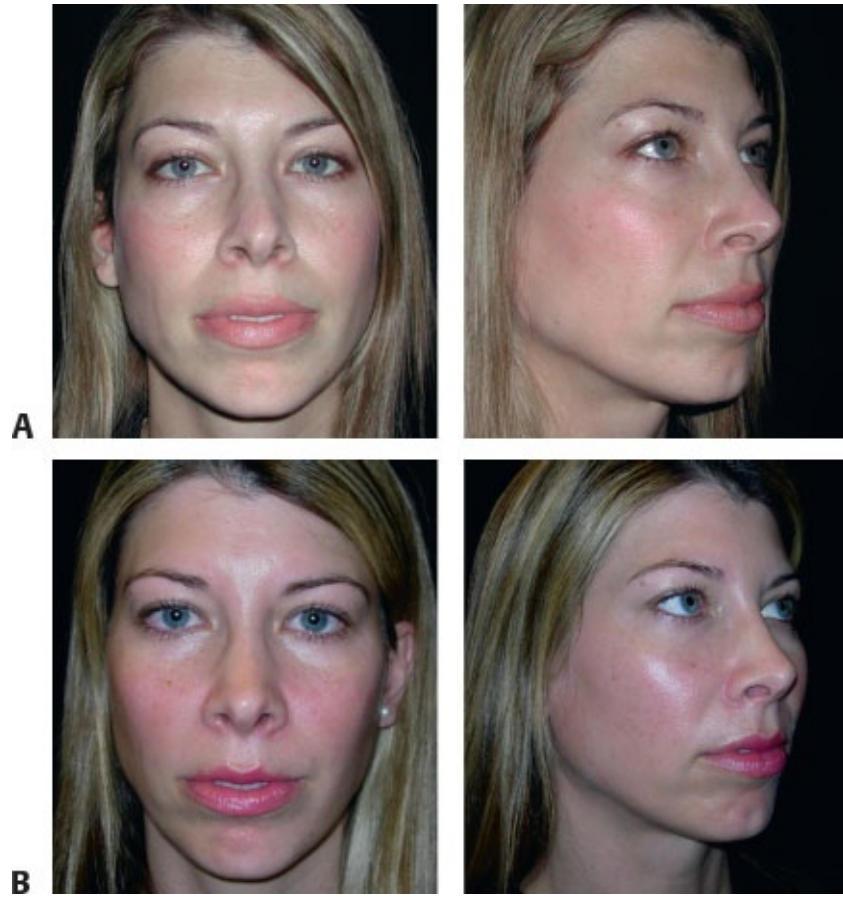


FIG 4 • Before **(A)** and 2 year after **(B)** placement of malar implants.



FIG 5 • Before (A) and 1 year after (B) placement of malar, chin, and mandible implants.

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CHAPTER Mandible Implants

Michael J. Yaremchuk, Dev Vibhakar, and Erez Dayan

DEFINITION

Patients with three types of skeletal morphology can benefit from implant augmentation of the mandibular body, angle, and ramus. These skeletal morphologies include those with:

- Normal dimensions. Most patients who desire mandible augmentation have lower face horizontal dimensions within normal range. These patients either desire a wider lower face (increased bigonial distance) or desire more definition and angularity to the mandibular border.¹
- Skeletal deficiency. Approximately 5% of the population in the United States has skeletal mandibular deficiency leading to a class II occlusal problem. Most of these patients can have their dental relationships corrected by orthodontic treatment, which leaves their skeletal contours deficient. These patients can have their mandibular contours improved with implant augmentation.
- Surgically altered anatomy. Patients with mandibular deficiency who have had their class II malocclusion corrected by osteotomy and rearrangement remain deficient, but in another way.² Resultant displeasing postoperative contours include step-offs at the osteotomy sites and malposition of the aesthetically important angle and ramus. Alloplastic implants, particularly those designed and manufactured by computer imaging, can be used to improve contour in these cases.

ANATOMY

- All transverse facial dimensions are greater in men than in women with the greatest difference being the bigonial distance.²
- Skeletal anatomy

- The aesthetically important portions of the mandible are the chin and ramus. The chin determines lower face height and projection in the midline, and the ramus determines lower face width (**FIG 1A**).
- The mental foramen from which the mental nerve exits lies approximately at the interspace between the two premolars and about midway in the height of the dentulous adult mandible (**FIG 1B**).
- Muscular anatomy (**FIG 1C**)
 - The four muscles of mastication are predominantly responsible for movement of the mandible and include masseter, temporalis, medial pterygoid, and lateral pterygoid muscles. The only muscles of mastication encountered during mandibular augmentation are the masseter and indirectly the medial pterygoid which together form the pterygomasseteric sling.³
 - The buccinator is also encountered during exposure for mandibular augmentation. It is principally a muscle of the cheek and forms the lateral wall of the oral cavity.^{2,3}
- Nerve anatomy (see **FIG 1B,C**)
 - Inferior alveolar nerve is a branch of the mandibular nerve (V3). It enters the mandibular canal alongside the inferior alveolar vessels through the mandibular foramen, which is located in the lingual aspect of the ramus approximately halfway between its anterior and posterior borders. It is important to visualize the path of the inferior alveolar nerve when placing screws to immobilize mandibular implants.³ This nerve (now termed the mental nerve) exits at the mental foramen. It provides sensation to the ipsilateral portion of the lower lip.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Detailed history should include skeletal trauma, orthodontic therapy, or orthognathic procedures.
- Physical examination should explore occlusal relationships, skeletal contour, and relation of the mandible to other facial contours.
- Life-size posteroanterior and lateral photographs can be helpful when discussing aesthetic concerns and goals with the patient.
- Sample implants and model skulls are useful to demonstrate the application and visual impact of facial implant.

IMAGING

- Posteroanterior and lateral cephalograms provide useful data to aid in choosing

an implant to best suit the patient.

- Three-dimensional computerized tomographic scans and the models obtained from their data can be invaluable in designing implants to correct asymmetries associated with congenital, posttraumatic, or postsurgical deformities (**FIG 2A,B**).

NONOPERATIVE MANAGEMENT

- Soft tissue augmentation in the form of autogenous fat grafts or synthetic fillers can simulate the visual effect of skeletal augmentation to camouflage limited skeletal deficiencies.²⁻⁴
- More aggressive soft tissue augmentation may expand the volume of the soft tissue envelope but at the expense of skeletal definition.²

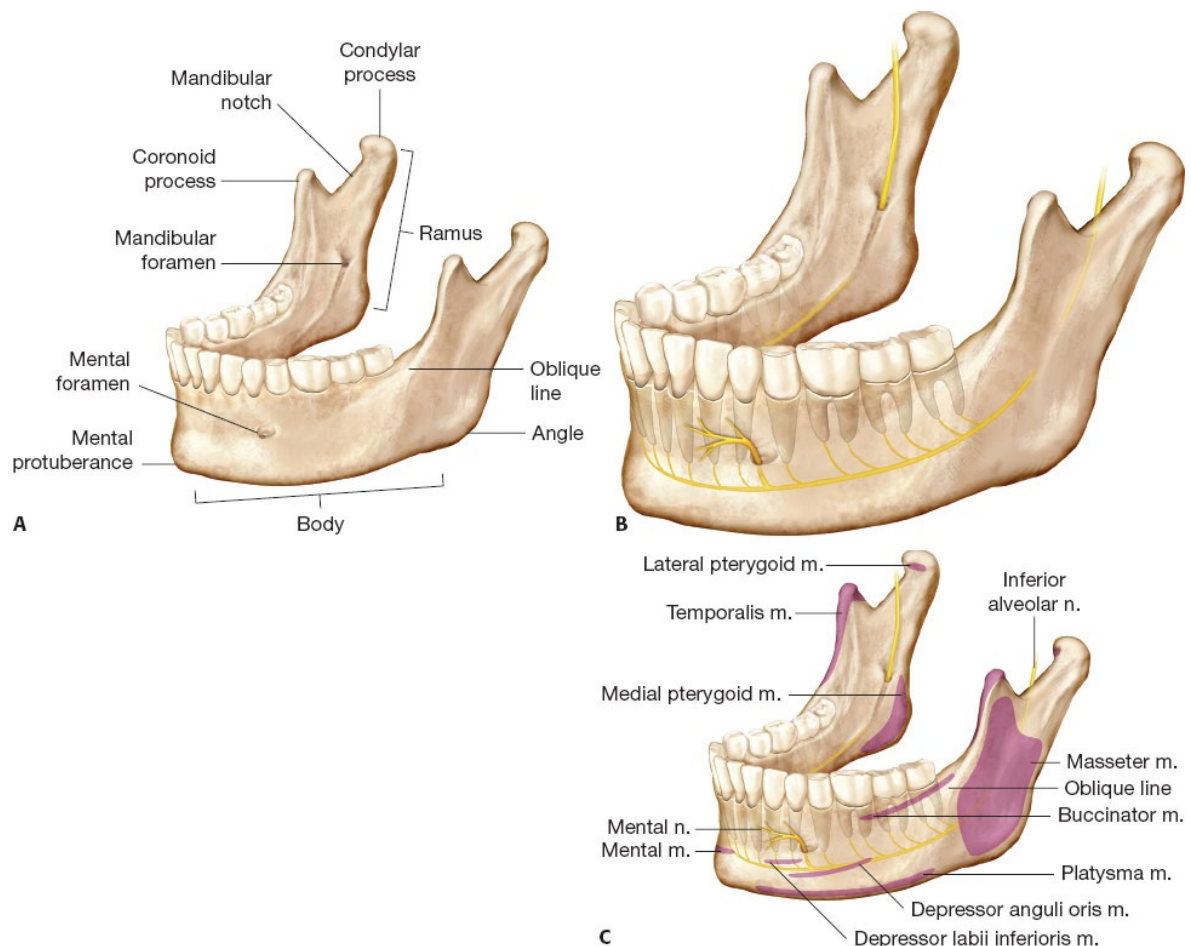


FIG 1 • A. Boney anatomy and relationships of the mandible. **B.** Relationship of mental foramen to dental anatomy. **C.** Muscular anatomy of the mandible.

SURGICAL MANAGEMENT

Preoperative Planning

- Patient history, physical examination, possible imaging, and review of patient photographs as well as pictures of others deemed attractive by the patient are all part of the preoperative planning.
- Numerous implant designs are available to change the shape of the mandible in three dimensions: bigonial width, ramus height, and body length, as well as the inclination of the mandibular border.
- Informed consent should include intrinsic risks and benefits of mandibular augmentation, such as the possibility of infection, extrusion, displacement, asymmetry, deformation, hematoma, seroma, motor/sensory nerve injury, as well as the risks of anesthesia.
- Prior to the induction of anesthesia, the area desired for augmentation is determined with the patient in a sitting position. This is marked on the surface of the skin.
- 0.12% chlorhexidine gluconate oral rinse is prescribed for daily use beginning 3 days preoperatively and including the day of surgery.

Positioning

- Patients are placed supine on the operating room table at a 90-degree perpendicular position relative to the anesthesiologist to allow for maximal exposure.

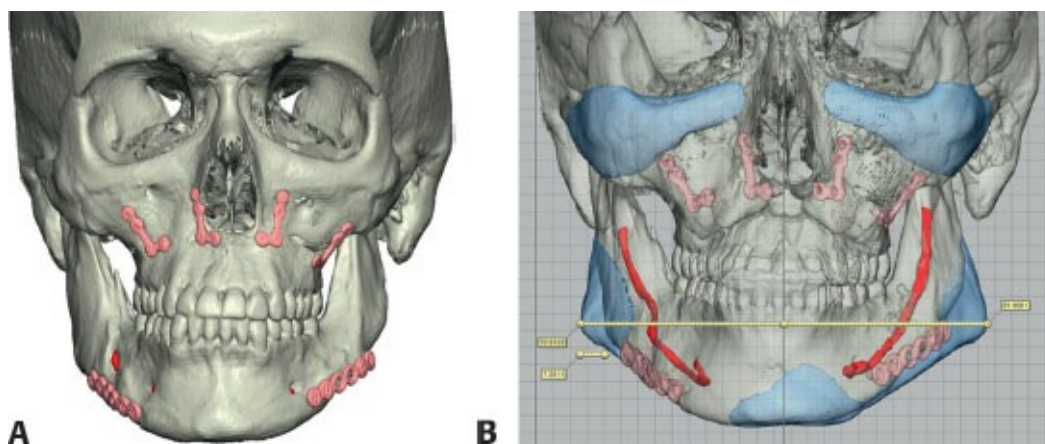


FIG 2 • A,B. Custom implants designed using CT scan data to correct irregularities and imbalance after

orthognathic surgery.

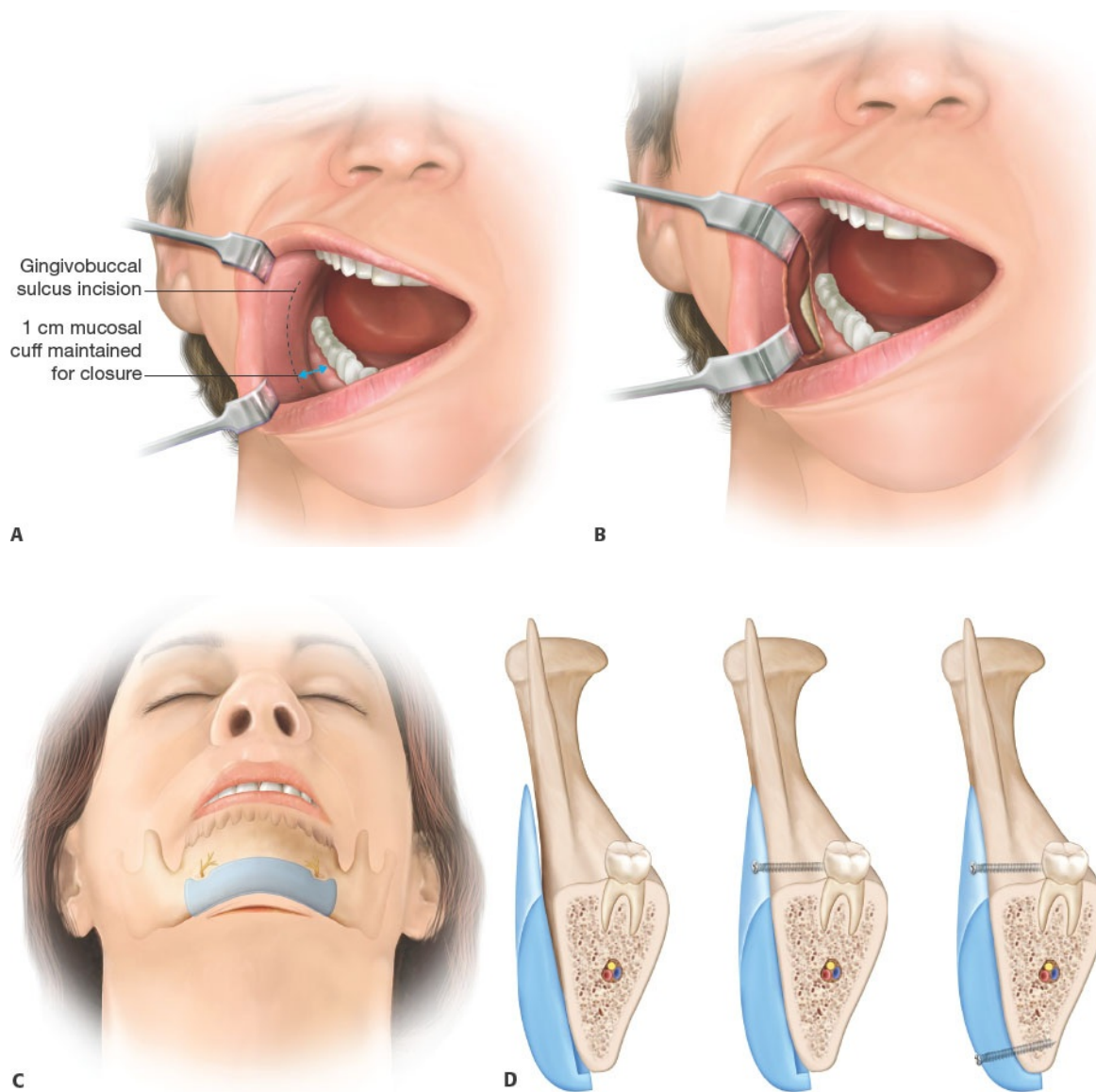
TECHNIQUES

■ Preoperative Preparation

- Prior to antiseptic preparation and draping, a dilute solution of lidocaine and epinephrine (1:100 000) is infiltrated into the operative site for postoperative pain control and intraoperative hemostasis.
- Intravenous antibiotic prophylaxis is administered approximately 30 minutes preoperatively. Oral equivalents are continued for 5 days after surgery.
- The authors' preference is to use general nasotracheal anesthesia. This allows optimal preparation of the operative site and control of the airway. However, skeletal augmentation can be performed with local anesthesia and sedation.
- The face and oral cavity are prepared with an iodine solution after placement of the throat pack.

■ Incision

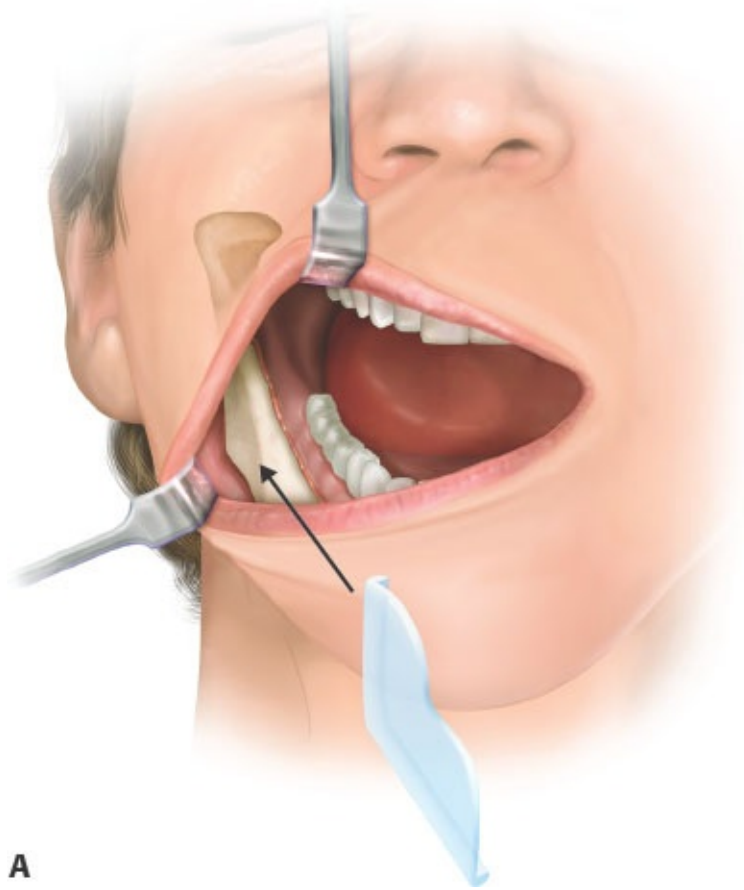
- A generous intraoral incision is made at least 1 cm above the inferior gingivobuccal sulcus on its labial side to expose the ramus and body of the mandible (**TECH FIG 1A**).
- The anterior ramus and body of the mandible as well as their inferior borders are freed from their soft tissues in a subperiosteal plane. Care is taken to avoid minimal disruption of the pterygomasseteric sling. Disruption of the sling will result in roll-up of the masseter with an unsightly midramus bulge (**TECH FIG 1B**).
- If the mental area is also being augmented, a submental incision is made for access and exposure of the anterior mandible (**TECH FIG 1C**).
- The inferior alveolar nerve is visualized in its anticipated path to avoid its injury during screw fixation of the implant (**TECH FIG 1D**).
- As determined preoperatively, the implant can be trimmed with a scalpel or bur before its placement on the mandible.



TECH FIG 1 • A. Placement of intraoral incision, at least 1 cm above the inferior gingivobuccal sulcus for optimal exposure. **B.** Soft tissues are elevated off the anterior ramous and body of the mandible in subperiosteal plane. **C.** Submental incision for genioplasty. **D.** Anatomic relationship of inferior alveolar nerve is anticipated to avoid injury during screw fixation of the implant.

■ Implant Positioning and Fixation

- Registration features at the inferior and lateral borders of the implant aid in appropriate implant positioning (**TECH FIG 2A**).
- Once satisfactory positioning of the implant is achieved, the implant is fixed to the mandible with titanium screws.
- A clamp designed to stabilize the implant to the mandible is useful in maintaining implant position during screw fixation (**TECH FIG 2B**).
- Intraoral screw fixation requires aggressive soft tissue retraction.
 - This limited access obligates the fixation screws to be placed obliquely. This oblique screw placement obligates screws to be from 8 to 14 mm in length.
 - Screw placement should anticipate the expected path of the inferior alveolar nerve (**TECH FIG 2C**).
- When an external approach is preferred for screw fixation, access is obtained through stab wound incisions made in the neck skin.
- The one or two fixation screws not only immobilize the implant but also eliminate any gaps between the posterior surface of the implant and the anterior surface of the mandible (**TECH FIG 2D**):
 - Gaps result in unanticipated increases in effective implant augmentation.
 - Gaps may arise when there are prominences on the surface of the mandible. This is often the case at the oblique line of the mandible body. Reduction of these prominences allows for congruent application of the implant to the mandible.



TECH FIG 2 • A. Registration tabs of inferior and lateral borders of implant aid in correct positioning. **B.**

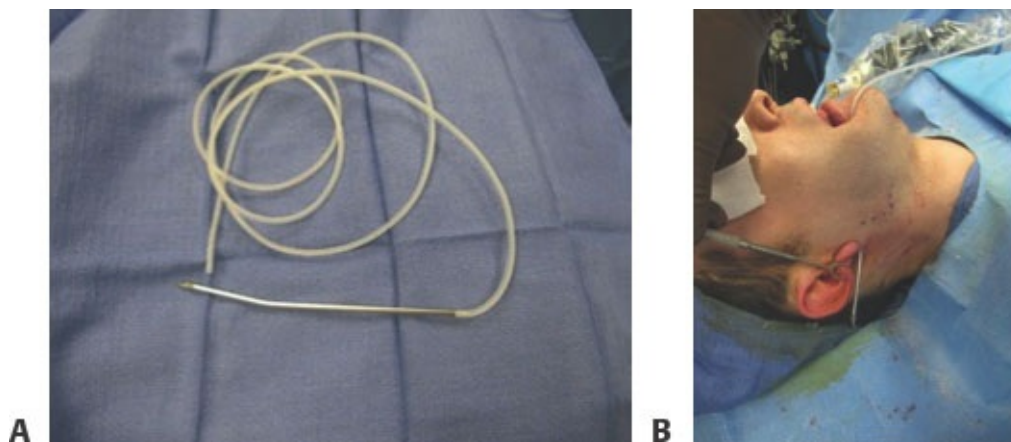
Clamp used to stabilize implant to the mandible during screw fixation. **C.** Screw placement should anticipate the expected path of the inferior alveolar nerve. **D.** Close apposition of implant to the mandible is necessary with screws to avoid gaps leading to overprojection.

■ Assessment of Implant and Contour

- After implant fixation, mechanical contouring may be necessary to assure an imperceptible transition between the implant and mandible.

■ Closure

- The implant pocket is irrigated with antibiotic solution.
- A no. 10 French round suction drain is left in until the next morning:
 - The drain skin exit is placed behind the ear lobule (**TECH FIG 3A,B**).
- The intraoral incision is closed in layers with absorbable sutures.



TECH FIG 3 • A,B. Placement of drain behind the ear lobule.

Surgical approach	■ Transoral approach provides rapid and precise placement of mandibular implants.
Implant fixation	■ Failure to fix the implant to the facial skeleton with a screw may lead to asymmetry or implant malposition. ■ Screw fixation applies the posterior surface of the implant to the surface of the bone, obliterating any gaps between the implant and the skeleton. Gaps result in unanticipated increases in projection of the implant.
Asymmetry	■ Asymmetry in the early postoperative phase may be related to asymmetric edema and tends to resolve within 1 to 2 mo. ■ Minor asymmetries are often aesthetically inconsequential due to overlaying thick masseter.
Secondary implant surgery	■ Expose both sides to compare implant position.

POSTOPERATIVE CARE

- A suction drain is routinely placed at the operative site and removed the morning after surgery. A supportive tape dressing is placed postoperatively and is usually removed the morning after surgery (**FIG 3**).
- Oral antibiotics are prescribed for 7 days after surgery (cephalexin 500 mg every 8 hours).
- Due to the intraoral incisions, patients are asked to eat a soft diet for 72 hours postoperatively. Patients are instructed to refrain from strenuous exercise for 2 to 3 weeks postoperatively.
- If there is significant edema the morning after surgery, then a standard steroid taper is prescribed for 6 days.
- The patient is instructed to apply ice for 48 to 72 hours and sleep with the head of the bed elevated greater than 30 degrees or with three or four pillows.
- Follow-up is at 1-, 2-, and 4-week intervals. Thereafter, long-term follow-up is at 6 months and 1 year.

OUTCOMES

- Appropriate patient selection and sound surgical technique provide a vast majority of patients with satisfactory aesthetic outcomes (**FIGS 4A–H, 5A–C**,

and **6A,B**).



FIG 3 • Placement of supportive tape dressing.

COMPLICATIONS

- Postoperative complications are uncommon when the before-described protocol is adhered to.
- Sensory or motor dysfunctions are usually transient.
- Epinephrine injection, meticulous hemostasis, and suction drainage minimize the likelihood of hematoma.
- Good oral hygiene, meticulous hemostasis, and watertight wound closure minimize infection risk.
- The above complications may be minimized with wide subperiosteal exposure to the area that needs to be augmented and screw fixation to prevent implant movement.

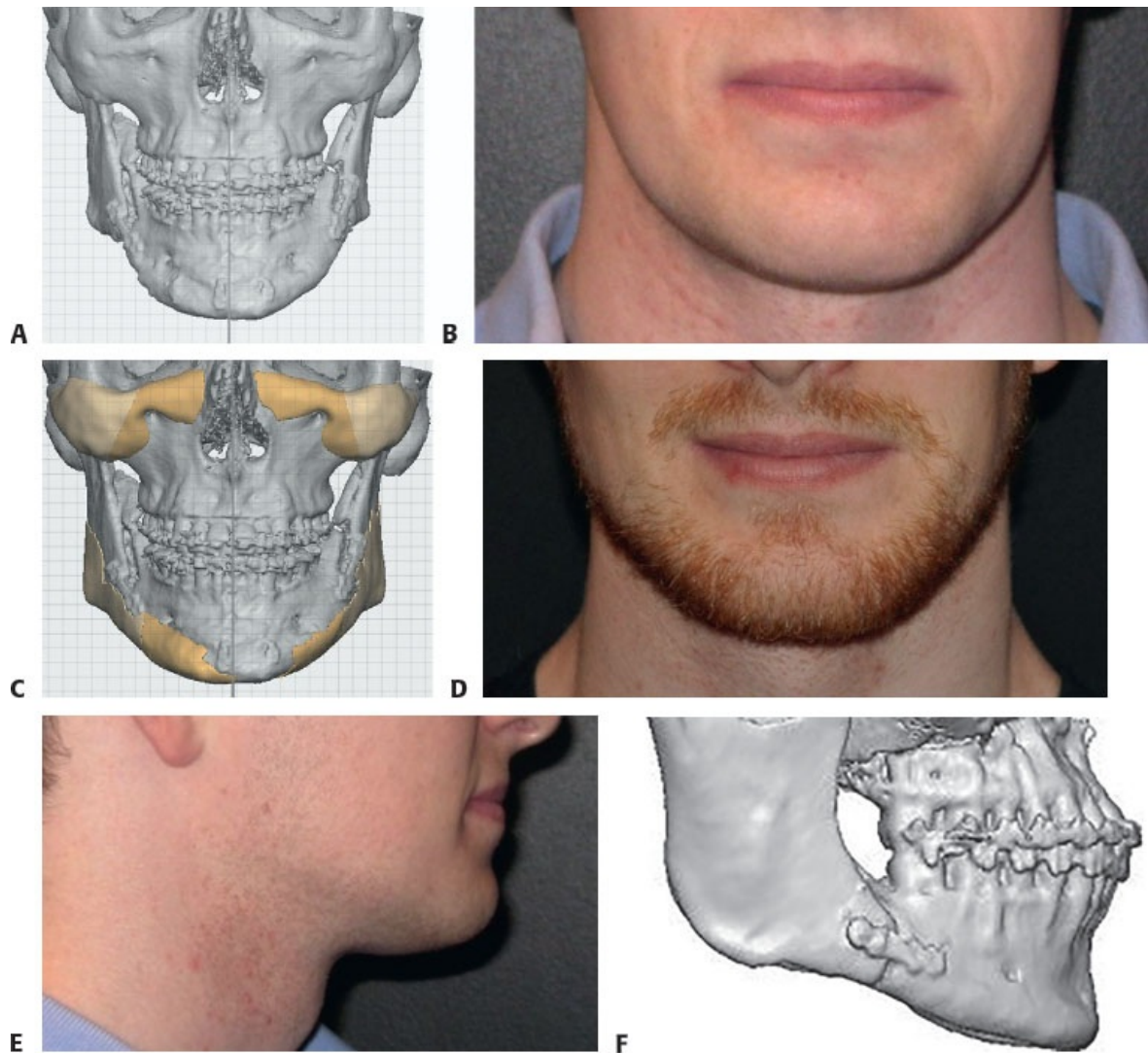
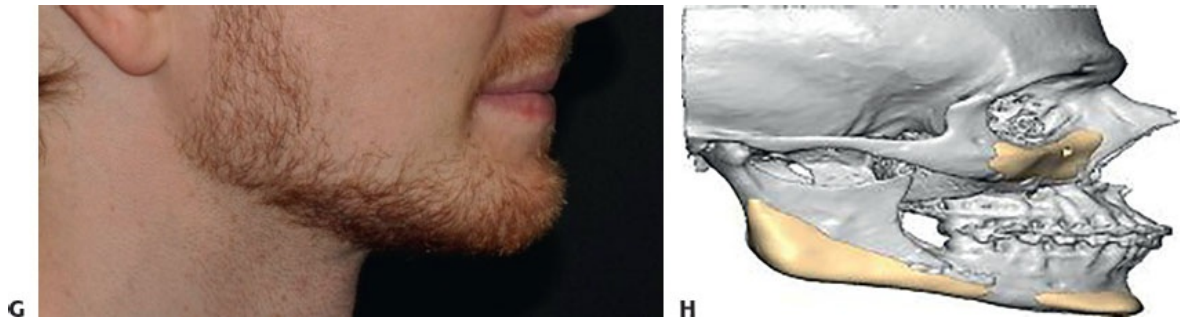


FIG 4 • (A,B) AP view of preoperative and **(C,D)** postoperative result of computer-designed mandibular implants to correct contour defect after orthognathic surgery (1 year postop). **(E,F)** Lateral view of preoperative and **(G,H)** postoperative result of computer-designed mandibular implants to correct contour defect after orthognathic surgery (1 year postop).



- In the senior author's overall experience with greater than 400 porous implants used for facial skeletal reconstruction, the infection rate was about 1.5%. If infection should occur, we recommend removal of the implant. Antibiotic therapy may temporarily suppress the infection, but the bacterial-induced biofilm prevents chemical eradication of the infection. Implant replacement 3 to 6 months after resolution of the infection has been effective.²
- Late implant infections (years after implant surgery) have been reported (eg, after dental surgery). To our knowledge, none of the senior author's patients have encountered this. We believe that infections that become apparent in the early months after surgery reflect small intraoperative bacterial contamination that was temporarily suppressed by perioperative antibiotics and host defenses.



FIG 5 • (A) Preoperative (*left*) and **(B)** postoperative (*right*) results of a patient who underwent bilateral sagittal split osteotomy with resulting deformity and asymmetry at the osteotomy site (*left*) 1 year postop. **C,D.** Implants were customized to correct the resulting deformity (*right*). **E.** Preoperative (*left*) and **(F)** postoperative (*right*) results after custom implants to correct osteotomy site deformity after bilateral sagittal

split osteotomy (1 year postop).

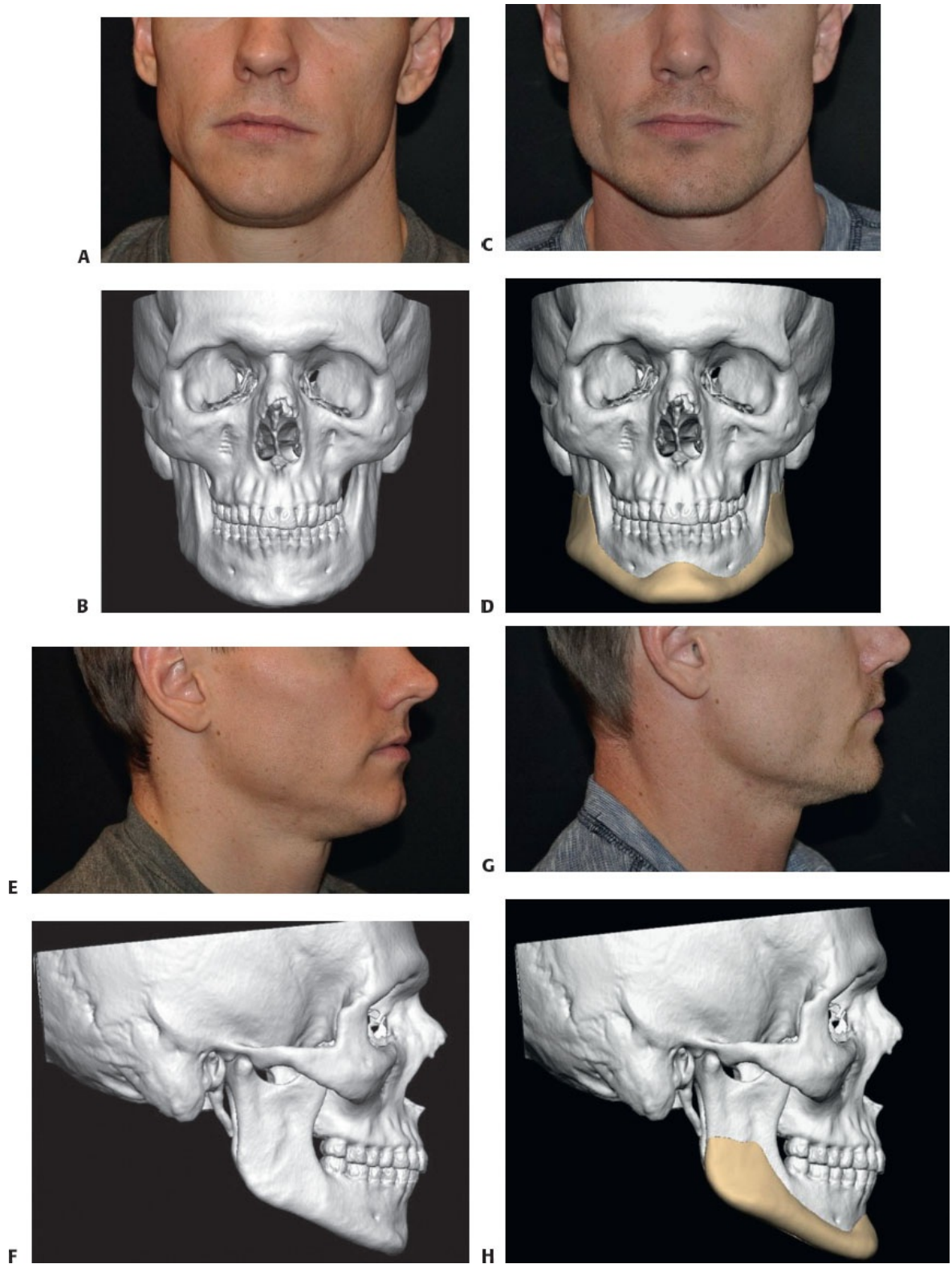


FIG 6 • (A,B) AP view of pre- (*left*) and **(C,D)** postoperative (*right*) results of aesthetic mandibular

augmentation (1 year postop). **(E,F)** Lateral view of pre-
(*left*) and **(G,H)** postoperative (*right*) results of aesthetic
mandibular augmentation (12 months postop).

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Section XIII: Skeletal Reduction

75 Technique for Chin Reduction CHAPTER

Jong-Woo Choi and Woo-Shik Jeong

DEFINITION

- Facial contours can greatly affect a person's facial image. In particular, the shape of the chin is one of the most important parts in terms of facial image according to a recent consensus among facial plastic surgeons who perform facial contouring surgery.
- There are several ways to perform a chin reduction.
 - One is to reduce the whole mandible, including the chin, which is performed through mandibuloplasty.
 - The other is to reduce only the chin, which is performed with genioplasty.
- In terms of the surgical direction for chin reduction, there are two acceptable methods.
 - One is horizontal chin setback, which is associated with the mandible setback or chin setback procedure.
 - The other is vertical chin reduction, which is related to vertical reduction genioplasty. This method reduces the volume of the chin using narrowing genioplasty.
- This chapter describes how chin reduction can be properly achieved by selecting the best solution from among these various options according to the patient's status.

ANATOMY

- The mental nerve innervates the lower lip and chin region and passes through the mental foramen on the anterior surface of the mandible. The mental foramen is generally located in the apical region of the first and second premolars.¹
- However, anatomical variation exists with respect to the mental foramen's location, and the anterior loop of the mental nerve should be considered with a safety zone left when the osteotomy line is planned.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The chin reduction procedure can be applied to patients who complain of a prominent and wide chin or of protrusion of the mentum.
- Reduction with mandibuloplasty can improve aesthetic contouring of the chin and the appearance of a square face.

IMAGING

- The appearance of the chin is easily visualized on three-dimensional computed tomography.^{2,3}
- Panoramic radiographs can also be helpful for locating the mental foramen.

SURGICAL MANAGEMENT

- Orthognathic surgery could be a good option for skeletal class III prognathism accompanied by chin protrusion. In contrast to reduction genioplasty, which is performed on the chin alone, mandibular setback resolves issues related to the whole mandible. Sometimes, simple reduction genioplasty cannot produce the desired results for patients with skeletal class III prognathism:
 - Regardless of the occlusion, the protruded mandible or chin should be corrected based on the whole facial profile. If the patient has a relative skeletal class III tendency, orthognathic surgery may be a better solution than simple chin reduction or mandibuloplasty would be. If the patient has a normal class I occlusion, clockwise rotational jaw/rotational mandibular setback could be a good alternative.
- In the past, mandible angle reduction was the common term for facial contouring surgery in Asia. However, this procedure should now be referred to as mandibuloplasty, as modern aesthetic facial contouring surgery primarily deals with the whole mandible, including the chin, body, and the mandibular angle:
 - To reduce the whole mandible, numerous modifications have been

introduced, such as mandible angle resection, long curved mandibulectomy, and sagittal mandibular corticectomy.

- Recent standards for mandibuloplasty include long-curved marginal mandibuloplasty with or without narrowing genioplasty. This method for one-piece mandibuloplasty should focus on the shape of the mandible as well as the amount of the marginal resection. Compared with traditional mandible angle resection or mandible reduction, one-piece mandibuloplasty affects the whole mandible.
- In contrast to mandibuloplasty, genioplasty techniques mostly affect just the chin. Various genioplasty techniques have been introduced. Advancing genioplasty is the most commonly used technique. For chin reduction, however, vertical reduction genioplasty is preferable.
- Vertical reduction genioplasty can reduce the vertical chin dimension directly with an approximately 1:1 hard-to-soft tissue ratio, whereas the maxillary movement was not correspondent at hard-and-soft tissue ratio. This effect suggests that reduction genioplasty is a very effective and intuitive procedure.
- Whereas vertical reduction genioplasty primarily affects vertical control of the chin, narrowing genioplasty primarily affects horizontal control of the chin. There are various chin shapes, such as the broad chin, square chin, long chin, short chin, and trapezoidal chin, and the shape of the chin greatly influences the facial contour. Narrowing genioplasty has become one of the most popular procedures in facial contouring surgery.
- Narrowing genioplasty can be performed with mandibuloplasty of the chin, body, and angle. An alternative method is one-piece mandibuloplasty. There are few differences in these procedures, so surgeons can choose which to perform based on their personal preference.

Preoperative Planning

- The extent of chin correction should be determined individually according to the patient's chin width, the degree of mental protrusion, the course of the inferior alveolar nerve, and the patient's preference regarding the final chin shape.
- For fixation of bone segments, titanium miniplates, lag screws, or wires can be used and should be available.

Positioning

- The patient should be positioned supine on the operating table under general

anesthesia via orotracheal or nasotracheal intubation.

- Horse-shaped supporting head table can be helpful for minimizing the head during the operation.

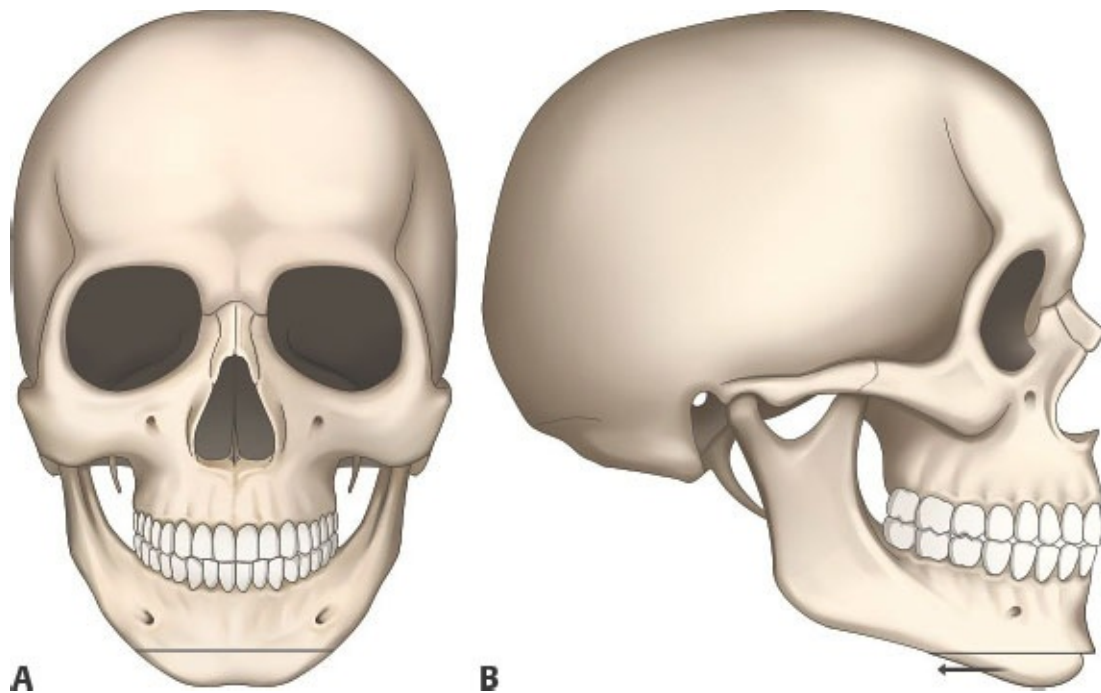
Approach

- The conventional intraoral vestibular incision is best performed after infiltration of hemostasis.
- Subperiosteal dissection is performed to expose the symphyseal region, except for the opening of the mental nerve with no. 15 blades or the cutting mode of Bovie coagulator.

TECHNIQUES

■ Mandible Setback or Chin Setback

- Chin reduction related to the whole mandible could be achieved with mandibular setback based on sagittal split ramus osteotomy or intraoral vertical ramus osteotomy with a reciprocating saw.
- After the nasotracheal intubation, a 3- to 4-cm buccogingival incision is made from the 2 cm above the occlusal plane to the first molar, disclosing the subperiosteal plane for the sagittal split osteotomy of the mandible.
- Using the periosteal elevator, the periosteum on the mandible is elevated laterally and medially. The pterygomasseteric sling is detached with the round elevator, and the periosteum on the inferior border of the mandible is stripped from the mandible bone.
- Using the bur hole in the medial side made before, the reciprocating saw is used for the sagittal split osteotomy (**TECH FIG 1A**). Then, the osteotome is used to split the mandible.
- For fixation of mandibular setback (**TECH FIG 1B**), one rigid fixation with a titanium 6-mm-length miniplate on each side of Champy line can achieve stable fixation.
- When a buccogingival incision is used, the periosteum should be sutured with 3-0 or 4-0 Vicryl for preventing hematoma and infection.
- Then, the buccogingival incisions are closed with 4-0 Vicryl in continuous fashion.



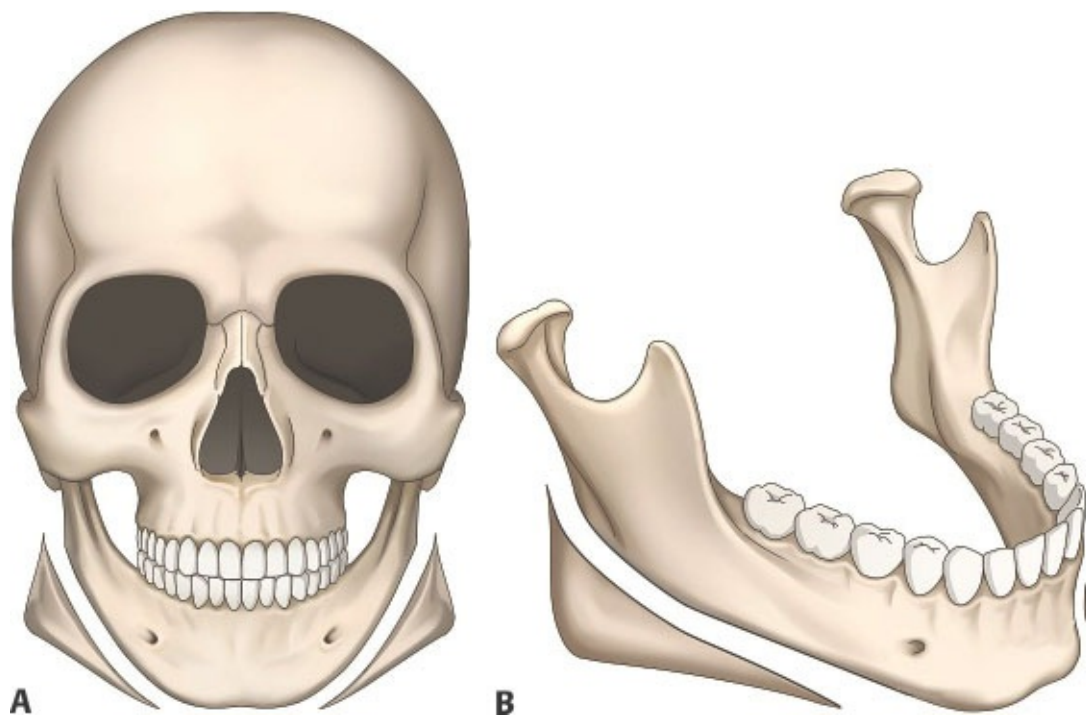
TECH FIG 1 • A. Sagittal split osteotomy. **B.** Chin setback.

■ Mandibuloplasty

- After the nasotracheal intubation, a 3- to 4-cm buccogingival incision is made from 2 cm above the occlusal plane to the first molar, and subperiosteal dissection is done using the curved round elevator while preserving the continuity of the periosteum:
 - The whole mandible should be exposed, except for the mucosal attachment above the mental nerve.
- Next, the pterygomasseteric sling is released with the subperiosteal elevator without tearing:
 - A tear in the periosteum can harm the facial vessels or the marginal mandibular branch of the facial nerve.
- There are two ways to cut the lower jaw, depending on surgeon preference: from the angle to the chin and from the chin to the angle (**TECH FIG 2**):
 - Generally, an oscillating saw is used for mandibuloplasty, but a modified reciprocating saw, such a curved one, can also be used.
 - When an oscillating saw is used, the most posterior part of the ramus should be cut meticulously to avoid following the wrong direction to the

condyle because direct visualization of the most posterior part of the ramus is not easy.

- In addition, surgeons should bear in mind the course of the mandibular nerve inside the mandible. A reduction that is too aggressive might cut the mandibular nerve, which results in the complete numbness of the lower lip.
- Finally, after removing the one-piece mandibular segments, the periosteum should be closed tightly to minimize soft tissue redundancy with 3-0 or 4-0 Vicryl.
- Of course, the mucosal closure should be both meticulous and watertight with 4-0 Vicryl in continuous fashion.



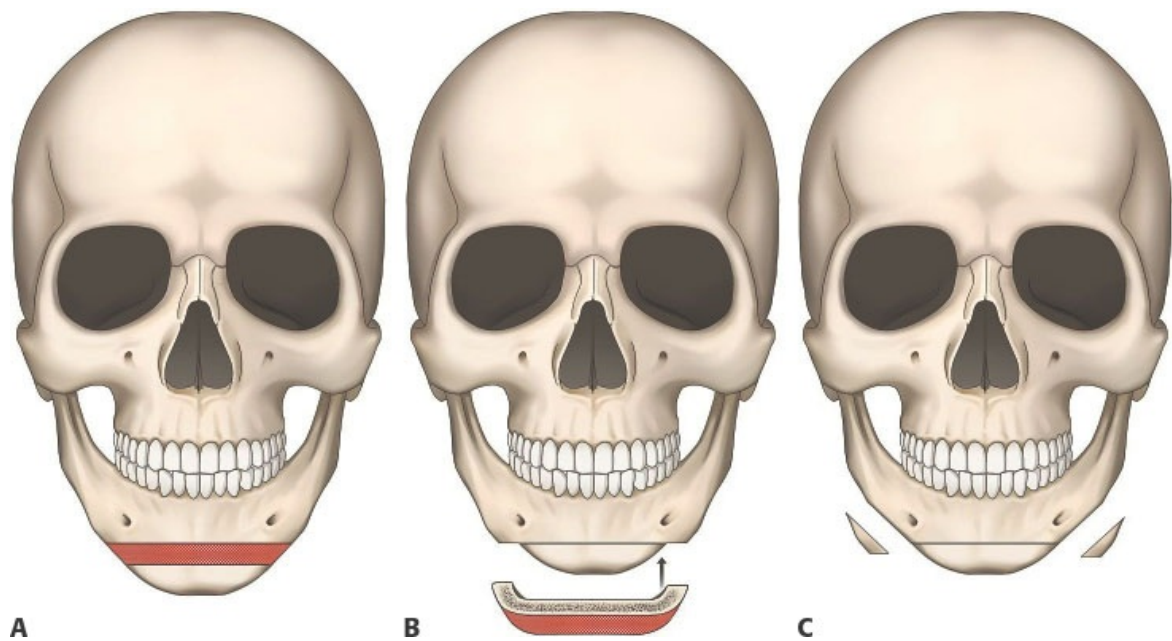
TECH FIG 2 • Mandibuloplasty.

■ Genioplasty

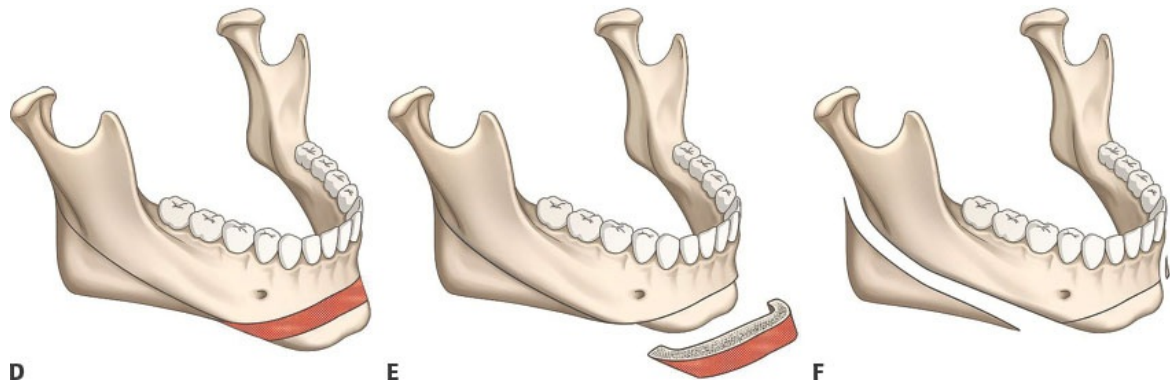
Vertical Reduction Genioplasty

- A 3-cm inverted-V-shaped buccomucosal incision is made from canine to canine, and subperiosteal dissection is performed, except for opening the mental nerve.
- Next, horizontal cutting can be performed with a reciprocating saw:

- Leave at least 5 mm of bone just above the upper horizontal cutting line, as the mandibular nerve passes approximately 5 mm lower than the bony opening.
- Generally speaking, the chin setback or genioplasty procedure is not recommended, because the submental soft tissue might be redundant after the procedure.
- After osteotomy, bone segment designed for reduction is removed, and lower segment of the chin is fixed to the mandible with titanium miniplate (**TECH FIG 3**).
- The midline of the chin must correspond to the midline of the mandible but can be intentionally different to correct an asymmetry of the mandible.
- The periosteum is closed to minimize soft tissue redundancy with 3-0 or 4-0 Vicryl.

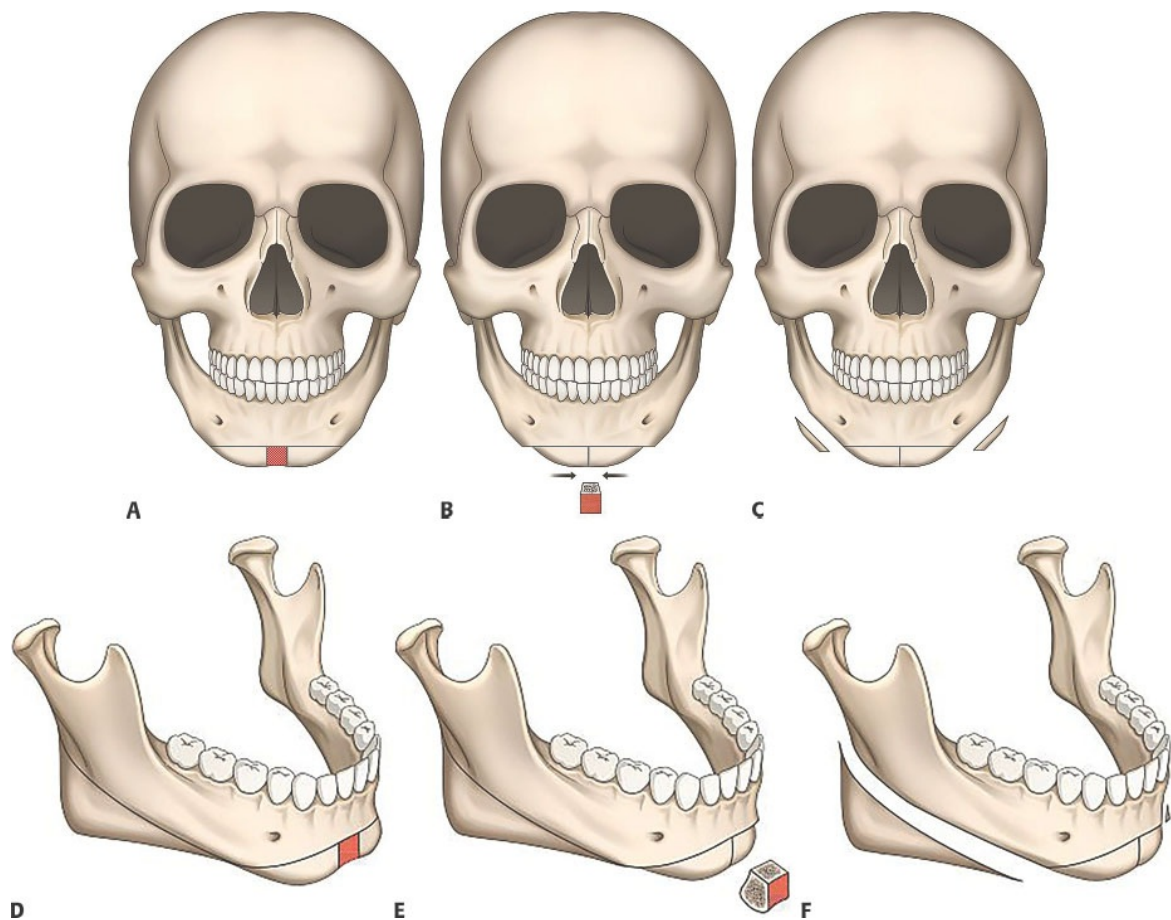


TECH FIG 3 • Vertical reduction genioplasty.



Narrowing Genioplasty

- The overall procedure is similar to vertical reduction genioplasty.
- However, a π -shaped osteotomy is made using a reciprocating saw (**TECH FIG 4A**), and the central bony segments of the chin are removed to reduce the horizontal dimension of the chin (**TECH FIG 4**):
 - The horizontal dimension is controlled based on the amount of bone resected.
- A step deformity along the margin can be smoothed easily using marginal mandibuloplasty with a reciprocating saw.
- The two segments of the chin are secured together with wiring and fixed to the mandible with titanium miniplate.
- The periosteum and the mucosa are closed to minimize soft tissue redundancy with 4-0 Vicryl.
- Although mild submental redundancy can occasionally be a problem, the overall satisfaction is generally very high.



TECH FIG 4 • Narrowing genioplasty.

PEARLS AND PITFALLS

Approach

- Subperiosteal dissection is performed except the opening of the mental nerve.

Osteotomy

- When horizontal cutting is done with reciprocating saw, the important thing is to keep at least 5 mm bone just above the upper horizontal cutting line as the mandibular nerve passes the 5 mm lower than the bony opening.
- To avoid cutting submental soft tissue during osteotomy, which can result in submental hematoma, the fingertip of the contralateral hand can be used to perform slight palpation of the tip of the reciprocating saw during osteotomy.

POSTOPERATIVE CARE

- To prevent submental hematomas, an elastic bandage on the chin area and a facial bandage can be applied 2 or 3 days postoperatively.

OUTCOMES

- Lee and Ahn retrospectively reviewed 52 patients who underwent narrowing genioplasty.⁴ All patients were satisfied with the more slender appearance of their chins:
 - The subjective grading was “much improved” in 67% of patients and “improved” in 33%.

COMPLICATIONS

- Complications are uncommonly noted in Sykes and Suarez’s study.⁵
- Submental hematoma
- Decreased sensation of the lower lip
- Submental bulging and soft tissue sagging
- Malunion or nonunion of bony segment
- Infection

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Section XIV: Osseous Genioplasty

76 An Osseous Approach to Chin Deformities

CHAPTER

S. Anthony Wolfe and Saoussen Salhi

DEFINITION

- Osseous genioplasty was introduced in 1942, when Otto Hofer described a horizontal osteotomy of the mandibular symphysis through an external approach to correct the deficient chin on a cadaver.^{1,2} However, we owe the first description of a genioplasty performed on a living patient to Gillies and Millard in 1957. They described a jumping genioplasty, through an external approach, where the lower border of the mandibular symphysis was osteotomized, advanced superiorly, and positioned on top of the upper mandibular segment.²
- In 1957, Richard Trauner and Hugo Obwegeser described the intraoral approach to the osseous genioplasty,¹⁻⁴ and later, in 1964, Converse and Wood-Smith expanded on the possible variations of the procedure.^{1,2} In their description of the surgical technique, the osteotomized caudal segment of the mandibular symphysis was stripped of all of its muscular attachments before advancing it, thereby converting it to a free bone graft. This resulted in significant bone resorption, which prompted these surgeons to preserve the blood supply to the caudal segment.⁴
- Despite its description more than half a century ago, osseous genioplasty remains less frequently performed than alloplastic chin implants.³ In 1950, Converse described the use of intraoral bone grafts for chin augmentation. These quickly fell out of favor because of their variable resorption, donor-site

morbidity, and the successful introduction of alloplasts.¹ In 1953, Safian introduced the first silicone chin implant.¹

ANATOMY

- When performing a genioplasty, pertinent anatomy relates to the mental nerve.
- The mental nerve is the terminal sensory branch of the inferior alveolar nerve, which is itself a branch of the mandibular division of the trigeminal nerve.
- The mental nerve provides sensory innervation to the lower lip and the chin.
- It exits the mandible through the mental foramen at the level of the second premolar.³
- The inferior alveolar nerve courses inferiorly prior to heading cephalad toward the mental foramen.⁵ For this reason, the horizontal osteotomy of the mandibular symphysis performed during a genioplasty has to be placed 5 to 6 mm below the mental foramen.⁵

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination starts by dividing the face along the trichion, glabella, subnasale, and menton.³ When these landmarks divide the face into equal thirds, the face is considered ideal.^{2,3}
- The lower third of the face, delimited superiorly by the subnasale and inferiorly by the menton, is further divided by the oral commissure into an upper third, the upper lip, and lower two-thirds: the lower lip, labiomental sulcus, and chin.² This allows assessment of the volume of the chin relative to the overall facial profile.
- The chin pogonion projection is assessed relative to the facial plane, the zero meridian, which is a line started at the nasion and dropped perpendicular to the Frankfurt horizontal. Ideally, the chin pogonion should be at or near the zero meridian, being more projected in men than in women. It should not be beyond the lower lip border.³
- Chin deformities are commonly divided into two categories: macrogenia and microgenia. Guyuron et al. distinguish seven different chin deformities based on the volume of the chin:
 - Class I: macrogenia or chin excess
 - Class II: microgenia or chin deficiency
 - Class III: combined excess in one dimension and deficiency in another
 - Class IV: asymmetric deformity

- Class V: witch's chin characterized by ptotic soft tissue and a deep labiomental groove
- Class VI: pseudomacrogenia or chin excess secondary to soft tissue excess overlying normal bony anatomy as evidenced by a normal cephalogram.⁶
- According to Guyuron et al., class II microgenia is the most commonly encountered chin deformity, followed by class II macrogenia and class III, a combination of both.⁶ It is important to note that the microgenia or macrogenia can be present in a number of planes: vertical, horizontal, or both.³
- The chin can also be characterized by its spatial position. It can be positioned posterior to its ideal position at the zero meridian, which is referred to as retrogenia.
- When the retrogenia is secondary to mandibular retrognathia (class II malocclusion) or vertical maxillary excess leading to a clockwise rotation of the mandible, this is referred to as pseudoretrogenia.³
- Osseous genioplasty alone cannot address this issue, and the patient likely needs orthognathic surgery to correct the underlying malocclusion.
- Often, patients who present complaining of a deficient chin have mandibular hypoplasia with or without chin deficiency.
- For this reason, all patients should undergo an intraoral examination including an evaluation of the skeletal relationship of the maxilla and mandible to exclude any underlying malocclusion.³
- Finally, the experienced surgeon needs to rely on his or her eye and the patient's desired result.³

IMAGING

- In most patients, clinical examination and photographic analysis are sufficient to determine if the chin shows any abnormality in both its position and its volume.³
- A lateral cephalogram can provide quantitative confirmation of these abnormalities.³
- A frontal cephalogram can be helpful in planning the genioplasty osteotomy aimed at correcting an asymmetrical chin.³
- A panorex is used to identify the mental foramen and the dental roots and to plan the osteotomy and hardware placement to avoid injury to these structures.³

SURGICAL MANAGEMENT

- Many aesthetic surgeons favor alloplastic genioplasty^{1,4} for its simplicity,^{1,3,4} shorter operating time, ease of reversibility, decreased risk of injury to the mental nerve, and ability to perform under local anesthesia.¹ However, they are associated with higher infection rates, risk of extrusion,^{1,7} erosion into the mandibular symphysis,^{1,3,7} migration, capsular contracture, and unpredictable soft tissue response.¹
- In contrast, osseous genioplasty eliminates the use of a foreign body, thereby avoiding the risk of infection, extrusion, migration, and bony resorption.⁸ It also results in a more predictable soft tissue response¹ and improves the cervicomental contour¹ when the lower symphyseal fragment with its attached musculature is advanced, thereby tightening the submental region.⁸ It is also a more versatile procedure^{1,3,4,8} to correct chin deformities that an implant cannot, such as vertical macrogenia or microgenia,^{3,4,7,8} chin asymmetry,^{3,4,8} and significant sagittal microgenia.^{3,7}
- We are not condemnatory of the use of alloplastic implants for the chin if they are used for the proper indication, ie, mild sagittal deficiency^{1,4} (generally less than 5 mm³) in a previously unoperated patient^{3,4} and properly performed (placed through a submental incision and rigidly fixed to the underlying bone). Several contraindications to chin implants are cited in the literature, including systemic diseases such as cardiovascular diseases, diabetes, severe periodontal disease, and young age.¹
- We do not however use them ourselves because we can do a genioplasty for every type of deformity, including mild retrogenia. Once a comfort level has been reached using power equipment to cut the mandibular symphysis, one can advance the chin, vertically shorten or lengthen the chin, and correct lateral deviations. This enables one to be able to treat the whole spectrum of chin deformities, not just the cases of mild retrogenia. A genioplasty has the added advantage of being a vascularized bone flap with its inferior attachments of geniohyoid, genioglossus, and anterior belly of the digastric muscle.^{8,9} Therefore, the advanced segment does not undergo resorption,^{8,9} and any postoperative buccal incision dehiscence maintains the potential to heal.

Positioning

- General anesthesia is preferred not because of pain issues but rather a concern that a good bit of blood and irrigating fluid in the mouth of a sedated patient

might result in aspiration.

- If a patient is adamant about having the procedure performed under local anesthesia, good anesthesia can be obtained by mental nerve blocks and infiltration of the submental muscles.
- If general anesthesia is used, a nasal intubation is not essential because an oral tube does not interfere with access. The head should be extended, without a doughnut.

TECHNIQUES

■ Osseous Genioplasty

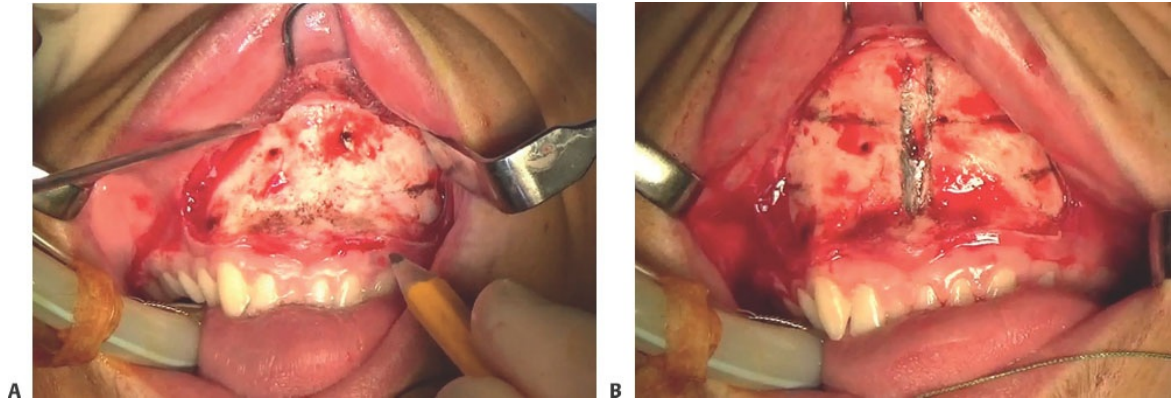


Video p1-c076_01

- The lower labial sulcus is infiltrated with a vasoconstrictive solution.
- An incision is made with the needle-tip electrocautery, from the cupid to cupid, on the labial side of the gingivobuccal sulcus leaving a cuff of 3 to 4 mm superiorly containing mucosa and very little mentalis muscle and sparing the frenulum.
- Cutting through large amounts of mentalis muscle denervates the superior portion of the muscle and may lead to lower lip incompetence and incisive show, which is very difficult to correct.
- The periosteum is incised and a subperiosteal dissection is immediately begun. This dissection is intentionally limited at the level of the anterior

surface of the symphysis, below the planned osteotomy line, to avoid ptosis of the chin pad.

- The dissection then proceeds laterally for identification and preservation of the mental nerves, located between the first and second bicuspid (TECH FIG 1A). Their vertical distance from the inferior border of the mandible can vary considerably. Dissection is carried beneath the nerves laterally and over the inferior border of the symphysis.
- The most important step is in marking for the cut. One must be able to see the patient's eyes. The midline is marked (a soft pencil is best), and then at right angles to this, a transverse line is drawn, being sure that it is parallel to the interlateral canthal line. This line must be at least 5 mm below the canine root and 6 mm below the mental foramen when extended laterally (TECH FIG 1B). This is to avoid injury to the inferior alveolar nerve, which dips down slightly before it exits the foramen. These lines are then scored using an oscillating saw (we prefer Aesculap, but the Stryker is also fine).
- The operator's left hand then holds the lower lip out of the way, and if possible, the entire full-thickness cut is made with the oscillating saw. Frequently, the bone laterally beneath the nerve may need to be cut with a reciprocating saw (the nerve should be gently shielded during the maneuver).
- The lower border should be cut free entirely with the saw; if one tries to wedge the basilar segment down with an osteotome, a fragment will remain on the basilar segment that interferes with proper movement.
- The basilar segment then can be moved as desired: forward, for retrogenia; upward, after removal of an appropriate strip of bone (remember the nerves), for macrogenia; downward with an interpositional bone graft for microgenia; and laterally for chin point deviation. An advancement genioplasty can be fixed with wires or several long screws; other movements often require titanium miniplates and screws.
- The buccal incision is closed in one layer with 4-0 chromic catgut sutures, incorporating as much of the mentalis cuff as possible. If bone graft has been placed, a few deep sutures are placed in the mentalis muscle. Drains are not used.



TECH FIG 1 • A. The right mental nerve can be seen just right of the pencil mark, exiting from the mental foramen. **B.** The superior horizontal pencil marks indicate the bilateral mental foramina. The inferior horizontal pencil mark indicates the level of the horizontal osteotomy, marked 6 mm below the level of the mental foramina. The vertical line marks the midline of the mandibular symphysis.

■ Variations



Video p1-c076_02

- Variations of the osseous genioplasty technique have been described to address all possible chin deformities.

- **Sliding genioplasty:** The basilar segment is moved anteriorly or posteriorly.^{3,9}
- **Jumping genioplasty:** The basilar segment is used like an implant, placed anterior to the mandible. The muscular attachments to this segment are carefully maintained to maintain its vascularity and minimize postoperative resorption.
- **Interpositional genioplasty:** A bone graft is interposed at the osteotomy line to increase the height of the lower third of the face.^{2,3,9} Converse et al. describe the use of iliac bone as bone graft.⁹ However, we favor using the outer table of the cranium harvested in the parietal region as a bone graft in these procedures.
- **Wedge genioplasty:** Two osteotomy lines are performed below the mental foramen, and the intervening bone segment is removed.^{2,3,9}
- **Stepladder genioplasty:** Two osteotomies create two bone segments. The most caudal of these segments is advanced over an already advanced more proximal segment.^{3,9}
- **Centering genioplasty** allows correction of chin asymmetries.^{3,9}

PEARLS AND PITFALLS

Occlusion	■ Occlusion has to be assessed preoperatively to rule out pseudoretrognathia secondary to mandibular hypoplasia, which is better managed with orthognathic surgery.
Intraoral incision	■ Incision has to be placed on the labial side of the gingivobuccal sulcus by leaving a mucosal cuff of 3–4 mm to facilitate closure.
Surgical technique	■ Subperiosteal dissection is limited to the anterior surface of the mandibular symphysis to avoid postoperative ptosis of the chin pad.
Mental nerve identification	■ The mental nerve is identified between the first and second bicuspid.
Mandibular osteotomy	■ The midline of the symphysis should be marked and the osteotomy line is drawn perpendicular to the midline, 5 mm below the canine root, and at least 6 mm below the mental foramen.
Incision	

closure

- Closure of the incision can be done in one layer making sure to incorporate the mentalis muscle in the closure.

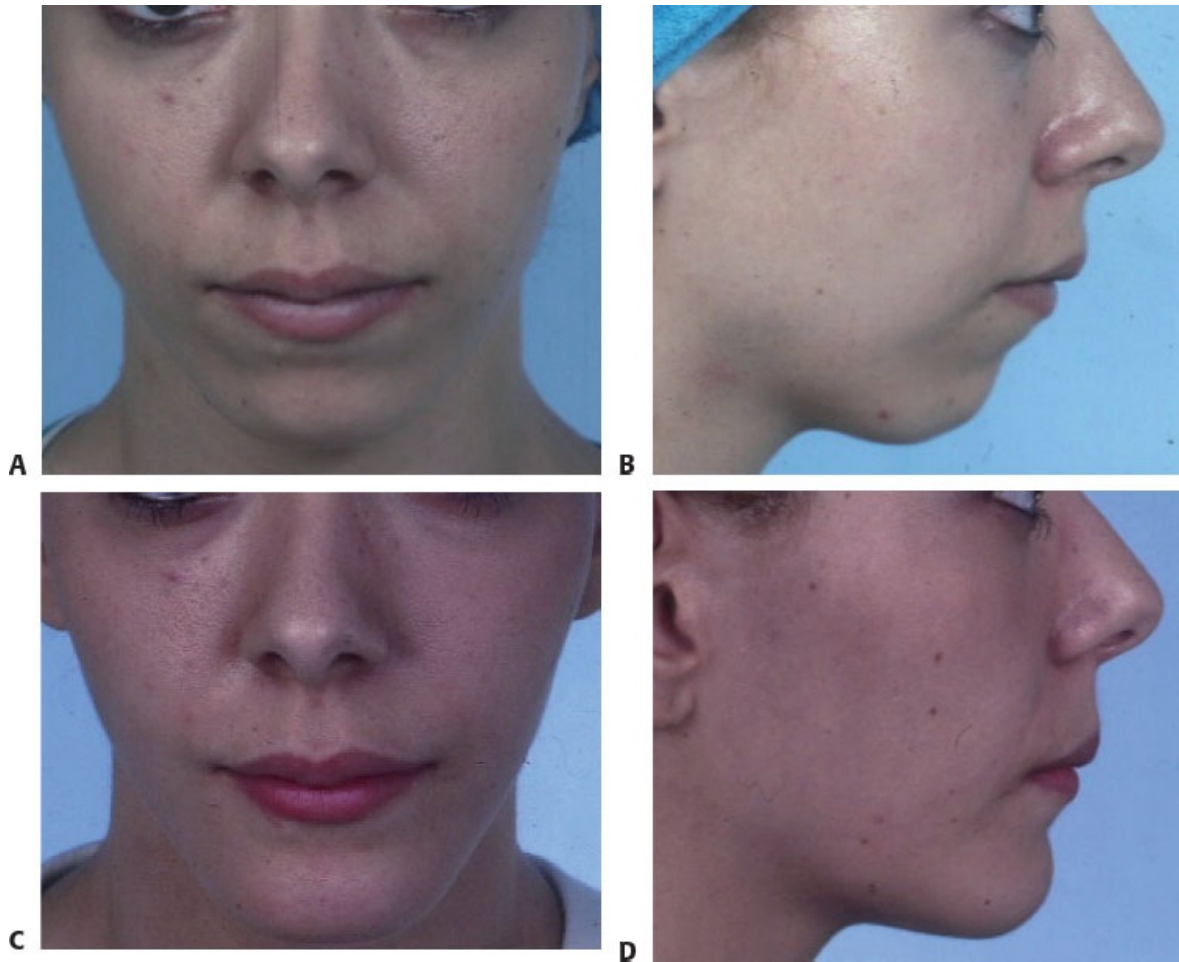


FIG 1 • Preoperative (**A,B**) and postoperative (**C,D**) photos of a patient who underwent jumping genioplasty for retrogenia.

POSTOPERATIVE CARE

- A light tape dressing is maintained for a few days.
- Patients may begin on a soft diet immediately.
- Patients are maintained on a soft diet for 3 weeks postoperatively.

OUTCOMES

- Before and after patient photos are shown in **FIGS 1** to **3**.

COMPLICATIONS

- Among the disadvantages cited for osseous genioplasty, when compared to alloplastic chin implants, need for general anesthesia, technical complexity, need to use power tools, risk of tooth root devitalization, and higher incidence of postoperative mental nerve paresthesias and postoperative discomfort were all cited.¹



FIG 2 • Preoperative (A,B) and postoperative (C,D) photos of a patient who underwent removal of a chin implant and jumping genioplasty for long retrogenia.

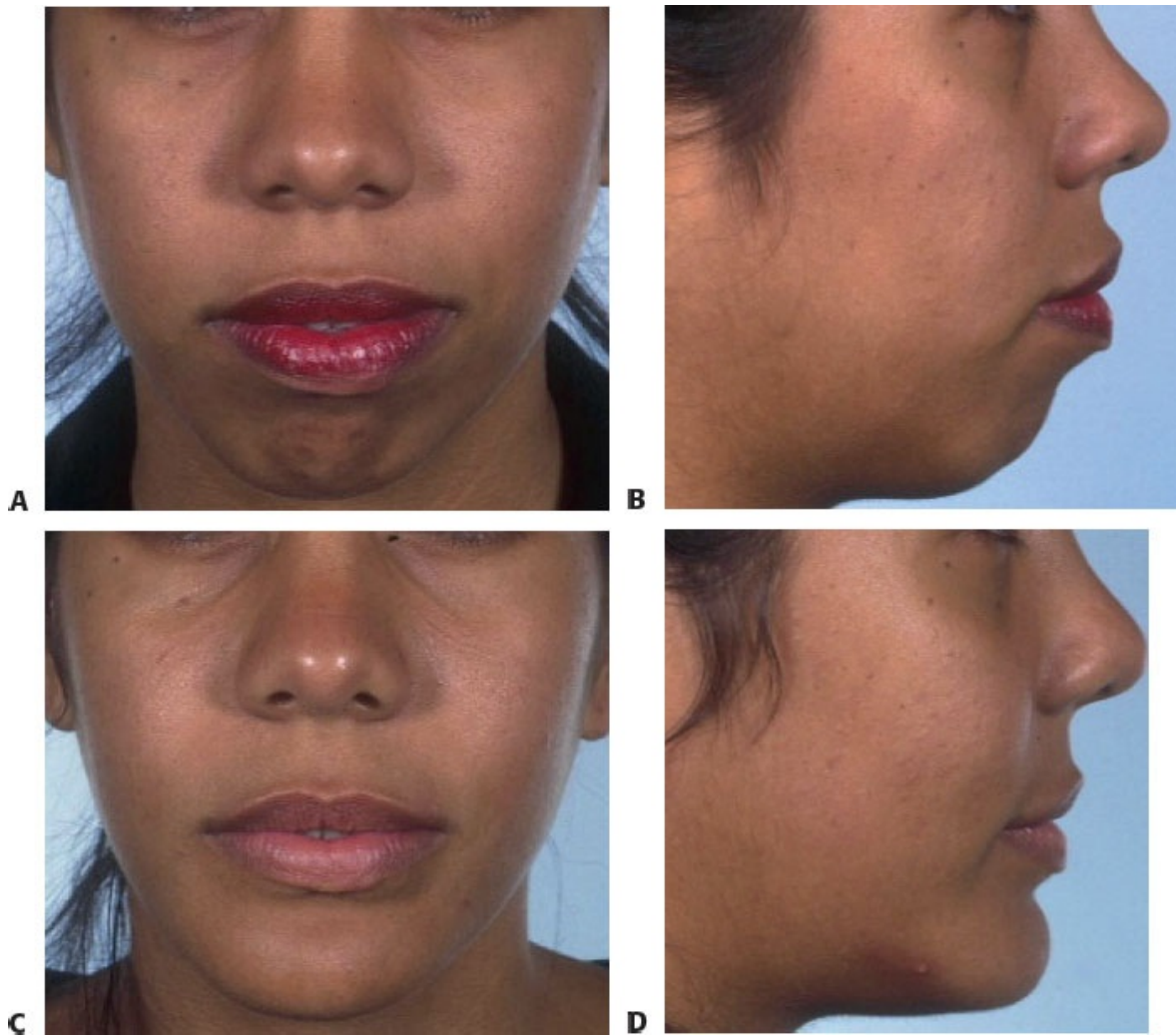


FIG 3 • Preoperative (A,B) and postoperative (C,D) photos of a patient who underwent wedge genioplasty and jumping genioplasty for long retrogenia.

- However, Guyuron et al. who compared osseous genioplasty and alloplastic chin implants, performed by a single surgeon, on two groups of patients, found no statistically significant difference in the amount of postoperative pain between the two groups of patients.¹
- They did show a statistically significant higher incidence of temporary sensory loss over the mental nerve distribution in the osseous genioplasty group.¹
- However, all patients experienced improvement over time, and this difference in incidence of nerve damage was no longer statistically significant over a long follow-up period.¹

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Section XV: Hair Transplantation

77 Indications and Techniques for Hair Transplantation

CHAPTER

Walter Unger and Robin Unger

DEFINITION

- Hair transplant surgery involves the transfer of hair from an area of anticipated lifelong permanence to an area of alopecia or evolving alopecia.
 - The principle of donor dominance, for this procedure, was established in 1959 by Dr. Norman Orentreich.
- Appropriate patients may include those with male pattern baldness (MPB), female pattern hair loss (FPHL), post-trauma and postsurgical areas of alopecia, as well as some cicatricial alopecias.
- Human scalp hairs grow naturally in individual bundles, called follicular units (FUs), composed of clusters of one to four follicles surrounded by layers of concentric collagen fibers.
 - Follicular unit transplantation (FUT), when performed properly, consistently results in a cosmetic appearance similar to natural scalp hair growth (**FIG 1**).
- The two primary methods of harvesting the donor hair are the strip excision method and follicular unit extraction (FUE).
 - The ratio of the donor/recipient area has expanded. Though it is 1:1 with large punch grafts, it is 1:2 to 4 with a strip excision and FUT, thus allowing surgeons to cover larger areas of alopecia with a natural appearance and good cosmetic density.
 - A 1 cm² section from the donor strip can cover 2 to 4 cm² of alopecia.
 - FUE in conjunction with strip harvest has further expanded the donor

availability.

- When FUE is used as the exclusive method for donor harvest, this decreases the number of relatively permanent scalp hairs that can be transplanted during a patient's lifetime, because each of the resultant punctuate scars (typically thousands) must be camouflaged by relatively permanent hairs.
- Good surgical planning in hair transplant surgery addresses current and future areas of alopecia. This principle is especially important when treating younger patients (because of their long-term donor/recipient area ratios) and those with limited long-term donor hair availability.
- Preoperative evaluation and determination of candidacy should include a physical exam, review of relevant laboratory tests, and a review of the family history of hair loss.

ANATOMY

- The scalp is composed of five distinct layers: skin, subcutaneous layer, galea aponeurotica, loose connective tissue, and pericranium.
- The scalp has an excellent blood supply provided by a system of anastomoses between branches of the external and internal carotid arteries. The arteries run centripetally within the subcutaneous layer. This rich blood supply helps promote exceptional healing after scalp surgeries (**FIG 2A**).
- The sensory nerve supply is also centripetal and subcutaneous. If larger nerve trunks are injured in surgery, there can be significant hypoesthesia in the postoperative period (**FIG 2B**).
- The anatomy of the hair follicle has been described in many texts. The terminal hair is divided into an upper (infundibulum), middle (isthmus), and lower (inferior segment) region. A good harvest will remove intact follicles, and all segments will be transplanted (**FIG 2C**).

PATHOGENESIS

- Androgenetic alopecia
 - Androgenetic alopecia is the most common cause of hair loss in both men and women. It is also the most common reason for hair transplantation.
 - In unaffected scalp, the hair has a growing anagen phase of 2 to 6 years, an involution catagen phase of 2 to 3 weeks, and a resting telogen phase of 2 to 3 months.
 - In affected scalp, the anagen phase is significantly shortened, leading to the production of shorter and finer hairs.

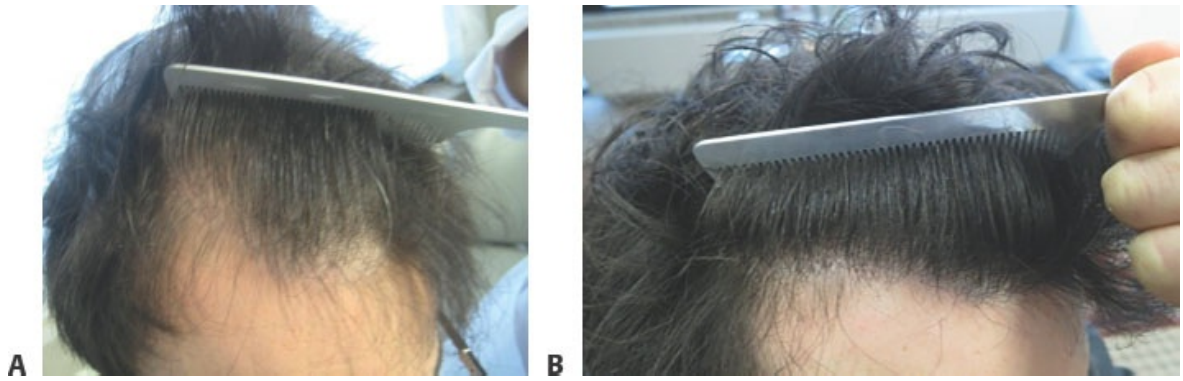


FIG 1 • **A.** Patient before surgery. **B.** Results after 1 year.

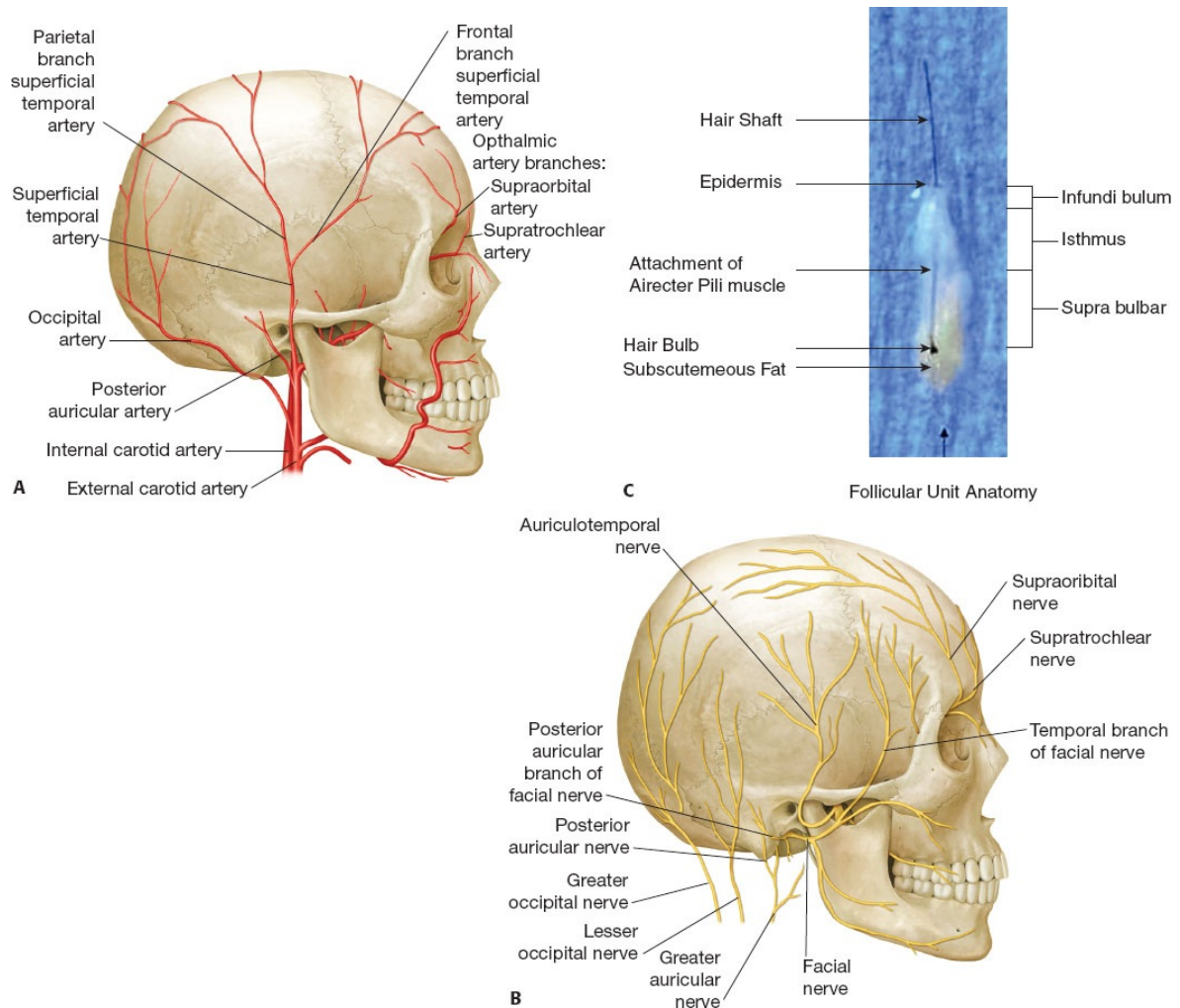


FIG 2 • A. Arterial distribution of the scalp. **B.** Nerve distribution of the scalp. **C.** Structure of the hair follicle.

- Androgens play a significant role in both MPB and FPHL, although FPHL has a more complex etiology involving multiple other potential sources, including inflammatory reactions and changes in estrogen and other hormone levels and the enzyme aromatase.
- Genetic factors are important in determining the likelihood of developing MPB and FPHL—however, it is a polygenic mode of inheritance, with incomplete penetrance.
- Cicatricial alopecias
- Cicatricial alopecias are, for unknown reasons, increasing in incidence in the population and therefore need to be considered in patients presenting with hair loss. The imposters of patterned hair loss to be wary of include frontal

fibrosing alopecia (FFA), lichen planopilaris (LPP), and central centrifugal cicatricial alopecia (CCCA). Their pathogenesis is described in detail in other texts.¹

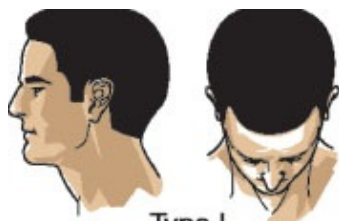
- Dermatoscopic exam and biopsy are helpful in diagnosis and evaluation of activity.
- Surgery should ideally be avoided until the condition has become quiescent for at least 1 year.²

NATURAL HISTORY

- The natural history of male and female pattern alopecia is one of progressive hair loss over the patient's entire lifetime. Current treatments may slow the progression, but as yet, there is no known treatment to stop the evolution.³
- The Norwood pattern is shown in **FIG 3**.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history should focus on factors that may contribute to hair loss, including symptoms of hypo- or hyperthyroidism, adrenal imbalances, prolactinomas, nutritional deficiencies, and scalp symptoms noted by the patient (burning, itching, tenderness, flaking).²
- The history in female patients should also include questions that may indicate symptoms of androgen excess, such as those seen in women with polycystic ovarian syndrome (hirsutism, irregular menses, reproductive challenges, indicators of insulin resistance).⁴



Type I



Type IV



Type II



Type IV a



Type II a



Type V



Type III a



Type V a



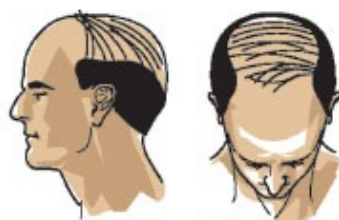
Type III



Type VI



Type III vertex



Type VII

FIG 3 • Norwood classification. (From Landeck L, Otberg N. Hair loss. In: Schalock PC, Hsu JTS, Arndt KE, eds. *Lippincott's Primary Care Dermatology*. Philadelphia, PA: Wolters Kluwer; 2010:410-436, with permission.)

- Events or conditions that cause telogen effluvium should be ruled out; these most often include major physical or emotional stresses, post-severe febrile illness, postsurgery, and postpregnancy. Hair transplant surgery should not be performed until at least 6 months after the resolution of the effluvium—this allows the donor hair to start regeneration and helps identify major areas of concern.
- The history should also clarify the pace of the hair loss and unusual accelerations—a very rapid onset of shedding raises suspicion for etiologies other than androgenetic alopecia.
- The family history of hair loss is pertinent as a guide to determine the eventual degree of patterned loss but is not accurately predictive in many patients.

IMAGING

- Dermoscopy has become a very useful tool in evaluating patients for hair transplant surgery (**FIG 4**).
 - A thorough dermatoscopic exam may reveal more subtle signs of diseases more appropriately treated with a medical rather than surgical approach—including frontal FFA, LPP, CCCA, and alopecia areata patchy or diffuse type.
 - Dermoscopy can also help to determine the degree of miniaturization in the hair-bearing rim. This may inform the surgeon as to how conservative or aggressive the surgical plan should be.⁵
- Biopsy and dermatopathological evaluation may be useful to confirm the underlying condition responsible for the alopecia. Again, dermoscopy guidance may be helpful in this process to guide the surgeon in the area most appropriate for biopsy.

DIFFERENTIAL DIAGNOSIS

- Patterned hair loss may be difficult to distinguish from these entities, especially in their less active periods.

- There also may be some coexistence with MPB/FPHL:
 - Alopecia areata and diffuse alopecia areata (“incognito”)
 - Telogen effluvium
 - FFA
 - LPP
 - Tinea capitis
 - CCCA
 - Discoid lupus erythematosus
 - Folliculitis decalvans
 - Syphilis

NONOPERATIVE MANAGEMENT

- Medical therapy
 - FDA-approved treatments with proven efficacy for MPB include minoxidil and finasteride (**FIG 5A,B**).
 - FDA-approved treatment with proven efficacy for FPHL is topical minoxidil 2% twice daily or 5% once daily. Off-label treatments include antiandrogens such as finasteride, spironolactone, and cyproterone acetate.²
 - Dutasteride 0.5 mg daily may also be used (off-label) in patients who fail to show response to finasteride.
- Prostaglandin analogs: Studies thus far have been limited and have failed to show a significant positive effect.



FIG 4 • A. Distribution of hair loss in a patient with frontal fibrosing alopecia (FFA). **B.** Dermatoscopic photo showing the periphery of FFA. Characteristics

include alopecic area devoid of follicular ostia, slightly white in color; hair in the periphery shows perifollicular casts and relative absence of vellus hair.



FIG 5 • Male patient before **(A)** and 1 year after **(B)** initiating medical treatment with finasteride 1 mg daily. Female patient with typical hair loss in the frontotemporal regions before **(C)** and 4.5 months after **(D)** one treatment with PRP/ACell/microroller.

- Low-level laser and light devices for hair loss have been shown in limited studies to produce some benefit as compared to sham devices—proposed mechanism of action is mediated by absorption of cytochrome oxidase, resulting in increased oxygen consumption and adenosine 5'-triphosphate (ATP) production. In some patients, it may also produce an anti-inflammatory effect.²
- Mesotherapy: Superficial scalp injections of pharmaceuticals and vitamin compounds. Compounds used include minoxidil, biotin, panthothenol, finasteride, dutasteride, tretinoin, and other vitamins and minerals. Further studies are necessary to determine efficacy and which compounds at which concentrations are optimal.
- Platelet-rich plasma (PRP): Very few controlled studies have been completed

to provide evidence-based data on this modality for hair loss treatment. Nevertheless, anecdotal reports and the experience of credible hair restoration surgeons (HRS) are encouraging.⁶

- There are many approaches being used by HRS for this procedure. Standardization is necessary and will enable more meaningful evaluation of the procedure's efficacy.
- Typically in our practice, 60 mL of blood is drawn from the patient and centrifuged to produce PRP. This is then mixed with 25 mg of ACell (an extracellular matrix derived from a porcine bladder) and injected into the area of hair loss. It may be used as a stand-alone procedure or to enhance the results in hair transplant surgery (in the latter scenario, it is also used to bathe grafts prior to implantation).⁷
- When done as a stand-alone procedure for hair loss by one of the authors, microneedling with a 2.5-mm microneedle is performed prior to injection of the PRP/ACell.
- PRP has been demonstrated to increase overall hair counts and hair diameter, while microscopic findings reveal thickened epithelium, proliferation of collagen fibers and fibroblasts, as well as greater numbers of blood vessels around hair follicles in areas that have been treated with PRP (**FIG 5C,D**).⁷
- More studies are needed to confirm the efficacy of this treatment, the ideal approach to be utilized, and frequency of treatments required.
- Micropigmentation is a technique that utilizes tattoos to simulate short hairs on the scalp.
 - It can be used to hide scars and create the illusion of greater hair density in hair-bearing areas. The type of pigment, color chosen, and depth of ink placement can impact the long-term appearance of this type of camouflage.
- Other camouflage techniques include
 - Small hairpieces
 - Powders or hair fibers that camouflage the color contrast between hair and scalp, thereby making hair appear fuller
 - Alternative hair styling

SURGICAL MANAGEMENT

- Donor area evaluation is undertaken to determine the area from which hair is most likely to be permanent and thus will ostensibly persist in the recipient area long after transplantation.
- The senior author conducted a study of 328 men aged 65 years or older in

whom areas containing at least 8 hairs per 4-mm diameter circle were measured.³ The dimensions established from this study represent the region of harvest that would be “safe” (ie, the hairs would persist) in approximately 80% of patients under the age of 80 years. This persisting region of the donor scalp was termed the “safe” donor area (SDA) and later the safest donor area to denote that no area is perfectly “safe” (**FIG 6A**).

- These boundaries have since been modified for FUE. Because of the less visible resultant punctate scarring from this alternative technique, Cole’s FUE SDA is somewhat expanded (203 cm²) and includes 14 subdivisions based on hair density but importantly was based on only 94 patients, nearly all of whom were in their 30s or 40s—and for both reasons, it is therefore most probably a less reliable guide regarding long-term planning (**FIG 6B**).
- Donor harvest approach
 - As previously mentioned, there are two main donor harvest approaches: strip harvest and FUE.
 - TABLE 1 summarizes the benefits and disadvantages of each method.

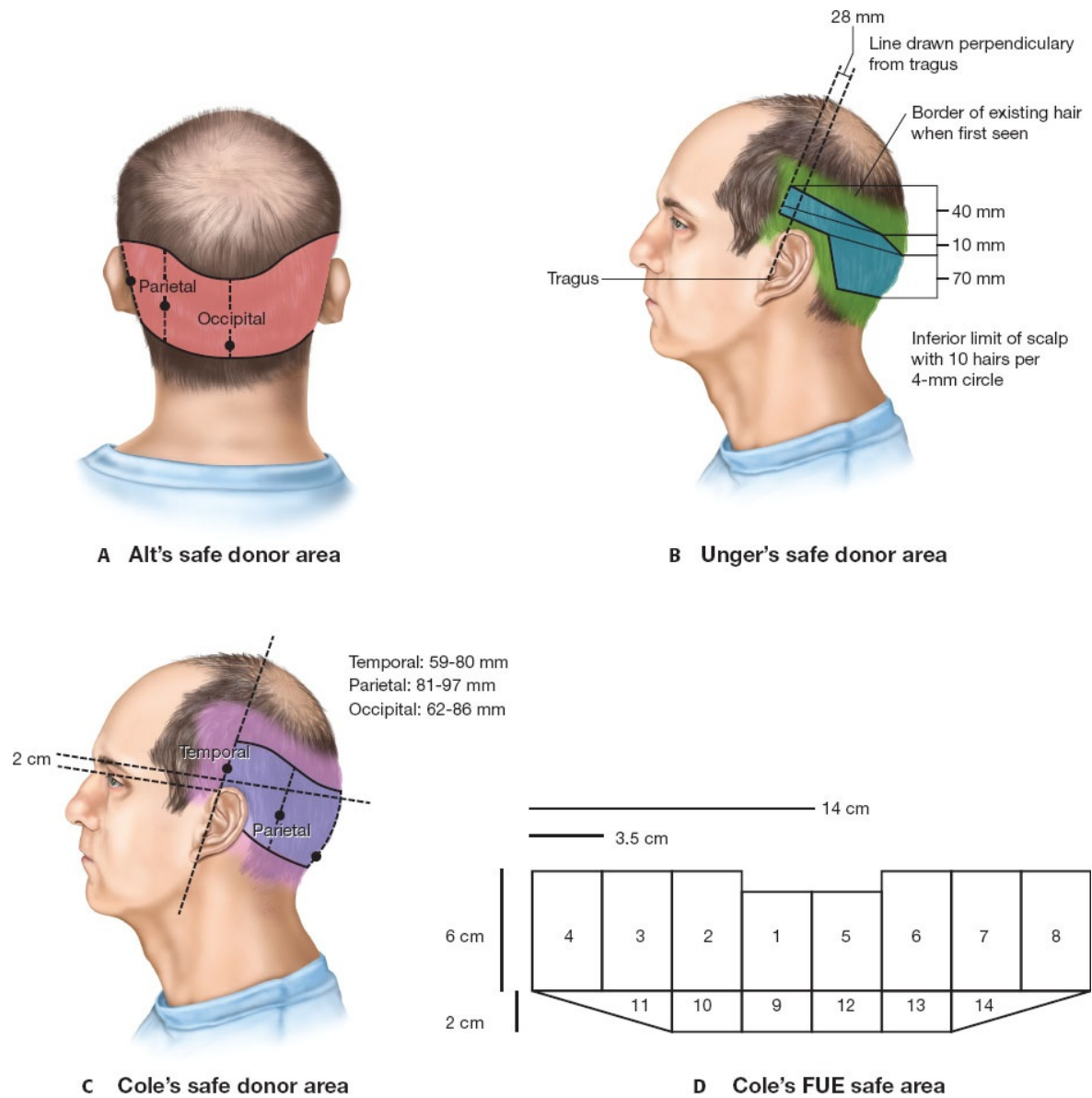


FIG 6 • Unger and Cole safe donor area.

Table 1 Benefits and Disadvantages of Follicular Harvest Techniques

Method	Pros	Cons
Strip harvest	• Higher FU yield • Narrow donor area • Higher follicle survival • More protective tissue surrounding hair follicles and	• Long linear scar that may be visible when the hair is cut short • More painful postop period • Longer postop healing

	predictable graft quality • Harvest stays within the confines of the safe donor area • Ability to choose the size of the grafts • Donor not visible under hair from day 1 postop	period with some exercise restriction • Potential for loss of dormant follicles—greater in unrecognized cases of telogen effluvium
FUE	• Shorter postop healing • Less painful postop period • Minute punctuate scars that are less visible even with the hair worn short especially with less contrast between hair and scalp color • A good complement technique when scalp laxity is limited or for repairs • Less tissue discarded with potential dormant follicles	• Lesser FU yield • Wider donor area harvested (some HRS extend past the safe donor area to achieve higher graft yield) • Less tissue around hair follicles (skinny grafts) and less predictable quality, contributing to lower follicle survival • Usually requires shaving the donor area for larger sessions • Lowers the density in the donor area perceptibly after larger harvests or multiple procedures

- Ideally, HRS should have all tools available to tailor the procedure to each patient's individual needs.
- Both methods of harvest primarily use follicular unit (FU) grafts almost exclusively in the recipient area.
- One of the authors sometimes uses double follicular units (DFU) when a strip harvest is use and the area to be treated has pre-existing permanent

hair. This very frequently pertains to women with thinning behind the hairline zone and older males with minimal hair/skin color contrast.

■ Donor strip harvest

- Goals
 - Minimize the amount of hair follicle transection as the strip is excised and dissected.
 - Extract donor strip widths with prudent caution in order to minimize closing tension.
 - Produce only a single scar regardless of the number of sessions performed on a single patient.
- Assessment of scalp laxity prior to surgery is of tantamount importance; this can be done with calipers or manually.
- The donor strip should be removed from the densest zone of the fringe hair. Any subsequent strip excision should include the previous scar so only one thin linear scar remains.

■ FUE

- Goals
 - Maximize the amount of hair removed from the most permanent hair-bearing fringe while minimally altering the architecture of the donor area. Keep in mind also that the fringe hair will continue to decrease in density somewhat over the patient's lifetime.
 - Minimize transection during extraction, yet try to harvest with some protective tissue; this should be a goal even if the technique involves fractional harvesting of follicular groups.
 - Minimize the amount of scar tissue within the donor area by varying punch diameters to keep it as small as possible (without increasing transection rates) and try to evenly disperse the harvest sites.
- FUE grafts may be removed from the Unger's traditional SDA and should ideally have a tapering zone superior and inferior to make the density change more subtle. The temporal regions may also be harvested more extensively with this technique than with strip harvesting.
- FUE may be used to harvest hairs from the beard area on the neck and inferior to the lower mandible.³ These grafts can be used to camouflage scars and to thicken regions that already have been transplanted. Other body hair survival is much more unpredictable.

■ Recipient area approach

- The authors strongly believe in planning that includes treating current areas of hair loss simultaneously with future areas of loss in the zone of the recipient area being addressed (front, midscalp, or vertex).
 - Although patients may intend to return to “complete things,” they may be unable to do so because of life events. A well-planned hair transplant should look natural over the patient’s entire lifetime.
 - On average, 25% to 30% of grafts may be placed in future areas of loss—this number is obviously higher in patients treating their MPB very proactively and is lower in those who present with more advanced hair loss.
- Other physicians believe that transplanting a maximum portion of currently noticeable hair loss is more important than concomitantly treating the less noticeable future areas of loss. As long as the patient is fully informed, this policy is reasonable: it gives the patient more immediate satisfaction, and the future areas of loss can be treated when needed.
- The authors do not ask patients to change their hairstyle or usual length of hair for the procedure. This hair serves as a guide for the placement of hair to be transplanted and also provides postoperative camouflage.
- Some surgeons shave the recipient area to facilitate the completion of larger surgeries with greater ease and within a more reasonable time frame.

Preoperative Planning

- Preoperative instructions include the discontinuation of medications or substances that may increase bleeding.
 - In particular, 10 days before surgery, acetylsalicylic acid (ASA), or any drugs containing it that influence platelet activity, should be discontinued—this instruction is suspended in patients taking ASA or anticoagulation for therapeutic purposes. The patient is also asked to abstain from alcohol consumption for 1 week preoperatively.
 - Twice-daily application of topical minoxidil to the recipient area is started 1 week prior to surgery due to the theoretical increase in blood flow that may decrease the likelihood or severity of temporary hair loss.
 - Patients with limited scalp laxity having strip surgery are instructed on how to massage their scalp during the 4 weeks prior to surgery in order to increase the laxity within the donor area, thus enabling a wider strip harvest and a greater FU yield.
- Prophylactic perioperative antibiotics are given to patients 1 hour prior to

surgery and 6 hours later as a precaution.

- The surgical design is drawn the morning of surgery and discussed again with the patient (**FIG 7A**).



FIG 7 • A. Markings for hairline and borders for surgery.
B. Preoperative period after donor area hair has been trimmed. A scar from the previous surgery is visible in the center of the trimmed region.

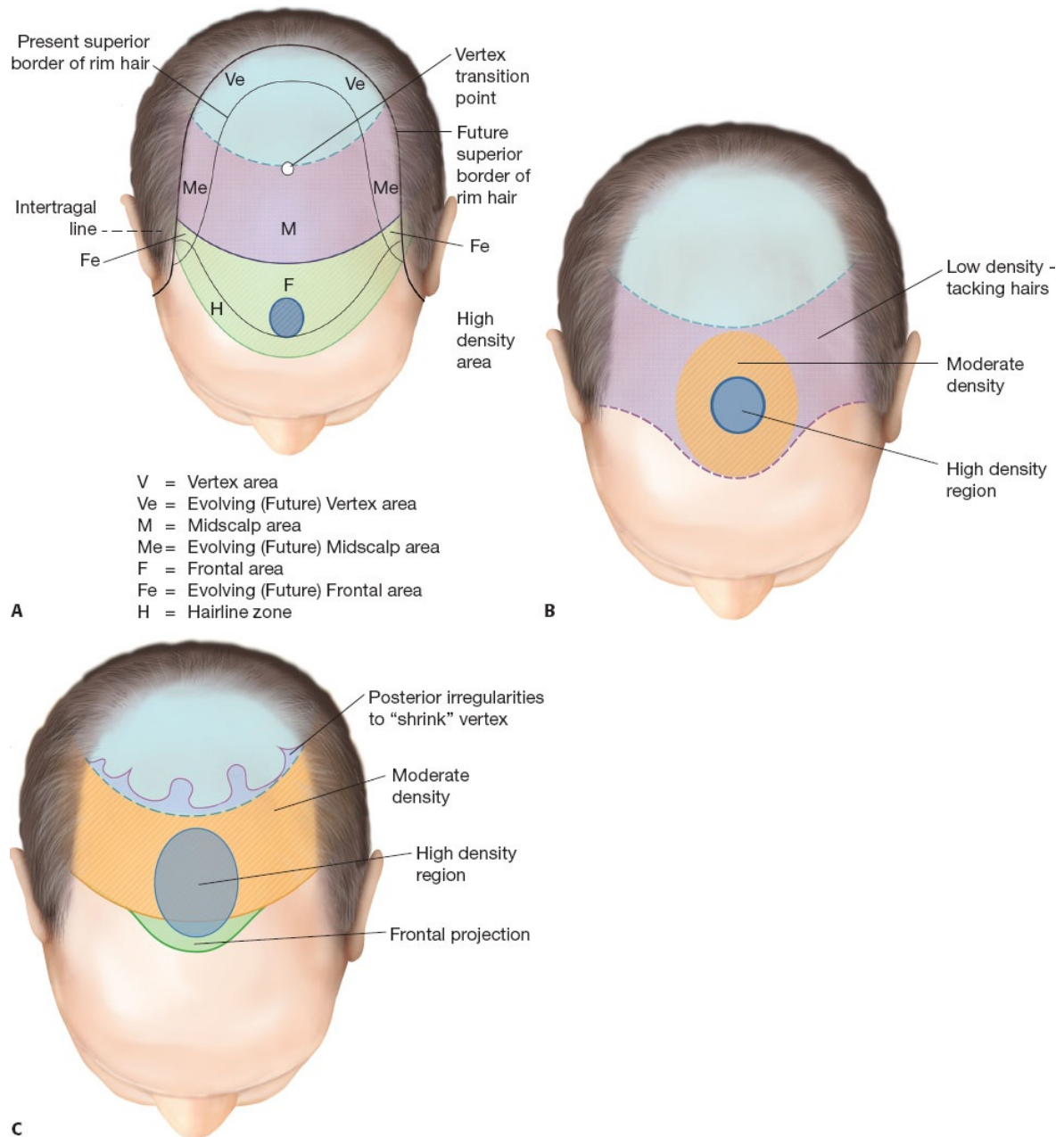


FIG 8 • Zones of treatment regions, including current and future areas of alopecia.

- Many photographs are taken on the morning of surgery, an even greater number if the recipient area contains pre-existing hair.
- Results are optimal and reproducible when photos are standardized. A ceiling or photographer's light immediately behind the photographer and a uniformly bright background color enhance the viewing of the scalp by creating contrast,

thus outlining the peripheral boundaries of progressing alopecia and hair.

- The laxity in the donor area is evaluated carefully with the neck in a neutral position.
- The donor area hairs to be harvested are trimmed to 2 to 3 mm in length to facilitate implantation and orientation of the hair at that time (**FIG 7B**).

Hairline Design

- The hairline design is arguably the most important step. There are no firm rules.
- The contour should be consistent with a natural aging hairline (different among ethnic groups). In most male patients, this involves incorporation of temporal recessions.
- The major anatomic landmarks, borders, and zones of normal hair-bearing scalp need to be well understood and effectively reproduced (**FIG 8**).
- With the increased demand for HRS among young adults in the early stages of MPB, one of the most important principles of hairline placement is “do not place a hairline too low.”
- A guideline for locating the anterior midpoint of a hairline is to look somewhere in the zone between the vertical and horizontal planes of the scalp. Discuss with the patients their wishes and desired hairstyle as this may influence somewhat the position of the superior “frame” of the face.
- To create the illusion of a slightly lower hairline without expending too many FU, surgeons may construct a “widow’s peak.”
- From the anterior midpoint, the frontal hairline should run more or less parallel to the ground or slope slightly upward when viewed from the side until it meets the temporal hairline at a point drawn from the lateral epicanthus to a point where it meets the remaining temporal hair.
- Throughout the hairline, the transition zone (the anterior 0.5- to 1-cm region) should contain both microirregularities (intermittent density clusters more noticeable under close examination than from a distance) and macroirregularities (protrusions along the path of the hairline that cause it to appear less linear when viewed from a distance).
- It is important to note that the macroirregularities may change the contour of the hairline and thus need to be chosen carefully.
- It is generally not advisable to advance temporal points in young male patients who may experience a progressive posterior recession of their temples that

their limited donor reserve may not be able to sufficiently address once the transplanted hair is placed too far anterior to the progressively receding temporal hairline (thus leaving an unnatural “island” of transplanted hair).

- When the donor-to-recipient ratio allows, however, temporal points should be advanced no farther than to an intersection of two lines: one drawn from the tip of the nose, over the pupil to the anterior tip of the temporal point, and a second line drawn from the most anterior midpoint to the tragus.
- In addition to hairline design varying with degree of hair loss, ethnic considerations should be made when creating this anterior-most pattern.
- Caucasians generally have dolichocephalic, or ovoid, skulls; East Asians tend to have brachycephalic, or rounded, skulls.
- The hairline design in East Asians is comparatively wider and flatter, with curved (rather than sharp) frontotemporal angles. The relatively higher caliber of East Asian vs Caucasian hair may make multihair FU more noticeable. It is therefore important to camouflage these higher-caliber haired FUs with additional rows of single-haired grafts anteriorly.
- Patients of African descent tend to have mesocephalic skull shapes of intermediate length and width that support hairlines that are flatter than Caucasian patients, but not as flat as those found in most East Asians. Unlike East Asian patients, however, a natural hairline appearance is more easily achieved in patients of African descent due to not only the hair curl and the finer caliber hair but also the minimal contrast between the color of the hair and skin and the frizz, which creates an illusion of density and any tendency for grafts to be noticeable.
- Appropriate facial framing in female patients often entails a more rounded hairline design that incorporates observations derived from examination of 360 female volunteers (**FIG 9**).

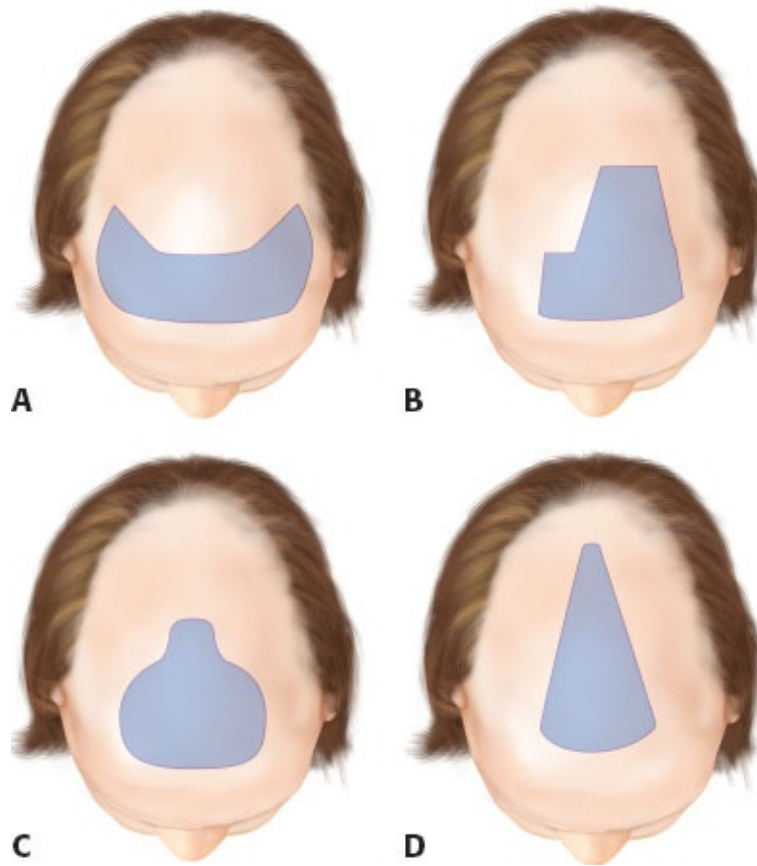


FIG 9 • Most advantageous patterns for graft distribution in female patients.

- A widow's peak (observed in 81% of female hairlines)
- An anterior midpoint placed a mean distance of 5.5 cm superior to the glabella
- Lateral mounds with an apex of 3.75 to 4 cm from the frontal midpoint (98% of females)
- Temporal mounds 3.5 to 3.75 cm lateral to the apex of lateral mounds
- Temporal recessions in a concave oval contour that contain fine hairs (87% of females)
- More often with females than with their male counterparts, native residual vellus hairs can be followed to recreate their hairline pattern.

Positioning

- During the donor removal in a strip harvest, the patient begins in a prone position, using a prone pillow to access the occipital donor area (**FIG 10**).

- The head can be turned from side to side to access the lateral regions of the donor area.
- During longer FUE procedures, the patient's position is changed multiple times, including prone position, lateral positions, and even supine positions with the head turned from side to side. This alleviates discomfort during the FUE harvest.
- Positioning in FUE procedures is very individual among surgeons and their teams. It has become apparent that the FUE grafts are very fragile and even short periods of desiccation or long periods without blood flow may be detrimental.³ Thus, positioning is optimized to allow overlap of excision, removal, and implantation phases.



FIG 10 • Positioning of patient in the prone pillow for donor excision.

- In most cases, the sites are created and the grafts are implanted with the patients in a supine position.
- If the vertex is the recipient area, however, the optimal position will be prone for a portion of sites and implantation.
- Some HRS perform the procedure with the patient in a sitting position for the entire procedure—often in a special chair with a head rest to stabilize the head. In the authors' experience, patients tend to find this fairly uncomfortable for long periods.
- Anesthesia
 - All patients are given long-acting oral medication to start the day, including an antianxiolytic (lorazepam 2 mg), a sedative (diazepam 10 to 20 mg), and

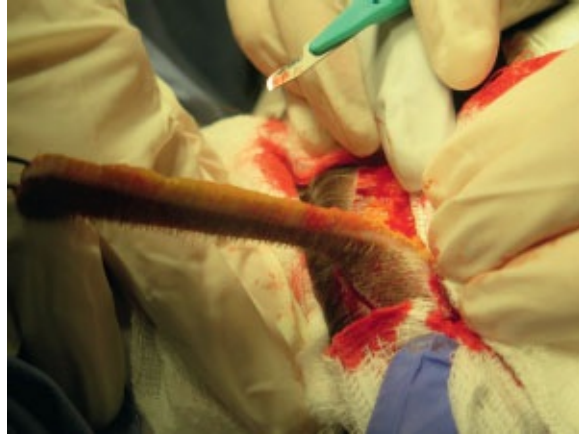
an analgesic (hydrocodone/acetaminophen 5/500 mg).

- Just prior to injecting the local anesthesia, the patient is given fentanyl and midazolam intravenously for immediate effect.
- Anesthesia is typically performed as a field block with lidocaine 2% with 1/50 000 epinephrine. First wheals are placed at 2.5-cm intervals, and then the block is completed by injecting laterally from within the anesthetized areas. Occasionally, stronger anesthetics are used.

TECHNIQUES

■ Donor Strip Harvest

- Magnification is used to assist in excision and dissection under direct visualization.
 - The transection rate in strip harvest varies depending on the surgeons' and technicians' experience and is generally less than 1%.
- The area to be harvested is tumesced in the subcutaneous layer with saline. This helps separate the follicles, thus minimizing follicle transection. It also lifts the tissue above the deeper and larger vasculature and nerves.
- A single no. 15 blade is used to incise along the inferior edge of the donor area followed by the superior edge.
 - The lateral ends of the strip are tapered before the tissue is removed.
 - Some HRS superficially score the surface with a blade to a depth of mid-dermis and use skin hooks to allow for greater visualization or tissue spreaders to bluntly separate the tissue and reduce transection rates further.
- The strip is removed from the bed using a single blade, again under direct visualization, to ensure dissection occurs in the relatively avascular plane just deep to the follicular bulbs (**TECH FIG 1**).



TECH FIG 1 • Excision has been started. Note the intact follicles and limited depth of incision.

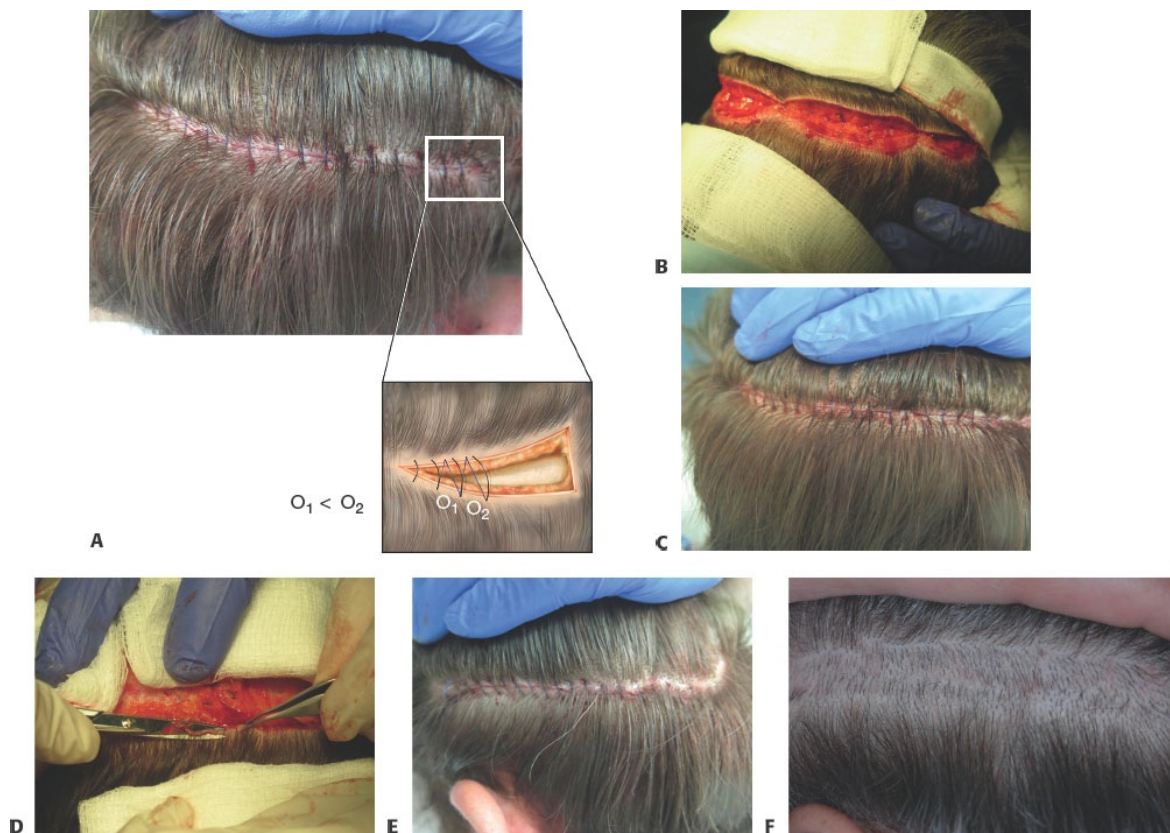
- Any significant bleeding vessels are cauterized, excepting those that are immediately adjacent to follicular bulbs.
- One very helpful pearl is to remove a strip from the occipital region first and close that area with sutures before reassessing the scalp laxity in the adjacent parietal and temporal regions and excising those strips. This is especially beneficial when the donor area tension is somewhat unpredictable.

■ Donor Site Closure

- Choosing the strip width and closing the donor wound in sections, as described above, is helpful to avoid any unexpected areas of tension.
 - One region of the scalp can “borrow” laxity from another area and lead to otherwise unanticipated increased tension.
- Over the mastoid region, where tension is more often higher than expected, wedge-shaped sutures may also help relieve tension.²
 - This technique eases the work (W) required for closure more effectively than sutures placed perpendicular to the wound edge by increasing the distribution of force (F) along the wound edge. With F and wound edge displacement (d) being constant in the formula for work ($W = Fd\cos\theta$), the magnitude of work is reduced as the angle (θ) increases (**TECH FIG 2A**).
- The donor area may be closed in a single layer or double layer, depending on the surgeon’s preference.
 - The double layer helps to decrease tension on the more superficial

epidermal layer, but it also carries the risk of worsening the scar in individuals with hyper-reactive healing.

- If the patient is undergoing a second surgery, the healing from the first surgery can be a guide. If the scar spread after suture removal and there was no hypertrophic healing, a double-layer closure nearly always results in a finer scar compared to a single-layer closure.
- If a double layer is used, the authors prefer PDSII 3-0 or Maxon 3-0.
- Depending on the wound length, four to eight buried interrupted sutures are placed deep to the level of the follicles, to approximate the base of the wound (**TECH FIG 2C**).



TECH FIG 2 • **A.** Suture pattern in a wedge shape to decrease tension on closure over the mastoid regions. **B.** Deep sutures in place in double-layer closure. **C.** Donor area after closure of the superficial layer. **D.** In trichophytic closure, the epidermal layer being trimmed is approximately 1 mm wide and 1 mm deep.

If the hair follicles are slightly further apart from one another, the width may need to also be slightly larger.

E. Partially completed trichophytic closure. **F.** Final appearance of scar in donor area.

- The superficial epidermal layer is closed with 3-0 Supramid or 3-0 Prolene. Usually, a running suture is utilized with stitches placed approximately 4 to 5 mm apart from one another, ensuring good approximation of the epidermal edges.
 - The needle should pass through the dermis and exit just below the level of the bulbs.
 - Beware sutures that are too close or too far from the wound edge.
- Trichophytic closure can be used to help further camouflage the resultant scar.
 - In this technique, prior to closure, a 1-mm section of epidermis is carefully removed from the superior or inferior ledge of the wound, maintaining a level superficial to the sebaceous gland (**TECH FIG 2D**).
 - The epidermal edges are then approximated and the wound is closed (**TECH FIG 2E,F**).

■ FUE Harvest

- FUE harvest can be accomplished by several methods: manual punch, oscillating or rotating motorized punch (dull or sharp or even a modified sharp punch), suction-assisted device, or robotic device.
 - Each of these methods has unique detailed requirements to produce ideal results.
- Originally involving the use of a sharp 1-mm “cookie cutter”-like punch, hair follicles trimmed to 2 mm in length were extracted manually in a random distribution so as to avoid overharvesting any particular area, which might result in a “moth eaten” appearance.¹
- Gradually, powered instruments for FUE largely replaced manual punches by demonstrating increased extraction speed and efficiency.⁶ Increased speed, however, requires heightened attention to avoiding follicle transection or follicle “decapitation” that may occur when a sharp punch is introduced at the improper angle.⁸

- Variable tissue and hair characteristics such as follicle curvature, angle of exit from the skin, or splaying arrangement beneath the skin surface may further increase the challenge of avoiding follicle transection.
- To minimize follicle transection, nonsharp motorized punches have been developed to perform “blunt” dissection of FUs from the skin. Rather than cutting the deep segment of a follicle with an unforeseen curvature, a dull punch can push the follicle within the cylinder and thereby reduce transection rates.
 - Alternatively, a two-step manual process involving an initial “scoring incision” at a 0.3- to 0.5-mm depth around the follicle followed by the insertion of a blunt dissecting cylinder that reaches the full depth of the follicle (approximately 4 to 5 mm) enables full separation of the intact follicle from its native tissue prior to manual extraction using forceps.
- A newer technique involves an oscillating motorized unit and a modified blunted thin-walled punch. Limited reports indicate this may lower transection rates dependably (below 3%) and allow removal of a graft with limited mechanical traction and more tissue surrounding the FU, regardless of patient’s tissue characteristics.
- Larger punches alter the architecture of the donor area and may leave more perceptible scars. In most cases, the punch should be smaller than 0.95 mm in its external diameter.
- A surgeon’s ability to properly position the punch according to the follicle’s angle of exit from the skin surface requires proper (5× to 6.5×) magnification.
- The following step-by-step description applies to most techniques:
 - For large FUE cases, the donor areas are shaved.
 - Sterile saline tumescence injected at both a superficial and deeper depth helps to increase the space between FU, increases the predictability of hair follicle angle deep to the skin surface by making the follicles more erect, and separates the follicle bulb from the underlying vascular and nerve plexus.
 - The tumescence can dissipate fairly quickly and therefore needs to be repeated frequently as the surgeon progresses to subsequent areas.
 - The punch is centered over the FU and advanced.
 - There is a tactile sensation that can be appreciated when the FU has been “released.”

- Initially, several of the grafts should be extracted to check if the depth is sufficient to minimize trauma during the extraction phase.
 - Once a depth has been determined, most physicians will incise up to a hundred grafts or more and then extract using a two-handed method to pull the grafts while simultaneously depressing the surrounding tissue to assist in release.
 - Depending on the position and region of harvest, occasionally, an assistant can follow along and extract while the surgeon continues incisions.
- Most physicians now employ a method of creating sites prior to the extraction phase and alternating graft extraction and graft implantation throughout the surgical day; thus, the more fragile FUE grafts do not remain outside the body for long periods.
- As noted earlier, the patient needs to be positioned and repositioned throughout the day to facilitate harvesting the grafts and maintaining good ergonomics for the surgeon.
 - Certain positions also enable the technicians to implant the grafts simultaneously while the harvest continues.
- It is worth repeating that the grafts need to be kept moist from the time of extraction to implantation.
- The robotic technique of harvesting FUE does make the process faster and also has a faster “learning curve” for the physician. Nevertheless, some patients complain of the discomfort of the positioning chair and prolonged immobility.
 - The smallest punch size used with the robot has an internal diameter of 0.9 mm, but external diameter of 1.1 mm, so the punctuate scars are larger than ideal.
 - The trend of “fractional harvesting of follicular groups”—removing only some hairs within a follicular group—helps preserve donor architecture and is not possible with the robotic punch.
- Many physicians, including the authors, pack the donor sites with PRP and ACell after the harvest is complete, to potentially minimize the visibility of the scars and alteration of the subcutaneous tissue during healing. Theoretically, this should facilitate a second FUE procedure.

■ Graft Preparation

- Once a strip is removed (**TECH FIG 3A**), it is immediately transferred to a dish with a chilled holding solution. The authors use HypoThermosol with liposomal ATP (10:1 mL proportion). This solution has been shown to improve survival of the grafts while outside the body, as compared to saline or other solutions.
 - Akin to organ transplantation, factors of negative influence include ischemia-induced hypoxemia and subsequent ATP depletion (resulting in subsequent apoptosis) as well as ischemia-reperfusion injury.
- Graft preparation takes place on ClearVue boards (translucent horizontal cutting surfaces made of polyurethane), which allow backlighting to project through the tissue. Lighting from above is provided by Meiji lights with adjustable intensity.
 - Magnification requirements vary between technicians; some prefer magnifying loupes, while others use microscopes.
- The strip is initially “slivered” into “slices” that are one FU in width (**TECH FIG 3B**).
 - The strip needs to be kept moist during this entire process with frequent spraying of chilled saline.
 - One end of the strip is anchored with a 20-G needle, and countertension is provided with Adson forceps. A single Personna blade held on a small blade handle is gently pulled toward the technician to carefully dissect the tissue between the follicles.
- The slices thus produced are then turned on their sides and divided into the individual grafts.
 - The grafts are sorted according to number of hairs and hair texture and stored again in the chilled holding solution (**TECH FIG 3C**).
- FUs are kept intact: they are not subdivided unless there is an insufficient number of single hair grafts for the hairline.
- The ideal “pear-shaped” graft (**TECH FIG 3D**) possesses little or no surplus epidermis and retains an appropriate amount of protective dermis and subcutaneous adipose tissue around the follicle, the intact sebaceous glands, and the dermal papilla so as to reduce sensitivity to traumatic handling, temperature changes, and graft desiccation (the main cause of poor graft survival).
 - These characteristics are rarely achieved with FUE grafts, which are mechanically pulled out of the skin with a combination of traction and

perifollicular pressure after a shallow circumferential incision and so are more fragile. Some of the newer developments in blunt dissection with a very thin-walled punch appear to improve the amount of surrounding tissue in the FUE grafts.

- FUE grafts rarely require much “preparation.” They are sorted according to number and caliber of hairs.



TECH FIG 3 • **A.** A strip harvest after removal. **B.** A “sliver” removed from the strip. **C.** FU grafts sorted in the dishes filled with a storage solution (HypoThermosol and liposomal ATP) and kept chilled. **D.** FUE grafts on the left and FU grafts from strip on the right.

■ Creation of Recipient Sites

- The recipient site creation is arguably the most important step in producing excellent cosmetic results.
 - The surgical plan should already include an estimate of how large an area needs to be addressed, including current and future areas of alopecia.
 - Then, the physician needs to determine approximately how many grafts will likely be harvested; this then guides the determination of the density of sites to be created.
 - There should be micro- as well as macroirregularity to create a very natural appearance. The density of the hairline should be lower than the density created posterior to the hairline to produce a feathered effect.
 - The lateral hairline is formed by the anterior “temporal humps.” These areas are re-created (at an angle very acute to the scalp) in patients who are severely receded in these regions.
- The angle and direction of recipient site incisions should in almost all cases mimic those of any significant amount of pre-existing hair, regardless of its location.
 - To do otherwise results in transection of those hairs, and every study on follicle transection has demonstrated decreased number and/or hair caliber

of transected follicles.

- Generally, the authors make sites parallel to the direction of the hair (**TECH FIG 4**).
- In the temporal regions and eyebrows or other areas requiring a very acute angle, sites are made perpendicular to the hair direction.
- If there is any movement of the FU within the site, it will not result in the hair direction being less flush with the scalp.
- The hairline zone should be completed with only single-hair FU, with the finer one-haired and some two-haired FU placed anterior to the higher-caliber ones.
- The sites are made using a 20-G needle and follow the angle and direction of existing hair.
- The density of sites may vary between 25 and 35 FU/cm² depending on the effect being sought.
- Behind the hairline zone, the sites are created using a 19-G needle for two-haired and some three-haired FU, and the three- or four-haired FUs are placed posterior to that in sites made with an 18-G needle or 1.3-mm blade that is cut to size.



TECH FIG 4 • Recipient site pattern.

- The density of these sites varies between 20 and 35 hairs, depending on the distribution of the graft size, the area needing coverage, and the overall density availability.
- The three-haired FU and follicular families are concentrated in regions where higher density is desired.

- This includes a region behind the hairline transition zone and within a larger oval-shaped region in the frontal forelock.
 - There is much debate regarding the ideal density of sites within the field of hair restoration surgery.
 - The authors believe the ideal density depends on many factors, including hair characteristics, final expected pattern of alopecia, donor availability, and patient objectives.
 - The ideal density achieves the greatest cosmetic impact over the largest area of the future pattern of alopecia; it is not a predetermined number.
 - Creation of recipient sites in the midscalp and vertex follows a similar surgical plan, in that, nearly always, current and future areas are treated.
 - The site density again depends on the size of area that has to be treated and the donor hair available over the patient's lifetime.
 - The vertex should ideally not be surgically treated until the frontal two-thirds of the area of MPB are satisfactorily completed.
 - This area responds best to medical treatment and is generally least cosmetically important to patients.
 - Pre-existing hair should be protected during site creation, and grafts should be placed in the future areas of loss to be certain that the transplanted area remains “connected” to the fringe hair.
-

■ Hair Transplantation in Women

- The most important aspect in hair transplantation in women is the planning stage.
 - **FIG 9** shows the most important cosmetic regions to treat in women to make the greatest impact in a single surgery.
 - Unlike male patients, who are totally alopecic in the areas of concern, most females' scalp hair is getting progressively sparser.
 - The recipient area is fairly diffuse and the donor area is generally smaller and more inferior in females. Density needs to be created very strategically.
 - The hairline zone should be more feathered in women than in men. If preauricular hair is being transplanted, the patient should be instructed that trimming the hair to make it more wisplike after surgery may be helpful.
- Sites for FU are usually made with 20-G or 19-G needles, depending on the size and caliber of the grafts following the exact angle and direction of the

existing hair.

- In women, the coarser hairs are more likely to be terminal hairs that will last over many years; these should be considered when choosing exactly where to place a transplanted hair.
- One of the authors makes some sites with a blade cut to size for DFU; grafts that contain two FUs.
 - After several samples of DFU are produced, the grafts are tested in the sites to ensure a good fit. The size is usually between 1.2 and 1.3 mm.
 - These grafts seem to produce more volume in the area in which they are placed and potentially reduce the postoperative telogen effluvium frequently seen in women.

■ Hair Transplantation into Scars From Cicatricial Alopecia, Trauma, or Postrhytidoplasty

- The major pearl for hair transplantation into scar tissue is related to the real-time evaluation of the vascular supply. No epinephrine should be used in the area prior to starting. This allows the surgeon to evaluate blood flow throughout the area.
- Sites are created using either a 20-G or 19-G needle, and the site should be made deeper than usual, to try to access the vascular bed beneath the scar tissue.
- Site density should be between 10 and 20 FU/cm² in the first pass.
 - If the blood supply seems quite good, density can be used adjacent to the scar (eg, anterior to a postrhytidoplasty scar).
- Patients should expect that at least a second surgery will be necessary to create acceptable hair density. Often, neovascularization after the first surgery has occurred and the density of sites can be higher.
- Sometimes, the tissue has poor recoil and the grafts tend to slide out.
 - In such cases, tissue glue can help hold the grafts in place.

■ Facial Hair Transplantation

- Scalp hair can be transplanted into the eyebrow, beard, mustache, and eyelash areas.

- The techniques involved in these procedures are very similar to those used to treat areas of patterned hair loss with a few exceptions.
 - The sites are created almost exclusively with the 20-G needle, and almost all grafts are one- or two-haired grafts.
 - The grafts should be cherry-picked from regions of the donor area with matching texture.
 - The angles of the sites need to be particularly acute on the face, and the hair needs to be oriented so it does not curl in the wrong direction.
 - Eyelash transplantation is particularly difficult to perform and produce natural results. The hairs at the nape of the neck are well suited for this purpose.
 - A curved needle is used to make sites in the lid margin and the hair is threaded through and directed to follow natural lash curvature.
 - Some surgeons used scalp hairs threaded onto a crescent needle, which is then threaded through the lid.
 - Trichiasis (misdirection of the eyelash) can be a significant complication.
-

■ Implantation of Grafts

- Graft implantation requires very skilled technicians with excellent hand-eye coordination and a gentle touch.^{9,10}
 - In our office, the grafts are bathed in PRP + ACell in small dental rings prior to implantation. The dental rings allow the grafts to remain moist while limiting the need for constant change of field of focus to retrieve more grafts.
 - The graft is grasped by the fat at the proximal portion of the follicle and gently placed with jeweler's forceps into the recipient site.
 - Implanters have been gaining in popularity, especially in FUE cases. They reduce graft handling and potential damage. They also reduce the need for highly trained technicians.
 - The graft is threaded onto an implanter by holding it by the hair.
 - The implanter is then inserted into the site and atraumatically delivered.
-

PEARLS AND PITFALLS

Planning	■ The surgical plan should take into consideration the long-term pattern. ■ The patient should be well informed and well educated about the probable outcome and the possible complications accompanying each technique. ■ Unrealistic long-term goals should be discouraged during the consult and the day of surgery.
Anesthesia	■ A thorough evaluation of the patient's overall health status should be obtained by good history and P.E. and coordinating with the patient's primary care physician for other health issues. ■ The physician should be knowledgeable of the medication's pharmacodynamics, side effects, toxic levels, and drug interaction and their corresponding management. ■ When indicated, it is best to get an anesthesiologist for the patient's overall safety.
Donor harvest	■ The surgeon should only take an optimally sized donor area to permit closure without tension to avoid the development of wide scars. ■ Using monofilament absorbable sutures in the subcutaneous layer helps eliminate "dead space" and lessen tension for good wound closure. ■ Hemostasis should always be employed to avoid blood clot formation in the donor area. ■ A solution of 3.33 mg/mL of triamcinolone (10 mg/mL) + 0.5% Marcaine can be injected into the donor area to lessen postoperative swelling.
Grafts	■ Avoid transections by making one follicle wide slivers to easily divide the grafts into its natural groupings. ■ Leave enough tissue around the grafts for protection during placement. ■ Eliminate the epidermis during graft cutting leaving a tear-shaped graft. ■ Always keep the grafts moist by frequently spraying with normal saline during cutting and storing them into normal saline solution or HypoThermosol + ATP solution.
Recipient sites	■ Create irregularities along the hairline to provide a natural look. ■ Meticulously follow the hair direction to minimize trauma and shock loss to the surrounding follicles. ■ The hair transplant surgeon should address the "future areas" of loss when making the recipient sites.

	■ The surgeon should always balance between “dense packing” especially the hairline and frontal area and doing a lower number of FU/cm² for wider recipient areas especially for patients with limited donors. ■ The angle of the recipient site should be determined before attempting to plant a graft.
Graft implantation	■ Avoid overhandling and unnecessary manipulation of the grafts to minimize traumatic injury. ■ Keep the grafts moist and store them in appropriate storage solutions such as normal saline or HypoThermosol with or without ATP. PRP can also be used to store the grafts right before implantation. ■ Always use “ring containers” when placing grafts to avoid drying and graft death. ■ In experienced hands, the use of implanters can be a safe and fast method of planting the grafts. ■ The grafts should ideally be at the same level of the original hairs. Buried grafts can cause ingrown hairs and skin dimpling of the recipient sites when healed.
	■ Elevated grafts can be prone to getting dislodged during the postop period and hair washing. ■ Assistants should be comfortably positioned when planting the grafts. This would improve their technique and would minimize traumatic handling of the grafts. ■ The recipient area should be thoroughly cleaned and the implanted grafts checked one more time before bandaging.

POSTOPERATIVE CARE

- Immediately after the procedure is finished, an antibiotic ointment is applied to the recipient and donor areas, and the head is bandaged overnight.
 - This practice has been continued by the authors because the occlusion provides a moist environment that is beneficial for healing and also acts as a physical barrier to microbial invasion.
- The bandage is removed the first day after surgery and nurses wash the recipient and donor areas.
 - Our patients are encouraged to continue soaking and cleaning twice daily to help dissolve any crusts that have formed and keep the surgical areas clean.
- Patients also apply lubricant to the surgical areas to keep them moist and use minoxidil 3.5% for its vasodilatory effect and potential for decreasing telogen

effluvium.

- Postoperative pain after strip harvest is usually minimal.
 - Patients complain of a “tight” feeling in the donor area.
 - After FUE, patients report very little discomfort, likened sometimes to a bad razor burn (**FIG 11**).
- In addition to analgesic use (acetaminophen or narcotics), patients are instructed to apply ice for 10- to 15-minute intervals along the nape of the neck to help decrease edema, which may add to the tension along the suture line.
- The authors generally remove sutures between 8 and 10 days after surgery.
 - In cases of an increased risk of wound dehiscence (eg, multiple donor area scars and marked tension upon donor wound closure) or instances of excessive scalp laxity upon donor site closure, sutures should be left in place for a longer period of time, usually 10 to 14 days.
- 4 to 5 weeks after surgery, patients are encouraged to return for evaluation.



FIG 11 • Donor area after FUE harvest.

- On occasion, there is excessive erythema or hyperesthesia in the donor area; this may be treated with intralesional triamcinolone acetonide (3.33 mg/mL).
- Patients should be alerted to possible postoperative sequelae:
 - Tissue edema may become most evident 3 to 5 days postoperatively in the forehead and temple areas.
 - Patients are encouraged to ice these areas and maintain a supine or lateral position as much as possible for the initial 72-hour postoperative period. It is generally mild, but in 1 out of approximately 50 patients, it may be severe enough to cause ecchymosis around the eyes.

- Scalp hypoesthesia resulting from severed sensory nerves during the processes of both donor harvest and recipient site creation
 - This generally resolves in 3 to 6 months however, depending on the size and location of the nerve, may take up to 18 months to return to normal.
- Telogen effluvium, or temporary hair loss sometimes referred to as “shock loss,” may be experienced by approximately 10% to 20% of male patients and 40% to 50% of females.
 - The temporary nature of this effluvium, which may affect 10% to 25% of the pre-existing recipient area hair, is emphasized during the consultation. It resolves in 2 to 3 months, but if a patient is not emotionally prepared for this likelihood, he or she should not undergo HRS.

OUTCOMES

- Although patients may vary considerably, the general timeline for hair growth after a session is as follows:
 - Newly transplanted vellus hairs begin to appear around the 3rd or 4th postoperative month, although the addition of PRP to our surgical procedures seems to result in some hairs being retained and growing without a dormant phase.
 - The number and caliber of transplanted hairs continue to increase until full growth can be appreciated approximately 18 to 24 months after a session.
- One surgery can create a cosmetically excellent result in any one region of the recipient area (**FIGS 12 to 14**).
- The hair transplanted will last as long in its new area as it would have lasted in the donor area.
- The results become less dense over time because pre-existing hair is lost over time and some donor area hair, even in the SDA, is lost with the passage of time.

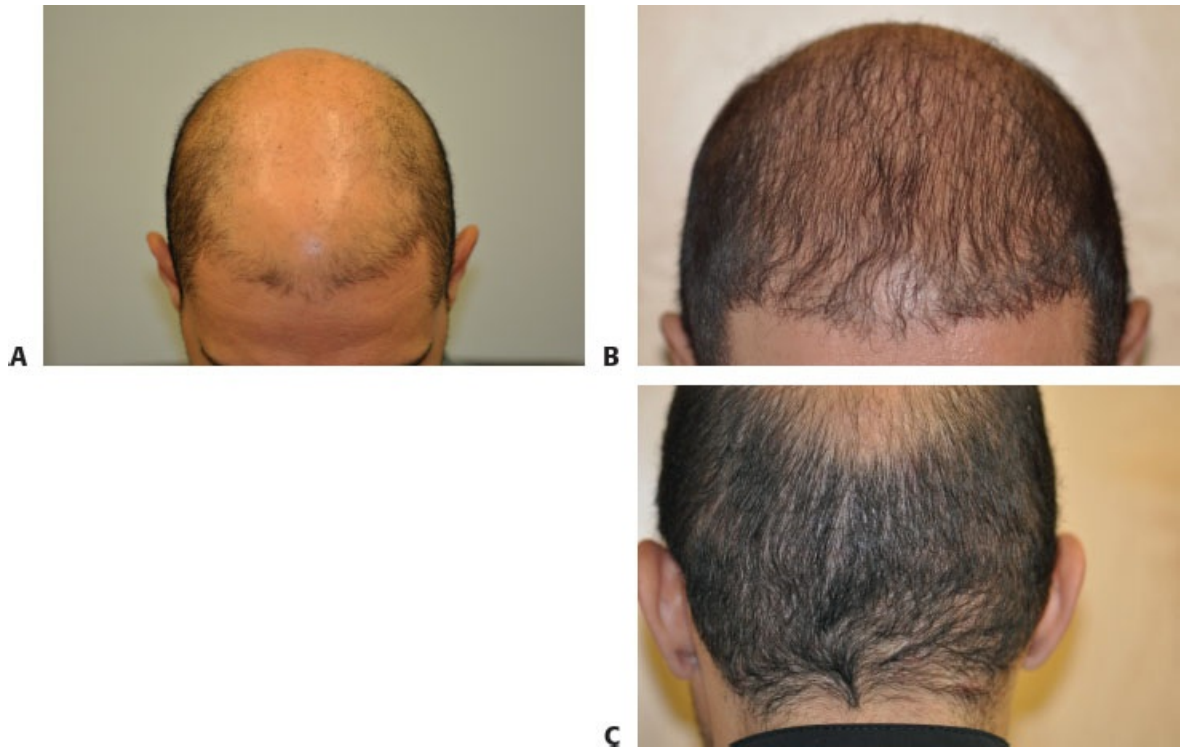


FIG 12 • A. Patient with limited donor hair available and a large alopecic area. **B.** Two lower-density hair transplants, covering both current and future areas of loss, provided the greatest cosmetic benefit for this patient. **C.** His limited donor area after two strip harvests. The scar is not visible, and all grafts were harvested from the safest donor area composed of hair that will last for the majority of his life.



FIG 13 • **A,B.** This patient has a very dense donor region. Given his age and objectives, a higher-density surgical plan was chosen. **C,D.** Appearance after one surgery.



FIG 14 • **A.** Patient postrhytidoplasty. **B.** Patient after one hair transplant to camouflage scars and thicken hairline.

- Medical therapy in conjunction with surgery will help mitigate this effect.
- One of the most important questions regarding FUE is whether the graft

survival is comparable to the survival of grafts obtained from a strip harvest.

- Limited studies performed to date suggest that survival is considerably lower.
- One study involving four patients and 3560 hairs/follicles, which was presented at the ISHRS annual meeting 2015, showed at 14 months only 61.4% of the FUE grafts had regrown, while 86% of the strip harvest–derived FU had regrown. More studies are required.

COMPLICATIONS

- Beyond focal neuralgia, uncommon donor area complications include wound dehiscence and arteriovenous fistulas as well as aesthetic complications of visible scarring, keloid or hypertrophic scarring, or donor hair effluvium.
- Within the recipient area, the uncommon, but most serious complication of central recipient area necrosis results from vascular compromise and is more likely in smokers, diabetics, and patients having undergone prior scalp surgeries.
- Folliculitis or ingrown hairs. These are uncommon and less severe complications that can occur in up to 20% of patients in a very mild form or a much smaller percentage in a more severe presentation. This may be treated with either warm compresses or a course of a first-generation cephalosporin, such as cephalexin, depending on the severity.

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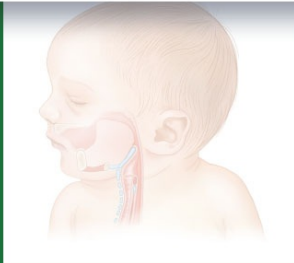
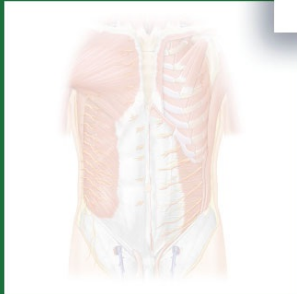
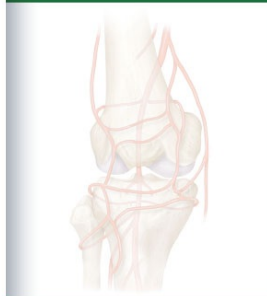
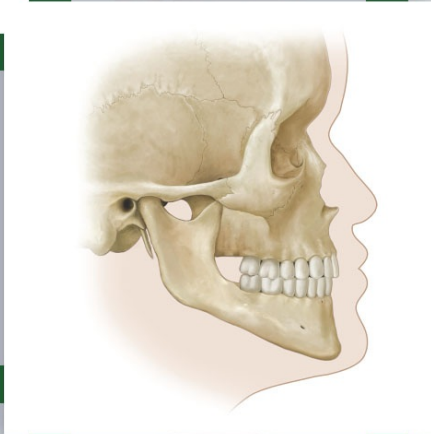
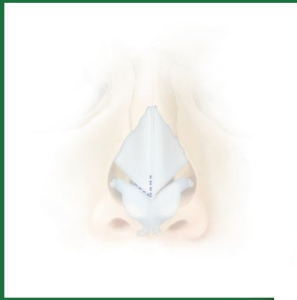
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PART 2

Craniofacial



1

Section I: Craniosynostosis

CHAPTER 1 Fronto-Orbital Advancement

Rajendra Sawh-Martinez and John A. Persing

DEFINITION

- Fronto-orbital advancement is a series of adjustments to modifications of anatomy in coronal and metopic synostosis.
- Fronto-orbital advancement strives to approximate normality of deficient supraorbital rim and adjacent frontal and temporal bone deformities.
- Unilateral coronal synostosis (UCS), bilateral coronal synostosis, and metopic synostosis have unique fronto-orbital deformities, which require individualized treatment for optimal results.

ANATOMY

- Unilateral coronal synostosis
 - Periorbital deformities are characterized by flattening of the frontal bone ipsilateral to the fused half of the coronal suture.^{1,2}
 - Recession of the ipsilateral supraorbital rim
 - Overprojection anteriorly of the ipsilateral zygoma
 - Convex deformity of the squamous temporal bone
 - Diminished mediolateral dimension of the orbit compared to normal
 - Increased vertical height of the ipsilateral orbit
 - Enlarged and more superiorly positioned ipsilateral orbital roof and accompanying greater wing of the sphenoid (harlequin deformity)
 - Depression of contralateral orbital roof/supraorbital rim
 - Ipsilateral nasal radix deviation
 - Contralateral chin point deviation
- Bilateral coronal synostosis
 - Characterized by premature fusion of the coronal sutures bilaterally and

brachycephaly (shortening) of the anteroposterior dimension of the skull, to include the anterior cranial fossa with compensatory widening of the skull³

- The frontal bones bilaterally, and the supraorbital rim adjacent to them, are hypoplastic and retrusive, relative to normal frontal bone development.
- Squamous temporal bone is more convex in form than normal.
- The zygomas are deficient in the anteroposterior projection.
- The malar area, as well as the midface, may be more significantly retruded in patients with syndromic forms of bilateral coronal synostosis.
- Metopic synostosis
 - Fusion of the metopic suture, associated with ridging of the midline frontal bone structure, and symmetric retrusion of the lateral frontal bones bilaterally⁴
 - Retrusion of the supraorbital rims bilaterally and flaring of the parietal bones as a form of compensation for continuing brain growth bilaterally
 - The orbits are symmetrical in appearance.
 - The squamous temporal bones are not convex, but flattened in profile and retrusive.
 - Hypotelorism

PATHOGENESIS

- Craniosynostosis occurs as nonsyndromic forms and as part of a varied number of syndromic patterns.
- Metopic and coronal synostoses are believed to have a positive family history in approximately 10% of cases.
- Ephrin-A4 has been implicated in nonsyndromic craniosynostosis, whereas FGFR3 and TWIST gene mutations may be linked to familial inheritance of craniosynostosis.⁵
- Syndromic craniosynostosis cases are linked to varied genetic mutations corresponding to the underlying syndrome.
- Multiple environmental factors have been suggested as promoters or risk factors for synostosis, including abnormal intrauterine position, multiple gestation, antenatal head compression, and infants large for their gestational age.
- Additionally, maternal smoking, advanced maternal age, gestation at high altitude, fertility treatments, and endocrine abnormalities have also been associated with the development of craniosynostosis.
- The natural history of all forms of craniosynostosis is that they are, at the very least, stable, if not progressive during early childhood due to the expanding

brain. Compensatory abnormalities increase the discrepancy between the fused bones and the remainder of the skull.

- The main theories of pathogenesis of premature fusion relate to timing of the fusion as either a primary event or a secondary occurrence as the effect of a yet undetermined cause.
- Despite ongoing research on the underlying mechanisms, general principles dominate the resultant morphology.^{1,6,7}
- Prematurely fused bones act as a single bone plate with limited growth potential.
- Asymmetrical, increased bone deposition occurs at perimeter sutures directed away from the affected bone plate.
- Unaffected, adjacent perimeter sutures compensate more in growth than do distant unaffected sutures.

PATIENT HISTORY AND PHYSICAL FINDINGS

Metopic craniosynostosis^{4,6,8}

- Premature fusion of the metopic suture.
- Key relevant anatomic features include the following:
 - Central ridging/bulged metopic suture
 - Characteristic triangular-shaped forehead (bilateral fronto-orbital hypoplasia) occurs to varying degrees, with classification schemes related to the severity of angulation
 - Hypotelorism
 - Lateral orbital rim posteriorly displaced and hypoplastic
 - Flattened profile of the squamosal bone
 - Biparietal widening of the skull

Unilateral coronal craniosynostosis^{6,9,10}

- Premature bony bridging of the coronal suture, typically in the approximate midpoint of the course of the coronal suture
- Patent sagittal suture is displaced away from the fused suture posteriorly and toward it anteriorly.
- Key features:
 - Flattened ipsilateral forehead
 - Contralateral forehead bossing
 - Intrinsic orbital changes (pathognomonic harlequin deformity)

- Ipsilateral flattened supraorbital rim and vertically taller/narrower orbit with steep superior orbital fissure and greater/lesser sphenoid wings
- Depression (inferior displacement) of contralateral supraorbital rim
- Squamosal-temporal bone convexity
- Depression of the free border of the superolateral orbital rim
- Protrusive zygoma, ipsilateral to the coronal fusion
- Raised eyebrow and widened palpebral opening ipsilateral to the fused suture
- Root of nose deviation *toward* the affected (fused) side and nasal tip towards the contralateral (open) side
- Ear displacement anteriorly/superiorly, ipsilateral to fused suture
- Contralateral chin point deviation
- Base of skull deformity
 - Severity can be determined by evaluating the sphenopetrosal angle and the degree of angulation from midline structures (cribriform plate) ipsilateral to fusion^{2,6,9}

Bilateral coronal craniosynostosis²

- Bilateral premature fusion of the coronal suture with symmetric foreshortened anterior cranial base
- Key features:
 - Bilateral retrusion of frontal bone and supraorbital rims
 - Bilateral lateral bulge of squamous temporal bones
 - Increased biparietal diameter
 - Syndromic vs nonsyndromic features include midface hypoplasia and mandibular deformity in syndromic cases
- Frontosphenoidal synostosis¹¹⁻¹³
- Rare case of anterior plagiocephaly
- Often misdiagnosed
- Requires 3D CT reconstruction to identify in isolated cases
- Angulation of the anterior cranial base
- Deflection of the anterior cranial fossa opposite to fused suture
- Altered relationship between cranial vault and facial skeleton, resulting in a phenotype similar to UCS
- Contralateral bossing and ipsilateral brow depression
- Nasal tip deviation reported in 50% of cases
- Harlequin deformity may not be present or be minimally evident.

- Key orbital/ophthalmologic evaluation
- Orbital size/shape
- Globe position/prominence
- Corneal inflammation (exposure)
- Distinct structural differences between ipsilateral and contralateral orbits
- Extraocular movement (strabismus), particularly superior oblique dysfunction
- Visual acuity
- Lid margin and levator function (anterior plagiocephaly)
- Supratarsal crease reduction (anterior plagiocephaly)
- Hypertelorism (brachycephaly) in some syndromic cases
- Malar recession in syndromic cases

IMAGING

- The definitive diagnostic study for craniosynostosis is a CT scan demonstrating fusion of a cranial vault suture.
- However, imaging of cranial anatomy has been used less frequently, as the typical clinical structure in the individual forms of craniosynostosis is more recognized.
 - This has been highlighted by concerns related to exposure of infants to ionizing radiation by CT scan and for sedation and anesthetics often required to obtain MR scans.
 - Ultrasound examinations, except in the very young, are not accurate enough to serve as a definitive diagnostic source and therefore used infrequently.
- Occasional cases of craniosynostosis are best examined using CT scan, with 3D reconstruction, which may help in certain forms of craniosynostosis for planning of surgery (**FIG 1**).

SURGICAL MANAGEMENT

- With a typical clinical exam, or confirmatory CT scan, cranioplasty is typically performed early in life to take advantage of the potential for better intellectual development (up to 6 months of age).^{4,7}
- The counterargument to earlier surgery is the potential increase in the number of cases requiring revision surgery, as structurally it is more difficult to account for continuing growth when surgery is performed at earlier stages of life.
- Bone manipulation and stabilities are enhanced in older-age children beyond 6 months of age, but the issue of deleterious impact on brain development is now

creating more concern, leading to promoting delayed surgery.^{14,15}

- An advantage of earlier surgery is better malleability of bone.
- Larger bone defects may fill in secondarily by subsequent growth of the brain and dura.
- Potentially improved neurologic outcome
- Disadvantages of early surgery include the following:
 - Increased risk for proportionate blood loss with smaller amounts of volume lost
 - A potential increased requirement for repeat surgeries in the future
- Advantages of later surgery (delayed to 1 year of age):
 - More mature brain and bone systems to be operated on
 - Blood loss is not as strong a concern due to increased body weight and proportionate circulating blood volume.
 - Structures may be fixed in place more securely with lesser concern about growth restriction.



FIG 1 • 3D CT reconstruction of craniosynostosis subtypes. Metopic craniosynostosis (trigonocephaly) in frontal view (**A**), oblique view (**B**), and top-down view

(**C**). Unilateral coronal craniosynostosis (anterior plagiocephaly) in frontal view (**D**), oblique view (**E**), top-down view (**F**). Bilateral coronal craniosynostosis (brachycephaly) in frontal view (**G**), right lateral view (**H**), left lateral view (**I**), and top-down view (**J**).

■ Disadvantages:

- Bone defects are more difficult to “fill in” nonoperatively.
- Bone is more difficult to remodel at approximately 1 year of age.
- Potential reduction in brain function related to delay

Preoperative Planning

- Generally, once the decision to perform surgery has been made, and with confirmatory clinical and/or CT exam, preparation includes appropriate supports from blood loss to include monitoring, review of current status of blood count, preparation for blood replacement, monitoring for air emboli (Doppler, end-tidal CO₂, mean arterial pressure, CVP), and, in selected cases, coagulation studies to support reduction in blood.
- Plan for admission to a postoperative care setting consistent with potential need for urgent care.

Positioning

- Typically, the patient is placed supine for optimal supraorbital rim advancement regardless of etiology of the nonsyndromic craniosynostosis.

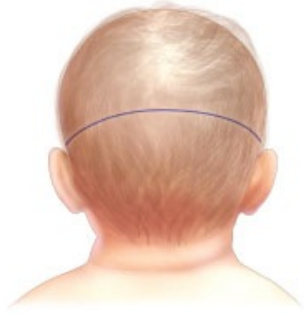
Approach

- Fronto-orbital advancement via the tilt procedure is the authors’ preferred approach.^{16–19}
- It has the main advantage of potentially greater preservation of baseline blood supply to the osteotomy segments.
- This procedure also addresses the issues of reducing the likelihood of postoperative depressions in the anterior temporal fossa and adds forward, stable projection of the supraorbital rim, without the added potential for restricting postoperative growth due to rigid fixation.

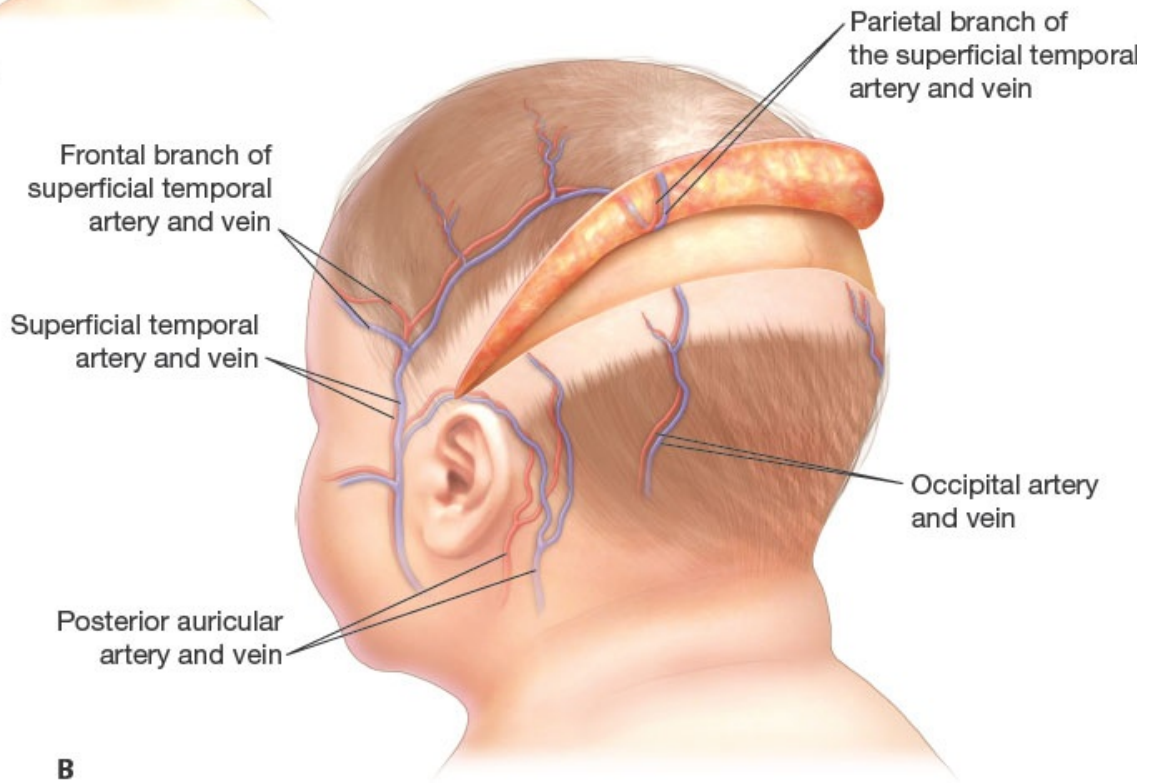
TECHNIQUES

■ Incisions for the Tilt Procedure

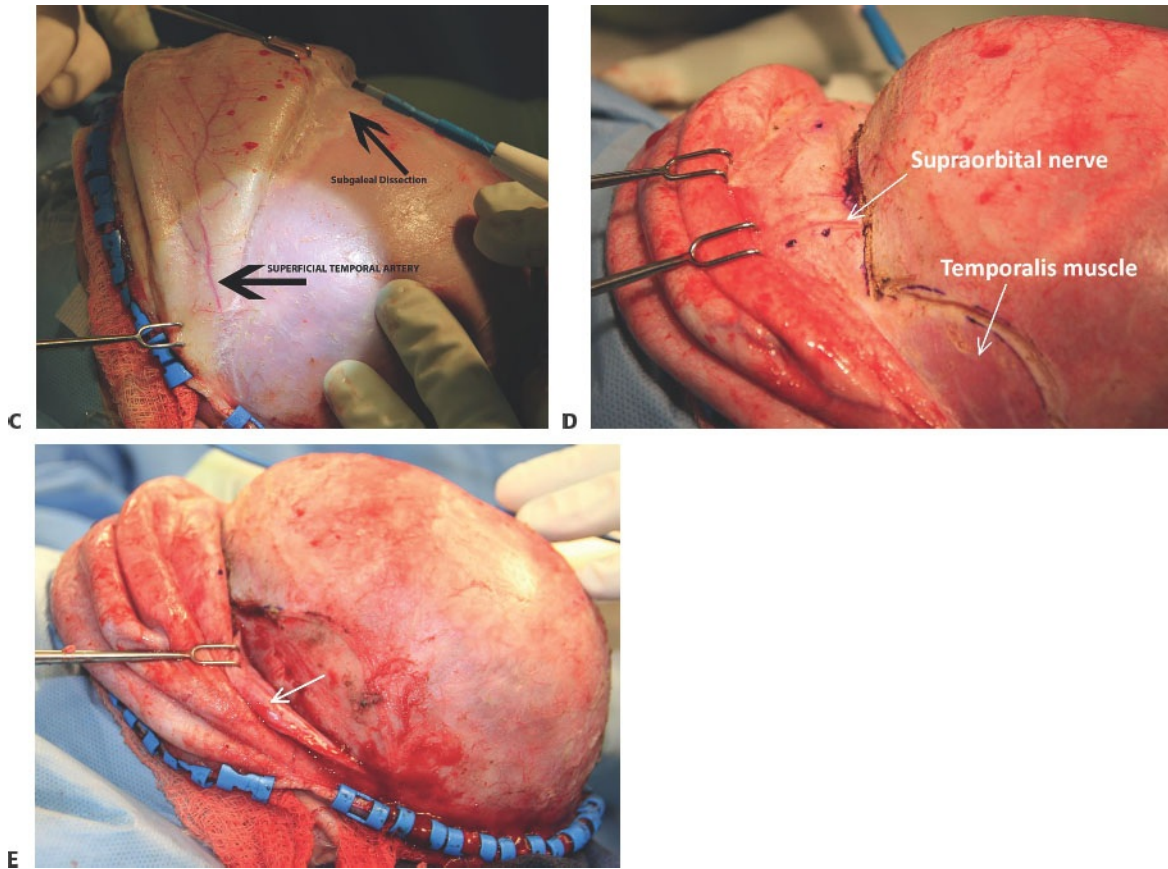
- Incision line is posteriorly inclined from the region just anterior to the ear, to the occiput below the level of the hair whorl to minimize scar visibility and ease of the visualization of the skull²⁰ (**TECH FIG 1A,B**).
- For the posteriorly inclined coronal incision, care must be taken to preserve the ascending branch of the superficial temporal artery to maintain appropriate vascularity for the scalp (**TECH FIG 1C**).
 - An alternative to this incision is to do either a straight coronal incision that is slightly posteriorly inclined or a stealth incision.
 - These alternatives, however, have more potential visible scarring and take longer to both incise and close.
- All incisions should include injection of local anesthetic with epinephrine and intraoperative use of clotting agents (such as aminocaproic acid and tranexamic acid).
- Exposure of the frontal and periorbital regions bilaterally is appropriate for both coronal synostosis and metopic synostosis to assess symmetry (**TECH FIG 1D**).
- Intraoperative confirmation of fused sutures is made.
- Subperiosteal dissection is performed at the level of the orbital rims to expose the deficient projection of the rims (**TECH FIG 1E**).
- General and specific operative steps and modifications are given below based on the individual sutural pathology.



A



B



TECH FIG 1 • **A, B.** Preferred incision line is placed posteriorly toward the occiput below hair whorl to maximize skull exposure and minimize scar visibility postoperatively. **C.** Elevation of scalp flap in subgaleal plane with preservation of superficial temporal vessels. **D.** Subperiosteal dissection 1 cm above the orbital rim border to preserve neurovascular bundle of supraorbital and supratrochlear vessels. **E.** Temporalis reflected to the level of pterion (*arrow*).

■ Unilateral Coronal Synostosis

Exposure and Bur Hole Placement

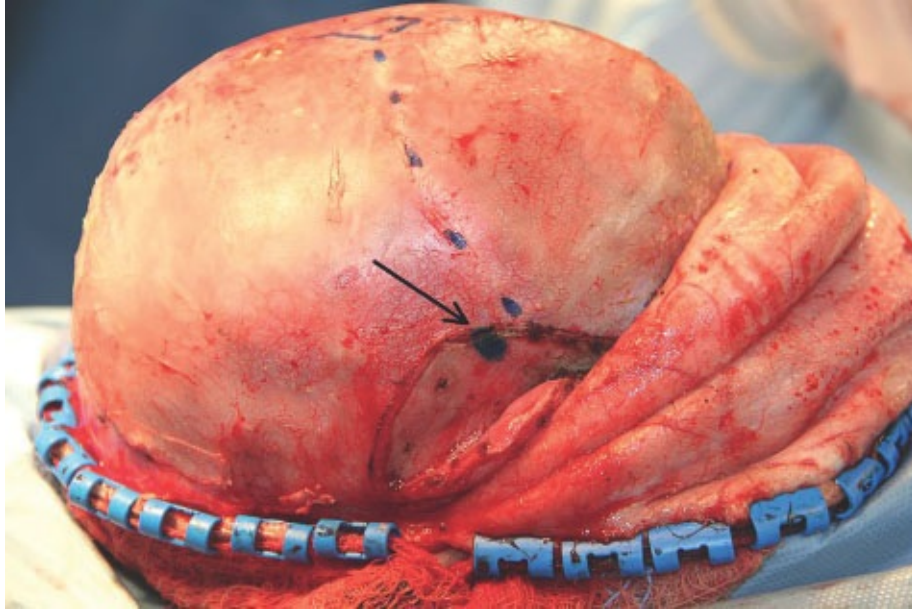
- Exposure of the frontal/parietal bones in the suprapariosteal plane (less blood loss)
- Bifrontal craniotomy is performed with exposure of bilateral supraorbital

rims, in a subperiosteal plane.

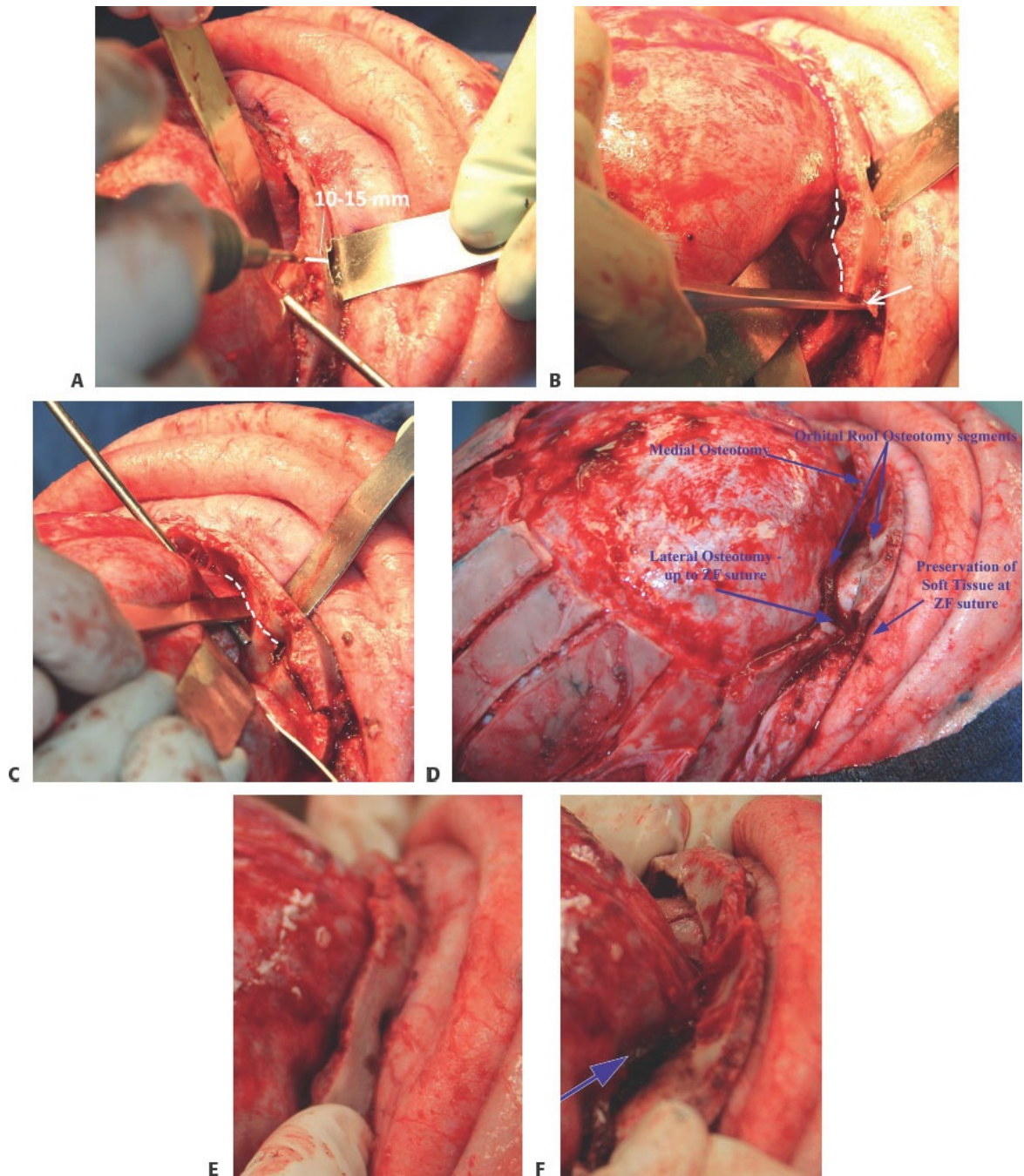
- Ipsilateral to the fused suture, the periorbita and anterior temporalis muscle (approximately the superior 50% of the origin of the muscle) is dissected from the underlying bone.
- Bur hole placement for the bifrontal craniotomy is placed more cephalad and posteriorly, so as to reduce the likelihood of depression in the frontal bone profile postoperatively.
 - Bur hole placed on the fused side, as the coronal suture is displaced anteriorly.
 - Measurement is made of the distance from the normal coronal suture, contralateral to the fused suture, to the midline. This distance is transferred to the side ipsilateral to the fused suture to define the position of the osteotomy line, to get a symmetrical bifrontal bone segment for remodeling the frontal region (**TECH FIG 2**).

Supraorbital Rim Osteotomy and Advancement

- An orbital roof osteotomy is performed in situ, with a side-cutting bur and osteotomes from the lateral orbit to the anterior cribriform plate region (**TECH FIG 3A–D**).
 - Care is taken to avoid extensive dissection around the frontozygomatic suture to prevent disruption of the frontozygomatic suture soft tissue with advancement of the orbital rim.
- Advancement of the orbital rim is performed in situ with as minimal as possible disruption of the metopic-frontonasal suture tissue junction medially and the frontozygomatic suture laterally (**TECH FIG 3E**):
 - Angulation forward can be up to 1 to 1.5 cm (usually 1–1.2 cm), depending on the degree of deformity.



TECH FIG 2 • Location of bur holes relative to fused suture (temporalis muscle). Placement of bur hole posterior to coronal suture (*arrow*) is to prevent worsened temporal hollowness.



TECH FIG 3 • Supraorbital rim osteotomy. **A.** Orbital roof osteotomy starts laterally, with adequate distance (10–15 mm) from the rim to account for a potentially thin supraorbital foramen. **B.** Lateral osteotomy (*dashed line*) is carried medially sequentially along orbital roof. Careful attention is paid so as to avoid

osteotomy beyond the frontozygomatic suture (*arrow*). **C.** Medial orbital roof osteotomy (*dashed line*) is carried out in midline anterior to the cribriform plate to avoid CSF leak. **D.** Completed orbital roof osteotomy demonstrating osteotomized segments, orbital contents, and preservation of soft tissue at frontozygomatic suture. **E, F.** Demonstration of the degree of tilt achievable after orbital roof osteotomy (*arrow*).

- Correction of the lateral orbital roof and greater wing of the sphenoid deformity (harlequin deformity) is performed with rongeur removal of abnormally positioned bone, to a point approximately 1 to 2 cm lateral to the superior orbital fissure.
 - This allows less impeded advancement of the anterior tip of the temporal and frontal lobe into the area of hypoplasia in the frontal region, consequently improving its contour.
- The squamous temporal bone has a more convex outward profile in UCS, on the fused suture side.
 - It is either removed by rongeur or remodeled in situ with the aid of barrel stave osteotomies.
 - Stabilization of the advancement of the orbital rim is desirable to prevent collapse with a reflection of the scalp flap later on, but “too rigid” fixation may impede further growth of the fronto-orbital complex postoperatively (if standard anterior and posterior rigid plate fixation is performed).

Bony Fixation

- A resorbable orbital rim advancement plate (KLS) is used to angulate the fronto-orbital bar anteriorly, which maintains its normal attachment point (pivot point), at the level of the frontozygomatic suture laterally and the metopic/frontal nasal sutures medially (**TECH FIG 4A,B**):
 - This angulated bone improves the potential for normal profile of the lateral orbital rim and supports bone continuity in this region of remodeled frontal bone later in development.
 - The absorbable plate is straight initially and should remain flat to diminish the abnormal convexity noted preoperatively in this region.

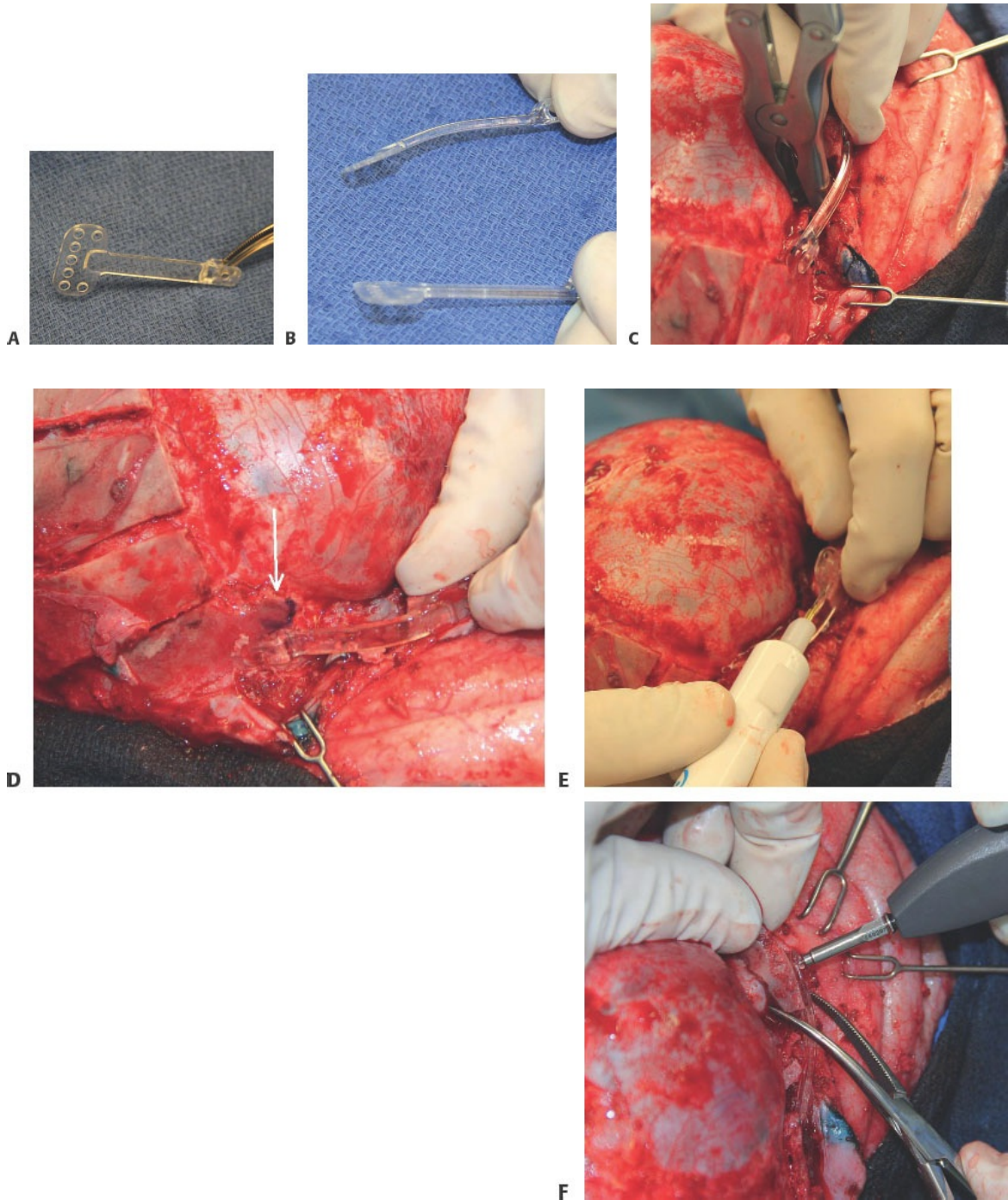
- The resorbable plate is remodeled anteriorly at the attachment point to the orbital rim, with the use of warm water bath (**TECH FIG 4C–E**).
 - Removal of the excess flare of the anterior footplate using an ophthalmology cautery is common.
 - Once released, the angle of the orbital rim is tilted forward as much as soft tissues will allow (usually approximately 10–12 mm). The posterior cup end of the plate is indexed to the anterior border of the cut squamous temporal bone.
 - This will be done in a series of approximations to be able to get the maximum of tilt and also security of the plate posteriorly.
 - This is typically done by leaving a “ledge” of bone at the superior border of the squamous temporal bone to facilitate greater stabilization without screw fixation.
 - Although there are holes placed in the wings of the posterior cup of the orbital rim plate for potential securing, we advise not to use them so as to allow the fronto-orbital complex to grow anteriorly, without constraint postoperatively.
- Testing is performed to determine the maximum advancement that can be achieved (**TECH FIG 4F**):
 - This is done by successive steps of placing the cup (posterior) end of the resorbable plate into a cut out segment of squamous temporal bone and tilting the orbital rim forward manually yet still preserving the zygomaticofrontal suture fibrovascular tissue.

Completion

- Minimal contouring of the mediolateral dimension of the internal surface of the fronto-orbital bar may be performed at this time, if there is a discrepancy of more than 2 mm:
 - This is accomplished with a shaping bur, to approximate the normal dimensions between the fused suture orbit and the nonfused suture orbit contralaterally.
- The frontal bone and the medial orbital rim are remodeled anteriorly with a bur, to reduce any unusual prominence of the advanced orbital rim-temporal bone complex.
- The bone chips that had been harvested from the squamous temporal bone and the greater wing of the sphenoid earlier in the operative procedure are now placed in the pocket between the advanced orbital rim and remaining

squamous temporal bone, beneath the temporalis muscle.

- The temporalis muscle is secured over the resorbable plate with a long-term resorbable suture to the advanced orbital rim anteriorly (primarily) and is released posteriorly, just anterior to the ear, to allow anterior rotation of that segment with less tension.

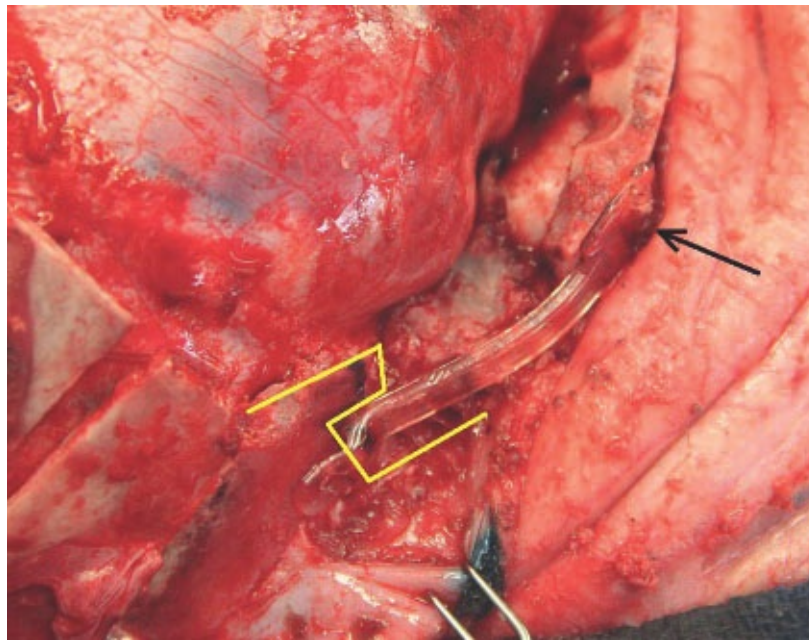


TECH FIG 4 • A. Resorbable plate for anterior bony fixation of FOA. **B.** The plates can be molded using a hot water bath to the desired convexity as needed. The top plate is convexed molded for metopic craniosynostosis. The bottom plate remains straight for coronal craniosynostosis. **C.** A bony ledge is created by resection of squamous temporal bone with a rongeur, creating a groove to interdigitate with the posterior cup of the absorbable plate. **D.** Angling the orbital rim forward, the cup of the plate is placed into the notch to test length, curvature, and interdigitation with supporting upper bony ledge (*arrow*). **E.** The plate is remodeled as needed with water bath and high-temperature cautery to ensure adequate fit of plate to superolateral orbital rim. **F.** The plate is secured anteriorly with resorbable screws. Determine tilt and secure with maximal tilt with pivoting on frontozygomatic suture. Drill holes, and place resorbable screws into superolateral orbital rim.

■ Metopic Synostosis

- Metopic synostosis is characterized by a triangular skull deformity, which is addressed through a bifrontal craniotomy with contouring of the prominent metopic ridge, and radial osteotomies to allow remodeling of the frontal bone to assume a more normal contour pattern once the orbital rims have been advanced.
 - The exposure of the orbital rims bilaterally is similar to that in the unilateral/bilateral coronal synostosis patients; however, the differences relate primarily to the revision of the tissues of the temporal region.
- Orbital roof osteotomy is performed as in coronal synostosis.
 - The distinction between metopic and coronal synostoses is noted in that the squamous temporal bone in metopic synostosis is “flatter” compared to the convex profile in UCS patients.

- The resorbable plate is made more convex to fit a more normal temporal profile.
- The plate is remodeled in a heated water bath to allow for a gentle curve (more convex form) in the supporting bar.
- The attachment to the advanced orbital rim and fixation or support through the squamous temporal bone posteriorly is otherwise identical to the coronal synostosis patients (**TECH FIG 5**).
- The bone chips removed are morselized and placed in the space between the temporalis muscle and the lateral temporal lobe/squamous temporal bone. The temporalis muscle is placed over the convex bar of the plate to expand the projection of the squamous temporal bone profile.
- Bleeding from the base of the skull can be addressed through standard bone wax, injectable collagen, and thrombin products.



TECH FIG 5 • The absorbable plate is fixed anteriorly with a resorbable screw (*arrow*). The posterior plate is cupped into bony groove created with overlying ledge to support the posterior cup of the absorbable plate (*yellow line*).

■ Bilateral Coronal Synostosis

- Bilateral coronal synostosis is handled similar to UCS patients with suprapariosteal dissection for bifrontal craniotomy, bilateral orbital rim exposure in a subperiosteal plane, and bilateral elevation of the periorbital tissue intraorbitally, to avoid injury during release of the orbital roof by side-cutting burs and osteotomes.
- Both orbital rims are tilted forward as described unilaterally in UCS, so as to include release of the bone just anterior to the cribriform plate in the crista galli, with an osteotome.
 - With this, there may be excess prominence of the orbital rims medially, and if so, local contouring is performed in situ, as described for UCS.
- There is no attempt to correct the hypoplasia of the zygomas bilaterally, particularly in syndromic cases, as this will be later addressed through Le Fort advancement procedures.
 - Early intervention risks possible injury to a developing malar region and tooth structure by the C-shaped osteotomy into the zygoma.²¹
 - C-shaped orbital osteotomy extending into the zygoma is used only for a limited number of cases to include minor degrees of depression of the zygomas in nonsyndromic bilateral coronal synostosis patients who are older than 1 year of age and who will not be undergoing Le Fort advancement later in life.
 - However, the patent frontozygomatic suture does not allow enough support to make substantial long-term advancement in the zygoma. Therefore, care is taken to avoid dissection in this plane in the young child (less than 1 year of age).
- The squamous temporal bone advancement is handled much like it is in the patient with UCS.
 - The exception being that in bilateral coronal synostosis, the greater sphenoid wing is not typically as abnormal, and ordinarily, does not require resection of this skull base segment.
- The forehead remodeling and reshaping is also the same (radial osteotomies in infants older than 1 year of age), as it is for UCS.

■ Alternate Methods

- There are two general categories of alternate techniques to advance the orbital rim.

- The “free floating” orbital rim technique relies on osteotomy at the frontozygomatic suture, orbital roof osteotomy, and greenstick fracture advancement of the orbital rim.
- This technique of advancement relies on the growing brain to propel the orbital rim forward with subsequent development. This technique has the advantage of being quick and easy, with in situ release of the orbital rim.
- Disadvantages include the following:
 - Short- and long-term scalp flap (soft tissue) restriction of the advancement of the bony rim
 - It does not correct the squamous temporal deformities (convex or planar) associated with coronal and metopic synostosis.
 - Detachment of the pivot point at the frontozygomatic suture results in subsequent posterior tilting of the rim with growth, creating a frontal bone depression locally, postoperatively.
- The other approach is the “fixed plate” overcorrected position technique, which has the advantage, in the immediate perioperative period, of overcorrection and prevention of orbital rim collapse after rigid fixation in the immediate postoperative period.
- This avoids the constricting influence of the skin flap that is likely to occur later on in the postoperative period from scalp replacement.
- It is particularly important because most rigid advancement techniques detach the zygomatic process to the frontal bone from the frontozygomatic suture. If not stabilized, this will collapse inferiorly and rotate the supraorbital rim posteriorly; this diminishes the profile of the frontal bone in this region.
- Advancements with fixation of larger distances (1.5–2 cm) have been used in order to try to address this restriction.
 - It remains to be seen if this is sufficient to be effective long term, as it also potentially restricts the ability of anterior growth postoperatively.
- Disadvantages:
 - “Posterior” rigid fixation with plates and screws restricts long-term forward growth of the supraorbital rims.
 - Rigid fixation with ex vivo remodeling of the bone, such as the use of templates, may contribute to longer-term devascularization and yield less bone production over the longer term.
 - Postoperative overcorrected “look” at the level of the orbital rims.

PEARLS AND PITFALLS

Technique

- Reduce temporal hollowing with more posterior placement of bur holes—just posterior to the coronal suture.
- Maintain fibrous/bony attachment at the frontozygomatic suture to have base support for pivoting of the orbital rim. This reduces the likelihood of posterior rotation of the superolateral supraorbital rim and adjacent frontal bone, leading to postoperative temporal depression.
- Resorbable, cupped plates prevent initial posterior collapse of the advanced orbital rim, with later scalp closure.
- Avoid growth-impeding, posterior rigid plate fixation.
- Individualize technique to specific deformities of unilateral coronal, bilateral coronal, and metopic synostosis.

POSTOPERATIVE CARE

- The patient is placed in a lightly wrapped head dressing:
 - Supine position is recommended primarily for patient comfort.
 - Typically, helmets or further supports to the bone are not required for metopic synostosis but may be for coronal synostosis.
 - If helmets are to be used, the decision is to be made 6 weeks postoperatively, when initial postoperative swelling is reduced adequately.
- Patients are often placed in the pediatric ICU for resuscitation (if needed) and monitoring:
 - Hemodynamics, urine output, hemoglobin, hematocrit, and serum chemistries are serially checked, and resuscitation is undertaken, until clinical stability is ensured.
 - Blood loss is an important consideration, and transfusions should be given for both laboratory and hemodynamic considerations.
 - Patients are transferred to pediatric floors and discharged once clinical stability parameters are met.
- Clinical monitoring for blood loss and visual responsiveness are carried out throughout the postoperative period.

OUTCOMES

- To date, there have been limited long-term assessments of fronto-orbital advancement techniques with current techniques and sufficient numbers, appropriately divided as to diagnosis, to state definitively “the” best method.
- Reports have related to development of frontal sinuses and fronto-orbital advancements.
- The major concern about long-term outcomes is that orbital rim projection and development will be diminished.
- Reports often cite a lack of normal growth of the supraorbital rim and the presence of frontotemporal hollowing in later postoperative reviews.
- The role of genetics on outcomes has yet to be determined.

COMPLICATIONS

- Complications are largely related to lack of growth with retained or new deformity, in normal fronto-orbital rim region development. This may be exaggerated by:
 - Loss of attachment of the temporalis muscle leading to a hollowing in the region just posterior to the advanced rim. This may be addressed by complete release of the temporalis muscle posteriorly and advancement of the muscle attachment to the orbital rim anterolaterally.
 - Fracture of the advancing orbital rim at the point of the supraorbital nerve foramen
 - This is addressed prior to surgery by using a thicker segment of bone superior to the foramen. Instead of 8 to 10 mm, use 10 to 12 mm in that region and/or wider segment of orbital roof to be advanced adjacent to the region of the supraorbital rim.
 - If fracture does occur at the supraorbital rim at the time of surgery, stabilize it with a resorbable plate.
 - Disruption of the frontozygomatic suture during the tilt procedure. If it becomes detached, it should be reattached with long-lasting resorbable suture through separate drill holes through the zygomatic process of the frontal bone, and frontal process of the zygomatic bone, surrounding the frontozygomatic suture.
 - Plate restriction of growth of orbital rims. Treatment is **avoidance** of posterior fixation of support for orbital rim advancement.
 - Postoperative changes may arise from incomplete knowledge of mechanisms of orbital rim growth, such as the role played by individual genetic factors, and vascularity of advanced bone segments.

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CHAPTER Fronto-Orbital Distraction

Jesse A. Taylor and Wen Xu

DEFINITION

- Craniosynostosis affects 1 in 2500 live births worldwide and is defined as the premature fusion of one or more cranial sutures.
- Craniosynostosis may affect a single suture or multiple sutures and may be idiopathic or associated with an underlying syndrome.
- The most frequently affected suture is the sagittal suture, followed by the coronal suture, the metopic suture, and the lambdoid suture.
- Cranial vault distraction allows for gradual expansion of bone and soft tissues of the cranium without leaving behind any indwelling hardware in the growing craniofacial skeleton.

ANATOMY

- There are four major calvarial sutures (metopic, sagittal, coronal, and lambdoid) that are patent at birth but close in a predictable and sequential manner in the first few years of life.
 - The metopic suture divides the two halves of the frontal bone in the sagittal plane.
 - The sagittal suture is located along the midline and divides the left and right parietal bones.
 - The coronal suture is located between the frontal bone and the parietal bone and can be divided into a left coronal suture and a right coronal suture.
 - The lambdoid suture is located between the parietal bone and the occipital bone and is continuous inferiorly with the occipitomastoid suture.
- The anterior fontanelle is a diamond-shaped membrane-filled space located at the junction of the metopic, sagittal, and coronal sutures that is present in

infants until approximately 18 months of age.

- The posterior fontanelle is a triangle-shaped space located at the junction of the sagittal and lambdoid sutures that ossifies 2 to 3 months after birth.

PATHOGENESIS

- Craniosynostosis involving a single suture is typically an isolated defect with no known direct cause and is not associated with a syndrome.
 - Presence of in utero fetal head constraint is associated with an increased incidence of craniosynostosis.¹
 - Other risk factors include endocrine disturbances (hyperthyroidism, mucopolysaccharidoses, rickets), teratogens (retinoic acid, valproic acid, warfarin), hematologic disorders (sickle cell anemia, polycythemia vera), and malformations (microcephaly, holoprosencephaly).²
- The most common forms of syndromic craniosynostosis are often the result of de novo autosomal dominant mutations in the fibroblast growth factor receptor (*FGFR*) and *TWIST* genes.
 - Apert syndrome is caused by mutations in the *FGFR2* gene on chromosome 10.
 - Crouzon syndrome is predominantly caused by mutations in *FGFR2*, although patients with Crouzon syndrome with acanthosis nigricans have a specific mutation in the *FGFR3* gene on chromosome 4.
 - Pfeiffer syndrome is caused by mutations in *FGFR1* and *FGFR2*.
 - Saethre-Chotzen syndrome is caused by mutations in the *TWIST* gene located on chromosome 7 but is also associated with mutations in *FGFR2*.

NATURAL HISTORY

- Premature suture fusion restricts growth perpendicular to the suture, thus leading to compensatory growth parallel to the suture that results in characteristic skull deformations.
 - Sagittal synostosis leads to scaphocephaly, which is characterized by increased anteroposterior (AP) and decreased biparietal width.
 - Unicoronal and lambdoid synostosis lead to plagiocephaly.
 - Anterior plagiocephaly is caused by unicoronal synostosis and is characterized by ipsilateral supraorbital rim flattening, forehead recession, deviation of the nasal root to the affected side, temporal retrusion, and vertical orbital dystopia (harlequin deformity).
 - Posterior plagiocephaly is caused by lambdoid synostosis and is

characterized by contralateral bulging and ipsilateral forehead recession.

- Metopic synostosis leads to trigonocephaly, which is characterized by a narrow, triangle-shaped forehead, superolateral orbital depression, and hypotelorism.
- Bicoronal synostosis leads to brachycephaly, which is characterized by decreased AP diameter and increased biparietal width and height.
- Multisuture synostosis typically involving the coronal, lambdoid, and metopic sutures can cause kleeblattschädel or cloverleaf deformity.
- Craniosynostosis may also have neurologic, psychiatric, and cognitive implications.³
- There is increasing evidence that patients with craniosynostosis have a high incidence of elevated intracranial pressure (ICP).⁴⁻⁶
- Earlier surgical intervention in craniosynostosis has been shown to be associated with improved neurocognitive outcomes⁷ and may be mediated by preventing ICP elevation.⁶

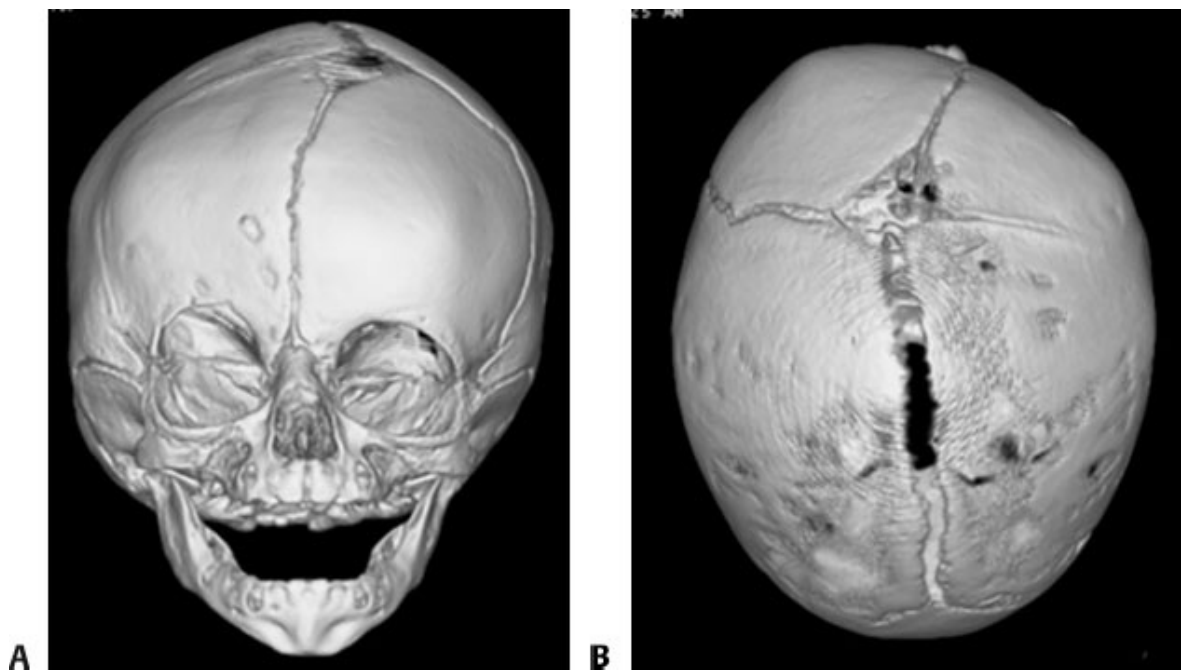


FIG 2 • 3D CT scans of the same female infant with right unicoronal synostosis.

- Hydrocephalus is more common in patients with syndromic craniosynostosis. Within the syndromic cohort, Crouzon syndrome patients tend to have the

highest incidence of hydrocephalus.

- Craniosynostosis is associated with a higher incidence of speech/language, behavioral, and neurocognitive developmental delays.^{3,8}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients will typically present with a history of abnormal head shape during infancy (**FIG 1A,B**).
- Physical exam is the mainstay of diagnosis for single-suture nonsyndromic craniosynostosis.
 - On exam, patients with single-suture craniosynostosis will have the characteristic skull shapes as described in natural history.
 - Physical exam should also focus on delineating underlying syndromic etiology, which includes assessing for abnormal facial features and limb anomalies.
- Clinical symptoms like headache and visual changes, with papilledema on fundoscopic examination, are signs of increased ICP, a possible sequela of craniosynostosis.

IMAGING

- Although physical exam is often sufficient for diagnosis, imaging with either plain radiographs or 3D computed tomography may be required in borderline or complex cases in order to accurately characterize the anatomy and aid in preoperative planning.
- Plain radiographs may be useful if the pretest probability of craniosynostosis (based on history and physical exam) is low.
- 3D computed tomography is useful for accurately identifying the suture(s) involved and characterizing the bony deformity but can also be used to evaluate the brain parenchyma and other soft tissues (**FIG 2**).
- In infants with suspected syndromic craniosynostosis, genetic testing for the most common genes (*FGFR* and *TWIST*) can be performed.
- Detection of optic nerve pathology and elevated ICP may also be possible through the use of visual evoked potential (VEP) testing or retinal imaging with optical coherence tomography (OCT).^{9,10}

DIFFERENTIAL DIAGNOSIS

- Positional plagiocephaly
- Congenital torticollis

- Craniosynostosis

SURGICAL MANAGEMENT

- Craniosynostosis is managed surgically through a variety of different techniques.
- The goals of surgery are twofold:
 - Functional: to prevent intracranial hypertension from damaging the developing brain
 - Aesthetic: to normalize the patient's appearance



FIG 1 • Female infant with right unicoronal synostosis at 1.5 months of age.

- The optimal timing of surgical intervention is an area of controversy.
 - Operating earlier may be associated with improved neurocognitive outcomes but has increased perioperative risks as well as an increased risk for needing additional surgery later in childhood.
 - Operating later may be associated with worse neurocognitive outcomes but has reduced perioperative risks and better long-term aesthetic outcomes.
- Traditionally, strip suturectomy was the mainstay of treatment, but current approaches include posterior calvarial remodeling (CVR), fronto-orbital advancement (FOA), posterior vault distraction osteogenesis (PVDO), and, most recently, fronto-orbital distraction osteogenesis.

- Distraction osteogenesis is the process through which slow and gradual expansion of osteotomized bone leads to new endogenous bone formation.
 - It has been used to lengthen mandibles as well as expand the posterior and anterior cranial vault.
 - It reduces the need for autologous bone grafts and aids in the expansion of the overlying soft tissues.¹¹
- Compared to traditional cranial vault remodeling, distraction osteogenesis has multiple benefits, including the following:
 - Perioperative: less invasive surgery, shorter surgical time, decreased blood loss, shorter ICU and hospital length of stay¹²
 - Physiologic: preserved bone vascularity, improved quality of bony regenerate, no implantation of permanent hardware in a growing skull
 - Minimizes dead space within the head, thereby minimizing the risk of a deep space infection
 - Outcomes: possible to make postoperative adjustments (depending on type of distractor utilized), increased magnitude of movement, increased volume expansion, gradual soft tissue envelope expansion, and decreased relapse^{13,14}

Preoperative Planning

- 3D head CT scans should be reviewed.
- The plastic surgeon and neurosurgeon should communicate regarding the surgical approach.
- The surgeon should be familiar with cranial distraction devices.

Positioning

- The patient is placed supine on the operating room table.
- General anesthesia is induced, and the head and neck are shaved, prepped, and draped in a sterile fashion.
- A curvilinear coronal incision is made with a marking pen and infiltrated with local anesthesia containing epinephrine.

Approach

- For both metopic and unicoronal synostosis, the approach for fronto-orbital distraction osteogenesis is the same as the approach utilized for conventional FOA.
- The curvilinear coronal incision is opened to the subgaleal plane, and

subperiosteal elevation of the anterior cranial and periorbital soft tissues is performed. The authors prefer a subperiosteal approach to the anterior cranial vault and base, but there is a paucity of data comparing this approach to the subgaleal approach.

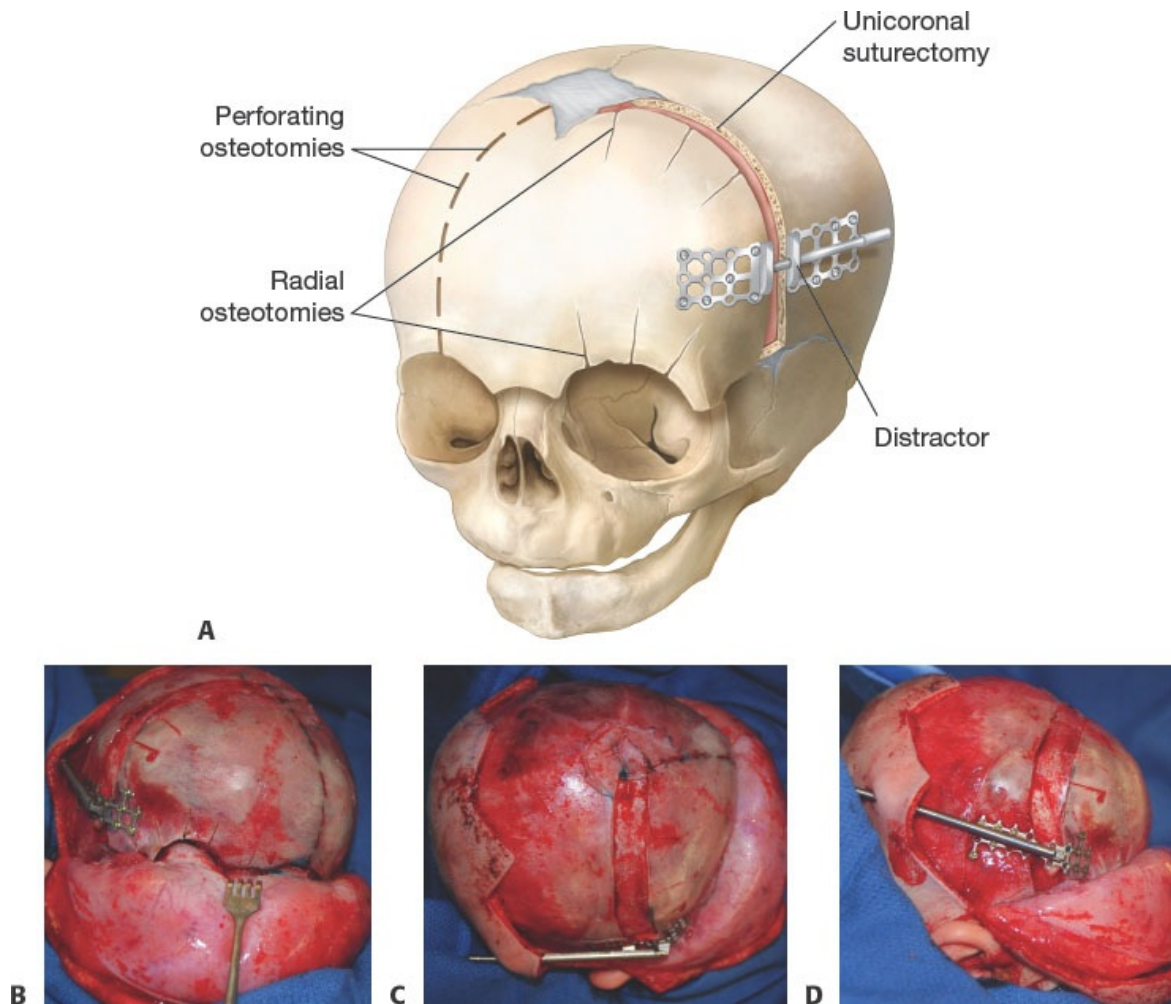
TECHNIQUES

■ Unicoronal Synostosis Fronto-Orbital Distraction Osteogenesis

Bone Cuts

- Perform a unilateral coronal suturectomy, 2 to 4 mm wide, with an ultrasonic scalpel (**TECH FIG 1A,B**).
- Place bur holes along the lines of anticipated osteotomies, making sure to place one bur hole at the base of the fused coronal suture in the pterional region, a so-called pterional window through which osteotomies of the greater wing of the sphenoid and the lateral orbital wall will later be made.
- Limit dural dissection to directly underlying the planned osteotomy, thus keeping the majority of the dura attached to the overlying frontal bone.
- Use the ultrasonic scalpel to perform all cuts similar to a typical FOA. Bone cuts include (**TECH FIG 1B–D**)
 - A vertical “perforating,” or incomplete, osteotomy from the contralateral orbit to the anterior fontanelle at the inflection point of the deformity
 - Inferior orbital cuts along the orbital roof with special care taken to retract the brain and globe
 - Radial osteotomies along the orbital roof to unfurl the horizontally short orbit
 - Careful osteotomies of the greater wing of the sphenoid, lateral orbital rim, and the lateral orbital wall.
 - Use malleable retractors to provide access through the “pterional window.”
 - One malleable retracts the frontal lobe, another the temporal lobe, and a third the soft tissues of the orbit.
 - Extend cuts to the medial third of the contralateral orbit.

- Keep the bandeau en bloc with the frontal bone.



TECH FIG 1 • A. Osteotomies for unicoronal synostosis correction using distraction osteogenesis. **B.** Radial orbital roof osteotomies and vertical perforating osteotomies. **C.** Unicoronal suturectomy. **D.** Frontal bone radial osteotomies.

■ Device Application

- Rigidly fixate a uniplanar cranial vault distractor to the low to midparietal region in the forehead.
 - Confirm an anterior and slightly inferior vector for orbital rim overcorrection.

- Place Gelfoam under the fixation screws to avoid dural injury during distraction.
- Activate the distractor to ensure completeness of the osteotomy.
- Return distractor to its original position.
- Place a drain under the forehead scalp flap.
- Perform a layered scalp closure.

■ Metopic Synostosis Fronto-Orbital Distraction Osteogenesis

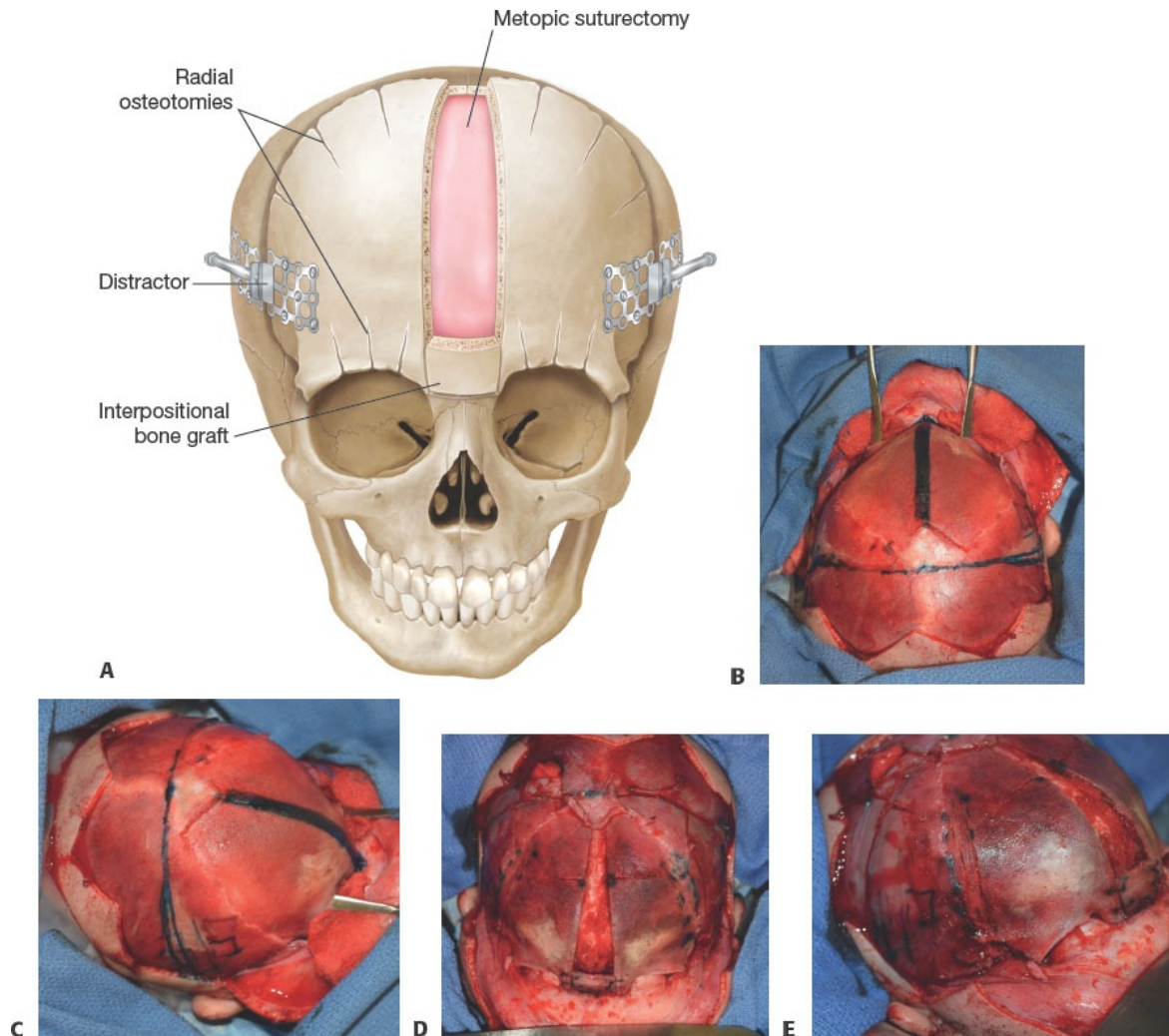
Bone Cuts

- Following subperiosteal elevation of the forehead soft tissues performed with conventional FOA, perform a narrow (5 mm) metopic suturectomy with a Hudson brace and ultrasonic scalpel under direct visualization (**TECH FIG 2A**).
- Make the pterional windows bilaterally, which permits limited dissection of the frontal and temporal lobes under the osteotomy sites.
- Dissect the dura directly underlying the osteotomy, keeping a portion of the dura attached to the overlying frontal bone.
- Use the ultrasonic scalpel to make all cuts typical of a conventional FOAR, including coronally oriented osteotomies posterior to the coronal sutures at the transition between “normal” occiput and “abnormal” forehead (**TECH FIG 2B–E**).
 - Do not separate the frontal bandeau from the frontal bone.
- Make the sphenoid wing and orbital roof osteotomies through the pterional window.
- Make additional radial osteotomies along the orbital roof and frontal bones to allow for gradual remodeling and flexing of bone during the activation phase of distraction.
- Fill in bone gaps, as necessary, with particulate bone grafts.

Rigid Fixation and Device Application

- Place the dura on stretch in the region of the metopic suture and place an interpositional bone graft (approximately 2 × 1 cm) at the nasofrontal junction.

- Fixate bone graft to the nasal bones and bilateral frontal bones in a slightly advanced position.
- No additional advancement of the nasofrontal region is meant to occur during distraction, and thus, the nasofrontal region should be placed in its final anteroposterior position.

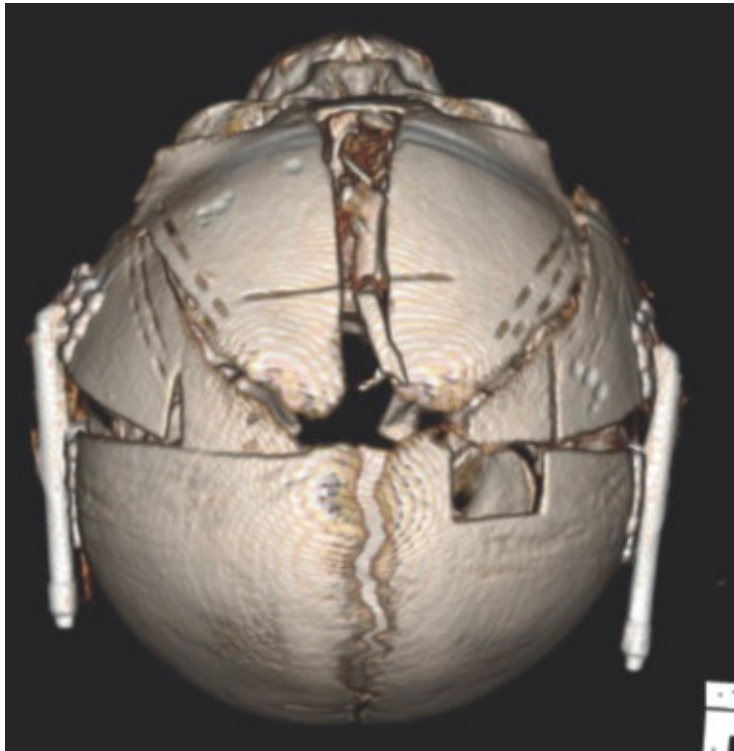


TECH FIG 2 • A. Osteotomies for metopic synostosis correction using distraction osteogenesis. Markings for the site of metopic suturectomy (**B**) and pterional window (**C**). **D,E.** Coronally oriented osteotomies and an interpositional bone graft are placed.

- Rigidly fixate the uniplanar cranial vault distractors to the midparietal region

in the forehead with an anteroposterior vector, ensuring translocation of the forehead and orbital rims to their proper location.

- Importantly, the vector of distraction should not narrow the forehead; instead, distractors should be parallel to one another in the sagittal plane (**TECH FIG 3**).
- Place Gelfoam under the fixation screws to avoid dural injury during distraction.
- Activate the distractor to ensure completeness of osteotomy.
- Return the distractor to its original position.
- Fill in bone gaps, as necessary, with particulate bone grafts.
- Place a drain under the forehead scalp flap.
- Perform a layered scalp closure.



TECH FIG 3 • When fixating distractors for correction of metopic synostosis, confirm that the vector of distraction does not narrow the forehead. Distractors should be parallel to one another in the sagittal plane, as seen in this bird's-eye view of a postoperative 3D CT scan.

PEARLS AND PITFALLS

Ultrasonic scalpel	■ Perform cuts with an ultrasonic scalpel for increased precision and safety.
Osteotomy	■ Always activate the distractor prior to closure to ensure completeness of osteotomies.
Bandeau	■ Unlike traditional FOAR, do not separate the frontal bandeau from the frontal bone for either metopic or unicoronal fronto-orbital distraction.
Gelfoam	■ Placement of Gelfoam under the fixation screws avoids injury to the underlying dura during the activation phase of distraction.
Dural dissection	■ Limit dural dissection to directly underneath the osteotomy, thereby maintaining vascularity of the bone flaps.

POSTOPERATIVE CARE

- Start distraction on the second postoperative day at a rate of 1 mm/day.
- For both metopic and unicoronal synostosis, the end point of activation is a slight overcorrection of the deformity, as optimal growth of the frontal region is not likely to occur.
- The consolidation phase ranges from 8 to 12 weeks.

OUTCOMES

- Fronto-orbital distraction is in its infancy, and though short-term data exist, there is a paucity of data relating to long-term outcomes (**FIGS 3 and 4**).
- Choi et al.¹⁵ first described one-piece FOA with distraction for coronal craniosynostosis in 2009 and found that compared to the traditional approach, anterior vault distraction was less invasive and resulted in satisfactory correction.
- In 2010, Choi et al.¹⁶ demonstrated that anterior vault distraction results in greater correction of the skull base angulation seen in unicoronal synostosis.
- Taylor et al. compared a cohort of six unicoronal synostosis patients undergoing fronto-orbital distraction to a cohort of six unicoronal synostosis patients undergoing conventional FOAR.¹²

- All 12 patients completed therapy without complications and with Whitaker I scores.
- The fronto-orbital distraction group had statistically shorter duration of surgery and length of hospital stay.
- The conventional FOAR group was significantly more likely to develop new-onset postoperative strabismus.
- However, Fearon et al.¹⁷ performed a similar comparison between conventional FOA and fronto-orbital distraction in syndromic craniosynostosis patients and found that distraction did not have significant advantages in terms of complication rates, reoperation rates, and anthropometric measurements.
- Anterior vault distraction has also been described for the treatment of multisuture craniosynostosis. Taylor et al. described the placement of two coronal distractors and one sagittal distractor in an effort to expand the cranial vault while limiting surgical invasiveness.¹⁸
- The nondevascularizing nature of fronto-orbital distraction has been hypothesized to have a positive impact on growth, but this has yet to be comprehensively studied.
- Long-term studies are needed to assess the outcomes of fronto-orbital distraction vs the outcomes of conventional FOAR.

COMPLICATIONS

- Dural and brain injury may be masked because bone flaps remain in place.
- Dural bleeding may be more difficult to control due to the presence of bone flaps.
- Incomplete osteotomy
- Transcutaneous position of distractors predisposes to superficial “pin-site” infections, which are typically treated with local wound care and antibiotics.
- Device failure:
 - Screw thread failure
 - Baseplate failure
 - Failure at the interface of bone and hardware
 - External distractor arm failure

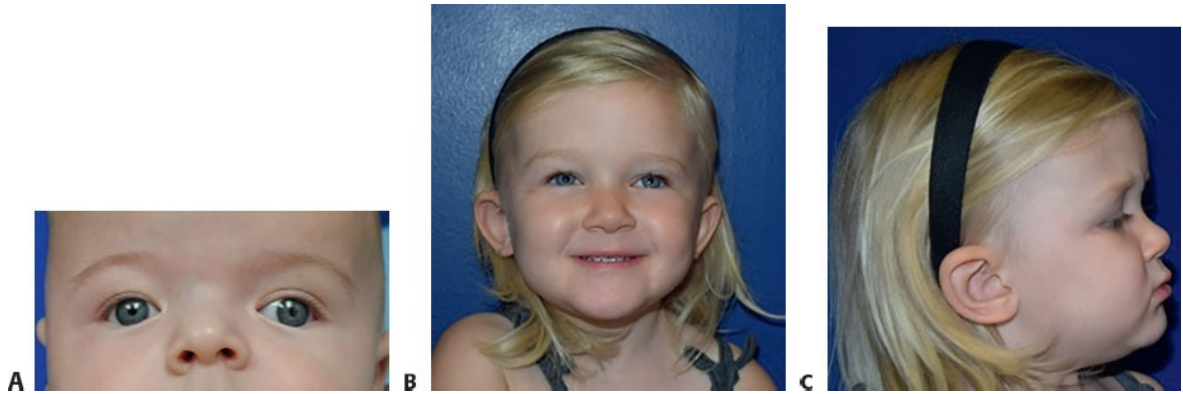


FIG 3 • **A.** Postoperative periorbital aesthetics. **B,C.** At age 26 months, 21 months after surgical correction.

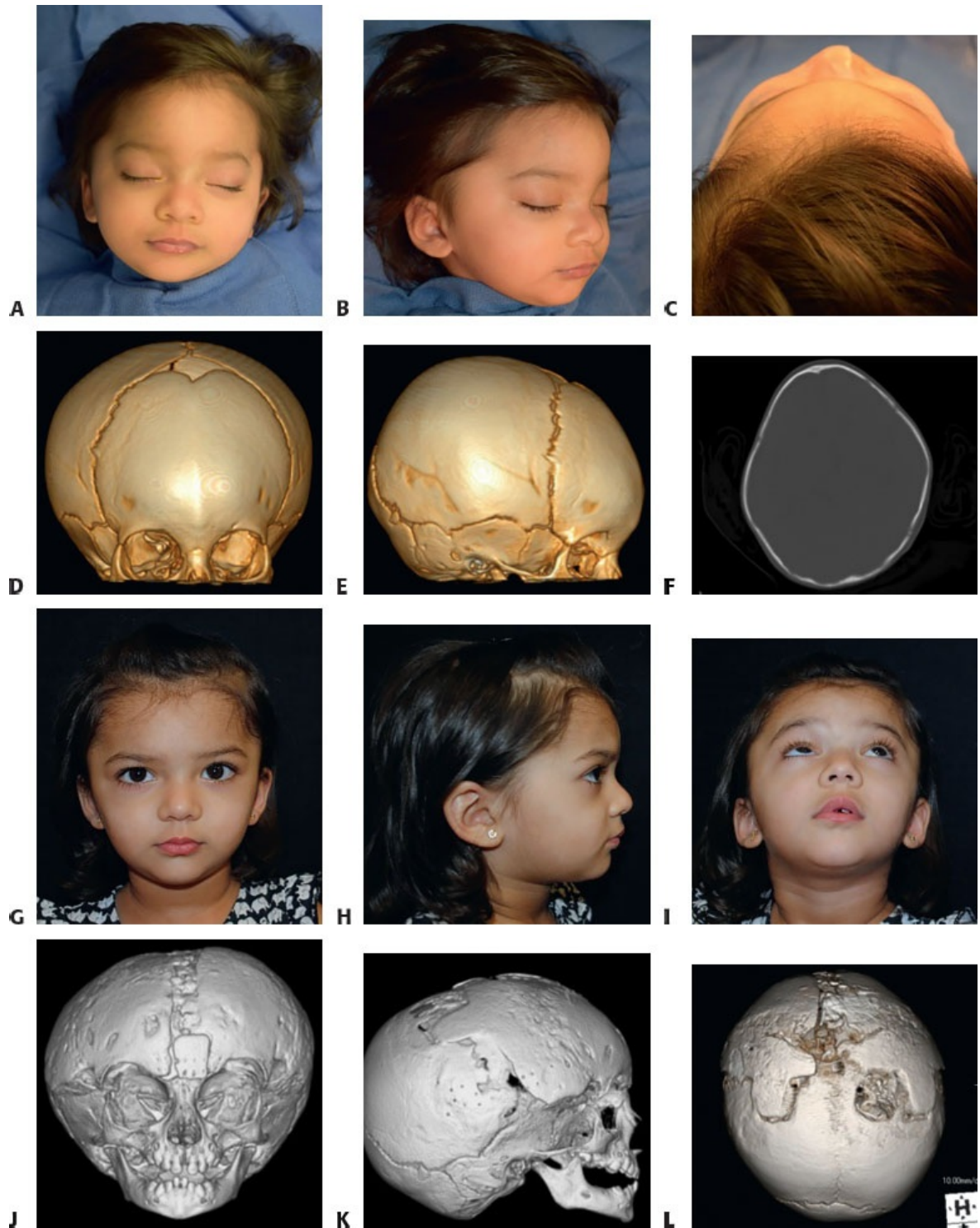


FIG 4 • Girl with metopic synostosis. Preoperative photographs (A–C) and CT scans (D–F) at 8 months of age. Postoperative photographs (G–I) and 3D CT scans (J–L) at 25 months of age (17 months postoperatively).

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3 Posterior Cranial Vault Expansion

CHAPTER

Alexander Y. Lin

DEFINITION

- Posterior plagiocephaly, or flattening of the posterior skull, can be the result of deformational (positional) forces or of fused sutures (lambdoid craniosynostosis) (**FIGS 1 and 2**):
- This distinction is critical, as deformational plagiocephaly can be improved nonsurgically with repositioning or orthotics, whereas craniosynostosis requires surgical repair.¹
- Surgical repair is necessary for craniosynostotic posterior plagiocephaly, which can be corrected with posterior cranial vault expansion.
- In craniosynostosis, some early presentations (before 3 and 4 months of age) may be improved with strip synostectomy and postoperative helmeting,² and other presentations may be candidates for posterior distraction osteogenesis, particularly syndromic patients without adequate bone stock.³
- Posterior cranial vault remodeling is the set of plastic surgery techniques to perform open repair in one stage, by designing full-thickness cranial bone grafts that are neurosurgically elevated and rebuilding the posterior cranial vault with these grafts via fixation (usually resorbable sutures or plates in infants, although nonresorbable hardware can be considered in older patients).

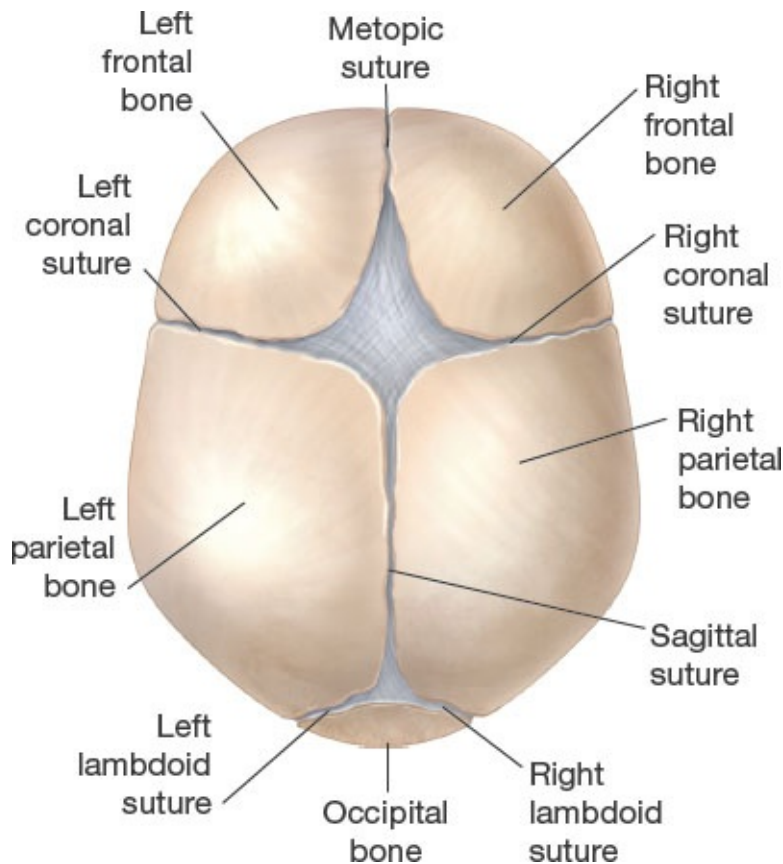


FIG 1 • Aerial view of infant's skull showing calvarial bones (paired frontals, paired parietals, single occipital) and sutures (metopic, paired coronals, sagittal, paired lambdoids).

ANATOMY

- The normal infant growing skull has five major bones separated by growth sutures: the metopic suture separates the two frontal bones, which posteriorly border the bilateral coronal sutures that adjoin the two parietal bones separated by the sagittal suture at the midline, which forms the lambda where it meets the bilateral lambdoid sutures that posteriorly define the occipital (**FIGURE 1**).
- Craniosynostotic posterior plagiocephaly is usually due to nonsyndromic lambdoid craniosynostosis (unilateral or bilateral) or multisutural syndromic craniosynostosis:
 - The resultant head shape is usually brachycephalic (short in the anteroposterior dimension), with unilateral disease leading to asymmetric posterior flattening (**FIG 2B**) and bilateral disease leading to bilateral

posterior flattening.⁴

- Cranial index (CI) is defined by cranial width divided by cranial anteroposterior length and is a relative index to help categorize scaphocephaly (CI less than 0.76) vs brachycephaly (CI greater than 0.86):
- Cranial vault asymmetry (CVA) is the difference of the two diagonals from frontozygomatic suture to contralateral occipital prominence (normal less than 4 mm).
- Cranial vault asymmetry index (CVAI) is CVA divided by the longer diagonal (normal less than 3.5).
- These measurements help assess the preoperative severity and postoperative outcomes (**FIG 3**).⁵
- The midline sagittal sinus ends posteriorly at the torcula, located at the occipital protuberance or inion, and then branches laterally along the superior nuchal line to the bilateral transverse sinuses, which emit emissary veins below the asterion and posterior to mastoid process, to become the bilateral sigmoid sinuses:
- In addition to the venous anatomy, occipital muscles insert at the occipital protuberance and superior nuchal line, which can also cause bleeding when stripped (**FIG 4**).⁶

PATHOGENESIS

- Craniosynostosis may be due to genetic or developmental etiologies. Growth of bone is perpendicular from the direction of the suture; therefore, suture fusion prevents perpendicular growth, leading to parallel compensatory growth along the line of the suture:
- Consequently, in unilateral lambdoid craniosynostosis, compensatory bossing occurs along the line of the suture, enlarging the ipsilateral mastoid and contralateral parietal regions, resulting in a trapezoidal head shape from bird's-eye view (see **FIG 2B**).⁴



FIG 2 • Aerial view of two forms of right posterior flattening: right posterior deformational forces (**A**) vs right unilateral lambdoid craniosynostosis (**B**).

- Deformational skull changes occur with a high prevalence because the infant skull is malleable to allow rapid brain growth (**FIG 2A**):
 - The “back-to-sleep” supine sleeping campaign has reduced sudden infant death syndrome (SIDS)⁷ but has resulted in a higher number of infants with deformational plagiocephaly.
 - In the setting of craniosynostosis, simultaneous deformational forces, from infant sleeping position, may unpredictably affect the craniosynostosis head shape pattern.

NATURAL HISTORY

- Craniosynostosis occurs about 1 in 2000 live births.
- The ranges in distribution of fused sutures are^{8–10}
 - Sagittal (40%–57%)
 - Metopic (10%–21.5%)
 - Coronal (15%–30%)
 - Lambdoid (1%)
 - Multisutural (13%)

PATIENT HISTORY AND PHYSICAL FINDINGS

- Head shape problems manifest early in infancy; rapid infant brain growth leads to rapid exaggeration of the abnormal vectors of growth.
- History should include questions about preferred sleeping position, head tilt related to torticollis, complete closure of eyes when asleep to infer supraorbital rim abnormalities, and neurological symptoms that may suggest elevated intracranial pressure (ICP).⁷

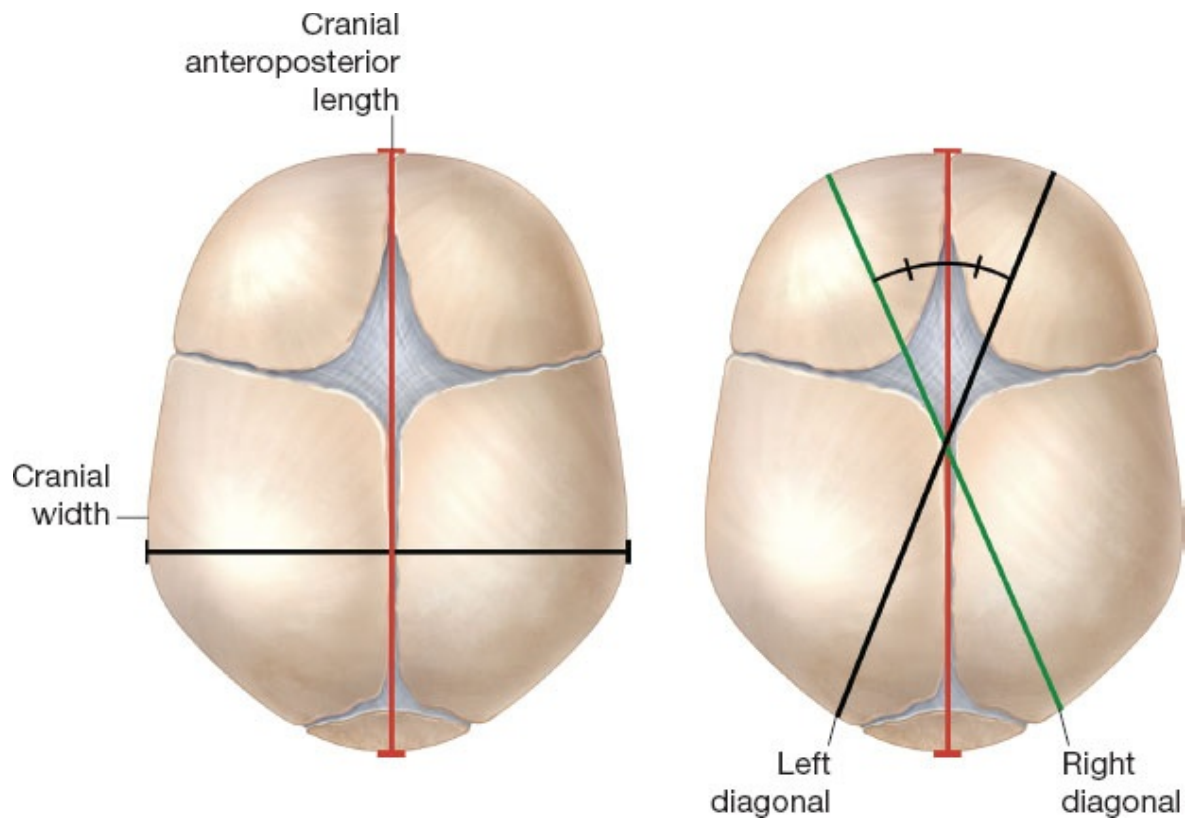


FIG 3 • Schematic of cranial width, cranial AP length, and cranial diagonals.

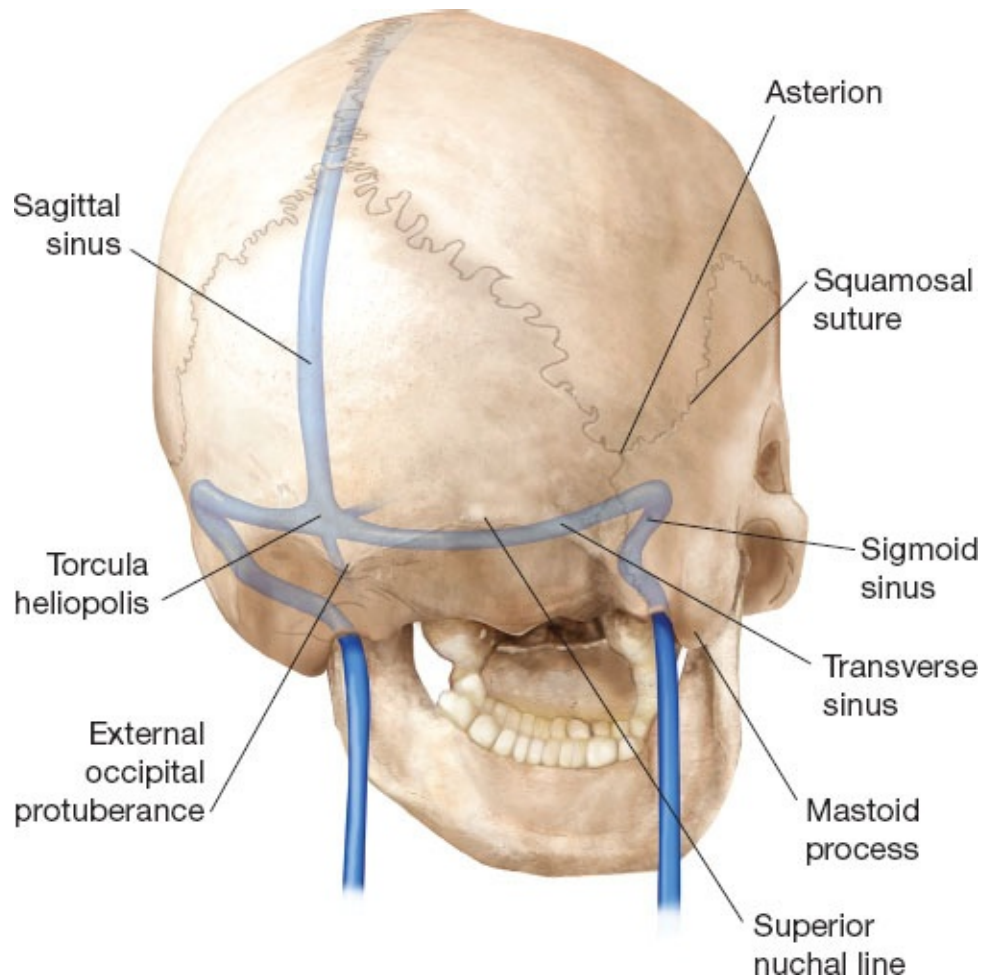


FIG 4 • Posterior skull anatomy showing cranial landmarks and underlying venous sinuses.

- For posterior plagiocephaly, the physical exam must distinguish the common deformational plagiocephaly, from the rare lambdoid craniosynostosis.
- Both can present with unilateral posterior flattening, but deformation causes a parallelogram-shaped head with ipsilateral forehead protrusion and contralateral occipital compensation.
- In lambdoid craniosynostosis, a trapezoidal shape occurs, with ipsilateral mastoid and contralateral parietal bossing, as well as ipsilateral posteroinferior movement of the ear, skull base, and foramen magnum (see **FIG 2**).⁴

IMAGING

- When diagnosis is equivocal, or multisutural craniosynostosis is suspected, CT

scan without contrast, with three-dimensional (3D) reconstructions (**FIG 5**), will elucidate each cranial suture.¹¹

- For syndromic patients, additional studies such as MRI with contrast may be necessary to rule out anomalous brain anatomy and vasculature that may affect the surgical approach or require additional neurosurgical procedures.^{11–13}

DIFFERENTIAL DIAGNOSIS

- Posterior deformational plagiocephaly
- Lambdoid craniosynostosis (isolated)
- Lambdoid craniosynostosis (multisutural)

SURGICAL MANAGEMENT

- The timing of surgery depends on the presenting symptoms but preferably before 12 months of age to take advantage of the osteogenic potential of the dura, which dissipates by about 2 years of age.¹⁴ In addition, frontofacial asymmetries are more likely to automatically improve with growth, if craniosynostosis surgery is performed before 12 months of age.¹⁵

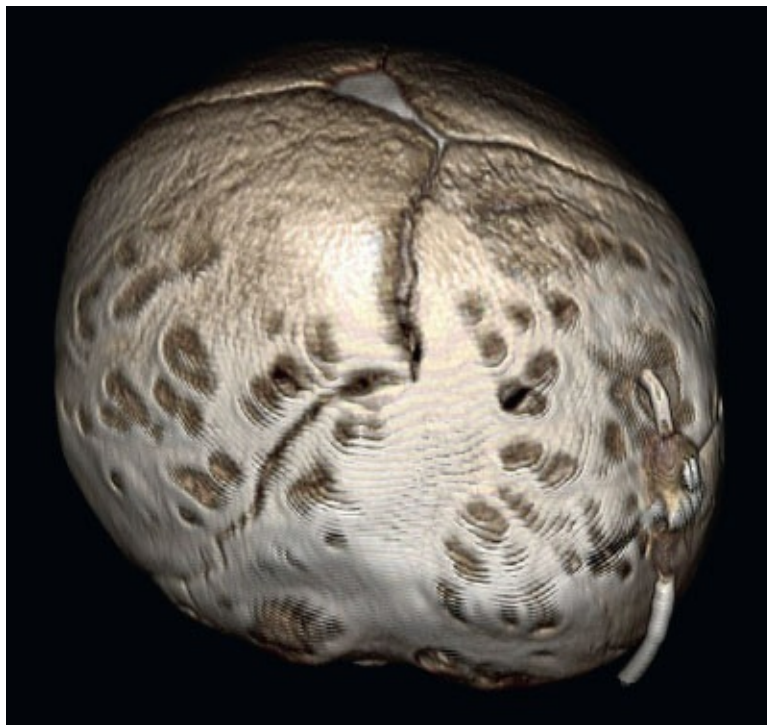


FIG 5 • Posterior coronal view of 3D CT scan of infant with right unilateral lambdoid craniosynostosis, who

also has a right shunt. Note the ipsilateral mastoid and contralateral parietal expansion, in line with the synostosed suture.

- Signs and symptoms of elevated intracranial pressure, especially in syndromic multisutural patients, may necessitate cranial vault expansion before 3 months of age.¹²
- Patients older than 12 months of age have begun to lose their dural osteogenic potential and will not heal bone gaps in the reconstruction. They will need bone grafts to augment the structural reconstruction.¹⁴
- The main objective of surgery is to expand the cranial vault volume from a posterior approach, as well as to normalize the head shape and appearance of the posterior skull.
- The main steps of the operation are:
 - Open approach to the posterior cranium usually via bilateral coronal incisions
 - Design craniotomies that allow volume expansion and reshaping of the posterior skull
 - Neurosurgical elevation of the bone grafts
 - Rearrangement and fixation of the cranial grafts to reconstruct the posterior vault
 - Potential bone grafting of bone gaps
 - Closure with possible soft tissue expansion techniques

Preoperative Planning

- Given that the major morbidity and mortality risk in craniosynostosis surgery is blood loss due to the infant's small total blood volume, and the bleeding nature of extensive cranial osteotomies required for cranial vault reconstruction,¹⁶ it is imperative that prior to surgery, blood bank and anesthesia are aware and prepared.
- Institutional blood conservation protocols may include preoperative medications such erythropoietin, intraoperative medications such as tranexamic acid, resuscitation protocols that include required ratios of fresh frozen plasma (FFP) to avoid dilutional coagulopathy, cell salvage blood recycling for autotransfusion, arterial line monitoring, and multiple lines for emergent resuscitation if necessary.
- Neurosurgical team needs to be aware of the plan, including any anomalous

brain anatomy, and standard neurosurgical precautions such as air embolism monitoring and end-tidal CO₂ monitoring.¹⁶

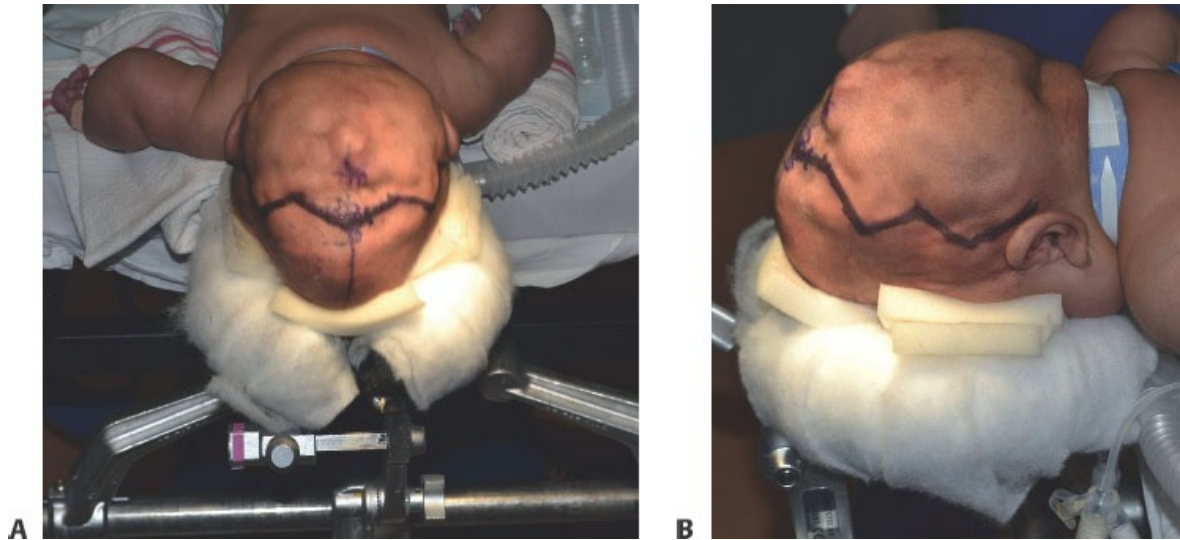


FIG 6 • Prone positioning on a well-padded horseshoe with foam protecting the periorbital regions, with bilateral coronal incision markings above the hairline that extend postauricularly.

- Preoperative imaging can be viewed in rotatable three-dimensional imagery, or even 3D-printed, for visualization and surgical planning.

Positioning

- For posterior cranial vault remodeling, prone positioning over a well-padded horseshoe headrest gives full exposure to the occiput and low craniotomies while allowing endotracheal tube management and monitoring of the globes to avoid pressure.
- Additional foam may be used to protect the periorbital bony prominences from pressure injury (**FIG 6**).
- Alternatively, a modified prone sphinx position may be used, requiring padding including neck rest, to gain access to both the anterior and posterior cranial vaults.¹⁷

Approach

- Bilateral coronal incision is usually preferred for full access to the entire

cranium. Rarely, a shorter scalp incision may be used for a limited approach to a specific portion of the skull.

- Previous skull incisions (such as previous cranial vault remodeling or shunt surgery) need to be recognized and incorporated into the incision, to avoid compromising scalp blood supply.
- Unilateral lambdoid synostosis with ipsilateral flattening can be approached with one or more large posterior cranial grafts that are turned 180 degrees or transposed front to back, to reverse the positions of the flattened side and the bossed side, improving overall symmetry.
- Bilateral and unilateral flattening can be approached with a vertex bandeau transposed to an occipital bandeau. A Marchac forehead template, preferably from the more protuberant occipitoparietal region, can recreate a new occiput.
- Barrel-stave technique and radial outfracturing can widen the cranial base and contour the above bone grafts to customize the reconstruction to fit the patient.

TECHNIQUES

■ Bilateral Coronal Exposure of Posterior Cranium

Markings

- Bilateral coronal incision is drawn from ear to ear crossing the skull vertex, keeping it above the hairline and extending it into the inconspicuous postauricular region if further exposure is necessary.
- Incorporate previous surgical scars or avoid them with adequate distance.
- Avoid critical structures such as shunt hardware or significant bony gaps seen on preoperative imaging.
- Plan for the possibility of future return via the same coronal incision, especially in the setting of a syndromic patient who may require multiple-staged future repairs.
- Typically, portions of the incision are zigzagged to break up the linear scar into a less noticeable future scar pattern.
- Hair may be shaved in full, or only over the planned incision, depending on parents' and surgeons' preferences (see **FIG 6**).

Incision and Exposure

- Incorporate techniques to decrease scalp blood loss during the duration of the surgery.
- Prior to incision, local anesthetic containing epinephrine appropriately dosed should be used for vasoconstriction.
- The incision itself can be made with scalpel or fine-needle point electrocautery on a low cut setting.
- Focused bipolar electrocautery, or direct pressure with Raney clips or temporary stay sutures, can be used to reduce scalp edge bleeding with minimal effect on hair follicles.
- The posterior skull can be exposed directly via subperiosteal elevation of the posterior scalp flap, or staged with an initial subgaleal posterior scalp flap, followed by elevation of the pericranial flap.
- The subgaleal plane is relatively bloodless; the subperiosteal plane is permeated with vascularized channels and muscular attachments, requiring diligent hemostasis using electrocautery, bone wax, and hemostatic agents such as thrombin or fibrin.
- The anterior scalp flap may need to be elevated to the coronal sutures to free the tension near the ear, allowing the posterior scalp flap to fully deglove and expose the posterior cranium.
- The amount of bone exposure depends on the technique used for posterior cranial vault reconstruction.
 - Usually, the temporalis muscle will need to be elevated subperiosteally out of its temporal fossa, preferably remaining mostly attached to the frontal scalp in order to reposition the temporalis muscle automatically when the frontal scalp is returned during closure.
 - Typically, the posterior scalp flap needs to be exposed to the level of theinion, where the occipital muscles insert.
- Both the insertions of the temporalis muscle and the occipital muscles may have significant bleeding when elevated and require vigilant hemostasis.

■ Bone Transposition

- Unilateral lambdoid synostosis generally leads to bilateral deformities. Unilateral flattening is usually associated with contralateral bossing to some degree.
 - Two types of bone transposition can be used together or separately to

rebalance these asymmetries: inverse (turning 180 degrees or upside down) transpositions or anterior-to-posterior (AP) transpositions.

Inverse Transpositions

- Inverse transpositions reverse the positions of the flattened synostotic side with the contralateral bossing, to improve lateral symmetry (**TECH FIG 1**).
- The anterior-most coronal marking should be at the limit of the posterior asymmetry, where the parietal bones become more symmetric. Markings should be designed so that the lateral edges of the bone graft segments reach this anterior coronal line and contain both the bossed portion and flattened portion to reverse.
- The posteroinferior osteotomy, or those between bone segments, should parallel the anterior coronal marking to allow the inverted segment to fit.
- More than one bone segment may be needed for neurosurgical reasons (avoiding venous sinuses) or to add more curvature posteriorly by combining inverse transpositions with AP transpositions.¹⁸



TECH FIG 1 • Inverse transpositions rotate each bone segment upside-down 180 degrees (inverting bone 1 and bone 2), to balance the protrusive and flattened sides. In this example, this is used in conjunction with AP transposition (switching AP positions of 1 and 2).

Anteroposterior Transpositions

- AP transpositions reverse the positions of the more curved vertex segment, with the flatter occipital segment, to transfer more normal curvature to the flattened occipital region (**TECH FIG 2**).
- Similar to inverse transpositions, the transverse osteotomy markings should go up to a portion of the parietal bone that is fairly symmetric.
- The transverse osteotomies should be fairly parallel so that the transposed pieces can align for bony fixation.
- Multiple segments can be used in this fashion, with the logical extreme equivalent to a single vertex thin segment to transpose as an occipital bandeau.
- As in the occipital bandeau technique described below, breaking up of the bone graft may be necessary to recontour and better fit the donor defect.

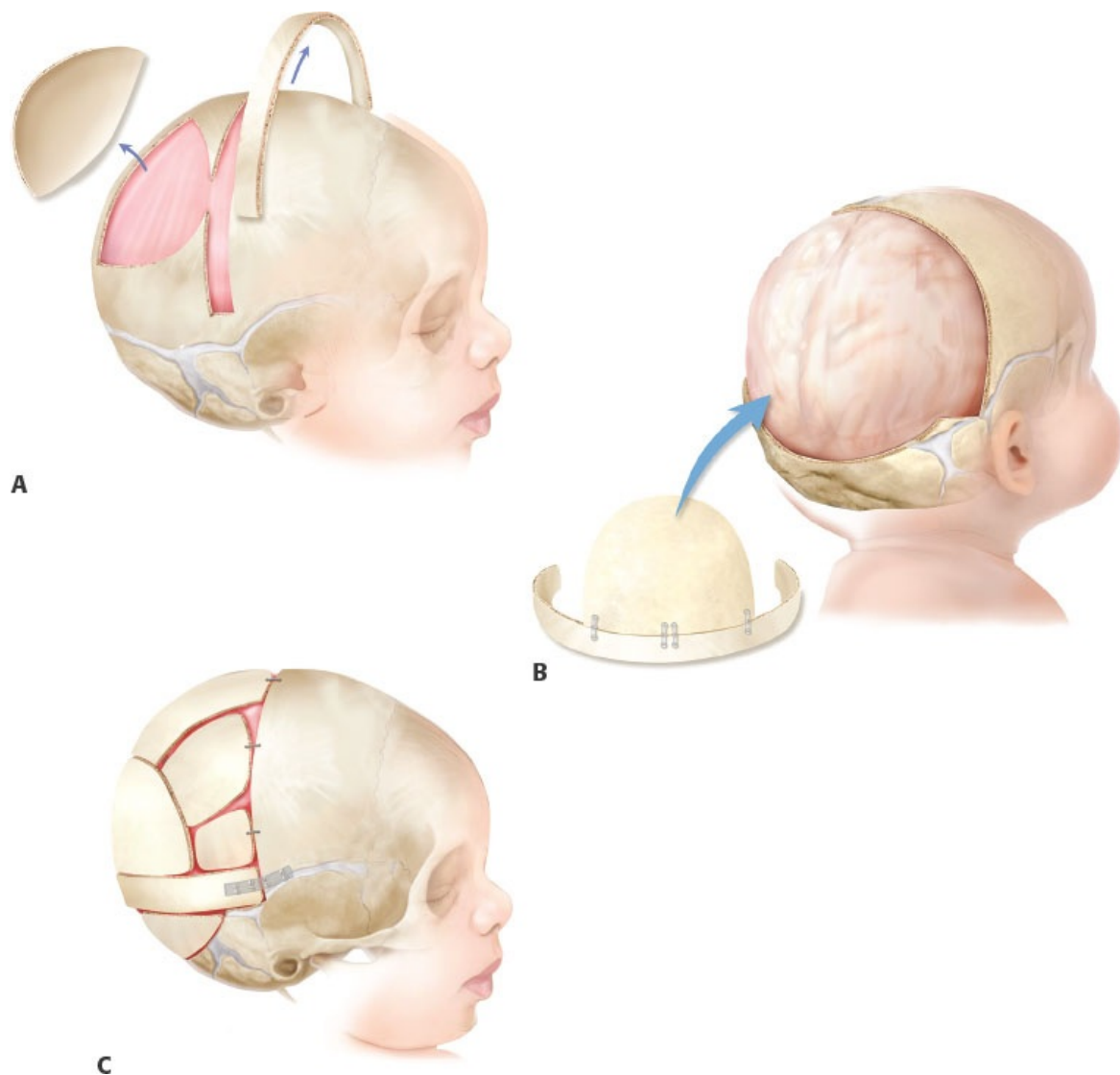


TECH FIG 2 • AP transposition of segments A (vertex)

and B (occipital). In this example, bone segment B is further osteotomized into multiple grafts to better fill the donor defect.

■ Occipital Bandeau

- Severe brachycephaly may not have any bone segments curved enough to structurally support an expanded occiput, which undergoes pressure from a contracting posterior scalp flap and sleeping positions.
 - In this scenario, an occipital bandeau can be harvested from the coronal curvature at the vertex and transposed to form the new structural occipital base.¹⁵
- The bandeau is marked as a 2-cm strip near the vertex where the calvarial curvature is most normal, extending from squamosal suture to squamosal suture.
- The bilateral asterion regions must be approached with great care during the bone elevation due to the underlying venous plexuses.
- A stairstep can be incorporated near the squamosal sutures to allow further posterior displacement of the transposed bandeau (**TECH FIG 3A**).
- If the bandeau still has significant asymmetry, it can be inverted to transpose the left and right sides.
- An age-appropriate Marchac forehead template can be used, preferable from the more protuberant occipitoparietal region, to recreate a new central occiput by fixating it to the transposed bandeau (**TECH FIG 3B**).
- The transposed bandeau delineates the posterior extent of the reconstructed cranium.
 - Tongue-and-groove contact with the base using temporary fixation (such as surgical clamps) can assist to estimate the amount of space left to fill with bone grafts, before permanent fixation of bandeau.
- 1After elevating the bandeau and posterior cranium bone grafts, the bandeau and Marchac grafts are fixed in place. Remaining areas are filled in with customized bone grafts contoured to fill in the defects (**TECH FIG 3C**).



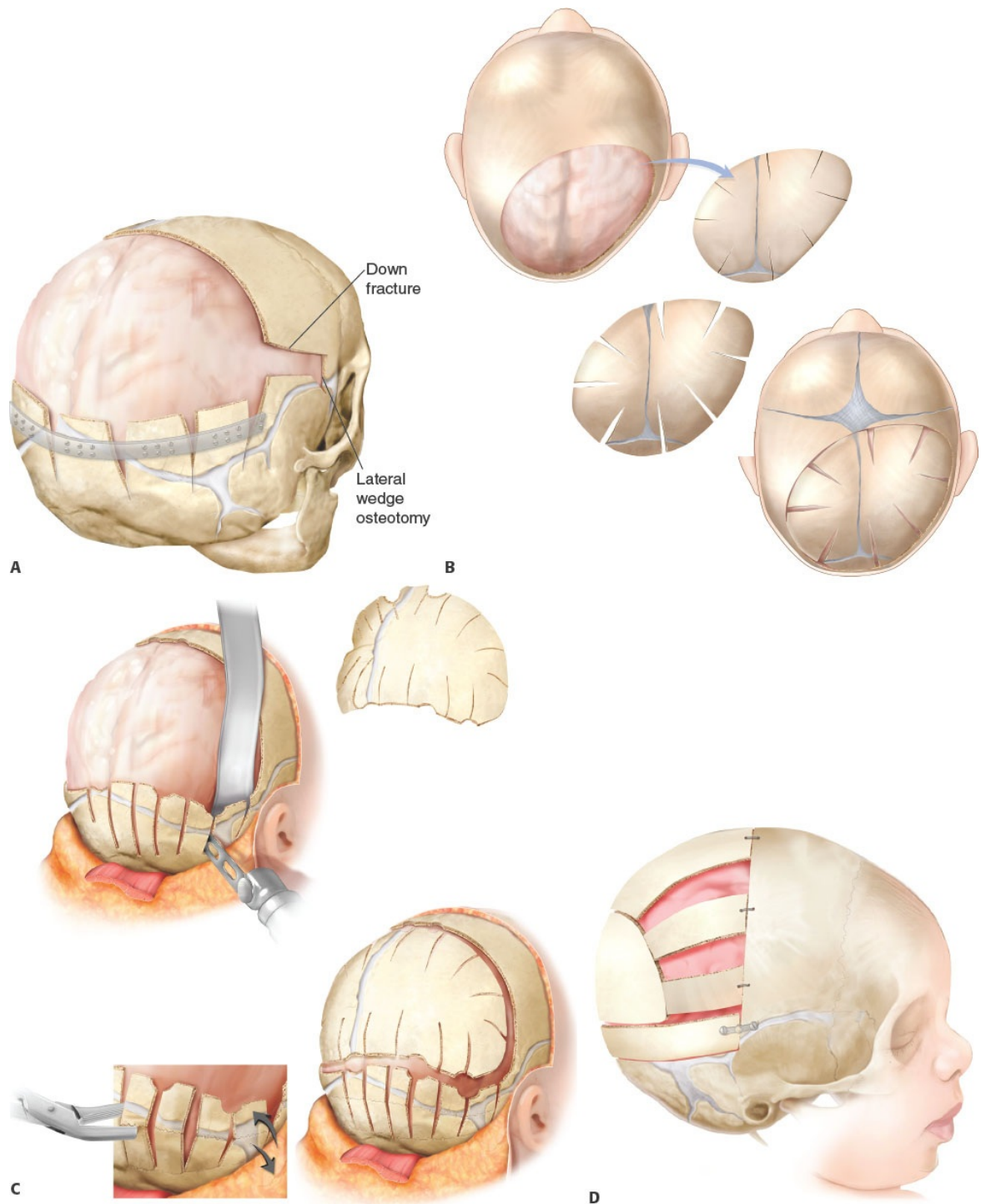
TECH FIG 3 • A. Occipital bandeau harvested from the vertex and neoocciput harvested with Marchac template from the side with more parietal prominence. **B.** Neoocciput and bandeau fixated to create new posterior extent of the cranium. **C.** Remaining bone segments can be recontoured as bone grafts to fill in the donor defect.

■ Barrel Staves, Contouring, and Bone Grafting

- Barrel staves can be used in a variety of ways to contour the bony skeleton,

depending on the morphological requirements.

- Barrel staves can be marked in multiple patterns, including linear and radial and infractured or outfractured to recontour the skull base or the large bone pieces.
- Osteotomies are made with power instruments (Midas Rex, reciprocating saw) or bone scissors and contoured with Tessier bone benders that can better control greenstick fracturing and contouring.
- Other osteotomies include lateral wedges to allow downfracture of remaining vertex to improve turriccephaly (**TECH FIG 4A**).¹²
- In the less frequent scenario of disease mostly limited to one side, a bone graft containing the depression and radial cuts with outfracture contouring can improve the defect (**TECH FIG 4B**).
- For the occipital skull base, vertical barrel staves allow outfracturing and widening of the base, to better approximate the expanded occiput (**TECH FIG 4C**).
 - Plating systems can be used to maintain the expanded barrel staves and reduce relapse of the expansion.¹⁷
- Bone defects can be minimized with split or full calvarial bone pieces, inner table particulate bone grafts, bone allograft, or other bone autografts (**TECH FIG 4D**).
- Bone graft pieces may be fixated with hardware or sutures and particulate bone graft with plates or topical fibrin glue sealant.



TECH FIG 4 • A. For syndromic associated turricephaly, lateral wedge osteotomies can allow downfracture to lower the vertex; note skull base vertical barrel staves to widen occiput. **B.** For unilateral disease with minimal contralateral changes,

a unilateral bone graft with radial barrel staves allows direct recontouring. **C.** Vertical barrel staves at skull base can be contoured with Tessier bone benders, along with contouring of bone segments. **D.** An example of occipital bandeau with neoocciput and bone grafts incompletely fill the donor defect; shaded areas indicate where additional bone grafting is needed.

■ Bony Fixation and Soft Tissue Expansion for Closure

- Bone fixation is usually performed with resorbable plating systems and resorbable sturdy sutures (2-0 polydioxanone).
 - Approximated bones can be temporarily held in place with surgical clamps and the plate with another clamp.
 - Holes can be drilled (for the plating system or sutures) and then plated or sutured before removing the surgical clamps.
 - Bone grafts can also be wired temporarily, to aid in plate or suture fixation. In an older patient, nonresorbable titanium hardware can be used.
- Scalp may need to be expanded with transverse galeal scoring to allow AP lengthening.
 - Each transverse score should be at least 1 to 2 cm from the previous one, to avoid injury to the blood supply.
 - Scoring may be performed with unipolar electrocautery on cutting, and blunt spreading can be used to widen the galeal score.
 - Avoid large blood vessels during scoring by interrupting the transverse score where there are visible blood vessels.
 - Both anterior and posterior scalp flaps may need galeal scoring to achieve soft tissue closure without undue tension on the bone reconstruction.
- Prior to final closure, check for final hemostasis.
 - The anesthesia team should perform a Valsalva maneuver to detect dural tears and cerebrospinal fluid (CSF) leaks.
- The bilateral temporalis muscles need to be resuspended to prevent temporal hollowing.

- If they are significantly attached to the anterior scalp flap, they may not need significant resuspension. They can be sutured to each other or to resorbable plates.
- Closure over a scalp drain may be performed through a stab incision away from the coronal incision, remaining above the hairline.
- The strength layer is the galea, which should be approximated with interrupted slow-resorbable sutures (such as 3-0 polyglactin or 3-0 poliglecaprone).
 - Revision surgery may lack a clear galeal plane, and in that scenario, the scarred layers including the dermis should be included for strength.
 - The skin can be approximated with running resorbable suture (such as 4-0 plain gut or 5-0 chromic gut).
 - For some closures, temporary stay sutures to hold the incision together may be needed and then removed after the above layers closed.
- The incision is dressed with antibiotic ointment and petroleum gauze, followed by rolled gauze and tube gauze covering the entire head with a window for the face.
 - Excess rolled gauze under the chin should be checked or cut to prevent constriction.

PEARLS AND PITFALLS

Hemostasis

- Vigilant blood loss monitoring and communication among all members of the team is critical: blood bank, anesthesia, plastic surgery, neurosurgery, and the ICU.
- Blood bank needs to have adequate matched blood products including FFP, to avoid dilutional coagulopathies in the setting of significant transfusion.
- Care teams need to attentively assess vitals, labs, urine output, and drain output in the immediate postoperative period.

Exposure

- Plan scalp incisions carefully, especially in syndromic patients who may need staged future surgeries for the anterior cranium.
- Preoperative imaging is especially important in syndromic patients with anomalous bone, brain, and vasculature; imaging determines the safe inferior extent of posterior osteotomies while avoiding underlying venous structures.

	■ Areas of fused and open sutures may have adherent periosteum and dura, requiring careful navigation to avoid injury. ■ Irrigate periosteal flaps during surgery to avoid desiccation.
Bone	■ The posterior cranium has significant venous sinuses and emissaries that require caution during elevation to avoid air embolism and bleeding. ■ Temporary wide and flat surgical clamps can hold together multiple bone grafts and resorbable plates, while drilling and fixation take place. ■ Malleable retractors protect the dura during drilling, bone suturing, and affixing hardware. ■ For additional bone, calvarial grafts can be split with thin osteotomes; particulate bone can be harvested from the inner table with a low-speed drill.
Closure	■ Prior to closure, establish hemostasis; perform Valsalva to examine for CSF leak; complete counts; and irrigate. ■ The drain may be left unsutured because it will be removed prior to discharge. ■ Some cases will have no drain to avoid negative suction near the dura. ■ Airway and globe protection during and after these extended prone position cases is especially important during and immediately after surgery.

POSTOPERATIVE CARE

- Overnight monitoring in the intensive care unit (ICU) includes vitals, arterial line, urine output, drain output, serial blood count, and coagulation assays, for possible further transfusions. Neurosurgical monitoring includes neurological checks and serum sodium.
- Transfer to floor on postoperative day (POD) 1. Dressings and drain removed on POD 2 or POD 3 before going home with daily dressing changes. Patients who are very active or prone to injury may benefit from a helmet for additional postoperative protection.

OUTCOMES

- Nonsyndromic posterior flattening has good long-term outcomes in terms of bone healing, relapse, and revision rate:
 - Lambdoid craniosynostosis has very low reported revision rates.^{13,15}
- Syndromic patients with anomalous bone growth are more likely to require

surgical revisions.^{14,19}

COMPLICATIONS

- Major morbidity and mortality risks are due to blood loss from multiple osteotomies in the small infant with low total blood volume.
- Infection is uncommon. If detected, the patient requires a washout in the operating room and antibiotics, with attempts to maintain the large bone grafts if possible, given their valuable structure.
- Suboptimal healing or resorption of bone grafts may lead to bone gaps that require future cranioplasty.
- Relapse, which is more prevalent in syndromic patients with anomalous growth, can lead to future revisions.

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4 Posterior Cranial Vault Distraction Osteogenesis

CHAPTER

Richard A. Hopper and Amy Lee

DEFINITION

- Posterior cranial vault distraction osteogenesis (PVDO) increases intracranial volume through gradual expansion of a circumferential cranial osteotomy using manually activated buried distraction devices.¹
- PVDO is indicated in patients with premature fusion of multiple cranial sutures (synostosis) resulting in craniofacial dysmorphism, cephalocranial disproportion, and the risk of increased intracranial pressure.

ANATOMY

- The anterior fontanelle is at the junction of the coronal and sagittal sutures.
- The pterion is an indentation at the anterior portion of the temporal bone corresponding intracranially to the lesser wing of the sphenoid.
- The petrous ridge is a focal elevation of the dural adhesion to the skull base at the posterior temporal bone in line with the inferior aspect of the lambdoid suture.
- The sagittal venous sinus of the brain is typically located in the upper midline but can be asymmetric in complex cases.
- The transverse venous sinuses are usually located in the middle of the posterior cranium but can be inferiorly displaced closer to the skull base in syndromic cases such as Apert and Pfeiffer syndromes.
- The confluence of the sagittal and transverse sinuses is the torcula.

PATHOGENESIS

- Brachy-turricephaly describes a cranial shape with restricted growth in the anteroposterior direction (brachy = short) with compensatory growth in the

superior direction (turri = tower).

- The development of brachycephaly typically results from premature fusion of one or more of the posterior cranial sutures (lambdoid and sagittal) in association with fusion of one or more of the anterior coronal sutures.
- The associated turricephaly results from compensatory vertical expansion of the developing brain through overexpansion and bone effacement in the squamosal and frontozygomatic sutures as well as the anterior and posterior fontanelles.
- Primary skull base anomalies in the pterion and petrous ridges of syndromic cases exacerbate this deformity.
- Most PVDO procedures are performed on patients with brachy-turricephaly associated with FGFR2 mutations such as Crouzon, Apert, and Pfeiffer syndromes.
- Complex multiple suture synostoses such as the kleeblattschädel deformity or Mercedes pattern (sagittal and bilateral lambdoid) synostosis can also benefit from PVDO.

NATURAL HISTORY

- Without surgical treatment through cranial release or expansion, the brachy-turricephaly deformity is progressive in the first years of life.
- Eventual closure of the fontanelles and patent sutures prevents continued compensatory growth, and cephalocranial disproportion occurs, resulting in increased intracranial pressure.
- Frontal surgeries such as fronto-orbital advancement and monobloc procedures provide less intracranial expansion than does PVDO but can be performed after PVDO if further expansion is required.
- PVDO provides more intracranial volume expansion per millimeter advancement than frontal surgeries due to the increased surface area of the transported bone.^{2,3}
- The severe thumbprinting of the posterior calvarium seen in patients prior to PVDO will progress without intervention.
 - With the improved cephalocranial proportion achieved by PVDO, this thumbprinting often resolves soon after activation is complete (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Interdisciplinary assessment of airway, feeding, genetics, and potential associated anomalies must be performed before PVDO.

- Neurosurgical assessment is completed for associated conditions such as Chiari malformation or hydrocephalus.
- Patients with documented hydrocephalus will require appropriate treatment with a cerebrospinal fluid (CSF) shunt procedure prior to PVDO to prevent progressive cranial deformity and nonhealing of the cranial expansion defects postoperation.
- Patients with documented symptomatic Chiari malformations will require treatment before PVDO, but in rare cases, bone decompression of the foramen magnum can be performed simultaneously through the coronal incision.

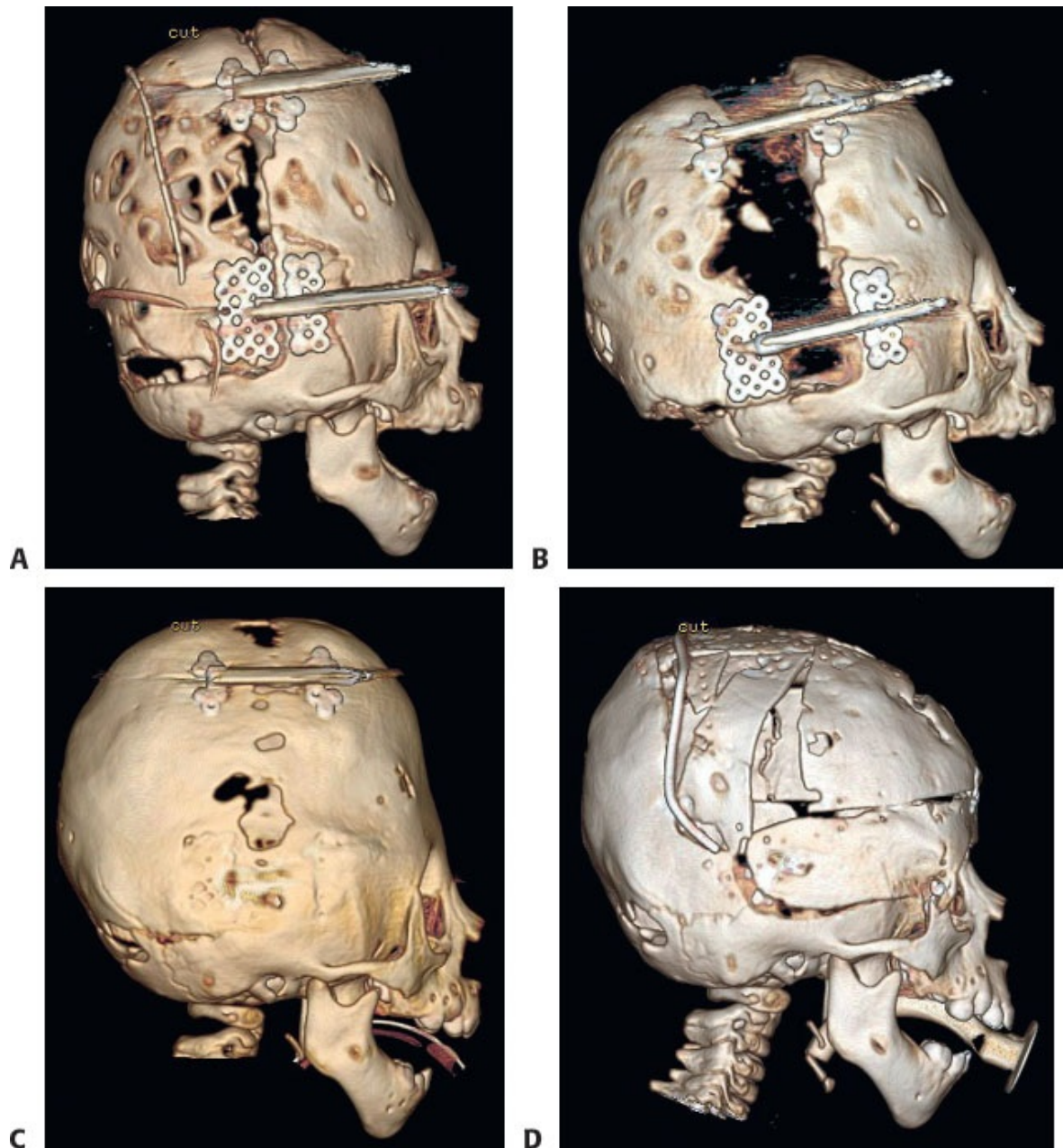


FIG 1 • CT scan images of a 4-month-old patient with pansynostosis and turribrachycephaly undergoing staged posterior and anterior cranial vault expansion. **A.** Prior to posterior vault distraction, the circumferential posterior osteotomy is bridged by paired parallel internal distraction devices. Note the preoperative posterior calvarial thumbprinting. **B.** At the end of activation at a rate of 1 mm/day, the posterior vault has

been expanded. Note the resolution of thumbprinting from increased bone formation with increase of the intracranial volume and decrease of the intracranial pressure. **C.** After the 2-month consolidation period, the osteotomy gap has largely healed. **D.** Age 18 months after fronto-orbital advancement. The posterior vault expansion in infancy created sufficient intracranial space to allow the anterior vault surgery to be performed at a later age, when stability and longevity of the result are improved.

- Asymptomatic Chiari malformations can improve with PVDO or be directly decompressed during the same procedure.^{4,5}
- Whenever possible, a full ophthalmologic examination including dilated funduscopy or visual evoked potentials should be performed prior to intracranial surgery.

IMAGING

- A low-dose three-dimensional CT scan can help in osteotomy marking, device placement, and vector planning.
- The thickest bone along the planned osteotomy is optimal for screw fixation of the devices.
- Vector planning on the images should optimize volume expansion and avoid shearing of the dura, and step-off deformities (see Technique section).
- A contrast CT scan or magnetic resonance angiogram is indicated for syndromic patients to assess the location of the transverse and sagittal sinuses, which can be more inferior and off midline respectively in these patients.
- Posterior circular cranial defects on CT scan can be indicative of anomalous intracranial venous drainage to the skin, and disruption of this drainage should be avoided to prevent increased intracranial hypertension^{6,7} (**FIG 2**).
- Virtual computer planning with or without stereolithographic models, cutting guides, and sinus marking can be beneficial in complex cases.
- Stereolithographic models can allow prebending of distraction device footplates to ensure a parallel vector.
- Serial lateral plain film cephalograms are effective in following cranial

expansion and to ensure devices remain stable on the cranium in cooperative patients.

SURGICAL MANAGEMENT

- PVDO treats the posterior volume restriction associated with brachy-turricephaly to permit unrestricted brain growth in infancy.
- Without the increased intracranial volume (ICV) achieved from a preceding posterior cranial expansion, turricephaly is often not able to be addressed with a frontal surgery alone due to an insufficient ICV to displace the brain inferiorly.
- PVDO is typically performed on patients with multiple suture synostosis in the first year of life to allow frontal surgeries such as fronto-orbital advancement or monobloc to be done at an older age when stability is more reliable and the complication and relapse rate is decreased.⁸

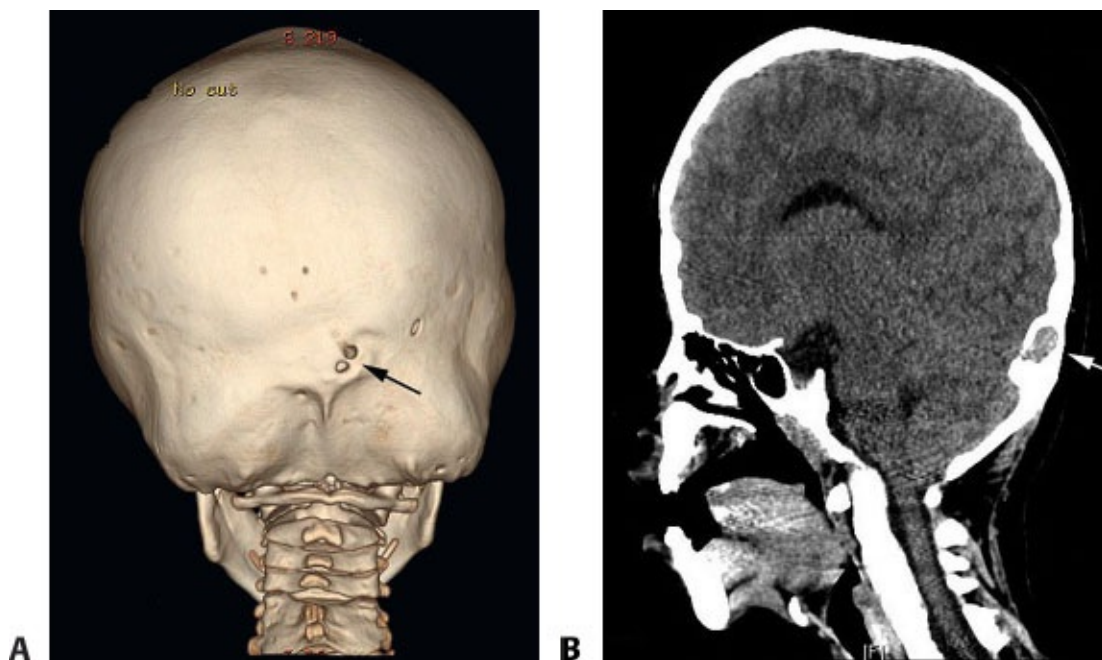


FIG 2 • A patient with Apert syndrome prior to posterior vault distraction. **A.** A circular defect (*arrow*) in the posterior calvarium was suggestive of anomalous transcranial venous drainage. **B.** The communication between scalp and transverse sinus was confirmed on sagittal view (*arrow*) and on MRI with contrast. To avoid

venous congestion, the draining vein was preserved during the scalp dissection.

- PVDO can be performed in appropriate patients in the first few months of life as long as there is sufficient bone to mount the distraction devices.
- If cranial bone is insufficient to mount devices due to bone effacement, preceding treatment of hydrocephalus or early strip craniectomy release may be required to temporarily achieve cephalocranial balance and subsequent bone deposition.

Preoperative Planning

- An end-tidal CO₂ of 30 mm Hg or less will decrease both intracranial and venous pressure, which will facilitate the craniotomy and decrease bleeding.
- The fluid shift expectations and anticipated blood product replacement needs should be discussed by the team.
- In many cases, blood transfusion can be avoided in posterior cranial vault distraction (PCVD) due to the limited craniectomy required.

Positioning

- The patient is placed in a prone position with appropriate chest, pelvis, and face padding (**FIG 3**).
- The neck is maintained in a neutral position to avoid venous compression and an increased risk of venous air embolism (VAE).^{9,10}
- A transesophageal or precordial Doppler can help in early detection of VAE.
- The endotracheal tube is secured in place with a circummandibular suture or wire to avoid displacement.

Approach

- The cranium is exposed from the coronal sutures and fontanelle anteriorly to the insertion of the neck musculature posteriorly through a zigzag coronal incision.
- Laterally, the pterions and petrous ridges are identified as key landmarks.
- A subperiosteal dissection will preserve the vascularity of the periosteum and increase soft tissue thickness over the devices but will result in more blood loss.
- A subgaleal dissection has less blood loss but will offer thinner scalp

protection of the devices, and the periosteum can be compromised during the dissection.

- A subgaleal approach is recommended if there are multiple cranial defects from thumbprinting to avoid damage to the dura.



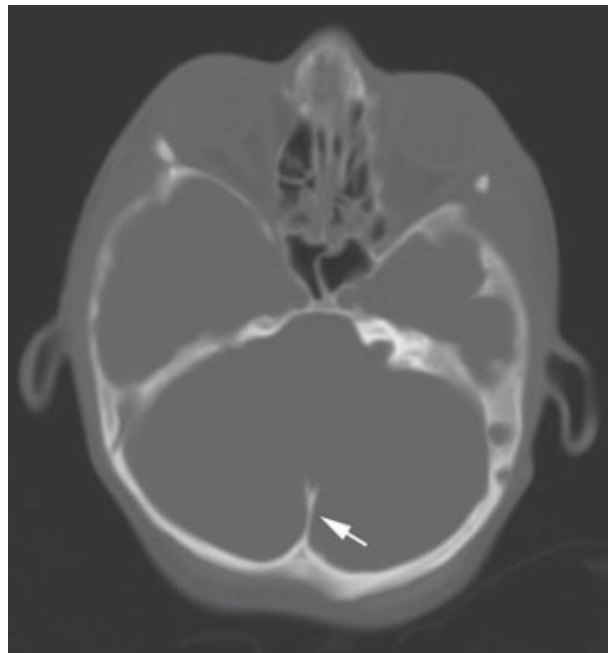
FIG 3 • A. The patient's face and forehead are protected with foam padding to avoid any pressure on the globes. **B.** The neck is supported in a neutral position with the head level with the heart in order to minimize the risk of venous air embolism.

TECHNIQUES

■ Osteotomy

- Unlike standard cranial vault remodeling, with PCVD, the posterior cranial bone is not dissected from the dura.
- A circumferential full-thickness osteotomy is marked from the anterior fontanelle inferiorly across the squamosal suture to the temporal bone, posteriorly just above the petrous ridge, along the inferior occipital bone just above the neck muscles and then returning to the anterior fontanelle on the contralateral side with a symmetrical pattern.
- The lower the osteotomy on the occiput, the more volume expansion and posterior fossa decompression will be obtained.

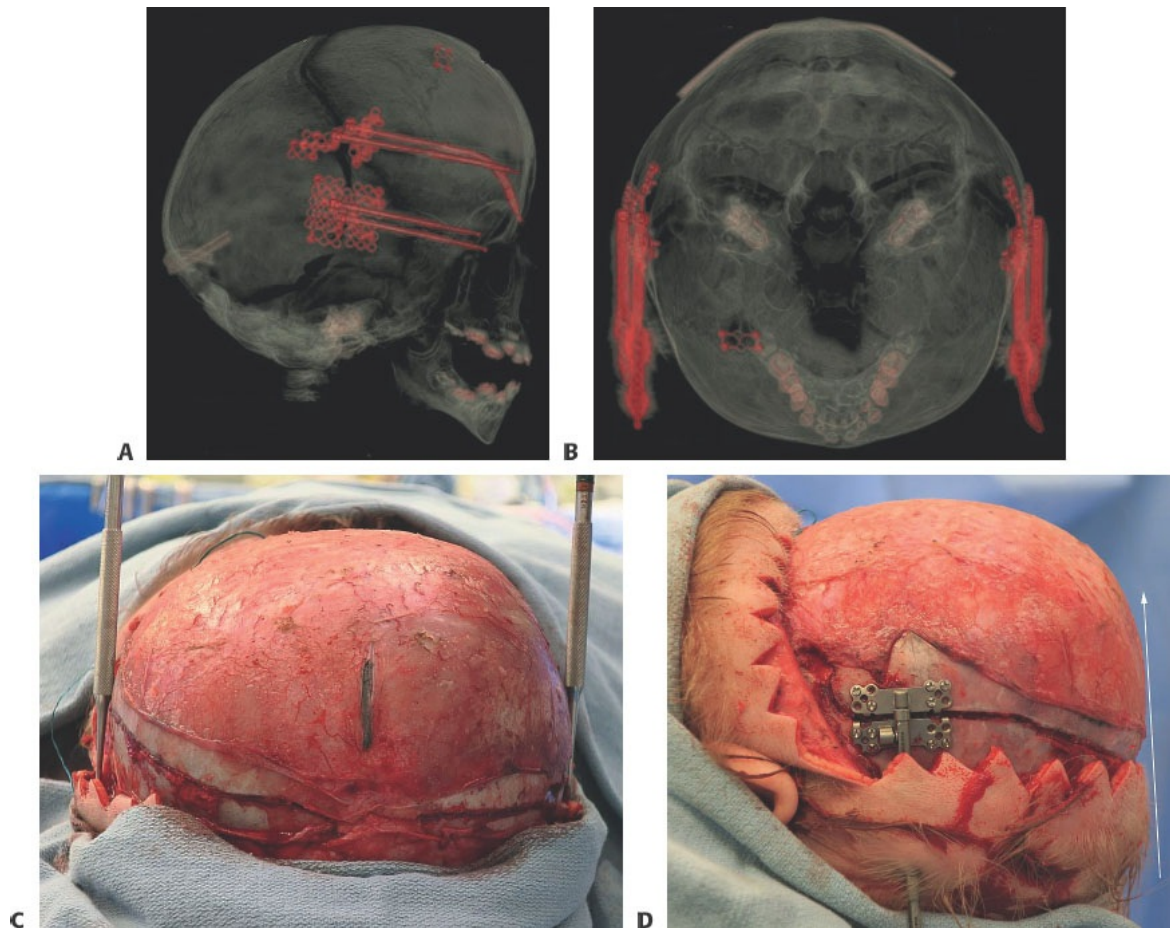
- Care must be taken to identify the venous sinuses through preoperative CT or MRI scanning.
- The osteotomy crosses the transverse sinuses lateral in the region of the petrous ridges.
- The posterior osteotomy should be inferior to the torcula but superior to the skull base. One of the major benefits of PCVD is that the occipital bone does not need to be dissected off the torcula, minimizing risk of exsanguination.
- There is often a keel or invaginated bone at the midline of the posterior osteotomy at the level of the skull base that may require careful rongeur use or drilling to remove (**TECH FIG 1**).



TECH FIG 1 • The inferior portion of the circumferential osteotomy for posterior vault distraction should go as close to the skull base as possible. This will achieve maximum volume expansion and place the osteotomy below the torcula of the sinuses. In many syndromic patients, there is a midline bone invagination at the junction of the skull base (*arrow*) that needs to be carefully dissected to avoid violation of the dura.

■ Device Placement

- The most stable bone in infant patients with syndromic synostosis is typically in the region of the temporal bone below the squamosal suture or in the parietal bone just above the suture.
- Paired, symmetric devices are placed across the osteotomy along the region of stable bone with parallel vectors when viewed from both the side and the top (**TECH FIG 2A,B**).
- The activation arms can extend either anteriorly or posteriorly depending on surgeon preference.
- Three 3- or 4-mm screws are placed in each footplate of the distraction device with protection of the underlying dura.
- The undersurface of the footplate bone is checked for any protruding screw points that can be removed with a rongeur if prominent.
- The paired temporal devices are then activated approximately 5 mm.
- If the osteotomy across the top of the cranium is opening symmetrically, no further devices are required and the devices are deactivated.
- If the superior osteotomy does not open symmetrically with the temporal osteotomy on device activation, additional devices can be applied more superiorly for symmetric activation and to decrease the likelihood of device strain and footplate loosening.
- The majority of cases can be managed with one device pair if the bone is sufficiently rigid.
- On vertex view, the vector of the devices is parallel and tangential to the osteotomy (**TECH FIG 2C**).
- On lateral view, the vector is tangential to the vertex osteotomy to avoid a step deformity with activation (**TECH FIG 2D**).



TECH FIG 2 • Transparent CT scan images of a patient immediately after circumferential osteotomy and placement of distraction devices. **A.** On the lateral view, the devices (in red) are seen parallel to each other and the vector is planned to avoid a step-off deformity as the vertex osteotomy is opened. **B.** Seen on the vertex view, a second pair of devices was needed in this patient to achieve even opening of the osteotomy. All four devices are parallel to the tangent of the widest part of the skull where the osteotomy is located. **C.** Intraoperative vertex view. Straight elevators can be placed against the parietal bone of the patient to ensure parallel positioning. The lateral osteotomy is then planned at the tangent of where the elevators touch the bone. **D.** Intraoperative lateral

view. The devices are placed at a vector parallel to the tangent of the vertex of the skull (*arrow*).

■ Scalp Closure

- The activation arms of the devices are passed through separate small incisions of the scalp (**TECH FIG 3**).
- The coronal incision is closed with galeal resorbable sutures and resorbable skin sutures.
- A percutaneous drain can be placed under the flap but is often not required.



TECH FIG 3 • The extension arms of the distraction arms exit percutaneously away from the coronal incision. They can exit either anterior or posterior depending on the patient. Posterior exit was chosen for this patient to avoid the non-hair-bearing forehead. The extension arms can be detached in the clinic once the activation is complete so that no percutaneous wounds exist during the consolidation period.

PEARLS AND PITFALLS

Timing

- Timing of PVDO should include a consideration of early intervention to optimize defect healing balanced with the thicker bone present at later surgery, which optimizes device stability.
- The typical age for PVDO is 6–9 months, which allows sufficient time for healing before the need for frontal surgery.

Technique

- Accurate identification of the torcula and lateral venous sinuses is essential to plan a safe osteotomy. In some syndromes like Pfeiffer syndrome, the torcula can be inferiorly displaced and in the line of the osteotomy.
- A piezoelectric saw can improve safety of performing the osteotomy due to its integrated irrigation and decreased risk of dura violation. Thermal injury to the dura and/or bone edges should be avoided when using high-speed drills.
- Prior to planning the osteotomy, a straight elevator in line with the desired vector can be used to identify the tangent to the bone (see **TECH FIG 2D**). The osteotomy is then placed at this tangential point to ensure parallel vectors.
- The scalp incision for the exiting activation arms should be far enough away from the osteotomy to ensure the device is fully buried after activation and removal of the activation arms. It needs to be posterior enough that the tenting of the skin by the activation arms does not cause skin injury.
- A red rubber catheter attached over the activation arm tip can be used to pass the arms through the percutaneous scalp incisions. Linear traction on these rubber catheters can then be used to ensure that the vectors of all devices are parallel.
- Some authors have recommended placing acellularized dermis or other padding on the intracranial surface underneath the device footplates to prevent dura tearing. This author has not observed this complication but recognizes the importance of ensuring no damage to the dura during the surgery. If there are protruding screw tips touching the dura, they can be removed using a rongeur.

Postoperative care

- Although postoperative imaging (radiograph or CT scan) can be valuable, in many cases, it is not necessary. Patients with shunts in place do benefit from imaging (ultrasound or CT scan) during large activations to ensure continued functioning of the shunt.
- If the devices are removed separately, and not at the time of a

frontal surgery, this can be done through small sagittal incisions over the footplates to minimize blood loss and dissection of the healing osteotomy gap compared to reopening the coronal scar.

POSTOPERATIVE CARE

- PCVD requires less bone dissection, less operative time, and less fluid shift than does traditional cranial bone removal and remodeling.
- In other types of distraction osteogenesis, the bone generated at the opening osteotomy is from formation of a unique undifferentiated generated tissue from the cross-sectional area of the opposing bone surfaces at the osteotomy site.
 - In PVDO, it is not clear whether distracted generate tissue forms, or whether the defect healing is from the osteogenic potential of the underlying immature dura. Because of this possibility, intact and healthy dura is important at the site of the osteotomy in PVDO.
- We typically start device activation the day after operation, but activation can be delayed 3 to 5 days based on surgeon preference.
- The rate of device activation ranges from 1 to 2 mm a day based on bone thickness and patient age.
- Patient caregivers should be educated and observed regarding appropriate and symmetric device activation.
- A typical length of distraction is 15 to 30 mm based on preoperative planning and patient cranial volume needs.
- Once the activation is complete, the percutaneous activation arms are removed and consolidation is begun.
- A typical consolidation period in an infant is 6 to 10 weeks before device removal. After 10 weeks, the devices can become encased in bone, complicating their removal.
- The devices can be removed either as a separate operation or at the time of subsequent frontal surgery depending on timing.

COMPLICATIONS

- Intraoperative complications such as VAE, sinus bleeding, or CSF leakage are shared with other cranial vault surgeries but minimized compared to traditional remodeling procedures due to less epidural dissection and shorter operating times.¹¹
- If the dura is violated during the intraoperative dissection, the surgeon needs to

decide whether the PVDO should be aborted or converted to an open remodeling procedure.

- PVDO can proceed in the presence of well-repaired dura tears away from the devices and areas of anticipated distraction strain.
- During activation of the devices, the dura is placed under strain and can tear if care has not been taken to avoid prominence of the mounting screws or if there is violation of the dura during the dissection.
- Cellulitis around the activation arm sites usually responds to cleaning and oral antibiotics, but persistent infection or signs of abscess formation require open procedure inspection, wound irrigation, and possible removal of the devices.¹²
- Exposure of the portions of the device during consolidation due to skin erosion does not require immediate treatment in the absence of deep space infection.
 - Closure of the erosion wounds is best achieved at the time of device removal due to improved skin laxity.
- Device dislodgement during or after activation may require operative treatment such as replacement of the device or stabilization of the achieved expansion with a resorbable plate if there is instability.

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5

Total Cranial Vault Remodeling

CHAPTER

Akira Yamada, Kenneth E. Salyer, Derek A. Bruce, and Frank R. Graewe

DEFINITION/ANATOMY

- Premature fusion of the sagittal suture restricts the transverse growth of the skull.
- The skull is longer in anteroposterior dimension and narrower in temporal and lateral width.
- Frontal and occipital bossing is characteristic, the degree of which depends on the exact location and extent of synostosis (**FIG 1**).

PATHOGENESIS

- Exact cause of primary (isolated) craniosynostosis is unknown.
- Sagittal synostosis has an approximately 2% familial or genetic predisposition.

NATURAL HISTORY

- Isolated nonsyndromic sagittal synostosis is infrequently associated with abnormal brain development. Intelligence is generally normal, but sagittal synostosis may be associated with subtle psychosocial and learning issues.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination includes assessment of suture ridging in the midline, evidence of other sutural patencies by manual palpation, overall skull and facial configuration, and an age-appropriate neurological examination.
- Although papilledema (signs of raised intracranial pressure) is rare in infants with sagittal synostosis, ophthalmologic examination, including visual acuity and the presence of diplopia, can be tested by a pediatric ophthalmologist.

IMAGING

- Plain radiographs may be used to document closure of the sagittal suture or to confirm the patency of other sutures.
 - Adjacent sutures may have compensatory widening due to elevated intracranial pressure.
- CT scan of the skull and skull base define brain and skeletal anatomy.

NONOPERATIVE MANAGEMENT

- Surgery is routinely advised as soon as the infant is physiologically capable of undergoing surgery.
- Nonoperative management is not available for this condition.

SURGICAL MANAGEMENT

Preoperative Planning

- Plain radiographs may be used to document closure of the sagittal suture or to confirm the patency of other sutures. Adjacent sutures may have compensatory widening due to elevated intracranial pressure.
- CT scan of the skull and skull base define brain and skeletal anatomy.
- 3D reconstruction of the cranium, orbit, and face is useful to use computer-aided design planning, especially for secondary cranial vault reconstruction (**FIG 2**).
- In suspected cases, MRI may be used to rule out the risk of tonsillar herniation, as in Arnold-Chiari malformation.
- The cranial vault is removed in three sections. Designing a new bandeau posterior to the coronal suture is the key point of reference for remodeling.



FIG 1 • Preoperative views: frontal (**A**), left profile (**B**),

and overhead (C).

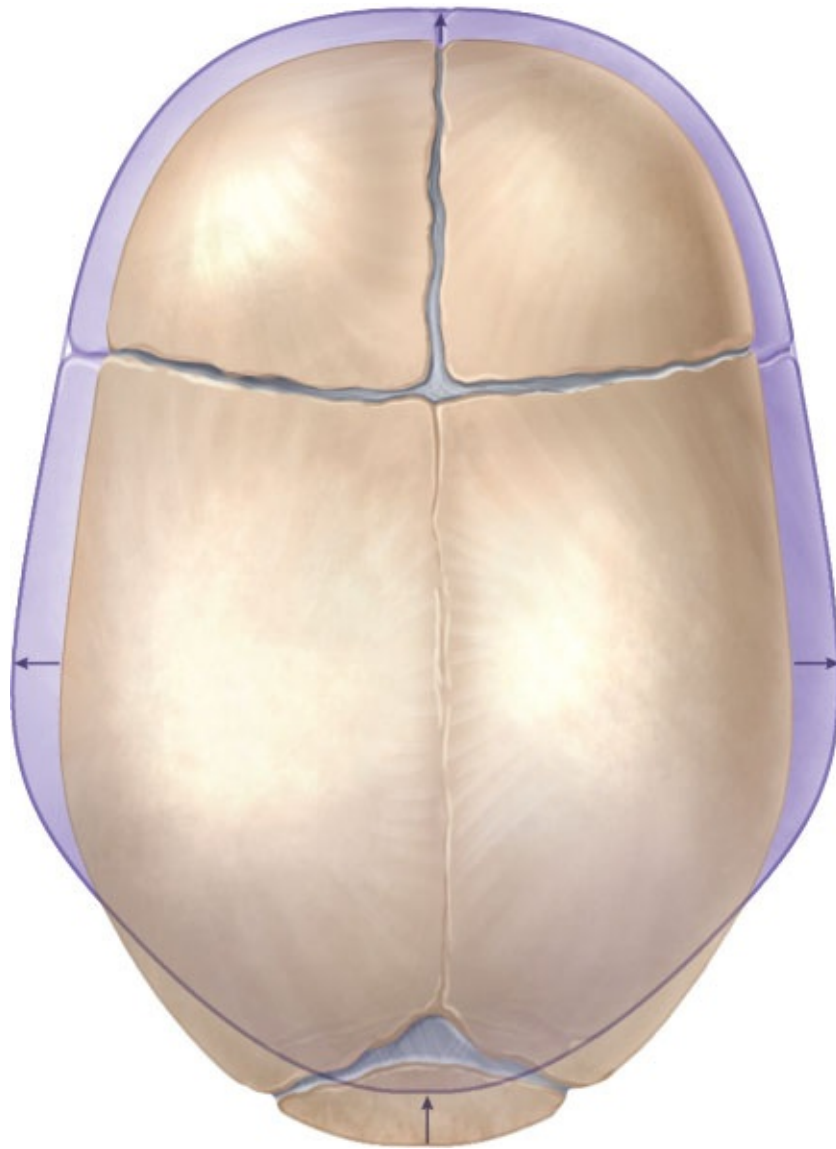


FIG 2 • Preoperative skull shape, in comparison with the goal of surgery (normalization of skull shape), as shown in *purple*. Goals are to widen at the posterior side, shorten in anteroposterior dimension, smooth the forehead, and make the occipital bone round.

- Access to the brain is planned using a bifrontal craniotomy, with expanding and widening of the forehead using the new bandeau and shortening of the anteroposterior dimension of the head.

Positioning

- The authors use a supine position for total cranial vault remodeling.
- Other centers use a modified prone position for total cranial vault remodeling.

Approach

- If the child presents at an age of less than 3 to 5 months, there are three options for treatment:
 - Endoscopic strip craniotomy with helmet therapy
 - Extended suture craniotomies with or without dynamic reduction of the abnormally long anteroposterior axis with parietal and occipital extensions
 - Total cranial vault remodeling¹
- Simple strip craniotomies with no further remodeling may result in suture refusion with persistence of an abnormally shaped head.
- If the child presents at 1 year or older in age, neither simple strip craniotomies nor extended suture craniotomies are appropriate:
 - Total cranial vault remodeling² is the first and only choice for treatment.
 - In this age group, the bone is generally much less malleable than in the child less than 1 year old, and bone remodeling techniques are adapted to the more brittle nature and handling characteristics.

TECHNIQUES

■ Exposure

- A zigzag skin incision is marked prior to preparation (**TECH FIG 1**).
- The initial incision is made with the Colorado needle and continued laterally on both sides simultaneously.
- The scalp is raised above the periosteal, and under the galeal, plane.
- The scalp dissection initially proceeds anteriorly first in the same subgaleal/supraperiosteal plane, until 2 cm above the supraorbital rim.
- A subperiosteal dissection is then initiated to identify the supraorbital nerves bilaterally, which are released from the bony canal using a small osteotome bilaterally.
- Malleable retractors protect the globe.
- Further subgaleal/supraperiosteal skin flap dissection is performed in the

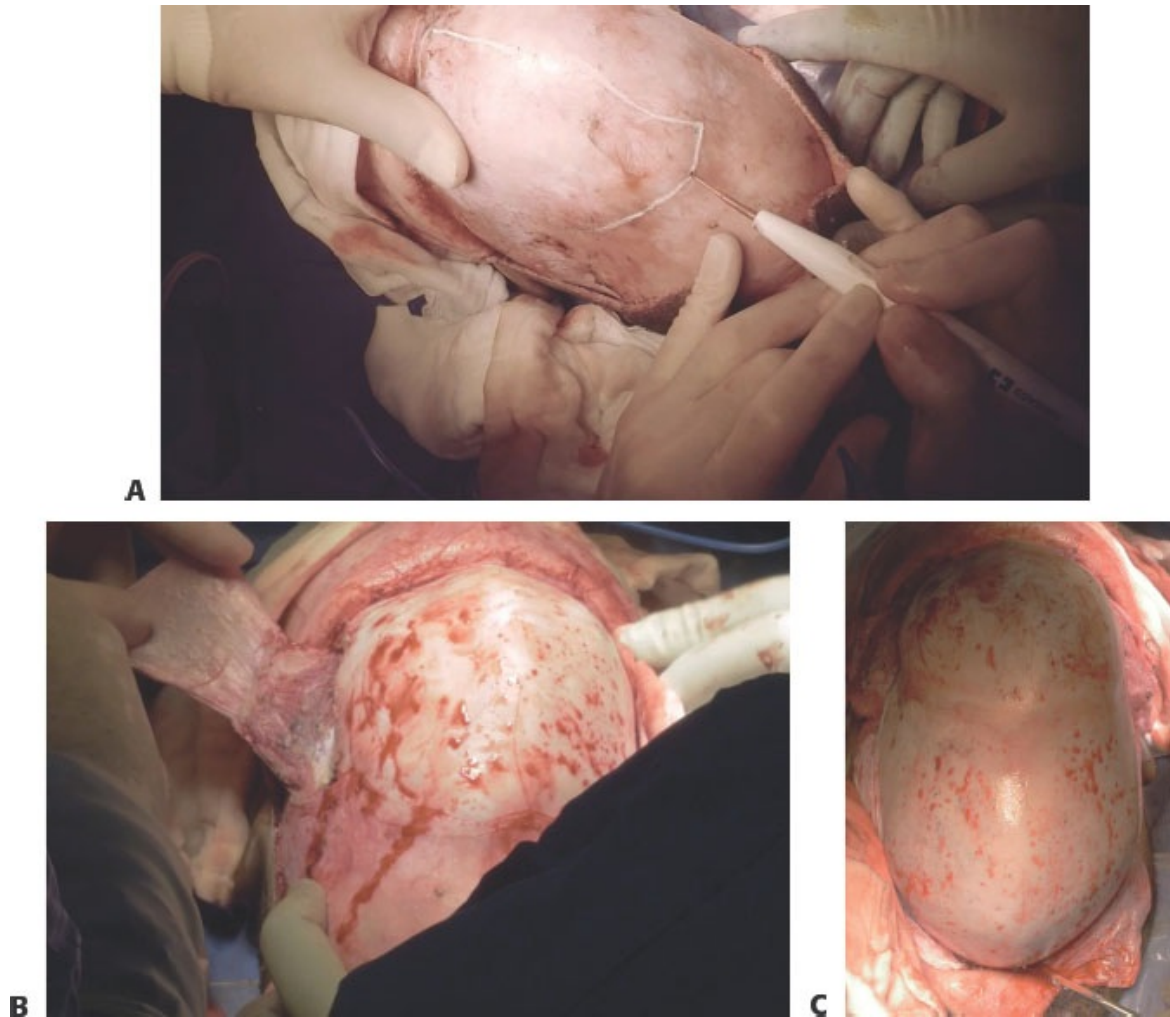
occipital region.



TECH FIG 1 • The child is placed in a supine position, and the skin is marked for a zigzag incision.

■ Pericranial Flap Dissection

- Four periosteal flaps are designed (**TECH FIG 2A**).
 - Anteriorly two periosteal flaps are based on the left and right temporal muscle.
 - The posterior two periosteal flaps are designed based on the occipital muscle (**TEC FIG 2B**).
- A Colorado needle facilitates the design of periosteal flaps. These flaps are raised with periosteal elevators and wet sponges.
- Bleeding from bone is controlled using bone wax.
- Skull exposure is finished after the completion of the pericranial flaps (**TECH FIG 2C**).



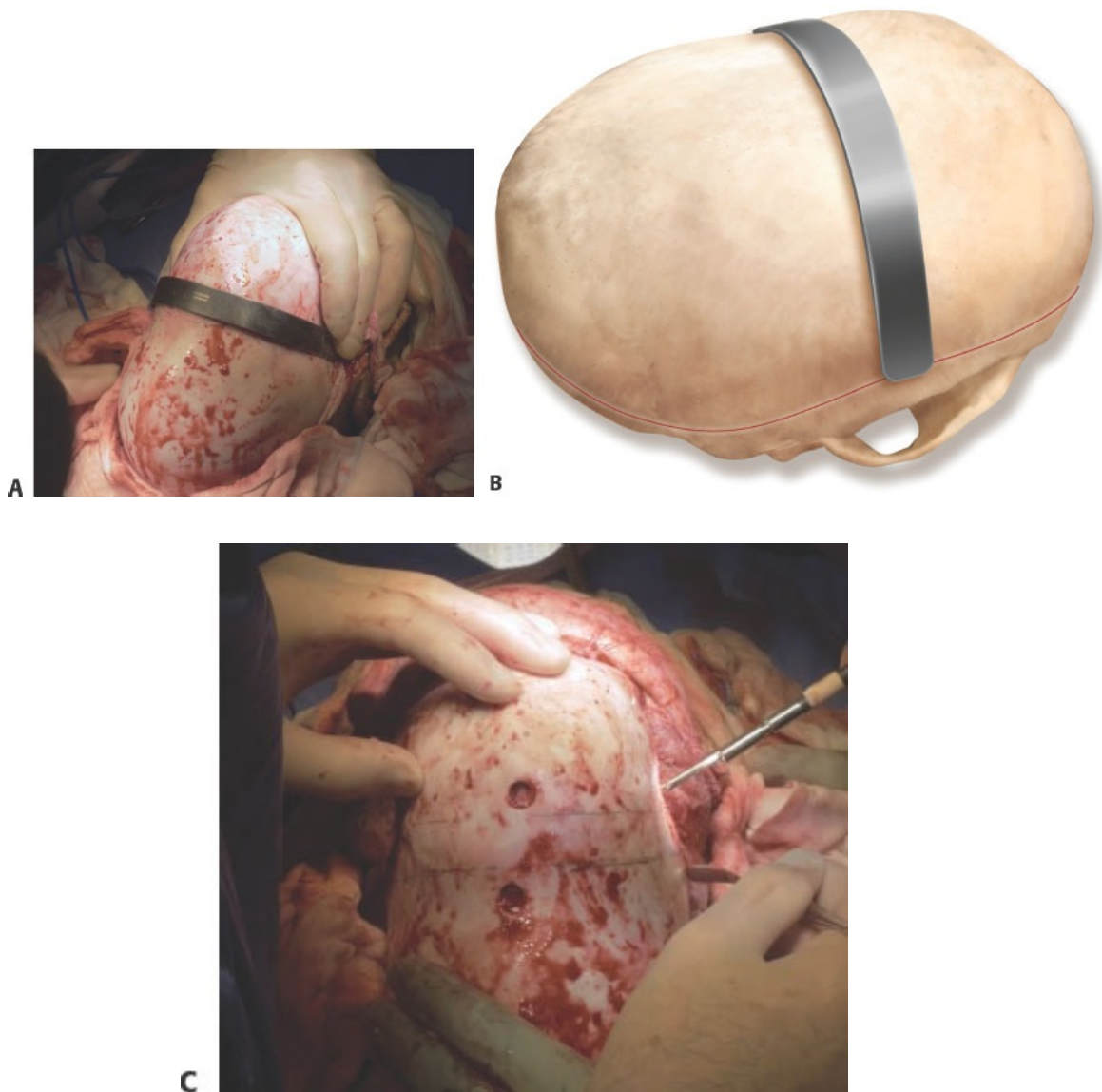
TECH FIG 2 • **A.** Design of anterior-based pericranial flap. **B.** Anterior pericranial flap is raised based on temporal muscle. **C.** The view of exposed skull, prior to total cranial vault remodeling.

■ Planning the New Bandeau and Removing the Forehead

- The new bandeau is marked with a pencil, using a malleable retractor, posterior to the coronal suture where the bone has the best contour and width for a more ideal forehead (**TECH FIG 3A,B**):
 - The initial bur hole is made in the midline, posterior to the new bandeau.
 - The second bur hole is made in the midline, anterior to the new bandeau

(TECH FIG 3C).

- Bone dust is collected for later use.
- The dura is entirely freed from overlying bone that will be removed.
- A craniotome is used to cut the bandeau.
- The bandeau is removed, and hemostasis is obtained.
- The forehead is marked with a pencil and cut, after the dura is completely freed from the overlying forehead.
- The forehead is freed and removed.
- Hemostasis is achieved.

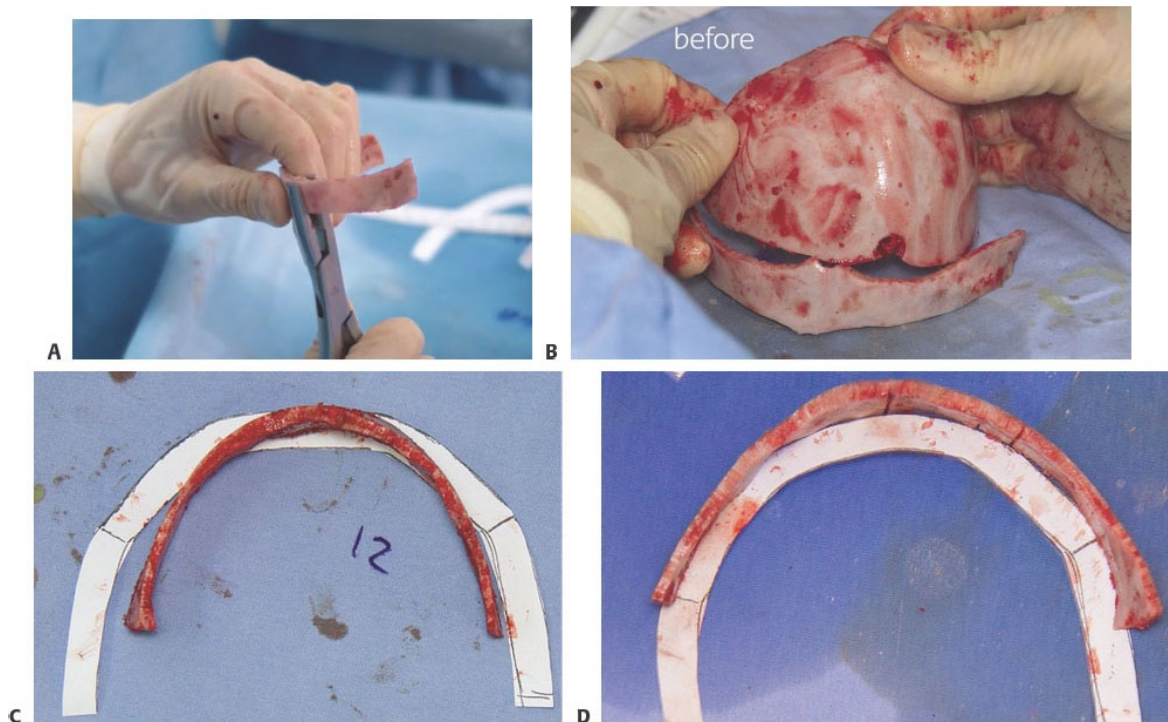


TECH FIG 3 • A. The new bandeau is designed,

posterior to coronal suture. **B.** Diagram to show the location of harvesting new bandeau. **C.** Two bur holes are placed in the midline, anterior and posterior to the marked new bandeau.

■ New Bandeau and Forehead Bone Remodeling

- On the back table, multiple partial-thickness cuts are made on the inner surface of the new bandeau, using a reciprocating saw.
- A Tessier bone bender is then used to change the arc of the bandeau for correcting the contracted, narrow forehead (**TECH FIG 4A**).
- A preoperative forehead pattern is used to assess the shape of the new bandeau.
- The removed forehead is narrow and contracted in comparison to the new bandeau (**TECH FIG 4B**):
 - Multiple radial cuts are made to allow for expansion.
- A Tessier bone bender is then used to change the arc of the bandeau to match the planned curve of the new bandeau (**TECH FIG 4C-E**).





TECH FIG 4 • A. Tessier bone bender is used to change the arc of bandeau. **B.** The original forehead is narrow, and contracted, compared with the expanded bandeau. The comparison between **(C)** a preremodeled bandeau and **(D)** a postremodeled bandeau. **E.** The view of expanded forehead and new bandeau.

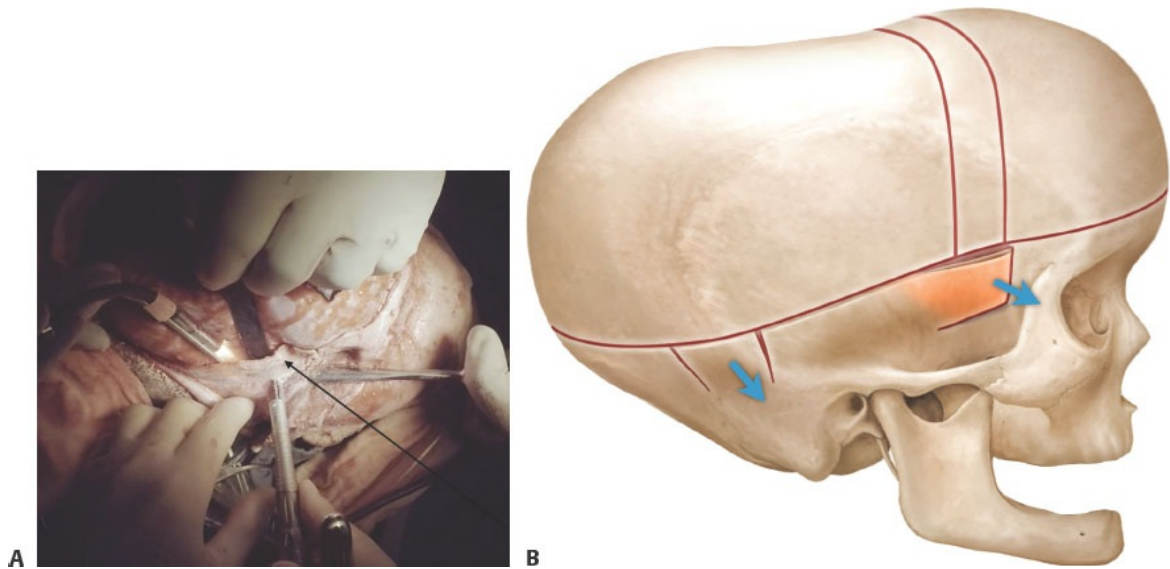
■ Removing and Remodeling the Occipital Bone

- The occipital bone is dissected from the underlying dura.
- A bur hole is made in the posterior midline of the occipital bone just above the lateral sinus.
- The occipital bone is cut with a craniotome and removed.
- Hemostasis is achieved with bipolar cautery.
- On the back table, multiple cuts are made in the bone and then remodeled.
 - A Tessier bone bender is used to change the arc of the bone, to expand it in a transverse dimension, changing the radius of the curve.

■ Expanding the Skull Base

- Attention is turned anteriorly, where the old bandeau is removed.

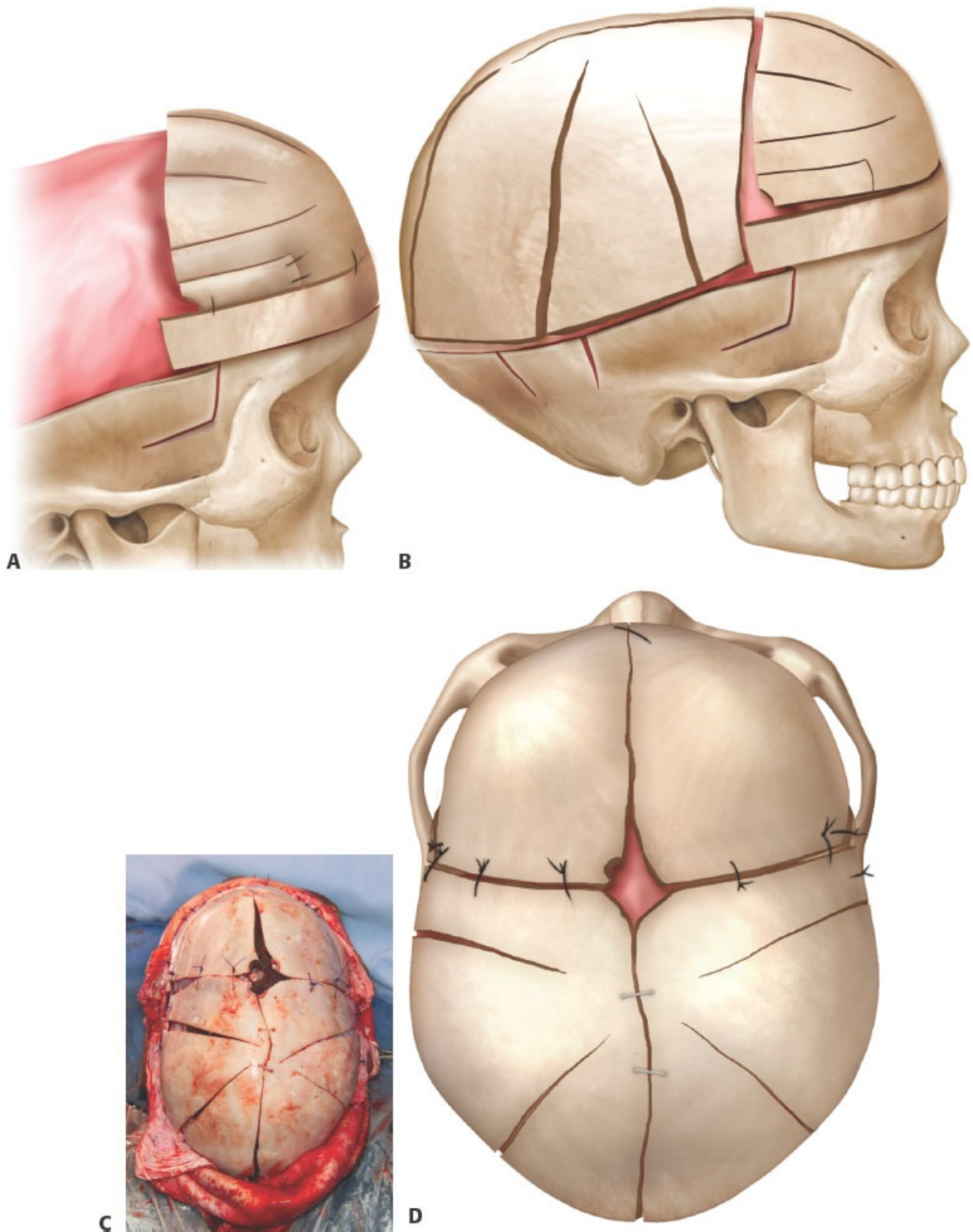
- The skull base is then widened by creating bone flaps.
- A bone flap is created on both sides in the temporoparietal region.
- The bone flaps are posteriorly based and expanded laterally to match the expanded forehead (**TECH FIG 5**).



TECH FIG 5 • The skull base is widened by creating bone flaps. **A.** A bone flap is created on both sides in the temporoparietal region. **B.** The bone flaps are posteriorly based and expanded laterally to match the expanded forehead.

■ Replacing the New Bandeau, Remodeled Forehead, and Occipital Bone

- The new bandeau and forehead are secured in place with multiple 2-0 PDS sutures (**TECH FIG 6A**).
- The skin is draped to assess the forehead shape.
- Posteriorly, the new remodeled occipital bone has been shortened and widened and is fixed in place (**TECH FIG 6B**), creating parietal eminences.
- Multiple 2-0 PDS sutures are used to secure the occipital bone (**TECH FIG 6C,D**).



TECH FIG 6 • **A.** The new bandeau and remodeled forehead are placed back in the remodeled skull. **B.** Posteriorly, the new remodeled occipital bone has been shortened and widened and is fixed in place. **C.**

The view of the remodeled total cranial vault. **D.**
Schematic presentation of totally remodeled skull.

■ Closure

- Pericranial flaps are secured over the bone with 4-0 Vicryl.
- After copious irrigation of the wound with saline, bone dust covered by Surgicel is used to fill the bony gaps.
- The skin incision is closed in two layers.

PEARLS AND PITFALLS

Hemostasis	■ The scalp flap is dissected with a micropoint needle to reduce blood loss. Using a low setting minimizes damage to tissues (both coagulation and cutting less than 10).
Fixation materials	■ Although older children may need resorbable plates and screws, 2-0 PDS and occasional wire fixation reduces surgical duration and provides adequate stability of the skull.
Team approach	■ When the neurosurgeon and craniofacial surgeon work together during the perioperative planning and care, outcomes are improved.

POSTOPERATIVE CARE

- Pediatric intensive care unit (PICU) for first night
- Head of the bed to 30 degrees; parents may hold the child when cleared by PICU staff
- O₂: FiO₂ 40% via face shield for O₂ saturations less than 93%
- Labs: complete blood count (CBC)/basic metabolic panel (BMP) at 6 PM, midnight, and 6 AM unless patient needs change
- Hemoglobin greater than 6.5 no concerns (evaluate clinically), less than 6.5 evaluate clinically, consider a repeat CBC
- Decadron is used only if airway issues are raised by anesthesia or the PICU team: up to four doses in 24 hours.
- Incision care: Cleanse with ½ strength peroxide twice daily, and then apply a

thin ribbon of bacitracin ointment twice daily.

■ Medications:

- Antibiotics: Ancef 30 mg/kg/dose IV; give two doses postop 8 hours apart starting 8 hours from the last intraoperative dose.
- Intravenous fluids: D5LR at maintenance rate, may saline lock when tolerating adequate PO per oral intake.
- Acetaminophen: 12.5 mg/kg IV dose q6h.
- Ketorolac/ibuprofen combo panel: ketorolac 0.25 mg/kg IV q6h exact “or” ibuprofen 10 mg/kg PO q6h (ibuprofen up to 400 mg max. dose). Try to stagger acetaminophen and ketorolac/ibuprofen every 3 hours.
- Ativan: 0.05 mg/kg IV up to a maximum of 0.5 mg per dose q6h prn for pain/anxiety, if no dexmedetomidine being used
- Precedex: 0.1-0.5 mcg/kg/h IV infusion, titrate to an appropriate level of consciousness, DC at 0600 hours on POD#1. Generally started at 0.5 and titrated the dose down. Keep the child arousable and not heavily sedated. The dose only goes above 0.5 if the child is significantly fussy.
- Zofran: 0.15 mg/kg up to a maximum of 4 mg IV q8h prn. May add Phenergan as needed 12.5 mg/kg IV

OUTCOMES

- Three-dimensional head shape is improved. The elongated A-P dimension of the skull is shortened. The pointed forehead and occiput become more rounded. The width of the head is increased (**FIG 3**).

COMPLICATIONS

- Perioperative airway complications
- Hypovolemic shock
- Dural tear, postoperative cerebral spinal fluid (CSF) leak
- Postoperative bleeding (epidural, subdural hematoma)
- Wound infection
- In the most severe case, any of the above can lead to death.
- Irregular head shape
- Incomplete bone healing (bone defect), especially for older children
- Recurrent deformities



FIG 3 • Six months postoperative views: frontal **(A)**, profile **(B)**, and overhead **(C)**.

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6 Spring-Assisted Surgery for Sagittal Synostosis

CHAPTER

Lisa R. David and Claire Sanger Dillingham

DEFINITION

- Craniosynostosis is the premature fusion of one or more cranial sutures (**FIG 1**).
- Sagittal synostosis is the premature fusion of the sagittal suture, which leads to a long narrow-shaped head with frontal and occipital bossing due to the restriction in lateral growth as predicted by Virchow law.¹
- It is the most common form of craniosynostosis accounting for 55% of cases and is called scaphocephaly.²

ANATOMY

- The skull is made up of bones that abut at sutures that allow growth of the underlying brain.
- The primary sutures in an infant skull are the sagittal, coronal, metopic, lambdoid, and squamosal.
- The sagittal suture is a dense, fibrous connective tissue joint that lies between the two parietal bones of the skull.
- The bregma is the intersection between the sagittal and coronal sutures often referred to as the anterior fontanelle at birth.
- The posterior portion of the sagittal suture ends at the intersection of the lambdoid sutures.
- The point between these two is the vertex of the skull and is often the highest point on the skull.

PATHOGENESIS

- Most craniosynostosis cases are not associated with a syndrome, although over

100 syndromes have been connected to this condition.³

- Single-suture sagittal synostosis is the most prevalent type of craniosynostosis with an incidence of 1 in 5000 births.⁴
- There is a higher observed incidence in boys compared to girls with a 4:1 ratio, respectively.⁵
- Genetic mutations in the cell surface receptor fibroblast growth factor receptor (FGFR) 1 to 3 have been linked to the development of nonsyndromic craniosynostosis and syndromic cases such as Apert, Pfeiffer, Jackson-Weiss, Crouzon, and Muenke.⁶
- Mutations identified in the targets TWIST1, bone morphogenetic proteins (BMPs), and RUNX2 have been linked to craniosynostosis.

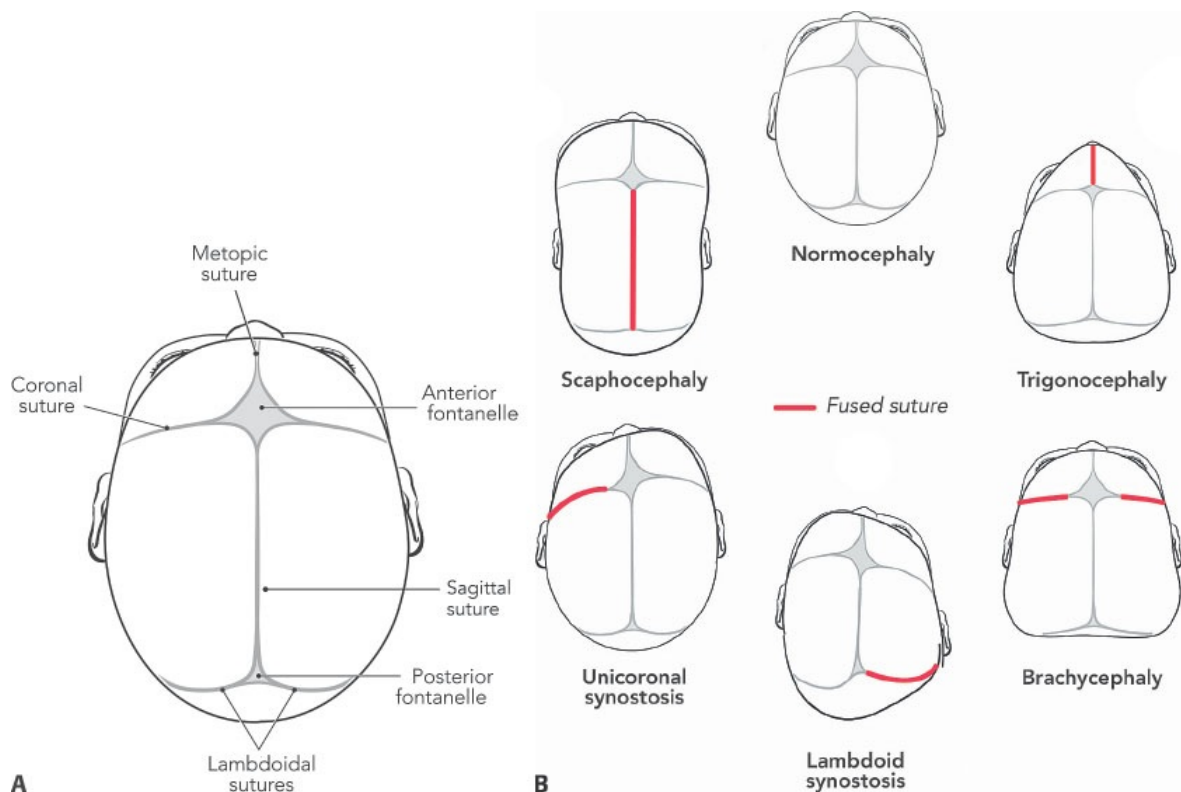


FIG 1 • A. Cranial sutures. B. Most common types of craniosynostosis and their associated shape change.
(© WFBHS Plastic Surgery Collection.)

- Transforming growth factor β (TGF β) mutations have been involved in suture fusion but have not yet been linked to a syndrome.

- Most craniosynostosis syndromes have an autosomal dominant inheritance.

NATURAL HISTORY

- The time period of the most rapid brain growth in healthy humans is from the third trimester of pregnancy to the first year of life.
 - The average cranial capacity at birth is 350 cm⁴ and triples by 9 months of age.
- In the absence of pathology, such as craniofacial malformations or malnutrition, the head circumference relates directly to the brain size, protein and DNA content, and the number of neurons.
- Most cranial sutures remain open until several years of age with the exception being the metopic suture that can close as early as 1 year.
- Most commonly, the sagittal suture begins to close from the posterior to anterior direction in the late second decade of life with complete closure seen at 35 years of age.
- Sagittal synostosis can be detected as early as the 16th week of gestation by magnetic resonance imaging (MRI) and sonography.⁷
- Sagittal synostosis is most commonly diagnosed in the first year of life.
- Patients with sagittal synostosis are typically referred to the craniofacial surgeon after the pediatrician observes one or more of the following: the narrow and elongated head shape or frontal and occipital bossing, or the parents have expressed concern regarding the skull shape.
- The incidence of elevated intracranial pressure (ICP) is low in patients with single-suture fusion; however, it is possible and should be considered.
- Neurocognitive deficits are linked to craniosynostosis especially with multiple suture involvement.
- Treatment aims to restore the calvarial shape, reduce ICP if needed, enhance development, and improve the appearance.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical exam can provide information that leads to a diagnosis of associated conditions and avoids errors in failure to address significant concerns prior to surgery.
- Perinatal history
 - Gestational age (this shape can be seen in prematurity without synostosis)
 - Age of parents
 - History of previous maternal miscarriages

- Multiple births such as twins or triplets
- Any perinatal distress
- C-section vs natural vaginal delivery or assisted delivery with a device
- Time spent in the ICU, intubated, or immobilized
- Feeding history and if any intolerance is noted
- Family history
 - Family members with any craniofacial anomalies or syndromes
 - Siblings of an affected child have double the estimated risk than the general population.
- Physical examination
 - The cephalic circumference and index are measured and documented as they will be followed postoperatively.
 - Documentation should include intraocular distance, any signs of exorbitism, airway compromise, midface hypoplasia, or limb anomalies.
 - Evaluation for cleft lip or palate
- An ophthalmology evaluation documenting the presence of increased ICP leading to optic nerve swelling, which results in papilledema
- Consultation with a geneticist is warranted.

IMAGING

- A computed tomographic (CT) scan provides valuable information as well as documentation of the condition (**FIG 2**).
 - It may also reveal additional pathologies that would have otherwise been hidden.
- An MRI is not part of the standard imaging assessment in single-suture craniosynostosis but may be indicated if there is evidence of increased ICP.
 - The presence of agenesis of the corpus callosum or ventriculomegaly should prompt further evaluation.
- A portable laser 3D scanning device is utilized at our institution and, if available, provides the team and family an objective analysis of cephalometric measurements, including cranial index (CI), 3D shape, and cranial volume calculated using Delta Scan Comparison software.

DIFFERENTIAL DIAGNOSIS

- Single-suture craniosynostosis
- Multiple suture craniosynostosis
- Scaphocephalic head shape with no synostosis seen with significant

prematurity

- Positional plagiocephaly
- Secondary craniosynostosis due to shunted hydrocephalus, lack of brain push, or trauma



FIG 2 • 3D CT scan showing fusion of the sagittal suture. (© WFBHS Plastic Surgery Collection.)

NONOPERATIVE MANAGEMENT

- Nonoperative treatment of craniosynostosis is not recommended.
- If there is a more serious life-threatening diagnosis, surgery for craniosynostosis should be delayed or undertaken with complete risks and benefits discussed with the family.

SURGICAL MANAGEMENT

- Operative intervention for craniosynostosis is widely accepted and is the standard of care for these conditions.
- The indication for surgical intervention for sagittal suture synostosis is full fusion of the suture or partial fusion with skull dysmorphology or increased ICP.

- The ideal age for spring-assisted surgical correction is between 3 and 7 months of age.
- This provides enough bone stock to handle the strength of the spring and a strong enough spring force to expand the skull bones.
- This age range also allows for native bone regeneration and correction of further skull growth.
- Risks to the patient include a scar on the scalp, bleeding, infection, spring dislodgement, cranial asymmetry, and need for further surgery.

Preoperative Planning

- Preoperative evaluation should include a 3D CT scan of the skull to confirm the diagnosis of isolated sagittal craniosynostosis and rule out additional intracranial anomalies such as a Chiari malformation.
- The CT also aids in operative planning for the selection of the spring strength and placement.

Positioning

- The airway is secured, and ophthalmic ointment is placed in the eyes and secured with tape to keep the eyes closed and protected.



FIG 3 • Sphinx positioning with appropriate padding. (© WFBHS Plastic Surgery Collection.)

- For the open and endoscopic approach, the patient is positioned prone on a beanbag in the sphinx position (**FIG 3**).
- Padding around the ears and shoulders is used to prevent pressure points.

Approach

- Standard ASA monitors should be used with inhalation induction followed by endotracheal intubation and placement of mechanical ventilation.
- Intravenous (IV) access with two lines is advised.
- IV fluid, muscle relaxants, and narcotic analgesics are administered during the procedure.
- IV antibiotics are administered.
- End-tidal CO₂ is decreased to approximately 30 mm Hg to decrease ICP.
- The surgical field is prepared with Betadine scrub and paint.

TECHNIQUES

■ Open Technique

Exposure

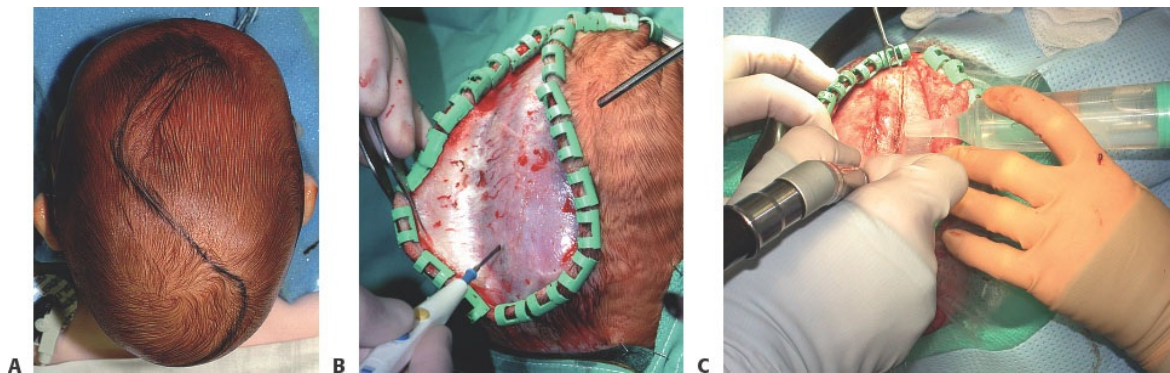
- A marker is used to draw an S-shaped longitudinal incision from the anterior to the posterior fontanelle landmarks (**TECH FIG 1A**).
- The marked incision site is infiltrated with bupivacaine 0.25% with 1:200 000 epinephrine (not to exceed 1 cc/kg) for improved intraoperative hemostasis.
- The incision is made and the sagittal suture exposed with minimal stripping of the periosteum to diminish bleeding (**TECH FIG 1B**).
- A 1-cm-wide strip craniectomy of the calvarium is performed, which should include the sagittal suture (**TECH FIG 1C**).
- Hemostasis of the bone edges is obtained as well as of the underlying dura.

Spring Placement

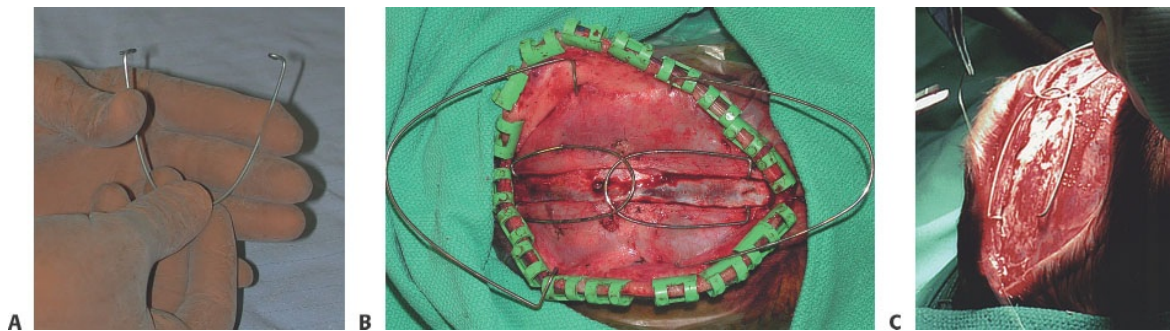
- The springs are selected based on the patient's age, bone thickness, and type of scaphocephaly.
 - Typical range is 6 to 8 Newtons for the 3 to 6 months' age group (**TECH**

FIG 2A,B).

- If significant frontal bossing is present, the child will need a stronger spring anteriorly.
- If significant elongation is present, the child will need a possible third spring.
- With postcoronal banding, the child will need a strong anterior spring.
- With significant posterior banding, the child will need a stronger posterior spring.
- The anterior spring is placed with the footplate anterior and behind the coronal sutures and the posterior spring with the footplate posterior and in front of the lambdoid sutures.



TECH FIG 1 • A. S-shaped incision used for the open technique. **B.** Sagittal suture is exposed with minimal periosteal stripping. **C.** A 1-cm strip craniectomy removing the sagittal suture is performed. (© WFBHS Plastic Surgery Collection.)



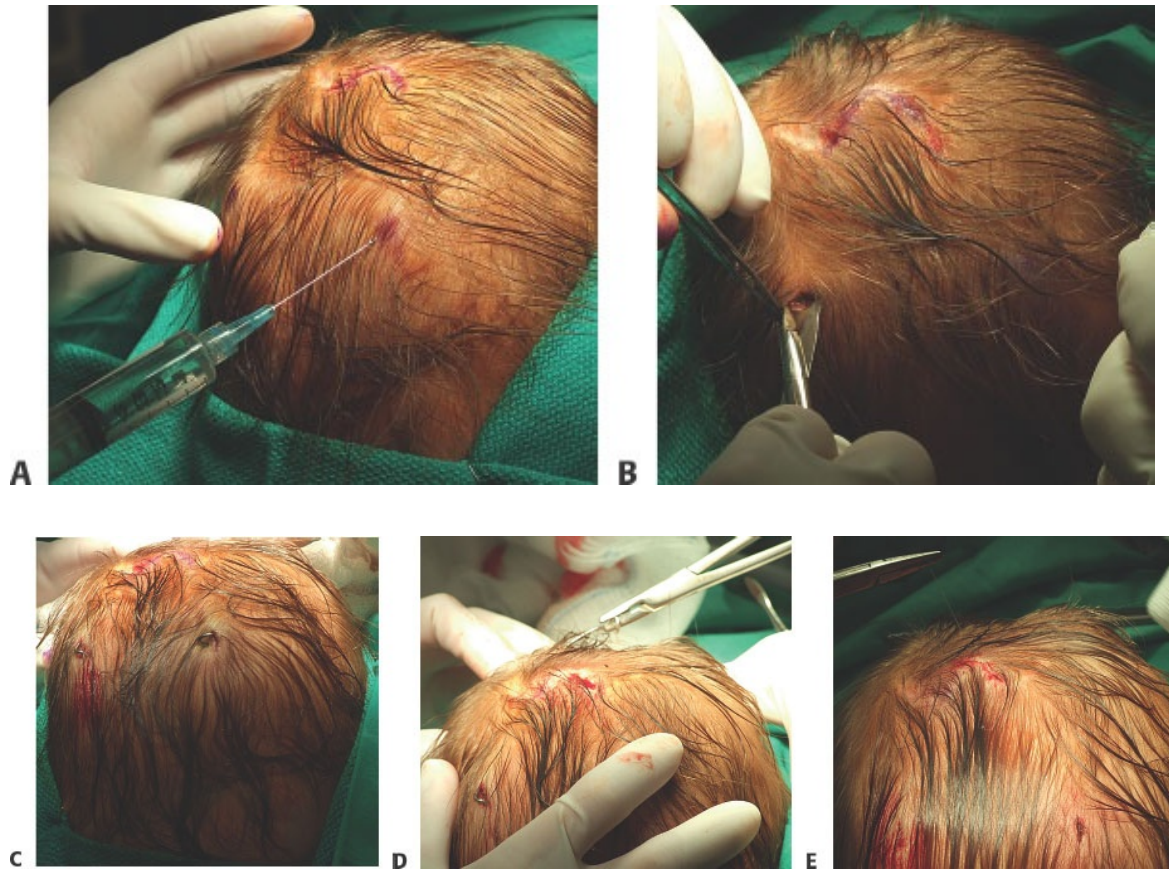
TECH FIG 2 • A,B. Springs are selected and placed in the calvarial defect. **C.** Springs are secured at point of

overlap using a Vicryl suture. (© WFBHS Plastic Surgery Collection.)

- An absorbable suture is placed around the two springs where they overlap in the midline to prevent rotation or shifting (**TECH FIG 2C**).
- Custom bending can be done to reduce the prominence of the spring but should be done minimally.
 - Every adjustment can change the force of the spring and so should be limited.
- The scalp is closed in two layers with absorbable, buried sutures.
- A drain is not necessary. The blood loss is negligible and transfusions have not been needed.

Spring Removal

- Once the skull defect has reossified, the spring can be removed. This is typically 4 to 5 months after the first procedure.
- This is an outpatient procedure.
- The patient is positioned as in the first case using a beanbag and in the sphinx position.
- Local anesthetic is injected over each of the footplates and in the midline incision where the springs overlap (**TECH FIG 3A**).
- Small incisions are made over each of the footplates as well as where the springs intersect in the midline (**TECH FIG 3B**).
- The springs are cut and the segments removed through the footplate incisions (**TECH FIG 3C, D**).
- Incisions are closed with buried and interrupted absorbable sutures (**TECH FIG 3E**).
- If there were no intraoperative concerns, the patient can be discharged from the recovery room.
- Spring removal takes an average of 20 minutes of surgical time and an hour of anesthetic time.



TECH FIG 3 • **A.** Local anesthetic is injected over the four footplates and previous incision for spring removal. **B.** Small incisions are made over the footplates. **C,D** The footplates are rotated out and the spring brought through the small individual incisions. **E.** The incisions are closed with absorbable sutures. (© WFBHS Plastic Surgery Collection.)

■ Endoscopic-Assisted Technique

Incisions and Endoscope Insertion

- The patient is placed in the sphinx position with the head on a beanbag, similar to the open approach (**TECH FIG 4A**).
- The marked incision site is infiltrated with bupivacaine 0.25% with 1:200 000 epinephrine (not to exceed 1 cc/kg) before incision for improved intraoperative hemostasis.

- A 3- to 4-cm W-shaped incision is made midway between the anterior and posterior fontanelle positions. Typically, it is placed where the head starts to curve to allow good access anteriorly and posteriorly (**TECH FIG 4B**).
- A lighted retractor is used to aid in visualization of the subgaleal plane to dissect the entire distance of the sagittal suture (**TECH FIG 4C**).
- A pediatric craniotome is used to make a single bur hole just under the incision.
- Kerrison rongeurs are used to enlarge the bur hole.
- The 30-degree rigid endoscope is then inserted under the bone and directed toward the anterior fontanelle (**TECH FIG 4D**).
- The suction tip is used to keep the field clear and dissect the dura free from the overlying bone.
- The dura should be protected throughout with an insulated brain retractor, and care should be taken not to disrupt the dural attachment to the fontanelle to avoid injury to the sagittal sinus.
- Hemostasis should be achieved with the monopolar Bovie, Surgiflo, or liquid thrombin (**TECH FIG 4E**).
- A 1-cm strip of calvarium with the sagittal suture is removed by the pediatric neurosurgeon using curved Mayo scissors or bone cutters (**TECH FIG 4F**).

Spring Placement

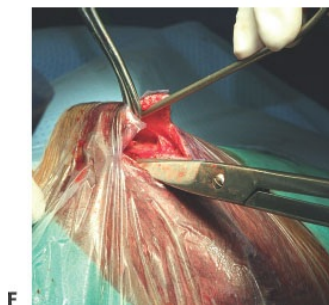
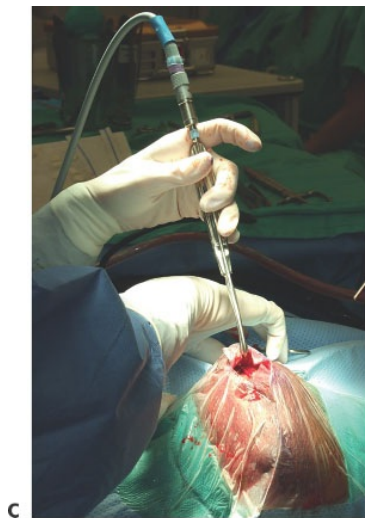
- The bone is inspected and springs are chosen based on the bone thickness, patient age, and head shape (**TECH FIG 5A**).
- Custom bending can be done to reduce the prominence of the spring but should be done minimally. Every adjustment can change the force of the spring and should be limited.
- The springs are secured where they cross with a small drill hole on each side in the bone using 4-0 Vicryl suture (**TECH FIG 5B**).
- The scalp is closed in two layers with absorbable buried sutures (**TECH FIG 5C**).
- A drain is not necessary. The blood loss is negligible, and transfusions have not been needed.
- A protective head wrap is placed for 24 hours (**TECH FIG 5D**).

Spring Removal

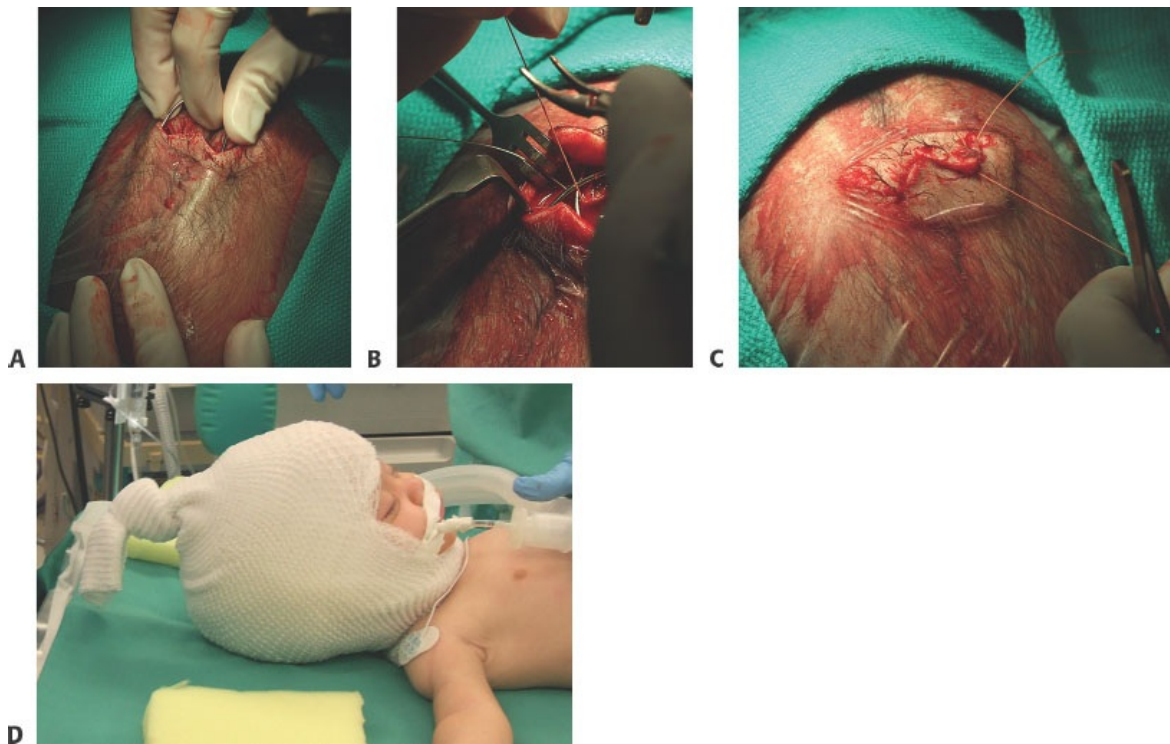
- Once the skull defect has reossified, the spring can be removed similar to the

open procedure.

- This is an outpatient procedure.
- The patient is positioned as in the open procedure.
- If there were no intraoperative concerns, the patient can be discharged from the recovery room.



TECH FIG 4 • **A.** Patient is positioned prone in the sphinx position with planned incision marked. **B.** W-shaped incision is incised with a no. 15 blade. **C.** The lighted retractor is used to visualize and give exposure of the sagittal suture. **D.** The endoscope is used to assist in freeing the dura from the overlying suture. **E.** Hemostasis is assured with use of a hemostatic agent. **F.** The suture is removed using a combination of bone scissors and rongeurs. (© WFBHS Plastic Surgery Collection.)



TECH FIG 5 • **A.** Springs are inserted through the W incision. **B.** Springs are secured to cranial bone with 4-0 Vicryl suture at overlap site. **C.** Scalp is closed in layers with absorbable suture. **D.** Protective head wrap is applied for 24 hours. (© WFBHS Plastic Surgery Collection.)

PEARLS AND PITFALLS

Hemostasis	■ Given the child's size and blood volume, careful attention to blood loss is critical. Good hemostasis must be attended for all steps of the procedure. This is optimized by giving the local anesthetic with epinephrine 7 min to work.
Spring choice	■ Spring choice is critical and clearly a part of the learning curve. If the spring is too strong, it will pull through the bone; if it is not strong enough, there will be undercorrection. Normal force range is 6–8 N.
Spring placement	■ The springs must be placed behind the coronal sutures and in front of the lambdoid sutures to get adequate expansion. The springs must be secured to the bone where they overlap to prevent spring dislodgement and rotation.
Operative approach	■ It is often best to start with the open approach and then change to the endoscopic approach once the surgeon is experienced enough to ensure adequate dissection, placement, and securing of the springs.
Helmet therapy	■ While the springs are in place, a soft helmet is used only for protection from accidental trauma. Helmets are not needed for shaping and not required once springs are removed.

POSTOPERATIVE CARE

- The patient is admitted to the general pediatric unit in our institution for overnight monitoring. The appropriate location for admission will depend on the skill set and familiarity each pediatric unit has with patients after this type of surgical procedure.
- The morning after surgery:
 - A hemoglobin level is obtained.
 - Anteroposterior (AP) and lateral skull film are obtained to assess spring placement.
 - The child is fitted with a noncompressive helmet for protection until reossification occurs (**FIG 4**).
- The child is seen by the craniofacial team at 10 days; 4, 8, and 12 weeks; and then at time of spring removal. After spring removal, the patient is seen at 10 days, 3 and 6 months, and then yearly.
- At the follow-up appointments, the cranial defect is assessed for reossification

and skull shape is assessed.

- The 3D laser scan is used to document three-dimensional changes in cranial shape and volume.

OUTCOMES

- Over 16 years of clinical outcomes in more than 200 patients with sagittal synostosis treated with spring-assisted surgery have shown successful correction of scaphocephaly with spring-assisted surgery.
- The mean initial bony gap immediately after placement is 1.5 cm.
- A final gap of 6.3 anteriorly and 6.4 cm posteriorly is the mean measure on follow-up skull films and can be expected.⁸
- Cephalometric analysis demonstrates a mean pretreatment CI of 69 and postoperative treatment of 75.4. The mean CI at 1 year is 74.8, at 3 years is 74.5, and 5 years is 76.6.
- The Delta Scan Comparison software can be used to calculate the cranial volume changes of each patient from the laser Doppler scans.
- As a result of frontal bossing seen with scaphocephaly patients, the ratios of the anterior cranial volume to the total cranial volume are expected to be higher preoperatively when compared to healthy controls. After treatment, the ratio decreases to a normal value.
- The mean age at spring placement is approximately 5 months with a mean duration of placement of 4 to 5 months and spring removal at a mean of 8 months of age.

COMPLICATIONS

- Scar revision of the scalp may be needed once cranial growth is complete. This is less likely with the endoscopic approach.
- Local skin infection may require debridement but is usually treated with antibiotic ointment and oral antibiotics.
- Prominence of the spring may be concerning for parents but will dissipate in time as the expansion continues.
- Spring dislodgement will require surgical replacement.
- No additional surgery has been required for persistent calvarial defects or recurrence of cranial deformity.
- One child has had additional surgery for undercorrection of the deformity.

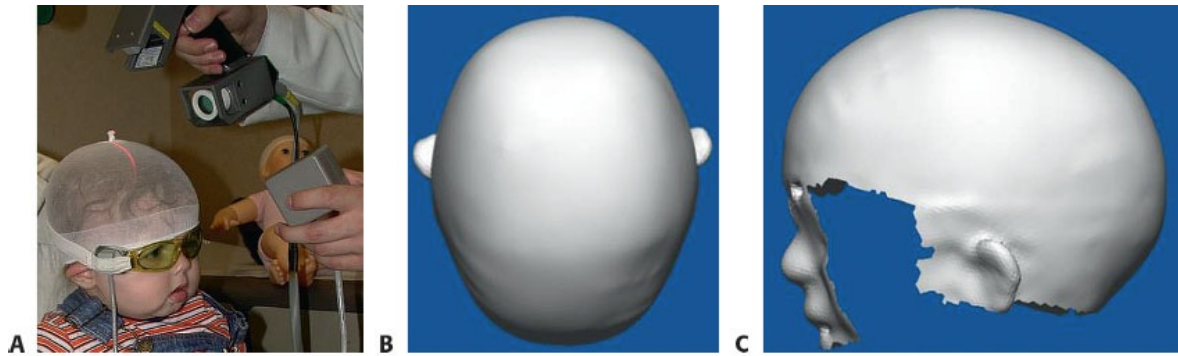


FIG 4 • Laser scan in use (**A**) and resultant scans (**B, C**) used for postoperative shape monitoring. (© WFBHS Plastic Surgery Collection.)

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7 Transparietal/Transtemporal Distraction for Sagittal Craniosynostosis

CHAPTER

Kristen Klement and Arlen Denny

DEFINITION

- Sagittal craniosynostosis
 - Premature fusion of sagittal suture. The sagittal suture normally fuses at an average of 26 years of age.
 - Results in scaphocephaly. Scaphocephaly is an abnormal head shape with an increased anteroposterior dimension and narrowed bitemporal distance. This can also be associated with frontal bossing and occipital bulging.
- Distraction¹
 - Repositions cranial vault gradually
 - Encourages intervening bony regeneration and decreasing bone grafts
 - Mitigates extradural dead space
 - Decreases blood loss
 - Shortens operative time and hospital stay
 - Promotes soft tissue acclimation
 - Minimizes relapse
 - Distraction is the ideal procedure in older infants and children.
 - Allows for better bone quality for mounting the distraction device
 - Decreases morbidity

ANATOMY

- Cranial vault is a series of bones with junctions that constitute the cranial sutures (**FIG 1**).
- The sutures are syndesmoses or a joint between cranial bones.
 - The major cranial sutures are metopic, sagittal, coronal, lambdoid, and

squamosal.

- Skull growth is normally perpendicular to sutures.
 - Premature fusion results in compensatory growth parallel to the affected suture.
 - Premature fusion of the sagittal suture results in scaphocephaly.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History
 - Developmental delays and learning disabilities
 - Behavioral issues
 - Signs of elevated intracranial pressure:
 - Chronic headaches
 - Papilledema
 - Color visual impairment progressing to optic nerve atrophy
- Examination
 - Expanded anteroposterior dimension due to compensatory growth at the active sutures
 - Narrowed bitemporal distance
 - Sagittal ridge
 - Frontal bossing due to fusion of the anterior sagittal suture and compensatory growth by coronal and metopic sutures
 - Occipital bulge due to fusion of the posterior sagittal suture and compensatory growth by lambdoid sutures

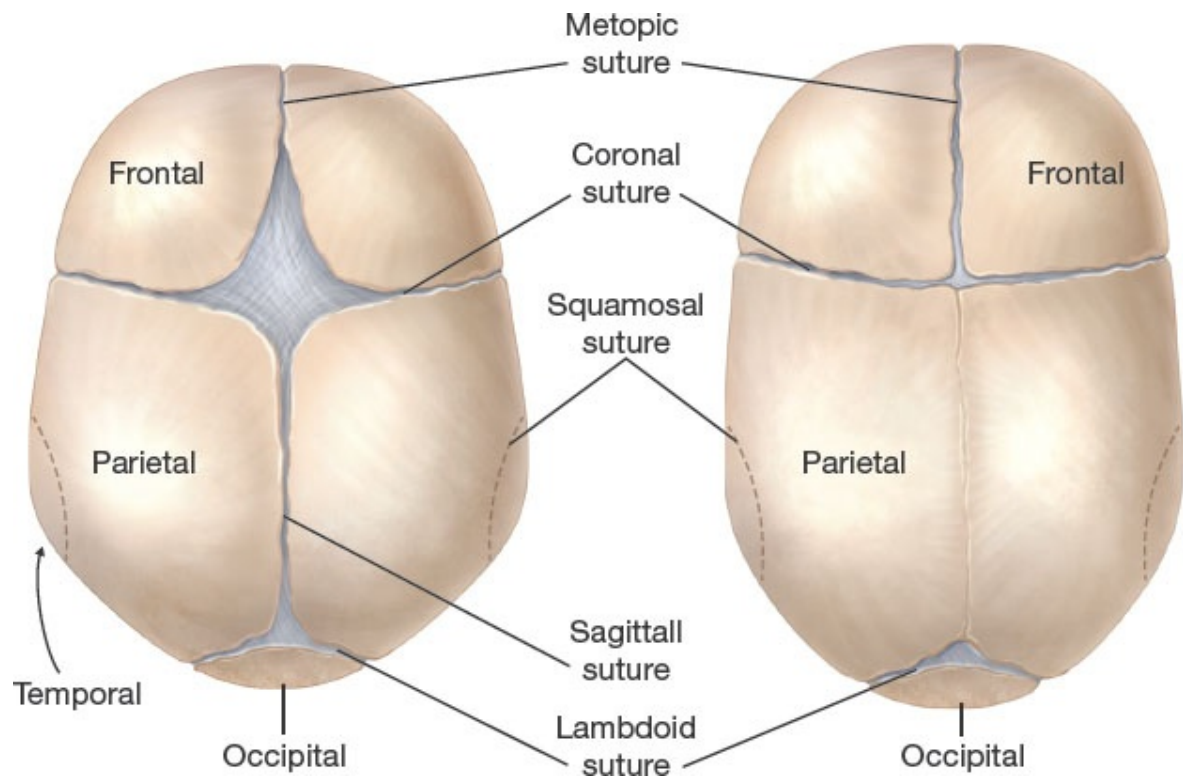


FIG 1 • Anatomy of normal skull bones and suture (**left**) and premature fusion of sagittal suture with resultant scaphocephaly (**right**).

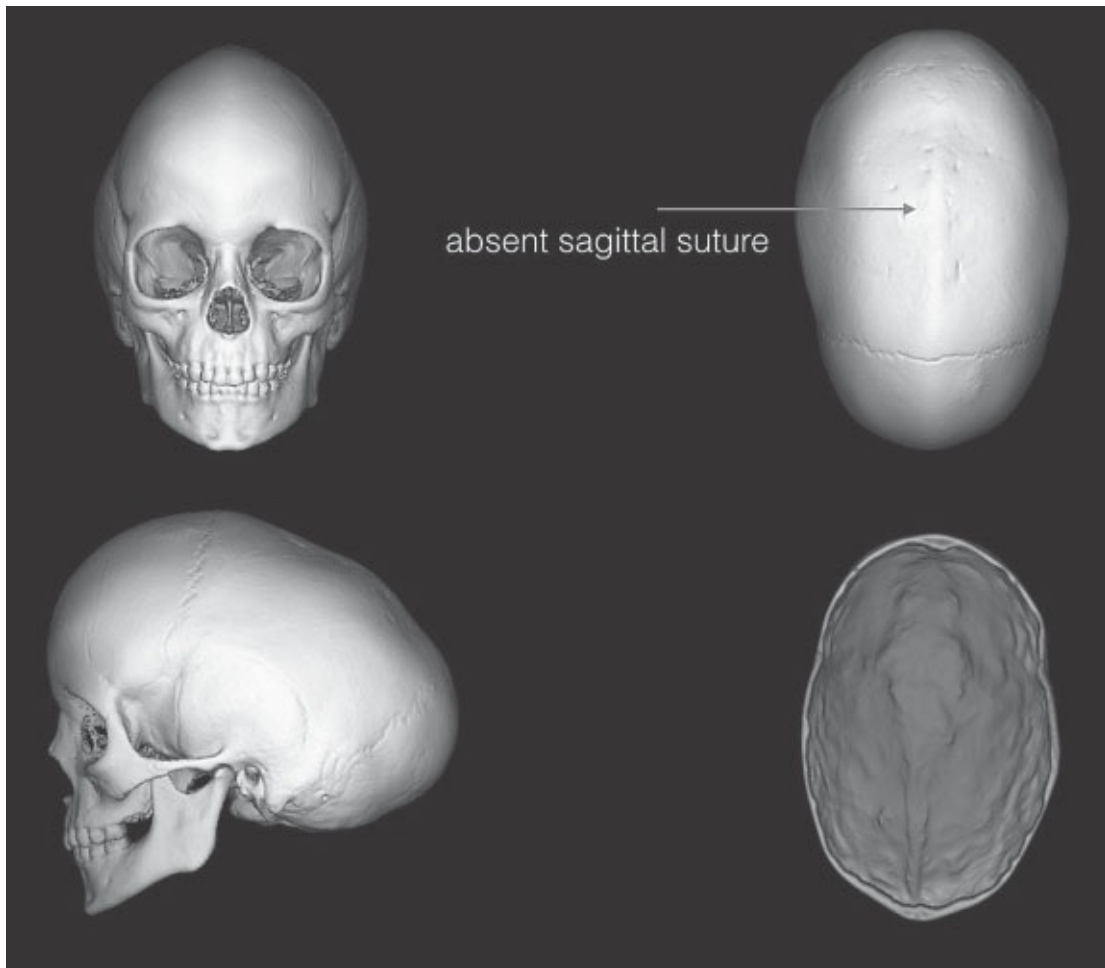


FIG 2 • CT scan with 3D reconstruction of the head demonstrating premature fusion of the sagittal suture with scaphocephaly with expanded anteroposterior dimension, narrowed bitemporal distance, sagittal ridge, frontal bossing, and occipital bulge.

IMAGING

- Computed tomography scanning of the head with 3D reconstruction (**FIG 2**) shows the classic findings in premature fusion of the sagittal suture:
 - Expanded anteroposterior dimensions
 - Narrowed bitemporal dimension
 - Sagittal ridge at the site of the absent suture
 - Frontal bossing
 - Occipital bulge

SURGICAL MANAGEMENT

Preoperative Planning

- Review CT scan preoperatively.
- Plan osteotomy patterns.
- Identify skull defects or sinus pericranium which may require changes in the planning.

Positioning

- Prone positioning with horseshoe headrest (**FIG 3**)



FIG 3 • Prone positioning with horseshoe headrest.

TECHNIQUES

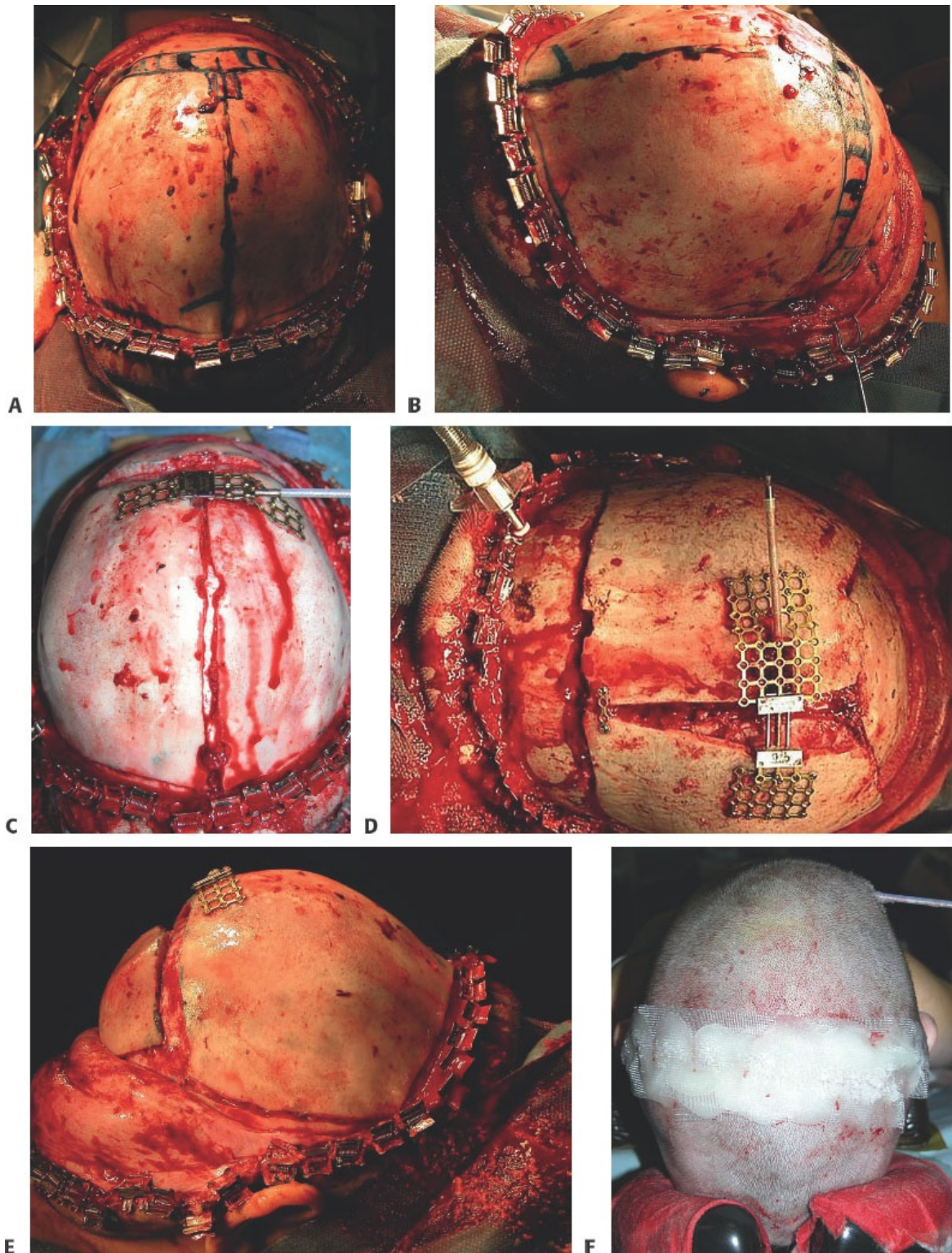
- **Asymmetric Transverse Distraction Osteogenesis of the Cranial Vault**



Video p2-c007

- Coronal incision is designed from above the helical rim, including back-cut in the hair-bearing scalp to improve access of the posterior skull.
- Elevate posterior scalp flap below the pericranium.
- Design craniotomy pattern on the skull with methylene blue (**TECH FIG 1A,B**).
- A neurosurgeon performs craniotomies posterior to the coronal, anterior to the lambdoid, and parasagittal using bur holes and a craniotome.
- Corticotomies along the base of parietal bone using bur
 - Creates hinge to allow for lateral expansion
- Occipital craniotomy along lambdoid suture using craniotome and corticotomy along the base using bur
 - These craniotomies and corticotomies can be added to the basic pattern to shorten the anteroposterior skull by hinging of occipital bone forward.
- Restriction plate at anterior sagittal and coronal osteotomy junction
 - Restricts lateral expansion anteriorly
 - Results in asymmetric expansion with the greatest distance in the posterior skull
 - Avoids visible step in temporal area
- Mount internal distractor to base plates at posterior sagittal osteotomy site across the parietal bone (**TECH FIG 1C**):
 - Mounting position of distractor device determines the area of the skull with maximum distraction distance due to the anterior hinge plate.
- Externalize drive rod through skin stab incision.

- Activate device to full distance of device under direct visualization to test maximum loading force (**TECH FIG 1D,E**).
- Reset device to 0 mm.
- Close the scalp.
 - 2-0 Vicryl stitch grabbing the periosteum and galea
 - Skin closure with staples
- Apply dressing with antibiotic ointment and nonadherent gauze (**TECH FIG 1F**).



TECH FIG 1 • A,B. Intraoperative markings of the skull with complete osteotomies made at the coronal, sagittal, and lambdoid sutures and incomplete

corticotomy at lateral parietal bone and inferior occipital bone to allow for hinging. **C.** Distractor mounted at posterior sagittal osteotomy. **D.** Distractor at full activation. Note the anterior hinge plate resulting in asymmetric distraction with full activation. **E.** Distractor at full activation of the lateral skull. Complete osteotomies are made at the lambdoid suture and incomplete corticotomy at lateral parietal bone and inferior occipital bone to allow for hinging. **F.** Postoperative dressing placement with externalized distractor rod.

PEARLS AND PITFALLS

Anesthesia	■ Recommend systolic blood pressure less than 90 to minimize bleed
Osteotomies	■ Complete just posterior to the coronal and parasagittal sutures and anterior to the lambdoid sutures
Corticotomies	■ Parietal bone skull base and inferior occipital bone to allow for hing (FIG 4)

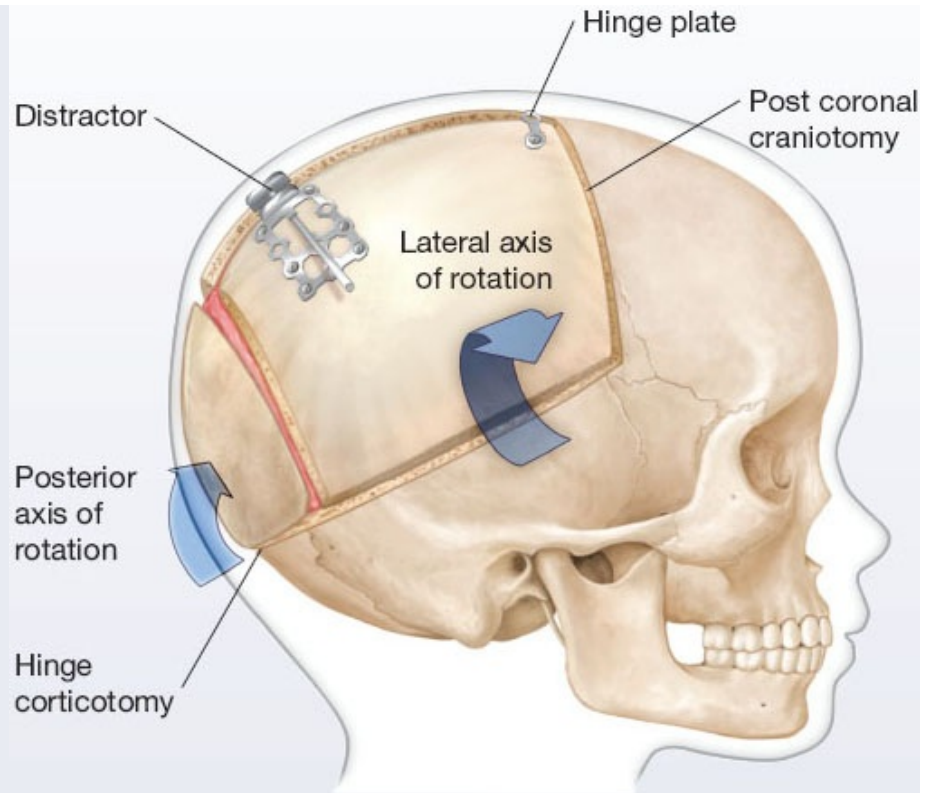


FIG 4 • Dynamics of transparietal posterior vault distraction.

Technique

- Limit dissection between the cranium and dura to osteotomy lines to maximize dura-bone flap vascular connections.
- Check device by fully expanding to test under maximum force load before closing.
- Anterior hinge plate results in planned asymmetric expansion.

POSTOPERATIVE CARE

- Intensive care unit until stable hemodynamically, followed by another 1 or 2 days on nonintensive floor
- Transfusion with whole blood for hematocrit less than 27
- Dressing optional
- Cleanse staple line and distractor site arms with half strength hydrogen peroxide, and coat with antibiotic ointment.
- Distractor protocol
 - Latency period of 5 days
 - Activation at 0.5 mm/d

- Full distraction within 4 weeks at 20 mm full device activation
- Rods removed in the clinic at full activation to prevent external trauma and inadvertent turning
- Computed tomography scan at 15 weeks of consolidation to confirm bone regeneration (**FIG 5**)
- Distractor removal at 16 weeks of consolidation, if bone regeneration is adequate

OUTCOMES

- Decreased intracranial pressures using intracranial pressure monitoring
- Increased intracranial volumes including both the ventricular and nonventricular spaces³
 - Ventricular volume expansion equivalent to 10% of total expansion
 - Nonventricular volume increased an average of 6% from preoperatively
 - Head shapes normalize postoperatively.
- Resolution of symptoms:
 - Parents report patient progress developmentally including speech, walking, and potty training
 - Improvement in vision detail and color demonstrated at ophthalmologic examinations

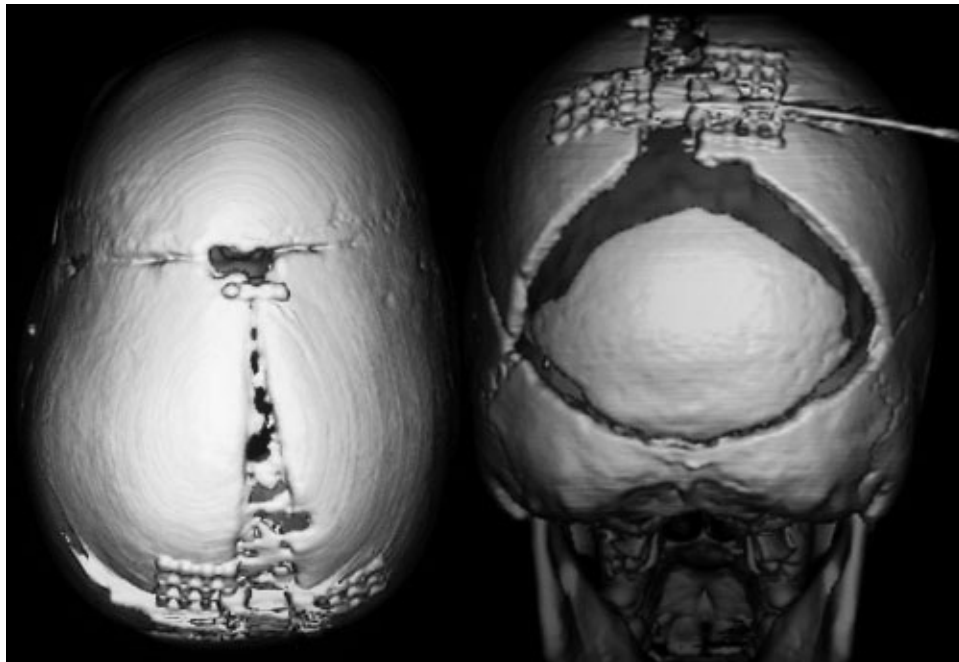


FIG 5 • CT scan at full distraction after consolidation.

COMPLICATIONS

- Our broad experience using this technique on children from age 1 to 16 has demonstrated minimal complications, and those that occur are minor⁴.
 - None of the patients required redistracted or advancement.
 - No patient has developed recurrent symptoms after up to 10-year follow-up.
- Premature consolidation
 - Poor parent compliance with device turning despite adequate parental teaching
- Bony defects requiring grafting

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8 Monobloc Frontofacial Advancement

CHAPTER

S. Anthony Wolfe and Nicole C. Cabbad

DEFINITION AND ANATOMY

- The Le Fort III–type osteotomy was first described by Gillies and modified by Tessier. (Tessier called it Le Fort III–type because the pterygoid plates were not fractured and it was subcranial.)
- This procedure represents the highest level of maxillofacial osteotomy performed without a craniotomy. It separates the face from the skull with osteotomies across the orbital floor, lateral orbital walls, zygomatic arches, and nasofrontal area and with a pterygomaxillary disjunction (**FIG 1A–C**).
- The orbital osteotomies go deep inside the orbit, behind the lacrimal system, and instead of going through the posterior hard palate—as originally described by Gillies—Tessier performed a disjunction between the maxillary tuberosities and the pterygoid plates (see **FIG 1B**).
- In Tessier’s patient, interpositional bone grafts were placed into all surgical gaps, with maxillary advancement of 20 mm. Traction to a head frame was maintained for months, and intermaxillary fixation for almost a year.
- Tessier then developed the simultaneous fronto-orbital advancement—referred to as the BO-Fort procedure—a combined anterior movement of the forehead with a Le Fort III–type advancement (**FIG 2**).
- The first true monobloc frontofacial advancement was performed in Mexico City and published in 1978,¹ and Tessier presented his modification of the procedure in 1995, which was designed to provide stable anterior movement of the entire facial skeleton.
- It leaves the effective orbit attached to the midface, differentiating it from the Le Fort III–type and BO-Fort that Tessier had previously developed.
- The monobloc was eventually associated with a facial bipartition.

- Monobloc frontofacial advancement with a facial bipartition includes removal of the interorbital naso-orbital-ethmoid maxillary bone for overcorrection of hypertelorism as seen in patients with Apert syndrome.
- The new, curved frontal bandeau made it possible to correct all of the morphological alterations of Apert patients (flat face, retrusive forehead, mild to moderate orbital hypertelorism, scaphymaxillism) in one operation.
- The monobloc advancement is a procedure that can make craniofacial dysostosis patients (Crouzon, Pfeiffer) look *normal* (**FIGS 3 and 4**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with a retrusive forehead and midface, proptosis, and class 3 malocclusion (common in craniofacial dysostosis patients such as Crouzon or Apert) benefit from the monobloc advancement.
- Orbital expansion corrects the proptosis; a bone graft is used to augment the nose with onlay grafts to the maxilla.^{2,3}

IMAGING

- Although skull x-rays and clinical exam were sufficient for Dr. Tessier in 1958, we now rely on CT scans with 3D reconstructions.
- Virtual surgical planning (VSP) is widely available.
- VSP can help the less experienced surgeon determine vectors of movement.

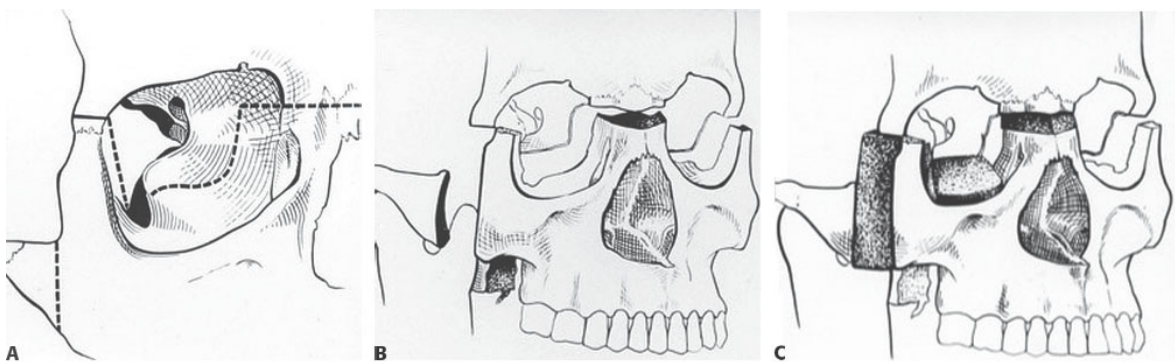


FIG 1 • Francine Gourdin's drawings of Dr. Tessier's first Le Fort III procedure. **A.** Osteotomy lines. **B.** Anterior movement of the midface. **C.** Bone grafts in position to stabilize the advancement. (From Wolfe SA. *A Man from Héríc: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press;

2011, with permission.)

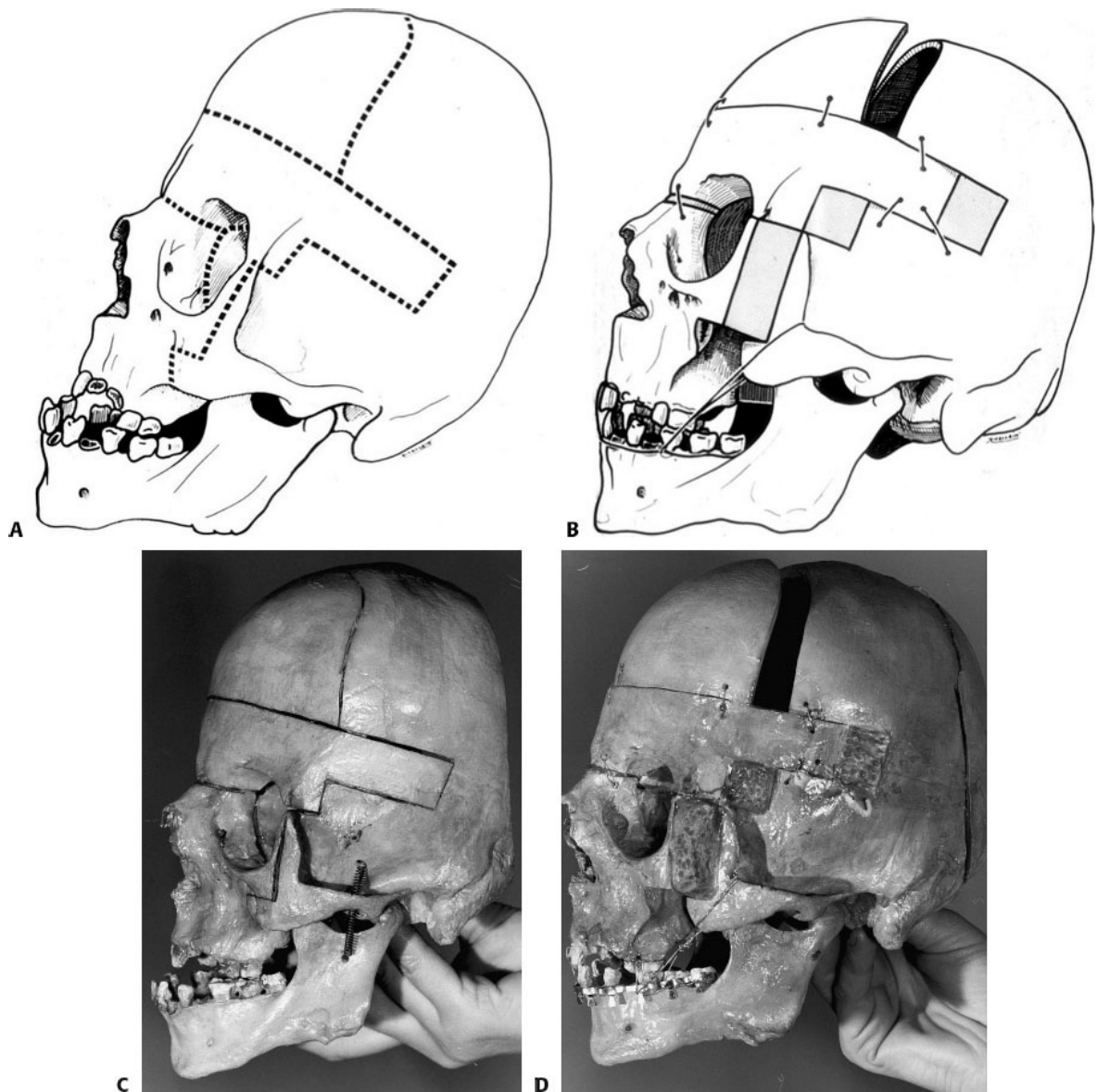


FIG 2 • Dr. Tessier's drawings of the osteotomies **(A)** and subsequent advancement **(B)** for his Bo-Fort osteotomies. Notice the addition of the forehead component as compared to a traditional Le Fort III procedure. Dr. Tessier's skull models showing his Bo-Fort osteotomies **(C)** and advancement **(D)** procedure. (From Wolfe SA. *A Man from Héríc: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press; 2011, with permission.)

SURGICAL MANAGEMENT

Preoperative Planning

- Evaluation by the primary care physician or pediatrician and requisite specialists (such as pulmonologists, neurosurgeons) should be completed prior to the procedure.
- Anesthesia should evaluate the patient preoperatively; airway concerns should be discussed with the surgeon, given that the airway might be challenging postoperatively.
- Type and cross +/- familial blood donation should all be done prior to the day of surgery.
- Several units of blood should be available at the time of incision.

Positioning

- Position the patient supine on the operating room table with the arms tucked in a padded, anatomically favorable position.
- The head should be placed on a hydraulic donut.
- A Foley catheter should be inserted.
- A warming blanket should be placed either under or over the patient's body.
- All wires and monitoring devices should be padded to ensure there are no pressure points on the body during a prolonged case.
- Secure the endotracheal tube with wire fixation to the dentition for easy maneuvering of the head without concern of extubation.

Approach

- Coronal and intraoral upper buccal sulcus incisions are used to access the osteotomy sites.

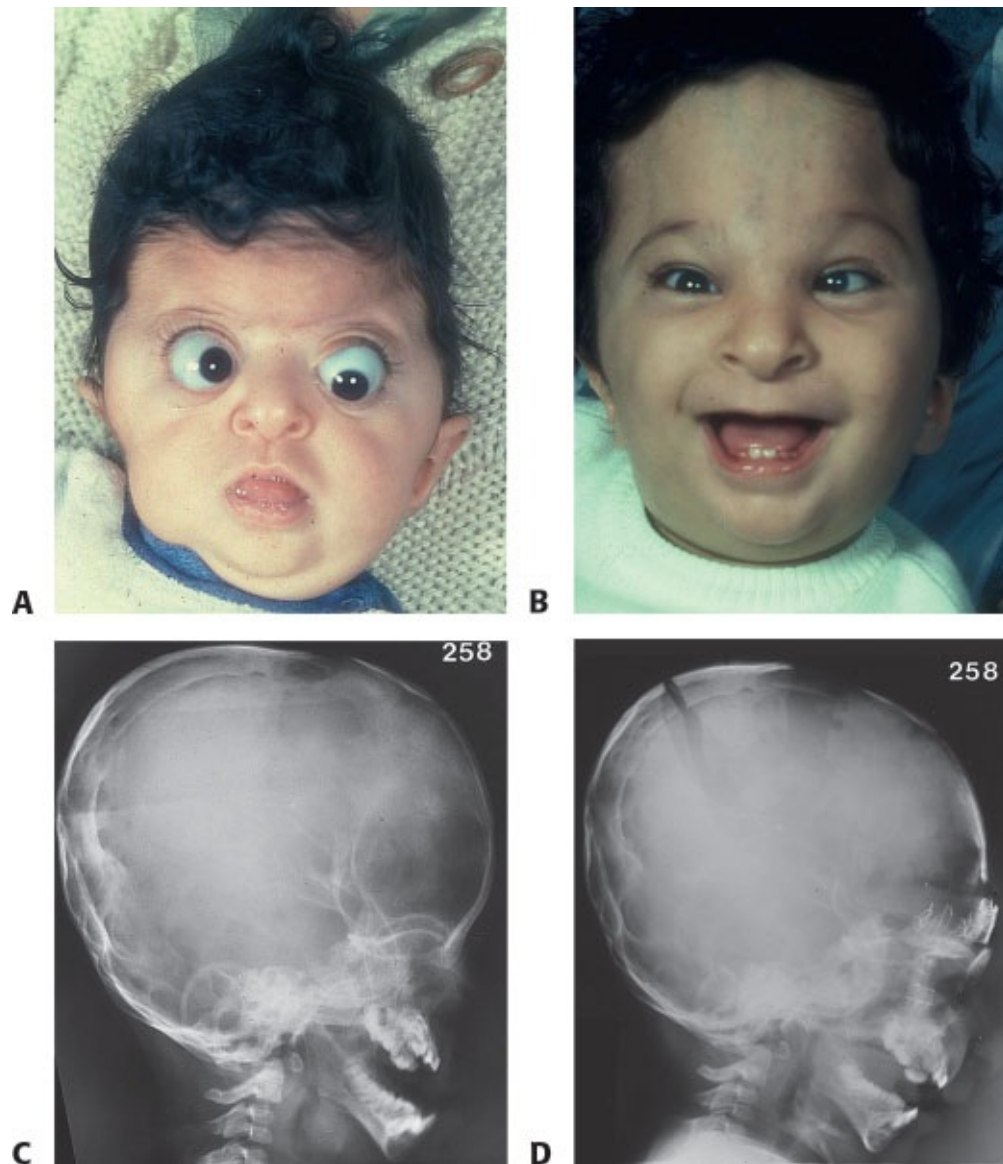


FIG 3 • These results show Dr. Tessier's ability to treat a 2-year-old child with a traditional monobloc facial advancement and wire-only fixation for the osteosynthesis. **A, C.** Preoperatively, the patient has forehead retrusion, proptosis, and midface deficiency. **B,D.** Postoperatively, the degree of advancement of the alveolus and forehead is harmonious. (From Wolfe SA. *A Man from Héríc: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press; 2011, with permission.)



FIG 4 • This patient underwent a monobloc facial advancement by Dr. Tessier around age 6. Postoperative pictures demonstrate normal facial features with a normal nasofrontal relationship. (From Wolfe SA. *A Man from Héric: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press; 2011, with permission.)

TECHNIQUES

■ Monobloc Using an Expansile Bandeau

Preparation and Exposure

- A metal-reinforced endotracheal tube is placed orally and fixated using circum-mandibular wires.
- If a tracheostomy is present, the tube is sutured to the chest wall to prevent dislodgement.
- The nose is packed with Neo-Synephrine-soaked pledgets.
- The coronal incision is marked; several mm both above and below the incision is shaved free of hair.
- Hair surrounding the incisions is braided and secured with ties.
- A sterile head wrap is placed and towels are stapled just below the incision to prevent occipital hair from entering the surgical field.
- The scalp is infiltrated with a dilute adrenaline solution (1:250 000).
- With the patient asleep, the eyelids are retracted with cotton tip applicators well beyond the equator of the globe—referred to as the “Tessier sign” (**TECH FIG 1**).
- The coronal incision is made with a knife; dissection continues to the plane between galea and pericranium anteriorly to the supraorbital ridges where the dissection becomes subperiosteal.
- Subperiosteal dissection of the upper orbital cavities, the lateral orbital wall and the anterior zygoma is performed through the coronal incision. Orbital floor dissection is extended to the infraorbital nerve.
- While dissecting through the fat layer to the superficial temporal aponeurosis, one should avoid injuring the frontal branch of the facial nerve.
- The temporalis muscle is dissected from the temporal fossa, including posteriorly.
- A limited oral dissection is performed with incisions over the maxillary molar teeth.

Osteotomies and Advancement

- Markings are then made for the osteotomies:
 - A methylene blue-impregnated 0 silk is used to provide a straight line about 12 mm above the supraorbital rim.
 - Bur holes are marked above this transverse line and then on either side of the midline posteriorly.
- The neurosurgery team performs a frontal craniotomy with a dissection of the anterior cranial base inferiorly to the crista galli with visualization and

preservation of the most anterior olfactory fibers. The dissection is extended beneath the sphenoid ridge into the temporal fossa (**TECH FIG 2A**).



TECH FIG 1 • Normal eyelids cannot be retracted behind the globe. This retraction is referred to as the Tessier sign.

- The osteotomy through the zygomatic arch is made with a reciprocating saw: through the arch from the temporal fossa to the orbit, flush with the cranial base, and then inferiorly to the inferior orbital fissure and superiorly across the orbital roof with the neurosurgery team directly observing the osteotomy through the intracranial route (**TECH FIG 2B,C**).
- Provide adequate irrigation to prevent burning the bone from the thermal energy of the saw.
- Pterygomaxillary disjunction is then performed with a curved Tessier osteotome.
- An osteotomy is made through the crista galli and then a double-guarded osteotome is placed through the cranial approach into this cut and aimed at the operator's finger placed at the posterior nasal spine.
- The Rowe forceps are then inserted and the midface down fractured and mobilized extensively (**TECH FIG 2D**).
- The distraction forceps are placed behind the maxillary tuberosity through the coronal approach and then through the oral approach to provide further mobilization of the midface.

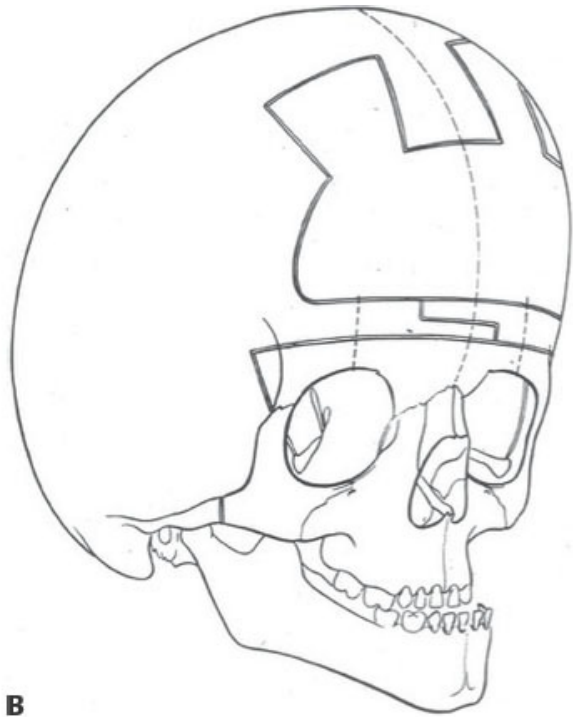
- The midface is freed to the point that it can be advanced into a class 2 occlusion.
- Nasopharyngeal tubes are passed under direct vision and palpated in the pharynx.

Grafting and Fixation

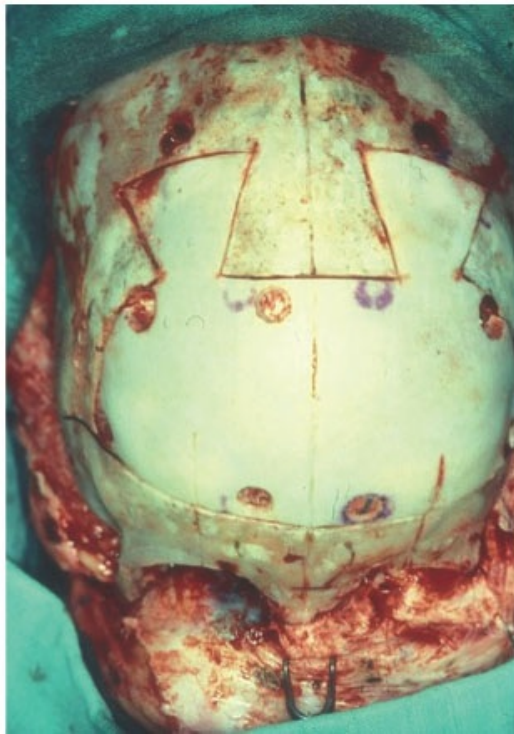
- With the midface separated from the anterior cranial base, a 6 × 6 cm pericranial patch is taken from the posterior parietal area and sutured over the anterior cranial base in a watertight fashion (**TECH FIG 3B**).
- Bone grafts from the skull can be placed over the cranial base defect to fill in the area of advancement (**TECH FIG 3C**).
- A 2.0-mm miniplate is fixed to the lateral orbital rim; a second plate is fixed to the cranium posteriorly and to the lateral rim medially (see videos).
- A gap is present at the zygomatic arch, which is roughly similar to the orbital distance. Another plate is placed across this zygomatic arch defect.
- Bone grafts are harvested from the inner table of the cranial flap and placed at the lateral orbital rim defects and within the zygomatic arch (**TECH FIG 3D**).
- The temporalis muscle is replaced and fixed with appropriate tension to the lateral orbital wall and posteriorly.
- Bilateral passive temporal no. 10 round catheters are placed but without suction.
- A lateral canthopexy is performed through the coronal approach grasping the tendon 6 or 7 mm lateral to the commissure and fixing it to the stabilized temporal fascia.
- The remaining portion of the temporal aponeurosis that was previously divided is now resuspended.
- The coronal incision is closed with bilateral passive drains, and the short oral incision is closed with a single chromic or Vicryl suture.
- The nasopharyngeal tubes are left in place and remain postoperatively for 5 to 6 days.



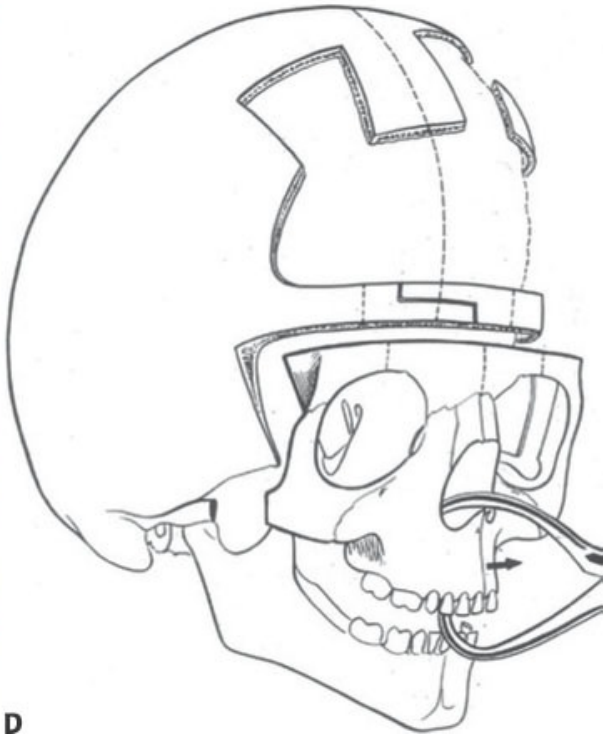
A



B



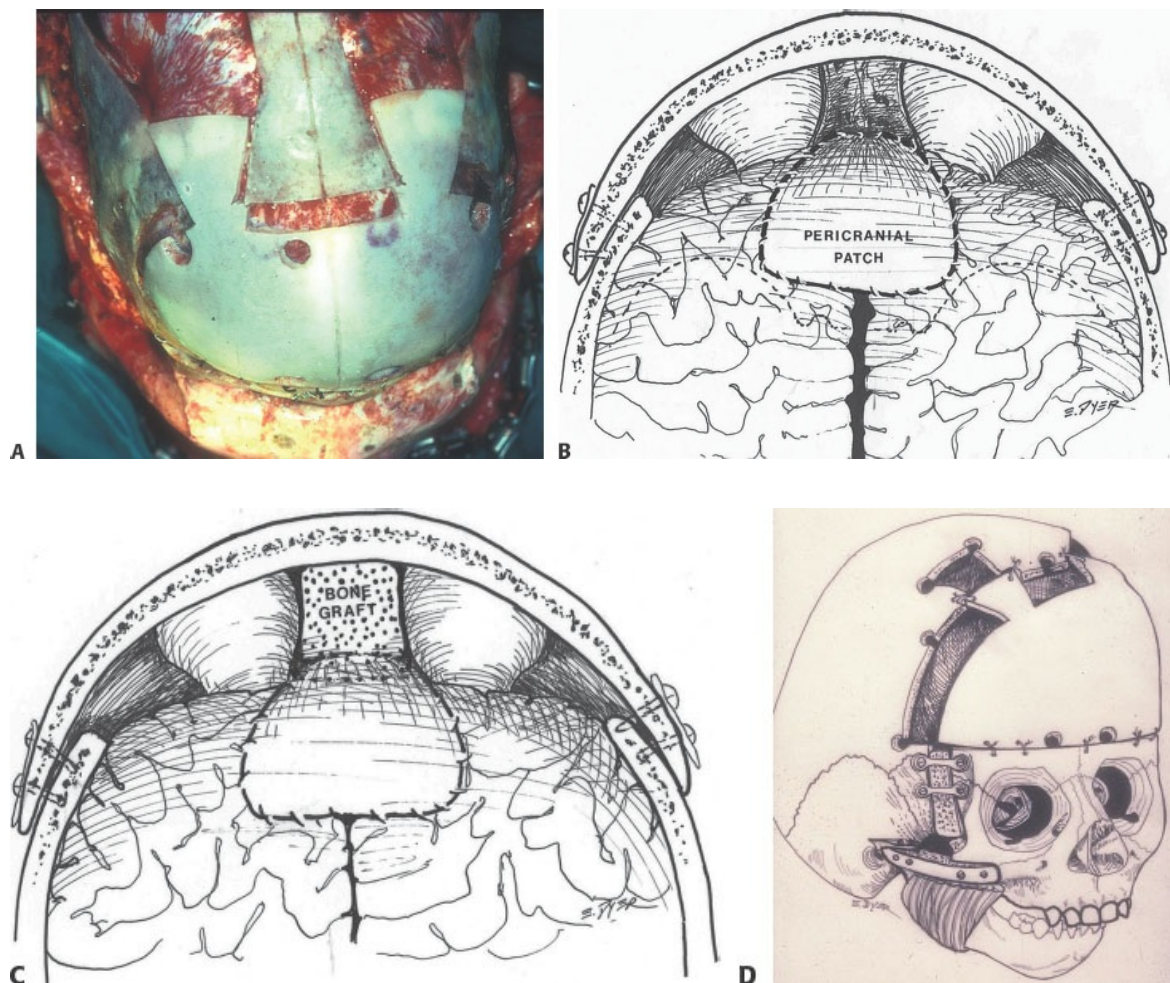
C



D

TECH FIG 2 • A. The method of monobloc frontofacial advancement without distraction that we have used over the years is modified from Henry Kawamoto's simplification of the Tessier/Ortiz Monasterio

procedure. The osteotomy is passed through the cranial base to the posterior nasal spine and is important in completely dividing the septum and ethmoid. Dr. Tessier's technique for monobloc used an expansile bandeau showing osteotomies (**B and C**) and monobloc advancement (**D**). (**B**, illustration by Evy Dyer; **C** from Wolfe SA. *A Man from Héríc: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press; 2011, with permission.)

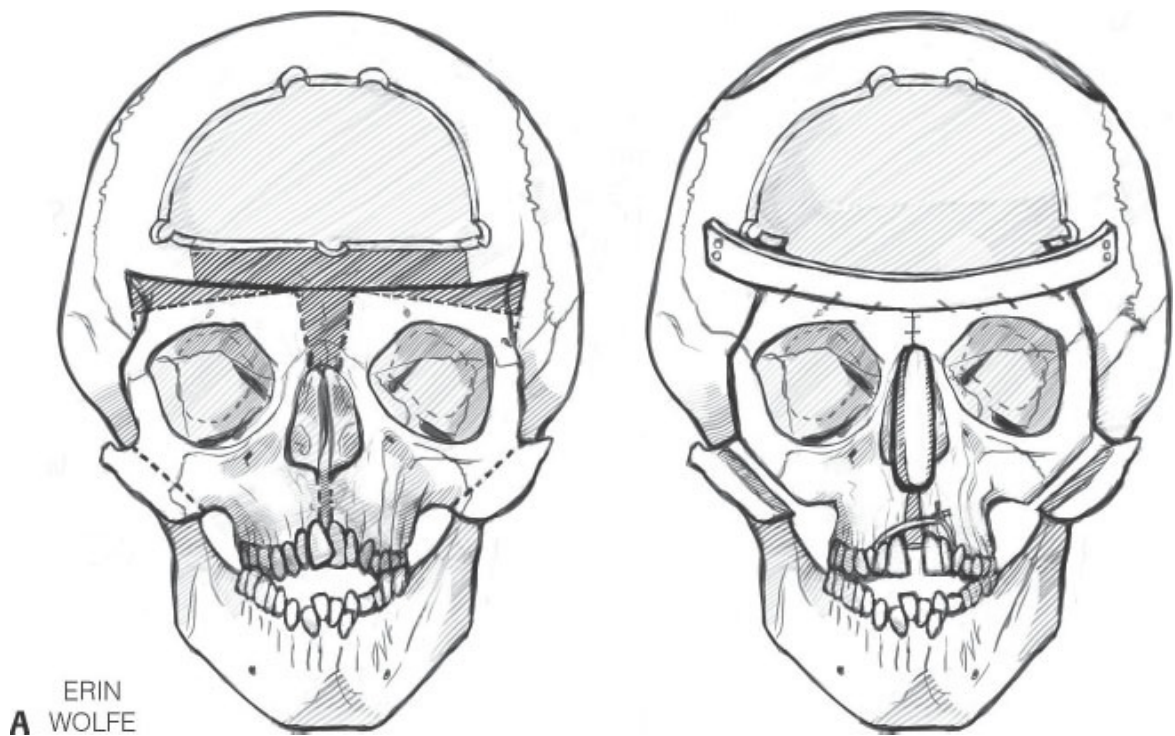


TECH FIG 3 • **A.** Intraoperative photo demonstrates the precision of the bone work in a monobloc advancement. **B.** The pericranial patch (*not* flap) is

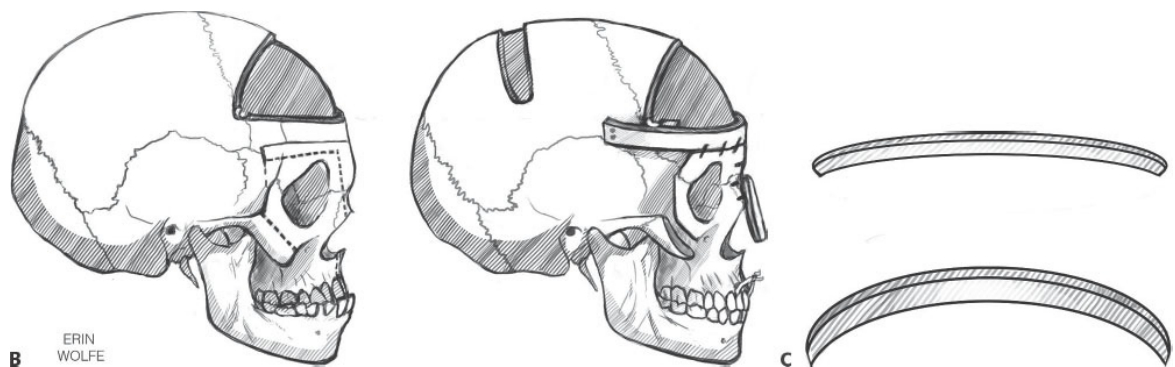
key in preventing CSF leaks. **C,D**. Note the use of bone grafts after advancement as needed. (**A**, from Wolfe SA. *A Man from Héric: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press, 2011; **B**, **C**, and **D**, illustrations by Evy Dyer, with permission.)

■ Modifications for Monobloc Frontofacial Advancement With a Facial Bipartition

- The frontal bandeau is maintained during the mobilization of the midface.
- A dissection of the palate is performed through two lateral palatal incisions dissecting across the midline to prevent an iatrogenic cleft palate.
- A careful intradental osteotomy is performed with a fine saw between the central maxillary incisors.
- Removal of a V-shaped segment of the interorbital naso-orbital-ethmoid maxillary bone is performed with overcorrection of the hypertelorbitism.
- Before removing the flat original frontal orbital bandeau, a new appropriately curved bandeau is harvested from the posterior parietal and occipital area (**TECH FIG 4**).
- This new bandeau is fixed in an appropriate position above the native flat frontal bandeau with 3.0 mm titanium screws.
- After fixation, the underlying original bandeau is removed.
- The previously mobilized orbital segments with the inner orbital bone appropriately removed are moved medially and fixed to the new fronto-orbital bandeau after trimming the supralateral portion of the orbital facial segment for appropriate fit.
- Wire is used for fixation to allow the vector to appropriately mobilize the facial segment into the desired position.
- Expansion of the dental arch may be noted, creating an appropriate diastema. If this is not desired, a wire loop is placed around the cuspids to prevent maxillary expansion during the correction of the hypertelorbitism.
- A lateral canthopexy is performed as described previously, and wound closure with passive drains is completed as in the monobloc advancement.



TECH FIG 4 • Monobloc frontofacial advancement (**A**) with facial bipartition (**B**) and fabrication of properly curved bandeau (**C**) from the posterior cranial vault. This procedure allows concomitant advancement of the face and forehead with hypertelorism correction. (Illustrations by Erin Wolfe and reproduced with permission.)



Physical findings

- A close relationship with neurosurgical colleagues is helpful when performing these procedures.
- Monobloc advancement for relatively mild to moderate Crouzon with no other complicating factors can safely be done without distraction and with a better result.

Technique

- Following separation of the face from the cranial base, cover the cranial base with periosteum, and fill the space with bone grafts.
- Always use bone grafts to stabilize the advanced monobloc segments.
- Monobloc advancement should be limited to 10 mm.
- Provide adequate irrigation to prevent burning the bone from the thermal energy of the saw.

Postoperative

- Extubation should not be rushed.
- Steroids may be used to diminish facial swelling.

POSTOPERATIVE CARE

- If the patient does not have a tracheostomy, the anesthetic team should be made aware that access to the airway may be limited.
- Extubation should not be rushed; the plan is to keep the patient intubated overnight and even a 2nd or 3rd day if there is persistent nasal bleeding.
- Nasopharyngeal tubes are removed on postoperative day 4 or 5 when airway swelling has decreased.
- Postoperative steroids may be used to diminish facial swelling.
- Monitoring for 3 to 4 days in the intensive care unit is required.
- We recommend cefazolin and clindamycin for 1 week following monobloc advancement.

OUTCOMES

- Monobloc advancement can be stable postoperatively (**FIGS 5 and 6**).
 - Stability is maintained with appropriate bone grafting to all advanced segments.
 - Respect the upper limit of advancement of 1 cm.
 - Monobloc distraction is utilized for movements of greater than 1 cm.
- Concerns persist for infection following advancement.¹⁻⁴
 - Separating the cranial base from the sinus spaces with periosteum decreases infection.

- Monobloc distraction has also decreased rates of infection.⁴

COMPLICATIONS

- Tessier operated on 6 adult patients with Crouzon disease using the “BO-Fort” procedure. Two patients developed retrofrontal fluid collections, epidural abscesses, and loss of the frontal bone, which led to abandoning the procedure.
- In 7 monobloc patients, Monasterio et al. reported one frontal bone loss; all 7 patients experienced transient CSF leakage, but no persistent CSF fistulas.¹
- Kawamoto et al. reported the first monobloc advancement in the United States and acknowledged a high percentage of CSF leaks, frontal bone loss, and meningitis.³
- Our monobloc experience with 93 patients demonstrated a similar spectrum of complications.²
- Kawamoto et al. presented monobloc distraction, introducing a 5-day latency with no CSF leaks.³
- Arnaud et al. presented 36 cases of monobloc distraction with significantly decreased complication rates.⁴
- Development of lateral canthal downward tilt, which may require correction (**FIG 7**)



FIG 5 • A1-A3. Frontal view of one of Dr. Tessier's patients operated on in the mid-1960s is shown with early and 20-year postoperative results, demonstrating the long-term stability of the procedure. **B1-B3.** Profile views of the patient. **A4** demonstrates a preoperative lateral cephalogram; **B4** demonstrates a 20-year follow-up cephalogram. (From Wolfe SA. *A Man from Héríc: The Life and Work of Paul Tessier, MD, Father of Craniofacial Surgery*. Miami, FL: Lulu Press; 2011, with permission.)

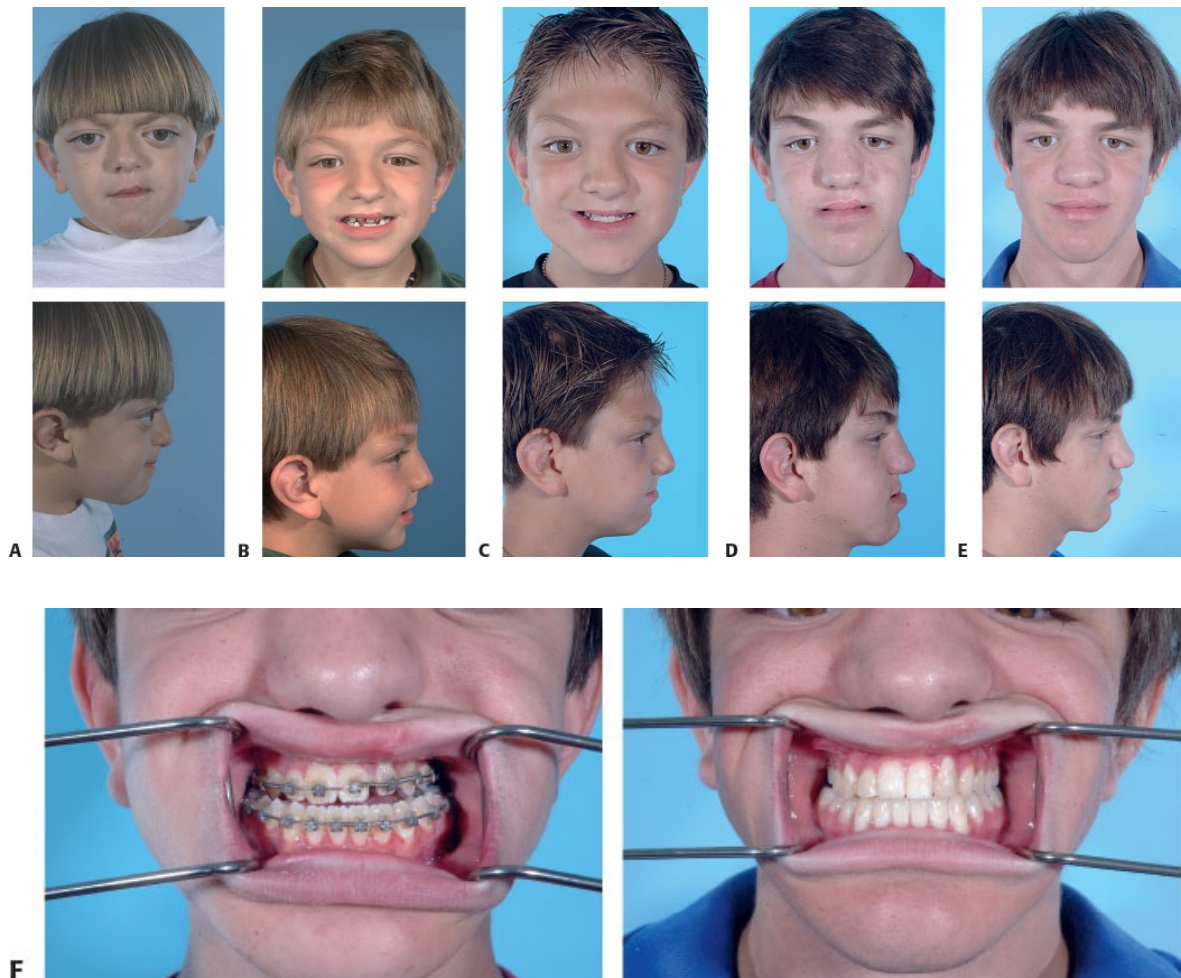


FIG 6 • This patient has Crouzon syndrome as well as a cleft lip repaired by Ralph Millard. He is shown

preoperatively (**A**) and after monobloc advancement at ages 6 (**B**) and 10 (**C**). By age 15 (**D**), he had evident maxillary retrusion, which was treated with a Le Fort 1 advancement (**E**). The lateral canthi have maintained their proper position. **F**. The patient's final occlusion after Le Fort 1 maxillary advancement. (Photographs by Jorge Insua.)

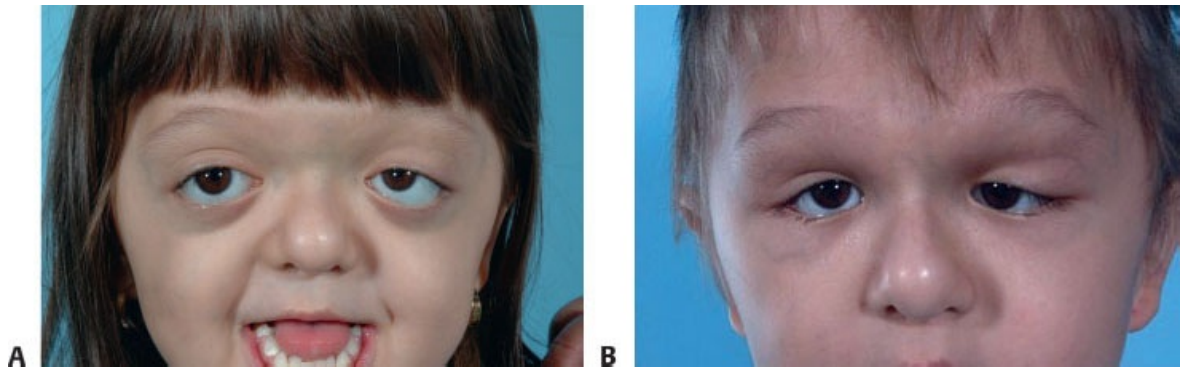


FIG 7 • A. Preoperative view of a patient with Apert's syndrome. **B.** In this postoperative result after monobloc advancement and facial bipartition, note the downward displacement of the lateral canthi. (Photographs by Jorge Insua.)

ACKNOWLEDGMENTS

We would like to acknowledge Erin M. Wolfe, BS, in preparing this chapter.

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CHAPTER Monobloc Distraction

Peter J. Taub and Vincent Chavanon

DEFINITION

- Craniofacial dysostosis syndromes result in disproportions of the skull and facial bones leading to reduced intracranial volume, midface retrusion, exorbitism, airway obstruction, and malocclusion.^{1,2}
- The midface hypoplasia associated with these syndromes may lead to corneal exposure that threatens vision, sleep apnea, and malocclusion, as well as deformities.

ANATOMY

- A combination of cranial vault and facial growth disturbances exists among multiple craniofacial syndromes.
- Monobloc advancement separates the anterior portions of the skull base, orbits, maxilla, and dental arch, which remain in continuity and are moved anteriorly.
- The scalp is composed of five layers: the skin, subcutaneous tissue, galea aponeurotica, loose areolar subgaleal tissue, and pericranium.
 - Dissection may proceed at different levels in different approaches.
- The temporal branch of the facial nerve (cranial nerve VII) lies immediately above the superficial layer of the deep temporal fascia and must be preserved when elevating the soft tissues of the forehead to avoid injury.
- The anterior ethmoidal artery exits the medial orbital wall approximately 24 mm deep to the orbital rim, and the medial wall osteotomy should be planned anterior to this landmark.
- The bones of the cranium and the facial skeleton articulate at the frontal bandeau, the floor of the anterior cranial fossa anterior to the cribriform plate,

the lateral orbital wall (greater wing of the sphenoid), the zygomatic arch, the medial orbital wall (ethmoid complex), the nasal septum, the orbital floor, and the pterygomaxillary fissure.¹

- The palpebral complex is anchored by the medial and lateral canthal tendons, which insert onto the posterior lacrimal crest and Whitnall tubercle, deep to the orbital septum.

PATHOGENESIS

- A number of genetic, molecular, cellular signaling pathways, as well as mechanical forces, interact to produce the craniofacial dysostosis syndromes.
- Patients with the same genotypes may have a broad variety of penetrance, influencing the level and severity of expression of the syndrome in individual patients.
- Different mutations in the fibroblast growth factor receptor-2 (FGFR-2) gene may lead to either Crouzon or Apert syndrome, which both display autosomal dominant inheritance.
- The restricted skull base growth in these syndromes leads to brachyturriccephaly and elevated intracranial pressure (ICP). Facial hypoplasia results in orbital retrusion and narrowing of the nasopharynx and Angle class III malocclusion.³

NATURAL HISTORY

- Cranial vault restriction may lead to elevated ICP, which has negative consequences on long-term cognitive, psychological, and functional outcomes.
- Chronic sleep apnea has an additional deleterious effect on psychosocial outcomes.³
- Reduced orbital volume may cause exorbitism, which may lead to corneal exposure and loss of vision.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough evaluation of the patient's cognitive, psychological, functional, and aesthetic status is required.
- Evaluation by a multidisciplinary team permits a 360-degree assessment of the patient and improves preoperative planning. The team comprises plastic surgeons, neurosurgeons, ophthalmologists, otolaryngologists, oral surgeons, pediatricians, geneticists, psychologists, speech-language pathologists, orthodontists, and pediatric dentists.

- The neurosurgical member of the team helps to identify Chiari malformations and is needed for exposure of the anterior cranial vault.
- An ophthalmologic exam identifies papilledema secondary to elevated ICP, increasing the urgency for surgery.
- A neuropsychological exam identifies baseline functional deficits that may improve with early surgical intervention.
- Genetics evaluation confirms the diagnosis, uncovers other potential medical problems in the child, and identifies risks for future family planning.

IMAGING

- True or reformatted lateral cephalograms may assist with advancement planning.
- Computed tomography (CT) with three-dimensional reformatting may show evidence of suture fusion, hydrocephalus, and signs of ICP elevation (copper-beaten skull).
- Magnetic resonance imaging is not usually necessary unless a brain abnormality requires evaluation.

DIFFERENTIAL DIAGNOSIS

- Apert syndrome or acrocephalosyndactyly (1:65 000)⁴
- Crouzon syndrome (1:25 000)⁴
- Pfeiffer syndrome (1:65 000)
- Carpenter syndrome
- Saethre-Chotzen syndrome¹
- Antley-Bixler syndrome²

NONOPERATIVE MANAGEMENT

- Continuous positive airway pressure (CPAP) or supplemental oxygen can be used for mild obstruction or tracheostomy for severe airway obstruction.
- Patching, moisturizing eye drops, and tarsorrhaphy are useful to protect the cornea against orbital exposure.¹
 - The benefit from tarsorrhaphy may be self-limited and ultimately ineffective due to tissue stretch and dehiscence.
 - Herniation of the globe after tarsorrhaphy may impede reduction of the globe resulting in loss of vision.¹

SURGICAL MANAGEMENT

- Indications for monobloc distraction:
 - Exorbitism with corneal exposure or visual loss
 - Upper airway obstruction
 - Malocclusion
 - Midface retrusion
- Patients with facial retrusion and a brow or infraorbital rim to cornea relationship of 5 mm (**FIG 1**) or 5 mm of negative overjet in occlusal relationship are optimal candidates for advancement.²



FIG 1 • Significant exorbitism due to maxillary hypoplasia.

- Timing for surgery has traditionally followed the sequence of craniofacial growth, starting with the cranial vault (0–5 years), orbit and midface (5–12 years), and lower face (greater than 12 years).
- Marchac and Arnaud³ have suggested benefits to a single-stage frontofacial monobloc distraction (at 18 months) after posterior vault expansion at 6 months. Their findings suggest improved ICP and long-term psychological results.

Preoperative Planning

- A cephalometric analysis should be performed prior to surgery to plan for the total distraction distance required.
- CT scans (both 2D and 3D) should be carefully reviewed prior to the operation.
- The surgeon must choose either internal or external distractors and be comfortable with the chosen technique.
- Adequate intravenous access and intra-arterial monitoring should be used. Packed red blood cells should be cross-matched and available in the room throughout the procedure.

Positioning

- The patient is positioned supine on the operating room table.
- The head is placed on a padded ring support and the arms are tucked by the patient's side.
- All bony prominences are padded.
- A Foley catheter is placed to monitor urine output as a measure of volume replacement.
- The table is rotated 180 degrees after intubation to permit unrestricted access by the surgeon and one or two assistants.
 - The head of the table is rotated back toward the anesthesiologist after the procedure to allow better airway management.

Approach

- A coronal (or bitemporal) zigzag incision for improved camouflage is used to create osteotomies of the orbital roofs, medial and lateral orbital walls, orbital floors, septum, and anterior zygomatic arches.
- A transoral (Keen) incision is used to access the pterygomaxillary osteotomy.
- A craniotomy of the frontal bone with retraction of the frontal lobes is used to expose the anterior cranial fossa and orbital roofs and allow for osteotomies of the roofs and septum.

TECHNIQUES

■ Exposure

- The coronal incision is marked and injected along its length with 0.5% lidocaine and 1:200 000 epinephrine to assist with hemostasis.
- The incision proceeds to the pericranium.
 - Raney clips on the scalp may be used for hemostasis.
- The scalp flaps are elevated in a subgaleal plane 2 to 4 cm and all bleeding vessels are cauterized.
 - Excessive use of cautery at the skin edges may lead to peri-incisional alopecia.
- Scalp elevation is continued anteriorly to the orbital rim.
 - The pericranium is incised transversely 2 to 3 cm above the level of the orbit.
 - Further anterior dissection into the orbit is continued in a subperiosteal plane into the orbit (**TECH FIG 1A**).
- Laterally, the temporalis is left in place to prevent temporal hollowing (**TECH FIG 1B**).
 - The lateral orbit may be approached using a limited dissection of the temporalis from the posterolateral aspect of the orbit.



Video p2-c009_01

- Continuing this dissection inferiorly, the anterior zygomatic arch is exposed.



Video p2-c009_02

- If the supraorbital and supratrochlear neurovascular bundles exit the frontal bone via foramina, they need to be released.
- A 2-mm osteotome is directed inferiorly from the opening on either side of the bundle to release the inferior bridge of bone and free the bundle from the foramen.



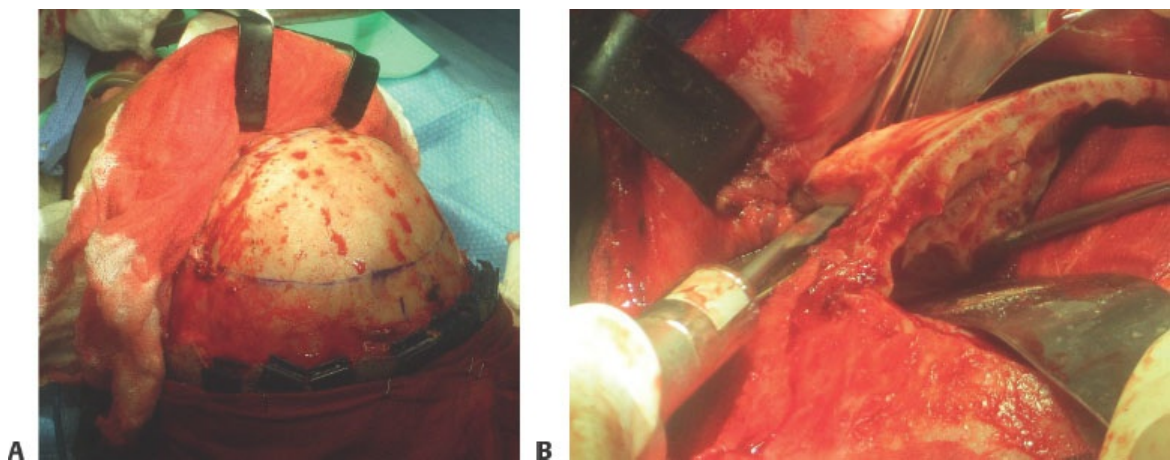
Video p2-c009_03

- Once this is done, or if no foramen exists, the coronal flap may be reflected further inferiorly to continue subperiosteal dissection within the superior portion of the orbit.
- Subperiosteal dissection is continued along the superior, medial, and lateral orbital walls and over the zygomatic body for access to the orbital floor.



Video p2-c009_04

- The medial canthi should be preserved. If the lateral canthi are released, they should be reconstructed after the skeletal surgery.
- The anterior ethmoidal artery will be visualized in the medial orbital wall and should be preserved.
- Bilateral intraoral incisions are marked and injected with 1% lidocaine and 1:200 000 epinephrine above the mucogingival junction.
- The incision is made through the mucosa using electrocautery and down to bone.
- The maxilla is exposed and the periosteum is elevated from the bone posteriorly with sharp periosteal elevators to allow access to the pterygomaxillary fissure.



TECH FIG 1 • A. Subperiosteal dissection of the orbit.

B. Limited dissection of the anterior temporalis muscle attachments to the lateral orbital wall to minimize temporal hollowing.

■ Osteotomies and Distractor Placement

- The forehead bone flap is removed by the neurosurgeon, who then retracts the dura to facilitate exposure of the orbital roofs.
- Osteotomies are made using reciprocating saw and small hand osteotomes.
 - The anterior portion of the zygomatic arch is cut with the reciprocating saw.



Video p2-c009_05

- Lateral tenons are created in the lateral portion of the orbital bandeau with the reciprocating saw.
- With a malleable retractor within the orbit to protect the globe, the tip of the reciprocating saw enters the infraorbital fissure from behind the orbit and is advanced superiorly to create an osteotomy along the lateral orbital wall.



Video p2-c009_06

- Using two malleable retractors, one within the orbit and another anterior to the frontal lobe, an osteotomy is made across the orbital roof anterior to the cribriform plate.



Video p2-c009_07

- The malleable retractor is then moved to the lateral aspect of the globe to protect and retract it, and the bilateral lateral orbital walls are similarly osteotomized.



Video p2-c009_08



Video p2-c009_10

- The osteotomy is made posterior to Whitnall tubercle where the lateral canthal tendon inserts.
- The osteotomy is continued through the lateral orbital floor to join the osteotomy made in the floor medially, thus completing the circumferential orbital osteotomies.



Video p2-c009_09

- While using a malleable retractor to protect the globe, bilateral medial orbital wall osteotomies are made using an osteotome. This osteotomy is made posterior to the insertion of the medial canthal tendon and is directed inferiorly to the medial aspect of the orbital floor.



Video p2-c009_11

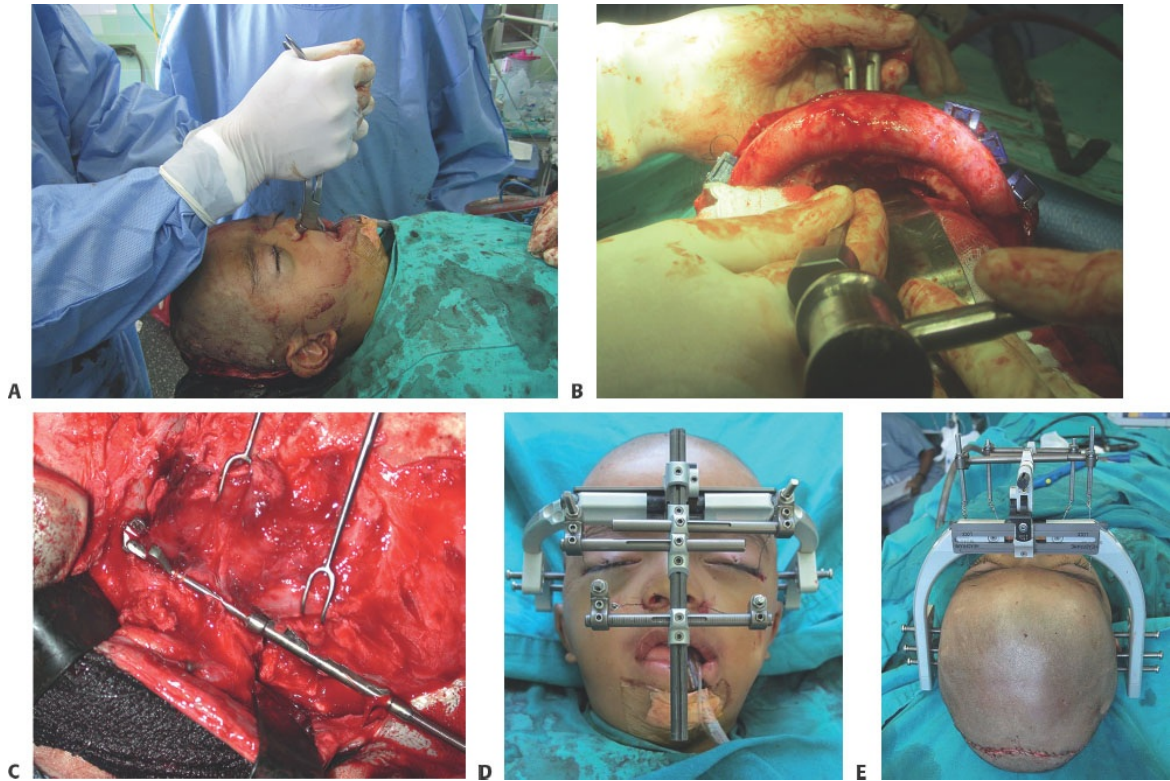
- A curved osteotome is placed through the transoral incision along the maxillary bone into the pterygomaxillary fissure. With one finger on the maxillary process medially, the osteotomy is made between the maxilla and pterygoid plates. Orient the osteotome properly to avoid injury to the terminal branches of the maxillary artery.



Video p2-c009_12

- Rowe disimpaction forceps are placed in the nasal cavities and over the palate to grasp the monobloc segment and downfracture it (**TECH FIG 2A**).
 - As the bone separates, a guarded septal osteotome is directed inferiorly from the anterior cranial fossa to make a septal osteotomy (**TECH FIG 2B**).
- With the monobloc segment fully downfractured, it may be mobilized side to side to loosen its soft tissue attachments and confirm completeness of the separation.
- The segment is returned to its original position for attachment of the distractor device.
 - An internal distraction device is secured anteriorly to the zygomatic body near the osteotomy (**TECH FIG 2C**).
 - Posteriorly, the distractor is secured to the temporal bone, immediately behind the zygoma and anteriorly to the external auditory canal.
 - If an external device is used, the frame is secured with percutaneous pins to the temporal bones, and percutaneous wires are attached to the monobloc segment (**TECH FIG 2D,E**).
- The distractors are then tested and returned to their initial position.
- The turning arms of the distractors exit posteriorly through stab incisions in the scalp.
- The forehead bone flap is secured to the frontal bandeau with miniplates to provide rigid fixation.
- A silicone drain is placed through a stab incision posterior to the ear.

- The galea is reapproximated using interrupted, buried 2-0 PDS sutures.
- A running, locking plain gut suture is used to close the skin. The intraoral incisions are closed with a running, locking 3-0 chromic suture.
- The skin incision is dressed with bacitracin, Xeroform, and sterile gauze dressings.



TECH FIG 2 • **A.** Placement of Rowe disimpaction forceps. **B.** Use of osteotome to create septal osteotomy. **C.** Fixation of internal distraction devices. **D,E.** External distraction device in place.

■ Removal of Distractors

- Distractors are removed after at least 8 weeks of a consolidation phase following completion of distraction.
- The same coronal incision from the initial surgery is used to access the distractors.
- Dissection is performed in a subgaleal plane to expose the zygomatic body and temporal bone.

- The distractors are removed and the incision is closed with resorbable sutures similar to the initial surgery.

PEARLS AND PITFALLS

Indications	■ Airway obstruction, exorbitism, occlusion, midface retrusion.
Exposure	■ Avoid electrocautery on the scalp to prevent peri-incisional alopecia. ■ Lidocaine with epinephrine should be injected 20–30 minutes prior to incision to assist with hemostasis. ■ In older patients with the presence of frontal sinuses, the central portion of the superior orbit osteotomy may be performed via a trans-sinus approach to avoid intracranial exposure to the nasal passage and avoid the midline structures.⁵ ■ Free the supraorbital neurovascular bundle to improve exposure of the orbit.
Osteotomy	■ The anterior zygomatic arch may be osteotomized via the coronal or the transoral approach. ■ Use caution during the pterygomaxillary disjunction to avoid injuring the terminal branches of the maxillary artery.
Distraction	■ 5–7 day latency period. ■ Distract 1 mm/d (0.5 mm twice a day). ■ Consolidation at least 8 weeks; some surgeons recommend longer.

POSTOPERATIVE CARE

- A 5- to 7-day latency period is used after the operation.
 - This delay allows healing of the nasal mucosa, which helps prevent infection.
- After the latency period, the pins are each distracted 1 mm/d at a rhythm of two turns per day (0.5 mm twice daily).
- The pin sites are monitored closely for infection.
- Following completion of distraction, the turning arms are removed.
- A consolidation period of 8 weeks to 6 months has been used, after which the distractors are removed.

OUTCOMES

- In comparing the traditional technique of monobloc and immediate advancement to monobloc by distraction, Bradley et al.⁶ noted the distraction group had less morbidity and achieved greater advancement with less relapse compared with conventional methods of acute monobloc advancement accompanied by bone grafting.
- Monobloc distraction is an alternative to staged fronto-orbital advancement followed by Le Fort III advancement.
- Gwanmesia et al.⁷ reviewed 20 patients with a mean follow-up of 10 years.
 - The authors reported no significant relapse in these patients.
 - Fourteen of the 20 patients had moderate to severe sleep apnea and 7 required tracheostomies; 5 were decannulated.
 - Of the younger patients receiving this treatment, 9 of 11 were in mainstream education. Of the older patients, 7 of 9 sought higher education or had jobs.
- Arnaud and Di Rocco⁸ analyzed 104 patients undergoing monobloc distraction with a mean follow-up of nearly 5 years and noted significant improvement in exorbitism, respiratory function, and occlusion.

COMPLICATIONS

- Death
- Bleeding
- Frontal bone loss
- Meningitis
- CSF leak
- Wound infection
- Pin site migration

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10 Split Calvarial Bone Graft Harvest

CHAPTER

Peter J. Taub

DEFINITION

- Calvarial bone grafts are used for replacement of deficient bone.
- These grafts are ideal for calvarial, orbital, nasal, and midfacial reconstruction.
- Paul Tessier previously described, and extensively used, autologous bone grafts from the calvarium for facial and cranial reconstruction.¹

ANATOMY

- Because many primary craniofacial procedures are performed via a coronal incision, there is no additional access for the donor site.
- Calvarial bone has a diploic structure including an inner and outer “table” of rigid cortical bone surrounding a center of softer cancellous bone.
- A rich vascular system allows for rapid revascularization, and its intramembranous lineage is thought to undergo less resorption compared to endochondral bone grafts.
- The natural curvature of the calvarium can be useful in reconstructing similarly curved structures, and additional bending is possible by incorporating kerfs on the concave surface (**FIG 1**).

PATHOGENESIS

- Bone graft healing is affected by numerous variables.
- Adequate blood supply is arguably the most important. Devascularized bone is unable to activate the process of remodeling and over a period of 6 to 12 months becomes necrotic and predisposed to infection and repeat fracture.

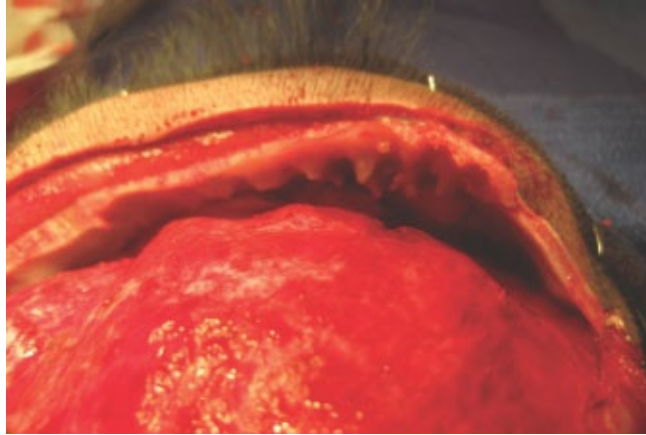


FIG 1 • Kerfs created on the concave surface of a calvarial bone graft to facilitate curvature of the bone.

- Revascularization occurs through a process known as haversian remodeling. The process begins with osteoclasts traversing the fracture line. Vascular endothelial growth factor (VEGF) regulates the process of angiogenesis by increasing vascular sprouting, endothelial cell migration, and proliferation adhesion. Capillaries and osteoblasts follow to form vascularized lamellar bone.²
- External radiation impairs secondary reconstruction by inhibiting bone healing and growth, limiting microvascular supply, and decreasing the integrity of surrounding soft tissue.³
- Stability (elimination of motion) of the bone graft is critical to primary bone healing, whereas micromotion has been shown to facilitate bone healing through osteogenesis.⁴ Insufficient fixation leads to the deposition of fibrous tissue within the gap between bony segments, resulting in nonunion.
- Patient age plays an important role in bone graft healing.
 - Younger patients demonstrate faster rates of healing than do adults, likely secondary to the increased angiogenic potential of younger bone.
 - Advancing age decreases angiogenesis, stem cell function, signaling cascades, and periosteal structure, all of which are essential to bone graft healing.

NATURAL HISTORY

- Bone grafts heal via three mechanisms: osteointegration, osteoinduction, and osteoconduction.

- Osteointegration refers to the connection between the surface of the native, living bone and that of the bone graft.
- Osteoinduction refers to the process of stimulation of undifferentiated pluripotent cells into bone-producing cells through the release of growth factors.
- For bone grafts, the architecture of the graft (cancellous vs cortical) dictates the success of incorporation. Cancellous bone graft incorporation tends to be more favorable compared to cortical bone, owing to its open architecture, which allows for more rapid revascularization and differentiation of osteoprogenitor cells into bone forming osteoblasts.⁵
- Osteoconduction refers to bone formation from either adjacent bone or periosteum via the ingrowth of capillaries and osteoprogenitor cells from the recipient bed to, around, and through the graft. The graft acts as a scaffold for new bone formation.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Among bone replacement materials, autogenous bone grafts remain the standard. They are the only material that is truly osteogenic; cells from the bone graft contribute to new bone formation.
- Bone grafts can be used for replacing acquired bone defects, such as following tumor extirpation or continuity defects following trauma; augmenting deficient skeletal surfaces, such as placement of bone graft for zygomatic or chin augmentation; or reconstructing congenital anomalies, such as alveolar cleft defects or hypoplastic mandibular rami.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Preoperative evaluation should include a CT scan to assess the thickness of the parietal bones for harvesting grafts and of any potential midline abnormalities.
- Younger patients may lack a true diploic architecture (**FIG 2**), whereas older patients may have areas of thin calvarial bone.

SURGICAL MANAGEMENT

Preoperative Planning

- Care must be taken when choosing the site of bone harvest. In general, the flat parietal region is ideal for most applications.
- The midline sagittal suture overlies the sagittal venous sinus and must be avoided. Similarly, the anterior coronal and posterior lambdoid sutures are sites

of dural adherence and should be avoided.

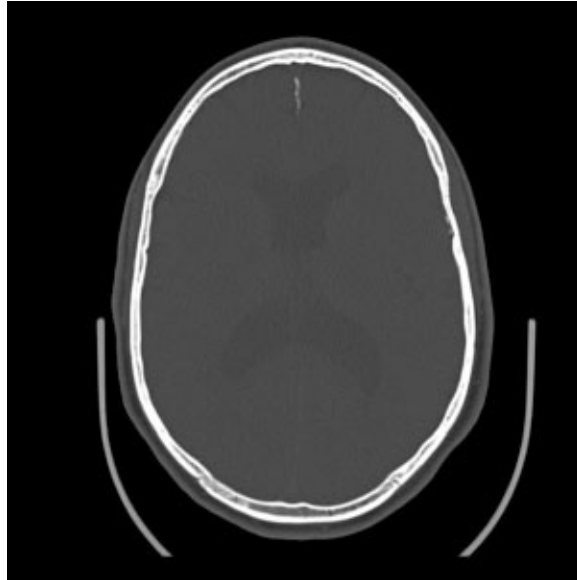


FIG 2 • CT scan demonstrating diploic architecture of calvarial bone.



FIG 3 • Preparation of the scalp for a coronal incision by shaving a strip of hair and excluding the remaining hair from the operative field.

Positioning

- The patient is best positioned supine with the head stabilized. This may be as simple as a foam “donut,” a horseshoe extension of the operating table, or a Mayfield clamp.
- The torso should be restrained with a belt in case the table is rotated during the procedure.
- A strip of hair can be shaved over the coronal incision and the hair on either side combed away from the incision and gathered into elastics for control (**FIG 3**).
- The surgical prep should include the hair (and face if needed) down to the level of the bed.
- Care should be taken to avoid exposure keratitis by applying ointment to the eyes and using a more dilute prep solution in this area.
- The face can be draped out of the operative field or incorporated into it as desired.

Approach

- Access to the parietal calvarium may be achieved in two ways depending on the amount of bone required.⁶
- A small zigzag incision directly over the parietal scalp may be used when a smaller graft is needed and is easily hidden by a patient’s hair.
- A coronal incision provides ideal exposure for larger grafts. The dissection proceeds through the skin, underlying soft tissue and galea, to the pericranium. The pericranium may be dissected from the calvarium or left in place to maintain continuity of loose bony fragments of the outer table. Elevation of the pericranium is performed with an Obwegeser-type periosteal elevator.
- Hemostasis from underlying perforating vessels to the periosteum may be achieved with direct electrocoagulation or with sterile bone wax.

TECHNIQUES

■ Shave Graft

- The thinnest type of calvarial graft is a “shave” graft performed with a wide, sharp chisel.
- The graft is taken midway through the outer table of cortical bone, and

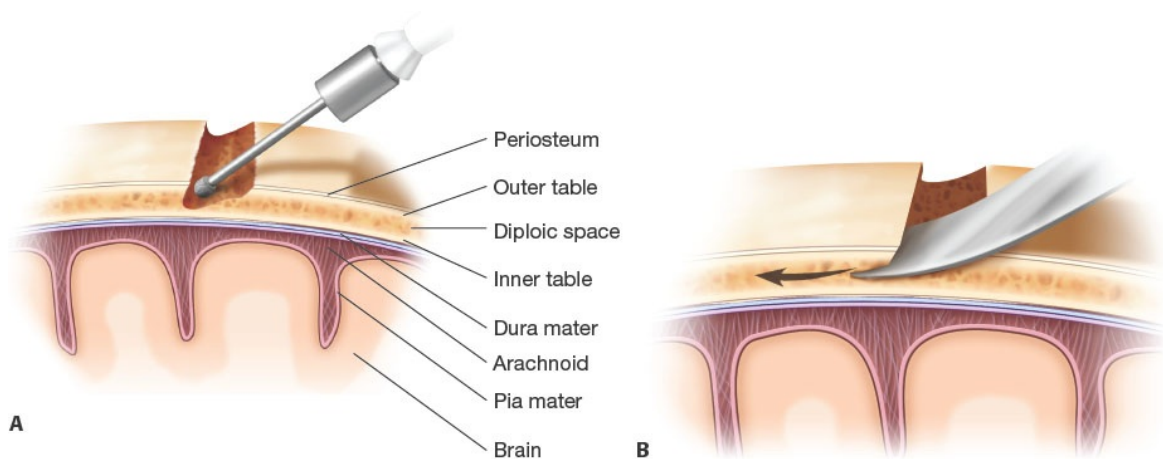
although harvested as numerous shavings, they are held together by the overlying pericranium.

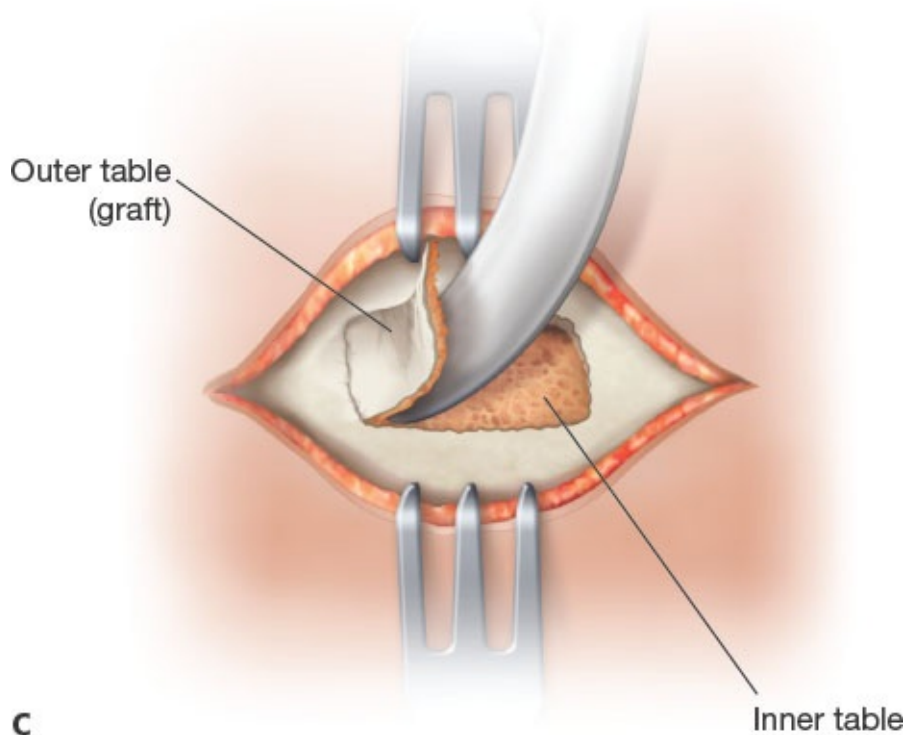
- When removed, the graft actually curves to simulate the natural floor of the orbit.
- A shave graft is useful for reconstruction of the orbital floor and is harvested through a small zigzag incision in the parietal region.
- Dissection in this instance should not violate the pericranium, which can be dissected laterally with a blunt instrument.
- An outline of the graft is made through the pericranium with the Bovie electrocautery. This should be slightly larger than the actual bone graft size because the pericranium will contract after being incised.
- A wide osteotome is then angled at roughly 30 degrees and directed down the length of the graft. The graft may be wider than the osteotome, and thus, the instrument may need to move side to side to capture the full width of the graft required for harvest.
- The graft often comes off in small pieces held together by the pericranium. The osteotome should not be advanced too superficially so as not to violate or tear the pericranium. It should also not be advanced too deeply to avoid entering the diploic space or cranial cavity.
- The intervening diploic space often provides a “warning track” to indicate excessive depth and when to redirect the osteotome more superficially.
- Gentle finger pressure over the graft is recommended, so the graft is not inadvertently lost from the operative field.
- The graft is removed and the donor site inspected. Bleeding can be managed with Gelfoam, Surgicel, bone wax, cautery, or any combination of the above. The base should be palpated to rule out inadvertent violation of the cranial vault.

■ Outer Table In Situ Split Calvarial Graft

- A thicker split calvarial graft may be harvested in situ through a direct incision over the harvest area or through a coronal incision.
- This thicker graft may be used in areas that require greater stability, such as the orbital rim, forehead, or remaining calvarium.
- The graft will retain its natural shape but may be gently bent if thinned. Alternatively, kerfs can be added to facilitate manipulation (see **FIG 1**).

- With this type of graft, preservation of the outer pericranium is not necessary because the graft should be removed as a single piece.
- The border of the graft is created with a small fissure bur. This should extend down to the level of the diploic space, which is indicated by slight bleeding easily controlled with bone wax. The surgeon should confirm that the channel extends all the way around the border of the graft.
- Common areas that are often incompletely burred are in the graft corners where there is a change in direction of the bur.
- In the proximal channel of the graft, the outer edge can be further burred down to create a slope to allow the osteotome to be directed at a more acute angle beneath the graft (**TECH FIG 1A**).



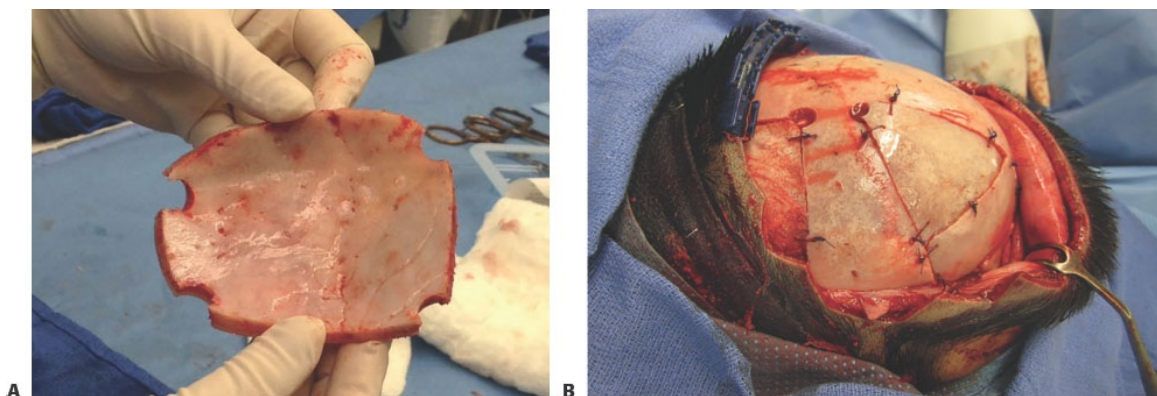


TECH FIG 1 • A. Using a cutting bur to create a beveled edge to the diploic space. **B.** Direction of the curved osteotome to avoid violation of the inner table. **C.** Removal of a portion of the outer table to be used as graft material.

- Curved osteotomes of varying widths are then advanced within the diploic space along the length of the graft (**TECH FIG 1B**).
- An assistant surgeon should keep a finger on the graft to prevent it from being lost off the operative field.
 - The graft is then removed for further contour (**TECH FIG 1C**).
- As above, the donor site may be covered with Gelfoam, Surgicel, and bone wax or cauterized.
- The harvest site base should be visually inspected and palpated to rule out violation of the intracranial space. The pericranium should be reapproximated if possible, followed by the galea and subcutaneous tissue and skin.
- A closed suction drain is left prior to final closure of the scalp with sutures or staples.

■ Outer Table Ex Vivo Split Calvarial Graft

- Removal of an entire segment of calvarial bone may also be used for harvest. A team approach with a neurosurgeon is recommended in these instances.
- An intracranial approach may be a better option, especially in the pediatric patient for whom in situ splitting may not be feasible secondary to a thin or irregular skull. If a formal craniotomy has already been performed, the segment can be retrieved from the free edge of the bone.
 - Alternatively, a segment of bone can be removed separately.
- Usually, four small craniotomies are made in the corners of the proposed graft for access (**TECH FIG 2A**). Care must be exercised to avoid injury to the underlying dura.
 - Modern craniotomes have been designed to cut only bone and preserve the dura. The diameter of each corner opening is often large, however, and a standard craniotome may be preferable.
- The dura should be visualized through each of the openings. A no. 4 Penfield or Freer elevator is inserted into the opening and gently used to free the dura from the undersurface of the calvarium. Ideally, the elevator should be able to pass from one opening to the other.
- With an extradural path created between all the openings, an osteotome with a footplate is advanced from opening to opening until the graft is free for removal.
- The dura should be inspected to ensure that it has not been violated. A moist laparotomy pad is placed on the exposed dura.
- On a sterile, back table, the outer table of bone is separated from the inner table at the level of the diploic space. This may be done with a reciprocating saw or a hand osteotome. Often, the saw blade is too short to traverse the width of the graft, and an osteotome is required.
- Once separated, half of the bone—either the outer or inner table—can be used to repair the donor defect. The other half is used for the reconstruction.
 - In either instance, the bone is rigidly fixed with titanium plates and screws (**TECH FIG 2B**).
- The wound is irrigated and the scalp closed in layers over a subcutaneous drain.



TECH FIG 2 • A. Full-thickness cortical bone graft harvested via four corner osteotomies. **B.** Replacement and fixation of bone segments.

PEARLS AND PITFALLS

Graft harvest

- Safety first. Calvarial bone overlies the dura and brain. Dural injury can result in persistent and worrisome CSF leak. Brain injury can result in permanent neurologic deficit.
- Review the preoperative imaging (preferably CT scan) to determine the best location for graft harvest.
- Before harvesting the bone graft, decide if the overlying periosteum is to be preserved or reflected.
- “Visualize” the path of the osteotome to minimize inadvertent graft fracture or intracranial violation.

Fixation

- Adequate fixation of bone graft is important for healing.

POSTOPERATIVE CARE

- A simple dressing of bacitracin and nonstick gauze is applied to the incision.
- A gauze head wrap is applied.
- If a drain is placed, it should be monitored and emptied daily (or twice daily, as needed). The drain can be removed early if the output is low and there is no suspicion of a cerebrospinal fluid (CSF) leak. The space between the scalp and bone is small and heals quickly.

OUTCOMES

- In the absence of inner table violation and associated dural injury, the outcome following harvest of calvarial bone is relatively good.
- The healing of calvarial bone grafts parallels that of fracture repair. Although osteocytes from the donor site seldom survive following grafting, bone viability is usually maintained following transfer.
- The duration of exposure to air should be minimized.
- On the back table, the graft should be wrapped in a blood-soaked sponge with a moist, saline sponge on top and labeled to avoid inadvertent disposal.
- The recipient site should be healthy and well vascularized. If not, debridement to healthy tissue is required.
- Poor harvest technique may lead to decreased viability with impaired healing and bone strength. Osteocyte activity takes place primarily at the recipient site.⁵
- Viability is affected by the size and thickness of the graft, as well as the suitability of the recipient site. Onlay bone grafts tend to resorb, whereas inlay bone grafts have more favorable survival.⁷

COMPLICATIONS

- The complication rate of calvarial harvest is reported to be as low as 0.25%.⁶
- Similar to other donor sites, pain, paresthesia, and hemorrhage are the most frequent complications.
- Palpable irregularities may also occur, whereas visible deformities are rare and usually covered by hair.
- Alopecia along the incision line occurs with spreading of a tight closure and/or injury to the hair follicles and may be minimized by avoiding thermal injury to this area.
- Any violation of the dura should be repaired to avoid leakage of CSF. This may be performed with either interrupted or running 4-0 Nurodon suture. Bone outside the repair may need to be removed for access and to facilitate placement of one or more sutures. Pericranial or galeal grafts with fibrin sealant may be used to augment the repair.

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11 Cranioplasty Reconstruction with Autogenous Rib Graft

CHAPTER

Scott J. Rapp

DEFINITION

- Cranial defects resulting from trauma, oncologic resection, decompressive craniotomies, osteomyelitis, congenital defects, and cranial vault expansion/remodeling for craniosynostosis may require reconstruction when the defect is large. In the young patient, defects greater than 4 cm² will not close spontaneously, leading to gross contour irregularities and risk of intracranial herniation or injury if left unrepaired.¹
- Other factors that influence healing of bone include age of patient, nutritional status, previous scarring, and surgeries.
- Autogenous rib inlay grafting represents a useful cranioplasty technique to provide structural rigidity to the cranial vault, maximizing bony integration while minimizing infection and resorption.

ANATOMY

- The neurocranium arises from paraxial mesoderm and neural crest cells (**FIG 1**).
- The calvaria develops through intramembranous ossification.
- The cranial base develops through endochondral ossification.
- A definitive diploic space forms by around age two to three and thickness varies on anatomic location.
 - Craniosynostosis leads to both thin calvarial wall and diploic thickness.²

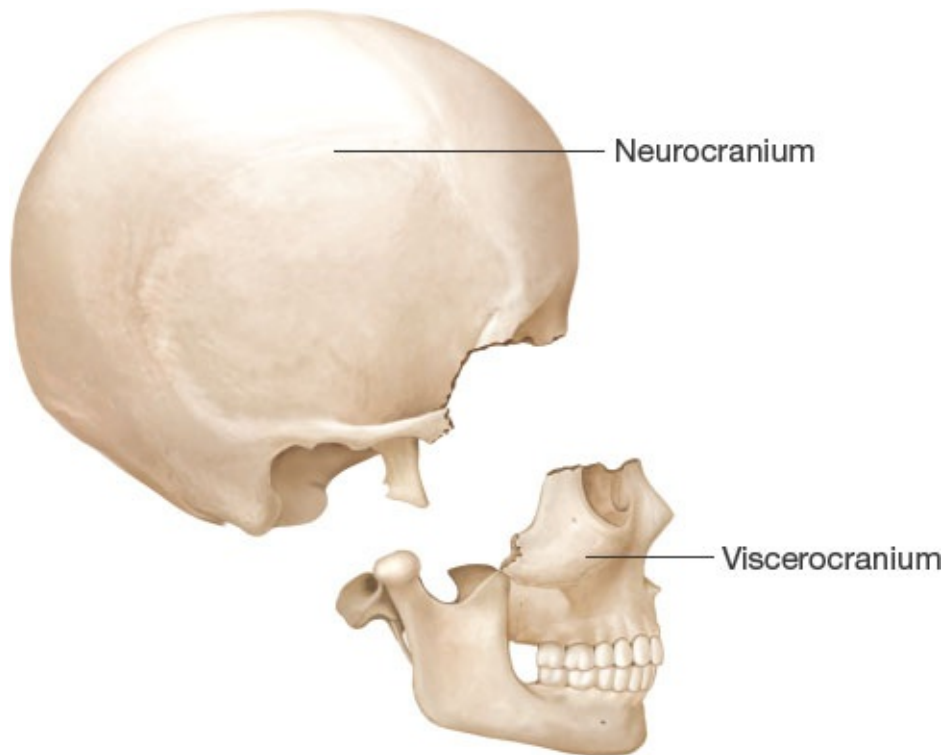


FIG 1 • The neurocranium develops from both endochondral and intramembranous ossification.

- Rib development occurs from paraxial mesoderm and arises from sclerotome cells within the costal process of thoracic vertebrae.
 - True ribs (1–7) attach to the sternum directly by their own cartilage.
 - False ribs (8–10) attach to the sternum by synchondrosis.
 - Floating ribs (11,12) do not attach to the sternum (plain film; **FIG 2**).

PATHOGENESIS

- A critical-sized defect is one that will not heal spontaneously and leads to a fibrous nonunion.
 - 4-cm² gaps are considered “small” with defects greater than 5 cm in diameter or 25 cm² considered “large.”
- Healing of bone gaps in the cranial vault occur through multiple pathways:
 - The dura mater is an important contributor providing a primary source of osteogenic cells and the source of osteoinductive growth factors.
 - Bone growth occurs both centrally and peripherally within the defect.³
 - The periosteum, when present, provides an important source of growth factors and mesenchymal cells including osteoblasts, pericytes, fibroblasts,

and periosteum-derived stem cells.

- Growth factors released include BMP-2, IGF-1, and TGF- β .
- Partial bone growth from the margins of the wound occurs from local osteoblasts through osteogenesis.

NATURAL HISTORY

- Surgical intervention to reintroduce structural integrity within the defect may be accomplished through alloplastic, allograft, and autograft sources.
- Alloplastic materials are biocompatible and hold the advantage of ease of use, ample supply, and no donor-site morbidity.
- The bone substitute acts as a structural lattice, and new bone formation occurs through osteoconduction.
 - May provide greater mechanical strength to the repair
- Useful for small defects utilizing a “spackle” technique
- Larger-sized defects under 5 cm require an absorbable or titanium mesh underlay to provide support against the pulsing dura beneath.
- Titanium mesh may provide intracranial protection rapidly when the defect is large.



FIG 2 • Plain film of floating ribs 11 and 12.

- Alloplastic materials are not recommended in the rapidly growing pediatric skeleton and are associated with higher rates of extrusion and infection.

- Infection rates have been reported to be 5 times higher than other bone grafting materials.⁴
- Avoid using these materials in a postradiated wound bed with diminished blood supply.
- Allograft materials are derived from cadaveric bone.
 - May be fresh or frozen bone
 - Most available source is demineralized bone matrix.⁵
 - Bony regeneration occurs predominately through osteoconduction but may also confer osteoinduction properties as some osteoclasts may survive the free transfer.⁶
- Autogenous bone grafting is the current “gold standard” to correct vault defects long term.
 - Bony healing occurs through osteoinduction, osteoconduction, and osteogenesis—whereby the transplanted osteoblasts survive and contribute to the creation of de novo bone formation.
 - Indications for use include complex or large-sized defects, need for staged procedures, defects near sinuses, previous reconstruction failures, radiated tissue beds, and colonized or infected sites.
 - Autogenous bone grafts can become revascularized.
 - Most frequent autogenous sources of bone grafting to the skull include
 - Iliac crest
 - Split calvarial bone
 - Split rib
 - Parascapular osteocutaneous flap
 - Vascularized bone grafting based on superficial temporal vessels
 - The use of rib grafts as a surgical intervention was first described in 1917 by Brouet.⁷
 - Multiple ribs may be used.
 - Once healed, the bone is smooth and radiographically indistinct by CT imaging.⁸

PATIENT HISTORY AND PHYSICAL FINDINGS

- Cranial defects can first be identified by physical exam and palpation.
- In the young pediatric population, even large-sized defects can be observed for closure spontaneously until patients are more physically active.

- Intervention is usually performed when the patient with a large skull defect becomes more mobile, exposing intracranial contents to risk for harm or herniation.
- Congenital bony abnormalities requiring intervention can result from:
 - Cutis aplasia
 - Cleidocranial dysplasia
 - Craniofrontonasal dysplasia
 - Encephaloceles, gliomas
 - Hypophosphatasia
 - Hypothyroidism
 - Fibrous dysplasia
 - Elevated intracranial pressure from multisuture craniosynostosis

IMAGING

- Noncontrast CT with 3D reconstructions identifies defects adequately.
 - Coronal cuts are useful to evaluate diploic space thickness to assess split calvarial bone grafting as an alternate option for treatment.
- In complex or the multiply operated cranial vault, virtual surgical modeling may be helpful in determining calvarial thickness and location of multiple defects within an area of concern.

NONOPERATIVE MANAGEMENT

- If the patient is unable to undergo surgical reconstruction for any reason and the cranial defect is such that the intracranial contents are at risk, a protective orthotic helmet may be used until comorbidities are corrected.

SURGICAL MANAGEMENT

- Calvarial defects with surface areas large enough to put the intracranial contents at risk necessitate reconstruction.
- Small defects less than 5 cm in size may be repaired with bone substitutes or allograft.
 - Bone substitutes are composed of various polymers:
 - Methyl methacrylate
 - Bioactive glass
 - Hydroxyapatite cement
 - Hydroxyapatite/polylactide
 - Polylactide-co-glycolide

- Polylactide-polyethylene glycol
- Tricalcium phosphate
- Porous polyethylene
- PEEK customizable implant
- Allograft materials include
 - Demineralized bone matrix
 - Frozen cadaveric bone
 - Bone morphogenetic protein-2 growth factor
- Autogenous grafting sources:
 - Particulate bone
 - Bone dust
 - Vascularized bone
 - Corticocancellous bone
 - Cancellous bone

Preoperative Planning

- Involving the neurosurgical team may be warranted.
 - Using a two-team approach is more efficient when harvesting rib grafts with concomitant exposure of the cranial defect.
 - Multiple previous operations have a higher risk of dural injury during dissection and defect exposure.
- Understanding the previous surgical history is integral in planning the reconstruction.
 - Ensuring an adequate surrounding blood supply optimizes bony healing and regeneration.
 - Multiply operated scalp tissue or destruction of periosteum may increase rates of nonunion, infection, or resorption rates.
 - Osteomyelitis, infected hardware, or other alloplastic materials should be removed or debrided to healthy bone/tissue.
 - May require staging operations before bone grafting

Positioning

- Positioning is determined by location of the calvarial defect.
 - If prone positioning is required, securing the endotracheal tube in place may be necessary.

- Secure the airway with circumdental, circum-mandibular, or transalveolar suturing/wiring to reduce intraoperative malposition of the endotracheal tube.
- For rib harvest, use of a shoulder roll and hip bump can improve exposure (**FIG 3**).
- Turning the table 90 or 180 degrees allows access to both sides of the patient.
- Proper pressure relief is necessary due to potential lengthy time of operative intervention.



FIG 3 • Exposure to rib harvest is improved with a shoulder roll and hip bump.

- Use foam or gel under the occiput, elbows, hips, knees, and heels.
- Serial compression devices are used in older patients.

Approach

- Approaches to the cranial defect may often be accomplished through utilization of previous incision sites.
- Complex or large defects may require extension of the previous craniotomy incision or a conversion to a coronal incision for maximal exposure.
- Wide exposure is critical for adequate bone debridement and the ability to control hemostasis as well as reduce iatrogenic dural injury.

TECHNIQUES

■ Cranial Defect Exposure

- Hair is trimmed along the planned incision site approximately 2 cm in width to prevent contamination during closure.
 - It is not necessary to shave the entire head or to use a straight razor.
 - A combination of alcohol and Betadine paint is used to cleanse the entire scalp.
- Ioban drapes may be used to help keep hair out of the incision site.
- The planned incision site is infiltrated with dilute epinephrine and 10 minutes allowed to elapse.
 - It is the author's preference to use 0.25 % Marcaine with epinephrine 1:200 000 in the pediatric population for ease of weight-based calculations.
- The skin is incised sharply, and the small perforating vessels are controlled with bipolar cautery to prevent hair root damage and resultant alopecia.
- Skin hooks help elevation of the scalp in the subgaleal plane while exposing the bony defect.

■ Creation of the Bony Defect

- The periosteum is left undisturbed to the edge of the bony defect.
 - Electrocautery and periosteal elevators help separate the periosteum or fibrous scar tissue from the bone-dural interface.
- Once the defect edge is identified, assessing the quality of the tissue overlying the dura is important.
 - Often, blunt sweeping with a periosteal elevator is all that is required to elevate the scalp tissue off the dural surface.
 - When fibrous tissue is densely adherent to the dura, bipolar cautery may be necessary to develop a dissection plane.
 - Extensive scar tissue overlying the dura should be left in place, and electrocautery is utilized to divide this scar tissue in a location overlying intact calvarial bone.
- With neurosurgical team assistance, the dura is then reflected from the inner table of the calvarium to allow screw or plate fixation safely.

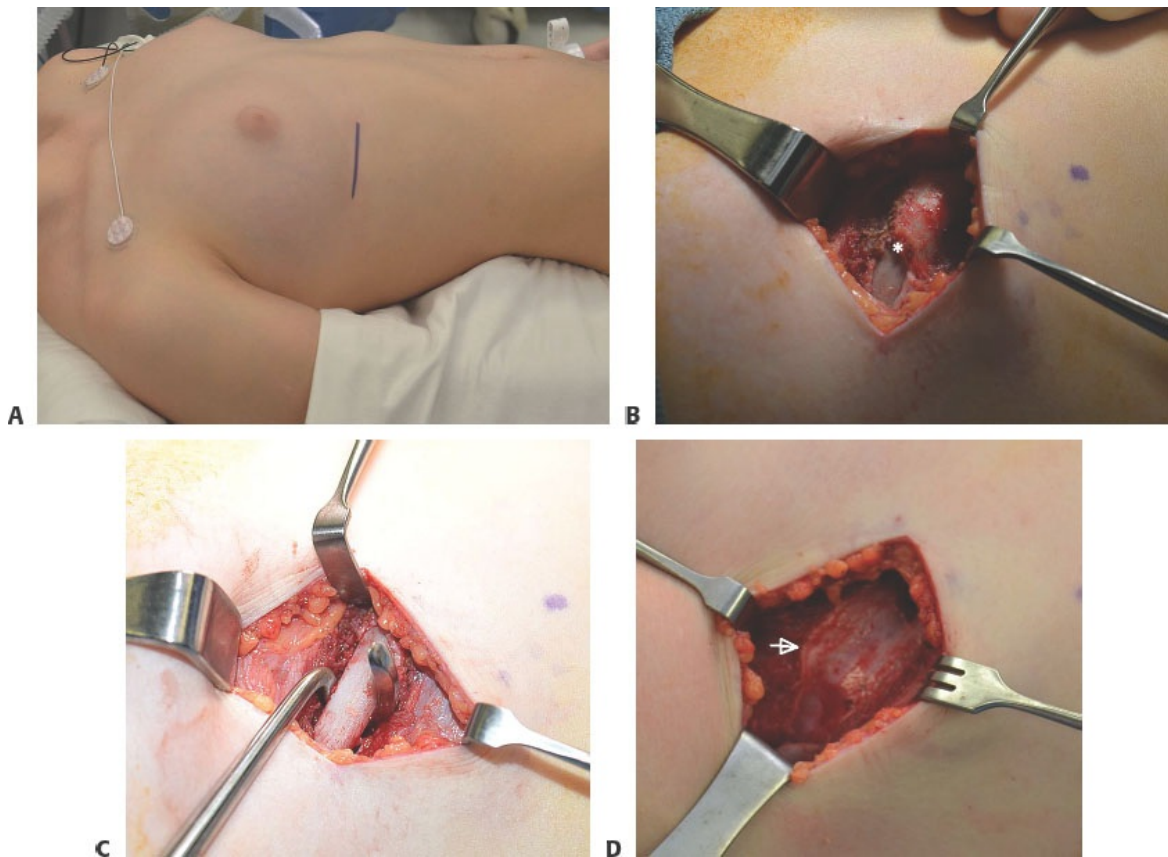
- Useful instruments include
 - Penfield no. 1 or 4
 - Cottle elevator
 - Small bone curette
-

■ Rib Harvest

- For ease of access, plan for harvesting the ribs on the same side of the cranial defect.
- The sixth or seventh rib is easiest to harvest.
- Overlying skin incision length is usually around 3 to 6 cm depending on the patient's age.
 - Orientation should be horizontal in females for better concealment of scar (**TECH FIG 1A**).
 - Be cognizant of breast bud location in the pediatric patient when multiple rib removal is required.
- Infiltrate the skin incision with local anesthesia and epinephrine.
- Dissection should be over a palpable rib to prevent iatrogenic pleural cavity injury.
- Split the periosteum over the anterior portion of the rib sharply and preserve the entire periosteal layer.
 - Limit electrocautery use when elevating the periosteum from the bone to preserve its function and regenerative cambial layer.
 - Bluntly dissect the periosteum from the rib circumferentially with a periosteal elevator (Freer or Molt no. 9) or a Doyen rib dissector.
- Expose the rib medially and laterally until the desired length is required (**TECH FIG 1B**).
- The Freer elevator or no. 10 blade scalpel with the Doyen protecting the pleura can be used to separate the costochondral junction (**TECH FIG 1C**).
- Once the cranioplasty is completed, morselize any remaining bone and place it back into the periosteal sleeve of the donor site.
 - Close the periosteum primarily to allow for maximal regeneration of rib bone (**TECH FIG 1D**).⁹
- Irrigate the wound and submerge the donor site.
 - Anesthesiologist should perform Valsalva of the patient to check for air

leak (bubbles) if pleural injury is suspected.

- Close the remaining layers of tissue.

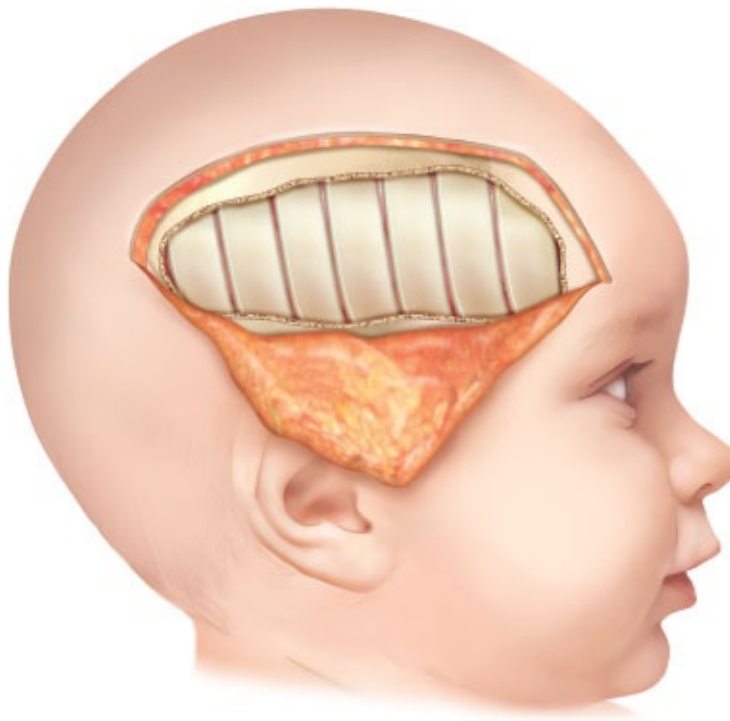


TECH FIG 1 • **A.** An incision is placed in the inframammary fold providing access to ribs 4 to 8 while being aesthetically sensitive to scar location. **B.** Oblique muscles are divided until rib periosteum is identified and divided longitudinally to the level of costocartilage junction. **C.** A Doyen rib elevator is used to remain in the subperiosteal plane and avoid pleural injury. **D.** Following rib harvest, primarily close the periosteum (*arrow*) for rib regeneration. A pleural leak test is performed by submerging the donor site under saline while in Valsalva maneuver to check for air bubbles.

■ Split Rib Technique

- Once the rib has been harvested, place the graft in normal saline or saline-soaked gauze sponges.
- The bicortical osteotomy is made by a Sonopet ultrasonic osteotome (Stryker, Kalamazoo, MI).
 - Selected tips include the Nakagawa knife or an aggressive serrated tip.
 - Precise cuts can be made even in thin bone and unintended fracturing of the bone is limited.
 - Alternatively, a reciprocating saw may be used with bone clamps to provide stabilization.
- Tessier bone-bending forceps help contour the bone to the curvature required to fill the cranial defect (**TECH FIG 2**).
 - To prevent fracture, make small crisscross adjustments when applying pressure with the forceps.

TECHNIQUES



TECH FIG 2 • Contour ribs to fill defect with maximal surface area contact to calvarial bone.

■ Cranioplasty Technique

- Debride calvarial bone to healthy bleeding portions if the bone has previously been infected or demonstrated nonhealing.
 - After contouring the split rib, rongeur forceps are used to tailor the shape to fit the defect.
 - Lag screws or thin titanium plates can be used to fixate the rib with 3- to 4-mm unicortical screws.
 - Rib graft remnants can be morselized and placed in the gaps.
 - Fibrin glue can help to secure the small pieces.
 - Demineralized bone matrix or other bone substitutes can be added to smooth the rough edges of ribs or fill in small gaps.
-

■ Scalp Closure

- After cranioplasty has been performed, a channel drain is placed near the wound and exited through a separate puncture site in the scalp.
 - The incision is closed with interrupted Vicryl suture in the galea followed by a running absorbable suture in the scalp.
 - Dermabond application reduces drainage from the incision postoperatively.
 - Telfa pads are placed over the incision.
-

PEARLS AND PITFALLS

Reducing resorption rates

- Preserving overlying cranial periosteum adds improved regenerative capacity and improved blood supply. Maximizing surface area contact of the rib to calvarial edge improves outcomes.

Donor-site contour irregularity

- All remaining unused bone graft should be morselized and placed into the periosteal sleeve at the donor site. The periosteum/perichondrium should be preserved and reapproximated during closure.

Pleural cavity disruption

- Close the pleural defect around a red rubber catheter with a purse-string suture, including the catheter. Anesthesia team delivers a Valsalva breath to the patient; at the peak of the delivered breath,

	remove the catheter as the purse string is tightened. A residual leak after repair can be tested for by submerging the area with saline and checking for bubble leaks with a second Valsalva maneuver.
Graft failure	■ Ensure there is rigidity to the repair. Mobile bone graft has a higher infection rate and will likely not integrate and will slowly resorb over time.
Inadequate coverage of defect with rib graft alone	■ Multiple techniques can be combined including split calvarial grafts or inner table particulate bone harvest along with allograft materials.

POSTOPERATIVE CARE

- Antibiotics covering the skin flora are prophylactically given for 3 days postoperatively if alloplastic materials are utilized.
- The drain is removed when output is <30 cc for 2 consecutive days.
- The absorptive dressing is removed approximately 2 days after surgery when the hair and wound can be washed.
- Bone healing and bridging are evident at 6 months.
 - Contact sports and strenuous physical activity that could expose the surgical site to trauma should be limited during this time.

OUTCOMES

- Complications reported in the literature are few.
 - There are two reported cases of infection and one case of bony resorption in a meta-analysis of 138 patients in 17 studies undergoing split rib grafting in the face and cranium.¹⁰
- Structural integrity and bone integration are evident postoperatively by 6 months when imaged.¹¹
- Pneumothorax/hemothorax rates are <1% with only four reported cases.^{10,12}

COMPLICATIONS

- Infection
- Resorption
- Contour irregularities in the skull or donor site
- Donor-site pneumothorax
- Hemothorax

- Respiratory problems
- Donor-site pain
- Unsightly donor-site scarring
- Longer operative times

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12 Three-Dimensional Implant Reconstruction for the Cranial Vault

CHAPTER

Barry L. Eppley and Sunil Tholpady

DEFINITION

- Three-dimensional (3D) implant reconstruction of the cranial vault involves the reconstruction of full-thickness skull defects with implants of various materials made from a 3D computed tomography (CT) scan and by computer design.¹

ANATOMY

- The external shape of the skull is composed of six bones—the frontal, parietal (two bones), temporal (two bones), and occipital.
- The only soft tissues of relevance to the external skull shape are the temporal muscles on the side of the head.
- The front to back shape of the skull is a convexity, whereas the sides of the skull are more linear or slightly concave.
- The thickness of the skull and its three layers (two cortices and diploid space) vary widely at different positions of the skull as well as among different genders and ethnicities.

PATHOGENESIS

- Full-thickness skull defects can occur due to the following:
 - Craniotomy/surgical defects
 - Traumatic injuries
 - Congenital skull deformities

NATURAL HISTORY

- Skull growth is complex and the result of both endochondral and

intramembranous ossification.

- It becomes a more united and solid structure when both the fontanelles close and the sutures become more rigid.
- This occurs as early as 2 years of age; the thickness of the skull continues to increase up until adulthood to accommodate brain growth and expansion.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Determine
- Location and size of the skull defect
- Quantity and quality of overlying soft tissue coverage
- Underlying dural integrity
- Frontal sinus proximity and potential exposure
- Indwelling fixation hardware/alloplastic skull coverage (eg, metal mesh)
- History of radiation

IMAGING

- High-resolution (slices of 1 mm or less) 3D CT scan is essential to evaluate the size and thickness of the skull defect as well as for computer design of the reconstructive implant (**FIG 1**).

DIFFERENTIAL DIAGNOSIS

- A full-thickness skull defect is obvious on physical exam and by 3D CT scan.
- The following questions need to be addressed:
 - Is there adequate soft tissue coverage to cover an expanded bone contour?
 - Are the bone and soft tissues healthy (nonirradiated)?
 - Is there exposure of the frontal sinus into the defect, or will there be in order to properly inset the implant?

NONOPERATIVE MANAGEMENT

- There are no nonoperative methods to recreate the shape of the skull.
- In large nonoperative skull defects, protective headwear may be recommended for protection of the brain.

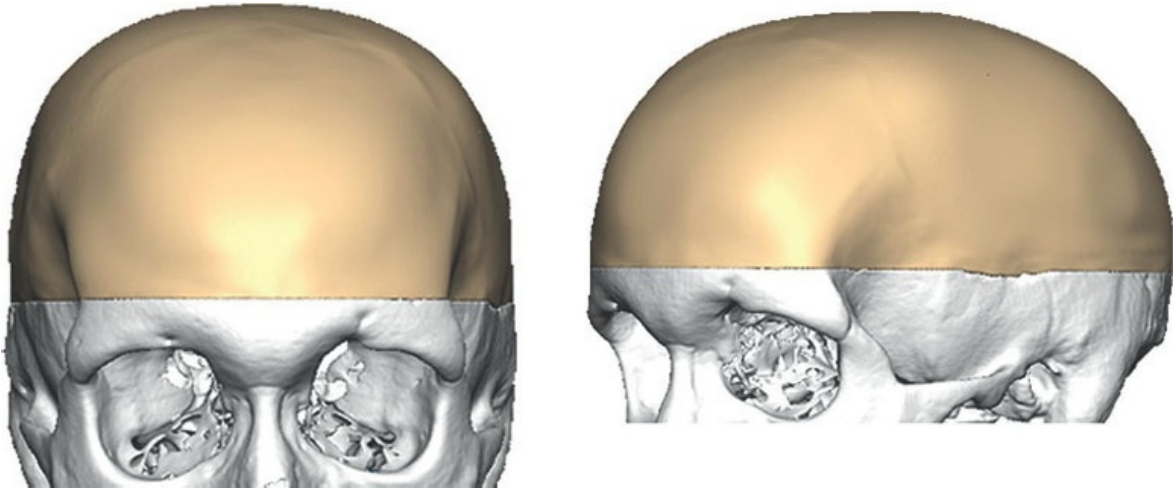


FIG 1 • Three-dimensional total custom skull implant replacement design.

SURGICAL MANAGEMENT

- Determine what type of implant material and size of custom skull implant that are needed to rebuild the skull thickness and shape (HTR-PMI, Titanium, PEEK, PEKK material options).¹
- Choice of implant is based on surgeon preference. There is no proven biologic advantage to any implant material over any other. However, they do have different handling characteristics.^{1,2}
- Ensure that adequate and healthy overlying soft tissue coverage exists.
- If the skull defect has been previously irradiated, vascularized soft tissue coverage will need to be completed first (eg, free flap).²
- If the frontal sinus is exposed or will be in contact with the implant, vascularized coverage must be needed (eg, pericranial flap).

Preoperative Planning

- 3D CT imaging is needed for the computer design and fabrication process from a manufacturer who offers this capability.

Positioning

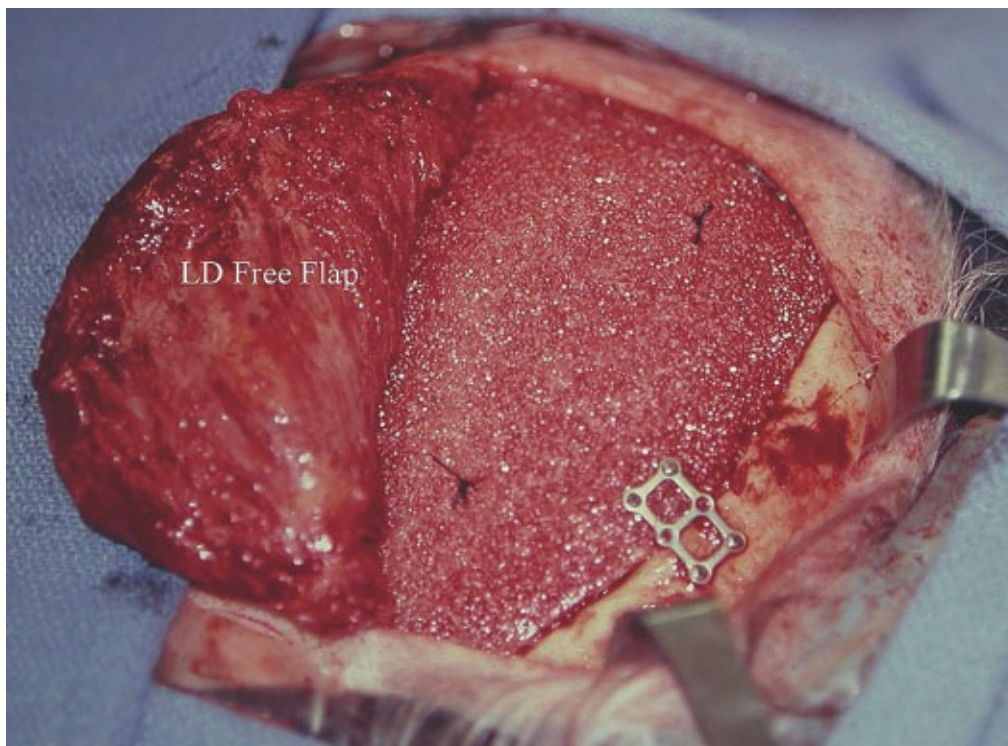
- The patient is placed in the supine or prone position on a Mayfield head rest on the operative table depending upon the location of the skull defect.
- The procedure can only be done under general anesthesia.
- Hair may or may not be shaved depending upon the patient's current hairstyle.

- Local anesthetic such as 2% Xylocaine with 1:100 000 epinephrine is infiltrated into the previous scalp incision, which exists in most cases.
- If no incision is present, a coronal scalp incision can be considered.

TECHNIQUES

■ Exposure and Pocket Creation

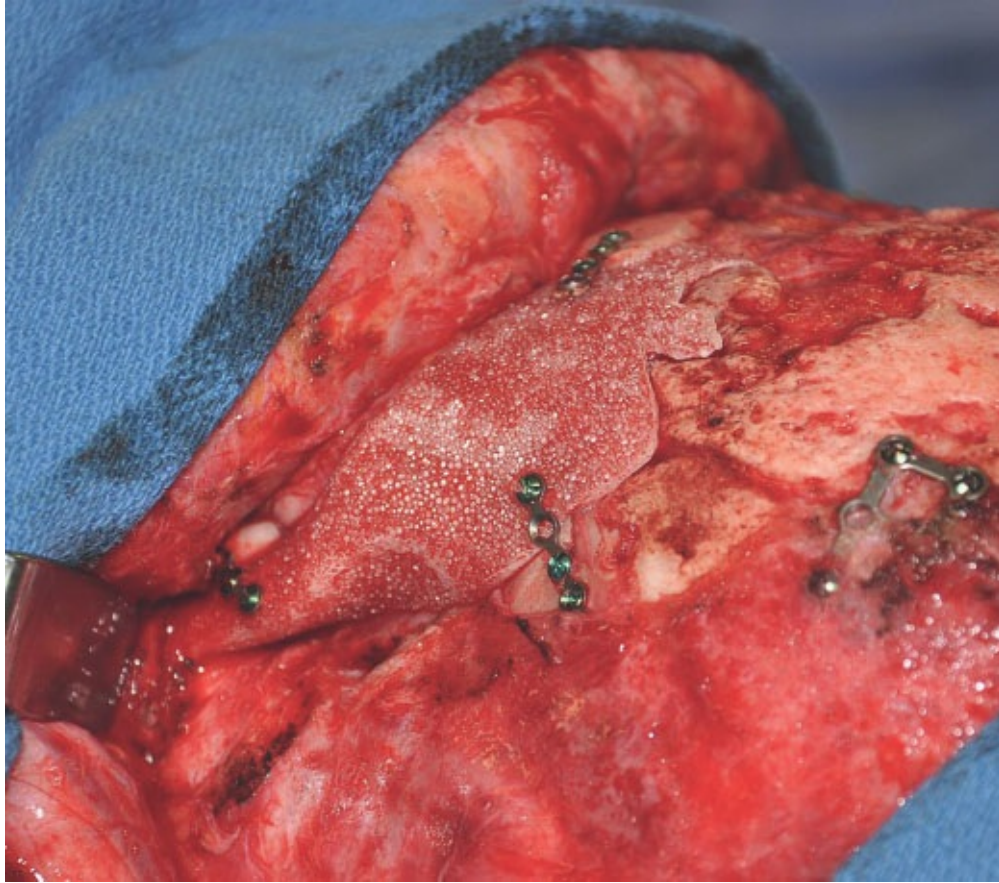
- The previous scalp incision is fully opened for wide access to the skull defect (**TECH FIG 1**).
- In the event that no scalp incision exists or is inadequate for access, extensions of the prior incision will be needed, or a new full coronal scalp incision is made.
- Wide subperiosteal undermining to raise the overlying scalp flaps is needed for full skull defect exposure.
- Any existing metal fixation hardware is removed.
- The dura is elevated from the skull defect edges and repaired if its integrity is violated.



TECH FIG 1 • Free flap coverage (latissimus dorsi muscle) of previously irradiated full-thickness frontal skull defect prior to placement of custom skull implant.

■ **Implant Placement and Fixation**

- The custom skull implant is initially soaked/washed in an antibiotic solution (gentamicin and Betadine) and placed into the skull bone defect.
- The fit of the implant should be perfect due to the initial CT-based computer design.
- Any adjustments to make the external shape smooth and confluent with the surrounding skull bone, as well as the edge transitions, is almost always done on the implant but also is necessary on the skull edges and can be performed with a handpiece and bur.
- Fixation of the custom skull implant is advised and is best done by low-profile plates and screws (1.1–1.6-mm plate profiles and screw diameters) in at least three locations for a triangulation fixation effect (**TECH FIG 2**).
- Wire and suture fixation can also be used, but low-profile plate and screw fixation is preferred.



TECH FIG 2 • Plate and screw fixation.

■ Closure

- Closure over the implant should be done in three layers—galea, dermal, and epidermal skin.
- Closure of any portion of the incision immediately over the implant must be waterproof and tension-free.
- If possible, avoid placing the incision directly over the implant.
- The use of a surgical drain is often used but is up to the surgeon's discretion.

PEARLS AND PITFALLS

Presurgical

- A 3D CT scan is used to design the custom implant to precisely fit

assessment with CT	the full-thickness skull defect.
Implant material selection	■ Custom implant material selection includes HTR, titanium, PEEK, and PEKK. None of these materials have been proven to be superior to the other; they all work equally well.
Subperiosteal defect exposure	■ Wide tissue release and exposure are needed, so take full advantage of any existing scalp incisions or extend them as needed.
Implant positioning	■ The surgeon can modify the implant or the edges of the bone to obtain the best transition between the implant and the outer bone surface.
Implant fixation	■ Plate and screw fixation is essential to optimally stabilize the implant into the skull defect site.
Postoperative management	■ Patients need to wait at least 12 weeks after surgery for an accurate assessment of skull contour results.

POSTOPERATIVE CARE

- A head dressing is applied for the first night of surgery. It is removed the following day.
- If a drain has been placed, it is also removed the day after surgery.
- IV antibiotics are given as long as the patient is hospitalized. Oral antibiotics with coverage of Staphylococcal organisms are given for 7 days after surgery when the patient is discharged home.

OUTCOMES

- Custom 3D skull implants always improve the outer cranial contour and provides enhanced brain protection.^{3,4}
- The external aesthetic appearance is a reflection of adequate design and surgical inset of the implant and having normal overlying soft tissue thickness (**FIG 2**).

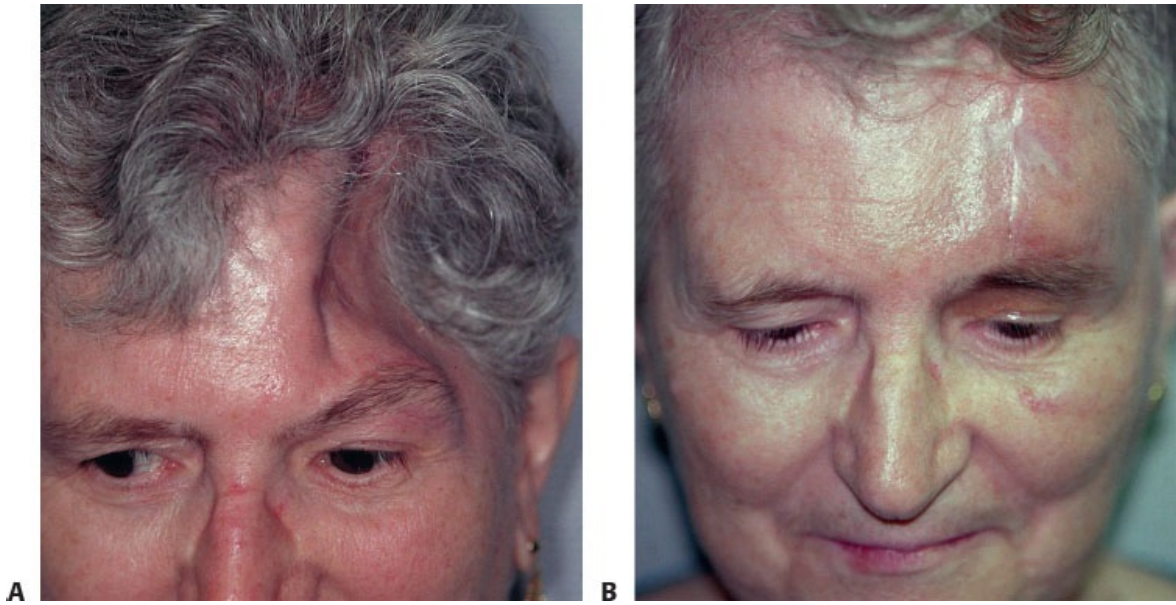


FIG 2 • A,B. Reconstruction result. Preoperative view (A) of a patient with a left forehead and temporal defect, with postoperative improvement in skull contour (B) after implant placement.

COMPLICATIONS

- Infection usually presents as swelling and drainage anywhere from 2 to 6 weeks after surgery. This is of greatest occurrence when the implant is close to or has involved the frontal sinus.
- Asymmetry/edging can be assessed no sooner than 6 weeks after surgery when most of the swelling is gone to determine the true skull shape.
- Overcorrection/undercorrection: One should allow a full 3 months after surgery for all swelling to subside and for the patient to adjust to his or her new look. Earlier interpretations, particularly that of overcorrection, may be premature.

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13 Alloplastic Reconstruction of the Calvarium

CHAPTER

Peter J. Taub

DEFINITION

- Cranioplasty involves reconstruction of the bony anatomy of the skull.
- This may be done with autogenous bone grafts, an alloplastic implant, or a titanium mesh.

ANATOMY

- The calvarium in the adult is composed largely of an outer cortex or cortical bone, a matrix of cancellous bone and marrow, and an inner cortex of cortical bone.
- The specific curvature of the calvarium in the area of the defect should be observed and taken into account when performing the reconstruction.

PATHOGENESIS

- Loss of calvarium may have multiple etiologies.
- Patients may require craniotomy for tumors, during which the resected bone cannot be replaced at the index procedure secondary to cerebral swelling and the need to avoid increased intracranial pressure.
 - The bone graft is left buried in the subcutaneous layer of the abdomen for later replacement.
 - Occasionally, the graft becomes infected and can no longer be replaced.
- Patients with benign or malignant osseous or soft tissue tumors that invade the bone require resection of a portion of the calvarium (**FIG 1**).
- In cases of trauma, portions of the skull may be shattered such that they cannot be used for reconstruction.
 - The mechanism of injury is generally blunt rather than penetrating.

- Prior to the routine installation of seat belts in automobiles, a preponderance of cases was caused by motor vehicle accidents. More recently, assaults have become more prevalent.
- Other causes of skull injury include sports injuries, occupational incidents, and falls.

NATURAL HISTORY

- Patients should be medically stable prior to considering cranioplasty.
- The timing may also be related to the presence of associated symptoms.
- Postcraniectomy patients may present with “the syndrome of the trephined.” This is an infrequent and delayed complication.
- Common radiologic findings include paradoxical herniation, deviation of the midline structures, and sunken skin flap.¹
- The spectrum of symptoms ranges from seizures to headaches to neuropsychiatric disturbance to focal weakness to midbrain syndromes² and parkinsonian symptoms.^{2,3}

PATIENT HISTORY AND PHYSICAL FINDINGS

- In the acute setting, the primary concern for any patient with head injury is possible cervical spine trauma.
- Specific signs and symptoms of cervical spine injury include a neurologic deficit, point-specific neck pain, and possible palpable step-off on neck exam.
- There may be a noticeable area of deficient bony support for the overlying soft tissues of the scalp (**FIG 2**).
- The laxity of the soft tissues over the defect should be evaluated. Generally, the amount of concavity produced by the defect will match the convexity of the implant. Thus, preoperative tissue expansion is generally not required.
- If soft tissues appear to be tight and firm to palpation, tissue expansion should be considered prior to reconstruction.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Preoperative evaluation should include a computed tomography (CT) scan to evaluate the size and extent of the potential defect (**FIG 3**). The data may be reformatted into a three-dimensional representation.

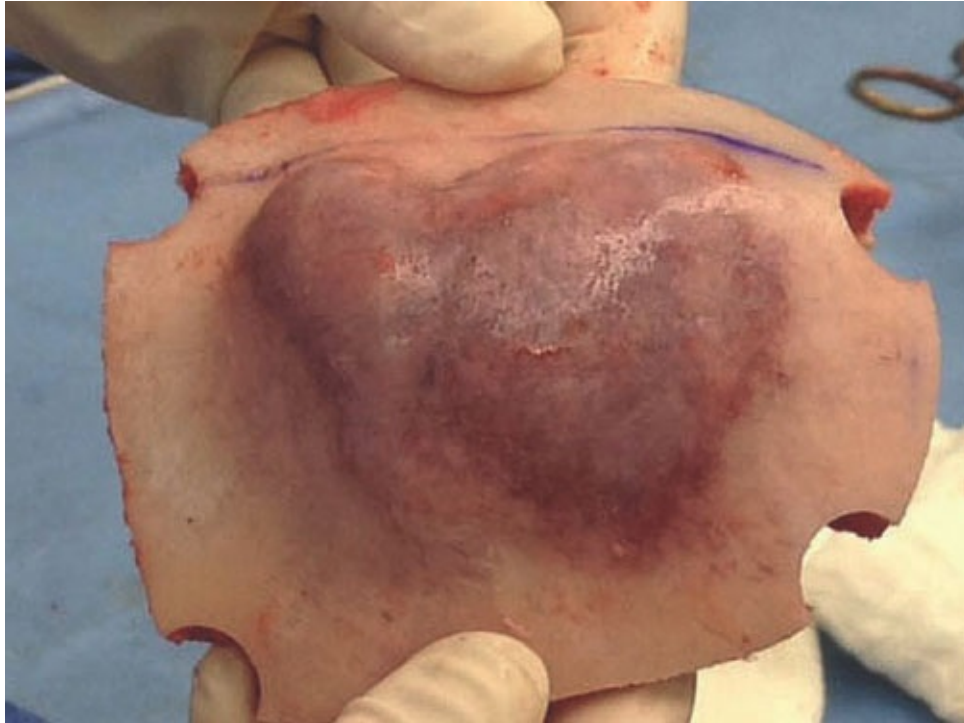


FIG 1 • Resected calvarial tumor specimen.



FIG 2 • Patient with a significant left parietal skull defect.

- The CT should also be used to rule out additional craniomaxillofacial injuries.
- A cervical spine series should be done at the time of injury to rule out cervical spine fracture or dislocation. This is done prior to discontinuing the protective collar.

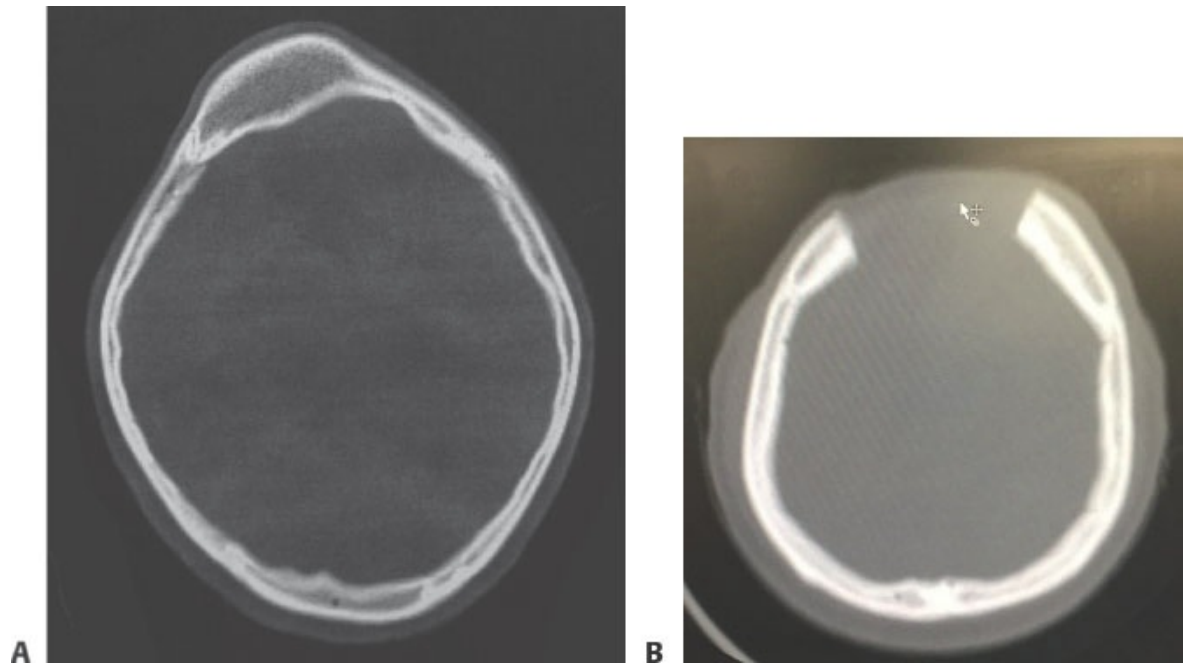


FIG 3 • Preoperative axial CT scans of a tumor **(A)** and of a left frontal defect **(B)**.

SURGICAL MANAGEMENT

Preoperative Planning

- The CT scan should be reviewed to determine where the screws may be placed to fixate the titanium mesh in place.
- Danger zones, including the midline sagittal suture, should be avoided.

Positioning

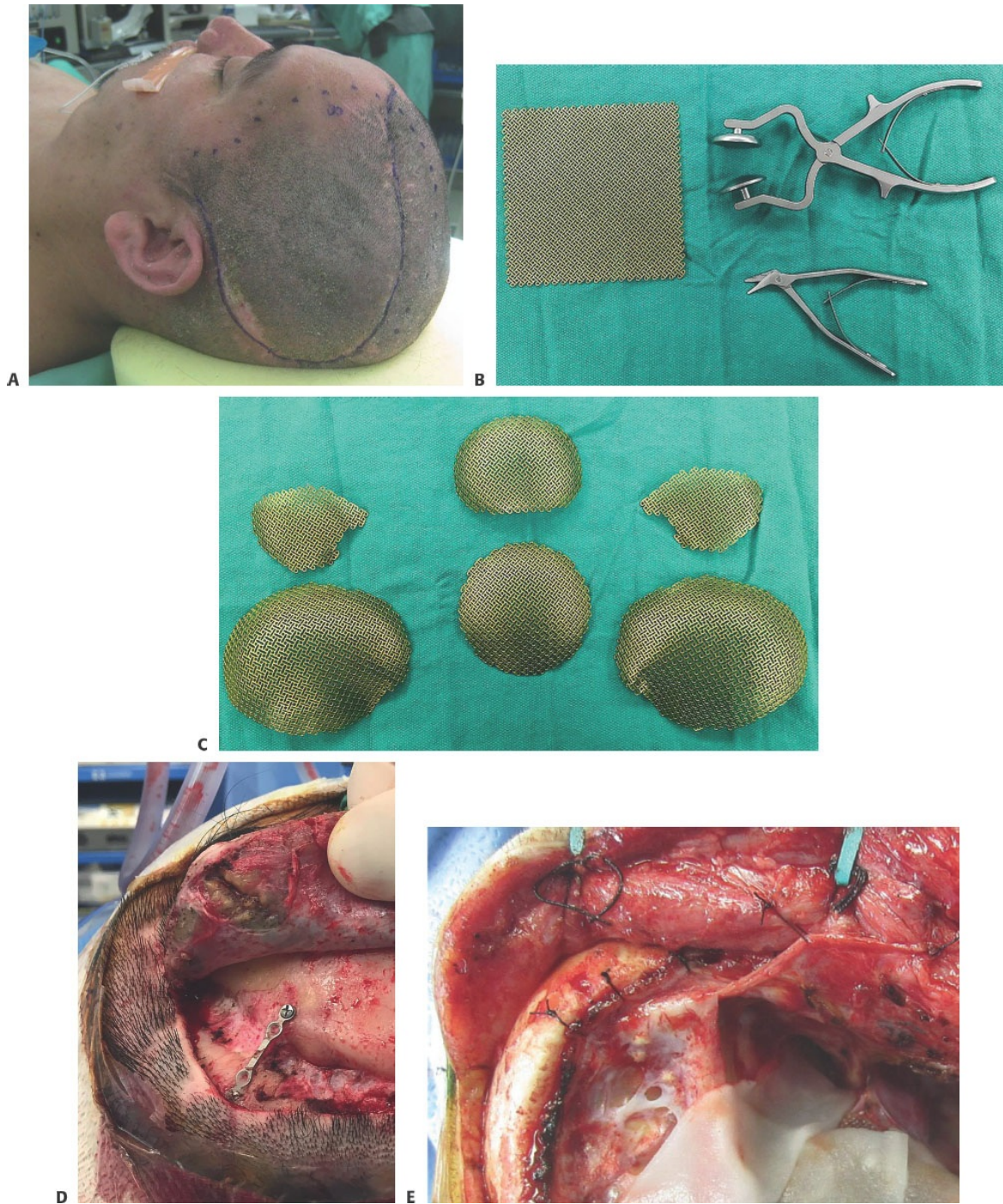
- The patient is positioned supine with the head stabilized. This may be achieved with a foam donut, a horseshoe extension of the operating table, or a Mayfield headrest.
- The torso should be restrained with a belt in case the table is rotated during the procedure.

- A strip of hair may be shaved where the coronal incision is to be made and hair on either side combed away from the incision and gathered into elastics.
- The surgical preparation should include the hair (and face if needed) to the level of the headrest.
- Avoid exposure keratitis by applying ointment to the eyes and using a more dilute prepping solution near the eyes.
- The face can be draped out of the operative field or incorporated into it based on surgeon preference.

TECHNIQUES

■ Alloplastic Cranioplasty

- Existing incisions should be considered for exposure (**TECH FIG 1A**). If insufficient, they can be extended while being cognizant of the vascular pattern of the scalp.
- A coronal incision provides ideal exposure for the entire calvarium. Dissection proceeds through the skin, underlying soft tissue, and galea, to the pericranium. The pericranium may be dissected from the bone or left in place to hold loose fragments of the outer table together. Elevation of the pericranium is performed with an Obwegeser-type periosteal elevator.
- Bleeding from underlying perforating vessels to the periosteum may be controlled with direct electrocoagulation or with a minimal amount of sterile bone wax.
- Bone around the margin of the defect should be exposed and freed of overlying soft tissue to allow the implant to sit on the edge of the bone.
- Most titanium mesh implants are thin enough to easily bend or conform to the margins around any given defect (**TECH FIG 1B**).
- Some implants are prebent by the manufacturer (**TECH FIG 1C**).
- Excess mesh should be trimmed.
- Sharp edges should be removed.
- It should be noted that alloplastic implants are not completely inert and can erode into the overlying soft tissues (**TECH FIG 1D**).
- Dural tack-up sutures should be placed to minimize postoperative epidural collection (**TECH FIG 1E**).



TECH FIG 1 • A. Intraoperative lateral photograph with the prior anteriorly based scalp flap incision marked. **B.** Standard titanium mesh plates and bending forceps. **C.** Prebent titanium plates to address left parietal, right parietal, or frontal defects. **D.** Erosion of

a titanium plate into the overlying soft tissues of the scalp. **E.** Placement of dural tack-up sutures.

PEARLS AND PITFALLS

Implant choice

- Cranioplasty may be safely done with a variety of materials, including autogenous bone graft(s), an alloplastic implant, or a titanium mesh.

Technique

- The entire margin of the defect must be identified and freed of overlying soft tissue.
- Material, including screws and plates, should be as flush with the bone as possible to minimize the risk of extrusion.

Monitoring

- Postoperative observation should note any changes in hemodynamics or mental status.

POSTOPERATIVE CARE

- A simple dressing of Bacitracin and nonstick gauze is applied to the incision.
- A gauze head wrap is applied.
- If a drain is placed, it should be monitored and emptied daily (or twice daily, as needed). The drain may be removed fairly early if the output is low and there is no suspicion for CSF leak. The space between the scalp and bone is limited and heals relatively quickly.



FIG 4 • Postoperative titanium mesh exposure following cranioplasty.

OUTCOMES

- Patients generally do well following cranioplasty with low reported rates of complications.⁴
- Some authors have reported that performing cranioplasty during a subsequent hospitalization may reduce the risk of graft infection. They surmise it may be related to a higher hemoglobin level and lower bacterial colonization.⁵

COMPLICATIONS

- Dural or CNS injury
- Epidural bleed
- Wound infection
- Hardware infection⁶

- Hardware erosion (**FIG 4**)
- Hardware malposition

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CHAPTER Craniopagus Twins

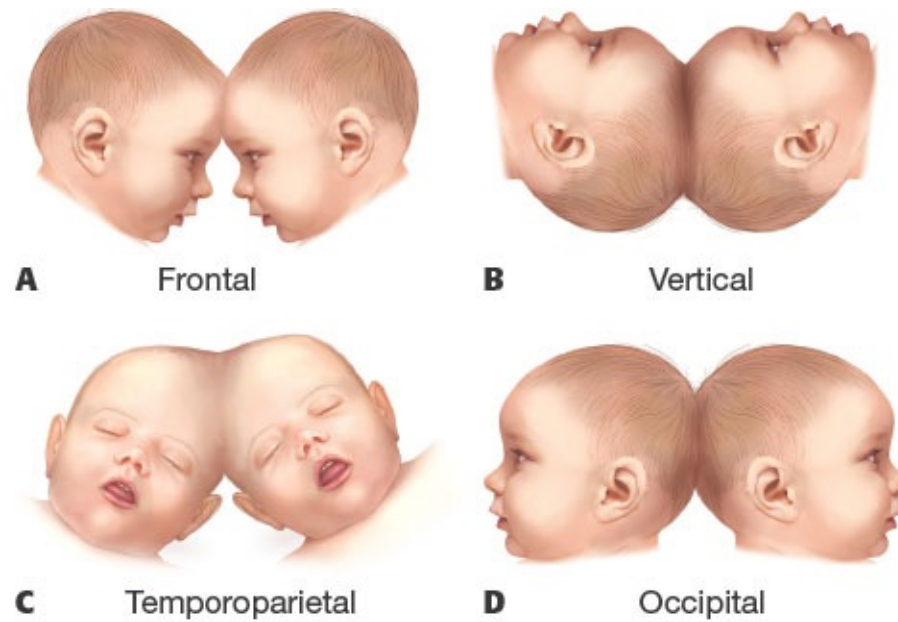
David J. Dunaway and Noor Ul Owase Jeelani

DEFINITION

- Craniopagus twins (conjoined at the head; CPT) are extremely rare, occurring in about 1:2.5 million live births. They account for 2% to 6% of all conjoined twins.¹⁻³
- Classifications include (**FIG 1**)⁴:
 - Partial (localized) or total
 - Angular or vertical (types I to III)
- The degree of union varies, and shared tissues may include skin, bone, dura, brain, and venous drainage system.
- The possibility of separation is dependent on the degree and pattern of tissue sharing and whether or not this allows the possibility of leaving an uninjured well-vascularized brain.

ANATOMY

- Partial CPT is less common than total CPT and may involve any number of tissue layers including the dura. The cortical gyri may interdigitate but are usually separable. Significant intracranial dural venous cross circulation is rare. Union is usually either frontal or occipital.



O'Connell Classification of Vertical Craniopagus

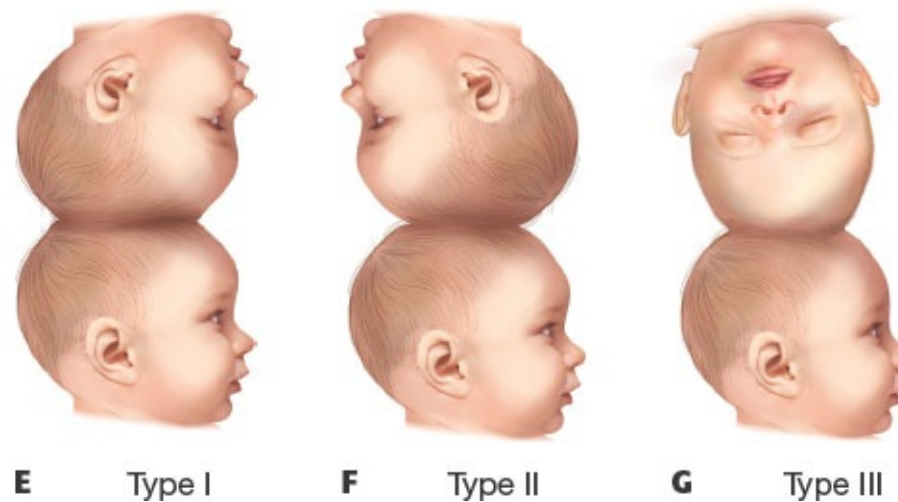


FIG 1 • Classification of craniopagus.

- Total vertical CPT has a longitudinal stovepipe configuration, and the three O'Connell subclasses describe the angulation of the twins (see **FIG 1**).
- The scalp derives its blood supply from both twins allowing skin flaps to be raised across the twins to aid reconstruction.
- The calvarium is fused. Both sagittal sutures are absent and replaced by a ring suture running circumferentially around the cylindrical skull.
- The dura separating the two brains is single layered and usually incomplete.

- Cerebral arterial supply is generally separate, although minor degrees of crossover occur.
- The cerebral venous drainage is shared and complex. The superior sagittal sinus is absent from both twins and is replaced by a complete or incomplete circumferential venous sinus (CVS). Mixing of the venous circulations occurs and blood generally drains preferentially to one twin (**FIG 2**).⁵
- The brains abut in a flattened, tilted plane that does not align with the circumferential cranial suture. Areas of cerebral cortex may be fused.
- Total angular CPT form a heterogeneous group, and there are several classifications. Classification is generally by area of union. Winston proposed a grading system based on the deepest structure involved, which is prognostically useful.⁶

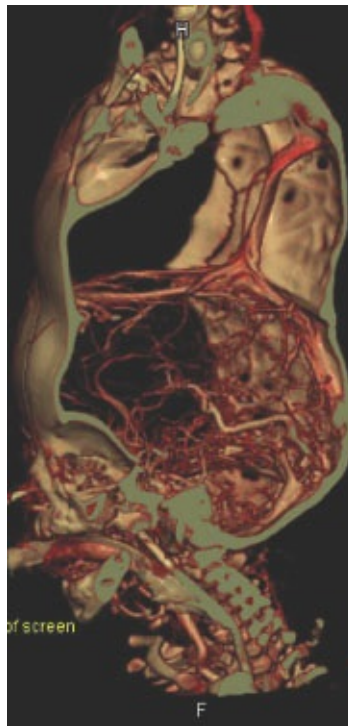


FIG 2 • CT angiography demonstrating the circumferential venous sinus (CVS) and venous drainage across the twins.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Diagnosis is usually made antenatally. Planning separation of CPT relies primarily on information gained from imaging. The history and physical

examination are important in eliciting physiological effects in planning surgical access.

- Extracranial and general effects include the following considerations:
 - Airway: It may be difficult to position the twins to protect both airways. Airway support or tracheostomy may be required.
 - Circulation: Total CPT results in significant mixing of venous blood that usually drains preferentially to one twin. This has two major consequences:
 - Cardiovascular: Increased venous return increases cardiac load and in severe situations can lead to cardiac failure. The unequal venous drainage and fluid distribution generally results in hypertension in one twin and hypotension in the other. This asymmetrically shared blood supply has significant anesthetic implications.
 - Renal: Large volumes of urine are generally produced by the hypertensive twin, whereas the other produces very low volumes of urine.
 - Nutrition: In situations where there is significant venous shunting, the high metabolic demands placed on the twin with high cardiac output generally produce an underweight twin.

IMAGING

- Detailed multimodality imaging provides key information for general management and is essential for surgical planning (**FIG 3**).⁷
 - CT: Visualizes bony morphology, sutural pattern, and the relationship of the brain, skin, and dura to the skull
 - MRI: Delineates brain and dural anatomy indicating areas of possible cortical fusion and dural defects
 - Digital subtraction angiography: Provides anatomical information about arterial and venous systems and the extent and direction of vascular crossover between the twins. This modality also characterizes the relationship between the deep and superficial venous drainage systems of the brain for planning separation.
 - CT angiography: Characterizes the anatomy of the dural venous sinuses
 - 3D medical modeling: Stereolithographic models assist in interpreting complex venous and bony anatomy and improve surgical planning (**FIG 4**).⁸

NONOPERATIVE MANAGEMENT

- It may not be possible to separate some pairs of CPT because of unfavorable vascular anatomy and brain fusion. Even more straightforward cases carry a

risk of brain damage and death. The decision to attempt separation is based on an assessment of risk to the two individuals, in addition to ethical and social issues, and may be different for each individual. There are several examples of unseparated twins who live fulfilling lives. A decision not to separate brings its own challenges. These include potential psychosocial difficulties as life progresses and the physiological challenges associated with a shared circulatory system.

SURGICAL MANAGEMENT

- CPT require complex multidisciplinary management and often present with cardiac, renal, and general pediatric problems. General care is complicated by difficulties in positioning. When planning separation, consideration must be given to the issues of each twin, in turn, followed by shared issues.
- Many approaches for the separation of CPT have been described, but they essentially fall into two categories, a single-stage separation often preceded by an episode of tissue expansion or a multistage approach.^{9–11} There is now general agreement that a multistage separation encourages adaptation in the blood supply to the brain and reduces the risk of cerebral damage and is the procedure of choice for total extensive CPT.¹² This chapter will describe our experience with multistage separation.

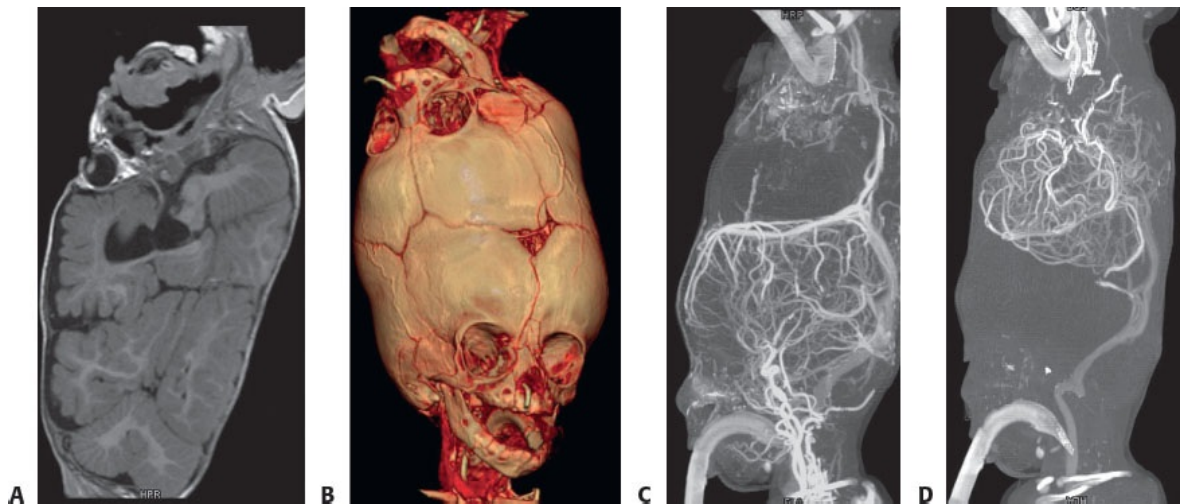


FIG 3 • Radiological imaging. Twin A is at the top and Twin B at the bottom. **A.** MRI delineates brain anatomy and areas of cortical confluence. **B.** CT with 3D reconstruction delineates skin bone and vascular

anatomy. **C.** Angiography showing injection from twin A. **D.** Injection from twin B.

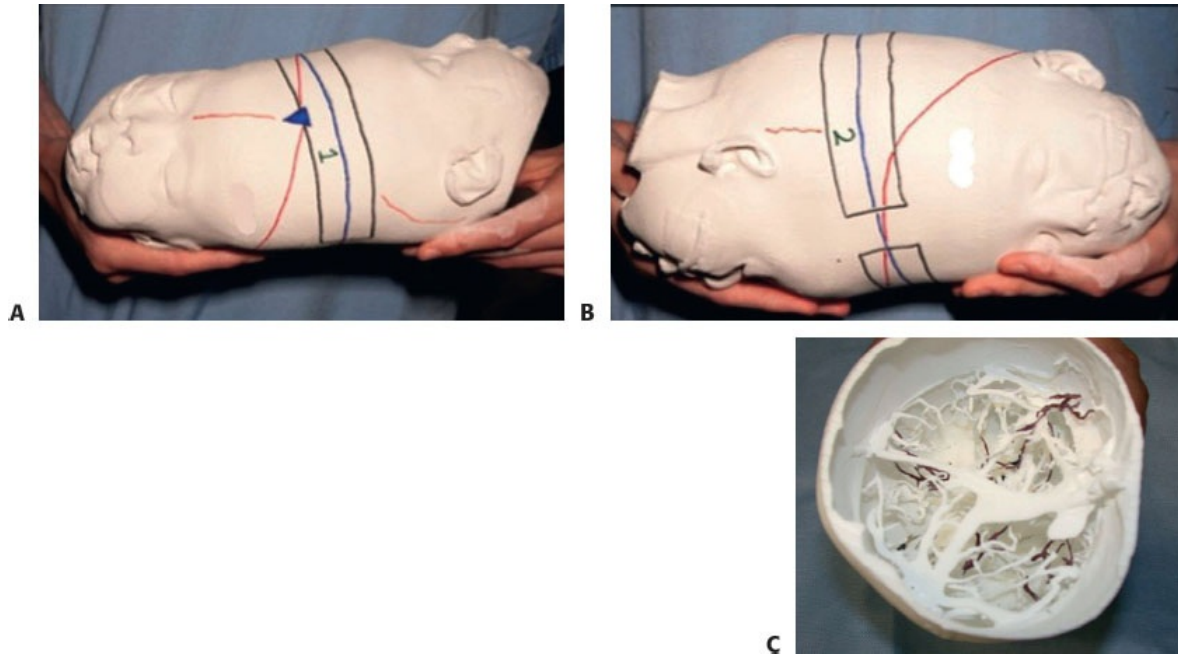


FIG 4 • 3D models used to plan incisions **(A)**, craniotomies **(B)**, and vascular surgery **(C)**.

Preoperative Planning

- Detailed preoperative planning is essential for successful separation. CT, MRI, angiography, and stereolithographic models provide essential information (see **FIGS 3** and **4**). The surgical separation of CPT requires attention to planning for the following tissue layers.
- Skin
 - The form and position of the initial skin incision must allow access for the separation and provide useful skin flaps that will give a watertight closure at separation.
 - We have found that a sinusoidal-shaped incision running circumferentially around the conjoined heads, centered on the proposed line of separation, provides good access (**FIG 5**).
 - The sinusoidal design should produce a single broad-based flap for each twin that can be enlarged by tissue expansion.¹³
 - Planning of the flaps is facilitated by the use of stereolithographic models.

■ Bone

- Broad craniotomies over the line of fusion are required to gain access for the intracranial separation.
- In a staged approach, these craniotomies need to be rigidly plated back into position at the end of each procedure to maintain the rigidity of the skull during the multistage operative approach.

■ Dura

- The two brains are usually separated by an incomplete single dural layer. The dural layer must be given to one twin, leaving the other with a wide dural defect.
- The decision about which twin receives the dural layer is based on the venous sinus anatomy. The ring sinus is donated to the twin who retains the shared dural layer. The other twin must therefore rely on the remaining parts of the superficial drainage system, along with the deep venous drainage system.
- Staged separation encourages the formation of collateral drainage from the superficial to deep system and reduces the risk of venous infarcts at final separation.

■ Brain

- The brains are usually separate, or minimally conjoined, in total CPT.
- Extensive areas of cortical fusion may make separation impossible.

■ Veins

- Decisions about sharing and separating the veins are discussed in the section on managing the dura.
- It is essential that the twin who loses the shared dural venous sinuses during separation has an independently draining deep system capable of accommodating the entire venous drainage of the brain.

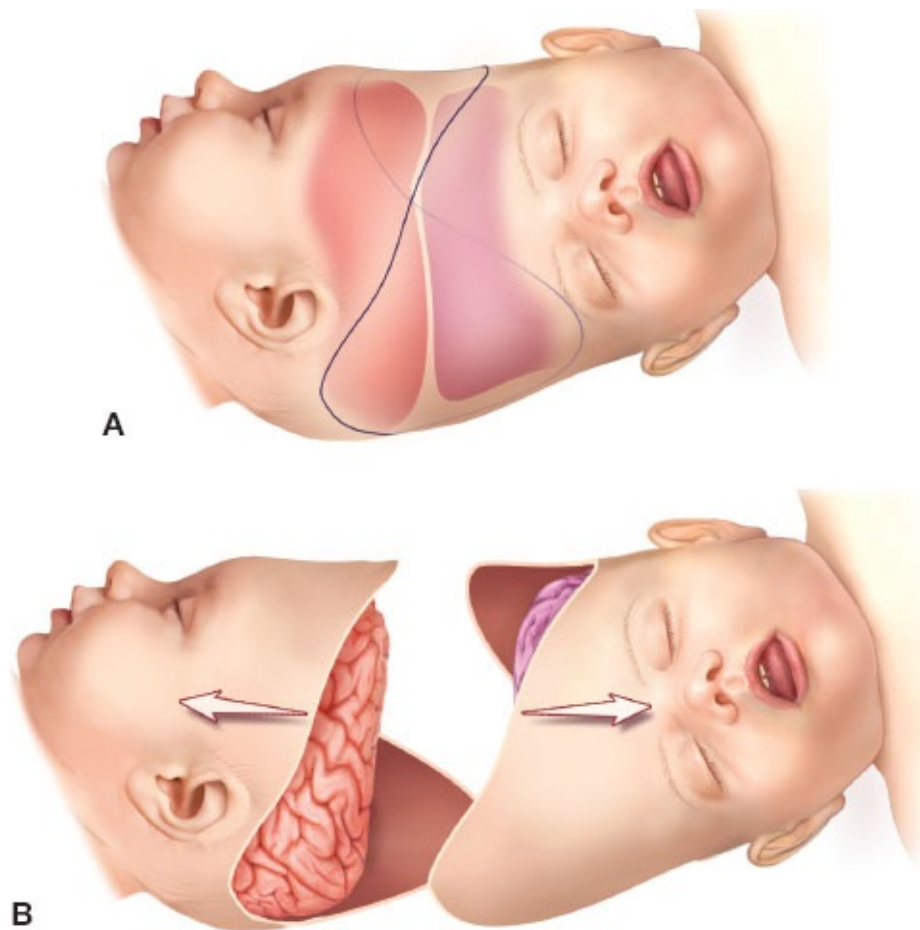


FIG 5 • Incisions and flap design.

Positioning

- Until separation, the twins are placed together on a single operating table. The theater needs to be laid out so that the two anesthetic teams looking after each twin have adequate access to the operating area.
- Depending on the area of the skull that requires separation, the twins will be either in the supine, lateral, or prone position. Depending on the McConnell subtype, the position of each twin will vary.
- We have found it helpful to elevate the conjoint heads above the level of each body by placing a bolster beneath the heads.
- This elevation reduces venous pressure and, because infant skulls are flexible, provides a gentle force to retract the two parts of the conjoint head during surgery.
- In the final operation, once the twins had been separated, one twin is moved to a separate operating theater.

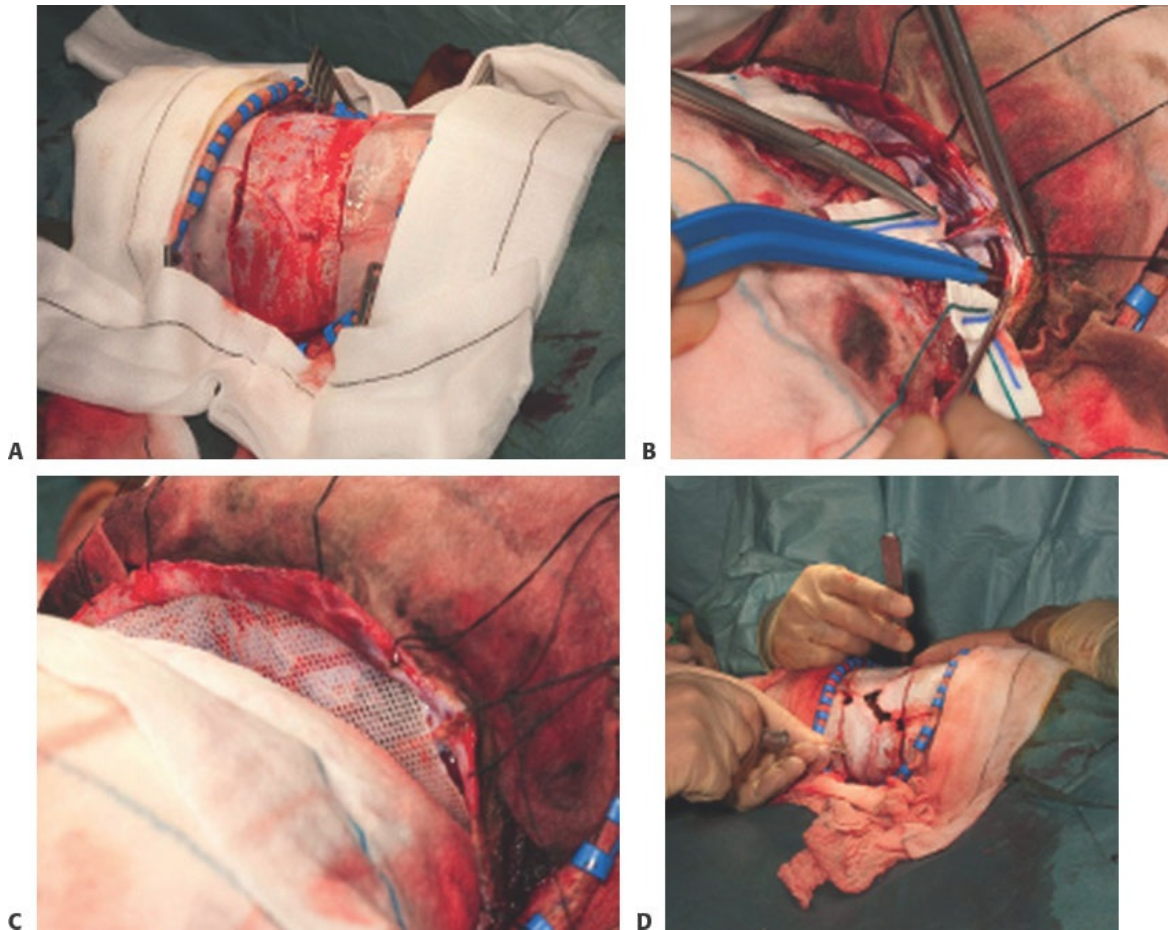
Approach

- A single-staged approach may be appropriate for partial CPT.
- Most total CPT twins require the multistaged approach described below.

TECHNIQUES

■ Stage 1: Defining Skin Flaps and First Stage Neurovascular Separation

- Sinusoidal incision line is marked to give access for craniotomies and intracranial separation. This incision will be the only incision line and so must give access circumferentially and form the flaps for cranial closure at the final separation.
- Skin flaps should be raised in a subperiosteal plane for maximum durability over multiple procedures.
- An access craniotomy is performed to widely expose the dura around the area of proposed separation (**TECH FIG 1A**).
- The dura is opened parallel to the CVS on the side where the parasagittal veins are to be divided from the venous sinus.



TECH FIG 1 • **A.** Scalp flaps retracted with access craniotomy. **B.** Venous tributaries from one twin divided from the CVS. **C.** Silicone sheet placed between cerebral hemispheres to prevent revascularization. **D.** Craniotomy secured with titanium plates to maintain a rigid connection between the twins.

- The parasagittal veins are serially divided with bipolar diathermy from the CVS. The brain is carefully observed for signs of venous congestion, and vein division is halted if there are venous drainage concerns (**TECH FIG 1B**).
- A reinforced silicone sheet is placed in the area of division to prevent adhesions and revascularization between the twins (**TECH FIG 1C**).
- The dura is closed to ensure a watertight seal, and the craniotomy is replaced

using a 1.5 mm titanium unicortical plating system (**TECH FIG 1D**).

- A vacuum drain is placed, and the wound is closed in layers.

■ Stages 2 and 3: Neurovascular Separation

- The number of stages required for complete neurovascular separation will depend on the venous anatomy and the degree of separation possible at each stage before venous insufficiency is experienced. Ideally there should be a minimum of 4 weeks between separation stages to allow complete neovascularization.
- Subsequent stages use the same incision plan as stage 1.
- The twins are rotated to access the next area to be separated, and the operative sequence of stage 1 is repeated.
- These stages are repeated until complete intracranial separation is achieved with silicone sheeting separating the twins. Rigid integrity of the calvarium must be maintained to facilitate nursing in the interoperative period.

■ Tissue Expansion

- Following completion of the neurovascular separation, it is necessary to provide a considerable amount of skin to cover the expected defects. Extra tissue (both length and breadth) is required in the area of the broad-based flaps created by the sinusoidal incision.
- The expanders are inserted into the subperiosteal plane through incisions in the pre-existing sinusoidal scars. The full-thickness flaps are robust and will expand easily with minimal risk of expander extrusion (**TECH FIG 2**).
- High-profile rectangular smooth expanders with soft pliable bases are an effective design for scalp expansion.
- It is important to place injection ports away from areas where they may cause pressure problems.



TECH FIG 2 • Tissue expanders are placed beneath scalp flaps. The expanders must be positioned to avoid possible pressure necrosis of the overlying flaps. Injection ports are placed to avoid pressure areas and to facilitate injection of saline.

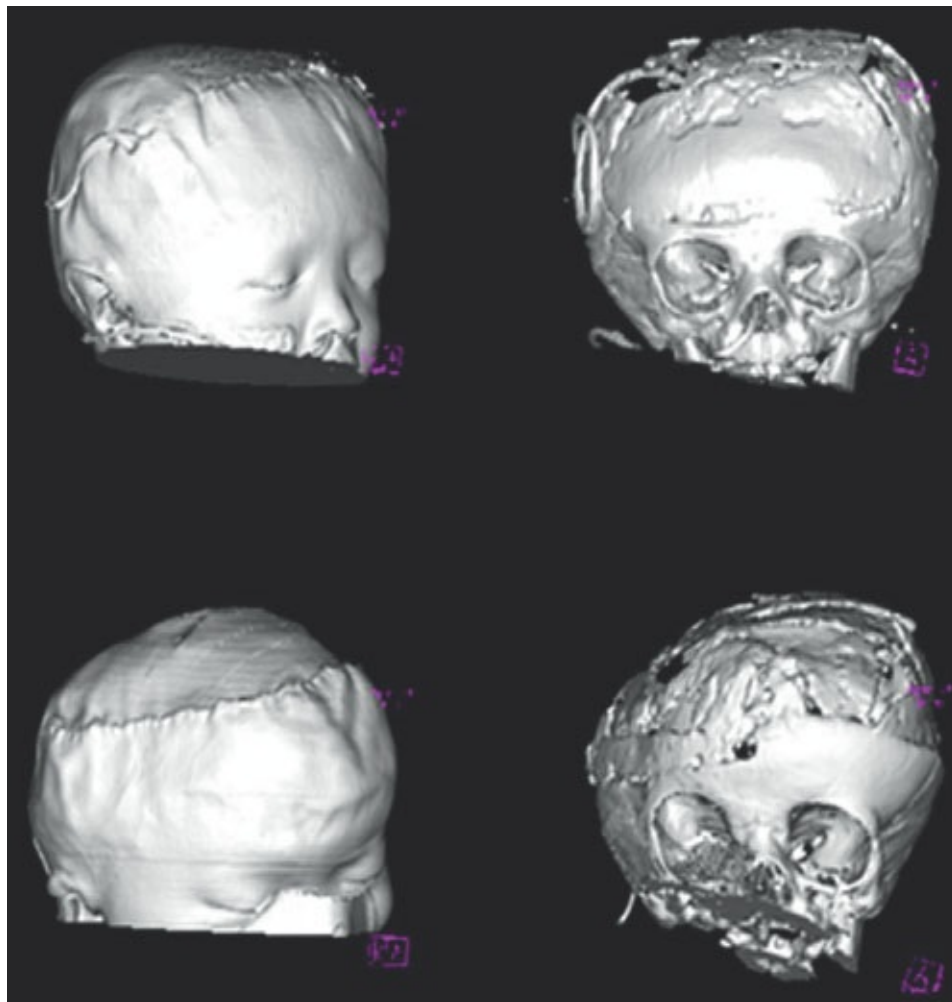
- Following insertion of the expanders, the wounds are allowed to heal for 2 weeks before starting twice-weekly injections of the expanders. The process takes approximately 4 weeks, and the final stage separation should be planned 2 weeks after the completion of expansion.

Final Separation

- By this stage, the key elements of the separation are complete. The two brains and intracranial blood supply have been separated with enough scalp created for soft tissue reconstruction.
- Careful logistical planning is required as the operation starts in a single theater with one surgical team and finishes as two separate procedures.
- Separation involves raising the skin flaps and reopening the now circumferential craniotomy. Both bone and dura have healed by this stage. There may be some final areas of cortical separation to undertake.
- Once separate, dural reconstruction is undertaken. The area to reconstruct is very large on the twin who did not receive the CPT and smaller or negligible on the other twin. Our preference is to use autologous fascia lata to provide a

watertight seal rather than artificial alternatives.

- Even in infancy, the calvarium has a rudimentary diploic cavity, and in our experience, it is possible to split the calvarium to produce sufficient bone to reconstruct the calvarial defects. The calvarial reconstruction is achieved by suturing and wiring the bone fragments into place (**TECH FIG 3**).
- Skin closure can generally be achieved with minimal tension. The sinusoidal flap design results in a suture line distant from the dural reconstruction line and helps to prevent CSF leaks.



TECH FIG 3 • CT images demonstrating bony and soft tissue reconstruction of each twin.

PEARLS AND PITFALLS

Preoperative planning

- Careful planning is required from the whole multidisciplinary team for all of the stages.
- Use 3D models to plan circumferential incisions, which must give access for all stages and provide local flaps for final reconstruction.
- Based on vascular imaging, decide which twin will retain the circumferential venous sinus.

Nonsurgical care

- Nursing: Avoid pressure sores, and maintain nutrition.
- Cardiac: Venous shunting across twins leads to asymmetric cardiac load.
- Renal: Shunting across twins may adversely affect renal function.

Decision-to-separate issues

- Ethical and social issues must be discussed.
- Identify risks to each twin and the combined risk.
- Assess likely quality of life for the twins, either conjoined or separate.

POSTOPERATIVE CARE

- Immediate postoperative care is undertaken in a pediatric intensive care (PICU) environment. Our preference is transfer of the children awake to the PICU rather than ventilate them postoperatively.
- CT and MRI scans are obtained immediately to assess both brain and quality of reconstruction.
- Early physiotherapy is required to mobilize the newly separated twins.
- Consider orthotic molding helmets for head shape.

OUTCOMES

- Mortality (per individual)
 - Total CPT 48%
 - Partial 14%
 - Single stage separation 46%
 - Multistage separation 21%¹¹
- Neurological disability
 - Mild-moderate or normal
 - Total CPT 25%

- Partial CPT 73%¹
- Severe disability
 - Total CPT 22%
 - Partial CPT 14%¹

COMPLICATIONS

- Death (see above) commonly due to brain infarction, infection, and blood loss
- Neurological damage/developmental delay
- Hydrocephalus
- CSF leaks
- Wound infection
- Wound breakdown
- Plagiocephaly
- Calvarial defects

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15 Endoscopically Assisted Approaches for Craniosynostosis

CHAPTER

Timothy W. Vogel and Brian S. Pan

DEFINITION

- Craniosynostosis is a condition caused by the premature fusion of calvarial sutures.
 - The fused suture restricts the growth of the developing brain, leading to compensatory morphologic changes of the calvarium.
- Endoscopically assisted approaches for the treatment of craniosynostosis entail removal of the affected suture through small scalp incisions. The technique is passive, dependent on the natural growth of the underlying brain to facilitate correction once the site of growth restriction is released.
 - The use of postoperative molding helmets is commonly coupled with this technique to actively direct the vectors of brain growth.¹
- Although variations in the timing of surgery exist between craniofacial centers, this technique is generally reserved for patients less than 6 months of age.
 - Decreased operative times, blood loss, cost, and length of hospital stays have all been reported as advantages to this minimal access approach.²

ANATOMY

- The normal calvarium is composed of five major bones and sutures (**FIG 1A**).
 - The bones include two frontal bones, two parietal bones, and a single occipital bone.
 - The major sutures consist of three paired sutures (the coronal, lambdoidal, and squamosal) and two single sutures (the sagittal and metopic)
- There are six fontanelles, soft membranous gaps that represent the confluence

of the bones and the sutures of the skull. These include the anterior and posterior fontanelles and the paired sphenoid and mastoid fontanelles (**FIG 1B**).

- Partial or complete fusion of the affected suture can occur.

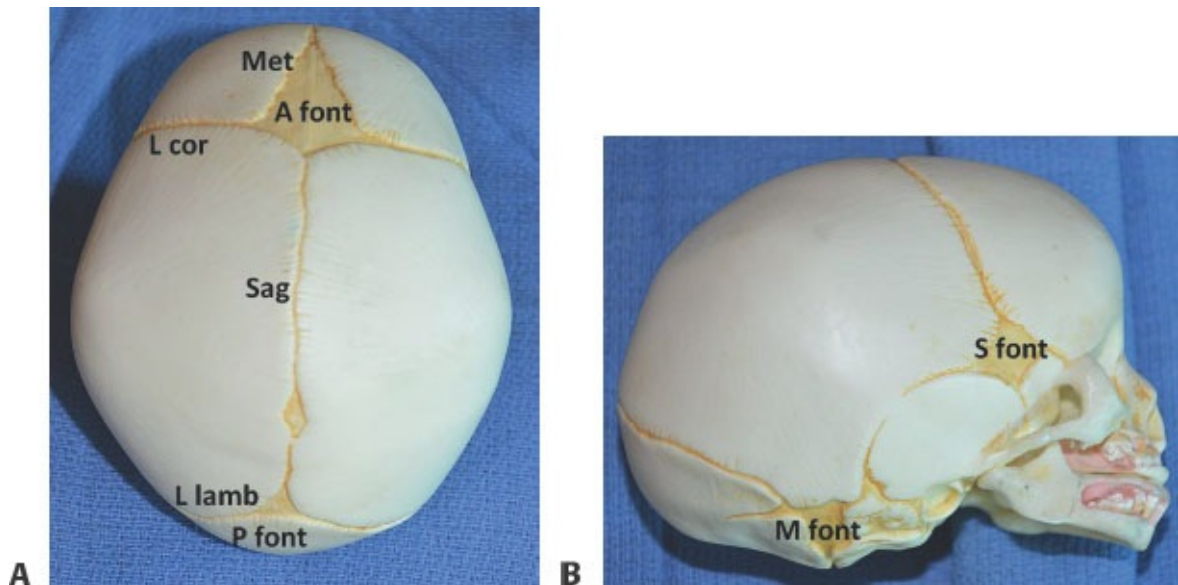


FIG 1 • Sutures and fontanelles of the skull. **A.** Met, metopic suture; L cor, left coronal suture; Sag, sagittal suture; L lamb, left lambdoid suture; A font, anterior fontanelle; P font, posterior fontanelle. **B.** S font, sphenoid fontanelle; M font, mastoid fontanelle.

- Identification via palpation of the anterior and posterior fontanelles, or the confluence of the affected sutures if the fontanelles have closed, is critical for incision placement.
- This allows adequate exposure of the targeted suture and avoids injury to the underlying dura if the fontanelles are open.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are usually diagnosed within the first few months of life, but the diagnosis may not be readily apparent due to temporary deformation of the head following birth.
- A thorough clinical history should be obtained including length of gestation, weight, and complications during gestation and following birth.

- Sleeping position, overall health, and a family history regarding abnormal head shape should also be obtained.
- The neck should be assessed for torticollis, and hands and feet should be inspected for abnormalities associated with syndromic craniosynostosis.
- Although CT scans are routinely obtained for confirmation purposes, physical examination alone has been shown to be 98% reliable for diagnosis in a level 1, prospective multicenter study.³
- Growth inhibition occurring perpendicular to the fused suture is the classic teaching for determining the suture responsible for the morphological changes of the calvarium in affected patients.
 - Growth inhibition is in actuality multidimensional, however, with the remaining open sutures compensating for the area of restriction.⁴
- Sagittal synostosis
 - In addition to an elongated head (dolichocephaly), there is a decrease in the posterior skull width and height, often with narrowing of the occipital bulb.
 - Compensatory growth occurs anteriorly involving the coronal and metopic sutures, which results in frontal bossing.
 - Clinoccephaly, presenting as a saddle-shaped deformity dorsal to the open coronal sutures, is often present as well.
- Metopic synostosis
 - The classic physical examination findings include a triangular head shape (trigonocephaly) with reduced bifrontal width, supraorbital pinching, and increased posterior width of the calvarium.
 - The open sagittal and lambdoid sutures facilitate this compensatory growth pattern.
 - Hypotelorism may also be appreciated.
- Coronal synostosis
 - The growth restriction caused by closure of the coronal suture results in ipsilateral flattening of the forehead, elevation of the orbit, and anterior positioning of the auricle.
 - The dorsal aspect of the calvarium is often flattened.
 - The open coronal suture compensates leading to contralateral frontal bossing and a more dorsally positioned auricle.
 - The nose is often deviated toward the fused suture.
- Bicoronal synostosis
 - Symmetrical flattening of the forehead with widening of the bilateral

temporal regions and elevated height of the calvarium (turribrachycephaly) is the result of fusion of the bilateral coronal sutures.

- Concomitant elevation of the supraorbital aspect of the frontal bones may lead to a proptotic appearance.
- Lambdoid synostosis
 - The hallmark of lambdoid craniosynostosis is a mastoid bulge on the affected side.
 - There is flatness and decreased height of the posterior skull on the affected side as well.
 - The unaffected lambdoid and sagittal sutures compensate for the growth restriction leading to a contralateral posterior bossing.
 - This presentation can be easily confused with deformational plagiocephaly.

IMAGING

- A three-dimensional (3D) computed tomographic (CT) scan is the ideal study for the diagnosis of craniosynostosis and preoperative planning and to facilitate discussion with patient families.
- The patency of sutures and fontanelles can be assessed, the skeletal deformity visualized, and underlying brain abnormalities (eg, Chiari malformation) may be ruled out.

SURGICAL MANAGEMENT

- The authors offer a minimal access approach for infants between 6 and 12 weeks of age. In children with mild deformation, this approach may be considered until 16 weeks of age.
 - In general, posterior vault distraction is recommended for children with bicoronal, bilateral lambdoid, and synostosis.
- The main objective of the endoscopic-assisted operation is to completely remove the fused suture using a small incision that will be concealed with hair growth and to avoid injury to the underlying dura.
- The main steps of the procedure:
 - Strategically make incisions that exposes the fused suture or sutures.
 - Create an optical tunnel to see the fused suture and for removal of the bone.
 - Make a small craniotomy and enlarge it enough to place the endoscope and to facilitate epidural dissection.
 - Perform craniectomy of the affected suture either en bloc or in multiple pieces.

- Achieve hemostasis that is confirmed with endoscopic visualization and close the skin.

Preoperative Planning

- The risks, benefits, and realistic expectations are discussed with the parents prior to surgery.
- The postoperative appointment with the orthotic supplier is confirmed.
- The risks of bleeding, infection, cerebrospinal fluid leak, dural injury, seizure, stroke, blood transfusion, and the potential need for secondary operations may be reinforced.
- The surgeon should confirm the availability of specialized instruments, positioning equipment, and blood products before proceeding to the operating room.

Positioning

- The positioning of the patient during the operation depends on the affected suture or sutures.
 - Appropriate positioning facilitates exposure and removal of the affected suture, as well as the comfort of the surgeon during the operation.
- Supine positioning on a well-padded horseshoe headrest is used for patients with metopic, coronal, and bicoronal craniosynostosis.
- A modified sphinx position is the authors' preferred position to address sagittal craniosynostosis (**FIG 2**).
- Prone positioning is used for lambdoid craniosynostosis.

Approach

- Incision placement is critical to permit removal of the affected suture(s) and concealment within the hair. The general considerations made for incision placement include the following:
 - Placement perpendicular to the affected suture
 - Limiting incisions to no more than 3 cm in length
 - Ensuring the incision placement to address the fused metopic suture is behind the hairline using loupe magnification if needed
 - Using one (or possibly two incisions) to safely facilitate removal of the sagittal, lambdoid, and coronal sutures



FIG 2 • A modified sphinx position is utilized to address sagittal craniosynostosis.

TECHNIQUES

■ Markings

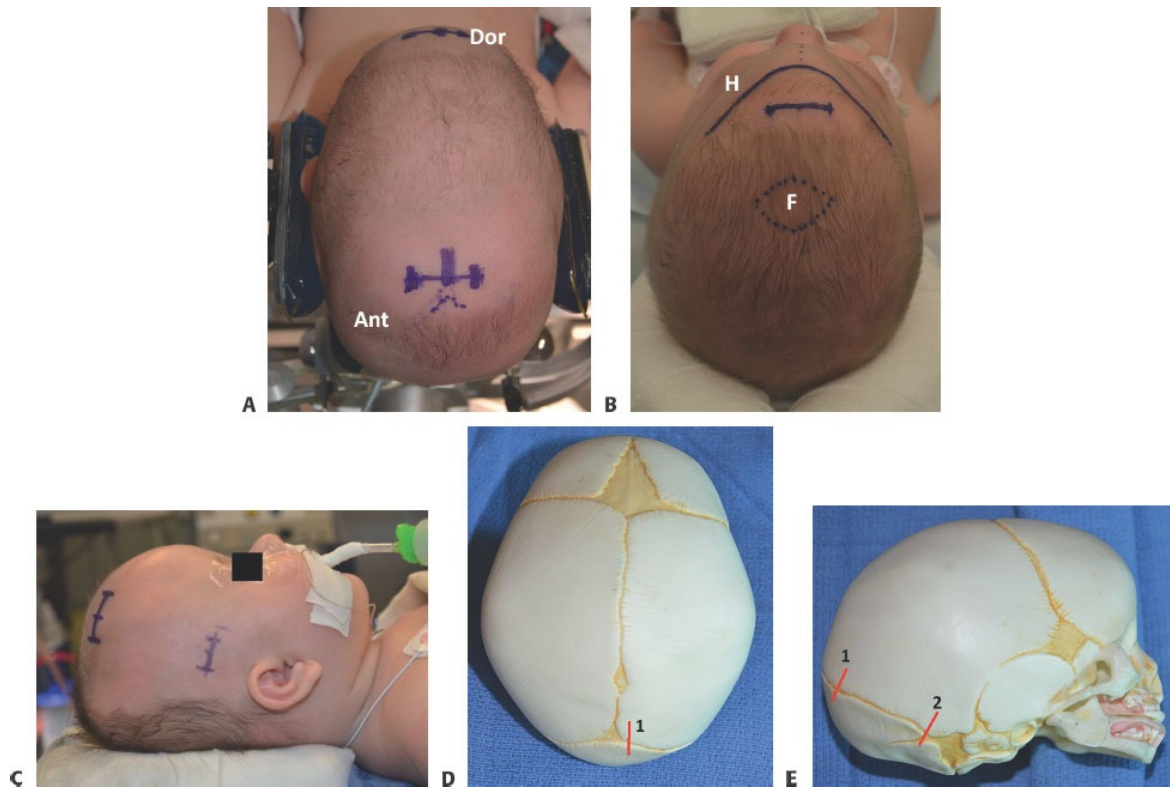
- The hairline is identified and marked. Use loupe magnification if hair is difficult to visualize.
 - The hair-bearing scalp in the region of the planned incisions is clipped and cleaned.
- For sagittal craniosynostosis, the anatomic anterior incision is designed dorsal to the anterior fontanelle, and the dorsal incision is designed anterior to the posterior fontanelle (**TECH FIG 1A**).
- The incision for metopic craniosynostosis is designed dorsal to the hairline and anterior to the fontanelle (**TECH FIG 1B**).
- The incision placement for coronal craniosynostosis is perpendicular to the affected suture and lateral to the anterior fontanelle.
- If visualization of the suture is inadequate, a second smaller incision may be made caudally to facilitate suturectomy (**TECH FIG 1C**).
- Similar to coronal synostosis, the incision for lambdoid synostosis is made perpendicular to the suture with the cephalically oriented incision placed just

caudal to the posterior fontanelle.

- The second smaller incision may also be made to confirm the complete removal of the suture (**TECH FIG 1D,E**).
- Local anesthetic is infiltrated subcutaneously along the planned incision and within the region of the optical tunnel.

■ Exposure and Tunnel Creation

- The skin is incised and extended into subcutaneous tissue until the galea is identified.
- The galea is incised to expose the loose areolar plane of the scalp.
 - Meticulous hemostasis is maintained to achieve a blood-free field.
- Subgaleal undermining is performed with electrocautery and blunt dissection.
 - This plane has minimal vasculature; dissection should be performed under direct visualization using a lighted retractor to maintain a dry field.
 - Typically, 2 cm of additional dissection is performed lateral to the incision markings to create a wide enough area to permit exposure and placement of instrumentation.

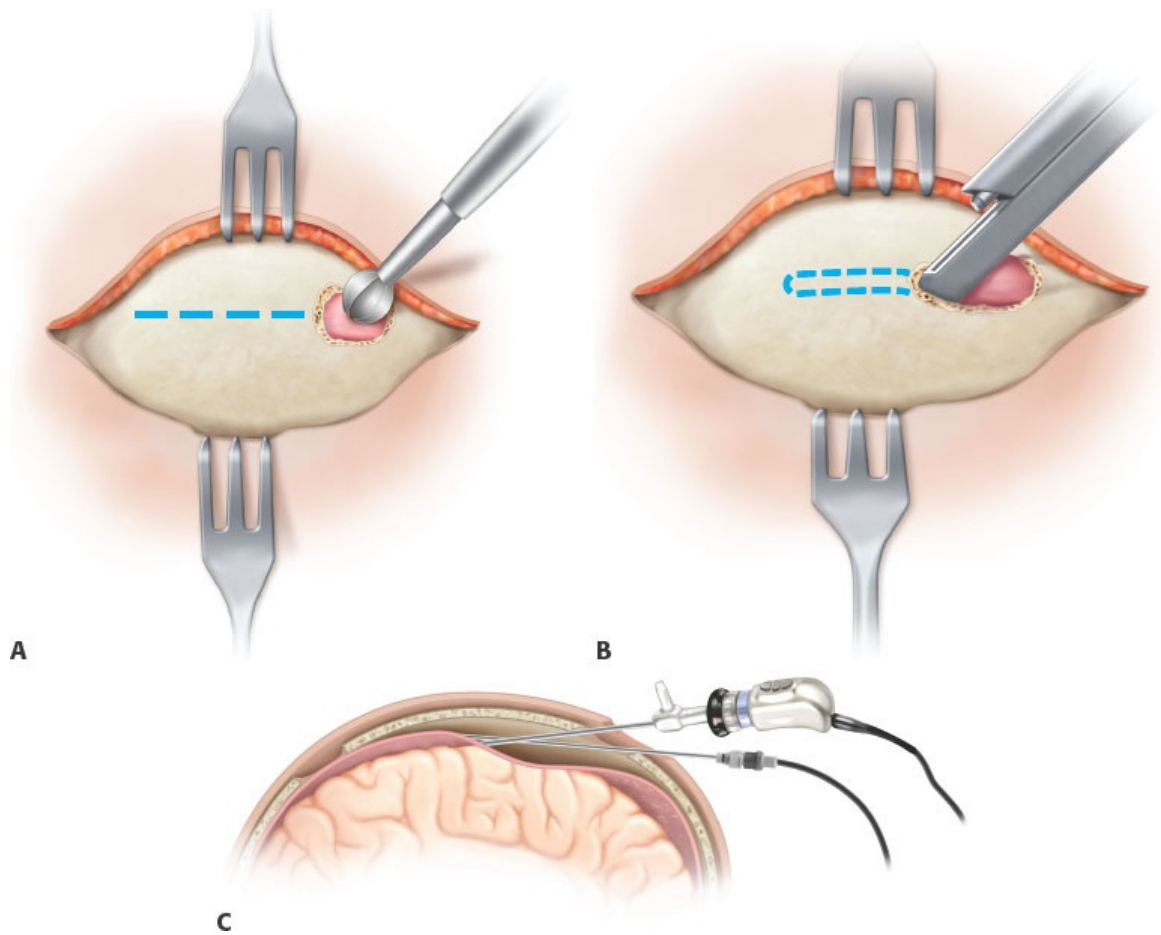


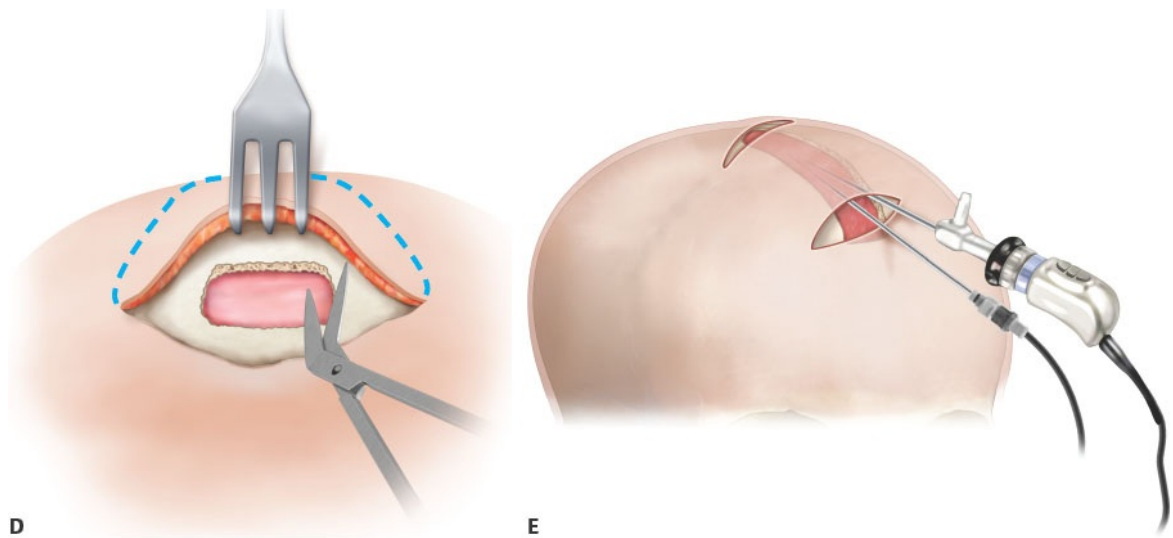
TECH FIG 1 • A. Sagittal craniosynostosis. The anatomic anterior incision (*Ant*) is designed dorsal to the anterior fontanelle, and the dorsal incision (*Dor*) is designed anterior to the posterior fontanelle. **B.** The incision for metopic craniosynostosis is designed dorsal to the hairline (*H*) and anterior to the fontanelle (*F*). **C.** The incision placement for coronal craniosynostosis is perpendicular to the affected suture and lateral to the anterior fontanelle. If visualization of the suture is difficult, a second smaller incision may be made caudally to facilitate visualization and suturectomy. **D,E.** The incision for lambdoid synostosis is made perpendicular to the suture with the cephalically oriented incision (1) placed just caudal to the posterior fontanelle. The second smaller incision (2) may also be made to confirm the complete removal of the suture.

■ Craniectomy

- Regardless of the affected suture, the procedure for craniectomy is similar.
 - Handheld Senn retractors are used to expose the underlying calvarium.
 - A high-speed pneumatic drill with attachment is used to perform a small craniotomy (**TECH FIG 2A**).
- Avoid penetrating the dura covering the brain. The dura is stripped from the overlying calvarium and a Kerrison punch forceps is used to complete a troughlike craniectomy by avoiding damage to the underlying venous sinuses that may be present along the surgical path (**TECH FIG 2B**).
 - The width of the craniectomy will encompass the synostosis.
- A similar trough is made under the second incision (if indicated) to serve as the destination for completion of the endoscopic dissection.
- With the surrounding dura stripped from the overlying calvarium, a handheld suction catheter is placed through the incision, followed by an endoscope.
 - The endoscope is surrounded by an irrigating sheath to promote visualization.
 - Under direct visualization, the suction and endoscope are advanced to slowly peel the dura from the overlying calvarium (**TECH FIG 2C**).
- At this point, the craniosynostosis can be viewed and confirmed.
 - Suction-monopolar cauterization is used to isolate and coagulate vessels that may connect the dura to the calvarium.
 - The dissection is continued to the second craniectomy trough (when used).
 - Lateral dissection of the dura from the calvarium is confirmed under direct visualization to ensure adequate space for insertion of instruments.
- Bone-cutting scissors are introduced under direct visualization with a lit retractor (**TECH FIG 2D**).
 - Cuts are made on both sides parallel to the affected suture and carried from trough to trough.
 - The bone can then be removed with forceps or may require further cutting to remove through a small incision.
- When a single incision is used (coronal, lambdoidal, metopic), a Kerrison punch or Takahashi bone-cutting forceps are used to ensure the complete removal of the affected suture.
- After bone removal, an endoscopic retractor is introduced to protect the dura and provide visualization of the bone edges.

- Using suction-monopolar cauterization, the bone edges are cauterized (**TECH FIG 2E**). Thermal injury to the dura must be avoided.
- After confirmation that bleeding is controlled, the area is reinspected and irrigated.





TECH FIG 2 • **A.** A craniotomy is developed to permit separation of the dura from the calvarium. **B.** The initial craniotomy is expanded to permit dural dissection and insertion of instruments. **C.** An endoscope with an irrigating sheath is inserted, followed by a suction dissector, to separate the dura from the overlying calvarium. **D.** Bone-cutting scissors are inserted under direct visualization and the fused suture is removed. **E.** The endoscopic retractor is inserted to allow visualization of the bone edges. A suction-monopolar cautery is introduced and used to obtain hemostasis.

■ Closure

- After hemostasis is achieved, the skin is closed in layers with simple, buried dissolvable sutures (4-0 Vicryl).
 - A superficial, running, dissolvable suture is then used to coapt the skin edges (4-0 Rapide).
 - Our practice is to apply a thin layer of Dermabond to the incision followed by another occlusive dressing (Tegaderm).
-

PEARLS AND PITFALLS

Physical findings

- Physical examination is generally reliable for diagnosis, but a CT scan is recommended to document the affected suture.³

Technique

- Incisions are concealed within and behind the hairline. This is of particular importance for patients with metopic craniosynostosis. If the hairline is difficult to visualize, loupe magnification is indicated to avoid placement of the incision on the forehead.
- The incision should be as small as possible to ensure an excellent cosmetic outcome.
- Stripping the dura from the overlying calvarium should be done cautiously to avoid bleeding from an underlying venous sinus.
- Thermal injury to the dura should be avoided to prevent cerebrospinal fluid leak. All CSF leaks must be repaired immediately.

Postoperative

- Helmet therapy is initiated after surgery, typically within 1 wk.
- The infant is seen every 3 mo to check helmet fit and head shape improvement.
- Helmet therapy is generally discontinued 1 y from the time of surgery.
- Frequent communication between patients, surgeons, and helmeting personnel should take place to ensure proper helmet fit and function.
- Helmet care should be encouraged including frequent washing protocols to maintain a clean environment for the healing incisions.
- Helmets should be worn according to an established schedule to avoid starting and stopping helmet therapy. Re-establishing helmet wear after prolonged periods of disuse can be difficult for children to tolerate.

POSTOPERATIVE CARE

- Incision care is initiated after the occlusive dressing is removed on postoperative day 2.
 - Care includes gently washing the incision with warm water and soap.
 - Skin glue and dissolvable sutures are not removed.
- Molding helmet therapy is initiated within 1 week of the operation.

- The child is seen in clinic postoperatively at 2 weeks, followed by 3-month intervals until 1 year has elapsed from the time of surgery.
- Head shape correction is monitored via laser scans when the patient presents for helmet adjustments to the orthotic provider.
- Molding helmet therapy is discontinued 1 year from the time of surgery.

OUTCOMES

- Outcomes from minimally invasive endoscopic-assisted suturectomy are excellent.
- This approach results in decreased operative time, blood loss, length of hospital stay, and the use of extensive and costly hospital resources.
- Less than 10% of patients require a blood transfusion, and this figure can be considerably lower with surgical experience and careful postoperative monitoring.²
- Frequently a child may avoid admission to an intensive postsurgical unit. This can be facilitated if appropriate protocols are in place for checking blood volume status postoperatively.

COMPLICATIONS

- Widened scar formation due to hair follicle injury caused by rough tissue handling and thermal injury from electrocautery
- Inadvertent incision placement on the forehead
- Incomplete resection of the fused suture
- Need for secondary surgery to increase intracranial volume or improve cosmesis
- Bleeding, infection, and CSF leakage
- Helmet-related complications: poor compliance, pressure ulcer formation, and alopecia

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Section II: Orbital Dystopias

16 Box and U-Shaped CHAPTER Osteotomies

Sunil Tholpady, Robert J. Havlik, and Barry E. Eppley

DEFINITION

- Orbital dystopia is used to describe a vertical or horizontal displacement of the entire orbit and its contents.
- The most common dystopia encountered is orbital hypertelorism.

ANATOMY

- Hypertelorism is an abnormal interorbital distance and should not be confused with telecanthus, which is lateral displacement of the medial canthi without normal bony architecture (**FIG 1**).

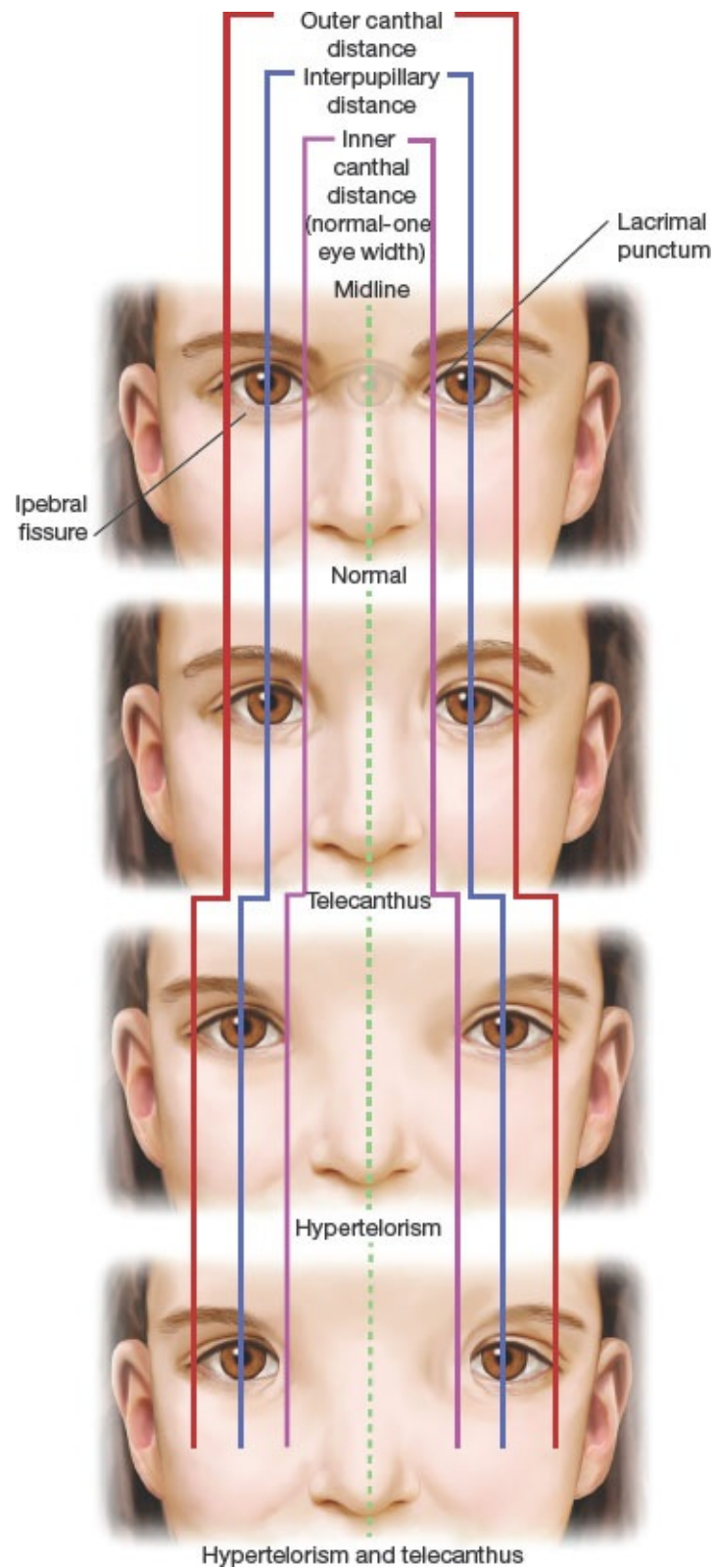


FIG 1 • Differences between telecanthus and hypertelorism.

- Ethmoid sinuses are often overexpanded with excess medial soft and hard tissue.
- Severe hypertelorism can be associated with inferior displacement of the cribriform plate.
- The interorbital distance (dacryon to dacryon) is used to diagnose and classify hypertelorism. (The intercanthal distance is 4 to 6 mm greater than the interorbital distance due to soft tissue.)
 - Normal is 25 mm in women and 28 mm in men.
 - First degree: 30 to 34 mm
 - Second degree: 34 to 40 mm
 - Third degree: greater than 40 mm¹

PATHOGENESIS

- Orbital dystopias are a heterogeneous group of disorders that usually arise as a consequence of congenital or traumatic conditions:
 - Craniofrontonasal dysplasia
 - Apert or Crouzon syndrome
 - Encephaloceles or craniofacial clefts
 - Frontal sinus mucocele
 - Neurofibromatosis
 - Fibrous dysplasia
 - Craniofacial trauma
- Orbital positioning will at best be maintained and may worsen with time and growth.
- Traumatic dystopias can occur at any age.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Symmetric hypertelorism with wide set brows
- Vertical malposition of the orbit
- Epicanthal folds
- Wide nasal dorsum
- Amblyopia or strabismus
- Inferolaterally positioned zygomas
- High-arched palate

IMAGING

- Neurosurgical consultation is appropriate for intracranial exposure.

- Ophthalmologic consultation for amblyopia, strabismus, or extraocular dysfunction and postoperative visual changes
- Three-dimensional computed tomographic reconstruction of the face and skull is necessary.
- Three-dimensional printed models may be useful for visualizing and teaching surgery.

SURGICAL MANAGEMENT

- Most surgical corrections of hypertelorism in the pediatric population are performed between the ages of 4 and 8.
 - Psychosocially, this is a period of development during early school years.
 - The cranium has had a period of explosive growth, and the interzygomatic distance is nearly adult-sized by age 6.
 - The sinuses have not yet pneumatized.
 - Most stable results are obtained in adults, and there may be a need for revision when the procedure is performed in the pediatric population.
- There are no absolute contraindications, but patients with a high-arched palate, narrowed midface, inferolaterally displaced orbits, or very severe cases may benefit from a facial bipartition procedure to correct these concerns.
- Box osteotomies can be used to correct both horizontal and vertical dystopias. An intracranial approach is preferable with significant (greater than 40 mm deformity), as this provides access to the central ethmoidosphenoidal area. Orbits are sectioned in a 360-degree fashion (**FIG 2A**).²
- U-shaped osteotomies may be used when the interorbital distance is less than 40 mm and a smaller movement performed in a completely subcranial fashion is desired. Orbits are sectioned in a 180-degree fashion (**FIG 2B**).^{2,3}

Preoperative Planning

- Medical models of the skull abnormalities enable preoperative knowledge of osteotomy positions and predicted movements (**FIG 3**).

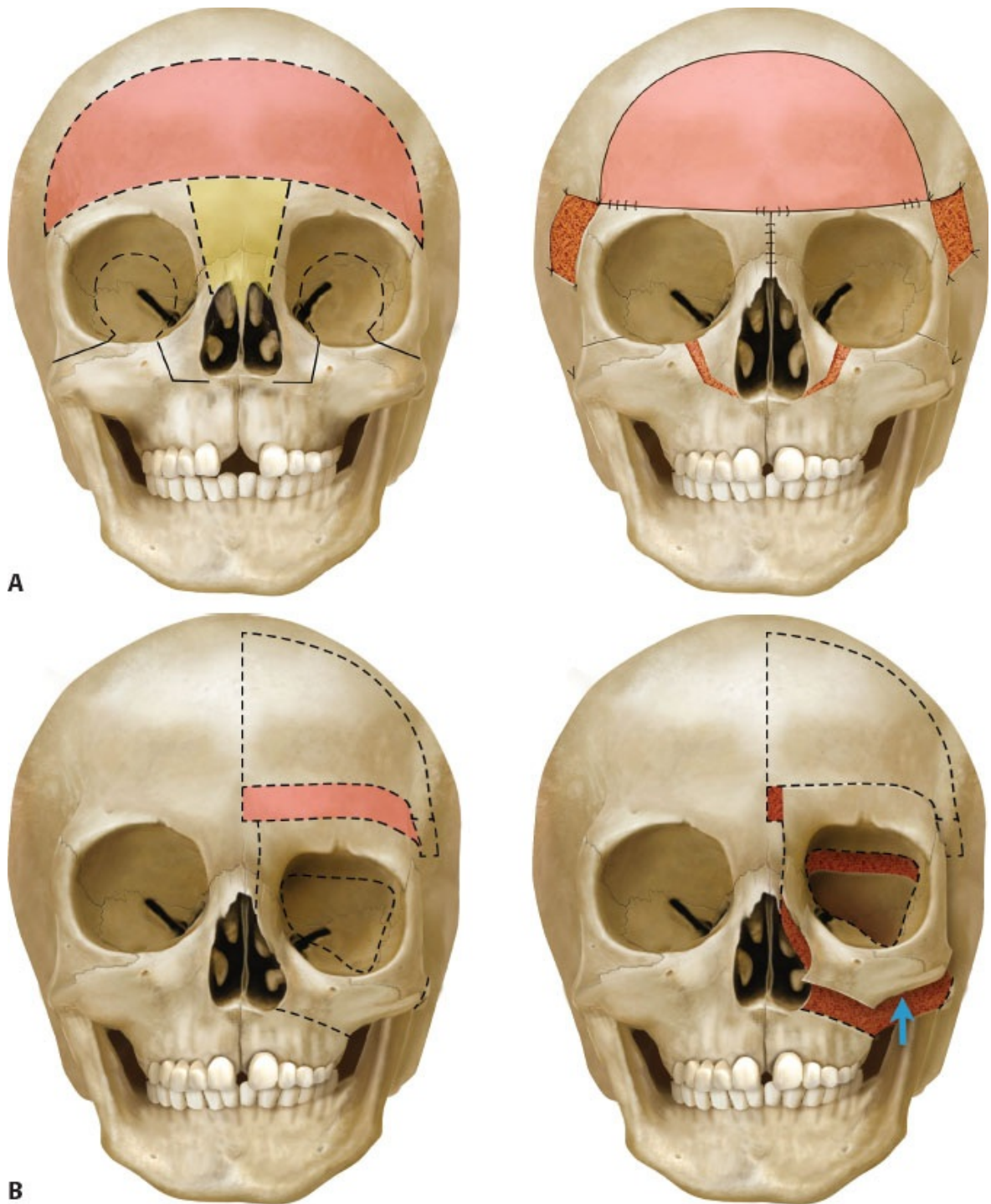


FIG 2 • Medical modeling with proposed osteotomies and final result. **A.** Demonstrates box osteotomies and **(B)** demonstrates U-shaped osteotomies.

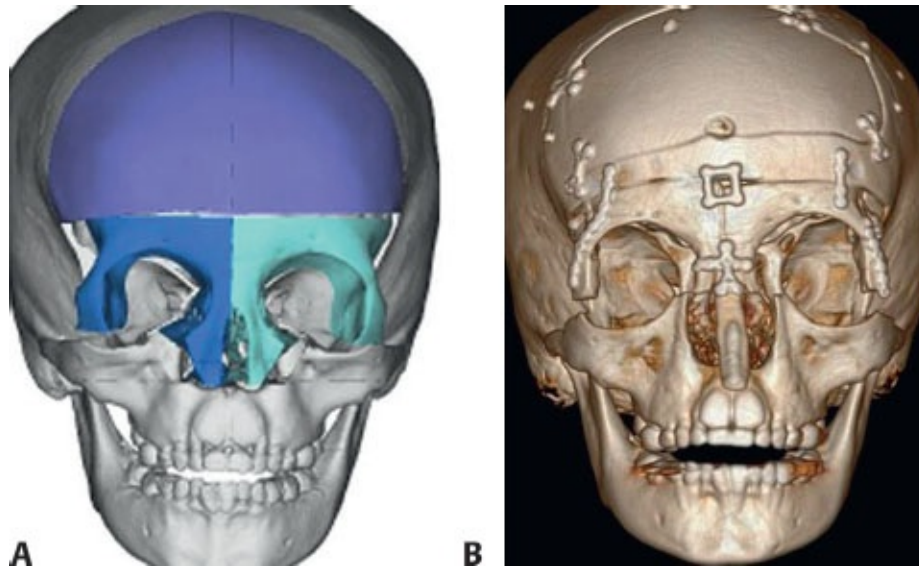


FIG 3 • Proposed cuts for a box osteotomy **(A)** or a U-shaped osteotomy **(B)**.

Positioning

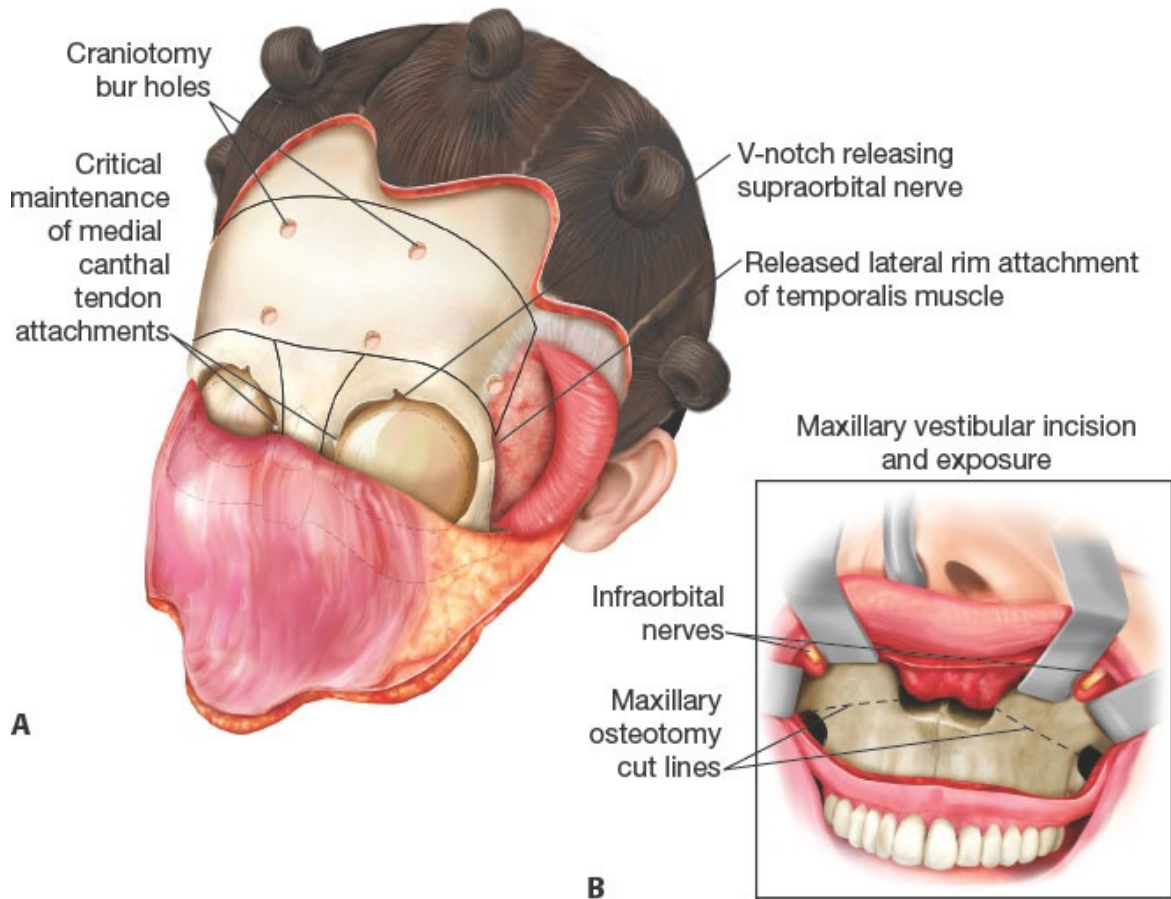
- The patient is placed in the supine position on a Mayfield headrest.
- An oral RAE tube is ligated to the lower central incisors with 26-gauge steel wire.
- Corneal protectors are placed with ophthalmic ointment, and the lids are sutured together with a single stitch.
- Afrin-soaked pledgets are placed in the nose.

TECHNIQUES

■ Exposure

- A standard coronal approach is used to raise the scalp in the subperiosteal plane.
- The shape of the incision and choice of hemostasis (cautery, Raney clips) are entirely dependent on surgeon preference.
- At the superior orbital level, the supraorbital nerves are spared as they exit their foramina. The periorbital tissue is released circumferentially, including the lateral third of the floor.

- Dissection proceeds above the deep temporal fascia. When the zygomatic arch is palpated, incision is placed on the bone. Any attachment of temporalis to the lateral orbital wall is released.

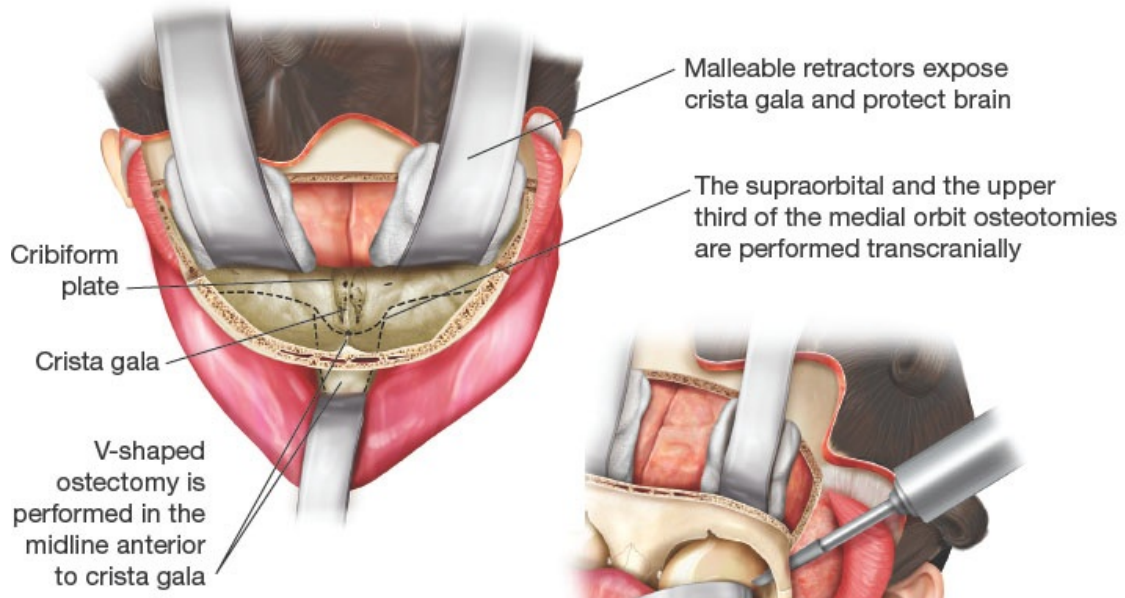


TECH FIG 1 • A,B. Incisions and exposure.

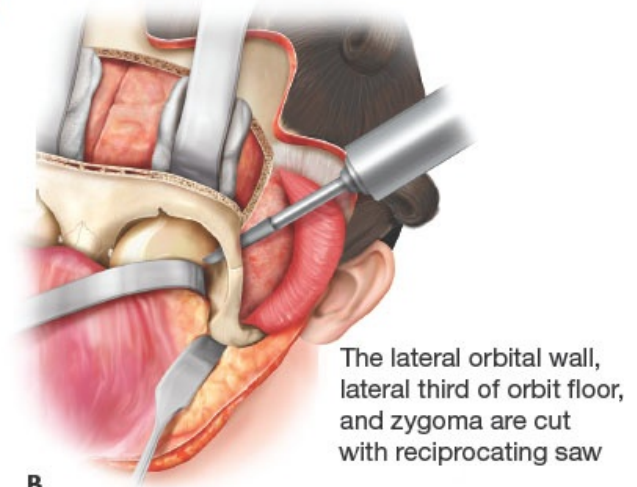
- The nasal dorsum and medial orbital wall are meticulously exposed, maintaining the medial canthal attachments to bone.
- A maxillary vestibular incision is performed from first molar to first molar. Subperiosteal dissection exposes the bony nasal aperture, the bilateral zygoma, and the remainder of the orbital floor.
- Neurosurgical assistance with the frontal bone flap reveals the orbital roof, sphenoid, and cribriform plate (**TECH FIG 1**).

■ Osteotomies

- Superior orbital osteotomies are not performed for U-shaped osteotomies but are performed for box osteotomies.^{2,3}
- Malleable retractors are used to protect the brain and orbital contents.
- Orbital cuts should be made posterior to the equator of the orbit to capture the functional orbital volume.
- Superiorly, a reciprocating saw is used to create osteotomies in the superior orbit extending laterally to the posterior portion of the lateral third of the orbital floor, as well as the zygoma (**TECH FIG 2A,B**).
- Medial orbital osteotomies are performed with a 3-mm osteotome to complete the posterior orbital cut.
- The maxilla is osteotomized with a reciprocating saw to connect the piriform aperture to the zygomatic eminence. This is performed through an upper gingivobuccal sulcus or eyelid incision.
- A rectangular piece of bone is removed from the nasal bones extending posteriorly to the crista galli (**TECH FIG 2C**).
 - A septal osteotomy anterior to the cribriform plate will be necessary if this is considered.
 - Alternatively, a central portion of the nasal bones may be left with bilateral paramedian excisions of the nasal bone and posterior tissue.
- Ethmoid sinuses are exenterated to assist with translocation.
- Bone is stored for later bone grafting at the lateral orbital rims.

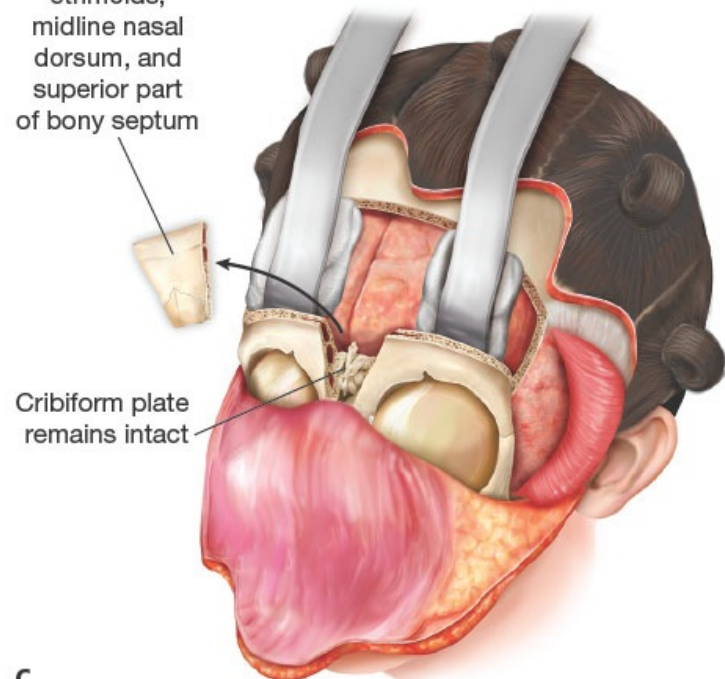


A



B

V-shaped midline osteotomy includes frontal bone, ethmoids, midline nasal dorsum, and superior part of bony septum



C

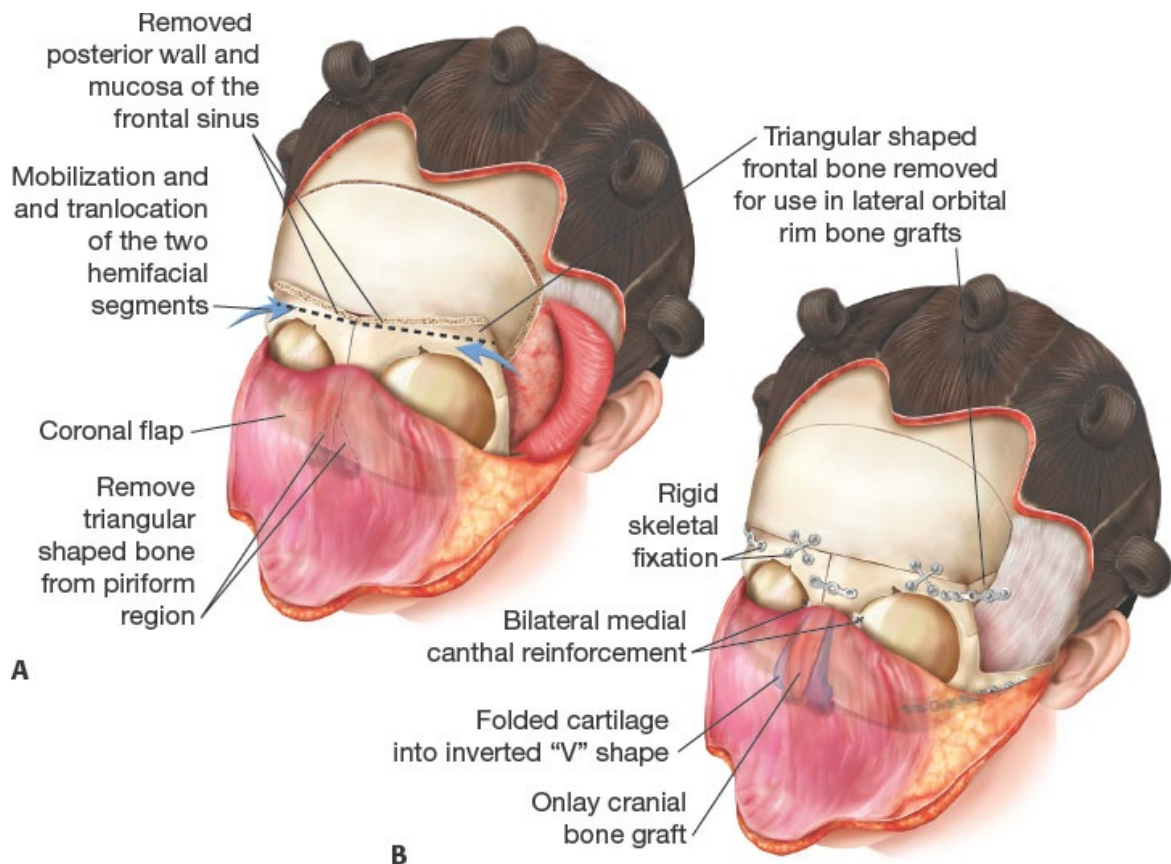
TECH FIG 2 • Cranial (A), orbital (B), and facial (C) osteotomies.

■ **Translocation**

- Smith spreaders are used to gently walk the lateral orbital rim medially.
- Finger pressure is sufficient to translocate orbits to the midline.
- A 24-gauge wire is used to ligate orbits temporarily into the correct position.
- Bony distance at the medial wall is 17 or 18 mm. Because of soft tissue mechanics, more bony reduction may be necessary in severe hypertelorism.

■ **Fixation**

- Rigid fixation is necessary with titanium plates at the midline, zygoma, and maxilla. Absorbable plates and screws can be considered in the growing patient.
- Exposed sinus structures are obliterated and cranialized.
- An inferiorly based pericranial flap can be elevated from the scalp flap to separate the brain from these structures, but there should be bony continuity between the cranial bases after translocation.



TECH FIG 3 • Mobilization (A) and fixation (B).

- Bone removed from the dorsum is placed laterally to augment the lateral orbital and zygoma bone movements (**TECH FIG 3**).

■ Canthal and Nasal Reconstruction

- The 24-gauge wire temporarily placed is now removed.
- If the canthal tendons are attached to mobilized bone segments and the soft tissue repositioning is sufficient, no further treatment may be necessary.
- If the tendons have been stripped or there is telecanthus, transnasal wiring can be used to reposition medial canthal tendons.
- Nasal dorsal tissues can be plicated to enhance projection. A cranial bone graft can also be used to enhance nasal projection as a cantilevered bone graft.
- If nasal projection is insufficient and a bone graft will be placed at a later time, nasal soft tissue should not be excised to allow for a larger envelope

to later accommodate the cantilevered bone graft.

■ Closure

- All cranial tissues are copiously irrigated with half-strength peroxide, saline, and saline containing bacitracin.
 - A drain can be placed to minimize swelling.
 - Nasal soft tissue can be debulked from the inner scalp flap and reapproximated internally to avoid an external scar.
 - Hypertelorism of greater distances may require external skin removal, preferably at the junction of the dorsum and sidewall subunits.
 - Scalp is closed in two layers.
 - Maxillary incision is closed last with a single layer of suture.
-

PEARLS AND PITFALLS

Orbital floor osteotomies

- Osteotomies across the orbital floor should be made 8–10 mm from the sphenoid ridge to obtain translocation of the functional orbit. Too anteriorly placed osteotomies will not allow adequate translocation.

Approximation of orbits

- Ethmoidal cell exenteration is essential to reapproximate orbits. Resection of a portion of the middle turbinates may also help with translocation.

Preservation of cribriform

- Olfaction is preserved with preserved continuity of the cribriform plate with the septum.

Medial canthal splinting

- Care should be taken with postoperative splinting as pressure necrosis at the medial canthus can occur with vigorous splinting at the medial canthus.

Post-operative forced duction test

- Postoperative strabismus is common, but a forced duction test should be performed after mobilization to verify that the medial rectus muscles are not being impinged upon by the bony step-off from the posterior orbital osteotomy.

POSTOPERATIVE CARE

- ICU monitoring for one night postoperatively to monitor for increase in intracranial or intraorbital pressure due to bleeding
- Use of a drain can increase pressures and periorbital swelling that makes eye examination difficult.
- Postoperative steroids and head-of-bed elevation can alleviate swelling.
- IV antibiotics with coverage of staphylococcal and oral flora are preferred for 24 to 48 hours with continuation of oral antibiotics for 10 days.
- External nasal splinting can assist with molding soft tissue of the nose.
- Vasoconstrictor and steroid nasal sprays can alleviate bleeding and nasal congestion for 1 to 2 weeks.

OUTCOMES

- Usually good correction is possible (**FIG 4**).
- The closer the procedure is performed to skeletal maturity, the more stable the outcome is.

COMPLICATIONS

- Infection: May require a return to the OR for drainage. Usually presents as unilateral swelling and pain 2 to 3 weeks after surgery.
- Hematoma: Increased brain or eye pressure necessitates return to the OR and can be identified with serial neurologic and ophthalmologic examinations. Postoperative CT scan can also serve as a basis for comparison in case of change in neurologic status after surgery.
- CSF rhinorrhea: Uncommon but may require a short-term lumbar drain



FIG 4 • Before and after photos of a patient who underwent box osteotomies for hypertelorism.

- Visual disturbances: Diplopia is not uncommon and usually resolves spontaneously. Ophthalmologic evaluation before and after surgery is necessary to identify extraocular muscle dysfunction.
- Anosmia: Very uncommon and without treatment options; it is a preoperative risk of which the patient should be informed.

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CHAPTER Facial Bipartition

Jessica Ching and Christopher R. Forrest

DEFINITION

- Orbital hypertelorism, or hypertelorbitism, is increased distance between the bony orbits and represents true lateralization of the orbits (**FIG 1**).
- Interorbital hypertelorism is defined as increased distance between the medial orbital walls.
- Telecanthus is an increased distance between the medial canthi with a normal interorbital distance and associated with a normal interpupillary distance.
- The severity of hypertelorism may be interpreted according to patient age.
- The presence of an epicanthal fold can give the illusion of hypertelorism and may be termed *pseudohypertelorism*.
- Hypertelorism is a clinical finding, not a diagnosis, and is etiologically heterogeneous.
- It may be surgically corrected through facial bipartition, 360-degree box orbital osteotomy, segmental orbital osteotomy, or a camouflage rhinoplasty.
- Facial bipartition is a complex craniofacial osteotomy developed by Paul Tessier after first being described by van der Meulen.^{1,2} This technique separates the frontal-orbital-zygomatic-maxillary complex from the skull base and removes a segment of bone between the medial nasal-orbital region and splits the palate down the middle—mobilization allows for a medialization and rotation of the orbits with lateralization and expansion of the maxillary arch and lengthening of the midface.
- It is traditionally performed for less severe cases of hypertelorism.

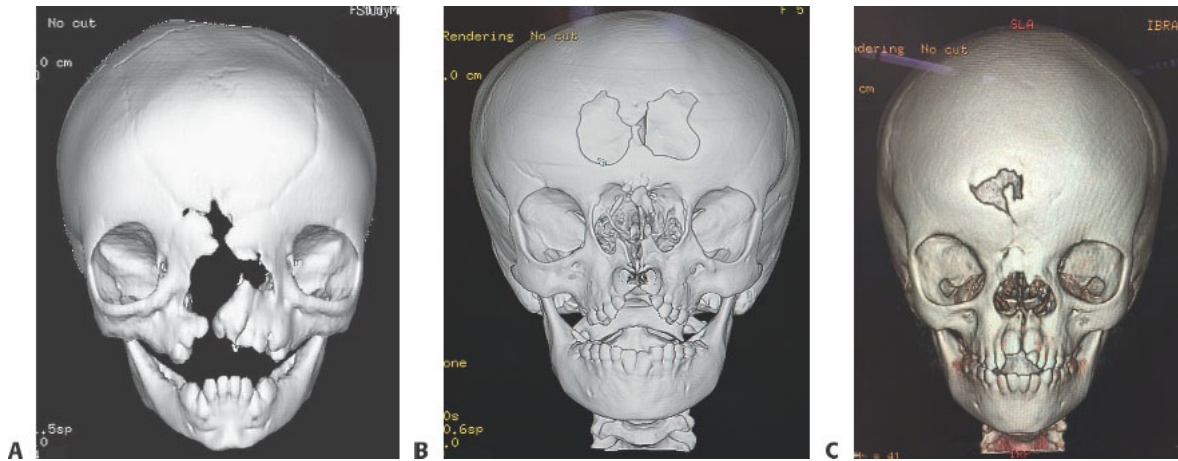


FIG 1 • A–C. CT scan examples of patients who would benefit from facial bipartition.

- Facial bipartition may be performed in conjunction with a frontofacial monobloc advancement procedure.
- Facial bipartition can be performed in the young patient, whereas 360-degree box orbital osteotomies are usually performed in older children when the maxillary sinuses have developed, tooth buds descended and orbits have near-completed growth around age 7 years.

ANATOMY

- The degrees of hypertelorism may be measured using soft tissue and bony landmarks.
- The dacryon is the most medial portion of the bony orbit, lying at the intersection of the frontal, lacrimal, and maxillary bones. This is the most common landmark for measuring interorbital distance (IOD).
- Important bony landmarks are used to measure the inner canthal distance (ICD) between the two medial canthi measured at the level of the posterior lacrimal crest and the outer canthal distance (OCD) measured between the two lateral canthi.
- The interpupillary distance (IPD) between the two midpupillary regions in front gaze is a useful measure, but taken by itself, increased IPD may not be indicative of hypertelorism. It may be seen in post-traumatic cases or in cases of exophoria due to extraocular muscle imbalance.
- ICD, OCD, and IPD are always increased in cases of true hypertelorism (**FIG 2**).

- Hypertelorism exhibits an increased IOD due to intervening excess bone and soft tissue.

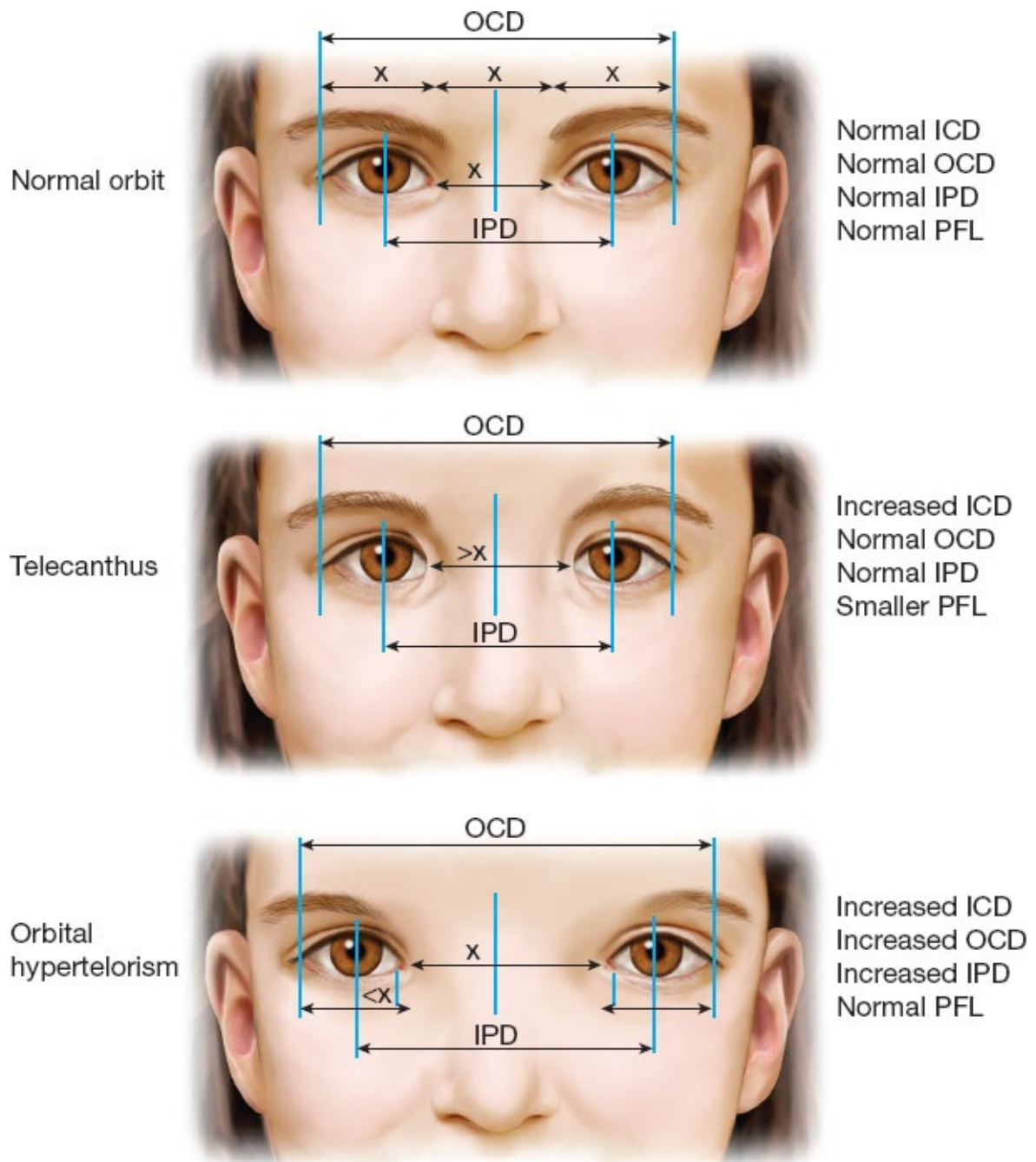


FIG 2 • Graphic representation of orbital measurements in the normal orbit, telecanthus, and orbital hypertelorism. ICD, inner canthal distance; OCD, outer canthal distance; IPD, interpupillary distance; PFL,

palpebral fissure length. (Redrawn from Sharma RK. Hypertelorism. *Indian J Plast Surg.* 2014;47(3):284-292.)

- IPD will be increased, and orbital aperture dimensions (height and width) are usually normal.
- For children, the average interorbital distance increases with age³:
 - 1 year old: 18.5 mm
 - 2 years old: 20.5 mm
 - 3 years old: 21 mm
 - 5 years old: 22 mm
 - 7 years old: 23 ± 4 mm
 - 10 years old: 25 ± 2 mm
 - 12 years old: 26 ± 1 mm
- For adults, average interorbital distance is 25 mm in women and 28 mm in men.³
- Degree or severity of hypertelorism is graded in children and adults by the amount of deviation from the average interorbital distance (Table 1).

PATHOGENESIS

- During embryologic development, lateral optic placodes move medially during weeks 5 to 9 and become the orbits and associated ocular structures.
- A persistent divergence of the orbital axes reflects early developmental arrest.
- Mechanisms of arrest include the following:
 - Deficient growth affecting the brain and eyes
 - Deficient closure of the rostral neuropore with the development of sincipital encephaloceles
 - Deficient differentiation of the nasal capsule
 - Compensatory accommodation of the cranial base to the growing brain
- Hypertelorism may result from syndromic and nonsyndromic etiologies, such as
 - Encephalocele (nasofrontal, nasoethmoidal, naso-orbital, and combined)
 - Craniofrontonasal dysplasia
 - Median facial clefting or frontonasal dysplasia
 - Syndromic craniofacial dysostoses (ie, Apert, Crouzon, Pfeiffer)

- Tumors
- Vascular malformations

Table 1 Severity of Hypertelorism Defined in Children and Adults		
Degree of Hypertelorism	Children^a	Adults^b (Gunther's Classification)⁴
First	2–4 mm	30–34 mm
Second	4.1–8 mm	35–40 mm
Third	>8 mm	>40 mm

^aReported as distance of deviation from average interorbital distance by age.

^bReported as absolute interorbital distance.

NATURAL HISTORY

- Hypertelorism may remain stable or worsen with growth, depending on the etiology, but it does not improve over time.
- Relapse is common when surgery is performed in young children (under 8 years of age).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation includes assessment of prenatal and birth history, general development, medical diagnoses, genetic findings, family history of similar conditions, the level of patient's and parents' concern regarding the hypertelorism, psychosocial issues, and eagerness to undergo surgical correction for hypertelorism.
- A history of sleep disordered breathing may suggest the need for a frontofacial advancement to increase the size of the airway.
- Previous intracranial surgical history is important to document including cranio-orbital reshaping and insertion of a VP shunt.
- Physical examination: a basic examination of the head and neck is mandated with specific attention paid toward the cranio-orbital and midface region.
- Soft tissue measurements including ICD, OCD, and IPD are documented recognizing that soft tissue intercanthal measurements can be increased greater than 10 mm over underlying bone measurements.⁵
- Presence or absence of midface and zygomatic hypoplasia
- Nasal appearance recognizing that hypertelorism may be masked by surgical

augmentation of a depressed nasal dorsum

- Other contributors to the appearance of hypertelorism should also be assessed, such as exotropia, dystopia canthorum, epicanthal folds, narrow palpebral fissures, and widely spaced eyebrows.
- Extraocular muscle function, gross vision, presence of exorbitism, and degree of corneal protection should be noted.
- Evaluate for soft tissue excess that may be present or be created by medialization of the orbits.
- In assessing the need to correct hypertelorism, a technique to obscure the naso-orbital region can help determine whether the lateral orbital wall distances are abnormal and if so, would necessitate either facial bipartition or box osteotomies. If not, then medial wall osteotomies or camouflage rhinoplasty procedures would be effective (**FIG 3**).
- The cranial shape and fontanelle patency should be assessed for associated craniosynostosis in cases of craniofrontonasal dysplasia and craniofacial dysostoses, which may alter surgical planning.
- Further examination should identify other findings suggestive of an underlying syndromic diagnosis, which may influence treatment planning and timing such as midface retrusion, severe exorbitism, and indications of elevated intracranial pressure.
- Preoperative consultations are routinely obtained from ophthalmology, neurosurgery, and anesthesia.



FIG 3 • A technique to determine whether a camouflage or medial wall procedure would be of benefit. Placing the hand in front of the medial naso-orbital region highlights the discordance of the lateral orbital regions. **A,B.** This patient looks abnormal with the hand obscuring the midorbital region and would benefit from a true orbital hypertelorism correction. **C,D.** This patient would benefit from nasal reconstruction alone.

IMAGING

- Preoperative imaging with computed tomography (CT) scans (axial, sagittal, and coronal) of the craniofacial skeleton should be obtained, preferably with a low-dose, bone-only window radiation protocol to obtain a 3D reconstruction

for full visualization of the craniofacial region.

- MRI is indicated for assessment of midline tumors and encephaloceles and to assess the hypothalamic-pituitary system in specific cases.
- Vascular studies (CT angiogram/venogram, MR angiogram). A CT arteriogram and venogram of the head and neck, or comparable vascular study, may be indicated in select cases for the purpose of identifying cerebral venous drainage anomalies commonly found in these patients as well as the vascular pathways in cases of encephaloceles.
- Printing of 3D surgical models from CT scans is of great benefit in surgical planning and mock surgery (**FIG 4**).

DIFFERENTIAL DIAGNOSIS

- The following conditions should be considered when assessing a patient with hypertelorism for a facial bipartition procedure.
 - Sincipital encephaloceles (nasofrontal, nasoethmoidal, naso-orbital, and combined)
 - Craniofrontonasal dysplasia
 - Facial clefting and frontonasal dysplasia
 - Craniofacial dysostoses (eg, Apert, Crouzon, Pfeiffer)
 - Tumors
 - Vascular malformations

NONOPERATIVE MANAGEMENT

- Hypertelorism does not always necessitate operative intervention.
- A mild degree of hypertelorism is considered attractive and may not warrant extensive surgical procedures for correction.

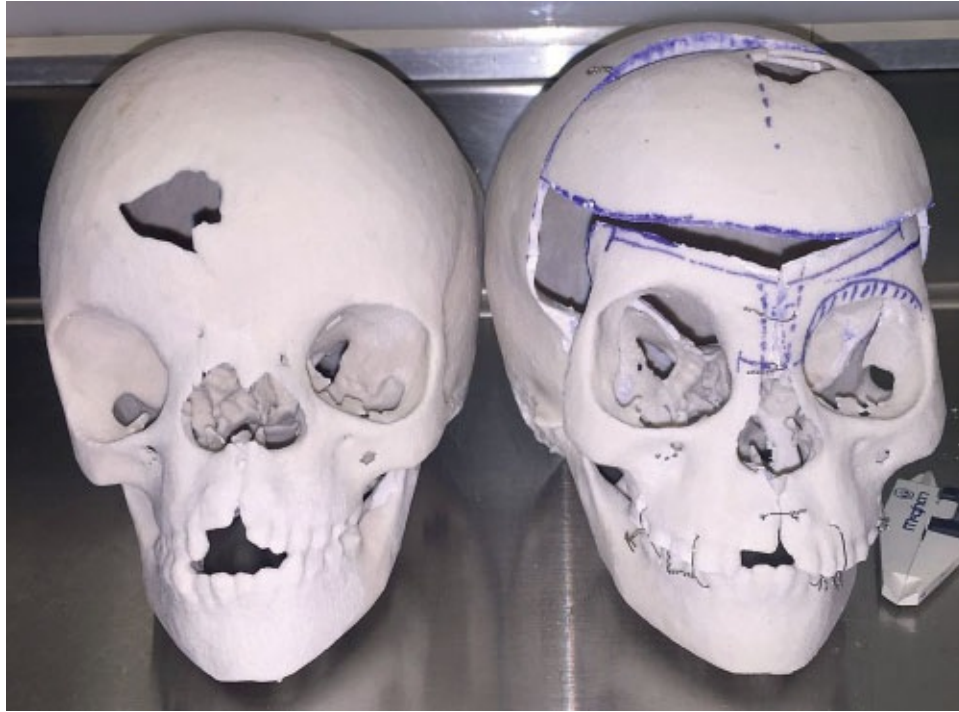


FIG 4 • Example of a 3-D skull model before and after mock surgery.

- Surgical management of hypertelorism may be directed toward the nose as a camouflage procedure such as nasal dorsal augmentation and correction of epicanthal folds.

SURGICAL MANAGEMENT

- Indications
 - Facial bipartition is indicated to simultaneously correct mild to moderate hypertelorism and maxillary arch constriction with anterior open bite deformity.
 - Hypertelorism with concomitant intracranial hypertension and/or airway compromise due to midface retrusion are indications to combine the facial bipartition with a frontofacial monobloc advancement procedure.
 - Facial bipartition when performed as a distraction advancement is effective in “unbending” the facial concavity associated with Crouzon, Pfeiffer, and Apert syndromes.
 - Facial bipartition works best with symmetric conditions.
 - Facial bipartition may be performed safely in young (less than 5 years) children but can be associated with high rates of relapse when performed at

this age.

- Surgical timing of facial bipartition requires consideration of several factors.
 - The older the patient, the less likely there will be postoperative relapse of hypertelorism.
 - Some studies indicate performing facial bipartition in children less than 6 to 8 years old has a high degree of relapse on long-term follow-up.^{6,7}
 - Early intervention may also lead to decreased future midface growth.⁵⁻⁷
 - Timing of surgery must account for the child's psychosocial development and interaction with peers.
 - A midline cleft or encephalocele may leave the brain vulnerable to injury.
 - Surgical management of sincipital encephaloceles is out of the scope of this chapter but is best performed in infancy.
 - Severe hypertelorism may affect development of stereotactic vision if treatment is delayed; however, this is not well substantiated.⁸
- Hypertelorism may be addressed through facial bipartition or box osteotomies, depending on the goals of the intervention.
 - Facial bipartition can be performed in younger children, whereas orbital box osteotomies should be done when the orbits have completed as much growth as possible, the maxillary sinus has developed, and canine tooth buds have descended away from the surgical field.
- Correction of hypertelorism with facial bipartition may be limited by the degree of maxillary expansion.
- Facial bipartition medializes the orbits through rotational movement of both the orbits and maxilla, which alters the canthal axis and maxillary occlusal relationship (**FIG 5**).
 - Box osteotomies medialize the orbits through a translational movement of the orbits alone, which should not change canthal axis or maxillary occlusion.
 - Overlying soft tissue diminishes the clinically observed difference of bone medialization.

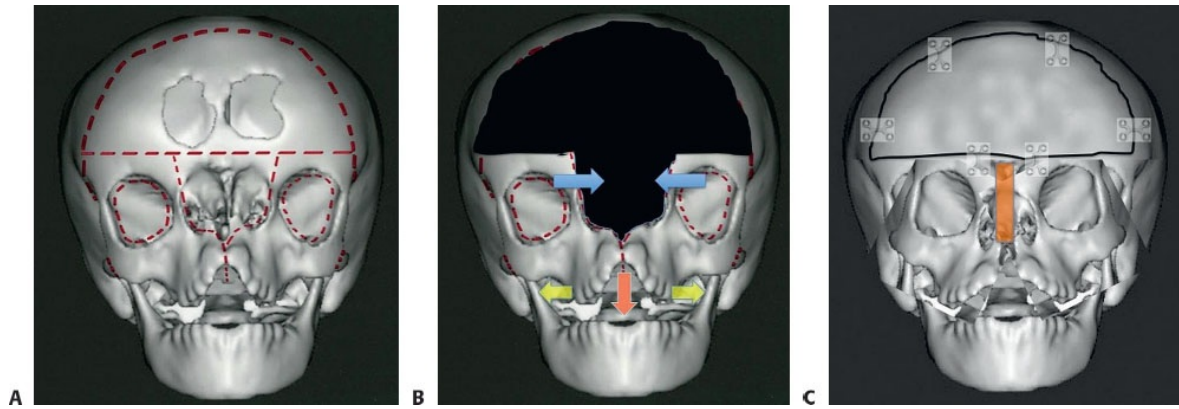


FIG 5 • Facial bipartition osteotomy. A. Markings. B. When fully mobilized, narrowing of the orbits results in midface lengthening and widening of the palate. **C.** After fixation has been applied.

- If midface advancement or increased facial convexity is desired, distraction osteogenesis may be performed postoperatively with use of a rigid external distraction device.^{9,10}
- A staged facial bipartition procedure may be indicated in patients with significantly increased intraoptic nerve distance to prevent blindness.

Preoperative Planning

- Risks of facial bipartition should be discussed with the patient and family, including but not limited to
 - Risks associated with an intracranial procedure, including brain and dural injury, damage to the venous sinuses, infection, CSF leak, bleeding, and the need for transfusion
 - Risks to the orbital contents such as blindness, extraocular muscle injury, and diplopia
 - General concerns, such as scarring, hardware failure, need for revision surgery, and asymmetrical outcome
- A CT scan assists in planning the amount and angle of midline resection to achieve the desired medial rotation of the lateral segments (**FIG 6A**).
- If available, a life-sized 3-D printed model allows the surgeon to plan the surgical procedure, perform the osteotomies, and anticipate bony interferences and consequences of segmental facial bone movements (**FIG 6B**).
- The amount of bone resection necessary to obtain the desired interorbital

distance should be calculated (**FIG 6C,D**).

- The angle of resection (with convergence between the maxillary central incisors) should be determined based on the desired resection width at the radix, internal rotation of the orbits, and leveling of the maxillary dentition (see **FIG 6B**).
- In the presence of an encephalocele, an MRI delineates whether resection or volumetric reduction of its contents is possible.
- Hydrocephalus, craniosynostosis, or other pathologic findings may require intervention prior to hypertelorism correction.
- The surgeon should be familiar with techniques for addressing soft tissue excess and canthal position that may be combined with facial bipartition.
 - In cases of severe nasal dysgenesis or excessive soft tissue in the midline, a plan for resection and nasal obstruction should be considered.
 - Delayed or staged resection and nasal reconstruction may be an option.
- The surgeon should decide if facial bipartition will be combined with monobloc frontofacial advancement.

Positioning

- The patient is positioned supine on the operating table using a slightly elevated Mayfield head rest. A shoulder roll is placed to decrease neck flexion and anteriorly position the head.
- Oral intubation is performed with an endotracheal tube that is secured with an interdental or circum-mandibular wire.
- Note any preprocedural cuff leak as a comparison to determine timing for postoperative extubation.
- Corneas should be protected through temporary tarsorrhaphy sutures or similar means.
- A Foley catheter, adequate intravenous access, and arterial lines are placed.
- Antibiotics are administered.
- Injection of local anesthetic or tumescent solution is performed.

Approach

- A bicoronal incision is used for access from the cranium; limited bilateral upper buccal sulcus incisions may be used for access to the central maxilla.
- If direct excision of excess soft tissue is desired, this is normally performed at the end of the procedure after the bone segments are stabilized and the coronal

incision has been closed. Excess soft tissue may be left to contract, with the option of later revision, if needed.

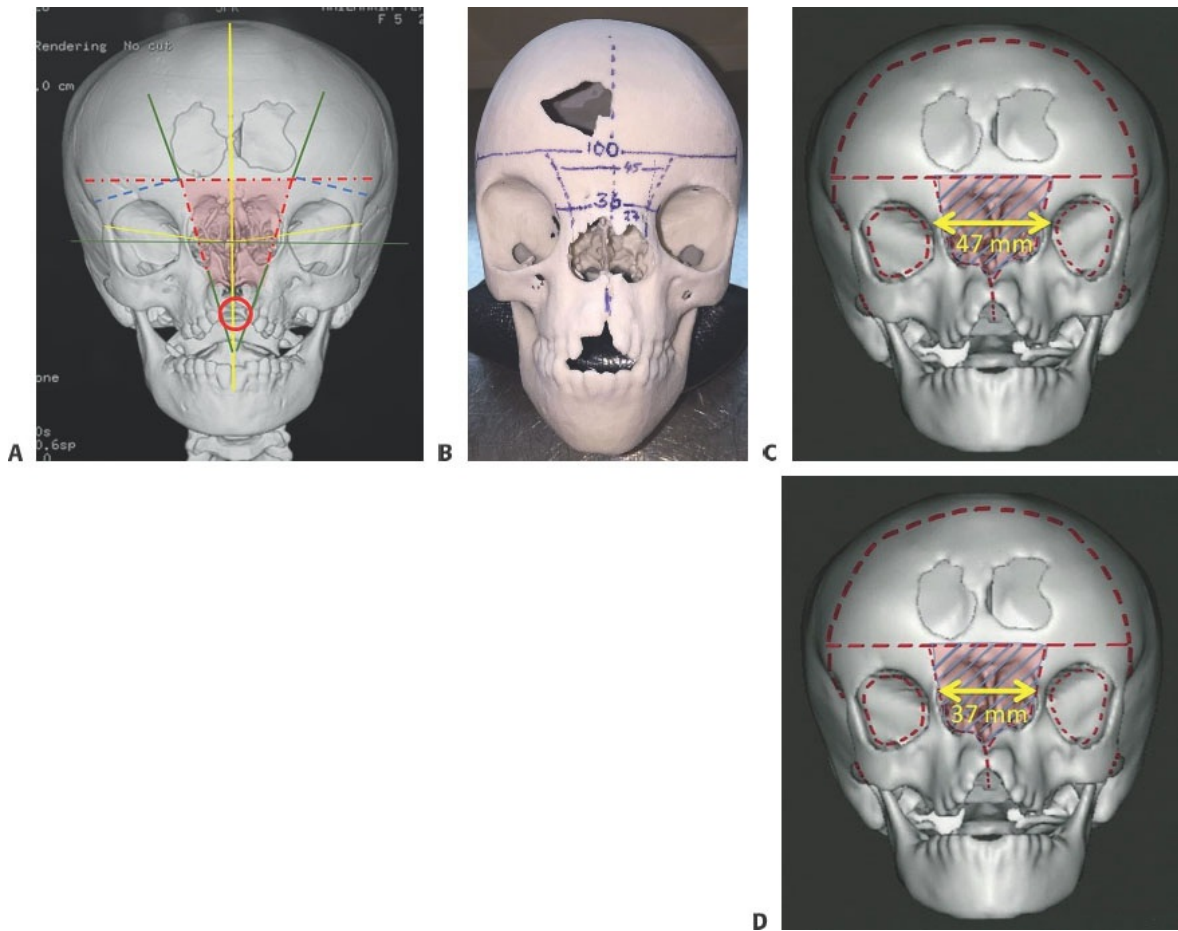


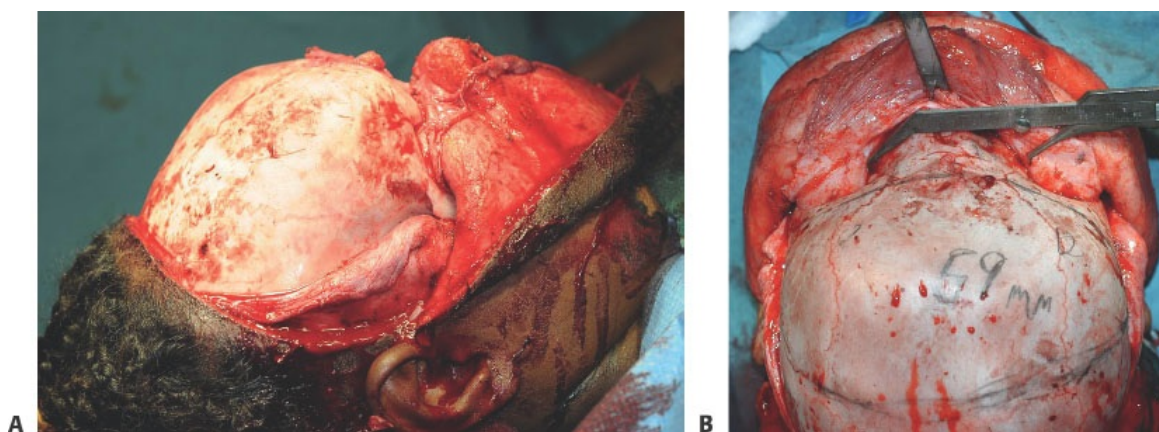
FIG 6 • A. Planning the surgical movements on a CT printout can help understand the anticipated movements of the facial skeleton. *Yellow lines* indicate facial midline and canthal axes demonstrating mild asymmetry between the two orbits. *Red dashed lines* indicate the surgical cuts. *Green reference lines* centered on the axis of rotation (*red circle*) will help demonstrate the change in occlusal and orbital planes after the rotation. The *blue dashed line* indicates the position the supraorbital osteotomy should be placed in order to attain a level supraorbital bar after repositioning. **B.** A life-sized 3-D printed model allows

the surgeon to plan the surgical procedure, perform the osteotomies, and anticipate bony interferences and consequences of segmental facial bone movements. **C,D.** Calculation of the amount of resected bone with maintenance of sufficient bone around the orbital perimeter to maintain skeletal integrity.

TECHNIQUES

■ Exposure

- Through a bicoronal incision, the frontal region is dissected in a subgaleal plane inferiorly to the level of the superior orbital rim and laterally along the deep temporal fascia to the level of the zygomatic arch.
- The periosteum is incised, elevating an anteriorly based pericranial flap extending down along the lateral orbital rim.
- Dissection proceeds anteriorly to the end of the nasal bone complex, facilitated by a midline incision through the periosteum.
- Incisions through the periosteum are made along the lateral orbital rim and down to the junction of the zygomatic arch and body.
- The temporalis muscles are elevated and detached from the lateral orbital wall and temporal fossa. A posterior back-cut may be made to advance them to the lateral orbital wall at the end of the procedure to prevent temporal hollowing.
- Circumferential orbital subperiosteal dissection mobilizes all orbital contents except for the medial canthus. It is critical not to detach the canthus from its bony insertion (**TECH FIG 1**).

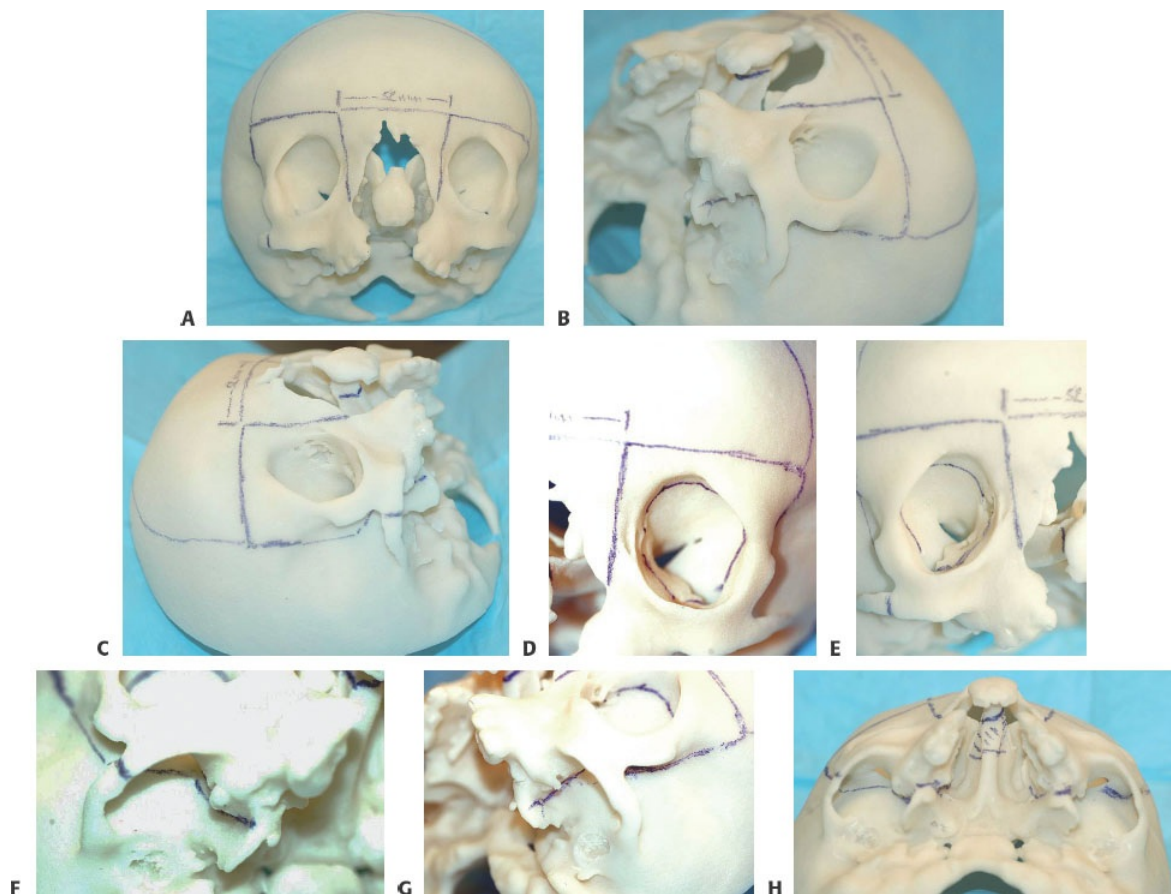


TECH FIG 1 • A. Craniofacial exposure through a bicoronal incision elevating an anteriorly based pericranial flap and taking down the temporalis muscles to expose the lateral orbital regions. Dissection proceeds circumferentially into the orbits, with preservation of the medial canthal attachments and simultaneous exposure of the entire nasal bone complex. **B.** The amount of bone to be resected is measured.

- Anatomic landmarks during the orbital dissection include the anterior and posterior ethmoidal arteries, the lacrimal fossa on the medial orbital wall, and the anterior extent of the infraorbital fissure along the lateral wall.
- A midline maxillary upper buccal sulcus incision is used to access the nasal surface of the palate.
- The mucosa is elevated from the piriform region along the maxillary crest and, if necessary, the septum is detached.
- If distraction is to be performed, the piriform margins are exposed as percutaneous traction (24-gauge) wires can be placed through the thick robust medial maxillary buttress.
- The bifrontal craniotomy is marked leaving the bandeau intact.
- A supraorbital bar is not left intact in this procedure.
- Neurosurgery performs a bifrontal craniotomy in the standard fashion. It is important to be able to access the middle cranial fossa for protection of the temporal lobes during the orbital osteotomies.

■ Circumferential Orbital Osteotomies

- With the brain dissected from the anterior and middle cranial fossae and safely retracted, the orbital roof osteotomy is performed medial to lateral using a reciprocating saw about 1 cm behind the superior rim, exiting the temporal bone.
- The lateral orbital wall is osteotomized using a reciprocating saw as well, taken down to the junction of the orbital floor and lateral wall, using the anterior extent of the inferior orbital fissure as a landmark (**TECH FIG 2**).



TECH FIG 2 • A–H. Details of the positions of the osteotomies in a 3-D model.

- The orbital floor osteotomy is made gently with a narrow osteotome, approximately 9 to 10 mm behind the inferior orbital rim.
- The medial orbital wall osteotomy is also completed with a narrow osteotome located anterior to the anterior ethmoidal vessel but behind the

lacrimal fossa.

- Parts of the medial and floor osteotomies are performed blindly; visualization would place too much traction on the orbital contents.
 - This should complete the circumferential orbital osteotomies.
-

■ Zygomatic and Maxillary Osteotomies

- The zygomatic arch osteotomy is made using a reciprocating saw at the junction of the arch and zygomatic body.
 - Pterygomaxillary osteotomies may be performed from superior to inferior with a straight 1-cm osteotome. The osteotome is placed behind the zygomatic body aiming downward and behind the maxillary tuberosity.
 - Palpating the maxillary tuberosity with one hand while the other hand directs the osteotome is a helpful tactic.
 - An elevator placed through the anterior extent of the inferior orbital fissure provides a useful landmark to guide the pterygomaxillary osteotomy.
-

■ Frontonasal Osteotomies

- The final osteotomy is made using a reciprocating saw across the anterior cranial fossa immediately in front of the cribriform plate. This osteotomy is best done just prior to downfracture because bleeding may occur.
 - Orbital contents should be retracted during the osteotomies.
 - Once the osteotomy has been made across the anterior cranial base, a 1-cm straight osteotome is driven downward and posteriorly, aiming for the posterior nasal spine going through the septum.
 - A finger in the mouth behind the soft palate may be a useful tactile guide.
-

■ Downfracture

- Rowe-Kelly forceps are applied and the entire fronto-orbito-maxillary complex is levered anteriorly testing for areas where the osteotomies are not complete.
 - Ideally, the surgeon should see the anterior cranial fossa osteotomy expand during the anterior movement of the frontofacial complex.
- A downfracture of the frontofacial complex is performed. This may involve

completing the midline septal osteotomy when visualization is improved with the downfracture.

- A straight osteotome is advanced through the nasofrontal osteotomy site, aiming down to the posterior nasal spine to complete the nasal osteotomy.
 - Pterygomaxillary spreaders are very useful at this point and are placed behind the maxillary tuberosity to further loosen and advance the midface segment.
 - It is critical to fully mobilize the entire frontofacial complex.
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■ Central Wedge Excision

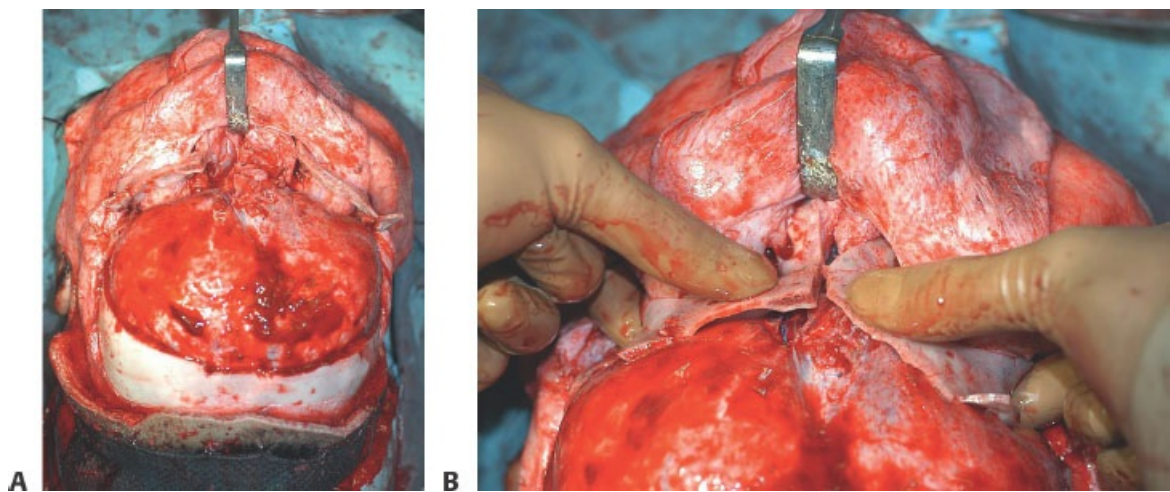
- The frontonasal wedge of bone is marked out maintaining at least 5 to 6 mm of medial orbital margin on each side.
 - This is necessary to maintain the integrity of the orbital bony margin and the position of the medial canthal complex.
 - From the mobilized segment, a central wedge of interorbital and nasal bone is removed using a reciprocating saw. This should be carefully measured according to the preoperatively determined specifications.
 - Nasal mucosa may be resected and repaired as needed to prevent soft tissue interference with medialization of the two facial halves.
 - The ethmoid air cells are removed with a rongeur to allow medialization.
 - The maxilla is split along the edge of the maxillary crest between the central incisors. This can be started with a reciprocating saw, but a dental osteotome is useful when performing osteotomies between the two central maxillary incisors.
-

■ Stabilizing the Two Halves

- The upper portion of two facial halves are rotated to close the space at the nasofrontal region and restore the midline and checked for symmetry (**TECH FIG 3**). Any bony interferences are removed.
- The point of rotation should be at the level of the maxillary incisors to prevent a diastasis between the dentition (see **FIG 6A**).
- Fixation is placed at the nasofrontal area. Our preference is to use two 26-gauge wires followed by a titanium plate.
- Stabilization of the frontofacial complex may be assisted with application of

intermaxillary fixation. This may require an endotracheal tube exchange during surgery (see Pearls and Pitfalls below).

- If no distraction osteogenesis is planned, the facial bipartition segments are oriented anteriorly with proper relation to the globes and fixed laterally with titanium plates to the temporal bone and the zygomatic arches.
- If distraction osteogenesis is planned, the facial bipartition segments are secured laterally with nonpermanent suture (4-0 PDS) for stabilization during the latency period.
- Plates and drill holes needed for attachment of the rigid external distraction device are placed.
- Orbital aperture shape may be contoured with a rongeur or bur for symmetry.



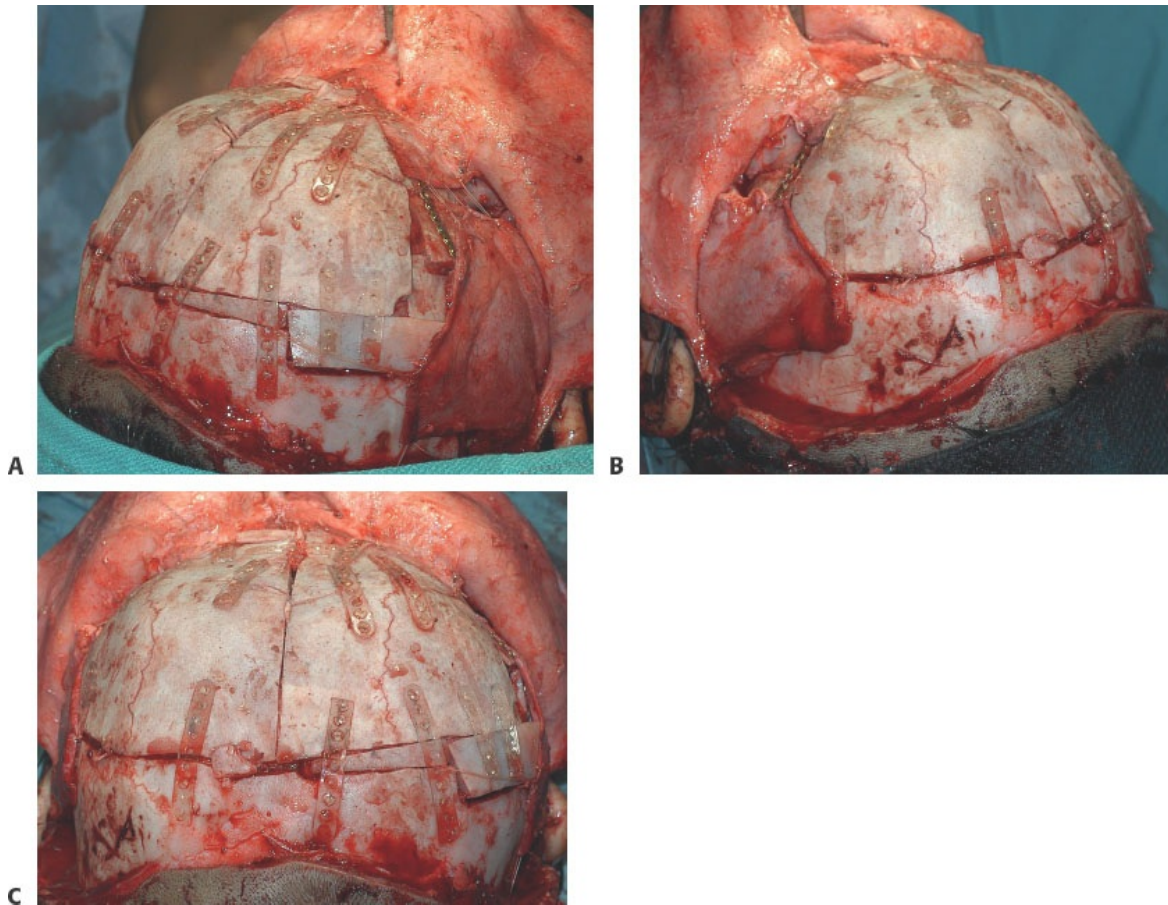
TECH FIG 3 • Following mobilization of the frontofacial complex and excision of the bone wedge in the nasofrontal region **(A)**, the two halves of the face are brought together in the midline **(B)**.

■ Anterior Vault Reconstruction

- The anterior cranial fossa is sealed from the nasopharynx with split skull bone graft, pericranial flaps, tissue glue, or other suitable materials, as available.
- The pericranial flap may be folded down into the anterior cranial fossa and held in place with sutures before sealing with tissue glue (**TECH FIG 4**).
- Forehead reconstruction is performed using the frontal bone, which may

need to be narrowed and adjusted.

- Titanium or resorbable fixation may be used to secure the frontal bone reconstruction to the bandeau.
 - With distraction osteogenesis, titanium hardware may offer more stability of the construct against anterior distraction forces.
- Frontal bone reconstruction may be secured posteriorly to the intact cranial bone with titanium mesh or resorbable plates.
 - If distraction is planned, securing with nonpermanent suture provides stability during the latency period.
- If nasal support or augmentation is required, nasal bone grafting is performed using calvarial bone graft.
- Remaining bone fragments are packed into calvarial defects.
- Larger defects may be reconstructed with titanium mesh.
- Temporal muscles are advanced and sutured to the lateral orbital wall via drill holes.
- Any remaining pericranial flap may be used to contour a concavity or secure over the cranial reconstruction.



TECH FIG 4 • After stabilization of the frontofacial complex, the anterior vault is reconstructed and soft tissue is resuspended. **A,B.** The temporalis muscles are advanced and attached to the lateral orbital walls. **C.** Note the pericranial flap that has been folded into the anterior cranial fossa before the frontal bone was replaced.

■ Soft Tissue Reconstruction

- It is critical to resuspend the soft tissues of the face prior to closure (**TECH FIG 5**).
 - However, lateral canthoplasties may or may not be formally done depending on surgeon preference.
- If performing distraction, place any remaining hardware or wires needed to secure the rigid external distraction device. Distraction may be done using

internal devices or external headframes depending on surgeon preference.

- Two suction drains are placed over the temporalis muscles, exiting posterior to the coronal incision.
- Close the coronal incision.
- Close the upper buccal sulcus incision.
- Excise excess midline soft tissue, if desired.
- If performing distraction, attach rigid external distraction device.



TECH FIG 5 • A. Once the soft tissue has been redraped, excess tissue can be marked and removed.
B. It is useful to employ external soft tissue bolsters to allow the tissue to redrape along the naso-orbital valley.

PEARLS AND PITFALLS

Planning

- 3-D models are extremely useful to plan for a facial bipartition.
- Positioning the bifrontal craniotomy and measuring anticipated bone resection in the nasofrontal region ensures better accuracy and saves valuable time during the procedure.
- Performing the osteotomies on a 3-D model allows the surgeon to understand the movements of the facial skeleton and anticipate the areas of bony interference.
- The model surgery allows the surgeon to understand the relationship between narrowing the interorbital distance and its

	impact on occlusion.
Airway	■ If the facial bipartition is being performed in combination with a frontofacial monobloc advancement, the entire procedure can be performed with an endotracheal tube. ■ In the event of a facial bipartition without distraction advancement, the endotracheal tube may require a change to a nasotracheal tube to facilitate application of intermaxillary fixation. This should be done after mobilization of the frontofacial complex with experienced anesthesia support. Only rarely is a tracheostomy required.
Osteotomies	■ The upper facial osteotomies are basic and easy to perform unless there has been previous cranio-orbital reshaping. It is crucial to protect the anterior projection of the temporal lobe of the brain, which is susceptible to injury when the reciprocating saw extends through the lateral extension of the sphenoid wing. ■ The pterygomaxillary osteotomies are performed blindly and can be a challenge. It is useful to place a finger intraorally behind the maxillary tuberosity and aim the osteotome toward your finger. ■ Performing standard pterygomaxillary osteotomies through an intraoral approach may also be a useful maneuver, especially in older patients.
Mobilization	■ The key to mobilization is completing the osteotomies. ■ Fully mobilize the frontofacial complex before splitting it into two segments. ■ Invariably, the soft tissues in the pterygomaxillary region are the reason for restricted movement and can be stretched by judicious placement of pterygomaxillary spreaders behind the maxillary tuberosity, which allows manipulation of the maxillary segment.
Bony interferences	■ Removal of bony interferences allows apposition of the bone edges. ■ Marginal excision of the region of the anterior nasal spine allows better apposition of bone in this region.
Soft tissue	■ Soft tissue excess will be generated by orbital medialization. ■ This tissue may be left to contract with possible revision at a later date. ■ External bolsters may be applied to guide redraping of tissue in the medial canthal region. ■ If direct excision is desired, perform this after closure of the coronal incision. ■ Orient soft tissue excision vertically at the midline or paramidline

if felt to be aesthetically more appropriate in terms of closure.

Advancement ■ When combining facial bipartition with monobloc advancement, distraction osteogenesis exhibits decreased complications compared to a single intraoperative advancement.

POSTOPERATIVE CARE

- Postoperatively the patient remains intubated in the intensive care unit for observation and airway protection. Neurological vitals (best verbal, best motor response, and assessment of neurological status after craniotomy) and visual and pupillary checks are carried out regularly.
- Extubation is preferred on the first postoperative day. While only a theoretical concern, positive pressure ventilation may force air into the anterior cranial fossa and increase the risk of infection.
- There is no consensus about the use of perioperative antibiotics for prolonged periods.
- If performing distraction, the latency period is typically 7 days, followed by activation of approximately 1 mm/d until advancement is achieved.
 - After advancement, the consolidation period is 8 to 12 weeks, prior to removal of the distraction device.
- The patient is started on a clear liquid diet and advanced to a soft no-chew diet for the duration of bone healing.
- A postoperative low-dose bone-only CT scan is routinely done to assess the extents of the osteotomies and facial configuration.
- Discharge home occurs when the patient has eyes open and adequate pain control.

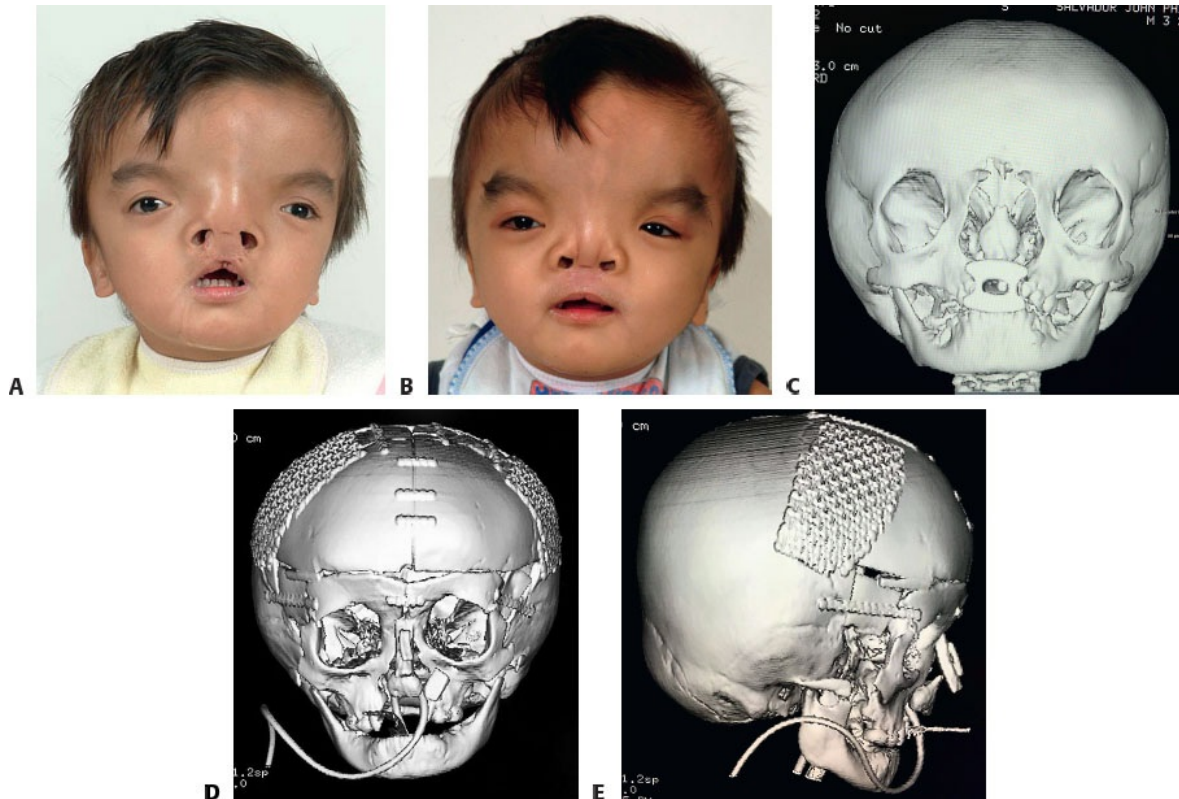


FIG 7 • A 4-year-old boy with severe frontonasal dysplasia and bilateral cleft lip and palate before **(A)** and 3 months after **(B)** a facial bipartition with nasal dorsal augmentation using calvarial bone graft. Titanium mesh was used to reconstruct full-thickness calvarial defects. CT images before **(C)** and immediately after **(D,E)** reconstruction.

OUTCOMES

- Achieving a normal postoperative appearance with facial bipartition is not common (**FIGS 7** and **8**) and should be stated clearly in preoperative discussions. The intent is primarily to improve hypertelorism and occlusal discrepancies.
- When performed as a monobloc frontofacial advancement, additional benefits include increased intracranial volume, improvement in exorbitism, increased size of nasopharyngeal airway, and resolution of obstructive sleep apnea; unbending of the concave facial profile in specific craniofacial dysostoses syndromes; and improved dental and skeletal balance.

- Breakey et al.⁵ determined movement of the medial canthi is proportionate to the change in interorbital distance, although the absolute distance between the medial canthi remains larger than the interorbital distance.
- Intercanthal width was increased by 10.2 to 13.8 mm compared to bony interorbital distance, due to the thickness of the overlying soft tissue.
- Wan et al.⁷ performed a retrospective review of patients treated with facial bipartition and box osteotomies for hypertelorism, focusing on patients with greater than 5 years of follow-up. Patients undergoing simultaneous monobloc advancement were not excluded.



FIG 8 • A 6-year-old girl with bilateral Tessier 1/13 clefts before **(A)** and 1 year after **(B)** a facial bipartition procedure followed by composite ear grafts to reconstruct the bilateral nasal clefts. CT images are shown preoperatively **(C)** and immediately after **(D)** reconstruction.

- Patients ($n = 33$) were analyzed by age (less than 6 or greater than or equal to 6 years) and hypertelorism severity.
- Mean surgical age was 9.2 years. Average follow-up length was 14 years.
- All patients less than 6 years old at the time of surgery ($n = 6$) exhibited relapse compared with normal interdacryon distances for their ages.
- In patients older than 6 years at the time of correction ($n = 27$), only three patients exhibited relapse.
- All patients with severe hypertelorism ($n = 4$) exhibited relapse, with an average surgical age of 6.3 ± 3.2 years.
- Five patients had complications, including wound infection ($n = 2$), meningitis ($n = 1$), seizures ($n = 1$), and postoperative bleeding requiring a return to the operating room ($n = 1$). There were no mortalities.
- Raposo-Amaral et al.⁶ in a similar retrospective review ($n = 22$ patients) concluded that patients younger than 8 years old at the time of surgery have a significantly increased risk of relapse. Patients were excluded if monobloc advancement was simultaneously performed.
- This finding was regardless of procedure (facial bipartition or box osteotomy) and regardless of the severity of hypertelorism.
- Average follow-up length was 15.2 years (5–30 years).
- Complications included recurrent meningitis secondary to a dural leak ($n = 1$) and seizures ($n = 1$). There were no mortalities.
- Frontal lobe ischemic changes have been demonstrated on postoperative imaging in 64% of patients ($n = 50$) undergoing monobloc with and without bipartition, corresponding with points of intraoperative cerebral retraction.¹¹
- Five of these children ($n = 38$) suffered new-onset postoperative seizures, whereas two children without ischemic changes ($n = 12$) also experienced seizures.
- Long-term significance of these findings is not known.
- Combining distraction with facial bipartition has demonstrated consistent improvement of midface retrusion and concave facial profiles, through differential central face distraction.^{9,10}
- In cases with frontofacial advancement, the increased use of distraction osteogenesis instead of a single intraoperative advancement has led to a significant reduction in postoperative infections and complications.¹²
- Occlusal abnormalities are treated after presurgical orthodontic treatment and skeletal maturity, typically after the age of 16 in girls and 18 in boys.¹²

- Additional nasal reconstruction with split calvarial grafts, costochondral grafts, or forehead flaps may be performed 12 months postoperatively.

COMPLICATIONS

- Failure to adequately treat hypertelorism is the most common complication.
- Even when initial results have sufficient correction, relapse of hypertelorism is possible.
- Infection is a significant complication and may result in bone resorption or nonunion.
- Visual (diplopia, visual loss)
- Asymmetries and orbital dystopia
- Enophthalmos
- Anosmia
- CSF leakage postoperatively may require a temporary lumbar drain.
- Meningitis
- Seizures
- Blood transfusion

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Orbital Expansion for Anophthalmia and Microphthalmia

18

CHAPTER

Brad Morrow and Rogerio I. Neves

DEFINITION

- Anophthalmia, either congenital or acquired, is a rare condition in the pediatric population.
- Development of the globe is critical for the stimulation of orbital and maxillofacial growth.
- Absence of a globe results in severe facial asymmetry due to bony and soft tissue hypoplasia.^{1,2}
- Anophthalmia presents a unique challenge to the reconstructive surgeon to create an aesthetic orbit, restore facial harmony, and improve the psychosocial well-being of the affected child.
- Orbital expansion is a minimally invasive technique that avoids the morbidity of orbital osteotomies. In properly selected patients, accelerated orbital growth is achievable and can reverse the midface discrepancies by bone remodeling.

ANATOMY

- Although the orbit is a pear-shaped cavity with a posteriorly tapering apex to the optic canal, it can be thought of as a box with four walls: medial, lateral, floor, and roof (**FIG 1A**).
- The medial wall, composed of the ethmoid, lacrimal, maxillary, and sphenoid bones, is the thinnest section and adjacent to the ethmoid and sphenoid sinuses.
- The lateral wall, composed of the zygoma and the greater wing of the sphenoid, is the thickest section and extends to the equator of the globe to protect the posterior portion, yet allow for peripheral vision. It is separated

from the lesser wing of the roof by the superior orbital fissure (**FIG 1B,C**).

- The floor, composed of the maxillary, palatine, and zygomatic bones, ends at the pterygopalatine fossa and contains the infraorbital neurovascular structures.
- The roof, composed of the frontal bone and the lesser wing of the sphenoid, also forms the base of the anterior cranial fossa.
- The diameter of the globe exponentially expands during the first 12 months of age.³ The rate of expansion begins to slow during 12 to 35 months of age and tapers off by 8 years of age when the diameter is approximately 96% of mature growth. Orbital dimensions and subsequent bony growth are significantly correlated with changes in globe diameter.
- Based on anthropometric soft tissue measurements, Farkas et al.⁴ determined that approximately 90% of orbital growth occurs by 5 years of age.

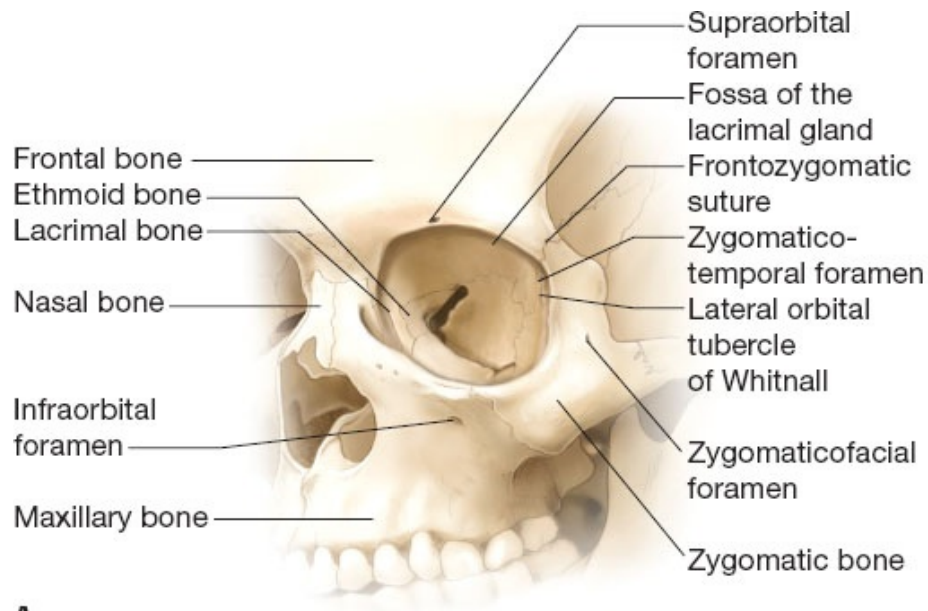
PATHOGENESIS

- Congenital anophthalmia occurs in the first weeks of gestation during neural tube formation when the neuroepithelium of the ventral forebrain fails to invaginate and form the optic vesicles.
- Etiology
 - Primary genetic defect
 - SOX2
 - PAX6
 - CHX10
 - GDF6
 - Gestational
 - Rubella
 - Varicella
 - Herpes simplex virus
 - Cytomegalovirus

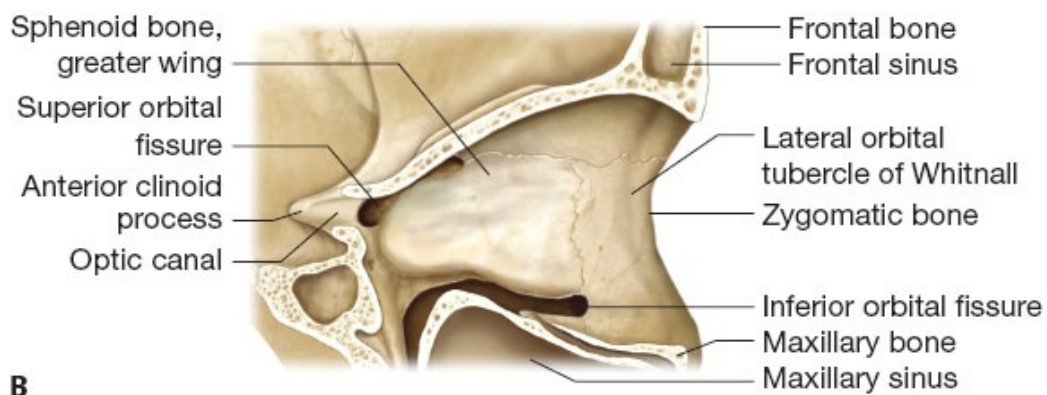
- Intrauterine exposure to thalidomide
- Vitamin A deficiency
- Incidence
 - The reported incidence ranges from 0.2 to 1.5 per 10 000 births.
- Acquired enucleation or evisceration after birth secondary to:
 - Tumor
 - Retinoblastoma
 - Choroidal melanoma
 - Trauma
 - Infection

NATURAL HISTORY

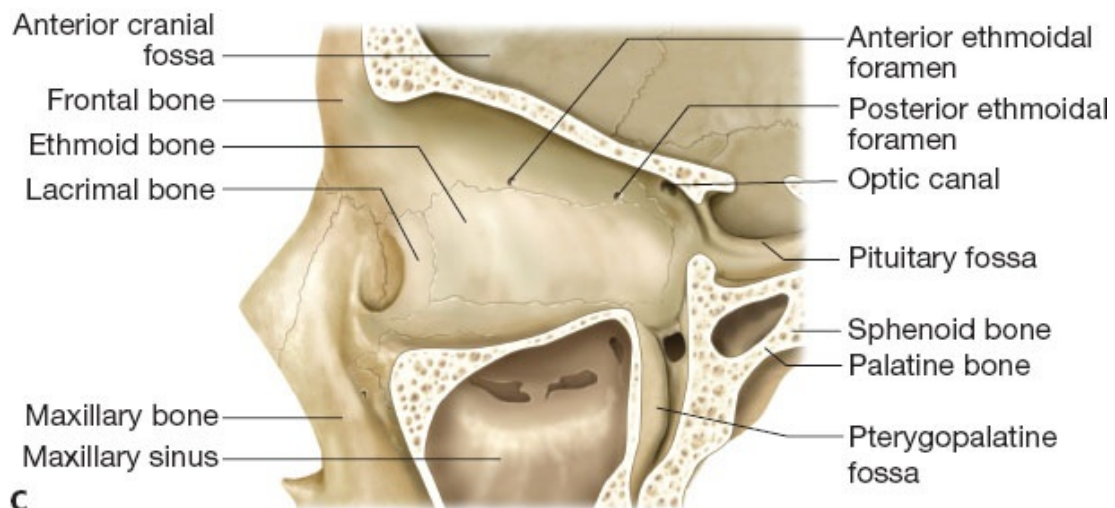
- The developing globe is critical for the stimulation of orbital and maxillofacial growth.
- Absence of a globe creates a three-dimensional midface hypoplasia of the skeletal, soft tissue, and adnexal structures.^{1,2}
- The resulting bony orbit is markedly reduced in volume and dimensions of the aperture.
- Horizontal and vertical zygomaticomaxillary development is subsequently affected with ipsilateral deficiencies manifested as a canted occlusal plane, loss of facial width, and projection of the malar prominence.
- The hypoplastic skeletal foundation creates significant soft tissue asymmetries with an inferiorly displaced eyebrow and short phimotic eyelids.
- Adnexal structures are also poorly developed with contraction of the conjunctiva and fornices.
- Enucleation in early childhood results in arrest of symmetric orbital growth. The severity of hypoplasia depends on the age at surgery as the orbit rapidly expands during the first 5 years of life.
- Without restoration of intraorbital volume and pressure, through autologous or alloplastic material, the socket and fornices contract, which compromises the ability to wear a prosthesis.
- As the infant progresses through childhood to adolescence, facial asymmetries will become more pronounced.



A



B



C

FIG 1 • A. Frontal view of the orbital bones. **B,C.** Lateral and medial walls of the orbit.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Anophthalmia or microphthalmia is predominantly unilateral but can be bilateral (**FIG 2**).
- Children with severe microphthalmia may retain potential for vision, and a complete examination is critical. A pediatric ophthalmologist should assess vision, including electrodiagnostic studies.
 - Flash visual evoked potentials establish optic nerve dysfunction and the presence of residual vision.
 - Electroretinogram may identify retinal dysfunction.
- In unilateral cases, the contralateral globe, lens, and optic nerve must be examined for additional anomalies such as a coloboma, cataract, glaucoma, retinal dystrophy, or optic nerve hypoplasia.
- The lacrimal system may be dysfunctional ranging from canalicular stenosis to nasolacrimal duct obstruction that requires dacryocystorhinostomy.
- A complete assessment of the child must be undertaken to determine the presence of associated systemic abnormalities including craniofacial, cardiac, genital, respiratory, neurologic, or metabolic.
 - Anophthalmia-plus syndrome includes anophthalmia, cleft lip and palate, facial clefts, and sacral neural tube defects.

IMAGING

- Diagnostic imaging should be obtained to evaluate the intraorbital contents.
- Ultrasound of the orbit may determine whether an ocular remnant or cyst is present. Simultaneous renal ultrasound is recommended due to the association of ophthalmic and renal anomalies.
- Computed tomography (CT) precisely delineates the bony anatomy but poorly defines the soft tissue structures and exposes the child to radiation. The implementation of low-dose radiation protocols has significantly lowered this theoretical risk (**FIG 3**).



FIG 2 • Six-month-old patient with right unilateral congenital microphthalmia.

- Magnetic resonance imaging (MRI) provides superior detail of intraorbital soft tissues and intracranial visual pathways and screens for brain anomalies.
- MRI has the additional advantage of avoiding radiation exposure; however, sedation is required in order to obtain a high-quality study in a young child.

DIFFERENTIAL DIAGNOSIS

- Clinical congenital anophthalmia refers to a phenotypic spectrum of blindness due to a developmental defect of the globe:
 - Anophthalmia: the complete absence of ocular tissue
 - Microphthalmia: the presence of a hypoplastic, rudimentary cyst; ocular remnant; or globe
- The distinction is not clinically relevant as the management does not differ and the terms are frequently interchanged.

NONOPERATIVE MANAGEMENT

- Multidisciplinary team care is essential for the management of affected children and includes plastic surgery, pediatric ophthalmology, prosthetic ocularist, optometry, genetics, and social work.
- In unilateral cases, vision in the contralateral unaffected eye must be protected with regular ophthalmologic examinations and safety glasses to prevent trauma.
- Conventional treatment of anophthalmia is initiated in the first few weeks of

life by serial placement of progressively enlarging custom-made static acrylic, glass, or silicone intraorbital and scleral conformers. Although this technique can enlarge the orbit, it is not without several limitations including the following:

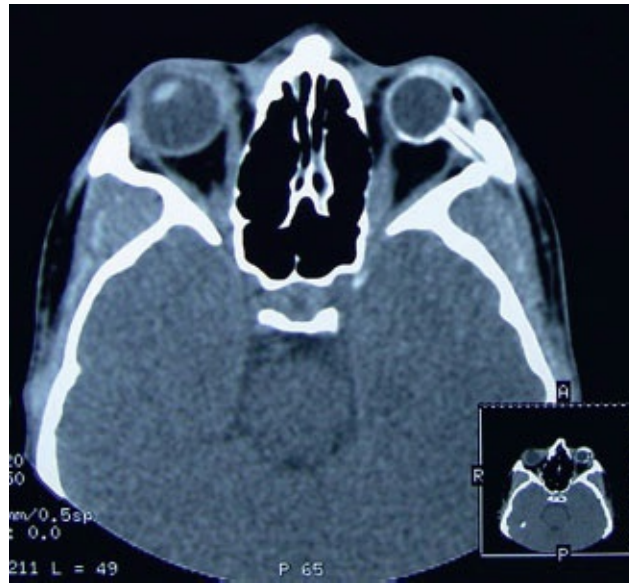


FIG 3 • Follow-up CT scan showing the appropriate position of the intraorbital tissue expander.

- The treatment plan requires significant dedication from the family because frequent office visits and examinations under anesthesia are necessary.
- Serial static conformers provide minimal stimulation for orbital growth, and despite frequent upsizing, development lags behind the contralateral unaffected side.
- If the conformer is not worn for a prolonged time, the socket will undergo contraction.

SURGICAL MANAGEMENT

- Orbital expansion is indicated for the correction of asymmetry in patients with congenital or early-age acquired anophthalmia before the completion of orbital growth.
- The technique is designed to stimulate orbital growth by recreating the pressure that would ordinarily be exerted by the globe. Physiologic pressure allows for orbital expansion and supraphysiologic pressure will lead to accelerated, or catch-up, growth to correct asymmetries.

- Various minimally invasive techniques have been described to avoid the morbidity of orbital osteotomies.
- Autologous techniques, such as dermal-fat grafts and free tissue transfer, have been described but are limited due to an unpredictable stimulus for orbital growth.^{5,6} Graft resorption secondary to the recipient site's potential for revascularization, notably with prior radiation, and hypertrophy secondary to obesity have been reported.⁷
- Tissue expansion is minimally invasive, with controlled gradual expansion to avoid uncomfortable rapid inflation pressure and the capability to stimulate accelerated growth of orbital bony and periorbital soft tissue structures to achieve a reconstruction symmetric to the unaffected side with minimal complications.^{8,9}
- Defining the goals of reconstruction and setting realistic expectations is paramount before proceeding with orbital expansion.
- The age of the patient is a critical factor when utilizing an orbital expander. Clinical and experimental studies have examined the effect of increasing skeletal maturation on the ability to stimulate orbital growth with a tissue expander. Results have demonstrated that both early and delayed expansion can generate accelerated, or catch-up, growth; however, delayed expansion has a significantly decreased ability to reduce orbital hypoplasia and asymmetry.
- Orbital expansion should begin as early as possible and must be initiated before complete synostosis of the orbital sutures.⁶
- The precise upper age limit has not been well defined, but a study has shown that the efficacy of orbital expansion may be compromised as early as 4 years of age.⁹
- Proper patient selection is essential. The surgeon should ensure that the patient's family will be compliant with regular follow-up in the clinic for monthly orbital expansion.
- The patient's family must also understand that it is a gradual process to expand the relatively inelastic bones of the orbit. This is in stark contrast to soft tissue expansion in which elastic structures are rapidly expanded. Complete correction of orbital asymmetries may require several years with multiple exchanges to larger expander sizes.
- Orbital expansion should be approached with caution in patients with acquired anophthalmia who have previously undergone periorbital radiation as the complication rate may be significantly increased.

- Maintenance of intraorbital volume and pressure to prevent contraction is indicated in patients who have completed correction of orbital asymmetries or those with acquired anophthalmia after skeletal maturity.
- Alloplastic options, including hydroxyapatite or silicone implants, retain the potential for motion in a prosthesis if the extraocular muscles are preserved, but infection and extrusion can be problematic.
- Autologous options, including dermal-fat grafts or free tissue transfer, can be utilized, although unpredictable growth remains a concern. Free tissue transfer has the advantage of a skin paddle to aid in conjunctival or soft tissue reconstruction.

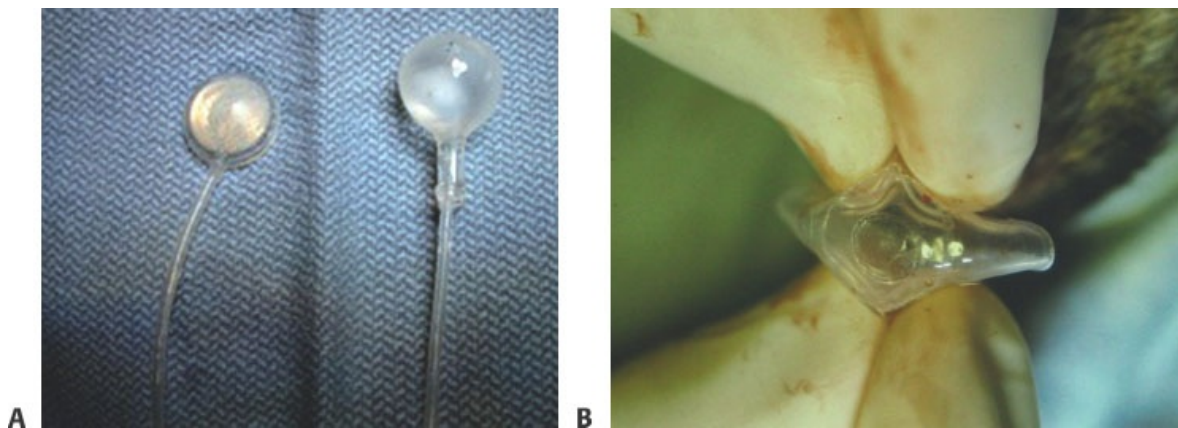


FIG 4 • A. Inflated silicone expander with remote microport. **B.** A larger expander needs to be folded to fit in an infant orbit, creating pressure points with higher extrusion rates.

Preoperative Planning

- After the patient has undergone a thorough ophthalmologic and radiologic examination, minimal preoperative planning is required for orbital expansion.
- Estimation of orbital volume can be difficult, and various sizes of expanders should be available at the time of implantation. Backup expanders should be present in case of inadvertent puncture.
- In general, a 1- to 2-mL spherical expander can be utilized in a 3- to 6-month-old patient (**FIG 4A**).
- Selecting the proper sized expander is crucial to minimize potential complications.

- If the implant is too large, a fold in the expander can create a flaw in the integrity of the shell and cause device failure (**FIG 4B**).
- Furthermore, a crease can also cause pressure necrosis on the conjunctiva and subsequently develop into wound breakdown and expander exposure.
- When deciding between two expanders, placement of the smaller expander lessens the likelihood of a crease or fold. This does not hinder the reconstruction as expanders can be overinflated in excess of the manufacturer's recommended fill volume or exchanged for a larger size at a later date.
- A consolidation period of 3 months is strongly recommended between expander exchanges.

Positioning

- The patient is positioned supine on the operating table such that the orbit and temporal and parietal scalp are accessible.
- Anesthesia should be induced with a secured endotracheal tube because repositioning and rotation of the head are required during surgery.
 - A gel pad or Mayfield headrest may be used.
- In a unilateral procedure, the contralateral eye is protected by taping the eyelids closed and using ophthalmic Betadine to prevent potential corneal abrasions or chemical injury.
- All potential pressure points on the body must be padded.

Approach

- Placement of an orbital expander is approached through the periorbita and temporal hair-bearing scalp.

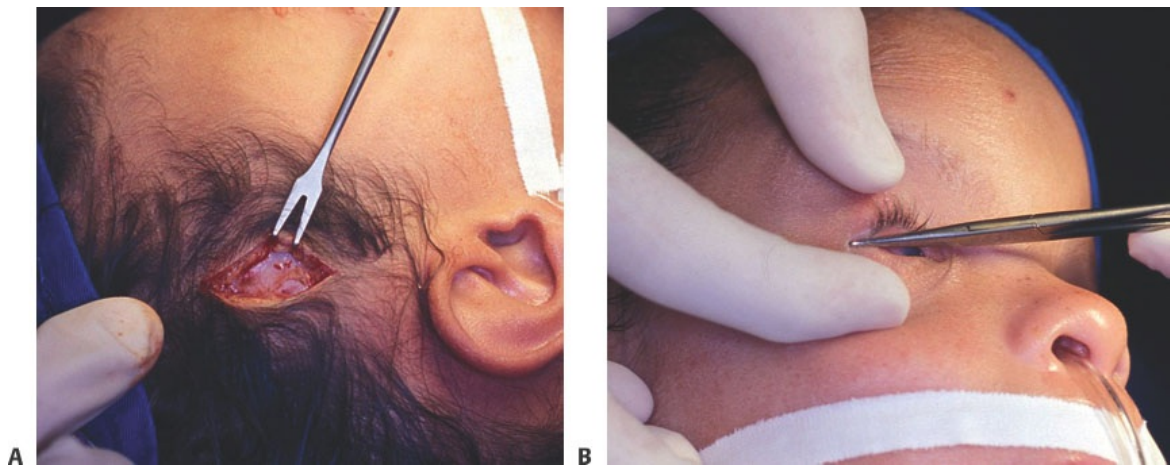
TECHNIQUES

■ Exposure and Orbitotomy

- An incision measuring 2 to 3 cm is made in the temporal hair-bearing skin (**TECH FIG 1A**). Superficial to the temporal fascia, a tunnel is created to the lateral orbital wall and the temporoparietal scalp.
- The conjunctiva is incised to gain access to the intraorbital contents.
 - If present, enucleation of residual orbital contents can be performed in

conjunction with expander placement.

- Through an extended lateral canthotomy incision, the lateral orbital wall is exposed (**TECH FIG 1B**).
- A lateral wall orbitotomy is created.
 - Depending on the patient's age and ossification of the bone, this may be achieved with a bur hole or a biopsy punch.



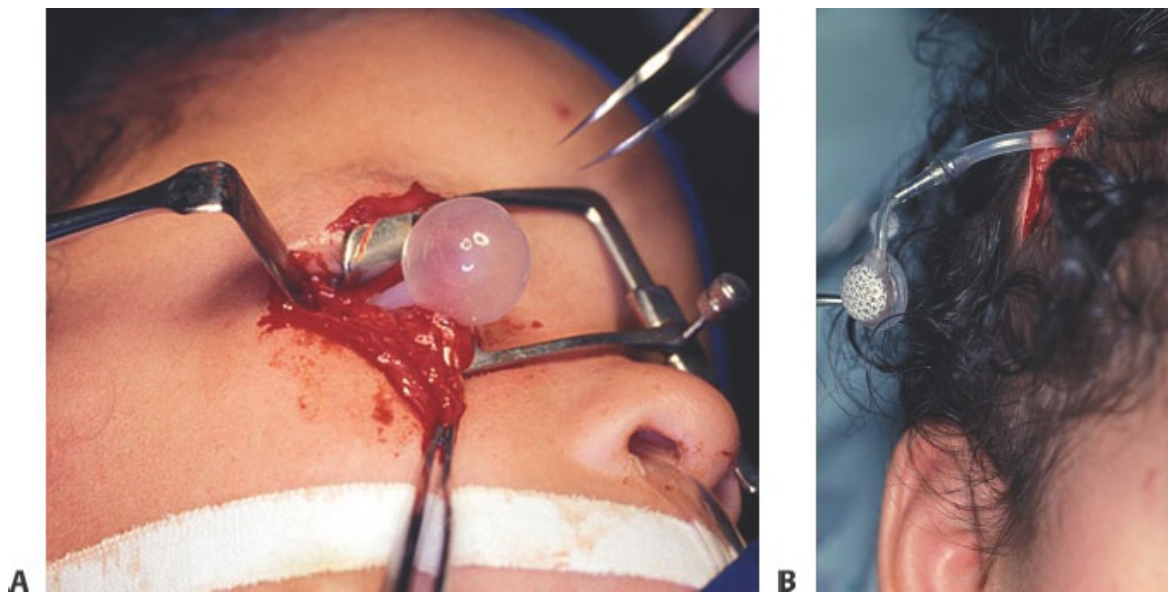
TECH FIG 1 • A. An incision is made in the temporal hair-bearing scalp superficial to the temporal fascia, creating a tunnel between the lateral orbital wall and the temporoparietal scalp. **B.** Through an extended lateral canthotomy incision, a lateral wall orbitotomy is created. The orbital expander is anchored through the orbitotomy to prevent migration.

■ Orbital Tissue Expander and Microport Placement

- The silicone expander is placed in the orbit with the collar firmly anchored through the lateral orbital wall (**TECH FIG 2A**).
 - This prevents expander migration and allows for a controlled expansion process.
 - The expander is placed in the intraconal, anatomic position of the globe to recreate the pressure normally exerted on the bone and soft tissue during development. Subperiosteal placement is avoided as the periosteum is inelastic and this would prevent a symmetric 360-degree spherical

expansion.

- Through the temporal incision, a pocket is developed in the temporoparietal scalp for placement of the remote microport.
- The remote microport allows for easy access without distorting the scalp anatomy.
- A 30-gauge needle is recommended for inflation to create minimal discomfort and to avoid leakage from the port.
- The tubing from the expander and microport are joined with a straight connector (**TECH FIG 2B**).



TECH FIG 2 • **A.** Intraorbital placement of silicone expander. **B.** Placement of remote microport in the temporoparietal scalp.

■ Expander Inflation and Closure

- The expander is inflated with injectable saline and examined for a leak or crease.
- As previously mentioned, a fold or crease in the expander must be avoided as it can cause device failure or conjunctival breakdown and exposure.
- If a crease is identified, the expander should be inflated additionally.
- If the crease is not corrected or this causes excessive tension on the closure, the expander must be exchanged for a smaller size.

- The conjunctiva is closed in layers with Tenon capsule, if present.
- The final fill volume of the expander is determined by the tension on the conjunctival closure. Tension must be minimized to prevent wound healing complications.
- A tarsorrhaphy suture is placed at the conclusion of the procedure.

PEARLS AND PITFALLS

Accelerated growth	■ Expansion should be initiated at the earliest age possible, preferably within 3 months, and before synostosis of the orbital sutures. Early age at expansion can achieve accelerated growth and correct orbital discrepancies.
Controlled expansion	■ Anchoring the expander through the lateral wall orbitotomy prevents migration and creates a controlled expansion.
Iatrogenic puncture	■ A remote port allows for expansion without the patient visualizing the needle and reduces the risk of iatrogenic puncture.
Exposure of the expander	■ Aggressive inflation of the expander should be avoided, especially in a patient with prior radiation; risk of exposure increases in this scenario. ■ Choosing a smaller expander prevents exposure because folds or creases may cause friction or pressure necrosis on the conjunctiva and lead to wound breakdown.
Upsizing the expander	■ A significant consolidation period is required between upsizing expanders, preferably 3–6 months.
Leakage	■ Leakage from the port or connector may occur. This may happen when multiperforating the microport or using needles larger than 30 gauge (FIG 5). With leakage, inflation volume may not represent the actual intraexpander volume. The port alone may be replaced without exchanging the entire tissue expander.

POSTOPERATIVE CARE

- Placement of an orbital expander may be performed as an outpatient procedure.

- Patients return to clinic 4 weeks postoperatively to begin the expansion process, which then proceeds on a monthly basis.
- Topical anesthetic cream is applied directly over the port site by the parents 1 hour prior to the clinic visit.
- Placement of the microport in the temporoparietal scalp allows for expansion in the clinic without the patient visualizing the needle. This avoids an anxious, moving patient and can prevent iatrogenic rupture.
- Inflation of the expander is terminated when the patient displays physical signs of intolerance.

OUTCOMES

- Multiple investigators have explored orbital expansion for anophthalmia in an animal model. The data demonstrate a direct relationship between intraorbital pressure and orbital growth. Expansion at physiologic pressure stimulated normal orbital growth, but supraphysiologic pressure accelerated growth.
- Expanders have shown a statistically significant increase in orbital volume when compared to static conformers of increasing size.¹⁰

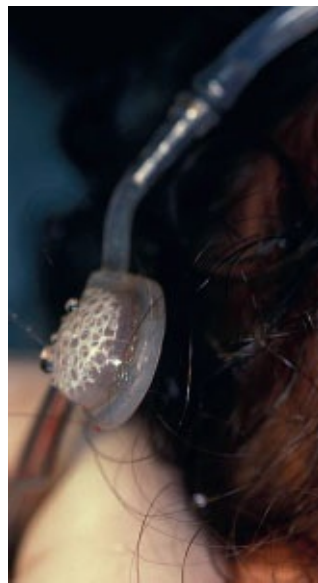


FIG 5 • Multiperforated microport showing leakage of the injected saline.

- Expanders have also exerted trophic effects on periorbital soft tissue and reduced the degree of zygomaticomaxillary hypoplasia.^{10,11}

- There are limited clinical data in the literature except for case series due to the rarity of the condition.
- Existing data support orbital expansion as a safe and effective procedure to correct the asymmetries of anophthalmia and microphthalmia.^{8,12,13}
- Additional data also indicate that expansion should be initiated at the earliest possible age as the rate of accelerated growth is inversely proportional to age.⁹

COMPLICATIONS

- Unplanned expander removal
 - Exposure
 - Rupture
 - Infection
- Leakage
- Inadequate correction
- Residual asymmetry
- Further soft tissue reconstruction

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Section III: Maxillary Surgery

19 Surgically Assisted Rapid Palatal Expansion (SARPE)

CHAPTER

Omri Emodi, Nezar Watted, and Adi Rachmiel

DEFINITION

- Maxillary transverse deficiency can be treated either orthodontically or surgically using rapid palatal expansion (RPE). This technique, which involves enlarging the maxillary dental arch and the palate (roof of the mouth) to re-establish balance between the width of the jaws through use of an orthodontic device, forces open the palatal bones via a screw mechanism that is turned daily.^{1,2}
- In children and adolescents, conventional orthodontic RPE has been successful when applied prior to palatal suture closure.³
- In skeletally mature patients, the possibility of successful maxillary expansion decreases as sutures close and resistance to mechanical forces increase.⁴
- Indications for RPE include^{5,6} the following:
 - To increase maxillary arch width, which corrects a posterior crossbite
 - To widen the maxillary arch as a preliminary procedure prior to LeFort I advancement
 - To provide space for crowded maxillary dentition
 - To widen maxillary hypoplasia associated with clefts of the palate prior to bone grafting¹⁻³

ANATOMY

- Relevant anatomic regions that contribute to resistance:

- Anteriorly—piriform aperture pillar
- Laterally—zygomatic buttress
- Posteriorly—pterygoid junction
- Medially—midpalatal suture
- Important anatomical landmarks:
 - Greater palatine neurovascular bundle—passes through the palatine bone in the posteromedial wall of the maxillary sinus
 - Nasal mucosa—located medially and should be preserved
 - Root of the canine—apex of the root is more superiorly positioned compared to other teeth and should be avoided when performing the horizontal osteotomy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical examination reveals a constricted upper arch, with a narrow and high palatal vault.
- Maxillary dental crowding is present in combination with midface hypoplasia.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Posteroanterior cephalogram (interjugal distance, intermolar width)

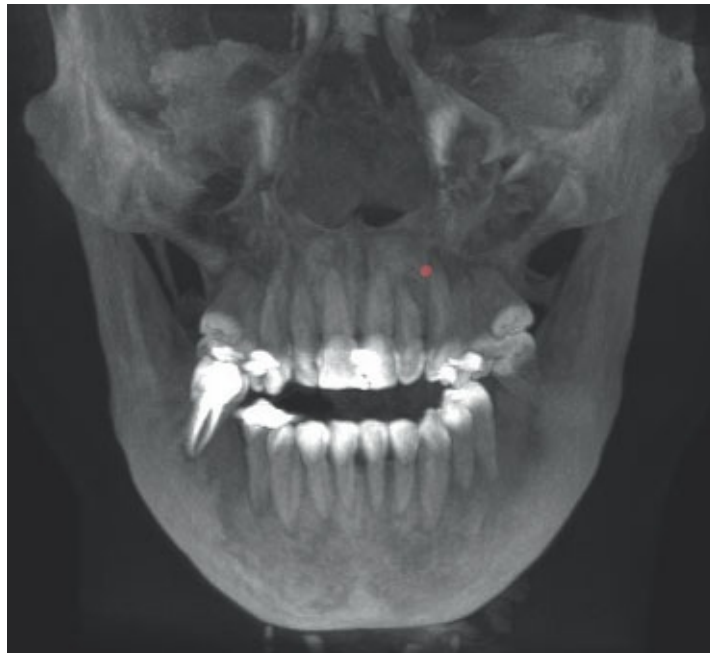


FIG 1 • Cone-beam computer tomography showing maxillary transverse deficiency.

- Cone-beam computer tomography (CBCT; **FIG 1**)
- Cast models of the upper and lower jaws: In cases of maxillary transverse deficiency, a deep curve of Wilson in the lower dentition may mask the maxillary transverse constriction.
- Assessing the models in the articulator

DIFFERENTIAL DIAGNOSIS

- Unilateral or bilateral posterior crossbite (**FIG 2A**)
- Narrow tapering maxillary arch form (**FIG 2B**)
- Narrow and high palatal vault
- Excessive buccal corridors (space between the teeth and the corners of the mouth)
- Maxillary dental crowding, when extractions are not indicated
- Maxillary hypoplasia associated with clefts of the palate

NONOPERATIVE MANAGEMENT

- RPE without surgical intervention can usually be applied until the age of 15.

SURGICAL MANAGEMENT

Preoperative Planning

- Dental casts
- Preoperative CBCT or panoramic x-ray as well as posteroanterior cephalograms (see **FIG 1**)
- The Hyrax device for expansion is applied by the orthodontist before surgery in cases where a tooth-borne device is required. A bone-borne device is placed intraoperatively.

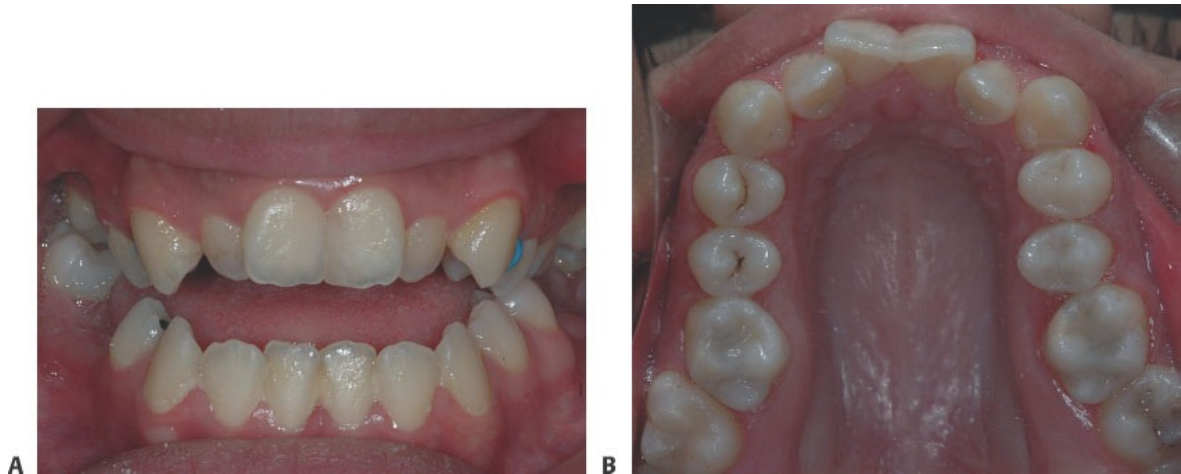


FIG 2 • A. Bilateral posterior crossbite with anterior open bite. **B.** Narrow maxillary arch form with dental crowding.

Positioning

- The patient is placed in the supine position.
- Nasal intubation is used to allow intraoral access.
- IV muscle relaxant is administered for better mouth opening during the case.
- A bite block is placed and maintained throughout surgery for easier mouth opening.
- Local anesthesia, such as lidocaine 2% combined with adrenaline for vasoconstriction, is administered.

TECHNIQUES

■ Exposure

- A bilateral horizontal incision is made within the maxillary vestibule, 2 to 3 mm above the attached mucosa, between the lateral incisor anteriorly and the first molar posteriorly, keeping the midline frenulum attached for better aesthetic results (**TECH FIG 1**).
- Develop exposure of the lateral maxilla from the central incisors toward the pterygomaxillary junction posteriorly.
- Separate the nasal mucosa from the lateral nasal wall using a periosteal or

Freer elevator.

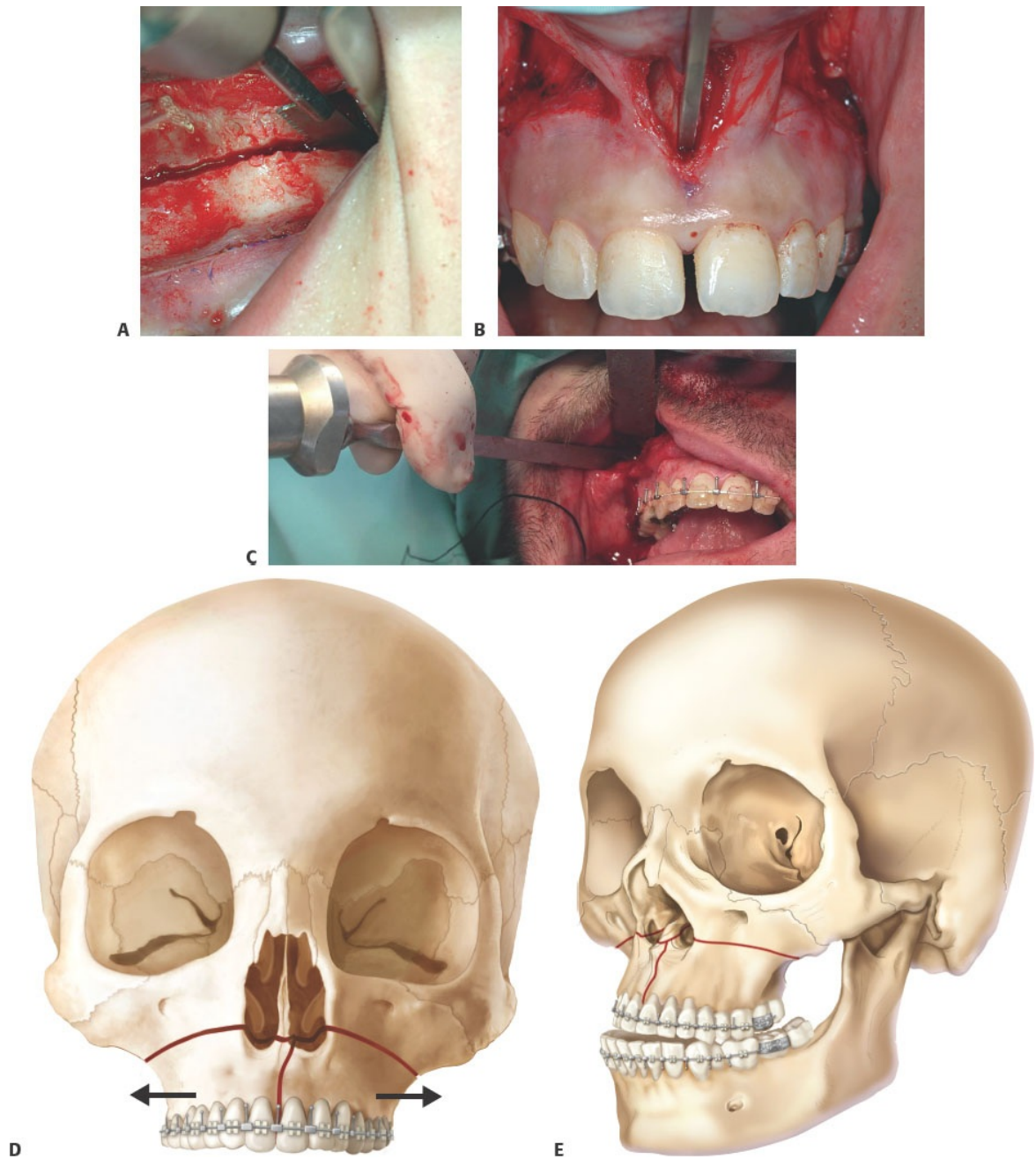


TECH FIG 1 • Horizontal incision is made in the maxillary vestibule 2 to 3 mm above the attached mucosa.

■ Osteotomies

- Using a reciprocating saw, a lateral, horizontal maxillary osteotomy is made on the lateral maxilla at least 5 mm above the apex of the teeth at the level of the nasal floor; the osteotomy extends from the pterygoid plate posteriorly toward the lateral wall of the nose anteriorly.
 - Avoid damage to the canine apex, which is higher than the other tooth roots (**TECH FIG 2A**).
- The nasal septum and the nasal wall should be separated from the palate using a fine osteotome to protect the nasal mucosa.
- A sagittal osteotomy is performed between the central incisors (**TECH FIG 2B**).
 - A thin osteotome is introduced between the two central incisors and an osteotomy of the midpalatal suture is performed.
 - Avoid perforating the palatal mucosa by palpating the mucosa with a finger during the osteotomy. The osteotomy is continued until independent movement of both lateral maxillary segments is accomplished.

- The pterygomaxillary fissure is osteotomized using a curved osteotome.
- This step is optional due to the risk of causing uncontrolled bleeding from the internal maxillary artery or the pterygoid venous plexus. If it is performed, it is critical to position the osteotome correctly, in an inferior and medial position (**TECH FIG 2C**).
- The desired osteotomies are demonstrated in **TECH FIG 2D,E**.

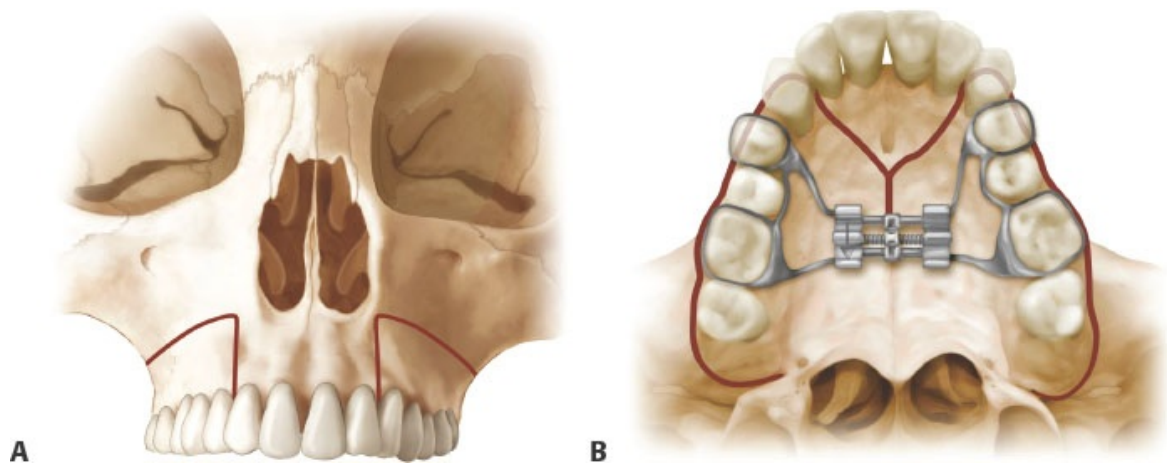


TECH FIG 2 • A. A lateral horizontal maxillary osteotomy on the lateral maxilla is made at least 5 mm above the apex of the teeth. **B.** A thin osteotome is introduced between the two central incisors and osteotomy of the midpalatal suture is carried out. **C.** The pterygomaxillary fissure is osteotomized by a curved osteotome. This procedure is optional. **D,E.**

Illustration of SARPE design.

■ Alternate Technique: Bilateral Transverse L-shaped Maxillary Osteotomy

- In cases in which there is need to avoid displacement of the premaxillary segment, an L-shaped osteotomy is performed bilaterally.
- Osteotomies are made laterally from the pterygoid plate posteriorly to a position above the roots of the second incisor (**TECH FIG 3**), continuing with a vertical osteotomy between the lateral incisor and canine teeth toward the horizontal osteotomy.⁶



TECH FIG 3 • Inverted L osteotomy design, frontal (**A**) and occlusal (**B**) views.

PEARLS AND PITFALLS

Orthodontic appliance

- The Hyrax should be activated before closing the mucosa. The opening of the midpalatal suture should be directly viewed.

Nasal apparatus

- It is critical to release the nasal septum from the maxilla during the midpalatal osteotomy to avoid septal deviation.

Bleeding

- Osteotomy of the pterygoids is optional due to the risk of

	iatrogenic injury to the internal maxillary artery and pterygoid venous plexus. Positioning the osteotome correctly, in an inferior and medial position, is critical.
	■ When separating the lateral nasal walls, avoid the descending palatine vessels posteriorly.
Anesthetic consideration	■ SARPE can be done under local anesthesia with IV sedation and without osteotomy of the pterygopalatine suture due to the high risk of bleeding.
Midline osteotomy	■ The midline cut carries the potential to damage the roots of teeth, compromising perfusion to both bone and soft tissues.

POSTOPERATIVE CARE

- Activation of the device is initiated on the first postoperative day by turning the device once a day at a rate of 0.3 mm/d (**FIG 3A**).
- Postoperative panoramic x-ray, posteroanterior cephalography, or CBCT should be performed during postoperative expansion (**FIG 3B**).
- Following complete bony and dental arch expansion, orthodontic dental alignment is performed.

OUTCOMES

- Increased transverse dimension of the maxilla
- Wide diastema between central maxillary incisors
- Elimination of dental crowding

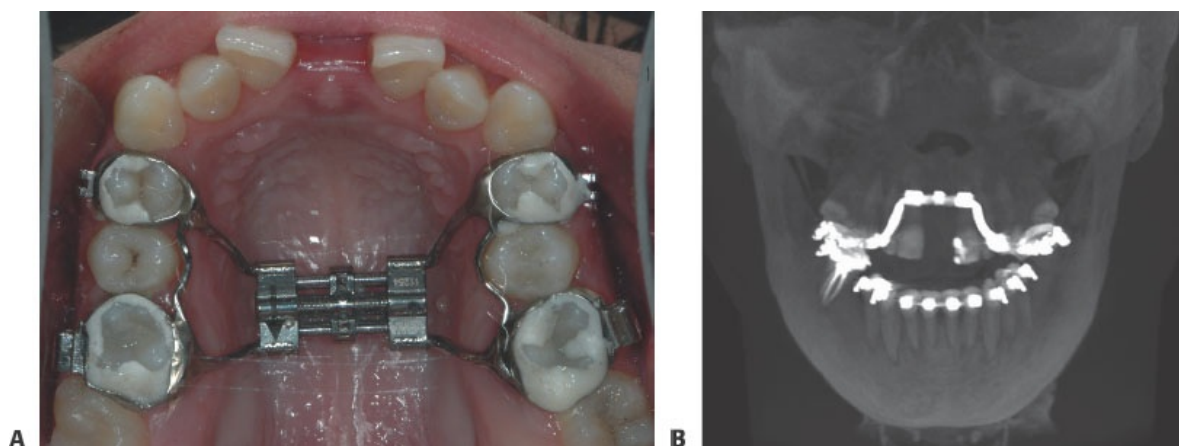


FIG 3 • Several weeks after activation of the Hyrax palatal expander. **A.** Photo. **B.** Radiograph.

- Reduction of wide black buccal corridors (open space between the lateral aspects of the posterior maxillary teeth) when smiling
- Improved nasal breathing

COMPLICATIONS

- Infection
- Postoperative bleeding can also occur up to 3 weeks postoperatively, due to injury of the greater palatine vessels or venous plexus.
- Periodontal recession
- Loss of tooth vitality at the osteotomized area
- Detachment of the orthodontic appliance
- Asymmetrical expansion
- Nasal septal deviation^{2,3}

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20 Premaxillary Segment Setback

CHAPTER

Omri Emodi

DEFINITION

- Orofacial clefts (OFCs) are the most common birth defect with a prevalence of 17 in every 10 000 live births.¹
- OFCs are most common in Amerindian and Asian populations (15–36/10 000) and least common among African populations (5/10 000).^{2,3}
- OFCs involving the lip have a male-to-female ratio of 2:1.
- Bilateral cleft lip and palate (BCLP) is the most severe of the common OFC subtypes and represents 1 in 10 patients with clefts of the lip.
- Subjects with BCLP usually present with maxillary retrognathism, a smaller mandible with an obtuse gonial angle, greater anterior upper and lower facial heights, and retroclined maxillary incisors.
- The premaxilla associated with BCLP may present in multiple positions, including severe protrusion (**FIG 1**).

ANATOMY

- The nasomaxillary process (including the nose and premaxilla) is separated from the lateral maxillary segments.
- There is significant variation in the position of the premaxilla in patients with BCLP.⁴
 - It may be in correct position in relation to the lateral maxillary segments.
 - The premaxilla may also project anteriorly or rotate up under the nose, with significant deviation to either side.
 - Severe protrusion of the premaxilla is possible.



FIG 1 • A child with protruded premaxilla.

- The prolabium (soft tissue on the premaxilla) is composed of skin, subcutaneous tissue, and fat and is without a muscle layer.
- Vascular and neural findings include the following:
 - The pterygopalatine portion of the maxillary artery provides major branches to the maxilla, teeth, palate, and linings of the nose and sinuses.
 - The posterior septal artery alone cannot fully meet the needs of the premaxilla and requires a complementary supply from the prolabial circulation (**FIG 2**).

PATHOGENESIS

- The embryological development of the upper lip and nose requires a sequence of complex, genetically programmed events:
 - Fusion of the five major facial prominences occurs between the 3rd and 8th weeks of gestation.
 - Lip development occurs between the 3rd and 7th weeks.
- Multiple genetic mutations disrupt facial development, resulting in OFCs.¹⁻³

PATIENT HISTORY AND PHYSICAL FINDINGS

- BLCP patients with protrusive premaxillae may present at several time points

where treatment can be initiated.

- Prior to lip repair, presurgical orthodontics may be used to retrocline the premaxilla.⁵

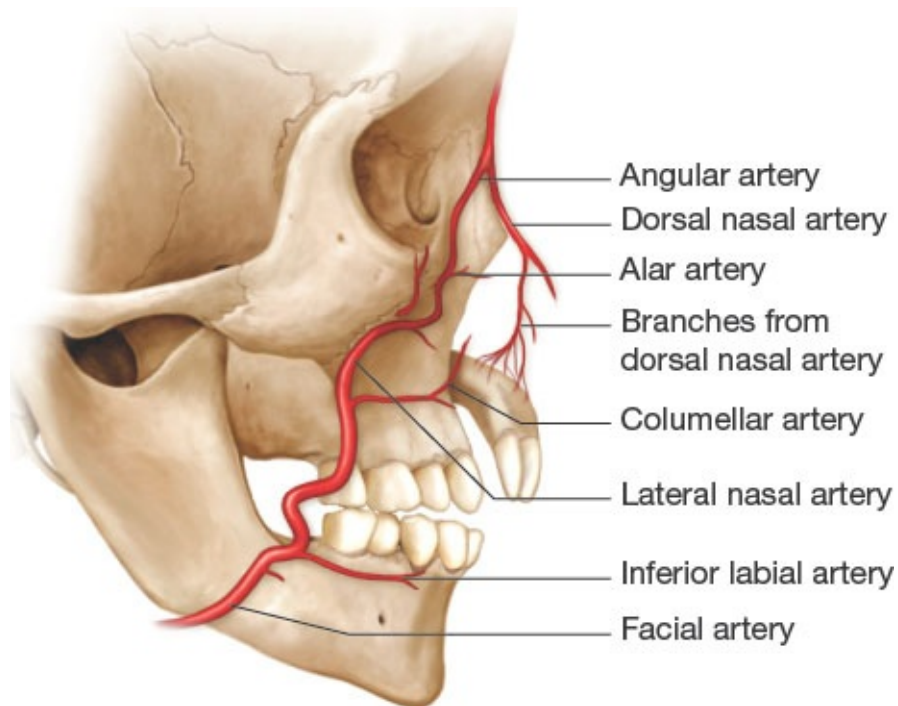


FIG 2 • Anatomical description of the blood supply to the premaxilla in patients with bilateral cleft lip and palate. Branches from the dorsal nasal artery and the columellar artery contribute to the blood supply of the premaxilla.

- After lip repair, when the patient may require surgical setback of the premaxilla as an isolated procedure.
- During mixed dentition (6–8 years of age), when the premaxillary setback can be performed with a bone grafting procedure.⁶
- At the time of skeletal maturity, when orthognathic surgery is planned. Premaxillary setback should be avoided at the time of orthognathic surgery; the setback should be completed prior to orthognathic surgery.
- In an adult, where premaxillary setback can be performed with lip repair.⁷

NONOPERATIVE MANAGEMENT

■ Nasoalveolar molding (NAM)⁷

- A presurgical orthopedic device can be used to guide the lateral alveolar ridges and premaxillary segment into an improved arch form.
- Shortly after birth, impressions of the upper jaw and the nose are made. These impressions serve to construct the orthodontic plate. The purpose of this plate is to retrocline and symmetrically position the premaxillary segment.
- Weekly adjustments are required for maximal effectiveness of the presurgical appliance.

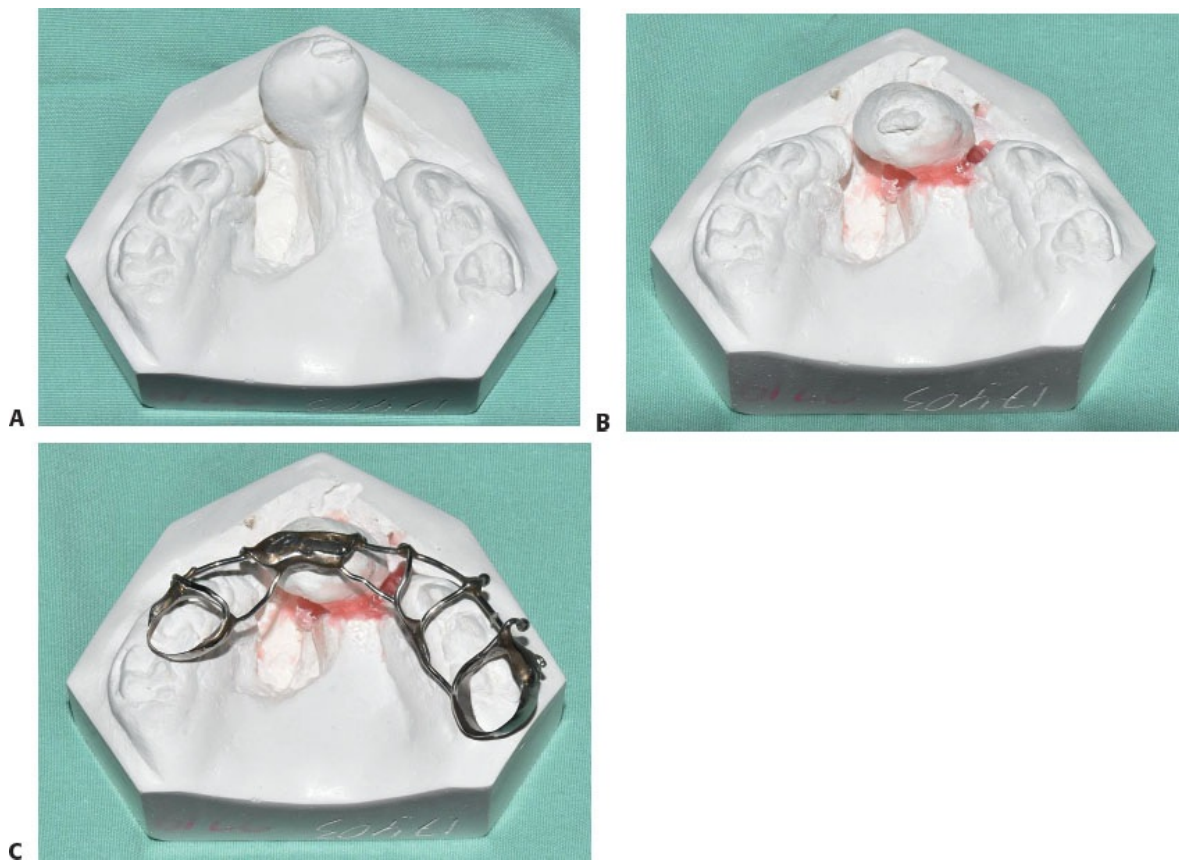


FIG 3 • Cast model before **(A)** and after **(B)** ostectomy. **C.** Demonstration of the appliance on the cast model for postoperative fixation.

- This process needs to be completed by 4 to 6 months of age. After this time, the premaxillary segment becomes ossified and cannot be manipulated by NAM.

SURGICAL MANAGEMENT

Preoperative Planning

- A dental impression of the upper jaw is taken using silicone material.
- A cast model is fabricated from the impressions (**FIG 3A**).
- Mock surgery is performed on the model as follows:
 - The premaxilla is osteotomized.
 - The protruded segment is repositioned into the desired location for correction of the skeletal disorder (**FIG 3B**).
- An orthodontic fixation appliance is fabricated to stabilize the segment in its new position during healing (**FIG 3C**).

Positioning

- The child is positioned supine on the operating room table, at 90 degrees from the anesthesia staff.
- A shoulder roll is placed for neck extension.
- An oral RAE tube is used for intubation, and a bite block is used to maintain the mouth in an open position during surgery.

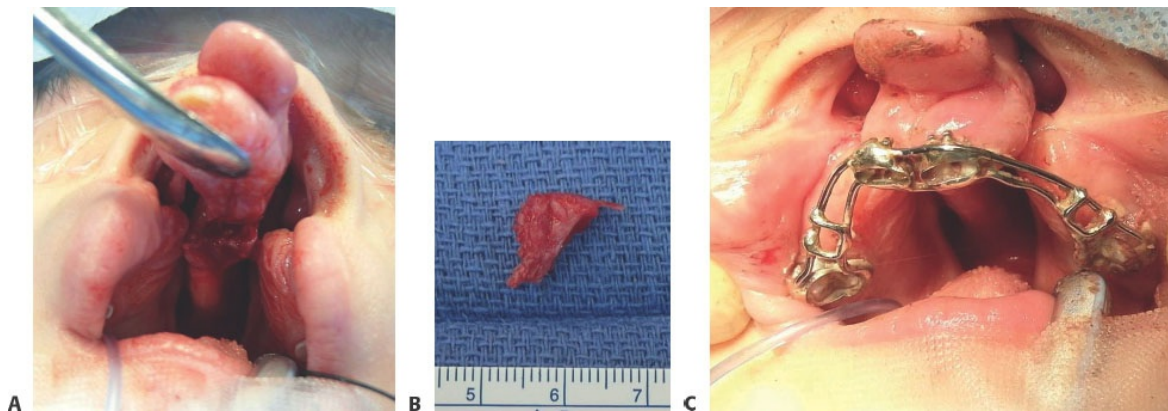
TECHNIQUES

■ Premaxillary Segment Setback

- The child's protruded premaxilla is exposed using an intraoral approach to the vomer.
- The blood supply to the premaxilla must be maintained to prevent vascular necrosis of the segment.
- Infiltrate local anesthetic (2% lidocaine with 1:1 000 000 epinephrine) to the upper vestibule and vomer.
- A vertical incision is made from the anterior to the posterior vomer using a no. 15 blade (**TECH FIG 1A**).
- The nasal layer is separated from the vomer to provide complete exposure of the underlying cartilage.
- A 10- to 15-mm osteotomy of the vomer-maxilla junction is performed at the oral base of the vomer. It should be narrow at the top—facing the nasal side

—and wider at the base, shaped like a triangle (**TECH FIG 1B**).

- The triangular space will be closed once the premaxilla is down-rotated and aligned to the posterior aspect of the vomer.
- Keep the buccal mucosa intact to maintain adequate blood supply to the osteotomized premaxilla.
- Create perfect alignment between the two sides of the reduced vomer.
- The premaxilla is then fixed with the custom-made orthodontic appliance with dental wires to adjacent teeth (**TECH FIG 1C**).
 - In the absence of teeth for fixation of the orthodontic appliance, a K-wire is used to fixate the premaxilla to the vomer.
- The mucosa covering the vomer is then sutured with a 4.0 Vicryl suture, providing watertight coverage of the vomer to reduce infection in the area of the osteotomy.
- Mild pressure should be applied to the premaxilla to determine the degree of stabilization.
- If lip repair is planned, it is completed in traditional fashion.⁸
- The custom-made orthodontic appliance with dental wires is left in place for 3 months.



TECH FIG 1 • **A.** Surgical exposure of the osteotomy region. **B.** Osteotomy of the vomerine segment. **C.** Postoperative results with the premaxilla rigidly fixed with appliance after repositioning.

PEARLS AND PITFALLS

Approach

- Consideration must be given to the blood supply of the premaxilla. If this is injured, loss of the premaxilla is likely.
- The surgeon should approach the premaxilla intraorally with the use of a Dingman retractor.
- Surgical exposure of the vomer should be in proximity to the premaxilla.
- Nasal layer closure should be watertight for appropriate healing.

Fixation

- Rigid fixation of the osteotomized premaxilla is crucial for appropriate healing.
- In the absence of teeth to fixate the orthodontic appliance to the premaxilla, a K-wire can be used to fixate the premaxilla to the vomer.

Stabilization

- Lip closure can be performed routinely after the premaxilla is repositioned.
- The premaxilla may remain mobile without fixation until bone grafting to the maxillary cleft.

POSTOPERATIVE CARE

- All patients maintain a strict soft diet for 12 weeks.
- Oral hygiene is maintained with frequent mouthwashes and gentle brushing.
- The orthodontic fixation appliance should be left in place for 16 weeks postoperatively.
- After removing the orthodontic fixation appliance, a continuous orthodontic arch wire should be worn by the patient.

OUTCOMES

- Premaxillary setback with accurate positioning of the premaxilla leads to:
 - Appropriate maxillary arch form
 - Improved success of bone grafting procedures
 - Improved lip cosmesis
 - Improved overall oral function and dental aesthetics⁵⁻⁷

COMPLICATIONS

- Infection

- Avascular necrosis of the premaxillary segment
- Mobility of the premaxilla
- Iatrogenic damage to tooth buds in the premaxilla^{6,7}

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21 Le Fort I Osteotomy and Advancement

CHAPTER

Kathlyn K. Powell, Ahmed Elshebiny, and John H. Grant III

DEFINITION

- A procedure that involves cutting and repositioning the maxilla to the correct position
- It is one of the most common procedures used to correct maxillary dentofacial deformities including size, position, orientation, shape, and/or symmetry.
- Often performed with corrective mandibular ramus surgery such as a bilateral sagittal split osteotomy (BSSO)
- Corrects in three planes: vertical, horizontal, and transverse

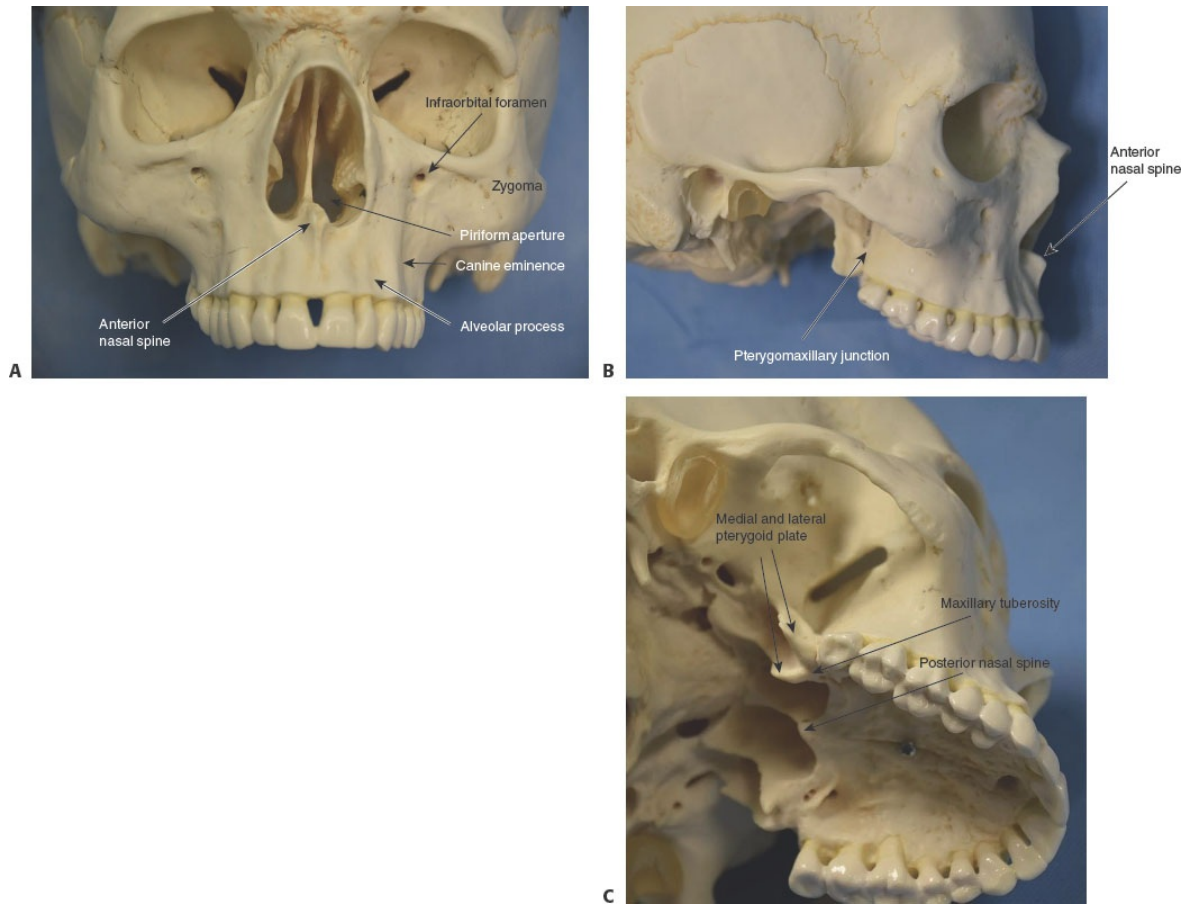


FIG 1 • Osseous anatomy of maxilla: anterior **(A)**, lateral **(B)**, and basal oblique **(C)** views.

ANATOMY

Osseous Structures

- In the anterior view of the skull, the maxilla (**FIG 1**) forms the piriform aperture and inferior and medial border of the orbit.
- The anterior surface of the maxilla is the anterolateral wall of the maxillary sinus.
- From the piriform rim to the descending palatine canal, the mean length of the medial sinus wall is 34 mm; therefore, when creating the osteotomy in the lateral nasal wall, it should be no further posterior than 25 to 30 mm from the piriform rim.¹
- The infraorbital foramen is at a variable distance from the inferior orbital rim and the maxillary alveolus, 8 to 20 mm from the nasal floor.

- The nasolacrimal duct lies within the thin bony wall of the maxillary sinus and the nasal cavity. The duct ends at the inferior nasal meatus through the valve of Hasner.
- The inferior nasal meatus is 11 to 14 mm posterior to the piriform aperture and 11 to 17 mm above the nasal floor.²
- The root prominences are occasionally visible through the maxillary alveolar process.
 - The canine is the longest root.
 - Anterior teeth roots are typically more visible.
- The maxillary suture at the inferior midline of the piriform aperture forms the anterior nasal spine (ANS), and the anterior maxilla surrounds the piriform aperture.
- Extending posteriorly from the ANS is the nasal crest of the maxilla, which joins the nasal septum. The nasal floor is formed by the maxillary roof.
- The piriform rim (nasomaxillary buttress) is a vertical pillar of medial midface support. The zygomaticomaxillary buttress is the pillar of lateral midface support.
- The septal or quadrangular cartilage, the vomer, and the perpendicular plate of the ethmoid bone articulate in the midline with the nasal crest.
- The junction of the premaxilla and the maxilla contains the incisive foramen, which contains the nasopalatine vessels and nerves.
- The hard palate is formed by the fusion of the palatine processes of the two hemimaxillae and the horizontal lamina of the palatine bones.
- The posterior border of the maxilla is the maxillary tuberosity.
 - The pterygomaxillary fissure is located between the maxillary tuberosity and the pterygoid plates of the sphenoid bones.
 - The descending palatine artery is 10 mm medial to the maxillary tuberosity.¹

Muscular Structures

- The orbicularis oris surrounds the stomion (origin: buccinators, depressor anguli oris, levator anguli oris).
- Risorius (origin, fascia overlying the parotid gland; insertion, angle of the mouth)
- Zygomaticus major (origin, zygomatic bone; insertion, skin at the angle of the mouth and orbicularis oris)
- Zygomaticus minor (origin, zygomatic bone; insertion, skin of the upper lip)

- Levator labii superioris (origin, maxilla; insertion, skin of the upper lip)
- Levator labii superioris alae nasi (origin, frontal process of the maxilla; insertion, skin of the upper lip)
- Levator anguli oris (origin, maxilla; insertion, skin of the upper lip)
- Levator labii superioris alaeque nasi (origin, upper frontal process of the maxilla; insertion, upper lip and ala of the nose)
- Depressor septi (origin, incisive fossa of the maxilla; insertion, base of the columella and the nasal septum)
- Nasalis muscles (origin, maxilla; insertion, alar cartilage)
 - Medial fibers blend with depressor septi.
 - Responsible for compression and dilation of nares
 - Primary muscle in alar base cinch

Vascular Anatomy

- Arteries
 - Perfusion of the maxilla via three main vessels
 - Ascending pharyngeal
 - Ascending palatal
 - Soft palate vessels
 - Must maintain posterior pedicle when sacrificing the descending palatine arteries
- Veins
 - Pterygoid plexus
 - Surrounds the maxillary artery
 - Deep to the lateral pterygoid muscle
 - Pterygoid plexus drainage
 - Drains to the maxillary vein
 - Drains to the deep facial vein and then the facial vein
 - Drains to the cavernous sinus through the foramen ovale
 - Drains to the middle meningeal veins through the foramen spinosum

PATIENT HISTORY AND PHYSICAL FINDINGS

- Past medical history, surgical history, allergies, social history, and family history should be elicited.
- Patient history should include questions regarding difficulty chewing food,

headaches, temporomandibular joint dysfunction (TMD), speech, growth, and breathing.

■ Growth evaluation may include the following:

- Serial physical examinations
- Serial cephalometric radiographs
- A hand-wrist film
- Evaluation of maturation of vertebrae on a lateral cephalometric radiograph

■ TMJ examination

- Examine muscles of mastication of TMJ capsule for tenderness to palpation.
- Examine for clicking, popping, or crepitus.
- Examine for excursive movements, protrusion, and maximal incisal opening.
- Examine for deviation upon opening.

■ Skeletal examination

- Vertical orbital dystopia
- Measure intercanthal distance.
- Placement of nose in relation to facial midline
- Transverse dimension
 - Maxillary midline in relation to facial midline
 - Mandibular midline in relation to maxillary midline and facial midline
 - Chin point in relation to facial midline
 - Maxillary occlusal plane and cant in relation to the maxillary canine teeth
 - Mandibular occlusal plane level vs canted
 - Mandibular angles level vs canted
 - Maxillary arch width (evaluate utilizing handheld dental models)

■ AP dimension

- Overjet
- Nasolabial angle
- Labiomental fold
- Chin position
- Profile

■ Vertical dimension

- Facial thirds
- Maxillary incisor length
- Maxillary incisor show at rest and high smile
- Gingival show at rest and high smile

- Dental examination
 - Overall dental health
 - Missing teeth
 - Presence of third molars
 - Overbite
 - Overjet
 - Angle class of occlusion
 - Arch width (evaluate utilizing handheld dental models)
 - Curve of Spee
 - Dental decompensation
 - Periodontal health
- Soft tissue examination
 - Upper lip thickness and length
 - Nasolabial angle
 - Nasal tip rotation
- Patients with maxillary deficiency often appear to have a retruded upper lip, flat malar eminences, deficiency in the infraorbital rims as well as paranasal sinuses, inadequate tooth show, and a prominent chin relative to the midface
 - Patients have a “psuedoprognathism” with reverse anterior overjet.
- Patients with vertical maxillary excess (VME) have a long face with excessive gingival show
 - Mouth breathing is common.
 - Class II malocclusion is common.

IMAGING

- Panoramic radiograph should be examined for the following:
 - Health of dentition
 - Presence of third molars
 - Pathology
 - Health of the temporomandibular joint
 - Presence of hardware from previous facial surgery
- Lateral cephalometric radiograph with the patient’s lips relaxed and the mandible in centric relation
 - Assess the anteroposterior (AP) position of the maxilla.
 - Assess the AP position of the mandible.
 - Assess the AP discrepancy between the maxilla and the mandible.

- Assess the maxillary incisor inclination.
- Assess the mandibular incisor inclination.
- Assess the facial type.
- Assess the chin.
- Preoperative profile, frontal (smiling and rest), and occlusal photographs should be obtained.
- Dental models made of stone casts or digital scans are used to evaluate the dentition as well as to establish the new occlusion.
- Cone beam computed tomography (CBCT) or computed tomography (CT) is done for virtual surgical planning (VSP) and/or complex asymmetry cases.
- PA cephalometric radiograph may be needed in complex cases if CBCT or CT is not an option.

NONOPERATIVE MANAGEMENT

- Orthodontic camouflage is an option for nonoperative management if the deficiency falls within the envelope of orthodontic treatment as described by Proffit.³

SURGICAL MANAGEMENT

Preoperative Planning

- Panoramic dental x-ray, cephalometric analysis, and/or cone beam CT should be reviewed.
- Model surgery or VSP should be performed in order to determine the most appropriate movements of the maxilla.
- A surgical splint will be fabricated from the model surgery or virtual surgical planning.
- The need for a bone graft for stability should be determined.
 - Autogenous bone should be harvested prior to the start of the Le Fort I osteotomy.
 - Allogenic bone is used frequently as well.

Positioning

- A standard nasotracheal intubation is performed with a Nasal RAE endotracheal tube.
- The tube is secured with a headwrap over the forehead. This brings the tube out of the operative site (**FIG 2**).

- The eyes are lubricated and covered with Tegaderm.
- The patient is placed supine with the head of bed slightly elevated.
- The arms are tucked at the patient's side and padded in standard fashion.

Approach

- An upper buccal sulcus incision with lateral back cut has the advantage of better preservation of blood supply with sufficient access when compared to the traditional longer incision.
- A vertical incision up the zygomatic buttress improves both vascularity and access.



FIG 2 • Fixation of the endotracheal tube.

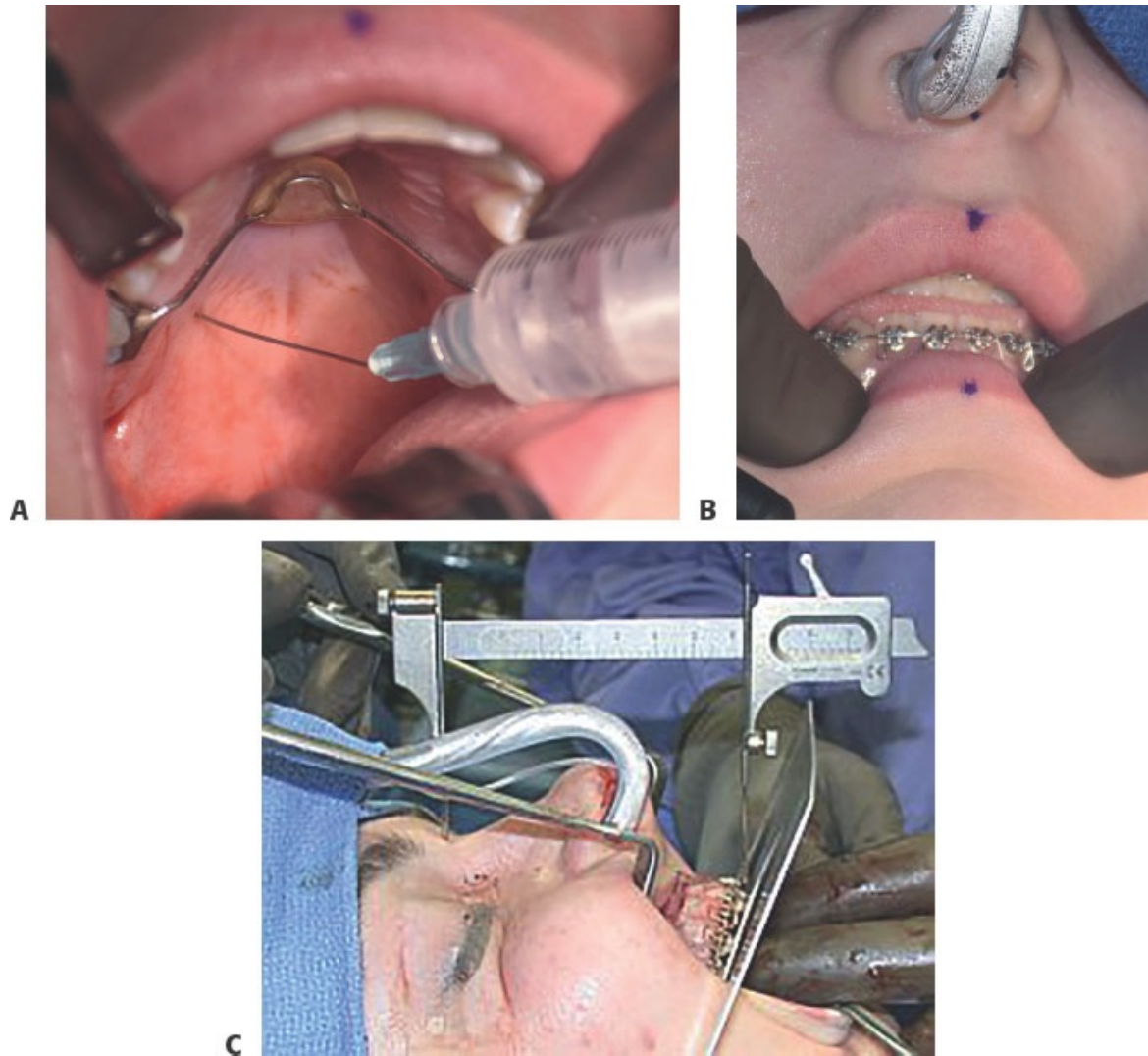
TECHNIQUES

■ Preparation and External Reference

- The patient is prepped and draped with four towels and a head and neck drape.
- The mouth is thoroughly irrigated with chlorhexidine gluconate 0.12% oral

rinse.

- The orthodontic appliances are carefully examined. The surgeon should know which teeth have bands and brackets and if any brackets are missing. This is in the event that brackets are dislodged during the case. The surgeon will know to look for them and not inadvertently leave them in the wound. This is particularly important when there is a mandibular vestibular incision for a simultaneous sagittal split osteotomy.
- If possible, hypotensive anesthesia with a MAP less than 60 should be performed when the maxilla is down-fractured.
- Local anesthesia with epinephrine is infiltrated into the maxillary vestibule from second molar to second molar. Bilateral posterior superior alveolar and greater palatine nerve blocks are administered (**TECH FIG 1A**).
- An external reference in addition to directly measuring marks on the bone is more accurate when the vertical position of the maxilla is going to be changed.
- A 0.035-inch K-wire is placed in the glabella (nasal bone) as an external stable reference. Soft tissue markers are not accurate.
 - A measurement from the K-wire to the maxillary arch wire at the central incisors is recorded utilizing a Boley gauge (**TECH FIG 1C**).
- The soft tissue midline is marked on the upper lip and verified with the dental midline (**TECH FIG 1B**).

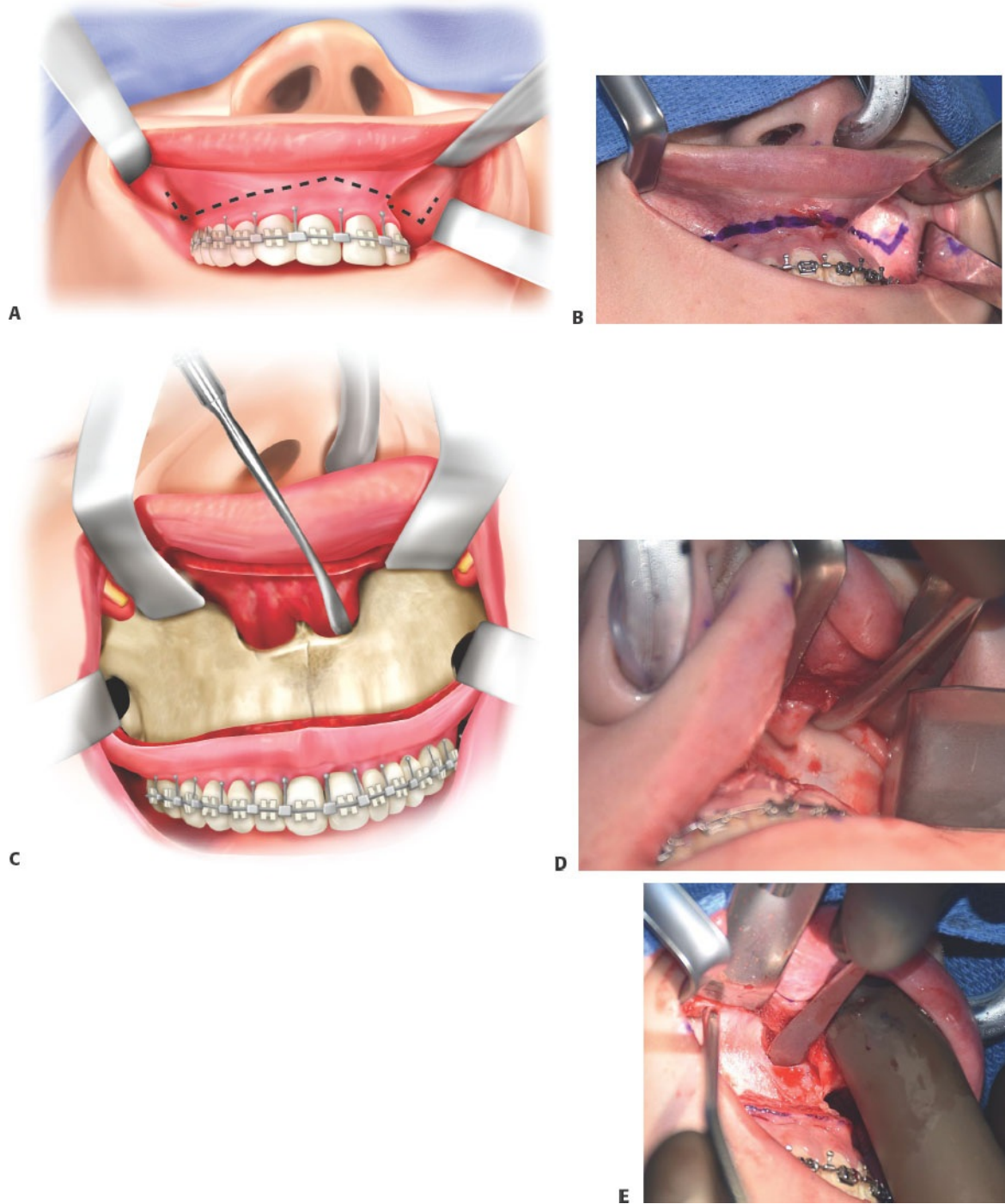


TECH FIG 1 • **A.** Greater palatine nerve block given in the right side. **B.** External reference placed on the upper lip midline. **C.** Glabellar K-wire and Boley gauge.

■ Incision and Exposure

- Retraction is performed with two toe-in retractors placed under the upper lip while resting on the maxilla.
- A modified maxillary vestibular incision is made in the unattached mucosa 4 to 5 mm above that attached gingiva with guarded needle tip electrocautery from first molar to first molar (**TECH FIG 2A**).

- This preserves a cuff of mucosa, which makes closure easier at the end of the case.
- The incision laterally ends with vertical releasing incisions posteriorly to increase the vascular flap and perfusion of the maxilla while helping provide adequate visualization (**TECH FIG 2B**).
- The soft tissue is reflected, and the piriform rim, lateral maxillary sinus walls, ANS, infraorbital foramen, and zygomatic buttresses are exposed (**TECH FIG 2C,D**).
- The posterior maxillary sinus wall and the pterygomaxillary junction are then exposed.
- A Freer elevator is used to reflect the nasal floor mucosa from the palatine bone (**TECH FIG 2E**).

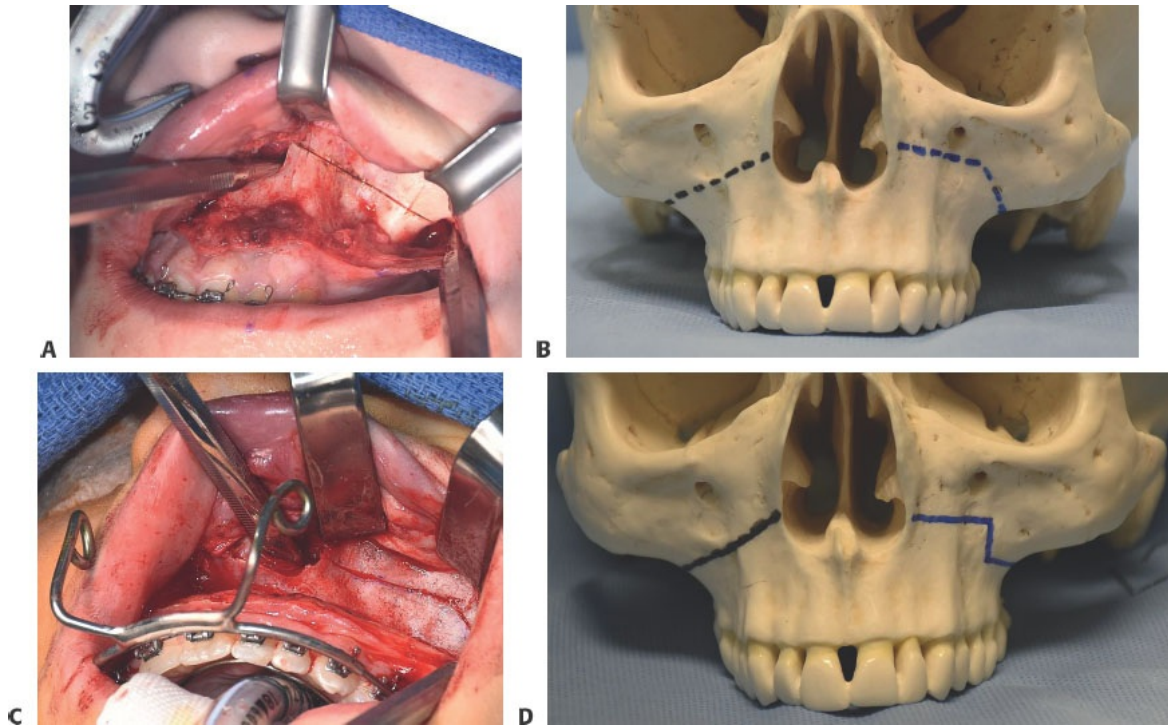


TECH FIG 2 • A. The planned vestibular incision showing the lateral vertical releasing incision to preserve cuff of mucosa at the lateral end of the incision. **B.** Left end of incision. **C.** Exposure of maxilla. **D.** Exposure around the infraorbital nerve (left

side). **E.** The start of piriform aperture dissection (patient's right side).

■ Lateral Osteotomies

- A Seldon retractor is placed posterior to the maxilla.
- A periosteal elevator is placed inside the piriform rim on the osteotomy side.
- A sagittal saw is used to make a cut at least 3 to 5 mm above the apices of the teeth and inferior to the infraorbital foramen from the maxillary buttress to the piriform rim.
- The horizontal cut starts 3 to 4 mm above the nasal floor at the piriform rim and runs obliquely as it moves laterally (**TECH FIG 3A**).
- The same steps are repeated on the other side.
- In cleft distraction cases, the osteotomy is made higher and, in a more horizontal direction, then sharply curved caudally toward the usual pterygoid osteotomy site. A rigid external device (RED) is used for fixation (**TECH FIG 3B,C**).
- Some surgeons prefer a modified step osteotomy to prevent vertical impaction with the advancement and feel it may provide better bone grafting/fixation (**TECH FIG 3D**).

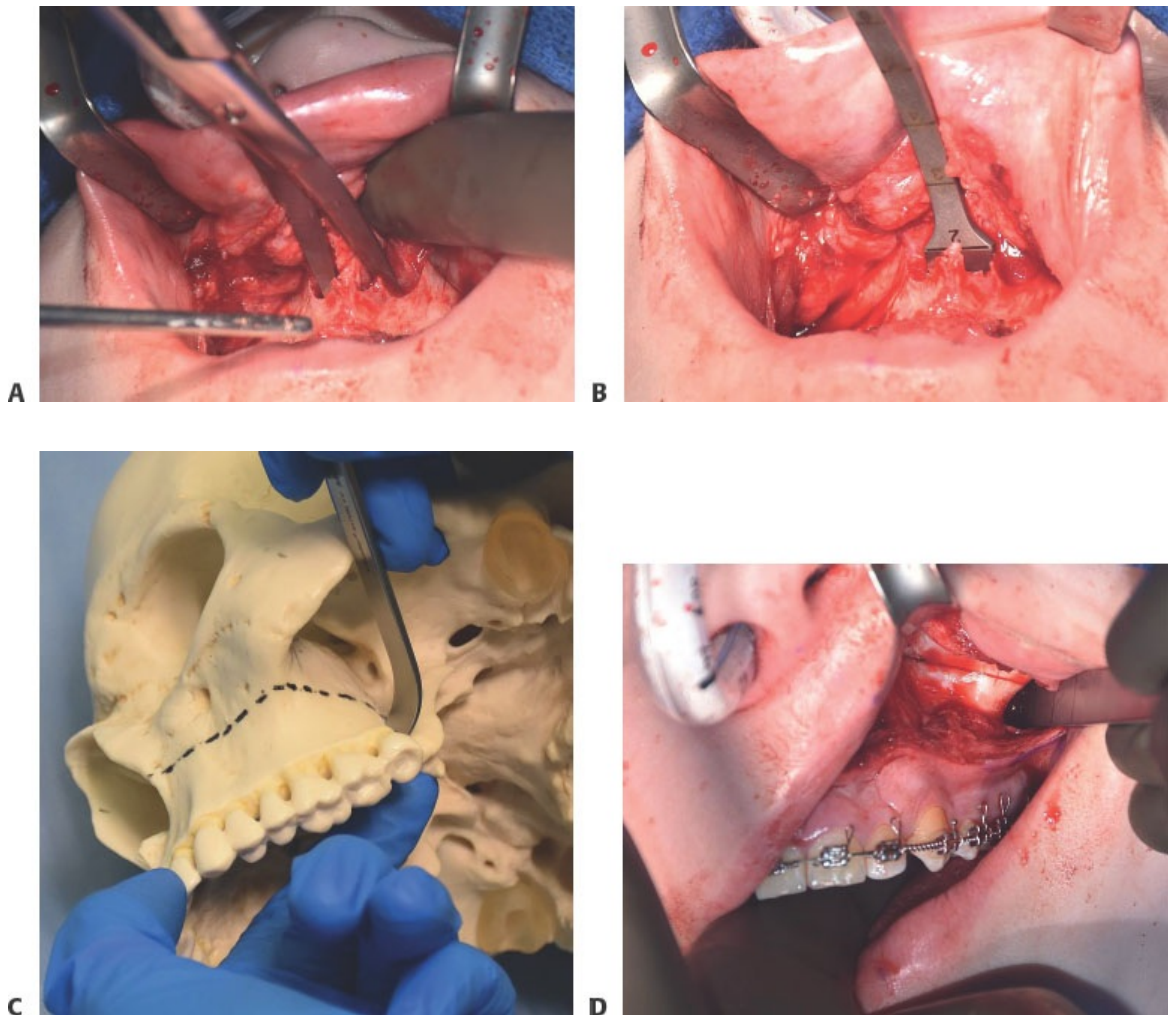


TECH FIG 3 • A. The anterior maxillary osteotomy is completed with the saw. **B.** Difference between the conventional osteotomy (black, skull right) and the osteotomy in cleft patients (blue, skull left), which is higher and more horizontal. **C.** The pattern of the anterior maxillary osteotomy in cleft patients. **D.** The modified step osteotomy (blue, skull left).

■ Septal Osteotomy and Pterygoid Plate Separation

- Curved Mayo scissors are used to separate the nasal septum from the maxillary crest in an anterior to posterior direction (**TECH FIG 4A**).
- Keep the tips of the scissors on the palatine bone as they move posteriorly.
- Place a finger between the soft palate and the endotracheal tube to prevent cutting the endotracheal tube.
- Alternative technique (**TECH FIG 4B**):
 - A guarded V-shaped osteotome is placed at the top of the ANS and is driven inferiorly and posteriorly along the nasal floor until the septum is fully separated from the maxillary crest.

- The chisel will be palpated at the level of the soft palate. The nondominant index finger is placed posterior to the soft palate.
- A curved pterygoid osteotome is placed from the lateral side of the pterygomaxillary junction aiming inferiorly, medially, and anteriorly parallel to the occlusion plain.
- A finger is placed in the oral cavity medial to the junction of the hamulus and the tuberosity to give support and tactile feedback of the progress of the osteotomy (**TECH FIG 4C**).
- A mallet strikes the osteotome to drive it through the pterygoid plates so that the maxilla is then separated from the pterygoid plates (**TECH FIG 4D**).
- Movement of either the pterygoid plate or the chisel is palpated.
- The chisel should not be driven through the mucosa.

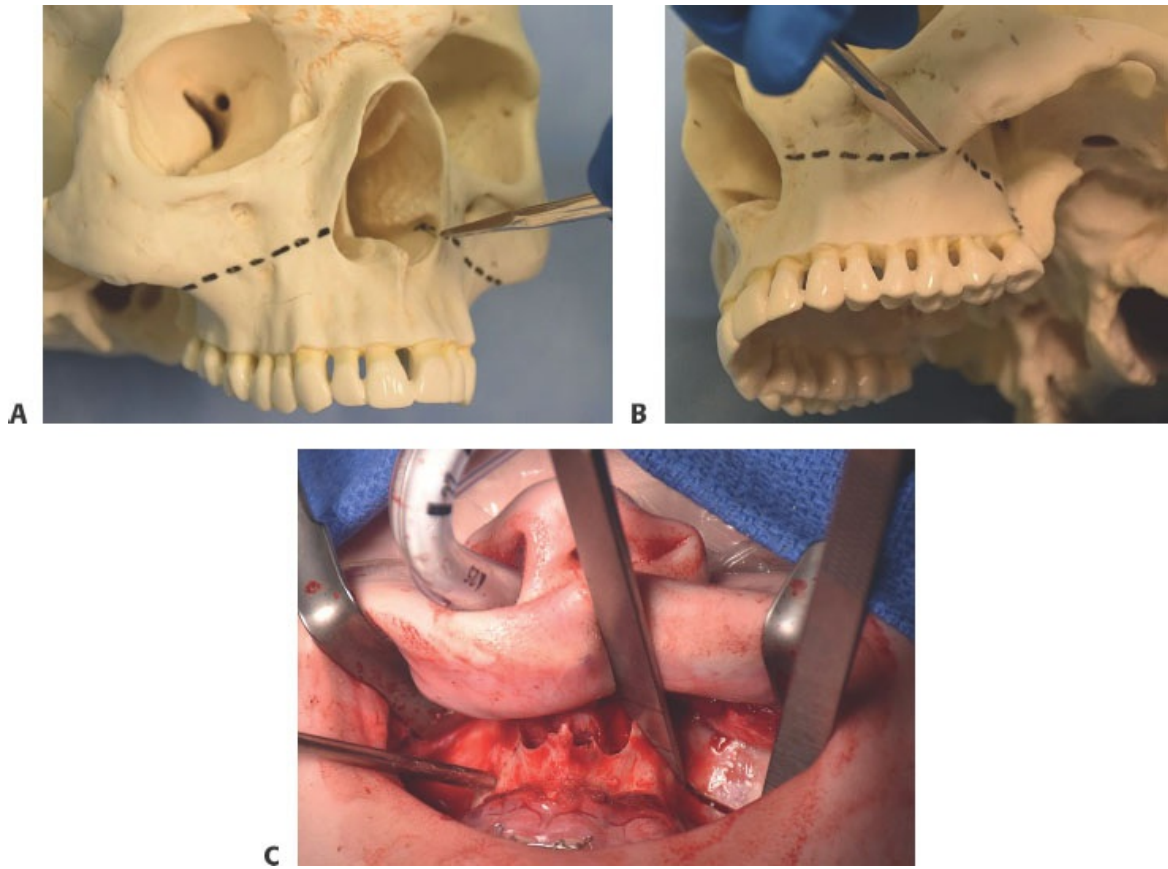


TECH FIG 4 • A. Septal disconnection by curved

Mayo scissor. **B.** Alternatively, septal disconnection by guarded V-osteotome. **C.** Pterygoid plate osteotomy is performed with the index finger placed in the oral cavity medial to the junction of the hamulus and the tuberosity. **D.** A mallet strikes the curved pterygoid chisel, driving it to separate the maxilla from the pterygoid plates.

■ Completion of Lateral Osteotomies and Lateral Nasal Wall Osteotomies

- A straight osteotome is placed on the lateral side of the osteotomy that was created with the sagittal saw, aiming posteriorly and medially to complete the osteotomy of the lateral wall of the maxillary sinus (**TECH FIG 5A,B**).
- A second straight osteotome is placed at the piriform rim and directed posteriorly to complete the osteotomy of the medial wall of the maxillary sinus (lateral nasal wall; **TECH FIG 5A,C**).
- The same steps are repeated on the contralateral side.

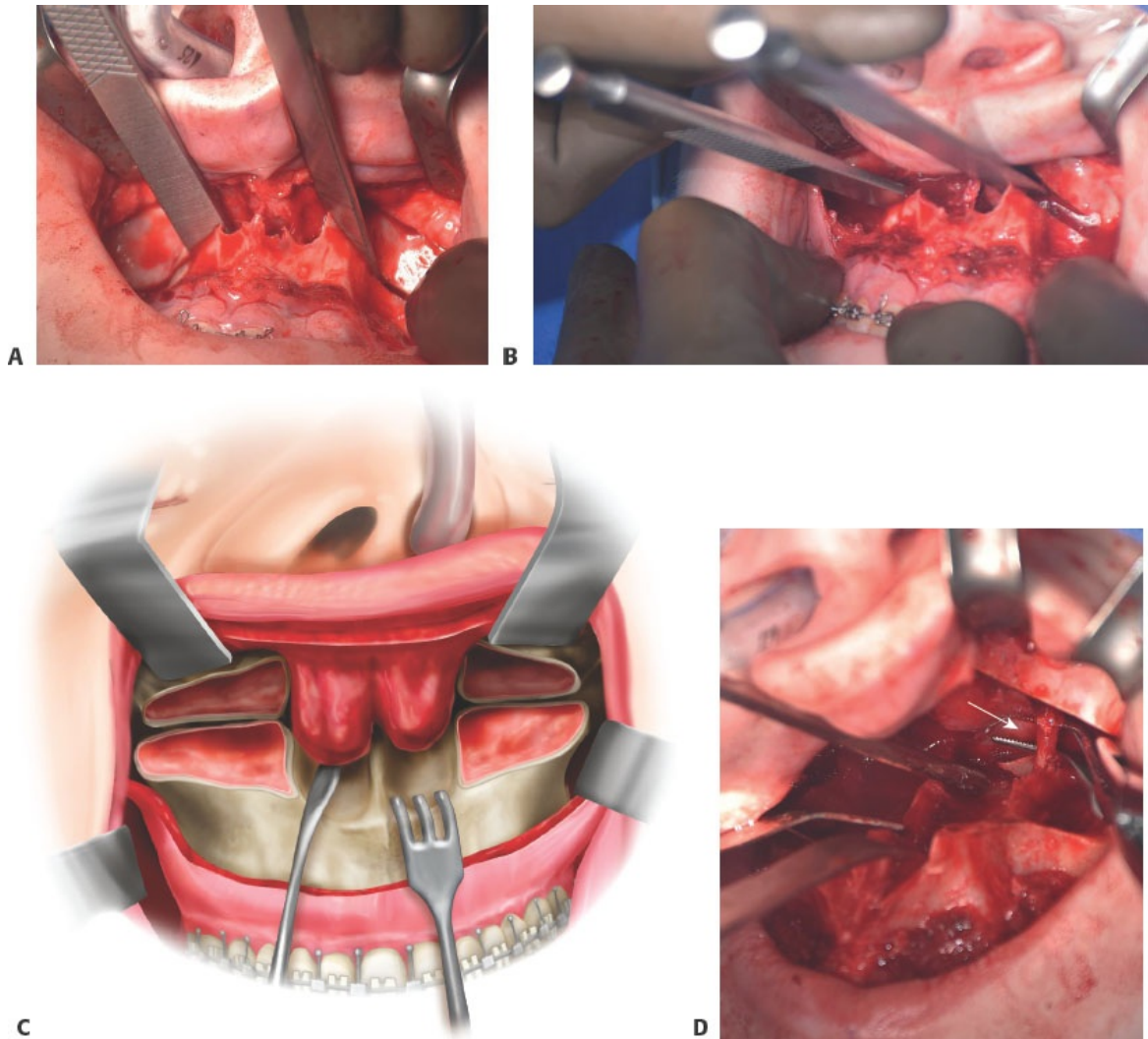


TECH FIG 5 • The medial (**A**) and lateral (**B**) maxillary sinus wall osteotomies are demonstrated in a skull model. **C**. Completing the medial and lateral maxillary sinus wall osteotomies by straight osteotomies on the left side.

■ Maxillary Down-Fracture and Mobilization

- Down-fracture of the maxilla is achieved with finger pressure placed in the anterior maxilla and/or with pressure downward on two periosteal elevators placed in the piriform rim osteotomies bilaterally (**TECH FIG 6A,B**).
- If the down-fracture is difficult, then recheck all of the osteotomies to make sure that they are complete. Roe disimpaction forceps are usually not needed if the osteotomy is adequate. The forceps may crush the pharyngeal blood supply and compromise blood flow.
- After down-fracturing the maxilla, the nasal mucoperiosteum is elevated off the hard palate in an anterior-to-posterior direction (**TECH FIG 6C,D**).

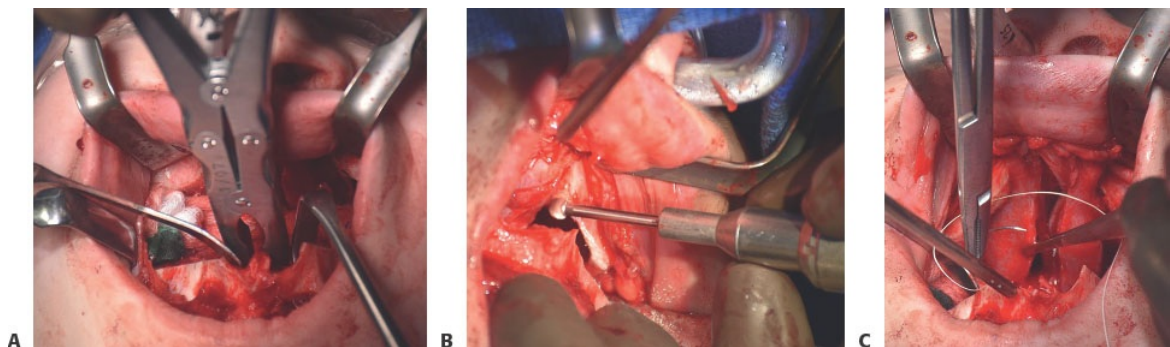
- Ensure that the maxilla is adequately mobilized to provide postoperative stability.
- A wooden handle Obwegeser osteotome can be used to further mobilize the maxilla.



TECH FIG 6 • A,B. Down-fracture of the maxilla assisted by two osteotomes placed in the piriform rims. **C.** The nasal mucoperiosteum is elevated from the nasal floor from anterior to posterior. **D.** Location of the descending palatine neurovascular bundle (arrow).

■ Removal of Interferences

- Place a Seldon retractor posterior to the tuberosity on the left side and a lighted retractor along the anterior nasal floor.
- Use a periosteal elevator to elevate the mucosa from the nasal floor.
- Use double action rongeurs to remove the medial sinus wall (**TECH FIG 7A**). This will facilitate sinus drainage in the postoperative period.
- A guarded needle tip electrocautery is used to cauterize the descending palatine artery to reduce postoperative bleeding (**TECH FIG 6D**).
 - Some surgeons prefer to preserve the palatine artery believing it will reduce the risk of avascular necrosis of the maxillary.
- The Seldon retractor is placed posterior to the maxillary tuberosity, and the steps are repeated on the right side.
- The nasal floor mucosa is examined for tears; if present, repair them with 4-0 resorbable suture (**TECH FIG 7C**).
- Surgical guide
 - The prefabricated surgical splint is placed in the oral cavity to place the maxillary teeth into the preset occlusion.
 - The maxilla is wired to the mandible with 26-gauge stainless steel wire around the surgical hooks.



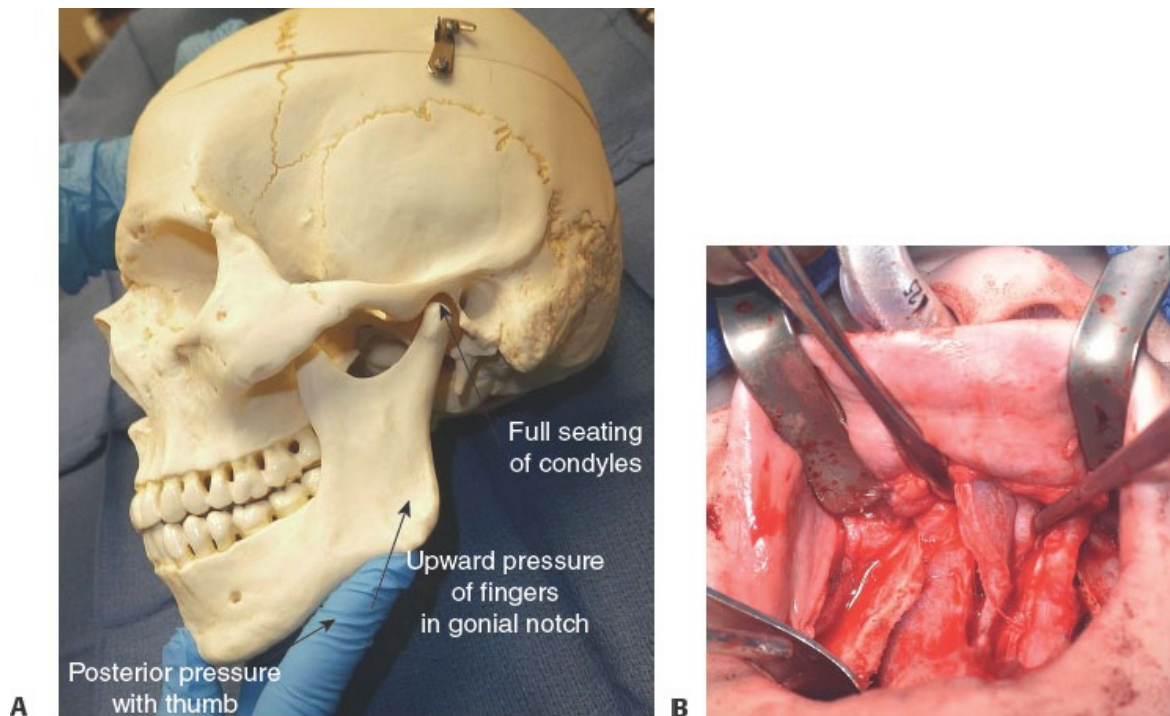
TECH FIG 7 • A,B. Removing interferences. **C.** Closure of any mucosal tears at the nasal floor.

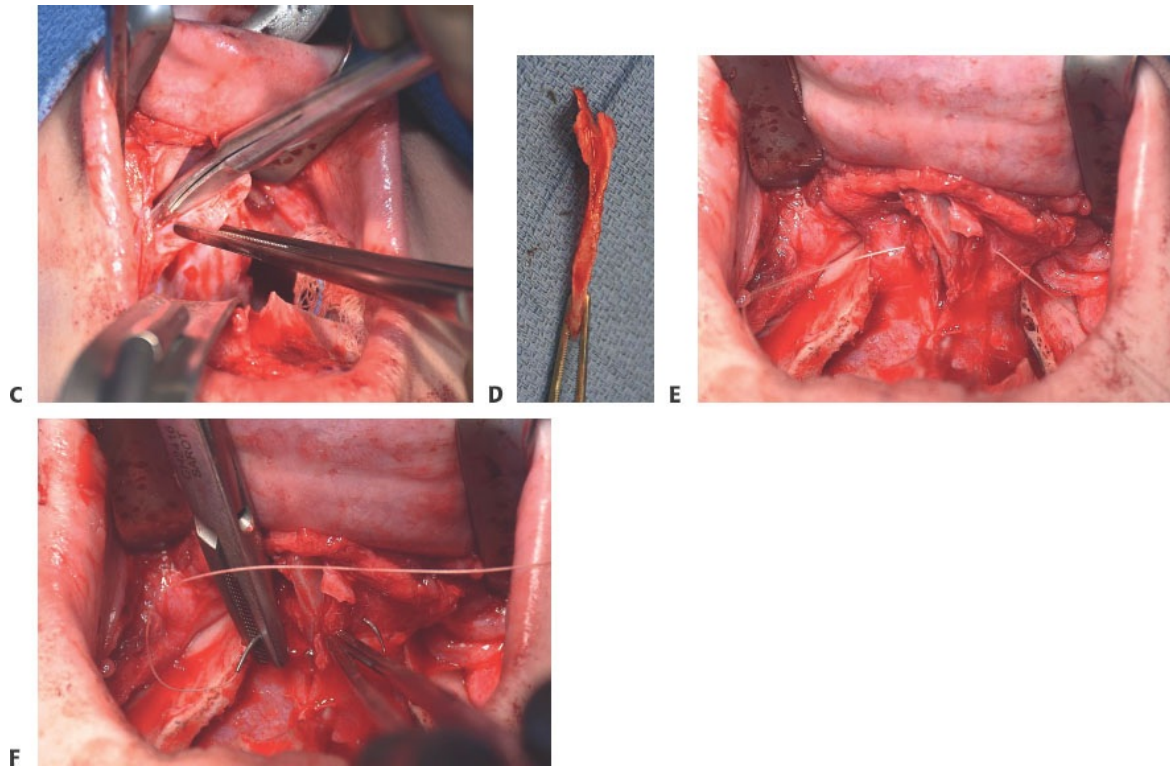
■ Vertical Positioning of the Maxilla

- The condyles are seated by placing posterior pressure with the thumb on the chin and upward pressure of the fingers at the gonial notches bilaterally

(**TECH FIG 8A**).

- Maxillary bony interferences are removed with a round bur until the maxilla passively seats in the correct vertical position (**TECH FIG 7B**).
- If the vertical placement of the maxilla is determined by measuring the distance from the K-wire to the orthodontic wire
 - Interferences are then removed as needed to achieve the correct vertical placement of the maxilla.
 - Proper vertical position is determined esthetically by dental tooth-lip show.
- The condyles must be appropriately seated during this step to ensure proper placement of the maxilla and to prevent postoperative malocclusion.
- If the caudal edge of the septum appears crooked, the free edge of the septum is dissected from the nasal mucosa and excised. This is also important if the maxilla requires impaction (**TECH FIG 8B-D**).
- The nasal mucosa is then reapproximated with resorbable 4-0 sutures (**TECH FIG 8E,F**).





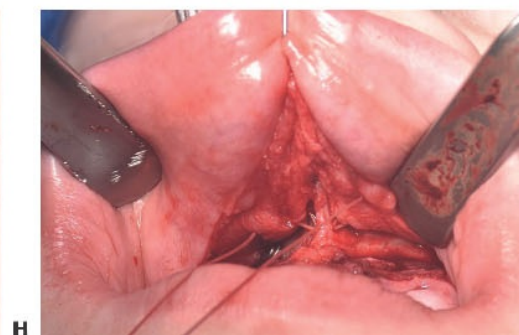
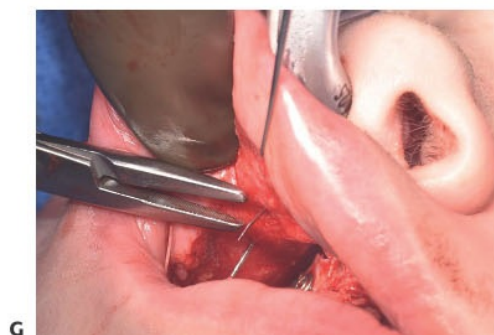
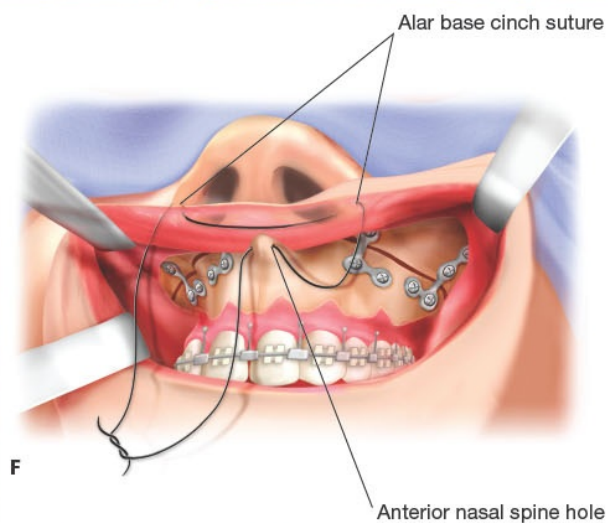
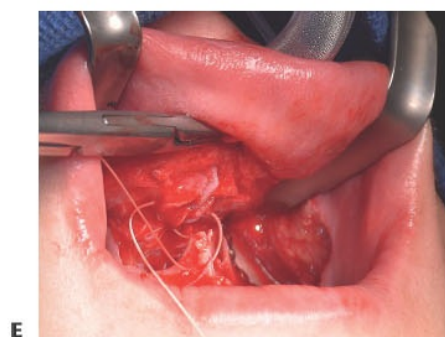
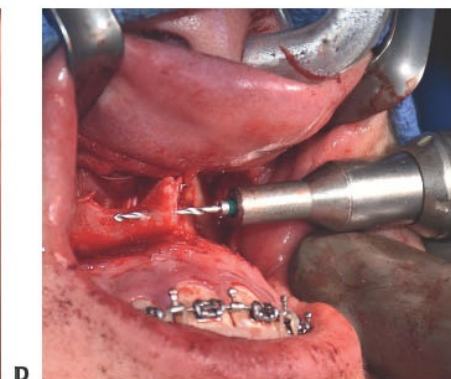
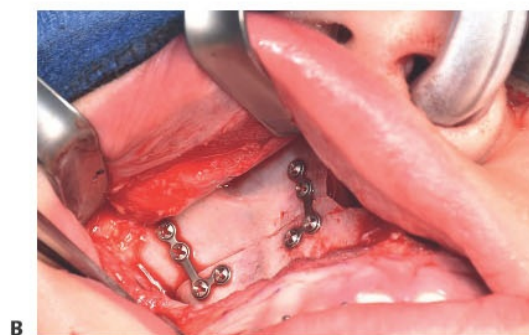
TECH FIG 8 • **A.** Check for any interferences to be removed to achieve the desired vertical height. **B.** Dissection of the caudal edge of the septum showing its crookedness. **C.** Excision of the crooked edge of the septum. **D.** The excised part of the septum. **E,F.** Closure of dissected nasal septum back to the other side.

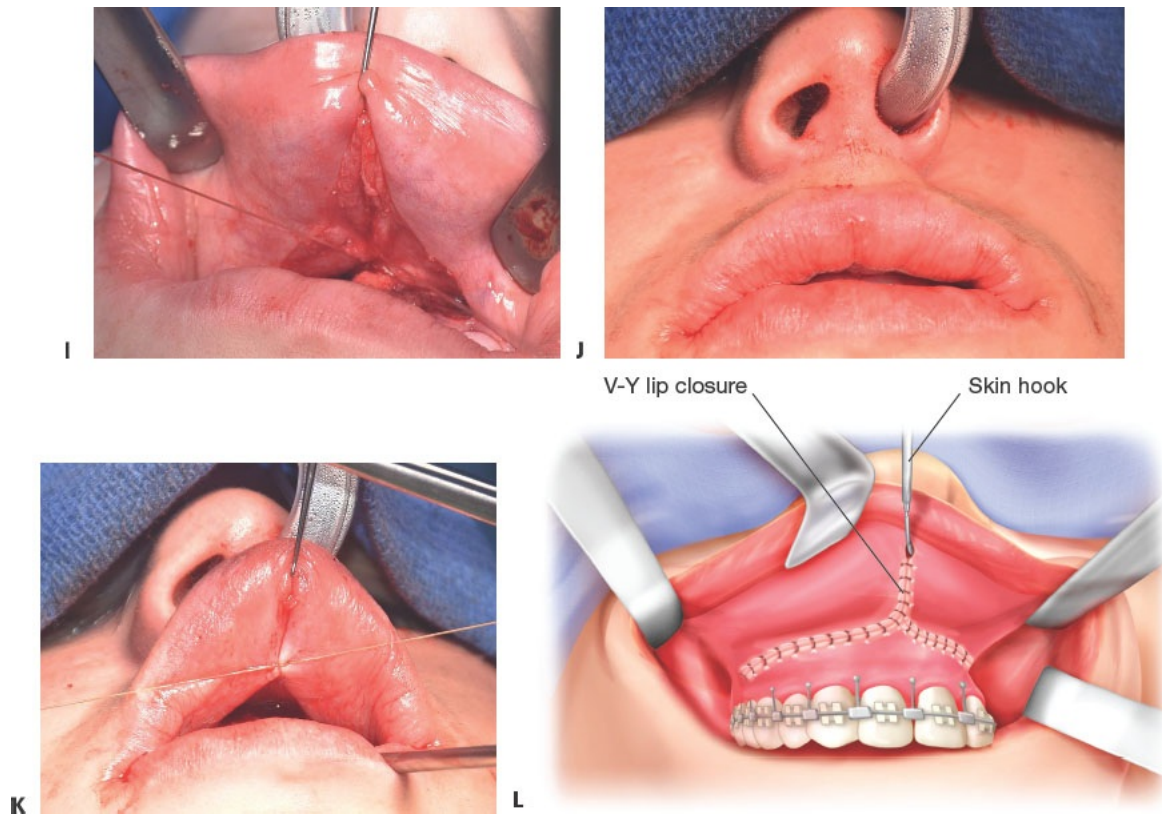
■ Fixation, Occlusal Check, and Closure

- After the maxilla is properly positioned, it is stabilized with 2.0- or 1.5-mm titanium miniplates at the piriform rims bilaterally and the zygomatic buttresses bilaterally (**TECH FIG 9A–C**).
- At least two screws on either side of the osteotomy are needed.
- Large gaps may require greater fixation and/or bone grafts secured at the lateral wall of the maxilla.
- Thin bone may require greater fixation along the nasal and zygomatic buttress.
- The vertical placement of the maxilla is confirmed with the Boley gauge

after bone grafting and fixation are complete.

- Maxillomandibular fixation is released by cutting the intermaxillary wires.
- Occlusion is confirmed.
 - Retractors are used to hold the cheeks out of the way.
 - A thin instrument is used to move the tongue out of the way.
 - The condyles are hinged and passively rotated posteriorly and then anteriorly.
 - The teeth should contact evenly into the occlusal splint without deviation or sliding.
 - Wounds are irrigated with normal saline.
- A wire passing fissure bur is used to make a hole in the ANS (**TECH FIG 9D**).
- 2-0 Vicryl is used to suture the nasal septum to the midline (**TECH FIG 9E**).
- An alar base cinch is performed with 2-0 Vicryl (**TECH FIG 9F–J**).
 - The index finger is placed lateral to the ala on one side, and the lip is retracted upward with the thumb.
 - The suture is passed through the paranasal musculature and through the hole created in the ANS.
 - The piriform ligament and dilator nasalis muscle are sutured to the ANS in order to prevent alar dilation.
 - The suture is tightened until the appropriate width of the nasal based is created and then secured.
 - This maneuver avoids iatrogenic alar base widening that may occur after a Le Fort I osteotomy advancement.
- A V-Y closure is performed in the vestibular mucosa with 3-0 chromic gut (**TECH FIG 9K,L**).
 - A single skin hook is placed in the midline of the upper lip incision, and the lip is retracted upward.
 - Two to three interrupted sutures are placed vertically across the incision.
 - This helps prevent lip shortening, lip thinning, and decreased vermilion show.
- The vestibular incision is closed by running the 3-0 chromic gut.
- Guiding elastics are placed at the canines.
- Gastric contents are suctioned from the stomach with a nasogastric tube.
- A facial pressure dressing such as a jaw bra with ice packs is placed.





TECH FIG 9 • Fixation is done by two plates in each side. **A.** Fixation by two miniplates in the right maxilla. **B.** Fixation by two L-shaped miniplates in the right maxilla. **C.** Fixation by specially designed prebent T-shaped miniplate. **D.** Drilling the anterior nasal spine. **E.** Suturing the caudal septum to the anterior nasal spine. **F.** Modified alar base cinch suture. **G.** Suture bite of paranasal musculature in the right side. **H.** After catching paranasal muscles in each side and through the anterior nasal spine hole. **I.** Tying the stitch. **J.** The effect of alar base cinch suture. **K.** A single skin hook is placed in the midline of the upper lip incision, and the lip is retracted upward to perform V-Y closure showing during placement of a stitch at the V-Y junction. **L.** After complete closure.

PEARLS AND PITFALLS

Preoperative	■ Fully understand the patient's desires and goals of surgery. ■ Do not rush into surgery. Make sure that patients are orthodontically set up well for the surgery. ■ Communicate often with the patient's orthodontist. ■ Patient evaluation and planning are keys to success. ■ Consider VSP for double jaw or asymmetric cases. ■ May need consent for bone graft (which may be taken from the cranium or the iliac crest).
Approach	■ A short vestibular incision will improve the blood supply to the maxilla, whereas posterior vertical releasing incisions will allow increased access. ■ Be sure to place the incision superior enough above the attached mucosa. This gives a cuff of unattached mucosa to close to at the end of the case.
Nasal septal deviation	■ If the maxilla is impacted or simply advanced, it is important to trim the base nasal septum to prevent buckling or deviation of the nasal septum.
Osteotomy and fixation	■ If the maxilla does not easily down-fracture, then retrace the osteotomies. Do not force the down-fracture. ■ Be sure to seat the condyles completely prior to fixation, or malocclusion will occur. ■ In thin bone, do not overtighten the screws.

POSTOPERATIVE CARE

- Intravenous antibiotics are recommended for 23 hours postoperatively.
 - Some surgeons choose to give antibiotics by mouth for an additional 5 to 7 days.
- Intravenous steroids are given up to three doses.
- Most patients are extubated postoperatively and placed on a humidified oxygen face mask and transferred to the post-anesthesia care until recovered.
 - Postrecovery, they are transferred to the floor for overnight observation and monitoring.
 - Most patients are discharged on postoperative day (POD 1).
- Diet
 - Clear liquids for 24 hours

- On POD 1, diet is advanced to full liquids.
- Puree diet for 2 weeks
- No-chew, soft diet for 2 to 6 weeks
- Ice packs, as well as a facial pressure dressing, are used for 24 hours postoperatively.
- Head of bed is elevated to 45 degrees.
 - Once home, patients should sleep with two pillows or in a recliner for several days.
- Oral care: Patients should brush their teeth at least twice daily starting on POD 1.
- Sinus precautions/care
 - Open mouth sneezes and no nose blowing
 - Guaifenesin with pseudoephedrine is prescribed for patients who have no contraindications to decongestants, such as hypertension, for 14 days.
 - Use nasal saline rinses at least twice daily.
- Elastics training is provided to patient and family. Maintain guiding interarch elastics for at least 2 weeks.
- Follow-up is at 1 to 2 weeks, 4 weeks, and 6 weeks.
 - Orthodontic care can resume as early as 4 weeks and usually by 6 weeks.

OUTCOMES

- Most relapse is within the first 6 months.⁴
- Proffit et al. described a hierarchy of stability from most stable to least stable³.
 - Maxilla up (most stable): open bit and nonopen bite
 - Mandible forward
 - Maxilla forward
 - Maxilla up/mandible forward
 - Maxilla forward/mandible back
 - Mandible back
 - Maxilla down
 - Maxilla wider (least stable)
- Relapse has been reported to be greater than 2 mm in 14% of nonsyndromic maxillary advancements alone.⁴
 - Another study showed a similar relapse rate of 20%.⁵
 - VME patients also had a similar relapse rate.⁶
- Horizontal relapse rates are as high as 37% in cleft patients. Relapse is higher

in cleft patients than noncleft patients.⁷

- A meta-analysis of MMA revealed 85.5% surgical success rate (AHI less than 20) and a 38.5% cure rate (AHI less than 5) for OSA patients.
- Surgical cure most likely with preoperative AHI less than 60. AHI greater than 60 had very low cure rates but did have significant improvements.⁸

COMPLICATIONS

- Hemorrhage
- Damage to the teeth
- Unfavorable fracture
- Propagation of fracture to the skull base
- Propagation of fracture to the septum and cribriform plate
- Palatal fracture or horizontal fracture of the pterygoid process resulting in limited maxillary advancement
- Hardware failure
- Anosmia
- Blindness
- Infection
- Persistent postoperative pain
- Neurosensory disturbance (greater and lesser palatine, nasopalatine, infraorbital nerves)
- Malunion or fibrous union
- Vascular compromise and maxillary necrosis
- Relapse
- Malocclusion
- Unfavorable facial aesthetics
- Pulpal necrosis
- Lacrimal duct injury
- Taste alteration
- Permanent cranial nerve damage
- TMJ dysfunction
- Deviated septum
- Nasal deformity

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22 Le Fort I Distraction Osteogenesis

CHAPTER

Nicholas S. Adams and John W. Polley

DEFINITION

- Maxillary hypoplasia poses both functional and aesthetic challenges.
 - Compromised mastication, speech abnormalities, nasal and pharyngeal airway constriction, dental malocclusion, and abnormal facial proportions are common.¹
- Maxillary hypoplasia is a common finding in patients with orofacial clefts.
 - Soft tissue scarring of the palate, pharyngeal structures, and lip may be severe, creating significant difficulties with traditional maxillary advancement.¹
- Distraction osteogenesis (DO) is a powerful alternative to traditional Le Fort I advancement in patients with severe maxillofacial abnormalities. DO allows for greater advancement (greater than 8 mm) while avoiding the need for rigid internal fixation or bone grafting.^{2,3}
- Rigid external distraction (RED) allows rigid, multivector control over the distraction process, allowing for successful and predictable outcomes.
 - The method outlined in this chapter focuses on Le Fort I DO using the RED system.²

ANATOMY

- The maxilla is composed of two adjacent bones that play several roles: separating the oral and nasal cavities, housing of developing and mature dentition, supporting the soft tissue of the face, and providing a stable platform for mastication.
- In patients with orofacial clefts, the hypoplastic maxilla may be deficient in all dimensions with thin or structurally weak bone. The mandible is typically

normal in size and morphology.⁴

- Severe maxillary hypoplasia can be defined as a negative overjet of 8 mm or greater.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Many patients requiring Le Fort I DO have a history of cleft lip and/or cleft palate.
- In addition to a complete history and physical examination, complete dental and orthodontic examination should be done to establish a multidisciplinary treatment plan.
- Common physical examination findings in patients with severe maxillary hypoplasia include a concave facial profile and class 3 relationship with a large negative overjet, often greater than 8 mm (**FIG 1**).
- Scarring of the gingival mucosa may be present if the patient has undergone correction of orofacial clefts.



FIG 1 • Profile photograph of a patient with severe maxillary hypoplasia.

IMAGING

- Preoperative panoramic radiographs are routinely done to assess dental and

osseous anatomy.

- Cephalograms and photographs are used for preoperative planning and postoperative comparisons (**FIG 2**).
- Computed tomography is not required but may provide further anatomic details in complex cases.
- Virtual surgical planning is not necessary for Le Fort I DO.



FIG 2 • Preoperative cephalogram.

SURGICAL MANAGEMENT

- Criteria for Le Fort I DO include patients with severe maxillary hypoplasia (horizontal, vertical, and transverse vectors), patients requiring greater than 8 mm of horizontal advancement, severe palatal or pharyngeal scarring, concave facial profile, and airway obstruction or sleep apnea with normal mandibular position and morphology.
- Surgery is delayed until dental and skeletal maturity, if possible, usually around age 16 to 18 years. Indications for earlier intervention are airway compromise, severe occlusal disease, or severe psychosocial issues.

Preoperative Planning

- Preoperative orthodontics are placed to align and level the dental arches prior

to distraction.

- These movements are planned with dental impressions, casts, and models.
- If the maxilla and dental arches are severely hypoplastic, preoperative orthodontics are not used, and the alignment and occlusion are addressed after distraction is complete.
- The dental impressions are sent to a dental lab for creation of a custom-made intraoral splint.
- The splint acts as the link between the Le Fort I segment and the distraction device and is applied a few days before the surgical procedure.
- The splint is then cemented to the first permanent or second primary maxillary molar (**FIG 3**).
- Two large, removable traction hooks made of heavy rectangular wire are constructed and will be placed when the distraction phase is initiated, postoperatively.
- These are not present at the time of surgery to facilitate intraoral manipulation and airway management.

Positioning

- Patients are positioned supine with the head supported by a Mayfield headrest.
- Both arms are padded and tucked at the patient's side.
- The bed is placed in a slight reverse Trendelenburg position.
- Oral intubation is achieved and secured in place with circumdental wiring.



FIG 3 • Intraoral splint design used during maxillary

distraction. Anterior square tubes are used to insert removable traction hooks. The splint is usually anchored to the maxillary first molars and secured anteriorly to maxillomandibular fixation screws placed at the time of Le Fort I osteotomy.

- Nasal intubation is not required as mandibulomaxillary fixation and occlusal analysis are not necessary during the operation.
- Tarsorrhaphy sutures are placed centrally to protect the cornea, and a throat pack is placed.
- A thorough maxillofacial prep including half-strength peroxide oral brushing, alcohol skin scrub, and betadine paint is completed.
- Sterile drapes are applied leaving only the face exposed.
 - Exposure of only the nose and mouth is possible as no intraoperative aesthetic analysis for advancement of the maxilla is necessary.

Approach

- Access to the maxilla is achieved through an upper buccal sulcus incision.
- Compared with traditional advancement, the transverse maxillary osteotomy may be performed much higher allowing for distraction of a larger portion of the midface.
 - This is possible as preservation of adequate bone stock for internal skeletal fixation hardware is not necessary.

TECHNIQUES

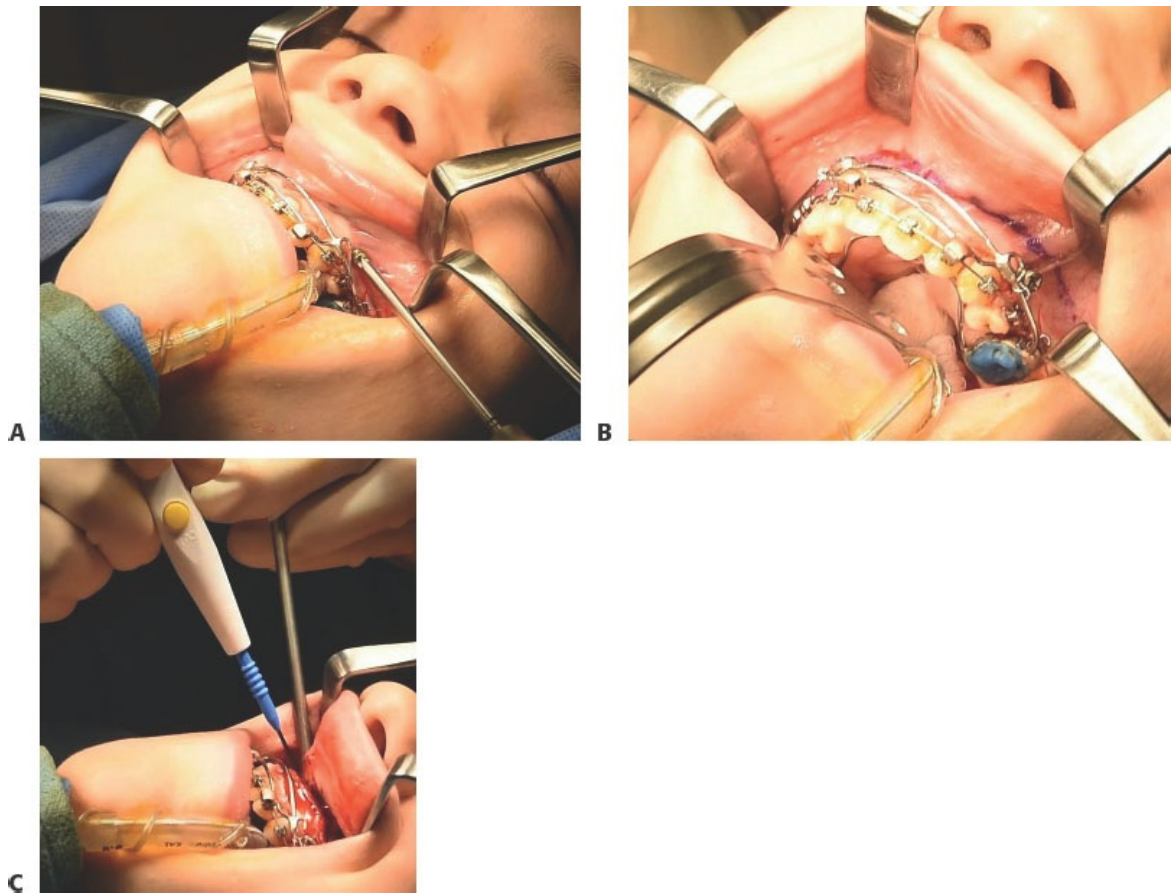
■ Le Fort I Osteotomy

Soft Tissue Release

- Local anesthetic with epinephrine is injected at the site of the upper buccal sulcus incision to minimize bleeding and improve pain control.
- Maxillomandibular fixation (MMF) screws are placed adjacent to each maxillary canine tooth root (**TECH FIG 1A**).
 - A 25-gauge wire is used to attach the preoperatively applied dental splint to

the MMF screws. This provides additional support to the splint during the distraction phase.

- The maxilla is approached through an upper buccal sulcus incision extending between the first maxillary molars bilaterally (**TECH FIG 1B**).
 - Care is taken to maintain a 3- to 5-mm cuff of buccal mucosa attached to the gingival mucosal to aid in an eventual watertight closure.
- A no. 15 scalpel is used to incise through mucosa; dissection is then continued to bone with needle-tipped electrocautery (**TECH FIG 1C**).
 - Once through the periosteum, initial elevation of the periosteal dissection can be done with electrocautery to aid in further subperiosteal elevation.
 - A periosteal elevator is used to release the soft tissue from the maxilla.
 - Dissection is carried out around the pyriform aperture to release the floor and lateral walls of nasal mucoperiosteum.
 - Superiorly, exposure beyond the level of the planned transverse osteotomy is performed. Care should be taken to avoid damage to the infraorbital nerves.
 - Posteriorly, dissection is carried around the maxillary tuberosity toward the junction of the pterygoid plates for later disjunction.



TECH FIG 1 • A. Intraoperative placement of bilateral maxillomandibular fixation screws to provide additional security of the splint to the maxilla. **B.** Intraoral incision in the upper buccal sulcus is made through the mucosa with a no. 15 scalpel. A small cuff of buccal mucosal is left attached to the gingiva to aid in a watertight closure. **C.** Needle-tip electrocautery is used for dissection through periosteum. Initial elevation of the periosteum with electrocautery will aid in further dissection with the periosteal elevator. Tension and countertension should be applied with the suction tip.

Bony Release

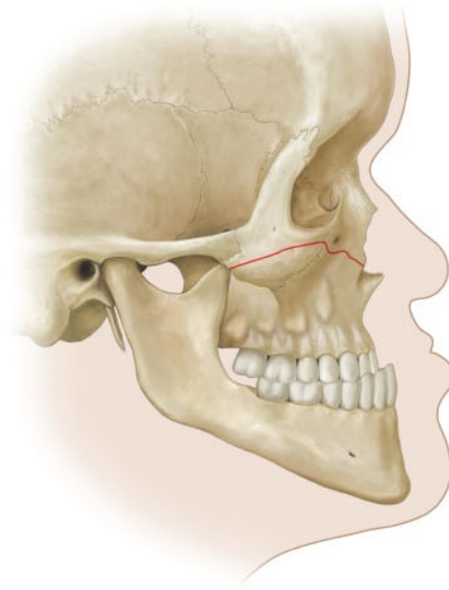
- The transverse osteotomy is marked with a sterile pencil.

- In the mature skeleton, placement should begin at the base of the pyriform aperture and swing superiorly to include much of the anterior maxillary sinus wall and as much of the zygoma as desired. Higher osteotomy on the zygoma will result in a more convex facial profile.
- The medial portion of the osteotomy is placed low at the pyriform aperture to prevent excess widening of the nasal base during distraction.
- Placement should be above the dental roots (**TECH FIG 2A**). In patients with mixed dentition, this may be superior to the level of the infraorbital foramen. In these patients, the osteotomy will circumvent the foramen to protect the neurovascular bundles and the permanent tooth buds (**TECH FIG 2B**).
- A malleable retractor is placed through the pyriform aperture between the bone and periosteum to protect the nasal mucosa from damage.
- The marked transverse osteotomy is made with a reciprocating saw from lateral to medial (**TECH FIG 2C**).
 - The posterior portions of the osteotomies are completed with a fine osteotome along the lateral nasal wall and laterally toward the pterygomaxillary junction.
 - The plane of the osteotomy should be canted medially and slightly inferiorly to avoid fracturing into the orbit.
- The nasal septum is separated with a guarded osteotome to protect the nasal mucosa (**TECH FIG 2D**).
 - The index finger is placed in the pharynx to palpate and stop the osteotome as it is pushed through or struck gently with a mallet (**TECH FIG 2E**).
- Pterygomaxillary disjunction is achieved with a curved osteotome placed just posterior to the maxillary tuberosity against the pterygoid plate.
 - The osteotome is directed slightly inferiorly to avoid the internal maxillary artery and the pterygoid plexus.
 - The index finger is placed in the hamular notch to palpate the tip of the osteotome as an assistant carefully strikes the osteotome with a mallet (**TECH FIG 2F**).
- After all osteotomies have been completed, the maxilla is down fractured (**TECH FIG 2G**).
 - Complete bony release should be confirmed, but aggressive mobilization is not necessary, as repositioning is not required.
 - Additionally, bone grafting and fixation hardware are not needed.

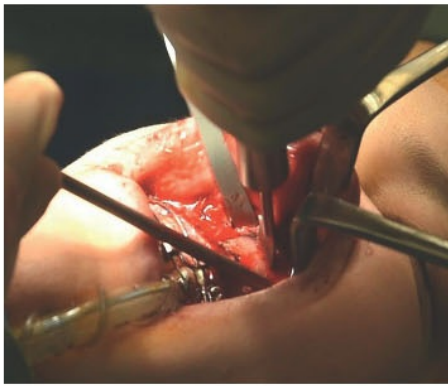
- Once complete release of the maxilla is confirmed, the intraoral incision is closed with absorbable sutures. A watertight closure should be achieved.



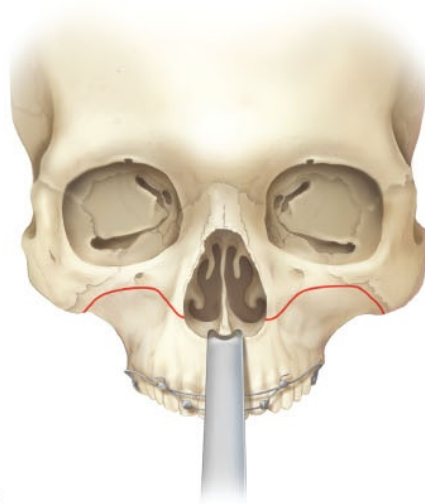
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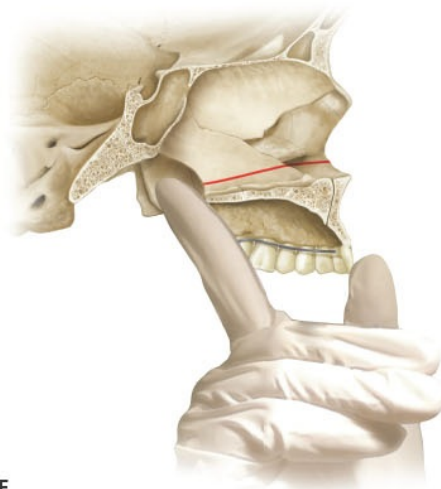
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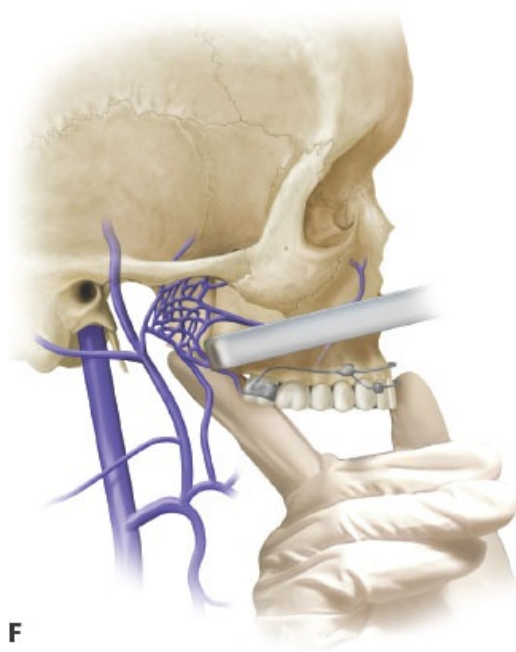
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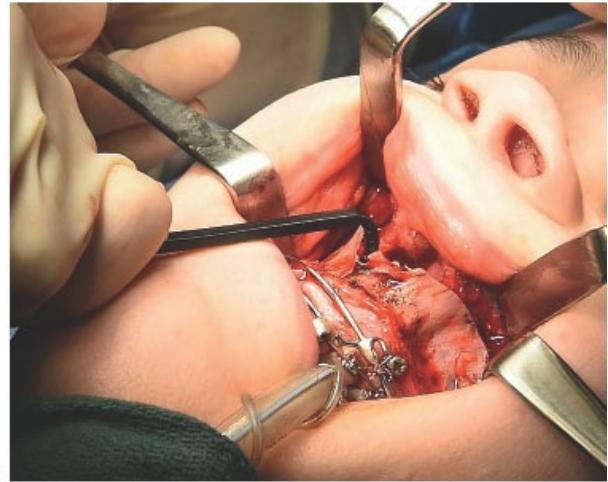
D



E



F



G

TECH FIG 2 • A. The transverse osteotomy is marked with a sterile pencil. This can be placed higher than with traditional Le Fort I advancement. The maxillary canine tooth roots are marked to help prevent damage during the osteotomy. **B.** The transverse osteotomy may extend above the level of the infraorbital foramen to allow for a greater segment of midface to be advanced. The osteotomy should circumvent the foramen to prevent damage to the neurovascular bundle. This also may be necessary to avoid permanent tooth buds in patients with mixed dentition. **C.** A reciprocating saw is used to make the transverse osteotomy from lateral to medial. A malleable retractor is placed between the lateral nasal wall and the mucoperiosteum of the nose to prevent soft tissue damage. **D.** The nasal septum osteotomy is completed with a guarded osteotome. Palpation behind the soft palate verifies completion while minimizing trauma to the posterior pharyngeal wall.

E,F. A curved osteotome is placed just posterior to the maxillary tuberosity, against the pterygoid plates. The index finger is placed in the hamular notch to palpate and confirm proper positioning of the osteotome. This osteotomy should be directed parallel or inferior to the plane of the alveolar arch to avoid excess bleeding. **G.** Down fracturing is done with the aid of a bone hook. Aggressive mobilization is not required but complete release should be confirmed.

■ Application of the Rigid External Distraction Device

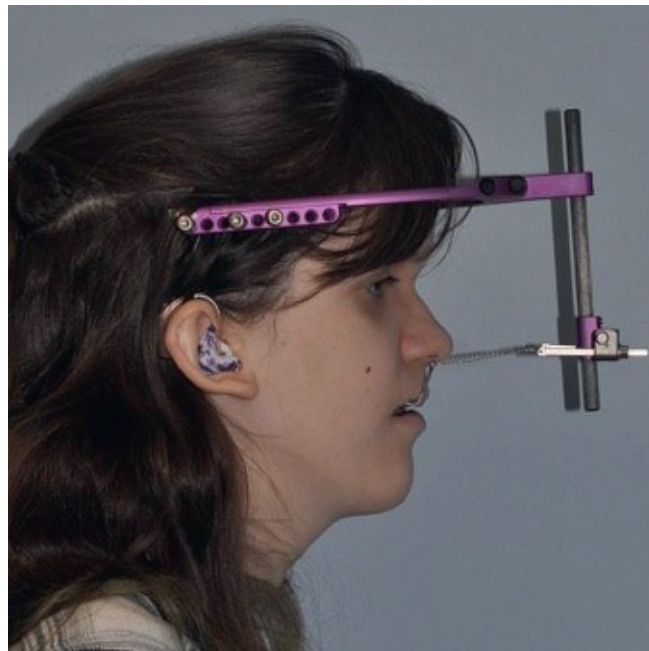
- The halo portion of the RED device (**TECH FIG 3A**) is placed immediately after the intraoral incision is closed.
 - Attaching the vertical bar to the halo helps with centering and aligning the halo during application.
- The plane of the halo should parallel the Frankfort horizontal plane (horizontal line through the superior portion of the external auditory canal and the orbitale) and be placed two fingerbreadths away from the forehead (**TECH FIG 3B**).
- Three scalp pins are used on each side of the halo.
 - These are placed within the hair-bearing scalp and are finger tightened symmetrically.
 - Finger tightening with the screwdriver completes halo application (**TECH FIG 3C**).
- Ensure the halo is secure by applying force to the metal ring in multiple directions.



TECH FIG 3 • A. Halo, vertical bar, and adjustment tools for the RED device. **B.** The halo portion of the distraction device is placed parallel to the Frankfort horizontal plane one to two fingerbreadths away from the forehead. Use of the vertical bar during application can aid in alignment. **C.** The halo is secured with three scalp pins bilaterally. These are symmetrically tightened with the screwdriver using fingertip strength only.

■ Rigid External Distraction

- 4 to seven days (latency phase) following Le Fort I osteotomy, the remainder of the distraction device is applied in the office.
 - The two large traction pins are connected to the intraoral splint, so the hooks are in line with the plane of the palate. These are then connected bilaterally to the traction screws via wires (**TECH FIG 4**).
- Distraction of the maxilla is initiated at a rate of 1 mm/d, usually divided into two 0.5-mm advancements.
 - The distraction vector is determined by preoperative cephalometric analysis.
- The distraction phase typically lasts from 12 to 15 days but the duration should be dependent on the severity of deficiency.
- Clinical evaluation of the anterior dental relationship and facial aesthetics can help guide the extent of distraction.
 - In patients with mature skeletal growth, a class I occlusion is desired.
 - In the growing skeleton, overcorrection of 2 to 3 mm may be desired, leaving the patient in a moderate class II occlusion.
- Patients are followed weekly to monitor the distraction process and adjust the distraction vector as needed.
- When clinically adequate distraction is achieved (dental occlusion and facial aesthetics), the RED device is kept in place and on tension during the 3- to 4-week consolidation phase.



TECH FIG 4 • The patient wearing the RED system. The intraoral splint is connected to the traction screws and halo via wires.

- This allows the maxilla to become clinically stable through bone mineralization.
- The halo and dental splint are removed following completion of the consolidation phase and elastics are placed for 6 to 8 weeks. This is performed in the office setting.
- Determination of maxillary consolidation can be made through physical examination and manual manipulation of the maxilla.

PEARLS AND PITFALLS

Orthodontic splint

- In patients with no or inadequate dentition to support the RED device, plates anchored to the maxilla may be used to apply the traction force.

Le Fort I osteotomy

- Reverse Trendelenburg positioning (15 degrees) and hypotensive anesthesia can significantly minimize procedural blood loss.⁵
- Use of a malleable retractor between the lateral nasal wall and the nasal mucosa can prevent damage to the soft tissues of the nose (see **TECH FIG 2C**).
- Incomplete osteotomy will result in failure of distraction. The RED device will not break unreleased bone.
- Dissection of the soft tissues from the maxilla can be difficult on the cleft side in patients with orofacial clefts. Care should be taken to preserve the soft tissues.
- Marking of the tooth roots with a sterile pencil prior to osteotomy can prevent damage to the dentition (see **TECH FIG 2B**).
- Contouring and reduction of the nasal vault and anterior nasal spine in anticipation of advancement prevent widening of the alar base.

Pterygomaxillary

- Placement of the osteotome in a superior direction at the

disjunction	pterygomaxillary junction may damage the internal maxillary artery or pterygoid plexus leading to undesirable hemorrhage. In the event of significant bleeding, packing should be placed and hemostasis achieved. ■ Intraoral palpation of the osteotome with the index finger can help ensure proper placement (see TECH FIG 2E,F).
Rigid external distractor	■ Symmetrical, finger-tight placement of the scalp pins can avoid easily preventable complication such as pin loosening. If the patient has had prior cranial surgery (craniosynostosis), care should be taken to palpate the cranium for stable bone so as to avoid pin placement over a portion of the skull that may be missing bone (see TECH FIG 3C).
Postoperative	■ Continued orthodontic and dental care is required for occlusal alignment. A final “finishing” Le Fort I osteotomy may be required in young patients or those with very severe hypoplasia.²

POSTOPERATIVE CARE

- Patients are started on a clear liquid diet for 24 hours and then advanced to a soft diet.
 - Unrestricted diet is allowed throughout the distraction and consolidation processes.
 - Normal oral hygiene, including gentle tooth brushing, is begun on postoperative day 1.
- The head of bed is elevated to help minimize edema.
- Most patients are discharged from the recovery room or on postoperative day 1.
- Activity restrictions are in place while the patient wears the RED device to prevent dislodging or disruption.
- Patients are counseled preoperatively that they may require a final “finishing” Le Fort I procedure at skeletal maturity for final arch alignment.

OUTCOMES

- Several studies have shown long-term stability of the maxilla following Le Fort I DO.^{2,6–9}
- When compared with conventional Le Fort I advancement, Le Fort I DO allows for larger advancements with decreased rates of relapse (**FIG 4**).
 - This holds true for orofacial cleft patients that frequently present with

significant scarring, greatly restricting maxillary advancement.

COMPLICATIONS

- The most frequent complications are associated with the scalp pins.
 - Loosening of the pins can occur and should be tightened as needed. This can be performed in the clinic.
 - Serious complications associated with the halo are rare.¹³
 - Relapse rates are low and are less than those of traditional orthognathic Le Fort I surgeries.^{10–12}
- Dislodging of the halo is possible but uncommon.
 - Patients should be instructed to minimize activities that may jeopardize device position.
- Surgical complications including bleeding, dental injury, avascular necrosis, and surgical site infections are rare.
 - The lack of nonvascularized materials (hardware, bone grafts), along with minimal dead space associated with Le Fort I DO, reduces the incidence of infection.

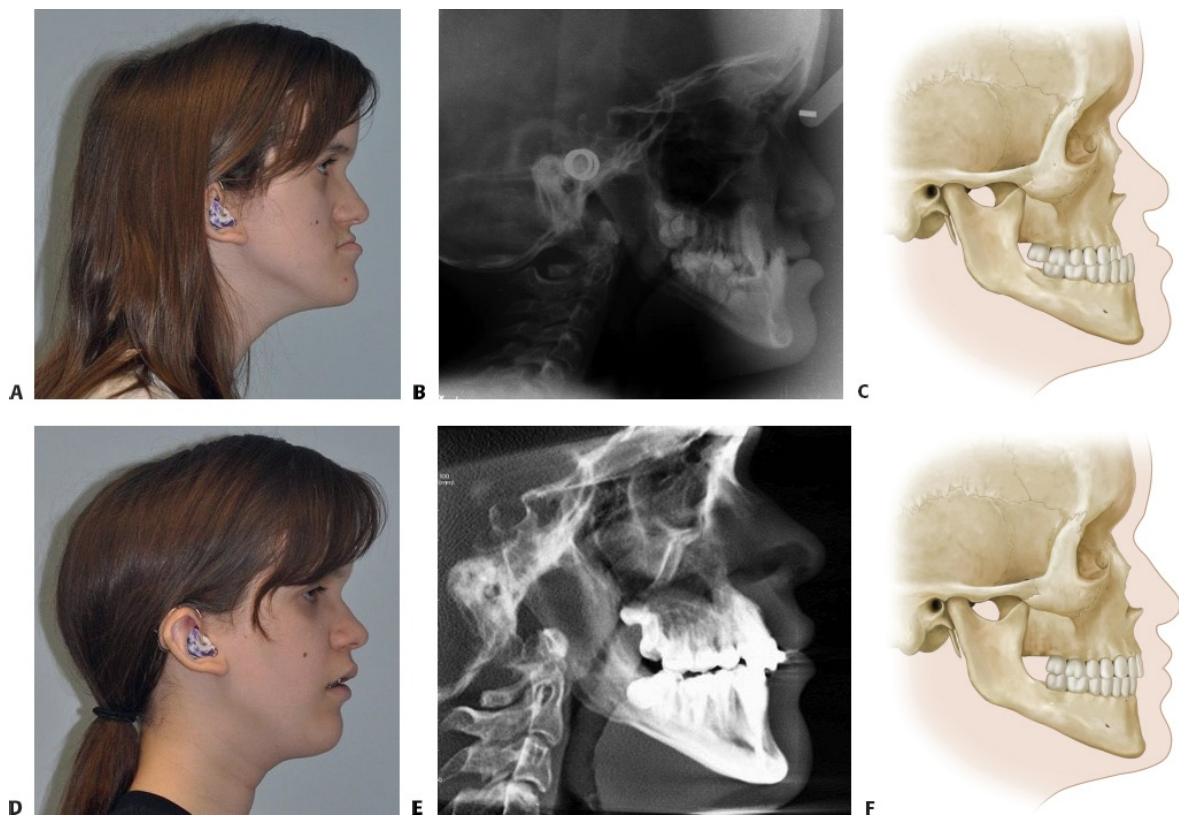


FIG 4 • Preoperative profile photograph (A),

cephalogram **(B)**, and rendering **(C)** of a patient with severe maxillary hypoplasia demonstrate a concave midface, class 3 relationship, and negative overjet. Postoperative profile photograph **(D)**, cephalogram **(E)**, and rendering **(F)** of the patient in **FIG 1** show improved midface projection, facial aesthetics, and dental occlusion.

ACKNOWLEDGMENTS

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23 Segmental Le Fort I Advancement: Two and Three Piece

CHAPTER

Leo J. Urbinelli and Jeffrey A. Hammoudeh

DEFINITION

- Le Fort I osteotomies (single or multipieced) are performed to reposition the teeth-bearing segment(s) of the maxilla and to surgically correct skeletal malocclusion, dentofacial asymmetries, and midfacial deficiencies or excess.
- Segmentation as a multipiece Le Fort I osteotomy is frequently used to modify the transverse dimension of the maxilla to provide a more optimal occlusion between the maxillary and mandibular teeth.
- Segmentation is more commonly performed when the presurgical orthodontia is suboptimally leveled, aligned, and coordinated, which is more common in the cleft palate patient.
- Skeletal malocclusion is best defined by Dr. Edward Angle's classification (**FIG 1**) to assess dentofacial deformities that may require orthognathic surgery or in particular a Le Fort I maxillary advancement.
- Class I occlusion is present when the normal relationship of the maxillary to mandibular teeth exists: the mesiobuccal cusp of the maxillary first molar intercuspatates within the buccal groove of the mandibular first molar.
- In class II malocclusion, the mesiobuccal cusp of the maxillary first molar sits too far anterior and does not seat into the mandibular buccal groove of the first molar, as in the case of mandibular retrognathia.
- In class III malocclusion, the mesiobuccal cusp of the maxillary first molar lies posterior to the mandibular first molar's buccal groove as is seen in mandibular prognathism.
- Le Fort I advancement surgery requires the surgeon to understand facial aesthetics, dentofacial relationships, and cephalometric norms in order to

accomplish a suitable and stable surgical outcome.

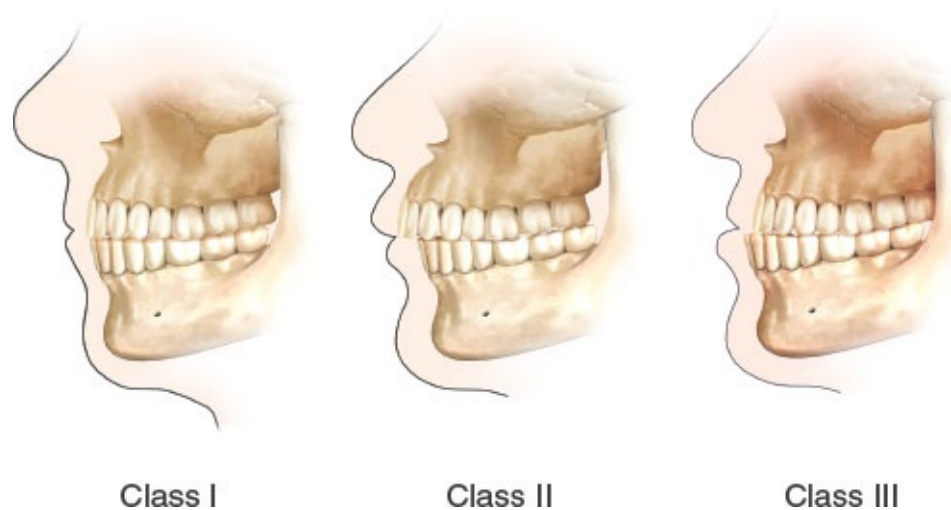


FIG 1 • Angle classification of occlusion.

- Cephalometric norms have traditionally been regarded standard in the workup of orthognathic cases and are important from an educational, academic, and historical standpoint.
- However, the limitations of cephalometric two-dimensional analysis have led to three-dimensional (3D) computed tomography scanning for virtual surgical planning (VSP).
- 3D VSP is our recommendation for complex orthognathic surgery.
- Two-piece segmental Le Fort I maxillary advancement surgery is indicated when maxillary advancement alone does not correct the transverse discrepancy.
- In the noncleft patient, the traditional segmentation of the maxilla is between the two maxillary incisors in a midsagittal osteotomy from the anterior nasal to the posterior nasal spine.
- In the cleft patient who has undergone alveolar cleft repair, it is reasonable to consider the segmentation at the alveolar cleft site to mitigate vascular compromise of the segments.
- Three-piece segmental Le Fort I maxillary advancement surgery is often indicated in the cleft lip and palate and/or syndromic craniofacial patient, when it is determined from physical exam that the patient has midfacial hypoplasia in the anteroposterior dimension and/or class III malocclusion in the setting of an arch that has suboptimal leveling, aligning, and coordination.
- This is exemplified by physical examination, dental model analysis,

cephalometric evidence, an acute sella to nasion to A-point angle (SNA angle less than 79 degrees), and VSP analysis (**FIG 2**).

ANATOMY

- Le Fort I osteotomy is defined by sectioning of the bony maxilla above the apices of the teeth but below the level of the nasal bones, through the nasal septum, and completing the disjunction at the pterygomaxillary junction.
- Segmentation of the Le Fort I maxillary segment is done by sectioning the maxilla between the tooth roots to allow expansion or reduction in the transverse plane, often completed after down-fracture of the tooth-bearing maxillary segment.
- Segmentation for a two-piece Le Fort is routinely between the maxillary central incisors in a midsagittal osteotomy (**FIG 3**).

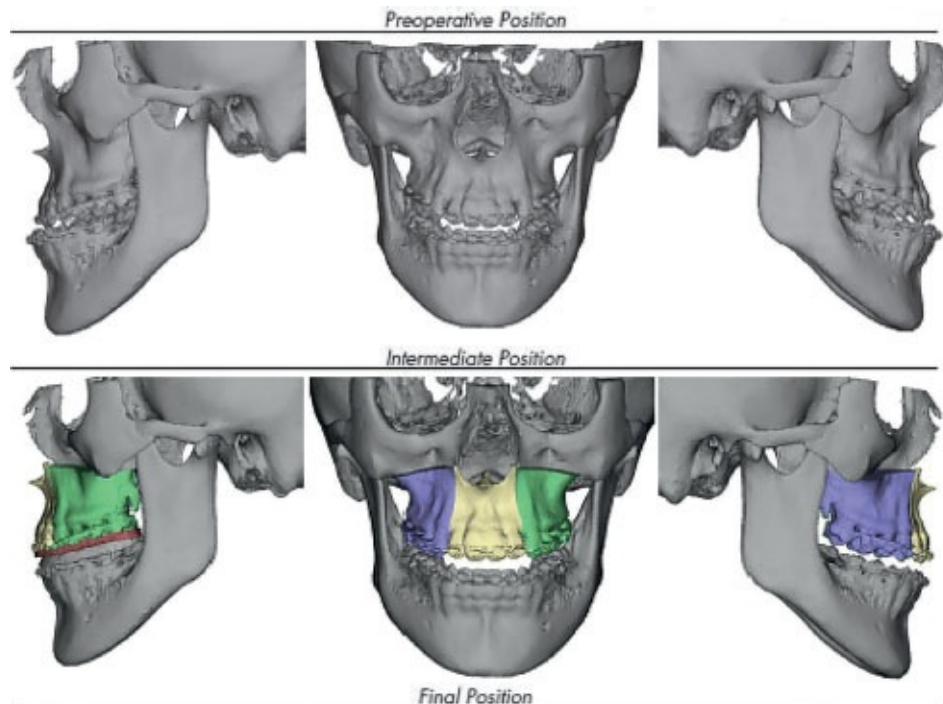


FIG 2 • Virtual surgical plan of three-piece Le Fort I osteotomy.

- In the cleft patient who has undergone alveolar cleft repair, if the alveolar cleft repair bone quality/take is less than optimal, it is reasonable to cut at the alveolar cleft site and extend the segmentation to the midsagittal osteotomy.
- This technique minimizes the potential vascular risks to the anterior

maxillary segment.

- Blood supply to the maxilla is rich and redundant in the noncleft patient.
 - After sectioning of the Le Fort I osteotomy, the blood supply depends on branches of ascending pharyngeal and ascending palatine arteries.
 - The descending palatine arteries can often be seen upon down-fracture and may be ligated if bleeding, as they will not compromise the vascularity of the maxilla if these are divided (**FIG 4**).¹
- Blood supply to the maxilla in the cleft lip/palate and syndromic craniofacial patient is less abundant and predictable due to potential previous surgical interventions, but maxillary segmentation can be done safely when risk mitigation techniques are used.

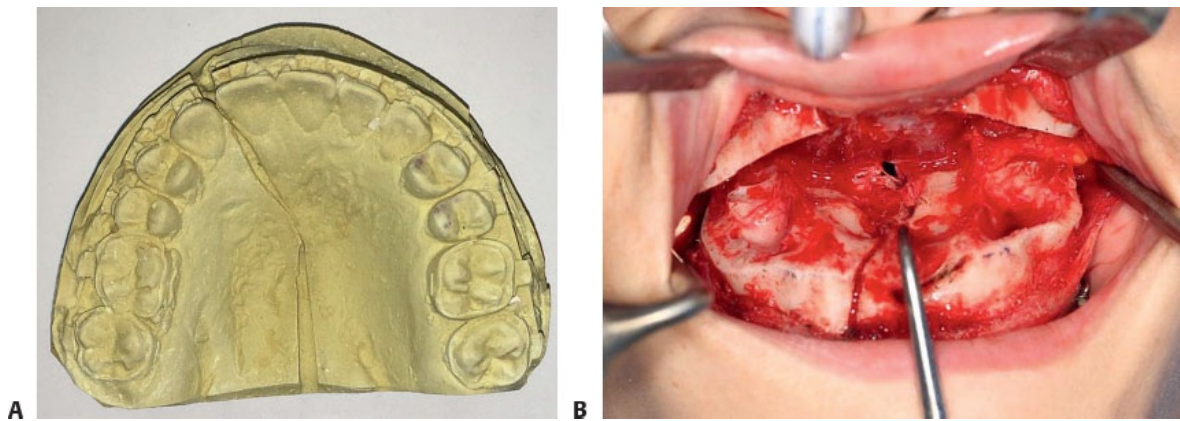


FIG 3 • **A.** Two-piece Le Fort I segmentation planned using the stone model. **B.** Intraoperative view after Le Fort I osteotomy, down-fracture, and two-piece segmentation.

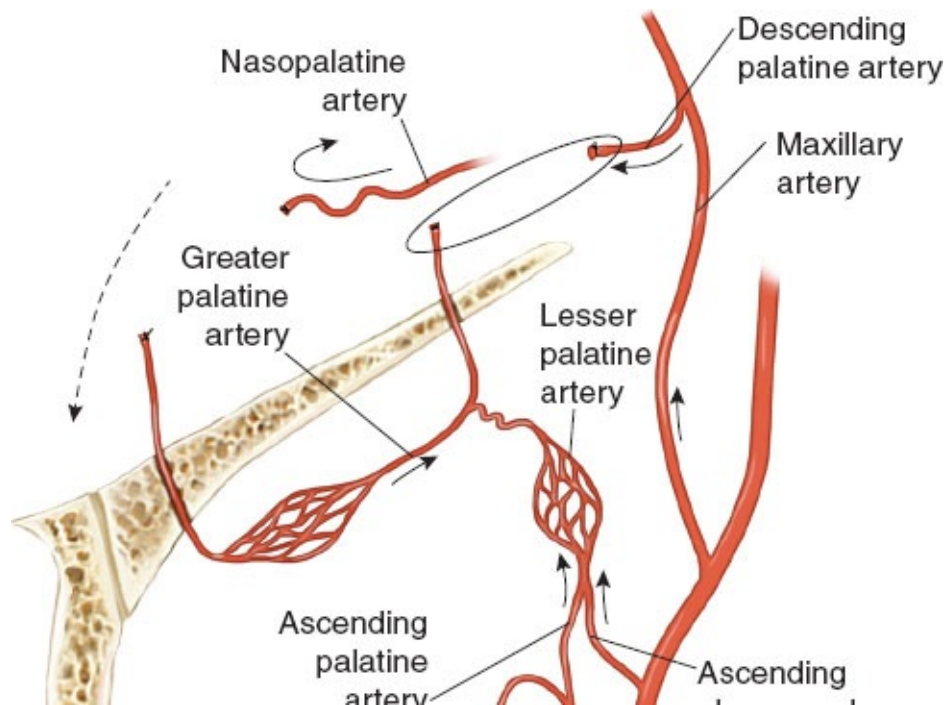


FIG 4 • Palatine arteries after down-fracture in Le Fort I osteotomy.

- These techniques include using a high-cuffed gingival incision, minimizing the dissection to what is needed, minimizing the segmentation to a two-piece maxilla if feasible, and keeping the total maxillary advancement to less than 10 mm.
- Potential maxillary vascular compromise in a cleft lip/palate patient undergoing a three-piece Le Fort I osteotomy must be discussed with the family and patient preoperatively as this multisectioning may predispose to a loss of teeth, bone, or even the entire premaxillary segment.
- These risks cannot be eliminated, but they can be mitigated using the techniques described above. A three-piece Le Fort segmentation can be performed reliably with stable and predictable results by experienced clinicians.

PATHOGENESIS

- Developmental skeletal dysplasia, in particular midfacial hypoplasia and dental class III malocclusion, is a multifactorial skeletal deformity of the face.
- Factors contributing to this deformity are genetic, environmental, idiopathic and potentially iatrogenic.

- This deformity can be found in cleft, noncleft/nonsyndromic, and syndromic craniofacial patients.
- Cleft palate repair and healing have been associated with a higher incidence of midfacial hypoplasia, transverse maxillary discrepancy, and overall malformation of the facial skeleton and dental malocclusion.
- Midfacial hypoplasia requiring a Le Fort I advancement is seen in up to 25% of complete cleft lip and palate patients.²

NATURAL HISTORY

- Children with orofacial clefts may or may not have normal occlusal relationships in early development; however, as they skeletally develop, maxillary growth often lags behind mandibular growth giving a concave midfacial appearance and class III malocclusion.
- With small disturbances in occlusion, orthodontics and headgear can be used to distract the maxilla in reference to the mandible.
 - However, the natural history of many orofacial cleft patients is that a larger midfacial discrepancy (4–15 mm) of a negative overjet exists, requiring surgical intervention to advance the maxilla in relation to the lower jaw as well as surgically correct transverse discrepancies.
- With anterior maxillary advancement of less than 10 mm, the prognosis for low relapse rates and long-standing, stable results can be accomplished with a segmented Le Fort I advancement.
- Maxillary transverse expansion is associated with a higher risk of relapse in both noncleft and cleft patients.
 - The cleft patient transverse relapse risk is higher and is correlated with the history of previous palatal operations, fistula repairs, pharyngoplasty/pharyngeal flaps, sequences/syndromes, and operative technique (fixation technique as well as the overall movement metrics).
 - We recommend minimizing the segmentation, using rigid fixation and postoperative splint retention with a palatal bar. In some circumstances where fixation is suboptimal, a period of closed reduction is indicated.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History should include inquiry into the past medical and dental history, documenting the extent and progress of presurgical orthodontia.
 - The clinician should note any pain on jaw opening and closing or difficulty eating, speaking, or closing the mouth without strain of the chin. One should

also elicit history of prior airway comorbidities, sleep disturbances (obstructive sleep apnea, enlarged turbinates), or prior surgery (palatal, speech or velopharyngeal surgery, prior jaw or nasal surgery).

- Additionally, one should ascertain if the patient has completed skeletal growth (continued height, foot, and hand growth), as Le Fort I advancement surgery is most stable and indicated when skeletal maturity is reached.
 - History of orthodontic treatment (duration, modalities) should be assessed.
- Physical examination should include an overall assessment of facial balance and proportions including photo documentation of the frontal, lateral, and oblique face in the repose and in full animation; this should include a focused intraoral exam.
 - This intraoral exam is imperative to assess overall dental health, missing/diseased teeth, previous palatal surgery, or scarring over the buccal/gingival mucosa.
 - Intraoral pictures should be obtained of midline occlusal as well as bilateral canine to mandibular molar relationships.
 - Intraoral exam should include inspection of orthodontia (wires, brackets, hooks, etc.) and clearly identify the dental malocclusion, skeletal dysplasia, and if any maxillomandibular cant exists.
 - Bimanual palpation of the temporomandibular joint on opening and closing of jaws for preoperative assessment of this complex joint is crucial.
- Palatal and oronasal fistulae should be noted. The pharynx should be examined as well as a detailed intranasal exam performed to check for any septal deviation, perforations, or enlarged turbinates.
- One of the most effective orthognathic surgical options in addressing midfacial hypoplasia with class III malocclusion is to combine a Le Fort III osteotomy in conjunction with a multiple-piece Le Fort I osteotomy.
 - This can make a profound change and correct a midface global hypoplasia in conjunction with severe dental malocclusion (**FIG 5**).

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Traditionally, posteroanterior and lateral cephalograms as well as a panoramic x-ray are obtained (**FIG 6**).

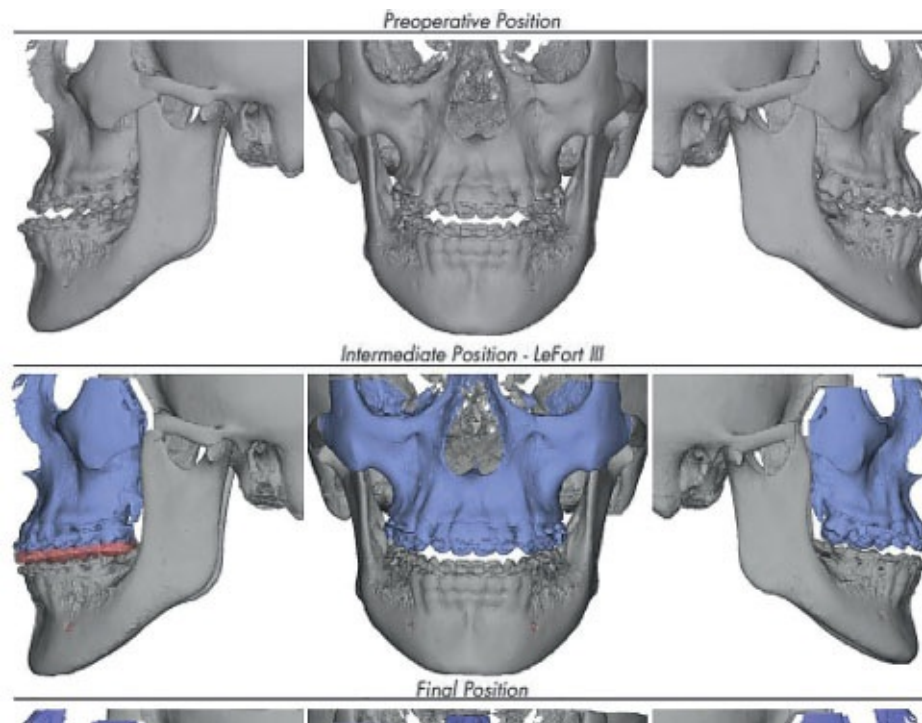


FIG 5 • Virtual surgical plan of combined Le Fort III osteotomy and advancement with three-piece Le Fort I segmentation.

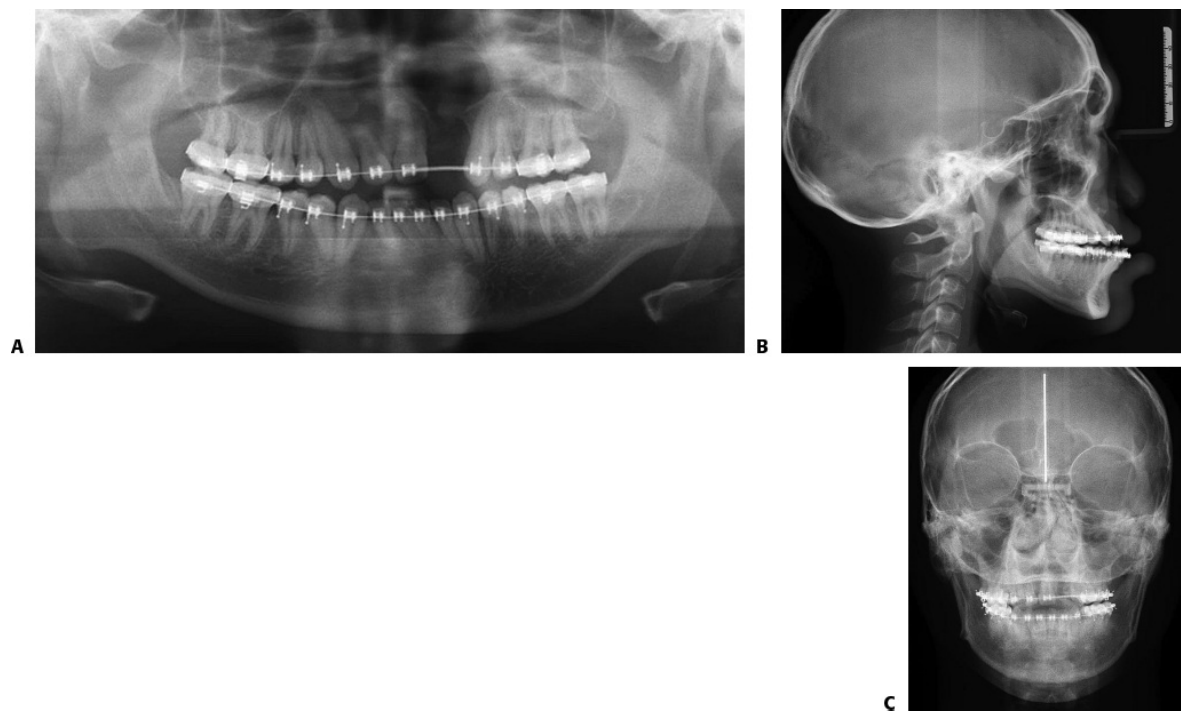


FIG 6 • Panorex (A) and posteroanterior (B) and lateral (C)

(C) cephalograms.

- Periapical views around missing bone along the alveolus may allow the surgeon to assess if simultaneous bone grafting is needed at time of Le Fort I advancement.
- Craniofacial CT scanning has become the mainstay in complex orthognathic surgery and is a requirement for 3D VSP, model, and splint fabrication.
- To facilitate the VSP, the preoperative occlusion must be obtained via dental stone models with bite registrations, or a digital dental scan of the teeth can be performed, which is then incorporated into the craniofacial CT for the VSP.
- 3D tissue rendering can also be used by overlapping the soft tissue window on top of the bony images.
- Traditional imaging, plaster model surgery, and splint fabrication still remain an acceptable preoperative workup for orthognathic surgery.
- Preoperative splint fabrication is key to achieving an intraoperative result, which matches the preoperative plan. Segmental Le Fort splints should have a palatal bar incorporated to provide additional stabilization and minimize relapse; this is particularly important in the cleft palate patient.

SURGICAL MANAGEMENT

Preoperative Planning

- Stress importance of education with family and patient on pre- and postoperative nutritional optimization, oral hygiene, postoperative activity restrictions, and the likelihood of having a splint in place postoperatively.
- In the cleft patient, discussion on the potential of remaining in maxillomandibular fixation (MMF) for a postoperative period of several weeks should be conducted.
- Duration of MMF is clinician dependent and is related to the extent and direction of movement in the maxilla, the previous surgical history, and the stability of the rigid fixation.
- The possibility of postsurgical MMF can be anxiety provoking for patients and made easier by thorough preoperative discussion and education.

Positioning

- Patient is placed supine on the operating room table with a padded shoulder roll placed to maintain the head and neck in a neutral or slightly extended

position.

- Intubation is often preferred via an endonasal-tracheal route to avoid difficulty in assessing occlusion during the procedure.
- Care must be taken to ensure the tube's security, and this is achieved by securing the endotracheal tube to the caudal nasal septum using a 2-0 silk suture in a horizontal mattress fashion with care to avoid the endotracheal tube from placing pressure on the nasal ala.
- The tube is draped cranially up over the forehead, padded, and secured with another circumferential 2-0 silk suture anchored to the scalp within the anterior hairline (again to avoid pressure of the tube on the alar rim of the nose or skin of the face; **FIG 7**).
- If the vertical position of the maxilla is going to be altered, it is helpful to use a reference marker.
- This is made either via Kirschner wire anchored at the nasofrontal junction or via tattoo at the medial canthus using 25-gauge hollow-bore needle and inked dye (methylene blue or gentian violet).



FIG 7 • Frontal (**A**) and lateral (**B**) views of intraoperative draping showing endonasal-endotracheal tube position, padding, sterile draping, and positioning.

- This reference mark will be used to measure preoperative measurements to the right and left occlusal surfaces of the maxillary teeth (or orthodontic

brackets) and ensure the postoperative vertical position of the maxilla is achieved as planned.

- Two large-bore IVs are placed at the start of the case for fluid resuscitation management.
- An arterial line and a Foley urinary catheter are typically placed. The arterial line will allow the surgeon and the anesthesiologist to assess the hypotensive anesthesia (mean arterial pressure less than 60) that is typically required during the maxillary down-fracture.
- A dose of IV dexamethasone is given in the OR as well for edema management. An IV dose of antibiotics (clindamycin or ampicillin) is given for prophylaxis.
- Intraoral chlorhexidine solution is used to wash the face and eyelids closed with occlusive dressings to avoid corneal abrasions. The face is prepped with dilute Betadine.

Approach

- Intraoral approach is standard with infiltration of local anesthesia (0.25% bupivacaine with 1:200 000 epinephrine solution) along the gingivobuccal sulcus of the maxilla as well as intranasally into the nasal septal mucosa.

TECHNIQUES

■ Incision and Dissection

- With the upper lip retracted atraumatically, an upper gingival incision is made leaving a generous (5–7 mm) cuff of gingiva in place to facilitate easy watertight closure.
- This incision is extended from first molar to first molar with needle tip electrocautery on a low setting. Incise perpendicular to the mucosa and then aim perpendicular to the bony maxilla to avoid perforations of the nasal mucosa and injury to the facial muscles or buccal fat. This also helps avoid... avoid “buttonhole” perforations in the gingiva.
- Once the periosteum is palpated and noted, it is scored with the electrocautery from the lateral maxillary buttress to below the level of the piriform apertures bilaterally.

- Using a sharpened periosteal elevator (Molt no. 9 or equivalent), a subperiosteal dissection is performed bilaterally over the face of the maxilla, extending medially along the medial buttresses, superiorly to the level of the infraorbital nerves, and laterally around alveolar processes of the maxilla to the pterygomaxillary junction.
 - Care is taken around the piriform apertures bilaterally to avoid perforation into the nasal mucosa; often, this dissection is performed with a Freer elevator to free the floor of the nose and caudal septum from the cranial surface of the palate.
-

■ Le Fort I Osteotomy of the Maxilla

- Once exposure is obtained, marking of the planned osteotomy with a sterile bone pencil or electrocautery scoring is performed to indicate the level medially and laterally of the height of the osteotomy that should be made.
 - Intranasally, this is never higher than the inferior turbinates and always above the level of the apices of the teeth (maxillary canine is the longest—up to 30 mm).
- Prior to sectioning the bone of the maxilla, hypotensive anesthesia is preferred with mean arterial pressures in the 45 to 59 mm Hg range to assist with visualization and mitigate blood loss from bony edges.
- The osteotomy is performed with either a reciprocating saw or an ultrasonic bone saw, cutting first from the medial (piriform rim) to lateral buttress or from lateral to medial along the anterior maxilla while placing a malleable Freer elevator to protect the nasal lining and endotracheal tube from saw injury.
- The same osteotomy is completed on both sides of the maxilla (**TECH FIG 1**).
- A curved blunt-ended “pitchfork” osteotome is then used to straddle the caudal septum with the nasal mucosa elevated in a protected manner, and a mallet or digital pressure is used to divide the vomer from the bony palate.



TECH FIG 1 • Le Fort I osteotomy.

- Often, a hand is placed intraorally along the soft palate to palpate when the osteotomy is complete and stop unwanted injury to the soft palatal tissues and associated local structures.
 - After separation of the septum from anterior to posterior nasal spine, the osteotomy of the lateral wall of the maxillary buttress is completed with a thin ribbon osteotome.
 - The posterior wall of the maxilla is gently sectioned using either an osteotome and a mallet or an ultrasonic saw.
 - The bone in this region is thin, and care should be taken to avoid injury to the descending palatine artery, internal maxillary artery, and the pterygoid plexus.
 - Using a curved narrow osteotome and mallet, the lateral and posterior most extent of the Le Fort I osteotomy is completed with a hand placed intraorally and finger placed in the retromolar area over the hamulus to palpate the medial extent of the osteotomy, serving as a guide to the separation and to minimize injury to the intraoral mucosa and local structures.
 - The curved osteotome should be placed posterior to the maxillary tuberosity within the pterygomaxillary groove, angling transversely and slightly caudal.
 - Prior to down-fracturing the maxilla, the clinician should identify the region for segmentation, and the corticotomy should be made meticulously under direct vision making sure not to injure the roots of the teeth.
-

■ Down-Fracture of the Maxilla

- When the lateral pterygoid plates are sectioned from the maxilla, the tooth-bearing maxilla will be separated from the cranial portion with gentle digital downward pressure.
- Bone spreader (laminar spreader) can be used at the thick medial and lateral maxillary buttresses to be sure maxillary down-fracture is complete.
- If down-fracture does not occur with digital pressure, take time to recheck all previous osteotomies for completion as the down-fracture should be controlled, along previous osteotomy lines in order to avoid unfavorable fractures.
- With maxilla down-fractured and soft tissues stretched, one should evaluate and control any bleeding with bipolar cautery and/or packing and evaluate for any tears in nasal mucosa, which should be repaired with absorbable suture to avoid synechiae or nasal bleeding postoperatively.
- With down-fracture completed, Rowe disimpaction forceps and/or pterygoid S-shaped retractors can be placed bilaterally in the piriform or behind the lateral pterygomaxillary osteotomies, respectively, to stretch and advance the maxilla in an anterior plane, taking care to do this in a controlled fashion on slow stretch to avoid avulsion of soft tissue and hence blood supply.

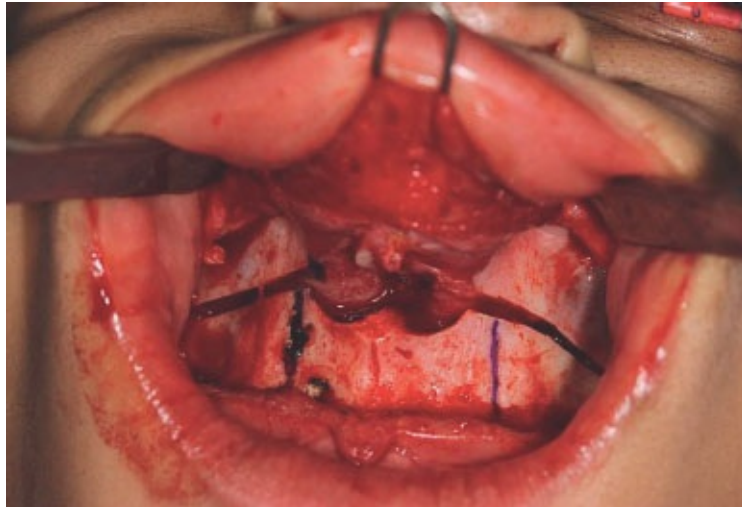
■ Segmentation of the Maxilla

- Controlled segmentation of the maxilla (into two or three pieces) is often performed in patients with unilateral/bilateral cleft palate and alveolus, in syndromic patients with skeletal dysplasia, and in otherwise healthy patients who have suboptimal orthodontia.
- Converting the segmentation corticotomies, made prior to down-fracture of the maxilla, to segmented osteotomies is now undertaken (Video 1).



Video p2-c023

- In the cleft palate patient requiring a two-piece segment, it is often preferred to go through the alveolar cleft anteriorly where the bone stock is lower in general.
 - This also helps mitigate vascular compromise.
 - The alveolar osteotomy is generally between the canine and premolars (sometimes between canine and lateral incisors), and then is extended posteromedially to meet a midsagittal osteotomy.
- In the cleft palate patient requiring significant transverse expansion and multiplane occlusal correction, three-piece segmentation is ideal.
 - Again, the alveolar segmentation is usually at the canine-premolar (or sometimes canine-lateral incisor) regions bilaterally, and then the osteotomy is extended posterior medially to parasagittal osteotomies in a “horseshoe” fashion.
 - The parallel parasagittal osteotomies provide the advantage of increased transverse expansion and minimized soft tissue trauma to the midpalatal region, which is generally more tenuous (**TECH FIG 2**).
- In a noncleft patient requiring a two-piece segmentation, this is traditionally achieved by planning a standard Le Fort I osteotomy in conjunction with segmentation between the two central incisors.



TECH FIG 2 • Three-piece segmentation of the maxilla along parasagittal markings.

- This can be accomplished by performing the traditional Le Fort I, and then prior to down-fracturing, a corticotomy is made from the anterior nasal spine caudally under direct vision between the central incisors.
- This can be done initially with the reciprocating saw or ultrasonic handpiece. The corticotomy then is made from the anterior nasal spine posterior with a small thin osteotome.
- Subsequently, the down-fracture is completed, and then the segmentation osteotomy can be propagated and completed after the down-fracture under direct vision.
- This stepwise method allows for a more controlled down-fracture of the maxilla and a directly visualized segmentation.
- For the noncleft patient requiring a three-piece Le Fort I osteotomy, the traditional Le Fort I osteotomy is made, and in similar multisegmentation sequence, the segmentation corticotomies are made prior to down-fracture; then, after down-fracturing, the segmentation osteotomy can be completed.
- The segmentation is traditionally between the canine and premolar teeth bilaterally and then extends posterior medially into the midpalatal area, which then gets propagated posteriorly to the posterior nasal spine (“Mercedes” configuration).
- Some clinicians prefer bilateral parasagittal osteotomies and a “horseshoe” configuration as this allows for increased transverse expansion and avoids potential midpalatal soft tissue injuries.

- Ultimately, osteotomy segmentation location, type, and configuration depend upon best fit occlusion, extent of transverse expansion, and cant correction as determined in preoperative model planning as well as clinical judgment.
- The osteotomies are made with a reciprocating saw, an osteotome and a mallet, and/or an ultrasonic saw from posterior to anterior and cranial to caudal directions.
 - Digital palpation along the palatal mucosa is used to detect when the saw has completed the bony cuts and to avoid injury to the palatal mucosa.
- Once the osteotomies are made, they are completed through the alveolar ridge and between the teeth carefully using fine osteotomes and mallets.
 - The attached gingiva is elevated atraumatically and remains intact over this interdental alveolar bone, which is segmented to maintain a rich blood supply to the segmented tooth-bearing maxillary segments.
- The osteotomies are propagated with a T-handle osteotome using small rotary movements to ensure the soft tissue can be stretched and the maxilla is spreading to show completion of osteotomies.
- Final maxillary splint is placed and wired to the teeth/orthodontia to ensure transverse expansion/reduction has been obtained.
- If a segmental Le Fort I is performed to reduce the height or transverse width of the maxilla, this can be done with soft tissue dissected using a Freer elevator to maintain periosteal blood flow to the maxilla.
- The caudal nasal septum may need reduction to avoid bowing or septal deviation postoperatively for a planned maxillary impaction.

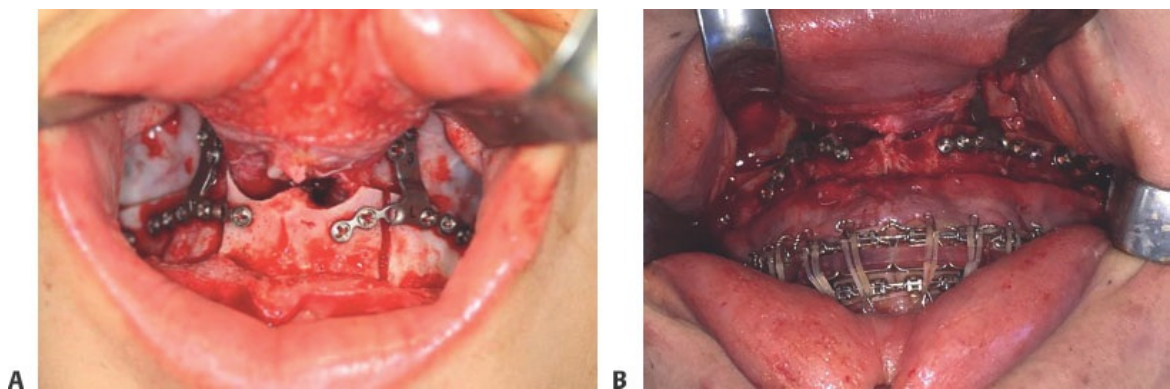
■ Transverse Expansion and Advancement of the Maxilla

- After down-fracturing of the maxilla and completion of the multisegmentation into two or three pieces (by propagating the segmentation corticotomies with an osteotome), the maxilla is seated into the splint with 26-gauge wires.
- The maxillomandibular unit is secured together with a 24-gauge wire by mobilizing the maxilla/splint into occlusion with the mandible.
- The maxillomandibular unit is rotated into its final position with bone-to-bone contact.

- This rotation should be accomplished passively to ensure that the mandibular condyles remain seated in the glenoid fossa.
- The position should be evaluated in relation either to internal reference markers or to external reference points (K-wire or tattoo) to ensure the planned postoperative movement is achieved; this is particularly important when there is a significant cant correction.

■ Fixation of the Maxillary Segments

- With the maxilla in proper position and seated appropriately in MMF with the occlusal surfaces fitting exactly into the splint, the maxillomandibular unit is passively rotated into the new position with stable bony contact.
- The maxillary segments are then fixated to each other and to the cranial aspect of the maxilla along the medial and lateral buttresses using 2-mm-thick L-shaped plates along the lateral buttresses and 2-mm-thick inverted-T-shaped (Lindorf style) plates along the medial buttresses to capture the central and lateral segments in three-piece maxillary movements.
 - Nonlocking plates and screws are acceptable, and these should be placed above the level of the dental roots.
- The plates are bent to follow the natural contours of the maxilla and newly advanced maxilla (**TECH FIG 3**).



TECH FIG 3 • **A.** Three-piece Le Fort I osteotomies fixated with Lindorf plates and screws. **B.** Completed three-piece Le Fort I osteotomies, fixation with Lindorf plates along medial buttresses, and L-shaped plates at lateral buttresses. Newly established occlusion is

confirmed with MMF into custom occlusal splints.

■ Release of MMF and Adjustment of Alar Base Width

- After rigid fixation of the maxilla, the MMF is released to check occlusion into the splint to ensure the mandible passively swings into the maxillary occlusion splint as planned in central relation.
- Midlines and external reference points are evaluated and should match preoperative planning.
- Upon release of gingiva, labial frenum, and periosteal attachments along the piriformis and anterior nasal spine in the setting of advancing the maxilla, the alar bases tend to widen after the nasalis muscle insertion has been released through the Le Fort I osteotomy incision and dissection.
 - We typically place a buried horizontal mattress suture 3-0 PDS as an alar cinch suture, pulling the alar bases together medially into their preoperative or desired position.
 - This is done through the intraoral incision, taking care to pass the suture just lateral to the alar base but not through the skin of the alar-jugal groove.

■ Closure

- With occlusion corrected and movements accomplished, one can now turn to watertight closure of gingiva. Prior to closure, hemostasis is verified and the intraoral wounds are irrigated with copious normal saline.
- Next, using interrupted 4-0 braided absorbable sutures in a horizontal mattress fashion, the incision is closed watertight from lateral to medial.
- A V-to-Y advancement closure of central gingival mucosa is performed in order to avoid excessive upper incisal show and a short/flap upper lip and maintain a full and pouty central lip.
 - The extent of the V-to-Y closure depends on the patient's preoperative incisal show in repose.

Endonasal-endotracheal tube intubation	■ Secure tube in multiple places with relief of any pressure on ala to avoid alar rim necrosis, and routinely reassess tube position.
Intraoperative hypotensive anesthesia	■ Maintain SBPs in 90s and MAP of 50s for best visualization and to help minimize blood loss from osteotomies.
Gingivobuccal sulcus incision	■ Maintain a generous cuff of tissue for closure because it shrinks and may leave insufficient tissue coverage over hardware.
Remain subperiosteal in maxillary dissection	■ Avoid slipping out of the subperiosteal plane laterally over the maxilla as it can violate the buccal fat pad, which can be pesky and obscure view of the operative field.
Maxillary osteotomy of posterior wall and pterygomaxillary junction	■ Maintain patience and control with these osteotomies; avoid plunging or big movements with osteotome; avoid injury to internal maxillary artery; and avoid severe hemorrhage.
Down-fracturing the maxilla	■ Gentle digital pressure. If it does not go, do not force it, retrace your osteotomies, and make sure they are complete. Do not rush into an unfavorable fracture.
Pulsatile intraoperative bleeding	■ If can be identified, stop with bipolar cautery; if unable to identify, apply pressure and reduce maxillary down-fracture to tamponade. ■ If unable to control bleeding after down-fracture, cautery, and tamponade, reposition the bony Le Fort segment. If bleeding continues, resuscitate and consider interventional radiologist consult for possible endovascular embolization procedure. Consider aborting the procedure.
Preoperative planning and splint	■ Key to successful outcome. Virtual surgical planning is helpful, predicable, and time saving over traditional model surgery. ■ This will provide a reliable outcome. Maintain patients in postoperative occlusal splint for greater stability.
If advancement greater than 9 mm	■ Consider distraction of the maxilla.

Verify bite is stable and easily reproducible	■ Bite should be reproducible and passively fit into prefabricated occlusal splint. ■ In noncleft patients without segmentation, remove the splint and place guiding elastics and allow to function with a soft diet. ■ In cleft patients with multisegmentation, keep the split in place for additional stability. Consider guiding elastics if there is excellent rigid fixation. Consider heavy elastic MMF if the stability is suboptimal or if degree of advancement/expansion is extensive or if there is significant palatal scar tissue.
Closure of incision	■ If maxilla is advanced, consider V-to-Y closure of central upper gingival incision to minimize excess central incisal show.
Cleft patients	■ These patients tolerate smaller advancements and expansions of the maxilla; consider bone grafting; use delicate care of premaxillary soft tissue when bilateral cleft patients undergo three-piece Le Fort I.

POSTOPERATIVE CARE

- Postoperatively, noncleft patients who have undergone segmental Le Fort I osteotomy are not routinely held in MMF; cleft patients, however, due to an altered bone stock along alveolar cleft sites, and the propensity of palatal scar tissue from previous interventions, are maintained in MMF with elastics or wires postoperatively for 4 to 6 weeks to minimize the propensity of relapse.
- Cleft and noncleft patient cohorts are both maintained in postoperative maxillary splints and remain on liquid/puree “no-chew” diets for 8 weeks.
 - Patients can drink with a straw but no negative pressure or “sucking” on straw as this can place undue stress on intraoral incisions.
 - However, they may use a squeeze bottle to passively instill liquids or purees intraorally to maintain their no-chew diet.
- Postoperatively, the head of the bed should be elevated 35 degrees.
 - Patients who remain in MMF postoperatively will have bedside scissors (for elastics) or wire cutter (for wires) at all times in case of airway emergency if MMF needs to be removed.
 - Patients and families are taught before discharge home how and when to use the scissors or wire cutter in case of emergency.
- The patients receive humidified blow-by supplemental oxygen to moisten mucous membranes overnight while in the hospital.

- Patients also receive two more tapering IV doses of dexamethasone to reduce facial edema, as well as topical triamcinolone cream over lips/oral commissures.
- Patients are given standing antiemetics if in MMF (ondansetron, scopolamine patch, and/or Compazine) to reduce nausea.
- All patients are watched overnight postoperatively for airway management (continuous pulse oximetry), and routine vitals are taken.
- Patients may start liquid diet immediately, transition to purees; if tolerating oral diet, ambulating, pain is tolerable and airway without issues, they may be discharged home as early as postoperative day 1.
- Patients are discharged home on liquid medication for analgesia, oral swish and gargle chlorhexidine solution, and oral antibiotics for 5 days with follow-up in 2 weeks.

OUTCOMES

- Routinely, patients who undergo Le Fort I osteotomy advancements, segmented or otherwise, show a profoundly positive impact on their facial balance, occlusal relationships, and overall quality of life.
- Some element of relapse can be seen in roughly 20% of all patients undergoing Le Fort I maxillary advancement and segmentation.
 - This is particularly the case for patients that have a history of previous cleft palate repair.
 - The risk of relapse in the transverse and anteroposterior dimensions is believed to be due to multiple sites for bony healing (or nonunion), previous velopharyngeal scarring, the palatal tissue constraints/scarring, and lower-quality bone stock in cleft patients.³
 - Most cases of relapse are minor in nature and can be corrected with postsurgical orthodontics and thus will have negligible effect on form and function.
- If the relapse is significant, has detrimental effect on function or stability, and cannot be corrected orthodontically, then secondary surgical intervention should be considered. Relapse appears most closely correlated with distance of maxillary advancement and history of previous palatal surgical intervention due to facial clefting.⁴

COMPLICATIONS

- Stability of the maxillary movement in cleft patients is less than that of

noncleft patients.

- The risk of other complications is greater in patients with unilateral and bilateral cleft palate and alveolus.
- Patients who undergo movements greater than 9 mm have a higher risk of complications.
- Complications include bleeding, infection, relapse, nonunion or malunion, loss of teeth, fistula, soft tissue recession, nerve injury, and necrosis of maxilla.⁵
- Early postoperative relapse is usually secondary to suboptimal fixation or position of the segmented maxilla. Late relapse, particularly in cleft patients, is more likely due to the palatal scarring.
- Loss of premaxillary segment has been reported in those patients with bilateral clefts undergoing multisegmented Le Fort I osteotomy.
 - We advocate for a large gingival cuff to be left over the premaxilla, atraumatic dissection along the alveolar ridge maintaining periosteal blood supply, and extensive preoperative discussion with the patient and family.

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24 Le Fort II Osteotomy and Advancement

CHAPTER

Adi Rachmiel, Dekel Shilo, and Omri Emodi

DEFINITION

- Patients with midface hypoplasia involving the maxilla and nasal complex, with an acceptable position of the zygomatic complex and orbits, benefit from Le Fort II advancement.¹⁻³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Midface deficiency can be secondary to
 - Traumatic deficiencies
 - Need to assess mechanism of injury
 - Assess for the presence of functional problems including
 - Breathing difficulty
 - Eating problems
 - Speech problems
 - Nasomaxillary dysplasia
 - Assess breathing, eating, and speech problems.
 - Cleft deformities
 - Assess breathing, eating, and speech problems.
 - Assess for potential palatal fistulas and need for bone grafting.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Lateral cephalogram
- Posteroanterior cephalogram
- Cone-beam computed tomography (CBCT) or spiral CT scan
- Cast models of the upper and lower jaws, setting the models in the articulator

DIFFERENTIAL DIAGNOSIS

- Nasomaxillary hypoplasia; may involve the dentoalveolar segment.
- Binder syndrome
- Nasomaxillary hypoplasia with normal dental occlusion

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative CBCT or spiral CT with lateral and posteroanterior cephalogram
- Model casts are placed for assessment of occlusion. Preoperative orthodontics require leveling, alignment, and decompensation-retrusion of the upper dental arch and protrusion of the lower incisors to increase the amount of skeletal advancement.
- Prefabricate an occlusal wafer according to the predetermined planned position of the midface.



FIG 1 • Bi-coronal approach. **A.** Marking of the coronal incision, notice the hairline. **B.** Following flap elevation notice the exposure of the nasofrontal suture and the medial orbital wall.

Positioning

- The patient is placed supine.
- Nasal intubation is used to allow both intra- and extra-oral access
- IV muscle relaxant for improved mouth opening.
- Bite block maintains mouth open during surgery
- Local anesthetic with adrenaline for vasoconstriction
- Access must be possible to both sides of the patient's face.

Approach¹⁻¹¹

- Intraoral buccal sulcus incision is used to approach the midface. This includes a circumvestibular incision from the right first molar to the left first molar.
- Different options for extraoral incisions include
 - A coronal incision (**FIG 1A,B**)

- Double Lynch, which includes a combination of a paranasal incision with an inner canthus incision to expose the nasal bone (**FIG 2A**).
- In older patients, it may be possible to use a single dorsal nasal incision via a skin-crease seagull incision (**FIG 2B**).

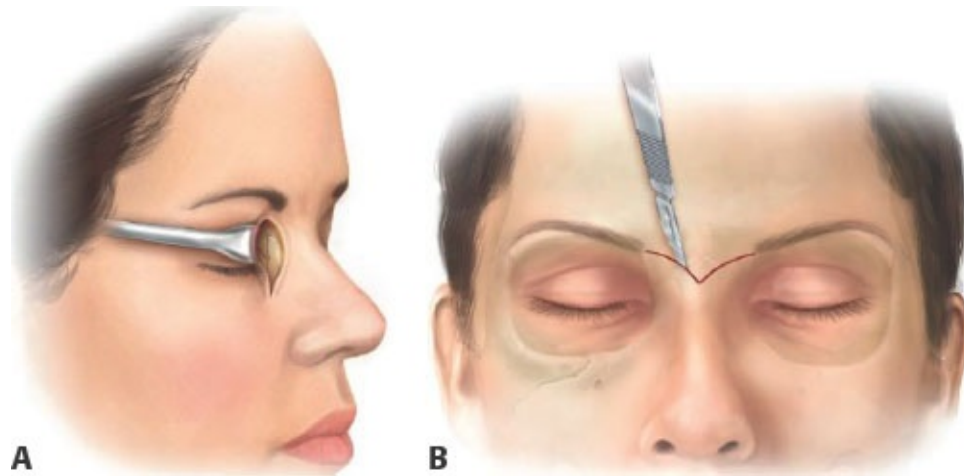


FIG 2 • Alternative skin incisions for older patients. **A.** Seagull – an incision on the frontonasal area. **B.** Lynch incision – Fronto-ethmoidal medial orbitotomy approach.

TECHNIQUES

■ Le Fort II Osteotomy

Extraoral Approach

- A skin incision is made according to the Lynch approach/dorsal nose crease/coronal approach (**FIG 1A**).
- The dissection is subperiosteal.
- The floor and rim of orbit are exposed medially and inferiorly. Both the infraorbital nerve and the nasolacrimal duct must be identified and preserved.
 - The osteotomy is made vertically between the nasolacrimal duct and the infraorbital nerve (**TECH FIG 1A**).
 - The cut is then continued via the intraoral incision toward the posterior maxilla as in a Le Fort I osteotomy.

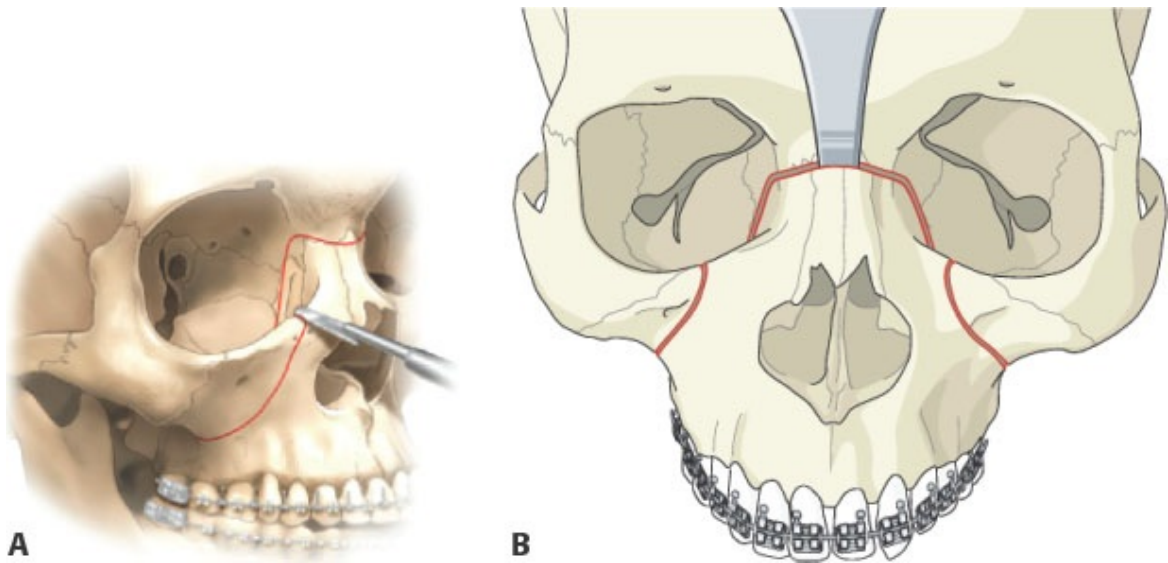
- The nasal mucosa is protected with a periosteal elevator during the vertical cut; the orbital contents should be protected with a malleable retractor.
- The nasal bridge is exposed.
 - The vertical cuts are connected via a horizontal osteotomy immediately below the nasofrontal suture and above the lacrimal crests. The osteotomy should be directed slightly downward to avoid penetrating the cribriform plate (**TECH FIG 1B**).
 - This osteotomy should be the last procedure before mobilization, after completing the intraoral osteotomies. This is due to a high risk of bleeding from blood vessels in that area of the nasal osteotomy.
- The nasal septum is divided through the frontonasal osteotomy using a chisel (**TECH FIG 1B**).
 - A finger should be placed intraorally in the area of the posterior nasal spine to mark the direction of the osteotomy and also to protect against penetration of the osteotome through the palate mucosa.

Intraoral Approach

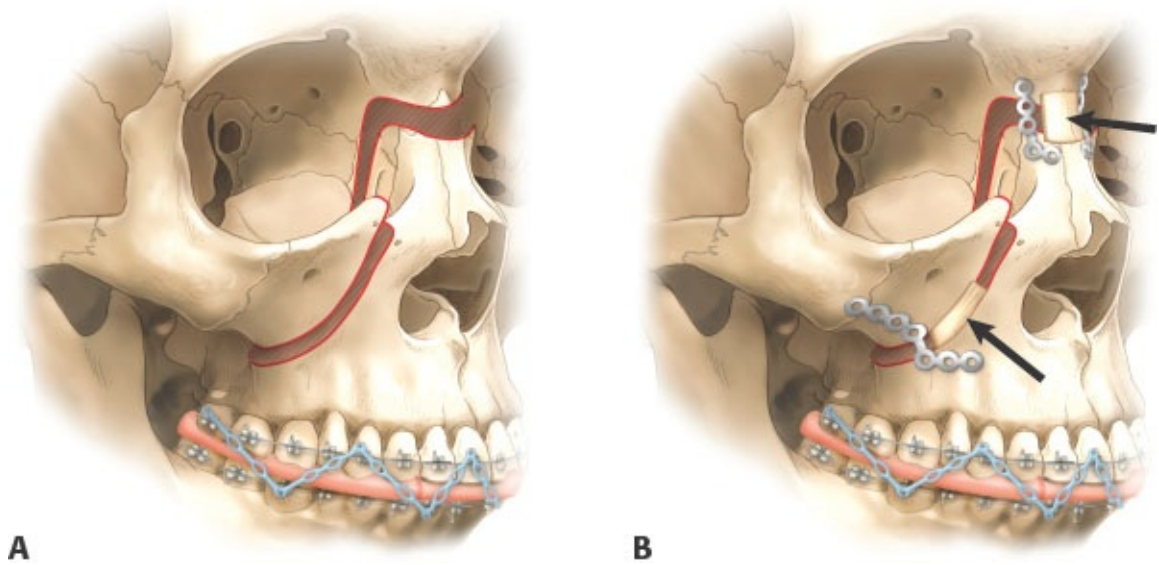
- A bilateral horizontal incision is made in the maxillary vestibule 2 to 3 mm above the attached mucosa, from the central incisor anteriorly toward the first molar posteriorly.
- Complete exposure is required of the lateral maxilla from the central incisors toward the pterygomaxillary junction posteriorly.
- Separating the nasal mucosa from the lateral nasal wall is preformed using a periosteal or Freer elevator.
- A lateral horizontal maxillary osteotomy is made on the lateral maxilla with a reciprocating saw; the osteotomy is made at least 5 mm above the apex of the teeth at the level of the nasal floor.
 - This cut extends from the pterygoid plate posteriorly to join the vertical cut from the inferior orbital rim anteriorly.
 - These cuts must avoid damage to the apex of tooth roots.
- The pterygomaxillary fissure is osteotomized using a curved osteotome. It is critical to position the osteotome correctly, in an inferior and medial direction.
- The midface osteotomy is mobilized with Rowe disimpaction forceps and advanced to the preplanned position. This procedure should be done firmly, but gently.

Fixation

- The desired osteotomy is shown in **TECH FIG 2A**.
- Intermaxillary fixation is applied according to the preplanned final occlusion using occlusal wafers and dental wires.
- Extraoral fixation is applied at the nasal bridge using an inverted Y miniplate or two L miniplates (**TECH FIG 2B**).
- L miniplates are used at the zygomaticomaxillary buttress bilaterally.
- Stabilization with bone grafts should be considered.
 - Bone grafts can be harvested from the calvarium if a coronal incision is used or from the iliac crest if facial-only incisions are used.
 - Allograft blocks are also an option.



TECH FIG 1 • Le Fort II Osteotomy. **A.** The osteotomy is made vertically between the nasolacrimal duct and the infraorbital nerve. **B.** A chisel is used to separate the segment in the nasofrontal area.



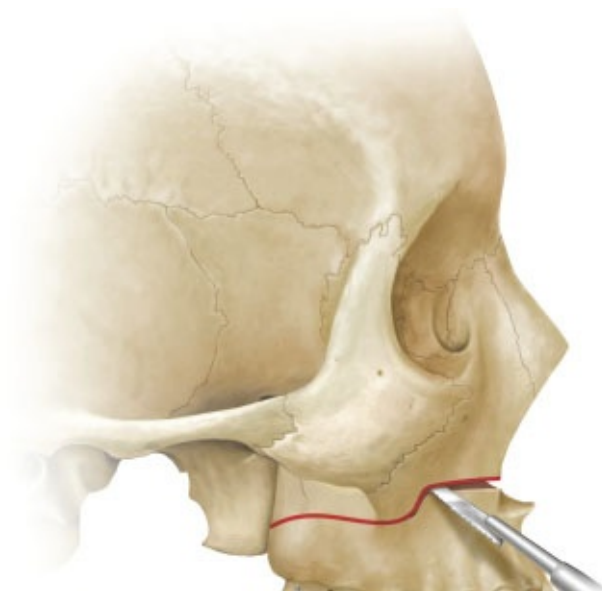
TECH FIG 2 • Le Fort II advancement and fixation. A. The completed osteotomy. **B.** Extraoral fixation is applied at the nasal bridge using an inverted L miniplate. Intraoral fixation is applied at the zygomatico-maxillary buttress. Bone grafts can be harvested from the calvarium if a coronal incision is used or an iliac crest bone graft when facial-only incisions are used. Allograft blocks are also an option. The purpose of the bone grafts is stability and avoiding relapse (*arrows*).

■ High Le Fort I With Nasal Augmentation

- This option is applied mostly in patients with Binder syndrome.
- A bilateral horizontal incision is made in the maxillary vestibule 2 to 3 mm above the attached mucosa, between the central incisor anteriorly and the first molars posteriorly.
- Expose the lateral maxilla from the central incisors toward the pterygomaxillary junction posteriorly.
- Separate the nasal mucosa from the lateral nasal wall using a periosteal or Freer elevator.
- A lateral horizontal maxillary osteotomy on the lateral maxilla is made using

a reciprocating saw; the osteotomy is made at least 5 mm above the apex of the teeth at the level of the nasal floor from the pterygoid plate posteriorly, making a high-step osteotomy in the area of the nasomaxillary buttress (**TECH FIG 3**).

- The pterygomaxillary fissure is osteotomized using a curved osteotome. Position the osteotome in an inferior and medial direction.
- The maxillary complex is mobilized with Rowe disimpaction forceps and advanced to the preplanned position.
- Intermaxillary fixation is applied according to the preplanned final occlusion using occlusal wafers if needed and dental wires.
- L mini plates are used at the zygomaticomaxillary buttresses and nasomaxillary buttress bilaterally.
 - Incisions for access may be through a coronal incision, a bilateral Lynch approach, or—in older patients—through a seagull approach (see **FIG 2**).
- The nasal bone is exposed and a pocket is created at the nasal tip.
- A costochondral bone graft or alloplast graft is fixated at the nasal bridge using an inverted T miniplates or double L miniplates.



TECH FIG 3 • High-step osteotomy in the nasomaxillary area.

PEARLS AND PITFALLS

Telecanthus	■ In large skeletal movements, place the medial nasal osteotomies anterior to the medial canthus to avoid telecanthus.
Nasal apparatus	■ When dividing the nasal septum, direct the osteotome slightly downward and backward toward the posterior nasal spine.
Nasolacrimal system	■ Avoid injury to the nasolacrimal system, especially to the lacrimal sac during the osteotomy; at the infraorbital rim, make the osteotomy as lateral as possible to avoid lacrimal system injury. Be aware of the infraorbital nerve position.
Nerve	■ The osteotome should be introduced medial to the infraorbital foramen in order to avoid nerve damage.
Bleeding	■ During osteotomy of the pterygoids, there is risk of iatrogenic rupture of the internal maxillary artery or pterygoid venous plexus. Position the osteotome correctly, in an inferior and medial direction to avoid injuring these vessels.
Deficient infraorbital region	■ Extend the osteotomy of the orbital floor more laterally as close as possible to the infraorbital foramen.
Scar	■ Paranasal incisions can be esthetically problematic. ■ Bicoronal incision may be considered as a better alternative in some cases.

POSTOPERATIVE CARE

- Intraoperative and postoperative intravenous steroids and antibiotics are given.
- Prophylactic antibiotic treatment is continued for 1 week. A short course of nasal decongestants is prescribed.
- Patient will be on a liquid diet for 4 weeks due to MMF.
- Once the patient has recovered, a CBCT, panorex and lateral cephalogram can be obtained.
- Skin suture removal should be performed at 2 weeks postoperatively.
- Dental wires should be removed at 4 weeks.

OUTCOMES

- Increased midface projection^{9,11}

- Class one dental occlusion—to avoid future relapse, the teeth of the upper jaw are placed in an overcorrected position creating a positive overjet; this is established by using prefabricated occlusal splints. Positioning of allograft/autogenous bone in the area of the nasofrontal gap may also minimize future relapse.

COMPLICATIONS

- Infection
- Postoperative bleeding can occur up to 3 weeks after surgery, due to injury of the greater palatine vessels or the pterygoid venous plexus.
- Loss of teeth near the osteotomy sites
- Telecanthus
- Loss of sensation in the infraorbital, supraorbital, and paranasal regions
- Damage to the lacrimal apparatus

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25 Le Fort II Advancement With Distraction Osteogenesis

CHAPTER

Eugenia K. Page, Colin M. Brady, and Joseph K. Williams

DEFINITION

- A Le Fort type II is a pyramidal fracture pattern that peaks at the nasofrontal suture and extends across the orbital floor and rim, underneath the zygoma, and then wraps around the pterygomaxillary fissure through the pterygoid plates. This was first described in 1901 by the French military surgeon Rene Le Fort.¹
- Variations of the Le Fort II osteotomy, including the anterior, pyramidal, and quadrangular types, have been utilized to advance the hypoplastic midface (**FIG 1**).
- The various osteotomy patterns can be utilized with distraction osteogenesis (DO) to achieve changes in the midface skeleton including nasal projection and maxillary advancement.

ANATOMY

- Identify the lacrimal system (ie, inferior lacrimal duct and sac) and the medial canthal attachment in the superior/posterior aspect of the medial orbit, located on the maxillary process of the frontal bone (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Nasomaxillary deficiency is commonly found in craniofacial syndromes such as Crouzon, Apert, and Pfeiffer syndromes but can also be due to craniosynostosis, hemifacial microsomia, Romberg disease, Binder syndrome, traumatic defects, and cleft and non-cleft-related nasomaxillary hypoplasia.^{2–5}



FIG 1 • Comparison of Le Fort II osteotomy patterns.
Blue, anterior; green, pyramidal; red, quadrangular.

- Presurgical assessment should include airway, speech, occlusion, mastication, and social/psychological consequences of the craniofacial deformity.
- Physical findings include maxillary hypoplasia with an associated class III molar relationship and varying degrees of recession of the nasal base as well as malar deficiency.⁶
- Exophthalmos is traditionally corrected with a Le Fort III advancement; however, successful repair has been reported using a Le Fort II osteotomy that includes the majority of the inferior orbital rim.⁷
- Nasomaxillary retrusion is the most common finding in patients who need a Le Fort II procedure in which a pyramidal Le Fort II pattern is used (TABLE 1).

IMAGING

- Cephalometric analysis of the facial skeleton may be used to characterize and quantitate the areas of deficiency.
- Overlay grids taken from age-matched norms of facial skeletons may highlight deficiencies and can be used to determine the amount of skeletal movement.
- Dental radiographs and orthodontic records are obtained for orthodontic preparation and timing of the procedure (mixed vs adult dentition).
- Computed tomography with three-dimensional (3D) reconstructions should be obtained.
 - Virtual surgical planning (VSP) uses CT images to improve accuracy of the osteotomies and decrease operative time. VSP is advantageous for planning vectors, advancement distances, manufacturing skull models and occlusal splints, molding distraction devices preoperatively, and avoiding potential periorbital asymmetries.^{8,9}
 - Skull models are constructed from the scans via either stereolithographs or 3D modeling for presurgical planning and device fitting in the operating room.
 - A polysomnogram may be needed to evaluate airway obstruction secondary to the midface retrusion.

SURGICAL MANAGEMENT

- In patients in whom the advancement required at the midface level is no more than 6 to 8 mm, mobilization of the mild hypoplastic midface can be performed with definitive advancement, bone grafting, and plate fixation.
- In syndromic patients, those with moderate to severe midface hypoplasia with significant negative overjet/class III malocclusal patterns, and adolescents still in active facial development, use of techniques for midface level DO is recommended.¹⁰

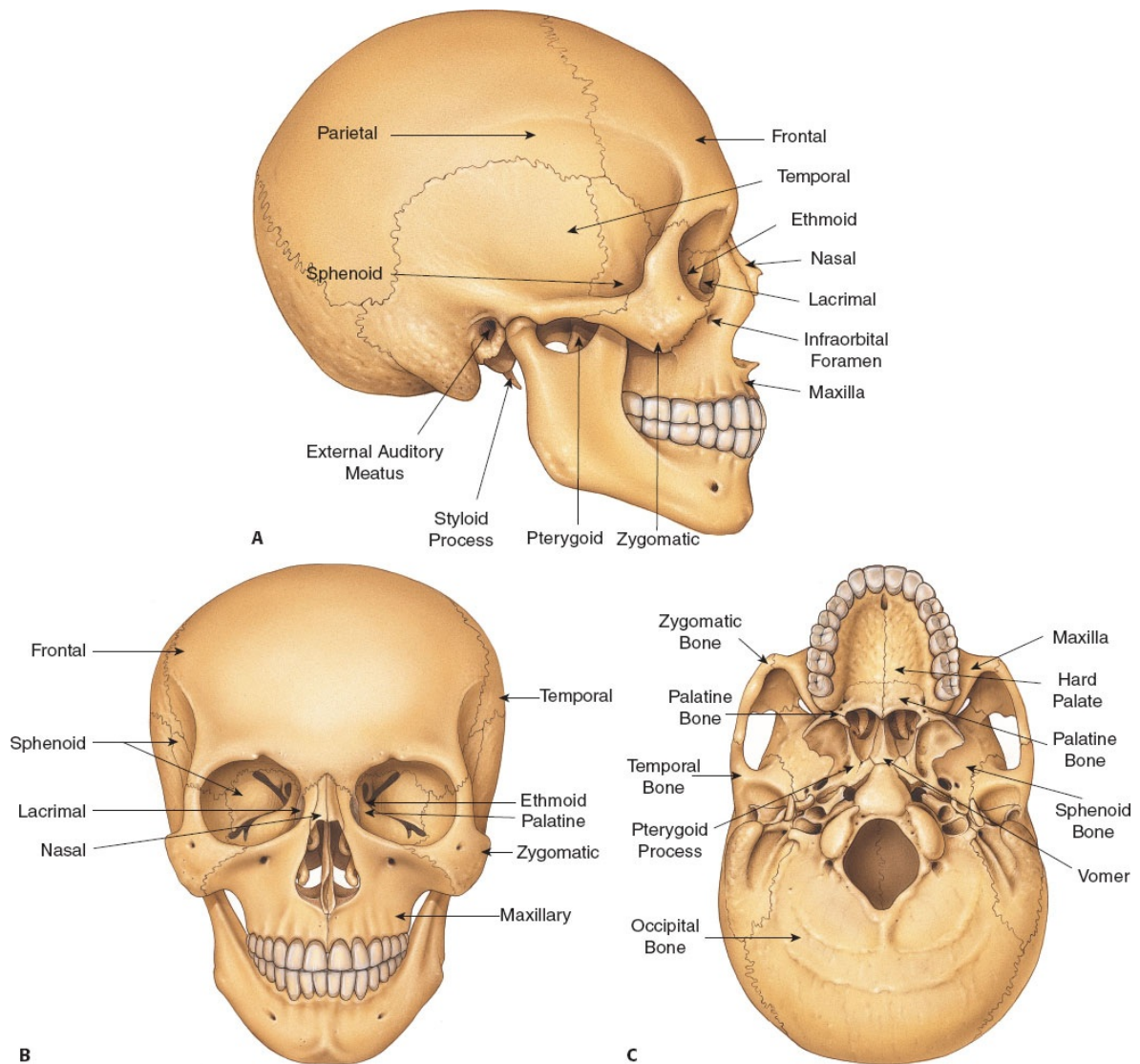


FIG 2 • Relevant skeletal anatomy. **A.** Sagittal view. **B.** Coronal view. **C.** Skull base view.

Table 1 Indications for Using Le Fort Osteotomies

Fort	Class 3 Malocclusion	Maxillary Hypoplasia	Nasal Projection (Short)	Inferior Orbital Rim (Retrusion)	Exorbitism	Malar Eminence (Retrusion)
I	*	Limited				
IIP	*	*	*			
IIQ	*	*		*	Limited	

IIC	*	*	*	*	*	*
III	*	*	*	*	*	*

IIP, Le Fort II pyramidal pattern; IIQ, Le Fort II quadrangular pattern; IIC, Le Fort II conversion from Le Fort III.

*Indications for level of Le Fort osteotomies and their capacity to address skeletal deficiencies.

Preoperative Planning

- Two commercially available external halo devices are available (External Midface Distractor, manufactured by Synthes, Oberdorf, Switzerland, and the Rigid External Distractor, manufactured by KLS Martin, Tuttlingen, Germany).
- The primary advantage of the external device is the ability to perform real-time modification of the vectors of force during distraction and its versatility for distraction at all Le Fort osteotomy patterns.
- Secondary benefits of the external device include the technical ease of device application and removal, as well as a decreased risk of unfavorable fracture patterns in areas of thin cortical bony stock during pin application.
- Disadvantages of the halo are patient noncompliance related to the psychosocial stigma of wearing the device, as well as frame- and hardware-related complications such as pin loosening and pin-site scarring.¹¹
- An internal maxillary device can also be used for both quadrangular and pyramidal patterns.
 - Despite improved compliance, these designs are criticized because they distract at a single pivot point, with an inability to adjust the vector of force during distraction.
 - The consequent vector may result in a clockwise rotation of the entire midface during distraction, leading to long midface and an uncorrected or undercorrected class III malocclusion with a posterior open bite.
- The potential for clockwise rotation of the midface during distraction at the Le Fort II level may be addressed by using temporary anchorage devices (TADs) or microimplants to hold interarch class III relationship elastics.
- Bollard plates or C-plates can be attached to the lateral buttresses bilaterally along with a single plate at the glenoid tubercle. Class III elastics can be applied to the associated hooks to aid control of the transport segment during distraction.

Approach

- Various access incisions can be used.
 - Upper buccal vestibular incision for degloving of the maxilla (**FIG 3A**)
 - Identify the inferior orbital nerve.
 - Coronal incisions are used for a superior approach to complete the nasal and medial orbital osteotomies (pyramidal technique and Le Fort II with zygoma fixation; **FIG 3B**).
 - The plane of dissection to the zygomatic arch is below the superficial layer of the deep temporal fascia at the level of the superior orbital rim.
 - The frontal branch of the facial nerve is located above the superficial layer of the deep temporal fascia.
 - Transconjunctival approach (quadrangular technique) is used to access the infraorbital rim and floor.
 - The incision is made several millimeters below the inferior border of the tarsal plate (**FIG 3C**).
 - Dissection is performed in the preseptal plane to the inferior orbital rim (**FIG 3D**).

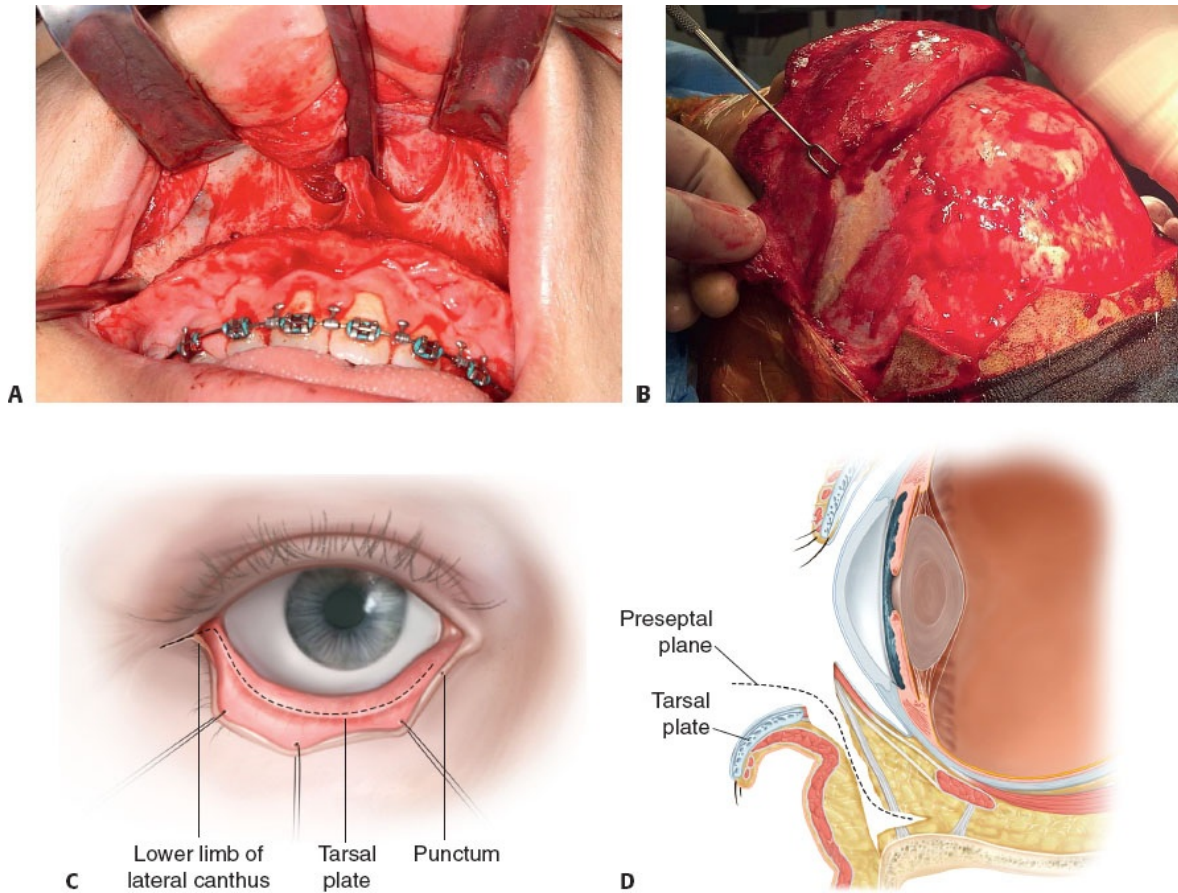


FIG 3 • Access incisions for Le Fort II level osteotomies. **A.** Maxillary vestibular incision. **B.** Bicoronal incision with deep temporal fat pad dissection. **C.** Transconjunctival approach with lateral canthal extension. **D.** Sagittal view demonstrating preseptal plane.

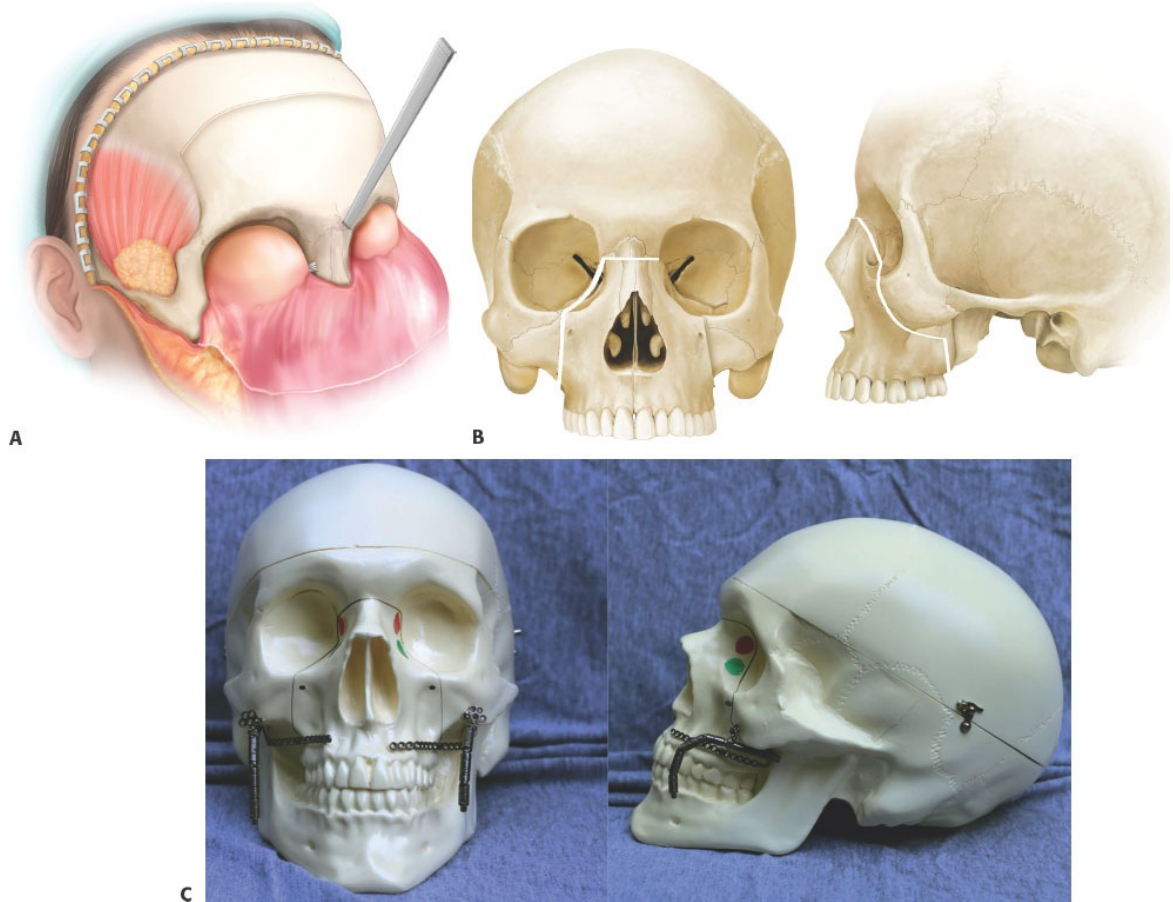
TECHNIQUES

■ Pyramidal Le Fort II Osteotomy

- Access is obtained through a coronal incision to access the nasofrontal junction and an intraoral vestibular incision to visualize the maxilla.
- Bony osteotomy proceeds transversely across the nasofrontal junction inferior to the anterior ethmoidal foramina with the use of a reciprocating

saw, an ultrasonic scalpel, or osteotomes (**TECH FIG 1A**).

- The osteotomy at the medial orbit is made posterior to the insertion of the medial canthus and the posterior lacrimal crest.
- The osteotomy is propagated posterior to the inferior orbital rim and across the orbital floor with the use of an osteotome or ultrasonic scalpel.
- The osteotomy is continued across the inferior orbital rim immediately lateral to the inferior orbital foramen.
- From the vestibule, the osteotomy is continued lateral to the inferior orbital foramen and then transversely at the Le Fort I level to the pterygomaxillary fissure staying cranial to the apical roots of the teeth (**TECH FIG 1B**).
- The pterygomaxillary disjunction is performed with a curved osteotome via the vestibular incision at the pterygomaxillary groove.
- Having dissected the nasal floor, Rowe disimpaction forceps are applied and the pyramidal Le Fort II complex is mobilized.
- An external halo device is applied with pin sites cranial and caudal along the medial buttress, with the addition (if needed) of another caudal pin along the lateral buttress above the apical roots.
- If an internal maxillary device is used, it is applied with footplates above and below the transverse osteotomy along the lateral buttress (**TECH FIG 1C**).
- Bollard plates, C-plates, or TADs can be applied intraorally, to allow placement of intermaxillary class III elastics to help prevent clockwise rotation of the midface during transport of the osteotomized segment.



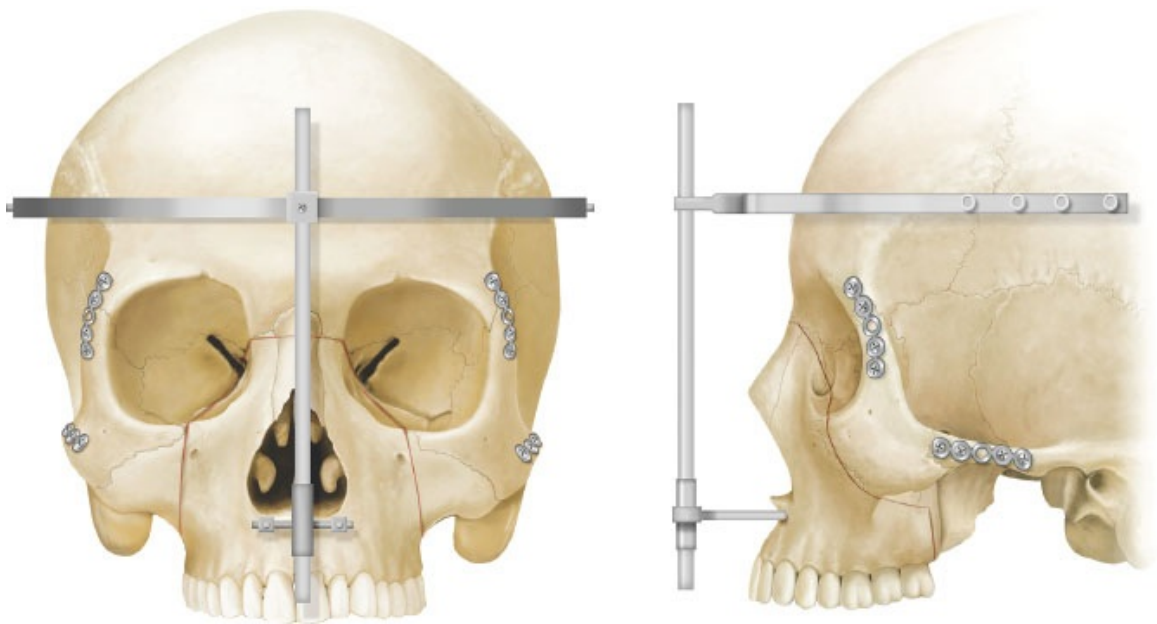
TECH FIG 1 • Le Fort II osteotomy: pyramidal pattern. **A.** Nasofrontal disjunction using an osteotome. **B.** Illustration of osteotomy pattern. **C.** Outline of osteotomy pattern with application of maxillary distraction device.

■ Le Fort II Distraction and Zygomatic Repositioning (Le Fort III Conversion to Le Fort II)

- In 2013, Hopper et al.¹² published an innovative approach to the unique central facial deformity encountered in Apert syndrome in which a Le Fort III osteotomy was performed and then modified by rigidly fixing the zygoma and placing the distraction device on the central midface.
 - The Le Fort II osteotomy pattern used most closely resembles the

pyramidal approach.

- Access incisions include a combined coronal, transconjunctival, and vestibular approach.
- A Le Fort III level osteotomy is performed, disimpacted, and advanced until the lateral orbital rims are level with the coronal corneal plane.
- Fixation of the posterior zygoma to the anterior aspect of the lateral orbital rim proceeds with 1.5-mm profile plates (**TECH FIG 2**).
- With the nasofrontal disjunction already performed as part of the Le Fort III osteotomies, the pyramidal Le Fort II pattern osteotomy proceeds through the inferior orbital rims and then caudally, lateral to the infraorbital foramen.
- An external halo device is applied with suspension wires attached to the piriform rim and inferior lateral maxillary buttresses.
- Distraction proceeds after a 3-day latency phase and is followed by 6 to 8 weeks of consolidation.



TECH FIG 2 • Le Fort II with zygomatic repositioning.

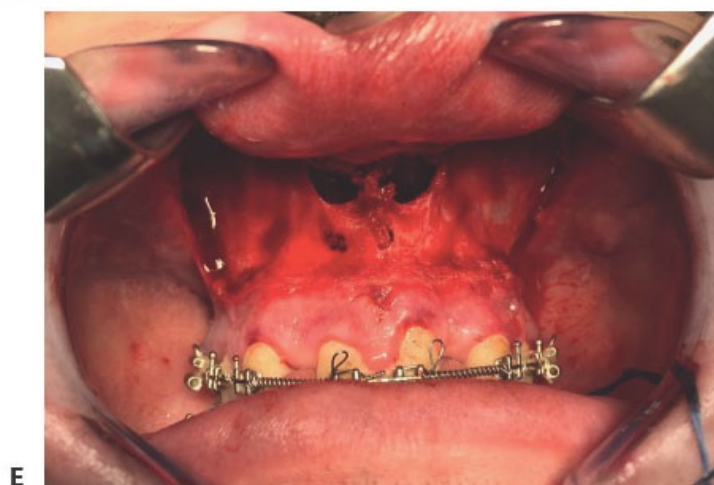
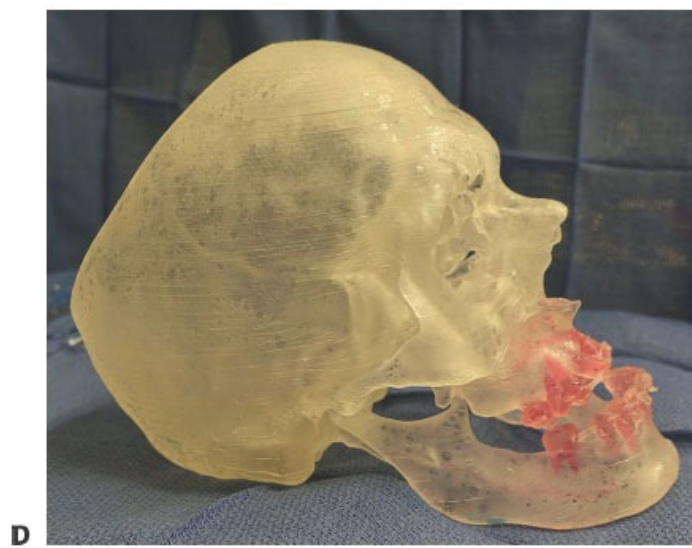
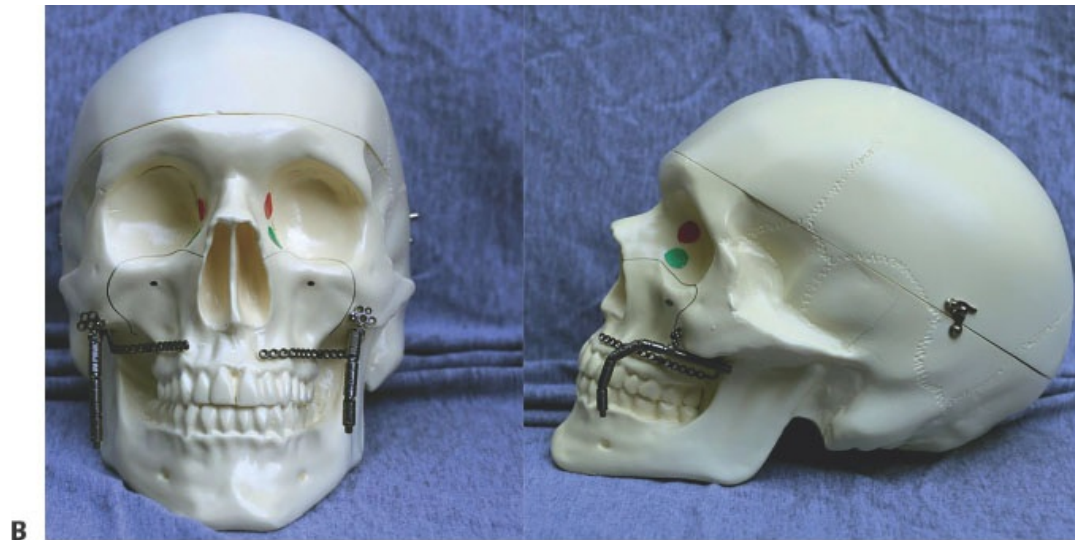
■ Quadrangular Osteotomy Le Fort II Level

Design and Exposure

- This pattern of osteotomy was first described by Kufner et al. in 1971¹³ (**TECH FIG 3A,B**).

- Use of this technique in the correction of midface hypoplasia can obviate the unfavorable “long-nose” deformity that inherently results from the Le Fort III advancement.
- As the nasofrontal junction does not need to be accessed for this osteotomy pattern, a coronal dissection can be avoided (**TECH FIG 3C,D**).
- Access to the relevant facial skeleton is obtained via a maxillary vestibular incision in addition to a transconjunctival approach with lateral canthal extension (**TECH FIG 3E**).





TECH FIG 3 • Le Fort II osteotomy: quadrangular

pattern. **A.** Illustration of osteotomy pattern. **B.** Outline of osteotomy pattern with application of maxillary distraction device. **C,D.** Intraoperative skull model representing a patient with a significant class III malocclusion and malar hypoplasia extending to the infraorbital rim. **E.** Intraoral buccal incision to expose the maxilla. The nasal floor is elevated and the septum has been separated from the vomer.

Maxillary Device Placement

- The maxillary device is prefitted onto the sterile skull model (**TECH FIG 4A,B**).
- The devices are placed onto the maxilla in situ. Two screws are used to secure the device, one screw on the malar area and the second on the lateral buttress (**TECH FIG 4C-E**).

Osteotomy and Completion

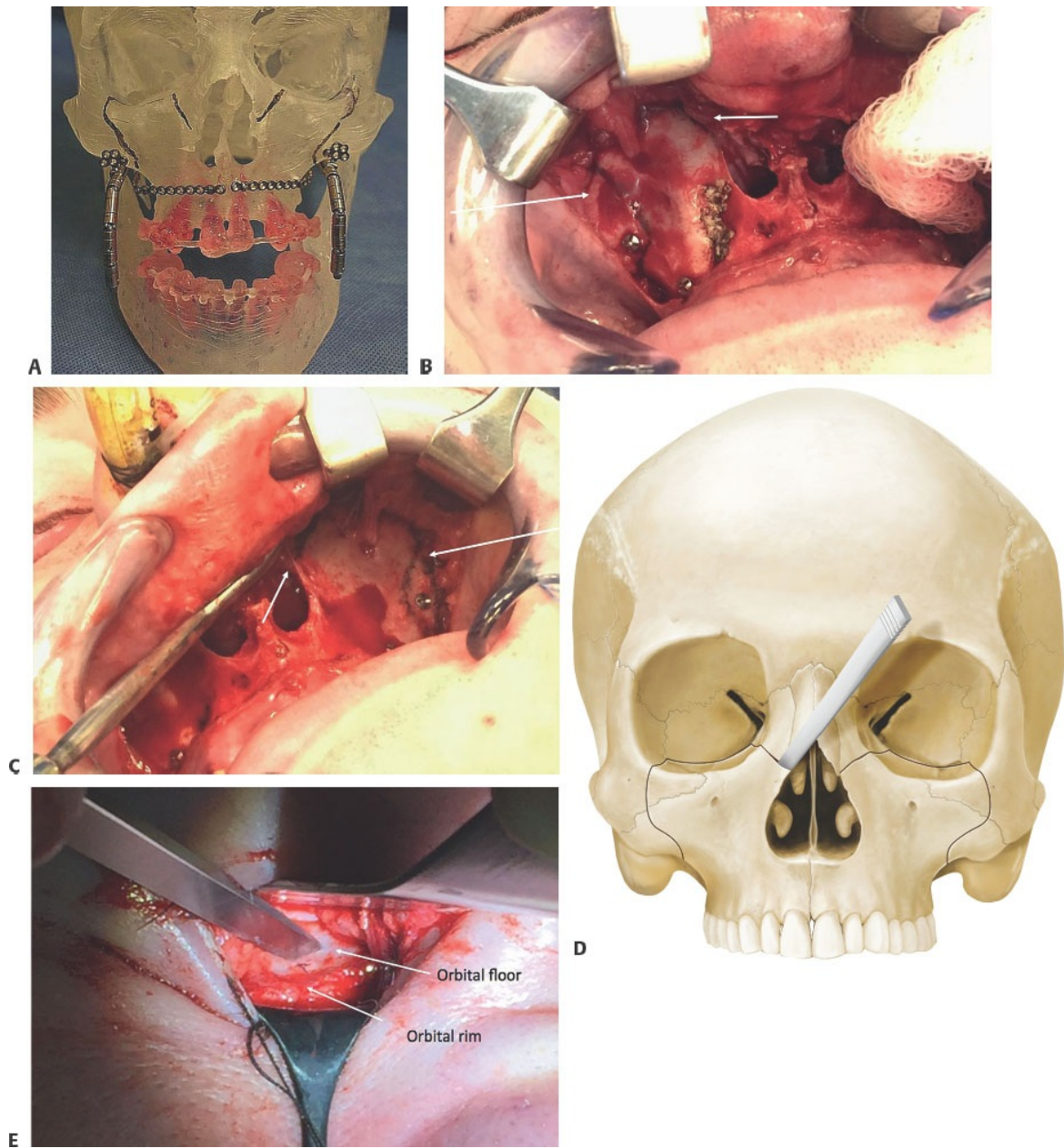
- Lines for the osteotomy are placed on the maxillae (**TECH FIG 5A-C**).
- The osteotomy begins medially via the transconjunctival incision from the medial aspect of the infraorbital rim through the frontal process of the maxilla into the cranial aspect of the piriform aperture bilaterally, allowing avoidance of the medial canthal tendon and lacrimal apparatus (**TECH FIG 5D**).



TECH FIG 4 • A,B. Prefitting the maxillary devices onto the skull model prior to placement in the patient. **C.** Placement of the marker screws in relation to the osteotomy sites. **D.** Initial in situ fitting of the distraction device prior to the osteotomies. **E.** The device has been removed and the marker screws have been placed. The screws allow the appropriate placement of the proposed osteotomy location in

relation to the devices. Screw placement also allows easy and accurate placement of the devices after completion of the osteotomies.

- The osteotomy continues via the lid incision with an osteotome or ultrasonic scalpel posterior to the infraorbital rim, extending medial to lateral, to the level of the lateral aspect of the infraorbital foramen (**TECH FIG 5E**).
- A lateral canthal extension of the transconjunctival incision allows the osteotomy to proceed through the lateral buttress in a number of vectors:
 - A high Le Fort I pattern down to the pterygomaxillary fissure
 - Through the zygomatic arch–zygoma junction
 - Through the caudal 5 mm of the lateral orbital wall in patients with more significant lateral malar hypoplasia
- The pterygomaxillary disjunction proceeds via the vestibular incision.
- Elevation of the nasal floor along the piriform aperture facilitates placement of the Rowe disimpaction forceps to allow a controlled mobilization of the midface segment.
- Two options exist for distraction:
 - An external halo device can be applied with pin sites along the medial and lateral buttresses above the apical roots.
 - An internal maxillary distractor can be applied with footplates above and below the transverse or oblique osteotomy along the lateral buttress.
- Control of the midface pitch during distraction is achieved with Bollard plates, C-plates, or TADs attached to intermaxillary class III elastics to help prevent clockwise rotation during transport.



TECH FIG 5 • **A.** Outline of the quadrangular osteotomy on the maxilla on the intraoperative skull model. **B.** After the marker screws have been placed, the lines for the osteotomy are placed on the right maxilla. **C.** Lines for the osteotomy are then placed on the left maxilla. The osteotomy is outlined medial to the marker screw on the malar eminence and must capture some of the malar eminence before extending

onto the lateral buttress. **D.** Illustration of the medial and lateral osteotomies of the maxilla extending to the infraorbital rim. **E.** Osteotomy across the orbital floor with an osteotome using the transconjunctival incision.

PEARLS AND PITFALLS

General

- Distraction procedures do not require intraoperative occlusal fixation or postoperative maxillary mandibular wire closure. Therefore, oral intubation is appropriate for these procedures.
- An oral RAE tube can be placed and is easily positioned away from the operative field. If prolonged intubation is anticipated, a regular endotracheal tube provides better access for suction in the ICU and is preferred.
- If Le Fort II distraction with an internal maxillary device is planned for a patient with a cleft and midface deficiency, a quad-helix orthodontic expansion device is placed prior to the procedure. The device is not used for expansion but provides a more rigid appliance during late distraction, when vector forces tend to be directed to the midline.
- A 2.0-mm bridging plate is placed across the alveolar cleft, even with adequate bone stock in the cleft, to stabilize the site and prevent uncoordinated movements of the maxillary segments.

Osteotomies

- Marking the medial canthal periosteal insertions with gentian violet or methylene blue prevents overdissection of soft tissues at the nasofrontal bridge and midline structures that can result in difficult-to-correct deformities.
- Mobilization of the Le Fort II transport segment, irrespective of osteotomy pattern chosen, should proceed via a two-operator approach.
- Capture an adequate amount of the malar eminence with the lateral osteotomy to provide stability of the infraorbital component of the quadrangular Le Fort II segment and avoid unfavorable fractures through the antrum.
- One operator should perform controlled movements with Rowe disimpaction forceps, while gradual mobilization of the segment is

performed by the second surgeon to mitigate unfavorable fracture patterns.

Distractors for Le Fort II osteotomy

- The use of the skull model with Le Fort II osteotomies is imperative; an ill-placed osteotomy may compromise the placement of the internal maxillary distraction device.
- Outlining the location of the osteotomies and temporarily placing the internal devices on the skull model avoids an inadequate bone platform for the zygomatic footplate.
- Placement of internal maxillary devices following completion of the osteotomies and disimpaction of the central midface is facilitated by placing a landmark screw on both the zygomatic footplate and the inferior maxillary plate of the device at the initial fitting in situ and prior to completion of osteotomies.
- The screws are removed and returned to the original holes after removal of the device.
- These screws are maintained during the bone cuts and then removed and reinserted into the original screw hole after the device is replaced appropriately (see **TECH FIG 3C,D**).
- If internal distraction techniques are used, Bollard plates, C-plates, or TADs attached to class III intermaxillary elastics prevent rotation of the midface during transport.

POSTOPERATIVE CARE

- Airway ICU management
 - Patients are transferred from the OR to the ICU. Extubation is possible in most patients. Excessive bleeding, concerns about airway, or prolonged operative time may warrant continued intubation.
 - IV steroids are given postoperatively for 48 hours to mitigate peak soft tissue and airway edema.
 - Perioperative antibiotics are given to cover oral and sinus flora for 7 days postoperatively.
 - Head of bed is elevated to more than 30 degrees.
 - Pain and anxiolytic management should be employed via continuous drips or administered as needed, and tailored to the patient's convalescence.
 - In patients with significant syndromic midface dysmorphism, severe preoperative obstructive sleep apnea, or submental intubations, extubation in the OR with easy access to anesthesia staff and advanced airway adjuncts should be considered.

■ Distraction

- We recommend a latency period of 5 days.
- Distraction is instituted on the morning of POD 5 at 0.5 mm twice daily (1 mm/d).
- Family members are instructed on how to perform rotation of the activating arms.
- The active phase of distraction averages 10 to 20 days (10 to 20 mm).
- If preoperative asymmetries exist, differential advancements of the activating arms may be required to achieve optimal facial harmony.
- Regular follow-up with clear communication from family via pictures can guide the distraction interval.
- Unlike advancement, the goal of distraction is not ideal occlusion, but midface harmony in profile. Occlusion is formalized via either postoperative orthodontic treatment or formal orthognathic surgery.
- Following completion of distraction, the activating arms can generally be removed in clinic.
- We recommend a consolidation phase of 3 months prior to device removal.
- If an internal Le Fort I level device is utilized for the Le Fort II distraction, the device can be removed with a vestibular incision.
- If Bollard plates, C-plates, or TADs have been used, they are removed simultaneously.
- Lateral canthopexies or lid-tightening procedures can be employed at this stage to complete reconstruction.
- If vertical orbital dystopia has resulted from the advancement, bone grafting (eg, split calvarium) of the orbital floor can be performed to achieve symmetry.
- Patients with severe obstructive sleep apnea should have a postoperative sleep study to assess breathing improvement; continuous positive airway pressure, or supplemental oxygen may no longer be required.

OUTCOMES

- Midface distraction distances ranged from 8 to 21 mm.
- Skeletal relapse is a significant concern, but long-term data are scant. Swennen et al.¹⁴ reviewed 285 articles on DO between 1966 and 1999, which included mandibular, maxillary, midface, and craniofacial distraction.
- Of the 96 patients identified who underwent midface or cranial distraction, only 19 patients had data on relapse.

- Of these 19 patients, only 2 (10.5%) demonstrated mild relapse.
- Much of the historical data suggest that unacceptably high rates of relapse after midface advancement were secondary to:
 - Underappreciation of the contradictory force vectors of the midface soft tissue envelope
 - Formal advancements of more than 10 mm prior to the advent of DO
 - Underuse or nonutility of at least 8 weeks of postoperative intermaxillary fixation with occlusal splints
 - Poor cortical bony stock for plate fixation in certain osteotomy patterns
- Relapse rates have been mitigated due to adherence of several principles:
 - Current use of internal and external DO techniques that allow for interval histogenesis of the midface soft tissue envelope
 - Guidance of the midface transport segment via halo device, intraoral Bollard plates, C-plates, or TADs
 - Adherence to 8 or more weeks of IMF in cases of formal advancement

COMPLICATIONS

- Infection
- Bleeding
- Bony malunion
- Nonunion
- Premature consolidation
- Skeletal instability
- Relapse
- Device failure
- Development of velopharyngeal incompetence
- Injury to the infraorbital nerve
- Partial or complete avulsion of the medial canthal tendon
- Injury to the nasolacrimal system

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CHAPTER Le Fort III Advancement

Ghassan S. Abu-Sittah and Rawad S. Chalhoub

DEFINITION

- Le Fort III, first described by Rene Le Fort in 1901, is a pattern of craniofacial fractures that involves the nasofrontal suture, traverses the orbital floor, and crosses the zygomaticofrontal suture and zygomatic arch (**FIG 1**).¹
- In the 1960s and 1970s, Gillies and Tessier applied Le Fort's classification to facial osteotomies for the treatment of patients with midface hypoplasia.
- Le Fort III osteotomy with advancement, also known as craniofacial disjunction, is currently used for the correction of functional and aesthetic problems in patients with craniofacial dysostosis syndromes such as Crouzon, Apert, or Pfeiffer syndromes.
 - These conditions usually present with midfacial retrusion, shallow orbits, exorbitism, malocclusion, obstructive sleep apnea, and facial imbalance (**FIG 2**).
- Le Fort III advancement restores normal midface projection, re-establishes normal dental occlusion, increases the vertical dimensions of the face, and corrects exorbitism.

ANATOMY

- Normal facial growth depends on the coordinated expansion of the brain and overlying skeletal elements.
- The skull is relatively well developed at birth to protect the brain, whereas the facial skeleton continues to grow during childhood to accommodate dental development, orbital modeling, and airway formation.

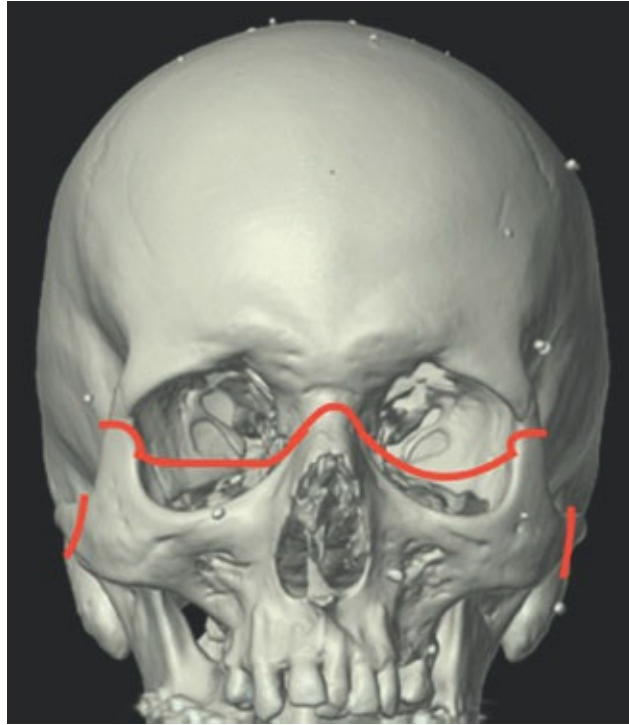


FIG 1 • Pattern of Le Fort III fracture pattern.

- Cranial dysostosis describes syndromic craniosynostoses in which suture involvement includes the cranial vault, cranial base, and midface skeletal structures.
- Midface skeletal hypoplasia leads to both functional and cosmetic problems.
- Le Fort III advancement is generally required in these patients.

PATHOGENESIS

- Mutations of FGFR genes 1 to 3 lead to syndromic craniosynostoses, including Apert, Pfeiffer, Crouzon, Beare-Stevenson, Jackson-Weiss, Crouzon with acanthosis nigricans, and Muenke syndromes.²
- Environmental causes include paternal occupation, maternal age, exposure to tobacco smoke, and medications during pregnancy, including nitrofurantoin and warfarin.³

NATURAL HISTORY

- Craniosynostosis occurs in an estimated 1 out of every 2000 live births; it can occur as an isolated condition or part of a syndrome.
- Syndromic craniosynostosis affects 1:30 000 to 1:100 000 live births.⁴
- The midface hypoplasia in these conditions is progressive, becoming more

noticeable as the patient grows.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Craniofacial dysostosis patients suffer from a series of sequelae from growth abnormalities.
- Increased intracranial pressure (ICP) can occur as a result of the rapidly growing brain during infancy with limited space for expansion.
- Untreated ICP can cause papilledema and optic nerve atrophy, which can eventually lead to blindness.
- Vision problems may also occur secondary to exorbitism (exophthalmos) leading to corneal exposure with ulceration.³
- Dental, occlusal, and hearing deficits are higher in patients with craniofacial dysostosis than in the general population.²
- The most severe consequence of midface deficiency is obstruction of the developing airway, with narrowing of nasal and nasopharyngeal spaces, leading to increased airway resistance.⁵
- Newborns are obligate nasal breathers; airway obstruction forces them to breathe through the mouth, resulting in an inability to feed and breathe simultaneously. These newborns are at high risk for malnutrition and failure to thrive.



FIG 2 • A. Exorbitism secondary to shallow orbits. **B,C.** Lateral views of a patient with Apert syndrome. Midfacial retrusion and shallow posterior fossa are evident.

- Patients with severe symptoms, generally obstructive sleep apnea or exorbitism, may require a combination Le Fort III advancement with cranial advancement. Monobloc advancement is preferentially performed as a distraction procedure.⁶
- Patients who are mildly affected undergo Le Fort III advancement at skeletal maturity.

IMAGING

- Preoperative imaging required for patients undergoing Le Fort III advancement includes
 - Anteroposterior and lateral x-rays
 - Panoramic x-rays
 - Two-dimensional (2D) and three-dimensional (3D) CT scans (**FIG 3**)
- These images will demonstrate midface hypoplasia, as well as the various anomalies associated with the cranial sutures.
- CT scans are the preferred imaging modality and can be used with computer-aided design and modeling for preoperative planning to optimized the surgical approach.⁷

SURGICAL MANAGEMENT

- In planning and timing of the Le Fort III advancement in patients with craniofacial dysostosis, the experienced surgeon should take several factors into account.

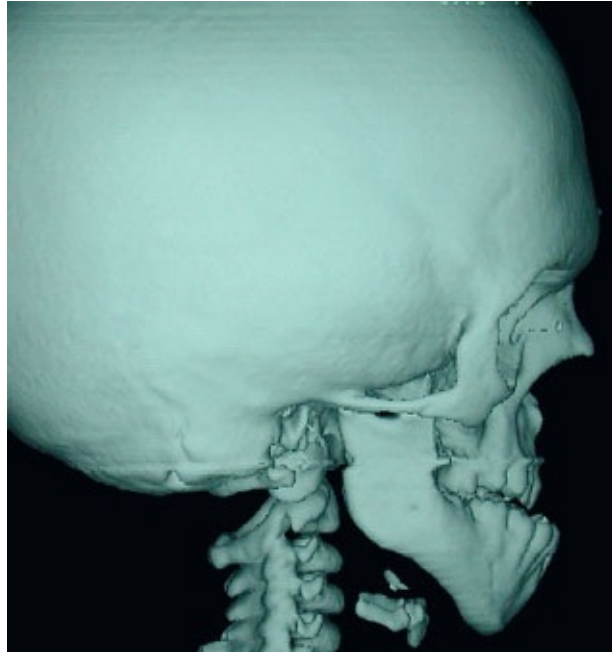


FIG 3 • 3D CT reconstruction of a patient with midfacial hypoplasia and malocclusion.

- Age at presentation, the presence of functional problems such as upper airway obstruction, the presence of elevated ICP, and the tendency of growth restriction in facial bones undergoing surgical manipulation
- The main steps of the Le Fort III procedure include
 - Osteotomies using a Le Fort III design through the frontozygomatic suture, floor of the orbit, and the nasion
 - Mobilizing the Le Fort III segment
 - Internal fixation to zygomatic arch
- The objective of the procedure is to address functional problems (breathing, feeding, ocular), advance and normalize the occlusion, and improve facial aesthetics.⁵

Preoperative Planning

- Preoperative imaging helps planning for the surgery, such as using CT scans with computer-aided design and modeling to create stereolithographic models for optimization of osteotomies and designing patient-specific implants for perfect bony match.
- Communicate openly and effectively with parents regarding expectations before, during, and after the surgery.

- A multidisciplinary team approach, with pediatric intensivists, pediatric anesthesia, and orthodontics should be assembled to perform the surgery.
- Cross-matched blood should be available in the operating room.
- Appropriate plating systems must be available.
- Appropriate surgical instruments must be available.

Positioning

- Patients are positioned supine with hands by their sides.
- A single IV is started.
- Orotracheal intubation is utilized, but nasal intubation may be necessary in certain conditions.
- A Foley catheter is placed to assess fluid status.
- A warming blanket is used for temperature regulation.
- Eyes are protected with moisturizing ointment and sterile plastic adhesives placed over the cornea after the skin has been prepped.³
- Preoperative antibiotics and steroids are administered.
- Tranexamic acid should be administered, because of evidence that it effectively reduces perioperative blood loss.⁸

Approach

- Approach is through a coronal incision.

TECHNIQUES

■ Exposure

- A coronal incision is marked on the scalp behind the hairline and injected with 0.5% lidocaine with epinephrine 1:200 000 based on pediatric weight guidelines (**TECH FIG 1A**).
- Exposure is obtained of the frontotemporal skull, lateral and medial orbits, nasion, zygomatic arch, and zygomatic body (**TECH FIG 1B**).⁵
- Dissection in the subgaleal plane is deepened subperiosteally about 1 cm above the orbits to preserve the supraorbital and supratrochlear nerves.
- To provide adequate visualization of the inferior orbital margin along with the lateral orbital wall and orbital floor, a subciliary incision is preferred.

Special care should be taken to protect the cornea from abrasions.

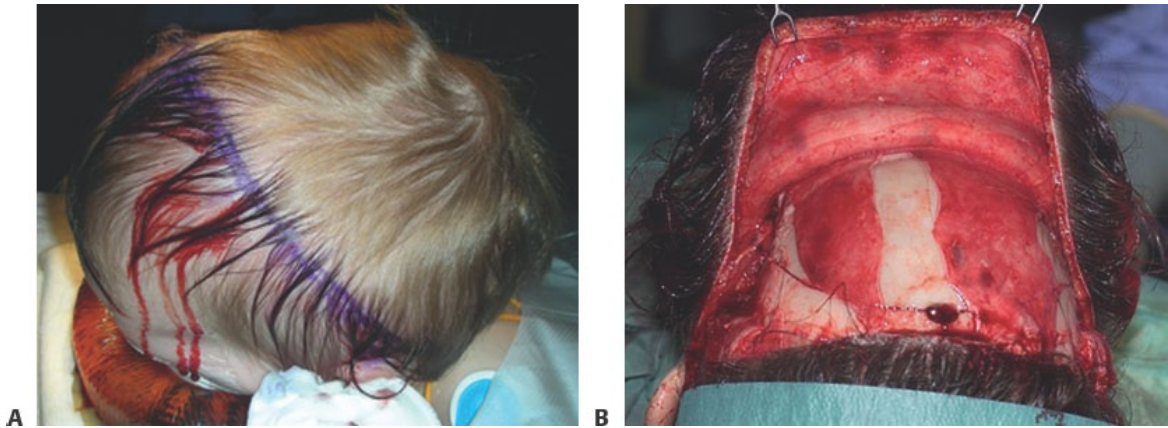
- An upper buccal sulcus incision provides access to the infraorbital region, maxilla, malar body, and anterior aspect of the malar arch. It is important to leave a cuff of mucosa on the alveolar aspect for easy closure of the incision.

Osteotomies and Advancement

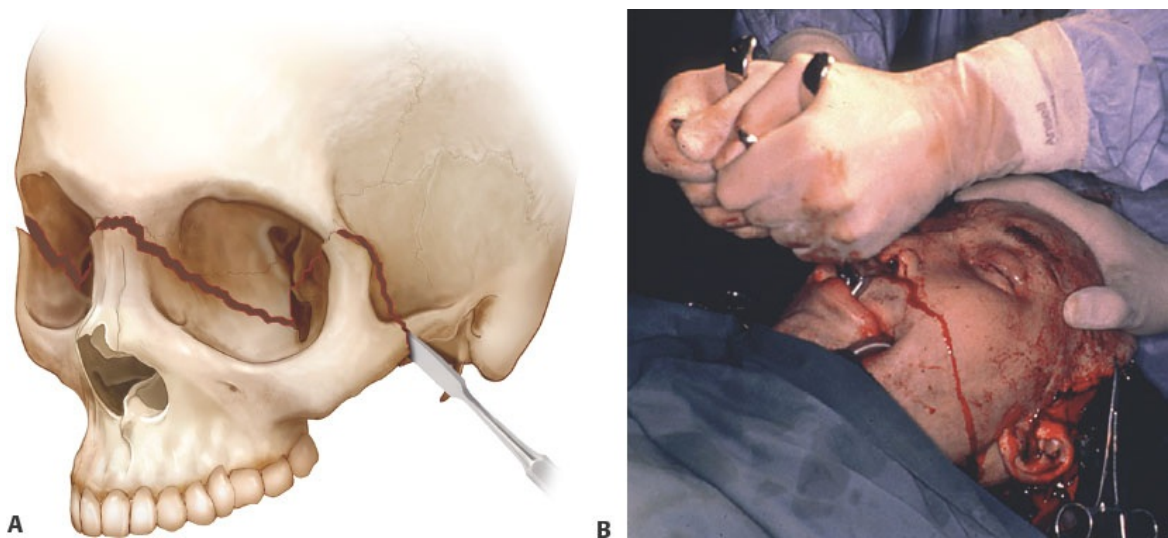
- Osteotomies are performed using the reciprocating saw through the zygomatic arch, followed by the lateral, inferior, and medial orbital walls.
- These cuts are then extended to the anterior region of the inferior orbital fissure and across the orbital floor.
- We complete the osteotomy by separating the medial orbital wall posterior to the nasolacrimal duct. The medial canthal tendon is left intact during this maneuver.
- Pterygomaxillary disjunction via sectioning the maxillary tuberosity from the pterygoid plates from above. Special care should be taken because in several craniosynostotic syndromes a dense bony block exists (**TECH FIG 2A**).
- A broad osteotome is used to cut the nasal septum.
- After performing the osteotomies, the facial skeleton is freely mobile and can be placed to its desired position using the Rowe forceps (**TECH FIG 2B**).
- The surgeon must be cautious during the mobilization of the Le Fort III as this step carries high morbidity in blood loss.

Fixation and Completion

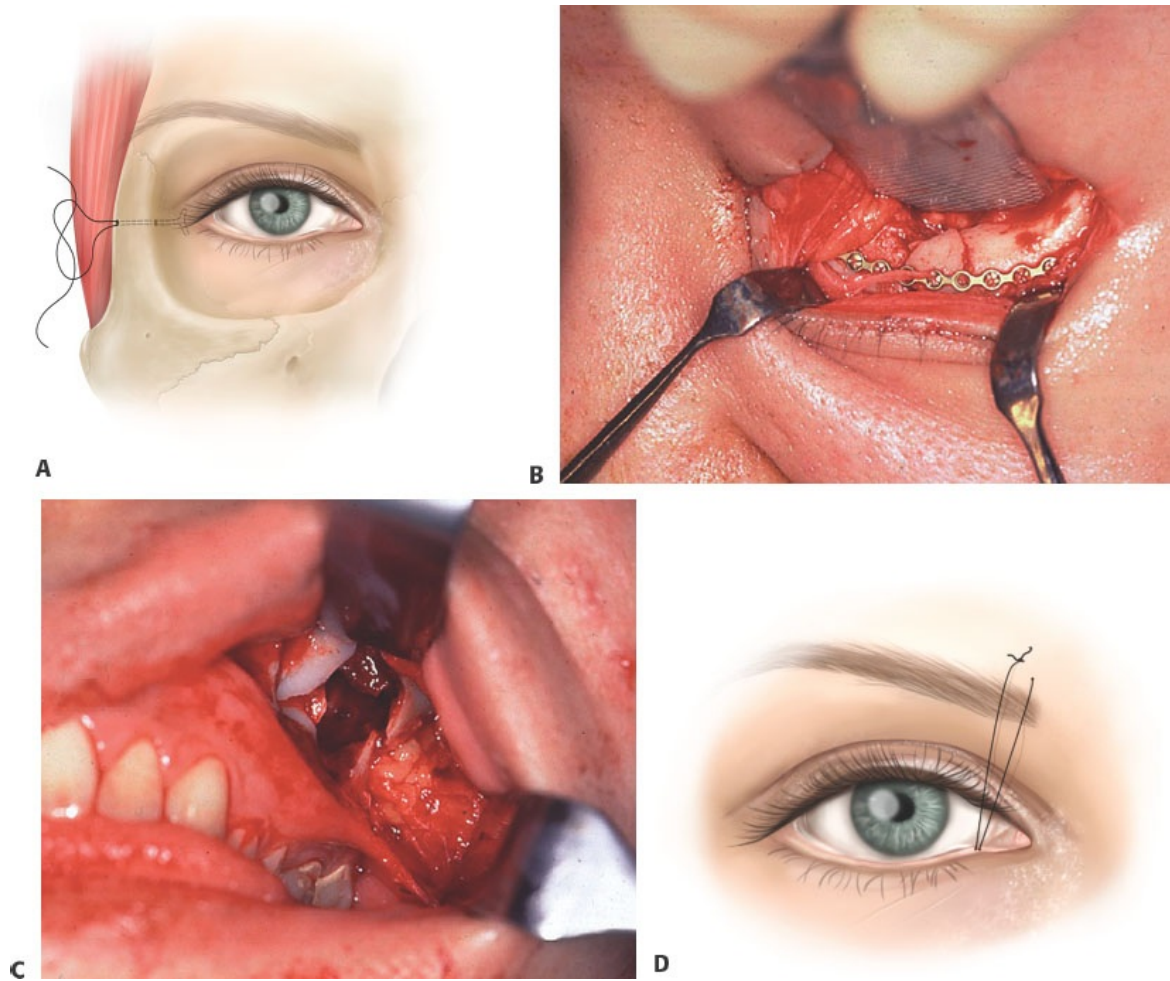
- Intermaxillary fixation is applied with an acrylic wafer to hold this segment in place until bone grafts are set in place.
- Bone grafts are harvested from either the calvarium or the ileum and designed to fit in the space created by the advancement at the zygomatic arches, lateral orbital wall, orbital floor, and nose.
- Bone grafts are secured in the desired position with titanium plates and screws.
- IMF is released and the soft tissue is released and resuspended with lateral canthopexies (**TECH FIG 3A**).
- A Jackson-Pratt drain is placed.



TECH FIG 1 • A. Coronal incision marked on the scalp. **B.** Exposure of the calvarium and facial skeleton.



TECH FIG 2 • A. Pterygomaxillary disjunction. **B.** Mobilization of the midfacial skeleton using the Rowe forceps.



TECH FIG 3 • A. Lateral canthopexy. The subciliary **(B)** and superior buccal sulcus **(C)** incisions. **D.** Frost suture.

- The coronal flap is closed in layers.
- Buccal sulcus and subciliary incisions are closed in layers, with meticulous care in closing the periosteum when using the subciliary incision (**TECH FIG 3B,C**).
- A nasopharyngeal airway is placed as well as a nasogastric tube for postoperative feeding.
- With the expected periorbital edema following such a procedure, Frost sutures are placed to prevent ectropion and corneal damage that would result from the edema (**TECH FIG 3D**).

PEARLS AND PITFALLS

Physical findings

- Midfacial hypoplasia can be accompanied by severe symptoms such as obstructive sleep apnea, increased ICP, and exorbitism.

Technique

- The craniofacial surgeon makes use of the naturally occurring weaknesses along suture lines to separate the facial bones into subunits.
- Infiltrating the facial soft tissues with a tumescent solution containing Harmtan, Xylocaine, Hyalase, adrenaline, triamcinolone, and Marcaine can significantly reduce postoperative swelling.
- A posterior flap may also be raised when additional exposure of the calvarium is needed.
- Protection of the brain, meninges, and venous sinuses is crucial in all craniofacial operations. Dural lacerations should be meticulously repaired in order to prevent postoperative CSF leaks.
- To prevent migration of the plates and screws as a result of bone growth, dissolving plates and screws made of polylactic acid polymers should be used.

Postoperative

- Hypovolemia is the most common problem after Le Fort III advancement. Signs include tachycardia, delayed capillary refill (less than 2 s), cool peripheries, and hypotension. Treat hypovolemia by giving an immediate fluid bolus of 10 mL/kg.
- Patients with a history of feeding difficulties and borderline swallowing status presurgery must be closely monitored postsurgery for potential feeding difficulties.
- All contact sports should be avoided for at least 3 months.



FIG 4 • Before (**A**) and after (**B**) photos of a patient with midfacial hypoplasia who underwent a Le Fort III advancement.

POSTOPERATIVE CARE

- Postoperative oral feeding is limited to water for the first week with liquid feeding via the nasogastric tube until the nasopharyngeal airway is removed.
- A soft diet is introduced and continued for the next 3 months while consolidation of the osteotomies is taking place. Follow-up CT scans are done 12 to 18 months postoperatively unless the patient has neurologic deterioration. For postoperative hematomas or hydrocephalus, an MRI is preferred over the risks of the ionizing radiation from CT scans.

OUTCOMES

- Le Fort III advancement achieves midface advancement anywhere between 8 and 12 mm⁹ (**FIG 4**).
- Adequate fixation of the osteotomies decreases the relapse rates of the advancement.^{9,10}
- Pseudorelapse is observed when the rate of mandibular growth is greater than that of the maxilla. This can be managed with a subsequent Le Fort I after skeletal maturity.¹⁰

COMPLICATIONS

- Nerve injuries, including transection of the infraorbital nerve
- Ptosis secondary to facial nerve injury
- Partial anosmia
- Strabismus⁵
- Respiratory distress necessitating tracheostomy
- Infection of hardware
- Cerebrospinal fluid leakage with fistula formation
- Visual loss due to nerve compression from a retro-orbital hematoma

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27 Le Fort III Osteotomy With External Distraction

CHAPTER

Gökhan Tunçbilek

DEFINITION

- The Le Fort III osteotomy corrects midface retrusion for patients with syndromic craniosynostosis and after the sequelae of Le Fort III fractures.
- Gillies performed the first Le Fort III advancement in a patient with Crouzon syndrome.¹
 - Tessier refined the technique using Le Fort III fracture lines as a guide for osteotomies (**FIG 1A–E**).²
- The first attempts of combining the Le Fort III procedure with distraction osteogenesis were in the mid-1990s and have become an effective, reliable technique for managing patients with midface hypoplasia.^{3,4}
- Midface retrusion may cause significant functional, morphological, and psychological impairment in patients with syndromic craniosynostosis.
 - All the parts of the face and forehead are affected, leading to breathing difficulties and ocular and occlusal problems, all of which impair the life of the patient.
 - Anterior movement of the facial skeleton addresses all of these problems.
- Combining Le Fort III osteotomies with gradual distraction overcomes soft tissue resistance and produces skeletal corrections greater than 10 mm, which is the upper limit for conventional osteotomies with rigid fixation alone.⁵

ANATOMY

- The midface consists of a maxilla-ethmoidonasal complex located between the two zygomas. This complex is suspended from the middle portion of the frontal bone anteriorly and the anterior cranial fossa posteriorly. The midface region is bounded above by a transverse line connecting the zygomaticofrontal sutures,

passes through the frontomaxillary and frontonasal sutures, and is defined inferiorly by the occlusal plane of the maxillary teeth. Posteriorly the region is limited by the sphenoethmoidal junction and includes the free margins of the pterygoid plates inferiorly.

- The skull and the facial skeleton have a fixed relationship. The facial skeleton is connected to the pterygoid process through the intermediate palatine bones and to the body of the sphenoid through the septonasal strut.
- It is fixed laterally by the zygomatic arch and suspended from the frontal bone by the processes of the zygomatic bones and of the maxilla (**FIG 2**).
- The facial region is subject to the vertical strains of mastication and therefore arranges its osseous trabeculae vertically and horizontally in areas of strength (*pillars*), which are separated by zones of weakness.
- The facial complex is weakened by the presence of two kinds of cavities—air cavities (sinuses) and receptor cavities (orbits)—and sutures.
- The sinuses are accessories to the nasal fossa, whose extent determines the degree of facial skeletal pneumatization; the receptor *orbits* house the peripheral receptors of vision.

PATHOGENESIS

- Midface retrusion is a major finding of syndromic craniosynostosis, caused primarily by autosomal-dominant FGFR mutations and MSX2 and TWIST 1 mutations.
- Most infants born with syndromic craniosynostosis present with bilateral coronal suture synostosis and a variable degree of midface retrusion.

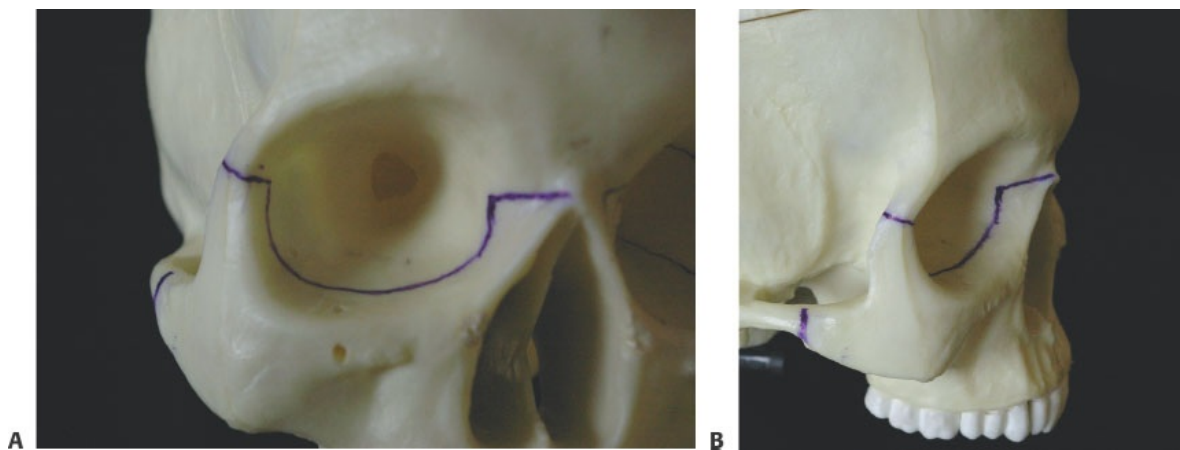
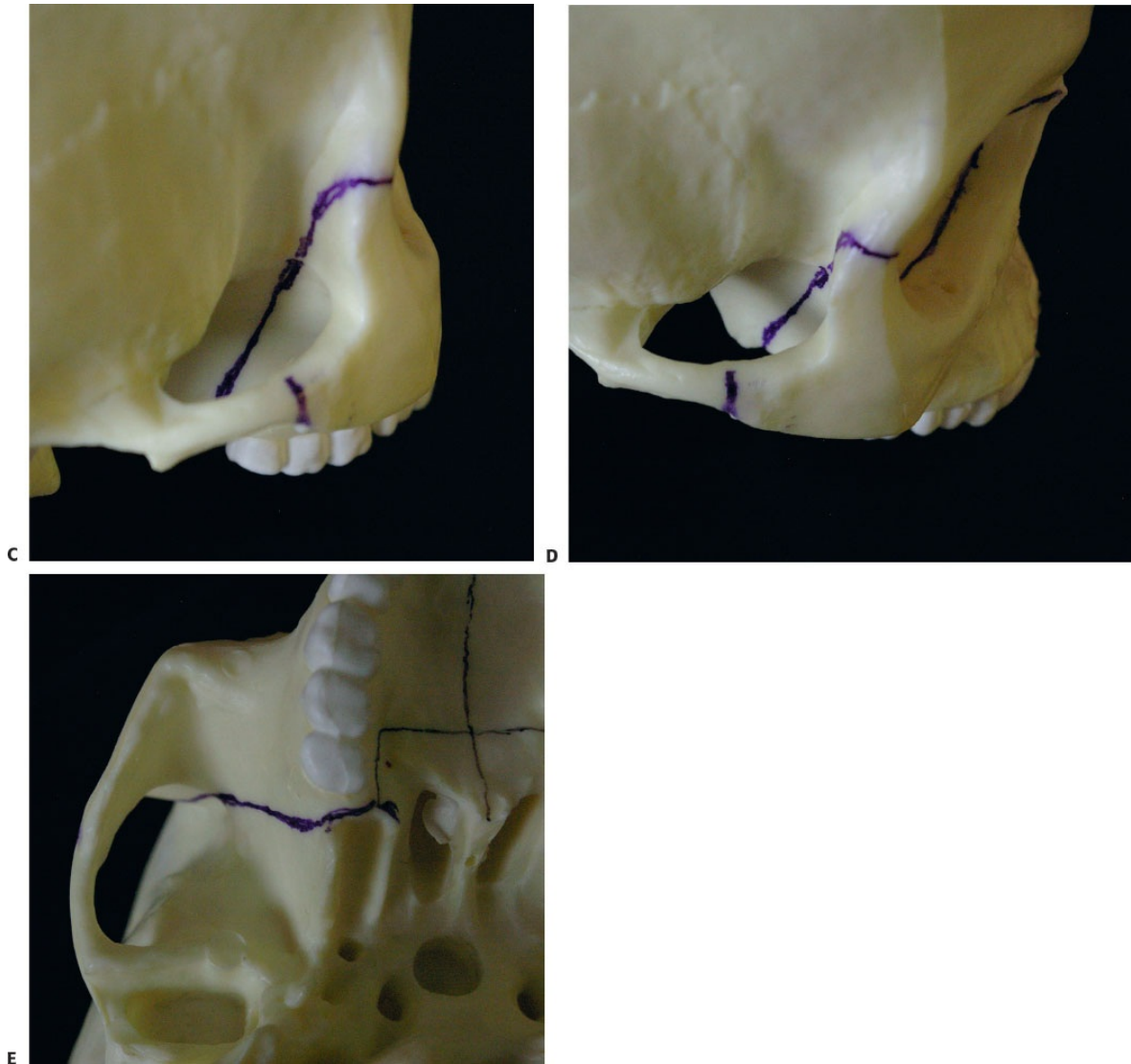


FIG 1 • A–E. Osteotomy lines of traditional Le Fort III

osteotomy.



PATIENT HISTORY AND PHYSICAL FINDINGS

- A family history or a resemblance of the child to a relative suggests an inherited trait.
- Pregnancy and birth histories are helpful with patient management.
- Lethargy, vomiting, and difficulty seeing or following objects may be clues to underlying neurological disorders.
- Seizure activity and developmental delays indicate abnormal brain function.
- Malar flatness and midface retrusion is a common constituent of syndromic craniosynostosis and secondary to growth restriction of the cranial base.
- Midface recession and concave profile can be severe, resulting in obstruction of nasopharyngeal airflow and respiratory distress (**FIG 3**).

- An evaluation of the extremities is essential in patients with syndromic craniosynostosis. Syndactyly is a major component of Apert syndrome. Abnormalities of the thumbs and toes are elements of Pfeiffer and Carpenter syndromes.

IMAGING

- Computed tomography (CT) is useful to determine evidence of sutural fusion, signs of increased intracranial pressure, and indications of pathologic neuroanatomy.
- Three-dimensional (3D) CT scan provides a clear image of the bony anatomy and deformities of the craniofacial skeleton (**FIG 4A**) and can be combined with plain films for surgical planning (**FIG 4B**).
- MRI is necessary only if further detail of the brain is required or if a Chiari malformation exists.
- Structural anomalies of the central nervous system should be evaluated by a pediatric neurosurgeon.



FIG 2 • Separation of the facial skeleton from the skull and skull base at the Le Fort III level.



FIG 3 • A,B. Malar flatness and exophthalmos in a patient with Pfeiffer syndrome. **C.** The cranium has a trigonocephalic shape, and thumb printing can be seen on the lateral x-ray. The close positioning of the posterior pharyngeal wall to soft palate can lead to

airway compromise.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients undergoing Le Fort III distraction require a multidisciplinary team, including a plastic and craniofacial surgeon, ophthalmologist, otolaryngologist, and orthodontist.
- The craniofacial surgeon and the orthodontist play important roles in the surgical planning and in managing the pre- and postintervention occlusion and appearance.⁶
- The treatment strategy of a child with syndromic craniosynostosis includes a series of operations separated over time responding to the growth and development of the craniofacial skeleton.
- This phased treatment plan is based on the differential growth patterns of the cranial vault, the midface, and the mandible. Institutional preferences and functional requirements may change the timing of these staged operations.
- Midface advancement using Le Fort III distraction is generally performed between 7 and 10 years of age.
- The degree of airway obstruction and exposure of the globes may accelerate timing of surgery to the midface.

Approach

- Advancement of the midface can be performed with a conventional Le Fort III osteotomy and rigid fixation or by using Le Fort III osteotomy with distraction.
- Le Fort III distraction has several advantages over the traditional technique.
 - The soft tissue envelope limits mechanical advancement of the midface with the traditional procedure.
 - Resistance of soft tissue is generally manageable for advancements of less than 10 mm.⁵
 - Elimination of soft tissue resistance using distraction leads to lower relapse rates than conventional midface advancement techniques.⁷
 - Conventional Le Fort III osteotomy often requires repeat surgery at completion of facial skeletal growth. Le Fort III overdistractor can compensate for future growth, avoiding the need for repeat surgery.⁸
 - Le Fort III distraction eliminates the need for bone graft, thereby decreasing

length of the procedure and eliminates donor-site morbidity. There is also significant decrease in blood loss and postoperative pain after the operation and hospital stay is shorter.⁷

- Le Fort III distraction can be performed with either internal or external devices.
- Internal systems are semiburied, laterally placed devices, and may be tolerated better than external devices.
- Internal systems limit control over the midfacial skeletal segments, especially in vertical and transverse vectors. Lack of control over the central midfacial structures tends to push the zygomas forward and create midline collapse and increased facial concavity.⁹
- The author's preferred technique is external distraction.
- Skull-anchored external halo distractors allow multidirectional, unlimited distraction, and multiplanar adjustability of distraction forces at any time during the distraction procedure.
- The surgeon has the ability to focus treatment on only the affected skeletal region, and there is no bone grafting or internal fixation device required.

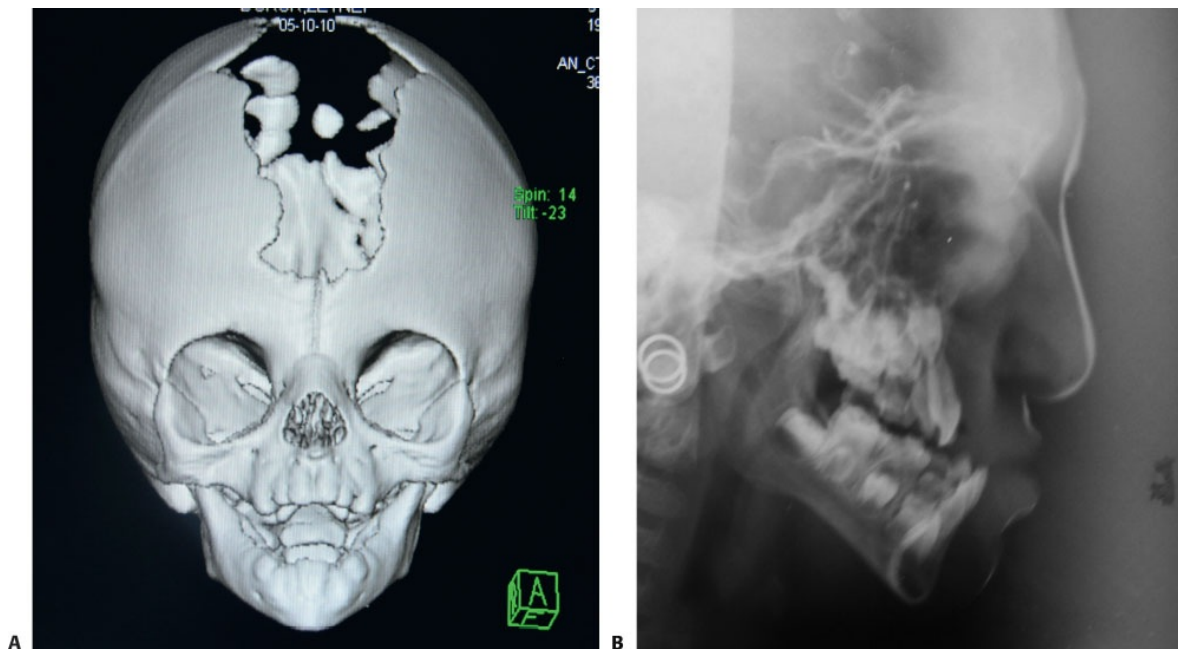


FIG 4 • A. 3D CT view of a patient with Apert syndrome. Bilateral coronal suture synostosis (note the ridging of the coronal sutures) and a large anterior fontanelle are

common. **B.** Severe midface retrusion and class III malocclusion of a patient with Crouzon syndrome.

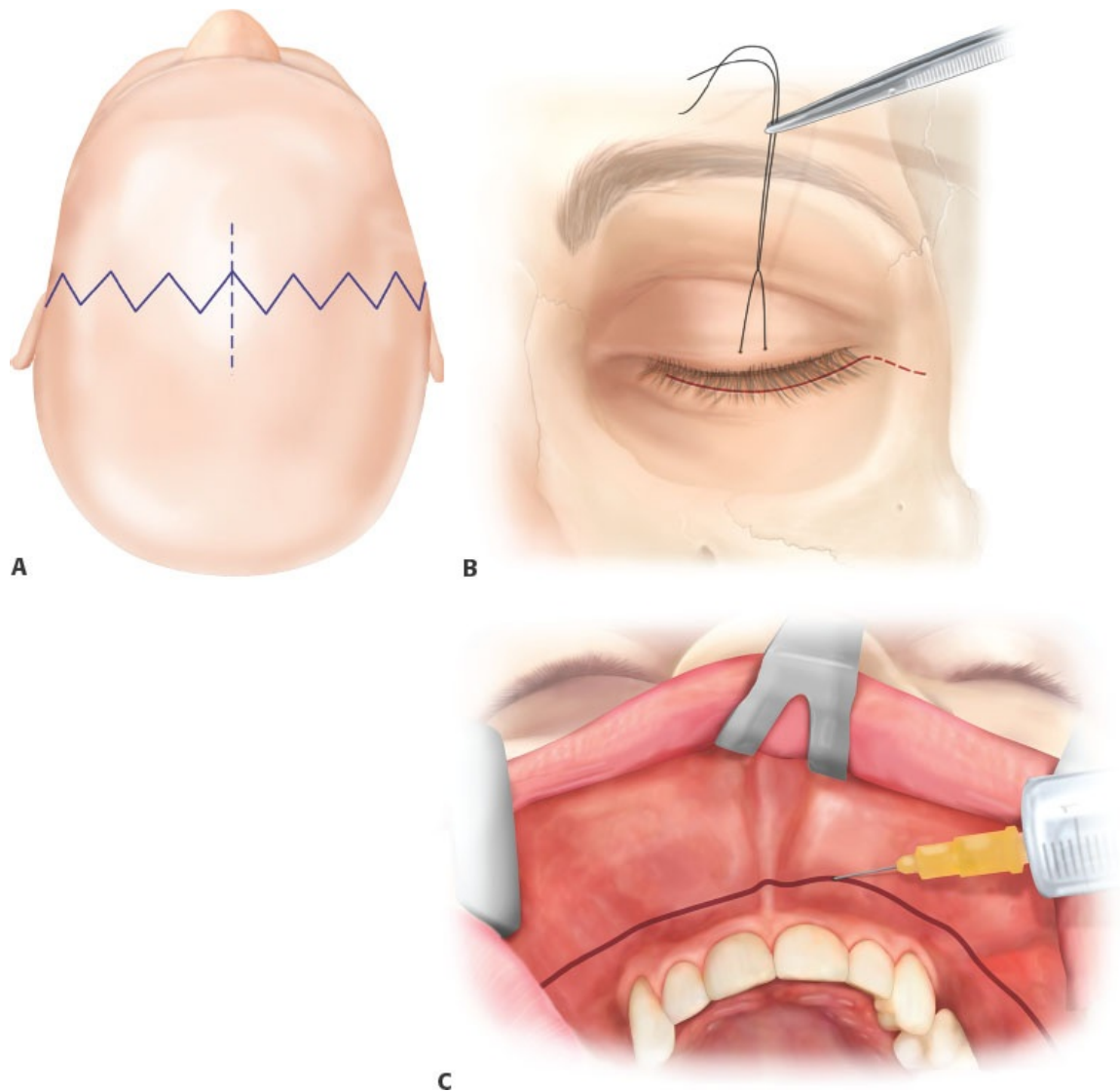
TECHNIQUES

■ Le Fort III Advancement With External Distraction

Exposure

■ Incisions

- The bitemporal (or bicoronal) zigzag incision provides exposure to the frontonasal junction, medial orbital wall, lateral orbital rim, and lateral orbital wall to the retromolar groove including the zygomatic arch (**TECH FIG 1A**).
- Infraorbital subciliary incisions provide exposure to the inferior orbital rim and the floor of the orbit (**TECH FIG 1B**).
- The superior vestibular sulcus incision provides exposure to the pterygomaxillary junction (**TECH FIG 1C**).
- After injecting local anesthetic with adrenaline at all sites, the bitemporal incision is performed first.
- Subperiosteal dissection is used and the coronal flap is turned down.

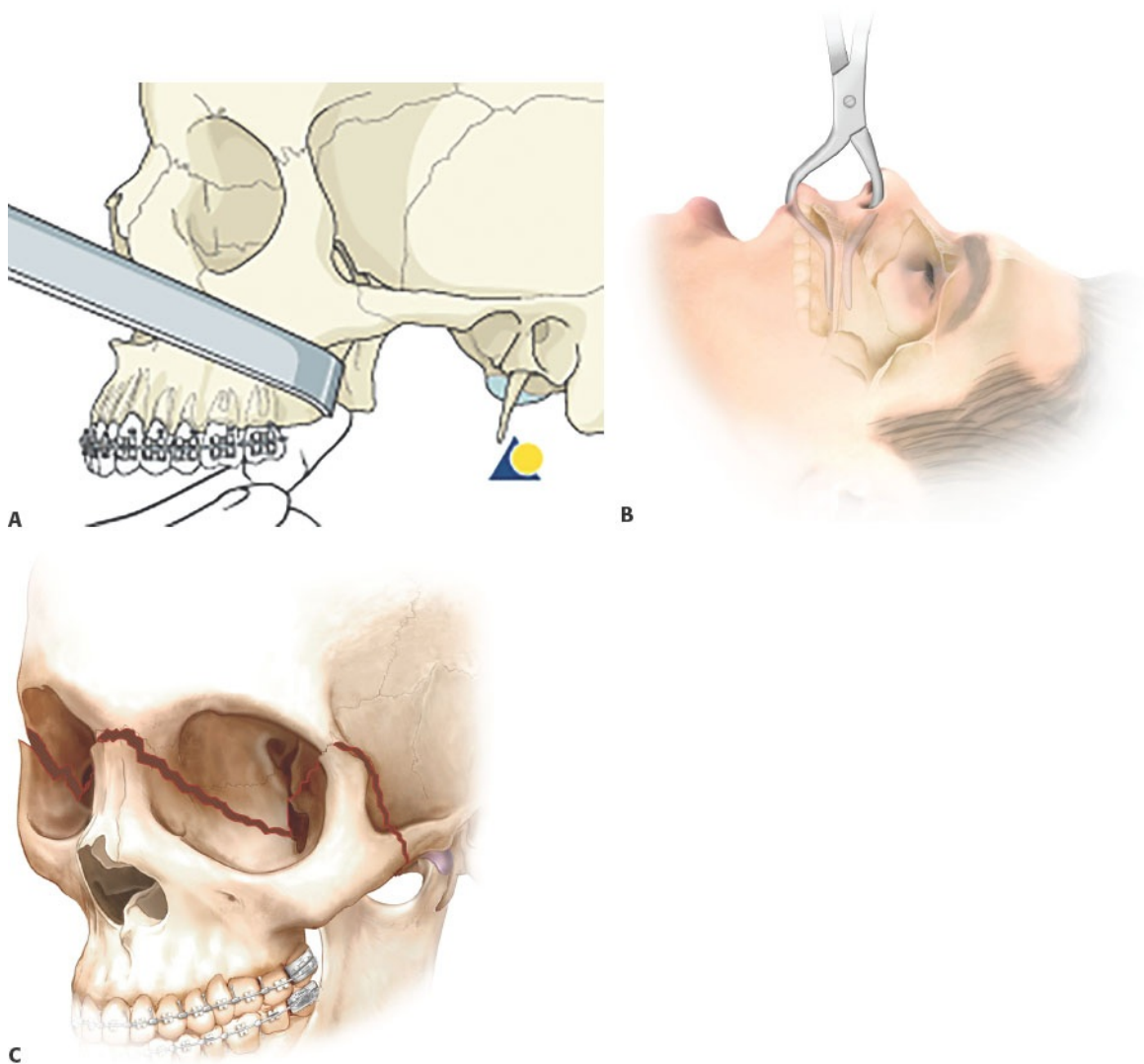


TECH FIG 1 • Combined incisions for the Le Fort III osteotomy include bicoronal **(A)**, subciliary **(B)**, and upper buccal sulcus **(C)**.

- The osteotomy sites are exposed with subperiosteal dissection around the superior half of the orbit from the nasofrontal suture to the zygomatic arch.
- The temporalis muscle is left in situ except in the areas posterior to the lateral orbital wall and the zygomatic arch.
- The subciliary and superior vestibular sulcus incisions are made in standard fashion.

Osteotomies and Mobilization

- Nasofrontal osteotomy is made with a reciprocating saw a few millimeters below the nasofrontal junction extending into the medial nasal wall, behind the posterior lacrimal crest (see **FIG 1A,B**).
 - The oblique section of the nasal septum is osteotomized with a curved osteotome.
- The lateral orbital wall osteotomy is made with a reciprocating saw, from the zygomaticofrontal suture to the lateral orbital wall toward the inferior orbital fissure.
 - A 4-mm osteotome is used for the orbital floor between 1 and 2 cm posterior to the orbital rim and behind the lacrimal crest.
- The same osteotome is used for the medial wall osteotomy behind the medial canthus to complete the osteotomy around the orbital contents.
 - The zygomatic arch is reached from the bitemporal incision superiorly a few centimeters below the lateral orbital rim and also sectioned with the reciprocating saw (see **FIG 1B**).
- A long, curved tip osteotome is used for pterygopalatine disjunction using the upper buccal sulcus incision (**TECH FIG 2A**).
- Once complete osteotomies are confirmed, the Rowe disimpaction forceps are used to complete the down-fracture (**TECH FIG 2B,C**).
 - Complete mobilization should be performed to stretch all soft tissues and separate remaining bony connections.



TECH FIG 2 • A. Pterygomaxillary disjunction is performed to complete anterior mobilization of the midface. Rowe disimpaction forceps are used to move the facial skeleton anteriorly **(B)** to complete the down-fracture of Le Fort III osteotomies **(C)**.

- Incomplete osteotomies may lead to unfavorable fractures and require higher forces for separation during the activation phase.

External Distraction Device Placement

- After adequate mobilization of the Le Fort III segment, for inferior anchorage, a custom-made rigid intraoral splint is attached to the maxillary teeth (**TECH FIG 3A**).

- For superior anchorage, special screw-plate devices may be an option (**TECH FIG 3B**).
- Alternately, the distractor system can be fixed directly to the infraorbital rims using a surgical wire (**TECH FIG 3C**).¹⁴
- In younger patients, disjunction of zygomaticomaxillary junction may occur when distraction is initiated.
 - To avoid this, the junction can be reinforced with a titanium plate, with the surgical wire placed around the plate.
- After placement of the traction wires, all incisions are closed in layers and drains are placed under the frontal flap.
- The halo of the rigid external device is assembled and adjusted for the width of the neurocranium. It is rigidly fixed around the head with three scalp screws on each side.
- Continuous traction force of 4 kg is sufficient to distract the midface after a complete Le Fort III osteotomy (**TECH FIG 3D,E**).¹⁰
- The halo is placed before extubation, but vertical rod and horizontal bars are placed on the 5th postoperative day before distraction is initiated. This maneuver allows the anesthesia team to extubate the patient safely (**TECH FIG 3F**).



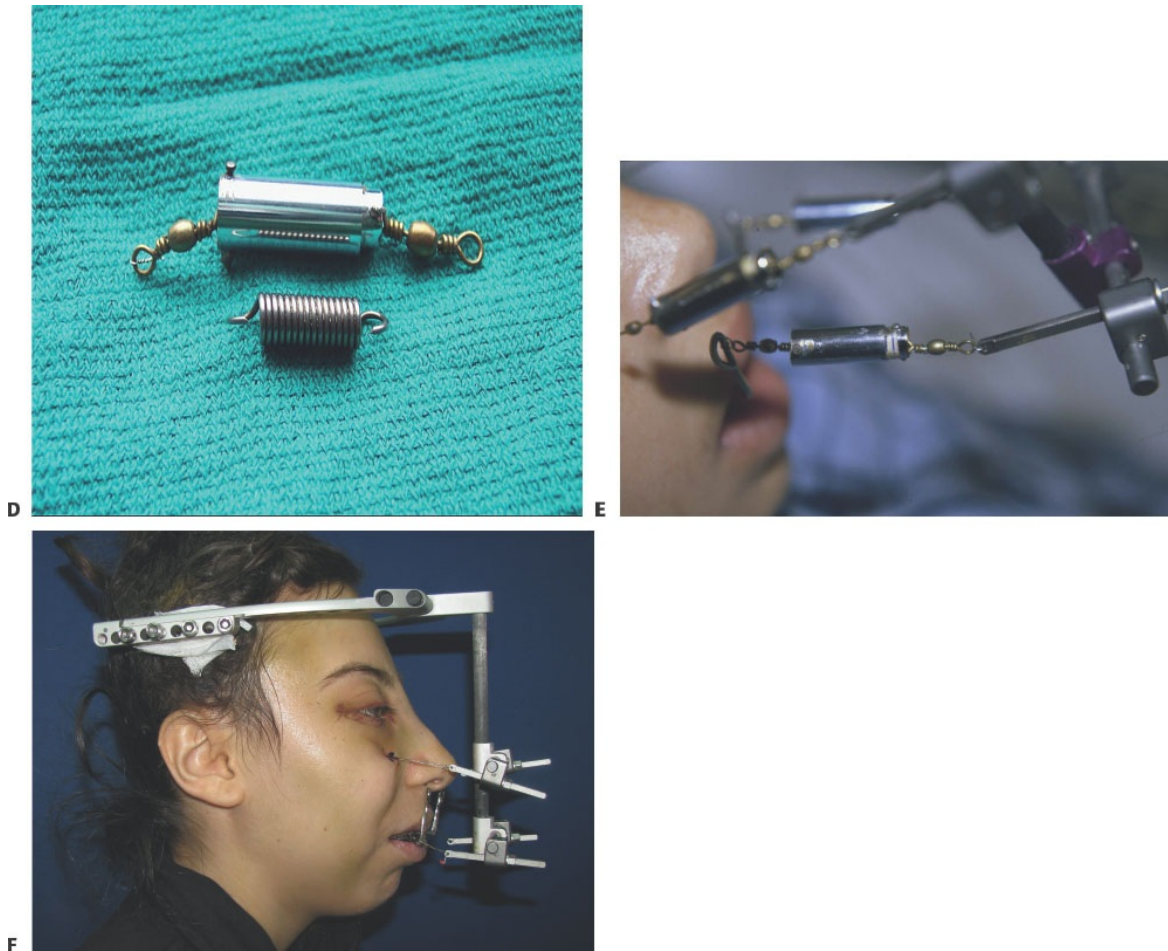
A



B



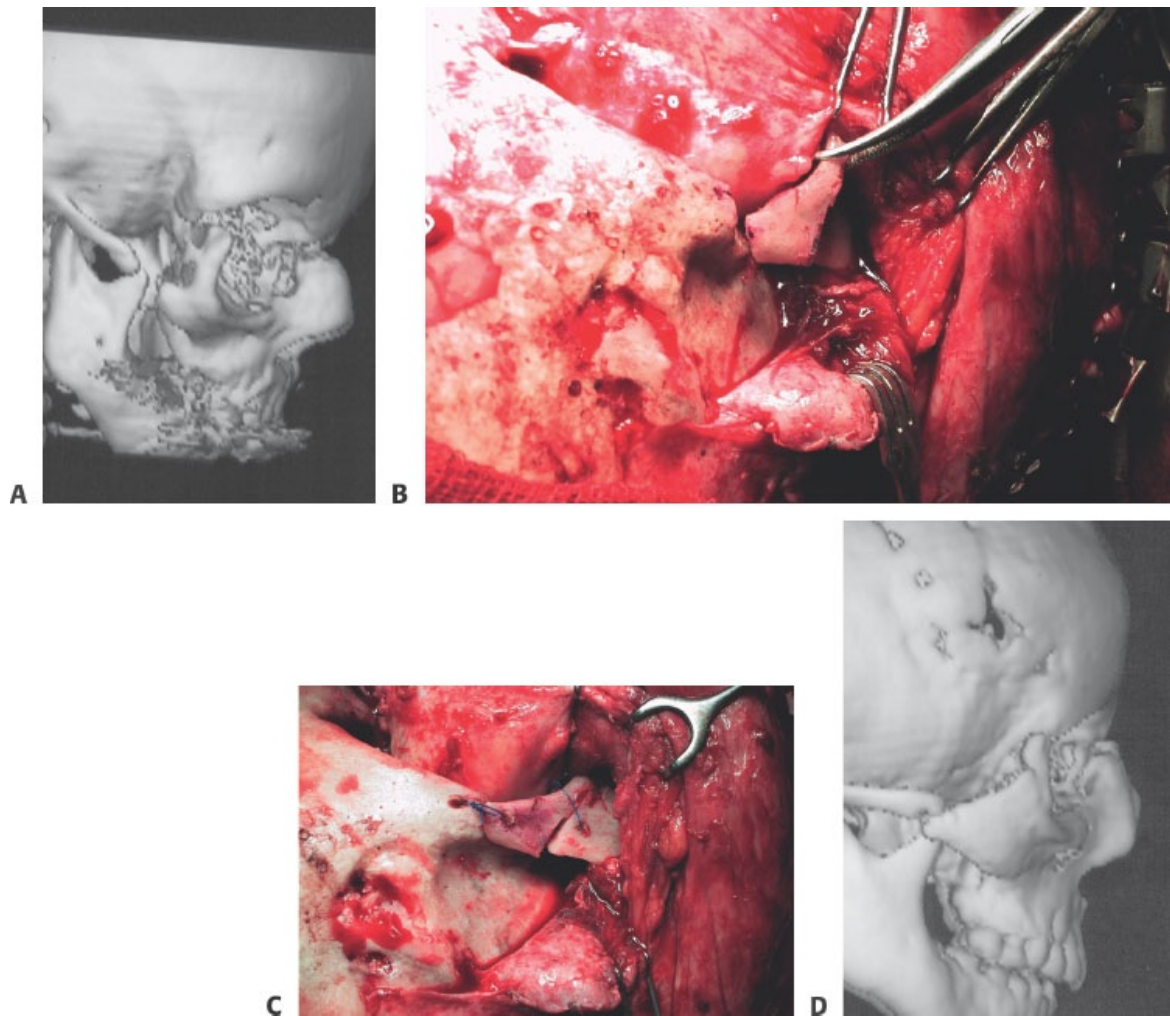
C



TECH FIG 3 • **A.** A custom-made rigid intraoral splint is attached to the maxillary teeth for the inferior level of anchorage. **B.** Screw and plate combinations designed by the manufacturer are placed through the subciliary incisions. **C.** A surgical wire connected directly to the infraorbital rim, immediately lateral to the infraorbital nerve. **D,E.** Custom-made spring scales attached to the distraction units. A continuous tension force of 4 kg is found to be sufficient to generate an advancement of 1.5 mm to the Le Fort III segment. **F.** Lateral view of a patient with Crouzon syndrome. The external halo distractor is anchored to the skull, and distraction units are attached to the midface during the activation period.

■ Modification of Technique for the Lateral Orbital Wall

- Le Fort III osteotomy with distraction results in further anterior positioning of the Le Fort III segment.
 - Thus, a step may occur between the superior-most margin of the advancement segment and the upper part of the lateral orbital rim above the osteotomy line (**TECH FIG 4A**). This step can be felt easily with palpation and may influence the appearance of the patient negatively.
- To modify the described technique, another osteotomy line is added 1.5 cm inferior to the original lateral wall osteotomy,¹² creating a bone fragment at the lateral wall.
 - This segment acts like a bridge between the frontal bone and the Le Fort III segment.
- The bone fragment is loosely attached to the frontal bone superiorly and Le Fort III segment inferiorly with a 4-0 nonabsorbable suture (**TECH FIG 4B–D**).
 - This loose attachment allows anterior movement of the Le Fort III segment with the inferior pole of the bone fragment and avoids unexpected movement of the bone fragment into another location.



TECH FIG 4 • A. 3D CT of the potential step that may occur between the superior-most margin of the advancement segment and the upper part of the lateral orbital rim above the osteotomy line. This step can be felt easily with palpation and may influence patient appearance. **B,C.** The bone segment, created at the lateral wall, will act like a bridge between the frontal bone and Le Fort III segment. **D.** Postoperative 3D CT of the patient showing the smooth connection of the osteotomy segments.

PEARLS AND PITFALLS

Physical findings

- Perform an ophthalmologic examination for functional and visual status of the eyes preoperatively, and document findings.
- Obtain appropriate imaging.
- Discuss each patient preoperatively with anesthesia, ophthalmology, and neurosurgery colleagues.

Technique

- It may be difficult to decide whether to perform Le Fort III advancement with or without distraction. Even for advancement distances less than 10 mm, distraction osteogenesis has demonstrated improved results.
- Suture the endotracheal tube to the columella and place surgical gauze intraorally to secure the airway while performing osteotomies.
- Meticulous bony technique is mandatory to avoid damage to the orbital contents.
- It is necessary to have complete osteotomy lines and full mobilization of the Le Fort III segment at the end of the operation. Check the osteotomy lines twice, especially the posterolateral walls of the maxilla, pterygopalatine junction, and nasal septum.
- While positioning the halo of the external distractor, place the fixation screws carefully. It is easy to apply too much torque using a wrench; therefore, if possible, place the screws manually.
- If there is any doubt regarding intracranial pin migration (persistent nausea and vomiting during the early postoperative period) after radiologic examination, check pin depth and change the position of the pins and/or halo, as necessary.

Postoperative care

- The early postoperative period may be troublesome because of soft tissue edema.
- External halo distractors are reliable and robust devices; therefore, device failure is rare.
- Wires connecting the Le Fort III segment to distraction units may break during activation and should be repaired immediately.
- Although overall characteristics of patients with syndromic craniosynostosis are similar, long-term results after Le Fort III distraction of Crouzon patients are better than others (including patients with Apert and Pfeiffer syndrome).

Therapy

- Postoperative orthodontic therapy is needed to correct occlusal problems and for fine adjustments.

POSTOPERATIVE CARE

- Distraction protocol
 - A 5-day latency period is followed by an activation rate of 1 mm/d.
 - Activation is completed when the desired amount of transport has been achieved.
- Plain radiographs are performed preoperatively and weekly during the postoperative period to follow the status of the bony segments and the distraction process
- The consolidation period may vary among patients and can be up to 12 weeks.
- Midface advancement can be associated with considerable blood loss and may be further complicated by challenging airways.
 - Postoperative care of these patients requires comprehensive intensive care management.

OUTCOMES

- Distraction is a safe and effective way of reconstructing the craniofacial skeleton using inductive bone generation rather than traditional grafting and repair and can be viewed as an endogenous form of tissue engineering.⁷
- Le Fort III distraction effectively treats respiratory and ocular problems.
- Normalization of appearance is also a major goal of the procedure. Midface hypoplasia is successfully corrected.
 - Patients should have an Angle class I occlusion after distraction (**FIGS 5 and 6**).
- Postoperative relapse may occur in up to one-third of patients and generally develops within the first 6 months after distraction.¹¹



A



B



C



D

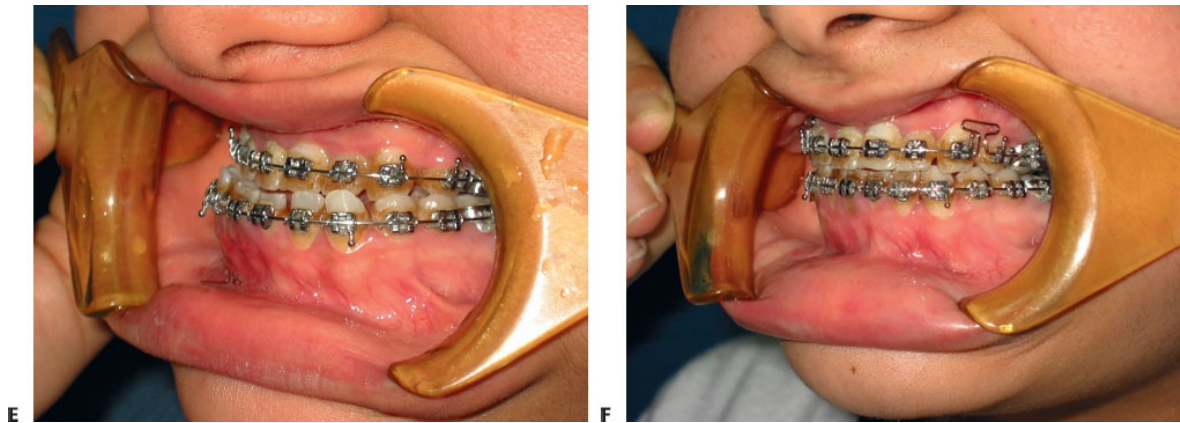


FIG 5 • Preoperative (**A,B**) and postoperative (**C,D**) views of a patient with Crouzon syndrome after Le Fort III osteotomy with external distraction. The advancement was less than 10 mm, and the results are stable after 2 years. Preoperative (**E**) and postoperative (**F**) intraoral photos.

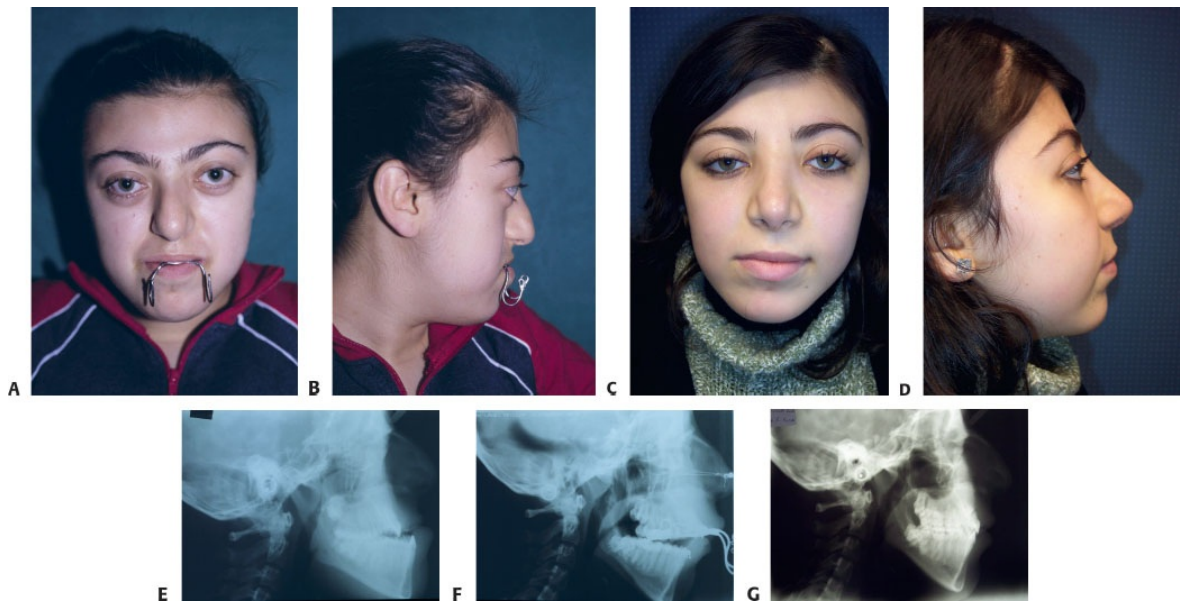


FIG 6 • Preoperative (**A,B**) and postoperative (**C,D**) views of a patient with Crouzon syndrome. The patient underwent rhinoplasty several years after the Le Fort III osteotomy with external distraction. Lateral cephalograms taken preoperatively (**E**), during

activation (**F**), and postoperatively (**G**) show that upward rotation of the maxilla created an open-bite deformity, which may be seen frequently, when the inferior anchorage is through the rigid intraoral splint. Postoperative orthodontic therapy resulted in angle class I occlusion.

- Long-term stability may be affected by the phenomenon known as pseudorelapse, which is defined as ongoing normal growth of the mandible combined with diminished growth of the maxilla, giving the perception of maxillary relapse.¹²
- Such relapse is typically seen in patients undergoing Le Fort III distraction during childhood and is managed at skeletal maturity with Le Fort I orthognathic surgery.
- Although major improvements can be achieved with Le Fort III distraction in patients with syndromic craniosynostosis, normalization of facial aesthetics may be difficult to obtain in patients with severe bony and soft tissue deformities (**FIG 7**).

COMPLICATIONS

- Superficial infections, mostly around the pin sites at the cranium
- External halo complications, including mechanical failure, pin loosening, frame migration, and intracranial migration of the fixation pins with dural violation (**FIG 8A,B**)
 - This last complication can be avoided by placing temporary titanium mesh or resorbable plates in the temporal areas at the sites of pin fixation (**FIG 8C–E**).¹³
- Ectropion after subciliary incision
- Excessive bleeding requiring transfusion
- Maxillozygomatic disjunction may occur in young patients and can be avoided by strengthening the suture with microplates and screws.
- Globe injury
- Infraorbital nerve injury
- Dural injury with subsequent cerebrospinal fluid leak
- Incomplete or atypical fractures



FIG 7 • Preoperative (A,B) and postoperative (C,D) views of a patient with Pfeiffer syndrome. Preoperative (E) photo. Angle class I occlusion is obtained after surgical and orthodontic therapy.

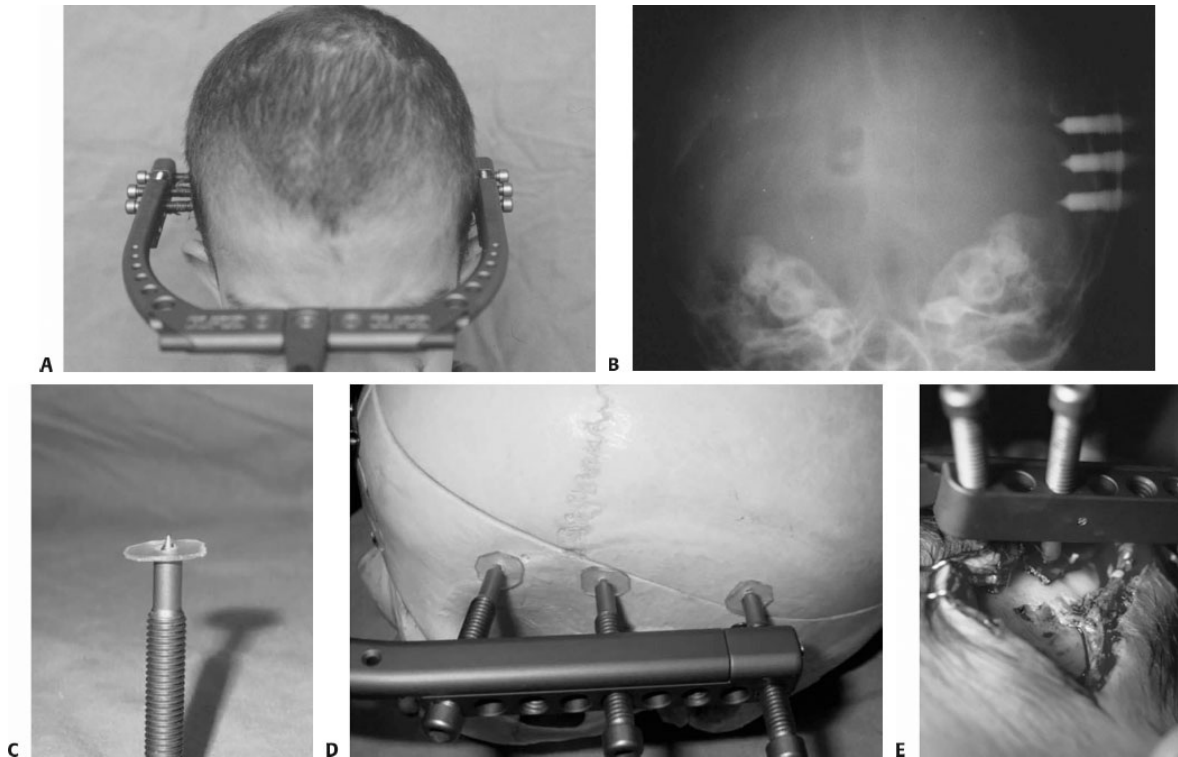


FIG 8 • Photograph (A) and plain x-ray (B) of a patient with intracranial migration of fixation pins after trauma. The distraction and recovery periods were completed without complication. C–E. Resorbable plates were placed in both temporal areas for pin fixation.

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Minimal Access Le Fort III Osteotomy for Midface Hypoplasia

28

CHAPTER

Scott J. Rapp and Christopher B. Gordon

DEFINITION

- Midface hypoplasia can lead to significant aesthetic and functional airway compromise.
- Le Fort III distraction osteogenesis is a useful surgical approach to address hypoplasia and facial dysmorphism at skeletal maturity or when severity of symptoms warrants earlier intervention.
- A Le Fort III approach involves osteotomies to the floor/lateral/medial wall of orbit, nasal bones, zygomaticofrontal suture, pterygoid plates of sphenoid, ethmoid, zygomatic arch, and posterior wall of maxillary sinus.

ANATOMY

- Midface hypoplasia (**FIG 1**) is characterized by:
 - Facial disharmony
 - Malar deficiency and concavity to profile
 - Exorbitism, lack of globe protection
 - Class III occlusion
 - Posterior airway space (PAS) narrowing
 - Dental crowding

PATHOGENESIS

- Events leading to severe craniofacial skeletal dysplasia are likely multifactorial but are believed to be associated with abnormalities in neural crest cell development and migration.¹
- Most are associated with genetic syndromes, but occasionally they may be

sporadic.²

- Midface sutures such as the speno-occipital suture may prematurely fuse leading to growth disturbances.³
- Genes associated with midface hypoplasia are the fibroblast growth factor receptor genes (*FGFR2*, *FGFR3*), twist-related protein gene (*TWIST*), and treacle ribosome biogenesis factor 1 gene (*TCOF1*).¹
- Midface hypoplasia is often observed with concomitant craniosynostosis, most often with bicoronal synostosis seen in syndromic patients:
 - Apert (*FGFR2*)
 - Crouzon (*FGFR2*)
 - Saethre-Chotzen (*TWIST*)
 - Meunke (*FGFR3*)
- Other syndromes leading to maxillary hypoplasia include Treacher Collins syndrome and craniofacial microsomia (hemifacial microsomia, Goldenhar syndrome).
- Neurologic dysfunction may be present including:
 - Hydrocephalus/ventriculomegaly
 - Gyral abnormalities
 - Hypoplastic/heterotopic white and gray matter
 - Corpus callosal agenesis
 - Kleeblattschadel/megalocephaly

NATURAL HISTORY

- Surgical approaches to the midface in syndromic patients were first reported by Gilles in the 1950s and then advanced through Paul Tessier's work in the 1960s.⁴
- Midface osteotomies have been historically performed at skeletal maturity to prevent undergrowth or reduce relapse rates.
- However, distraction techniques provide greater bony movements and more structural stability at an earlier age to address life-threatening airway compromise and ocular exposure.

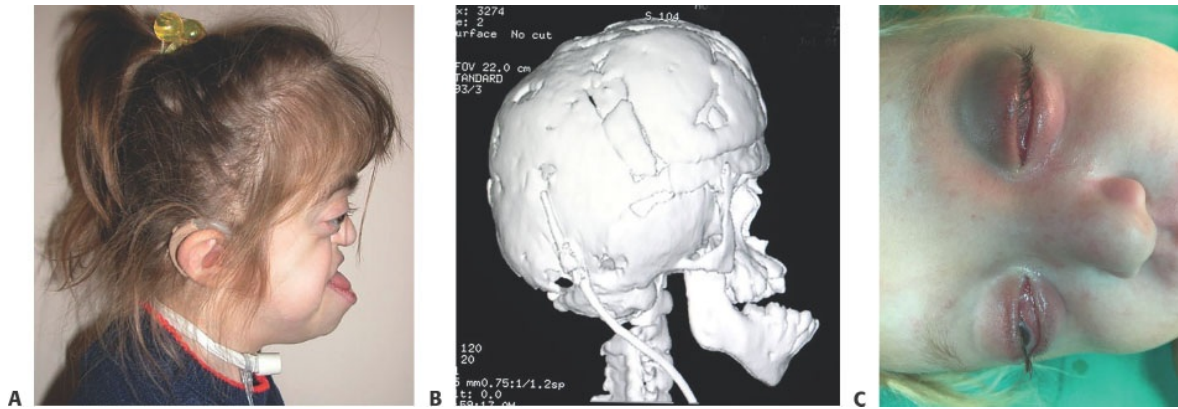


FIG 1 • Midface hypoplasia can have profound effects on projection **(A)**, occlusion and airway **(B)**, and eye protection **(C)**.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Clinical exam findings may include
 - Midface retrusion
 - Craniosynostosis
 - Exorbitism/shallow orbit
 - Keratitis/corneal ulcers
 - Lagophthalmos/scleral show
 - Orbital hypertelorism
 - Class III occlusion
 - Anterior open bite
 - Narrow arch/dental crowding

IMAGING

- Cephalometric consideration for PAS (**FIG 2A**)
- Nasopharynx
- Pterygomaxillare (pm) to posterior pharyngeal wall (upaw)
- Oropharynx
- Tip of uvula (U) to posterior pharyngeal wall (mpaw)
- Hypopharynx
- Tongue base (V) to posterior pharyngeal wall (lpaw)
- Plain film/CT exam findings (**FIG 2B**)
- Shallow orbits

- Hypertelorism
- Exotropia
- Bicoronal synostosis—brachycephaly
- Choanal stenosis/atresia

DIFFERENTIAL DIAGNOSIS

- Syndromes that may require Le Fort III advancement
- Crouzon
- Apert
- Pfeiffer
- Treacher Collins
- Nager

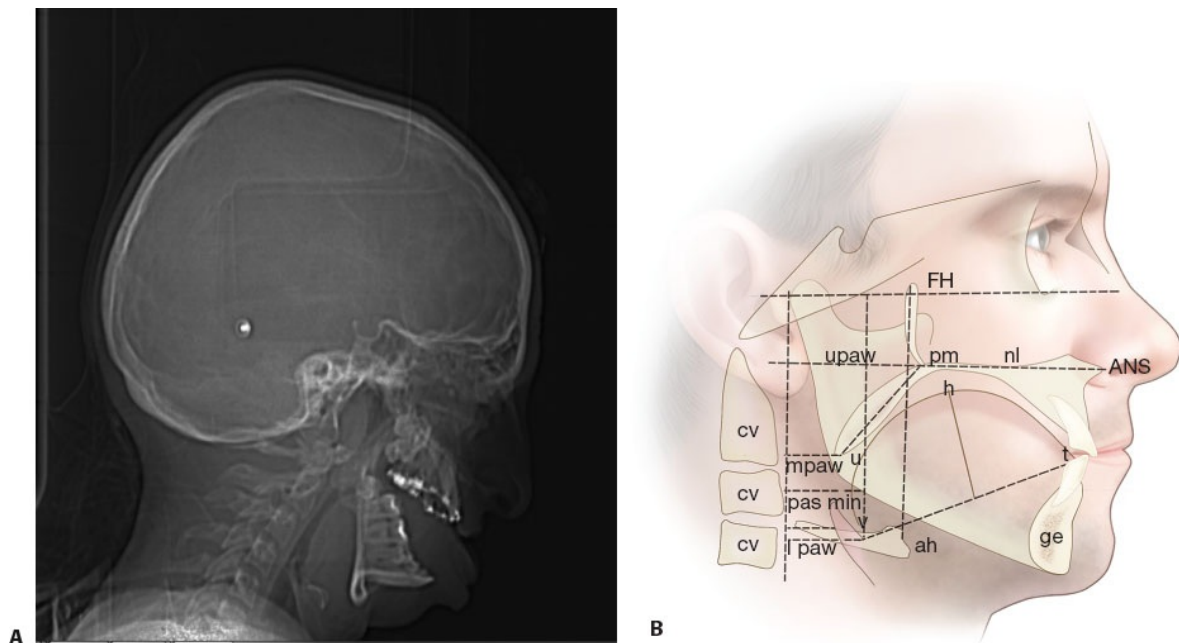


FIG 2 • Imaging **(A)** demonstrates posterior airway space narrowing that can be measured through cephalometrics **(B)** to determine distance required during distraction.

- Meunke
- Saethre-Chotzen
- Carpenter

NONOPERATIVE MANAGEMENT

- Severe midface hypoplasia observed in syndromic newborn may require early nonsurgical management.
- Airway compromise may be managed with:
 - Prone positioning
 - Positive pressure ventilation or assistance
 - Mandibular distraction for concomitant tongue-based obstruction
 - Globe protection
 - Taping
 - Eye lubrication

SURGICAL MANAGEMENT

- A multidisciplinary team is required for optimal surgical intervention, including:
 - Plastic surgery/oral surgery
 - Orthodontics
 - Genetics
 - Dentistry
 - Ophthalmology
 - Speech pathology
 - Otolaryngology and audiology
 - Social work and psychology

Preoperative Planning

- Planning between surgeon and orthodontist is critical to optimize the desired end point of centric occlusion.
- Virtual surgical planning (VSP) or model surgery assists in anticipated distance and vectors for distraction.
- Stereolithic models can assist with identification of permanent teeth and root location.



FIG 3 • Supine positioning with a shoulder roll and horseshoe headrest provides adequate access. Securing the endotracheal tube with circumdental, circum-mandibular, or transalveolar suturing/wiring to reduce intraoperative malposition of the endotracheal tube is recommended.

- Patient may require palatal expansion prior to Le Fort III osteotomy.
- Maxillary third molars may be removed prior to intervention; secondary Le Fort I osteotomy is anticipated to obtain class I occlusion.

- An ophthalmologic evaluation is required to assess for corneal ulceration and abrasion and to identify preoperative visual dysfunction (ie, strabismus, exotropia, V-pattern esotropia/exotropia).

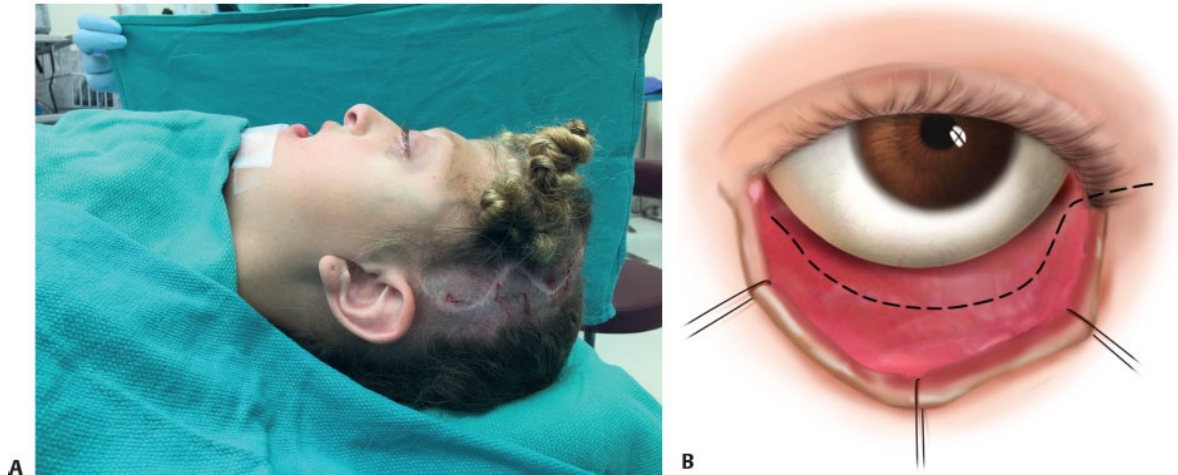


FIG 4 • Access for Le Fort III osteotomies can be exposed through a traditional bicoronal incision **(A)** or transconjunctival incision with extended lateral canthotomies **(B)**.

- Identify symptoms of sleep apnea including frequent snoring, apneic episodes during sleep, daytime somnolence, or growth abnormalities.
- Perform a sleep study to determine preoperative apnea-hypopnea index (AHI) or respiratory distress index (RDI).
- Perform tracheostomy if central sleep apnea is observed.
- Imaging should include CT exam with 3D reconstruction for bone/soft tissue evaluation and MRI for intracranial evaluation.
- Anesthesia consultation is important to assess perioperative airway risk.
- Ear, nose, and throat (ENT) consultation for airway assessment.

Positioning

- Access to the midface can be accomplished with supine positioning and the use of a horseshoe headrest **(FIG 3)**.
- Rigid cranial fixation is not required.
- A shoulder roll assists in creating a level facial plane.
- Secure the airway with either circumdental, circummandibular, or

transalveolar suturing/wiring to reduce intraoperative malposition of the endotracheal tube.

- In mixed dentition, avoid placing suture or wire through the alveolus, which would result in tooth bud injury.
- Oral RAE endotracheal tube
- Turn the table 90 degrees to allow access to both sides of the patient.
- Proper pressure relief is necessary due to length of case. Use foam or gel under the occiput, elbows, hips, knees, and heels.
- Serial compression devices are used in older patients.

Approach

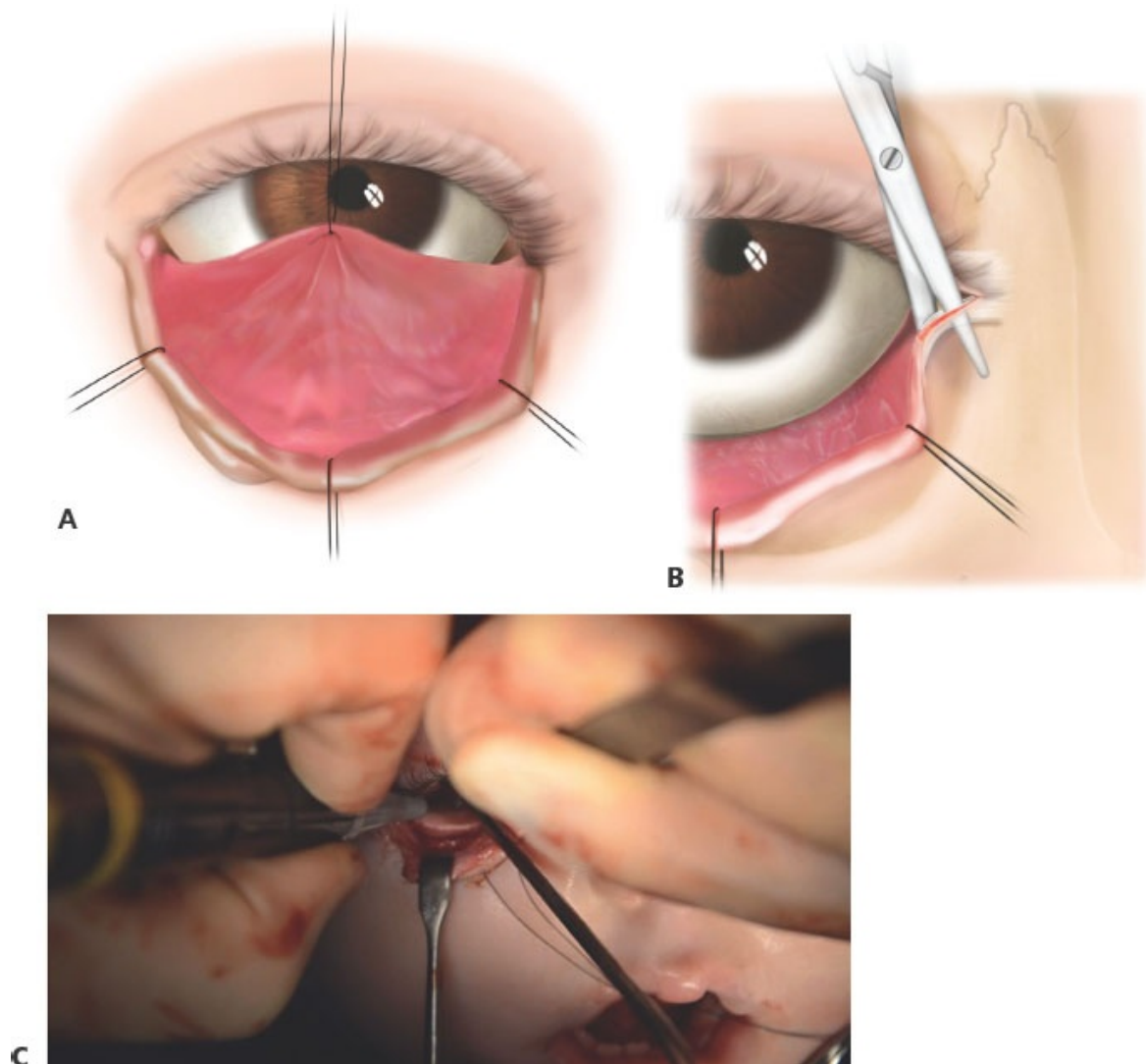
- Access to the midface is accomplished through a traditional coronal incision (**FIG 4A**) or extended transconjunctival incision (**FIG 4B**).
- The extended transconjunctival incisions may avoid intraoral incisions.

TECHNIQUES

■ Incision and Access to the Orbital Rim and Floor

- Clear corneal eye protectors are placed.
- The conjunctiva is infiltrated with 0.5% lidocaine with epinephrine 1:200 000 and 10 minutes are allowed to elapse.
- Medial and lateral traction stitches in the gray line of the lower lid help with identification of the lower lid tarsal border through retraction (**TECH FIG 1A**).
- An inferior lateral canthotomy is created sharply, extending 5 mm beyond the lateral canthus (**TECH FIG 1B**).
- Needle tip cautery with blend-cutting mode is used to divide the conjunctiva immediately inferior to tarsus.
- Bipolar cautery is used to coagulate prominent vessels in the dissection plane for controlled hemostasis.
- Cotton-tip applicators are used bluntly and atraumatically to develop a preseptal plane to the orbital rim (**TECH FIG 1C**).
- The periosteum at the orbital rim is divided with electrocautery with minimal anterior stripping of the maxillary periosteum.

- The orbital floor periosteum is elevated medially up to the nasolacrimal duct insertion, which is carefully identified and preserved. Dissection continues beyond the duct to the nasal and ethmoid bones.
- Laterally, subperiosteal dissection is extended up to the zygomaticofrontal suture.

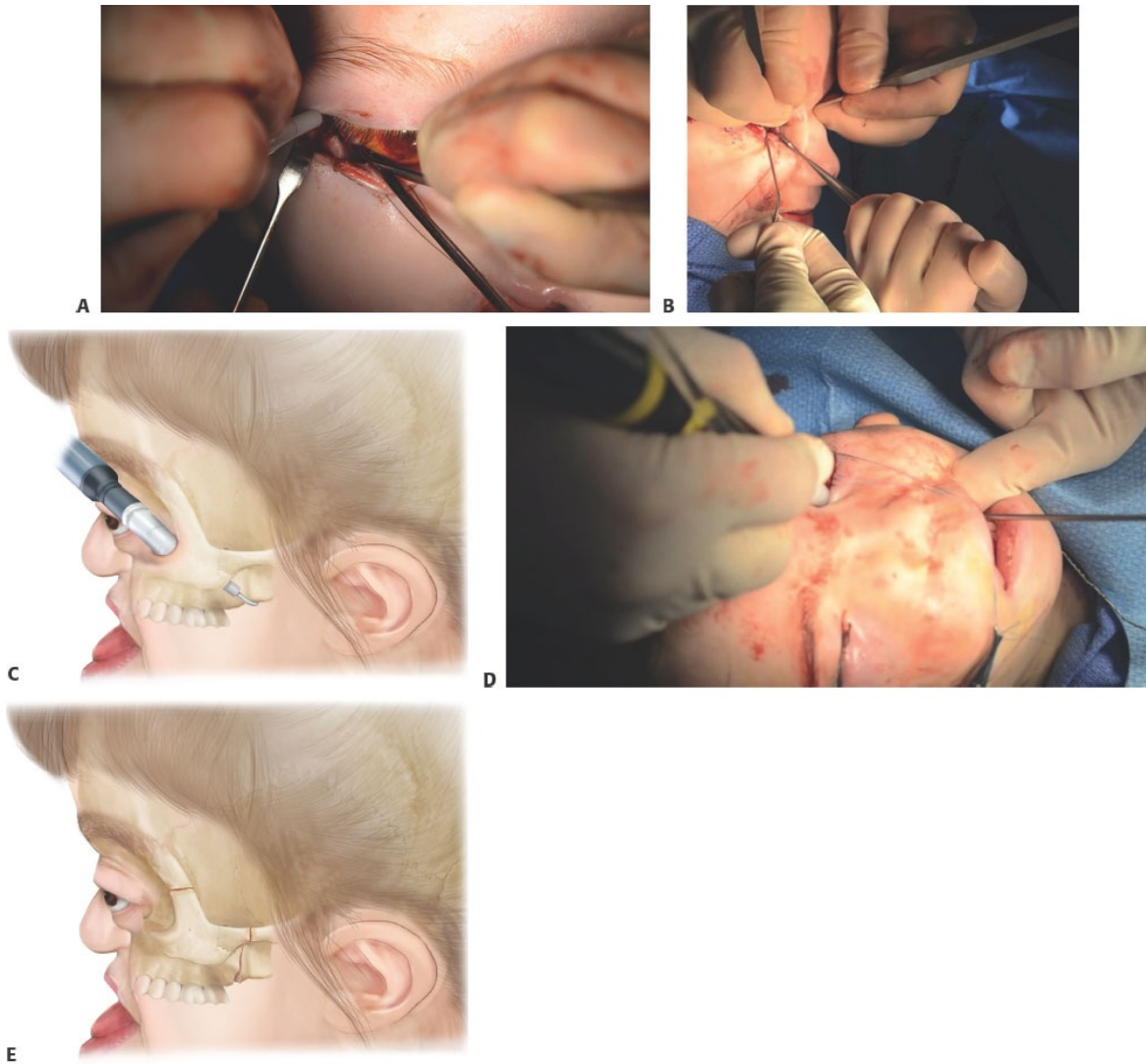


TECH FIG 1 • **A.** With extended transconjunctival incisions, medial and lateral tarsal retraction stitches assist in developing the appropriate preseptal plane to the orbital rim. **B.** Inferior lateral canthotomy. **C.** Orbital osteotomies are created under direct visualization. A larger lateral window is created so that

the Sonopet can reach the pterygoids from the orbit.

■ Osteotomies, Pterygomaxillary Disjunction, and Midface Mobilization

- A Sonopet Ultrasonic Osteotome (Stryker, Kalamazoo, MI) allows for minimal soft tissue disruption and carefully controlled osteotomies.
- Selected tips are the Nakagawa knife, micro claw, or aggressive serrated tip; the protective sheath is removed to reduce the diameter of the orbital floor osteotomy required.
- With the lid retracted and all soft tissue protected from the exposed Sonopet shaft, the osteotomies are made medially from the most anteromedial aspect of the inferior orbital fissure to the lacrimal fossa. The osteotomy extends posterior to the insertion of the nasolacrimal duct (**TECH FIG 2A**).
- A transcutaneous incision is made over the nasofrontal junction to expose the position where the orbital floor osteotomy meets the nasal bone.
- The nasal bones and underlying perpendicular plate of ethmoid bone are cut with the Sonopet. This leads to minimal disruption to nasal mucosa.
- Alternatively, an osteotome can be used to make these cuts (**TECH FIG 2B**).
- The orbital floor osteotomy is then extended laterally and cranially to the level of the zygomaticofrontal suture.

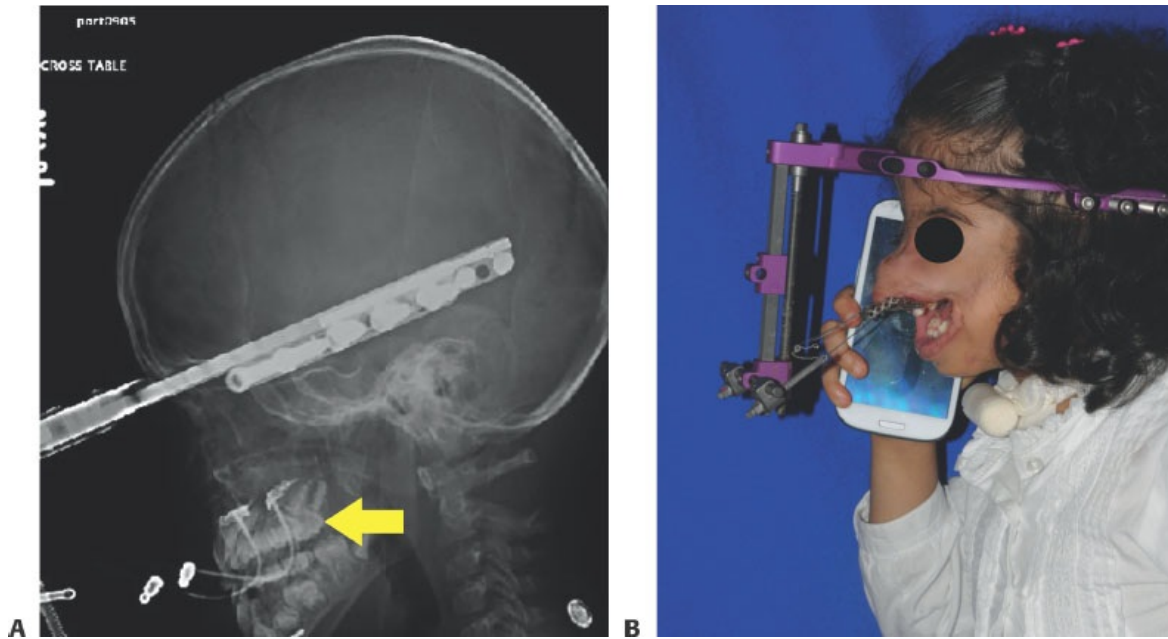


TECH FIG 2 • A. The lateral orbitotomy is extended through the zygomaticofrontal junction. **B.** The nasofrontal osteotomy is accessed through a small stab incision. The osteotomy can be started with the Sonopet and checked for completion with an osteotome. **C.** The pterygomaxillary osteotomy is reached from the lateral orbital floor window. **D.** Correct placement and angle is confirmed by digitally palpating the tip of the Sonopet. **E.** To ensure adequate pterygomaxillary dysjunction, perform gentle passes to remove small portions of bone.

- Within the orbit, the lateral floor osteotomy is widened to facilitate pass of the Sonopet through the antrum to approach the pterygomaxillary junction (**TECH FIG 2C**).
 - The Sonopet is then obliquely angled from within the antrum of the maxilla to divide the posterolateral maxilla at the junction with the pterygoids (**TECH FIG 2E**).
 - The zygomatic arches are accessed from the lateral orbitotomy.
 - Alternatively, the arch can be cut transmucosally with an osteotome; however, this is not recommended due to oral contamination.
 - A 3-mm osteotome is used to ensure that all cuts are complete.
 - Down-fracture is possible by digital manipulation alone if osteotomies are performed correctly.
-

■ Rigid External Device Placement

- A rigid external device (RED) is placed in the horizontal plane as just above the superior helix of the ear.
- The screws are advanced by hand and turning stopped when “finger tight.”
- Two maxillary titanium L-plates are positioned over the zygomaticomaxillary buttress with the arms bent, curving around the soft tissue, and fixated to the RED by 24-gauge dental wire (**TECH FIG 3A**).
- Locking screws are used to fixate the plate transmucosally avoiding disruption of tooth roots (**TECH FIG 3B**).
- Orbital plates may be positioned along the inferior orbital rim to more evenly distribute the forces of distraction.



TECH FIG 3 • **A.** Titanium plates are placed transmucosally with locking screws (*arrow*). They are bent to prevent ulceration to the upper lip when distracting. **B.** Use of a rigid external device allows for multiple vector movements and extended distraction distance.

■ Distraction Protocol

- Distraction is started on postoperative day 1.
- Movement is 0.5 mm twice daily for 1 mm/day.
- Weekly lateral cephalograms performed at 72" follows progress of distraction.
- The consolidation period is 5 days before the RED, plates, and screws are removed.

PEARLS AND PITFALLS

Bony

■ Osteotomy plane

regenerate	■ Avoid intranasal or intraoral mucosal disruption to minimize bacterial contamination of the bone callus during distraction. ■ The Sonopet causes thermal injury to bone if stationary and is capable of burning through soft tissue, vessels, and nerves.
Technique	■ Incomplete osteotomy ■ The midface should be freely mobile using digital pressure alone. ■ Confirm all osteotomies with a 3-mm osteotome. ■ Tooth root disruption ■ Utilize screw lengths of 6 mm or less and refer to medical model for aberrant tooth locations.
Distraction protocol	■ It is the senior author's preference to forego a latency phase. ■ Movement can be up to 2 mm/d. ■ Confirm bony consolidation with CT.
RED on infant	■ Thin calvarial bone ■ Overtightening of screws may lead to inner calvarial table penetration. ■ Risks can include dural disruption, cerebrospinal fluid (CSF) leaks, or brain injury. ■ Mesh underlay can add thickness to areas of thin bone to prevent overpenetration.

POSTOPERATIVE CARE

- The patient should remain intubated and admitted to the ICU following surgery.
- Extubation may be performed with ENT/anesthesia at bedside once airway swelling has subsided or demonstration that PAS is improved in cases of severe sleep apnea.
- A nasogastric feeding tube may be used in severe cases but is often unnecessary for oral intake.
- Distraction can be continued as an outpatient, and consolidation can be confirmed with CT imaging.
- Weekly lateral cephalograms can be used to determine end point of distraction, with slight overcorrection by a few millimeters.
- The RED device and oral plates can be removed as an outpatient procedure following cessation of distraction.

OUTCOMES

- Average maxillary advancements of 16 mm have been reported (6–31 mm).^{5,6}

■ **FIG 5** demonstrates expected nasopharyngeal airway improvement.

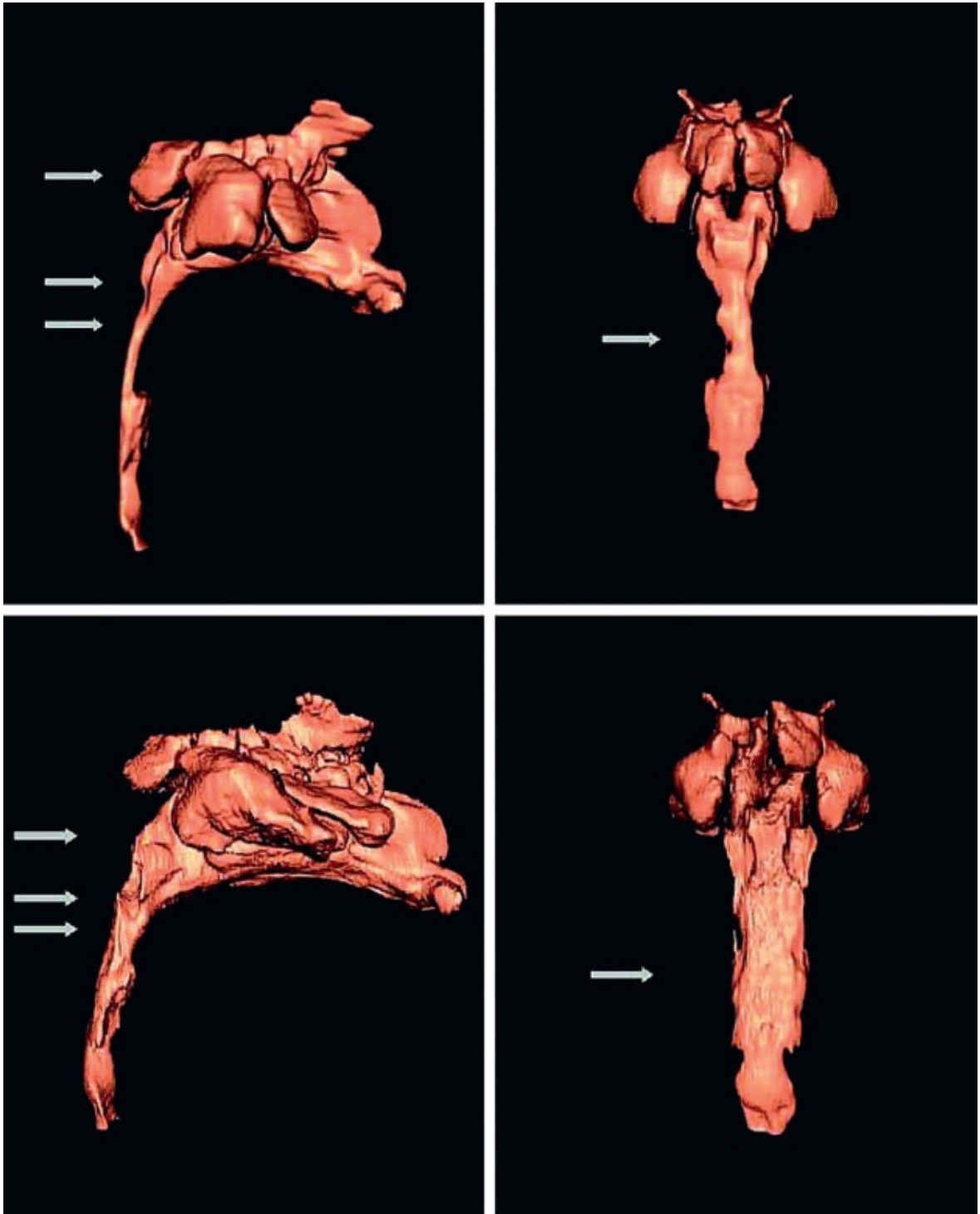


FIG 5 • 3D reconstructions of the upper airway following distraction show improved volume and space.

- Soft tissue changes can drastically improve midface projection, occlusion, and globe protection (**FIG 6**).
- There is evidence that a reduction in the respiratory disturbance index or apnea/hypopnea index can be achieved in over 50% of patients^{6,7} (**FIG 7**).
- RED devices are tolerated well with proper education and counseling.

COMPLICATIONS

- Incomplete osteotomy
- Premature consolidation
- Zygomatic fracture during distraction
- Permanent tooth damage
- Excessive pressure on globe during pterygomaxillary osteotomy
- Nonunion following advancement
- Relapse of advanced bony segment
- Malocclusion
- Fracture propagation
- Blindness



FIG 6 • Soft tissue aesthetics are greatly enhanced with

successful Le Fort III distraction. **(A)** demonstrates pre-operative midface hypoplasia; **(B)** demonstrates improved facial form.

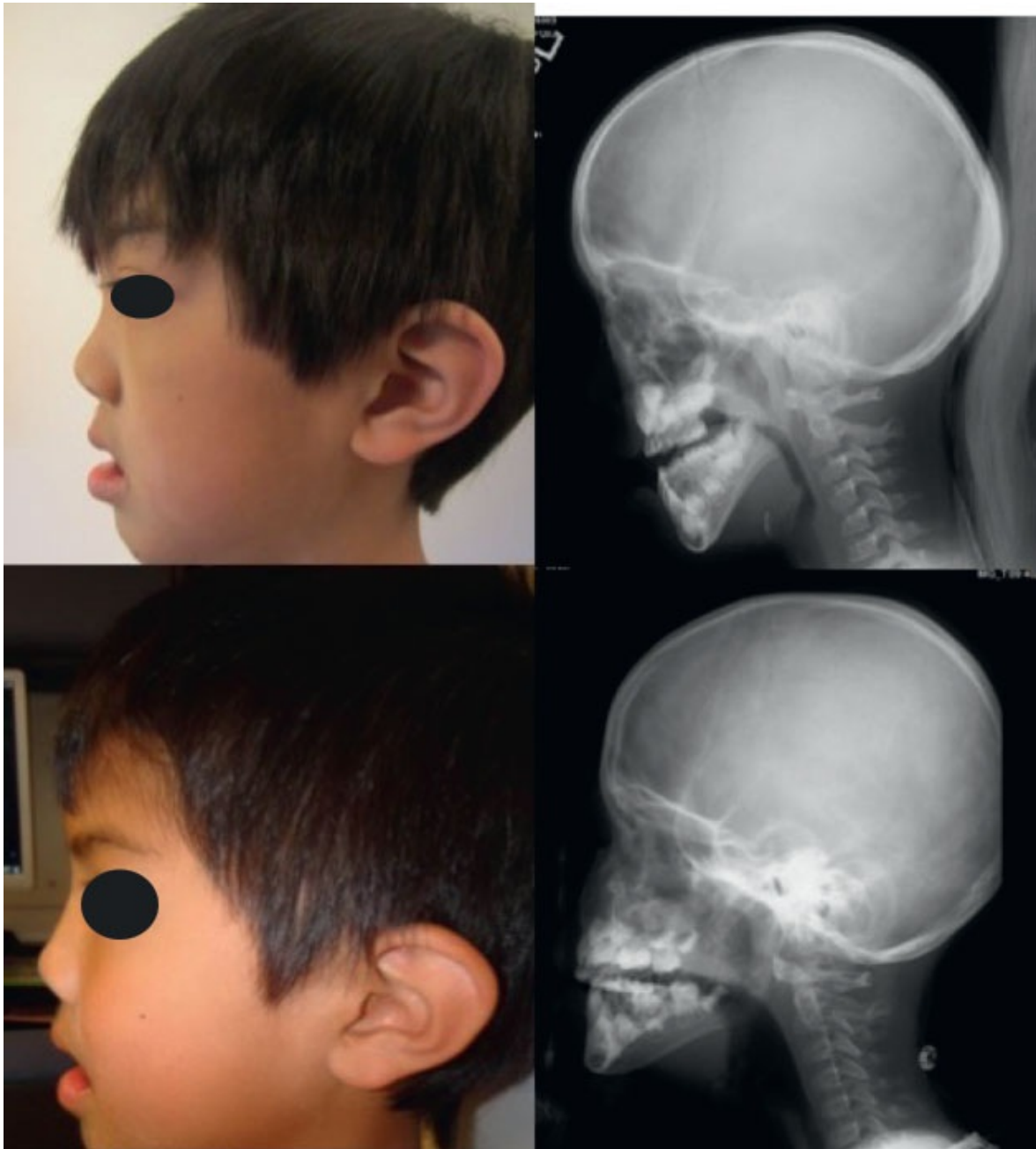


FIG 7 • Symptoms of obstructive sleep apnea can be mitigated or entirely corrected within posterior nasopharyngeal space after Le Fort III distraction.

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Secondary Alveolar Bone Grafting of the Cleft Alveolar Defect in Cleft Palate

CHAPTER

Richard E. Kirschner, Michelle A. Scott, and Matthew A. Hiersche

DEFINITION

- Alveolar clefts are present in patients with orofacial clefts that involve the maxillary alveolar ridge.
 - The defect can range from a simple alveolar notch to a complete cleft that involves the alveolus, maxilla, and inferior piriform rim.
- Secondary alveolar bone grafting, as originally described by Boyne and Sands,¹ is the final step in closure of the orofacial cleft. This procedure closes the nasoalveolar fistula, unites the maxillary arch in preparation for definitive orthodontic treatment, creates support for the affected nasal structures, and provides alveolar bone for the support of the lateral incisor (if present), the canine, and surrounding dental structures.
- Alveolar bone grafting is most often performed by utilizing autogenous bone from the iliac crest, which remains the standard.
 - Other donor sites include the cranium, tibia, and mandibular symphysis.^{2–4}
 - The use of allogenic bone and bone morphogenetic protein (BMP) has also been reported.^{5,6}

ANATOMY

- An alveolar cleft is a three-dimensional cleft in the maxilla most often extending from the piriform rim to the alveolar margin.
 - The bony cleft is shaped as an inverted pyramid with its base at the piriform rim and its pinnacle at the alveolar margin (**FIG 1**).
- Distal to the cleft, the alveolus may be hypoplastic, and the lateral maxillary

segment may be displaced posteriorly and collapsed medially.

- The alveolus/piriform rim acts as the “foundation” for the overlying soft tissue of the lip and nasal tip.
- Alveolar clefting and displacement of the lateral maxillary segment may thus result in displacement and distortion of the lip, nasal sill, and alar base.
- Dental anatomy adjacent to the cleft is often anomalous, demonstrating abnormalities in the position, shape, and presence of the canine and lateral incisor. Likewise, abnormalities in dental structure (eg, enamel hypoplasia, root abnormalities) and in dental eruption patterns are often noted.⁷

PATHOGENESIS

- The face is formed through the fusion of five facial prominences that develop and fuse in weeks 6 to 8 of development. These facial prominences are the midline frontonasal prominence, the paired lateral nasal prominences, and the paired maxillary prominences.
- The frontonasal prominence (median nasal prominence) forms the forehead, nasal bridge, nasal tip, columella, philtrum and central upper lip, septum, and premaxilla (primary palate).
- The paired lateral nasal prominences form the alae of the nose.
- The paired maxillary prominences form portions of the cheek, the lateral components of the upper lip, the maxilla, and the lateral palatal shelves (secondary palate).
- In normal development, the primary palate, which receives its blood supply via the sphenopalatine artery from the septum, fuses with the bilateral palatal shelves to complete the development of the palate.
- In clefts involving the alveolus, the primary palate and secondary palate fail to fuse at the alveolus, maintaining a connection between the oral and nasal cavities.

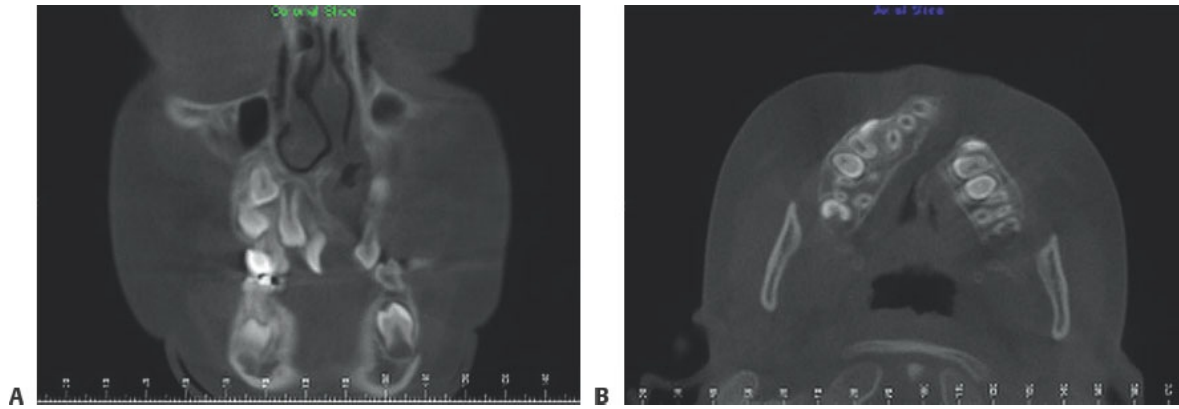


FIG 1 • A,B. Cone-beam CT demonstrating the pyramidal defect of the alveolar cleft.

- The etiology of cleft lip and palate is multifactorial with both genetic and environmental factors contributing to the development of orofacial clefts.
- To be etiologic, environmental factors must affect the fetus between weeks 6 and 8 of development, as this is the critical time for development of the primary palate.
- Medications that have been implicated in the development of a cleft lip and palate include anticonvulsants, folate antagonists, benzodiazepines, corticosteroids, and beta-blockers.
- Certain maternal factors have been implicated in the development of cleft lip and palate, including smoking, excessive alcohol consumption, and obesity.
- Maternal health conditions may also contribute, including diabetes and maternal fever.
- Lastly, a family history of cleft lip and palate is one of the strongest risk factors for the development of a cleft lip or palate, implicating a complex genetic component.

NATURAL HISTORY

- The need for repair of the alveolar cleft is generally accepted; however, timing of alveolar bone grafting remains controversial.
 - Primary alveolar bone grafting is not practiced at most centers in light of evidence that it has a negative influence on maxillary growth.^{8,9}
 - The remainder of this chapter is pertinent to secondary alveolar bone grafting.
- In the absence of primary alveolar bone grafting or gingivoperiosteoplasty, the

alveolar cleft remains as a persistent nasoalveolar fistula following closure of the lip and palate.

- The persistent fistula allows regurgitation of oral contents into the nose and passage of nasal secretions into the oral cavity. Additionally, the cleft traps food products, reduces oral clearance, obstructs basic hygiene, and may contribute to periodontal disease and dental decay.
- Without alveolar bone grafting, patients may maintain a flat, depressed lip, nasal sill, and alar base secondary to inadequate bony support of the soft tissues overlying the deficient piriform rim. Likewise, inadequate bone stock may lead to dental loss due to insufficient periodontal support.
- The reconstructed alveolus and piriform rim support the overlying nasal structures.
- Following closure of the alveolar cleft, orthodontic canine substitution may be employed to camouflage the defect resulting from an absent lateral incisor. Alternatively, the graft may be used to support replacement of the absent lateral incisor through implant placement.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Regurgitation of liquids or solids into the nose through a persistent nasoalveolar fistula may be reported.
- Oral hygiene practices, regular dental evaluations, and current or prior orthodontic treatment must be documented and discussed in detail, as the proper coordination of dental and orthodontic care is important in ensuring optimal outcomes in secondary alveolar bone grafting.
- It is important to solicit the patient's surgical history as it pertains to any prior cleft lip or palate procedures, as well as prior surgical treatment of the alveolus, whether primary or secondary.
- Additional treatment for or the presence of additional oronasal fistulae should be assessed.
- On physical examination, the presence, location, stability, and morphology of the dentition adjacent to the cleft should be assessed, as well as noting overall oral hygiene, dental decay, and periodontal disease.
- Overall, arch form should be assessed, as orthodontic preparation of the arch through expansion is often necessary to place the alveolar segments in an optimal position for bone grafting.
- Evaluation for the presence of an additional oronasal fistula should be

performed, noting the prior method of palate repair.

IMAGING

- Panoramic and occlusal x-rays have been traditionally used to image the alveolar defect and to assess graft take postoperatively.
- When available, a cone-beam CT scan offers improved three-dimensional evaluation of the cleft area and the adjacent dentition.
 - It may be used to more accurately assess bone graft take by providing a high-resolution, three-dimensional image of the alveolus.

NONOPERATIVE MANAGEMENT

- Patients who are not candidates for or who decline alveolar bone grafting may be offered prosthetic habilitation of the cleft site.
- This can be achieved with a variety of fixed and removable devices for aesthetic replacement of the missing dentition and acrylic coverage of remaining fistulae.^{10,11}

SURGICAL MANAGEMENT

- Repair of the alveolar cleft is generally performed during the stage of mixed dentition, which ranges from 6 to 10 years of age.
 - Graft placement should be performed before eruption of the permanent canine (or lateral incisor, when present) adjacent to the cleft.
 - Imaging is performed to assess root formation of the canine or lateral incisor, and grafting is performed once approximately half of the root has developed.
 - Performing the surgery at this stage provides bony support for the tooth as it erupts, and eruption of the tooth through the bone graft supports retention of graft volume.
 - Delayed tooth eruption into the graft area may result in loss of alveolar height and bony support. Thus, the goal is to provide early bony support for tooth eruption while minimizing the time between grafting and eruption of the permanent canine or lateral incisor.
- The main steps in the procedure are as follows:
 - Development of soft tissue flaps to close the nasal floor, surface the buccal gingiva, and close any residual palatal fistulae
 - Approximation of the nasal and palatal flaps to line the periosteal pocket for the bone graft
 - Harvest of cancellous iliac crest bone graft

- Placement of the bone graft into the prepared pocket
- Approximation of the buccogingival flaps
- Placement of an intraoral splint, if necessary
- Closure of the iliac donor site in layers, including closure of the cartilaginous cap of the iliac crest
- Indications for surgical management: patent alveolar fistula, dental arch collapse, deficiency of the piriform rim, support of adjacent teeth, and completion of dental habilitation (orthodontics and prosthodontics)
- Contraindications to surgical management: noncompliance with preoperative orthodontic preparation and poor oral hygiene resulting in gingivitis or caries adjacent to the alveolar cleft

Preoperative Planning

- Panoramic and occlusal radiographs or cone-beam CT scan should be obtained to determine stage of root development and bony support of teeth immediately adjacent to the cleft.
- Physical examination is performed to assess the condition of soft tissues and dentition, arch form, and presence of oronasal fistulae.
- Dental/orthodontic consultation should be obtained to assess the patient's overall oral hygiene, readiness for bone grafting, and the need for dental extractions, restorations, and alignment prior to bone grafting.
- Orthodontic consultation should be obtained to determine the need for maxillary expansion to restore arch form and transverse width (**FIG 2**).
- Teeth that have erupted horizontally in such a way as to impede access to the surgical site or that are in traumatic occlusion should be repositioned with orthodontic devices using caution to avoid moving the roots of teeth into the cleft defect.
- Teeth that have erupted into the cleft site or primary teeth that will interfere with the soft tissue closure of the graft site should be extracted prior to alveolar bone grafting.

Positioning

- The patient is placed in the supine position.
- If an autologous bone graft from the iliac crest is to be harvested, the operative hip should have a small bump placed beneath it to assist in exposure for the graft harvest.

- A small shoulder roll and slight extension of the head will assist with exposure.
- A Dingman retractor may be utilized for exposure, placing the hooks on the upper lip for exposure of the alveolus and on the alveolar ridge for exposure of the anterior palate.

Approach

- Intraoral exposure of the cleft site is obtained through the elevation of buccogingival and, if necessary, palatal flaps.
- The donor site is approached through a 3-cm incision placed 2 cm posterior to the anterior superior iliac spine to avoid the lateral femoral cutaneous nerve.
- The incision should be placed slightly lateral to the most prominent portion of the iliac crest in order to avoid irritation from clothing postoperatively.

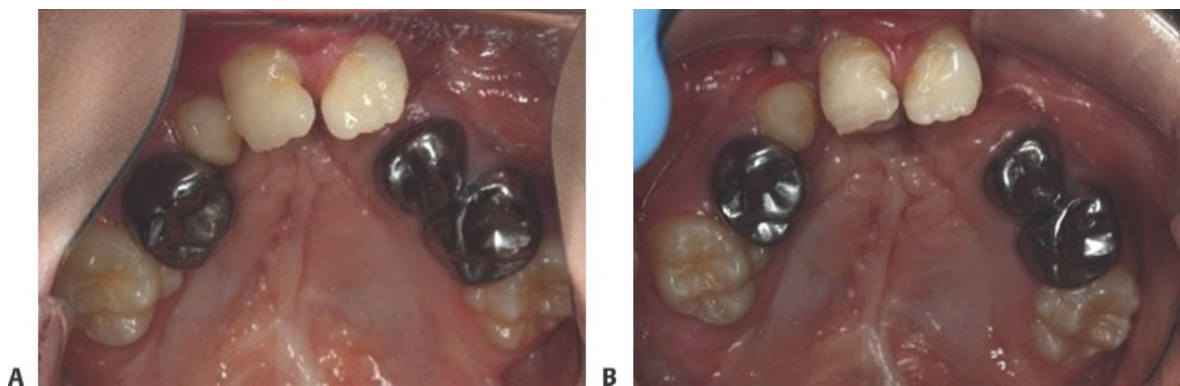


FIG 2 • Maxillary dental arch before **(A)** and after **(B)** orthodontic expansion.

TECHNIQUES

■ Alveolar Cleft Dissection

Preparation

- The oral splint should be fit prior to the procedure to ensure proper retention postoperatively.
- Slight extension of the neck is ideal for exposure, particularly if a palatal fistula is present and will require closure.

- Corneal protection is imperative for the duration of the procedure. The senior author's preference is to apply adhesive dressings over the eyes prior to skin preparation, but protection methods vary and are at the discretion of the surgeon.
- After skin preparation and draping, the oral cavity is rinsed with Peridex solution.
- A Dingman mouth gag is then used to provide exposure to the alveolus (**TECH FIG 1**).
 - The hooks are placed on the upper lip to provide retraction of the lip and exposure of the labial alveolus and dentition.
 - The cheek retractors should be used to retract the cheeks and stabilize the mouth gag.
- The alveolar and, if present, palatal fistulae should be examined closely at this time. Lacrimal probes may be used to interrogate the fistulae and define their extent.



TECH FIG 1 • Placement of the Dingman retractor for proper exposure.

Dissection of the Fistula



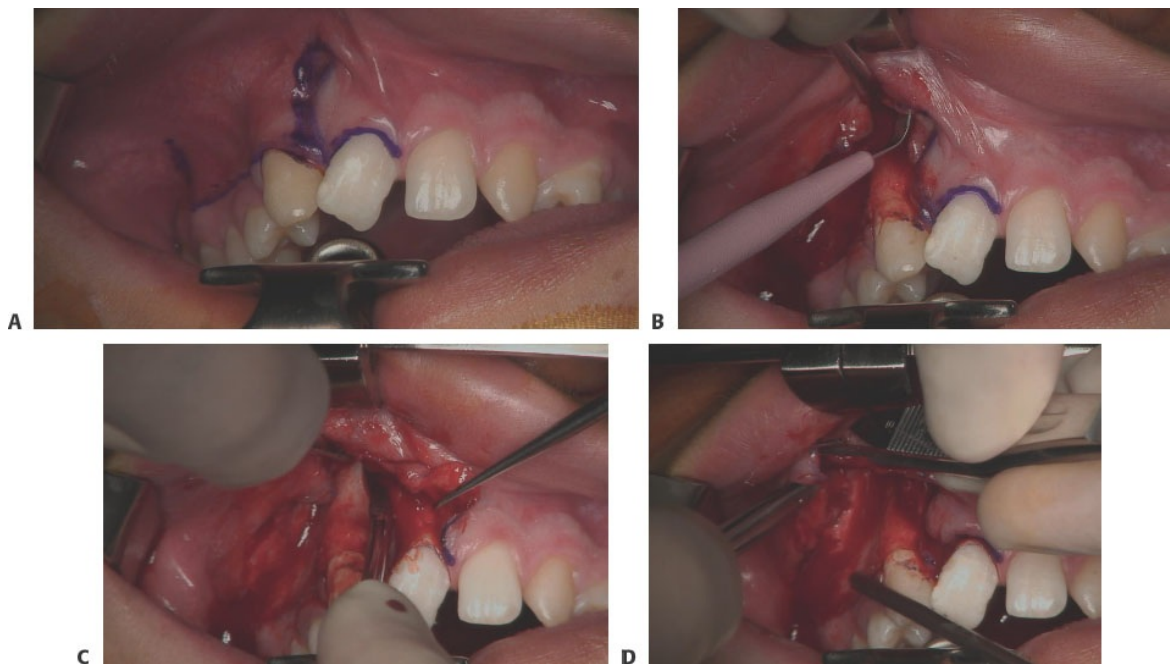
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- The incisions are marked along both the lateral and medial aspects of the alveolar fistula. The incision is marked along the gingival margin extending from the cleft mesially no further than the midline.
 - Laterally, the incision begins at the lateral cleft margin and extends along the gingival margin.
 - Distal to the tooth adjacent to the cleft, the incision may be extended obliquely from the gingival margin, extended just above the attached gingiva, and then posteriorly to the position of the first molar.
 - At the first molar, a back cut can be made to facilitate advancement of the gingival flap (**TECH FIG 2A**).
- The fistula and surrounding labial/palatal mucosa are injected with a 1:200 000 epinephrine solution for hemostasis.
 - As the mucosa is highly vascular, it is traditionally recommended that the surgeon wait 7 to 10 minutes between injection and incision to allow for vasoconstriction. However, recent studies indicate that waiting 26 minutes, when clinically feasible, may provide optimal vasoconstriction.¹²
- The incisions are then made at the gingival margin, avoiding injury to the papillae while dividing the periodontal ligament.
 - This dissection is extended onto the alveolus in a subperiosteal plane.
 - The incision proceeds around the cleft margin, a maneuver that may be facilitated by use of an angled crescent knife (**TECH FIG 2B**).
 - The lateral and medial buccogingival flaps are then elevated to expose the bony cleft margin to the piriform rim (**TECH FIG 2C**).
 - The periosteum at the base of the lateral flap is then scored in order to

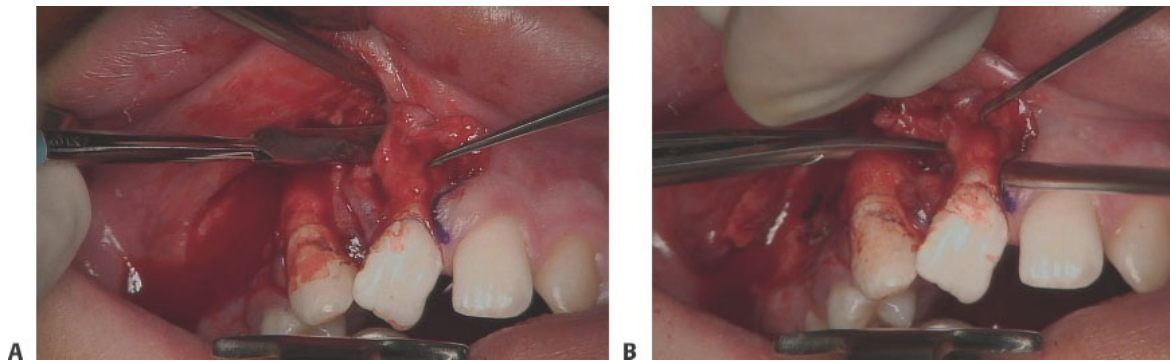
facilitate its mobilization (**TECH FIG 2D**).

Dissection Within the Cleft

- Once the labial margin of the fistula has been dissected and the buccogingival flaps elevated, attention can be turned to dissection of the soft tissues within the cleft.
 - Subperiosteal dissection should be continued along the medial and lateral cleft margins. This dissection should be performed/extended from the piriform rim to the alveolar margin and to the posterior extent of the fistula.
 - After elevation, the mucosa lining the lateral and medial aspects of the cleft can then be incised to create the nasal and oral flaps.
 - Sharp iris scissors can be used to incise the flaps posteriorly along the floor of the cleft (**TECH FIG 3**).
 - This dissection should be extended posteriorly just beyond the posterior extent of any residual anterior palatal fistula.
- If a palatal fistula is present, the palatal mucosa is elevated from the palatal gingival margin.
 - Elevate the previously incised oral mucosal flaps from within the cleft in continuity with the palatal mucosa.
 - Often, wide dissection of the palatal flaps is necessary for visualization and closure of the palatal fistula.



TECH FIG 2 • **A.** Markings demonstrating the extent of the surgical incisions. **B.** The incision is extended to the apex of the labial cleft. **C.** Exposure of the maxilla on the lateral cleft up to the level of the defect in the piriform rim. **D.** Scoring the periosteum of the lateral flap to facilitate medial transposition of the flap and fistula closure.

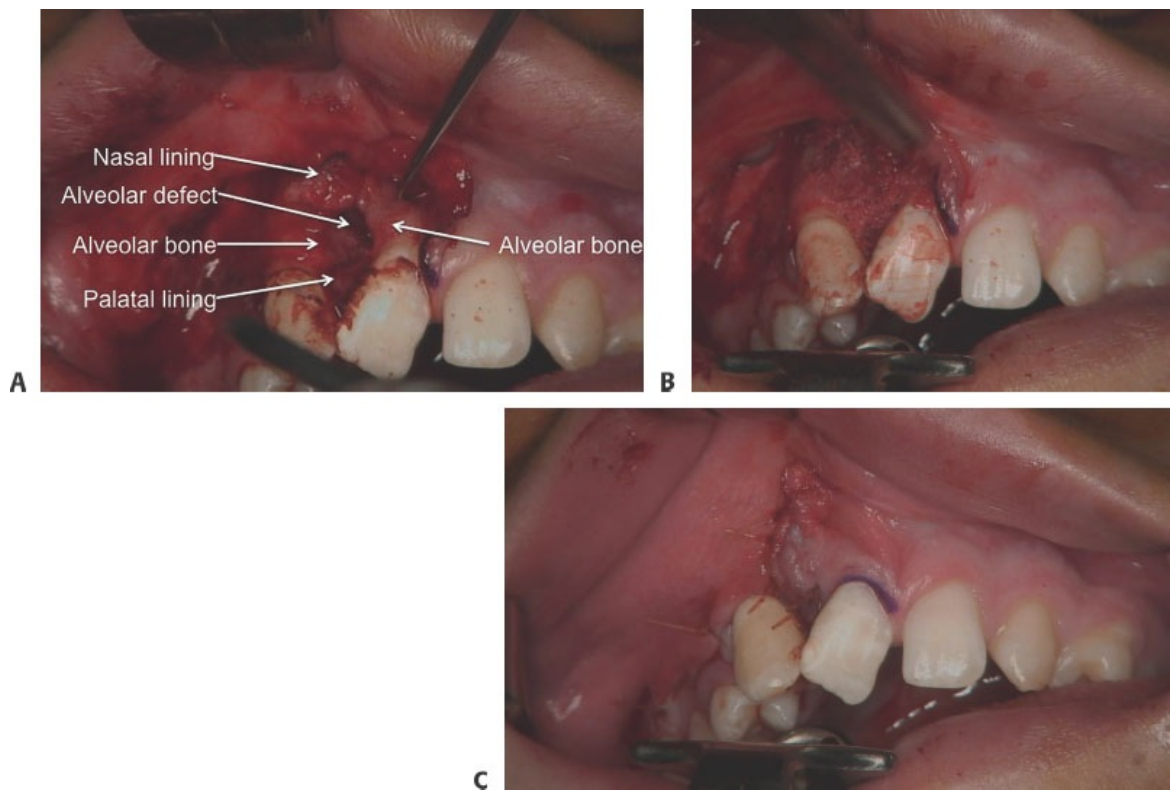


TECH FIG 3 • **A.** Elevation of the mucosa within the cleft on the medial side of the cleft. **B.** Division of the mucosal flaps within the cleft for creation of the nasal floor of the alveolus.

Closure

- Closure of the nasal lining should be performed prior to closure of the palatal defect as the nasal closure is often the most technically demanding portion of the procedure and is facilitated by optimal exposure.
 - The senior author prefers use of a 5-0 Vicryl suture on a P-2 needle for closure of the nasal lining.
 - Regardless of the needle selected, a small radius of curvature will facilitate manipulation of the needle within the confined space of the alveolar cleft.
- Closure of the palatal fistula is then performed. Use of horizontal mattress sutures optimizes healing through eversion of the edges of the stiff palatal mucosa.
- If palatal flaps have been elevated, the palatal mucosa can be resuspended and circumdental sutures secured above the cingulum.

- The space created for the bone graft can now be visualized in three dimensions (**TECH FIG 4A**; see **FIG 1**).
- The cancellous bone graft is packed into the alveolar cleft from the piriform rim to the alveolar margin (**TECH FIG 4B**).
- The gingival flaps are then sutured to cover the labial fistula.
 - The lateral and medial flaps are sutured to one another with resorbable everting horizontal mattress sutures.
 - The inferior margins of the gingival flaps are sutured to the palatal flaps with simple, interdental sutures (**TECH FIG 4C**).
- If a splint is to be used, it should be secured prior to awakening the patient.



TECH FIG 4 • **A.** The alveolar cleft can be visualized with nasal and palatal closure. **B.** Demonstrating placement of the bone graft within the cleft. **C.** Final closure of the cleft after placement of the bone graft.

■ Iliac Crest Bone Graft Harvest

- The incision should be marked prior to the surgical prep.
 - The anterior superior iliac spine (ASIS) is identified and marked.
 - The distal aspect of the incision is placed 2 cm proximal to the ASIS to protect the lateral femoral cutaneous nerve (**TECH FIG 5**).
 - The incision should be designed by rolling the lateral skin medially over the iliac crest. This maneuver allows the surgeon to identify a point lateral to the iliac crest that can be easily positioned over the iliac crest for surgical dissection while keeping the incision off of the bony prominence.
 - Designing the incision lateral to the iliac crest will avoid a painful scar over the iliac crest that may be irritated by clothing.
 - The incision should measure approximately 3 cm in length.



TECH FIG 5 • Design of the incision for harvest of the iliac crest bone graft.

- The skin is infiltrated with 1% lidocaine with epinephrine prior to surgical preparation in order to facilitate hemostasis.
- After allowing adequate time for vasoconstriction, the incision is extended sharply to the iliac crest.
 - A self-retaining retractor may be used to assist with exposure.
 - The iliac crest should be identified at the junction of the insertion of the external oblique musculature and the origin of the tensor fasciae latae.
 - Entering the iliac crest through the junction will eliminate an incision

through deep fascia and minimize postoperative pain.

- The lateral and medial surfaces of the iliac wing are palpated to identify the angle of the iliac wing.
- An osteotome is then used to open the cartilaginous cap in line with that angle.
- The senior author prefers to make a single linear opening in the middle of the cartilage cap that parallels the lateral and medial surfaces of the iliac wing.
- This linear opening in the cartilage cap may be widened with a small curette to allow access to the cancellous bone, without elevating the cartilage cap.
- A small curette is then used to harvest the cancellous bone graft; avoid perforating the lateral or medial cortices of the ileum.
- When sufficient cancellous bone has been harvested, the wound should be irrigated and 0.25% Marcaine infiltrated along the periosteum and instilled into the medullary cavity for analgesia.
- A resorbable suture may be used to close the cartilaginous cap of the ileum.
- The incision is then closed in layers, and a sterile dressing applied.

PEARLS AND PITFALLS

Physical findings	■ Closure of residual oronasal fistulae must be performed prior to or at the time of alveolar bone grafting. ■ Evaluation and optimization of oral hygiene prior to alveolar grafting is essential to successful bone graft surgery.
Dental/orthodontic preparation	■ Orthodontic evaluation and preparation with appropriate restorations, extractions, and palatal expansion is essential.
Technique	■ Watertight closure of the nasal floor is essential for bone graft take. ■ Wide exposure of the cleft allows adequate visualization of the nasal floor and access to the cleft for grafting. ■ Sufficient bone graft should be harvested to allow the alveolar cleft to be filled from the piriform rim to the alveolar margin.

Postoperative care

- Tension on flap closure should be minimal and may be assisted by scoring the periosteum at the base of the lateral buccogingival flap.
- A splint should be utilized in patients with uncorrected traumatic occlusion and in those who have undergone transverse maxillary expansion.
- A soft diet should be maintained for 3 wk postoperatively to minimize the risk of traumatic injury to the surgical site.
- Contact sports should be avoided for 4 wk following surgery if the iliac crest is used as the donor site.

POSTOPERATIVE CARE

- An intraoral splint is used to maintain palatal expansion if orthodontic appliances are removed prior to surgery. The splint will also relieve traumatic occlusion, potential injury to the surgical site, and impaction of food.
- A liquid diet is advocated for the first 24 hours, and a soft diet is appropriate for 3 weeks postoperatively.
- The patient maintains the splint in position while eating and only removes the splint to perform an oral rinse after each meal.
- At 3 weeks, the patient may remove the splint and begin brushing gently.
- The patient may bear weight as tolerated on the donor hip immediately but should refrain from contact sports for 4 weeks.

OUTCOMES

- Outcomes assessment includes clinical evaluation and radiographic imaging of the alveolar bone graft.
- Clinically, the presence of an alveolar or palatal fistula is a primary outcome determining surgical efficacy of closure of the fistulae.
 - It may be necessary to use a fine dental probe to assess for small fistulae.
 - In the absence of an overt fistula, clinical symptoms of liquid regurgitation into the nose should alert the physician to the presence of a persistent or recurrent fistula.
- Dehiscence of the oral and/or nasal suture lines jeopardizes the viability of the alveolar bone graft.
- Radiographic evaluation of the alveolar bone graft is usually deferred until 6 months following bone grafting, so as to allow for bony regeneration across the alveolar cleft.

- The Bergland Scale Score serves as a radiographic gold standard for assessing alveolar bone graft take. The scale is a four-point scale that serves to assess the height of interdental bone as viewed on occlusal radiographs.¹³
- This scale may fail to adequately evaluate the presence of interdental bone as it is a two-dimensional analysis of the alveolar cleft. Occlusal radiographs fail to clearly demonstrate the overall quality of bone retention in the coronal plane.
- Recently, the Americleft Project has introduced a new assessment standard, the Standardized Way to Assess Grafts (SWAG).¹⁴ This is a six-point scale with scores of 0 to 1 indicating graft failure, 2 or 3 indicating a poor graft requiring regrafting, 4 or 5 indicating a successful graft that may require augmentation, and 6 a successful graft.
- Cone-beam computed tomography has emerged as a safe, rapid, and effective means of obtaining a three-dimensional evaluation of the graft site. While a scale using cone-beam CT has not been validated, studies have shown that scales using standard radiographs do not identify bone resorption in the buccopalatal dimension.¹⁵
- Resorption of approximately 50% in this transverse dimension has been reported within the first year following bone grafting.¹⁶

COMPLICATIONS

- Infection
- Bleeding
- Partial or complete graft loss
- Recurrence of the oronasal fistula
- Tooth damage or loss
- Hip pain
- Fracture of the iliac wing
- Injury to intra-abdominal contents
- Paresthesia of the lateral femoral cutaneous nerve
- Hypertrophic scar
- Scar irritation with clothing if the incision is placed directly over the iliac crest
- Anesthetic complications

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30 Surgical Management of Facial Clefts

CHAPTER

David C. Matthews, Samer Abouzeid, and Edward W. Kubek

DEFINITION

- Craniofacial clefts are rare congenital anomalies of facial development involving the facial bones, overlying soft tissue, and temporomandibular joint.
- Facial clefts are classified by their involvement of the orbitomaxillary anatomy according to the Tessier classification.¹
- Each craniofacial cleft is associated with characteristic, yet highly variable, bony and soft tissue changes ranging from mild hypoplasia to total agenesis.
- Facial clefts and labiopalatine clefts are separate entities with key differences in surgical management and incidence.
- The extreme variation of facial cleft anatomy mandates a unique surgical approach for every patient.²

ANATOMY

- Dr. Paul Tessier published his 0 to 14 organizational system in 1976 (**FIG 1**).¹
 - Because of its clinical utility and relative simplicity, Tessier's nominal system continues to be used widely.
- For purposes of nomenclature, the palpebral fissure/orbit separates lower facial clefts from their cranial extensions.
 - When they occur together, the numerology of the lower facial cleft plus its cranial extension always equals 14.
- Tessier's 0 to 14 system is based on clinical experience, not embryologic study (Table 1).

PATHOGENESIS

- The etiology of facial clefting is incompletely understood but likely involves

both genetic and epigenetic factors.²

- Abnormalities or premature resolution of the stapedia artery during fetal development is known to cause facial clefting.
- The severity of the deformity relates to the timing of stapedia artery regression in utero.

PATIENT HISTORY AND PHYSICAL FINDINGS

- In facial clefts, the bone and soft tissue are rarely affected to the same degree.

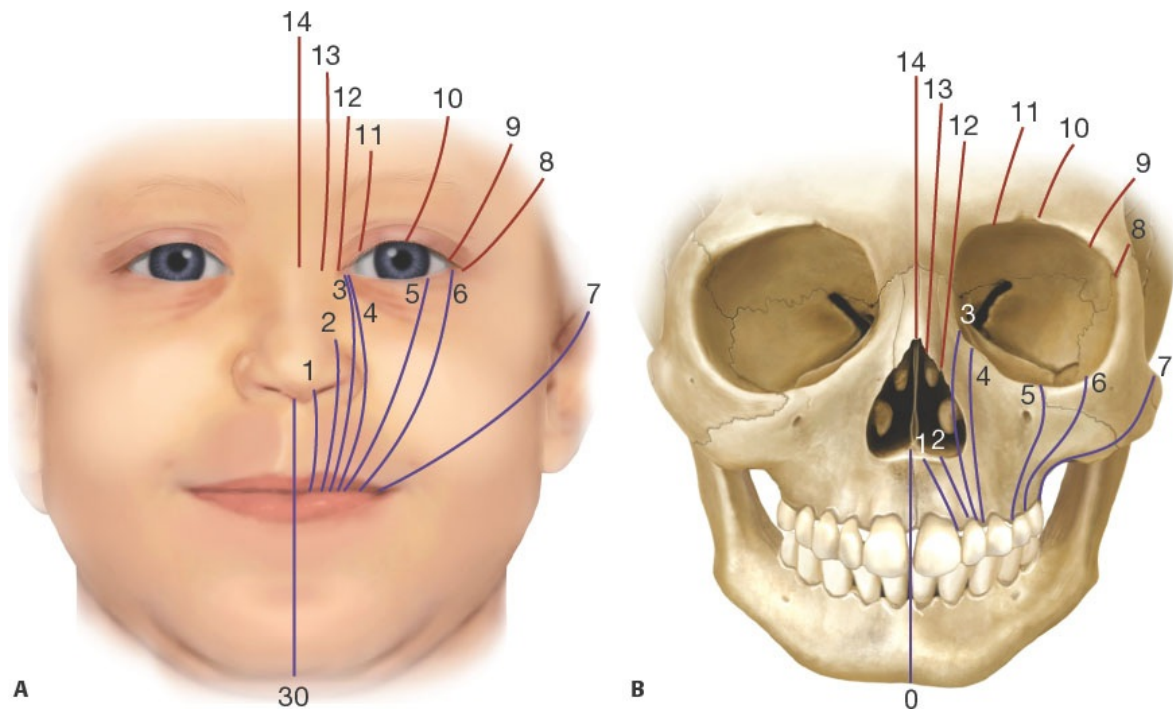


FIG 1 • Tessier classification of clefts. **A.** Paths of various clefts on the face. **B.** Location of the clefts on the facial skeleton. (From Tessier P. Anatomical Classification of facial, craniofacial and lateral-facial clefts. *J Maxillofac Surg.* 1976;4:69-92.)

Table 1 Tessier System of Cleft Identification

Tessier Cleft No.	Description	Cranial Extension Equivalent Cleft No.	Bony Abnormalities	Effects on Soft Tissue and Appearance

0	Median craniofacial dysraphia	14	• Similar to labiopalatine cleft but located at the midline (teeth fall into cleft)² • Wide nasal bones with enlargement of the sphenoid and ethmoid sinuses • Duplication of the crista galli • Cleft of the primary and secondary palate • Maxilla lacking vertical height • Hypertelorism	• Broad philtral columns • Duplication of midline nasal structures, including the nasal spine and septum • Bifid nose and labial frenulum
1	Paramedian craniofacial cleft	13	• Traverses nasal bone and maxilla into the pyriform • Results in an anterior open bite • Effect on the ethmoids results in orbital hypertelorism	• Traverses the dome of the alar cartilage, giving a notched appearance • Widening of the columella and nasal tip
2	Paramedian craniofacial cleft	12	• Traverses the	• Traverses

			lateral mass of the ethmoid with malformation of ethmoidal labyrinth • Localization on the frontal bone (corresponding with no. 12 cleft) is anatomically imprecise • Flat glabella with enlarged frontal sinus	between the nasal tip and the base of the alar cartilage • Associated with cleft lip • Ipsilateral absence of the lacrimal apparatus • Hypertelorism
3	Medial orbitomaxillary cleft or paranasal cleft	11	• The oblique course of the cleft traverses the lacrimal groove • Frontal process of maxilla is often absent • Medial wall of maxillary sinus is often absent	• Traverses the alar base, nasolabial fold and alveolus, causing a cleft lip

4	Median orbitomaxillary cleft	10	• Traverses infraorbital rim and floor medial to infraorbital nerve • Traverses the maxillary sinus leading to sinus exstrophy • Associated	• Vertically traverses the lacrimal segment of the lower lid • Cleft lip is located between philtral crest and commissure

			alveolar cleft appears similar to the typical alveolar cleft	
5	Lateral orbitomaxillary cleft	9	• Traverses the infraorbital rim lateral to infraorbital foramen • Results in an alveolar cleft of the premolar region	• Traverses the medial third of the lower lid • Soft tissue groove is visible on the cheek from lower lid to lateral lip near the commissure
6	Intermaxillozygomatic cleft	8	• Located between the maxilla and zygoma; opens into the inferior orbital fissure	• Laterally located coloboma of the lower lid
7	Temporozygomatic cleft	7	• Absent or atrophic zygomatic arch • Shortening of the ascending ramus and	• Absence of the coronoid process accompanied by ipsilateral absence of the temporalis muscle

			reduced height of the maxilla • Absence of the coronoid and mandibular condyle is common	• Microtia and pretragal enchondroma • Macrostomia
8	Frontozygomatic cleft	6	• When the malar portion of zygoma is absent, the greater wing of sphenoid becomes the lateral-most border of the orbit	• A true cleft of the lateral canthus is associated with Goldenhar syndrome
9	Superolateral orbital cleft	5	• Traverses the superolateral orbit	• Traverses the lateral third of the upper lid
10	Central superior orbital cleft	4	• Traverses medial third of supraorbital rim and orbital roof • Lateral to the supraorbital nerve	• Coloboma of the upper lid can be severe (clinical ablepharia)
11	Superomedial orbital	3	• Traverses the	• Coloboma of

	cleft		ethmoid or supraorbital rim lateral to the ethmoid	the medial third of the upper lid • Cleft traverse the medial brow
12	Paramedian craniofacial cleft	2	• Traverses frontal bone and lateral mass of the ethmoid • Enlargement of the frontal sinus	• Coloboma at the root of the eyebrow
13	Paramedian craniofacial cleft	1	• Traverses the frontal bone and olfactory groove of the cribriform plate • Absence of the ipsilateral nasal bone	• Cleft is medial to the eyebrow • Associated with encephalocel and hypertelorism
14	Median craniofacial dysraphia	0	• As with cleft no. 0, often see duplication or widening of midline structures • Bifid crista galli and ethmoid plate may be present • Rotation of the sphenoid wings causes	• Widening or duplication of midline anatomy, including frontonasal encephalocel hypertelorism and telecanthus

			attenuation of the middle cranial fossa	
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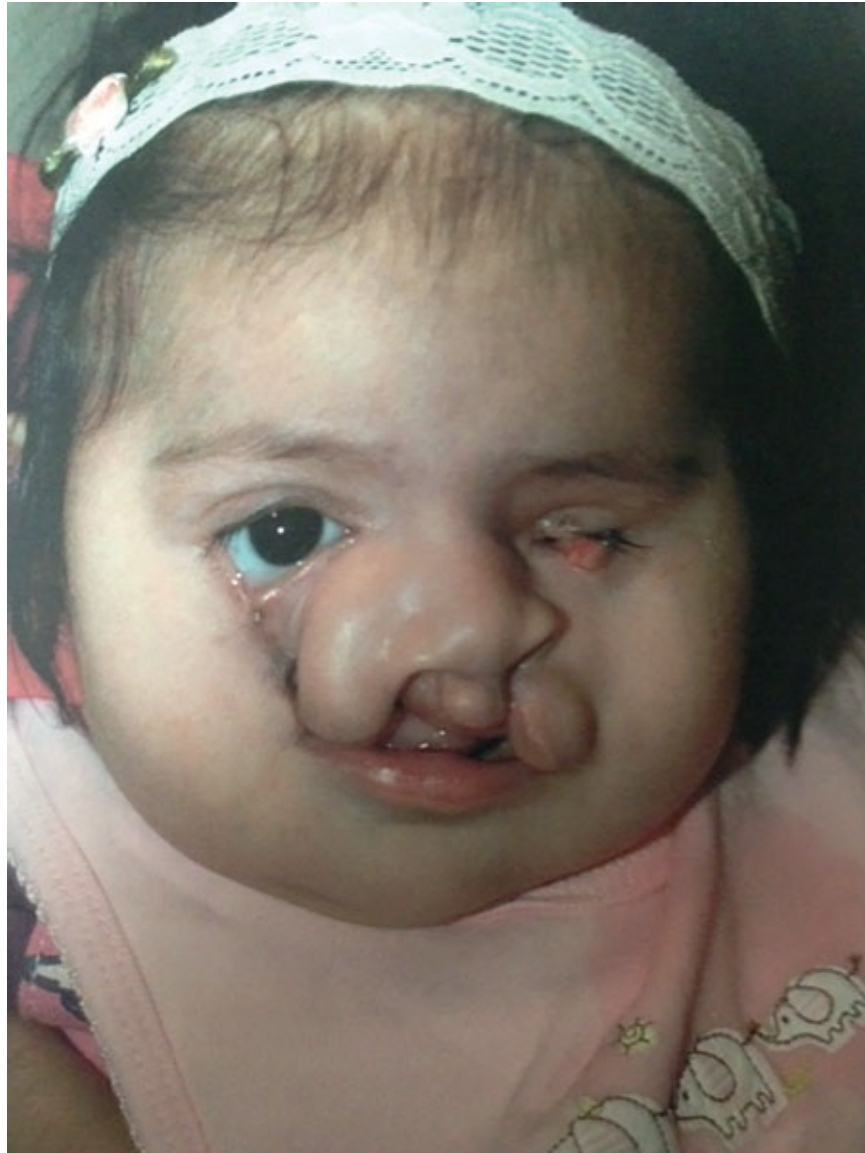


FIG 2 • Patient with a Tessier no. 5 cleft on the right side of the face and no. 3 cleft on the left.

- From midline to the infraorbital foramen, the physical deformity and morbidity of the soft tissue defects are more evident compared to the bony defects (**FIG 2**).

- From the infraorbital foramen to the temporal bone, bony defects are more clinically severe with the exception of changes to the external ear.
- The spectrum of soft tissue deficiency of facial clefts varies more widely than standard labiopalatine clefts.

IMAGING

- A maxillofacial CT scan helps define the anatomy of the orbit and maxilla.
- The orbital floor defect and position of the zygoma are key features to examine.
- Evaluate for comorbid conditions (eg, cardiopulmonary anomalies).

DIFFERENTIAL DIAGNOSIS

- Hypertelorism
- Microphthalmias
- Orbital dystopias
- Treacher Collins syndrome
- Goldenhar syndrome
- Hemifacial microsomia are all associated with facial clefting

NONOPERATIVE MANAGEMENT

- Management is tailored to each individual patient and guided by principles over protocols.
- The older the patient at the time of bone grafting, the better.
- The one exception is if the cornea is compromised. Earlier surgery is mandatory in this case.
- The eye should always be hydrated if exposure is suspected due to facial clefting.

SURGICAL MANAGEMENT

- This chapter focuses on the management of Tessier no. 3, 4, and 5 clefts.
- Tessier clefts other than 0/14, 0/13, and 2/13 require a large amount of bone.
 - Otherwise, the bone resorbs and has to be regrafted several times because it does not grow with the patient.
- There can be major soft tissue defects with minor bone defects and vice versa.
- Marked individuality is the rule.
- Careful attention to eyelid colobomas is mandatory.
- There may be a future for cadaver grafts for initial surgeries because the bone

graft sources are limited in children.

- The ideal time for grafting is after facial growth is nearing completion. At this time, grafts do not resorb to the same extent.

Preoperative Planning

- Ophthalmologic exam is documented preoperatively.
- Goals of surgical management of Tessier clefts no. 3, 4, and 5^{2,3}:
 - Protect the cornea from exposure keratopathy and blindness with early repair of colobomas (upper greater than lower lid).
 - Early repair of soft tissue deformities with rotation advancement and avoidance of Z-plasty incisions that violate subunit principles.⁴
 - Address anatomic structures for optimal symmetry (lip, nasal ala, alveolus, inferior orbit/globe, and medial canthus).
 - Plan incisions along subunit lines whenever possible.
 - Dissection and anatomic repositioning of facial musculature improves future animation and midface growth.⁴
 - Liberal use of secondary tissue expansion for wider clefts where medial subunit incision lines were not feasible initially.²
- As a general rule, 2 to 3 mm of overcorrection is required when suspending the medial canthus, adding bone to the inferior orbital rim, and dropping the cleft-side alar base are essential to durable results.⁴
- Split calvarial bone grafts can be obtained after 5 years of age.
- Orthodontic management of occlusion follows a timeline similar to labiopalatine clefts.

Positioning

- Supine with shoulder role to extend the neck
- The endotracheal tube is positioned at midline.
- The face and neck receive a sterile prep (Betadine); eyes are irrigated with balanced salt solution (BSS) and closed with ophthalmic ointment.
- The head is draped with the entire face in the field.

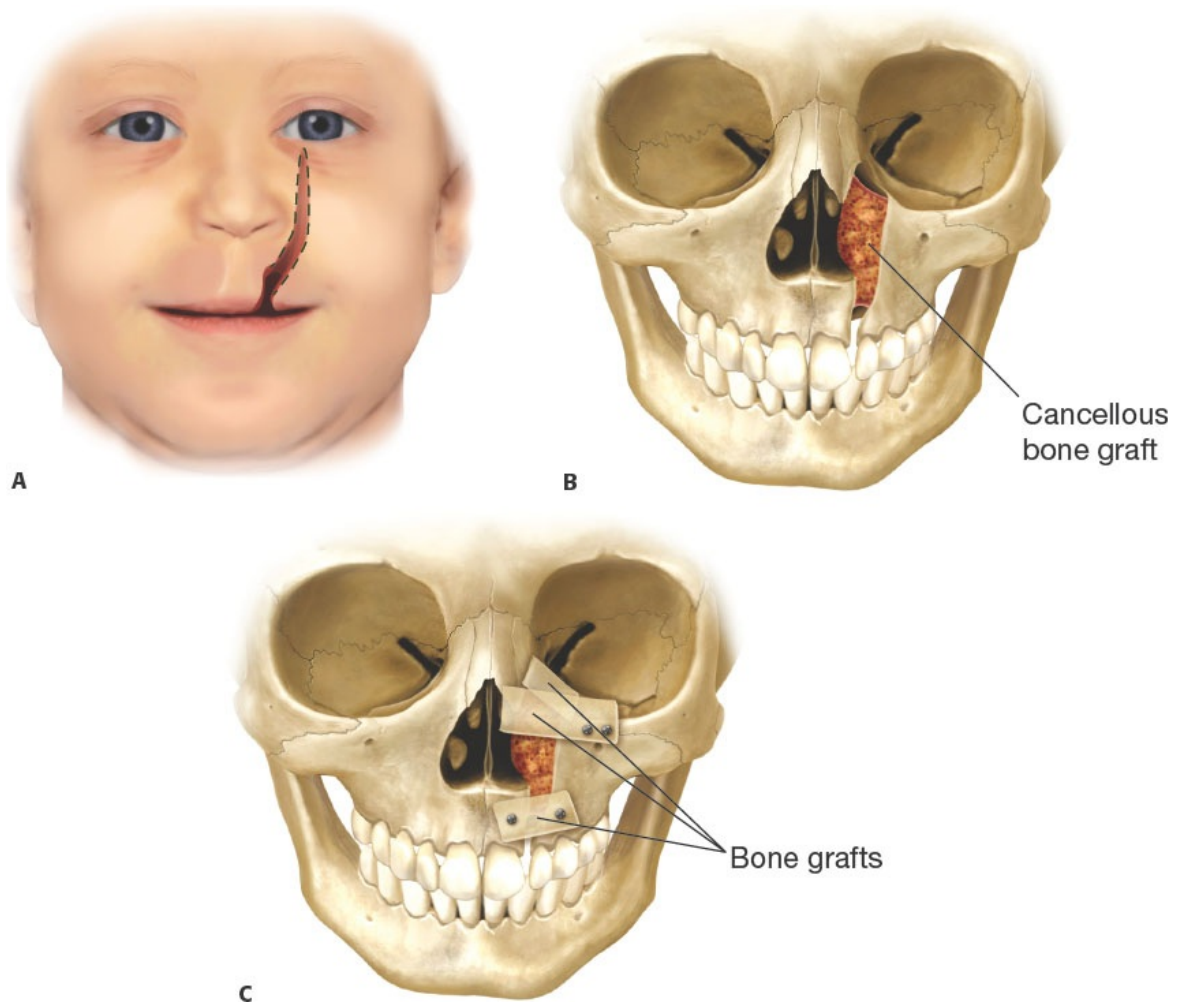
Approach

- The designs for skin incision must be tailored to the severity of soft tissue deficiency between the nasal ala and medial canthus. A simple Z-plasty approach is shown.

TECHNIQUES

■ Management of Tessier Cleft No. 3, 4, or 5

- The skin is incised along subunit lines medially (**TECH FIG 1A**).
- Incise the medial side of the cleft and then the lateral side. The subunits are the lip, nose, and then the cheek-nose junction.
- For soft tissue–only operations, facial muscles are reapproximated (nasalis, orbicularis oculi, and oris).
- For bony clefts, dissection is extended to the bony cleft margin (**TECH FIG 1B**).
- The bony margins are exposed with subperiosteal dissection.
 - Unlike labiopalatine clefts, our practice is to refresh the bone edges with a bur similar to the technique described by Tessier.
- The dimensions of autologous bone needed for harvest are measured and confirmed.
- Autologous bone (calvarial, iliac, tibial) is preferred over nonautologous bone, but in our experience, demineralized cadaveric bone substitutes are also useful.
- Bone grafts are placed to bridge the cleft and approximate normal anatomic contours while anticipating a significant degree of graft resorption.
- Overcorrecting natural anatomic contour is recommended to the maximal extent that soft tissue coverage allows.
- To that end, wide periosteal elevation of soft tissue, as advocated by Tessier (lateral to the molars on each side), is allowed.
- To gain additional soft tissue mobility for wide or bilateral facial clefts, Tessier advised a back-cut in the periosteum along the lateral maxillary buttress.
- The bone grafts are fixed as necessary using lag screws, 2-0 Vicryl, or are simply held in place by the soft tissue envelope and globe (**TECH FIG 1C**).



TECH FIG 1 • A. To access the underlying bony defect, incisions are made along the border of the cleft, at the junction of skin and mucosa. **B.** Once incisions are made, the body margins of the cleft are exposed, and cancellous bone is used to fill the entire defect. **C.** In addition to cancellous bone filling, cortical bone should be used along the alveolar edge and the orbital edge and then fixed into position with screws.

- Medullary (cancellous) bone is used like plaster to fill gaps between cortical bone grafts and should lay over the interface of graft and maxilla.
- Lower eyelid support is achieved with bone grafts to the orbital rim and inferiorly based frontonasal flaps.
- Bone grafts to the orbital rim should exceed the normal height by 2 to 3 mm

anticipating partial resorption.

- Medial canthopexy is best done using a transnasal wire technique.
- The lateral canthus is suspended vertically with anchoring sutures to the orbital periosteum superiorly. Lateral traction places the medial canthopexy at risk.
- Proper bone graft volume necessitates moderate tension of the soft tissue at the time of closure.
- Meticulous layered closure of periosteum, mucosa, muscle, and skin is performed top-down to align lower lids, malar soft tissue, alar bases, and involved lip segments. Approximating the orbital to malar periosteum is essential for malar suspension.
- A tarsorrhaphy is recommended.
- If parietal bone is harvested, a 7-French closed suction drain is placed and removed at 24 to 48 hours.
- The goals of revision at the time of secondary surgery are to conceal incisions along medial subunit lines.
 - A combination of planning far into the future at the time of initial surgery, nasalis muscle dissection and reinsertion, and tissue expansion to allow medialization of scars is essential to achieve optimal surgical and psychosocial outcomes.^{2,4}

PEARLS AND PITFALLS

Physical findings

- Soft tissue and bone deformities often do not correspond to each other.
- Medial to the infraorbital nerve, the soft tissue deformities predominate.
- Lateral to the infraorbital nerve, bony deformities predominate.

Technique

- Z-plasty incisions that violate subunit principles will not improve with time.²
- For wide clefts where Z-plasties are used for initial closure, future use of tissue expansion to reposition scars along medial subunit lines markedly improves appearance.²
- The orbital rim bone graft is essential for lower eyelid support and correction of dystopia.

- Raising the rim and globe 2–3 mm (on-table) compared to the noncleft side is advised.
- We recommend periosteal coverage of bone grafts whenever possible.
- Calvarial bone is preferred over rib grafts.
- Overcorrecting the alignment of key structures by 2–3 mm is advised.^{2–4}
- Upper eyelid colobomas pose a greater risk to vision loss and should be corrected early.²

Postoperative

- Eye ointment should always be used to protect the eye.
- Repeat bone grafting may be required.

- For more severe deficiencies, an inferiorly based paramedian frontonasal flap can be designed to rotate 90 degrees toward the facial cleft to provide exposure and additional soft tissue between nasal ala and medial canthus (this maneuver helps to lengthen the nose and support the lower lid).
- Anatomic structures along the facial cleft margins are often hypoplastic or absent.
- A Doppler probe can be used to assess and preserve the ipsilateral angular artery. If the angular artery is absent, collateral flow from the contralateral system will perfuse an inferiorly based frontonasal flap.
- The lacrimal system is absent or nonfunctional in most Tessier cleft number 3 cases. If present, the anatomy is defined using probes and a lacrimal duct stent is placed.
- The insertion and function of muscles located between the cleft and nasal midline (nasalis, levator labii superioris, orbicularis oris, and orbicularis oculi) are often abnormal.

POSTOPERATIVE CARE

- Eye ointment should be used to keep the eye lubricated.
- Chlorhexidine mouth wash should be used if patient is old enough to cooperate; if not, water gargle after each meal is advised.
- After healing, a light massage to the eyelid to soften scar tissue should be applied.

OUTCOMES

- Secondary bone grafts may be required due to lack of growth in the area of the graft.

- Bone resorption and/or loss should be anticipated.

COMPLICATIONS

- Bone infection, especially involving areas of the bony reconstruction where it will take the longest for the avascular bone graft to be replaced with new vascular bone
- Wound dehiscence
- Bone resorption
- Skin retraction (especially involving the lower eyelid)

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CHAPTER Gingivoperiosteoplasty

Mark C. Martin

DEFINITION

- Involvement of the alveolus in an oral cleft requires treatment to establish bony continuity of the divided maxilla.
- Closure of the alveolar cleft has many positive effects including preventing nasal regurgitation of liquids, preservation of crestal bone height necessary for periodontal health, allowing safe orthodontic movement of teeth, and improving stability of the maxillary arch against relapse after occlusal correction.
- The ideal age for alveolar cleft closure is controversial.^{1–4}
- Gingivoperiosteoplasty (GPOP) refers to repair of the alveolar cleft without bone grafting with the intention of promoting osteogenic bridging of the cleft by surgically creating a closed space across the alveolar cleft lined by mucoperiosteal flaps.

ANATOMY

- The alveolar cleft ranges from a minor notch to a complete cleft of the primary and secondary palate.
- The cleft presents as a variable gap that involves displacement, deformity, and hypoplasia.
- The cleft margin on the major segment flares anteriorly and deviates toward the noncleft side, and the alveolar stump curves cranially as the growth force of the vomerine septum lacks a restraining connection to the lesser maxillary segment (**FIG 1A**).
- The cleft margin of the minor segment is positioned posteriorly, and its alveolar stump curves in a cranial direction from the frontal view as it

approaches the cleft (**FIG 1**).

- The maxillary primary central incisors erupt at a variable age (usually between 6 and 12 months) and depending on the age of presentation and the surgeon's preferred timing for GPOP, these teeth may or may not be present at the time of surgery.
- The primary lateral incisor erupts between 12 and 18 months and on the cleft side is commonly hypoplastic or may be absent or accompanied by supernumerary teeth.
- Natal teeth may go unnoticed early in life in the setting of the cleft and be present high in the nose, which can affect the design of mucoperiosteal flaps.
- The abnormal anatomy of the lateral cleft must be recognized as failure to develop different tissue types with heterotopic placement of existing tissues; choosing nonosteogenic membranes to line the alveolus repair may diminish the chance of adequate bone formation (**FIG 1B-D**).
- Synergistic with correct lining of the GPOP, the use of a medial nasal lining flap to resurface a lateral vestibular releasing incision between vestibular skin (vibrissae) and vestibular mucosa (hairless) allows correction of alar base position without using nonanatomic flaps.
- The anatomy of the medial cleft is difficult to visualize due to the three-dimensional deformity (**FIG 1E-G**).
- Dislocation of the caudal septum into the noncleft nasal floor and the cranial inclination of the medial stump of the alveolus creates an acute angle between the septal mucoperichondrium and nasal floor mucoperiosteum, which can be challenging to dissect and mobilize.
- By lifting the medial nasal lining flap in continuity with the septal mucoperichondrium and subsequently correcting the caudal septum in the midline, the medial nasal lining flap can be used for tension-free reconstruction of the nasal floor, as well as to line the vestibular release with thin supple tissue (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Age of patient at presentation is important.
 - Early institution of nasoalveolar molding (NAM) is thought to have more lasting effects on nasal cartilages due to the presence of maternal hormones.⁵
 - Older children are more likely to disturb the appliance creating compliance difficulties.

- An alveolar cleft with alveolar segments in apposition may not benefit from NAM but should be monitored for unfavorable changes in position (increased gap) of the maxillary segments that can occur with oral-digital habits or feeding behaviors.
- An isolated cleft of the lip (primary palate) may benefit from the nasal molding effects of NAM, but the change at the alveolus will be limited by the rigidity imparted by bony continuity of the secondary palate.
- Infants with medical comorbidities will often tolerate NAM therapy, but individualized attention to the appliance's effect on feeding and weight gain is indicated.

IMAGING

- Imaging in the setting of isolated cleft lip and palate is not normally obtained before GPOP, but may be indicated to evaluate more extensive craniofacial clefts.
- Imaging to assess results of GPOP is not standardized and may involve a variety of modalities.
- Plain occlusal radiographs are commonly used to assess alveolar bone formation in young patients (primary and early mixed dentition) and periapical and/or panoramic radiographs in older patients (late mixed and permanent dentition).
- Cone-beam computed tomography (CBCT) is increasingly used and provides more detailed information than plain films regarding the adequacy of alveolar bone; the clinical utility of CBCT use is still under evaluation.

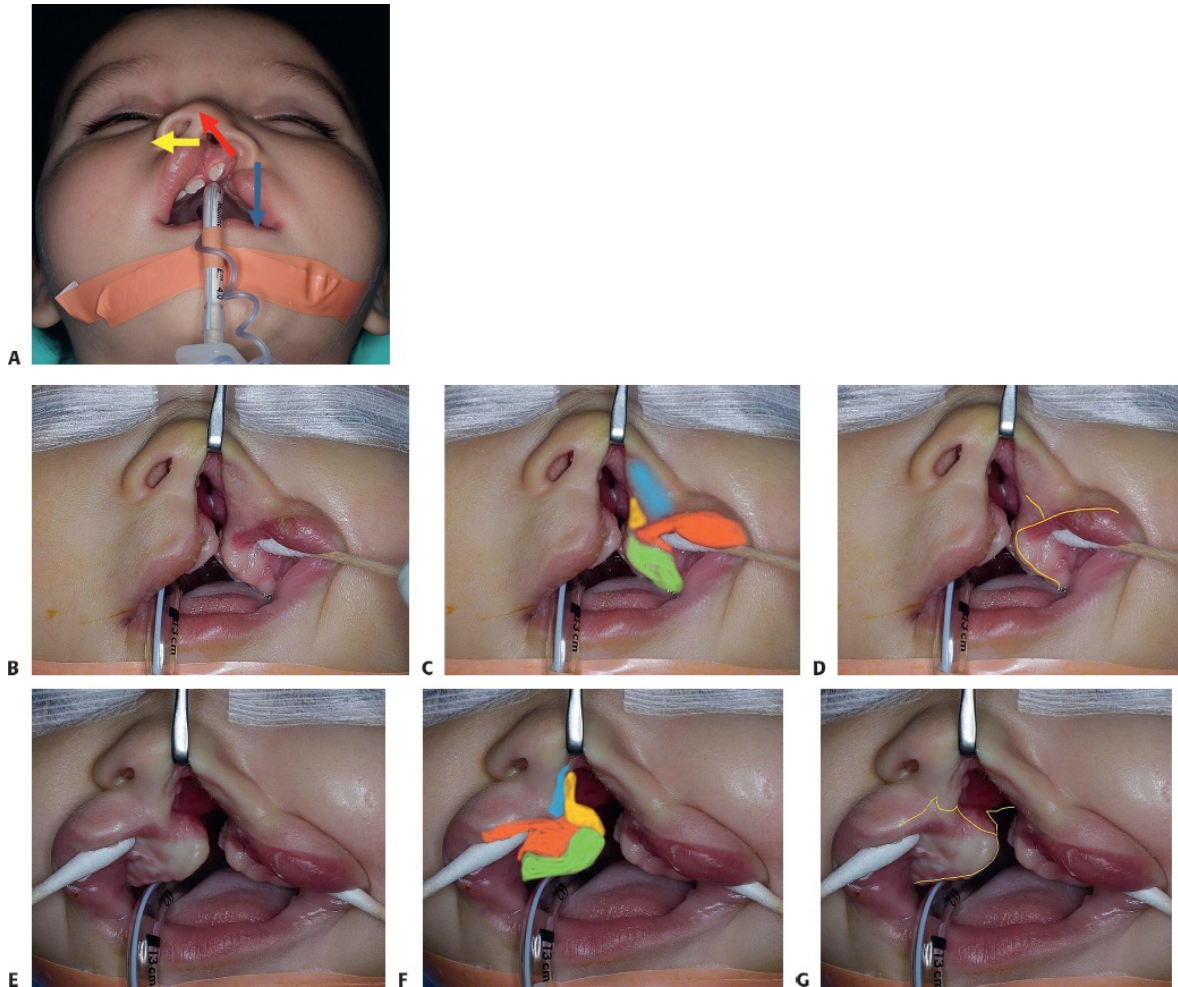


FIG 1 • A. The cleft alveolus deformity. The columellar base is displaced toward the noncleft side (*yellow arrow*). The greater segment alveolus stump is flared anteriorly (*red arrow*). The alar base on the cleft side is displaced posteriorly through its relationship to the pyriform rim (*blue arrow*). **B.** Lateral cleft anatomy. **C.** Gingival mucoperiosteum shaded *green*, labial mucosa shaded *orange*, vestibular skin with vibrissae shaded *blue*, vestibular mucosa *pink*, and hairless shaded *yellow*. **D.** *Yellow* incision plan including vestibular release between vestibular skin and vestibular mucosa to achieve medial nasal lining flap during closure. **E.** Medial cleft anatomy. **F.** Gingival mucoperiosteum

shaded *green*, labial mucosa shaded *orange*, vestibular skin with vibrissae fixed to medial crus shaded *blue*, mobile vestibular mucosa of membranous septum and nasal floor mucoperiosteum shaded *pink*, and hairless shaded *yellow*. **G.** Incision plan including medial nasal floor mucoperiosteal lining flap for nasal floor repair and lining of lateral vestibular back cut.

NONOPERATIVE MANAGEMENT

- There is no dispute that alveolar clefts benefit from repair; however, the timing and techniques for repair remain controversial.^{1–4}
- If GPOP is not done in infancy by design, or if it has been done unsuccessfully, secondary alveolar cleft repair with autologous bone grafting (most commonly with cancellous iliac crest bone) is a well-established procedure with a high success rate.⁶

SURGICAL MANAGEMENT

- GPOP in infancy is technically challenging and reported outcomes vary widely among authors.^{1–3,6–8}
- Some authors have reported an increase in midface growth deficiency, whereas others have not.^{2,4}
- A surgeon's technique has been shown to be an important determinant of facial growth after repair of oral clefts in general.
- Modern authors have demonstrated useful bone filling of the alveolar cleft from 73% to 100% depending on the specific technique and protocol.^{1,6}
- Even in patients who do not form adequate bone after GPOP, it has been reported that subsequent successful standard mixed dentition bone grafting is technically easier than in those not having undergone GPOP.⁶
- Successful GPOP eliminates one operation at school age and the need to use a painful distant donor site (most commonly the iliac crest in North America).
- GPOP is often preceded by NAM, which requires a skilled dental professional, significant time commitment from caregivers, may be costly, and can be ineffective in the setting of noncompliance.⁹

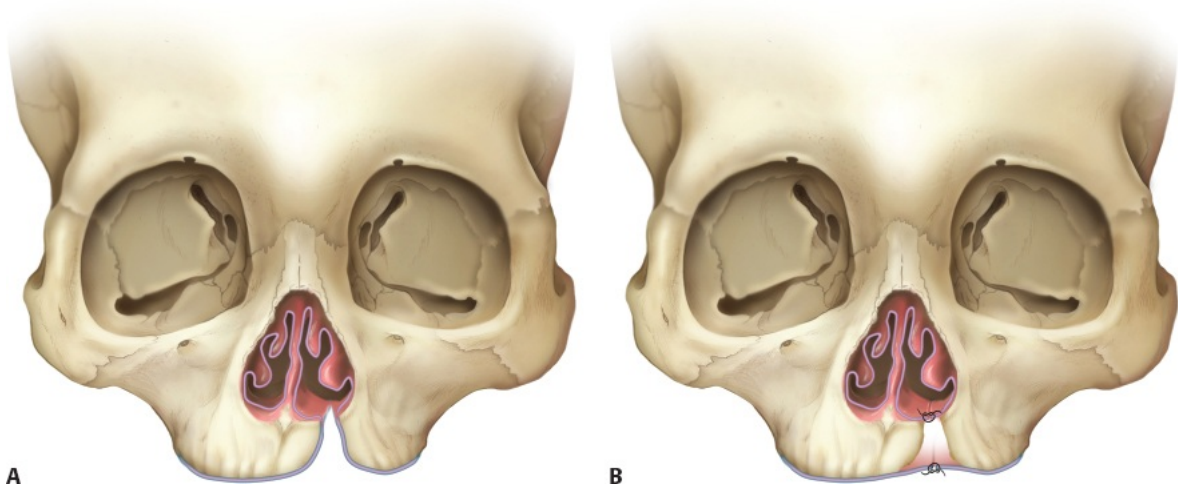


FIG 2 • A. Infant skull schematic showing caudal septal dislocation into noncleft nasal floor with *dark pink* nasal lining and *light pink* palate mucoperiosteum. **B.** Midline correction of the caudal septum allows lateral movement of the in-continuity medial nasal floor lining flap in concert with palatal mucoperiosteal repair.

- GPOP is most often performed at the time of cleft lip and nasal repair in North America either after NAM or in the setting of a pre-existing narrow cleft gap.
- Alternatively, mucoperiosteal repair of the alveolus can also be highly successful when performed at the time of palate repair, after muscle forces of the repaired lip mold the palatal segments into proximity.^{1,10}

Preoperative Planning

- Children with cleft lip and palate should be evaluated before surgery by a multidisciplinary team including the cleft surgeon, pediatrician, medical geneticist, otolaryngologist, pediatric dentist, speech and language pathologist, and social worker.
- Children with complete cleft lip and palate with an alveolar gap and/or significant nasal deformity benefit from NAM by a pediatric dentist or orthodontist with training and experience in the technique.
- The purpose of NAM is to gradually approximate the alveolar segments and to mold the nasal deformity in order to allow GPOP with minimal dissection and to facilitate cleft lip and nasal repair (**FIG 3**).
- Patients should be evaluated and treated by a trained pediatric anesthesiologist.

Positioning

- An oral Ring-Adair-Elwyn (RAE) tube is used and is secured in the midline.
- A short “mesentery” of tape allows use of a Dingman retractor without pinching the lower lip (**FIG 3B**).
- The infant is treated in the supine position using a soft headrest with mild neck extension and routine warming measures.
- The eyes are irrigated with balanced salt solution and protected with skin tape.

Approach

- Skoog reported a technique using wide undermining of the maxilla and periosteal flaps with Surgicel implantation in an attempt to promote bone formation at the alveolar cleft without bone graft.
- Skoog’s technique utilizing periosteal flaps has been generally abandoned due to reports of midface growth inhibition and poor bone formation.¹¹



FIG 3 • A. A wide cleft alveolus gap at initial presentation. **B.** After nasoalveolar molding with abutted alveolar segments.

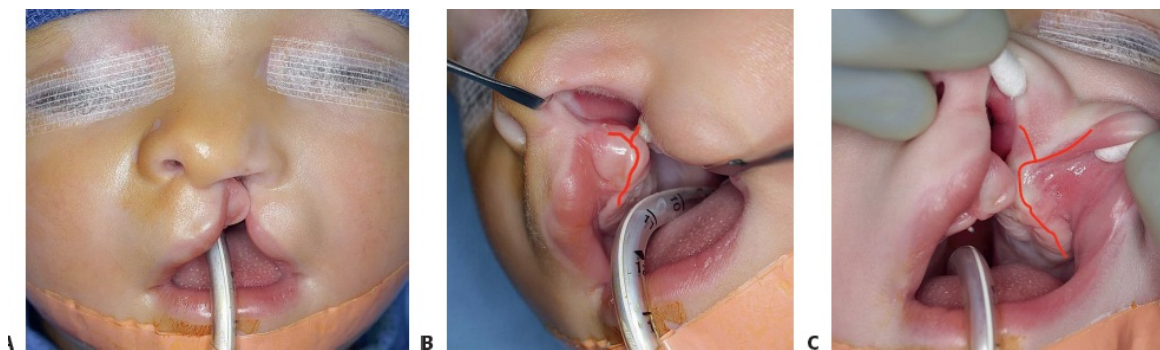
- Millard reported a protocol involving a pin-retained appliance for maxillary segment positioning followed by GOP with small flaps.³
- Concerns about midface growth inhibition, possibly related to strong forces generated by the screw-activated facial orthopedic appliances, limit the current use of protocols relying on active pin-retained appliances.

- Smith et al. suggested an anatomic repair of the primary palate with mucoperiosteal flaps after physiologic alveolus molding occurred following initial nasolabial and soft palate repair, but reported no long-term outcomes.¹⁰
- Meazzini et al. used a similar protocol to that suggested by Smith et al. and reported a 100% success in avoiding secondary bone grafting.¹
- Wood et al. reported that a Millard-type GPOP after NAM did not result in early midface growth inhibition.⁴

TECHNIQUES

■ Markings and Incisions

- The plan for the cleft lip repair is marked per the surgeons' preferred technique.
- The alveolar cleft is inspected, and local anesthetic with epinephrine is injected along the gingival margins, palatal mucoperiosteum, nasal septum, and nasal floor (**TECH FIG 1A**).
- Incisions are made on the crest of the alveolus, mesial and distal to the cleft at the junction of gingival mucoperiosteum and palatal mucoperiosteum (**TECH FIG 1B,C**).
- Incisions are then made on the palatal surface along the margins of the cleft at the junction where the *deep red* nasal floor lining meets the *light pink* palatal mucoperiosteum.
- As part of the concurrent lip repair, the mobile labial mucosa is incised from the nasal vestibular mucosa on the lateral segment and the mobile mucosa of the membranous septum on the medial segment (**TECH FIG 1B**).
- The alveolar ridge incision between gingival and palatal mucoperiosteum converges with the incision between labial mucosa and vestibular mucosa at the entrance to the floor of the nose (**TECH FIG 1C**).



TECH FIG 1 • **A.** Frontal view of an infant with complete cleft lip and palate. **B.** Greater segment incisions between gingival and palatal mucoperiosteum on the crest of the alveolus and diverging at the nasal floor to define the medial nasal floor lining flap. **C.** Lesser segment incision between gingival and palatal mucoperiosteum along with vestibular release incision between vestibular skin and vestibular mucosa.

■ Flap Elevation

- The lateral segment gingivoperiosteal flap is elevated gently with a fine periosteal elevator.
 - Dissection should proceed mesial to distal and caudal to cranial starting at the crest of the alveolus and proceeding up the maxilla.
 - The teeth in the lateral segment are typically unerupted at the usual time for GPOP, and it is important to be gentle with dissection here as *forceful dissection directed from cranial to caudal has the potential to avulse unerupted teeth.*
- Dissection at the crest of the alveolar ridge should be completed sharply with scissors or scalpel to leave the tooth bud intact and not expose the crown.
- A lateral segment palatal mucoperiosteal flap is gently elevated with a Freer elevator with similar precautions to avoid traction on teeth at the crest of the alveolus.
- The mucoperiosteum of the lateral nasal floor is carefully elevated with a periosteal elevator.

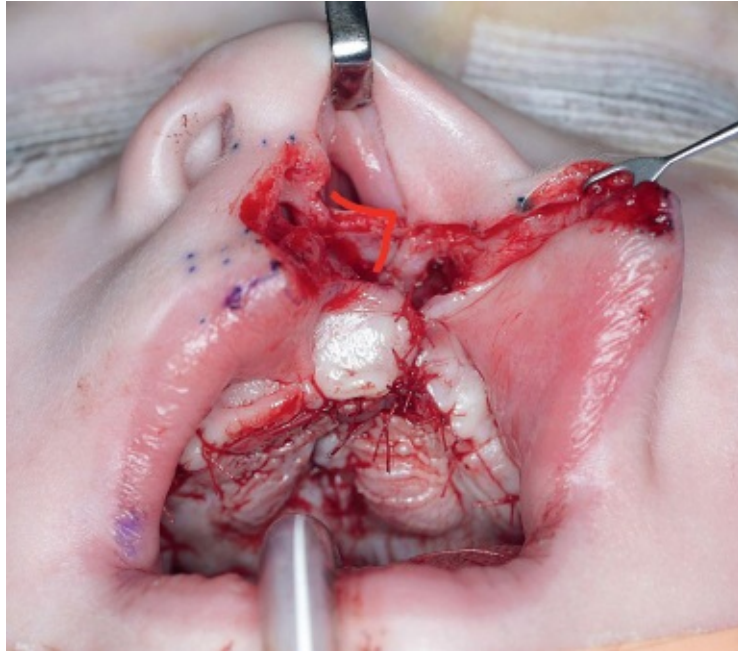
- Elevation of the gingival, palatal, and nasal floor mucoperiosteal flaps on the lateral segment is performed progressively, only up to the point where tension-free closure becomes possible.
- On the medial segment, the gingivoperiosteal flap is elevated distal to mesial with a periosteal elevator in a subperiosteal plane, except at the crest of the alveolus where sharp dissection with scissors or scalpel frees the flap from the soft tissue of the tooth bud; the crown is not exposed if it has not yet erupted.
- A medial segment primary palatal mucoperiosteal flap is elevated with a Freer elevator.
- A medial segment nasal lining flap is elevated from the bone of the nasal floor, over the nasal surface of the primary palate up to the junction with the septum.
- The septal-nasal floor angle may be very acute, and gentle dissection is important to avoid flap perforation or injury to the caudal septum.

■ Repositioning of Elements

- At this point, contralateral subperichondrial dissection on the cartilaginous septum may proceed to allow midline relocation of the caudal septal cartilage.
 - The caudal septal cartilage is thin. Avoid damaging the septum during this step.
- Septal relocation to the midline has beneficial effects.
 - Subsequent primary rhinoplasty is easier when the septum is straight.
 - Bringing the septum to the midline lateralizes the medial nasal lining flap to allow tension-free nasal floor reconstruction (see **TECH FIG 1B**).
- The cleft deformity results in a posterior positioning of the bony nasal pyriform rim on the cleft side.
- The alar base and lateral crus of the lower lateral cartilage are tethered posteriorly and benefit from a vestibular releasing incision to allow repositioning of the alar base and lateral crus (see **TECH FIG 1C**).
- The medial nasal floor lining flap based on the cleft-side septal mucoperichondrium is used to span the nasal floor cleft and can also be used to line the defect resulting from a vestibular releasing incision (obviating the need for nonanatomic labial or inferior turbinate mucosal flaps; **TECH FIG**

2).

- At this point, the cleft-side alar dome can be easily repositioned without vestibular tightness or vestibular web formation.



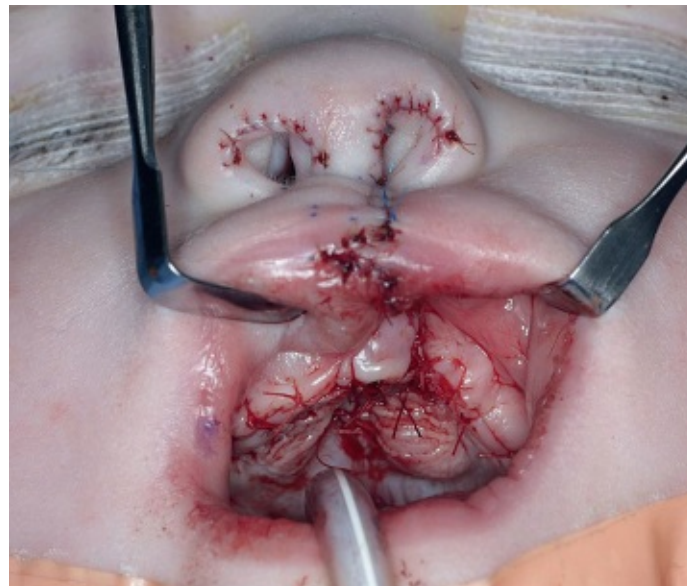
TECH FIG 2 • Repaired palatal and gingival mucoperiosteal flaps with view of medial nasal floor lining flap inset into apex of vestibular releasing incision.

■ Suturing and Completion

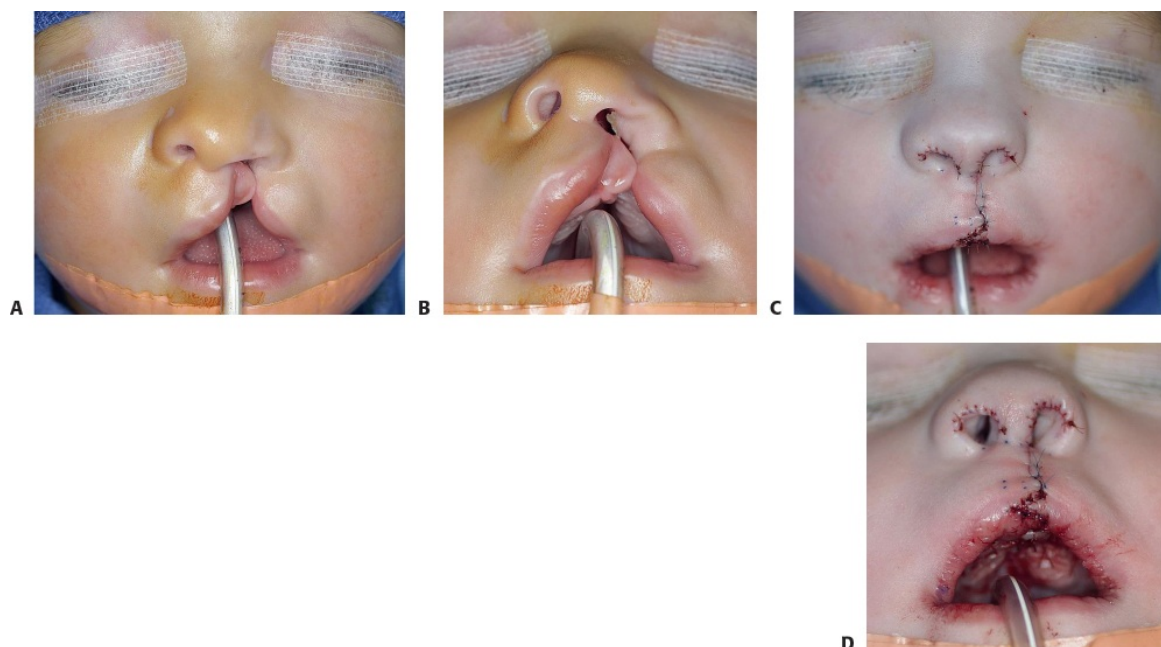
- Nasal floor mucosal repair is performed with 6-0 Vicryl or equivalent sutures.
- Nostril sill skin repair is completed with 6-0 chromic or equivalent simple sutures up to the junction of the sill and cutaneous lip.
- A short, locking Castroviejo needle holder is useful for intranasal suturing, where access is limited.
- If the ipsilateral septal mucoperichondrial undermining has been avoided up to this point, the septum will typically be held in passive midline correction by the effect of the nasal floor repair.
- If the ipsilateral septal mucoperichondrium was inadvertently undermined,

the caudal septum may be sutured superficially to bone with an absorbable suture to maintain it in midline position.

- Palatal mucoperiosteal flaps are repaired with 5-0 Vicryl or equivalent sutures.
- Gingivoperiosteal flaps are repaired with 5-0 Vicryl or equivalent sutures (**TECH FIG 3**).
- Lip and nose repair proceed per the surgeon's preferred technique (**TECH FIG 4**).
- Vestibular tightness will normally have been eliminated by this point with nasal floor and vestibular repair allowing untethered lower lateral cartilage repositioning.
- Using medial nasal floor mucosa to line the resulting lateral vestibular defect allows anterior positioning of the cleft-side alar base so that cartilage repositioning can be achieved without posterior restraint.



TECH FIG 3 • Repaired cleft of the alveolus and lip.



TECH FIG 4 • Unilateral cleft lip and palate before (A,B) and after (C,D) gingivoperiosteoplasty along with lip and nasal repair showing the beneficial effect of formal nasal floor and vestibular reconstruction on the anteroposterior position of the cleft alar base.

PEARLS AND PITFALLS

Hemostasis

- GPOP is technically demanding and cannot be safely completed in the setting of active bleeding.
- Careful use of epinephrine-containing local anesthetic is essential.

Technique

- The anatomy of the unerupted dentition is unfamiliar to many surgeons and should be studied before attempting GPOP.
- Rough, blunt dissection of gingival flaps can easily luxate unerupted or recently erupted teeth.
- Perform gentle subperiosteal dissection over bone and sharp dissection over unerupted teeth.
- A short, locking Castroviejo needle driver is useful for suturing in tight spaces such as the nasal floor.

	■ Short radius needles such as the P2 are useful for suturing in areas with limited access.
Nasoalveolar molding	■ Close approximation of maxillary segments is critical for minimizing the growth inhibiting effects of surgery. ■ Prolonged NAM has diminishing returns because older infants are more adept at removing the device. ■ Significant skin irritation from taping the device may occur and impede identification of lip landmarks. Discontinuation of the appliance several days before surgery may be indicated for significant skin irritation. ■ The alveolar cleft gap must be diminished through alveolar molding and not through transverse collapse of the segments, as this will lead to loss of arch length and “locking in” of improper arch form.
Cleft lip and nose	■ Midline relocation of the cartilaginous septum simultaneously facilitates primary rhinoplasty and GPOP. ■ By using the primary palatal nasal lining flap to fill the lateral vestibular releasing incision, the use of nonanatomic labial or turbinate mucosal flaps is avoided.

POSTOPERATIVE CARE

- Arm restraints are used only until the effects of general anesthesia have worn off.
- A well-repaired alveolus is not at risk from the infant’s fingers.
- Feeding is resumed using the patient’s preoperative routine with the exception of limiting the use of any hard feeding implements (eg, plastic spoons and cups) or toys until primary healing is observed in the outpatient setting (typically between 10 and 14 days).
- Patients remain in hospital until normal feeding and adequate pain control are achieved (1–2 nights in most cases).
- Patients are seen in the outpatient clinic at weekly intervals until primary healing is confirmed and then at intervals otherwise dictated by early aftercare requirements of associated lip and secondary palate repairs.
- The child is subsequently seen at least yearly in the Cleft and Craniofacial Team Clinic until the end of growth and treatment.

OUTCOMES

- The NYU group studied patients treated with NAM and GPOP using Millard’s

technique at the time of primary lip repair.^{6,8}

- The alveolar cleft sites treated with GPOP did not require secondary alveolar bone grafting in 73% of cases.⁶
- Using cephalometric analysis of unilateral cleft lip and palate patients evaluated before puberty, they found no significant difference in vertical or sagittal midface growth between those receiving GPOP and those who did not.⁸
- Brusati and colleagues performed a technique of gingivoalveoloplasty in concert with palatal repair with more extensive mobilization of mucoperiosteal flaps analogous to those used in secondary bone grafting procedures.
- In a study of 87 unilateral and 29 bilateral cleft lip and palate patients, none required secondary alveolar bone grafting.¹
- In a retrospective study, 15 gingivoalveoloplasty patients were compared with 10 receiving only secondary bone grafts. An increased need for orthognathic surgery was projected for gingivoalveoloplasty patients (26.6%) vs secondary bone grafted patients (10%).²
- Interpreting studies attempting to measure the effect of GPOP on facial growth must account for the wide variability in the rate of orthognathic surgery reported at different centers.
- Daskalogiannakis and Mehta reported a 48% rate of orthognathic surgery for unilateral cleft lip and palate patients.¹²
- Such intercenter variability can relate to many factors:
 - Differing rates of syndromic diagnoses
 - Anthropometric differences between population groups under study
 - Lack of standardized orthognathic surgery indications
 - Variability in acceptance of orthodontic camouflage
 - Cultural variations in concepts of attractiveness
 - Variation in access to interceptive dental treatment
 - Changes in technique over time
 - Errors relating to incomplete records and follow-up
- Preclinical studies have demonstrated risks of neurotoxicity from exposure to common anesthetic agents.¹³
- There has been increased interest in limiting anesthesia exposure in the pediatric population while ongoing clinical studies attempt to quantify the actual risk.
- The possible detrimental effect of early anesthesia may be a consideration

when choosing between surgical lip adhesion and NAM therapy for the purpose of alveolar cleft approximation.

- The burden of multiple surgeries is significant for cleft patients. McIntyre et al. found in their single center retrospective study that unilateral cleft lip and palate patients averaged 9.4 surgeries between birth and age 21.¹⁴ Limiting numbers of surgeries may have significant benefit to patients.
- NAM therapy may be a useful means of reducing secondary operations.
 - Dec et al. found that out of 178 patients undergoing NAM and subsequent staged lip and palate repair, only four palatal fistulas occurred with only one requiring repair.⁷
- Patel et al. found that only 3% of NAM-treated unilateral cleft lip and palate patients required early nasal revision vs 21% of non-NAM patients.⁵

COMPLICATIONS

- Fistula
- Tooth injury
- Suture granuloma
- Growth restriction
- Inadequate bone formation requiring secondary bone grafting
- Infection

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32 BMP Use in the Craniofacial Skeleton

CHAPTER

James P. Bradley and Kristen S. Yee

DEFINITION

- Synthesized recombinant human bone morphogenetic proteins (BMPs) have osteoinductive activity (ability to induce new bone formation) for use in the craniofacial skeleton and may replace bone grafts, which have a high morbidity, and alloplastic grafts, which are incompatible with the growing skeleton.
- Craniofacial operative procedures that utilize BMP-2 and a resorbable matrix include (a) alveolar cleft repair (both primary and secondary), (b) cranial vault defect reconstruction, and, less commonly, skeletal reconstruction, like (c) mandibular defect repair with supportive crib or (d) rare Tessier cleft repair.

ANATOMY

- Alveolar cleft defects may be unilateral or bilateral and are thought of as three dimensional (3D) trapezoid shapes that span from the floor of the nose (superiorly), to the alveolar ridge (anteriorly), to the bottom of the gingiva or adjacent tooth root with attached gingiva (inferiorly), and to the incisor foramen (posteriorly) (**FIG 1A,B**).
- Cranial vault defects vary in size and location and may be complete or incomplete; these defects have varying degrees of intervening scar from the deep dura to the more superficial periosteum, galea, or skin. Reconstructions of skull defects near the frontal sinuses or other areas lined with mucosal membranes are fraught with infectious problems.¹
- Mandibular defects also vary in size and location and present after tumor resection or as a result of complications of trauma (including nonunion and osteomyelitis).² They may be separated into anterior (symphyseal,

parasymphyseal), lateral (body, ramus), or posterior (condylar).

- Rare Tessier clefts are associated with bony defects in the facial skeleton based on defined embryologic zones numbered from 0 to 14 (**FIG 2**). Skeletal defects correlate with overlying soft tissue deficits and may extend from the maxilla, through the maxillary sinus, into the orbit and/or into the cranium. These skeletal defects benefit from bony reconstruction.

PATHOGENESIS

- Congenital: Facial clefts (common, cleft lip and palate, and rare, Tessier-numbered clefts) occur due to failure of fusion of facial embryologic elements.

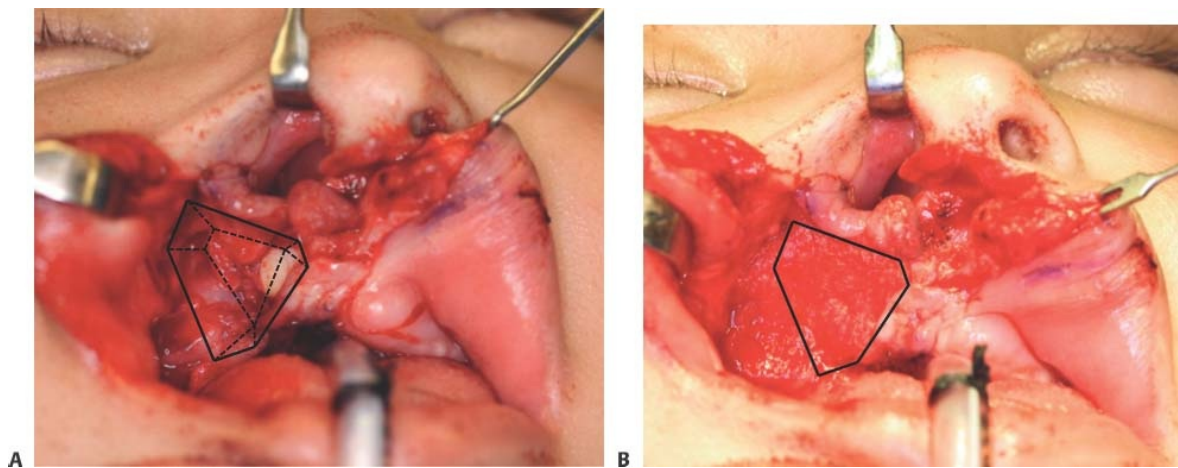


FIG 1 • Intraoperative image of right cleft lip and palate patient during primary lip, nose, and GPP with BMP-2 repair. **A.** The alveolar defect is represented anatomically as a 3D trapezoid that extends from the floor of the nose (superiorly), to the alveolar ridge (anteriorly), to the bottom of the gingiva or adjacent tooth root with attached gingiva (inferiorly) and to the incisor foramen (posteriorly). **B.** The BMP-2–impregnated collagen gel fills the alveolar defect after deep mucosal flaps are closed. Careful soft tissue closure over the implant is then performed.

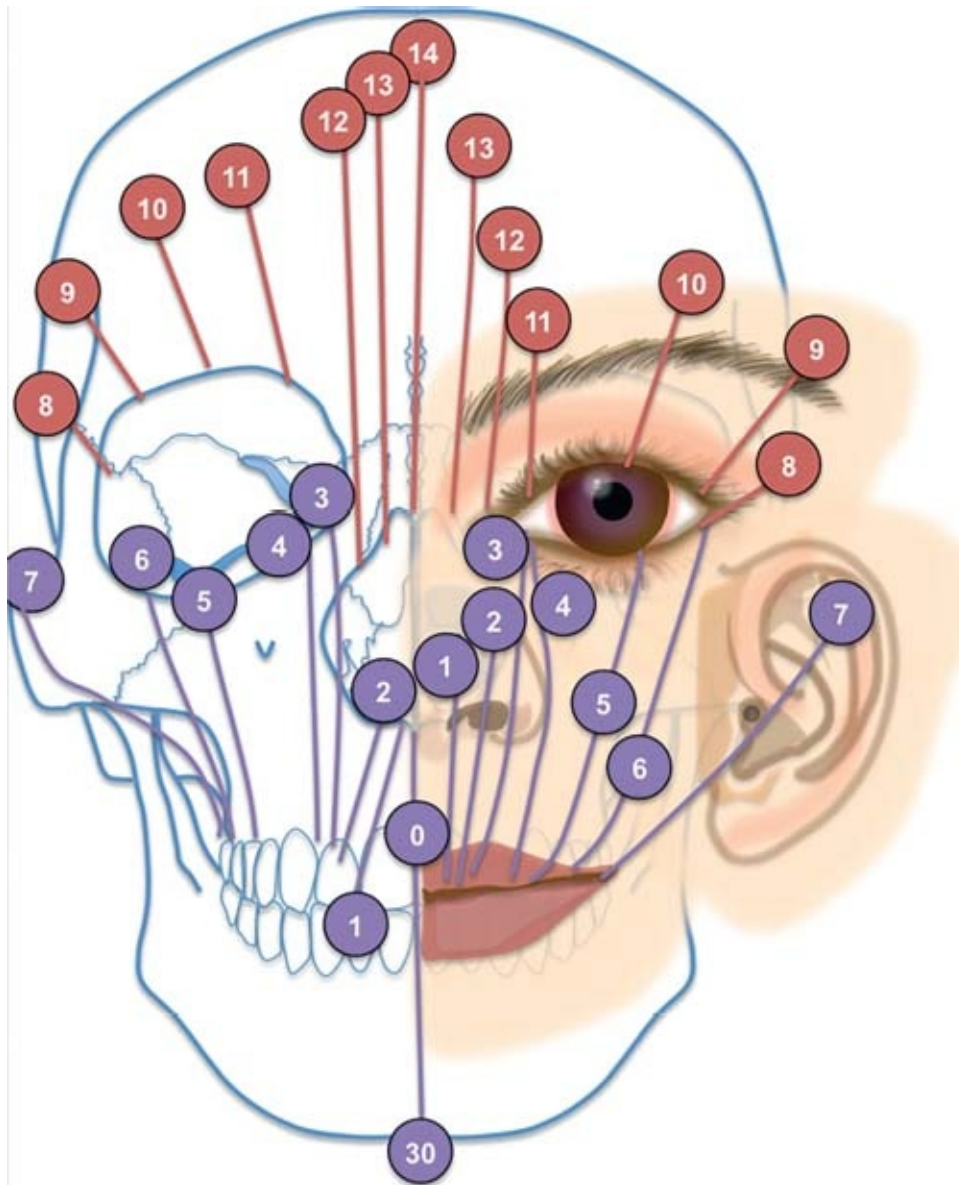


FIG 2 • Tessier classification of craniofacial clefts. Skeletal locations of numeric clefts are depicted on the right side of the face, and soft tissue landmarks are outlined on the left side of the face. Facial clefts are numbered 0 through 7, and cranial clefts are numbered 8 through 14. A mandibular midline facial cleft is number 30.

- **Oncologic:** Tumors in the craniofacial skeleton may arise from a variety of pathologies involving bone or adjacent soft tissue.

- Traumatic: Defects typically arise as sequelae of initial bony repair, such as nonunion, osteomyelitis, or absorption of a bone flap or graft.^{3,4}

NATURAL HISTORY

- Alveolar clefts that are not repaired (or poorly repaired) can have several consequences.
 - A persistent oronasal fistula may result in poor speech and difficult hygiene.
 - Insufficient or absent bone may prevent eruption of teeth in the cleft area and also result in malocclusion due to maxillary arch collapse.
 - Discontinuity of the maxillary arch increases difficulty of a future Le Fort I advancement.
 - Lack of bone under the nasal base results in nasal asymmetry.
- Large cranial defects necessitate the use of helmets to protect the brain and may result in the “syndrome of the trephine”—neurologic cognitive deficits related to disruption of equilibrium of intracranial pressure secondary to exposure of the brain to atmospheric pressure.⁵
- Unrepaired mandibular defects can result in difficulties with mastication and speech and an “Andy Gump” deformity, characterized by severe retrognathia and the appearance of an absent chin from contraction of the soft tissues over the area with missing bone.
- Rare Tessier craniofacial clefts repairs that do not receive adequate skeletal support will result in soft tissue collapse and progressive worsening of the deformity over time.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Alveolar cleft: An alveolar defect can be associated with nasal regurgitation and poor feeding when associated with a cleft palate or oronasal fistula; a gap or notch in the alveolar ridge is seen on examination.
- Cranial defect: The history may include head trauma or prior intracranial hemorrhage necessitating decompressive craniotomy; the edges of the bony defect are palpable, and with long-standing, large defects, the skin may be contracted into the depression (sunken skull deformity).
- Mandibular defect: The patient’s history includes prior mandibular surgical resection. The patient may report problems with mastication, oral competence, or pain. Malocclusion and soft tissue collapse can be seen on exam.
- Rare craniofacial cleft: Larger clefts can be noted on prenatal ultrasound and consultation may be planned before delivery; findings vary depending on the

site and severity of the cleft. Careful examination of the eye and lid structures, and nasal and oral cavities should be performed, particularly when the cleft is adjacent to these structures.

IMAGING

- Alveolar cleft: Although imaging should be used sparingly in infants and children due to risks of radiation exposure, a CT scan can be useful to assess the volume of the defect and the graft “take” after surgery (**FIG 3**). Routine records for secondary alveolar grafting include a panorex and periapical films.
- Cranial defect: A CT scan (1-mm cuts from the apex to the hyoid) with 3D reconstruction gives an accurate assessment of the defect size and location, as well as record of brain pathology, including ventricular size. In addition, a 3D CT scan model may be helpful for intraoperative resorbable plate shaping.
- Mandibular defect: A CT scan with 3D reconstruction, with or without model reconstruction, acts as a road map for reconstruction and guide for creation of custom-made supportive cribs (**FIG 4**).
- Rare Tessier clefts: A CT scan with 3D reconstruction is of paramount importance with these cases because of the unique skeletal abnormalities that occur within Tessier-numbered regions that the outward soft tissue findings only partially suggest.

SURGICAL MANAGEMENT

- Alveolar cleft: Primary alveolar cleft closure at the time of cleft lip or palate repair with gingivoperiosteoplasty (GPP) and BMP-2 is possible after presurgical molding approximates alveolar segments within 2 mm (**FIG 5A,B**). Secondary alveolar closure may be performed after orthodontic palatal expansion at approximately age 6 to 10 years of age.

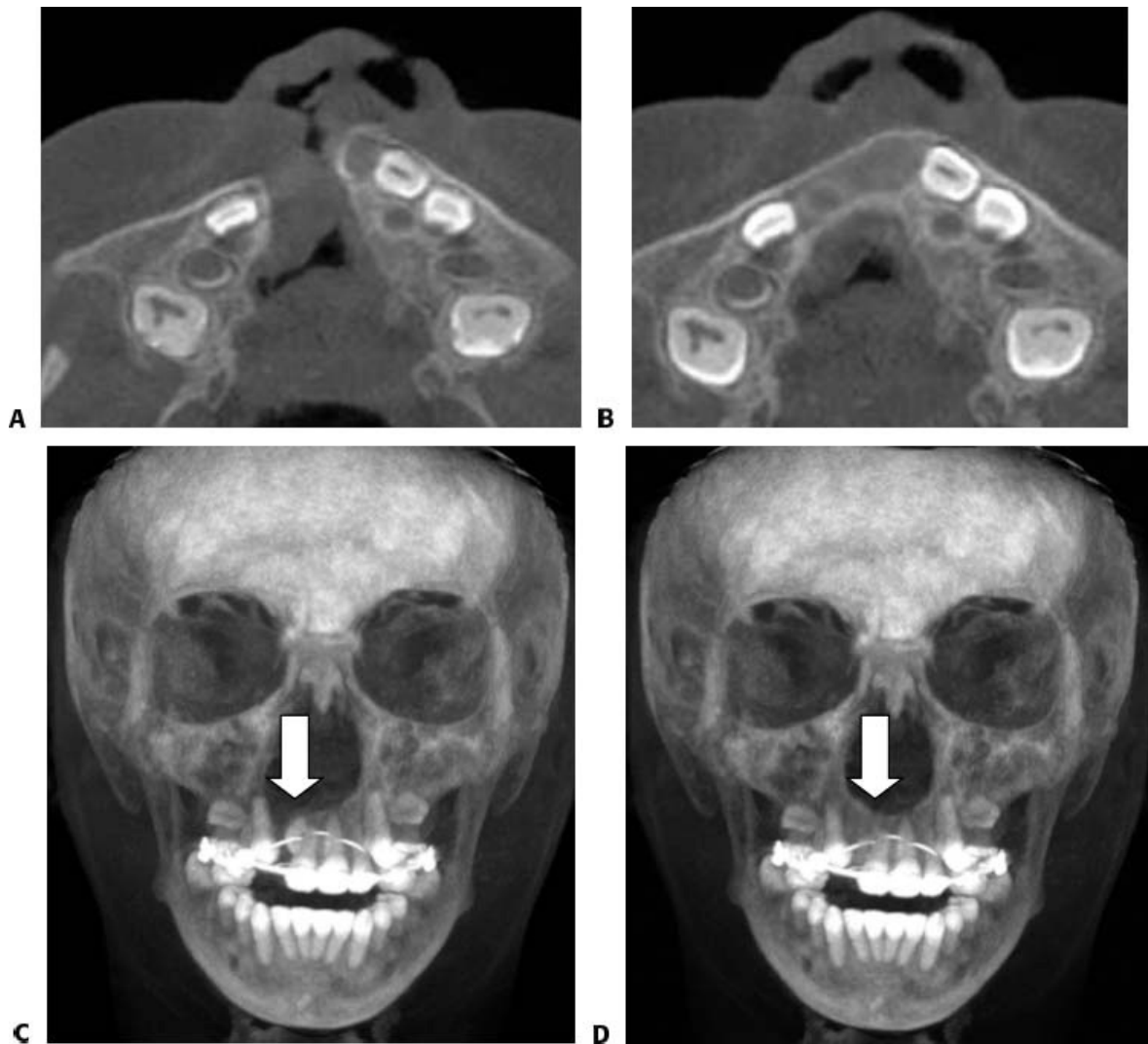


FIG 3 • CT scan with axillary cuts of a patient with right cleft lip and palate. **A.** Preoperative image shows the alveolar defect. **B.** Postoperative image 6 months after gingivoperiosteoplasty (GPP) and BMP-2 grafting shows bony healing and closure of the alveolar defect. 3D CT scan of a patient with right cleft lip and palate. **C.** Preoperative image shows the alveolar defect. **D.** Postoperative image 6 months after GPP and BMP-2 grafting shows bony healing and closure of alveolar defect.

■ Cranial defect: Bilaminar resorbable matrix with BMP-2 reconstruction is an

alternative to titanium, alloplastic, or autologous bone reconstruction (**FIG 6A,B**). Each of these techniques provides structural support to protect the underlying brain. The bilaminar resorbable matrix with BMP-2 reconstruction has the added benefit of decreased donor-site morbidity and eventual resorption of all foreign material.⁶



FIG 4 • 3D model created for mandibular reconstruction with BMP-2 and titanium plate crib.

- Mandibular defect: The indication for BMP-2 crib reconstruction is similar to an iliac crest bone graft in that there is a defect size limit of 5 to 8 cm after which vascularized fibular bone is preferred. Importantly, this technique is not performed after oncologic resection because of concern that BMP-2 can cause unrestricted bone growth.
- Rare Tessier clefts: During the initial procedure, when soft tissue flaps are raised for repair of the cleft, there is excellent access to the osseous defect. Autologous bone donor sites may be limited at the time of this initial repair due to the patient's age, so the use of BMP-2 becomes a good option.⁷

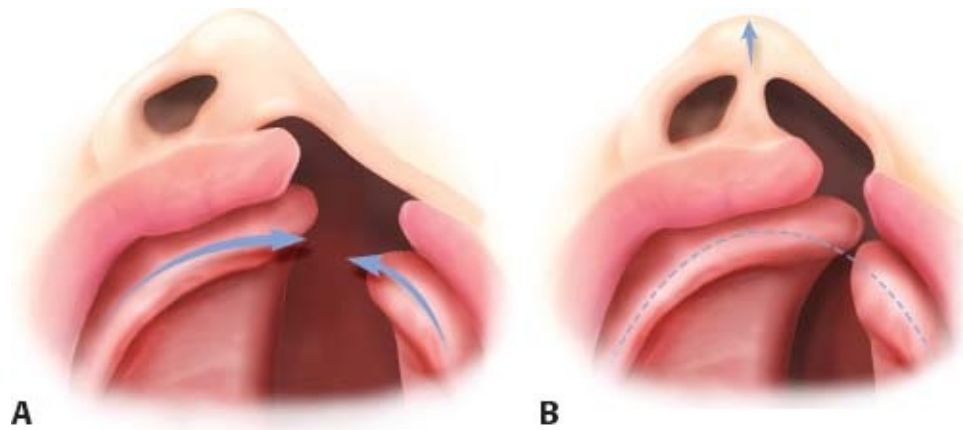


FIG 5 • 3D Illustration of alveolar segments in a patient with left cleft lip and palate. **A.** Prenasoalveolar molding (NAM) shows collapse of the lesser segment. **B.** Post-NAM image shows approximation of the alveolar segments and creation of a normal alveolar “U shape.”

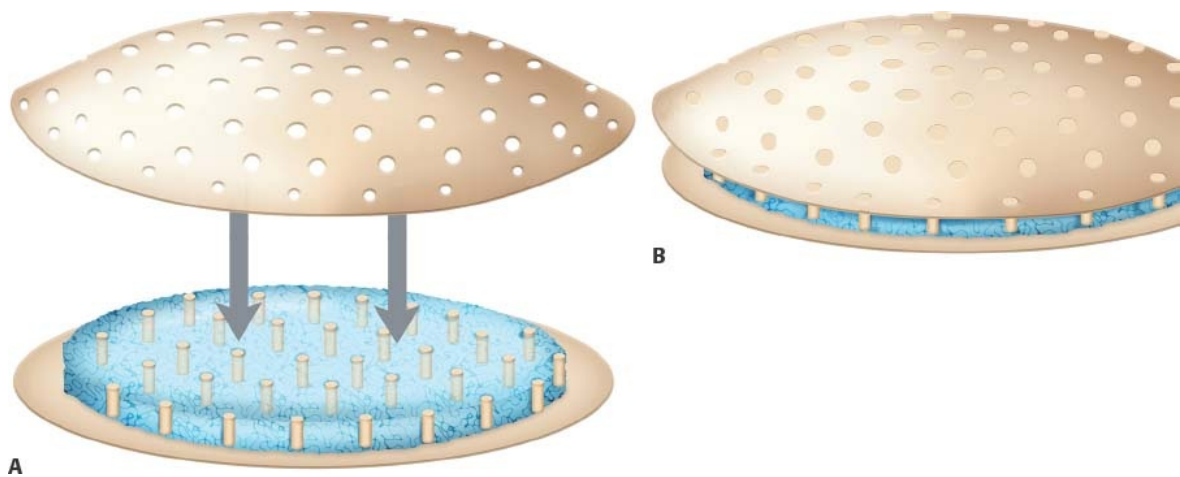


FIG 6 • Illustration of customized bilaminar construct. **A.** The bottom (endocranial) resorbable plate has supportive struts (pins); the BMP-2–impregnated resorbable sponge (*blue*) is placed between the plates. **B.** Ectocranial plate (*top plate*) is placed on top of the pins (*supportive columns*) which were previously placed through the endocranial plate and sonic welded.

TECHNIQUES

■ Alveolar Cleft Repair

Gingivoperiosteoplasty With BMP-2

- Markings vary slightly depending on whether the repair is performed at the time of the cleft lip (3 months) or cleft palate repair (10 months).
 - Alveolar segments have been approximated within a few millimeters so vertically designed flaps within the cleft are possible for closure without significant dissection.
 - Vertical markings within the cleft separate the deep gingival flaps from the anterior gingival flaps.
 - Deep flaps for palatal closure are marked as extensions of the nasal floor flaps.
 - For the inferior aspect of the gingival closure, separate triangular flaps are marked for a Z-plasty-type closure. Injection along incisions and under the flaps is performed.
- A no. 15 blade or Beaver blade is used to make the incisions. Limited subperiosteal dissection within the alveolar cleft is performed with a Freer elevator.
 - Avoid injury to tooth buds because alveolar bone is soft before age 1.
- Nasal floor closure is performed with interrupted Vicryl or chromic suture on a P-2 needle.
- Next, the deep flaps are approximated.
 - Gingival bottom flaps are transposed and sutured across the defect to the other side.
- Resorbable collagen matrix is impregnated with BMP-2 for 20 minutes and then implanted within the defect.
 - Demineralized bone matrix may be added for support if the collagen matrix is collapsible.
 - The implant is packed into the defect and at the inferior edge of the piriform aperture for alar base support.
- Anterior gingival flaps are then sutured with vertical mattress 5-0 chromic or Vicryl sutures.
 - If deep or anterior closure does not create a watertight seal, then thin

AlloDerm may be used to supplement the closure (**FIG 7A,B**).

Secondary Alveolar Cleft Repair

- Papillary (or gingivobuccal) incisions are marked, extending from within the cleft to the first molar with a backcut planned cephalad into the buccal mucosa.
- Local anesthetic with epinephrine is injected along the incisions and under the flaps.
- A no. 15 blade is used to make the incisions, and subperiosteal degloving of the maxilla and nasal region is performed with a periosteal elevator.
- With the maxillary mucosal flaps elevated, lateral backcuts are made underneath the flaps in the periosteum to provide a release for a “sliding sulcus” advancement.
 - Within the cleft, elevation of the lateral cleft flap (from the lesser segment) and the medial cleft flap (from the premaxilla), including a vomer flap, is performed in a subperiosteal plane.
 - Separation or bisection of flaps is sharply performed for intraoral palatal and nasal floor closures.
- Nasal floor closure is performed with interrupted Vicryl or chromic suture on a P-2 needle. Intraoral palatal closure is performed with vertical mattress chromic sutures.
- Resorbable collagen matrix impregnated with BMP-2 (with or without demineralized bone matrix) is implanted into the alveolar cleft defect and along the piriform aperture for alar base support.
- Lateral gingivobuccal flaps are advanced to the anterior mucosal flap for closure over the implanted graft. Dental Coe-Pak is placed as a dressing.

■ Cranial Defect Repair

- Although a coronal zigzag incision is preferred when marking, previous craniotomy incisions must be considered. Scalp hair is removed by limited clipping to access previous scars and plan incisions that maximize scalp blood supply.
- The incision is made down through the periosteum overlying the bone. In the area of the defect, an elevator is placed between the subgalea and scarred dura to protect the deep structures.
- Skin flaps are raised and subperiosteal dissection around the entire defect is

performed. Along the bony borders of the defect, a small endocranial rim is developed. Power burring is performed along the osseous borders to promote osteoconductive healing.

- A 3D CT scan skull model is helpful for shaping the resorbable mesh plates (Resorbex, KLS Martin, Jacksonville, FL) (**FIG 8A,B**).
 - The endocranial plate is placed on the endocranial side of the model, trimmed, and molded with hot saline.
 - Resorbable pins (7 mm) are placed through holes and welded to the plate as supportive columns.
 - BMP-2 is soaked onto the resorbable collagen matrix for 20 minutes and then placed with DBM around the pins.
 - The ectocranial plate is contoured to the ectocranial surface of the model allowing 1 cm of plate to overlap the in situ bone for fixation.
 - The endocranial plate is then placed on top of the pins (columns) and collagen seeded with BMP-2.
 - This is welded together with a flat sonic weld tip to create the bilaminar “sandwich” (**FIG 9A,B**).
 - The bilaminar construct is implanted into the cranial defect and sonic weld pins are used for fixation.
 - Skin flaps are closed in two layers over a drain placed away from the construct.
-

■ Mandibular Defect Repair

- A gingivobuccal incision or Risdon incision is marked depending on previous incisions.
- Recreation of the mandibular skeletal defect is performed by dissecting subperiosteally to bone and retained hardware.
 - Intervening soft tissue is excised.
 - A fresh osteotomy cut or burring at the bony edges is performed to ensure influx of preosteoblasts for implant healing.
- The titanium or resorbable crib is fashioned to outline the mandibular defect with lingual lip and complete coverage of the inferior and anterior borders.
 - The crib is secured with screws (for titanium plate) or pins (for resorbable implant).
- Resorbable matrix impregnated with BMP-2 (for 20 minutes) with or

without demineralized bone matrix is packed into the crib.

- Meticulous closure is performed with running, locking 3-0 chromic sutures.
 - Temporary placement into maxillomandibular fixation is recommended.

■ Rare Tessier Cleft Repair

- During the initial soft tissue repair when flaps are raised, there is excellent access to the osseous defect.
 - Autologous bone donor sites may be limited in infants and young children, so the use of BMP-2 becomes a good option (**FIG 10A,B**).
 - An example of this is a no. 3 or 4 rare facial cleft with ocular-sinus-oral communication.
- Soft tissue flap designs respecting natural facial aesthetic lines are used with nasal rotation, eyelid switch flaps, and lateral cheek advancement.⁷
- After injection and incisions, thick flaps are raised to ensure an adequate blood supply.
- Skeletal defects are completely dissected, and intervening soft tissue is excised. For complete clefting, deep mucosal flaps within the cleft are raised for closure.
- After closure of the deep flaps, BMP-2 is applied to collagen matrix for 20 minutes and implanted into the skeletal defect.
- Anterior flaps are rotated, transposed, and closed in layers with resorbable sutures.

PEARLS AND PITFALLS

Techniques

- Implant and construct must have enough structure to conform to the defect area and prevent soft tissue collapse into the defect.
- Complete closure with well-vascularized tissues is important for healing and to resist exposure of the implant and infection in the perioperative period.
- To limit ectopic bone formation, the implant with BMP-2 should be confined to the defect area.

Alveolar

- For primary alveolar grafting during infancy, limited dissection

defect	during GPP is required to avoid growth disturbances. ⁸ ■ “67” Beaver blade should be used to make incisions.
Cranial vault	■ Large surface area of resorbable plates may cause soft tissue swelling during resorption phase, months after healing.
Mandibular defects	■ Dental implants can be placed in select patients, months after osseous healing, but “jaw in a day” (implants at the time of free fibular reconstruction) cannot be performed. ⁴ This technique is limited to smaller defects.
Tessier Clefts	■ Bone reconstruction with BMP-2 may be performed during the initial soft tissue repair when soft tissue flaps are raised and defects are most accessible.

POSTOPERATIVE CARE

- Alveolar cleft repair: Soft diet for 1 week or until complete mucosal healing. For secondary repair, remove the Coe-Pak at 1 week.
- Cranial vault repair: Customized helmet provides protection for the first few weeks but is not absolutely necessary. Avoid contact sports for 6 weeks.
- Mandibular defect repair: Placement into MMF for a week; liquids until complete mucosal healing and then soft diet for 1 week

OUTCOMES

- Alveolar cleft repair: Francis et al. retrospectively reviewed 55 patients who underwent secondary alveolar cleft reconstruction, 36 of whom received rhBMP-2 with demineralized bone matrix (DBM) scaffold; the remainder underwent the standard iliac crest bone grafting.⁹
 - Bone stock was evaluated using occlusal radiographs. Clefts repaired with rhBMP/DBM was 97% successful (based on volumetric fill), compared with 84% in patients with iliac-derived bone grafts.
 - Patients with iliac bone grafts had a significantly higher rate of intraoral infection postoperatively.
- Cranial defect repair: rhBMP has been used in the pediatric population, for whom availability of split grafts can be limited. Beidas et al. demonstrated that the addition of rhBMP can improve rates of defect closure when added to particulate autogenous bone graft.¹⁰
- Mandibular defect repair: Sweeny et al. retrospectively reviewed 17 cases of vascularized bone grafting to the mandible for osteoradionecrosis in which

rhBMP-2 was added to the union of native bone and fibula flap. Rates of infection and malunion were similar; there was no increase in cancer recurrences noted with the use of rhBMP-2.¹¹

- Rare Tessier cleft repair: Because these clefts are rare, no randomized studies of these patients have been performed; however, early bony healing in these cases has been documented. Secondary procedures during midchildhood and at skeletal maturity for patients with rare craniofacial clefts are more common and may require grafting with rhBMP-2.

COMPLICATIONS

- Local reactions
- Graft failure
- Infections
- Wound complications¹²

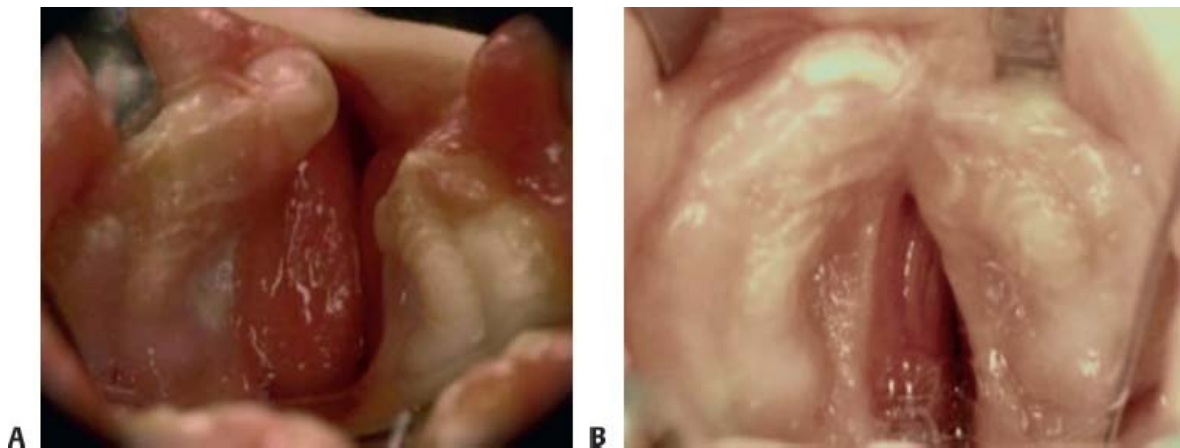


FIG 7 • View of the palate and alveolar segments in a patient with left cleft lip and palate. **A.** Pre-NAM shows wide separation of the alveolar segments. **B.** Postoperative image after NAM and GPP with BMP-2 shows healing of the alveolar segments just prior to cleft palate repair.

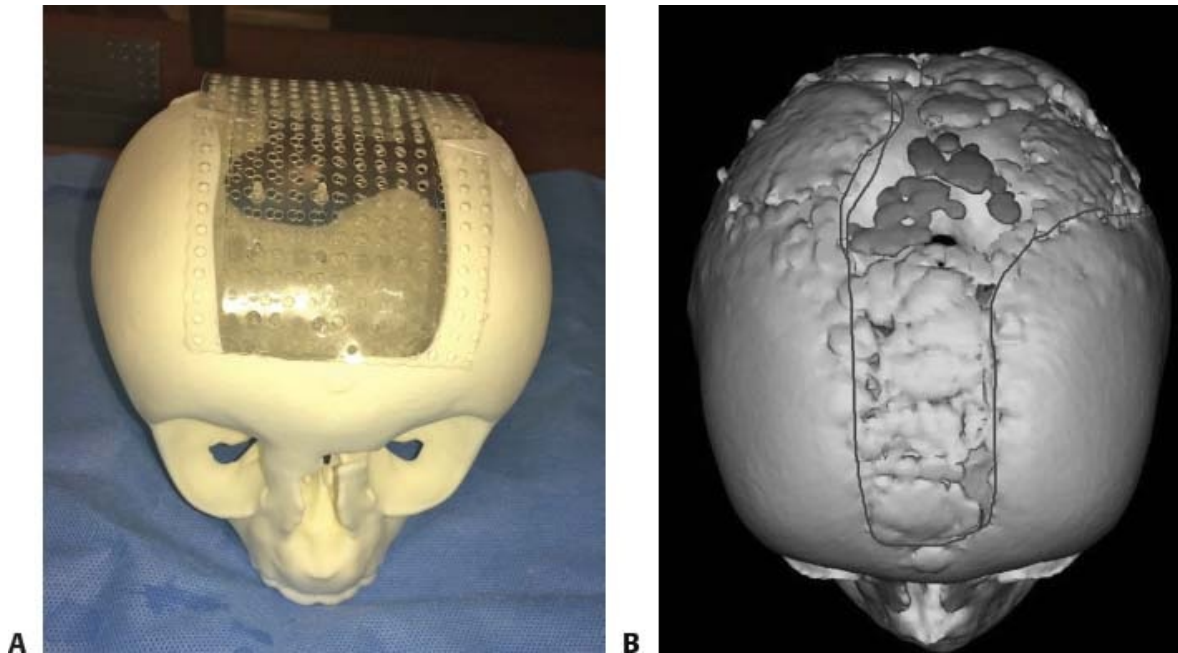


FIG 8 • Large pediatric cranial vault defect involving the frontal, parietal, and occipital regions. **A.** 3D model created for reconstructive planning using bilaminar resorbable plate construct with intervening BMP-2. **B.** 3D CT scan 6 months after surgery demonstrates healing at the periphery and centrally. The patient demonstrated complete calvarial healing at 1 year.

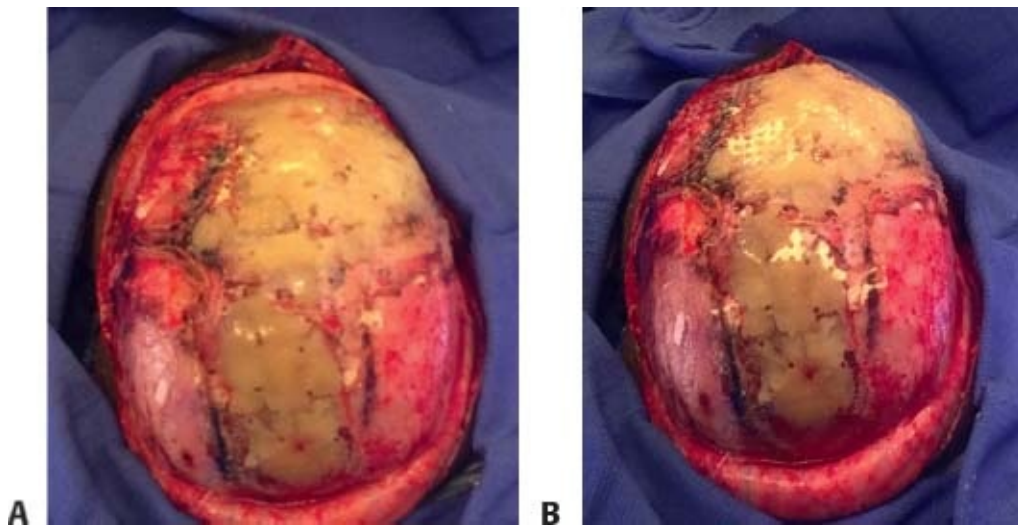


FIG 9 • Intraoperative apical views during reconstruction

with bilaminar resorbable plate and BMP-2. **A.** View following placement of endocranial plates with supportive struts (pins) and BMP-2-impregnated collagen. **B.** View after ectocranial plates have been placed and fixated to surrounding bone edges.

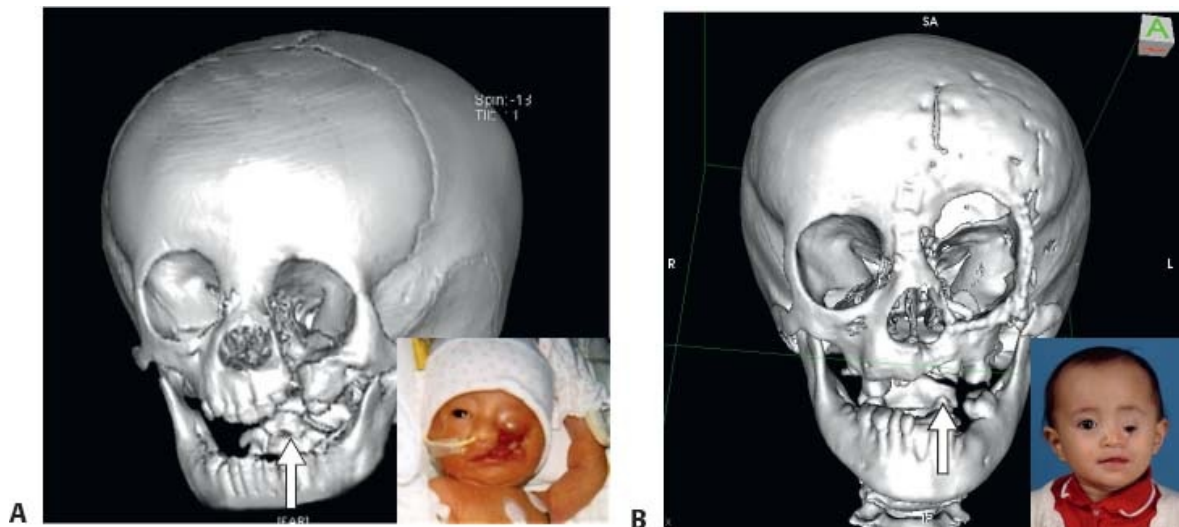


FIG 10 • 3D CT scan of Tessier no. 4 orbitofacial cleft and accompanying inset of patient with no. 4 cleft. **A.** CT scan at birth demonstrates the osseous defect with communication between the orbit, maxillary sinus, and oral cavity. **B.** CT scan demonstrates bone healing of the maxilla and alveolus after primary soft tissue and BMP-2 repair. Orbital reconstruction is planned in the future.

- Ectopic bone formation
- Transformation in an oncologic field¹³
- In pediatric reconstructions
 - Closure of nearby facial sutures after alveolar cleft treatment
 - Closure of cranial sutures after cranial vault defect treatment¹⁰

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Section IV: Mandibular Surgery

33 Costochondral Reconstruction for Absent Temporomandibular Joint

CHAPTER

Patrick A. Gerety and Scott P. Bartlett

DEFINITION

- Costochondral graft is a rib graft harvested with osseous and cartilaginous portions.
- Hemifacial microsomia (HFM) is a congenital condition in the distribution of the 1st and 2nd branchial arch embryology affecting the mandible, ear, orbit, facial soft tissue, and facial nerve function.
- Pruzansky-Kaban modified classification system¹ is a four-point scale (I, IIA, IIB, III) used to rate mandibular hypoplasia in patients with HFM.

ANATOMY

- Mandibular anatomy (**FIG 1A**)
 - Ramus: vertical, posterior height often deficient in HFM patients; often shifted medially in HFM; site of costochondral reconstruction
 - Coronoid process: insertion of temporalis muscle; affected by ramus hypoplasia
 - Condyle: may be hypoplastic or absent in HFM
 - Body
 - Symphysis/parasymphysis
 - Alveolar process

- Temporomandibular joint (TMJ; **FIG 1B**)
 - Synovial articular joint of the mandible
 - Complex multicomponent structure that includes the condyle, glenoid fossa, capsule, articular disk, lateral pterygoid muscle, and ligaments
 - Joint allows rotation and anterior translocation.
- Glenoid fossa
 - Site of mandibular articulation on the temporal bone just anterior to the external auditory meatus/canal
 - In severe HFM, this structure is absent/hypoplastic.
- Rib osteocartilaginous junction (**FIG 1C**) is located at approximately the midclavicular line. This location will allow a portion of rib that has a long osseous and shorter cartilaginous portion for mandible reconstruction.

PATHOGENESIS

- Disorder of 1st and 2nd branchial arch development causing facial hypoplasia
- Theories:
 - Stapedial artery disruption/hematoma
 - Neural crest cell migration error

NATURAL HISTORY

- The hypoplastic mandible does grow but does not attain catch-up growth and is outpaced by the normal side.²
- Facial asymmetry may worsen with growth in more severe cases.

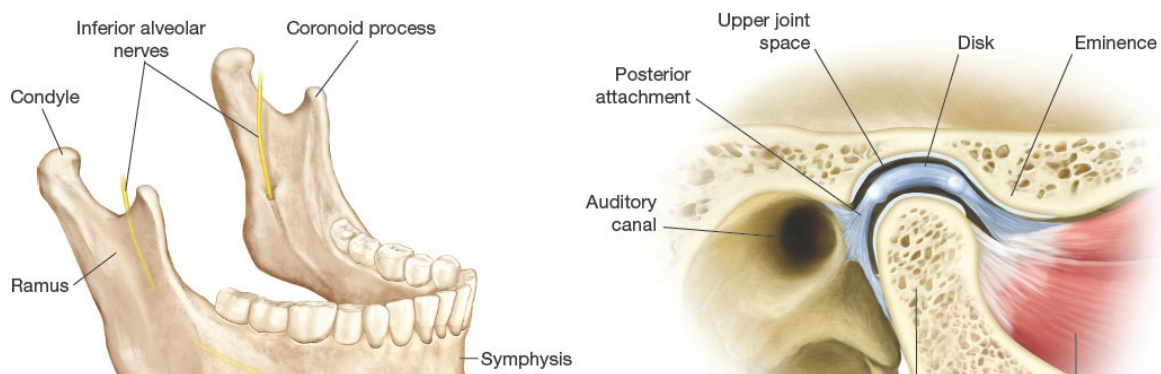


FIG 1 • A. Mandible. B. Temporomandibular joint. C. Rib harvest. An incision is designed in the inframammary

crease to harvest an osseocartilaginous rib graft.

PATIENT HISTORY AND PHYSICAL FINDINGS

- OMENS+ classification describes abnormalities in HFM patients.³
 - Stands for orbit, mandible, ear, facial nerve, and soft tissue
 - Extracraniofacial manifestations—requires medical workup
- Mandibular hypoplasia can be variable in morphology and degree (**FIG 2A**).
 - Vertically shortened ramus—loss of posterior facial height and blunted gonial angle
 - Occlusal cant up toward the affected side
 - Loss of posterior facial width with a medially shifted mandible
 - Displaced dental midline
- Severity of mandibular hypoplasia
 - Pruzansky-Kaban classification
 - Type I: small mandible with normal morphology
 - Type IIA: mandible with a ramus that is abnormal in size and shape, but with a TMJ that is normally situated
 - Type IIB: abnormal ramus and a TMJ that is medially displaced
 - Type III: absent ramus, condyle, and TMJ (**FIG 2B**)

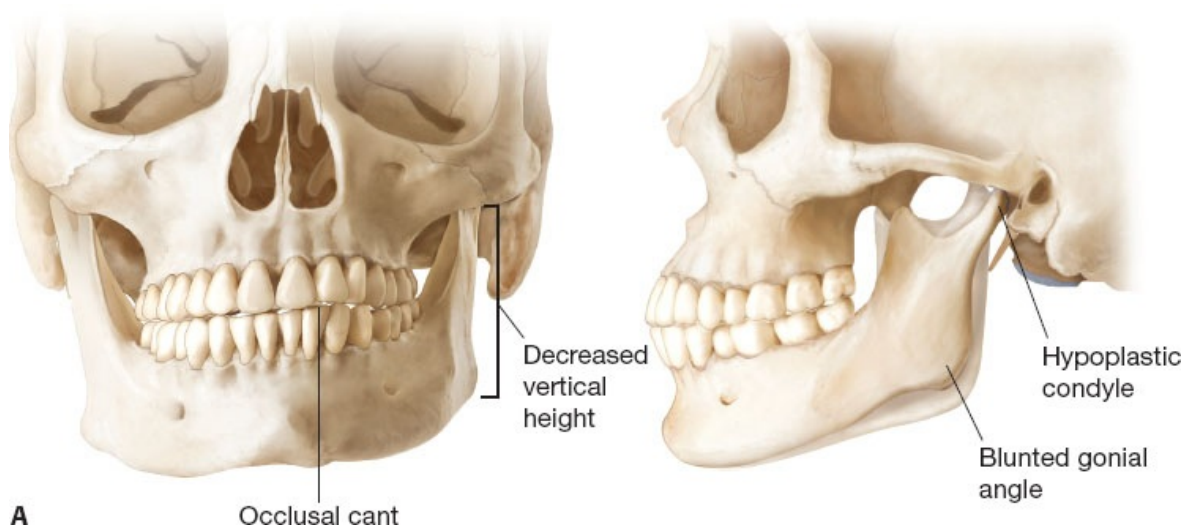


FIG 2 • A. Hypoplastic mandible. Features include an occlusal cant, vertically short ramus with loss of facial height, effacement of the gonial angle, and

medialization of the ramus-condyle. **B.** Pruzansky type III mandible deformity. The ramus, coronoid process, and condyle are absent.

- This classification system has been shown to have low inter-rater reliability, which is largely related to the highly variable morphology of the hypoplastic mandible in HFM. There is no system in use that has better inter-rater reliability.
- Ramus and condyle reconstruction typically performed on type IIB and type III patients

IMAGING

- Three-dimensional (3D) computed tomography (CT) of the craniofacial skeleton provides definitive assessment of mandibular morphology.

DIFFERENTIAL DIAGNOSIS

- Hemifacial/craniofacial microsomia
- Treacher Collins syndrome
- Condylar-coronoid collapse
- Condylar hyperplasia
- Hemifacial hypertrophy

SURGICAL MANAGEMENT

Preoperative Planning

- CT scan to determine mandibular and TMJ morphology
- Orthodontic evaluation and preparation

Positioning

- Supine
- Nasal intubation

Approach

- Splints delivered by orthodontist or via computer planning service
- Two-team approach:
 - Rib harvest
 - Mandibular exposure

- Surgical goals:
 - Leveling of mandibular occlusal cant
 - Alignment of dental midline
 - Creation of neo-TMJ (“pseudoarthrosis”)
 - Rigid fixation plus maxillomandibular fixation (MMF)

TECHNIQUES

■ Open Costochondral Graft Harvest

Rib Harvest (see **FIG 1C**)

- Incision: 5 to 8 cm at inframammary crease, midclavicular line.
 - Typically allows access to rib 5, 6, or 7
- Infiltration: An epinephrine-containing local anesthetic is placed in the wound at all levels including directly onto the rib to aid hemostasis and limit intraoperative narcotic use.
- Skin incision is made sharply.
- Electrocautery is used through the subcutaneous tissue and superficial fascia down and through the pectoralis major/rectus muscle fascia.
- Muscle division
 - Either the rectus muscle may be divided in the direction of the rib directly over the chosen rib or it may be divided along the direction of its fibers and retracted.
 - The senior author generally divides the muscle directly. This allows for rapid visualization of the rib and much less strenuous retraction.
- Rib dissection
 - This portion of the harvest should be performed carefully to avoid large pleural tears and defects with possible lung injury. Large defects are typically impossible to close primarily and may require local intercostal muscle flaps and/or a thoracostomy (chest) tube.
 - Many rib approaches have relied upon subperichondrial dissection, but we find this to be time-consuming, difficult, and unnecessary.
 - Maintaining perichondrium on the rib is also critical to the stability of the osteochondral junction.
- The osteochondral junction is identified as a sharp ridge medially.

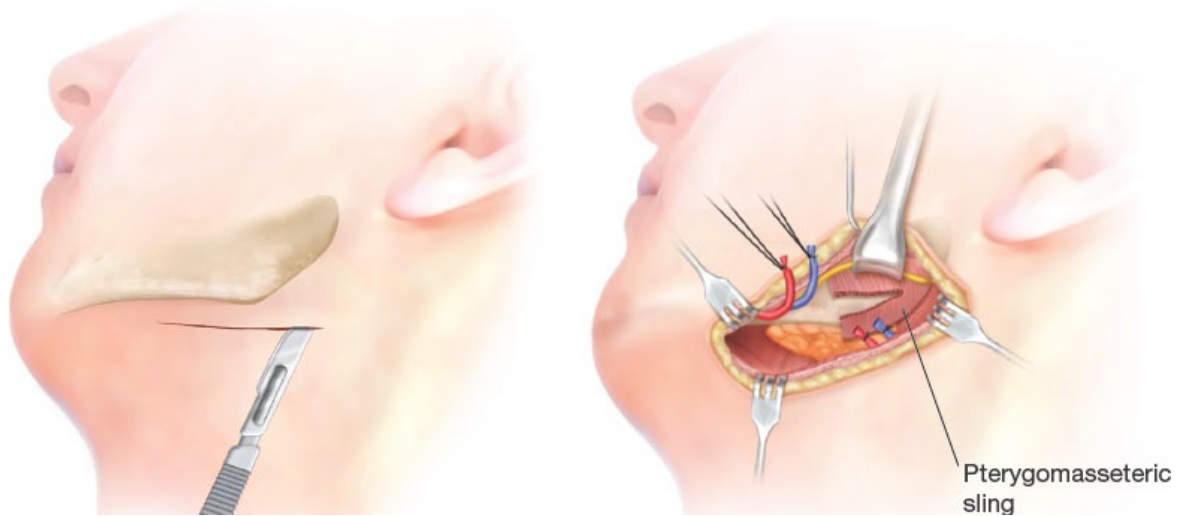
- The anterior surface of the rib is now completely exposed.
- A rib dissector is now carefully rotated around the back side of the rib around the midpoint of the desired graft. This dissector is then moved up and down the rib. This is typically a fairly forceful maneuver. Dense intercostal muscle fibers that are encountered can be divided with cautery.
- The surgeon performing mandibular exposure should communicate the expected length of rib that is required.
- Length is typically 6 to 10 cm (this can be planned from the preoperative CT).
- The cartilaginous medial margin is transected with a fresh knife. Place a protective retractor on the pleural side.
 - 1 cm of cartilage should be harvested to serve as the articular surface at the TMJ. This end will be rounded before inset. The total length of the final osteocartilaginous construct is typically 7 cm.
- The rib is then elevated, and any deep muscle fibers can be cut with cautery.
- The osseous, lateral end is then cut with a bone cutter.
- The chest is examined for an air leak using saline solution in the dissection pocket with a Valsalva maneuver performed by anesthesia (typically 20-cm H₂O above peak inspiratory airway pressure for 5–10 seconds).
- The wound is closed in layers with particular attention to a quality muscle closure.
- Bupivacaine rib blocks or an On-Q pump may be used to decrease postoperative pain.
- A drain is typically not placed.

Mandible Exposure and Pocket Creation

- A submandibular incision is marked below the mandibular border, typically one to two fingerbreadths below the border (**TECH FIG 1A**).
- The incision should be infiltrated with epinephrine-containing local anesthesia.
- The incision is made sharply and extended through the platysma (**TECH FIG 1B**).
- Blunt dissection is used to expose the inferior border of the mandibular periosteum.
- The periosteum is incised with a knife or cautery.
- A subperiosteal dissection is performed with an elevator. Dissection should

be fairly wide to place a reconstruction bar.

- A tunnel is made bluntly toward the temporal bone; this will create a pocket for the rib graft.

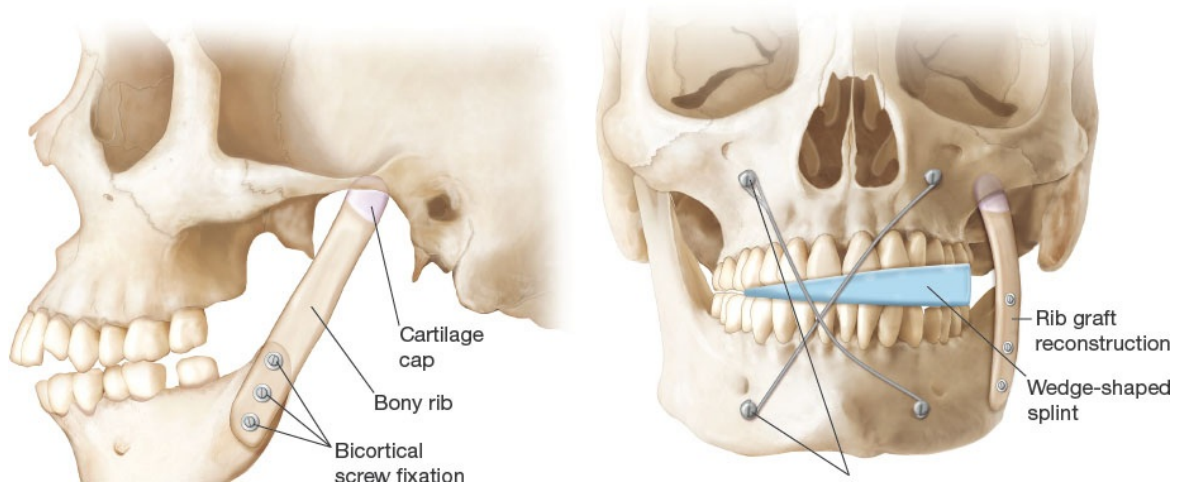


TECH FIG 1 • Submandibular approach. **A.** An incision is placed one to two fingerbreadths below the mandibular border (one in children, two in adults). **B.** The facial vessels may need to be divided. The marginal mandibular branch is preserved by designing a low incision, dividing the platysma low after confirming with a nerve stimulator that no branches are present. The platysma is then reflected, and the inferior border of the mandible is approached.

- This can be done with a uterine sound, a Cobb elevator, or a gloved finger.
- There will not be a normal glenoid fossa present.
- Creation of a narrow tunnel that firmly ends at the temporal bone will allow articulation at the pseudoarthrosis, maintenance of posterior facial height, adequate facial width, and less chance of graft migration.
- The patient is then placed into occlusion using an orthodontic splint and intermaxillary fixation (IMF) screws. This levels and aligns occlusion and corrects midline asymmetries.

Rib Placement and Fixation

- The graft is moved to the face.
- An approximately 0.7- to 1.0-cm cartilaginous end should be kept. This should be rounded with a knife.
- The graft is then inserted into the pocket and firmly placed against the temporal bone.
- The graft should lie lateral to the mandibular body, where there will be bone-bone contact.
- The native mandible and rib graft are then fixated with bicortical screws through the rib into the mandibular body (**TECH FIG 2**).
 - A single hole of a miniplate can be used as a washer to increase the surface area of the screw head to prevent fracturing/splintering of the graft.
- Some surgeons advocate a suspension suture placed through the neocondyle and then high into the pocket.
 - This is a technically difficulty maneuver and may not be necessary with a narrowly defined pocket and good fixation.
- The deep fascia/pterygomasseteric sling, platysma, and skin are then closed in layers. A drain is not typically used.



TECH FIG 2 • A. Placement of rib graft. **B.** Rib graft in place with patient in dental splint and MMF via bone-anchored IMF screws.

PEARLS AND PITFALLS

Appropriate shape of the articular surface

- The neocondyle should be rounded to mimic a normal condyle. Costal cartilage is used to avoid bony ankylosis.

Positioning of the graft at the cranial base

- When possible, place the neocondyle in a symmetric position to the other side. This requires attention to the A-P and medial-lateral positioning. A tunnel that is too large or was made on multiple attempts may not ensure that the graft stays where intended. Positioning can be a challenge because of the curvature of the rib. Most often, the glenoid fossa is absent; therefore, the construct articulates with the cranial base just medial to the zygomatic process of the temporal bone.

Avoidance of pneumothorax

- Careful dissection directly on the rib graft, and a postoperative Valsalva check

MMF management

- Can be removed after 3 weeks if adequate internal fixation is attained. If there is inadequate fixation, then a CT scan or panorex should be used to follow bony union.

Management of posterior open bite

- This can be done after MMF is removed with either orthodontic rubber bands to brackets or bone anchors. This encourages downward maxillary growth. A splint that is progressively ground down may also be used.

POSTOPERATIVE CARE

- Pain control particularly of rib harvest site
- Perioperative antibiotics for 72 hours
- MMF with pureed diet postoperatively
- TMJ dysfunction—TheraBite⁴
 - Used if mouth opening is worse or inadequate; begins 4 to 8 weeks after surgery
 - Protocol: five 30 second stretches, 5 times per day

OUTCOMES

- Twenty-two HFM patients, 33 rib grafts, average age 7.2 years⁵
- Eighty-two percent required no additional mandibular expansion (grafting,

distraction osteogenesis).

- TMJ ankylosis was noted in one patient.⁵

COMPLICATIONS

- Infection, abscess
- Graft resorption
- Bony nonunion
- TMJ ankylosis
- Overgrowth/undergrowth

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34 Prosthetic Reconstruction of the Temporomandibular Joint

CHAPTER

Anthony P. Tufaro and Srinivas M. Susarla

DEFINITION

- Alloplastic reconstruction of the temporomandibular joint (TMJ) is frequently required to address myriad issues relating to skeletal derangements,^{1–6} including arthritic conditions (rheumatoid, osteoarthritis, and post-traumatic arthritis), ankyloses, avascular necrosis of the condyle, sequelae from condylar/subcondylar fractures, benign and malignant neoplasms, degenerative joint disease, and congenital deformities (eg, hemifacial microsomia).^{2–4}

ANATOMY

- The TMJ is a diarthrodial synovial joint.
 - As a complex apparatus, it allows full range of mandibular movement.
 - The condylar head of the mandible on each side articulates with a fibrocartilaginous disc to form, in conjunction with the glenoid fossa of the temporal bone, a joint for hinge and gliding movements.
- Derangements of the disc and the condyle frequently necessitate autologous or alloplastic replacement.
- Alloplastic joint replacement is commonly used to address end-stage deformities in the adult skeleton, multiple operated joints, and those that have failed prior autologous reconstruction.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with end-stage TMJ disease can have widely variable clinical presentations.
 - Pain is a commonly reported symptom but is not, in and of itself, an

indication for surgical intervention.

- The clinical history obtained should focus on discomfort, limitation of motion, difficulties with mastication/nutrition, prior operative and nonoperative interventions, and a focused dental history relating to occlusion and parafunctional habits.
- A complete head and neck examination should be performed, with particular emphasis on evaluation of the occlusion, TMJ findings (tenderness, crepitus, maximal incisal opening, and right and left excursive movements) and tenderness of the muscles of mastication.

IMAGING

- Magnetic resonance imaging is the preferred modality for assessing disc pathology and to obtain real-time imaging of the disc position during mandibular motion.
- Thin-cut helical maxillofacial computed tomography (CT) is the preferred modality for assessing bone pathology of the joint (**FIG 1**).
 - This may be combined with angiography in cases of ankylosis, in which the ankylotic mass shares an intimate relationship with major vessels in the region (eg, pterygoid plexus, internal maxillary artery).

DIFFERENTIAL DIAGNOSIS

- Myofascial pain
- Arthritis
- Ankylosis
- Congenital deformity
- Trigeminal neuralgia
- Internal derangement of the TMJ

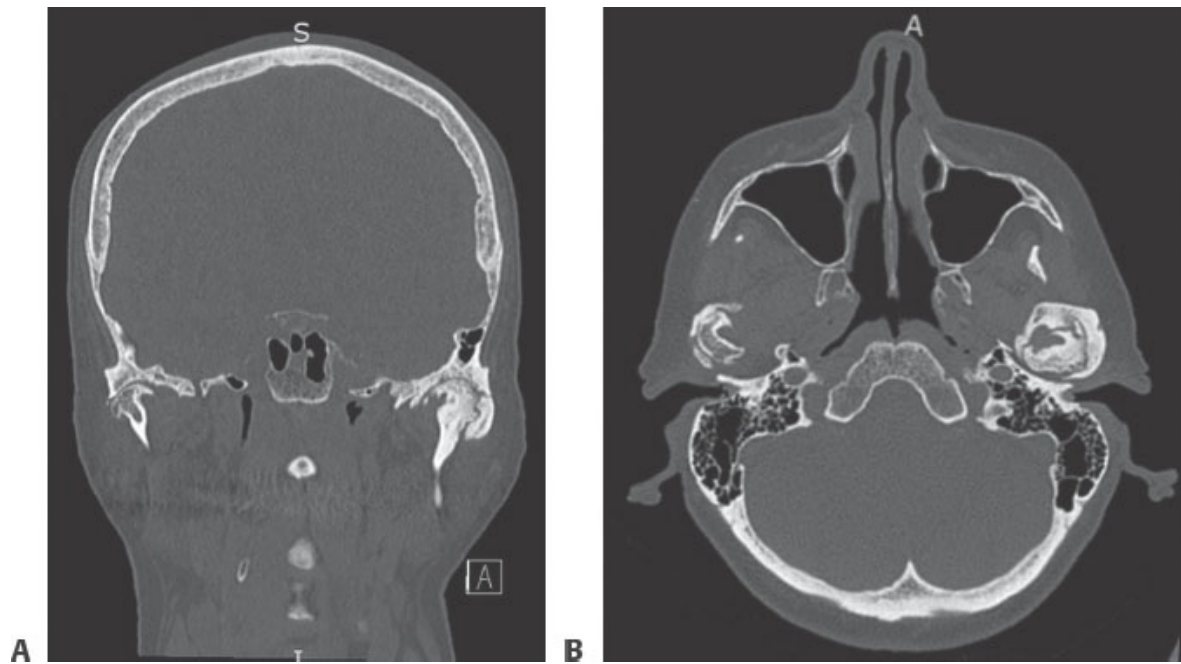


FIG 1 • Coronal (A) and axial (B) computed tomography views of a patient with left-sided temporomandibular joint ankylosis.

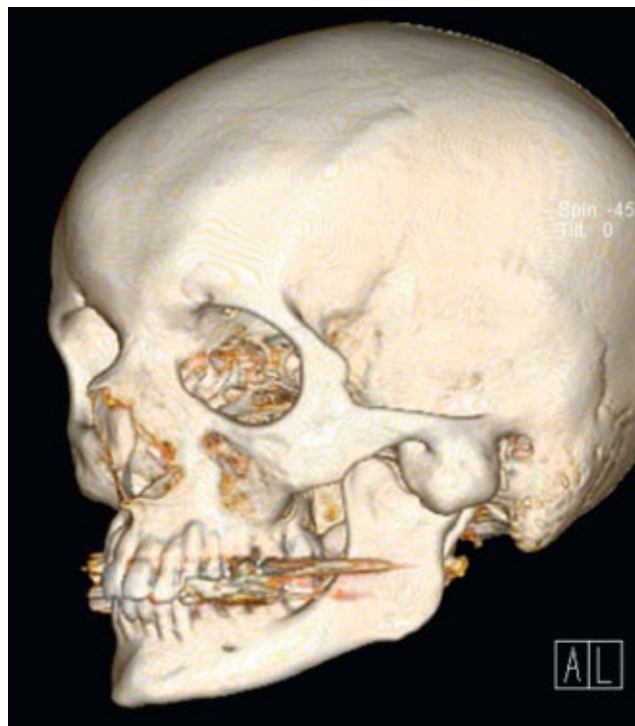


FIG 2 • Three-dimensional reconstruction demonstrating

a large ankylotic mass involving the left temporomandibular joint. Ankylosis release and arthroplasty with a stock or custom temporomandibular joint prosthesis is one approach for management.

NONOPERATIVE MANAGEMENT

- Diagnosis is the key to treatment. Patients should be evaluated by both a surgeon and a facial pain or TMJ disorders specialist.
- Many patients will benefit from trials of nonoperative therapy (muscle relaxants, nonsteroidal anti-inflammatory drugs [NSAIDs], etc.) or dental appliance therapy (mandibular repositioning appliances, occlusal equilibration, bite guards, etc.).
- Patients who fail nonoperative therapy often begin with diagnostic and minimally invasive therapeutic maneuvers (arthroscopy, arthrocentesis), with invasive interventions (arthroplasty) reserved for refractory cases or end-stage deformities.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative planning for alloplastic TMJ reconstruction involves a preoperative decision about the use of custom or stock TMJ prostheses. In both situations, a maxillofacial CT scan with thin cuts is required to visualize the local bony anatomy and for construction of three-dimensional (3D) model templates for prosthesis fabrication (**FIG 2**).
- Patients who are candidates for alloplastic reconstruction are those who have failed conservative management and have end-stage joint disease.
- Patients with active infections, those who are skeletally immature, those with muscle hyperactivity disorders (clenching and grinding), and those with active resorptive bony processes or inadequate bone stock are not candidates for alloplastic reconstruction.³

Positioning

- The operation is completed with the patient in the supine position on the operating table.
- Nasotracheal intubation is required, as the surgeon will have to verify the

occlusion intraoperatively following prosthetic replacement (**FIG 3A**).

- The anesthetist should be told not to use long-acting paralysis, as monitoring of facial nerve branches may aid with dissection.
- The nasotracheal tube is secured to the nasal septum using a 2-0 Vicryl suture.
- A moistened pharyngeal pack is not required, but may be preferred by some surgeons.
- The patient should have a mechanism for maxillomandibular fixation in place prior to initiation of the operation. This can be orthodontic appliances, Erich arch bars, or intermaxillary fixation screws.
- If intermaxillary fixation appliances are to be applied intraoperatively, it is necessary to do so before prepping and draping, so as to avoid contamination of the facial incision with oral secretions.
- Once the maxillomandibular fixation appliances are applied, the oral cavity can be sealed off with a clear plastic occlusive dressing, and the face can be prepared in the standard fashion (**FIG 3B**).
- If the surgeon anticipates using fascia or fat grafts around the prostheses, the donor site should be prepped and draped as appropriate.

Approach

- Surgeons should be familiar with three sets of approaches to the TMJ.
- Preauricular approach
 - This entails making an incision in the preauricular skin, sometimes with extension into a coronal incision, depending on the indication.

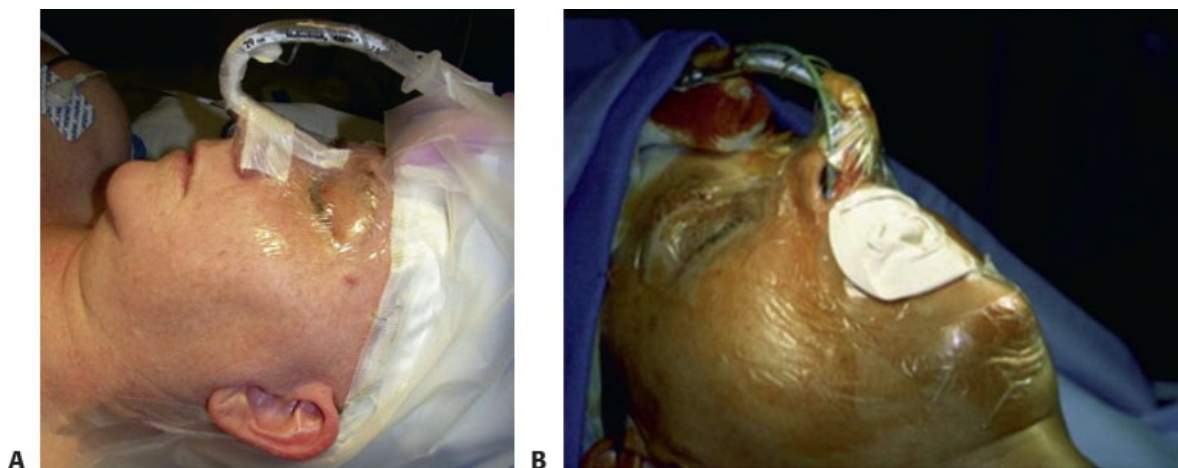


FIG 3 • Standard views of patient preparation and

positioning. A nasotracheal intubation is performed to afford access to the oral cavity for manipulation of the occlusion **(A)**. The oral cavity is isolated from the surgical field for the majority of the case **(B)**. (Reprinted from Granquist EJ, Quinn PD. Total temporomandibular joint replacement (Stock). In: Kademani D, Tiwana P, eds. *Atlas of Oral and Maxillofacial Surgery*, 2015 with permission from Elsevier.)

- The frontal branch of the facial nerve is at risk with this approach. Traction injury is the most common cause.
- This approach provides excellent visualization of the zygomatic arch, glenoid fossa, temporomandibular disc, and condylar head.
- It is often insufficient as a single approach for alloplastic reconstruction and is often combined with a submandibular approach.
- Retromandibular approach
 - This approach entails making a skin incision over the posterior border of the mandibular ramus, followed by a retro- or transparotid dissection to reach the posterior mandibular ramus.
 - Structures at risk with this approach are the retromandibular vein and branches of the facial nerve.
 - This approach affords excellent visualization of the entire posterior mandibular ramus and is a single-incision technique for reconstruction.
- Submandibular approach
 - This approach entails making an incision 2 cm below the inferior border of the mandible to see the inferior border and lateral portion of the ascending ramus. It provides limited access to the condyle and disc.
 - Structures at risk with this incision are the facial artery, facial vein, and marginal mandibular branch of the facial nerve.
 - It is often combined with a preauricular approach.

TECHNIQUES

■ TMJ Reconstruction With Stock/Custom Prosthesis

Markings

- The preferred surgical approach is marked. It is our preference to use a combination of preauricular and submandibular or retromandibular approach (**TECH FIG 1**).
 - The preauricular incision is marked from the helical insertion to immediately superior to the lobule and crosses the tragus in an endaural fashion.
 - The submandibular incision is marked by identifying the inferior border of the mandible and the mandibular angle.
 - A linear incision is marked 2 cm inferior to the inferior border; this will assist in avoiding the marginal mandibular branch of the facial nerve.
- Once the incisions are marked, the areas are infiltrated with local anesthetic with vasoconstrictor.
 - Alternatively, dilute epinephrine solution (1:100 000) may be used if there is concern about local anesthetic effects on the facial nerve branches.

Preauricular Incision and Dissection

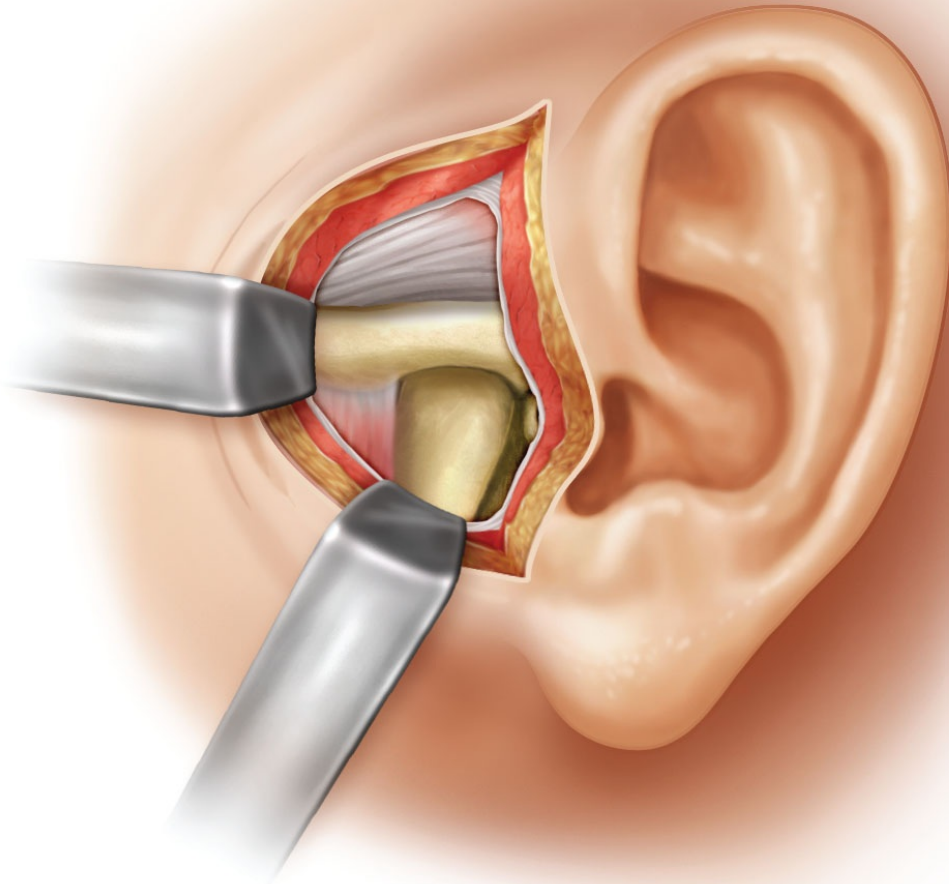
- The preauricular incision is made first.
- A blade is used to incise through the skin and dermis.
- The next layer encountered is the superficial musculoaponeurotic system, which is contiguous superiorly with the galea. One should hug the tragal cartilage as the dissection proceeds in this layer, for the frontal branch of the facial nerve can be as close as 8 mm anterior to the tragus (**TECH FIG 2**).



TECH FIG 1 • Preauricular and submandibular/retromandibular incisions marked. (Reprinted from Granquist EJ, Quinn PD. Total temporomandibular joint replacement (Stock). In: Kademani D, Tiwana P, eds. *Atlas of Oral and*

Maxillofacial Surgery, 2015 with permission from Elsevier.)

- Once the dissection is through the SMAS, attention is directed toward identifying the superficial layer of the deep temporal fascia, which is contiguous with the pericranium superiorly and the parotidomasseteric fascia inferiorly. This layer is easily identifiable above the zygomatic arch and is distinct in its shiny white appearance.
 - Once identified, this layer can be incised at the level of the tragus and a periosteal elevator can then be used to dissect toward the zygomatic arch.
- Once the zygomatic arch is palpated, the pretragal incision can be extended inferiorly to expose the zygomatic arch. Dissection in this manner will elevate the facial nerve with the skin flap and avoid injury.
- Once through the periosteum over the proximal zygomatic arch, the dissection continues inferiorly to expose the lateral capsule of the TMJ. This dense connective tissue is incised transversely, exposing the temporomandibular disc and condylar head.



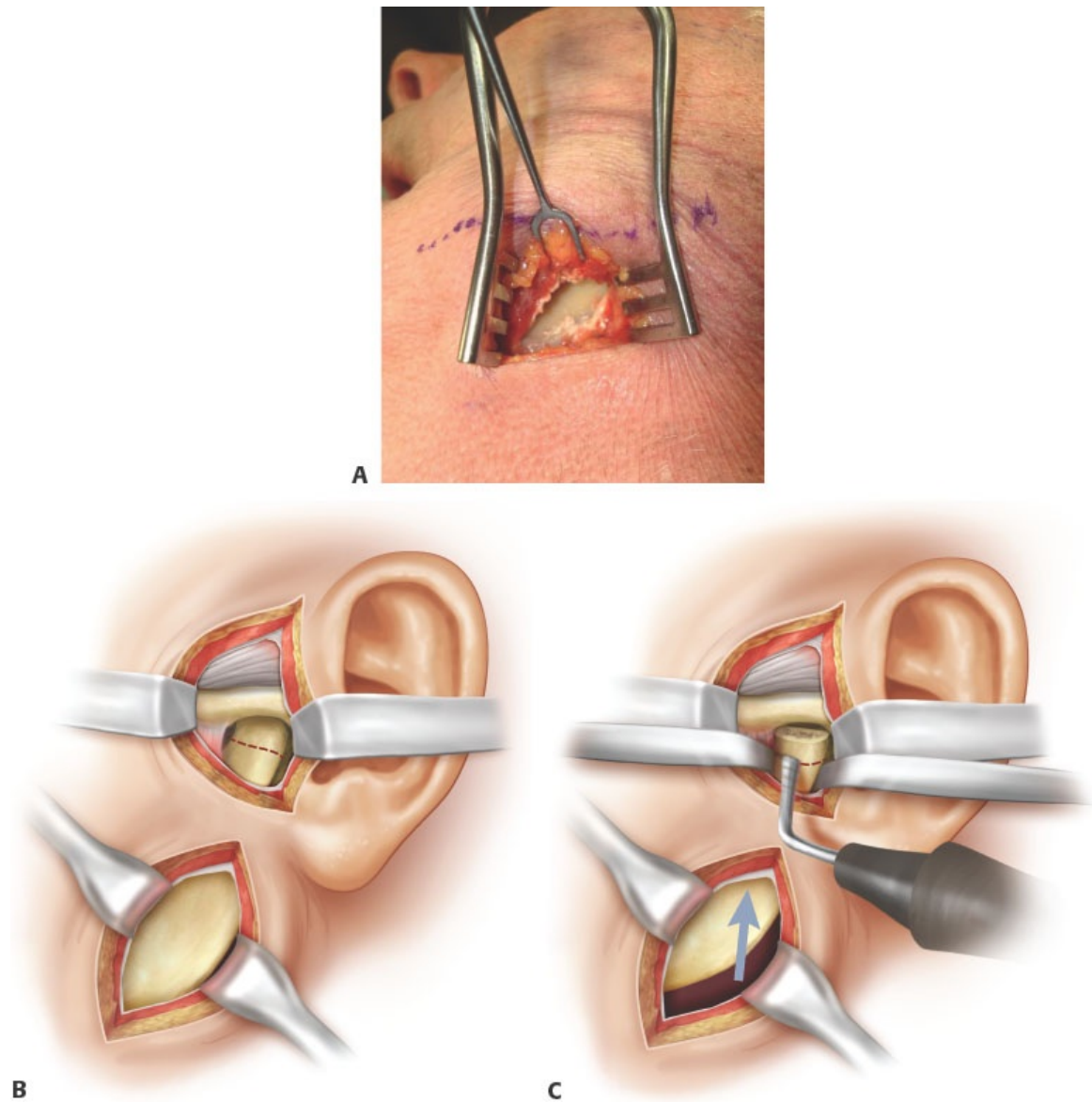
TECH FIG 2 • The preauricular dissection is initiated first. Dissection through the skin and deeper tissues is completed immediately anterior to the tragal cartilage, so as to avoid the temporal branch of the facial nerve, which crosses the zygomatic arch as close as 8 mm from the tragus.

- The disc is bluntly dissected free of its anterior, posterior, and medial attachments, and removed. Caution should be exercised when dissecting the disc posteriorly and medially, as these areas are common sources of bleeding.

- Hemostasis is achieved with bipolar cautery.
- The dissection continues to expose the condylar head and neck, in preparation for condylectomy.
- The condylar neck should be exposed to the level of the sigmoid notch. Once this has been accomplished, the wound is inspected for hemostasis and vasoconstrictor patties are placed into the bed.

Submandibular Incision and Condylectomy

- Next, the submandibular incision is made (**TECH FIG 3A**). This is done through skin and subcutaneous tissue, until the platysma is visible.
- The platysma is then divided at the same level as the skin incision and the superficial layer of the deep cervical fascia is identified.
 - This layer is developed bluntly and then incised, with careful monitoring for marginal mandibular nerve branches.
- Once through this layer, the dissection continues superiorly onto the submandibular gland capsule, toward the inferior border of the mandible.
 - The inferior border is identified, and the fibers of the pterygomasseteric sling are incised at the inferior border.
 - A periosteal elevator is used to develop a pocket lateral to the mandibular ramus, in continuity with the previously developed preauricular dissection.
- Once the zygomatic arch, glenoid fossa, TMJ, mandibular ramus, and condyle are exposed, the condylectomy is performed (**TECH FIG 3B,C**). This is done with a reciprocating saw or oscillating saw.
 - A malleable retractor is placed on the medial side of the condyle to prevent inadvertent soft tissue injury.
 - The condylar osteotomy should be obliquely oriented, starting from the sigmoid notch and angling posteroinferiorly to the posterior border of the ramus.
 - Once complete, the condyle is removed and the bed inspected for hemostasis.
- The same exposure, dissection, and condylectomy are then completed on the contralateral side (for bilateral cases).



TECH FIG 3 • A. Division of the pterygomasseteric sling to expose the mandible. (Reprinted from Granquist EJ, Quinn PD. Total temporomandibular joint replacement (Stock). In: Kademani D, Tiwana P, eds. *Atlas of Oral and Maxillofacial Surgery*, 2015 with permission from Elsevier.) **B.** Once the zygomatic arch, condyle and articular disc, lateral ramus, and inferior border are exposed, the condylectomy is marked. **C.** The condylectomy should be performed at least 15 mm below the glenoid fossa, to allow

adequate space for the fossa component and condylar prosthesis.

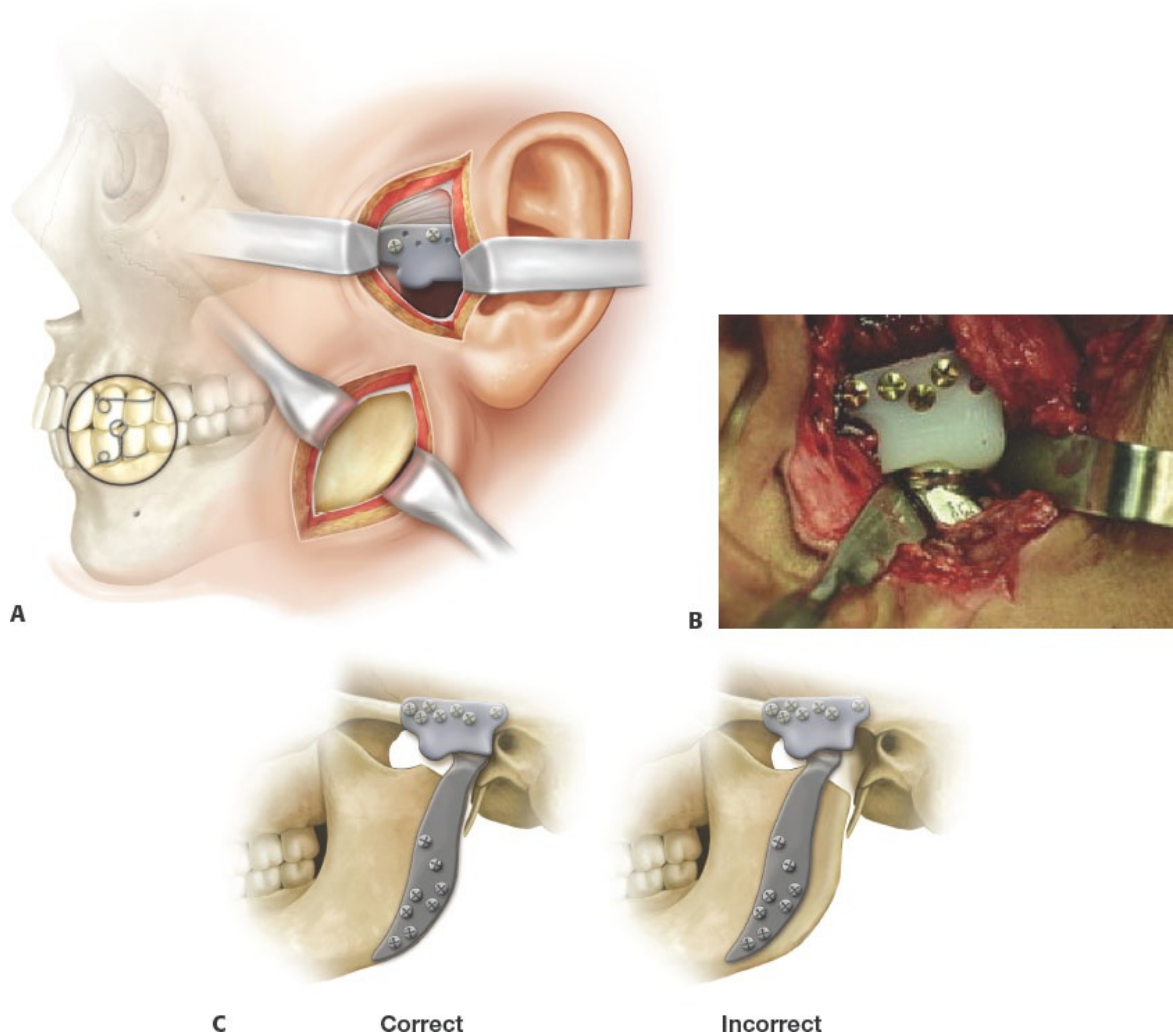
Maxillomandibular Fixation and Prosthesis Insertion

- Once both condylectomies and discectomies are complete, the wounds are packed with sterile gauze and covered with sterile towels.
- The surgeon, or assistant, then changes gloves and places his or her hand in the oral cavity to verify that the mandible is freely mobile (particularly important in cases of ankylosis) and that the occlusion is stable and reproducible.
- Once this is done, the patient is placed into intermaxillary fixation, and the oral cavity is again isolated from the sterile field.
- With the patient in maxillomandibular fixation, attention is now turned to inserting the TMJ prosthesis.
 - The glenoid fossa component is inserted first and affixed using the prescribed number of screws in the planning guide (**TECH FIG 4A,B**).
 - These screws are drilled under copious irrigation.
- Following insertion of the fossa component, the condylar head component is inserted through the submandibular incision and aligned with the fossa component (**TECH FIG 4C**).
 - Once the condylar head position is seated correctly (it should be oriented posteriorly and superiorly), the prosthesis is fixed using the prescribed screws.
- In bilateral cases, the procedure is repeated on the contralateral side.

Completion

- The wounds are again packed with sterile gauze and covered. The surgeon returns with glove change to the oral cavity and inspects the patient's occlusion.
- Intermaxillary fixation is now released and verified to be stable and reproducible with the prostheses in place. Once this is completed, the oral cavity is again sealed off.
- The wounds are irrigated thoroughly with antibiotic irrigation. Abdominal fat or fascia can be used to cushion the prosthesis laterally.
- A small (7–10 Fr) drain is placed, and the wounds are closed in layers.
- The throat pack is removed, and the patient is returned to the anesthetist for

emergence from anesthesia.

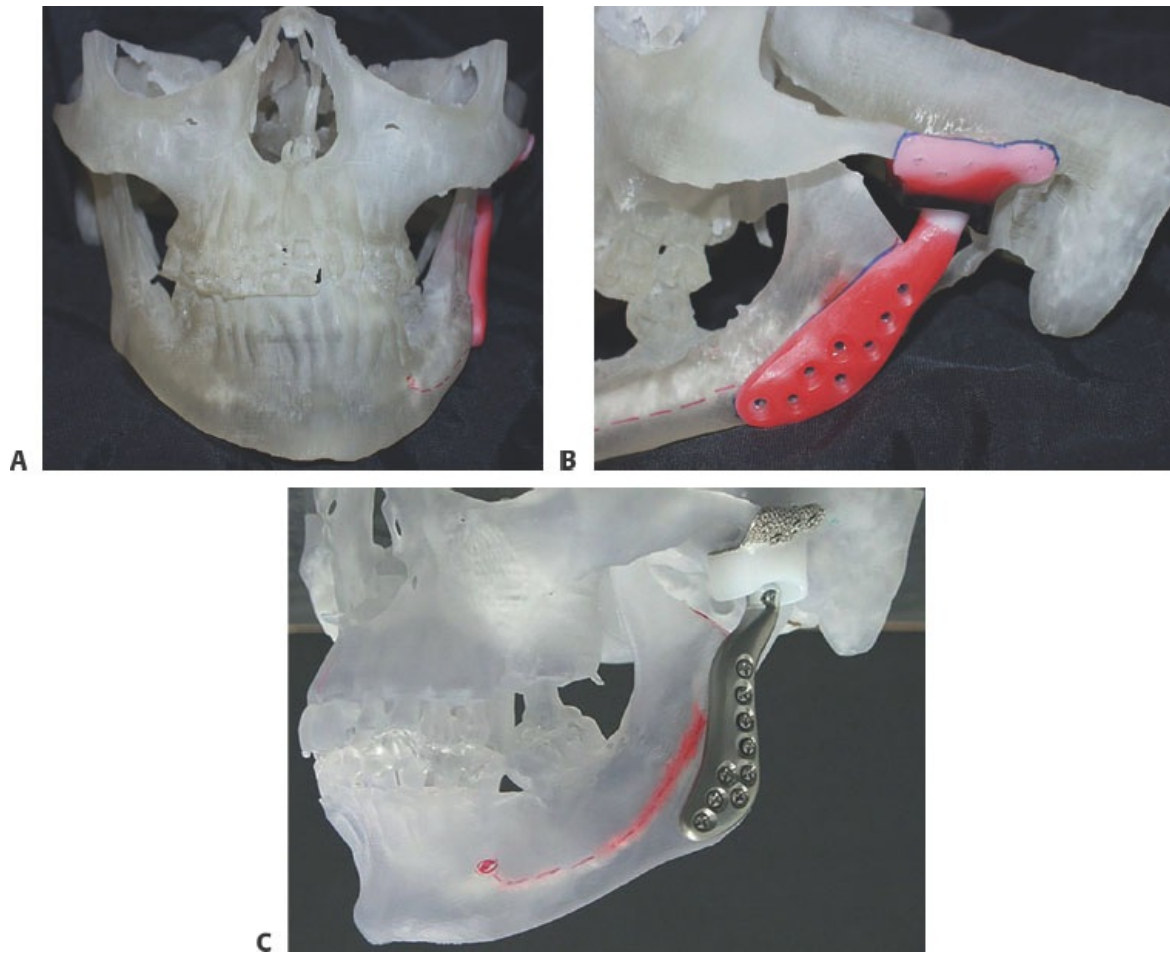


TECH FIG 4 • A,B. The fossa component is inserted and affixed into position after the patient has been placed into maxillomandibular fixation (*circle*). (**B**, Reprinted from Granquist EJ, Quinn PD. Total temporomandibular joint replacement (Stock). In: Kademani D, Tiwana P, eds. *Atlas of Oral and Maxillofacial Surgery*, 2015 with permission from Elsevier.) **C.** Meticulous attention to detail is required to ensure the correct orientation of the condylar component into the fossa. The insertion vector should recapitulate the natural angulation of the condyle

relative to the inferior border of the mandible.

■ Design of a Custom Prosthesis

- The surgical steps for a custom prosthesis are the same as for a stock prosthesis. The difference is in the presurgical planning.
- Once the diagnosis is established and the decision to proceed with total joint replacement is made, the surgeon obtains a high-resolution maxillofacial CT scan.
 - From this scan, a stereolithographic model of the TMJ and mandible is made.
- The condylectomies are performed on the model and the appropriate final occlusion is established.
- From this new mandibular position, the clinical engineer fabricates a wax-up model of the TMJ prosthesis (**TECH FIG 5A,B**).
 - The surgeon will inspect the models, looking for appropriate contour, size, and position.
- Once the design is approved, the wax-up models are cast into metal components (**TECH FIG 5C**).
 - These components are sterilized and ready for use.
 - Information from the 3D models and custom implants allows the engineer to provide exact screw lengths for each fixation point on the prosthesis.



TECH FIG 5 • **A,B.** Stereolithographic model with wax-up prosthesis. **C.** Cast titanium custom mandibular joint prosthesis.

PEARLS AND PITFALLS

Hemostasis	■ At various points during the procedure, problematic bleeding can be encountered. Meticulous hemostasis is necessary at all times, but particularly during the medial dissection of the condyle and disc.
Nerve injury	■ The facial nerve is at risk during any approach to the TMJ. Careful attention to the local anatomy as well as conservative dissection and nerve monitoring can help prevent injury.
Infection	■ Because a portion of the operation requires the surgeon to enter the

oral cavity, it is paramount that all members of the operative team be aware of this to avoid cross-contamination. The protocols for transitioning to intermaxillary fixation should be reviewed during the procedure briefing and roles clearly established.

Condylar malposition

- The surgeon should ensure that the condylar position is appropriate. The condylar inclination should be oriented posteriorly and superiorly.

POSTOPERATIVE CARE

- Patients are admitted to the inpatient unit for 1 to 3 days postoperatively.
- Standard postoperative pain management should be initiated. It behooves the surgeon to discuss pain management with the patient and any treating pain specialists prior to surgery.
 - Many patients with TMJ disorders use chronic pain medications.
 - Inpatient pain service consultation should be used as needed.
- Postoperative antibiotics are not indicated.
- Patients may be kept in light intermaxillary fixation with elastics or full intermaxillary fixation with wires, depending on the final occlusion and the patient's ability to reliably occlude.
- A headwrap or JawBra may be useful for reducing edema and helping with pain.
- Patients should be maintained on a soft, nonchew diet for 6 weeks postoperatively.
- Lateral and anterior posterior skull films (or panoramic radiograph) are sufficient to verify positioning of the implants and are cost-effective.

OUTCOMES

- TMJ stock prostheses have been FDA approved for more than a decade.
 - Prospective data have demonstrated that, at 3 years postoperatively, patients had decreased pain (mean of 8.5/10–2.8/10), with improved mouth opening (20–29 mm), with 99% of patients reporting that they would undergo surgery again.^{3–6}
 - Reported revision rates are below 5% and are most commonly due to infection or heterotopic bone formation.⁵ Mechanical failures are rare.
- For custom joint prostheses, the results are similar, with noted improvement in pain and mandibular motion.^{1,2}
 - Eighty-five percent of patients with custom alloplastic reconstructions

reported improved quality of life.²

- There is a paucity of long-term data regarding durability of the prostheses, but reports in the literature suggest appropriate functioning at 10 years after insertion and up to 14 years after insertion.^{2,7}

COMPLICATIONS

- Revision rates are relatively low (less than 5%) and are related to infection or heterotopic bone formation.
- Facial nerve injury is perhaps the most significant complication.
 - The risk of attendant nerve injury increases with previously operated sites or otherwise aberrant anatomy (eg, tumor, ankylosis). Meticulous dissection and intraoperative nerve monitoring are necessary to avoid nerve injury.
 - Many patients will experience a postoperative neuropraxia simply from traction. This will typically resolve within 6 to 12 weeks.
 - Frank transections should be repaired immediately (within 72 hours).
 - Delayed recognition of a nerve injury or lack of recovery after 3 months typically requires additional procedures (eyelid weights, facial reanimation) for correction of the deficits.

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Osteocutaneous 35 Parascapular Flap for CHAPTER Mandibular Reconstruction

Ravi K. Garg and John W. Siebert

DEFINITION

- The parascapular osteocutaneous free flap serves as a versatile reconstructive option for composite head and neck defects involving the mandible.
- The lateral border and angle of the scapula are the most commonly used osseous flap components, although harvest of the medial scapular border has also been described.
- Soft tissue elements that may be incorporated into the flap include skin, fat, fascia, muscle such as the serratus and latissimus, and nerves, including the thoracodorsal nerve.

ANATOMY

- The parascapular osteocutaneous free flap is based on the subscapular system emerging from the distal third of the axillary artery.
- The circumflex scapular artery branches from the subscapular artery and serves as the primary blood supply to the parascapular osteocutaneous flap.
- The circumflex scapular artery can be reliably identified in the triangular fossa, which is bound by the teres major and minor muscles as well as the long head of the triceps (**FIG 1**).
- The thoracodorsal artery also branches from the subscapular artery and sends a branch to the scapular angle either directly or as a side branch of the serratus muscle branch.
- The angular artery can be useful for augmenting the blood supply of the scapular border or can be used to harvest the scapular angle as a separate osseous flap.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Determine if the patient has had previous head and neck surgery that would limit recipient vessel options or donor sites for microsurgical reconstruction.
- Assess the patient's level of function and which donor site will result in the least morbidity.
- A scapular flap may be advantageous for older patients with compromised mobility who will have greater difficulty ambulating after surgery if a lower extremity donor site is chosen.¹
- Inspect the patient's dental occlusion and determine whether any diseased dentition needs to be managed perioperatively and whether dental rehabilitation will be performed.²

IMAGING

- Preoperative CT angiography may be useful to exclude lower extremity flap options such as the fibular flap in a patient with claudication and suspected peripheral vascular disease.
- Virtual surgical planning may be helpful for complex head and neck reconstruction. A three-dimensional reconstruction of the recipient and scapula donor sites can be produced using CT imaging. Osteotomy sites at both the recipient and donor scapula locations may be planned preoperatively and a cutting jig developed to facilitate scapular contouring and inset.³

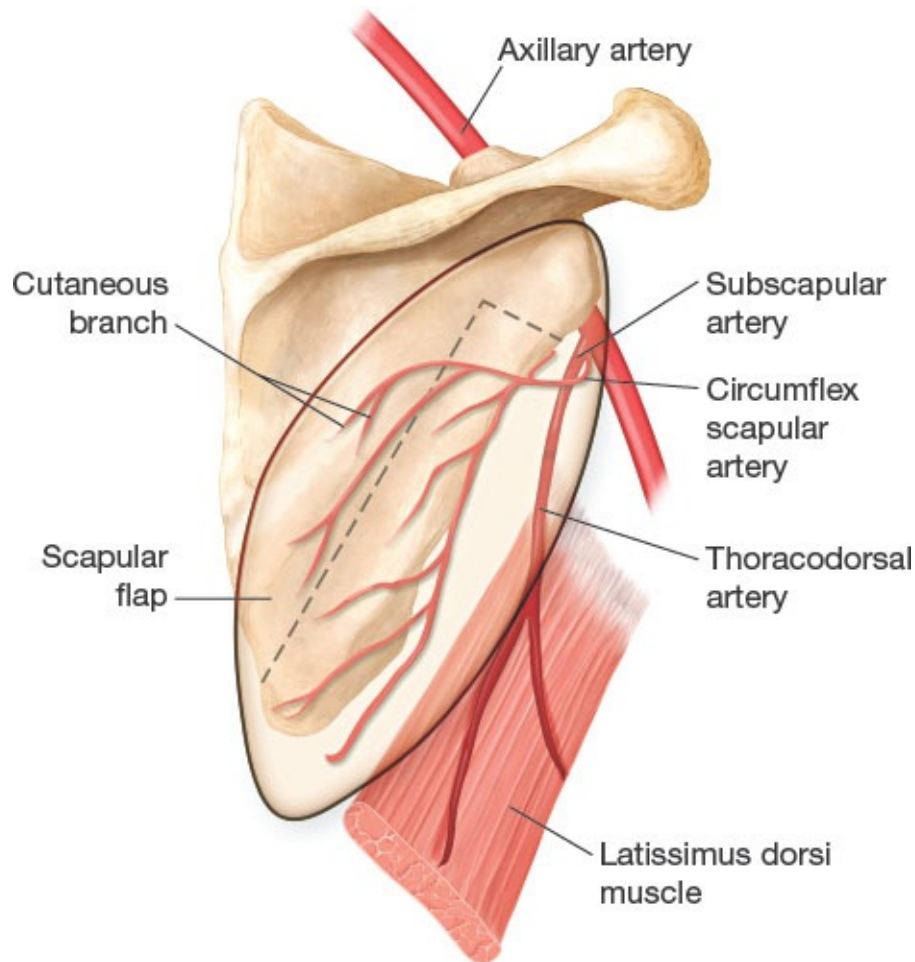


FIG 1 • Demonstration of the cutaneous branch of the circumflex scapular artery exiting the triangular fossa defined by the teres major, teres minor, and long head of triceps. The versatility of the scapular osteocutaneous flap relates to the multiple soft tissue elements including skin, fat, fascia, and the latissimus and serratus muscles that can be elevated with the flap based on the subscapular system. Additionally, the lateral scapular border is perfused by both the circumflex scapular and angular arteries, enabling separate bone flaps to be harvested.

SURGICAL MANAGEMENT

- The parascapular osteocutaneous flap is particularly useful for composite

tissue defects with a large soft tissue component.

- Multiple skin paddles and muscle flaps, including the latissimus and serratus, can be transferred with scapular bone based on the circumflex scapular artery,^{2,4} enabling reconstruction of some of the most complex three-dimensional defects.
- This flap is unique among other choices used for mandibular reconstruction including fibula, iliac crest, and radial forearm free flaps, because the lateral scapular bone is vascularized by a circumflex scapular pedicle branch independent from the branch supplying the skin paddle.
- The bone can be inset into segmental defects of the mandible or used as a mandibular onlay, whereas the skin paddle can be safely rotated up to 180 degrees in relation to the bone.

Preoperative Planning

- Determine the anticipated length of the bony deficit at the recipient site and whether a scapula flap will provide sufficient bone to reconstruct the defect.
- Discuss with the patient and surgical team the functional goals of the reconstruction. Most male patients will be able to accommodate osteointegrated implants into their scapula flaps, although some female patients will have insufficient bone stock.⁵
- Decide whether a two-team approach will be possible based on the positioning needs of the team working at the head and neck prior to transfer of the microsurgical free flap.

Positioning

- The patient is placed in the supine position for induction of general anesthesia.
- A bump is placed under the shoulder ipsilateral to the flap harvest site. This provides sufficient exposure of the upper back, and no beanbag is required for immobilization.
 - Following flap harvest, the bump may be removed, enabling a simple transfer to the supine position.
- A Z-arm is placed on the side of the operating table opposite the back (**FIG 2A**). The patient's arm will be suspended to this following sterile preparation and draping.
- The arm ipsilateral to the flap harvest site is prepped and draped in addition to the upper back.

- A Mayo stand cover is placed over the Z-arm, and this is wrapped with two rolls of gauze (**FIG 2B**).
- A sleeve is placed over the prepped arm past the level of the elbow (**FIG 2C**). The sleeve is secured with a roll of gauze wrapped from the hand up.
- Two Kocher clamps are then used to suspend the patient's arm to the Z-arm (**FIG 2D**).
- This technique avoids any areas of concentrated pressure on the arm and minimizes the risk of peripheral nerve injury.
- The back is then draped with sterile towels and sheets.

Approach

- The operative approach to raising the osteocutaneous parascapular flap depends upon the design of the skin paddle. We tend to design the skin paddle on the back along the axis of the arm so that the donor-site scar will be hidden under the arm. However, the skin paddle can be oriented in any direction around the triangular fossa.
- Once the skin paddle has been designed, we approach flap elevation and pedicle identification by raising the flap from caudad to cephalad. However, the flap pedicle may also be approached by raising the skin paddle from its lateral or medial aspect.



FIG 2 • **A.** The patient is positioned with a bump under the back on the side of flap harvest. The arm is elevated and will be suspended to a Z-arm that crosses the patient's body. **B.** The goal of the setup is to minimize pressure on the forearm and avoid complications of neurapraxia and nerve palsy. A sterile Mayo stand cover is placed over the Z-arm and secured in place with two rolls of gauze. **C.** A sterile arm sleeve is placed over the arm after it has been sterilely prepared. **D.** The sleeve is secured to the arm with a gauze roll, and then, the gauze is secured to the Z-arm using two Kocher clamps. This strategy provides plenty of cushioning for the forearm without creating any areas of focal pressure that could result in nerve injury.

TECHNIQUES

■ Flap Elevation

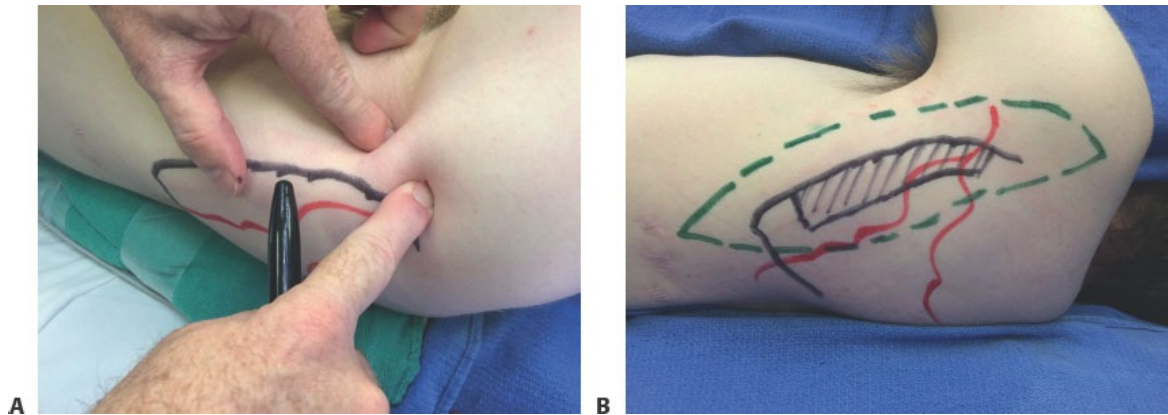
Flap Design

- Landmarks: lateral scapular border, teres major, teres minor, long head of triceps
- The skin paddle of the flap is designed around the triangular fossa through which the circumflex scapular artery passes.
 - A depression superior to the teres major can usually be palpated and used to identify the triangular fossa (**TECH FIG 1A**).
- The teres major measures two fingerbreadths wide and runs almost parallel to the lateral scapular border.
 - If the muscle cannot be palpated, then the lateral border of the scapula may be identified and traced just proximal to the glenohumeral joint.
 - The triangular fossa is located two fingerbreadths medial to this junction of the lateral scapular border and glenohumeral joint.
 - Confirmation can be performed with a pencil Doppler.
- A skin paddle 5 to 10 cm in width and 16 to 46 cm in length can be harvested and enable primary closure (**TECH FIG 1B**).
 - Cadaver studies have demonstrated that branches of the circumflex scapular artery emerge radially from the triangular fossa and even perfuse the anterior chest wall at least as far as the anterior axillary line.⁶ The implication is that a long skin paddle can be harvested and followed into the inframammary fold to keep the donor site discrete.

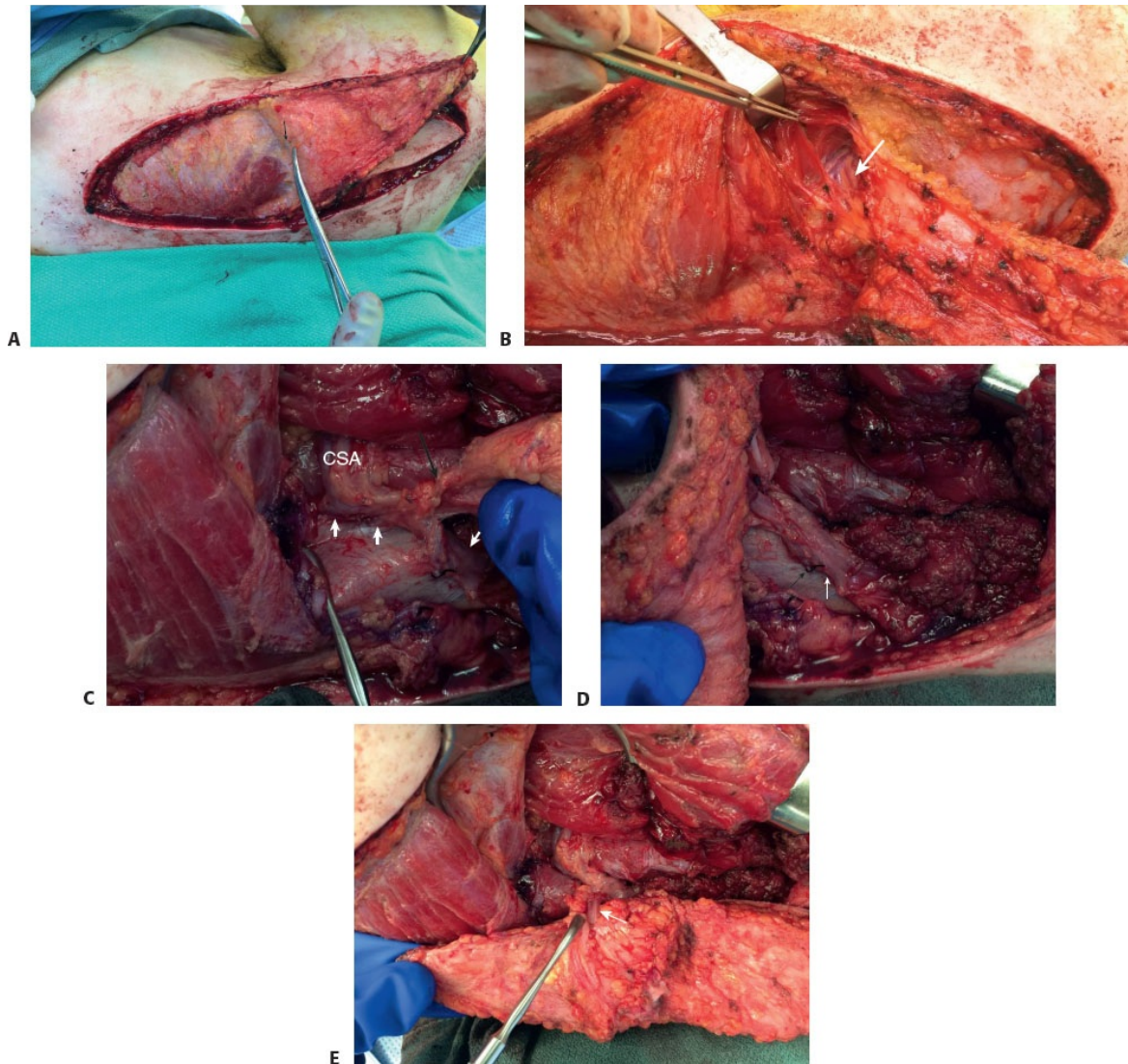
Soft Tissue Dissection

- Once the patient is prepped and draped in a sterile fashion, skin cuts are made along the outline of the elliptical skin paddle.
- The skin paddle is elevated from caudad to cephalad using electrocautery (**TECH FIG 2A**).
 - Elevation can be performed in a subfascial or suprafascial manner.
 - If additional flap bulk is desired, a subfascial dissection may be desirable and may incorporate a fascial extension beyond the borders of the skin paddle.

- Paralyzing agents are used to facilitate electrocautery dissection.
- As the superior border of the teres major is approached, a tenotomy is used to expose the border of the muscle until the cutaneous perforator to the skin paddle is identified.
- The cutaneous perforator is followed proximally to the main trunk of the circumflex scapular vessels.
 - As the vessels are traced, distinct branches will be identified that directly penetrate the lateral scapular border or that travel closely along the muscle and fascia overlying the lateral scapular border (**TECH FIG 2B**).
- Usually, the circumflex scapular artery sends two or three branches directly to the lateral scapular bone (**TECH FIG 2C**).
- A transverse branch investing the overlying scapular muscle and fascia supplies the medial scapular border and may serve as the basis for a medial scapular osteocutaneous flap.
 - We tie this branch off and prefer to use the lateral border of the scapula for reconstruction.
 - Distinct, descending branches of the circumflex scapular vessels travel along the lateral border of the scapula and are identified and preserved (**TECH FIG 2D**).
- At this point, the remainder of the skin paddle is elevated cephalad to the cutaneous branches of the circumflex scapular vessels.
 - The skin paddle is now completely free and perfused only by these cutaneous branches (**TECH FIG 2E**). This enables the skin to be moved back and forth to facilitate exposure of the lateral scapular border.
 - The skin paddle can be rested on a stack of green towels to help expose the scapular border while minimizing tension on the circumflex scapular vessels.
- The teres minor and portions of the teres major and infraspinatus muscles are dissected off the lateral border of the scapula in order to prepare the bone for osteotomy.
 - A thin cuff of muscle is left on the lateral bone in order to preserve its periosteal blood supply.



TECH FIG 1 • A. The triangular fossa, where the cutaneous branch of the circumflex scapular artery emerges, can be identified on physical examination. The teres major is pinched cephalad to the latissimus. The depression superior to the teres major is where the cutaneous branch emerges and can be confirmed with Doppler. **B.** The skin paddle to be elevated is outlined based on the course of the circumflex scapular artery. The scapula is palpated and the lateral border is marked.

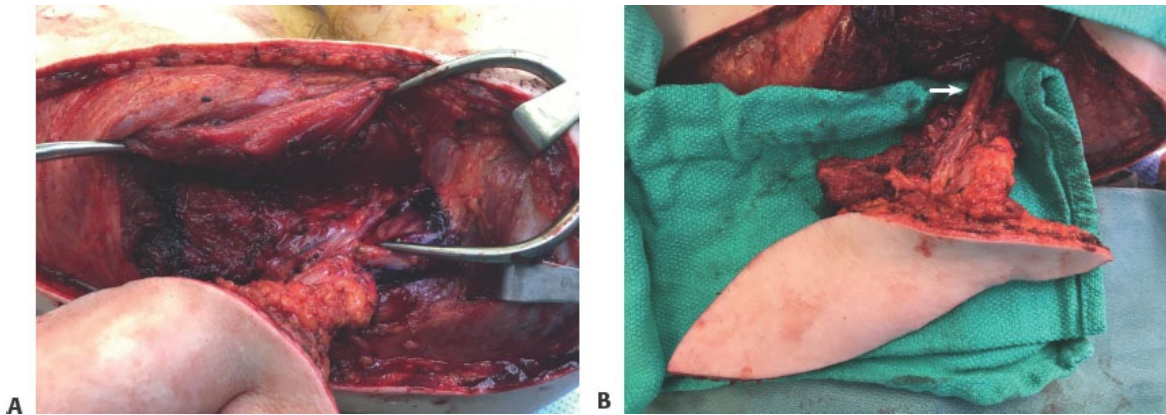


TECH FIG 2 • A. After completing the skin cuts, the skin paddle is elevated from caudad to cephalad. The dissection was performed leaving some fascia over the latissimus muscle. Midway through the skin paddle elevation, the cutaneous pedicle became visible (*black arrow*). **B.** The cutaneous pedicle is followed into the triangular fossa. Here, the teres major is being retracted with a forceps and the pedicle to the skin paddle (*white arrow*) can be seen branching from the circumflex scapular artery. **C.** Further dissection of the circumflex scapular artery (CSA) reveals multiple

direct branches to the bone (*arrowheads*) and a descending branch traveling along the lateral scapular border (*white arrow*) in addition to the cutaneous pedicle (*black arrow*). **D.** The skin paddle is flipped the opposite direction and the circumflex scapular arterial branch traveling along the muscle cuff at the lateral scapular border (*white arrow*) can be easily seen. A transverse branch traveling across the scapula has been tied off (*black arrow*). **E.** The skin paddle has been dissected completely off the back now that the circumflex scapular artery is fully defined in the triangular fossa. *Arrow* points to the cutaneous pedicle.

Bone Flap Creation

- At least 1 cm of lateral scapular bone is preserved below the glenoid fossa to avoid disruption of the glenohumeral joint.
 - The area of bone to be harvested incorporates the direct bony branches to the scapula as well as the descending scapular branch, resulting in a robust blood supply to the bone (**TECH FIG 3A**).
- Electrocautery is used to divide the infraspinatus muscle directly over the portion of the scapular bone that will be harvested.
- A sagittal or reciprocating saw is then used to make transverse cuts through the bone beginning at the lateral border as well as a longitudinal cut to join these initial osteotomies.
 - An osteotome is used to release any areas of bony adherence.
- The osteotome is then levered through the caudal, transverse bone cut, exposing the subscapularis muscle on the undersurface of the scapular bone.
 - The muscle is divided parallel to the border of the bony cut, leaving the entire bony segment free with a cuff of infraspinatus and subscapularis muscle on each surface (**TECH FIG 3B**).



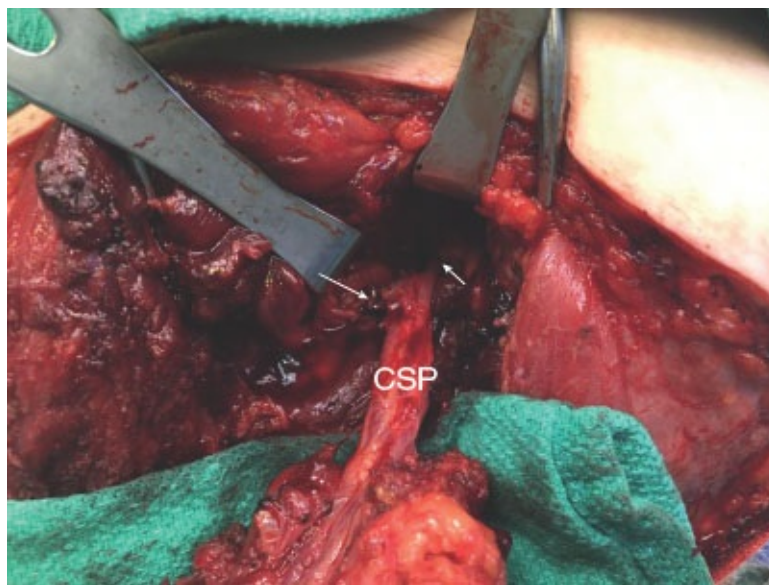
TECH FIG 3 • A. The segment of lateral scapular bone to be harvested is outlined with purple ink. The outline incorporates the direct bony perforators of the circumflex scapular artery in addition to the descending branch along the scapular border. The muscle is then divided down to bone along the marking, and a sagittal saw is used to perform the osteotomies. **B.** The lateral scapular bone segment has been completely freed from the donor site in addition to the cutaneous paddle. The circumflex scapular artery is seen (*arrow*) tethering the composite flap to the triangular fossa.

- The total length of lateral scapular bone that may be harvested including the scapular angle is approximately 10 to 14 cm in an adult.

Vascular Pedicle Dissection

- With the skin paddle and bony components of the flap free, the circumflex scapular vessels are now followed through the triangular fossa to gain pedicle length.
- Side branches of the circumflex scapular vessels to the surrounding musculature are ligated.
 - The pedicle can be followed to the bifurcation of the subscapular artery into circumflex scapular and thoracodorsal branches.
- The vascular pedicle is approximately 2 to 3 mm in diameter, and the pedicle length is about 4 to 9 cm.⁷

- If additional length is needed, the thoracodorsal vessels may be ligated and the subscapular artery traced to its branch point from the axillary artery (**TECH FIG 4**).
 - Alternatively, the thoracodorsal artery can be harvested and used for reverse arterial inflow, resulting in a pedicle length of 15 to 27 cm.⁸
- Once flap harvest is complete, some surgeons drill holes in the residual scapular bone and suture the teres major and minor muscles to the bone.
- One or two drains are placed over the donor site, and the back is closed in layers.



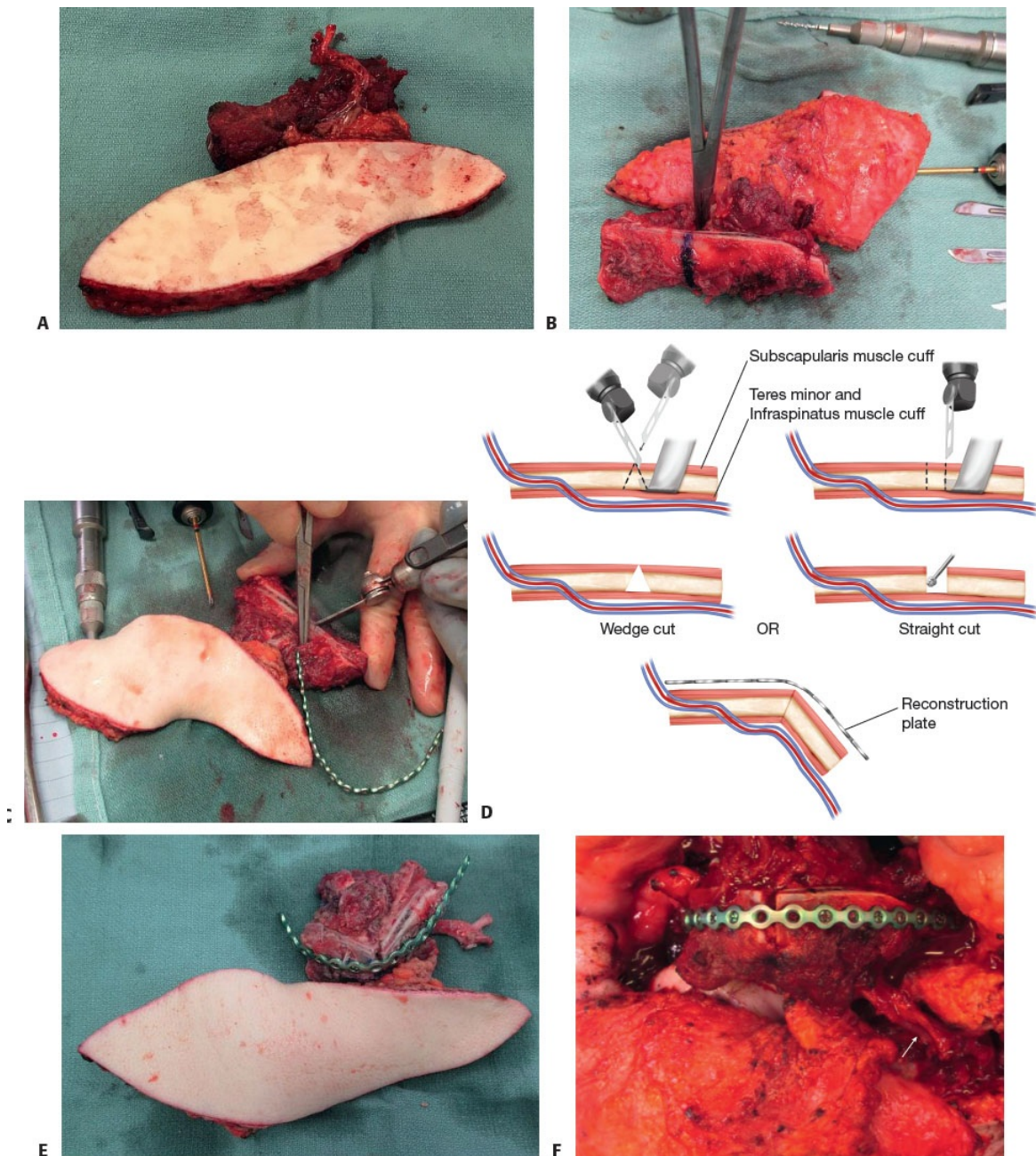
TECH FIG 4 • To lengthen the circumflex scapular pedicle (CSP), the thoracodorsal pedicle is clipped (*large arrow*) at its branch point from the subscapular artery and the subscapular artery (*small arrow*) is followed toward the axillary artery.

■ Flap Contouring and Inset

- The flap pedicle is divided and the flap is brought to the back table for any necessary osteotomies (**TECH FIG 5A**).
 - Some surgeons choose to perform osteotomies while the flap is still perfused on the back, although this does create a risk of pedicle torsion.
- To perform an osteotomy, it is important to protect the vascularized muscle

cuff in addition to the branch of the circumflex scapular artery descending along the lateral scapular border.

- A right-angled instrument can be used to dissect around the scapula bone at the planned osteotomy site (**TECH FIG 5B**).
- A wedge of bone is then excised with a sagittal saw while the right-angled instrument is used to protect the vascularized muscle cuff and flap pedicle (**TECH FIG 5C**).
- Further contouring of the osteotomy can be performed with a bur so that the bone conforms to the arch of the reconstruction plate (**TECH FIG 5D**).
- The scapula bone segments are then drilled into a reconstruction plate (**TECH FIG 5E**) or a combination of miniplates.
- The parascapular flap skin and bone are reperfused at the recipient site following completion of microvascular anastomosis (**TECH FIG 5F**).



TECH FIG 5 • A. The parascapular osteocutaneous flap has been divided and is taken to the back table. **B.** A right angle retractor is used to dissect between the vascularized muscle cuff and the scapular bone, protecting the descending branch of the circumflex scapular artery. The planned osteotomy site is marked with purple ink. **C.** An oscillating saw is used to make

a wedge-shaped osteotomy to enable the bone to conform to the reconstruction plate. **D.** Different methods of performing the wedge osteotomy to contour the scapular bone to the reconstruction plate. Once the flap pedicle and muscle cuff are protected, an oscillating saw can be used to remove a wedge of bone. This can be freehanded or performed with the help of a cutting jig. Alternatively, a straight osteotomy can be performed and a bur can be used to shave the posterior cortex. This latter method enables controlled, gradual contouring of the scapular bone until the bone segments fit together correctly. **E.** The scapular bone segments are secured to the locking, reconstruction plate using monocortical screws. **F.** The flap is inset into a segmental mandibular defect and the flap pedicle is sewn to recipient vessels in the neck (*arrow*), resulting in revascularization of the composite tissue.

■ Reconstruction of Facial Atrophy

- In addition to being used for segmental reconstruction of the mandible, the parascapular osteocutaneous flap can also be used as an onlay reconstruction for severe facial atrophy.
- The osseous component can be used to augment the jawline, while the soft tissue is used to balance the contour of the face and establish symmetry (**TECH FIG 6**).



TECH FIG 6 • This patient presented with impairment of left-sided facial growth following removal of a tumor and adjuvant radiation therapy when she was a young child. She had loss of soft tissue volume in the left midface and lower face, in addition to deficiency of the left mandibular angle and ramus. **A.** Intraoperative markings indicate areas of soft tissue and bony deficiency where the osteocutaneous flap will be used as an onlay reconstruction. The preauricular incision was used to develop a pocket for the soft tissue component of the flap, while the neck incision was used to develop a space for the osseous component of the flap and isolate the facial vessels for microvascular anastomosis. **B.** Markings for the osteocutaneous parascapular flap are demonstrated prior to flap elevation. **C.** The flap is depicted following harvest with the vascular pedicle displayed over the yellow background. **D.** Postoperative appearance following flap inset along the left face. **E.** Preoperative

appearance. **F.** Appearance 6 weeks after surgery.

PEARLS AND PITFALLS

Patient positioning

- Supine positioning with a bump behind the shoulder enables simultaneous dissection at the recipient and donor sites.
- Suspension of the arm on the side of the flap being elevated minimizes pressure points.

Cutaneous pedicle dissection

- While dissecting the cutaneous pedicle of the circumflex scapular artery from the triangular fossa, preserve the fibrofatty tissue that surrounds the pedicle.
- This fatty tissue serves as a sort of mesentery, incorporating small branches from the circumflex scapular artery at the base of the septum to the skin paddle. Preservation of this fibrofatty tissue enhances blood supply to the skin paddle.

Skin paddle elevation

- The cutaneous branch of the circumflex scapular artery will usually arise abruptly just cephalad to the teres major muscle.
- Dissection should proceed carefully at this level to avoid injury to the cutaneous blood supply.

Hemostasis

- The scapular osteotomies usually result in the most bleeding, typically from contact of the saw with surrounding muscle fibers.
- Be sure to cauterize any perforating vessels through the subscapularis muscle as it is divided.
- Bleeding will usually decrease substantially once the osteotomies are complete.

Flap pedicle dissection

- The circumflex scapular artery radiates small branches to the surrounding musculature of the triangular fossa in addition to branches to the scapular bone.
- To identify these branches without disrupting them, it helps to spread through the soft tissue perpendicular to the main axis of the pedicle.
- This strategy helps the surgeon minimize bleeding and enables him or her to decide which pedicle branches to preserve and which pedicle branches to sacrifice.

POSTOPERATIVE CARE

- Shoulder movement is permitted as tolerated after surgery.

- As patients progress, they may work on rebuilding shoulder strength and range of motion.
- An occupational therapist can be very helpful for creating a graduated program for the patient.

OUTCOMES

- Swartz is widely regarded as the first surgeon to popularize the osteocutaneous scapula flap for mandible reconstruction.⁹
 - In his series of 26 patients, 21 patients underwent mandibular reconstruction and there was a 100% flap survival rate.
- The senior author has also had 100% survival of the osteocutaneous scapular flap.

COMPLICATIONS

- The soft tissue elements of the subscapular system carry a robust blood supply. However, if soft tissue ischemia occurs, local debridement and wound care may be necessary.
- Osteocutaneous fistulas may occur and can usually be managed with local wound care.¹⁰
- When scapular osteotomies are performed, there is a risk of ischemia involving the distal scapula bone beyond the osteotomy site. Swartz described two patients who experienced nonunion due to bone loss beyond the scapular osteotomy site.⁹
- If multiple osteotomies are being planned, incorporation of both the circumflex scapular and angular arteries to the lateral scapular bone may be considered to augment the blood supply and reduce the risk of distal bone ischemia.¹

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Reverse Distraction to Create a Temporomandibular Joint

36

CHAPTER

Joseph Lopez and Anand R. Kumar

DEFINITION

- Distraction osteogenesis is a process of slow bone expansion in which new bone forms between an osteotomy gap secondary to tension stresses placed across the bone gap.¹
- Functional remodeling—the process of functional tissue formation—can be used to create a neocondyle through distraction osteogenesis.

ANATOMY

- The mandible is composed of seven zones: symphysis, body, dentoalveolar, angle, ramus, coronoid, and condyle.
- The mandible articulates with the squamous portion of the temporal bone at the condyle by forming the temporomandibular joint (TMJ).
- The TMJ allows rotational and translational movement of the mandible.
- The TMJ joint is surrounded by several muscles:
 - The masseter muscle, temporalis muscle, medial and lateral pterygoid muscles elevate or protrude the mandible.
 - The superior portion of lateral pterygoid inserts on the fibrous capsule and meniscus of the TMJ (stabilizes the meniscus during movement of the mandible).
 - The inferior portion of the lateral pterygoid inserts on the neck of the condyle (helps protrude the mandible when contracting).
 - The geniohyoid muscle and the anterior belly of the digastric muscle depress and retract the mandible.
 - All muscles are innervated by cranial nerve V.

- The TMJ articular surface (articular disc) contains a dense fibrous, connective tissue known as fibrocartilage (unlike other synovial joints, which contain hyaline cartilage).
- The central portion of the TMJ articular disc (fibrocartilage) is avascular, whereas the periphery is innervated and receives a tributary of blood vessels. The retrodiskal tissue, which is responsible for the nutrition of the TMJ, are perfused by branches of the maxillary artery (posterior auricular, anterior tympanic, and meningeal medial arteries), drained by the temporomandibular veins, and innervated by the auriculotemporal and posterior auricular nerves.
- This fibrocartilage material divides the region of the joint into two spaces:
 - The upper joint space extends from the glenoid fossa to the articular eminence.
 - The lower joint space begins above the insertion of the lateral pterygoid and then spreads out over the condyle.
- The upper joint space is involved in translational movement of the mandible (arthrodial).
- The lower joint space is involved in rotational movement (ginglymus).

PATHOGENESIS

- TMJ reconstruction is required in both pediatric and adult populations. The most common conditions that often require TMJ reconstruction include TMJ ankyloses after resection arthroplasty, micrognathia/retrognathia (hemifacial microsomia), and juvenile idiopathic arthritis that can present in both adult and pediatric patient populations.
 - TMJ ankylosis refers to a pathologic condition in which the mandible is fused to the cranial fossa by bony or fibrotic tissue. TMJ ankylosis can be caused by trauma, infection, congenital deformities, idiopathic factors, or iatrogenic causes.
 - Micrognathia is a congenital condition involving an abnormally small mandible. It is associated with upper airway obstruction and tends to occur in conjunction with tongue malposition.
 - Retrognathia is a condition in which there is lack of development of the mandible; more specifically, it refers to the retruded position of the mandible in relationship to the maxilla.
 - Juvenile idiopathic arthritis (JIA): JIA is the most common rheumatologic disease in children of unclear etiology that can commonly affect the TMJ.
- Other common causes of TMJ pathology include degenerative joint disease,

traumatic injury, rheumatoid arthritis, and TMJ ablation following tumor resection.

NATURAL HISTORY

- Distraction osteogenesis for TMJ reconstruction involves moving a segment of bone, known as the transport disc, slowly away from the host bone into the defect or future TMJ location (**FIG 1**).

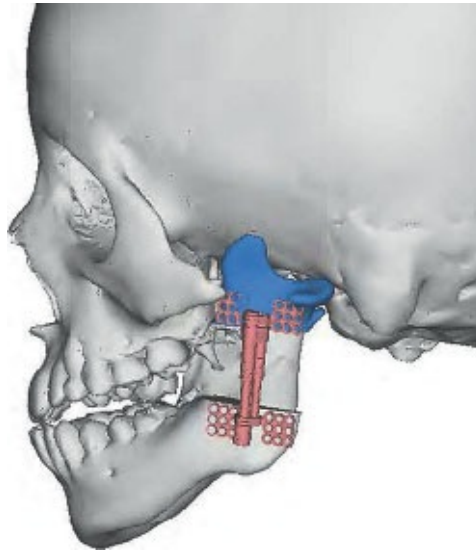


FIG 1 • A digital image demonstrating the transport disc in its new simulated position in the region of the newly generated TMJ joint. Note the vertical vector of distraction and the largest possible piece of bone used as the transport disc.

- The transport disc is formed from the vertical ramus remnant or angle of the mandible and is slowly moved into the glenoid fossa or neoglenoid fossa region of the temporal bone.
- New bone formation (osteogenesis) occurs at the interface between the transport disc and the host bone. The newly formed bone trailing at the leading edge of the disc forms the new ramus or condylar neck.
- Similarly, a fibrocartilagelike structure forms at the disc's leading edge. This neofibrocartilage cap becomes the new articular surface.
- Experimental studies provide support for the remodeling steps described above:

- Zhu et al.² investigated the histomorphologic changes in the newly formed condyle reconstructed by transport distraction osteogenesis in a nonhuman primate model. This study found that “bone regeneration was perfect in the distraction gap between the transport disc and the pre-existing mandible” and the resulting neocondyle was “similar to the original condyle in appearance and structure.”
- Similarly, Hikiji et al.³ investigated articular remodeling capacities of distraction osteogenesis for TMJ reconstruction in New Zealand white rabbits and found that after 8 weeks of lengthening, “mature cortical bone” formed between the transport disc and the host bone mandibular segment. Similarly, this experimental study found that a collagenous-like structure formed a cap over the leading edge of the transport segment, suggesting this may “substitute for an articular disc.”

PATIENT HISTORY AND PHYSICAL FINDINGS

- Inspection of the head and neck region
 - Assess soft tissue asymmetry or skeletal deformities.
 - Assess ear canals and tympanic membrane for primary benign or malignant disease.
 - Assess dentition for malocclusion, mobility of teeth or prosthetics, or mandibular displacement during teeth contact.
 - Assess oral mucosa for periodontal disease, mucosal lesions, or swelling.
 - Assess for overjet, overbite, or open bite.
- Neurovascular exam
 - Cranial nerves 5 and 7 are checked, particularly examining function of the lip depressors (marginal mandibular nerve). This is the most common facial nerve palsy in hemifacial microsomia.
- Palpation of the head and neck region
 - Palpation of the TMJ region to detect crepitus, clicking, or popping
 - Palpation for swelling or tenderness of the TMJ region
 - Assess TMJ range of motion (ROM). Normal measurements in adults:
 - Interincisal opening = 40 to 50 mm
 - Lateral interincisal movement greater than 10 mm on each side
 - Any restriction in lateral movement, deviation on mouth opening, or developing of an open bite should be noted.

IMAGING

- A panoramic radiograph can identify gross fractures, arthritic changes, bone cysts or tumors, malformation, or bony abnormalities.
- Computed tomography (CT) provides bone pathology information via sectional imaging in both the coronal and sagittal planes (taken in both open and closed joint positions)
- CT remains the most frequently used modality to image in 2D and 3D the abnormal bone defect or morphology. The CT can also be used to perform virtual surgical planning (**FIG 2**).
- Magnetic resonance imaging (MRI) provides soft tissue, disc, and bone pathology information. MRIs are most often used to assess soft tissue and/or synovial disease.
- Benefits of MRI vs CT:
 - Absence of ionizing radiation
 - Imaging in multiple planes
 - Adequate soft tissue detail

DIFFERENTIAL DIAGNOSIS

- Condylar resorption after orthognathic surgery
- TMJ ankylosis
- Degenerative joint disease
- Micrognathia
- Retrognathia
- Hemifacial microsomia
- TMJ resection after pathology
- Degenerative joint disease of the TMJ
- Juvenile idiopathic arthritis of the TMJ

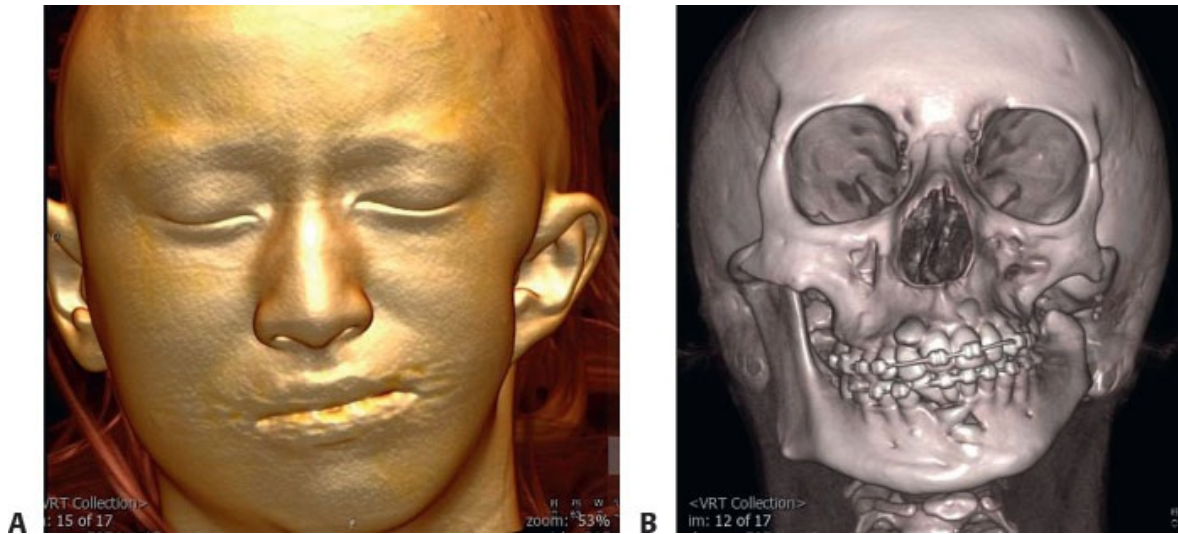
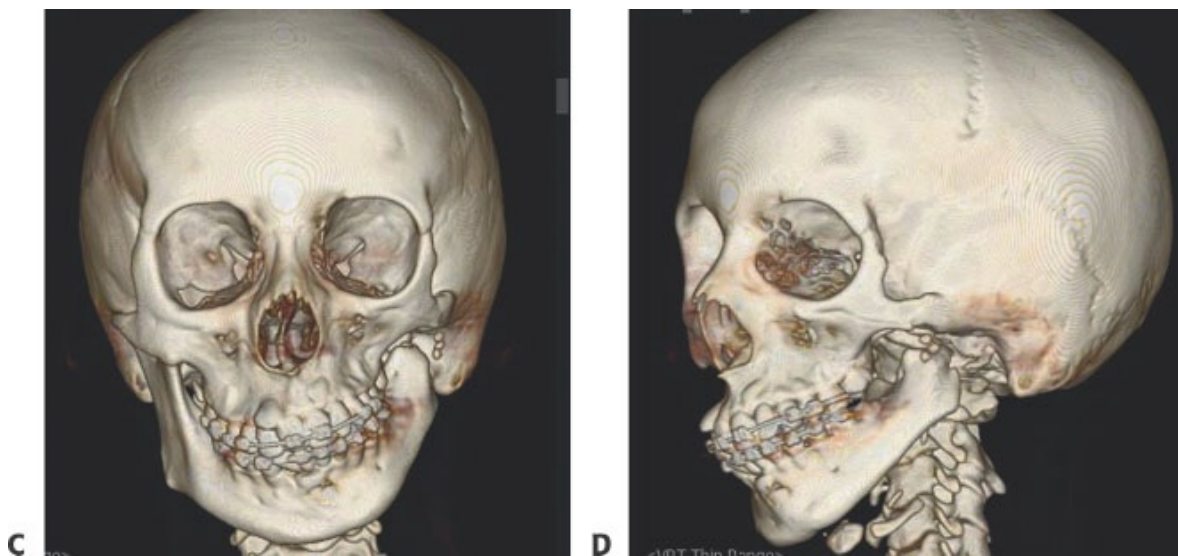


FIG 2 • Soft tissue (**A**), bone 3D CT scan (**B**), and AP (**C**) and oblique (**D**) bone window 3D CT scans demonstrating a shortened vertical ramus (type IIB) mandible with significant distance between the malshaped condyle and the proposed glenoid fossa location.



SURGICAL MANAGEMENT

- The indications for TMJ reconstructions are fairly broad:
 - Tumor resection
 - Degenerative joint disease

- Ankylosis
- Congenital anomalies
- Unrepairable trauma
- However, the goals are fairly specific:
 - Restoration of normal occlusion and jaw function
 - Pain relief
 - Restoration of mandibular ramus height (condylion to gonion distance)
- Distraction-based TMJ reconstructions has many benefits:
 - The TMJ is reconstructed with autogenous material that is immunologically inert and therefore capable of remodeling and growth.
 - A second donor site is not required so as to minimize overall surgical morbidity.
 - Distraction osteogenesis allows jaw mobility, decreasing the risk of restricted range of motion.

Preoperative Planning

- Radiographs of the mandible should be reviewed to determine the size of distractor needed to form a properly sized defect.
- An MRI may be useful to evaluate the soft tissue surrounding the TMJ joint.
- CT is the most useful imaging study to determine the extent of vertical ramus and transport disk anatomy for securing the hardware (**FIG 1**).

Positioning

- The patient is positioned supine on the operating table with the head in extension using a shoulder roll.

Approach

- Intraoral approach (preferred approach) with cheek trocar for screw insertion
- Extraoral/submandibular approach is an alternative.

TECHNIQUES

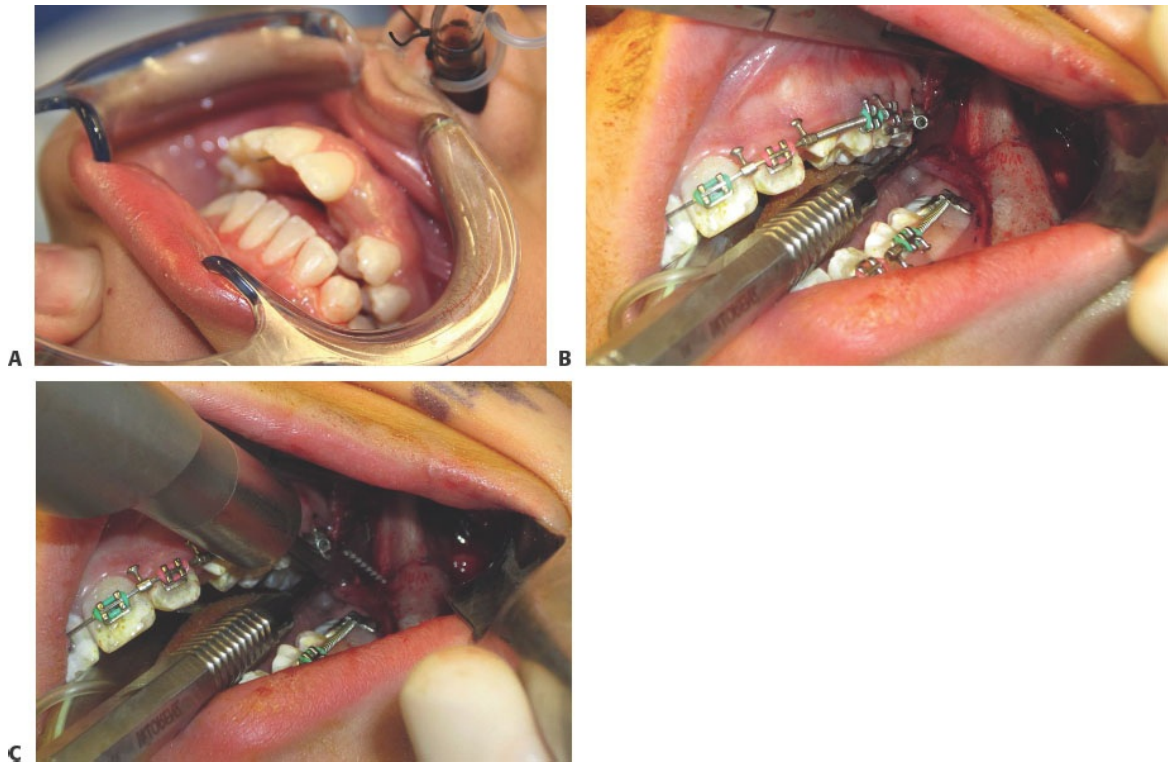
■ Reverse Distraction for TMJ Reconstruction

Exposure and Osteotomy

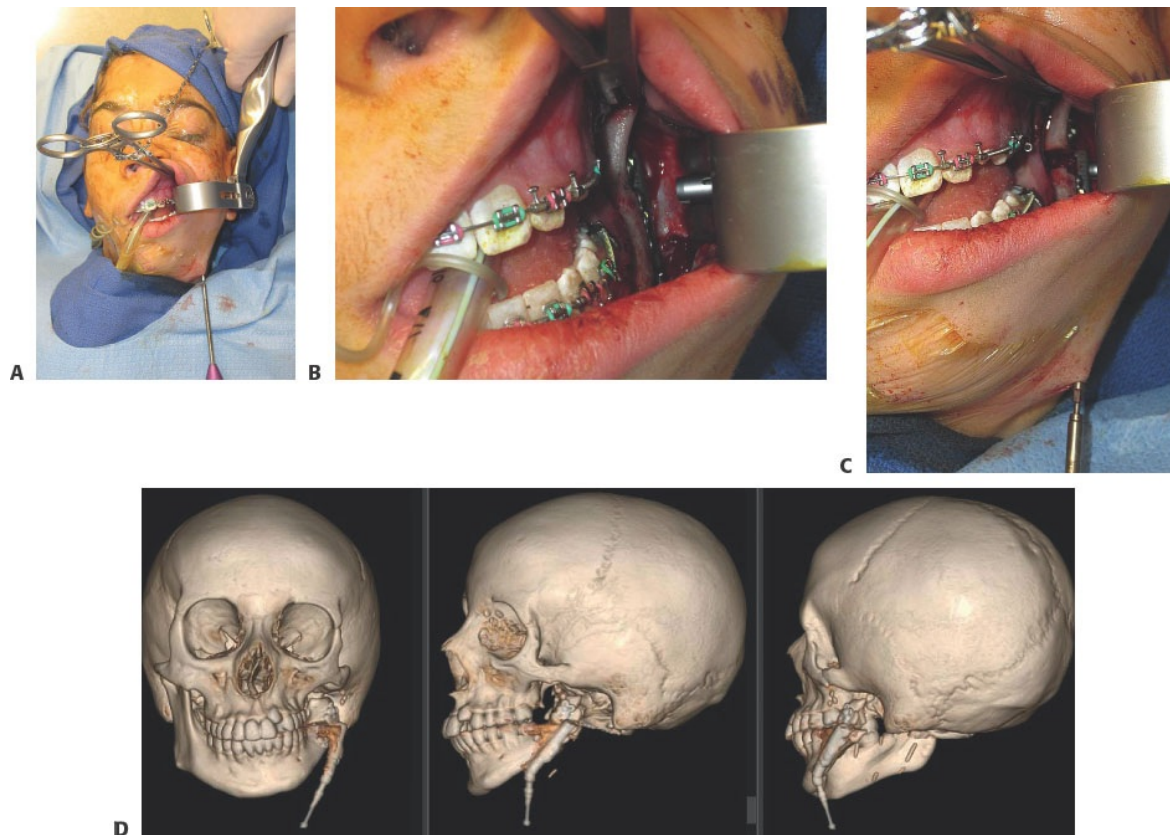
- An intraoral sulcular or submandibular incision is made beneath the angle of the mandible (**TECH FIG 1A,B**).
 - Our preference is an intraoral approach in late mixed dentition (9 to 12 years-of-age).
- A partially completed transverse osteotomy of the vertical ramus remnant is made to create the transport disc (**TECH FIG 1C**).
- The medial periosteum and muscle attachments are left intact so as not to compromise the transport disc's blood supply.
- The superior surface of the transport disc is *not* adjusted because postdistraction remodeling will allow for an anatomical articular pseudosurface to form without direct shaping.

Distractor Placement and Activation

- A properly sized distractor is chosen and is attached with a single screw using the percutaneous cheek trocar system or a right angle drill/screw driver in the inferior attachment plate (**TECH FIG 2A,B**).
 - The distraction vector is then adjusted to ensure growth into the glenoid fossa.
- The remainder of the screws are placed. We prefer 1.5-mm-diameter screws that are 5 mm in length, with a minimum of three screws on each side of the osteotomy.
- After placement of all the screws, the device is activated, and the osteotomy is partially opened and then completed with an osteotome as needed. Then, the disc is ready to be mobilized.
- A separate, single stab incision in the neck region is made to externalize the activation rod (**TECH FIG 1C**).



TECH FIG 1 • A. Severe class II bite with an overjet of more than 10 mm. **B.** Transoral approach to the vertical ramus and dissection of the buccal and lingual surfaces in preparation for the horizontal osteotomy of the vertical ramus remnant. **C.** Reciprocating saw position just prior to beginning the lingual osteotomy.



TECH FIG 2 • A. Use of the transbuccal trocar for screw placement and the activation rod exit site in the ipsilateral neck, ensuring a vertical vector. **B.** Close-up view of the trocar and activation rod of the internal distraction device in place. The device is well adapted to the underlying transport disc. **C.** The distraction device is shown in place with the transport disc activated and displaced cephalad into the region of the new glenoid fossa. **D.** Postprocedure CT scans demonstrating the device in place after vertical ramus osteotomy but prior to activation during the latency period of 72 hours after surgery.

- If simultaneous removal of pathology is necessary (eg, tumor, mass, ankylosis, or degenerative joint disease resection), a separate preauricular incision can be created to facilitate the dissection.
- After a latency period of 72 hours, distraction of 1 mm daily is performed

until completion of distraction (**TECH FIG 1D**).

- End points of distraction include symmetric vertical ramus length based on clinical exam and the creation of an anterior crossbite and posterior open bite in hemifacial microsomia cases.
- Distraction is considered complete when the occlusion reaches the desired final position based on the pathology being treated.
- Once distraction is no longer needed, the activation rod is removed and the skin is allowed to close.
- After a consolidation period of 3 to 4 months, the distractor can be removed through the original intraoral incision or rarely using a separate submandibular incision.

PEARLS AND PITFALLS

Indications	■ Tumor resection, degenerative joint disease, ankylosis, congenital anomalies, and unreparable TMJ trauma
Goals	■ Restore normal occlusion and jaw function ■ Pain relief ■ Restoration of mandibular ramus height
Distractor placement	■ Accurate placement and correct distraction vector are crucial factors that can influence long-term clinical success.
Postoperative diet	■ Patients should be maintained on soft diet until the consolidation period is complete, typically 12 wk.
Postoperative physical therapy	■ Mouth range-of-motion exercises are crucial to minimize the risk of joint stiffness after distraction-based TMJ reconstruction.

POSTOPERATIVE CARE

- Postoperative physical therapy is critical since functional remodeling continues after removal of the distraction device.
- Patients are encouraged to open/close the mouth and masticate during the

distraction process.

- All patients are placed on a soft diet until the consolidation phase is complete.
- Some surgeons encourage the use of a flat plane TMJ occlusal splint while sleeping at night for a minimum of 6 months.

OUTCOMES

- Over the past three decades, only a handful of studies have explored surgical outcomes after distraction-based TMJ reconstruction.
 - Almost all of the studies have been case series.¹⁻⁶
 - No high-level evidence studies have been published.
- In one of the largest series in the literature, Schwartz et al. assessed surgical outcomes in 12 patients who underwent reverse distraction for TMJ reconstruction.
 - At an average follow-up of 32 months, all patients demonstrated evidence of “stable occlusion” with adequate range of motion and no postoperative symptoms.⁵
- Stucki-McCormick⁶ presented their outcomes in two patients who underwent transport distraction osteogenesis for TMJ ankylosis and degenerative TMJ disease.
 - At 18 months follow-up, the interincisal opening of both patients improved from 6 to 28 mm and from 5 to 45 mm, respectively.
 - None reported pain with mastication at 18 months’ follow-up, and both patients demonstrated radiographic evidence of neocondyle development.
- To date, only one study (level III evidence) has compared surgical outcomes in patients treated with distraction osteogenesis vs arthroplasty for TMJ reconstruction.
 - Gabbay et al.⁴ examined nine congenital TMJ bony ankylosis patients, four of whom underwent distraction osteogenesis and five of whom underwent arthroplasty reconstruction.
 - Because TMJ ankylosis is prone to relapse, the primary outcome of this study was the rate of relapse. At 11 months postintervention, the authors found that TMJ arthroplasty had lower rates of relapse (8% vs 48%) when compared to distraction osteogenesis.
 - Although distraction osteogenesis patients demonstrated adequate initial mean incisor openings (27.5 vs 33.4 mm), these patients relapsed to 14.3 mm by 12.5 months postdistraction.

- Given the lack of high-level evidence evaluating the role of distraction osteogenesis in TMJ reconstruction, more studies are necessary to further elucidate the efficacy of this treatment modality when compared to other options (ie, arthroplasty, vascularized bone grafts, etc.).

COMPLICATIONS

- Hardware extrusion
- Surgical site infection
- Relapse
- Facial nerve palsy
- Seroma/hematoma
- Fistula
- Poor wound healing (eg, dehiscence)

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Bilateral Sagittal Split Osteotomy for Mandibular Deficiency

37

CHAPTER

Stephen B. Baker

DEFINITION

- The mandible supports the lower 16 teeth, and its position is important for occlusion, airway function, jawline aesthetics, and facial form.
- It is a U-shaped bone that has three points of contact: two condylar heads, which rest in the glenoid fossa of the skull base, and the mandibular teeth, which are in occlusion with the maxillary teeth.
- Mandibular growth abnormalities can result in malocclusion as well as other functional problems such as airway obstruction, articulation difficulty, masticatory problems, and temporomandibular joint (TMJ) problems.^{1,2}
- The bilateral sagittal split osteotomy (BSSO) is a procedure that allows movement of the mandible in an anterior or posterior direction while maintaining overlap of the osteotomized bone segments.
- The fact that the proximal and distal osteotomized bone segments overlap facilitates return to normal jaw strength and function as healing occurs.
- Dal Pont modification
 - The anterior vertical portion of the sagittal split osteotomy should be made in the region of the mandibular first molar or slightly anterior.
 - The reason for this recommendation is that the inferior alveolar nerve (IAN) is more medially positioned within the mandible in this region and therefore is less at risk of injury during the osteotomy.¹
- Hunsuck modification
 - Hunsuck proposed that the horizontal portion of the BSSO on the medial ramus did not need to extend through and posterior to the lingula.

- He proposed correctly that this portion of the osteotomy would split naturally if the posterior cut did not go posteriorly to the lingula.²

ANATOMY

- The mandible is divided into several regions: the condyle, ramus, angle, body, parasymphysis, and the symphysis.
- The lingula is a triangular bony projection on the medial surface of the mandible, immediately in front of the mandibular foramen. It provides attachment for the sphenomandibular ligament.
- The genial tubercle is on the lingual side of the symphysis and is attached to the genioglossus and the geniohyoid.
 - In a mandibular advancement, the genial tubercle will bring these two muscles forward, which may improve the airway as well as tighten submental laxity.
 - In contrast, posterior positioning may impair the airway and cause submental fullness.
- The IAN is a continuation of the third branch of the trigeminal nerve and enters the mandibular foramen, located on the medial aspect of the ramus. This nerve travels through the mandible in the inferior alveolar canal before exiting the mental foramen to become the mental nerve.
 - The mental nerve supplies sensation to the soft tissue of the ipsilateral chin with a varying degree of cross innervation to the contralateral side.
 - Of note is that the IAN is 4 to 5 mm below the mental foramen before it ascends to exit the foramen.

Angle Occlusal Classification

- Class I: Neutro-occlusion
 - Molar relationship: The mesiobuccal cusp of the maxillary first permanent molar occludes with the mesiobuccal groove of the mandibular first permanent molar.
 - Canine relationship: The mesial incline of the maxillary canine occludes with the distal incline of the mandibular canine. The distal incline of the maxillary canine occludes with the mesial incline of the mandibular first premolar.
 - Mesognathic: normal, straight face profile with flat facial appearance
- Class II: Disto-occlusion (overjet)
 - Molar relationship: The molar relationship shows the mesiobuccal groove of the mandibular first molar is *distally* (posteriorly) positioned when in

occlusion with the mesiobuccal cusp of the maxillary first molar. Usually, the mesiobuccal cusp of maxillary first molar rests in between the first mandibular molar and second premolar.

- Canine relationship: The mesial incline of the maxillary canine occludes *anteriorly* with the distal incline of the mandibular canine. The distal surface of the mandibular canine is *posterior* to the mesial surface of the maxillary canine by at least the width of a premolar.
- Retrognathic: convex facial profile resulting from a mandible that is too small or maxilla that is too large
- Class II malocclusion has two subtypes to describe the position of the anterior teeth:
 - Division 1: The molar relationships are like that of class II, and the maxillary anterior teeth are protruded. Teeth are proclined and a large overjet is present.
 - Division 2: The molar relationships are class II where the maxillary central incisors are retroclined. The maxillary lateral incisors may be proclined or normally inclined. Retroclined and a deep overbite exist.
- Class III: Mesio-occlusion (negative overjet)
 - Molar relationship: The mesiobuccal cusp of the maxillary first permanent molar occludes *distally* (posteriorly) to the mesiobuccal groove of the mandibular first molar.
 - Canine relationship: Distal surfaces of the mandibular canines are mesial to the mesial surface of the maxillary canines by at least the width of a premolar. Mandibular incisors are in complete *crossbite*.
 - Prognathic: concave facial profile with prominent mandible is associated with class III malocclusion.

PATHOGENESIS

- Variation in mandibular projection, either prognathia or retrognathia, has a multitude of etiologies:
 - Heredity
 - Congenital syndromes
 - Endocrine abnormalities
 - Neoplasms
 - Autoimmune disease
 - Trauma
- It is important to identify the etiology and ensure mandibular growth is stable

prior to performing a surgical correction.

PATIENT HISTORY AND PHYSICAL FINDINGS

- *Dental compensation* is the term used to refer to the tendency of teeth to tilt to decrease occlusal discrepancies. For instance, in a class II occlusion, dental compensation refers to the tendency of the maxillary anterior teeth to become retroclined (moving posteriorly) while the mandibular teeth become proclined (moving anteriorly).
- The degree of dental compensation is assessed with a lateral cephalometric radiograph; the degree of dental compensation must be accounted for when treatment planning for surgery.
- Surgical procedures are usually planned based on the teeth in an uncompensated position. In compensated occlusion, the degree of potential mandibular movement may be underappreciated given the relationship of the compensated occlusion.
- Mastication difficulties should be assessed. Dentally uncompensated retrognathic patients typically have an increased overjet, which compromises the ability of the incisors to cut and shear foods during mastication.
- Airway obstruction, primarily in retrognathic patients, should be assessed. It is important to inquire about any history of snoring or sleep apnea.
 - If sleep apnea has not been diagnosed but is suspected based on the patient's history, a sleep study should be obtained. Results should be incorporated into the treatment plan.
 - If sleep apnea is present, a two-jaw procedure may be indicated in order to open the airway while correcting the occlusion.
- Aesthetic considerations of orthognathic surgery are important to consider. In particular, when treatment planning the correction of a prognathic patient, it is important to be aware of the soft tissue redundancy and submental fullness that may result with posterior positioning of the lower jaw.
 - Occasionally, even though the SNB is increased and the SNA is normal, the aesthetic result may be optimized by correcting the occlusion with upper jaw advancement to optimize soft tissue draping over the underlying skeletal relationship.³
- Many syndromes are associated with mandibular deficiency and should be identified prior to treatment. Although the treatment may not require technical modifications, it is important to be aware of any associated syndromes prior to treatment.

- Lower third facial asymmetry is not an uncommon finding in patients with dentofacial deformities.
 - It is important to note whether the asymmetry is due to mandibular deviation, mandibular asymmetry, or any asymmetry of the chin relative to the mandible.
 - Additionally, there may be maxillary asymmetry associated with mandibular asymmetry, which requires movement of the upper jaw as well.
- In patients who are concerned about the aesthetic impact of insufficient mandibular projection but demonstrate a mild or minimal occlusal abnormality, advancement of the chin is a treatment option that frequently achieves the patient's aesthetic goals without subjecting them to a sagittal split osteotomy.

IMAGING

- A panoramic radiograph is a two-dimensional representation of the mandible from condyle to condyle. It is a useful screening tool for any pathology of the mandible as well as the presence of impacted third molars.
- A lateral cephalometric radiograph can be used to identify soft tissue and skeletal cephalometric landmarks to perform cephalometric analyses.
- Imaging of wrist growth plates is a useful tool to determine whether skeletal growth is complete or ongoing. Growth plate closure is an indication that skeletal growth is complete.
- The cone-beam CT (CBCT) produces three-dimensional radiographic images of the patient's face that can be used for computerized treatment planning and splint fabrication. The technology used in a CBCT allows the image to be obtained with a far lower dose of radiation compared with traditional CT scan.
 - This image is invaluable in treatment planning for the surgical approach to correct dentofacial deformities. It also aids in the fabrication of surgical splints.
- Nuclear imaging is indicated to assess bone activity. It is nonspecific but is indicative of bone activity. This allows the clinician to assess the degree of bone metabolism in the condyles.
 - Useful applications might be to monitor rheumatoid arthritic changes, fracture healing, neoplastic activity, or condylar hyperplasia.¹⁻³

DIFFERENTIAL DIAGNOSIS

- Neoplasm: Infrequently, a neoplasm may be the source of excessive mandibular growth. A neoplastic etiology typically presents as an asymmetric mandible with the teeth out of occlusion. The rapidity of tumor growth will

produce a mandibular shift that exceeds the ability of the maxillary teeth to remain in occlusion. Mandibular asymmetries without a crossbite are typically associated with more chronic processes such as hemifacial microsomia or an early history of condylar trauma.

- Trauma: Injury to a condyle before skeletal maturity may stunt growth, leading to mandibular asymmetry and a crossbite.
- Autoimmune: Rheumatoid arthritis can cause condylar resorption resulting in an anterior open bite or mandibular retrognathia. It is important to ensure good medical control of the disease prior to undertaking surgical correction.
- Developmental anomalies: Anomalies such as Pierre Robin sequence, hemifacial microsomia, or congenital syndromes may result in hypoplastic mandibles. By the time these patients are old enough to be considered for surgery, the underlying etiology has typically been elucidated and should be considered when developing the final surgical plan.
- Endocrine: Acromegaly and other hormone abnormalities can lead to anomalies of mandibular size and position.

NONOPERATIVE MANAGEMENT

- In mild cases of mandibular prognathia or retrognathia, it may be possible for the orthodontist to dentally compensate for the skeletal abnormality and produce a dental class I occlusion.
- Occasionally, extraction of premolars may be necessary to create the space necessary to move the teeth and allow for appropriate dental compensation.
- A nonsurgical approach to mandibular retrognathia frequently results in the appearance of a large nose and a weak chin. This occurs because the orthodontist has to retrocline the maxillary incisors to normalize the dental overjet. Since the incisors support the upper lip, the lip moves posteriorly as well as giving the nose an overprojected appearance.
- If these patients are unhappy with their facial appearance, rhinoplasty and a genioplasty or chin implant are methods to camouflage the underlying skeletal discrepancy of the jaws and improve facial proportions.

SURGICAL MANAGEMENT

- The author performs sagittal split osteotomies after the completion of facial growth.
- The goal of this procedure is to anteriorly or posteriorly position the lower jaw. Additionally, this procedure may be performed to improve mandibular

asymmetry.

- The main steps of the procedure are as follows:
 - Make incisions in the mandibular mucosa.
 - Perform the osteotomy from the medial ramus down the ascending ramus along the external oblique bridge to the inferior mandibular cortex.
 - Perform the sagittal split by ensuring the IAN stays within the distal segment.
 - Position the patient's teeth in a class I occlusion.
 - Verify condylar seating and align the proximal and distal segments with a bone clamp.
 - Apply rigid fixation with use of the transbuccal trocar.
 - Release the intermaxillary fixation and verify that the patient's occlusion is in the desired class I position.
 - Close the mucosa with chromic sutures and the trocar incision with a layered subcutaneous closure.
- After the occlusion has been verified and the wounds are closed, heavy elastics are used to keep the patient's occlusion stable and immobile.
 - Half of these elastics are removed 1 week postoperatively, and the remaining elastics are removed 2 weeks postoperatively.

Preoperative Planning

- Prior to performing mandibular surgery, the patient's occlusion should be leveled and aligned by the orthodontist. The anticipated occlusion can be evaluated by hand in articulating a maxillary and mandibular plaster cast to verify that the postoperative occlusion will be stable.
- Additionally, to reduce the complication of an unfavorable split, the mandibular third molars should be extracted 4 to 6 months prior to the date of the sagittal split osteotomy.
- Risks and complications are reviewed with the patient, and include the following:
 - Injury to the IAN
 - Infection
 - Need for revision surgery
 - Need for removal of titanium fixation
 - Injury to tooth roots
 - Unfavorable split possibly requiring intermaxillary fixation if rigid fixation cannot be achieved

- If the maxillary and mandibular plaster casts are placed in the anticipated position and a stable class I occlusion is achieved, a splint may not be necessary. However, if the orthodontist desires that the mandible be moved prior to orthodontic treatment, the resulting occlusion may be unstable and benefit from a splint to stabilize the mandible while the osteotomy is healing. In cases in which the occlusion does not “lock in” after the osteotomy, a splint is recommended and it is our approach to use virtual surgical planning and CAD/CAM technology to fabricate the surgical splint.⁴

Positioning

- The patient is placed supine on the operating room table, the knees are flexed at 30 degrees with a pillow, and the heels are padded with foam cushions.
- Pneumatic compression stockings are placed and their function is verified prior to induction of general anesthesia.
- Anesthesia is achieved with the nasotracheal tube sutured to the nasal septum with a 2-0 Prolene mattress suture that is padded on either side of the septum with Xeroform gauze.
 - The knot for the suture is on the same side as the endotracheal tube, and the redundant portion of the suture is then circled around the nasotracheal tube twice before being tied down to secure the tube.
- A head drape is then placed and secured to the patient’s head with 4- × 4-in. gauze underneath the anesthesia tubing (**FIG 1A,B**).
 - The anesthesia tubing is then secured to the head drape using silk tape in a way that ensures no pressure from the nasotracheal tube is applied to the nasal ala.
- Antibiotics and steroids are administered prior to the incision; local anesthesia is injected prior to prepping and draping the patient (**FIG 1C**). The epinephrine takes effect during prepping and draping so that when the incision is made, blood loss is minimal.
- We request anesthesia to achieve a mean arterial blood pressure of 55 to 60 mm Hg as long as the patient’s health can tolerate it.
- Prior to the incision, chlorhexidine oral mouth rinse is placed in the patient’s mouth and allowed to sit for 5 minutes before removal.
- Steroid ointment is applied to the lips to reduce swelling after surgery. The desired blood pressure is verified with anesthesia, and if acceptable, the procedure begins.

Approach

- The operative team is given a list of all necessary equipment as well as a summary of the steps of the operation.
- Additionally, an image of the Mayo stand with all the instruments and the position in which they are to be placed is projected on the operating room computer screen.
- The instruments are aligned in sequential order so that the scrub nurse can hand them to the surgeon efficiently.
- A headlight is extremely helpful in these cases.
- The tooth-bearing portion of the osteotomy is the distal segment, and the condylar portion is the proximal segment.



FIG 1 • A,B. A nasotracheal tube is secured with a 2-0 Prolene suture that is tied as a horizontal mattress through the septum with Xeroform gauze to reduce pressure necrosis. A surgical towel is then wrapped as a head drape and secured with silk tape to the head as shown. The tube is then resecured to the head drape with gauze padding making sure the endotracheal tube is not applying pressure to the nasal ala. **C.** Ten mL of 1% lidocaine with 1/100 000 epinephrine is injected into each side of the sagittal split site before surgical draping is performed. The injections are in the mucosal vestibule from first molar to the ramus. Lidocaine is also injected in the medial ramus and in the retromolar

trigone.

TECHNIQUES

■ Exposure

- The Molt mouth prop is placed on the nonoperative side and is opened as far as possible.
 - A sweetheart retractor pulls the tongue away from the operative side and is secured to the mouth retractor with a 4- × 4-in. gauze (**TECH FIG 1A**).
- The incision is made from the retromolar region to the first molar at least 1 cm from the teeth.
 - This will retract after being incised and will be difficult to close if made too close to the teeth.
 - A Minnesota retractor is used by the surgeon to retract the cheek while he/she is making the incision.
- A periosteal elevator is used to expose, in a subperiosteal plane, the lateral mandible from external oblique ridge to ascending ramus.
 - The posterior lateral mandible does not need to be exposed because it is not necessary and impairs the blood supply of the posterior segment.
 - The medial ramus is dissected as well. The anterior portion of the ramus is dissected to the tip of the coronoid process. Exposure in this dissection is facilitated by the use of the coronoid notch retractor.
 - A curved periosteal elevator is swept along the inferior border of the mandible to release muscular attachments that can restrict postosteotomy positioning of the mandible.
- Exposure is key to facilitating this procedure.
 - A chained Kocher is clamped to the coronoid process, and the chain is then pulled posteriorly and clamped to the head drape to retract the mucosal tissue (**TECH FIG 1B**).
 - A Seldin retractor is placed medial to the ramus and is lowered toward the mandibular body until it meets resistance from the mandibular nerve. The Seldin should be parallel to the occlusal plane and then rotated slightly in a clockwise direction on the right side (counterclockwise on the left side) to expose the medial ramus (**TECH FIG 1C**).



TECH FIG 1 • A. To optimize exposure, a mouth prop is placed and a sweetheart retractor is then positioned to pull the tongue medially. These instruments are secured with surgical gauze. The surgeon now can use a Minnesota retractor and the free hand for an instrument. **B.** Once the incision and initial dissection has been completed, a Kocher with a chain is clamped on the coronoid process to retract tissue. The

chain can be clamped to the head drape to eliminate the need for an assistant. **C.** A Seldin retractor is placed between the medial ramus and the soft tissue parallel to the occlusal plane and then is rotated so its superior border moves away from the ramus exposing the bone. The surgeon uses this exposure for the horizontal medial ramus osteotomy.

■ Osteotomy and Sagittal Split



Video p2-c037_01



Video p2-c037_04

- A reciprocating saw with a short blade is now placed against the medial ramus to cut the anterior two-thirds of the medial ramus above the mandibular foramen through the cortical bone (**TECH FIG 2A**).
- Once the medial cut is completed, the saw blade is rotated so that the cut continues in an oblique fashion to the anterior ramus; the cut then continues along the external oblique ridge down to the inferior border of the mandible.
- Ensure that the cortical bone at the inferior mandibular border is cut completely to generate a smooth split.
- A mandibular body retractor is used to optimize visualization for the vertical cut.
- The retractor can be placed anterior to the location of the vertical cut and rotated in a counterclockwise fashion so the posterior edge retracts the cheek tissue away from the area, facilitating visualization while making the cut.
- A small osteotome is used to verify that the osteotomy is complete along the horizontal portion of the medial ramus as well as the inferior mandible at the anterior portion of the osteotomy (**TECH FIG 2B**).



Video p2-c037_02

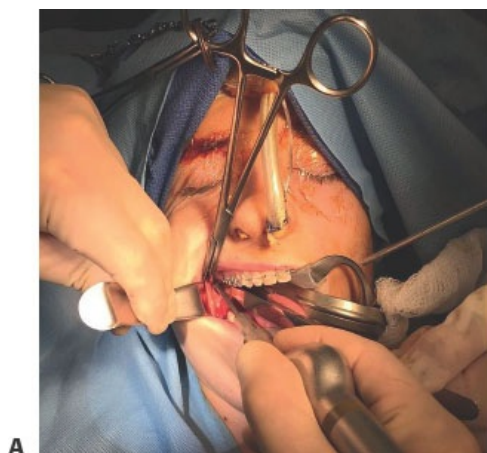


Video p2-c037_05

- A small osteotome is tapped along the osteotomy to begin to separate the segments. It is important not to tap the osteotome too deep to avoid hitting the IAN.
- Once the superior portion of the osteotomy is wide enough to fit a Frazier suction between the edges, a three-prong spreader is placed between the segments and gradually opened.
- The surgeon must ensure that the IAN is not in the proximal segment prior to the split. A sudden split could avulse the nerve if it has not been released from the inferior alveolar canal in the proximal segment (**TECH FIG 2C**).
- Under direct visualization, the osteotomes can be used to complete the split to avoid the nerve.
 - Alternatively, once the nerve is confirmed to be in the distal segment, larger fiber-handled osteotomes can be used in tandem to complete the split. They can be placed in the osteotomy site and rotated to complete the split.
- The split is verified by attaching a Kocher to the proximal segment and moving it independently from the distal segment.



Video p2-c037_03



TECH FIG 2 • A. The osteotomy is now made on the medial ramus. The surgeon should feel the nerve below the Seldin retractor to ensure the cut is above the nerve. The osteotomy is made from the medial ramus obliquely inferior as it then continues down the ramus and onto the external oblique ridge to the inferior border of the mandible. **B.** Osteotomes are then used to verify the osteotomy at the medial ramus and the inferior border of the mandible. **C.** Cadaver image of IAN in the proximal segment. It is important prior to completing the osteotomy to verify that the inferior alveolar nerve is not within the proximal segment or it may be avulsed during the split. This image shows the nerve with the proximal segment as the split is occurring. If this is noted, an osteotome is used to release the cancellous bone from the inner cortical bone to release the nerve. If the nerve is not actually within cancellous bone, it can easily be freed with a periosteal elevator.

■ Occlusal Correction and Maxillomandibular Fixation

- Once both sides of the sagittal split osteotomy are complete, the lower jaw is placed into the desired occlusion with either a surgical splint or by placing the patient's mandible in class I maximum intercuspal position.
 - It is the author's preference to use many heavy elastic bands for intermaxillary fixation. Multiple elastics provide solid fixation; if there is any occlusal shifting, the elastics will return occlusion to the desired position.
 - Wire stretches and needs to be prestretched prior to making wire loops for maxillomandibular fixation (MMF). If manipulation of the jaws during fixation moves the occlusion, wire is not elastic and the occlusion may shift while rigid fixation is applied.

- If wire loops are used, it is important that the surgeon periodically verify the desired occlusion during the fixation process.
- Avoid excessive torque when applying wire loops because the orthodontic brackets may loosen or become detached.



Video p2-c037_06

- The proximal segment is rotated with the condyle seated in the fossa to align the superior edges of the proximal and distal mandibular segments.
 - A curved Kocher is placed to secure this position by placing it posteriorly along the osteotomy sites, where there are overlapping bony segments.
- A small curved hemostat is then placed in the mouth at the area where the screws will be placed (along the superior border of the mandible posterior to the second molar).
 - The tip is pushed out toward the skin so the surgeon can palpate where the trocar incision should be placed (**TECH FIG 3A**).
- An incision is then made long enough to accommodate the diameter of the trocar without avulsing the wound.
 - A slightly longer incision that does not avulse the skin as the trocar is inserted will be aesthetically superior to a shorter incision that is avulsed as the trocar is placed through it (**TECH FIG 3B**).
- Once the trocar is in place, the trocar cheek retractor is attached (**TECH FIG 3C,D**).



TECH FIG 3 • **A.** A small hemostat is placed in the mouth adjacent to the location of the screws and is pushed toward the skin to denote the location of the trocar incision. **B.** After the incision is made, a small hemostat is used to gently spread the tissue to facilitate the passage of the trocar. **C,D.** The trocar is placed through the incision, and then, the surgeon's

finger is used to keep the tip of the trocar exposed until the cheek retractor is attached to the trocar.

■ Rigid Fixation

- The stability of MMF and occlusion is verified prior to fixation.
 - The Kocher is released and the proximal segment is rotated with the condyle so the superior edges of the segments are aligned.
 - The Kocher is then secured to hold the segments while the position is set (**TECH FIG 4A**).
 - Fixation is now applied.
- A color-coded drill is used to drill holes through the osteotomy for fixation.
 - Irrigation is applied to the drill throughout this process so as to avoid excessive heat generation (**TECH FIG 4B**).
 - It is the author's preference to place three screws in a row at the superior border, but other patterns are acceptable as long as they do not violate the IAN or tooth roots.
 - While drilling, there is initial resistance as the drill goes through the outer cortical bone, a loss of resistance as the drill enters the gap between the bone segments, a second zone of resistance as the drill goes through the cortical bone of the distal segment, and then a final loss of resistance as the drill passes through this bone.
 - The color on the drill as the second loss of resistance occurs is noted, as this indicates the length of the desired screw (**TECH FIG 4C**). If one is uncertain which color corresponds to the loss of resistance, it is recommended to use the longer length screw.
- Once three screws are applied in this manner, the same technique is applied to the opposite side.
 - The stability of MMF and occlusion is periodically checked. Occasionally, manipulation of the mandible while applying fixation can loosen wire loops and compromise the occlusion.
 - Any change in occlusion needs to be rectified prior to application of fixation.



TECH FIG 4 • A. Prior to drilling the fixation holes, the segments are positioned with the condyle seated and the superior edges of the segments aligned. A curved Kocher is placed posteriorly and an assistant squeezes the Kocher to immobilize the segments while the fixation is applied. **B.** The drill is irrigated as the holes are drilled. **C.** The drill is color coded, and each color corresponds to the length of a screw. The color of the drill as it passes through the cortical bone of the distal segment (the second loss of resistance) is noted, and the appropriate size screw is then selected.

■ Completion

- Once fixation is applied, MMF is released and the desired occlusion is verified by rotating the mandible with seated condyles to ensure the desired intercuspal position has been achieved.



Video p2-c037_07

- If occlusion is not ideal, the process is repeated until the correct occlusion has been achieved.
- If the desired occlusion has been achieved, elastics are placed to provide MMF and the wounds are irrigated and then closed with 3-0 chromic on an SH needle.
- The author typically will close the wound with a running locked suture.
- The trocar sites are closed with a deep 5-0 Monocryl and transdermal 6-0 Prolene.
- Prior to extubation, a nasogastric tube is used to empty the stomach.
- Ice packs are applied to the cheeks in the recovery room, and the head is elevated.
- No compression dressing is used.

PEARLS AND PITFALLS

Intraoral incision

- A common error is making the intraoral incisions too close to the teeth.
- The incision should be made at least 1–1.5 cm from the teeth.
- Once the mucosa is cut, it retracts, making mucosal closure difficult at the end of the case.

Incomplete osteotomy

- The most likely areas for incomplete osteotomy are at the inferior border of the mandible of the vertical cut and at the junction of the

	ramus with the posterior horizontal cut that is lingual to the ramus. ■ Each of these areas is verified with an osteotome prior to the split to decrease the likelihood of an unfavorable split.
Nerve damage	■ Prior to splitting the segments, it is important to confirm that the nerve is not within the proximal segment. ■ If a portion of the nerve remains in the proximal segment, a sudden split could avulse the nerve. If the nerve is noted to be in the proximal segment, it is not recommended to try to dissect the nerve free from the cancellous bone. This approach has a high likelihood of nerve injury. ■ In contrast, use an osteotome to separate the cancellous bone from the cortical bone in a safe plane. The nerve will remain enveloped within the cancellous bone and should be minimally traumatized.
Bad split	■ Avoiding a bad split is key to a successful BSSO. ■ Removal of mandibular third molars 6 mo prior to the osteotomy allows time for the sockets to heal, which decreases the likelihood of a bad split. ■ If the segments do not appear to be easily separating, the surgeon should verify that the osteotomies are complete. ■ Do not use excessive force, which increases the chance of an uncontrolled mandibular split. ■ If a bad split occurs, the segments can be plated to re-establish normal anatomy, and the proximal and distal segments can then be secured into the desired position with rigid fixation.
Fixation	■ Be certain the condyles are seated when aligning the proximal segment during fixation. Verify that occlusion remains in its desired position during application of fixation. ■ Wire loops may loosen and compromise the result if not corrected prior to fixation. The author prefers heavy elastics for this reason. If a shift occurs during fixation, elastics will dynamically reset the occlusion as opposed to the static nature of a loose wire.
Screw holes	■ When drilling screw holes, ensure that the drill does not stop and that the movement is smooth in and smooth out. ■ Never have the drill running without movement. ■ Any small drill whip will enlarge the drill hole and compromise the holding power of the screw.
MMF	■ Orthodontic brackets may break during the case. If the surgeon loses the orthodontic surgical lugs, another method of MMF must be employed. ■ Rather than time-consuming arch bars, the author uses the rapid

screw-anchored MMF sets. The entire arch bar can be used or individual lugs can be cut and secured with screws as needed.

- The author does not recommend MMF screws for routine use because they do not distribute forces as evenly as the screw-anchored MMF system.

POSTOPERATIVE CARE

- The patient is placed on a liquid diet for 2 weeks. Feeding is facilitated through the use of a red rubber catheter and a Toomey syringe to inject full liquids into the mouth behind the second molars. Instant breakfast, nutrition drinks, smoothies, and anything blended into a liquid are recommended. Protein powder and vitamins can be added for additional nutritional supplementation.
- Ice packs to cheeks and elevation of the head are recommended for 1 week.
- Chlorhexidine mouth rinse is used BID for 2 weeks.
- Gentle tooth brushing with a soft bristle brush can begin as soon as the patient feels comfortable enough to insert a brush.
- At the 1-week postoperative appointment, approximately half of the elastics are removed, and sutures are removed from the trocar incision.
- Two weeks after surgery, all the elastics are removed and any necessary guiding elastics are employed. Usually, the orthodontist will dictate the use of postoperative guiding elastics.
- After all elastics are removed, the patient begins range-of-motion exercises to regain normal interincisal opening.
- The patient is instructed to avoid any contact activity for 10 weeks.
 - A soft mechanical diet is instituted 2 weeks after surgery and is advanced as tolerated.
 - The patient is told to refrain from firmer foods for 8 weeks.

OUTCOMES

- The sagittal split osteotomy is a predictable method to correct underlying mandibular skeletal deformities.
- Stability of mandibular advancement is greater than that of mandibular setback.

COMPLICATIONS

- If a malocclusion intraoperatively or postoperatively is noted due to improper

condyle position during fixation or improper indexing of the splint, fixation must be removed and reapplied. It is wise to verify splint fit prior to surgery.

- Paresthesia or anesthesia of the lip may occur from injury to the IAN. Postoperative sensory disturbances in the lower lip and chin have been reported to occur in 9% to 85% of operated sides.⁵ The lack of standardization of objective methods and time to the evaluation of sensory dysfunction after BSSO results in a vast range of prevalence of neurosensory disturbance at 1 or 2 years postoperatively (0% up to 85%).⁶
- The incidence of bad splits has been shown to be 2.0% per site. The only predictive factor for a bad split is the removal of third molars at the same time as BSSO. There is no significant association between bad splits and age, sex, class of occlusion, or the experience of the surgeon. It has been demonstrated that doing a BSSO with splitters and separators instead of chisels does not increase the risk of a bad split and is therefore safe with predictable results.⁷

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38 Inverted L Osteotomy for Mandibular Surgery

CHAPTER

Raymond J. Harshbarger

DEFINITION

- Various procedures have been developed to alter the shape and position of the mandible, including the sagittal split osteotomy, vertical ramus osteotomy, and inverted L osteotomy (ILO).
- The ILO allows separation of the proximal condylar bearing segment and the distal occlusal bearing mandibular segment, for advancement of the distal segment.
- Improvements with distal segment advancement:
 - Enhancement of airway space at the tongue base, thus improving breathing functions
 - Treatment of class II dentofacial deformity, establishing abnormal bite, chewing, and speaking

ANATOMY

- The mandible is a ring structure articulating with the skull base at the glenoid fossa.
- In addition to bearing responsibility for the foundation of the lower third of the face, the mandible contains the lower dentition, and the inferior alveolar nerve transverses the marrow space through the ramus and body.
- Pertinent features on the lateral (buccal) surface of the mandible include the anterior/posterior ramus, sigmoid notch, condylar process, and coronoid.
- Medially, key landmarks include the sigmoid notch, lingua, mandibular foramen, and position/occlusal surface of molars.
- The marginal mandibular nerve changes position depending on patient age: in neonates, the marginal mandibular nerve travels along mandibular border; with

increasing age, the nerve migrates inferiorly. By skeletal maturity, the nerve is about two fingerbreadths below the mandibular border.

- The lingula is present along the medial surface of ramus and is halfway from anterior to posterior ramus and halfway down from sigmoid notch to mandibular border. It is found 1 to 1.5 cm cephalad to molar occlusal surface, in skeletally mature individuals.¹⁻³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients who benefit from ILO are generally divided into two groups:
- Neonates and children:
 - May present with airway obstruction, difficulty feeding, gastroesophageal reflux, and failure to thrive
 - Physical examination demonstrates micrognathia, glossoptosis, and possible cleft palate.
- Skeletally mature patients:
 - May have had a history of obstructive sleep apnea, TMJ disorder (with pain), and chewing and speaking dysfunction
 - Physical examination demonstrates a sagittal deficiency of the lower third of the face with class II malocclusion.

IMAGING

- Computed tomography demonstrates sagittal deficiency of the mandible. Typically, other components exhibit normal morphology.
- Operative airway evaluation (rigid and flexible exam) is done to assess glossoptosis, tongue-based airway obstruction, and prolapsed epiglottis. An anterior tongue pull and jaw thrust will improve the obstruction.

DIFFERENTIAL DIAGNOSIS

- Pierre Robin sequence
- Craniofacial microsomia
- Treacher Collins
- Micrognathia
- Juvenile rheumatoid arthritis

SURGICAL MANAGEMENT

- Candidates for ILO include patients with sagittal deficiency of the mandibular body, including neonates, children, and skeletally mature patients. Distraction

may be performed in all three groups. Orthognathic surgery is indicated in skeletally mature patients; ILO may be chosen over a sagittal split osteotomy, or vertical ramus osteotomy, especially when dealing with patients who have asymmetric skeletal findings. With a single-step mandibular advancement, bone grafts are used to bridge the created gap.

Preoperative Planning

- Neonates
 - Computed tomography
 - Operative airway (rigid/flexible) evaluation
 - Polysomnography
 - Possible virtual surgical planning with creation of operative cutting and positioning guides
- Children and skeletally mature
 - All of the above
 - Placement of orthodontic appliances, with preparatory orthodontics

Positioning

- Neonates: Supine position, with head on a gel roll, a shoulder roll, neck in extension, and an oral ET tube that is microcuffed. ET tube should be taped to the upper lip, brought cephalically, and fixed at the hairline over egg crate foam with 2-0 silk. Eyes are protected with Tegaderm (**FIG 1**).
- Children and skeletally mature patients: Nasal RAE tube sutured at the septum and at the hairline over egg crate foam with 2-0 silk. A shoulder roll should be placed, with eyes protected using Tegaderm. The patient's head should be placed on a gel roll or foam.

Approach

- The ILO technique may be approached from either an extraoral or intraoral incision or both.



FIG 1 • Patient positioning (neonatal) for extraoral inverted L osteotomy.

TECHNIQUES

■ Extraoral Inverted L Osteotomy

Exposure

- This technique is commonly used for mandibular distraction osteogenesis.
- Incision marking is designed to facilitate the osteotomy and protect the marginal mandibular nerve.
- In neonates, the neck is placed in extension; palpate the mandibular angle, marking the incision one finger breadth below the angle. Starting posterior to anterior at the angle and maintaining one fingerbreadth below the mandibular border, the incision should be 2.5 cm in length. It may be helpful to dot the midline of the neck, to view the projected path of each incision, and to improve symmetry (**TECH FIG 1A**).
- In children and skeletally mature patients, a similar approach is used; however, with increasing age, begin increasing the distance between the

mandibular border and incision placement, migrating caudally to a position of two fingerbreadths below the border in adults.

■ Vasoconstriction:

- To protect the marginal mandibular nerve and promote a bloodless field for surgery, a saline and epinephrine mixture is used. The nerve will then be responsive during dissection. Despite proper incision placement, the nerve can be encountered during approach to the mandible. There will be a greater chance of nerve preservation if it remains active during surgery.

■ Incision and approach in neonates and children undergoing distraction

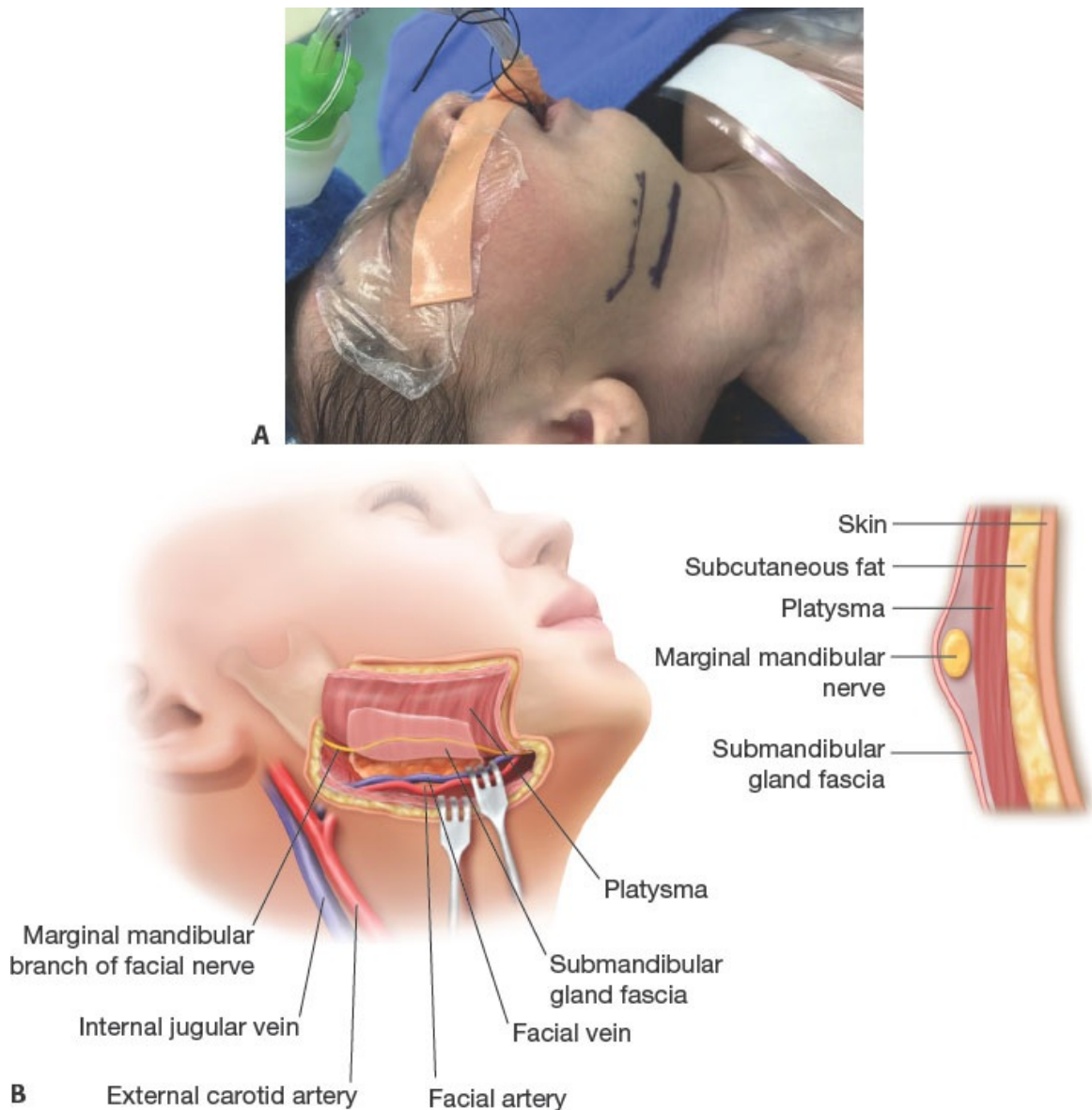
- After adequate epinephrine effect, the skin is sharply incised with a 15 blade.
- Monopolar current on cutting is used to dissect through the fat and platysma muscle (dissection should be in a straight posterior direction).
- Look for the submandibular gland and any evidence of the marginal mandibular nerve. Dissect through the investing fascia of the submandibular gland, and then begin a cephalad plane of dissection (**TECH FIG 1B**).
- Tenotomy scissors may be used during these steps to help orient the surgeon, and expose critical structures such as the submandibular gland, marginal mandibular nerve, and the facial artery/vein.
- The dissection at this point should be aimed toward the mandibular angle. This is a “safe zone” to approach the mandible.
- As the facial vessels are encountered running vertically in the field of dissection, leave them intact and generally reflect them anteriorly, although posterior reflection may be performed. Once the mandibular angle is encountered, use a small toe-in retractor.
- Incise horizontally just above the mandibular border, and enter the subperiosteal plane. The lateral surface of the mandible can now be exposed using a periosteal elevator (the author prefers a small Obwegeser elevator) (see **TECH FIG 1B**).
- Mandibular exposure is complete when all key landmarks are exposed, including the anterior and posterior ramal borders, proximal portion of condylar process, and sigmoid notch and body.

Osteotomy

- The proposed osteotomy can now be marked using a sterile no. 2 pencil.
- Marking considerations include device footplate position, vector, and

avoidance of the inferior alveolar nerve as well as tooth buds (**TECH FIG 2A**).

- The vertical portion of the inverted L is marked first. For a sagittal or sagittal-oblique vector, the device is best brought out posterior and inferior to the ear lobule.
- An anterior exit for the device is also possible but can lead to increased problems with incision healing, and contamination, especially in children with a tracheostomy.
- For a posterior device exit, create a tunnel in the subcutaneous plane from the deep pocket of dissection posterior and inferior to the auricle, exiting the skin through a stab incision.

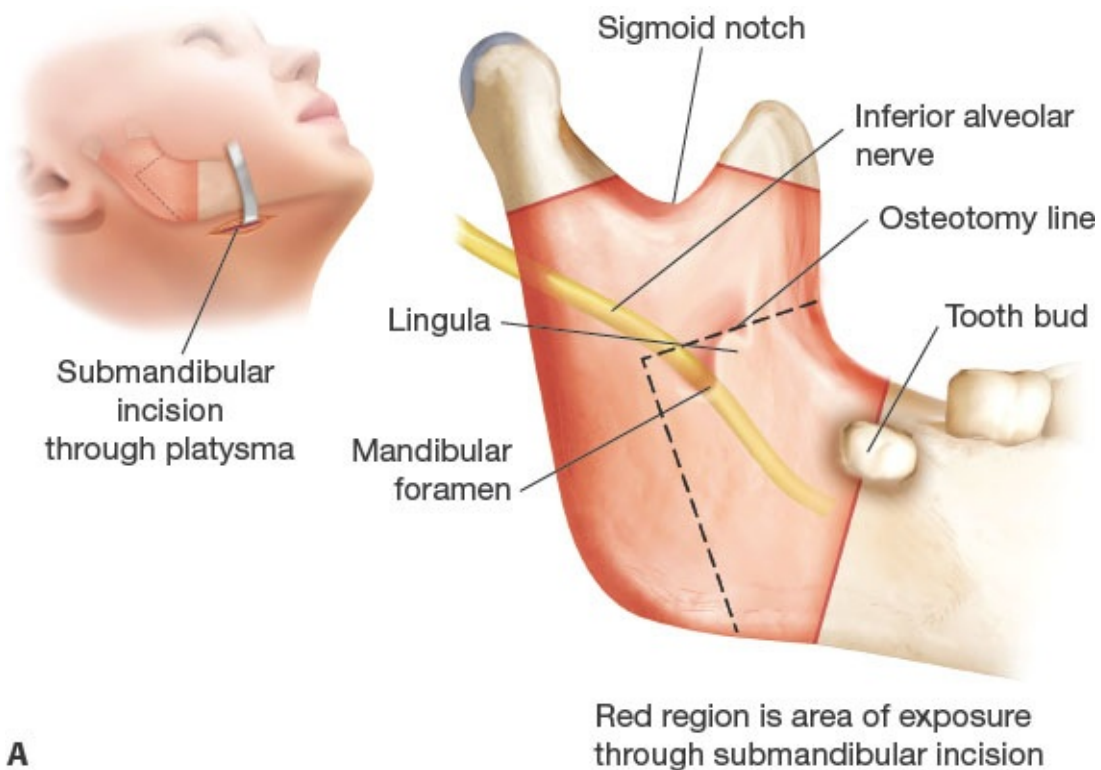


TECH FIG 1 • A. Markings for incision. **B.** Submandibular approach to expose the mandible. Note anatomic layers and plane of dissection deep to the marginal mandibular branch of the facial nerve.

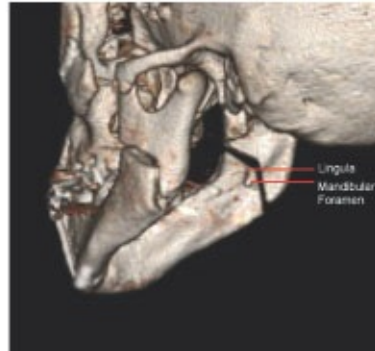
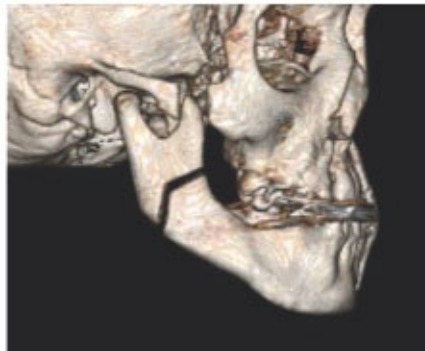
- A turning arm is attached to the device (preferred is KLS Martin microZurich with rigid externally removable arm).
- The device is placed into the field, bringing the turning arm through the tunnel and skin and positioning the device over the mandible near the angle. The desired vector is determined, with positioning of the footplates to allow

placement of three screws in each footplate.

- A line is marked between the footplates, and the device is removed from the field. This mark is extended into the vertical portion of the osteotomy, running from the mandibular border to immediately caudal to proximal condylar process. The mark should be roughly parallel to the posterior ramal border.
- The upper extent of the vertical mark is made immediately proximal to the condylar process.
- Identify the convexity in the ramus, caudal to the sigmoid notch. Proximal to the vertical flattening of the convexity is a safe place to orient the horizontal portion of the osteotomy (this places the osteotomy above the lingula and tooth buds).
- The horizontal mark comes off the anterior ramus roughly perpendicular to the border and intersects the upper extent of the vertical component (see **TECH FIG 2A,B**).
- Generally, the lingula of the ramus is at the halfway point posteriorly and caudally from the sigmoid notch to the inferior border.
- Once properly marked, the sagittal saw is used to complete the vertical and anterior portions of the inverted L, saving the posterior cortex for a few millimeters anterior to the intersection of the vertical and horizontal limbs (**TECH FIG 2B,C**).
- The sagittal saw is preferred due to the limited kurf compared to the reciprocating blade.
- Next, position the device straddling the footplates on either side of the vertical aspect of the osteotomy near the mandibular border.
- The device is positioned along the ideal sagittal or slightly oblique vector (the orientation of the vertical limb of the osteotomy dictates this). Make sure the device is “zeroed” prior to positioning.
- If a more vertical vector is planned, the osteotomy needs to be a stair-step variation of the inverted L.
- Subsequent to device positioning, place three self-drilling high-profile screws in each footplate. (Length of the screws will be 5 mm in neonates and infants, but may be 7 mm in children and skeletally mature individuals.)



A



TECH FIG 2 • A. Anatomic landmarks for inverted L osteotomy. Shaded (*red*) is area of subperiosteal exposure. Relationship of inferior alveolar nerve and tooth buds to osteotomy (*dashed line*) is shown. **B.** Inverted L osteotomy, buccal view. **C.** Posterior lingual view.

- Place an Obwegeser elevator underneath the proximal (condylar) segment for support when placing screws in this segment, to avoid shearing of the posterior ramus from the condyle.
- After the device is secured to the mandible, use a mini-osteotome to separate

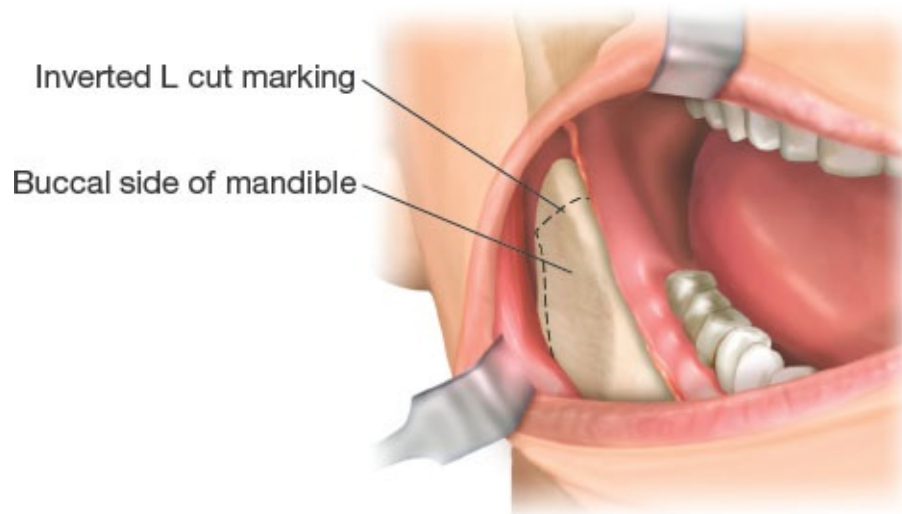
the posterior cortex near the intersection of the horizontal and vertical limbs (the portion remaining intact after sagittal saw use).

- Confirm completion of the osteotomy by activating the turning arm of the device. If the device turns freely, then the osteotomy is complete. Resistance may be encountered. Use the mini-osteotome to identify and separate the unfractured posterior cortex.
- After confirming osteotomy completion, return the device to the zero position, and activate the ratchet mechanism (prevents down-turning of the device, essentially undoing the distraction).
- Irrigate the operative pocket with saline, and approximate the platysma and dermis.
- Note: VSP may be used to optimize osteotomy and device position. This should allow for the production of operative guides to delineate osteotomy and device position.
- A similar procedure is performed on the contralateral side.
- The contralateral device should be placed along the same vector as the first operative side.
- To achieve device symmetry, estimate the proposed vector, place one screw, center the head, and palpate the rod of each device, rotating the newly applied device to achieve a parallel vector; then apply the remainder of screws.
- If VSP is used, apply footplate drill hole positioning guide, drill the desired holes, remove, and apply the device.

■ Combined Extraoral-Intraoral Inverted L Osteotomy

- The above approach is reliably used in neonates and young children. Older children and skeletally mature individuals undergoing mandibular distraction may benefit from a combined extraoral-intraoral approach.
- The horizontal limb of the inverted L can be difficult to reach from a submandibular approach in older patients.
- The extraoral portion of the surgery is similar to neonates and infants, except that the initial incision migrates lower with increasing age to nearly 1 in. below the mandibular border in skeletal maturity.

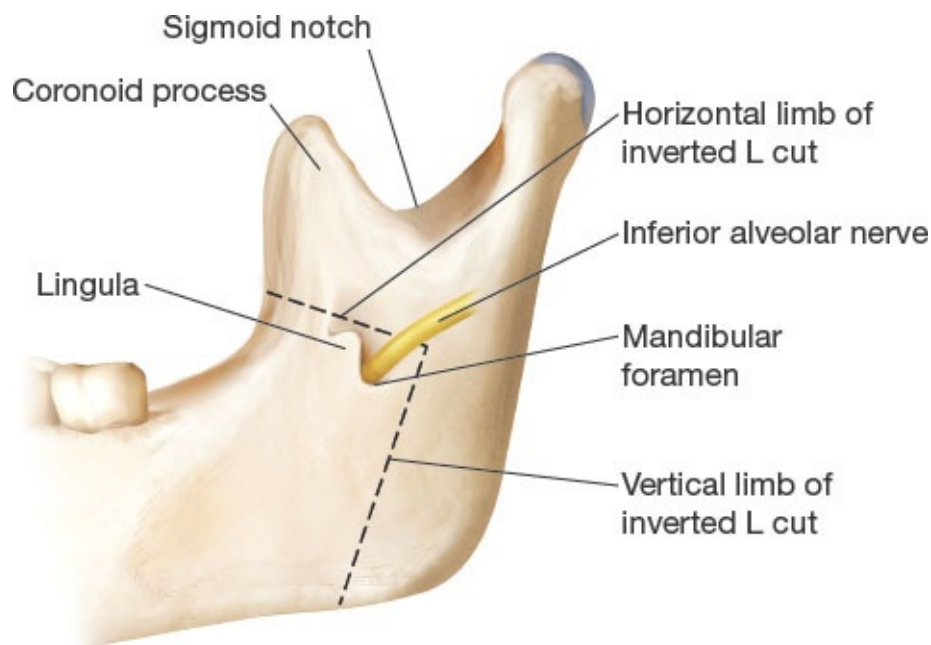
- To complete intraoral access, be certain the patient has full muscular relaxation, and place a bite block on the contralateral side.
- Incise the buccal mucosa with a cuff to the attached gingiva near the first molar, extending the incision vertically to immediately below the maxillary occlusal plane.
- Achieve a subperiosteal plane of dissection; then skeletonize the soft tissue from the ramus of the mandible on both the buccal and lingual aspects.
- On the medial aspect of the ramus, identify the lingula (**TECH FIG 3**).
- If the extraoral component was performed first, connect the dissection, creating a single surgical pocket.
- For those less familiar with the dissection, the intraoral component may be performed first, so that finding the proper plane from the extraoral approach is facilitated.
- Mark the vertical portion of the osteotomy as described above.
- Under direct visualization, mark the horizontal limb of the inverted L above the lingula and connect to the markings of the vertical limb.
- Complete the vertical osteotomy with the sagittal saw.
- The horizontal osteotomy remains incomplete (save the posterior cortex near the vertical-horizontal junction).
- The device can be positioned (as in earlier description) with turning arm placed either anterior or posterior.
- Affix device to mandible with self-drilling screws (use the above description for details).



TECH FIG 3 • Surgical view for intraoral inverted L osteotomy.

■ **Intraoral Inverted L Osteotomy**

- Skeletally mature patients undergoing orthognathic procedures may benefit from a completely intraoral approach to the ILO.
- Approach is through a buccal sulcus incision as mentioned in the above section.
- Once the mandible is skeletonized and the lingula visualized, mark the horizontal limb above the lingula and the vertical portion posterior to the lingula, parallel to the posterior ramal border (**TECH FIG 4**).
- The horizontal osteotomy is completed with the reciprocating saw, whereas the vertical limb is cut with a fan blade oscillating saw.



TECH FIG 4 • Lingual view illustrates relationship of osteotomy to lingula.

Mandibular anatomy	■ Complete understanding of mandibular anatomy is critical to perform a safe and effective inverted L osteotomy. This includes the location of the lingula and tooth buds/teeth.
Facial nerve anatomy	■ Intimate knowledge of craniocaudal and depth location of the marginal mandibular nerve is important in accessing the mandible for extraoral inverted L osteotomy.
Condyle and proximal segment relationship	■ Prevention of shear fractures in the proximal segment—which inadvertently separate the condyle from the ramus—is key to a successful inverted L osteotomy.
Changes in soft tissue and bone anatomy with growth	■ There are notable differences in marginal mandibular nerve position, bone anatomy and strength, in the growing craniofacial skeleton.

POSTOPERATIVE CARE

- Immediate postoperative care for ILO patients will vary depending on the age of the patient, indications for the procedure, and the type of skeletal fixation utilized.
- Neonates/infants: A mandibular distractor will be applied after the osteotomy, by providing semirigid fixation across the osteotomy. Bacitracin ointment is applied to the device exit site. Incisions are covered with Steri-Strips. During distraction, the patient is fed through an NG tube and kept intubated for a few days to allow the airway to improve. Timing of extubation is determined by the surgeon in concert with the multidisciplinary team.
- Children: At this age, patients are often extubated immediately after surgery, by virtue of the fact that they have a tracheostomy or are capable of protecting their airways. Incision care is similar to neonates.
- Skeletally mature patients: Patients are often undergoing orthognathic surgery, in which case they will have some form of maxilla-mandibular fixation (MMF) post-surgery. Most of these patients will have an intraoral incision, which requires a Peridex rinse daily.

COMPLICATIONS

- *Marginal mandibular nerve*—Temporary neuropraxia is common; permanent palsy is possible when performing extraoral ILO.
- *Inferior alveolar nerve injury*—Placement of the vertical or horizontal portion

of the osteotomy in proximity to the lingula can lead to inadvertent damage to the nerve by the reciprocating, sagittal saw, or Sonopet.

- *Tooth bud injury*—Anterior displacement of the vertical portion of the osteotomy in neonates/children may result in damage to developing dental structures.
- *Undesired fracture*—Neonates are especially susceptible to this occurrence as their mandibles are thin. Inadvertent fracture of the coronoid process will not hamper the outcome; however, separation of the condyle from the proximal segment will cause failure of the operation and requires immediate correction, by plating the disjoined segments with resorbing fixation in neonates and titanium in older children.
- *Infection*—Extraoral ILO with distractor placement can result in cellulitis/purulence at the device skin exit site and can generally be treated with antibiotics/irrigation. In most cases, return to the operating room is not required.

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39 Intraoral Vertical Ramus Osteotomy of the Mandible

CHAPTER

Deepak G. Krishnan and Haithem M. Elhadi Babiker

DEFINITION

- The vertical ramus osteotomy of the mandible performed intraorally is a popular and simple technique used to achieve mandibular setback in patients with prognathism or asymmetry.
- A variation of this technique was described first by Limberg in 1925.¹ Many others have attempted to modify his approach and found that it can be performed intraorally and can be used to reduce the horizontally excessive mandibular ramus.
- A version of the vertical ramus osteotomy performed through a neck incision was popularized by Caldwell and Letterman in the 1950s.²
- In 1968, Winstanley performed the first intraoral vertical ramus osteotomy (IVRO).³ It was the work of Hall and McKenna⁴ in the 1970s that simplified, refined, and thus popularized the procedure.

ANATOMY

- The mandible is the horseshoe-shaped bone that forms the structural foundation of the lower third of the face. It is the only movable bone of the skull, articulating with the temporal bones at the temporomandibular joints.
- It consists of a horizontal curved body and two broad and oblong rami projecting upward. The alveolar processes of the mandible house and support the mandibular teeth.
- The inferior alveolar nerve enters the mandibular foramen on the medial surface of the ramus near its center.
- It then runs downward and forward within the body of the mandible and exits at the mental foramen, which is located on the external surface midway

between the alveolar process and the lower border, in the interval between the premolar teeth.

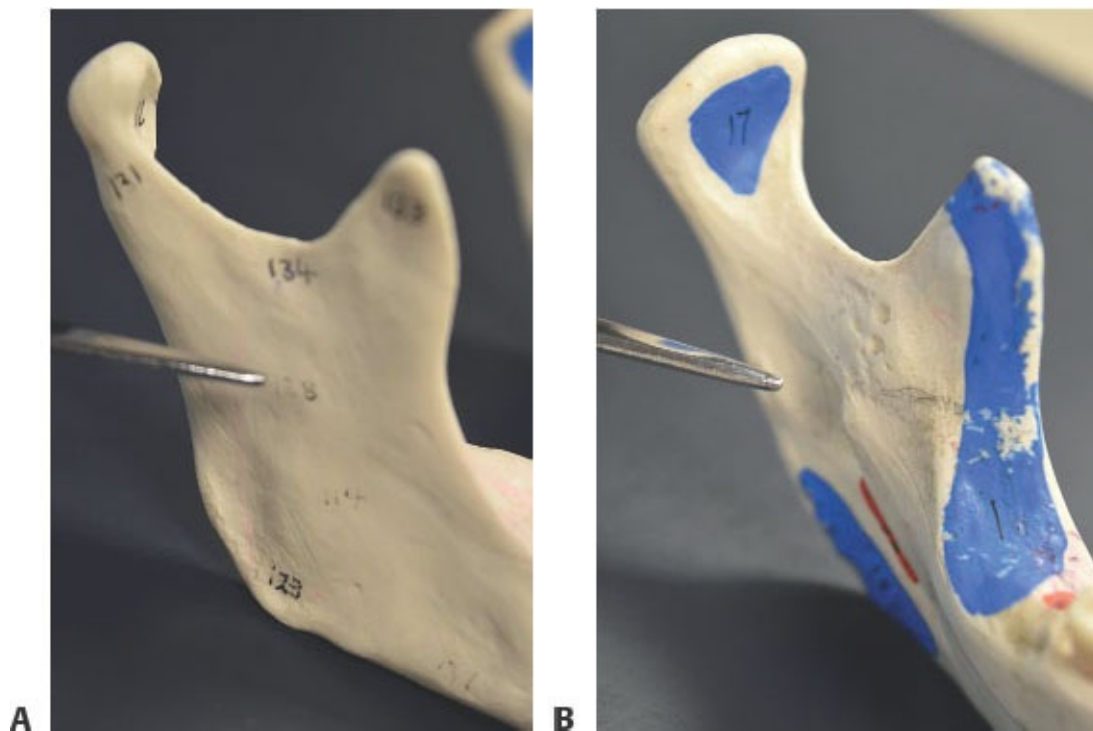


FIG 1 • A. Facial aspect of mandible demonstrating a small anatomic elevation in bone referred to as antilingula. **B.** Lingual aspect of mandible demonstrating position of lingula and the mandibular foramen.

- The anteromedial margin of the mandibular foramen is guarded by an upward tonguelike projection, the lingula.
- Along its course, the inferior alveolar nerve innervates the mandibular teeth and associated soft tissue and terminates as the mental nerve, which supplies sensation to the skin and mucous membrane of the lower lip and chin.
- The muscles of mastication directly attach to the surface of the mandible. The masseter and medial pterygoid muscles attach to the lateral and medial surfaces of the ramus, respectively.
- These two muscles together form the pterygomasseteric sling, which straddles the mandibular ramus.
- The temporalis muscle reaches into the external oblique ridge along the rami

through its tendons and helps with opening and closing of the jaw.

- The lingual nerve, before reaching the tongue, comes in close contact with the inner surface of the alveolar border of the mandible in close proximity to the mandibular third molar tooth.
- An antilingula or the antilingular prominence is a lateral bony protuberance that approximately corresponds to the lingula and the entry of the inferior alveolar nerve into its canal, on the medial aspect of the mandible (**FIG 1**).
 - This is a useful but not an entirely reliable landmark in this technique.
 - The position of the lingula is posteroinferior relative to the position of the antilingula. This has been substantiated in cadaver studies.⁵

PATHOGENESIS AND NATURAL HISTORY

- Mandibular prognathism is a condition wherein the mandible is positioned anterior to the maxilla resulting in a malocclusion.
- In the NHANES study (1989–1994), 0.3% of the US population was reported to have mandibular prognathism severe enough to require orthodontic-surgical treatment.
- About 14% of the youth in the United States have a class III malocclusion. Roughly a quarter of these patients have an isolated mandibular prognathism, whereas the remaining three-quarters have a combination of maxillary deficiency in addition to mandibular protrusion.
 - Often, a midface deficiency is wrongly diagnosed as mandibular prognathism, whereas in reality upon cephalometric investigation, the mandibular position may be normal.
- Mandibular prognathism causes aesthetic concerns, in addition to chewing and speaking difficulties, leading patients to seek surgical treatment at a younger age.
- In cases of severe mandibular prognathism, bimaxillary surgery is the preferred method of treatment (mandibular setback combined with maxillary advancement).
 - This is because excessive mandibular setback may result in obstructive sleep apnea and is also subject to higher rates of relapse.
- Mandibular growth can occur until late teens and early 20s in young men and several years past menarche in women.
 - Surgery should be deferred until there is proof of growth cessation.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present during the teenage years.
- The main functional complaints related to chewing and deglutition, difficulty with speech and enunciation, and TMJ dysfunction in addition to the aesthetic concerns. Often, the malocclusion also presents as an open bite.
- The patients are usually first seen by an orthodontist and eventually referred to a surgeon when ready for surgery.
- Orthodontic treatment is usually undertaken for about a year and serves to align the teeth in the dental arches and remove any dental compensation.
- Surgery is undertaken when the patient reaches skeletal maturity (girls 16–18 years, boys 18–20 years).
- When working up for an IVRO, it is useful to note the functional status of the patient's temporomandibular joints (TMJs). The IVRO may be preferred in patients with TMJ dysfunction over a bilateral sagittal split osteotomy (BSSO), because the condyle seats itself passively in an unloaded position during healing.
- Patients with a V-shaped mandible as assessed from a *norma basalis* are probably better candidates for an IVRO as opposed to a BSSO for a mandibular setback (**FIG 2**).
- The preoperative workup includes records that replicate the relationship of the jaws to the skull base, and model surgery to fabricate the surgical splints.
 - Unlike in a BSSO, a splint may not be required in an IVRO in patients with stable occlusion and orthodontic setup.
 - In the case of double-jaw surgery (Le Fort I advancement combined with a mandibular procedure) for severe class III malocclusion, however, two splints are made—an intermediate splint used intraoperatively to position the maxilla in its final position and a final splint to position the mandible.

IMAGING

- Lateral cephalometric radiographs are obtained for cephalometric analysis.
- Panoramic radiographs are obtained to determine the presence and location of mandibular third molar teeth, level of the inferior alveolar canal.
- A submentovertex view of the mandible could be used in determining its shape and flare.
- A CT scan may be obtained, in case virtual surgical planning is undertaken in lieu of traditional model surgery.

DIFFERENTIAL DIAGNOSIS

- Class III skeletal relationship can be due to mandibular prognathism, maxillary hypoplasia, or a combination of both.
- Accurate diagnosis is important to determine the appropriate surgery.
- The diagnosis is confirmed by detailed clinical evaluation combined with cephalometric analysis.

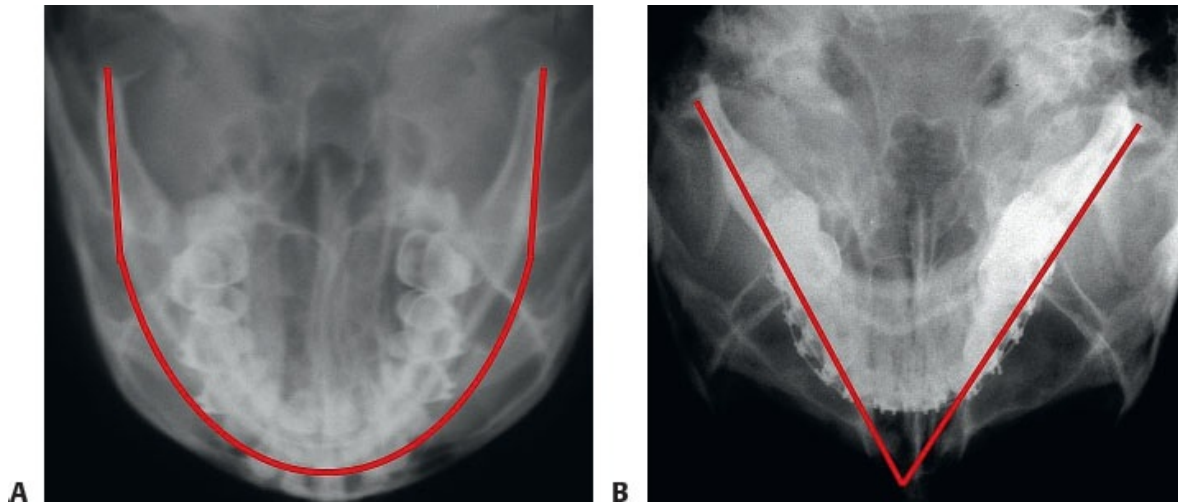


FIG 2 • U-shaped **(A)** and V-shaped **(B)** mandibles as seen in norma basalis. (Courtesy of Myron R. Tucker, DDS, Scientific Liaison, OsteoScience Foundation.)

- Acromegaly and pituitary hyperactivity should be suspected in mandibular prognathism that presents later in life, and appropriate workup is indicated.
- Unilateral hyperplasia of the mandible can cause an asymmetric prognathism and malocclusion. The surgeon should rule out a neoplasm of the mandibular condylar structures in these cases. Unilateral condylar hyperplasia is an idiopathic, rare condition that can also cause an asymmetric mandibular prognathism.

NONOPERATIVE MANAGEMENT

- Mild class III malocclusion can be treated with orthodontic management alone.
- True skeletal class III relationships and asymmetries can be treated only by surgical intervention, however.

SURGICAL MANAGEMENT

- The IVRO setback procedure is usually performed during the late teenage years after the patients have reached skeletal maturity.
- The main objective of the operation is to reduce the horizontal mandibular width that contributes to the prognathism and to reposition the mandible posteriorly to meet the maxilla in a normal class I relationship.

Preoperative Planning

- The risks, benefits, and complications are discussed with the patient on the day of surgery.
- Preoperative photos are obtained for documentation purposes.
- Lateral cephalometric radiographs are obtained for cephalometric analysis.
- Panoramic radiographs are obtained to determine the presence and location of mandibular third molar teeth, level of the inferior alveolar canal.
- A CT scan may be obtained, in case virtual surgical planning is undertaken in lieu of traditional model surgery.

Positioning

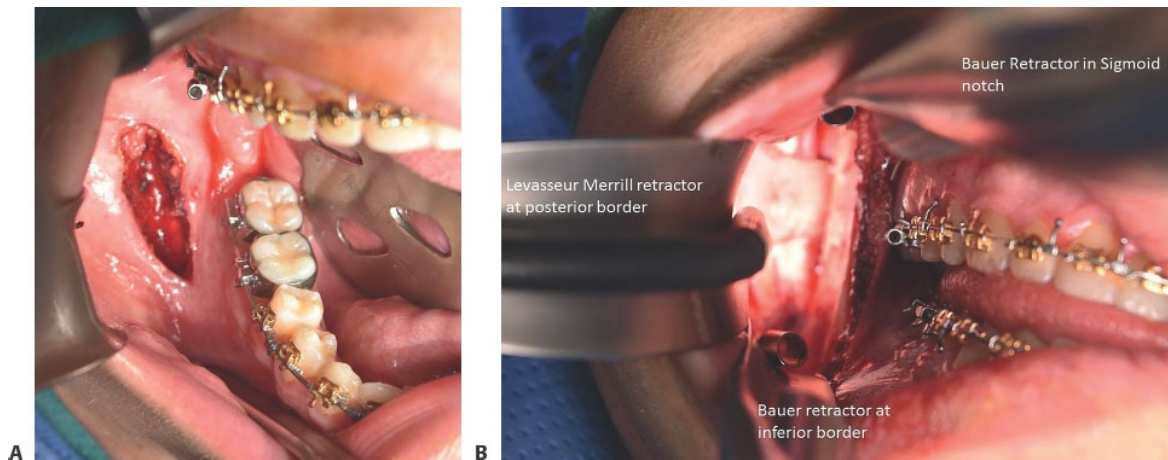
- The patient is positioned supine with the arms tucked.
- He or she is intubated nasally, and the endotracheal tube is secured appropriately to the forehead.
- IVRO setback is performed through an intraoral approach.

TECHNIQUES

■ Exposure

- Cleanse the oral cavity with chlorhexidine or an equivalent antiseptic mouth-rinse, and place a throat pack.
- Inject a local anesthetic containing a vasoconstrictor to infiltrate the area of dissection.
- Access to the ramus is obtained through a lateral approach.
- A ramus-exposing incision is made from the level of the occlusal plane to the level of the first molar tooth (**TECH FIG 1A**). An adequate cuff of gingiva (2 to 4 mm) is maintained adjacent to the molar teeth for relaxed wound closure.

- It is important to make this incision in that appropriate position. If the incision is too lateral, it can heal causing a scar band that can cause a pocket that traps food and makes hygiene difficult to maintain, especially during the healing phase.
- A full-thickness mucoperiosteal flap is elevated, exposing the entire lateral border of the ramus of the mandible. This extends from the inferior border of the mandible to the sigmoid notch in that plane.
 - The periosteum along the posterior border of the mandible is left unreleased. There is no exposure on the medial aspect of the mandible.
 - A Bauer retractor is placed in the sigmoid notch, and a second Bauer retractor is placed at the inferior border.
- A variant technique uses a Levasseur-Merrill retractor, which is placed at the posterior border. This, however, requires stripping the periosteum from the posterior border of the mandible (**TECH FIG 1B**).



TECH FIG 1 • **A.** Appropriate incision for exposure of the mandible. **B.** Placement of appropriate retractors and exposure of the lateral ramus.

■ Intraoral Osteotomies

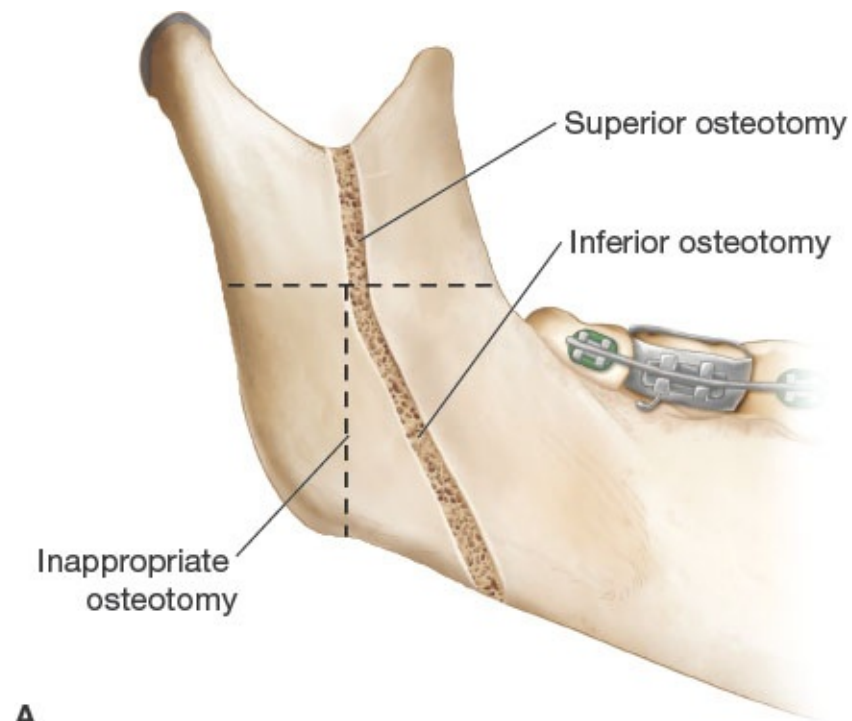
- This is a two-step procedure—first a superior osteotomy and then an inferior osteotomy (**TECH FIG 2**).

Superior Osteotomy

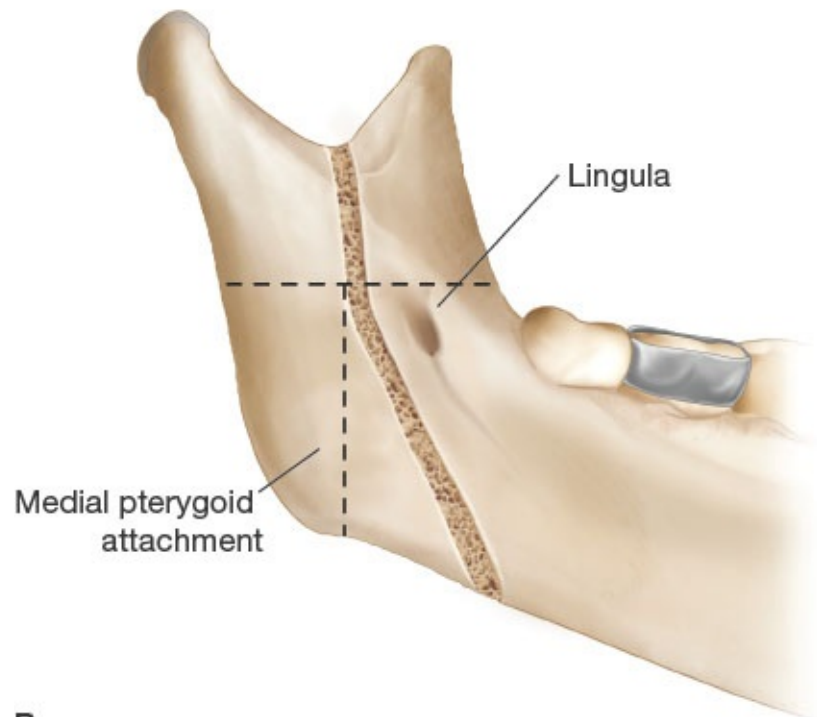
- The exposed lateral border is inspected and the antilingual prominence is

identified.

- The antilingula is not always a reliable indicator of where the lingula would coincide medially. However, staying posterior and inferior to the antilingula places the cuts in a safe zone, avoiding injury to the inferior alveolar neurovascular bundle.
- Using an oscillating saw with an 11.5- × 7-mm blade (**TECH FIG 3A**), the surgeon makes an osteotomy outline approximately a centimeter in front of the posterior border of the mandible.



A



B

TECH FIG 2 • Lateral **(A)** and medial **(B)** views of the two-step osteotomy. Appropriate two-step osteotomy ensures optimal medial pterygoid attachment.

- A curved Freer elevator is placed at the posterior border to approximately measure this distance and to ensure that the marking is in the appropriate position (**TECH FIG 3B**).
- Cuts made anterior to the antilingula or too close to it will damage the mandibular canal and its contents.
- Following confirmation of the position of the cut, the oscillating saw is now used to complete the osteotomy (**TECH FIG 3C**).
- The cutting edge of the blade is first directed toward the sigmoid notch.
- Saw movement should never be forced and is directed with a gentle, back and forth rotational movement of the shaft.
- The bone is thinner as the blade approaches the sigmoid notch, and its depth of insertion should be adjusted accordingly (**TECH FIG 3D**).

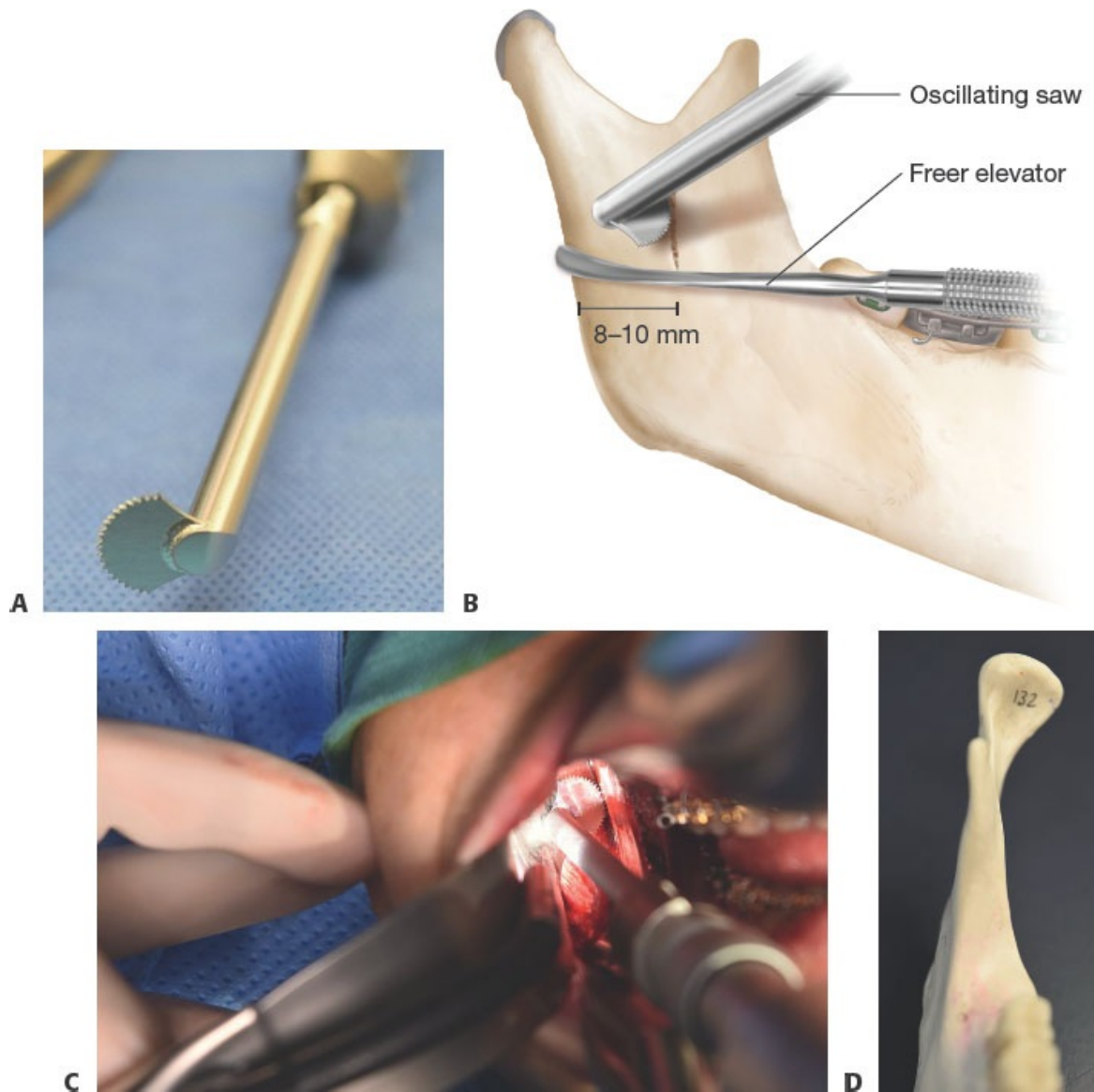
Inferior Osteotomy

- The upper Bauer retractor is removed to make the access easier for the inferior part of the osteotomy.
- The inferior cut is made with the same saw blade by directing it inferiorly within the same cut.
- The osteotomy is performed anteriorly and inferiorly below the antilingula, aiming away from the posterior border. This provides a robust proximal segment on completion of the osteotomy.

Mandible Repositioning

- After confirming that the osteotomy is complete along the entire ramus, the mandible is positioned into a class I relationship by separating the proximal segment and moving it lateral to the distal segment (**TECH FIG 4A**). An occlusal splint can be used if needed.
- Final occlusion is established with maxillomandibular fixation (MMF).
- Trim the proximal segment with a round bur to allow passive overlap of the segments.
- Though the IVRO is usually a bilateral procedure, it is occasionally performed only unilaterally to correct minor asymmetries and setbacks. When performed bilaterally, the same steps are repeated on the contralateral side.
- Following ramus osteotomies bilaterally, irrigate the wounds, and suction the oral cavity; remove the throat pack, and establish the planned occlusion, and secure MMF.

- Inspect both osteotomies for lateral overlap and passive positioning of the proximal segment. If the tip of this segment can be palpated in the submandibular area, it needs to be trimmed (**TECH FIG 4B**).
- The wounds are closed with continuous 3-0 chromic in a watertight fashion.



TECH FIG 3 • **A.** Oscillating saw with an 11.5- × 7-mm blade. **B.** A curved Freer elevator is placed at the posterior border of the mandible to approximately measure the distance to ensure the osteotomy is in the appropriate position. **C.** Oscillating saw in position

for the osteotomy. **D.** The bone is thinner at the sigmoid notch.



TECH FIG 4 • A. When the osteotomy is completed, the proximal segment of the mandible is separated and moved laterally to overlap the distal segment. **B.** If the proximal segment is too prominent and is palpable in the submandibular area, it is trimmed.

PEARLS AND PITFALLS

Physical findings

- Class III skeletal relationship can be caused by mandibular prognathism, maxillary hypoplasia, or a combination of both. Accurate diagnosis is critical to determine the appropriate surgery to correct the deformity.
- V-shaped mandibles are better suited for setback using the IVRO technique than are U-shaped mandibles (see **FIG 2**).
- IVRO is better suited for mandibular setbacks in patients with pre-existing TMJ symptoms.
- IVRO has limited application in mandibular advancements.

Technique

- Leaving an insufficient cuff of gingiva when making the incision will lead to difficulty suturing and possible wound dehiscence.

- Too thick a cuff produces a scar band and a pocket for food impaction.
- Marking the osteotomy position behind the antilingula is prudent to avoid the mandibular canal during osteotomy.
- Alternatively, a 30-degree endoscope can be inserted into the wound to inspect the position of the planned osteotomy.
- The saw should be lightly applied and never forced.
- The saw blade may be too long in areas of thinner mandible when approaching the sigmoid notch.
- If the 11.5- × 7-mm blade is too short to complete the osteotomy, there is a good chance that the planned osteotomy is positioned too far anteriorly and likely in the mandibular canal.
- IVRO should not cause mandibular nerve hypoesthesia. If it does, the cuts violated the canal.
- Directing the saw anteriorly and inferiorly while making the cut inferior to the antilingular prominence ensures a robust proximal segment with a good amount of medial pterygoid attachment.
- Angled instruments can be used to rigidly fixate IVRO segments. This is seldom utilized and is generally unnecessary.

POSTOPERATIVE CARE

- The patient is generally extubated in the operating room and taken to recovery breathing spontaneously. However, if there are any airway concerns, the patient may be left intubated and taken to the ICU.
- MMF is left in place for anywhere from a few days to a few weeks, depending on operator preference.
 - Most surgeons prefer MMF for at least a few days following the procedure.⁶
 - Light guiding elastics may be required to help train the occlusion after removal of rigid interdental wiring.

OUTCOMES

- Although IVRO is a reliable technique for mandibular setback and closure of small open bites, it can occasionally be used for mandibular lengthening or counterclockwise rotation of the mandible.
- Stripping of masseter and medial pterygoid can lead to a 14% incidence of open bite at the time of MMF release. This was described as a result of “condylar sag.”
- In general, up to 10 mm of mandibular setback is possible with an IVRO. The magnitude of the setback should not exceed the width of the medial pterygoid

attachment on the proximal segment.

COMPLICATIONS

- Risks from an IVRO include injury to the inferior alveolar and/or lingual nerves, condylar sagging and malpositioning, relapse, bleeding including pseudoaneurysms, infection, and fibrous union.
- Direct injury to the inferior alveolar nerve may occur while making the osteotomies, but an indirect injury can also occur if the proximal segment slips medially and impinges on the nerve bundle.
- Condylar sagging occurs when the muscles are excessively stripped or when the osteotomies create a small proximal segment.
- Significant bleeding can occur if the blade injures the masseteric artery within the sigmoid notch, or larger vessels like the internal maxillary artery or its branches in the medial ramus area. Other potential sources of bleeding are the facial artery and the retromandibular vein. Bleeding can be prevented by careful surgical technique and protection of the soft tissue.
- Wound dehiscence and/or infection are a rare complication and are most often related to poor oral hygiene.

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40 Internal Mandibular Distraction

CHAPTER

Michael Alperovich and Roberto L. Flores

DEFINITION

- Mandibular hypoplasia or an underprojected and diminutive mandible can have functional consequences including tongue-based airway obstruction, sleep apnea, reduced intraoral opening, and malocclusion.¹
- Mandibular hypoplasia can also result in facial disharmony and distressing aesthetic concerns.²

ANATOMY

- The normal mandible can be divided into two, symmetric halves from the midpoint of the mandibular symphysis.
- Each hemimandible can be subdivided into several segments: the parasymphysis, body, angle, ramus, and condyle (**FIG 1**).
- The symphysis is the midline of the mandible. The parasymphysis is a region bound by the roots of the mandibular canines. The mandibular body extends from the mandibular canine roots to the mandibular third molar.
- The mandibular angle is the triangular region that represents the junction between the mandibular body and ramus. The mandibular ramus is the vertical component of the mandible extending from the angle to the sigmoid notch.
- The mandibular condyle is the portion of posterior mandible extending cephalad from the sigmoid notch and articulating with the temporomandibular joint.
- The Pruzansky-Kaban classification is widely used to define mandibular deficiency and is most commonly used to classify craniofacial microsomia severity (**FIG 2**).³

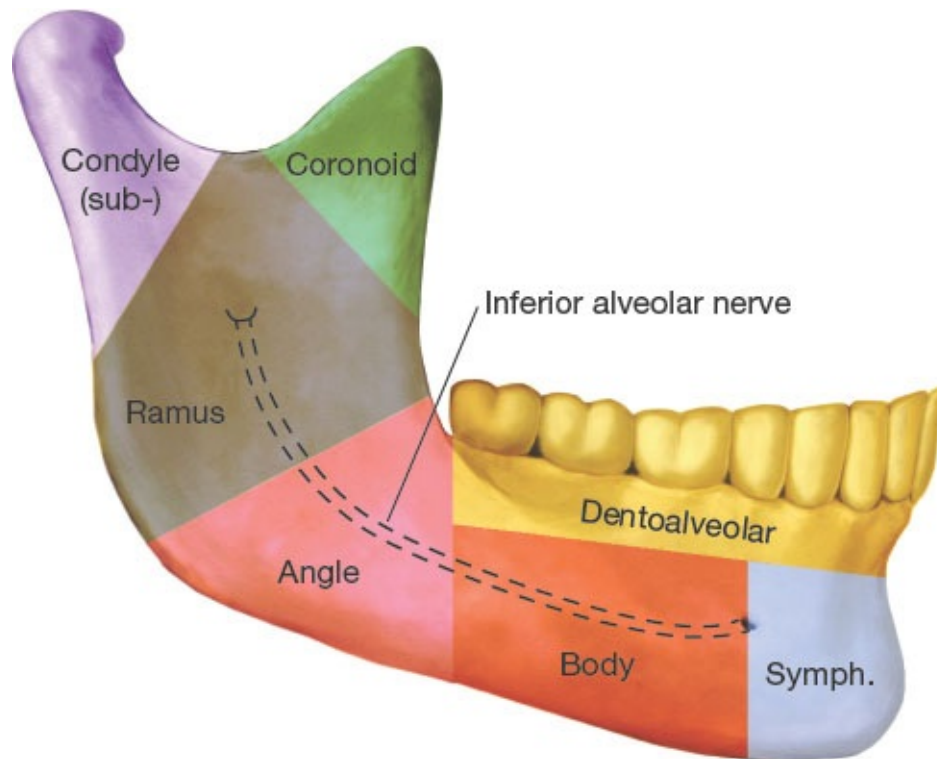


FIG 1 • Schematic demonstrating the anatomic subdivisions of the hemimandible.

- A type I mandible features hypoplasia of the mandibular ramus and condyle with a normal mandible morphology.
- A type IIA mandible features reduction in the volume of the body, ramus, and condyle but has a preserved temporomandibular joint.
- A type IIB mandible features reduction in the volume of the body, ramus, and condyle, as well as medial inclination of the ramus displacing the condyle from the glenoid fossa.
- A type III mandible features severe ramus reduction or complete absence with no evidence of a temporomandibular joint.

PATHOGENESIS

- Mandibular hypoplasia has congenital and acquired causes, with congenital causes predominating.
- Craniofacial microsomia and Pierre Robin sequence are the most common congenital causes followed by Treacher Collins syndrome.⁴

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with mandibular hypoplasia secondary to craniofacial microsomia can have malformations in other structures derived from the first and second branchial arches, including the external ear; midface (zygoma and orbit); facial nerve, with the marginal mandibular nerve most commonly affected; muscles of mastication; as well as soft tissue deficiencies.
- Unilateral craniofacial microsomia patients will present with asymmetric facies and an upward occlusal cant on the affected side. The ramus is predominantly affected in craniofacial microsomia.
- In addition to a hypoplastic mandible, Pierre Robin sequence patients fulfill the triad of micrognathia, glossoptosis, and airway obstruction. Retropositioning of the tongue is responsible for airway obstruction and increased work of breathing. Most patients will also present with a U-shaped cleft palate.
- Mandibular hypoplasia in Pierre Robin sequence patients is characterized by bilateral and symmetric mandibular hypoplasia most severely affecting the body.
- Up to 50% of Pierre Robin sequence patients have an associated syndrome, with Stickler syndrome as the most common.⁵
- Pierre Robin sequence patients may present with failure to thrive, feeding difficulties, developmental delay, reflux, carbon dioxide retention, heart failure, and desaturations most pronounced in the supine position.



FIG 2 • Pruzansky-Kaban classification of mandibular deficiency.

IMAGING

- Preoperative imaging should include a craniofacial CT to evaluate mandibular morphology including the TMJ and for planning the ideal vector for

mandibular distraction (**FIG 3**).

- A Panorex may be obtained to evaluate occlusion and identify the location of the unerupted tooth buds but is often not necessary if a CT image is obtained.
- If applicable, dental study models should be obtained for future orthodontic splint fabrication (ie, correction of any resulting open bite and molding the newly generated bone).
- A polysomnogram should be performed to confirm the presence and etiology of sleep apnea.
- Bronchoscopy and endoscopy should be performed to identify other potential causes of obstruction.

DIFFERENTIAL DIAGNOSIS

- Causes of airway obstruction in addition to retrognathia include the following:
 - Adenoid/tonsillar hypertrophy
 - Bronchial stenosis
 - Bronchomalacia
 - Central sleep apnea
 - Laryngomalacia
 - Subglottic narrowing
 - Tracheomalacia

NONOPERATIVE MANAGEMENT

There is no nonoperative management for mandibular hypoplasia. Airway compromise associated with retrognathia can be managed through conservative and invasive techniques.

- Initial conservative techniques include the following:
 - Prone positioning
 - Supplemental oxygen



FIG 3 • Representative craniofacial CT of a patient with Pierre Robin sequence and mandibular body deficiency prior to mandibular distraction.

- Nasopharyngeal tubes
- Continuous positive airway pressure
- Interventional techniques include the following:
 - Intubation
 - Tracheostomy
 - Tongue-lip adhesion
 - Mandibular distraction osteogenesis
- Intubation stabilizes airway management and can be temporizing prior to more definitive approaches.
- Tracheostomy will provide a definitive airway; however, the procedure can lead to tracheomalacia, chronic pneumonia, laryngeal stenosis, complex nursing care needs, and impaired psychosocial development.⁶
- Tongue-lip adhesion provides less relief to the obstructed airway when compared to mandibular distraction. It has been associated with lower oxygen saturation levels and higher apnea-hypopnea indices postoperatively, as well as higher conversion rates to tracheostomy.⁷

SURGICAL MANAGEMENT

Preoperative Planning

- Mandibular distraction has functional indications that include improving lower jaw position and morphology, correcting tongue-based airway obstruction and obstructive sleep apnea, obviating the need for tracheostomy, optimizing the airway for decannulation, treating temporomandibular joint ankylosis, and lengthening a shortened mandible due to trauma or extirpative surgery.
- Mandibular distraction has aesthetic indications to treat facial disharmony or augment a hypoplastic mandible in the absence of a functional deficit.
- If neonatal distraction is considered, patients need to be evaluated by otolaryngology, neonatology, genetics, pulmonology, and a pediatrician prior to surgery.
- If the patient is an older child (non-neonate) or adult, consultation and partnership with a craniofacial orthodontist are recommended.

- In cases in which airway obstruction is a concern, bronchoscopy and laryngoscopy must be performed by an otolaryngologist to rule out secondary airway anomalies (tracheomalacia, subglottic stenosis, tracheal rings).⁸
- Craniofacial CT is used preoperatively to evaluate the mandibular shape, tooth bud position, and course of the inferior alveolar nerve and to plan the distraction vector.
- Polysomnography preoperatively can help differentiate between central and obstructive sleep apnea, establish a baseline apnea-hypopnea index, and confirm retention of carbon dioxide.⁹

Positioning

- The patient is positioned supine, endotracheally intubated, and placed on a horseshoe for maximal maneuverability of the craniofacial region.
- The entire face and neck are prepped into the field.

Approach

- Extraoral and intraoral approaches have been described. Only the extraoral approach will be described below.
- External and internal distraction devices are used, but this chapter will exclusively focus on internal distraction devices.¹⁰

TECHNIQUES

■ Internal Mandibular Distractor Placement

- Mark a Risdon incision parallel and 2 cm inferior to the mandibular body. This distance can be shortened to 1 cm in neonates (**FIG 4**).
- Inject weight-based local anesthetic along the planned skin incision; avoid anesthetic toxicity in the pediatric population.
- Incision and dissection are extended sharply through skin, subcutaneous tissue, and platysma. Superior and inferior platysmal flaps are raised to provide a tension-free, layered final skin closure.
- Be vigilant to remain inferior to the marginal mandibular nerve; if the nerve is identified during dissection, it is carefully protected.
- Preoperative craniofacial CT imaging informs the type and location of the

osteotomy as well as the distraction vector. These factors influence the type of exposure required. Although there is no consensus on the optimal osteotomy type, the most popular are body, ramus, inverted L, and transport distraction.

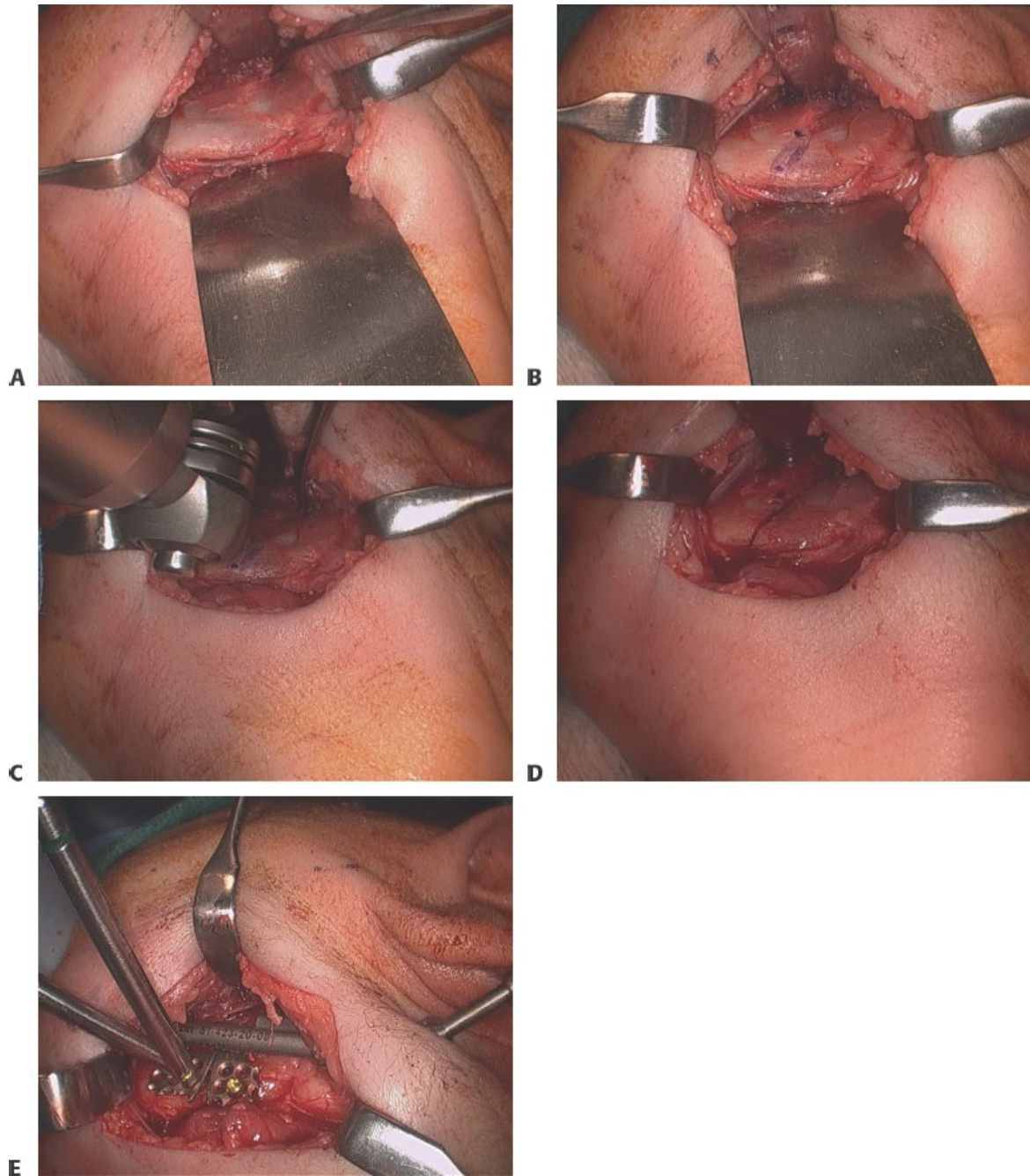
- The periosteum is identified and incised along the inferior border of the mandibular body. Subperiosteal dissection is extended across the entire buccal surface of the mandible from the proximal ramus through the distal body. This includes exposure to the coronoid and sigmoid notch if an inverted-L osteotomy is considered (**TECH FIG 1A**).



FIG 4 • Risdon incision drawn on a neonate. The chin is to the left. The ear is superior and to the right. Note the incision may be drawn 1 cm below the mandibular border in neonates.

- If the mandibular deficiency is predominant in the body, the inverted-L osteotomy is favored. Alternatively, a transverse mandibular body, mandibular angle, or transverse ramus osteotomy can also be used (**TECH FIG 1B**).
- For the inverted-L osteotomy, a near-complete vertical ramus osteotomy is performed from the sigmoid notch to the antegonial notch. Coronoidectomy is performed using a sagittal saw or Kerrison punch (**TECH FIG 1C**).

- A full corticotomy is performed over the buccal surface and the cephalad and caudal margins of the lingual surface. A bony bridge in the center of the lingual surface of the mandible is maintained to preserve mandibular alignment during distractor placement (**TECH FIG 1D**).
- If the mandibular deficiency is predominant in the ramus as is commonly seen in Treacher Collins syndrome, a vertical distraction vector is utilized. This osteotomy may risk injury to the temporomandibular joint and cause ankylosis of the joint.
- A semiburied distraction device is affixed to the lower border of the mandible (if a horizontal vector is used) with the activation arm exiting behind the earlobe. The maximum distraction length is determined on a case-by-case basis with 20 mm favored in infants and 30 mm in older children or for cases of severe mandibular deficiency.
- High-profile screws are used to secure the distraction device for ease of removal after consolidation (**TECH FIG 1E**).
- After the device is secured, it is activated for several millimeters to confirm the absence of resistance. The lingual surface osteotomy is often completed with device activation alone. Complete osteotomy is confirmed using an osteotome or suction cannula.
- Prior to soft tissue closure, the bony edges are returned to apposition and any intervening soft tissue is removed.
- The platysma muscle is reapproximated using resorbable suture followed by closure of the dermis and epidermis.



TECH FIG 1 • A. Wide subperiosteal dissection is needed to perform an inverted “L” osteotomy. This includes the distal body, the angle, the ascending ramus, and sigmoid notch. If a mandibular body osteotomy is planned, less undermining is required. **B.** Inverted “L” osteotomy is drawn. Note the vertical osteotomy extends from the sigmoid notch to the

antegonial notch. **C.** Coronoidectomy can be performed with a sagittal saw or Kerrison punch. **D.** The inverted-L osteotomy is made to near completion with preservation of the lingual cortex just superior to the mandibular border and inferior to the sigmoid notch. This narrow bony bridge will maintain anatomic bony position, while the hardware is placed. Completion osteotomy is performed after the hardware is secured. **E.** High-profile screws may be used to facilitate placement and removal of hardware.

■ Internal Mandibular Distractor Removal

- Remove the distraction device 8 weeks following consolidation.
- Use the prior Risdon incision to access the device while remaining vigilant of the course of the marginal mandibular nerve and raising platysmal flaps to maintain a tension-free skin closure.
- Assess the integrity of the generated bone across the distracted segment by visual inspection and manual palpation.
- Removing the device is easiest when the minimum number of high-profile screws is used initially.
- As with device placement, reapproximate the platysma muscle first followed by the dermis and epidermis.

PEARLS AND PITFALLS

Incision

- At the start of the procedure, raise supraplatysmal skin flaps to close the platysma muscle as a deeper layer separate from the skin. Removing tension from the skin closure can improve long-term scar appearance.

Warning

- In neonatal distraction, the mandibular bone can be very soft. Gently incise the periosteum with a 15 blade or when using an elevator as both instruments can damage the outer cortex.
-

Technique	■ If using an inverted-L osteotomy, the inferior mandibular osteotomy should be planned posterior to the antegonial notch to avoid tooth buds.
Implant burden	■ Minimize the number of high-profile screws placed to secure the distractor (four per side) for easier distractor removal after consolidation.
Theory	■ Premature consolidation is more commonly a result of incomplete lingual corticotomy. Test the distractor, and confirm the absence of any resistance before completion of surgery.
Therapeutic success	■ When performing mandibular distraction to improve the airway, serial cephalograms and a repeat polysomnogram should be performed 3 months after completion of distraction.

POSTOPERATIVE CARE

- A latency period of 5 days is routinely used followed by activation at a rate of 1 mm/d.
- Serial cephalograms are used to monitor progress with device removal following 8 weeks of consolidation.
- If distraction has been performed to relieve airway obstruction, a follow-up polysomnogram should be performed.
- In neonatal patients, mandibular distraction can prevent tracheostomy. In chronically tracheostomy-dependent patients, mandibular distraction can result in decannulation of the tracheostomy.
- Overcorrection of the mandible is advised when distraction is performed in a skeletally immature patient with some studies advocating 40% to 50% overcorrection.¹¹

OUTCOMES

- Mandibular distraction has a success rate of 92% to 100%.¹²
- Risk factors for failure of mandibular distraction in Pierre Robin sequence include GERD, need for Nissen fundoplication, and absence of a cleft palate.¹²

COMPLICATIONS

- Major complications
 - Marginal mandibular nerve injury
 - Inferior alveolar nerve injury
 - Tooth bud injury

- Temporomandibular joint ankylosis
- Death
- Moderate complications
 - Device failure or fracture
 - Premature consolidation/incomplete osteotomy
 - Device exposure
 - Pin dislodgment
 - Fibrous nonunion
 - Dentigerous cysts secondary to distraction across a tooth follicle
- Minor complications
 - Marginal mandibular nerve neurapraxia
 - Pin-tract soft tissue infection
 - Unfavorable scars

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41 External Mandibular Distraction for Micrognathia

CHAPTER

Haithem M. Elhadi Babiker

DEFINITION

- Distraction osteogenesis of the craniofacial skeleton was first attempted by Snyder in 1972.
- In 1991, McCarthy et al. published their experience with mandibular distraction, popularizing the technique.¹
- Mandibular distraction osteogenesis (MDO) can be performed with either an external or internal technique. Both techniques have been proven to be successful and safe to lengthen the mandible.²
- External mandibular distraction involves making a mandibular osteotomy and applying an external device to slowly and gradually lengthen the mandible. This technique is used to lengthen the hypoplastic mandible seen in multiple craniofacial conditions.

ANATOMY

- The mandible is a unique U-shaped bone with two vertical rami and a horizontal body. It articulates with the skull at the temporomandibular joints and is the only movable bone of the facial skeleton.
- The inferior alveolar nerve enters the mandibular foramen on the medial aspect of the ascending ramus and then extends within the mandibular body, exiting at the mental foramen.
- The lingual nerve is located medial to the ramus in close proximity to the alveolar process near the third molar.

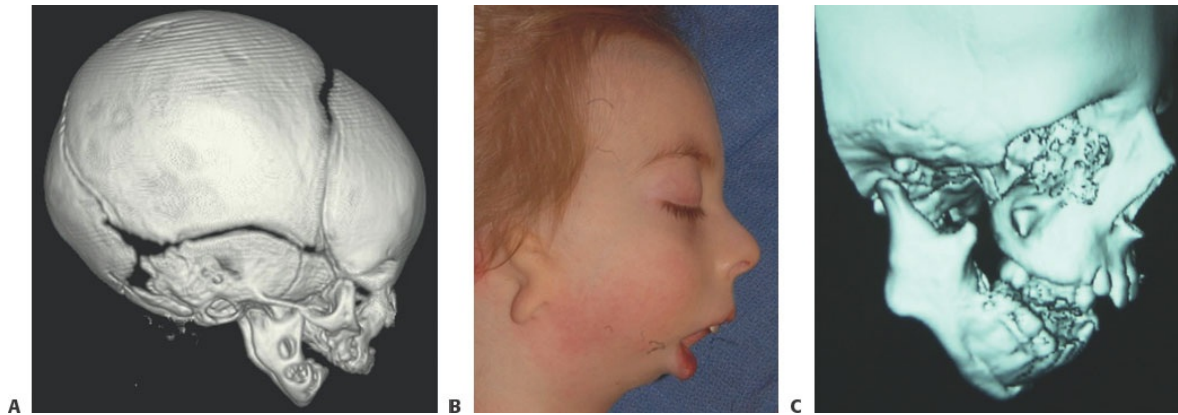


FIG 1 • **A.** CT scan showing the bilateral micrognathia in Pierre Robin sequence (PRS). **B.** Patient with hemifacial microsomia (HFM) demonstrating severe micrognathia. **C.** Patient with Treacher Collins syndrome (TCS) exhibiting severe micrognathia (both mandibular body and ramus), and an anterior open bite.

- Patients with Pierre Robin sequence (PRS) are characterized by a hypoplastic mandibular body; the condyle and ramus are generally of normal size (**FIG 1A**).³
- Hemifacial microsomia (HFM) is usually unilateral and is classified using a spectrum of severities from type I to type III (**FIG 1B**).
- In Treacher Collins syndrome (TCS), the hypoplasia is similar to that seen in PRS but also includes a deep antegonial notch and downslanting mandibular body (steep occlusal plane) associated with an open bite. Some TCS mandibles may exhibit features similar to HFM (**FIG 1C**).⁴
- Post-traumatic condylar fractures may also lead to mandibular hypoplasia associated with bilateral TMJ ankylosis.

PATHOGENESIS AND HISTORY

- Mandibular hypoplasia occurs either as an isolated condition (possibly due to intrauterine physical growth restriction) or as part of a genetic abnormality.
- Patients with mandibular hypoplasia present most commonly during the neonatal period due to obstructive sleep apnea (OSA).
- HFM is the second most common craniofacial congenital anomaly, with an incidence of 1/3000 live births.

- Once a child is born with mandibular micrognathia, the deformity is not progressive.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with micrognathia usually present during infancy with tongue-based OSA, ranging from mild to very severe.²
- The small mandible pushes on the tongue causing it to fall back and obstruct the airway.
- Mild cases present with noisy breathing during sleep.
- More severe cases present with apneic episodes, cyanotic spells, and feeding abnormalities.⁵
 - The child expends most of his or her energy trying to breathe, and hence has no energy to feed.
 - Poor weight gain and failure to thrive are strong indicators of severe OSA.⁶
- Neonates with severe OSA require urgent admission to the neonatal intensive care unit (NICU) for airway stabilization.
 - Treatment modalities include prone positioning, nasopharyngeal airway, tongue-lip adhesion, and in very severe cases, tracheostomy.
- The main objective of mandibular distraction is to avoid a tracheostomy or to achieve decannulation in patients with a tracheostomy.

IMAGING

- Lateral cephalometric radiographs can be used to identify the mandibular micrognathia. In neonates, a lateral skull x-ray at a distance of 72 in. is used to evaluate the hypoplastic mandible.
- The best imaging modality is a three-dimensional computed tomography (3D CT) scan to characterize the mandible and to render a volumetric measurement of the airway.
 - Low-dose CT scans use very low radiation (comparable to traditional radiographs) without compromising image quality (**FIG 2**).

DIFFERENTIAL DIAGNOSIS

- HFM, 1:3000 live births
- PRS, 1:14 000⁷
- TCS, 1:50 000 live births⁸
- Nager syndrome
- Post-traumatic condylar fractures

- Stickler syndrome, velocardiofacial syndrome, fetal alcohol syndrome, trisomy 21 and 22, and Kabuki syndrome⁹

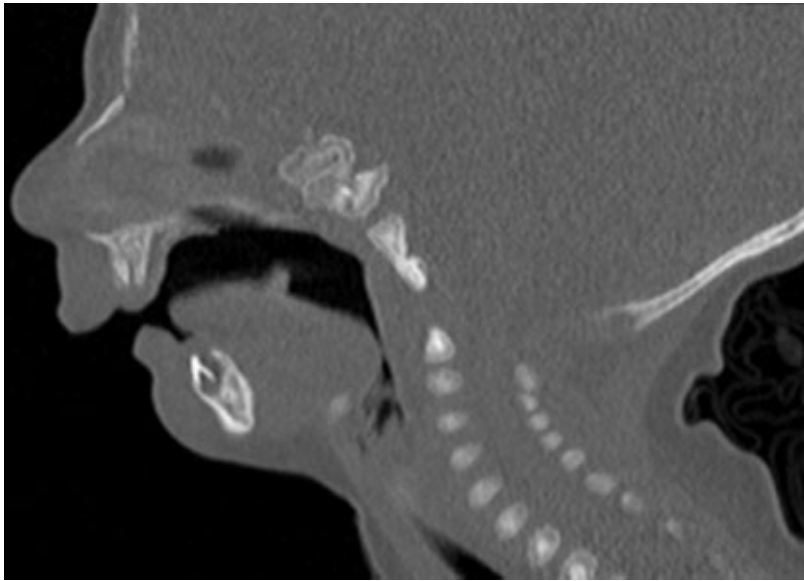


FIG 2 • CT scan showing mandibular micrognathia, retropositioning of the tongue, and narrow airway stripe.

NONOPERATIVE MANAGEMENT

- Prone and lateral decubitus positioning.
- Nasopharyngeal airway, oxygen support, and possible tongue suture.¹⁰
- ICU care and close monitoring is critical to prevent rapid deterioration.
- A multidisciplinary team comprised of neonatology, otolaryngology, pulmonology, plastic surgery, and genetics should make the decision regarding treatment planning.
- The infant is evaluated with a polysomnography and a microlaryngoscopy/bronchoscopy, which examines the entire airway and differentiates lower airway from upper airway problems.
- Mild cases are treated with conservative measures.

SURGICAL MANAGEMENT

- Tongue-lip adhesion is advocated by some centers with variable success.^{6,11}
- Tracheostomy remains the standard in very severe cases of OSA.^{8,11}
- Mandibular distraction is generally undertaken during the neonatal period.
- The main objective of the operation is to lengthen the mandible, which pulls

the tongue forward to relieve the tongue-based respiratory obstruction.

- The main steps of the surgery are as follows:
 - Intraoral incision(s) to expose the posterior aspect of the mandible.
 - Saw or bur to make a corticotomy in the ascending ramus/angle of the mandible.
 - Self-drilling pins into the mandible proximal and distal to the corticotomy site.
 - If a rigid external distraction (RED) device is used, place the anterior mandibular plate and secure it to the mandible with monocortical screws.
 - Use a 5-mm osteotome to convert the corticotomy into an osteotomy to completely liberate the mandibular segments.
 - Attach the distraction device to the pins.
 - If an RED is used, attach the halo component to the anterior mandibular plate using 25-gauge wire.
 - Close the intraoral wound in watertight fashion.
 - Wait 1 to 3 days (latency period) and then activate the device (activation period) until the desired final position of the mandible is achieved.
 - Maintain the device in position until the new bone mineralizes (consolidation period).
 - Remove the distraction device at the end of the consolidation period.
- The operation is performed bilaterally in cases of PRS, TCS, and Nager syndrome; or unilaterally in cases of HFM.
- Selection criteria for mandibular distraction include severe mandibular micrognathia (maxillomandibular differential of greater than 8 mm), polysomnogram showing severe OSA, and difficulty with breathing and feeding.⁸

Preoperative Planning

- A 3D CT scan is obtained to delineate the morphology of the mandible, the position of the inferior alveolar nerve and the teeth follicles.
- Cephalometric measurements can be obtained from the CT scan to quantify the mandibular hypoplasia.

Positioning

- The patient is positioned supine.
- The procedure is generally performed in conjunction with ENT and pulmonology to perform the MLB and assist with intubation.

- The procedure is done under general anesthesia.
- The patient is intubated nasally; the endotracheal tube is sutured to the nasal septum and secured appropriately to the forehead (**FIG 3**).
- A foam donut stabilizes the head.

Approach

- Surgery is performed through an intraoral approach with percutaneous placement of the pins.



FIG 3 • Endotracheal tube secured to the forehead and sutured to the nasal septum.

TECHNIQUES

■ External Mandibular Distraction With Pins

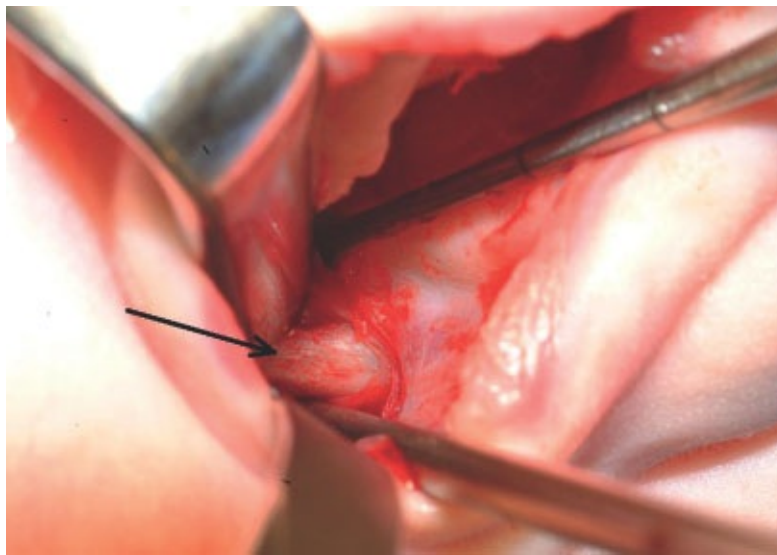
Exposure and Dissection

- Inject local anesthetic with vasoconstrictor to infiltrate the area of dissection in the posterior mandible.
- Insert a bite block/gauze sponge on the opposite side of dissection to adequately open the mouth.

- Expose the area of dissection by placing two Langenbeck retractors to pull away the cheek.
 - In very small babies, malleable retractors can be used instead. Place a tongue retractor to protect the tongue.
- A 3-cm incision is made in the area of the ascending ramus and angle of the mandible.
- Sharp dissection is carried through mucosa, muscle, and periosteum to raise a full-thickness mucoperiosteal flap exposing the entire ascending ramus and posterior body of the mandible (**TECH FIG 1**).
- Dissection is also performed on the lingual aspect of the ramus, while protecting the inferior alveolar nerve.
- A malleable retractor is inserted on the medial aspect of the ramus to retract and protect the neurovascular bundle.

Corticotomy

- Using an ultrasonic saw (**TECH FIG 2A**) or a reciprocating saw, a corticotomy is made at the angle of the mandible.



TECH FIG 1 • Exposure of the posterior aspect of the mandible. 1: Arrow pointing to the angle of the mandible.

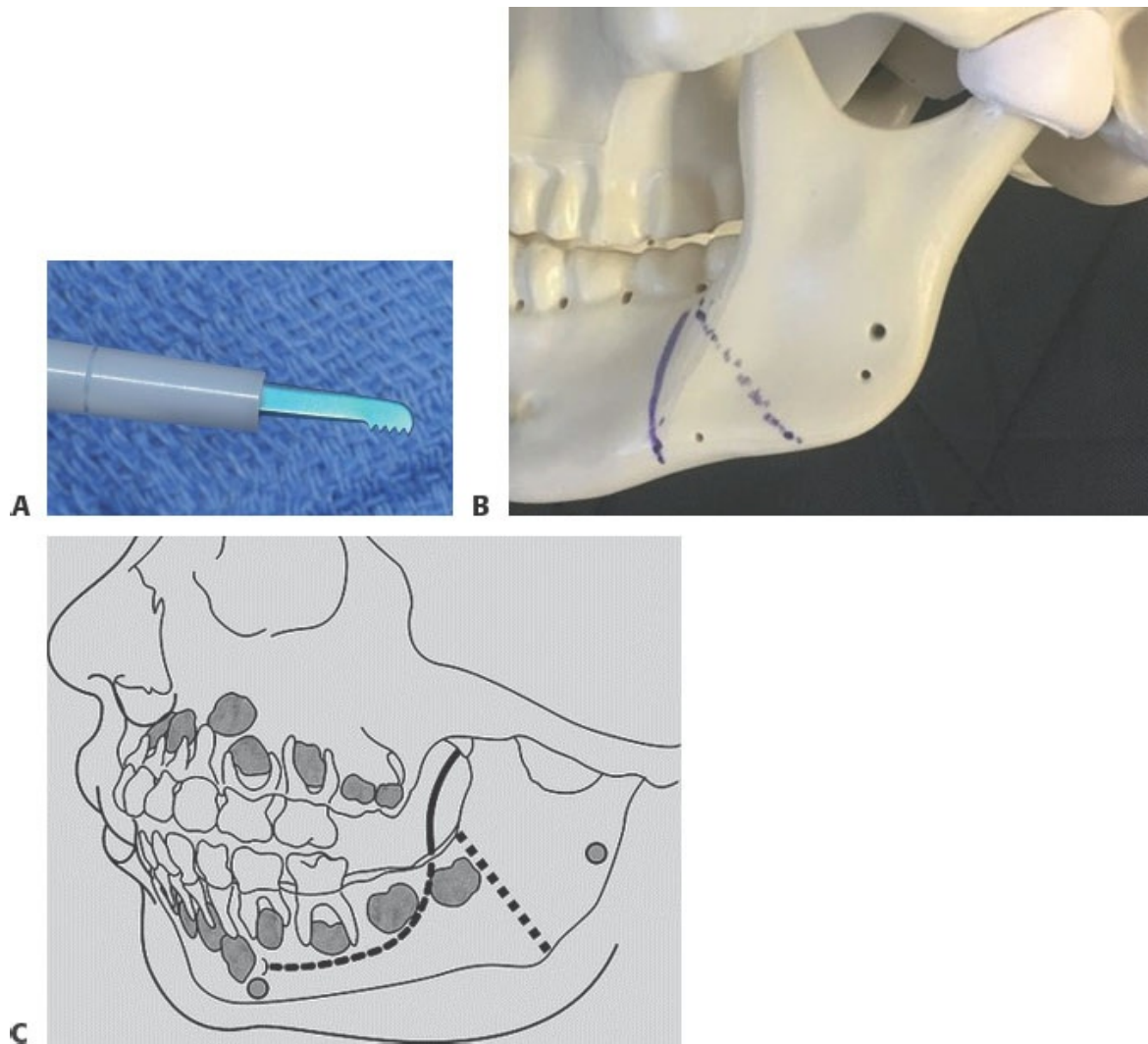
- The site of the osteotomy is determined from the CT scan to avoid the teeth

follicles.

- The direction and orientation of the osteotomy determines the desired vector of distraction. Distraction can occur in the horizontal, vertical, or oblique direction (depending on the relationship of the vector to the long axis of the mandibular body).¹²
 - A horizontal vector along the long axis of the mandible will lengthen the mandible in a purely horizontal plane. This is the case of bilateral micrognathia seen in PRS and TCS patients where most of the deficiency is in the mandibular body.
 - A vertical vector of distraction is preferred for lengthening a deficient ramus in a vertical direction as seen in HFM.
 - An oblique vector simultaneously lengthens the body of the mandible and elongates the ramus.
- The corticotomy extends from the alveolar process to the inferior border of the mandible, where the bone is thicker (**TECH FIG 2B**).
 - The thick inferior mandibular border must be completely cut to prevent a bad split of the mandible (**TECH FIG 2C**).

Pin Placement

- The site of pin placement is determined based on the angle and orientation of the osteotomy, and the location of tooth follicles.
- One or two self-drilling and self-tapping pins (40 mm long) are then placed percutaneously proximal to the corticotomy (**TECH FIG 3A**).
- A stab incision is made in the skin immediately below the inferior border of the mandible to gain access to the bone, and the pins are screwed into the bone using a manual pin driver (**TECH FIG 3B**).
 - Ensure that the pins are perpendicular to the bone and advanced far enough into the bone to engage both cortices (**TECH FIG 3C**).
- The skin immediately anterior to the proximal pin/s is retracted posteriorly, and one or two more pins are drilled distally in a similar fashion. Retraction of the skin creates redundancy and allows stretching as distraction progresses and minimizes the scar.
 - The pins are placed parallel to each other with a distance of 3 cm between them (**TECH FIG 3D**).



TECH FIG 2 • **A.** Ultrasonic saw. **B.** The desired vector of distraction determines the site and orientation of the osteotomy. **C.** Osteotomy extends along the entire height of the mandible and must ensure that tooth follicles are avoided.

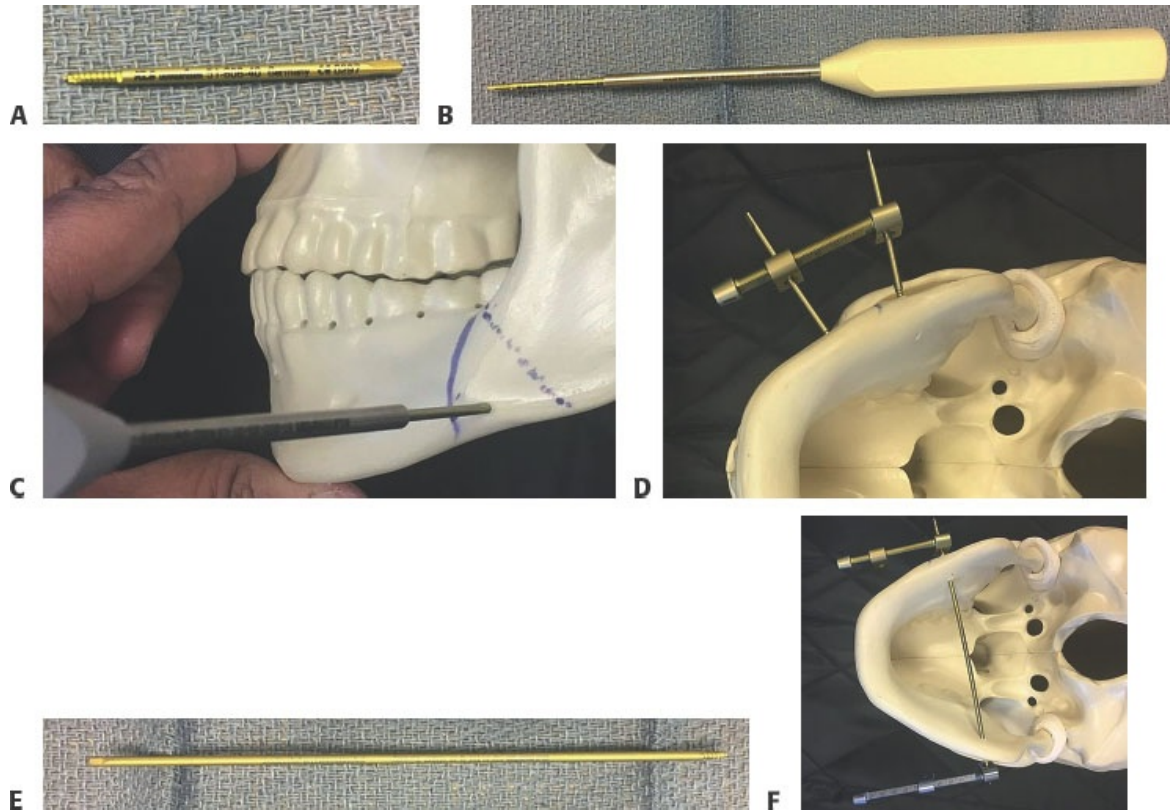
- Another option is to use two long pins (120 mm) to penetrate both sides of the mandible for added stability (transfixed pins; **TECH FIG 3E,F**).

Placement of the Distraction Device

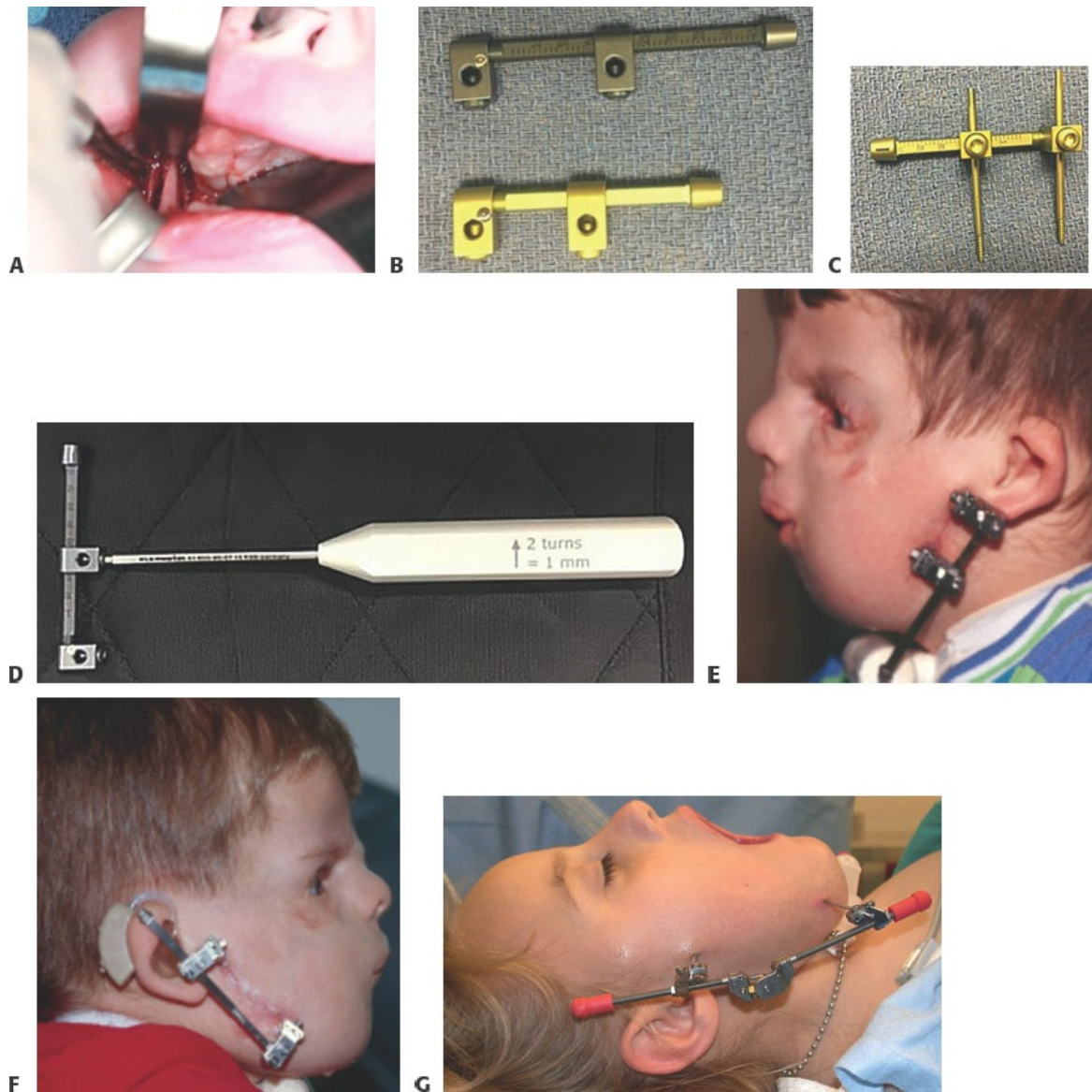
- A 5-mm osteotome completes the osteotomy to liberate the two segments of the mandible (**TECH FIG 4A**).
- The intraoral wound is closed with absorbable sutures in a watertight

fashion.

- The distraction device is then attached to the pins and adjusted using the activator screwdriver (**TECH FIG 4B–D**).
- A uniplanar or multiplanar distraction device can be used depending on the desired end point of distraction (**TECH FIG 4E–G**).



TECH FIG 3 • **A.** Self-drilling, self-tapping percutaneous pins. **B.** Manual screwdriver is used to drive the pins percutaneously into the mandible. **C.** Percutaneous pins are placed perpendicular to the bone and advanced far enough to engage both cortices. **D.** Pins are placed parallel with about 3 cm distance between them. **E.** Long percutaneous pin (120 mm). **F.** The transfixated pin traverses both sides of the mandible.



TECH FIG 4 • **A.** Osteotomy of the mandible. **B.** Distraction devices of 30 and 45 mm showing the slots for engaging the pins. **C.** Distractor device connected to the pins. **D.** Activation driver is used for both activating the device and securing the pins to the distractor. **E.** Uniplanar distractor with the activation arm emerging anteriorly. **F.** Uniplanar distractor with the activation arm emerging posteriorly toward the ear. **G.** Multiplanar distractor that can lengthen both the body and ramus of the mandible.

■ External Mandibular Distraction With Rigid External Device

- If a RED device is used instead of the pin technique, the same initial steps are followed.
- After creation of the corticotomy, the anterior mandibular retention plate is secured to the menton of the mandible (**TECH FIG 5A**).
- A small stab incision is made in the buccal vestibule below the lower mandibular incisors.
 - A 2-mm Steinmann pin is advanced through this incision in an intraoral to an extraoral direction to exit through the skin of the chin and create a passage for the plate (**TECH FIG 5B**).
 - Ensure that the most anterior portion of the symphysis is captured with the pin so that the plate rests within a groove in the mandible for added stability.
- The T-shaped plate (1.5 mm thickness) is then inserted to follow the passage created by the pin and exits through the skin (**TECH FIG 5C**).
 - The plate is bent and adapted to conform to the anterior part of the mandible overlying the mucosa (**TECH FIG 5D**).
- Self-drilling screws are then drilled transmucosally using a cordless driver to secure the plate to the mandible.
 - Three screws (7 mm in length) are used per side (**TECH FIG 5E**).
- The free end of the plate is then bent upward, and a wire loop is inserted through it (**TECH FIG 5F**).
- The halo of the RED device is then applied to the skull using a minimum of three fixation screws per side (**TECH FIG 5G**).
- Ensure that the halo is parallel to the Frankfort horizontal.
- After wound closure, the halo is secured to the retention plate using 25-gauge stainless steel wire, which is passed from the slidable loop and through the eyelet of the activation spindle attached to the horizontal crossbar assembly.
 - The wire is then twisted securely (**TECH FIG 5H,I**).



A



B



C



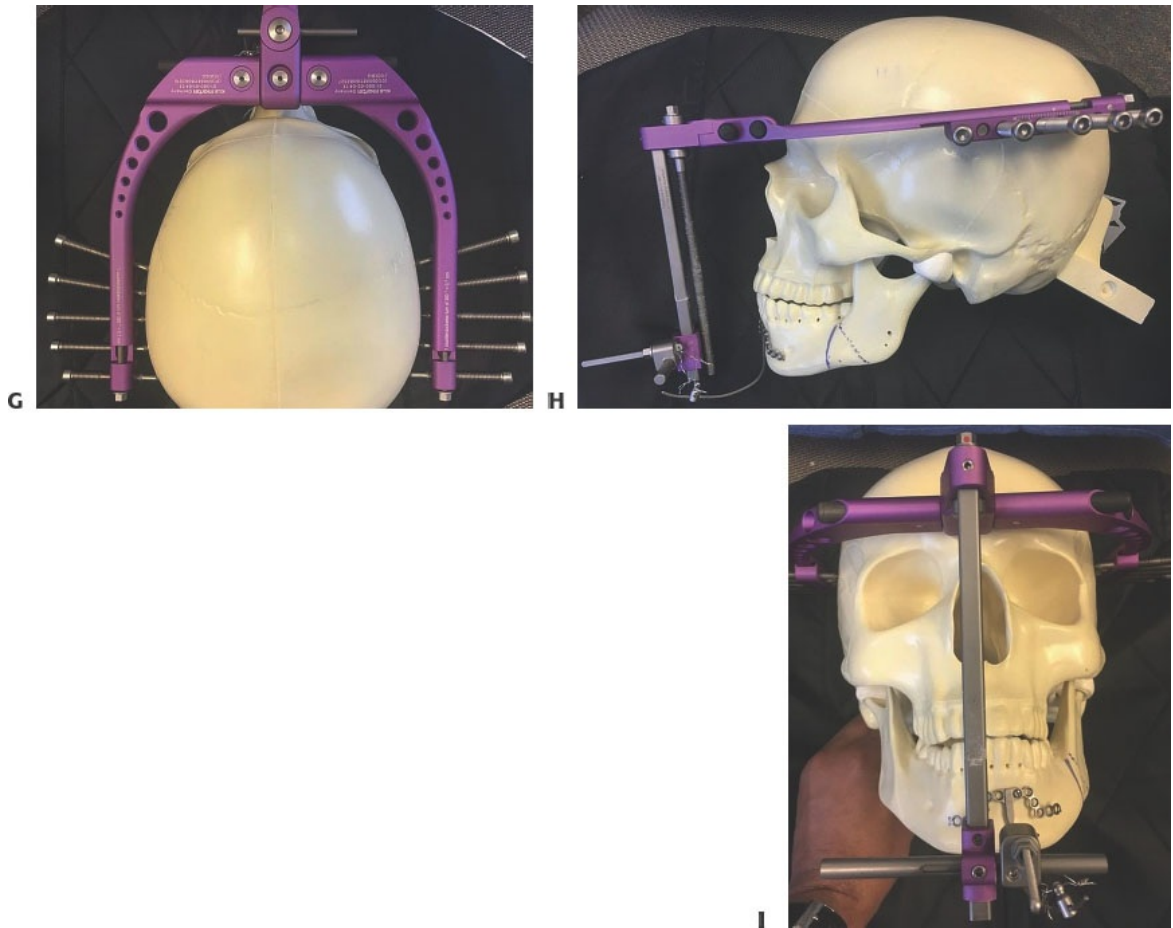
D



E



F



TECH FIG 5 • A. Skull model showing anterior mandibular retention plate used with the rigid external distraction (RED) device. **B.** A cordless drill is used to drive a 2-mm Steinmann pin through the anterior mandible to exit through the skin below the chin. **C.** T-shaped retention plate is advanced through this passage created by the pin, capturing the bone of the symphysis. **D.** The plate adapted to the anterior mandible. **E.** A minimum of three screws per side are used to secure the plate to the mandible. **F.** Anterior mandible plate exiting the skin, with the free end bent upward for attachment to the halo. **G.** The halo is secured to the skull using at least three screws per side. Ensure parallel placement of the halo to the floor. **H.** A 25-gauge wire is used to attach the mandible

plate to the crossbar attachment of the halo. I.
Completed assembly of the RED device.

PEARLS AND PITFALLS

Physical findings

- Mandibular micrognathia most commonly presents during the neonatal period due to obstructive sleep apnea.
- There is a wide range of severity; clinical correlation is critical to select the appropriate candidates for distraction.
- Successful mandibular distraction can alleviate the airway obstruction and avoid a tracheostomy.

Technique

- Careful tissue handling is critical in the neonate due to the delicate anatomy.
- Selection of the osteotomy site and pin site is crucial to avoid injury to the tooth buds and the alveolar neurovascular bundle. Radiographic imaging assists to locate the tooth buds.
- Orientation and location of the osteotomy is chosen based on the region of the mandible desired to be lengthened. A vertical vector is chosen in cases of HFM to lengthen the ramus; a horizontal vector is required in bilateral micrognathia seen in PRS and TCS. Multidirectional distraction can be used in select cases.
- Ensure complete liberation of the proximal and distal mandible segments.
- Use of the ultrasonic saw has the added advantage of avoiding injury to tooth follicles and the neurovascular bundle.
- Pins must be placed bicortically or they will dislodge.
- Ensure that the pins are parallel.
- Advantages of the RED device over pin technique:
 - Less risk of damaging tooth buds
 - Less load on the temporomandibular joints
 - Greater length of distraction
- Main disadvantages:
 - Bulkiness that is cumbersome and less accepted socially
 - Inability to use in neonates
 - Multiple components of the RED device make hardware failure more common requiring return to the operating room.
 - An anterior open bite usually results from mandibular distraction,

and this can be particularly problematic in older patients. A “jaw bra” can be used in neonates to minimize the open bite and assist with feeding.¹³

- Postoperative**
- After 6–7 days of distraction, the mandible is lengthened sufficiently to improve the airway and allow extubation.
 - The neonate is monitored in the NICU to prevent airway compromise.
 - The consolidation period is generally twice the activation period. Prolonged consolidation theoretically leads to reduced relapse, but at the expense of feeding difficulty.

POSTOPERATIVE CARE

- The neonate is transferred to the NICU intubated.
- Distraction activation is started on the day after surgery and proceeds at a rate of 2 mm/d.⁸
 - The frequency of distraction is generally twice daily.
 - A pin driver is used for turning the activating arms (two turns of 360 degrees correspond to 1 mm distraction) (**FIG 4A**).
- After 1 week of activation, the mandible is advanced sufficiently to allow safe extubation of the infant.
 - ENT is present to perform microlaryngoscopy/bronchoscopy, which determines the safety of extubation.
- Distraction is then continued at 1 mm/d because the skin tension has reached its maximum at this point. Continued distraction at 2 mm may exceed skin elasticity and lead to wound breakdown.
- In older children, distraction is usually started after a 3-day latency period and the rate is 1 mm/d.
- Pin sites are washed daily with soap and water followed by topical antibiotic ointment. The skin surrounding the pins appears red and stressed, but infection is rare.
- Weekly radiographs are obtained to monitor the progress of distraction and hardware stability.
- The end point of distraction is determined clinically with the aid of serial radiographs to determine the position of the mandible and quantify the airway improvement (**FIG 4B**).
 - The mandible is lengthened to a point anterior to the maxilla (slight class III

occlusion) in anticipation of minor relapse (**FIG 4C**).¹⁴

- Distraction is generally completed within 3 to 4 weeks. The device is left in place for an additional 6 to 8 weeks to complete consolidation.
- At the end of consolidation (radiographic evidence of mineralization), the pins (or the RED device) are removed under sedation in the operating room.
- In older children or teenagers, orthodontic elastics may be used during the activation or consolidation phase in an attempt to close the anterior open bite created during the distraction process.
- Feeding is resumed normally following surgery but may become increasingly difficult as the mandible is advanced. A nasogastric tube is generally needed to aid with feeding and is removed at the end of distraction.

OUTCOMES

- Mandibular distraction is effective in the treatment of airway obstruction associated with micrognathia.¹⁵ Given the high success rate with minimal complications, it has become the standard of care for neonatal OSA (**FIG 5A–E**).
- The procedure should be performed by a surgeon experienced in craniofacial distraction, with the help of a multidisciplinary team.
- The objective of mandibular distraction is to avoid tracheostomy or achieve decannulation in patients who have previously received a tracheostomy. The cost-effectiveness is clearly in favor of MDO over tracheostomy with less morbidity.¹⁶
- Patients with isolated PRS (nonsyndromic) generally require one mandibular distraction procedure to clear the airway. Predictors for repeat distraction include a syndromic diagnosis like TCS, Nager syndrome, Goldenhar, and Stickler syndrome.⁸

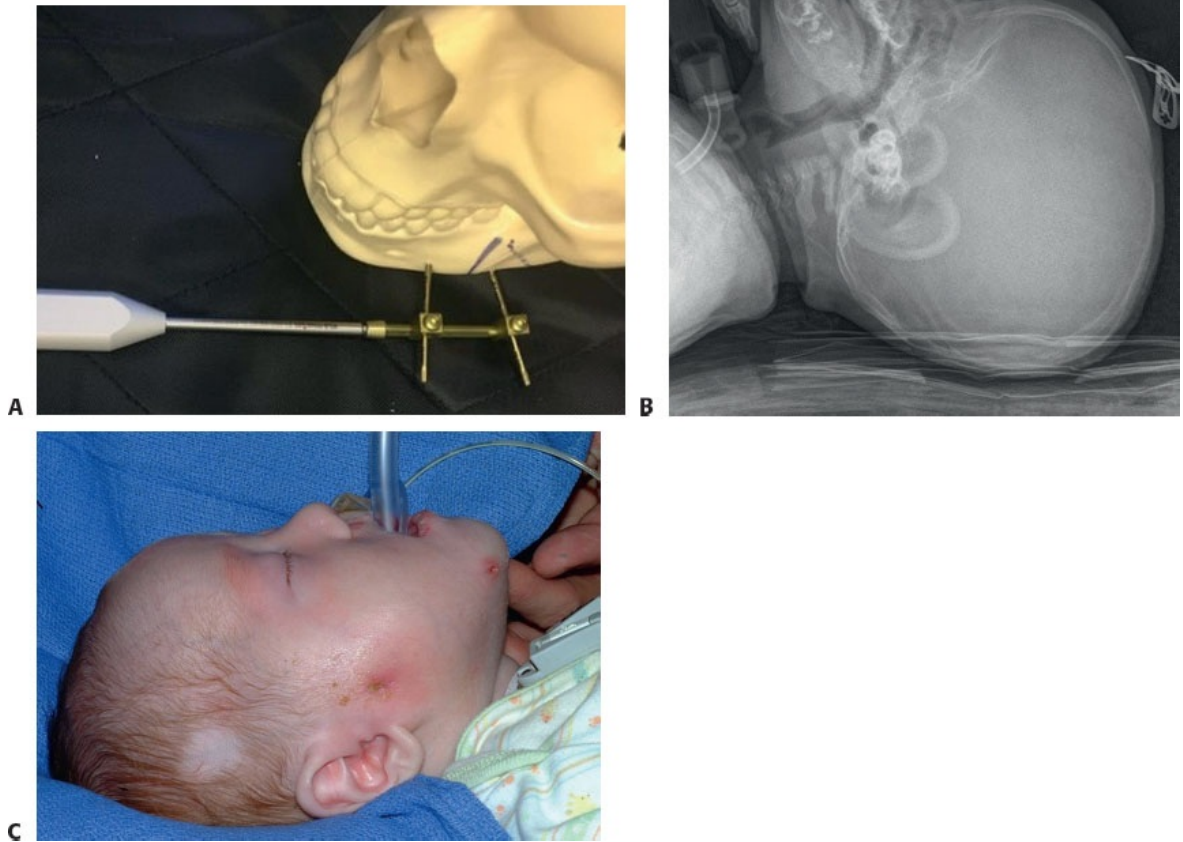


FIG 4 • A. Driver engaging the distractor arms and turning. **B.** Bedside radiograph demonstrating advancement of the mandible and improvement of the airway. **C.** A neonate at the time of distractor removal demonstrating overcorrection of the mandible.

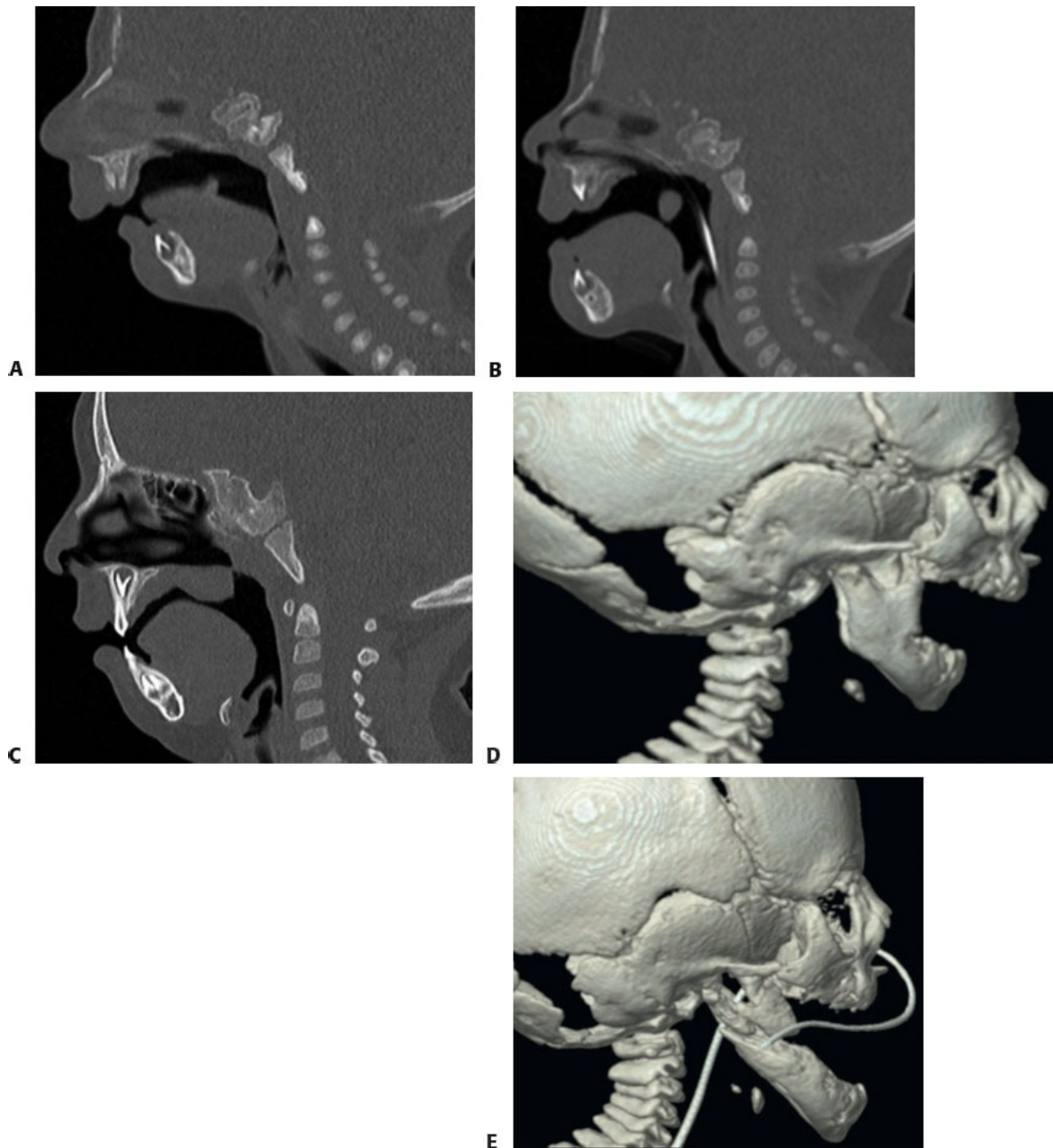


FIG 5 • A. Preoperative sagittal view CT scan demonstrating mandibular micrognathia and narrow airway. **B.** Airway improvement at the end of distraction, showing overcorrection. **C.** Two-year postoperative view demonstrating relapse, but with maintenance of airway clearance. **D.** Three-dimensional CT scan before distraction. **E.** Extent of mandibular advancement at the end of the distraction.

- In patients with underlying neurological problems and low muscle tone, MDO generally has a lower success rate. Careful team discussion should precede distraction in this patient population.^{2,6,8}

COMPLICATIONS

- Injury to the inferior alveolar nerve or the tooth buds from inaccurate selection of osteotomy site or pin placement.
- Temporomandibular joint ankylosis due to overloading of the TM joints. This occurs less frequently with the internal technique than with the external technique.
- Infection is a rare occurrence. Pin site infections can be treated with local wound care.
- Pin dislodgement is a common complication. Use of transfixion pins that penetrate both sides of the mandible offers better stability.¹⁷
- Hardware failure and screw loosening is common with use of the RED device.
- Permanent scars from percutaneous pin placement and skin stretching during distraction (**FIG 6**).
 - These scars are generally well accepted by parents and preferable to tracheostomy scars.
- Anterior open bite is a common complication and can be problematic for feeding.
- Relapse is expected; slight overcorrection at the time of distraction is advised (see **FIG 5B,C**).
- Failure of distraction resulting in conversion to tracheostomy is seen in severe cases of OSA. Predictors of failure include PRS without a cleft palate, gastroesophageal reflux, and the need for Nissen fundoplication.¹¹
- Early consolidation may occur if the rate of distraction is too slow, requiring a return to the operating room to repeat the osteotomies.



FIG 6 • Acceptable appearance of the scars 2 years after distraction.

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42 External Transfacial Mandibular Distraction

CHAPTER

Brian S. Pan

DEFINITION

- Neonates with tongue-based airway obstruction encompass a heterogeneous group of patients, the most common of which are those with isolated Pierre Robin sequence (PRS).
- Initially described in 1923, patients with PRS share a triad of signs that are micrognathia, glossoptosis, and upper airway obstruction.¹
- The clinical strategies employed to treat these patients are (a) bypassing the tongue base, (b) repositioning the soft tissues to alleviate the obstruction, (c) and correcting micrognathia, the anatomic source of the obstruction.
- Since the original description of mandibular distraction, both internal and external approaches have been demonstrated to be safe and effective options.
- The approach outlined herein includes further modifications to techniques originally described by McCarthy² and Denny.³

ANATOMY

- The mandible is a unique bone composed of vertical and horizontal elements that form a U-shaped construct.
- The typical growth pattern of the pediatric mandible occurs in a superior and posterior direction resulting in a downward and forward displacement of the mandibular body and symphysis.⁴
- From infancy through adolescence, the inferior alveolar nerve migrates superiorly from the lingual, inferior border of the mandible to a more superior position.
- The primary morphological difference between the hypoplastic mandible in PRS and the normal mandible is a small mandibular body. The ramus and

condyles tend to be of normal size.⁵

PATHOGENESIS

- The incidence of PRS is difficult to define but is thought to be more frequent than 1:14 000.⁶
- Micrognathia is hypothesized to be the result of either a genetic growth abnormality or a physical growth restriction.
 - Mandibular hypoplasia may be an isolated problem or related to a craniofacial syndrome, the most common of which are Stickler syndrome, velocardiofacial (VCF) syndrome, fetal alcohol syndrome (FAS), Treacher Collins syndrome (TCS), Nager syndrome, hemifacial microsomia (HFM), trisomy 21 and 22, and Kabuki syndrome.⁷
 - Intrauterine growth restriction causing head flexion, secondary to multiple births, or oligohydramnios is also thought to limit mandibular growth.⁸

PATIENT HISTORY AND PHYSICAL FINDINGS

- Neonates with tongue-based airway obstruction present along a spectrum of severity.
- Those patients with mild to moderate micrognathia may exhibit sonorous breathing during sleep, apneic events, feeding difficulties, and poor weight gain.
- Neonates with more significant micrognathia not only will present with the aforementioned signs and symptoms but may be in severe respiratory distress and appear cyanotic. Sternal and suprasternal retractions and the use of accessory muscles to breathe may also be apparent.
 - In such cases, urgent admission to a neonatal intensive care unit to stabilize the airway is indicated.
- In addition to a small mandible, glossoptosis is observed with a posteriorly positioned tongue that collapses into the pharynx.
- Patients with mild to moderate symptoms may fail to thrive due to the work of breathing during sleep and while feeding.
- The increased negative pressure required to inhale may also result in reflux and aspiration of the gastric contents.⁹

IMAGING

- A lateral cephalogram appropriately evaluates the hypoplastic mandible. The degree of maxillomandibular discrepancy and the posterior airway space can

also be measured.

- A three-dimensional computed tomography scan (3DCT) may also be performed to further characterize the mandible and assess the location of the inferior alveolar nerve and mental nerve foramina.

DIFFERENTIAL DIAGNOSIS

- Although this diagnosis is typically made based on clinical findings and physical examination, a genetic evaluation is an important component of the multidisciplinary management of these patients.
 - This evaluation establishes an accurate diagnosis and anticipates future medical needs if a syndrome is also present.

NONOPERATIVE MANAGEMENT

- Prone and lateral decubitus positioning are the core maneuvers to assist with airway patency while the child is awake and sleeping.
- The use of tongue sutures, nasopharyngeal airways, palatal obturators, and mandibular traction have also been described as effective conservative measures. Their efficacy has been reported to be between 33% and 69% in their respective patient populations.¹⁰
- If long-term conservative care is indicated, close observation and a capable caregiver are critical. Excess movement, coughing, and swallowing can easily displace many of these devices leading to gagging, reflux, aspiration, and potential loss of airway.

SURGICAL MANAGEMENT

- The decision to operate is based upon the consensus of a multidisciplinary team composed of representatives from neonatology, pulmonology, otolaryngology (ENT), genetics, and plastic surgery.
 - In addition to the facial CT, a polysomnogram and direct evaluation of the airway (microlaryngoscopy, bronchoscopy, or nasopharyngoscopy) are typically obtained to aid in decision-making.
- The main objective of the operation is to lengthen the mandible, thereby advancing the attached soft tissues anteriorly, relieving the tongue-based airway obstruction.
- The main steps of the procedure include the following:
 - Expose the mandibular body, angle, and coronoid process bilaterally through intraoral incisions.

- Pass the first transfacial Steinmann pin caudal to the coronoid processes.
- Pass the second transfacial pin just dorsal to the menton.
- Perform bilateral mandibular osteotomies using an ultrasonic osteotome.
- Apply external distractors.
- The patient typically remains intubated following surgery and is transferred to the NICU for postoperative management.

Preoperative Planning

- Risks, benefits, and realistic expectations are discussed with parents prior to surgery.
- Risks include pin migration, tooth damage, injury to the inferior alveolar and mental nerves, bony relapse, scarring, and the possible need for tracheostomy.
- The operation is coordinated with ENT who will assist the anesthetist with nasotracheal intubation if poor visualization of the larynx is anticipated.

Positioning

- The patient is placed in a supine position with several small towels serving as a shoulder roll.
- A foam donut should be used to stabilize the head.
- The nasotracheal tube is sutured to the septum to prevent inadvertent extubation during the operation (**FIG 1**).

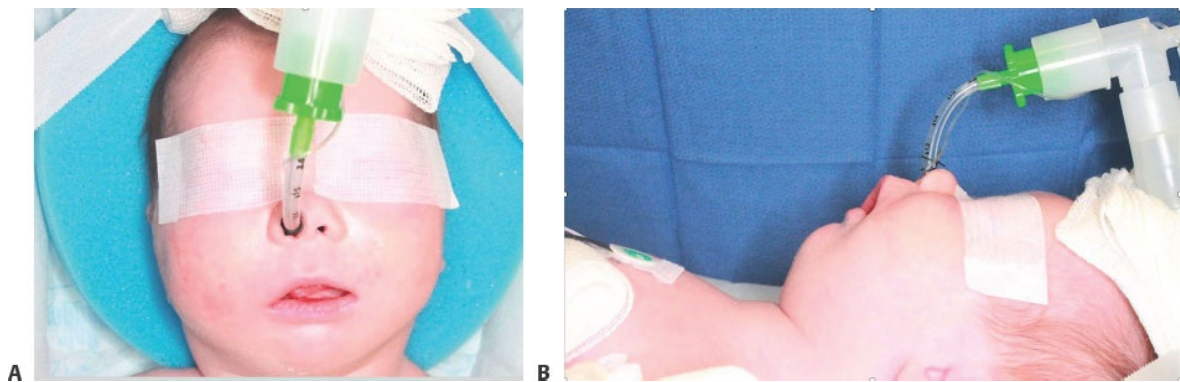
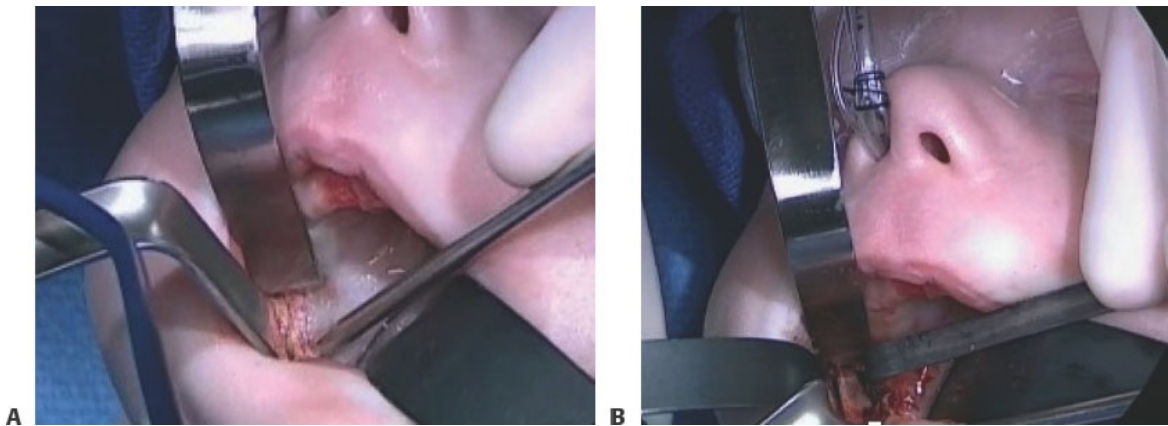


FIG 1 • A foam donut is used to stabilize the head. The nasotracheal tube is sutured to the septum to prevent extubation.

TECHNIQUES

■ Exposure

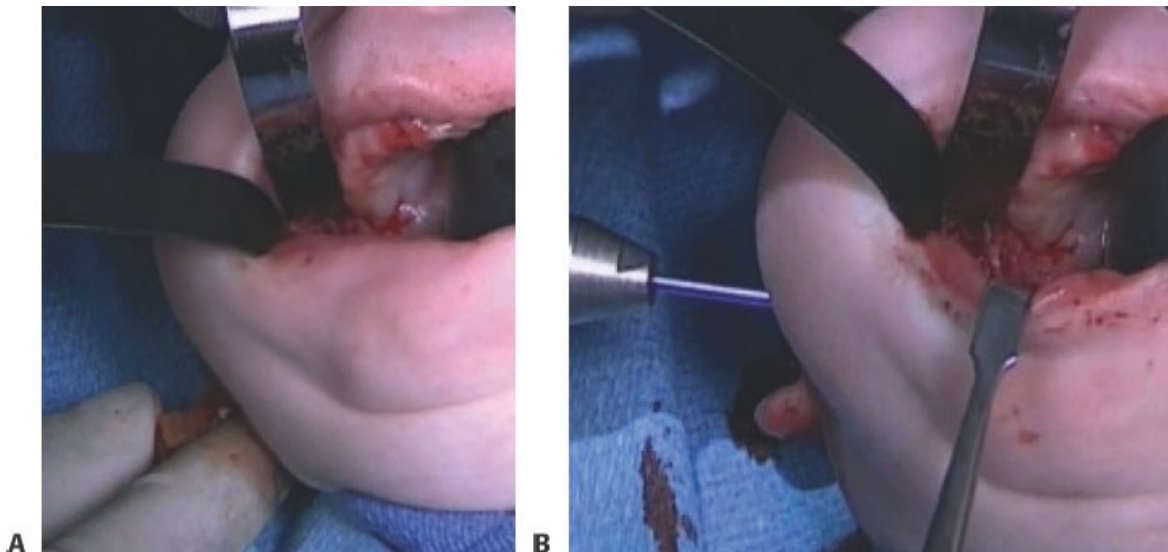
- Lidocaine with epinephrine is infiltrated into the lingual and buccal tissues overlying the dorsal mandibular bodies, angles, and along the ascending ramus.
- Exposure is achieved with a notched ramus retractor and a toe-in Obwegeser. An incision is made over the ascending ramus and extended along the buccal mandibular body (**TECH FIG 1A**).
- Subperiosteal dissection is performed with a Freer elevator, exposing the buccal surface of the mandible to identify the coronoid process, the ascending ramus, the mandibular angle, and the body.
- The lingual surface of the ascending ramus is then exposed to protect the inferior alveolar nerve (**TECH FIG 1B**).

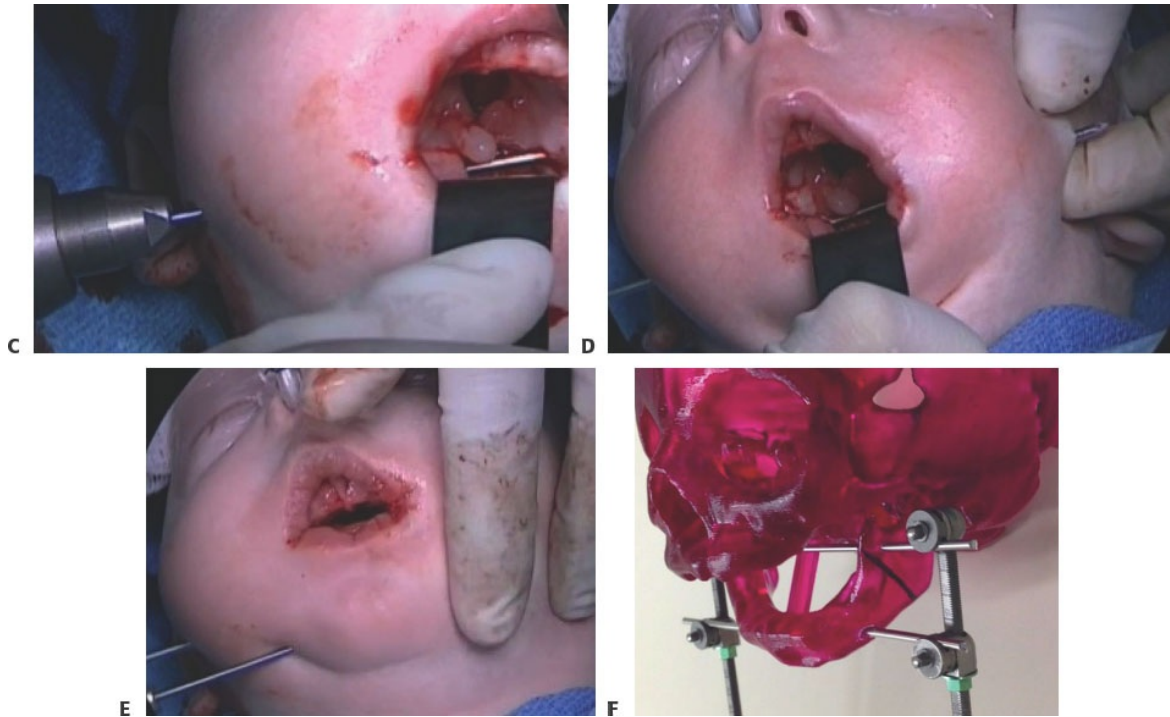


TECH FIG 1 • A. A notched ramus retractor and a toe-in Obwegeser are used to provide exposure. An incision is made over the ascending ramus and extended along the buccal mandibular body. **B.** The buccal surface of the coronoid process, the ascending ramus, the mandibular angle, and the body are exposed. The lingual surface of the ascending ramus is then exposed to protect the inferior alveolar nerve.

■ Pin Passage

- A 25-gauge needle is passed through the cheek to identify the most direct path to the coronoid process (**TECH FIG 2A**).
 - This step is important to avoid traction on the skin from the Steinmann pin, and the resultant scarring that may occur.
 - The site is then marked.
- A 2-mm Steinmann pin is passed transmurally through the cheek into the mandible just inferior to the coronoid process (**TECH FIG 2B**).
- The pin is passed through the buccal mucosa, dorsal to the maxillary tuberosity and caudal to the palate. The pin is advanced transorally and through the contralateral side (**TECH FIG 2C,D**).
 - The ends of the pin are then protected.
- The skin immediately dorsal to the menton is retracted cranially, and the second Steinmann pin is inserted into the mandible through the floor of the mouth, exiting the contralateral side (**TECH FIG 2E**).
- This pin must be kept dorsal to the menton to avoid the mental foramina.
 - The pin should be placed close to the inferior edge of the mandible to avoid the tooth roots but at least 2 to 3 mm above the inferior border to prevent pin migration through the bone (**TECH FIG 2F**).

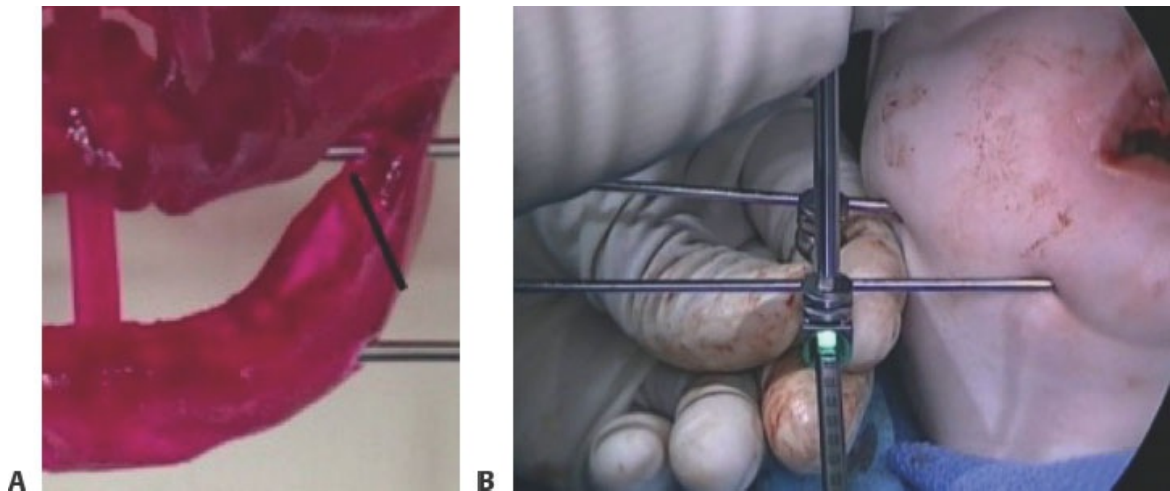




TECH FIG 2 • **A.** A 25-gauge needle is passed through the cheek to identify the most direct path to the coronoid process. **B.** A 2-mm Steinmann pin is passed through the cheek into the mandible inferior to the coronoid process. **C.** The pin is then passed through the buccal mucosa, dorsal to the maxillary tuberosity and caudal to the palate. The pin is advanced transorally and then through the contralateral side. **D.** Note the hemi-uvulae superior to the Steinmann pin. **E.** The skin just dorsal to the menton is then gently retracted cranially, and the second Steinmann pin is then inserted into the mandible exiting the contralateral side. **F.** The inferior pin should be dorsal to the menton and avoid the mental foramina. The pin should be placed close to the inferior edge of the mandible to avoid the tooth roots. Note the superior pin placement in relation to the coronoid process.

■ Osteotomy and Completion

- The skin on the contralateral side is also retracted cranially. The purpose of this maneuver to prevent traction on the soft tissue and scarring as the mandible is distracted.
- The notched ramus retractor is then placed at the level of the coronoid process, followed by a thin insulated ribbon retractor placed on the lingual aspect of the mandible to protect the inferior alveolar nerve.
 - A toe-out Obwegeser is placed on the buccal aspect of the mandible to expose the mandible for the osteotomy.
- The osteotomy is then made using an ultrasonic osteotome and assessed for completeness with a traditional 5-mm osteotome (**TECH FIG 3A**).
- The external distractors are applied. The distractors are not advanced and are set in a position that maintains the length of the native mandible.
- The pins are then clipped (**TECH FIG 3B**).
- The intraoral incisions are closed with dissolvable suture.



TECH FIG 3 • **A.** The osteotomy is performed similar to a sagittal osteotomy below the level of the cranial pin. It is initiated along the oblique ridge. A thin insulated ribbon retractor should be used to retract the lingual soft tissues and inferior alveolar nerve. **B.** The external distractors are applied. The distractors are not advanced and are set in a position that maintains

the length of the native mandible.

PEARLS AND PITFALLS

Physical findings

- Neonates with tongue-based airway obstruction present along a spectrum of severity.
- Feeding difficulties and poor weight gain in neonates with mild micrognathia may indicate clinically significant obstructive sleep apnea.

Technique

- Steinmann pin placement is critical to avoid injury to tooth buds, inferior alveolar and mental nerve, and to avoid pin migration through the adjacent skin and mandibular border.

Postoperative

- Postoperative extubation is typically safe within 3–5 d following surgery depending on the degree of micrognathia.
- The distraction callus consolidates 2 days for every day of distraction.
- A JawBra may be utilized to mold the mandible following distractor removal if an anterior open bite is present.

POSTOPERATIVE CARE

- The intubated child is transported to the NICU.
- After a 24-hour latency period, distraction proceeds at 1 mm of advancement performed twice daily for a total of 2 mm daily.
- The pin sites are gently cleaned and antibiotic ointment is applied twice daily.
- Extubation generally occurs between postoperative days 3 to 5.
- Weekly cephalograms and physical examination are utilized to monitor the progression of mandibular advancement, view the increase in posterior airway space, and confirm the proper position of the Steinmann pins.
- Distraction is complete when the mandible appears to have 5 mm of reverse overjet based on a lateral cephalogram (**FIG 2**).
- The distraction callus is consolidated 2 days for each day of distraction.

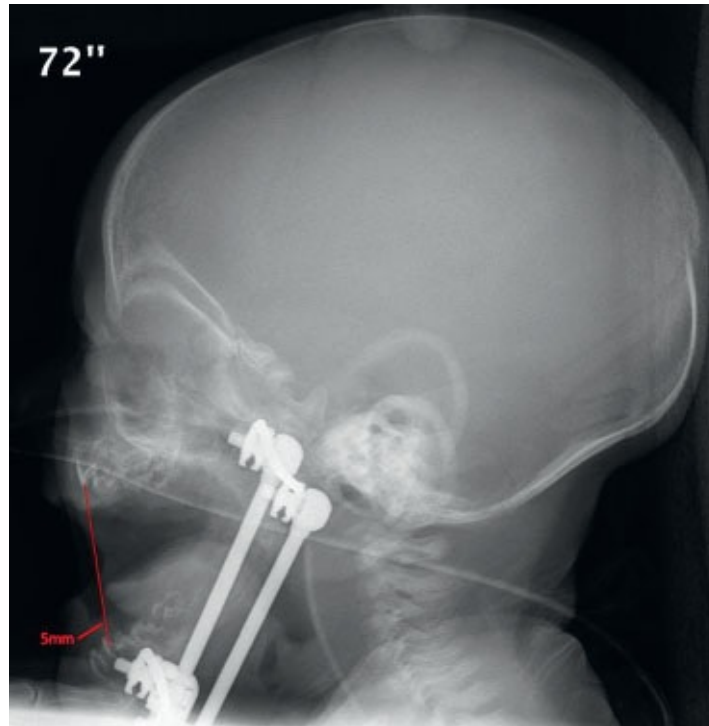


FIG 2 • Cephalograms are used to evaluate progression of the mandibular advancement, view the increase in posterior airway space, and confirm the placement of the Steinmann pins. The distraction is completed when the mandible appears to have 5 mm of reverse overjet based on a lateral cephalogram and physical exam.

- At the conclusion of the consolidation period, the external distractors and the Steinmann pins are removed under general anesthesia.

OUTCOMES

- Mandibular distraction osteogenesis (MDO) is safe and effective to treat obstructive sleep apnea (OSA) secondary to tongue-based airway obstruction from micrognathia.¹¹
- Compared to tracheostomy, the cost of treatment is markedly less due to the decreased need for airway procedures and home care costs.^{12,13}
- In general, prematurity, low birth weight, preoperative intubation, and syndromic diagnosis in addition to cardiac and pulmonary abnormalities, are not predictors for failure, defined as conversion to tracheostomy.¹⁴

COMPLICATIONS

- Infection is relatively uncommon due to the external placement of the distractors.
- Facial scarring is minimal unless pin traction occurs. This can be avoided with proper skin retraction during the initial placement of the Steinmann pins (**FIG 3A**).
- Improper pin and osteotomy placement can lead to tooth bud injury, pin migration through the bone, and injury to the inferior alveolar nerve (**FIG 3B,C**).
- Some relapse is anticipated due to the short consolidation period. This is compensated for with 5 mm of overdistraction.
- In our experience, anterior open bite has not been either a common short- or long-term finding. If encountered immediately following distractor removal, a JawBra is applied for mandibular molding.¹⁵
- We have not found TMJ ankylosis to be a common complication associated with this technique. By inserting the Steinmann pins anterior to condyles, loading is avoided through the distraction process.
- Failure of mandibular distraction with conversion to tracheostomy has been associated in neonates with a diagnosis of PRS without a cleft palate and those with gastroesophageal reflux and who required Nissen fundoplication.¹⁴



FIG 3 • **A.** Facial scarring is minimal unless pin traction occurs due to improper skin retraction during the initial placement of the Steinmann pins. Note the traction scarring from the mandibular pin. **B.** Note the placement of the pin beneath the tooth buds. **C.** Following removal of the pin, the tooth buds are spared.

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CHAPTER Mandibular Setback

Haithem M. Elhadi Babiker and Deepak G. Krishnan

DEFINITION

- Surgical correction of maxillofacial skeletal deformities dates back to the late 19th century.
- Numerous techniques have been described for repositioning of the maxilla and mandible through various osteotomies.
- The bilateral sagittal split osteotomy (BSSO) is the most common surgical procedure for correction of mandibular deformities.
 - It was first described by Obwegeser in 1957.¹
 - The technique was modified by Dalpont in 1961² and further refined by Epker in 1977.³
- The BSSO setback is a procedure used for correction of mandibular prognathism and asymmetries through a series of connected osteotomies that posteriorly reposition the mandible.⁴

ANATOMY

- The mandible is a U-shaped bone forming the lower jaw. It is the only movable bone of the skull, articulating with the temporal bones at the temporomandibular joints.
- It consists of a horizontal horseshoe-shaped body and two broad and oblong rami projecting upward. The alveolar processes of the mandible house and support the mandibular teeth.
- The inferior alveolar nerve enters the mandibular foramen on the medial surface of the ramus near its center. It then extends downward and forward within the body of the mandible; it exits at the mental foramen, located on the external surface midway between the alveolar process and the lower border, in

the interval between the premolar teeth.

- The anteromedial margin of the mandibular foramen is guarded by an upward tonguelike projection, the lingula. Along its course, the inferior alveolar nerve innervates the mandibular teeth and terminates as the mental nerve, which supplies sensation to the skin and mucous membrane of the lower lip and chin.
- The muscles of mastication directly attach to the surface of the mandible. The masseter and medial pterygoid muscles attach to the lateral and medial surfaces of the ramus.
 - These two muscles form the pterygomassetric sling, which straddles the mandibular ramus.
- The lingual nerve, before reaching the tongue, comes in close contact with the inner surface of the alveolar border of the mandible in close proximity to the mandibular third molar.

PATHOGENESIS AND NATURAL HISTORY

- Mandibular prognathism is a condition in which the mandible is positioned anterior to the maxilla, referred to as class III malocclusion.
- In the NHANES study (1989–1994), 0.3% of the US population was reported to have mandibular prognathism severe enough to require orthodontic-surgical treatment.⁵
- About 14% of youth (less than 18 years of age) in the United States have a class III malocclusion. Roughly a quarter of these patients have isolated mandibular prognathism, whereas the remaining three-quarters have a combination of maxillary deficiency, in addition to mandibular protrusion.
- Mandibular prognathism causes aesthetic concerns, as well as chewing and speaking difficulties, prompting patients to seek surgical treatment at a younger age.
- In cases of severe mandibular prognathism, bimaxillary surgery is the preferred method of treatment (BSSO setback combined with maxillary advancement). This is because excessive mandibular setback may result in obstructive sleep apnea and is also subject to higher rates of relapse.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients usually present during the teenage years.
- The main complaints are difficulty with chewing and speech, and the aesthetic concerns of a large mandible. Often, the malocclusion also presents as an open bite.

- Patients are usually first seen by an orthodontist and eventually referred to a maxillofacial surgeon when ready for surgery.
- Orthodontic treatment is usually undertaken for approximately a year and serves to align the teeth within the dental arches and corrects any dental compensation.
- Surgery is undertaken when the patient reaches skeletal maturity and there is proof of growth cessation (girls 16–18 years, boys 18–20 years).
- Preoperative workup includes obtaining
 - Dental models
 - Cephalometric analysis
 - Face bow transfer to record the relationship of the jaws to the skull base
 - Model surgery to fabricate the surgical splints
- In the case of single-jaw surgery, a single splint is fabricated to help position the mandible.
- In the case of double-jaw surgery (LeFort I advancement combined with BSSO setback) for severe class III malocclusion, two splints are made: an intermediate splint used intraoperatively to position the maxilla in its final position and a final splint to position the mandible.
- If third molar teeth are present, they may be extracted 6 months prior to surgery.

IMAGING

- Lateral cephalometric radiographs are obtained for cephalometric analysis.
- Panoramic radiographs are obtained to determine the presence and location of mandibular third molar teeth and also level of the inferior alveolar canal.
- A CT scan with 3D images is obtained and can be used for virtual surgical planning (VSP) in lieu of traditional model surgery.

DIFFERENTIAL DIAGNOSIS

- Class III skeletal relationship can be secondary to mandibular prognathism, maxillary hypoplasia, or a combination of both.
- Accurate diagnosis is important to determine the appropriate surgery.
- The diagnosis is confirmed by detailed clinical evaluation combined with cephalometric analysis. Often, a midface deficiency is wrongly diagnosed as mandibular prognathism, whereas in reality upon cephalometric investigation, the mandibular position may be normal.
- Acromegaly and pituitary hyperactivity should be suspected in mandibular

prognathism that presents later in life, and appropriate workup should be undertaken.

- Unilateral hyperplasia of the mandible can cause an asymmetric prognathism and malocclusion. A neoplasm of the mandibular condyle should be ruled out in these cases. Unilateral condylar hyperplasia is an idiopathic rare condition that can also cause an asymmetric mandibular prognathism.

NONOPERATIVE MANAGEMENT

- Mild class III malocclusion can sometimes be treated with orthodontic management alone.
- True skeletal class III relationship can only be treated by surgical intervention.

SURGICAL MANAGEMENT

- The BSSO setback procedure is usually performed during the teenage years after skeletal maturity.
- The main objective of the operation is to correct mandibular prognathism by cutting the mandible and repositioning it posteriorly to meet the maxilla in a normal class I relationship.
- The main steps of the procedure are as follows:
 - Make bilateral intraoral incisions to expose the posterior aspect of the mandible.
 - Perform bilateral sagittal split osteotomies of the mandible (**FIG 1**).
 - Position the mandible into a class I relationship using an occlusal splint.
 - Use wires to perform maxillomandibular fixation.
 - Remove any bony interference between the two cut segments of the mandible.
 - Establish a proper position of the condyles in the fossae bilaterally.
 - Rigidly fixate the mandible in its new position.

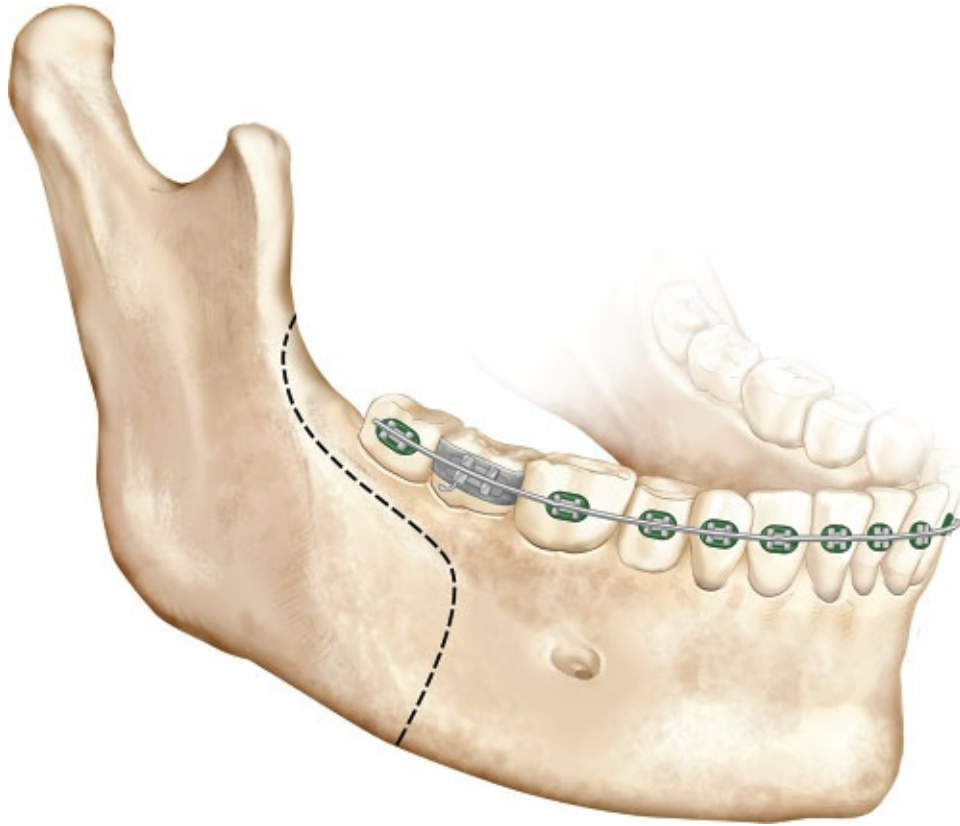


FIG 1 • The BSSO procedure includes a medial ramus osteotomy, an anterior ramus horizontal osteotomy, and a vertical osteotomy.

Preoperative Planning

- The risks, benefits, and complications are discussed with the patient prior to surgery. Discussing the risk of damage to the inferior alveolar nerve is mandatory.
- The mandibular third molar teeth are preferably extracted 6 months prior to the surgery to allow adequate time for healing.
 - If they have not been extracted previously, they may be removed during the procedure.⁶
- The occlusal splints are tested on the patient preoperatively to ensure adequate fit.
- Preoperative photos are obtained for documentation.

Positioning

- The patient is positioned supine with the arms tucked in.

- They are intubated nasally, and the endotracheal tube is sutured to the nasal septum and secured appropriately to the forehead (**FIG 2**).

Approach

- Surgery is performed through an intraoral approach.



FIG 2 • The patient is positioned supine and the endotracheal tube is sutured to the nasal septum and then secured to the forehead.

TECHNIQUES

■ Exposure

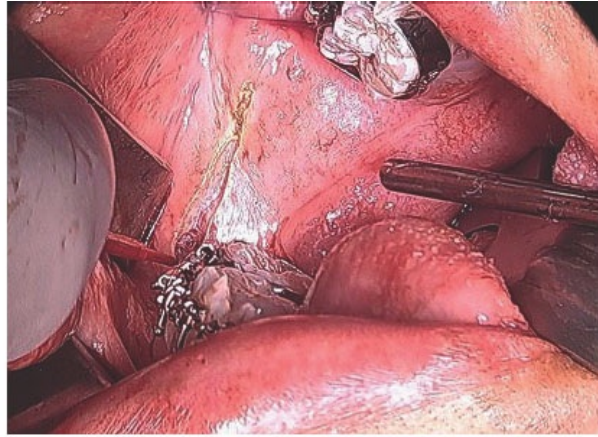
- Clean the oral cavity with chlorhexidine or an equivalent antiseptic mouth rinse, and place a throat pack.
- Inject local anesthetic containing a vasoconstrictor to infiltrate the area of dissection.
- Insert a bite block on the opposite side to adequately open the mouth.
 - Place two Langenbeck retractors to pull away the cheek.
 - Place a tongue retractor to protect the tongue (**TECH FIG 1A**).
- Make a 3-cm incision along the external oblique ridge of the mandible from midway on the ramus to the level of the second molar tooth (**TECH FIG**

1B).

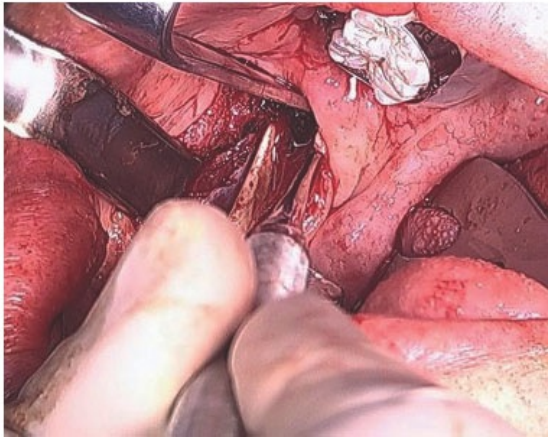
- If the mandibular third molar is present and indicated for removal, the incision is modified to incorporate the tooth.
- A sufficient cuff of gingiva (5 mm) is maintained adjacent to the molar teeth for a relaxed wound closure.
- Sharp dissection is extended through mucosa, muscle, and periosteum to raise a full-thickness mucoperiosteal flap, exposing the entire ascending ramus and posterior body of the mandible (**TECH FIG 1C**).
- Care is taken not to dissect the lateral muscular attachments along the anterior ramus ensuring adequate blood supply to the proximal segment of the mandible.
- Expose the inferior border of the mandible in the area of the planned vertical osteotomy.
 - Keep the periosteum intact to prevent excessive bleeding and herniation of the buccal fat.
 - Strip enough of the masseter muscle to adequately visualize the planned vertical osteotomy site (**TECH FIG 1D**). Keep as much of the masseter as possible attached to the proximal segment of bone to prevent bony devascularization. At the anterior extent of the incision, the depressor anguli oris attaches tenuously to the inferior border of the mandible. This area must be stripped off sternly to adequately mobilize the mandible after the osteotomy.
- Place a notched ramus retractor over the anterior border of the ramus and strip the lower fibers of the temporalis muscle from the coronoid process. A curved Kocher clamp is then inserted to retract tissue and expose the entire border of the ascending ramus (**TECH FIG 1E**).
- Dissect the periosteum from the internal oblique ridge to the medial side of the retromolar area (**TECH FIG 1F**). Then extend the dissection inferiorly to the region of the lingula and mandibular canal.
 - A malleable retractor is inserted on the medial aspect of the ramus to retract and protect the neurovascular bundle (**TECH FIG 1G**).



A



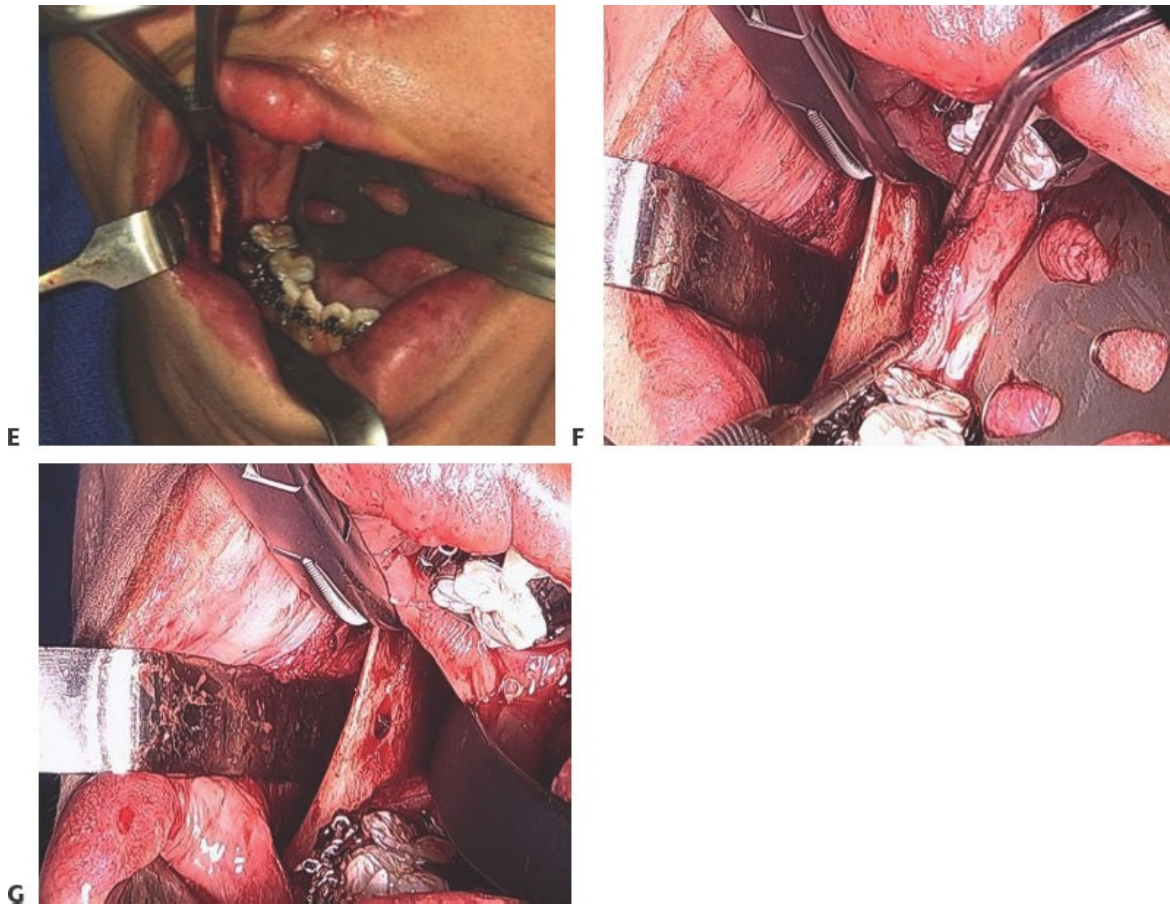
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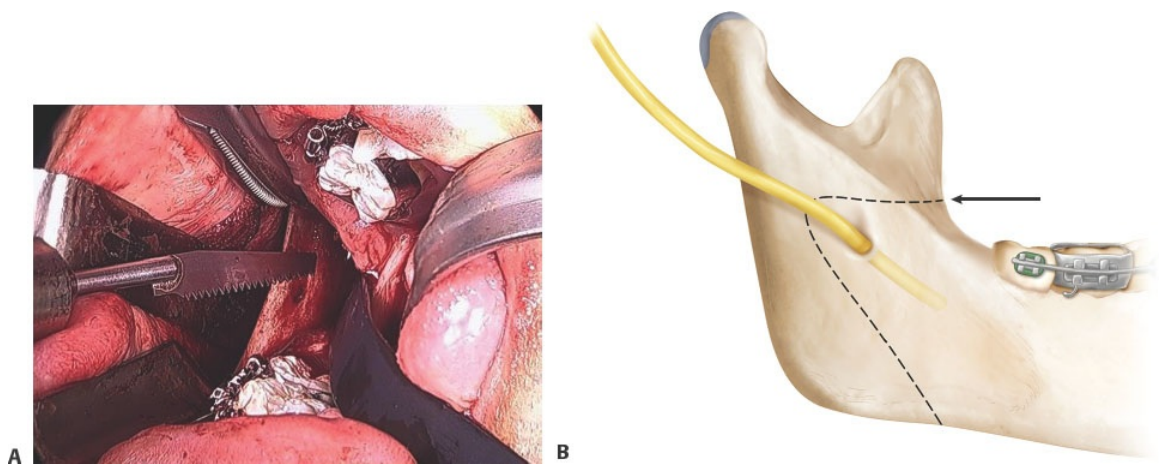
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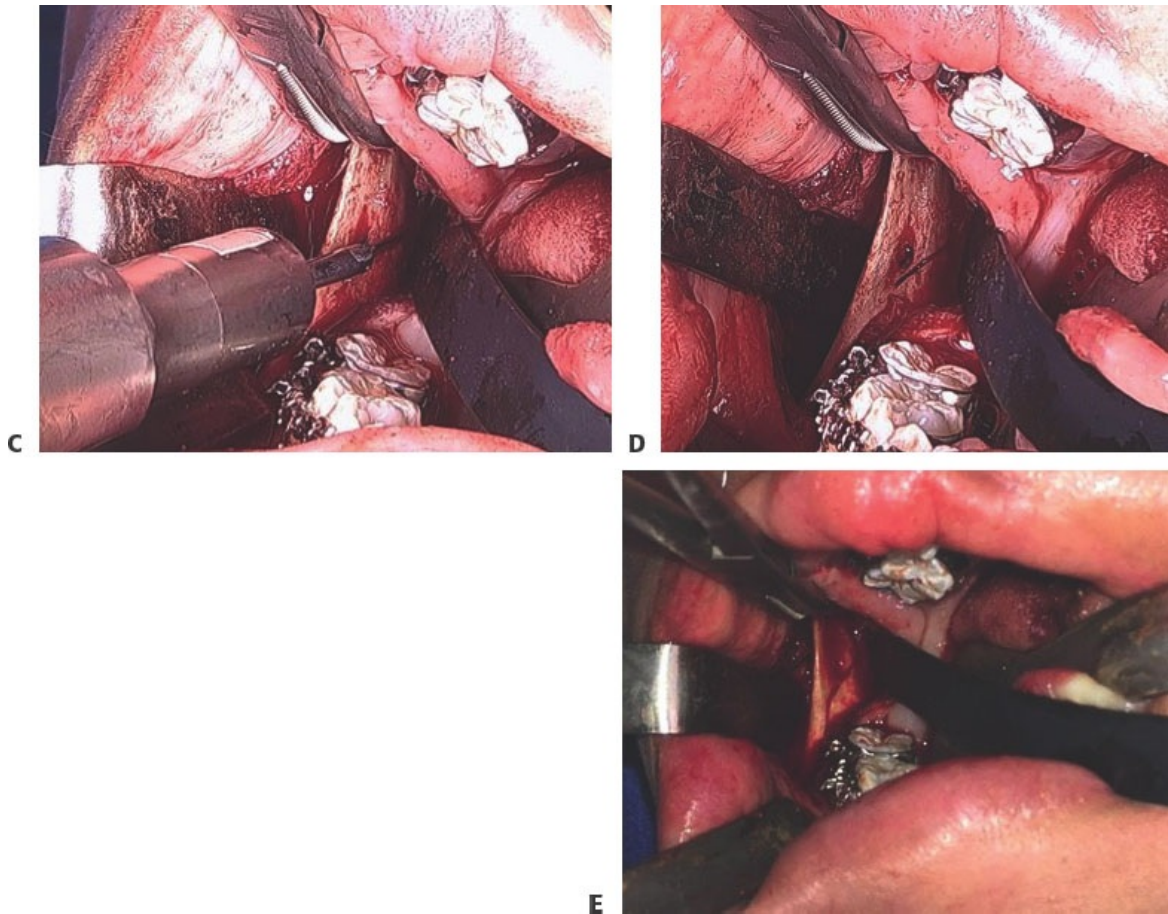


TECH FIG 1 • A. Exposure is obtained by Langenbeck retractors to pull away the cheek and a tongue retractor to protect the tongue. **B.** An incision is made along the external oblique ridge halfway up the ramus to the level of the second molar tooth. Leave enough gingival cuff to facilitate easy closure. **C.** Sharp dissection is undertaken to raise a full-thickness mucoperiosteal flap to expose the ramus and posterior body. **D.** Using a sharp elevator, the masseter muscle fibers are stripped to expose the planned vertical osteotomy site. **E.** A curved Kocher clamp is used to retract tissue over the ascending ramus. **F.** The periosteum is dissected from the internal oblique ridge to expose the medial ramus. **G.** A malleable retractor is used to protect the neurovascular bundle.

■ Osteotomy of the Medial Ramus

- The medial ramus osteotomy is performed first. This is a horizontal osteotomy through the medial cortex of the ramus.
- A short, straight-blade reciprocating saw or a Lindemann bur is used to make the osteotomy (**TECH FIG 2A**).
- The osteotomy should not extend more than 2 cm posteriorly (Hunsuck modification) and should be low and parallel to the occlusal plane (**TECH FIG 2B**).
- By keeping the medial osteotomy short and low (**TECH FIG 2C**); the incidence of a “bad split” is reduced.
- Ensure that the osteotomy extends to the medullary bone (**TECH FIG 2D**).
- The osteotomy is then directed anteriorly, remaining inside the buccal cortex, into medullary bone, and ends inferiorly, immediately lateral to the second molar tooth (**TECH FIG 2E**).
 - The presence of an impacted wisdom tooth may make the osteotomy difficult. In this case, the osteotomy is carried through the tooth as if it were bone.
 - Avoid excessive angulation of the saw blade, keeping it parallel to the osteotomy, so as not to weaken the buccal cortex and cause a fracture.





TECH FIG 2 • **A.** The medial osteotomy is made with a reciprocating saw blade. **B.** Hunsuck modification. The medial osteotomy should not extend more than 2 cm posteriorly to avoid a bad split. Horizontal osteotomy parallel to the occlusal plane (see arrow). **C.** The medial osteotomy is short, low, and parallel to the occlusal plane of the mandibular teeth. **D.** Ensure that the osteotomy is into bleeding medullary bone. **E.** The medial osteotomy is continued onto the anterior ramus and ends at the level of the second molar.

■ Mandibular Osteotomy and Split

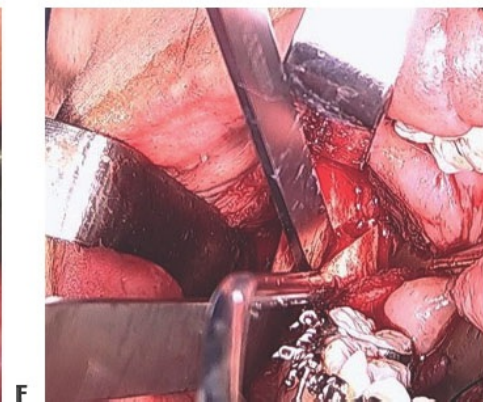
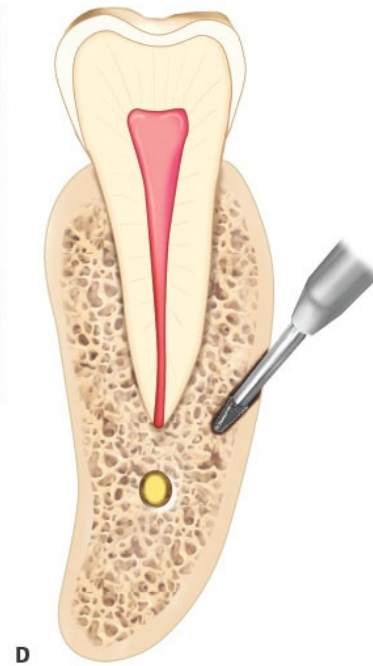
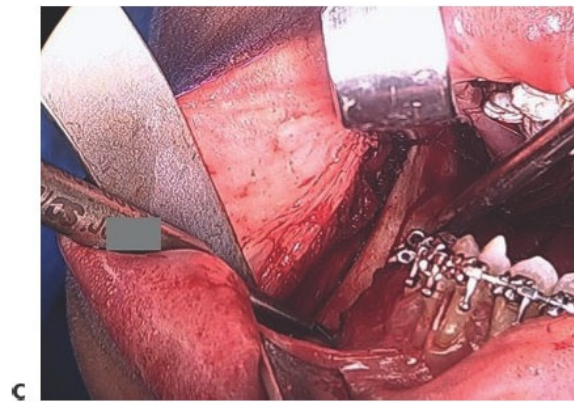
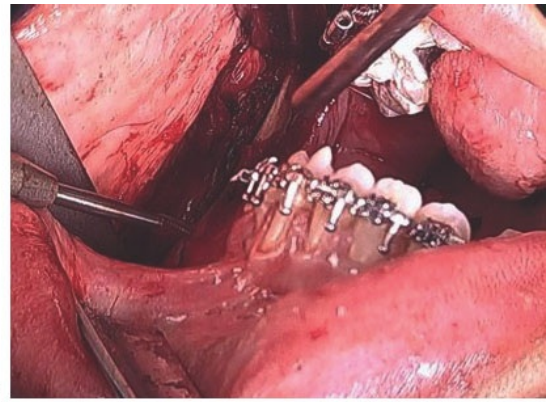
- The vertical osteotomy of the mandibular body is then made.
 - Remove the bite block and the curved Kocher clamp to relax the soft tissue

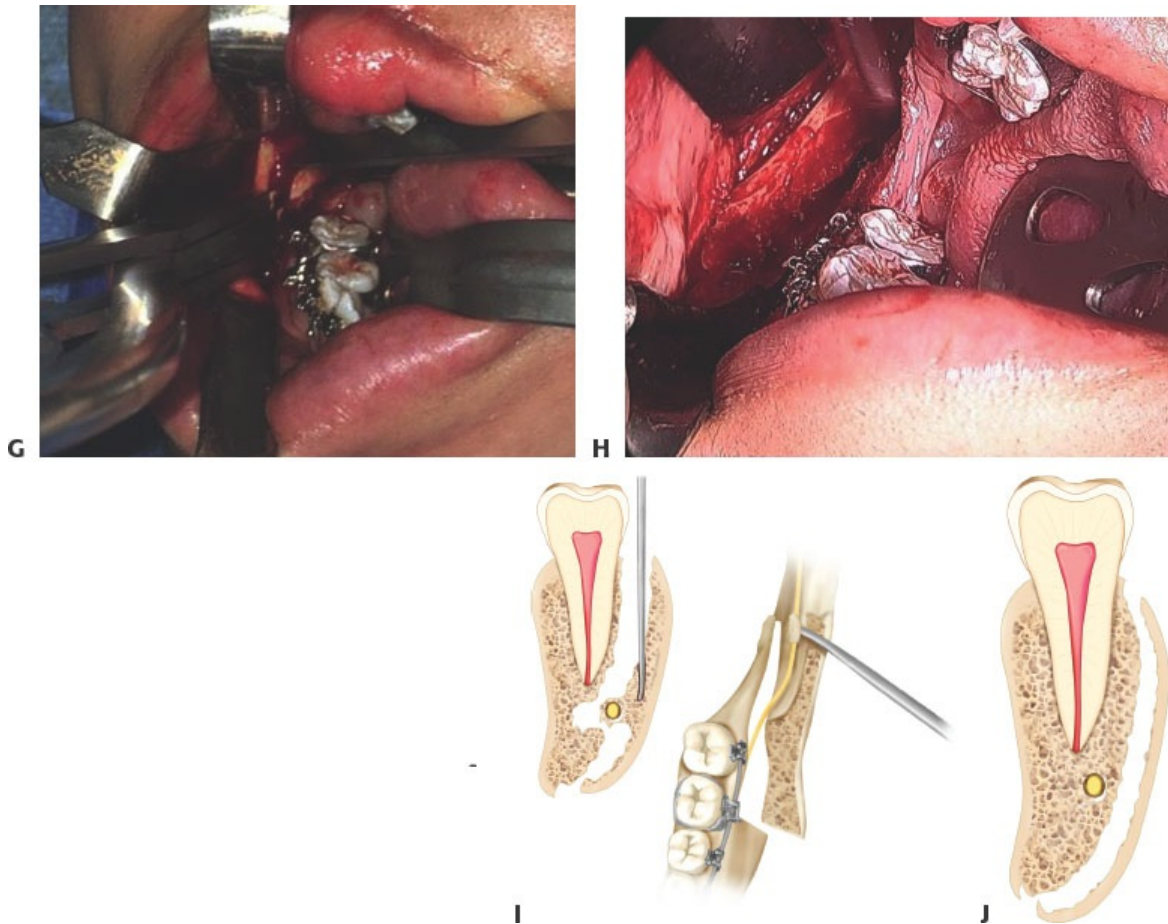
and improve access to the inferior border of the mandible.

- Place a Channel retractor at the inferior border of the mandible and rotate it into position to improve visibility of the planned osteotomy site.
- The assistant may pull on the mandible and rotate it in the opposite direction to enhance access (**TECH FIG 3A**).
- The osteotomy location will depend on the planned buccal extension of the proximal segment (Dalpont modification).
- A fissure bur is used to make the vertical osteotomy (**TECH FIG 3B**).
 - Start the osteotomy at the inferior border and angle it superiorly to join the anterior osteotomy that was previously completed (**TECH FIG 3C**).
 - Ensure that the bur penetrates the cortex into bleeding medullary bone. Take extra care not to injure the neurovascular bundle, which tends to be situated very close to the buccal cortex in cases of mandibular prognathism (**TECH FIG 3D**).
 - Adequately cut the entire inferior border of the mandible and include it in the osteotomy.
- After the vertical osteotomy is completed, retractors and bite block are reinserted in preparation for completion of the mandibular split.
- A thin 10-mm rigid osteotome is used with a mallet to tap along the entire length of the osteotomy to confirm completeness of the cortical cuts (**TECH FIG 3E**).
 - Twisting of the osteotome should produce movement between the segments including the inferior border (**TECH FIG 3F**).
- To split the mandible, a large, 10-mm osteotome is placed into the osteotomy near the second molar tooth and a smith (sagittal split spreader) forceps is placed near the inferior border.
 - By simultaneous twisting and spreading, the two segments are slowly split under direct vision (**TECH FIG 3G**).
 - If the split does not start spontaneously, stop and redefine all osteotomies.
- As the split starts, be certain that the neurovascular bundle is visualized and remains with the distal segment (**TECH FIG 3H**).
 - If the neurovascular bundle is still attached to the proximal segment, use blunt forceps to gently tease it free (**TECH FIG 3I**).
 - If the split results in transection of the inferior alveolar nerve, microneurosurgical repair is performed prior to proceeding further.
- Ensure that the inferior border splits with the proximal segment (**TECH FIG**

3J), so as to avoid a “bad split.”

- The mandible should be well supported during the splitting process to avoid damage to the temporomandibular joint.
- A curved Kocher clamp is applied to the distal part of the proximal segment and used as a handle to apply force in all directions to ensure complete separation of the two segments.
- The same steps are repeated on the contralateral side with sagittal splitting of the ramus.



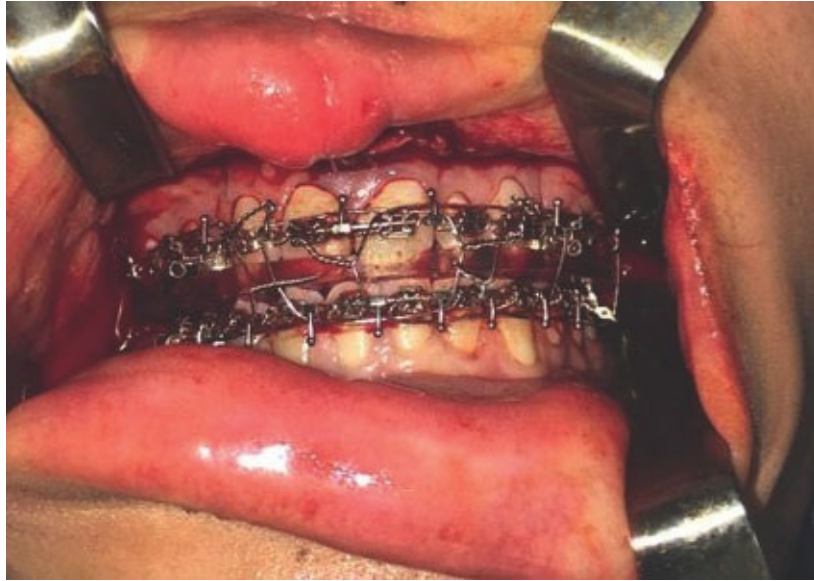


TECH FIG 3 • **A.** The bite block is removed and the assistant pulls the mandible laterally, away from the operator, to enhance access to make the vertical osteotomy. **B.** A bur is used to make the vertical osteotomy. **C.** Bur completing the vertical osteotomy and joining it with the anterior ramus osteotomy. **D.** Avoid injuring the neurovascular bundle when making the vertical cut. **E.** Use a rigid osteotome to complete the cuts. **F.** Before completing the split, twist the osteotome inside the osteotomy. Some separation of the segments should be seen indicating that the cuts are complete. **G.** Simultaneous twisting and spreading to complete the split. **H.** Split completed. Notice how the nerve is not visualized within the proximal segment and remains with the distal segment. **I.**

Neurovascular bundle being teased free from the proximal segment. **J.** Inferior border completely cut and remains with the proximal segment.

■ Occlusal Correction and Maxillomandibular Fixation

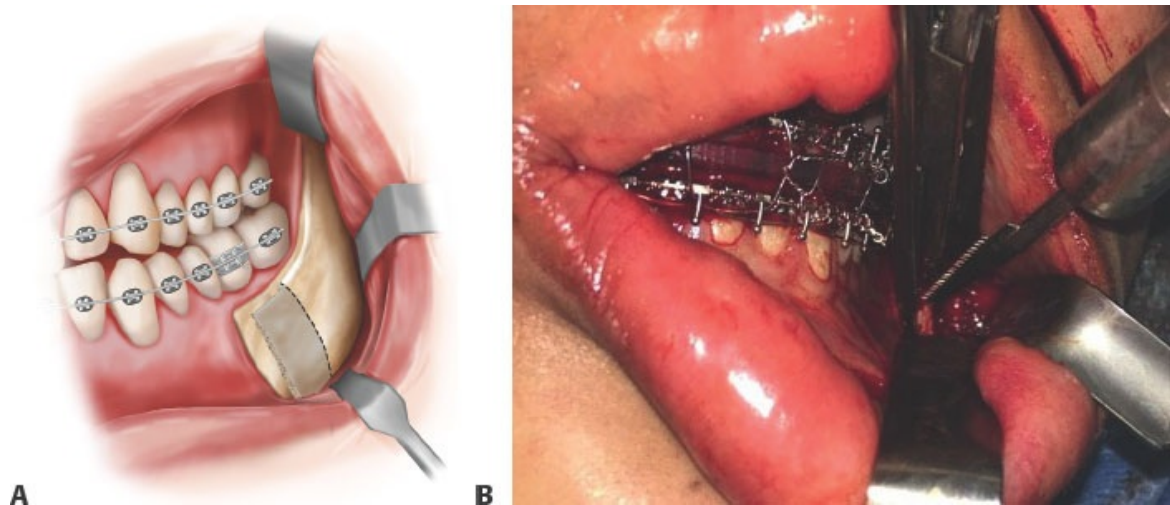
- If there are impacted mandibular third molars, they are removed at this point using dental elevators.
 - The wisdom tooth will be located within the distal segment and is usually cut while performing the anterior osteotomy.
 - Avoid fracturing the lingual cortex of the distal segment while removing the tooth.
- Using a sharp periosteal elevator, strip any remaining pterygomassetric sling at the inferior border of the distal segment.
 - This allows free movement of the distal segment and facilitate placement onto the occlusal splint.
- Similarly, strip the attachment of the medial pterygoid muscle from the medial aspect of the proximal segment.
 - This maneuver prevents interference when positioning the distal segment posteriorly and allows for proper seating of the condyle in the glenoid fossa.
- Use a large bur to smooth the contact areas between the two bony segments; this will ensure proper apposition and rigid fixation.
- Mobilize the distal segment with digital pressure to ensure that the two segments move freely.
- Using 26-gauge wire loops, wire the two jaws together into occlusion using the prefabricated occlusal splint (**TECH FIG 4**).



TECH FIG 4 • Occlusal splint used as a guide for maxillomandibular fixation.

■ Removal of Bony Interference

- Setting the mandible posteriorly will result in overlap between the proximal and distal segments.
 - This amount of overlap has to be removed for proper apposition between the two segments in preparation for rigid fixation.
- Position the proximal segment with a hemostat or wire positioner with the condyles properly seated.
- Mark the proximal segment for the amount of bony overlap that needs to be removed (**TECH FIG 5A**).
- The bony overlap should coincide with the planned setback (plus the width of the osteotomy cut). Protect the neurovascular bundle during removal the bony overlap with a saw or rongeur (**TECH FIG 5B**).
- Remove enough bone to facilitate optimal bone contact between the distal and proximal segments.
- Check the lingual plate of the distal segment to determine the need for removal of further bony interferences.

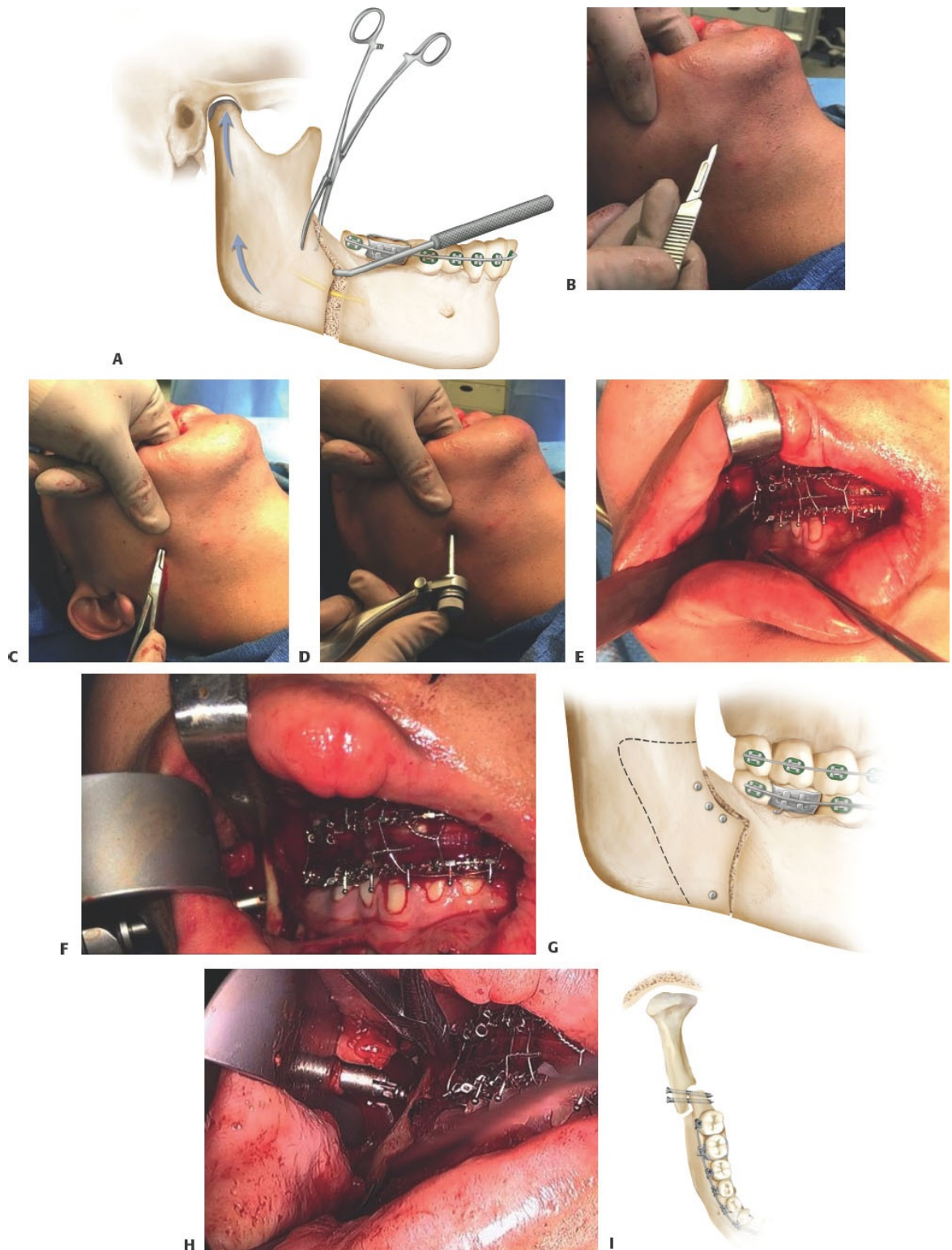


TECH FIG 5 • A. Marking the proximal segment for the amount of bony overlap indicated for removal. **B.** Bony overlap removed with a saw.

■ Condylar Positioning and Rigid Fixation

- Using a wire instrument or a fine curved hemostat applied to the most distal edge of the proximal segment, digital pressure is applied extraorally at the angle of the mandible to seat the condyle in the glenoid fossa.
 - Enough pressure is applied to seat the condyle into its preoperative centric relation (**TECH FIG 6A**).
 - The inferior borders of the proximal and distal segments are lined up so that there is no palpable step in the final position.
- A bone clamp is used to hold the two segments together in that position in preparation for rigid fixation.
- Rigid fixation is achieved by three or four bicortical screws placed transcutaneously.
- A lateral neck stab incision is made just below the inferior border of the mandible at the level of the gonial notch.
 - A hemostat is then used to bluntly dissect through the stab incision.
 - The trocar is introduced through the neck incision to gain access intraorally.
 - Use two fingers intraorally to guide the trocar to pierce the periosteum and reach the bone (**TECH FIG 6B–E**).
- Remove the pin and place the cheek retractor to improve visualization.

- The drill is introduced through the trocar and used to drill through both proximal and distal segments (**TECH FIG 6F**).
- The screw location is determined by areas of best bony contact, away from the neurovascular bundle.
- Screws should be placed as far apart as possible to improve stability.
- They are placed either in a straight line across the superior border or in a triangular fashion with one screw placed at the inferior border (**TECH FIG 6G**).
- After each hole is drilled, the trocar is maintained in position, the hole is measured, and the screw is placed accurately through the trocar and gently tightened (**TECH FIG 6H**).
- While tightening the screw, ensure that the screw is engaging the distal segment. If the two segments are able to be pushed apart, the screw should be removed and a new hole drilled.
- Ensure that the screws do not compress the bone segments, which may result in displacement of the condyle resulting in relapse (**TECH FIG 6I**).
- The same steps are repeated on the contralateral side to fixate the bony segments.
- An alternative to screws is to use a plate with monocortical screws to secure the two segments together.



TECH FIG 6 • A. A wire instrument is used to seat the condyle while simultaneously applying external digital pressure. The bone clamp is then tightened to hold

the two segments together in preparation for rigid fixation. **B.** Stab incision in the neck at the level of the gonial notch. **C.** Blunt dissection using a hemostat through the stab incision. **D.** The trocar is inserted through the incision. **E.** Trocar gaining access intraorally using two fingers as a guide. **F.** Drill introduced through the trocar. **G.** Screw configuration. **H.** Keep the trocar absolutely still after drilling the hole and then place the screw. **I.** Positional screws are placed to engage both segments without displacing the condyle from the glenoid fossa.

■ Completion

- Remove maxillomandibular fixation and determine the occlusion.
 - The mandible is opened and closed multiple times to check that the occlusion is symmetric, stable, and reproducible, as planned.
 - If the occlusion is not correct, do not be tempted to “manipulate” the mandible into occlusion with elastics or wires. Rather, remove the fixation and repeat the fixation steps as above, ensuring that the condyles are passively seated within the glenoid fossa.
 - The wounds are then thoroughly irrigated and closed with continuous, watertight 3-0 chromic.
 - The skin stab incisions are approximated with 5-0 nylon sutures.
 - The mouth is irrigated and suctioned and the throat pack is removed.
 - Place interdental elastics to secure the occlusion. The elastics are placed in a class III fashion to reinforce the setback movement.
-

PEARLS AND PITFALLS

Physical findings

- Class III skeletal relationship can be due to mandibular prognathism, maxillary hypoplasia, or a combination of both. Accurate diagnosis is critical to determine the appropriate surgery to correct the deformity.

- Mandibular setbacks in general reduce airway space at the level of the base of tongue. This can create obstructive sleep apnea.

Technique

- Leaving an insufficient cuff of gingiva when making the incision will lead to difficulty suturing and possible wound dehiscence.
- Improper handling of the tissue during dissection may lead to perforation of the periosteum, herniation of buccal fat, hemorrhage, and excessive postoperative swelling.
- Making the medial ramus osteotomy too far posteriorly may lead to a bad split. Keep the medial osteotomy short and low, closer to the occlusal plane of the mandibular teeth.
- Ensure that all the osteotomies are deep enough into bleeding medullary bone.
- The anterior ramus osteotomy should be precise to avoid weakening of the buccal cortex resulting in fracture of the proximal segment.
- When making the vertical osteotomy, be certain to completely cut the inferior border of the mandible to avoid a bad split.
- Be careful not to cut too deep in the area of the neurovascular bundle.
- When performing the split, the two segments should separate easily; the inferior border of the mandible splits and stays with the proximal segment. If the mandible is not splitting with ease, stop and redefine the osteotomies.
- If a bad split occurs, complete the splitting process as planned, and fixate the fractured fragments similar to a mandible fracture.
- Ensure that all bony interferences have been removed.
- Choose the location of the skin stab incisions carefully to avoid struggles with screw fixation. This step can be very frustrating if the trocar is not kept absolutely still after drilling the holes. Redrilling the holes multiple times may weaken the bone and jeopardize the fixation.
- Appropriate positioning of the condyle is the most critical step of the procedure.
- Immediately after removal of the maxillomandibular fixation, the occlusion should be exactly as planned. Do not accept an incorrect occlusion. There is no better time to correct this problem than at this stage, in the operating room.

POSTOPERATIVE CARE

- The patient is generally extubated in the operating room and taken to the recovery room breathing spontaneously. If there are any airway concerns, the patient may be taken to the ICU while still intubated.

- If any airway need arises, the interarch elastics may be removed and replaced later when the patient is stable.
- The patient is maintained on a soft diet for 6 weeks.
- The elastics and splint are removed in 2 weeks and guiding elastics placed.

OUTCOMES

- Relapse after the BSSO setback depends on the magnitude of the setback, especially in growing individuals. Relapse rates reported in the literature vary widely, with a range of 7% to 50%.
- Cessation of lower jaw growth in individuals with true mandibular excess may occur later than it does in individuals with normal occlusion. For this reason, surgery is best delayed until confirmation of growth cessation (comparison of lateral cephalograms obtained 6 months apart).

COMPLICATIONS

- An unfavorable bad split is not an uncommon complication, with an incidence of up to 23%.
 - A bad split could be a fracture of the buccal/lingual plate, or a more serious situation in which the condyle remains with the distal segment.
 - If this occurs, an additional osteotomy is required to free the condyle (**FIG 3**).
 - Occurrence of a bad split should be recognized intraoperatively and additional rigid fixation may be needed.
- Injury to the inferior alveolar nerve may occur while making the osteotomies or while placing the screws. The reported incidence varies greatly in the literature, but patients seem to adapt well to the sensory deficit in the long term.
- Lingual nerve injury is a rare complication. It occurs during the subperiosteal dissection along the medial ramus, or during bicortical screw fixation. Avoid using very long screws (more than 15 mm) that extend beyond the lingual cortex.
- Injury to the facial nerve can occur but is a very rare complication.

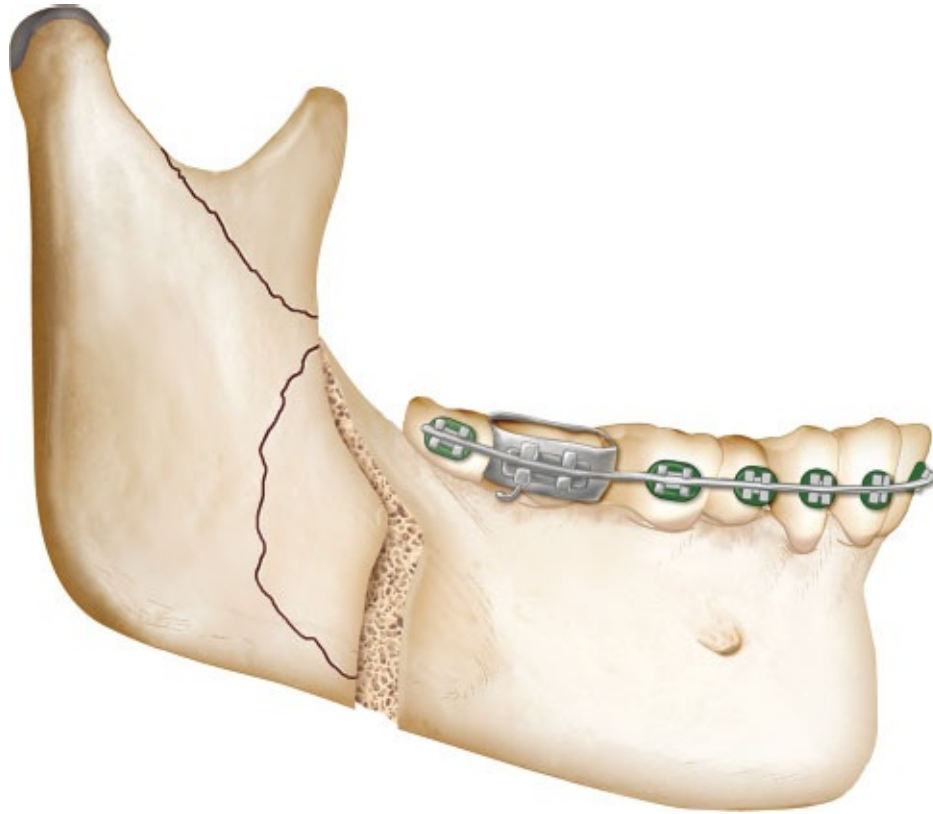


FIG 3 • A bad split can occur with fracture of the buccal cortex or higher near the condyle, resulting in a third segment.

- Significant bleeding is rarely encountered. Potential sources are the facial artery and the retromandibular vein. It is prevented by careful surgical technique and protection of the soft tissue.
- Wound dehiscence and/or infection are rare complications and are most often related to poor oral hygiene.

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CHAPTER Osseous Genioplasty

Mark E. Walker and Derek M. Steinbacher

DEFINITION

- Osseous genioplasty is an operative technique wherein the surgeon performs an osteotomy proximal to the mental prominence allowing for the repositioning of the chin to improve facial harmony.
- Mobilizing this segment enables the surgeon to address the complete spectrum of chin deformities including asymmetry, as well as vertical and sagittal deficiency, and excess.
- Size, shape, and position of the chin can enhance or detract from normal facial harmony and symmetry.
- Chin appearance influences social perceptions of masculinity and femininity.

ANATOMY

- Anterior labial vestibule of the lower lip is the outermost layer forming the labiogingival sulcus.
- Deep to the labiogingival mucosa, the two bellies and median raphe of the mentalis muscle insert onto and cover the chin.
- Mentalis muscle is the sole elevator of the lower lip and chin providing major vertical support.
- Mental nerve courses inferiorly (4.5 ± 1.9 mm) and anteriorly (5.0 ± 1.8 mm) within the canal prior to exiting at the mental foramen (**FIG 1**).



FIG 1 • Mental nerve courses inferiorly (4.5 ± 1.9 mm) and anteriorly (5.0 ± 1.8 mm) within the canal prior to exiting at the mental foramen.

- Osteotomy is designed inferior to this path to avoid damage to the mental nerve.
- Submental posterior insertion of the genioglossus muscle is responsible for blood supply to the bone flap following osteotomy.

PATHOGENESIS

- Chin asymmetry and/or malposition can be congenital or traumatic in etiology.
- Malocclusion and maxillomandibular discrepancy can contribute to chin malposition.

NATURAL HISTORY

- In the setting of an open bite, progressive worsening of retrognathia, often perceived as microgenia, should be investigated for possible temporomandibular joint resorptive processes, such as idiopathic condylar

resorption.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Inquire about any history of dentofacial trauma or prior maxillofacial surgery.
- Assess patient for maxillomandibular discrepancy or obvious dentofacial abnormalities.
- Simple visual inspection of the vertical and sagittal position can identify microgenia, macrogenia, and chin asymmetry.
 - Microgenia, or small chin, is defined as some combination of vertical and sagittal deficiency (**FIG 2A**).
 - Macrogenia, or large chin, is defined as some combination of vertical and sagittal excess (**FIG 2B**).
 - Asymmetry assessed on frontal view can present with vertical and/or rotational components (**FIG 2C**).
- Ideal chin projection is described in relation to the lips, nose, and midface.
- Cephalometrics is a powerful tool to generate objective descriptors of chin position.
 - Distance between soft tissue nasion to soft tissue chin (2 mm)
 - Depth of the labiomental fold (4 mm)
 - Cervicomental angle (acute vs obtuse)
 - Ricketts S-line
 - Line that connects the soft tissue nasion with the menton, the distance from which measures 2 mm at the upper lip prominence and 4 mm at the lower lip prominence¹ (**FIG 3A**).
 - Riedel plane
 - Line that connects but does not cross the most prominent portion of the upper and lower lips and connects with the soft tissue menton² (**FIG 3B**).

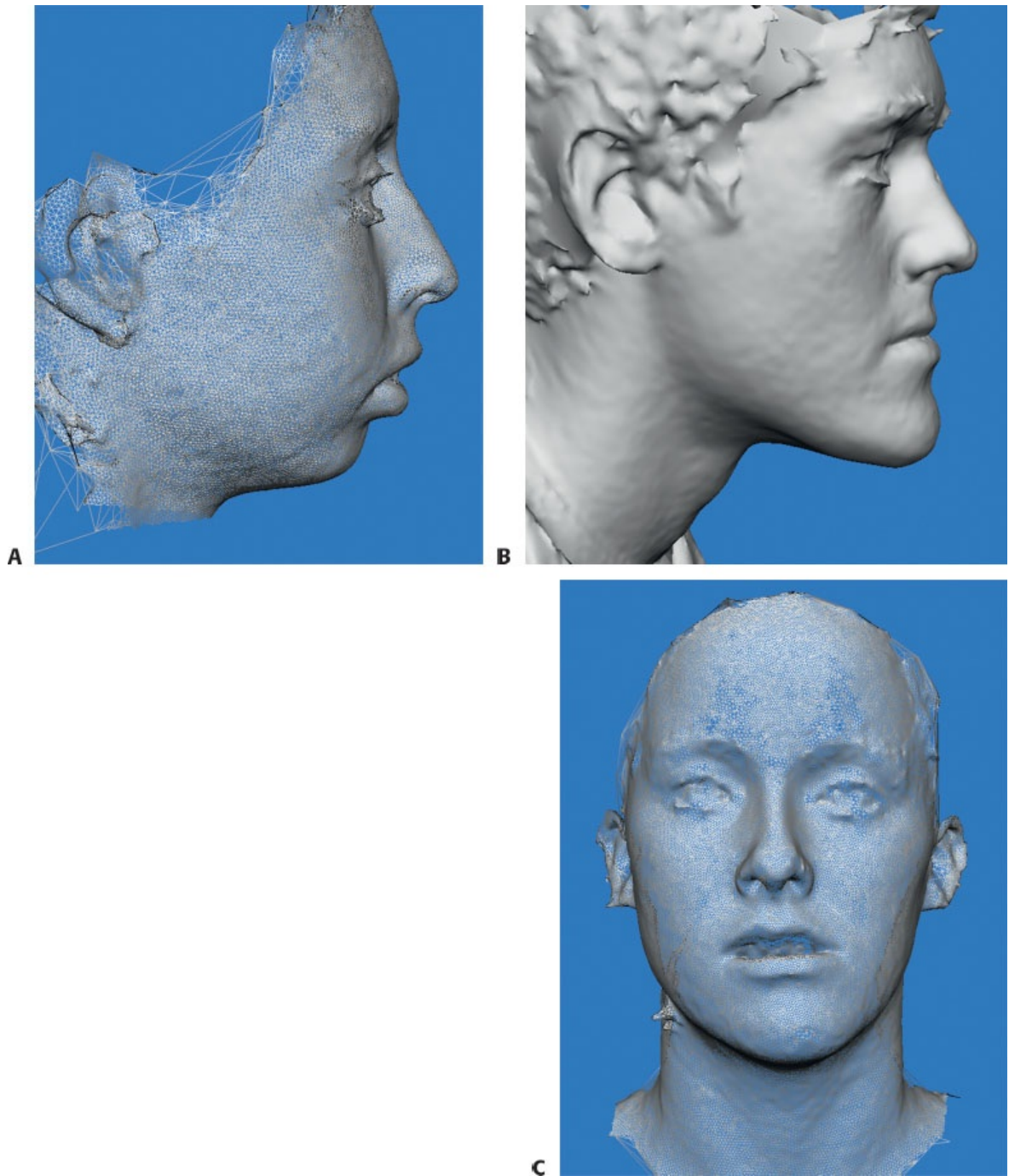


FIG 2 • **A.** Vertical and sagittal microgenia. **B.** Vertical and sagittal macrogenia. **C.** Frontal asymmetry secondary to unilateral vertical microgenia and rotation.

■ Facial convexity angle

- On lateral view, this is the angle defined by the pogonion position in relation

to a vertical line connecting the glabella and subnasale¹ (**FIG 3C**).

IMAGING

- Panorex to assess dentition and mandibular growth
- Cone-beam CT (CBCT) can be used for 3D assessment and surgical planning/modeling.
- Three-dimensional digital photography can be used to evaluate chin volume, position, and symmetry.
 - Simulation function can also be used for preoperative discussion/planning.
- Assess position of mental foramen, canal pattern, and tooth root apices.

DIFFERENTIAL DIAGNOSIS

- Isolated microgenia
- Isolated macrogenia
- Overall micrognathia or retrognathia
- Chin asymmetry
- Some combination of the above
- Craniofacial conditions or syndromes may be the underlying etiology.

NONOPERATIVE MANAGEMENT

- There are no conservative treatment measures available for correcting chin position.
- Patients do have the option for no intervention should they not wish to pursue surgery.

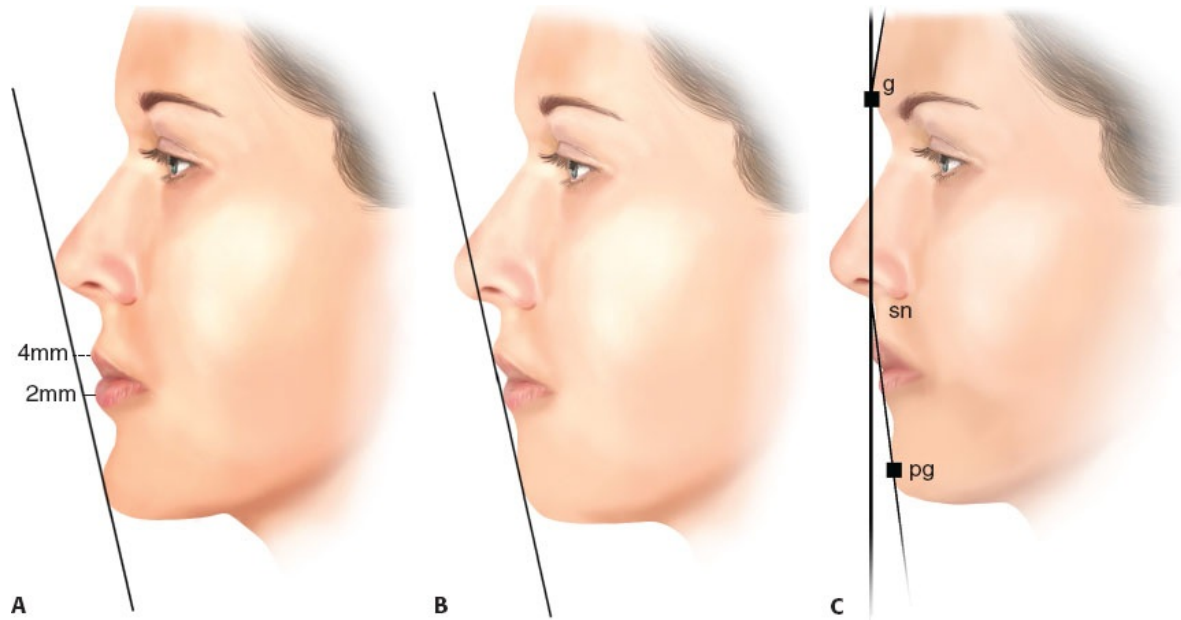


FIG 3 • A. Ricketts S-line. B. Reidel plane. C. Facial convexity angle.

SURGICAL MANAGEMENT

- Operative interventions to address chin aesthetics include the implantation of alloplastic materials (ie, porous polyethylene or silicone implants) and surgical osseous genioplasty.
- Indications for surgical intervention include displeasure with one's appearance, with the patient specifically identifying the chin as an area of focus.
- The balance between lip, nose, and midface position must be addressed with the patient, as any deformity or asymmetry in these areas may either be contributing to the appearance of chin disharmony or may become more obvious after the chin has been addressed.
- The risks of osseous genioplasty include bleeding, infection, injury to the mental nerve, paresthesias, injury to the mentalis muscle, “witch chin” deformity, mentalis muscle, pain, poor wound healing, scarring, persistent asymmetry, hardware malfunction, and the need for future additional operations.
- Each skeletal configuration on the differential diagnosis list calls for a unique surgical solution to address the problem or some combination of these.
- The surgical steps for correction vary primarily in the planning and execution

of the osteotomies and positioning and fixation of the bony segment:

- Microgenia, vertical—lengthen (vertically)
- Macrogenia, sagittal—setback (usually wedge removed)
- Macrogenia, vertical—shorten (wedge removed)
- Asymmetry, frontal—rotate (mediolateral)
- Asymmetry, vertical—wedge reduction
- Combination—combination of the above

Preoperative Planning

- Panorex and CBCT imaging should be reviewed prior to any surgical procedure to assess for dental maturity and cessation of bone growth.
- Based on clinical and skeletal analysis, the osteotomy is planned to address each patient on a case-by-case basis.
- The surgeon must explain to the patient that this is a primarily cosmetic procedure and expectations should be set early that this may include out-of-pocket expenses, even if combined with other insurance-covered surgery.

Positioning

- The patient is placed supine on the operating table with the head positioned in a semi-extending position on the head rest.
- Nasal RAE endotracheal tube is used for intubation with exception of concurrent rhinoplasty.
- The entire face, mouth, ears, and neck should be prepped with Betadine or chlorhexidine solution while protecting the corneas. Steri-Strips are placed to secure the eyelids.
- A head drape is placed securing the patient's hair and clearing the operative field.
- The surgeon must visualize the entire face given the chin's role in facial harmony.
- A throat pack is placed into the oral pharynx to minimize ingestion of irrigation solution and blood throughout the procedure.
- Local anesthetic with epinephrine is injected for regional anesthetic and hemostatic effect prior to incision.
- Decadron is administered preoperatively to control postoperative edema.
- Perioperative antibiotics are administered to prevent surgical site infections (ie, cefazolin or clindamycin).

TECHNIQUES

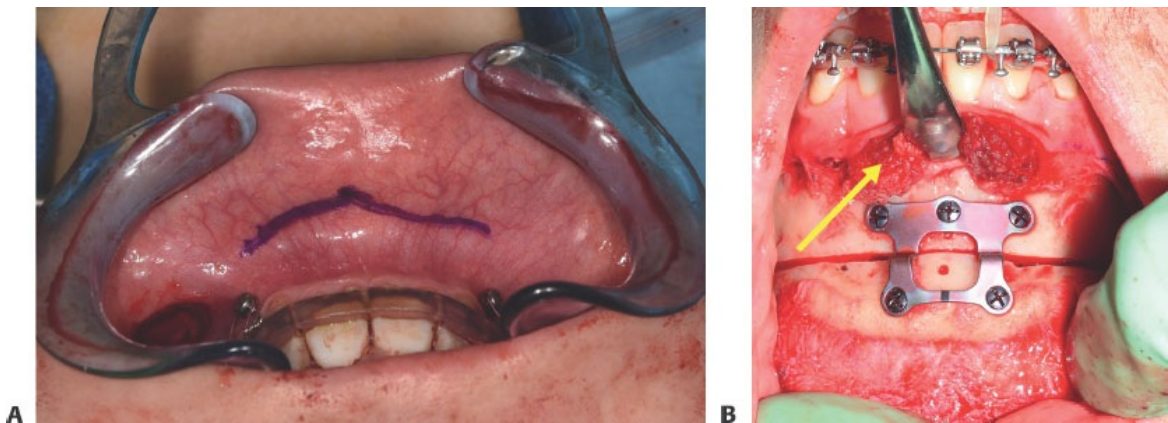
■ Basic Surgical Steps

Exposure

- The anterior labial vestibule is incised using a no. 15 blade scalpel perpendicular to the mucosa with a dart designed at the lower lip frenulum³ (**TECH FIG 1A**).
- This incision is placed at least 10 mm from the mucogingival line.
- Using a fine tip Colorado blade electrocautery, a horizontal incision is made through the mentalis muscle, preserving a cuff at the gingival border, allowing precise reattachment at closure (**TECH FIG 1B**).
- Blunt dissection is then performed with an elevator to expose and visualize the mental nerves as well as the mental prominence and associated structures.

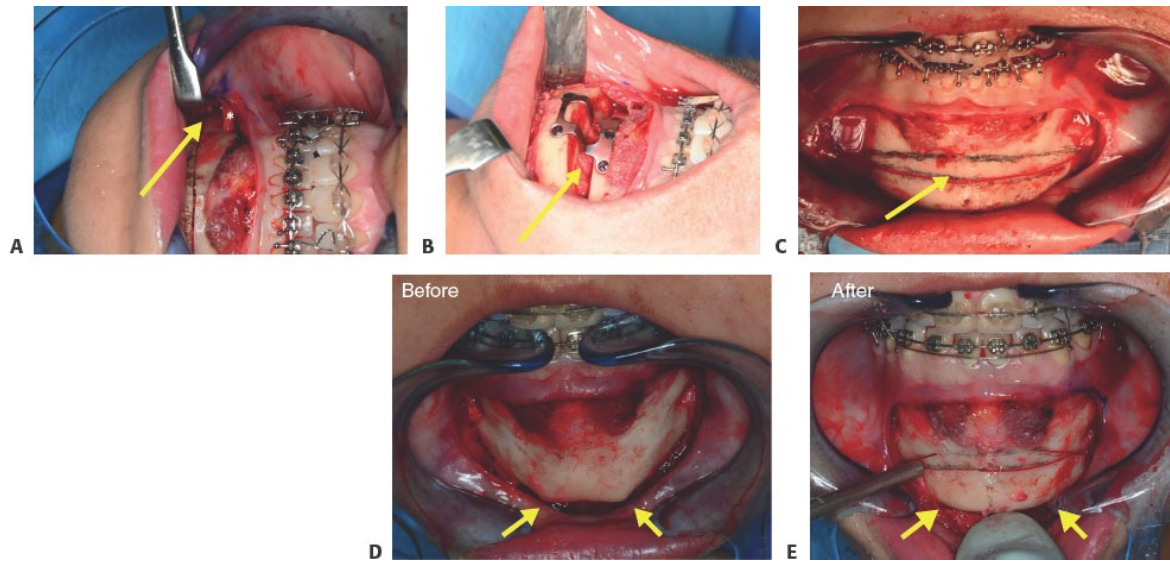
Osteotomy Design

- Midline should be marked prior to osteotomy design.
- The osteotomy is then traced with a sterile pencil above the pogonion, avoiding the mental nerves but typically extending laterally beyond the mental foramina (**TECH FIG 2A**).



TECH FIG 1 • **A.** The anterior labial vestibule is incised using a no. 15 blade scalpel perpendicular to the mucosa with a dart designed at the lower lip frenulum. **B.** Cuff of mentalis muscle remains attached

to mandible (*arrow*) to facilitate closure. Mental nerve (*).



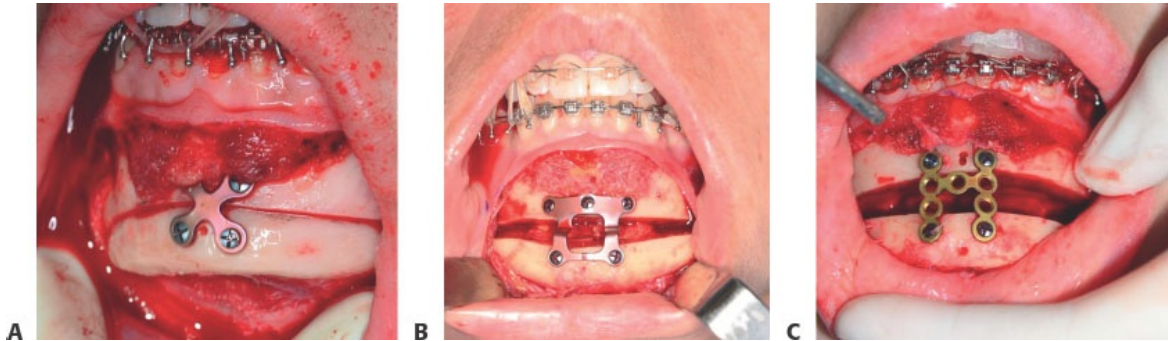
TECH FIG 2 • A. The osteotomy extends lateral to the mental foramen (*arrow*). Mental nerve (*). **B.** Genioglossus muscle remains attached to the mobile bony segment (*arrow*). **C.** Inferior osteotomy (*arrow*) is performed first in shortening genioplasty with planned wedge resection. In cases of prominent tubercles (**D**), a pineapple bur or reciprocating rasp is used to smooth the contour (**E**).

- Angulation and wedge resection might be planned based on anticipated course.
- Using the reciprocating saw, the planned osteotomies are performed. Irrigate the blade with saline to prevent thermal injury to the mandible and surrounding structures.
- Leave the genioglossus muscle attached to retain blood supply to the mobile segment(s) (**TECH FIG 2B**).
- In the case of a shortening genioplasty, where wedge resection is planned, the inferior osteotomy is performed first (**TECH FIG 2C**).
- In cases of asymmetry, wedge resection will be unilateral.
- For cases with prominent tubercles, the pineapple bur or reciprocating rasp is

employed to smooth the contour (**TECH FIG 2D,E**).

Fixation

- The mobile genioplasty segment is secured to the mandible using a variety of surgical plates and screws depending on the goals of the procedure.
- Options include the X-plate, step-off advancement plate, and straight H-plate (**TECH FIG 3A–E**).

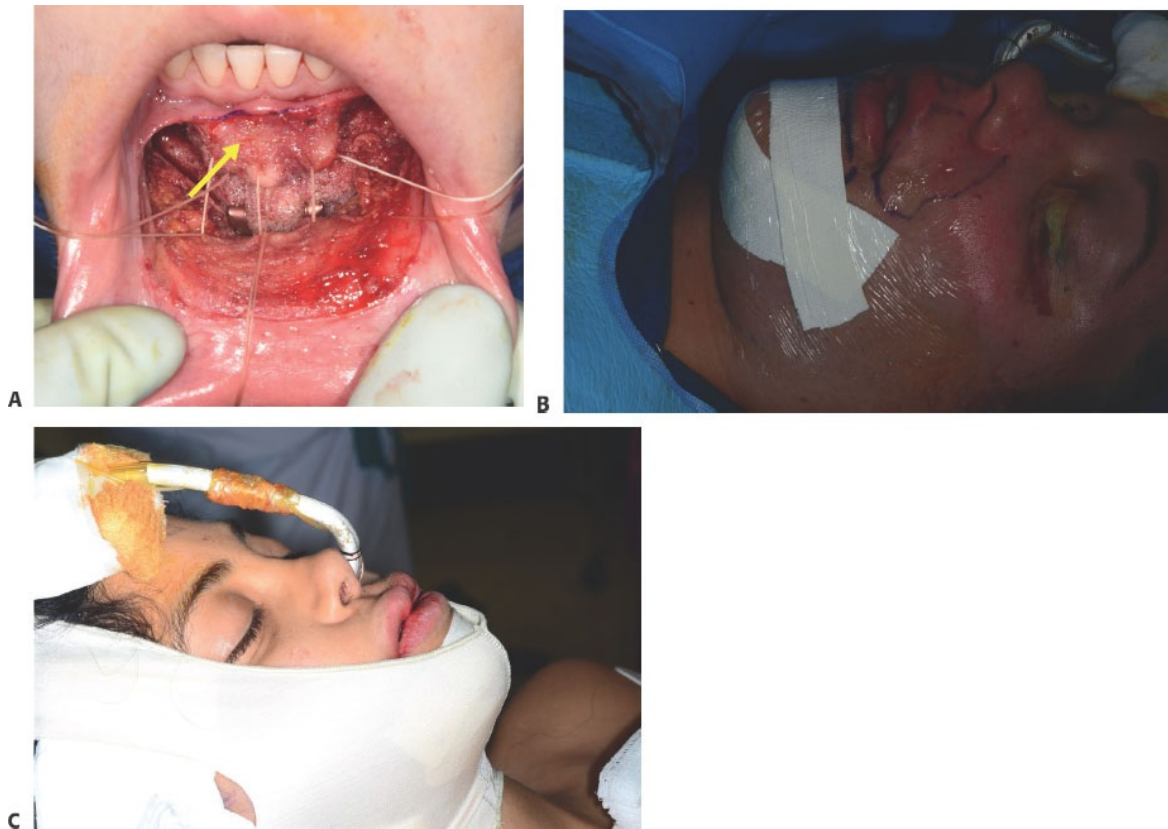


TECH FIG 3 • Fixation can be accomplished with a variety of plates, including the X-plate (**A**), the step-off advancement plate (**B**), and the straight H-plate (**C**).

Closure and Dressing

- Following bony fixation, the oral cavity and surgical field are irrigated with Betadine and normal saline solution.
- Precise reattachment of the mentalis muscle over the plate/screws is critical for good outcomes, both functionally (lower lip motion) and aesthetically (soft tissue volume/contour).
- Multiple interrupted 3-0 Vicryl sutures are used to reapproximate the muscle (**TECH FIG 4A**).
- The overlying mucosa is then reapproximated with 3-0 chromic gut sutures.
- A chin dressing is applied using Mastisol, surgical tape (elastoplasty tape is used by the authors), and Tegaderm designed to provide additional support and limit edema to the chin postoperatively (**TECH FIG 4B**).
- The patient is placed in a face bra once the dressing has been applied to provide additional external support to the mandible and soft tissues of the chin (**TECH FIG 4C**).
- This dressing is removed at the time of follow-up, approximately 1 week

after surgery.



TECH FIG 4 • A. Using 3-0 Vicryl suture, the mentalis muscle (*arrow*) is closed over the underlying hardware and precisely repositioned to avoid chin deformity. **B.** A chin dressing is applied using Mastisol, surgical tape (elastoplasty tape is used by the authors), and Tegaderm designed to provide additional support and limit edema to the chin postoperatively. **C.** The patient is placed in a face bra once the dressing has been applied to provide additional external support to the mandible and soft tissues of the chin.

■ Variations

Osseous Genioplasty for Sagittal or Vertical Microgenia

■ Advancement and vertical lengthening (**TECH FIG 5**)

Osseous Genioplasty for Sagittal Macrogenia

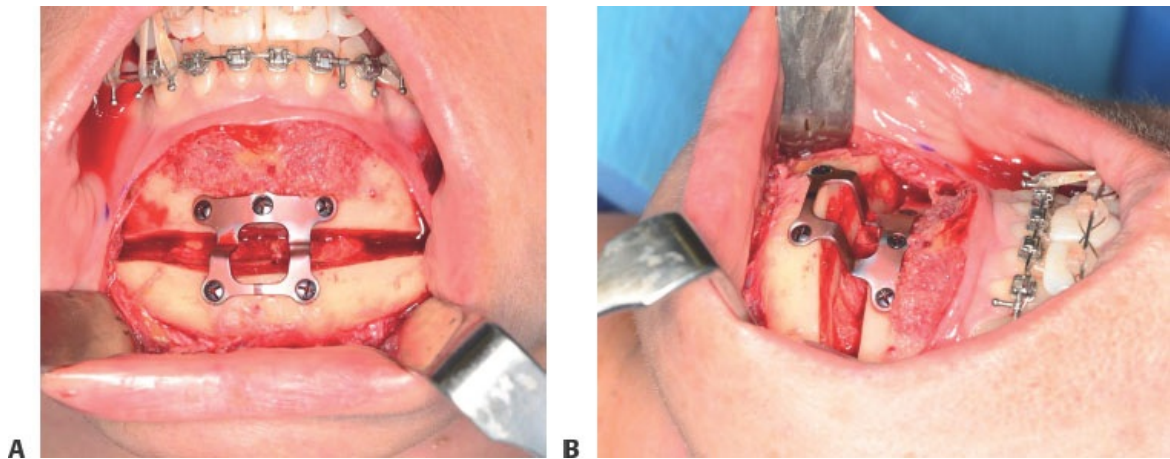
- Setback, typically with wedge resection (**TECH FIG 6A–D**)

Osseous Genioplasty for Vertical Macrogenia

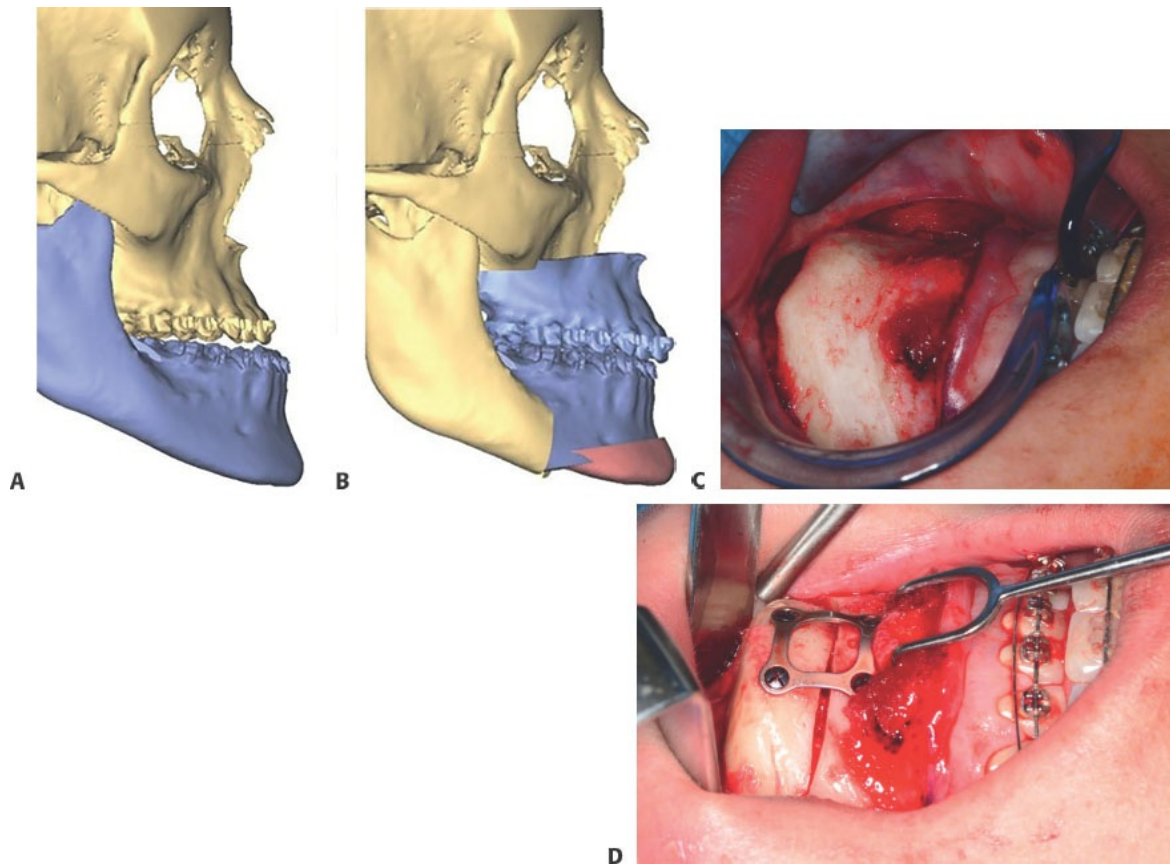
- Shortening, typically with wedge resection (**TECH FIG 7A,B**)

Osseous Genioplasty for Frontal or Vertical Asymmetry

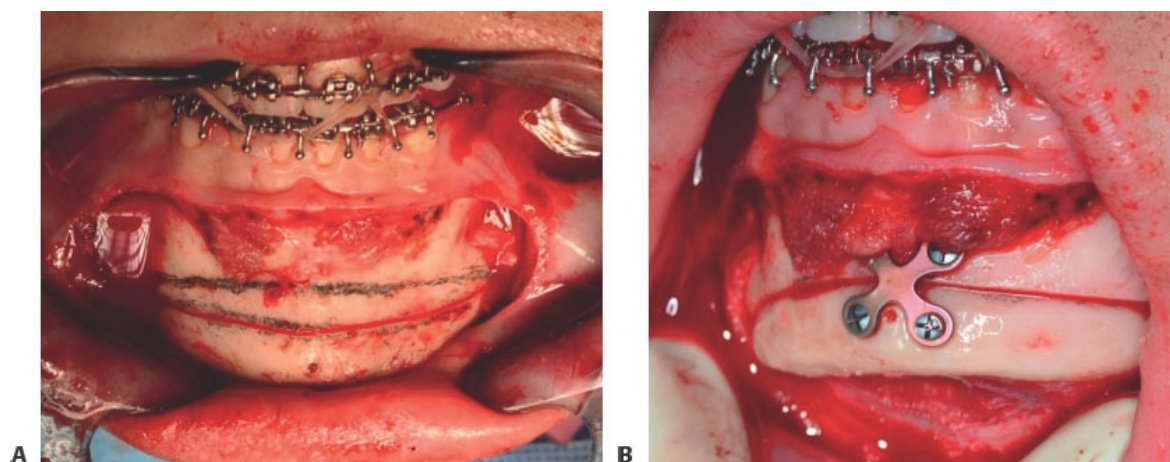
- Rotation (medial or lateral), typically with wedge resection and reduction (**TECH FIG 8A–D**)



TECH FIG 5 • A,B. In cases of both vertical and sagittal microgenia, a combination of advancement and vertical lengthening will be required to achieve the desired aesthetic result.

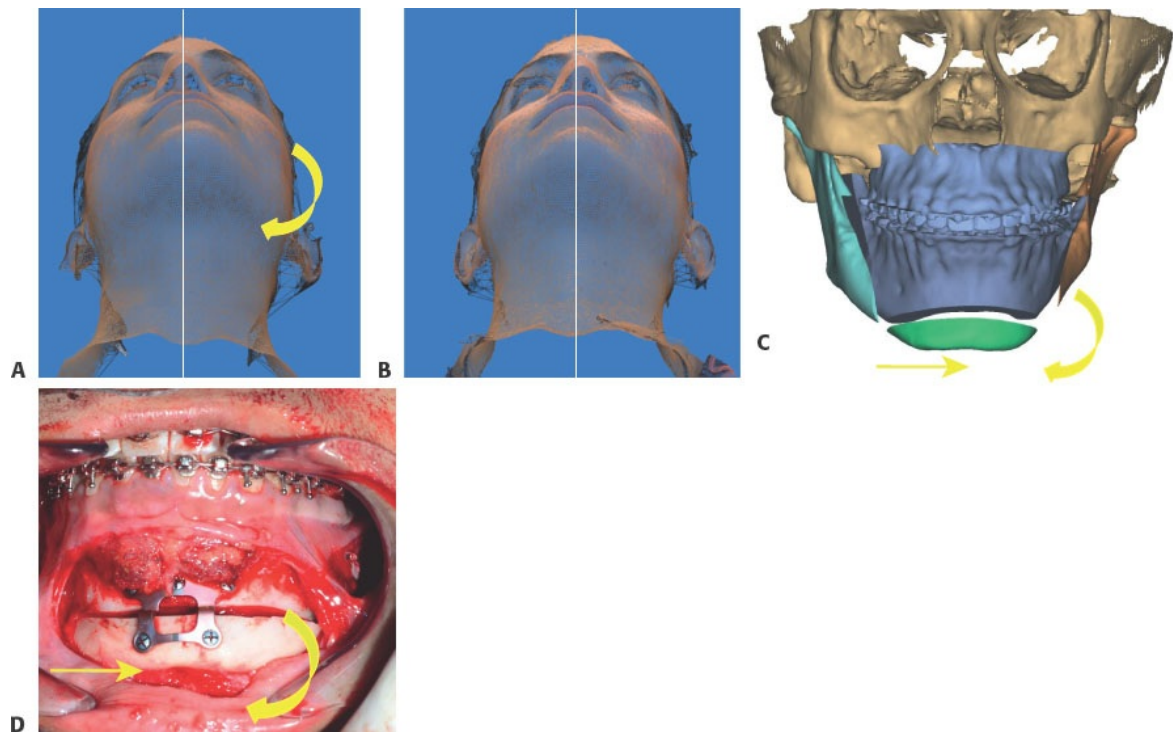


TECH FIG 6 • A,B. Preoperative planning for setback genioplasty in a patient with sagittal and vertical macrogenia. **C,D.** Setback genioplasty with wedge resection for a patient with sagittal macrogenia.



TECH FIG 7 • A,B. The osseous genioplasty for vertical macrogenia typically involves a wedge

resection and impaction of the bony segment, reducing the vertical height of the chin.



TECH FIG 8 • A–D. In cases of combined vertical and frontal asymmetry, a combination of wedge resection and unidirectional rotation may be required to achieve the desired result.

PEARLS AND PITFALLS

Preparation

- When draping, it is essential to visualize the entire face and upper neck given the chin's role in facial harmony.

Intraoperative edema management

- The use of preoperative Decadron can reduce postoperative edema and lead to faster patient recovery and satisfaction.

Incision

- Place the incision so that a cuff of muscle at the gingival border

planning	remains attached to the mandible to facilitate ease and precision of closure at the end of the case and minimize postoperative dehiscence.
Nerve preservation	■ Do not avulse the mental nerves when mobilizing the bony segment.
Blood supply	■ The genioglossus muscle should remain attached to the bony segment because this is the primary blood supply to the bone flap.
Closure	■ It is critical to precisely reattach the mentalis muscle at the time of closure to preserve functionality (lower lip motion) and aesthetics (soft tissue volume/contour) and prevent chin ptosis, or witch's chin deformity.

POSTOPERATIVE CARE

- Head elevation and ice pack application are encouraged to minimize edema.
- Patients are instructed to use warm salt water rinses and Peridex rinses postoperatively to manage oral flora.
- A short course of clindamycin or amoxicillin is prescribed postoperatively to reduce infection risk.
- Patients are instructed to avoid sports, physical exercise, or activities that might induce facial trauma for at least 6 weeks.
- Dental soft diet is recommended for the first 1 to 2 weeks after surgery.
- Pain control can be achieved with a combination of over-the-counter anti-inflammatory medications (ie, ibuprofen and acetaminophen) and narcotics (ie, hydrocodone or codeine prescriptions).
- Patients are instructed to follow up in the clinic 1 week after surgery for dressing removal and 3D photographic imaging (ie, Vectra camera).

OUTCOMES

- Functional and aesthetic outcomes are excellent in thoughtfully planned and well-executed procedures using osseous genioplasty to correct mild to moderate sagittal chin deficiencies.
- Osseous genioplasty provides the advantage of 3D versatility, larger advancements, and decreased foreign body-related complications when compared to alloplastic implants (ie, silicone, porous polyethylene).
- Only osseous genioplasty addresses both vertical excess and anterior mandibular asymmetry.

COMPLICATIONS

- Mental nerve sensory deficits following this dissection have been reported in the literature ranging from 6% to 10%.⁴⁻⁷



FIG 4 • Chin ptosis, or witch's chin deformity, may result if the mentalis muscle is not precisely reapproximated at the time of closure resulting in a senile appearance.

- Chin ptosis, or “witch’s chin” deformity, can result with failure to precisely reapproximate the mentalis muscle after dissection⁸ (**FIG 4**).

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45 Alloplastic Chin Augmentation

CHAPTER

Barry L. Eppley and Sunil Tholpady

DEFINITION

- Alloplastic chin augmentation involves a three-dimensional shape change using implants.
- The most common alloplastic chin augmentation used is with a silicone material.¹

ANATOMY

- The chin is the anterior extension of the mandible, which has a dominant influence on the shape of the lower face and the neck below it.
- The shape of the chin is a function of the thickness of the bone and how well the ramus and body of the mandible have developed.
- Class II and III malocclusions are always associated with obvious aesthetic chin deformities.
- The classic ideal chin position aligns with a vertical line dropped from the base of the nose and the forward position of the lips.
 - A male chin should fall close to this line, whereas an aesthetic female chin can be positioned behind this line (**FIG 1**).

PATHOGENESIS

- Chin hypoplasia should be viewed as a three-dimensional problem that involves
 - Horizontal chin projection
 - Vertical chin height
 - Transverse chin width

NATURAL HISTORY

- Once complete mandibular growth has occurred by the late teens or early 20s, no further change in the chin shape or forward projection will occur.

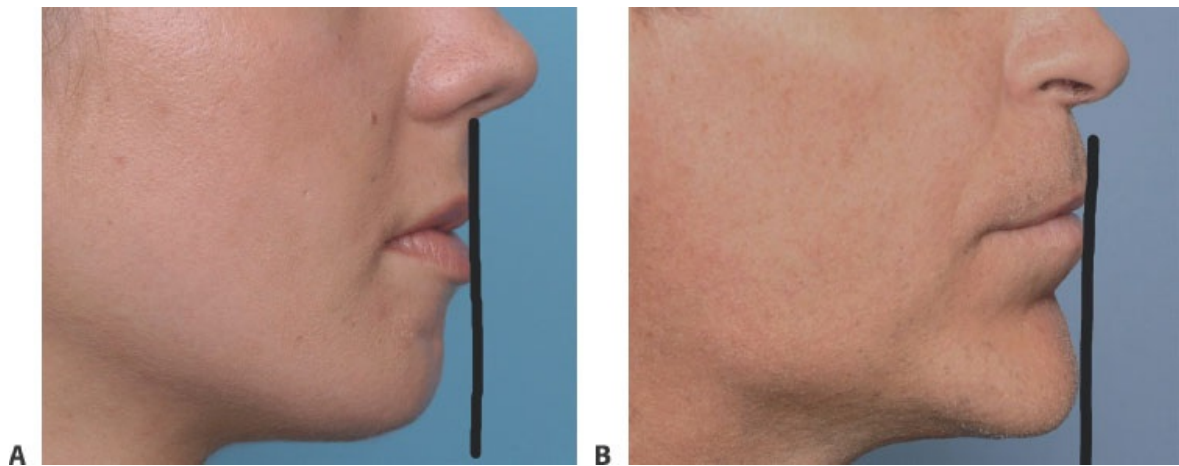


FIG 1 • Aesthetic chin projection assessment in a woman **(A)** and a man **(B)**.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Occlusion (class I or II)
- Amount of horizontal chin weakness
- Vertical chin height
- Depth of labiomental fold
- Desired position of chin determined with the help of computer imaging
- Presence of chin dimples or vertical chin cleft

IMAGING

- Standard imaging includes patient photographs from multiple views (front, side, and oblique).
- Cephalometric x-rays and pantomogram can be used to evaluate hard tissue position and mental nerve foramen location.
- Three-dimensional (3D) computed tomography (CT) is useful if a custom chin implant is needed or prior chin implant or bony genioplasty has been performed.

DIFFERENTIAL DIAGNOSIS

- Isolated chin deficiency vs total mandibular deficiency

NONOPERATIVE MANAGEMENT

- Synthetic injectable fillers
- Fat injections

SURGICAL MANAGEMENT

- Aesthetic chin augmentation can be performed at any age beyond the early teenage years. Absolute skeletal maturity does not have to exist in severe chin deficiencies.
- There are no absolute contraindications other than the patient's willingness to accept a synthetic facial implant.
- Determine what style and size of chin implant are needed based on aesthetic objectives (**FIG 2**).

Preoperative Planning

- Computer imaging of facial photographs should be completed before surgery to determine the exact goals and expectations of the chin augmentation surgery.

Positioning

- The patient is placed in the supine position on the operative table.
- The procedure can be performed with local anesthesia, IV sedation, or general anesthesia, depending upon patient and surgeon preference.
- Regardless of anesthetic choice, local anesthetic of 2% Xylocaine with 1:100,000 Epinephrine is infiltrated into the proposed incision and the region of the chin.
- Mental nerve blocks can be performed first if the procedure is done under local anesthesia.

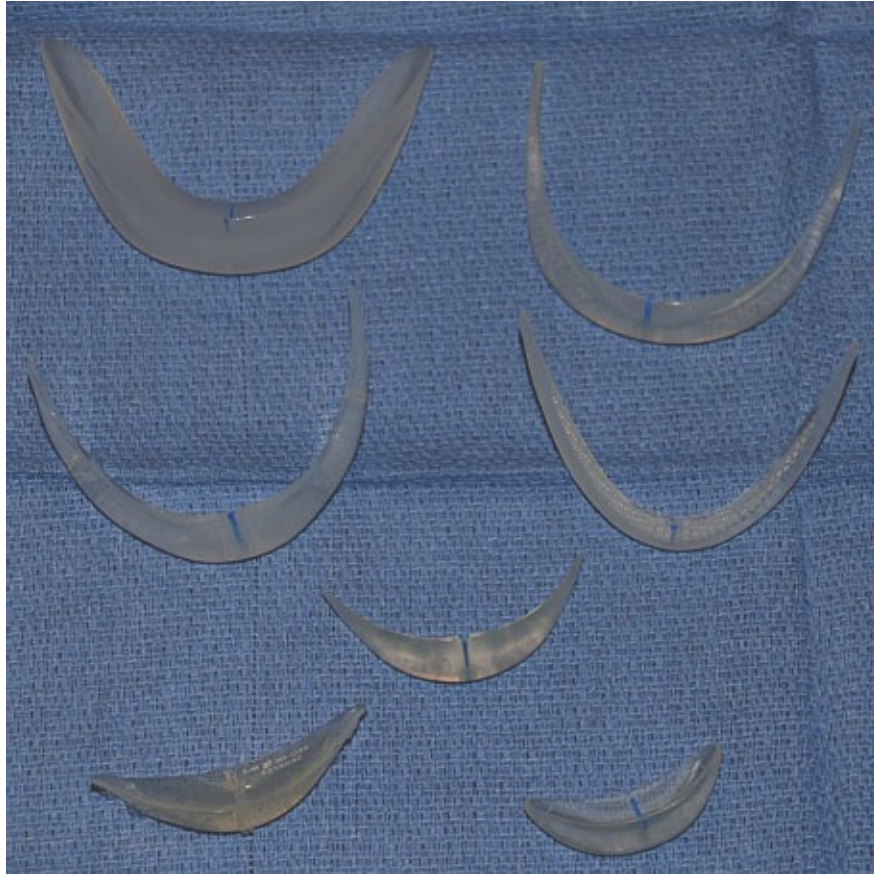


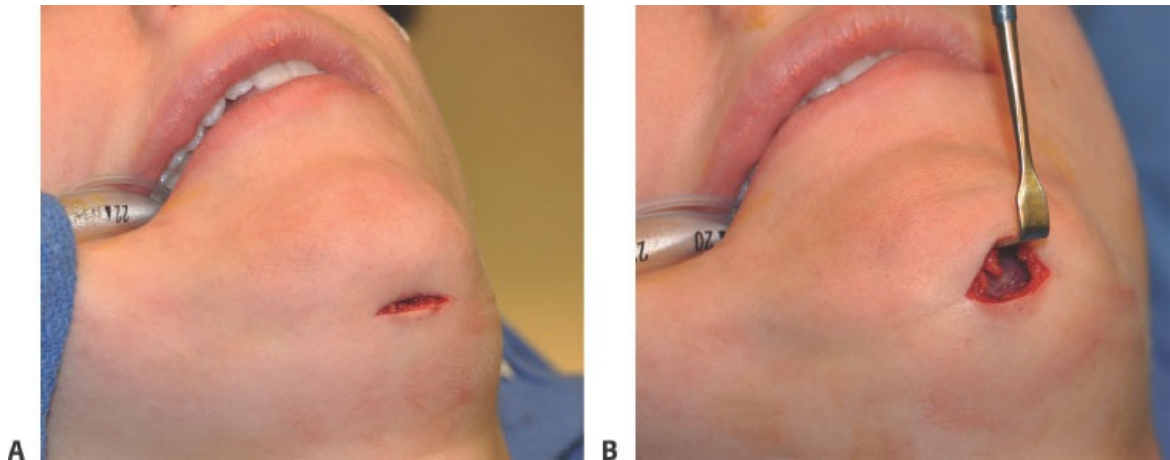
FIG 2 • Clinical examples of different chin implant styles.

TECHNIQUES

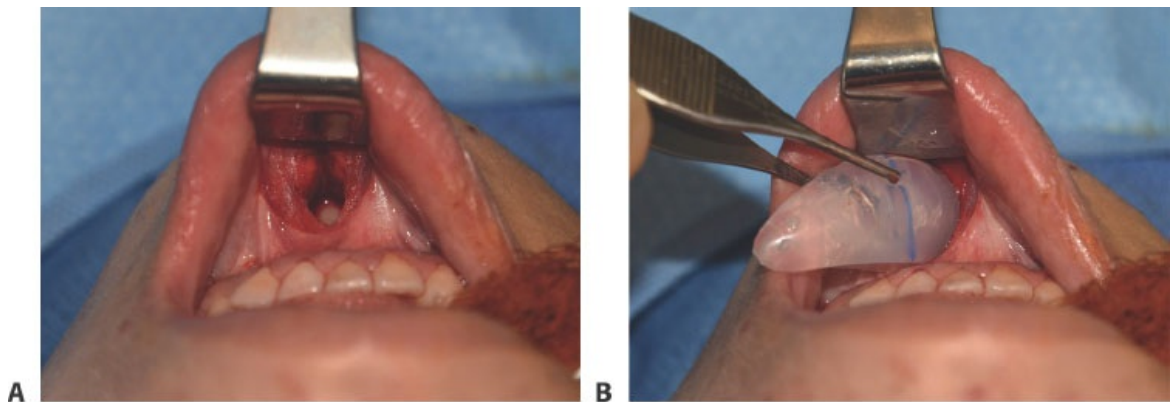
■ Exposure and Pocket Creation

- A submental incision employs a 3-cm incision within or directly behind the submental skin crease (**TECH FIG 1**).
 - When using larger or custom chin implants, the incision may be placed further behind the submental skin crease to compensate for significant forward positioning of the soft tissue chin pad.
 - Dissection proceeds through the mentalis muscle to reach the inferior portion of the bony chin.
- An intraoral incision uses a 3-cm mucosal incision above the depth of the vestibule on the lower lip side (**TECH FIG 2**).

- Dissection proceeds through the superior attachment of the mentalis muscle by leaving a cuff of muscle attached to the bone to aid closure.^{1,2}
- Subperiosteal dissection is performed over the entire chin bone, extending laterally below the mental nerve foramen if the chin implant has extended wings (such as an anatomic chin implant) (**TECH FIG 2B**).
- The dissection should extend inferiorly to the mandibular border and superiorly to accommodate the exact height of the implant.



TECH FIG 1 • **A.** Submental approach to chin augmentation. **B.** Retraction of soft tissue gives good exposure of the bony chin.



TECH FIG 2 • **A,B.** Intraoral approach to chin augmentation.

■ Implant Placement and Fixation

- The chin implant is placed into the pocket with the sides of the implant extended into the lateral dissection along the inferior border of the mandible.
 - The midline marker on the implant helps achieve a centric position on the bone.
 - Careful implant positioning includes checking for tilt, as this will lead to exaggerated asymmetry at the lateral wings.
 - Fixation of a chin implant is not always necessary but is highly desired.
 - In a submental approach, fixation can be achieved with sutures or small titanium screws (1.5 or 2.0 mm) along the inferior border.
 - In an intraoral approach, the only secure method to maintain the implant low on the bone is screw fixation.
 - Closure over the implant should be performed in three layers: muscle, dermis, and epidermal skin closure.
 - With intraoral approaches, resuspension of the mentalis muscle up and over the implant is critical.
-

PEARLS AND PITFALLS

Presurgical assessment with computer imaging

- Evaluate each patient for potential chin augmentation changes from three picture views.

Chin implant selection

- Chin implants change the projection of the lower face in three dimensions, not just from a profile view.

Subperiosteal implant placement

- There is no biological advantage to place the implant above the periosteum.

Implant positioning

- The implant needs to slide back and forth freely in the pocket to ensure that the lateral wings are not bent or folded.

Intraoral approach

- Screw fixation is essential to prevent immediate upward migration of the implant.

Postoperative management

- Patients need to wait 6 to 12 wk after surgery for an

accurate assessment of the implant results.

POSTOPERATIVE CARE

- A chin strap or tape may be used for a few days for postoperative compression.
- Intraoperative IV steroids can be used to help decrease swelling.
- Intraoperative IV and postoperative oral antibiotics with coverage of staphylococcal and oral flora are preferred for 5 to 7 days after surgery.

OUTCOMES

- Implants always increase chin projection.
- The style and shape of the implant, as well as the patient's expectations, will determine whether the aesthetic objectives are achieved.

COMPLICATIONS

- Infection usually presents as new swelling and pain 2 to 3 weeks after surgery.
- Asymmetry can be assessed no sooner than 6 weeks after surgery when most of the swelling has resolved in order to determine the midline positioning of the implant and/or wing asymmetry.
- Nerve impingement. Unremitting pain and numbness on one side that have been present for up to a month after surgery may indicate mental nerve compression by the wing of the implant.
- Overcorrection/undercorrection. The surgeon should allow a full 3 months after surgery for all swelling to subside and for the patient to adjust to his/her new look. Earlier interpretation, particularly that of overcorrection, may be premature.

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46 Surgical Removal of Fibrous Dysplasia From the Craniofacial Skeleton

CHAPTER

Alexander Govshievich and Gaby G. Doumit

DEFINITION

- Fibrous dysplasia (FD) is a benign bone disorder characterized by progressive replacement of normal bone by abnormal fibrous tissue.
- FD accounts for 2.5% of all bony tumors and 5% to 7% of all benign bony tumors.¹
- This disorder may be monostotic (MFD) or polyostotic (PFD), involving one or more bones. The term craniofacial fibrous dysplasia (CFD) has been used to describe FD confined to contiguous bones of the craniofacial skeleton.
- PFD accompanied by café au lait spots and endocrinopathies including hyperthyroidism, Cushing syndrome, and precocious puberty, is known as McCune-Albright syndrome (MAS).
- Craniomaxillofacial involvement in FD occurs in 27% of monostotic and up to 50% of polyostotic cases.²
- FD can remain asymptomatic or present with pain, stress fractures, localized swelling, or deformity.
- In the craniofacial skeleton, neurologic impairment can result from nerve compression by expansile FD lesions, potentially leading to blindness, deafness, or spinal cord compression.
- Diagnosis is based on an accurate clinical history, physical examination, and imaging studies.
- Bone biopsy is required to confirm diagnosis.

ANATOMY

- Any bone of the craniofacial skeleton may be affected by FD.

- Although the exact prevalence for each bone is unknown due to the relative rarity of this condition, the maxillary bone is the most frequently involved in several series.^{3–5}
- However, due to the compact and complex nature of the craniomaxillofacial construct, solitary FD lesions of the skull are seldom confined to individual bones, often affecting several contiguous structures.
- As a result, surgical approach and treatment principles are focused on general anatomic regions rather than individual bones.
- Chen et al. classified the craniomaxillofacial region into four major zones based on anatomic location, structures involved, surgical access, importance of reconstruction, and recommended treatment methods (**FIG 1**).⁶
 - Zone 1: Includes the frontal, nasal, ethmoidal, and zygomatic bones as well as the superior, non-tooth-bearing portion of the maxillary bone
 - Zone 2: Parietal, occipital, and squamous portion of the temporal bones
 - Zone 3: Petrous portion of the temporal bones including the mastoid process and the sphenoid bone
 - Zone 4: Tooth-bearing portion of the maxillary bone and the mandible and is separated into zones 4a and 4b

PATHOGENESIS

- FD is a noninherited genetic disease stemming from a postzygotically occurring missense mutation in the GNAS gene.
- Two mutations have been described, resulting from replacement of the arginine residue in codon 201 by either cysteine or histidine.
- The mutation leads to somatic activation of the alpha subunit of signal-transducer G protein (Gs), causing increased levels of cAMP and in turn resulting in high rates of cellular proliferation.⁷
- The abnormal proliferation and high cellular turnover produce poorly differentiated osteoblasts and immature mesenchymal cells, which are deposited within the bone and marrow of FD lesions.
- Elevated cAMP levels have also been demonstrated to upregulate the growth of thyroidal, adrenal, and gonadal cell lines resulting in the characteristic endocrinopathies seen in MAS.

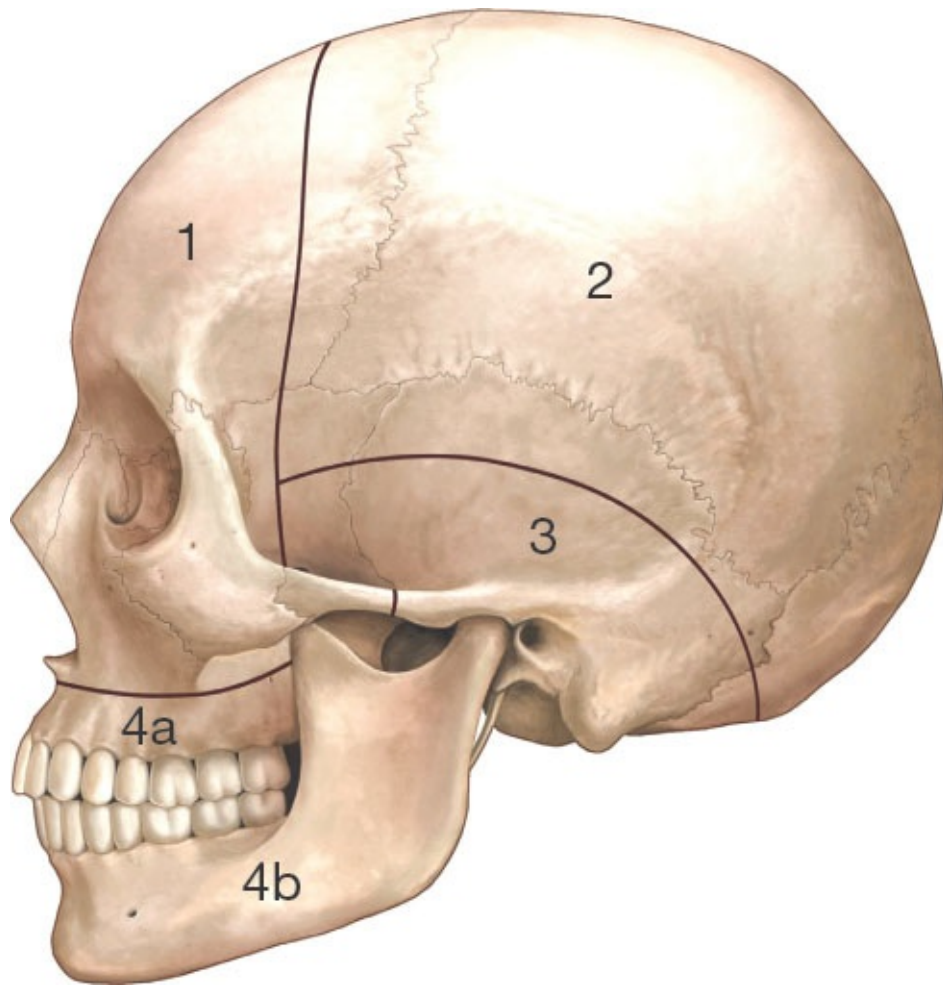


FIG 1 • Subdivision of the craniomaxillofacial region into 4 major zones as described by Chen et al.

NATURAL HISTORY

- The onset and natural evolution of FD can be variable and unpredictable, largely depending on lesion type.
- MFD lesions generally develop in childhood, progress through puberty, and arrest at the end of adolescence once skeletal maturity is complete.
- PFD and MAS variants have been associated with more aggressive growth patterns, demonstrating younger age at presentation and continued tumor growth into adulthood. Up to 90% of these lesions may present before 15 years of age.⁸
- Lesions seen in MAS can continue growing indefinitely, causing progressive disfigurement and functional deficits, requiring prompt surgical

intervention.^{9,10}

- Pregnancy and other settings of estrogen excess such as estrogen therapy have been associated with heightened lesion growth.^{9,11}
- Spontaneous malignant transformation in FD is possible but is rare. It can be observed in MFD, PFD, and MAS forms with reported frequencies ranging from 0.5% to 6.7%.¹²
- Any rapidly developing symptoms such as swelling or pain should raise suspicion of malignant change and prompt the appropriate investigations.
- Exposure to radiotherapy has been demonstrated to be the main risk factor for malignant transformation, being associated with a 44% rate of sarcomatous change. For this reason, radiotherapy is contraindicated in patients with FD.
- Osteosarcoma accounts for the majority of cases, with the remainder consisting of fibrosarcoma, chondrosarcoma, and malignant fibrohistiocytoma.¹³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history should include the age at presentation, evolution of the lesion (including periods of rapid growth), and associated symptoms.
- Physical examination should characterize the location of the lesion, its dimensions and any associated contour deformities, facial asymmetry, or functional deficits.
- Although FD is often asymptomatic, presenting as a slowly growing, painless, and nontender swelling, it may be associated with a variety of signs and symptoms that are specific to the anatomic zone affected.
 - Zone 1
 - Hypertelorism, vertical dystopia, and exophthalmos from fronto-orbital involvement and displacement of intraorbital contents
 - Changes in visual acuity and blindness can result from impingement of the optic nerve by lesions invading the anterior cranial fossa
 - Nasal obstruction and recurrent sinusitis can be caused by sinus involvement (**FIG 2**)
 - Facial asymmetry secondary to tumor enlargement
 - Zone 2
 - Headaches and elevated intracranial pressure (ICP) may result from calvarial involvement.
 - Cranial vault asymmetry secondary to tumor growth

- Macrocephaly
- Zone 3
 - Otalgia, fullness, conductive hearing loss, and cholesteatoma formation from external auditory canal (EAC) involvement



FIG 2 • Lateral (**A**) and anterior (**B**) views of a patient with large lower zone 1 fibrous dysplasia. Important nasal airway involvement is seen.

- Vertigo, tinnitus, sensorineural hearing loss, or facial nerve paralysis from invasion of the inner ear and internal auditory canal
- Visual disturbances or blindness with a lesion affecting the sphenoid bone
- Zones 4a and 4b
 - Displacement of teeth, vertical maxillary excess, or malocclusion
 - Patients with lesions neighboring the orbit, namely, those in zones I and III, must be followed with serial visual acuity and visual field measurements to rule out impingement of the optic nerve. Conduction of neuro-ophthalmological studies is also recommended.
 - Given that craniofacial FD can be part of PFD or MAS, the primary clinical assessment should include a full body examination looking for any additional bony lesions, café au lait spots, or findings suggestive of hyperthyroidism, Cushing syndrome, or precocious puberty.
 - When suspected, a multidisciplinary approach with an endocrinologist is

recommended for further investigations and follow-up.

IMAGING

- Radiologic investigation should be conducted in all patients with FD.
- Radiologic appearance of lesions demonstrates three radiologic patterns, namely, pagetoid, sclerotic, and cystic.¹³ Mixed changes also can be seen.
- Standard roentgenography is of limited diagnostic use in FD. Images can demonstrate expanded bone with ground-glass appearance, widened diploic space with displacement of the outer table and sparing of the inner table, cystic skull vault lesions, obliteration of paranasal sinuses, or dental malocclusions.
- High-resolution CT (1-mm cuts) is the preferred imaging modality, providing useful information for diagnosis, follow-up, and surgical planning. Three-dimensional (3D) reconstruction can further assist in surgical planning.
- Images obtained with CT scan:
 - Provide more accurate information regarding lesion size, location, surrounding structures, and potential compression sites (**FIG 3**).
 - Appearance is related to lesion age, with younger lesions appearing more radiolucent and mature lesions appearing more opaque. Ground-glass appearance is seen in established lesions and often represents the best diagnostic clue.⁹

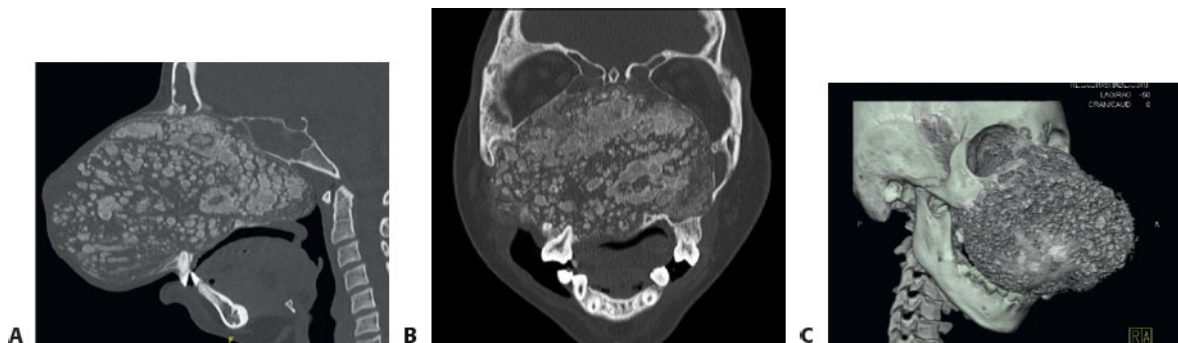


FIG 3 • CT scan of patient with large lower zone 1 fibrous dysplasia. **A.** Sagittal cut. **B.** Coronal cut. **C.** 3D reconstruction.

- Bones affected by FD are usually expanded with intact cortices. Normal corticomedullary differentiation is lost. The margin between abnormal and normal bone is often difficult to identify because the two regions blend into

each other.

- MRI is of lesser diagnostic value than CT. Image appearance is variable, depending on the degree of lucency vs sclerosis.
 - T1- and T2-weighted images generally demonstrate a heterogeneous appearance or decreased signal.
 - Injection of contrast demonstrates variable enhancement, which depends on lesion type.
- Bone scan has a very limited diagnostic role in FD; however, images can provide useful information regarding the presence of secondary lesions in the setting of PFD. Radionuclide uptake is variable.

DIFFERENTIAL DIAGNOSIS

- Paget disease of bone
- Cherubism
- Interosseous meningioma
- Garré sclerosing osteomyelitis
- Cemento-ossifying fibroma
- Craniometaphyseal dysplasia
- Sclerotic metastasis

NONOPERATIVE MANAGEMENT

- Nonoperative treatment in FD can be twofold, including expectant management or medical therapy.
- Expectant management is appropriate in most cases, particularly when lesions are small, slowly growing or static, asymptomatic, and causing minimal functional or aesthetic deficits.
- Regular follow-up and routine annual checkups with CT imaging are required to assess for progression or development of complications.
- Medical therapy is primarily aimed at providing symptomatic relief and can be used as an adjunct to surgery.
 - Acetaminophen and NSAIDs
 - Used for mild bone pain
 - Narcotics
 - Used for more severe bone pain
 - Bisphosphonates
 - Inhibit osteoclast activity, thus improving bone density and potentially

delaying progression of lesions into adjacent structures.⁴

- Reduce pain associated with FD, improve radiologic appearance of lesions, and decrease biochemical markers of bone remodeling (ie, serum ALP).¹⁴
- Typically used in more severe cases such as those seen in MAS.
- The most commonly used agent is pamidronate and is administered intravenously every 6 months (180 mg for adults and 3 mg/kg in children and adolescents).
- Alendronate and zoledronate have also been used.
- Monoclonal antibodies
 - The most commonly used agent is tocilizumab.
 - Decreases IL6 levels and subsequent osteoclast activity by binding to IL6 receptors.
 - Used for pain reduction in patients that fail to respond to bisphosphonate treatment.
- Calcium, phosphate, and vitamin D supplementation can be useful in patients with deficiencies or mineralization defects such as hyperparathyroidism, osteomalacia, and renal phosphate wasting.

SURGICAL MANAGEMENT

- Surgery is the mainstay of treatment for symptomatic FD and is the only definitive treatment modality.
- Because of the complexity of the craniofacial skeleton and the important structures it contains, a multidisciplinary team including otolaryngology, ophthalmology, neurosurgery, and plastic surgery is required.
- The presence of FD alone is not an indication for surgery because many lesions remain static and asymptomatic and are often found incidentally with CT imaging.
- Indications for surgery include the presence of pain not controlled by medical therapy, significant aesthetic deformity, functional deficit (ie, optic nerve compression), rapidly growing lesions, or malignant transformation.
- Surgical approaches are generally divided into shaving/contouring procedures, subtotal/partial resections, and total or wide excisions.
- Total resection of dysplastic bone is the preferred treatment modality (for rapidly growing, malignant, or recurrent lesions), minimizing the risk of recurrence and subsequent need for revisional surgeries. However, total resection may not be feasible, particularly in extensive CFD lesions where wide resection can significantly increase morbidity and the risk of

complications.

- It is of paramount importance to ensure that the defect caused by the procedure does not cause a greater functional or aesthetic deficit than present before surgery. Risks and benefits should be clearly described to patients and families.
- No guidelines exist for surgical management of FD. Treatment should be personalized and guided by the patient's age, lesion characteristics (location, extent, and evolution), and the presence of any functional or aesthetic deficits.
- Bone biopsy must be obtained before surgical intervention when diagnosis is uncertain or when there is concern for malignancy.
- Timing of intervention:
 - Defer surgical procedures until lesion growth subsides and skeletal maturity is attained.
 - Earlier intervention may become necessary if progressive expansion of the lesion causes significant functional, aesthetic, and psychological disturbances to the affected child.
 - Conservative shaving is recommended in these cases. However, patients should be informed that recurrence is possible and further contouring procedures may be required, particularly in cases of PFD and MAS, where continued growth is anticipated.
 - Conversely, if severe deformity is present, which cannot be corrected by contouring, radical excision and reconstruction is indicated. Patients should be made aware that recurrence is possible despite a wide excision.
 - In the adult population, static lesions causing a contour deformity can be appropriately managed by shaving of the lesion. The presence of a functional deficit (such as airway obstruction, oral obstruction or optic nerve compression, etc.) warrants a more radical resection or an en bloc resection, when feasible, and immediate reconstruction.
- Zone 1
 - Represents the most cosmetically sensitive part of the face and is of particular relevance to the craniofacial surgeon
 - Wide excision followed by immediate reconstruction is recommended in cases of significant aesthetic or functional deficit, rapidly growing lesions, malignant transformation, recurrent lesions, and severe pain.
 - The goals of reconstruction include restoration of facial skeletal integrity (reconstruction of horizontal and vertical buttresses), symmetry, globe position, and orbital volume and separation of cranial, orbital, and nasal

cavities.

- Separation between the intracranial and nasal cavities if the anterior cranial base is involved is of paramount importance to prevent infectious complications.
- Reconstruction is preferably performed using split-thickness calvarial bone grafts (SCBG). If the calvarium is unavailable as a donor site due to extensive involvement by FD, split rib grafts or iliac crest bone grafts may be used.
- In cases of incomplete resection of a growing lesion where recurrence is a concern, reconstruction can be temporized with a titanium mesh to match the contralateral normal anatomy.
- Zone 2
 - Represents most of the calvarial region of the cranium, a hair-bearing region of lesser aesthetic importance, where both conservative and radical treatments are possible.
 - Asymptomatic lesions can be adequately treated by shaving in order to restore a symmetric profile.
 - Symptomatic lesions often require wide resection with immediate reconstruction. A variety of materials can be used:
 - Autologous SCBG are preferred when the defect size does not exceed the amount of graft available. Rib grafts and iliac crest grafts are other potential donor sites. Reimplantation of autoclaved resected bone post remodeling has also been described but is not recommended by the senior author.³
 - Cadaveric calvarial allografts.
 - Alloplastic materials such as titanium mesh, methyl methacrylate, porous polyethylene, and polyetheretherketone (PEEK), particularly in the setting of larger defects where the quantity of autologous material is insufficient.
- Zone 3
 - Represents an anatomically complex area containing large vascular structures and multiple cranial nerves.
 - Surgical intervention is challenging, generally avoided, and reserved uniquely for symptomatic cases such as optic nerve compression or EAC stenosis.
 - Optic nerve decompression should be strictly performed in symptomatic cases in an effort to prevent further damage to the optic nerve and deterioration of vision. Improvement of symptoms is not guaranteed.
 - Unroofing of the canal is performed by the neurosurgery team following anterior craniotomy, using an intracranial approach. Simultaneous bilateral

anterior clinoidectomy is often performed.

- Prophylactic decompression based solely on radiographic measurement of optic canal narrowing is contraindicated and has been associated with severe complications such as blindness.¹⁵ Lee et al. have demonstrated that encasement of the optic canal in itself does not correlate with visual loss or results of neuro-ophthalmologic examinations. Hence, the risks of this procedure far outweigh the benefits.
- EAC stenosis: Decompression is performed by the ENT team. The primary goal of the procedure is to restore conductive hearing caused by EAC stenosis.
- Zone 4
 - Represents a functionally important area housing the dentition.
 - The main objective of surgical intervention in this area is to preserve the native dentition.
 - The lesion should be managed with serial debulking procedures during growth to address facial asymmetry.
 - Orthodontic management of malocclusion and orthognathic surgery following arrest of growth provide stable results.¹⁶ Orthognathic surgery within dysplastic bone is challenging as osteotomies must be performed through solid bone.
 - Radical excision should be reserved only for cases of massive bone involvement, severe functional impairment, or malignant degeneration.
 - Free bone graft techniques or free osseous flaps followed by placement of osteointegrated dental implants offer good anatomical and functional recovery.
 - Free flaps are indicated for bony deficits larger than 6 cm.

Preoperative Planning

- The surgeon should discuss the risks and benefits of the procedure with the patient and family.
- All major risks and complications specific to the zone being operated on should be explained, including the possibility of recurrence and need for additional surgery.
- The patient and family should be aware that intraoperative transfusion of blood products may be required in case of bleeding and appropriate consent should be obtained.
- It is recommended to perform a bone biopsy and obtain a final

histopathological diagnosis prior to proceeding with definitive surgery when the diagnosis is uncertain.

- A CT scan of the craniofacial skeleton is essential for preoperative planning. In cases of complex CFD, a 3D model of the craniofacial skeleton is helpful during resection. A mirror-image 3D model of the nonaffected side is helpful during reconstruction by facilitating bone graft reshaping and accurate plate bending.
- In the case of bilateral FD involvement, a 3D model based on CT data matched for age, sex, and race is used in the reconstruction process.
- Magnification loops with headlights can improve visualization during surgery.

Positioning

- The patient is positioned supine with the head centered on a Mayfield head rest.
- The entire head and neck area is prepped; drapes are positioned around the neck, and the head is left exposed to allow optimal intraoperative assessment of symmetry and access to the calvarium if bone grafts are required.
- For extensive lesions involving the nasal or oral airway where wide resection is anticipated, particularly those in lower zone 1, a tracheostomy should be performed by the ENT surgeon before the procedure. This is essential to ensure adequate operative exposure and secure the airway both during the surgery and in the postoperative period, as significant swelling may occur.
- If orotracheal intubation is performed, the endotracheal tube should be secured to the patient's teeth with a 26-Fr stainless steel wire as a precautionary safety measure.

Approach

- The surgical approach and choice of incision are determined by the location of the tumor, the anatomic structures involved, and the goal of the surgery.
- In general, wide resections require wide exposure and a more invasive approach is necessary.
- For shaving or contouring procedure, however, a minimally invasive approach should be privileged to minimize scar burden and avoid compromising facial aesthetics.
- In zone 1, the bicoronal and Weber Ferguson approaches are commonly used for wide resection of lesions involving upper (supraorbital bar and frontal bone

region) and lower zone 1 (naso-orbito-ethmoidal [NOE] and zygomaticomaxillary [ZM] regions).

- A superior gingivobuccal sulcus incision is used for shaving of lesions located in lower zone 1.
- The bicoronal approach allows adequate exposure of the anterior and posterior cranial vault for excision or shaving of lesions involving zone 2.
- Access to lesions in zones 4a and 4b is obtained using superior and inferior gingivobuccal sulcus incisions. In cases of wide resection, submandibular incisions can be used.

TECHNIQUES

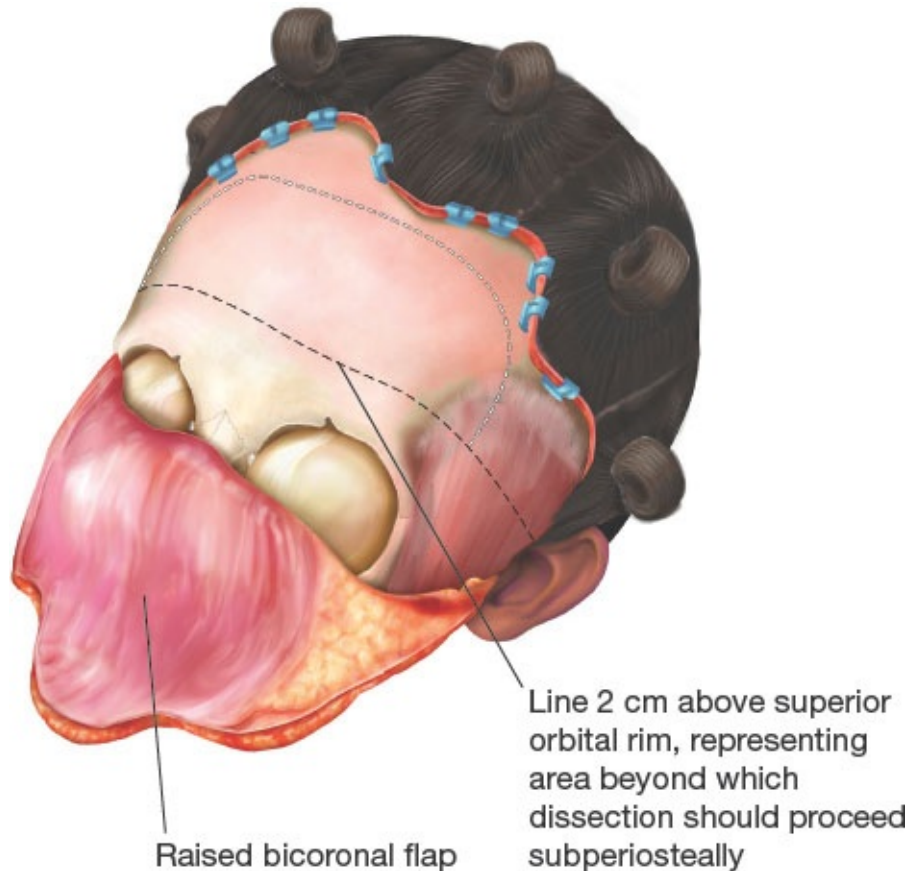
■ Surgical Removal of Fibrous Dysplasia in Upper Zone 1

Exposure

- The bicoronal incision is marked in a zigzag fashion at least 5 cm behind the hairline, extending from one auricular helix to the other.
- The hair is combed away from the marked incision line and grouped in bundles, which are twisted and secured with elastic bands.
 - A narrow corridor of hair (1–2 cm) can be shaved directly over the planned incision to facilitate wound closure; however, this is not necessary.
- The incision is infiltrated with a 1% Xylocaine solution containing 1:100 000 epinephrine. Incision is carried out with a no. 10 blade through skin, subcutaneous tissue, and galea, parallel to the orientation of the hair follicles.
 - Monopolar cautery use is minimized to diminish the risk of alopecia.
 - Bipolar cautery is used to perform hemostasis.
- Incision margins are lifted and Raney clips are applied along the anterior and posterior flaps for hemostasis.
- Anteriorly, dissection proceeds in the loose areolar plane until 2 cm above the superior orbital rim.
 - If no pericranial flap is anticipated, the periosteum is incised horizontally from one temporal fusion line to the other, and dissection proceeds subperiosteally until adequate exposure of the nasofrontal and supraorbital

regions is achieved.

- If a pericranial flap may be required, that is, with lesions involving the anterior cranial base, the periosteum is incised at the level of the skin incision and laterally along the temporal fusion lines. It is then dissected off the skull bone using sharp periosteal elevators and surgery proceeds as above (**TECH FIG 1**).
- Laterally, the temporal fusion lines are released. Dissection is carried immediately superficial to the deep temporal fascia until the superficial temporal fat pad is reached.
- At this point, the superficial layer of the deep temporal fascia is incised, and sharp dissection is carried just superficial to the temporal fat pad until the superior aspect of the zygomatic arch and posterior aspect of the lateral orbital rim are reached. Here, the periosteum is incised, and dissection is merged with that described for the anterior segment.
- If access to the orbital roof and medial orbital wall is required, the supraorbital neurovascular bundles must be identified and carefully released from within the confines of the superior orbital notch.
 - If a foramen is present, it is converted into a notch using a 2-mm osteotome by dividing a small bony wedge.
 - Dissection then proceeds subperiosteally until the orbital roof and medial wall are exposed.
- The trochlea of the superior oblique muscle can be released with minimal consequences if required.



TECH FIG 1 • After the anterior scalp has been raised in the subgaleal plane, a pericranial flap is designed. The periosteum is incised posteriorly at the level of the skin incision and laterally along the temporal fusion lines. It is then dissected off the calvarium using sharp periosteal elevators.

- Preserve the medial canthal ligament and lacrimal apparatus unless resection of the lacrimal bone is planned.
- Lateral orbital wall dissection is performed with a Freer while retracting the globe with a malleable. The lateral canthal ligament can be released from the Whitnall tubercle to increase exposure and facilitate supraorbital bar resection.

Resection

- Once adequate exposure has been achieved, the extent of the FD lesion is evaluated. Correlation to preoperative CT imaging and the use of anatomical

landmarks such as the distance to the zygomaticofrontal or nasofrontal sutures can further aid in accurate identification of lesion margins.

- Moderate to severe frontal bone deformities are marked for resection. Mild deformities are burred down to achieve symmetry.
- Resection begins with the frontal craniotomy segment, which is carried out by the neurosurgery team. Bur holes are made at the extremities of the planned resection and on either side of the sagittal sinus. A side-cutting saw with a footplate is used to connect the bur holes.
- The frontal bone is dissected off the dura. Dissection then proceeds inferiorly to expose the anterior cranial base if required.
- Optic nerve decompression is performed at this point by the neurosurgery team when indicated.
- Lesions involving the supraorbital bar are excised using a reciprocating saw. The orbital contents and brain must be protected with malleable retractors at all times to avoid injury.
- Constant irrigation is used to minimize thermal damage to surrounding tissues.
- Warm bone wax, bipolar cautery, and hemostatic agents (ie, Floseal) are used for hemostasis.

Reconstruction

- Once the CFD lesion is completely removed, the anatomical deficit is assessed.
- Preferred reconstruction is carried using SCBG.
- SCBG can be used to reconstruct all necessary segments, including the frontal bone, anterior skull base, and superior orbital rim.
- If all the above structures are involved, the superior orbital rim should be addressed first, followed by the anterior cranial base and the frontal bone.
- Ideally, grafts are outlined on the parietal cranium in the hair-bearing region to optimize symmetry and diminish donor-site morbidity. The graft is usually harvested from the parietal bone of the nondominant hemisphere, at least 1 cm lateral to the sagittal suture. The other hemisphere can be used if additional material is required.
- In cases of unilateral FD involvement, a malleable bent to the shape of the unaffected fronto-orbital bar can be used to help find a harvest site with a curvature most suitable to ensure a symmetric result.

- Strips of bone to be used for reconstruction are outlined and their outer cortex is burred with a 2-mm bur until diploe is reached. An osteotome is used to divide the diploic layer and elevate the outer cortex graft. Utmost care should be taken to avoid breaching the inner cortex. Hemostatic material may be used for the donor site if needed.
- A second option is full-thickness harvest of the outlined cranial bone by the neurosurgeon, followed by ex vivo division of the two cortices on a side table.
- Grafts should span the defect and be secured edge to edge to healthy bone on either end using plates and at least three screws from the 1-mm cranial set (4–5 mm long) on each side.
- Following restoration of the fronto-orbital bar, the anterior cranial base is addressed.
- It is advised to reconstruct the orbital roof with a titanium mesh as bony resorption is known to occur in this region. An overlay of bone graft can be placed if desired by the surgeon, but it is not necessary.
- In the event where the nasal cavity or ethmoid bone has been violated, the pericranial flap is secured over the titanium mesh to ensure a seal between the nasal and intracranial cavities.
- The pericranial flap is secured to the surrounding tissue and bone with a few simple interrupted 4-0 Vicryl sutures.
- It is of extreme importance to repair any dural tear and obtain a watertight seal prior to closure. Tisseel is often used for this purpose.
- Finally, the frontal bone deficit is addressed using the SCBGs, completing reconstruction of the FD defect.
- If the lateral canthal ligament was released, a lateral canthoplasty is performed with a 4-0 Vicryl or a lateral canthoplasty stainless steel suture.
- While protecting the globe, two 1.5-mm holes are drilled through and through, above and below the zygomaticofrontal suture (3 mm posterior to the rim).
- The lateral canthal ligament is grasped with a single hook. Lateral tension on the ligament with the hook should cause lateral movement of the corner of the palpebral fissure. Once properly identified, the lateral canthal ligament is sewn with a figure-of-8 stitch. One limb of the suture is passed through the hole superiorly, while the second is passed inferiorly and then tied.
- A Jackson-Pratt drain is placed on the cranium and the scalp is unfolded.

- Raney clips are removed and hemostasis is ensured.
- A two-layer closure is performed using interrupted 2-0 Vicryl sutures for the galea and a running 4-0 nonresorbable suture or staples for the skin.
- Antibiotic ointment is applied along the incision and a lightly compressive head dressing is placed.

■ Surgical Removal of Fibrous Dysplasia in Lower Zone 1

Exposure

- A subcranial approach using a Weber Ferguson incision is preferred and should be used for NOE and ZM lesions found below the nasofrontal suture and sparing the cribriform plate.
- Involvement of the cribriform plate will require the addition of a bicoronal incision, elevation of a pericranial flap as described above, and frontal craniotomy to ensure an adequate protection to the brain and a full seal between the brain and nasal cavities.
- A tracheotomy should be performed by the ENT surgeon for patients with extensive NOE lesions where wide resection is anticipated, particularly if the nasal airways are involved.
 - This is essential to ensure adequate operative exposure and secure the airway both during the surgery and in the postoperative period, as significant swelling may occur.
- The incision is marked along the ipsilateral philtral column, around the nasal ala, and superiorly along the nasofacial groove (**TECH FIG 2**).
- Markings can extend laterally along a subciliary incision line, which can be used if additional exposure is required.
- Cupid's bow is marked and tattooed to ensure exact reapproximation during closure.
- The incision line is infiltrated along its length with 1% Xylocaine with epinephrine 1:100 000.
- Using a no. 10 blade, the skin is incised along the nasofacial groove and around the nasal ala until the periosteum is reached.
- The superior lip is cut through and through.
- Intraorally, a superior gingivobuccal incision is made 5 mm buccal to the

sulcus in order to preserve a mucosal cuff for closure.

- Mucosa, submucosa, and muscles are divided directly down to bone.

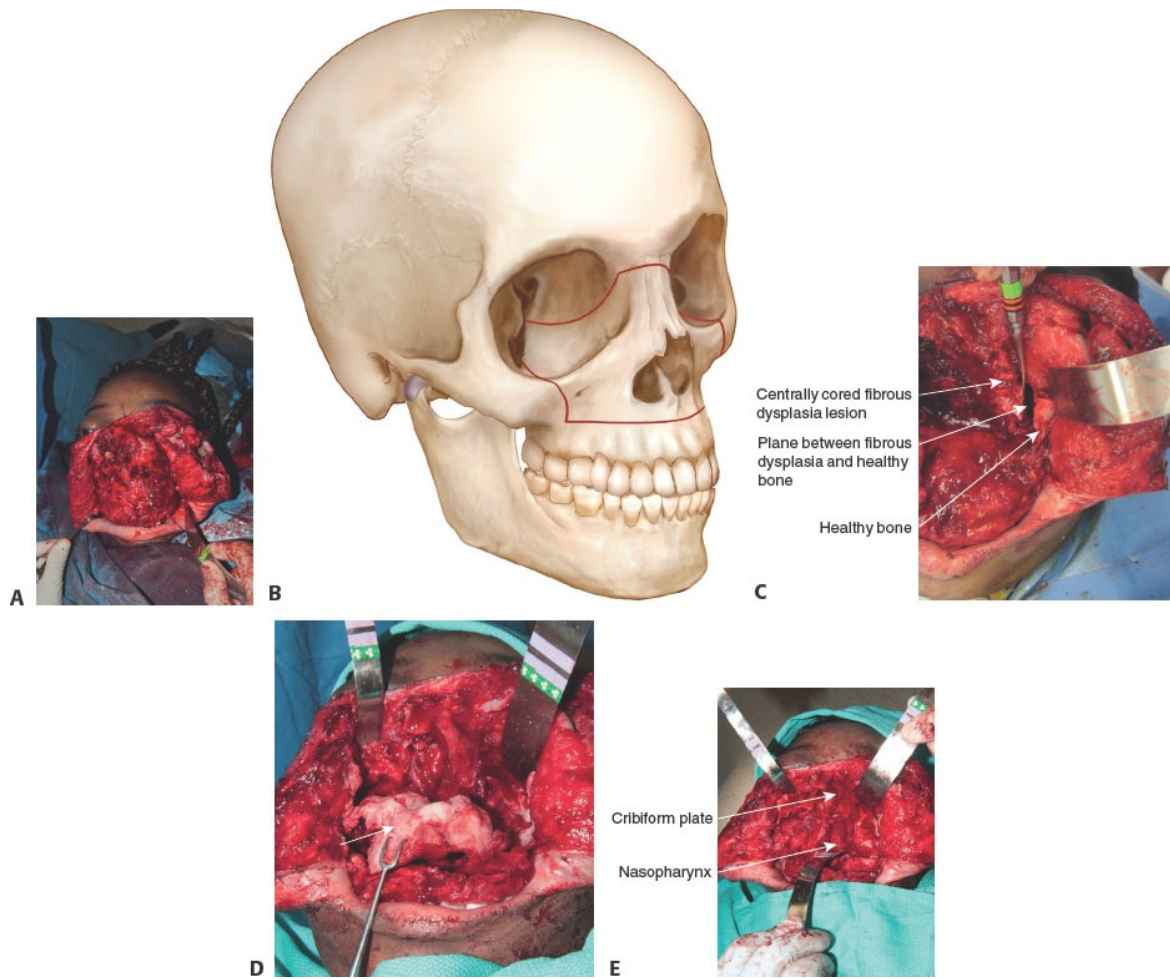


TECH FIG 2 • Weber Ferguson incision markings on the patient in **FIG 2**.

- The flap is then elevated using a no. 9 periosteal elevator in the subperiosteal plane, and the hemiface is retracted superolaterally. Identify the infraorbital nerve (ION), which is usually found 4 to 7 mm inferior to inferior orbital rim in line with the midpupil.
- The ION should be preserved if the lesion's location is medial to it. For more extensive lesions, the ION is scarified and dissection proceeds laterally until the FD is fully exposed.
- A subciliary incision can be added for further access. The skin is incised longitudinally 2 mm below the lash line. The pretarsal and some of preseptal orbicularis oculi muscle should be preserved to prevent postoperative ectropion.
- Sharp subcutaneous dissection is performed to raise the inferior skin flap over the muscle along the length of the incision. The muscle is transected at the level of the inferior orbital rim, and dissection proceeds until the periosteum to join the plane of the flap raised in the steps above.
- The arcus marginalis is released.
- The orbit is dissected with a Freer in a subperiosteal plane while protecting the globe with a malleable.

Resection

- With the entire lesion exposed, two approaches are available for complete excision (**TECH FIG 3A**).
- First, an en bloc resection can be performed with osteotomies carried peripheral to the FD lesion. The extent of resection varies depending on the size and location of the FD.
- For large and extensive inferior zone 1 lesions as demonstrated in this patient, resection begins superiorly by performing an osteotomy at the level of the nasofrontal suture using a reciprocating saw (**TECH FIG 3B**).
 - The position of the cribriform plate should be determined to avoid violating the intracranial cavity.
 - The osteotomy extends medially across the lacrimal and ethmoid bones and then extended laterally along the orbital floor using a 3-mm osteotome until the inferior orbital fissure is reached.
 - The globe is retracted and protected at all times with a malleable retractor.
 - Frequent communication between the anesthesiologist and surgeon is maintained to monitor for the oculocardiac reflex.
 - The zygoma is cut at the level of the body or arch with a reciprocating saw.
 - The osteotomy proceeds laterally along the lateral wall of the maxilla.
 - Inferiorly, the osteotomy should be at least 3 mm above the dental roots (as measured from preoperative CT or 30 mm from the crown of the canine) to preserve the native dentition, as reconstruction of this region is cumbersome, particularly in a growing child.
 - Osteotomy of the vomer is performed with a 5-mm osteotome from the nasofrontal suture, in a 45-degree posterior angle aiming toward the junction of the soft-hard palate.
 - The surgeon's nondominant hand is placed on the palate to prevent a full-thickness laceration.
 - Constant irrigation is performed during osteotomies to avoid thermal injury to the bone.
 - Once all osteotomies have been completed, the FD lesion is removed en bloc and hemostasis ensured using bipolar cautery, warm bone wax, and hemostatic agents such as Floseal.
- A second approach used by the senior author for very large lesions consists of centrally coring out the lesion and separating the FD from healthy bone along a well-defined plane. This technique is preferred with lesions abutting the cribriform plate as it may prevent the addition of an intracranial approach by limiting the extent of resection.



TECH FIG 3 • A. Raising of the flap is complete and the fibrous dysplasia lesion is completely exposed. **B.** Osteotomy lines for en bloc resection of a large bilateral lower zone 1 FD lesion as seen in our patient. The osteotomy begins superiorly at the level of the nasofrontal suture and extends medially across the lacrimal and ethmoid bones and then laterally along the orbital floor until the inferior orbital fissure. The zygoma is cut at the level of the body or arch, and the osteotomy proceeds laterally along the lateral wall of the maxilla. Inferiorly, it is important to keep the osteotomy at least 3 mm above the dental roots. **C.** After central coring of the lesion, a surgical plane is sought between the FD and healthy bone. **D.** Once

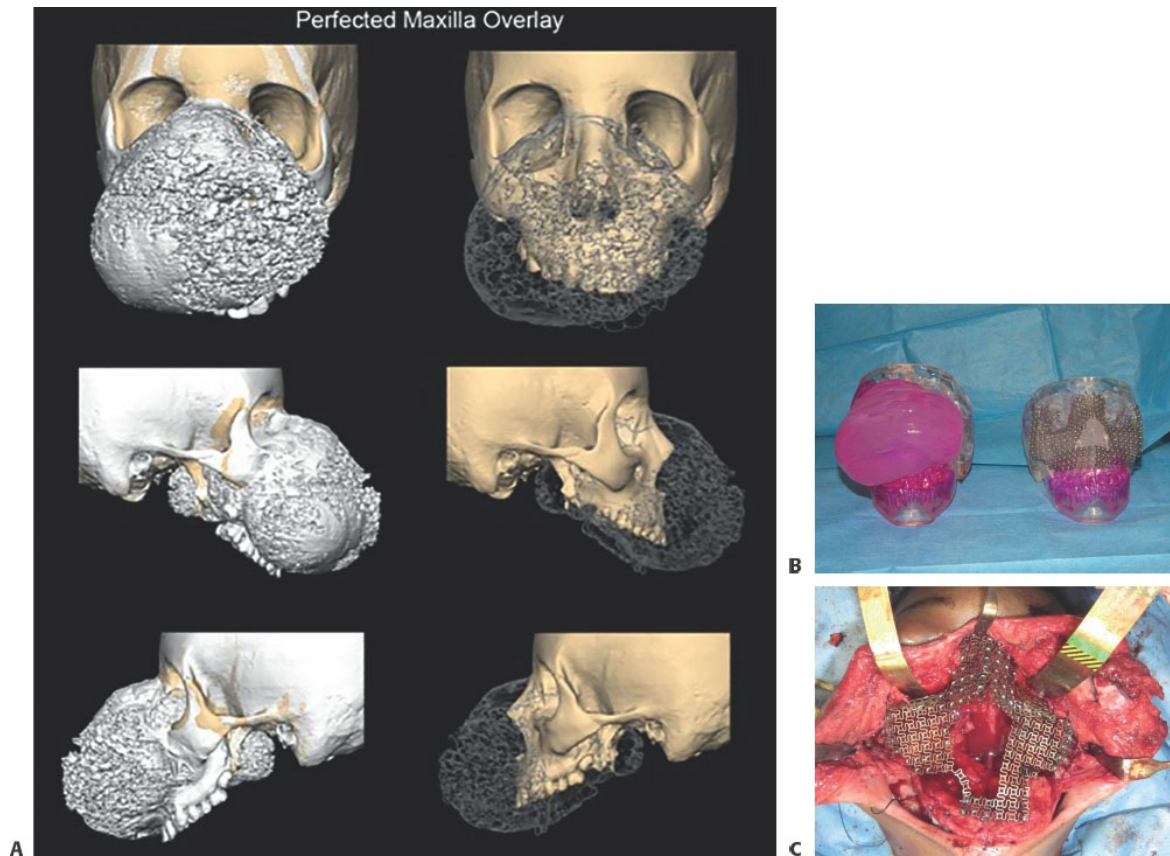
revealed, dissection proceeds along this distinct layer between the FD and healthy bone until the exophytic part of the lesion is removed (*arrow*) and the origin of the lesion identified. **E. Complete removal of FD lesion.**

- The exophytic core of the lesion is debulked using a reciprocating saw starting centrally and proceeding concentrically outward until the outer margin of the lesion is approached.
- At this stage, a surgical plane is sought between the FD and healthy bone. When present, the shell of the FD can collapse inward, revealing a distinct layer between the FD and healthy bone (**TECH FIG 3C,D**).
- Excision proceeds along this plane until the exophytic portion of the lesion is removed and the origin of the lesion identified. The latter is then burred until no dysplastic bone remains (**TECH FIG 3E**).
- In this case, the approach allowed removal of the FD lesion while sparing the cribriform plate and avoiding an intracranial approach.

Reconstruction

- Reconstruction of the midface must re-establish the normal skeletal anatomy. The horizontal buttress, vertical buttress, and nasal bone are essential to obtain normal projection and width of the midface.
- Reconstruction of the midface skeleton is performed preferentially with cranial bone graft. The bone grafts are harvested from the parietal cranium through a coronal or a sagittal incision, as described above.
- A perfected computer-aided design (CAD) 3D model of the patient's craniofacial skeleton can be ordered and printed with the midface segment virtually reconstructed (corrected to normal anatomy for patient age, race, and sex or a mirror image of the normal side when possible; **TECH FIG 4A**).
- The 3D model is used to shape the bone graft, bend the titanium plate (1.5-mm midface system), and facilitate positioning of the construct (**TECH FIG 4B**). This method of reconstruction increases symmetry and improves accuracy.
- Because of the expansile nature of this lesion and this patient's history of 10 previous debulking procedures, a 15 × 15 cm titanium mesh (1.0 mm thick) was bent on the corrected 3D model preoperatively.

- Independent mesh panels were used for both hemiface regions. The panels were sterilized for reconstruction.
- Bony construction was performed using large premolded titanium mesh, which was prepared prior to surgery and sterilized. This was done in order to preserve autologous reconstruction options in case of future recurrence.
- The prebent midface mesh panels were fixed to the zygoma, nasofrontal suture, and maxillary bone with multiple 4- to 6-mm screws (**TECH FIG 4C**).
- The orbital mesh was attached to the midface mesh with 28-gauge wires.
- An opening was made in the mesh to replicate the piriform aperture.
- For reconstruction of the orbital floor, titanium mesh was bent in a lazy S shape with extension to reconstruct the medial orbital wall. The mesh was fixed medially and superiorly to the frontal bone with 4-mm screws and laterally to the zygomatic bone.
- The medial canthal ligament is grasped with a 4-0 PDS (or canthal wire suture) in a figure-of-8 pattern and passed in a superior oblique vector across the mesh. A similar step is performed on the contralateral side. Both ends are tied together.



TECH FIG 4 • A. 3D CT perfected model with a virtually reconstructed midface segment corrected to normal anatomy for patient age, race, and sex. **B.** Once printed, the perfected 3D model is used to bend the titanium plates to the desired shape. **C.** Titanium meshes with medial extensions bent in a lazy S shape are used to reconstruct the orbital floors and medial walls bilaterally. These are fixed medially and superiorly to the frontal bone and laterally to the zygomatic bone. Two prebent midface mesh panels are then fixed to the zygoma, nasofrontal suture, and maxillary bone. **D.** Placement of SCBGs for reconstruction of large bilateral lower zone 1 defects. **E.** Closure of Weber Ferguson incision. Image of

patient in early postoperative period. **F.** Lateral view of patient in immediate postoperative period demonstrating adequate midface projection.

- The midface periosteum was suspended to the orbital rim with two 3-0 Vicryl sutures positioned at the level of the pupil and lateral canthus to prevent midface ptosis.
- A lateral canthoplasty was performed.
- Lacrimal duct system reconstruction was not performed but was delayed until a later stage.
- Strips of SCBG were used to reconstruct the orbital rim. The bone grafts were fixed with the 1.0- or 1.5-mm plating system using 4-mm screws.
- The orbital floor and medial wall are then reconstructed as described above with a titanium mesh or bone graft.
- The zygomatico-maxillary and nasomaxillary buttress are then reconstructed similarly with bone graft. These grafts are fixed with the 2.0-mm plating system.
- A cantilever bone graft was used to reproduce nasal contour and projection, secured to the frontal bone using miniscrew fixation (**TECH FIG 4D**).
- After ensuring hemostasis, closure begins with resuspension of the midface to avoid facial ptosis by reattaching the periosteum of the midface. At least two suspension sutures should be utilized, one at the level of the pupil and the second at the level of the lateral canthus. The sutures grasp the periosteum 3 cm inferior to the pupil and lateral canthus and suspend them to the orbital rim using 3-0 Vicryl sutures.
- The WF flap is then closed using standard two-layer closure using 3-0 Vicryl and 4-0 nylon (**TECH FIG 4E,F**).
- A lateral tarsorrhaphy suture is considered if the patient is likely to develop chemosis.
- Antibiotic ointment is placed over the incision line.

PEARLS AND PITFALLS

History and physical findings	■ Complete history and physical examination should be performed in order to differentiate between the various forms of FD (MFD, PFD, MAS). ■ Visual examination, including neuro-ophthalmological studies, should be obtained for lesions in zones 1 and 3.
Preoperative	■ High-resolution CT scan is the preferred imaging modality to plan for FD resection. 3D reconstruction can further assist in planning. ■ Bone biopsy and definitive pathological diagnosis are recommended prior to definitive surgical treatment when malignant fibrous dysplasia is suspected. ■ Medical therapy with bisphosphonates (ie, pamidronate) can be used as an adjunct to surgery, providing symptomatic relief for painful lesions.
Surgical management	■ Surgical management is the only definitive treatment modality and should be reserved for lesions causing pain unrelieved by medical therapy, significant aesthetic deformity, functional deficit (ie, optic nerve compression), rapidly growing lesions, recurrent lesions, or malignant transformation. ■ Surgical treatment should be deferred until growth of the lesion subsides and skeletal maturity. Shaving is recommended for growing lesions. ■ Optic nerve decompression should only be performed for symptomatic cases. Prophylactic decompression can be associated with severe complications such as blindness.
Technique	■ Goals of reconstruction include restoration of facial skeletal integrity, projection and symmetry (reconstruction of horizontal, vertical buttresses and nasal bone), globe position, and orbital volume. ■ A pericranial flap should be planned when anterior cranial fossa resection is planned in order to separate the nasal and cranial cavities. ■ Titanium mesh reconstruction should be used in orbital roof and anterior cranial fossa reconstruction as late bony absorption occurs with split cranial bone graft. ■ For large lesions, particularly in lower zone 1, central coring of the lesion should be attempted prior to en bloc resection, as a distinct plane may exist between FD and healthy bone, allowing to minimize the resection and potentially sparing an intracranial approach. ■ Inferior osteotomy for lesions in lower zone 1 should remain 3 mm above the dental routes when possible to preserve the native

dentition.

- The orbital contents and brain must be protected at all times using a malleable. Continuous irrigation should be used when using the reciprocating saw around these structures to avoid thermal injury to bone.
- Immediate reconstruction with SCBG is preferred; however, in cases of incomplete resection of growing lesions where recurrence is a concern, reconstruction can be temporized with a titanium mesh.

Postoperative

- Careful long-term postoperative follow-up is essential to survey recurrence. Annual CT scanning is recommended.

POSTOPERATIVE CARE

- ICU care is essential for intracranial resection or when airway swelling is expected.
- Visual assessment in the first 48 hours is performed every 4 hours while awake.
- Postoperative antibiotics for at least 24 hours are essential in the setting of intracranial resection.
- Lateral tarsorrhaphy sutures are removed when chemosis has resolved.
- Peridex mouth wash (TID and with oral intake) and teeth brushing are important in the 1st week following surgery.

OUTCOMES

- Careful long-term postoperative follow-up is essential to survey recurrence. **FIG 4** shows the patient 5 months following surgery.
- Annual clinical assessments and CT scanning are recommended.
- In a large series of pediatric CFD, the mean time to recurrence has been demonstrated to be 2.25 years.
- Recurrence rates are generally low and depend on several patient-specific and treatment-specific factors:^{15,16}
 - Time of intervention: Surgery before skeletal maturity is associated with a higher rate of recurrence.
 - Type of intervention: Debulking is associated with a higher rate of recurrence when compared to wide excision and reconstruction.
 - Type of lesion: Highest rates of recurrence are seen in patients with MAS, followed by PFD and MFD.

- Serum ALP has been demonstrated to be a useful marker to monitor for disease recurrence.
- Rising levels can be useful when malignant transformation is suspected.



FIG 4 • Anterior (**A**) and lateral (**B**) view of patient 1 year following surgery.

COMPLICATIONS

- General complications associated with operative management of FD in the craniofacial skeleton include bleeding/hematoma, surgical site infection, facial asymmetry, and recurrence.
- Zone 1
 - Superior sagittal sinus laceration
 - Dural tear/brain injury
 - Globe injury
 - Anterior cranial base fracture and communication between intracranial and nasal cavities
 - Meningitis
 - Optic nerve injury
 - Infraorbital or supraorbital nerve injury
 - Midface ptosis
 - Ectropion
 - Alopecia
- Zone 2
 - Superior sagittal sinus laceration
 - Dural tear/brain injury

- Zone 3
 - Optic nerve injury
 - Temporal hollowing
- Zone 4
 - Dental root injury
 - Inferior alveolar nerve injury

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Section V: Skull Defects

47 Autologous Bone Harvest to Correct Open Skull Defects

CHAPTER

Michael R. Pharaon

DEFINITION

- Skull defects can be congenital or acquired.
 - Congenital defects can be the result of encephalocele, cutis aplasia, or foramina parietalia permagna.
 - Acquired defects can be the result of trauma, tumor or tumor extension, osteomyelitis, bone flap loss, or persistent skull defects following surgery or prior cranioplasty.
- Skull defects can result in lack of bony protection to the brain, contour deformities resulting in visible defects, as well as visible pulsatile regions on the face that can cause significant body image concerns for the patients.^{1,2}

ANATOMY

- Layers of the scalp include the skin, galea aponeurosis, followed by a layer of loose connective areolar tissue, and the pericranium (periosteum).
- The mature skull consists of three distinct layers, the outer table, medullary cavity, and inner table.
- Deep to the skull is the endosteal layer of the dura mater.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Large skull defects are noticeable—particularly on the frontal and anterior temporal regions anterior to the hair line—due to the associated contour deformity. They may be associated with pulsatile movement of the overlying scalp.

- Skull defects posterior to the hairline may be palpable on exam, though not visually detectable.
- Bulging of soft tissue over a skull defect may be an indication of increased intracranial pressure. This is a particularly important finding in the setting of multisuture cranial synostosis with residual skull defects following prior cranioplasty and indicates the need for cranial vault expansion in addition to reconstruction of the skull defect.
- The soft tissue in the region of the bony defect should be evaluated. Evaluation should include assessment of prior surgical scars and evidence of previous radiation injury to the skin.
- The volume and contour of the soft tissue envelope over the calvarial defect should be evaluated. This is particularly important if the calvarial vault will undergo significant expansion with bony reconstruction. Expansion may result in inadequate soft tissue coverage over the bone grafts.¹

IMAGING

- A CT scan of the head and maxillofacial skeleton with fine cuts should be obtained for preoperative planning purposes.
- 3D reconstructions of the calvarium are used to visualize the defect and plan for reconstruction (**FIG 1**).

SURGICAL MANAGEMENT

- The goals of calvarial vault reconstruction are to provide adequate protection for intracranial structures and to re-establish an aesthetic cranial contour.

Preoperative Planning

- Preoperative CT scan with 3D reconstruction images should be reviewed.^{1–3}
- Location and size of the bony defect should be assessed.
- An appropriate calvarial donor site should be identified. Adequacy is determined by the presence of sufficient bicortical calvarial bone.
- If inadequate calvarial bone is available, iliac crest or split rib grafts should be considered.

Positioning

- The patient is placed in a supine or prone position, depending on location of the calvarial defect. A gel-padded Mayfield head rest (horseshoe) is positioned based on the location of the defect and bone graft donor site.

- If the patient is positioned prone, careful padding is required to avoid pressure on the globes.
- If a posterior calvarial donor site is planned for anterior bone grafting, the patient may require closure of the donor site and repositioning for access to the anterior calvarium.

Approach

- Surgical approach to the calvarial vault is typically performed via a bicoronal incision, which provides adequate access to the skull defect as well as to potential bone graft donor sites.
- A bicoronal incision can be modified based on prior surgical scars or if a noncalvarial donor site is planned.
- Transection of prior scars should be avoided because it compromises blood flow to the scalp.
- Iliac donor sites can be approached through either an anterior or a posterior approach.¹
- Split rib grafts are approached via a limited thoracotomy incision.⁴

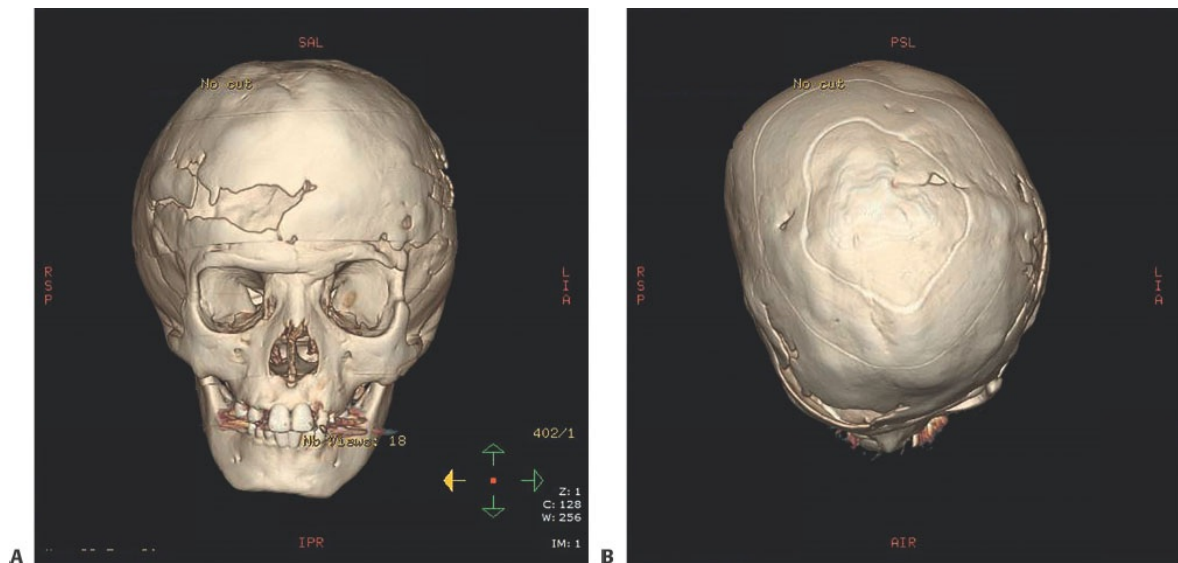


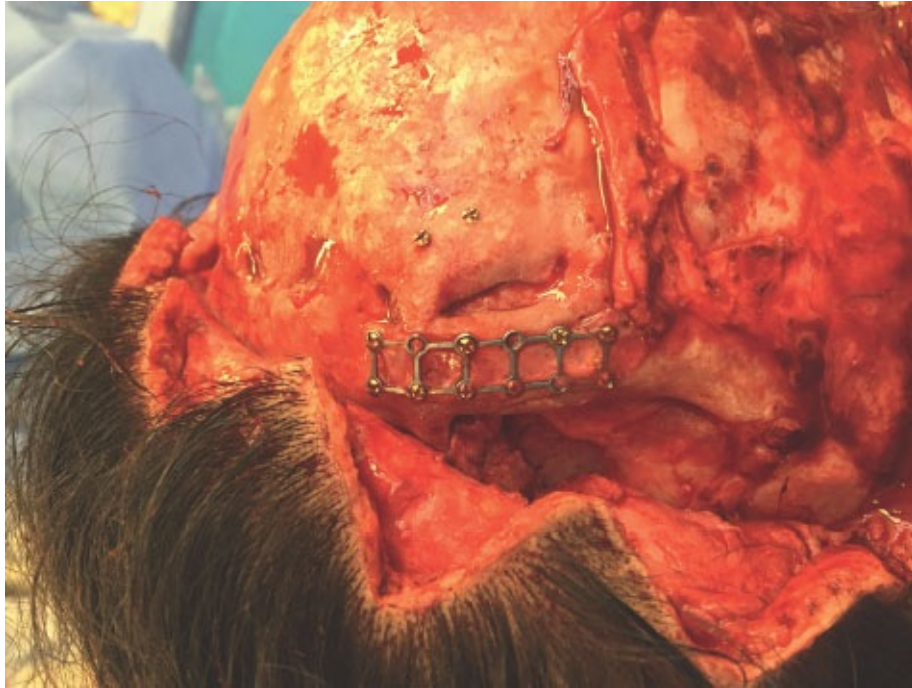
FIG 1 • Preoperative 3D CT scans of a patient with Saethre-Chotzen. **A.** The AP view demonstrates a right forehead skull defect and a left orbital rim defect. **B.** Right lateral view demonstrates the right lateral forehead defect. The parietal skull demonstrated

adequate thickness for split calvarial bone graft harvest.

TECHNIQUES

■ Preparation of the Skull Defect Site

- If no scalp scars are present, a zigzag bicoronal incision is marked.
 - If a pre-existing bicoronal scar is present, it is used as the incision (**TECH FIG 1**).
- A 1-cm-wide area of hair is trimmed on either side of the proposed incision.
- The hair is parted and secured with rubber bands.
- Along the incision line, the scalp is injected with 0.25% Marcaine with epinephrine, (1 cc/kg). If an infant is undergoing the procedure, the local anesthesia can be diluted with normal saline at a 1:1 ratio to increase the total volume injected.
- Bicoronal incision is made with Colorado tip Bovie cautery or scalpel.⁵ Scalp flaps are elevated in the subgaleal plane. In the region of the bony defect, avoid injuring the dura.
- In the region of planned osteotomies, including regions of split calvarial bone graft harvest, dissection is performed in the subperiosteal plane.
- With neurosurgery assistance, the soft tissues and dura are dissected away from the bony defect, and bone edges are debrided as necessary prior to harvesting bone graft material.



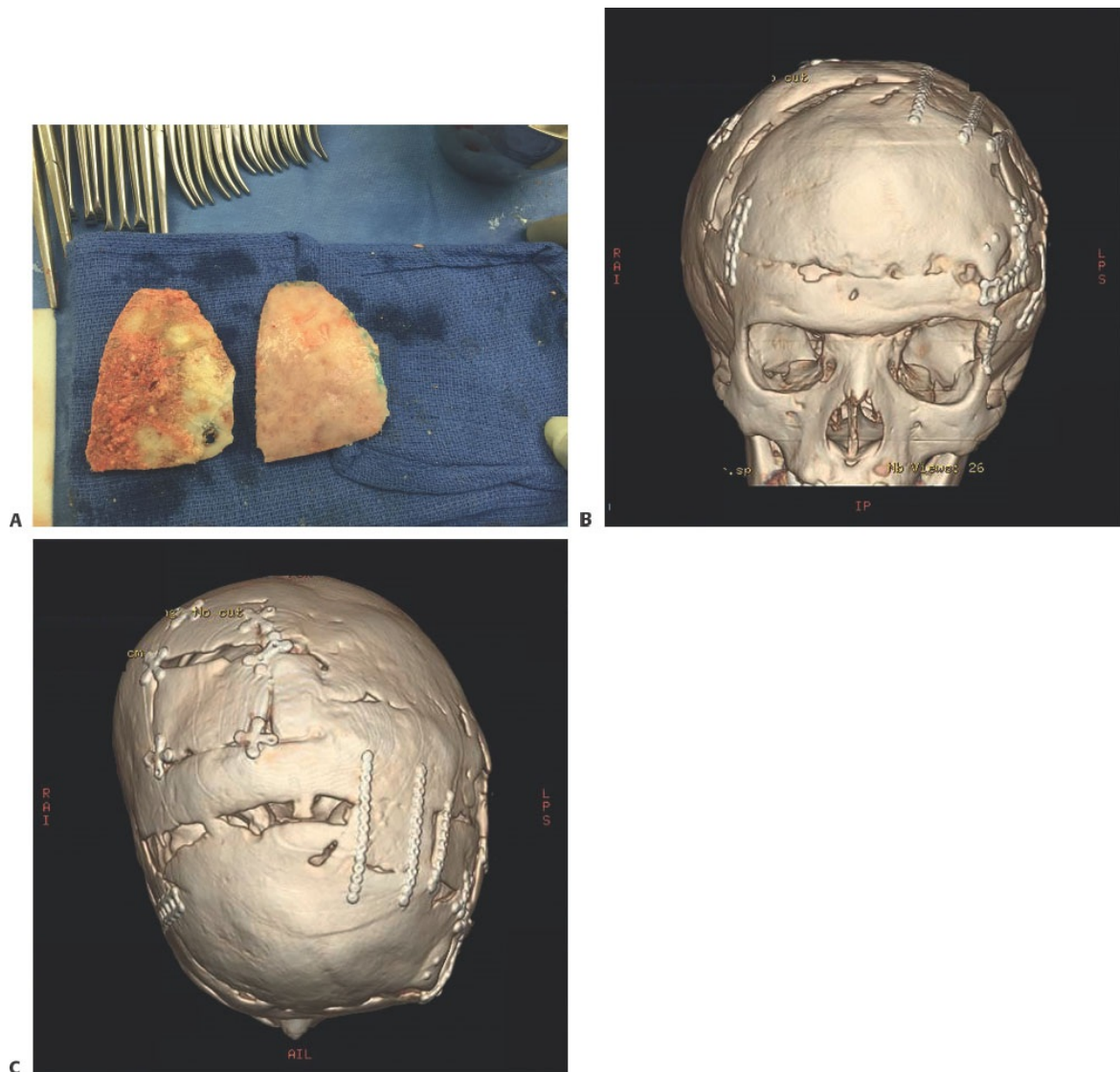
TECH FIG 1 • A prior zigzag bicoronal incision was used to access the calvarial vault. Note that this patient required hardware removal in addition to bone grafting to correct areas of bone reabsorption.

■ Split Calvarial Bone Graft

- The author prefers harvesting a full-thickness calvarial bone graft from the parietal calvarium with the assistance of neurosurgery (**TECH FIG 2A**).^{1,3}
- Once the full-thickness bone graft is harvested, it is split on the back table with the use of a reciprocating saw and a thin osteotome.
- The author prefers using the reciprocating saw along the borders of the full-thickness bone graft; the subsequent cleavage of the inner and outer tables is accomplished with the osteotome.^{1,3}
- If a large bone graft is harvested, it can be divided into smaller strips to facilitate separation of the inner and outer tables.
- The outer table is fixated at the donor site with plates and screws (**TECH FIG 2B,C**).
 - In the pediatric population, fixation is performed with resorbable plates and screws.⁶ In skeletally mature patients, either resorbable or titanium plates

and screws can be used to provide fixation.

- The inner table bone graft is then used to cover the calvarial defect and secured similarly.
- The scalp is reapproximated with transgaleal interrupted Vicryl sutures. (Typically, the author uses 3-0 and 4-0 Vicryl for pediatric patients and 2-0 and 3-0 Vicryl for adults.) The skin is reapproximated with a 5-0 Monocryl running baseball stitch or staples.
- The hair is washed with sterile saline and shampoo.
- The incision is dressed with bacitracin ointment followed by Xeroform sterile cotton fluffs, a sterile blue towel folded as a turban, and covered with burn stretch netting for gentle compression.



TECH FIG 2 • A. The inner (*left*) and outer (*right*) tables of split parietal calvarium were used to reconstruct the anterior calvarium. **B.** AP view CT scan demonstrating the reconstructed forehead following bifrontal craniotomy with rotation and readvancement of the left forehead with split calvarial bone grafting. **C.** Bird's eye view CT scan demonstrating the right parietal split calvarial bone graft donor sites and recipient sites in the left temple and orbital rim.

■ Iliac Crest Bone Graft

- The skin immediately lateral to the anterior superior iliac crest is retracted medially.
- A skin incision is then made over the iliac crest, with dissection through the subcutaneous tissue until the external oblique muscle fascia is encountered. The external oblique insertion is elevated in the subperiosteal plane from the iliac crest.
- On the internal iliac fossa, the iliacus muscle is elevated in the region of the planned bone graft harvest.
- Osteotomies are made with a reciprocating saw through a single cortex of the iliac bone. A right-angle reciprocating saw is used to cut the posterior aspect of the bone graft (**TECH FIG 3**).¹
- An osteotome is used to separate the medial cortex from the cancellous portion of the iliac bone.
- Thrombin-soaked Gelfoam is placed over the exposed cancellous bone. The iliacus muscle is resuspended over the iliac crest to the external oblique and tensor fascia lata.
- The subcutaneous tissue and skin is closed with resorbable sutures and the incision covered with Dermabond.

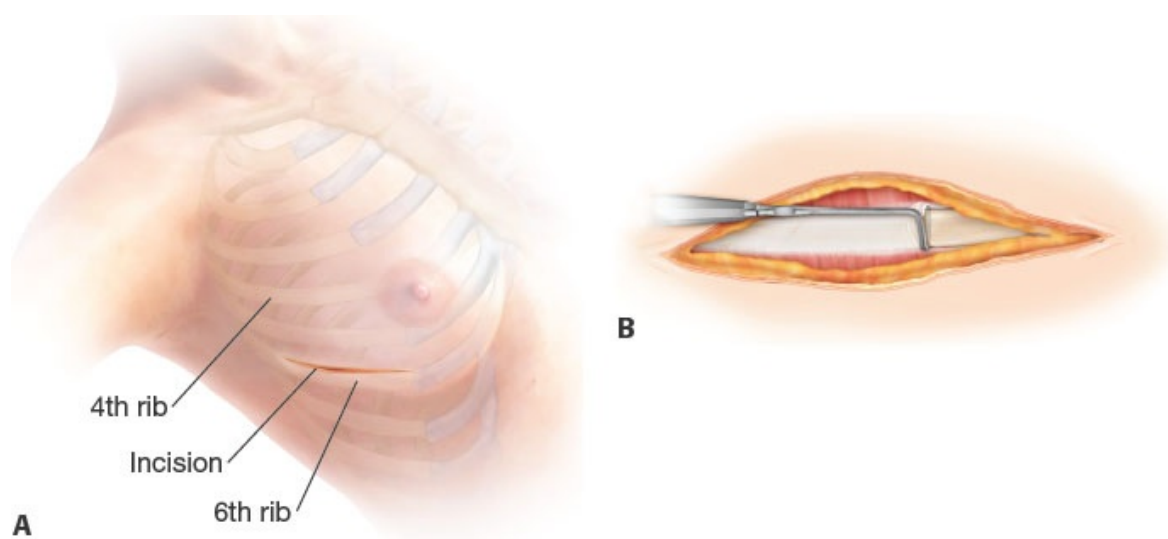


TECH FIG 3 • Harvest of iliac crest bone graft from iliac fossa via an anterior approach. Bone is harvested from the inner table with a variable amount of

cancellous bone.

■ Rib Graft

- The patient is placed in the supine position for smaller sized rib grafts. For larger grafts, the patient is placed in the lateral thoracotomy position.⁴
- The incision is planned at the level of the inframammary fold and extended posteriorly based upon the size of the graft.
- The incision is extended to the sixth rib. The periosteum is incised longitudinally and the rib bluntly dissected circumferentially from the periosteum. A rib periosteal stripper is used to release the posterior rib periosteum, without violation of the pleural space (**TECH FIG 4**).
 - Avoid injury to the subcostal neurovascular bundle.
- At the posterolateral aspect of the graft, the rib is divided with rib cutters.
- The rib is then elevated from lateral to medial ensuring that the pleura remains intact. Anteriorly, the rib is also divided with a rib cutter.
- The pleural lining is inspected for pleural tears. The dissection pocket is filled with sterile saline, and a Valsalva maneuver is performed to determine whether an air leak is present. If an air leak is noted, the pleura is repaired over a red rubber catheter. The catheter is removed at final wound closure during a Valsalva maneuver provided by the anesthesiologist. If no air leak is present, then the periosteum is reapproximated with 2-0 Vicryl suture, and the remaining wound is closed.
- If an additional rib is required, the fourth rib is harvested through the same incision in a similar manner. The fourth rib is harvested lateral and posterior to the breast.
- The soft tissues are then reapproximated with layered wound closure.



TECH FIG 4 • A. Rib graft harvest generally targets the sixth rib. **B.** A rib periosteal stripper is used to separate the posterior periosteum from the rib. The periosteum is repaired after removal of the rib.

PEARLS AND PITFALLS

CSF leak

- Dural tears need to be identified at the time of closure and repaired.
- Failure to recognize a CSF leak may lead to significant wound healing problems and necessitate return to the operating room.

Operative planning

- Careful preoperative planning is required to determine the size of required bone graft and donor-site availability.

Pneumothorax

- Postoperative chest x-rays are required if the pleural space is violated and repaired.
- Failure to treat an air leak following rib harvest can result in a postoperative tension pneumothorax.

Adjacent rib harvest

- Failure to harvest every other rib can result in paradoxical chest wall movement with inhalation.
- Leave an intact rib between harvested ribs (ie, fourth and sixth ribs with fifth rib intact).

POSTOPERATIVE CARE

- Perioperative systemic antibiotics are discontinued after 23 hours.
- The dressing is removed on postoperative day 2.
- Antibiotic ointment is continued on the incision for 1 week.
- The patient is allowed to shower on postoperative day 2.
- No swimming or contact sports for 4 weeks following surgery.

OUTCOMES

- The majority of patients undergoing reconstruction for calvarial defects with autologous bone reconstruction have satisfactory functional and aesthetic outcomes.
- Sahoo et al. demonstrated fewer complications with autologous reconstruction compared to all plastic materials.³

COMPLICATIONS

- Recipient site complications:⁷
 - Bone infection
 - Bone resorption⁸
 - Contour deformities
 - Recurrent skull defects
 - Prominence or exposure of titanium hardware
- Donor site complications:⁷
 - Seroma
 - Hematoma
 - Pneumothorax (rib)
 - Contour deformities
 - Paresthesias secondary to nerve injury
 - Gait disturbances
 - Fracture
 - Hernia
 - Injury to internal organs

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Section VI: Frontal Sinus

48

Frontal Sinus Cranialization

CHAPTER

Mohamad Masoumy, Prasanth Patcha, Robert C. Dinsmore,
and Jack C. Yu

DEFINITION

- Cranialization refers to the removal of the posterior table of the frontal sinus with occlusion of the inlet into the frontonasal ducts and allowing the neural structures, mainly frontal lobes of the brain and the intact dura, to move directly posterior to the anterior table of the frontal bone.
- Cranialization is performed in patients with frontal sinus fractures when the frontonasal duct drainage is interrupted and cannot be reconstituted even with intubation or endoscopic salvage procedures.^{1–4}
- Once frontonasal duct integrity is lost, the two surgical options are cranialization and obturation. Obturation is defined as filling of the frontal sinus with grafts, often consisting of adipose tissue. Both cranialization and obturation require the complete removal of sinus mucosa and closure of the cephalic part of the frontonasal duct with two key differences.
- In obturation, the posterior table must be preserved or restored. If there is any concern for CSF leak, remove the posterior table and inspect the dura for injury. During cranialization, the posterior table must be resected.

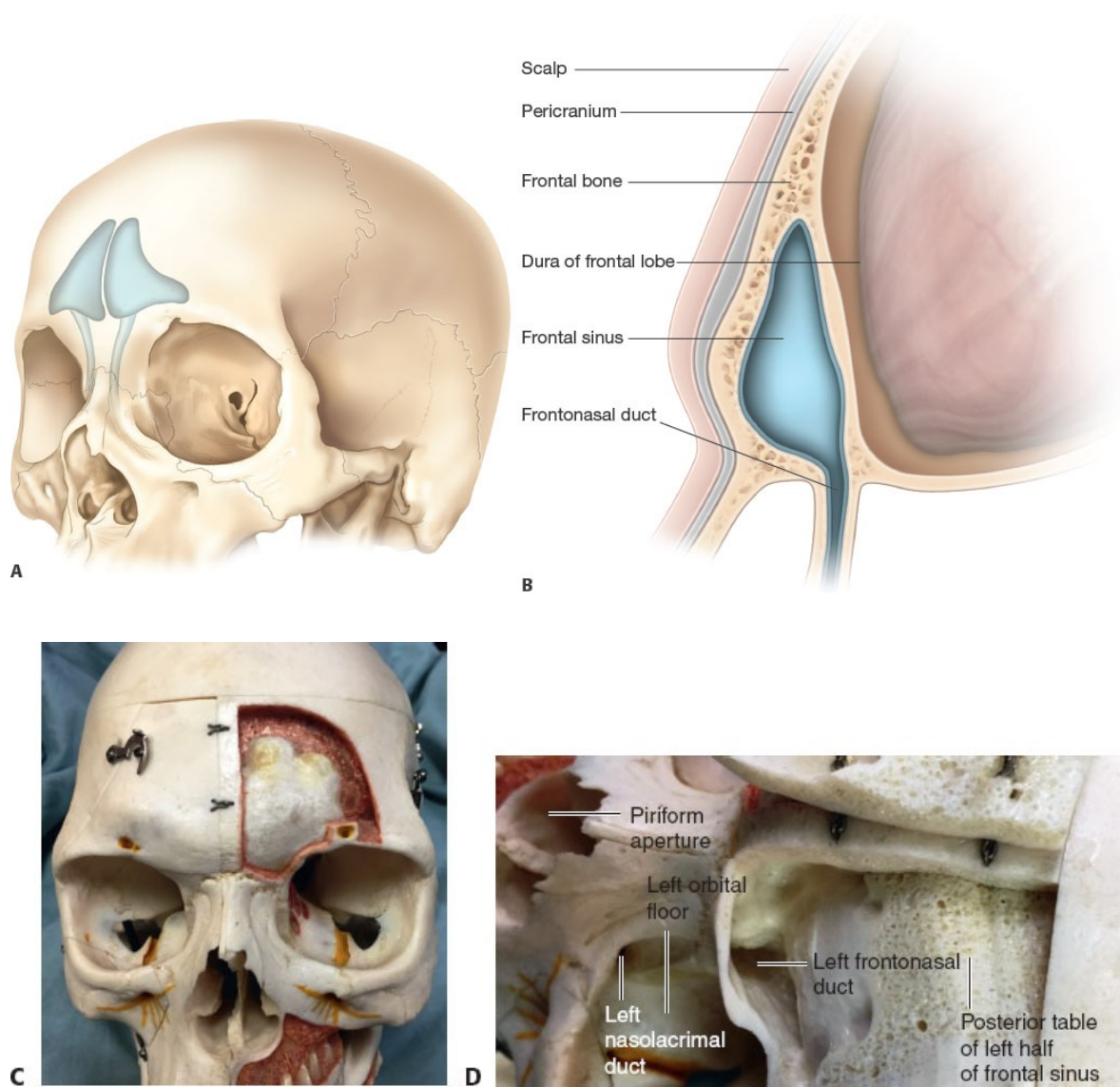


FIG 1 • A. Frontal sinuses in situ. **B.** Parasagittal section, normal anatomy. **C.** Supraorbital foramina (*arrows*) mark the lateral boundaries of the frontal sinus. The anterior table has been partially removed from the left half of the frontal sinus on this model. **D.** Anterior table of frontal sinus reflected.

- In obturation, bone, fat and other tissue are used to fill the frontal sinus space. In cranialization, this space is ultimately occupied by the brain and allows for brain edema without increased intracranial pressure; as the brain moves into this space, the anterior table of the frontal bone becomes the only bony layer

of the inferior anterior cranial vault.³

ANATOMY

- The frontal sinus is located in the lower 10% to 15% of the forehead and the width ranges from 2 cm to more than 10 cm. The supraorbital foramen can serve as an approximate indicator of the lateral extent of the frontal sinus. AP dimensions measure approximately 15 mm at the base with a gradual taper cephalically, extending 20 to 30 mm with a variable, scalloped border. Often a complete bony septum separates the sinus cavity into left and right compartments (**FIG 1**).
- Mucus-secreting respiratory mucosa completely lines the internal surface of the frontal sinus. The mucous drains through a funnel-shaped outlet leading into the frontonasal duct, which opens in the infundibulum of the middle meatus of the nose.
- Behind the posterior table is the triangular bony anchor of the falx cerebri, crista galli, bordered laterally by the cribriform plate of the ethmoid bone. The olfactory fibers exit the cranium into the most cephalic part of the nasal cavity to provide special visceral afferent innervations. Dural sleeves cover these olfactory fibers. In trauma, the laceration of these dural sleeves by bone fragments leads to CSF rhinorrhea.
- The anterior cranial fossa directly above the nasal cavity is and must remain completely sterile. Thus, the surgeon's primary objective in caring for patients with frontal sinus fractures is to restore this secure separation of the nose from the intracranial space to avoid infection from nasopharyngeal flora.

PATHOGENESIS

- During sudden compressive loading of the forehead, as in a blunt frontal impact, the anterior table will deform rapidly. If the strain exceeds the ultimate tensile strain of the bone, it fractures. Fracturing absorbs kinetic energy and greatly reduces force transmission, protecting the frontal lobe of the brain.
- Higher energy impacts can extend fractures across the apex and the floor of the sinus into the posterior table and the frontonasal duct.²
- Frontal sinus trauma resulting in severe and extensive fractures of the anterior and posterior tables frequently involves the frontonasal outflow tract.
- If there is greater than 25% disruption of the posterior table, cranialization should be considered.⁵
- Another indication for cranialization is for closure after anterior skull base

tumor surgeries or other craniotomy procedures involving the anterior vault.

NATURAL HISTORY

- Significant frontal sinus injuries involving the posterior table or frontonasal duct can lead to the complications of mucocele, mucopyocele, osteomyelitis, late CSF leak, meningitis, and cerebral abscess. Management via cranialization during the initial fracture can help to avoid these sequelae.^{1–8}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Blunt and penetrating traumas are often the cause of frontal sinus fractures. The patient may have a history of recent or remote trauma (**FIG 2**). In the setting of remote trauma, a high level of suspicion must be maintained for such sequelae as mucocele/mucopyocele, CSF leak (early or late), and osteomyelitis of the frontal bone.
- At the time of evaluation, assess contour abnormalities of the forehead, brow, and frontonasal region. Document presenting symptoms such as paresthesia, numbness, or paralysis. Furthermore, search for associated injuries of other facial regions, the cervical spine, brain, eyes, cranial nerves, and the major neck vessels. Advance Trauma Life Support protocols should always be followed.
- The initial note should document the patient's neurological status, olfaction, visual acuity, extraocular movements, pupil size and reactivity, rhinorrhea if present, maxillary and mandibular stability, occlusion, facial movements, and sensation. Cervical tenderness is important, especially if it is out of proportion to radiological or clinical findings. Lateral neck pain could represent carotidynia, a sign of carotid artery injury.

IMAGING

- CT imaging with thin-cut axial, coronal, sagittal with 3D reconstructions is the radiologic gold standard. These images evaluate both anterior and posterior table frontal sinus fractures as well as associated intracranial, facial, and spinal injuries (**FIG 3**).
- Some surgeons advocate intraoperative navigation using available CT data with a stable fiduciary and infrared multicamera system. The advances in stealth technology have rendered such guidance tools easier to use as well as simpler and faster to set up.
- 6-foot Caldwell x-ray with a coin reference is more of a historical relic to help

map the boundaries of the frontal sinus.³⁻⁵



FIG 2 • Massive craniofacial wound from shotgun blast at close range.

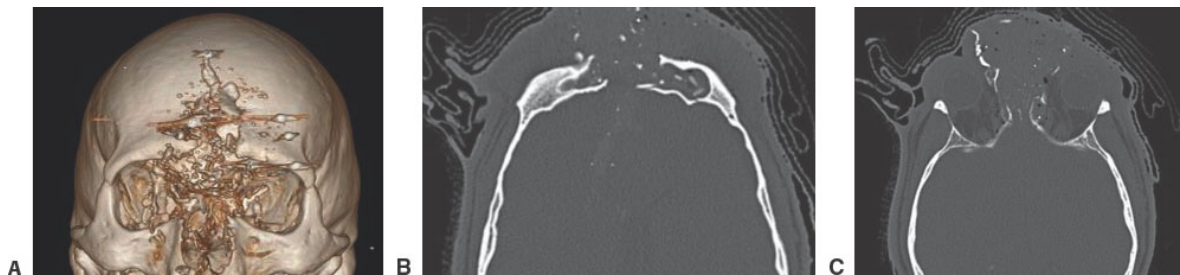


FIG 3 • **A.** 3D CT reconstruction demonstrating comminuted facial fractures with concomitant frontal sinus injury from the shotgun blast. **B.** Axial CT demonstrating massive injuries to the anterior and posterior tables of the frontal sinus with segmental bone loss. **C.** Axial CT image showing destruction of the frontonasal duct.

DIFFERENTIAL DIAGNOSIS

- Frontal sinus fractures need to be further characterized using the following variables to best guide treatment:
 - Extent of injury to the anterior and posterior tables including severity of displacement and comminution
 - The status of the frontonasal duct

- Dura integrity
- Status of the brain (see **FIG 3B,C**).^{3,4,6,7}

NONOPERATIVE MANAGEMENT

- Advise all patients to avoid pressurization of the nasal cavity and the paranasal sinuses. Instruct patients to sneeze through an open mouth and refrain from nose blowing to help prevent pressurization.
- Nonoperative management is not applicable for injuries that disrupt drainage from the frontal sinus via the frontonasal ducts, as inadequate drainage will inevitably result in mucocele formation and eventual infection.
- Posterior table fractures that are minimally or nondisplaced with intact frontonasal tract can be treated with simple ORIF of the anterior table if it is displaced. If the anterior table is not displaced, treatment with close observation is appropriate. If complications with frontal sinus drainage develop, salvage/drainage procedures can be performed endoscopically.^{3,4,6,7}

SURGICAL MANAGEMENT

- Main goals for cranialization
 - Removal of the posterior table
 - Repair of any dural lacerations
 - Removal of all sinus mucosa
 - Plugging the frontonasal outflow tract to create a secure barrier between the nasopharynx and the anterior cranial fossa
 - Correction of the frontal contour deformity¹⁻⁸

Preoperative Planning

- Obtain the necessary consults (neurosurgery, otolaryngology).
- Review risks (including acute and long-term complications), benefits, and expectations with patients on the day of surgery.
- Ensure coordination with the neurosurgical team and proper instrument availability for osteotomy and fixation techniques.

Positioning

- The patient is positioned supine with oral intubation and the table rotated 180 degrees.
- The patient's body can be tilted upward (30 to 40 degrees) and the neck retroflexed 15 to 20 degrees (when clinically feasible).

- The surgical preparation and draping should include the head and right lateral thigh for possible fat graft harvest.

Approach

- A coronal incision is used with various modifications taking into consideration hair pattern and density and exposure needs.

TECHNIQUES

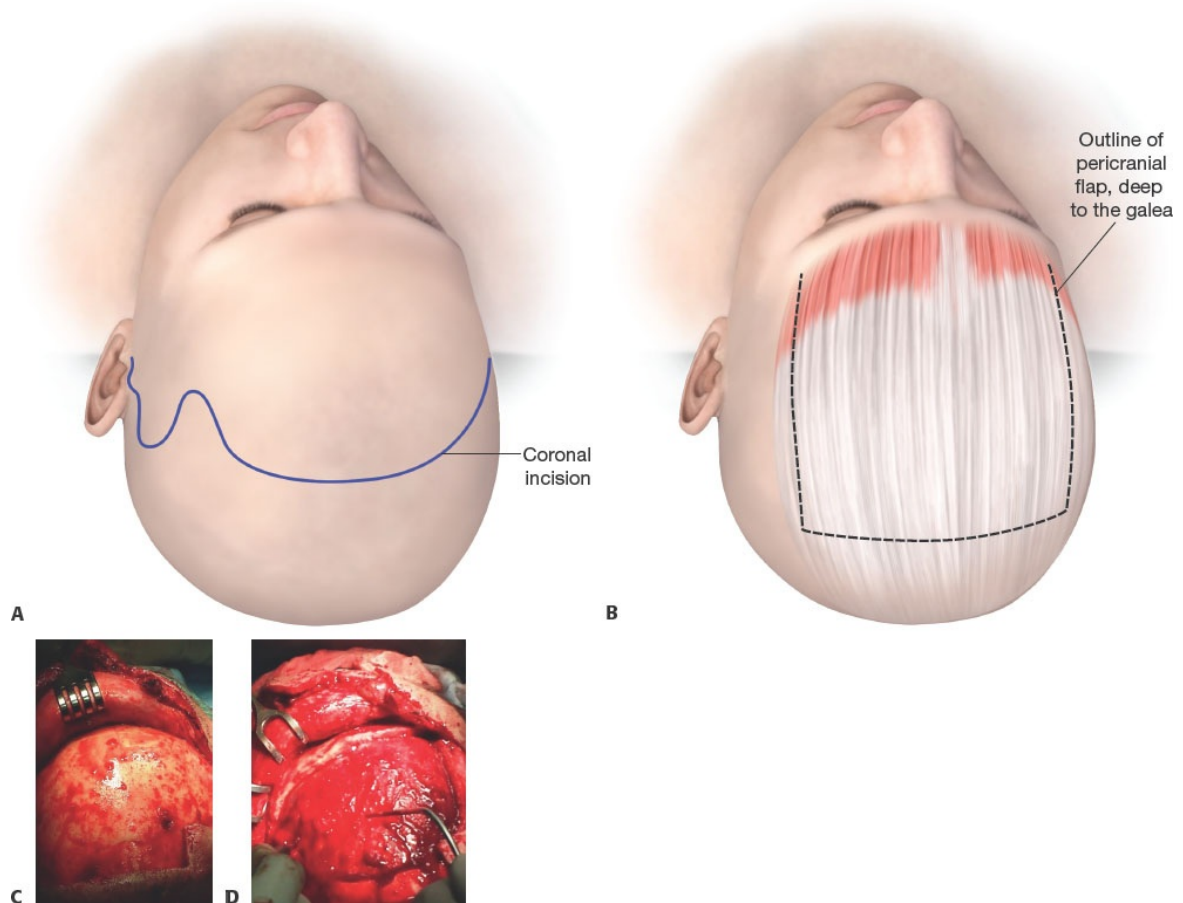
■ Preparation and Exposure

- The hairline in the forehead with lateral extension down to the preauricular areas is marked before shaving the hair back 1 to 2 cm.
- A standard coronal incision can be used for individuals with receding hairlines or baldness.
- Inject the planned incision site with 0.25% bupivacaine with 1:200 000 epinephrine.
- The entire face and the scalp are prepped and draped.
- Prep the abdomen if subcutaneous fat is to be used as graft.
 - Other potential donor sites are the right anterosuperior iliac crest with extension to lateral thigh or the right hemithorax if cortical-cancellous bone and fascial grafts are needed (**TECH FIG 1A**).
- The planned coronal incision is made sharply or with fine needle tip electrocautery to reduce bleeding.
 - To ensure sufficient length for the pericranial flap, the scalp can be dissected posteriorly in the subcutaneous plane for a significant length (6 to 8 cm or more if needed) before cutting through the galea while preserving the pericranium (**TECH FIG 1B**).
 - The anterior dissection then proceeds within this relatively avascular subgaleal, suprapariosteal plane until the superior orbital rims.
- The pericranial flap of the desired width and length is then marked, incised, and raised, from posterior toward the orbits.
 - Elevate the pericranial flap by incising the periosteum at the superior orbital rims. During this elevation, the supraorbital and supratrochlear neurovascular bundles located at the medial third of the superior orbital rim

must be carefully preserved as they provide the blood supply to the pericranial flap (**TECH FIG 1C**).

- If complete mobilization of the superior orbital nerve is needed, a 2-mm osteotome can be used to convert the foramen to a notch by cutting the most caudal part of the foramen medial and lateral to the neurovascular bundle.

The neurosurgery team then performs frontal craniotomy to provide access to the anterior cranial fossa; the frontal bone flap is a potential source of split-thickness cranial bone grafts (**TECH FIG 1D**).⁴

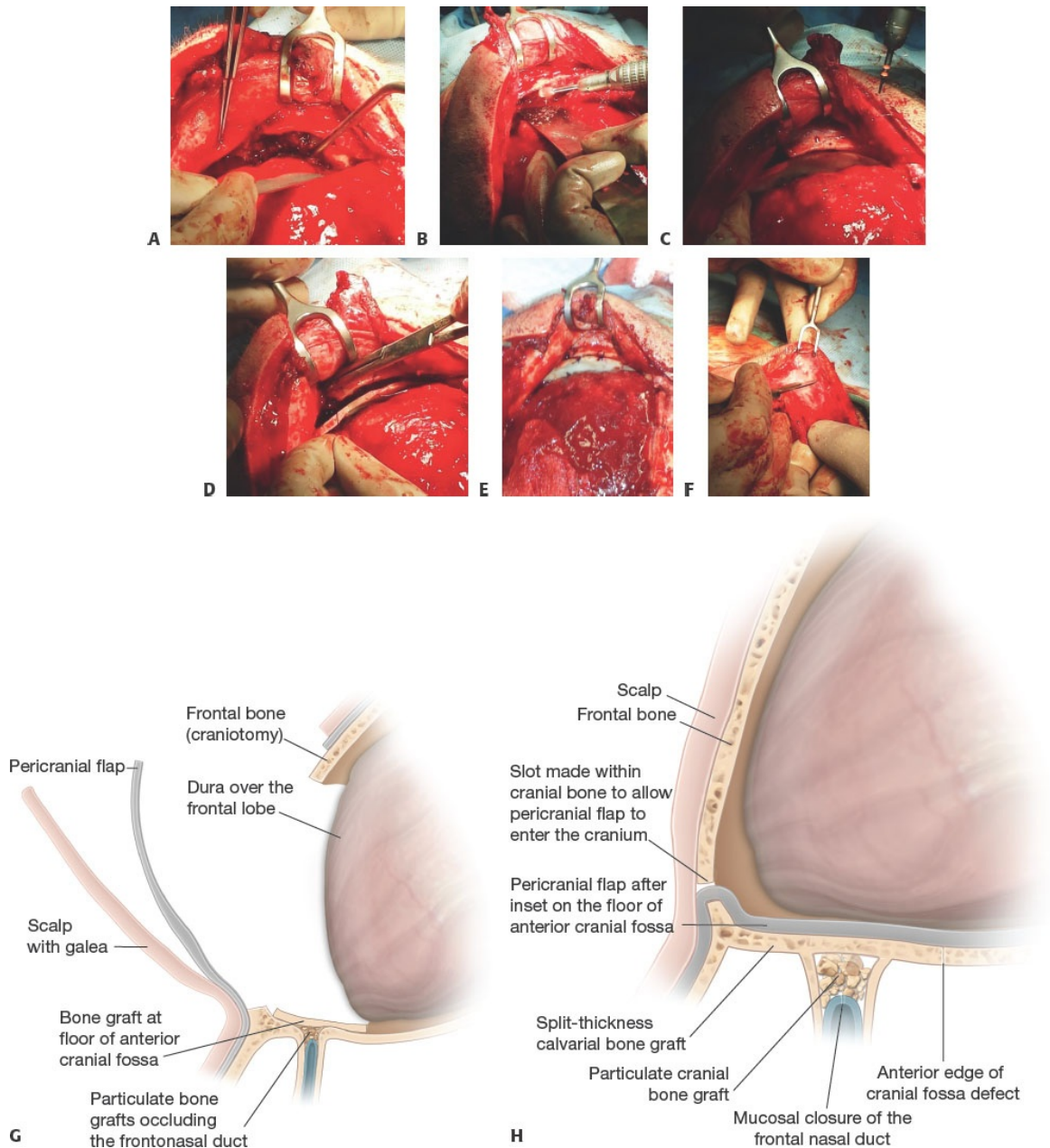


TECH FIG 1 • **A.** Planned incision for optimal exposure. **B.** Extent of planned pericranial flap that is anteriorly based. **C.** Coronal exposure to access frontal bone and sinus. Care is taken to avoid traction

injury to the supratrochlear and supraorbital neurovascular bundles. **D.** Frontal craniotomy performed with exposed dura.

■ Repair and Closure

- If the anterior table is intact, accurate ostomy and identification of the boundaries of the frontal sinus are paramount.
 - Techniques described include using bayonet forceps, transillumination, and intraoperative navigation or 5-foot Caldwell x-ray with coin reference.⁵
- After outlining the borders of the sinus, 1.5-mm plates are preapplied, spanning the margins prior to osteotomy allowing for accurate repositioning of the anterior table.
- The anterior table is then perforated with a sagittal saw or side-cutting bur; the hand piece should be angled at 45 degrees toward the sinus and away from the cranial vault to avoid violation of the posterior table.⁵
- There is often extensive fracturing of the anterior table. In these cases, label the frontal bone fragments before removing them to facilitate their reassembly and store them in moist gauze.
- Once the frontal sinus is exposed, the opening to the frontal nasal duct is inspected and the patency assessed by passing a 10- or 12-French red rubber tube for a distance of 7 to 10 cm (**TECH FIG 2A**).
- If the patency of the duct cannot be ensured, and the posterior table is also involved, remove the posterior wall and repair lacerations of the dura. This is usually performed by the neurosurgery team.^{1,2,4}
- Strip the frontal sinus mucosa completely and supplement by burring the irregularities on the internal bony surfaces of the frontal sinus (**TECH FIG 2B**).^{1,2,4,5}
- A cuff of mucosa at the most cranial end of the frontonasal duct is preserved and dissected free from the bony canal.
 - A purse-string suture of this mucosal cuff is placed to effectively seal off the frontal nasal duct. We suggest using 3-0 polyglactin on a small tapered needle.



TECH FIG 2 • A. With the dura retracted, the extent of the frontal sinus injury can be assessed. **B.** An egg-shaped bur is used to remove the mucosa of the frontal sinus. **C.** Split-thickness calvarial bone graft is used to reconstruct the floor of the anterior cranial fossa. Drill holes are made to allow fixation with absorbable 2-0 monofilament sutures. **D.** The split-thickness calvarial bone graft is secured in place to

reconstruct the floor of the anterior cranial fossa, forming a right angle joint posterior to the frontal bar. **E.** Split-thickness calvarial bone graft reconstructing the floor of the anterior cranial fossa after suture fixation. **F.** Elevation of pericranial flap from the deep surface of the coronal flap using a no. 15 scalpel. **G.** Elevating the pericranial flap. **H.** Completion of scalp closure.

- Pack particulate cortical-cancellous bone grafts above this closure to further re-enforce the separation. Any defect of the frontal sinus floor is reconstructed with split-thickness cranial bone grafts.
 - Two small holes are drilled on the posterior edge of the bone graft with a 3-0 PDS placed through them as a loop. These loops will provide a posterior anchor to the pericranial flap.
 - The posterior wall of the frontal sinus is completely removed, creating a smooth continuous floor of the anterior cranial fossa (**TECH FIG 2C–E**).
 - Introduce the pericranial flap into the intracranial space, lining the floor of the anterior cranial fossa. Secure the posterior extent of the pericranial flap with a 3-0 PDS loop on the posterior edge of the bone graft on the floor.
 - A 4 mm horizontal slot is made in the frontal bone to accommodate the base of the pericranial flap.
 - After inseting the flap, access to the orbital rims or the orbits themselves will be impossible. It is therefore critically important that all the work in the orbits and supraorbital rims is complete prior to inseting the pericranial flap (**TECH FIG 2F**).
 - Reassemble frontal bone fragments with care taken to remove all the mucosal tissue. The frontal craniotomy is then repaired using 3-0 PDS, plates, and screws as needed.
 - Close the deep dermis using 3-0 polyglactin and the scalp with suture or staples.
 - Drains are used in some cases, with care taken to assure that unimpeded removal can occur (**TECH FIG 2G,H**).
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PEARLS AND PITFALLS

Physical findings

- Search for and document any CSF leak or entrapment of mucosa within the intracranial space.^{1,2,4,5}
- Carefully examine for concomitant injuries and identify any numbness or paresthesia of the forehead indicating possible supraorbital and supratrochlear nerve injuries.
- Supraorbital foramen marks the lateral extent of frontal sinus.

Technique

- Bevel the incision to ensure that it travels parallel to the hair follicles to avoid alopecia.
- Once the level of the temporal line is reached, dissection should be carried deep to the superficial layer of the deep fascia to avoid transection of the temporal-zygomatic branch of the facial nerve.⁴
- Avoid raising the temporal fat pad, which devascularizes the fat pad leading to temporal wasting.⁵
- It is easier to dissect in the suprapericranial plane, leaving the pericranium on bone and then raising it as a separate layer in a second step.
- Remove all mucosa to avoid the formation of a mucocele.
- Watertight dural repair is of principal importance to help avoid CSF leaks and ascending infections from sinus spaces.
- Sufficient space between the frontal bone and supraorbital bar must be present to allow the pericranial flap to enter the intracranial space.

Postoperative

- Have a high index of suspicion to identify complications such as meningitis, mucocele, or mucopyocele leading to osteomyelitis.

POSTOPERATIVE CARE

- Immediate postoperative care should include evaluations of the neurological, visual, and olfactory systems.
- Patients should avoid nose blowing for at least 4 weeks following frontal sinus surgery.
- No aspirin for a week and avoid NSAIDs.
- Some surgeons may advocate steroid use for severe orbital trauma to help with postoperative edema; however, this must be balanced with the risk of complications related to perioperative steroids.

- Postoperative CT is recommended to assess complex fracture reductions.
- The scalp can be washed by postoperative day 5.
- Clinical follow-up should include counseling about signs and symptoms of complications, and patients should understand that these complications might occur years after the original trauma.^{1,6,7}

OUTCOMES

- Overall, cranialization has a very high success rate at preventing complications in both the short and long term after severe traumatic frontal sinus fractures and frontonasal duct disruption.
- One study of 72 patients with frontal sinus fractures reports a 6% mucocele rate. However, of the 30 patients who were treated with cranialization, none developed a mucocele.⁹ This prevention also helps avoid complications of mucopyocele, meningitis, and osteomyelitis.
- Overall, long-term studies after frontal sinus fractures are lacking because patients tend to have poor follow-up unless complications arise. Conservative observation has also been advocated in specific instances of limited CSF leak or when endoscopic measures can be used to temporize or relieve frontonasal obstructions.^{6,7,10}

COMPLICATIONS

- If all mucosal lining is not removed, the patient is at risk of developing a mucocele, which may progress to a mucopyocele and frontal bone osteomyelitis (a condition known as Pott puffy tumor) and subsequent brain abscess.^{2,3}
- A CSF leak may occur with unrecognized or incompletely repaired dural injuries.
 - Manage this injury with packing, bed rest, lumbar drain, endoscopic endonasal management, and revision surgery.
- Meningitis



FIG 4 • Intermediate postoperative photo showing the frontonasal region.

- Injury to the temporal-zygomatic branch of the facial nerve leading to ipsilateral forehead paralysis
- Hollowing of the temporal region secondary to excessive disruption of the temporal fat pad
- Widened scar from the coronal incision
- Chronic/severe frontal pain (**FIG 4**)

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49 Frontal Sinus Obliteration with Fat

CHAPTER

Matthew M. Smith and Alessandro de Alarcon

DEFINITION

- Obliteration of the frontal sinus is the process of replacing a diseased frontal sinus that is normally air-filled.
- The diseased frontal sinus is obliterated with another material, such as fat.

ANATOMY

- The midface is made up of five paired paranasal sinuses (maxillary, anterior ethmoid, posterior ethmoid, sphenoid, and frontal)
- The boundaries of the frontal sinus are as follows:
 - Anterior: Anterior wall of the frontal sinus
 - Posterior: Posterior wall of the frontal sinus and anterior cranial fossa
 - Inferior: Orbit
- The anterior wall of the frontal sinus is significantly thicker than the posterior wall.
- The frontal sinus is the last paranasal sinus to develop and usually begins to pneumatize around 6 years of age (**FIG 1**).
- It is innervated by the supraorbital and supratrochlear nerves, which are branches of the first branch of the trigeminal nerve (V1).

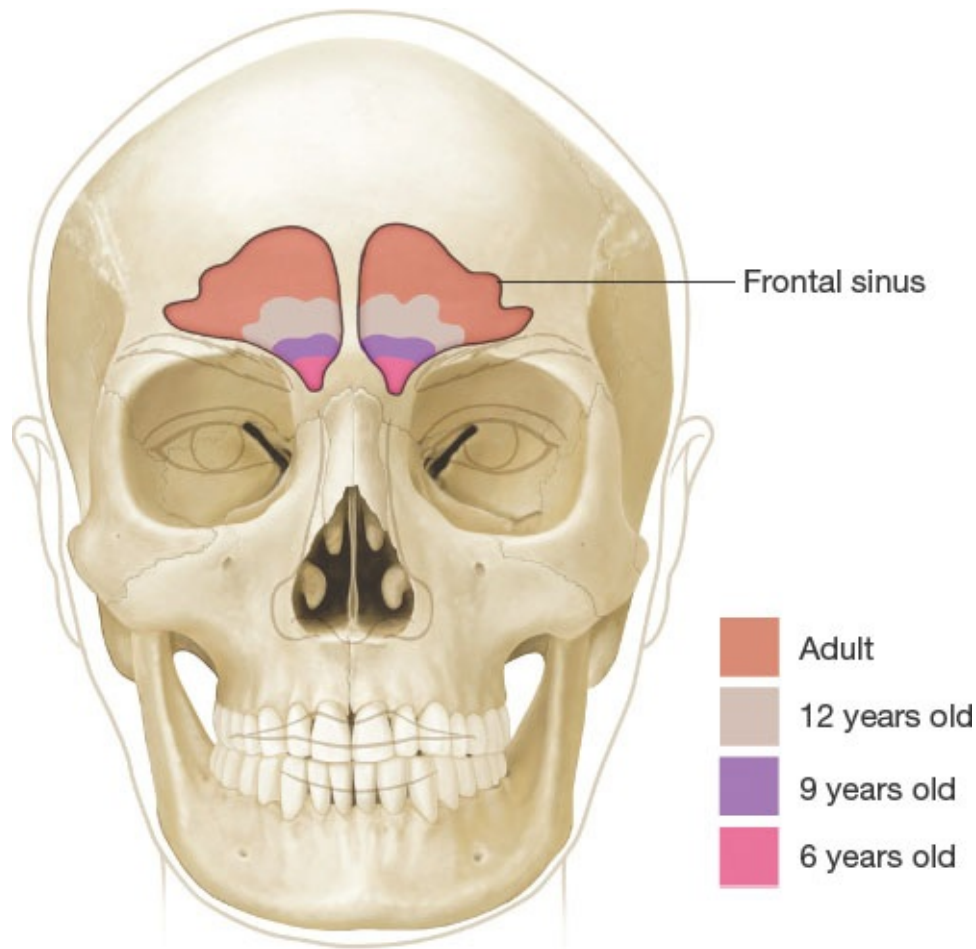


FIG 1 • Growth of the frontal sinus.

- The frontal sinus drains into the middle meatus via the hourglass-shaped frontal sinus outflow tract. The boundaries of the frontal sinus outflow tract are as follows:
 - Anterior: Nasofrontal bar, agger nasi cell
 - Posteroinferior: Ethmoid bulla
 - Posterosuperior: Anterior cranial fossa
 - Medial: Middle turbinate
 - Lateral: Lamina papyracea

PATHOGENESIS

- Frontal sinus injury is the primary indication for frontal sinus obliteration.
 - Chronic frontal sinusitis secondary to obstruction of the frontal sinus outflow tract.
 - Prior frontal sinus surgery with subsequent mucocele formation.

- Frontal sinus malignancy with subsequent need for obliteration after resection of tumor.
- Direct forehead trauma with subsequent frontal sinus wall fractures.
 - Isolated anterior frontal sinus wall fractures with displacement and nondisplaced posterior wall frontal sinus fractures without CSF leak are the most amenable to frontal sinus obliteration.
 - Displacement of the posterior frontal sinus wall and/or CSF leak is more frequently treated with cranialization of the frontal sinus rather than obliteration.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history for each patient will be directed toward the proposed cause of his or her frontal sinus problem.
- For all patients, it is important to obtain history regarding changes in vision, mechanism of frontal sinus injury (chronic inflammatory, traumatic), nasal obstruction, persistent clear rhinorrhea, purulent rhinorrhea, fevers, headaches, swelling of the forehead, changes or lack of smell, prior sinus surgeries, and symptoms of meningitis.
- A complete visual examination should be performed, including visual acuity, visual fields, pupillary reflex, accommodation, and extraocular movements.
- Anterior rhinoscopy should be used to examine the nasal cavities for any evidence of trauma, CSF leak (clear rhinorrhea), or malignancy prior to frontal sinus surgical intervention.
- Nasal endoscopy is not needed to view the frontal sinus prior to surgery but is useful if the patient has had prior surgery and allows the frontal sinus outflow tract to be easily viewed with an angled endoscope (45 or 70 degree).
- If the patient has symptoms of persistent or intermittent clear rhinorrhea, the patient should be instructed to sit in a sniffing position for 3 minutes with a small basin or cup to collect the clear nasal drainage. This fluid can then be sent for examination of beta-2-transferrin for confirmation of CSF leak.
- For those patients with a history of traumatic frontal sinus fracture, the evaluation for potential foreign bodies within the frontal sinus and other craniofacial fractures should be completed.

IMAGING

- CT scan of the sinuses is paramount for the bony framework of the frontal sinuses.

- Axial, sagittal, and coronal views should all be obtained to fully view the frontal sinus in different planes (**FIG 2A,B**).
- 0.5-mm cuts should be obtained in order to detect small defects in the frontal sinus.
- 3D reconstruction of the frontal sinus can be obtained and is helpful, but not necessary.
- Historically a 6-foot Caldwell view with an AP x-ray of the head was obtained. A quarter was placed over the patient's forehead during the x-ray to create an image that could then be laid over the patient for an actual size of the frontal sinus.
- MRI with contrast should be obtained prior to surgery if violation of the posterior frontal wall is suspected to ensure there is no evidence of an encephalocele and to further evaluate the surrounding soft tissues (**FIG 2C**).

DIFFERENTIAL DIAGNOSIS

- Chronic frontal sinusitis
- Pott puffy tumor
- Frontal sinus mucocele
- Frontal sinus fracture
- Encephalocele
- Frontal sinus malignancy

NONOPERATIVE MANAGEMENT

- For nondisplaced fractures of the anterior frontal sinus, observation is an option, but with any type of mucosal disruption, the patient will be at risk for mucocele or mucopyocele.
- Endoscopic management of the frontal sinus may also be explored for chronic frontal sinusitis and is frequently used as first-line treatment.

SURGICAL MANAGEMENT

Preoperative Planning

- All imaging must be reviewed prior to surgery to obtain a proper road map of the frontal sinus.
 - Evaluate for presence of anterior and posterior table fractures.
 - Evaluate for possible anterior cranial fossa communication/involvement.
- If there is any concern for CSF leak, attempts should be made to collect clear

rhinorrhea for beta-2-transferrin examination.

- If enough fluid cannot be collected for examination, a gross evaluation of the fluid can be performed by placing a few drops of the drainage on a white sheet and looking for a “halo sign.”
- A collection of blood in the middle with a clear ring of surrounding fluid is indicative of CSF.
- Preoperative discussion with the patient and family regarding the extensive nature of the coronal incision should be performed.
- Antibiotics should be given prior to surgical intervention.
 - Cefazolin, clindamycin, and ampicillin-sulbactam are all appropriate choices.
 - If the patient has a history of MRSA, then vancomycin should be added to the antibiotic regimen.

Positioning

- Patients are placed supine on the operating room table.
- If a neurosurgical team is involved with the operation, then fixation in a Mayfield retractor will be used with removal of the headboard. Otherwise, the patient’s head is placed on a foam donut and positioned in a neutral position.

Approach

- The primary approach to open frontal sinus obliteration is through a coronal incision.
- Endoscopic approaches to the frontal sinus (first reported in 2005) are feasible but should only be considered in chronic frontal sinusitis.¹



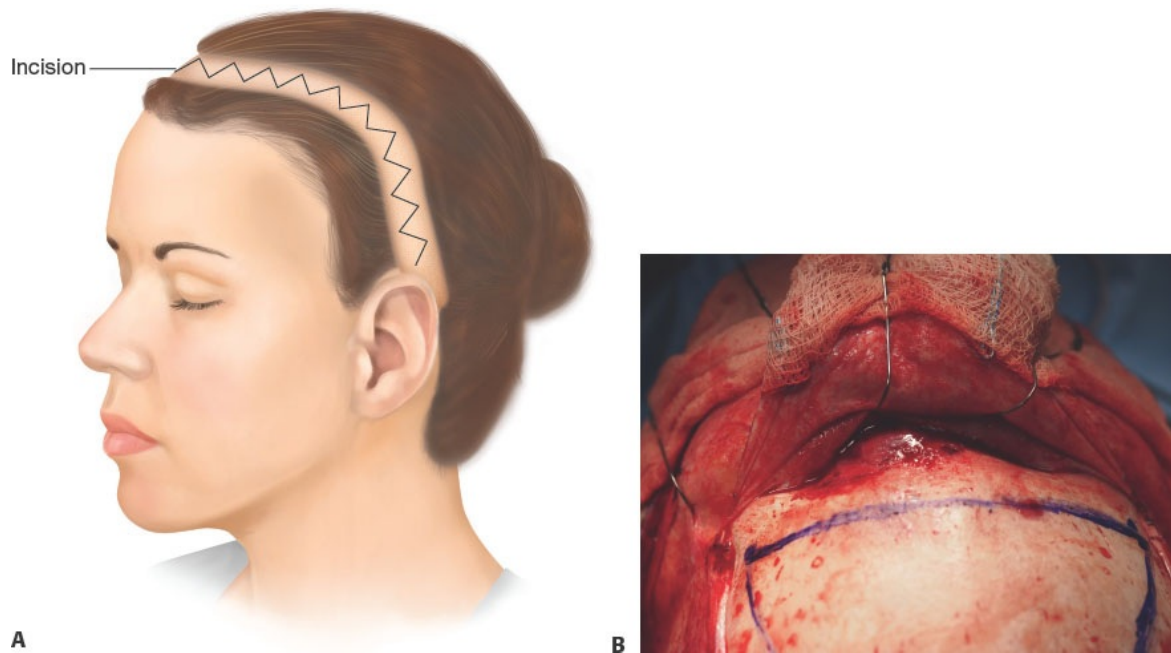
FIG 2 • **A.** Coronal CT showing bone window. **B.** Sagittal CT showing bone window. **C.** Sagittal MRI T2 sequence.

TECHNIQUES

■ Open Coronal Approach to Frontal Sinus Obliteration

Preparation and Exposure

- The eyes are coated with optical lubricant and then either covered with a clear dressing or sutured together by performing a tarsorrhaphy with a 5-0 or 6-0 monofilament colored suture (preferably blue or green so as not to blend in with eyelashes).
- A small strip of hair is cut with clippers where the planned coronal incision is to be placed (**TECH FIG 1A**).
- A clear plastic drape can be placed over the upper lip to separate the oral cavity from the surgical field.
- Stereotactic navigation is then calibrated if used during the case.
- The face and scalp are prepped with iodine solution and draped with full view of the anterior scalp, forehead, and upper face (including eyes and nose).
- The abdomen is then prepped over the periumbilical area for fat harvest and draped with blue towels.
 - This area is covered with surgical drapes and marked for the subsequent abdominal fat harvest. The surgical drapes can be cut with scissors for access to the already prepped abdomen.
- A coronal incision is made from temporal line to temporal line, just anterior to the helical crus.
 - For improved appearance, the incision line is hidden within the hair line and may be staggered in a saw-toothed fashion.
- The incision is taken down to the periosteum exposing the frontal bone completely.
- Using the stereotactic navigation, the frontal sinus is then outlined for the proposed bony incisions.
- The periosteum of the frontal bone is elevated with a Freer elevator over the planned incision, leaving it pedicled anteroinferiorly over the brow line (**TECH FIG 1B**).



TECH FIG 1 • A. Planned sawtooth coronal incision with hair removed from suture line. **B.** Purple marker outlines planned osteoplastic flap. The periosteal flap has been elevated and is pedicled anteroinferiorly and is retracted with hook retractors.

- The frontal osteoplastic bone flap is then created using a reciprocating or oscillating saw over the previously planned outline of the frontal sinus.
- A high-speed cutting drill may be used instead but can result in increased injury to the edges of the bone flap.
- If there was a previous fracture in the anterior table of the frontal sinus, then this can serve as one or all of the planned cuts into the frontal sinus.
- After the circumferential cuts are made, the only piece of bone that should be left attached is the frontal intersinus septum, which is removed with a reciprocating saw, an oscillating saw, a drill using a round drill bit, or an osteotome.
- The frontal osteoplastic flap is then wrapped in saline-soaked gauze and placed on the back table for later use.

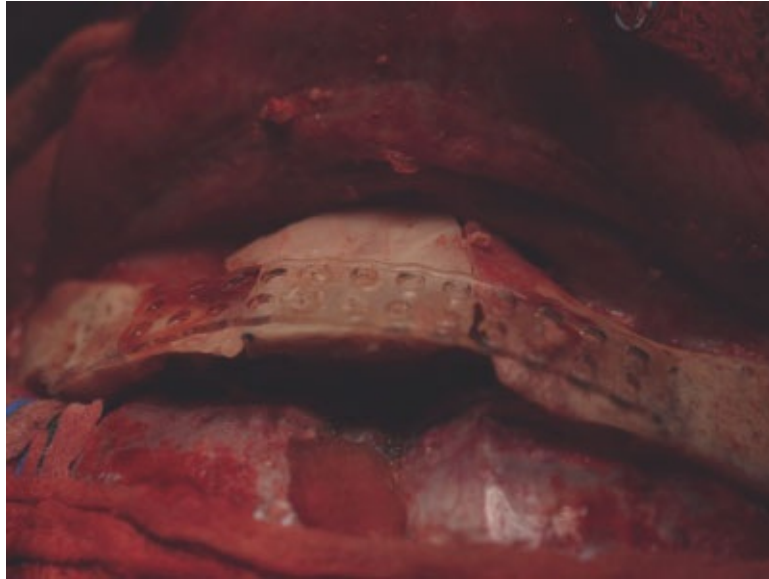
Obliteration of the Sinus with Fat

- If an infectious etiology has been identified, cultures are obtained immediately upon entry to the sinus.

- The frontal sinus lining mucosa is then completely removed using forceps.
- A high-speed drill with a diamond bur is then used to smooth the inner edges of the sinus to remove all microscopic areas of mucosa. This is also used to smooth any bony spicules or ledges.
 - We recommend using loupe magnification or the assistance of angled endoscopes to ensure that all of the mucosa is removed and bony edges are smooth.
 - If there is evidence of a nondisplaced frontal sinus fracture, extreme care is taken during removal of the mucosal lining of the posterior frontal sinus wall to prevent displacement of the fracture.
- Abdominal fat is then harvested for obliteration of the frontal sinus.
 - A no. 15 blade is used to make a periumbilical incision.
 - Blunt dissection with a hemostat is used to elevate the area and expose the proposed fat graft.
 - Fat is then harvested en bloc for obliteration of the frontal sinus. The total amount of fat is dependent on the volume of the frontal sinuses to be obliterated.
 - The incision is then closed in sequential fashion, and dressing is placed over the abdominal incision.
- A 1 × 1 cm piece of temporalis muscle is then harvested for obliteration of the frontal sinus outflow tract.
- The frontal sinus outflow tracts are then identified and plugged with the previously harvested temporalis muscle.
- The previously harvested fat is then used to fill and obliterate the frontal sinuses.

Plating and Completion

- The osteoplastic bone flap is replaced and secured with titanium or absorbable plates. If the frontal bar was removed or required reconstruction, it is replaced prior to plating the osteoplastic bone flap (**TECH FIG 2**).
- The periosteal flap is then laid over the bony flap and sutured to the surrounding periosteum with 3-0 suture.
- The wound is irrigated with saline and hemostasis is achieved with electrocautery.



TECH FIG 2 • Frontal bar is being reconstructed with an absorbable plating system. After plating the frontal bar, the osteoplastic bone flap is replaced and secured.

- Negative pressure drains are placed to collect blood or serous fluid collections.
- The incision is closed in multiple layers, with sutures or staples to close the skin.
- Antibiotic ointment is then applied to the incision, and the head is wrapped in a compressive dressing.

PEARLS AND PITFALLS

- | | |
|-------------------|---|
| Hemostasis | ■ Obtain hemostasis prior to closure. Negative pressure drains allow monitoring of postoperative fluid in this area. We recommend less than 30 mL of drainage in a 24-hour period and avoidance of any bending, Valsalva maneuvers, nose blowing, or excessive activity for 2 wk postoperatively. |
| Technique | ■ All mucosa must be removed from the frontal sinus to prevent subsequent mucocele formation. This can be ensured with drilling |

and smoothing of the frontal sinus bone.

POSTOPERATIVE CARE

- Patients should be placed on postoperative antibiotics for at least 14 days, usually amoxicillin-clavulanate.
 - If there is concern for meningitis or other complicated infectious etiology, the type and course of antibiotic should be tailored to the individual patient.
- For external incisions, antibiotic ointment should be used to coat the area to promote healing.
- Compressive head dressings can be removed in 48 to 72 hours.
- Negative pressure drains are kept in place until the output for each drain is less than 30 mL of fluid over a 24-hour period.
- Avoid bending, Valsalva maneuvers, nose blowing, or excessive activity for 2 weeks to prevent bleeding.
 - Patients should be instructed to “open-mouth sneeze” to avoid excessive nasal airflow pressure.
- Nasal saline rinses are recommended to prevent nasal crusting if endonasal surgery was performed.
- Staples or sutures in the scalp should be removed in approximately 10 days.
- Postoperative CT and/or MRI should be performed to establish a baseline of the newly obliterated frontal sinus.

OUTCOMES

- Greater than 90% success rate of frontal sinus obliteration has been reported.²

COMPLICATIONS

- Mucocoeles or mucopyocoeles may occur years later if any mucosa is retained in the frontal sinuses.
 - Weber et al. performed a long-term follow-up MRI study that detected mucocoeles in almost 10% of patients after frontal sinus injury.³
- CSF leak is a potential risk with any damage to the posterior frontal sinus wall and subsequent dural injury during surgery.
- Meningitis may occur through communication with the anterior cranial fossa if there is a defect in the posterior frontal sinus wall.

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50 Pericranial Flap Harvest for Frontal Sinus Obliteration

CHAPTER

Mahmoud Hassouba and John A. van Aalst

DEFINITION

- The pericranial flap is a well-vascularized, versatile cranial periosteal flap that can be based anteriorly on the supratrochlear and supraorbital arteries or laterally on the superficial temporal artery.¹
- The pericranial flap is most commonly used for reconstruction of anterior skull base defects, including obliteration of the drainage system of the front sinus following frontal sinus fracture.

ANATOMY

- The scalp consists of five layers: skin, subcutaneous connective tissue, galea aponeurotica, loose areolar tissue, and the pericranium.
- The pericranium is the periosteum of the skull bones and is continuous with the endosteum along the cranial suture lines.
- The pericranial flap consists of the skull periosteum with the overlying subgaleal areolar tissue.
- The blood supply of the anteriorly based pericranial flap is derived from the deep branches of the supraorbital and supratrochlear arteries, and both are branches of the ophthalmic artery.
- The deep branches arise from the supratrochlear and supraorbital artery exiting at the level of the supraorbital rim.²
- There is wide variation in the size of these arterial branches depending on the size of the frontal branch of the superficial temporal artery.²
- The axial length of these branches ranges between 15 and 60 mm and most commonly is approximately 40 mm in length.²
- In the horizontal plane, the anastomosis between the deep branches is not well

developed, and except for the glabellar region, no anastomoses cross the midline.

PATHOGENESIS

- The most common indication for sinus obliteration requiring pericranial flap is a fracture of the posterior wall of the frontal sinus.
- As with most craniofacial injuries, frontal sinus fractures result from high-velocity blunt trauma such as motor vehicle accidents.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Frontal sinus fractures are often associated with other facial injuries that require a detailed history, including the mechanism of trauma, as well as a thorough general and craniofacial-centric physical examination.
- History taking may be complicated due to patient head injury with loss of consciousness.
- The main presenting symptoms are forehead swelling with or without skin lacerations, forehead paresthesia, and forehead and nasal pain.
- Signs of frontal sinus fractures include forehead tenderness, contour deformity, crepitus, and cerebrospinal fluid (CSF) rhinorrhea.
- Displaced fractures without skin lacerations may be masked by the overlying soft tissue swelling.
- All lacerations should be examined under aseptic conditions to evaluate the integrity of both the anterior and posterior tables as well as the dura.
- The nasal cavity should be examined for the presence of CSF drainage.

IMAGING

- CT scan of the facial bones with coronal and axial cuts is the standard for diagnosis of fractures involving the frontal sinus.
 - 3D reconstructions may be helpful in diagnosing associated craniofacial injuries.

SURGICAL MANAGEMENT

- Indications for frontal sinus obliteration include fractures of the floor or posterior wall of the sinus, oncologic or inflammatory lesions of the frontal sinus such as osteomas or osteomyelitis, vascular lesions such as arteriovenous malformations, and failure of endoscopic sinus drainage surgery.³

PREOPERATIVE PLANNING

- Routine preoperative lab results should be reviewed, and any abnormal finding should be corrected to prepare the patient for surgery.
- All available imaging should be available and displayed in the operating room.
- A sterilized radiographic template of the frontal sinus can be prepared from a Caldwell radiograph.
- Doppler ultrasound should be available in the operating room for intraoperative localization of the flap pedicle if distorted anatomy is anticipated.

Positioning

- The patient is placed in supine position on the operating room bed.
- Oral intubation is preferred with the tube placed centrally and inferiorly.

Approach

- If a forehead laceration already exists, it can be extended into a natural crease.
- A midforehead incision or a butterfly transglabellar incision may be used.⁴
- The coronal incision is the most reliable and aesthetically favorable approach for exposure of the forehead and facilitates harvest of the pericranial flap.
- The sex of the patient and location of the anterior hairline should be taken in consideration when choosing the location of the coronal incision
- In individuals with posteriorly displaced anterior hairline or patients with male pattern baldness, the incision can be placed as far posteriorly as the upper occiput.

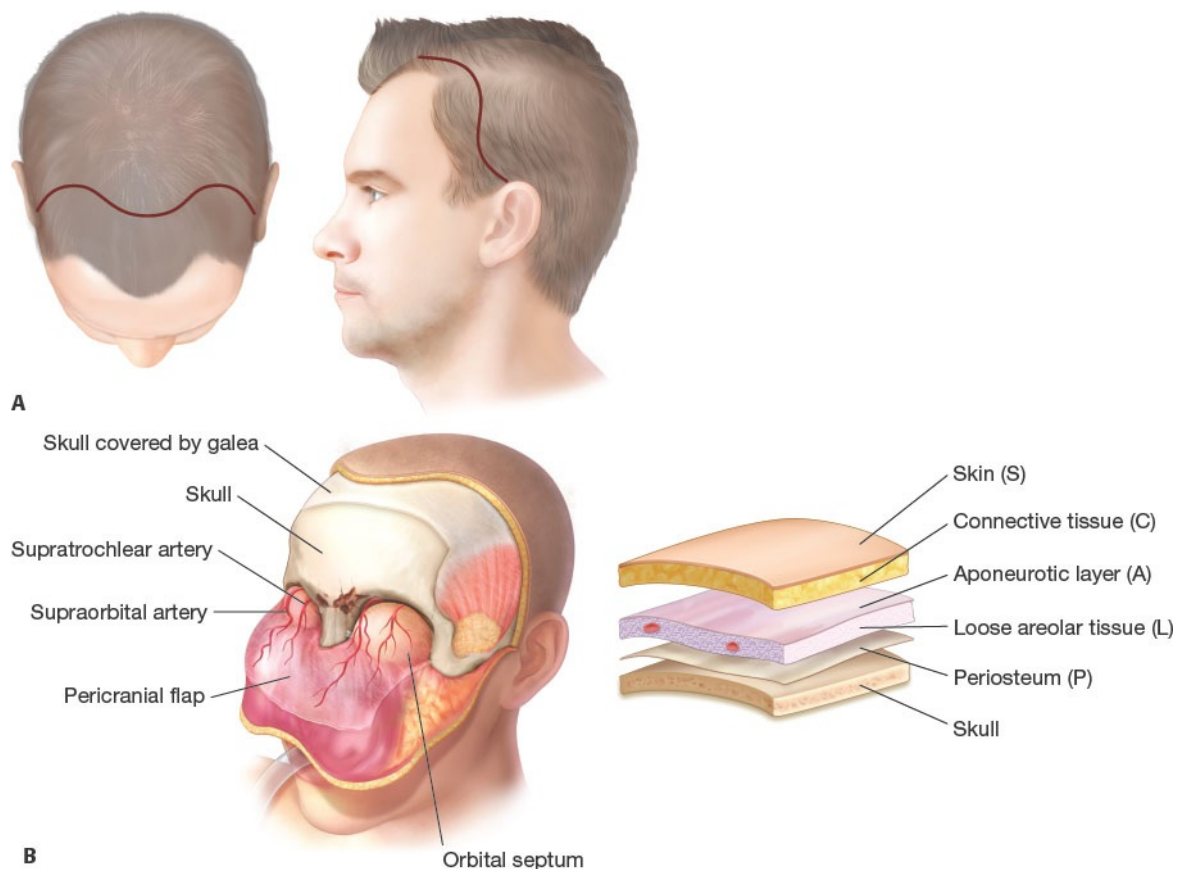
TECHNIQUES

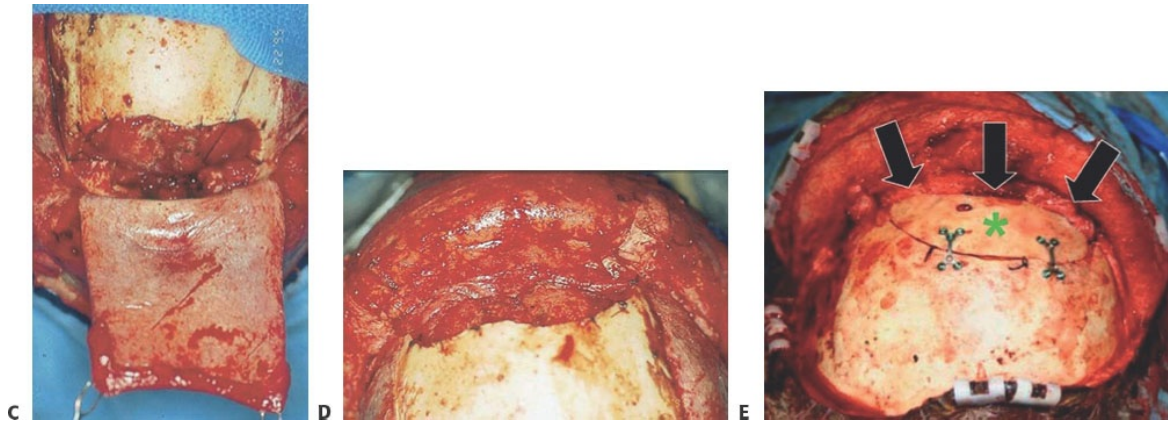
■ Anteriorly Based Pericranial Flap

- The coronal incision is made 2 to 3 cm posterior to the hairline and extends to the auricular helix on both sides (**TECH FIG 1A**).
- The flap is dissected anteriorly in the subperiosteal plane to the level of the supraorbital rim and may need to be extended to access other fractures of the craniofacial skeleton (**TECH FIG 1B**).
- Marking of the frontal sinus can be performed using the premade template.
- The frontal sinus is then accessed through a pre-existing anterior table

fracture or by removal of the frontal bone in conjunction with the neurosurgery team.

- Mucosal lining of the sinus is completely exenterated using a periosteal elevator; 0.5 to 1 mm of the osseous lining is then removed using a bur.
- At the ostia of the nasofrontal ducts, the mucosa is folded on itself.
- Doppler scanning may be used for accurate localization of the pericranial flap pedicle and aid in planning the flap.
- An anteriorly based periosteal flap is dissected from the coronal flap with a no. 15 blade in the subaponeurotic plane to the supraorbital rim (**TECH FIG 1C**).
- The flap is then folded against itself to fill and obliterate the frontal sinus, acting as a barrier between the brain and remaining sinus (**TECH FIG 1D**).
- The anterior table is then rigidly fixated in place leaving a 3- to 5-mm gap between its inferior border and the frontal bar to prevent compression of the blood supply to the flap (**TECH FIG 1E**).
- A suction drain is then placed in the subgaleal plane, and the coronal flap is redraped and the incision is closed in layers.





TECH FIG 1 • A. Placement of coronal incision. **B.** The coronal incision proceeds through the layers of the scalp to the subpericranial plane. (These layers can be remembered using the acronym SCALP.) Dissection is performed on the skull to the orbital rim and, as necessary, into the area of the orbits, exposing the zygomatic arches bilaterally. The pericranial flap is exposed and separated from the overlying soft tissue. **C.** Elevation of the pericranial flap from the coronal flap. Frontal sinus has been exposed by removal of anterior table of frontal sinus. **D.** Obliteration of the frontal sinus and frontal recess by folding pericranial flap onto itself and filling the frontal sinus. This serves as a barrier between the brain and remnant sinus cavity. **E.** Before the frontal bone (*asterisk*) is replaced, the anterior region of craniotomy is burred to ensure that the edges are smooth and do not impinge on the pericranial flap as it enters the intracranial cavity (*arrows*). The bone flap is then secured, and the skin is closed.

■ Laterally Based Pericranial Flap

- All operative steps are similar to harvest of the anteriorly based flap, with the exception that the flap is either harvested unilaterally with its base in the

temporal area with blood supply from the superficial temporal artery or bilaterally depending on the size of the sinus.

- The base of the flap is located approximately 2 cm from the gap between the temporoparietal fascia and the galea aponeurotica.
- The width of the flap base usually varies between 5 and 8 cm depending on the size of the frontal sinus.
- A unilateral flap should not extend beyond the midline.
- The dimensions of the flap may vary but can be up to 10 × 10 cm according to the tissue amount required to fill the frontal sinus.

PEARLS AND PITFALLS

Coronal incision	■ Zigzag or curved incision is made to facilitate accurate closure at the end of the procedure.
Dissection	■ Care should be taken while dissecting the flap medially to avoid injury to the deep branches of the supratrochlear and supraorbital artery and laterally to avoid injury to the frontal branch of the facial nerve.
Dura	■ If the dura is exposed, it should be carefully examined and fenestrations should be repaired.
Hemostasis	■ Careful hemostasis should be achieved before closure of the coronal flap to avoid hematoma formation that can lead to flap compression and necrosis.

POSTOPERATIVE CARE

- The patient will require monitoring in the ICU because of the high likelihood of head injury associated with frontal sinus injury.
- Head of bed elevated to 45 degrees to help venous drainage and avoid soft tissue swelling.
- Perioperative antibiotics are indicated because of intracranial extension for 7 to 10 days.
- Drain remains in place until output is less than 30 mL for 24 hours.
- Narcotic pain medications are preferred during the first week after the procedure and are titrated to the patient's level of pain.

OUTCOMES

- Successful outcomes of obliteration of the frontal sinus depend on multiple factors, mainly total removal of mucosal lining and complete obliteration of the sinus.
- Aesthetic outcomes of forehead contour after surgery are usually satisfactory.
- Most published series in the literature report 100% patient satisfaction with the aesthetic and functional outcomes after frontal sinus obliteration using pericranial flaps.^{1,4-7}

COMPLICATIONS

- Early
 - Sinus obliteration using pericranial flaps is associated with low rates of complication.
 - Seroma formation: Can be avoided by drain placement
 - Active bleeding leading to expanding hematoma requiring flap exploration
 - Place a postoperative drain.
 - Early recognition of the hematoma and re-exploration.
- Late
 - Persistent headaches
 - Forehead contour deformities
 - Sinus infection: requires admission, IV antibiotics, and possible surgical debridement
 - Inadequate mucosal removal leading to mucocele formation; may present more than a decade after sinus obliteration.¹

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51 Endoscopic Correction of Frontal Sinus Fractures

CHAPTER

Patrick M. Colley, Kibwei A. McKinney, and Brent A. Senior

DEFINITION

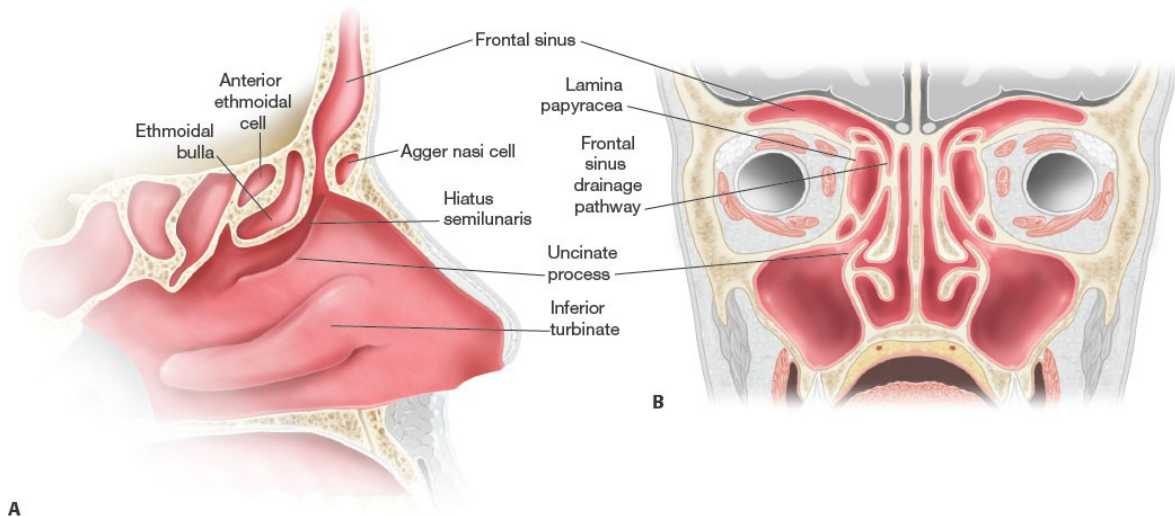
- Frontal sinus fractures involve the anterior or posterior table of the frontal bone.
- Displacement in frontal sinus fractures is classified as one width of the anterior or posterior table.

ANATOMY

- The frontal bone has both vertical and horizontal components.
 - The vertical component is the bone of the forehead and is composed of the anterior and posterior tables.
 - The horizontal component makes up the superior orbital roof and floor of the frontal sinus.
- The vertical portion of the frontal bone contains a pneumatized frontal sinus in greater than 90% of the population.
- The frontal sinus begins its development at 4 years of age and continues to develop until the late teenage years.
- The anterior table of the frontal sinus is a bicortical structure made of cancellous bone that begins at the nasofrontal suture line inferiorly and averages 4 to 12 mm in thickness.
- The posterior table of the frontal sinus is thinner than the anterior table, with an average thickness of 0.1 to 4 mm. Its inner cortex is closely adherent to the underlying dura.
- The anterior and posterior tables of the frontal sinus converge inferiorly to form the frontal recess or frontal sinus drainage pathway (FSDP), where the frontal sinus drains into the middle meatus or ethmoid infundibulum,

depending on where the uncinate process inserts superiorly (**FIG 1A,B**).

- At the superior-most portion of the FSDP is the frontal recess, a three-dimensional (3D) structure with the following boundaries:
 - Anterior—the agger nasi cell and/or the uncinate process
 - Posterior—the anterior wall of the ethmoid bulla and any suprabullar ethmoid cells
 - Lateral—lamina papyracea of the orbit
 - Medial—the lateral lamellae of the skull base and attachment of the middle turbinate to the skull base
- The soft tissue overlying the frontal bone consists of skin, subcutaneous soft tissue, frontalis muscle, and pericranium.
- At the glabella and medial portion of the supraorbital rim, the soft tissue is thicker than it is at the superior portion of the forehead due to the presence of the orbicularis oculi, procerus, and corrugator muscles.



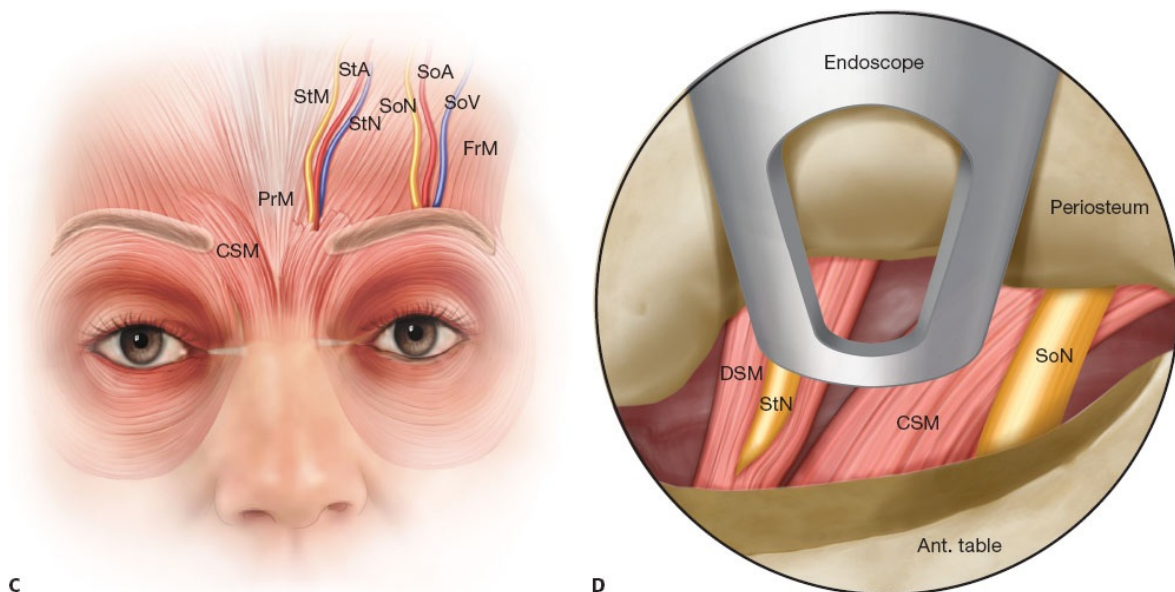


FIG 1 • A. Sagittal drawing of the frontal sinus drainage pathway (FSDP). The pathway passes posterior to the agger nasi cell and anterior to the ethmoid bulla before draining into the middle meatus. **B.** Coronal drawing showing the most common relationship of the FSDP to the lamina papyracea and middle turbinate. **C.** Anterior view of the face showing the location of the supratrochlear and supraorbital neurovascular bundles. The supratrochlear bundle can be located approximately 1.5 cm from midline, while the supraorbital exits its foramen approximately 2.5 cm from midline. CSM, corrugator supercilii muscle; PrM, procerus muscle; StN, supratrochlear nerve; StA, supratrochlear artery; StV, supratrochlear vein; SoN; supraorbital nerve; SoA, supraorbital artery; SoV, supraorbital vein; FrM, frontalis muscle. **D.** Endoscopic view of the supratrochlear and supraorbital bundles. StN, supratrochlear nerve; SoN, supraorbital nerve; DSM, depressor supercilii muscle; CSM, corrugator supercilii muscle; Ant. Table, anterior table of the frontal sinus. External palpation can aid in orientation while

dissecting inferiorly and alert the surgeon when the supraorbital rim is near.

- The subpericranial plane constitutes a bloodless space and provides access to the underlying anterior table of the frontal sinus.
- The supraorbital and supratrochlear nerves supply sensation to the forehead skin and course from the superior orbital rim, inferiorly, to the vertex of the scalp, superiorly (**FIG 1C,D**).
- The supraorbital nerve, the more lateral of these two structures, is a branch of V1 that passes through the supraorbital foramen and travels deep to the corrugator muscles, before penetrating the frontalis muscle and traveling within the subcutaneous tissue in its superior course.
- The supratrochlear nerve passes just above the superior oblique muscle and its trochlea before coursing in a similar plane to the supraorbital nerve superiorly along with the supratrochlear artery.
- Injury to these nerves via trauma or surgical incision leads to a loss of sensation superior to the site of injury.

PATHOGENESIS

- The frontal bone is one of the stronger bones in the human body, and fracturing it requires a pressure of 800 to 1600 ft-lb. However, an aerated frontal sinus reduces the ability of the frontal bone to withstand pressure, thus making pneumatized areas more susceptible to fractures than other regions of the frontal bone.
- The most common mechanisms of injury resulting in frontal sinus fracture are motor vehicle collision (42%), assaults (14%), motorcycle collisions (10%), pedestrians struck by motor vehicles (8%), and ballistic injuries (7%).¹
- The most common type of fracture is a combined fracture involving the anterior and posterior tables as well as the FSDP, occurring between 55% and 67% of the time. Isolated anterior table fractures are seen in 33% of frontal sinus fractures, with isolated posterior table fractures making up less than 5%.¹

NATURAL HISTORY

- Injury to the frontal sinus can lead to complications from cerebrospinal fluid (CSF) rhinorrhea, damage to the FSDP, or changes in the aesthetic structure of the facial skeleton.
- The posterior table of the frontal sinus is thin and adherent to the underlying

dura, making a tear and subsequent CSF leak more likely when the posterior table has been significantly injured or displaced.

- The FSDP is the only pathway of egress for mucus produced by the frontal sinus mucosa. Obstruction of this space can lead to chronic sinus disease and frontal mucocele formation.
- The frontal bone supplies the height and contour of the entire forehead. Fractures of the frontal bone as small as 2 to 3 mm can lead to significant alteration in the appearance of the forehead, particularly in the superior portion, where the overlying soft tissue is thinner.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history obtained from a patient with a suspected frontal sinus fracture should focus on the method of injury, neurologic complaints, visual changes, and the possibility of a CSF leak.
 - Because of the large amount of force required to produce a frontal sinus fracture, loss of consciousness is associated with over 70% of these injuries, while intracranial injuries are seen in 39%.²
 - Ophthalmologic injuries can be seen in 26% of frontal sinus fractures.²
- The physical examination in patients suspected of having a frontal sinus fracture involves a complete trauma assessment and typically requires consultation with otolaryngology, plastic surgery, neurosurgery, and ophthalmology.
- A thorough head and neck examination should be conducted including assessment of the airway and the neck, prior to focusing on maxillofacial injuries.
- Examination of the entire maxillofacial skeleton should be conducted, as 87% of patients with a frontal sinus fracture have other maxillofacial injuries.³
 - The forehead should be examined for abnormalities in contour, tenderness, crepitus, and paresthesias.
 - Lacerations should be examined under sterile conditions and probed carefully until the integrity of the underlying frontal bone can be assessed on imaging.
 - The orbital rims and integrity of the medial canthal tendon (MCT) can be assessed with palpation and by placing a thumb and index finger over the nasal root and carefully applying lateral tension on each lower lid. Minimal movement of 2 to 3 mm with a defined endpoint is normal, while excessive movement or orbital movement means that the integrity of the MCT has been compromised.

- MCT injuries are often seen with naso-orbital-ethmoid fractures
- CSF leaks should be suspected in all patients with frontal sinus fractures.
 - The nasal cavity should be cleared of debris and examined using nasal endoscopy
 - Any rhinorrhea should be examined using the halo test or sent for beta-2-transferrin analysis.^{1,3-6}
 - The halo test consists of capturing fluid from the nasal secretions on a cloth or gauze and observing whether a clear “halo” is visible around a central pool of blood within the drainage (CSF migrates faster than does blood). This test is suggestive of the presence of CSF but is not diagnostic as saline and mucus can also lead to false-positive results.
 - Testing of fluid for beta-2-transferrin is the mainstay of evaluation for CSF. This protein can be found in CSF, vitreous humor of the eye, and perilymph.

IMAGING

- Fine-cut, triplanar maxillofacial CT scans are the standard means of radiologic evaluation for frontal sinus fractures.
 - Coronal views provide excellent visualization of the frontal sinus floor, anterior ethmoid cells, and medial orbital walls. Injuries to any of these areas mean there is a high likelihood of damage to the FSDP and an increased risk of chronic sinusitis and mucocele formation.
 - Axial views are used to evaluate displacement of frontal sinus fractures and can demonstrate comminution or pneumocephalus (**FIG 2**).
 - The patency of the FSDP is best assessed on the sagittal views, though it requires careful assessment in all planes.
 - Fractures involving the FSDP typically occur with more severe maxillofacial trauma, and patients are 3 times more likely to have other facial fractures when this area is involved.¹
- 3D reconstruction is useful in minimally displaced fractures of the anterior table and can help determine if expectant management is an acceptable treatment option.

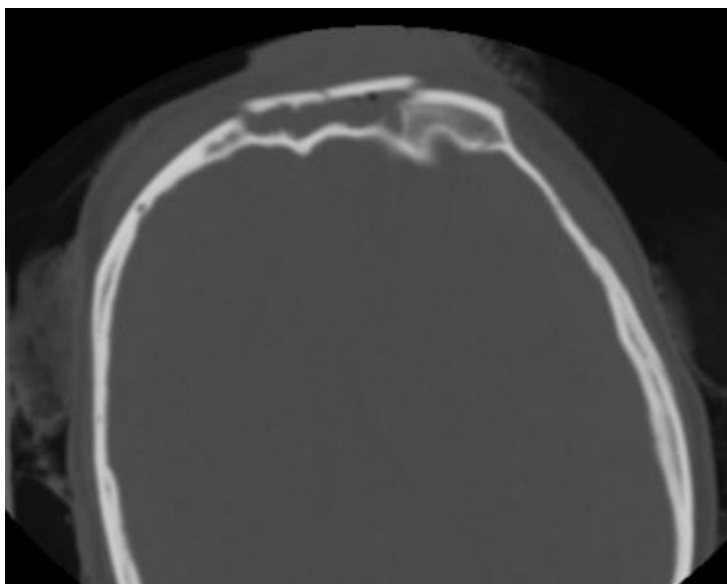


FIG 2 • An axial CT view of a minimally displaced frontal sinus fracture. The posterior table appears intact, and the frontal sinus is completely opacified.

- If expectant management with delayed endoscopic treatment is a possible treatment option, the axial views provide the most accurate means of estimating the size of the fracture, as they are not influenced by volume averaging.

NONOPERATIVE MANAGEMENT

- Based on the algorithm in **FIG 3**, expectant management of a frontal sinus fracture can be considered if no significant posterior table injury is present.
- Repeat imaging and physical examination should be conducted regularly at 3, 6, and 12 months on all patients who are observed after this injury.
- The frontal sinus mucosa normally regains proper mucociliary clearance spontaneously after a fracture. However, repeat imaging is required to confirm that the mucociliary clearance is functioning properly.
 - Patients can suffer from chronic frontal sinusitis or possibly mucocele formation if the mucosa does not function properly.
- Observation is an appropriate treatment option in patients with no evidence of FSDP injury who have nondisplaced fractures or fractures limited to either the anterior or posterior table.
- Isolated posterior table fractures can be observed once FSDP injury, dural tear,

and CSF leak have been ruled out. Mucocoele formation due to ingrowth of mucosa into the fracture is rare but should be evaluated at regular intervals.

- Minimally displaced anterior table fractures without FSDP injury can be observed with close follow-up. Should the patient have aesthetic deformities after resolution of the soft tissue edema, endoscopic cranioplasty can be a useful means of correcting this issue.
- These patients often have minimal cosmetic deformity 3 to 6 months after their injury, particularly those with thick brows.

SURGICAL MANAGEMENT

- In the acute setting, endoscopic reduction and internal fixation of anterior table fractures is a treatment option when there is a minimally displaced, isolated, noncomminuted anterior table fracture that does not involve the FSDP.

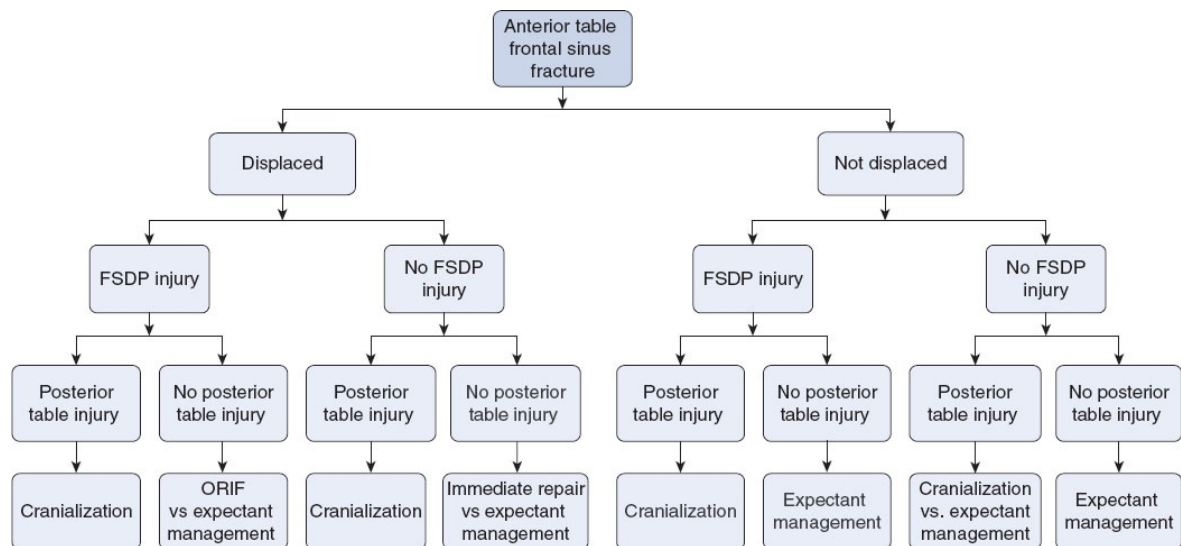


FIG 3 • Algorithm for the management of anterior table fractures. Endoscopic or expectant management can be considered in four of the eight clinical scenarios. Posterior table injury includes displacement of more than one table width, evidence of intracranial injury, a comminuted fracture, or a cerebrospinal fluid leak. FSDP, frontal sinus drainage pathway.

- Minimally displaced fractures are typically defined as less than 2 mm or 1 width of the anterior table.

- The patient with a receding hairline may not be an optimal candidate for this approach, as some endoscopic incisions are highly visible.
- Delayed endoscopic cranioplasty is indicated in the patient who was initially observed after sustaining a minimally displaced anterior table fracture without FSDP injury but has continued cosmetic deformity of the frontal area following resolution of the soft tissue edema.
- Discussion of traditional open surgical techniques for correcting frontal sinus fractures can be found in other chapters.
- Endoscopic management of these fractures can avoid a large coronal incision and allow for a quicker recovery.
- Endoscopic cranioplasty and fixation techniques should be performed by surgeons who are proficient in endoscopic browplasty procedures.
- Additional endoscopic endonasal sinus procedures required for the involved frontal sinus can accompany delayed treatment of the fracture.⁷
- Endoscopic frontal sinusotomy can be performed to improve aeration of the frontal sinus and can also be used to provide access for balloon catheterization of the frontal sinus.
- Transnasal endoscopic placement of a frontal sinus instrument or Foley catheter balloon into the frontal sinus can be used to reduce an anterior table fracture and provide the support required to place a screw into the fractured segment of bone.

Preoperative Planning

- CT imaging should be reviewed prior to the procedure.
- Proper antibiotic coverage should be started prior to the procedure.
 - Adequate coverage of typical sinus flora is provided by using ampicillin-sulbactam or clindamycin.
- Discussion with the patient regarding the possible need for conversion to an open procedure including the use of a coronal incision should be included in the consent prior to the procedure.
- The proper equipment should be present in the operating room, including 4 mm 30- and 70-degree endoscopes (**FIG 4**), a rigid endosheath, a camera, standard endoscopic browplasty instruments, endoscopic video tower, and either a plating system or a porous polyethylene sheet depending on the type of planned repair.
- Preoperative measurement of the fracture and trimming of the polyethylene

sheet (0.85 mm thick) or mesh to dimensions 10 mm larger than the fracture size is recommended. This allows for overlap of the sheet over the defect edges and an area for screw placement.

- Hydroxyapatite cement can also be used for endoscopic treatment of frontal sinus fractures and provides similar cosmetic results.
- Caution should be exercised when considering hydroxyapatite cement, as it typically fills a portion of the underlying frontal sinus and can increase the risk of mucocele formation after this procedure.

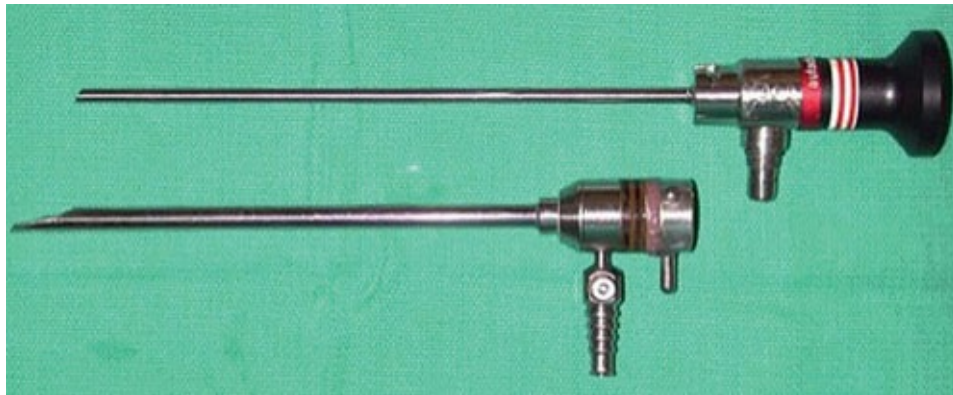


FIG 4 • A 4-mm endoscope with an endoscopic sheath should be used once an optical cavity is created in a subperichondrial plane.

Positioning

- The patient should be positioned supine on the operating table, and the head of the bed should be turned between 90 and 180 degrees for complete access to the patient's head and placement of the endoscopic equipment and tower.
- The surgeon should sit at the head of the bed, facing toward the patient's feet. The endoscopic video screen should be placed near the abdomen, facing toward the head of the bed (**FIG 5**).
- The patient's eyes should be closed and protected to prevent accidental trauma during the procedure.
- Sterile prep is applied from the upper nose to an area at least 2 or 3 cm posterior to the hairline.

Approach

- The endoscopic approach is the same for both delayed and acute scenarios.

- The entire anterior table to the level of the superior orbital rims, inferiorly, and the temporal lines, laterally, can be accessed through two or three small incisions just behind the hairline.



FIG 5 • The surgeon should be seated at the head of the bed facing the patient with the screen at the level of the patient's abdomen.

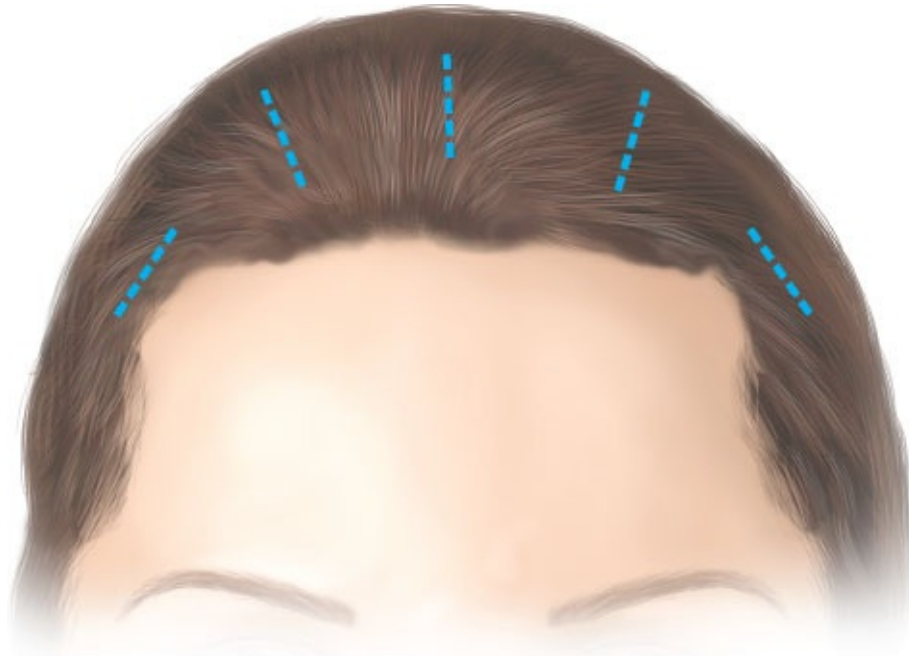
TECHNIQUES

■ Endoscopic Approach to the Anterior Table of the Frontal Sinus

- Two parallel incisions should be marked on the forehead, approximately 2 cm behind the hairline (**TECH FIG 1**).
 - The central incision should be made in the midline and is used for the endoscope.
 - The lateral incision should be made 4 to 6 cm lateral to midline, on the side corresponding to the larger portion of the fracture.
 - Another vertical incision can be made on the contralateral side, if greater

reach is required in that area.

- If a large piece of porous polyethylene or mesh is to be used, the scalp incisions may need to be enlarged, or a temporal incision 2 cm behind the hairline should be made to introduce this material.



TECH FIG 1 • Incisions for endoscopic repair of frontal sinus fractures. A midline incision is separated from two lateral incisions by approximately 2.5 cm and placed 1 cm posterior to the hairline. The optional temporal incisions are even further lateral and should be made just posterior to the temporal hairline.

- The use of temporal incisions creates greater tissue trauma, introduces the possibility of injury to the frontal branch of the facial nerve, and does not increase the size of the optical cavity. This incision should be used with caution.
- Incisions should be made with a scalpel through the skin and subcutaneous tissue.
- Electrocautery can be used to continue the dissection to the subperiosteal layer.

- Cautery should be used sparingly on the subcutaneous tissue and skin to avoid damage to the hair follicles and subsequent alopecia.
 - Blunt dissection using a sharp dissecting instrument, such as the endoscopic periosteal elevator, should be used to create a pocket in the subperiosteal plane.
 - Bimanual palpation should be used to confirm that the pocket extends from both temporal lines to approximately 2 to 3 cm anterior to the incisions.
 - Blind dissection of this pocket is required before placement of the endoscope into the incision.
 - Introduce the 30-degree endoscope through the central incision and the dissecting instrument through the lateral incision and continue the dissection in the subperiosteal plane to a level just below the inferior edge of the fracture.
 - Ensure that the fractured segments are not displaced during this portion of the dissection, as they can be very difficult to move back into the proper orientation using the endoscope.
 - Alternatively, comminuted fracture segments can be removed and plated together on the back table if they are displaced.
 - Dissection over the fracture segment can also be performed in the suprapericranial layer by making a small incision in the pericranium and identifying the proper plane.
 - This technique allows the fracture segments to remain attached and reduces the likelihood of displacement during the dissection.
-

■ Endoscopic Reduction and Internal Fixation of the Anterior Table

- A 25-gauge hypodermic needle is used to identify the proper areas for percutaneous port placement.
 - All fractured segments should have at least two points of fixation with larger pieces benefitting from three points.
 - Ideally, one port incision could be used to place screws into multiple plates in order to decrease the number of incisions.
- A no. 11 blade scalpel should be used to create a stab incision in this area for placement of screws and other percutaneous instruments.
- Once the fracture is dissected free from the overlying periosteum,

instruments including nerve hooks and Steinmann pins should be introduced through the percutaneous ports to reduce the fracture segments.

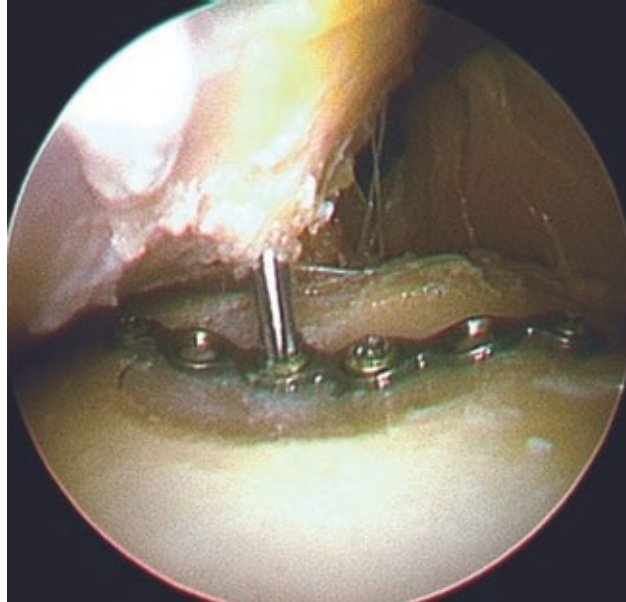
- Miniplates can be introduced through the scalp incisions and moved to positions overlying the fracture segment.
- 1.7-mm self-drilling screws (4 to 6 mm in length) can be used percutaneously to fixate the fracture segments to the stable bone.
 - A drill with a percutaneous drill guide can be used to create starting holes on the fracture segments if the screws are not taking hold.
- Acellular dermis or Vicryl mesh can be placed over the surface of the repair in the subperiosteal plane to provide further camouflage of any remaining contour abnormalities.
- The percutaneous port incisions can be closed with absorbable sutures or tissue adhesives.
- The access incisions should be closed with absorbable deep sutures and skin staples.

■ Endoscopic Placement of Mesh or Polyethylene Plate

- Complete the endoscopic approach to the anterior table of the frontal sinus as described above.
 - Ideally, one port incision can be used to place screws into opposing areas of the plate or mesh to decrease the number of incisions.
- A no. 11 blade scalpel should be used to create a stab incision in this area for placement of screws and other percutaneous instruments.
- The precut polyethylene plate or mesh is introduced into the optical cavity and moved into the proper position.
 - A mark should be placed on the superior portion of the plate to aid with orientation after the plate is placed into the optical cavity.
 - The entire fracture should be covered with a portion of the plate overlapping the surrounding stable bone.
- 1.7-mm self-drilling screws (4–6 mm in length) should be used through the percutaneous ports to secure the plate or mesh to the stable bone (**TECH FIG 2**).
 - All plates and mesh should have at least two points of fixation, with larger

pieces benefitting from three points.

- Screws should be placed at least 2 mm from the plate edge in order to avoid tearing.



TECH FIG 2 • Endoscopic view of a percutaneous screwdriver used to place screws in the reconstructive plate. The percutaneous incision should be made in an area that allows for access to the entire plate if possible to reduce cosmetic deformity.

- Acellular dermis or Vicryl mesh can be placed over the surface of the repair in the subperiosteal plane to provide further camouflage of any remaining contour abnormalities.
- The percutaneous port incisions can be closed with absorbable sutures or tissue adhesives.
- The access incisions should be closed with absorbable deep sutures and skin staples.

PEARLS AND PITFALLS

Indications	■ Frontal sinus fractures that involve the FSDP, surrounding maxillofacial bones, or are severely comminuted make poor endoscopic candidates. ■ Fractures that also involve the posterior table may be endoscopic candidates if they are observed first to ensure there is no CSF leak.
Consent	■ A discussion should take place with all patients regarding the need for a possible coronal incision and open reduction with internal fixation if the fractures are not amenable to the endoscopic approach.
Preoperative planning	■ Miniplates can be used for reduction and internal fixation in the acute setting. ■ Polyethylene plates or mesh should be used in the delayed setting and should be cut to appropriate size based on the axial cuts of the CT scan before the case.
Camouflage	■ A thin layer of Vicryl mesh or acellular dermis should be placed over the fracture after plating or fixation to camouflage further contour abnormalities.
Postoperative care	■ Patients should undergo routine physical and radiologic examinations 1, 3, and 6 mo after endoscopic treatment of their fracture no matter which type of surgery was used. ■ Osteomyelitis and mucocele formation occur infrequently but have better treatment outcomes when recognized early.

POSTOPERATIVE CARE

- A mildly compressive dressing is placed over the forehead immediately after surgery to prevent hematoma or seroma formation.
 - This can be removed after 48 hours.
- The patient should be warned to avoid activities that put him or her at risk for future trauma to the forehead.
- The patient can resume regular activities after approximately 2 weeks or after most of the swelling has resolved.
- The staples are removed 7 to 10 days after the surgery.
- The patient should still receive routine physical examinations and CT scans 1, 3, and 6 months after the surgery to monitor for osteomyelitis and mucocele formation.
 - Annual imaging should be obtained after this period.

OUTCOMES

- Endoscopic treatment of frontal sinus fractures has a similar success rate to open approaches in regard to cosmetic outcomes, with a lower rate of complications.^{1,5}
- A smaller subset of patients with less severe fractures qualify for endoscopic management that leads to an inherent decrease in complications.

COMPLICATIONS

- Complications from endoscopic repair of frontal sinus fractures are similar to those from open repair and include wound infections, osteomyelitis, mucocele, mucopyocele, aesthetic complications, paresthesias to the frontal area (secondary to injury of the supraorbital or supratrochlear neurovascular bundles), diplopia, hematoma or seroma formation, hardware infection, and bone resorption.^{1-6,8}
- Mucoceles can form at any point from the immediate postoperative period to 20 years after the surgery.

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Operative Management of a Late Presentation of Frontal Sinus Mucocele

52

CHAPTER

Kibwei A. McKinney and Brent A. Senior

DEFINITION

- A mucocele is a benign, cystic collection of mucus lined with respiratory epithelium that results from obstruction of the drainage pathway of a paranasal sinus ostium.
- The mucus within a mucocele may become infected and is then termed a pyocele or mucopyocele.¹
- Mucoceles present most frequently in the frontal and ethmoid sinuses, accounting for between 54% and 73% of lesions occurring within the paranasal sinuses.²
- The vast majority of mucoceles occur in the setting of pre-existing sinus disease (eg, nasal polyps or sinonasal neoplasms), whereas a minority present as a long-term sequela of prior trauma to the frontal sinus drainage pathway.³
- Trauma to the frontal drainage pathway is thought to result in post-traumatic scar formation, inflammation, and obstruction that prevent normal mucociliary clearance, thus resulting in mucocele formation.^{4,5}
- Frontal mucoceles can result in significant morbidity, due to their expansile, erosive nature, and close proximity to the orbit and brain. Complications include facial asymmetry, orbital proptosis, cellulitis of the orbit and facial skin, and intracranial extension.⁶
- The treatment of mucoceles of the frontal sinus is particularly challenging due to the limitations of external and endoscopic techniques.
- External approaches may result in poor appearance, hypesthesia of the facial skin, and poor access to the frontal sinus drainage pathway.

- Endoscopic approaches have decreased morbidity but are limited in their ability to access lesions localized to the superior and lateral aspects of the sinus.

ANATOMY

Frontal Sinus

- The frontal sinuses are paired structures of the forehead that are present in 90% of the population and exhibit different patterns of pneumatization among individuals.⁷
- The frontal sinus arises embryologically from an anterior ethmoid furrow that evaginates into the frontal bone, forming an inverted, pyramidal-shaped, air-filled structure, along the roof of the orbit.^{7,8}
- The anterior table of the frontal sinus varies between 4 and 12 mm and thickens at its inferior extent to form the frontal “beak,” where it forms an articulation with the frontal process of the maxilla.
 - The anterior table is covered by skin, subcutaneous fat, frontalis muscle, and pericranium.
- The posterior table is much thinner and forms the boundary between the sinus cavity and the intracranial space.
- The intersinus septum is a bony partition that divides the right and left frontal sinuses into two sinus cavities with independent drainage pathways.
 - These cavities may be asymmetric in size and can potentially communicate via an intersinus septal cell.

Frontal Recess

- This is an hourglass-shaped space through which the frontal sinus drains.
- The internal frontal ostium is the narrowest segment of this space.
 - It is bordered anteriorly by the frontal beak and posteriorly by the skull base.
- The ostium drains inferiorly into the frontal recess (previously referred to as the nasofrontal duct), a space that is defined by the following limits:
 - Anterior—frontal beak and posterior wall of the agger nasi cell
 - Posterior—anterior face of the ethmoid bulla
 - Lateral—lamina papyracea and lacrimal apparatus
 - Medial—lateral lamella of the cribriform plate, middle turbinate, and uncinate process^{7,8}

Frontal Pneumatization Patterns

- The anterior ethmoid cells may pneumatize in various patterns, thus resulting in a multitude of different orientations of the frontal sinus outflow tract.
- The development of these cells may lead to displacement of the frontal recess, thus resulting in a circuitous pattern of drainage.
- Agger nasi cell: the most anterior and most anatomically consistent anterior ethmoid cell, located between the lateral nasal wall and the uncinate process, directly anterior to the vertical attachment of the middle turbinate to the skull base (**FIG 1**)
- Type 1 frontal cell: a single cell located superior to the agger nasi cell. Its posterior border displaces the frontal recess posteriorly.
- Type 2 frontal cell: two or more stacked cells located superior to the agger nasi cell. These cells result in posterior displacement of the frontal recess.
- Type 3 frontal cell: a single, large anterior ethmoid cell superior to the agger nasi cell that extends superiorly beyond the internal frontal ostium, into the frontal sinus. It posteriorly displaces the frontal recess.
- Type 4 frontal cell: a single anterior ethmoid cell located entirely within the frontal sinus. Its anterior wall is either the anterior table of the frontal sinus or the floor of the frontal sinus.

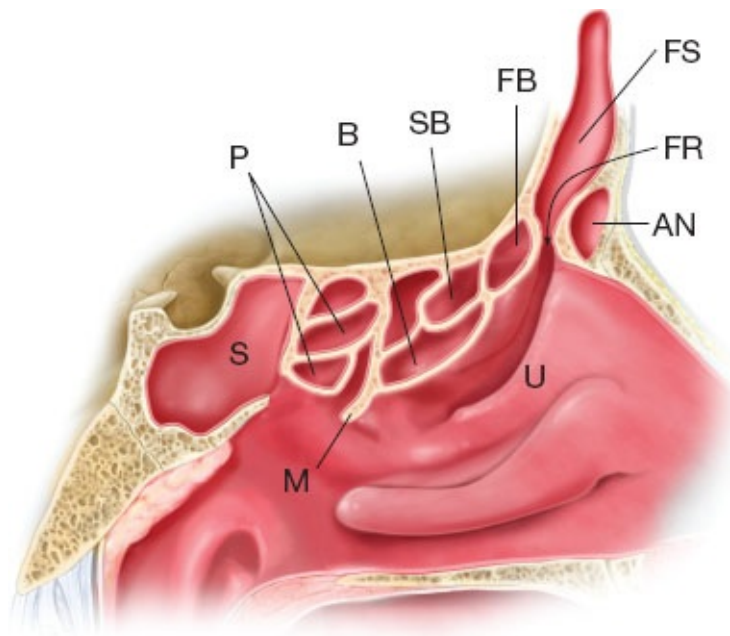


FIG 1 • Illustration of the named ethmoid cells, on parasagittal view. Demonstrated is the frontal recess

(*FR*), which is bordered anteriorly by the agger nasi cell (*AN*) and posteriorly by the frontal bullar cell (*FB*). The agger nasi cell is a reliable landmark, present in virtually all sinonasal cavities. Also shown are the uncinate process (*U*, *dashed line*), suprabullar cell (*SB*), ethmoid bulla (*B*), posterior ethmoid cells (*P*), basal lamella of the middle turbinate (*M*), and the sphenoid sinus (*S*).

- Supraorbital ethmoid cell: one or more anterior ethmoid cells that pneumatize superiorly into the frontal sinus. This is typically posterior and lateral to the frontal recess, resulting in anteromedial displacement of the drainage pathway. It may result in a septate appearance of the frontal sinus on coronal imaging.
- Frontal bullar cell: an anterior ethmoid cell located above the ethmoid bulla that extends into the frontal sinus. It borders the skull base and posterior table of the frontal sinus, causing anterior displacement of the frontal recess. It is thought to arise from pneumatization of the lamella of the anterior ethmoid bulla (see **FIG 1**).
- Suprabullar cell: an anterior ethmoid cell located above the ethmoid bulla that borders the skull base. Similar to the frontal bullar cell, it forms from pneumatization of the bulla lamella and displaces the frontal recess anteriorly. It does not, however, extend into the frontal sinus (see **FIG 1**).
- Intersinus septal cell: a pneumatized partition of the frontal sinus septum that drains inferiorly into one of the paired outflow tracts.^{7,8}

Soft Tissue Anatomy

- The afferent innervation of the frontal region is supplied by distal ramifications of the ophthalmic branch of the trigeminal nerve, the supratrochlear and supraorbital nerves.
- The supratrochlear nerve is the medial branch of the frontal nerve.
 - It courses superior to the trochlea (within the orbit) and penetrates the orbital septum at the medial aspect of the orbit.
 - The nerve then traverses the corrugator muscle to provide sensory innervation to the soft tissues of the inferomedial aspect of the forehead.
- The supraorbital nerve is the lateral division of the frontal nerve.
 - It exits the orbit through the supraorbital foramen, at the junction between the

medial one-third and lateral two-thirds of the orbital rim.

- It courses superiorly deep to the corrugator muscle and penetrates the frontalis muscle to provide sensory innervation to the upper and lateral forehead.
- Its distal branches enter retrograde through the anterior table of the frontal sinus (along with the diploic veins) to provide afferent innervation to the sinus cavity.

PATHOGENESIS

- The function of the frontal sinus is not known, but is thought to increase the surface area of respiratory mucosa for air humidification and serves as a protective barrier to forces directed toward the anterior cranium.
- The frontal sinus is lined by pseudostratified, ciliated, columnar epithelium.
- Mucocoeles are lined by the same respiratory-type epithelium, but their exact pathogenesis remains unknown.
- They are believed to arise from mucosal inflammation causing obstruction of the natural drainage pathway of the sinus in which they originate. This leads to retained secretions and osteolysis of the surrounding bone, thus resulting in the expansion that is often noted radiographically.^{2,6,9}
- Insults that lead to ostial obstruction vary considerably and include⁹
 - Trauma
 - Chronic sinusitis
 - Nasal polyposis
 - Iatrogenic (postsurgical)
 - Neoplasm

NATURAL HISTORY

- Due to their pathogenesis, frontoethmoidal mucocoeles tend to be slow-growing, with clinical manifestations occurring late in the disease process.²
- Alternatively, some mucocoeles remain completely asymptomatic and are only discovered incidentally through radiographic imaging for unrelated issues.
- Various series that have looked at postoperative complications from sinus surgery support the indolent nature of frontal mucocoele formation. They have found a mean duration to symptom onset of 5 years following the initial surgery.¹⁰
- Because of this, many of these lesions go unrecognized and may present dramatically with serious complications, due to intraorbital or intracranial

extension.

- Mucocoeles occurring secondary to antecedent trauma to the frontal sinus have been reported up to 50 years following the initial injury.^{1,11,12}
- The peak incidence of these lesions remains unknown. Therefore, all patients who have had any history of frontal sinus trauma are at risk for this late stage complication.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Because of indolent growth patterns, frontal mucocoeles tend to be asymptomatic for many years prior to their clinical presentation.
- They typically become clinically evident only after extensive expansion and erosion, due to compression of surrounding structures.
- Symptomatically, patients most often present with proptosis (61.5%), frontal pain/pressure (38.5%), and nasal drainage (38.5%).⁶
- Less commonly, patients may also experience headaches, nasal obstruction, diplopia, lid swelling, loss of visual acuity, and orbital cellulitis.^{4,6}

IMAGING

- Imaging is typically obtained in the axial, coronal, and sagittal planes, in order to demonstrate the location of the lesion and its relationship to the surrounding anatomical structures.
- CT scan of the maxillofacial skeleton with fine cuts through the paranasal sinuses is the standard imaging modality used in the diagnosis of frontal mucocoeles.
- Contrast enhancement may be utilized to better delineate the degree of intracranial or intraorbital extent and to differentiate these lesions from other pathologic entities.
- CT provides excellent bony definition and typically demonstrates a cystic, homogenous, fluid-filled structure with thinning of the surrounding bone (**FIG 2A,B**).
- MRI may be used in tandem with computed tomography, particularly if the diagnosis remains in question.
- The T2 sequence will reveal a hyperintense signal, consistent with a mucocoele's high fluid content.^{4,11}
- Alternatively, in lesions that have higher protein content, the T2 sequence images may demonstrate an isointense or hypointense signal.

- Postcontrast T1 sequence images may be used to identify dural enhancement, if there is evidence of skull base erosion (**FIG 2C,D**).

DIFFERENTIAL DIAGNOSIS

- Epidermoid cyst
- Dermoid cyst
- Cholesterol granuloma
- Fibrous dysplasia
- Encephalocele
- Meningoencephalocele
- Allergic fungal rhinosinusitis
- Inverted papilloma
- Nasal polyps

SURGICAL MANAGEMENT

- Three approaches will be discussed:
 - Endoscopic, endonasal marsupialization
 - Frontal sinus trephination
 - Combined open and endoscopic decompression

Preoperative Planning

- Sinonasal endoscopy plays a critical role in the evaluation of these patients.
- Purulent secretions may be seen emanating from the middle meatus and draining posteriorly into the nasopharynx.
- In the case of very large lesions, the uncinate process may be expanded medially, with obliteration of the middle meatus.
- Alternatively, if lesions are well-encapsulated or localized to the superior aspect of the sinus, the sinonasal endoscopy may appear completely normal.
- Ophthalmologic evaluation should be requested in any patient with ocular symptoms or radiographic evidence of orbital extension.
- Include a baseline assessment of visual acuity, extraocular movements, and visual field testing.
- Radiographic review
 - The axial, coronal, and sagittal imaging should be evaluated to determine the extent of the lesion and involvement of surrounding structures.
 - Of particular importance is the anteroposterior (AP) diameter of the frontal

sinus outflow tract, best depicted on the sagittal series.

- This dimension determines the ease with which frontal dissection may occur via the endonasal route.
- A narrow AP diameter is associated with an increased risk for damage to the skull base as well as mucosal stripping during the surgery that can lead to restenosis of the frontal sinus outflow tract.
- Other considerations include
 - Height of the olfactory cleft
 - Dehiscent bone of the posterior table
 - Dehiscent bone of the lamina papyracea
 - Presence of polyps
 - Location of the anterior ethmoid arteries
 - Slope of the skull base
- Preoperative antibiotics: In the acutely infected mucopyocele, preoperative antibiotics are indicated.



FIG 2 • Noncontrast CT scans of the paranasal sinuses in the coronal (**A**) and axial (**B**) planes. There is an expansile mucocoele of the right agger nasi cell and frontal sinus, with thinning of the bone constituting the lamina papyracea and anterior skull base. There is extension of the lesion across the midline, into the left frontal recess. T1-weighted post–gadolinium enhanced images in the coronal (**C**) and axial (**D**) planes demonstrate a heterogeneously enhancing cystic lesion of the right frontal recess, with erosion of the right lamina papyracea and skull base. The heterogeneity of the lesion is likely due to proteinaceous elements within the lesion.

Positioning

- Following induction, the head of bed is rotated 90 to 180 degrees away from anesthesia to permit access to the right side of the patient. The display tower is typically positioned on the contralateral side, opposite the surgeon, to provide an unobstructed view of the monitor.
- The patient should be placed in the supine position with the head of bed in a slightly elevated position relative to the heart. This minimizes blood loss, thus improving visualization.
- Pledgets are soaked in a topical anesthetic/decongestant solution and placed intranasally, to dilate the nasal airway.
- If an external approach or trephination is expected with a combined approach, local anesthetic is instilled into the planned incision sites. 1% lidocaine with epinephrine 1:100 000 is generally used.
- Any of the commercially available image guidance systems is acceptable and appropriate for use. The preoperative imaging should be formatted appropriately for use with the chosen guidance system.
- The use of an electromagnetic-based system requires fixation of a patient tracker that may limit access to the forehead, if an external approach is planned.¹³
- In this case, an infrared navigation system with line-of-sight registration may be preferred.¹³

Approach

- The surgical approach should be tailored to the extent of the mucocele and its involvement with surrounding structures.
- The goals of surgery are to marsupialize the mucocele cavity and restore the patency and function of the frontal sinus outflow tract.
- In most cases, this is achieved through an endoscopic approach, with or without removal of the floor of the frontal sinus (Draf IIb or III), depending on the amount of access that is required.¹²
- In the case of a Draf IIb, the floor of the sinus is removed from the supraorbital ridge to the septum, in the midline. This includes excision of the anterior attachment of the middle turbinate to the floor of the frontal sinus.¹²
- In a Draf III, a common cavity defect is created by removing the floor of the bilateral frontal sinuses. This includes the excision of both middle turbinates and the superior aspect of the nasal septum.¹²

- In the case of a superiorly or laterally situated mucocele, a frontal sinus trephination may be performed.

TECHNIQUES

■ Endoscopic Endonasal Marsupialization

- Following induction and positioning, the topical decongestant-soaked pledgets are removed.
- Dissection begins using the zero-degree endoscope.

Uncinectomy

- To access the frontal recess, an uncinectomy is first performed, using backbiting forceps to divide its horizontal and vertical segments (**TECH FIG 1**).
- The vertical segment is bluntly reflected forward and separated from its attachment to the lacrimal crest using the 90-degree Blakesley forceps.
- The horizontal segment is then sharply removed, with through-cutting instruments or a microdebrider. Preserve the basal lamella of the middle turbinate.
- For large lesions, wide exposure is warranted for panoramic exposure of the frontal recess.
- This requires a maxillary antrostomy and anterior ethmoidectomy.
- If there is more extensive involvement or erosion of the orbit, posterior ethmoid dissection may be required as well.

Maxillary Antrostomy and Anterior Ethmoidectomy

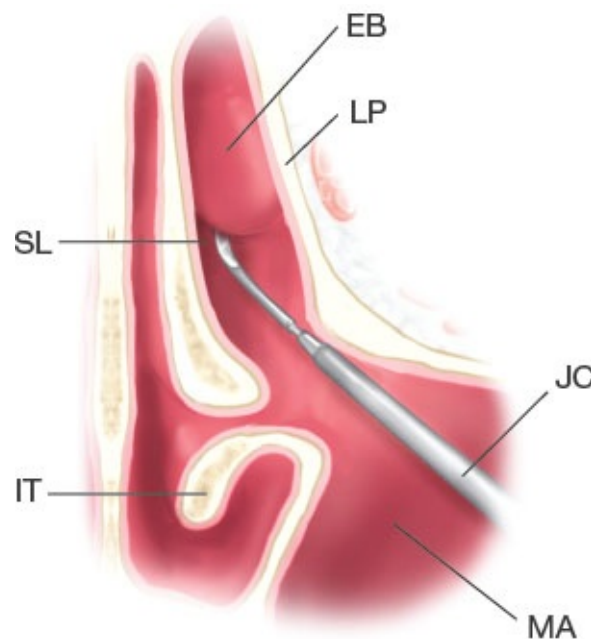
- The anterior fontanelle is identified and dilated, using the maxillary ostium seeker.
- The membranous medial wall of the maxillary sinus is taken down with straight through-cutting forceps, thus connecting the anterior and posterior fontanelles.
- A 45-degree angled endoscope should be used for greater visualization of the surgical antrostomy. This ensures that the surgical antrostomy is in continuity with the natural ostium of the maxillary sinus, thus avoiding postoperative

recirculation.

- The ethmoid bulla is a reliable landmark that is easily identified after the uncinectomy has been performed. It forms the posterior aspect of the frontal sinus outflow tract.
- It is removed via a retrobullar approach.
- A J-curette is placed into the sinus lateralis or retrobullar space and the bulla is dissected anteriorly and removed (**TECH FIG 2**).



TECH FIG 1 • Uncinectomy. The backbiter (*BB*) is placed within the hiatus semilunaris and used to transect the horizontal from the vertical portion of the uncinate process, thus opening the maxillary antrum. NS, nasal septum; MT, middle turbinate; LC, lacrimal crest; EB, ethmoid bulla.



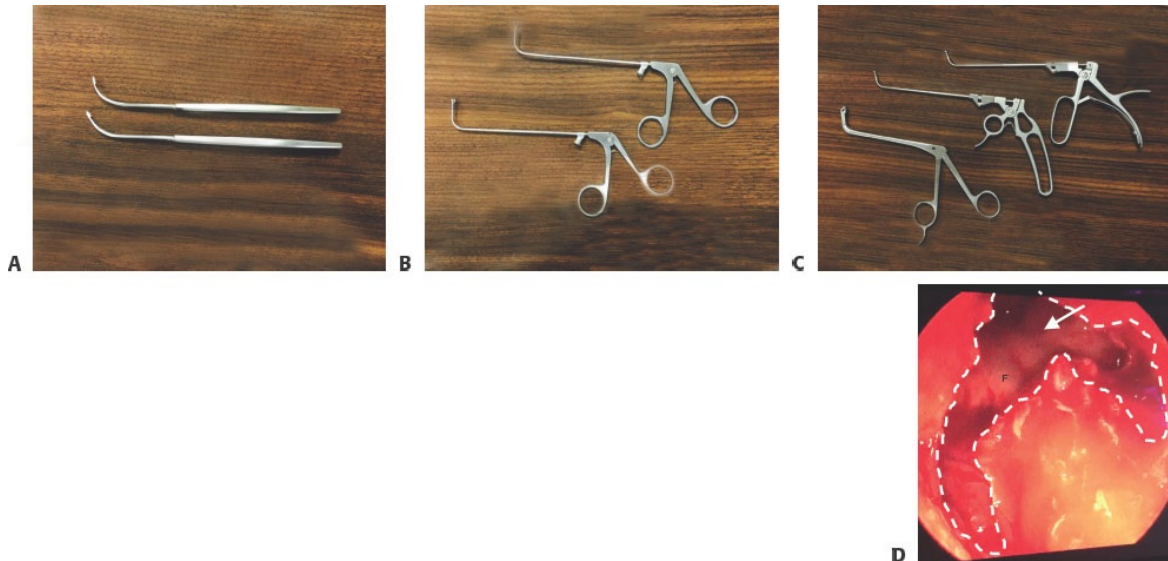
TECH FIG 2 • Anterior bulllectomy. The J-curette (*JC*) is placed within the sinus lateralis (*SL*), the space immediately posterior to the ethmoid bulla (*EB*). The bulla is disarticulated from the lamina papyracea (*LP*)

and skull base, thus opening the anterior ethmoid cavity. MA, maxillary antrum; IT, inferior turbinate.

Frontal Dissection

- With the anterior ethmoidectomy and maxillary antrostomy completed, frontal dissection is performed using the 45-degree endoscope.
- The anterior ethmoid artery is identified along the skull base, coursing from posterolateral to anteromedial.
- It is critical to identify this structure, as it marks the posterior limit of the frontal sinus outflow tract, approximately 2 to 5 mm posterior to the opening. Inadvertent injury to this structure may result in retraction of the lateral stump of the artery into the orbit, causing an orbital hematoma.
- The frontal sinus outflow tract is identified and widened using frontal sinus (Bolger-Kuhn) probes or curettes, which are specifically angled for this purpose (**TECH FIG 3A**).
- The tract is typically located posterior and medial to the agger nasi cell. In two-thirds of patients, it drains lateral to the uncinate process and into the ethmoid infundibulum.
- The agger nasi cell is removed in a posterior-to-anterior direction. Avoid inadvertent entry into the intracranial space through the posterior table of the frontal sinus.
- The horizontal table of bone along the anterior and medial aspect of the frontal drainage pathway is safe for resection. The posterolateral mucosa is left intact to permit re-epithelization of the frontal outflow tract.
- Removal of the floor of the frontal sinus is best performed using a combination of grasping and through-cutting giraffe forceps (**TECH FIG 3B**), curved rongeurs (eg, angled Kerrison 45 or 90 degrees), and Hosemann through-cutting punch forceps (**TECH FIG 3C**) or with angulated, powered drills to widely marsupialize the mucocoele cavity.
- 90-degree giraffe forceps are used to remove all free-floating fragments.
- Culture and Gram stain are obtained once the mucocoele cavity is drained, to direct the choice of postoperative antibiotics.
- In general, if there is significant lateral or superior extension of the mucocoele, the entire floor of the frontal sinus is removed, from orbit to the midline and posteriorly to the location of the first olfactory filament (Draf IIb).¹²

- In lesions that cross the midline, a superior septectomy with resection of the floor of the contralateral frontal sinus and partial septectomy is performed (Draf III) (**TECH FIG 3D**).



TECH FIG 3 • **A.** Frontal curettes used to enter into and widen the frontal recess to allow the use of other curved instruments. **B.** Kuhn frontal sinus forceps, designed to sharply cut or grasp ledges of bone for removal from the frontal sinus outflow tract. **C.** Frontal rongeurs, used to amputate dense or osteitic bone from the frontal recess, when delicate instrumentation is insufficient. **D.** Endoscopic view of a Draf III frontal sinusotomy defect. The *dashed line* indicates confluence of the right (*F*) and left (*f*) frontal sinus outflow tracts after removal of the superior aspect of the nasal septum and the leading edge of the bilateral middle turbinates.

Completion

- If the skull base and orbit are not dehiscent, the sinus cavity is irrigated with buffered saline solution to remove all debris and infectious contents.
- Visualization is achieved using the 70-degree endoscope to confirm the

patency of the frontal sinus outflow tract and to ensure that no residual septations exist that may result in postoperative obstruction or scar formation.

- The decision of whether to stent the frontal outflow tract depends on a number of factors that portend a poor prognosis, such as:
 - A-P diameter of the frontal outflow tract less than 8 mm
 - History or presence of nasal polyps
 - Prior recurrence of mucocele
 - Prior history of sinonasal surgery
 - Previous frontal sinus trauma^{14–16}
- A variety of stents are available, including steroid-eluting products that slowly resorb over time.
- Alternatively, a T-shaped stent may be fashioned from a piece of 1/100-in.-thick Silastic sheeting that is rolled and cut to the appropriate length to adequately traverse the frontal sinus outflow tract.
- Hemostasis is then achieved. Packing may be placed but is generally not necessary unless there is a substantial risk of postoperative epistaxis (ie, pre-existing coagulopathy, extensive intraoperative blood loss) or if there is significant destabilization of the middle turbinate that may lead to scar formation.

■ Frontal Sinus Trephination

- In mucoceles that are located laterally and superiorly within the frontal sinus, or those that have caused marked osteoneogenesis of the frontal sinus outflow tract, frontal sinus trephination may be required for extirpation of the infection.

Exposure

- Various incisions have been described, including the suprabrow, intrabrow, and infrabrow.
- The infrabrow is classically described, because it allows for safe entry into the frontal sinus medially and inferiorly, at the broadest and most dependent region of the sinus.
- 1% lidocaine with epinephrine 1:100 000 is injected into the planned surgical site (**TECH FIG 4**).
- The incision extends 1.5 to 2.0 cm horizontally along the inferior margin of the eyebrow beginning at the medial brow tuft.

- Medial extension beyond this point may result in noticeable scarring of the skin.

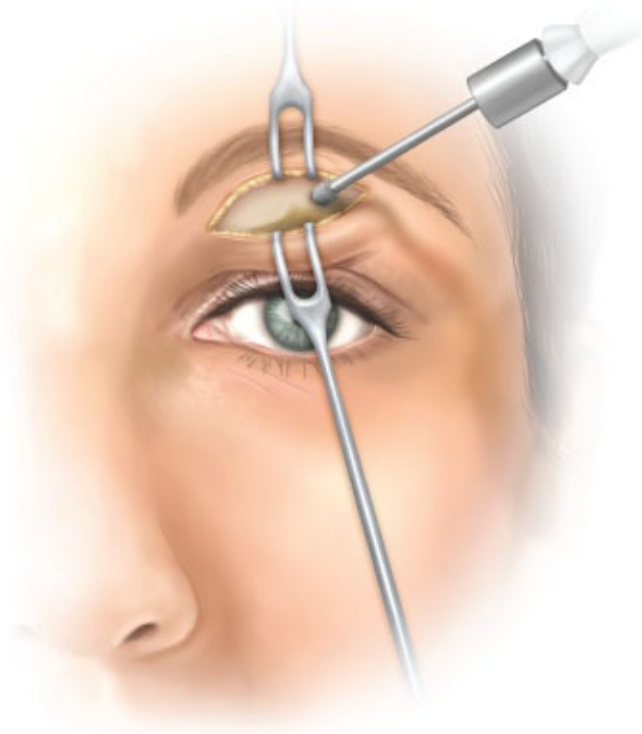


TECH FIG 4 • Incision sites for trephination. Infrabrow—immediately inferior to the brow, along the orbital rim. Intrabrow—directly through the midportion of the brow. Suprabrow—superior edge of brow.

- Placement of the incision too far inferior may result in trephination of the frontal sinus outflow tract, resulting in postoperative scarring and obstruction.
- The skin is then sterilely prepped and draped.
- The incision is made using a no. 15 blade. It is extended through the skin, subcutaneous tissue, orbicularis oculi and corrugator muscles, and periosteum.
- Hemostasis is achieved with bipolar (rather than monopolar cautery) in order to avoid thermal damage to the skin and periosteum.
- The periosteum is elevated from the frontal bone using a periosteal elevator, thus exposing a 1 × 1 cm area where the osteotomy may be performed.

Osteotomy

- The osteotomy is ideally made at the level of the floor of the frontal sinus (**TECH FIG 5**).
- This avoids the frontal sinus outflow tract, which is located inferiorly; injury to the tract results in postoperative neo-osteogenesis and obstruction.



TECH FIG 5 • The osteotomy is ideally made at the level of the floor of the frontal sinus. Using a 4-mm rough cutting round diamond bur, an approximately 8 to 10 mm of bone of the anterior table is saucerized.

- It also avoids entry into the anterior table of the sinus through which diploic veins course. Exposure of these vessels can cause seeding of the infection from the mucocele cavity, resulting in osteomyelitis of the frontal bone or intracranial extension of the infection.
- The osteotomy is made using a 4-mm rough cutting bur. An area measuring 8 to 10 mm is saucerized on the anterior table, without entry into the sinus cavity.
- The bone is drilled until close proximity to the underlying mucosa is reached.

- A curette is used to enter through the mucosa.
- The osteotomy is widened with the Kerrison rongeur to a diameter of 1 to 1.5 cm, depending on the size required for access to the mucocele and introduction of endoscopic instruments.
- The mucocele is then drained under direct visualization. Cultures are obtained to guide the postoperative antibiotic regimen.
- If the trephination is combined with an endoscopic, endonasal approach, instruments may be introduced transnasally, while visualization is provided from above through the trephination site.
- All bony septations of the mucocele and their associated mucosa are removed with powered drills and/or the Kerrison rongeur.

Completion

- The sinus cavity is then irrigated with buffered saline solution, except in the case of a dehiscence into the orbit or posterior table.
- One-to-two red rubber catheters can be placed through the trephination site to provide a conduit for postoperative irrigation.
 - These are secured with a 4-0 nylon suture to the skin.
 - The periosteum and surrounding soft tissues are closed with 4-0 Vicryl suture.
 - The skin around the drain is closed with interrupted nonresorbable suture.

■ Combined Endonasal-External Approach

- The above-mentioned approaches may be used in tandem for cases in which there is more extensive disease that does not lend itself to a single approach.
 - Trephination is rarely performed as a stand-alone procedure, as the likelihood of recurrence of the mucocele is high.
 - Marsupialization via trephination combined with the creation of a permanent drainage pathway via an endoscopic frontal sinusotomy provides a more permanent solution for frontal sinus mucoceles.
 - Other approaches to the frontal sinus, including osteoplastic flap and bicoronal approach, are covered elsewhere in this text.
-

PEARLS AND PITFALLS

Visualization	■ Endoscopic visualization of the frontal recess is difficult, even in the trained surgeon's hands. ■ Use of the 70-degree endoscope may improve visualization, by providing a more panoramic view of the frontal sinus outflow tract. ■ This will help to avoid mistaking a supraorbital ethmoid cell for the frontal sinus, thus ensuring proper dissection.
Mucosal stripping	■ Use through-cutting instrumentation, in order to avoid damage to the posterior and lateral mucosa of the frontal sinus outflow tract. ■ Failure to do so may result in extensive postoperative scar formation and disruption of mucociliary clearance of the sinus cavity.
Hemostasis	■ Obtain hemostasis prior to the reversal of anesthetic because of the fluctuations in blood pressure that may occur during this process. ■ Multiple hemostatic agents are commercially available that are effective in controlling mild oozing. ■ Brisk, arterial bleeding must be controlled with monopolar or bipolar cautery. ■ Avoid injury to the sphenopalatine and anterior ethmoid arteries. ■ Prior to reversal, a Valsalva maneuver should be performed to confirm that there is no persistent bleeding. ■ Resorbable or nonresorbable packing may be placed within the middle meatus for hemostasis. ■ Avoid vasoconstrictive agents toward the end of the case. This may conceal areas of active bleeding that will rebleed following reversal.

POSTOPERATIVE CARE

- Endoscopic, endonasal marsupialization
 - In cases approached endoscopically, postoperative care includes systemic antibiotics, and possibly steroids, depending on the amount of mucosal inflammation and polyposis noted at surgery.¹⁷
 - Patients are uniformly placed on 2 to 3 times daily sinonasal irrigation with a buffered saline solution to remove debris and promote mucosal healing.¹⁷
 - This may be impregnated with steroid and/or antibiotics, depending on the degree of polyposis and the culture result and sensitivity profile.¹⁷

- Patients are seen at 1 to 2 weeks postoperatively for the first debridement, which is performed endoscopically in the outpatient setting, with a topical anesthetic.
 - If packing was placed intraoperatively, it is removed at this time with a straight Blakesley forceps.
 - If a nonabsorbable stent was placed in the frontal recess, it is typically removed at the first postoperative visit but may be left longer if there is a significant concern for scarring of the frontal outflow tract.^{14–16}
- Patients are seen in the office every 2 to 3 weeks and examined using the endoscope for the first three months. Follow-up is then performed every 3 months for the first year and every 6 to 12 months thereafter.^{4–6}
- Frontal sinus trephination
 - Antibiotic ointment is placed on the drain twice daily until the first postoperative visit.
 - The external drains are irrigated 1 to 2 times daily with buffered saline solution for 3 to 5 days.
 - The drains are then removed and the surrounding skin defect is left to heal by secondary intention. Nonresorbable skin sutures are removed at 5 to 7 days postoperatively.

OUTCOMES

- Endoscopic drainage of sinonasal mucoceles has a high success rate, with a low rate of recurrence.¹⁸
- Studies evaluating lesions that are amenable to endoscopic drainage have reported long-term recurrence rates of 0% to 11%.^{4,9}
- In these cases, repeat endoscopic evaluation is critical in the surveillance of these patients for disease recurrence.
- External approaches are associated with a higher risk of recurrence, likely owing to the severity of the lesion or its location (making endoscopic detection difficult).
- Reported rates of recurrence for external approaches may be as high as 6.8% to 23.5%.²

COMPLICATIONS

- Complications associated with endoscopic, endonasal marsupialization of frontal mucoceles are similar to those associated with endoscopic sinus surgery.
- These risks include both major and minor complications.

- Major complications:
 - Orbital injury
 - CSF leak
 - Severe hemorrhage
 - Nasolacrimal duct injury
 - Meningitis
- Minor complications:
 - Minor hemorrhage
 - Violation of the lamina papyracea
- Overall, the incidence of complications is between 0.9% and 23%.^{19,20}
- The risk of complications is increased with revision surgery, as compared to primary surgery.
- External trephination is subject to the same complications as the endoscopic approach, but also has additional associated risks, including:
 - Hypesthesia of the forehead
 - Refractory pain
 - Poor cosmesis due to scarring and contour deformity

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Section VII: Orbital Trauma

Correction of Orbital Floor Blow-out Fractures: Variation 1

53
CHAPTER

Jean-Francois Lefaivre and David Charles A. Fisher

DEFINITION

- Orbital blow-out fractures commonly result from force directly applied to the globe with subsequent energy transmission through the thin surrounding bones. The affected bones are typically the orbital floor and medial wall. It may be accompanied by entrapment of the inferior rectus muscle and inferior oblique muscle. True entrapment is a rare clinical finding. It is often mentioned on radiology reports and must be differentiated from herniation.
- Orbital floor fractures are often associated with additional facial fractures and soft tissue injury.

ANATOMY¹

- The orbital floor is composed of thin maxillary and zygomatic bone. Anteriorly, just behind the orbital rim, the floor is concave and becomes convex, posterior to the axis of the globe. It is bordered laterally by the lateral orbital wall, which is relatively thick, and consists of the frontal process of the zygoma, and greater and lesser wings of the sphenoid. Medially, the floor slopes upward toward the medial orbital wall, which is also a thin bony structure, made of the frontal bone superiorly, lacrimal bone anteriorly, and lamina papyracea of the ethmoid and lesser wing of the sphenoid posteriorly. The lamina papyracea, as its name implies, is thin and fragile.
- The inferior orbital fissure is located between the orbital floor and lateral

orbital wall. Structures present in the fissure include the maxillary division of the trigeminal nerve, infraorbital artery, zygomatic nerve, branches of the sphenopalatine ganglion, and branches of the ophthalmic vein. The inferior orbital fissure is also known as the sphenomaxillary fissure (**FIG 1**).

- The orbital plate of the maxilla and a portion of the zygoma represent the orbital floor. The zygoma makes up the anterior portion of the orbital floor, anterior to the inferior orbital fissure. The infraorbital nerve runs through the orbital floor in the infraorbital groove posteriorly and in the infraorbital canal anteriorly. The nerve often provides a landmark and a good plane of dissection.
- The infraorbital rim is made of zygomatic bone and maxilla. The frontal zygomatic suture is exposed during dissection. Just inferior to the inferior orbital rim, the infraorbital foramen is located about 1 cm below the rim, generally in line with the midaxis of the pupil.
- Both the orbital floor and medial orbital wall are vulnerable to injury because they are relatively thin compared to the surrounding structures.
- Knowledge of anatomy is essential to perform safe dissection and optimal exposure of the orbital floor defect.

PATHOGENESIS

- Orbital blow-out fracture is often the result of blunt injury to the globe and/or orbital rim, sustained during altercations, falls, sports-related injury, or motor vehicle accidents. These injuries transmit an external force to the orbital contents and orbital bones. The weakest portion of the orbit then fractures, resulting in herniation of orbital contents through the bony defect. The anterior and posterior portions of the orbital floor are thicker. The middle portion of the orbital floor is thinner, which accounts for the majority of fractures into the maxillary sinus. The medial orbital wall also commonly fractures into the ethmoid sinus air cells.
- The globe typically moves posteriorly, inferiorly, and medially if there is significant prolapse or herniation of the orbital content into the orbital floor defect.

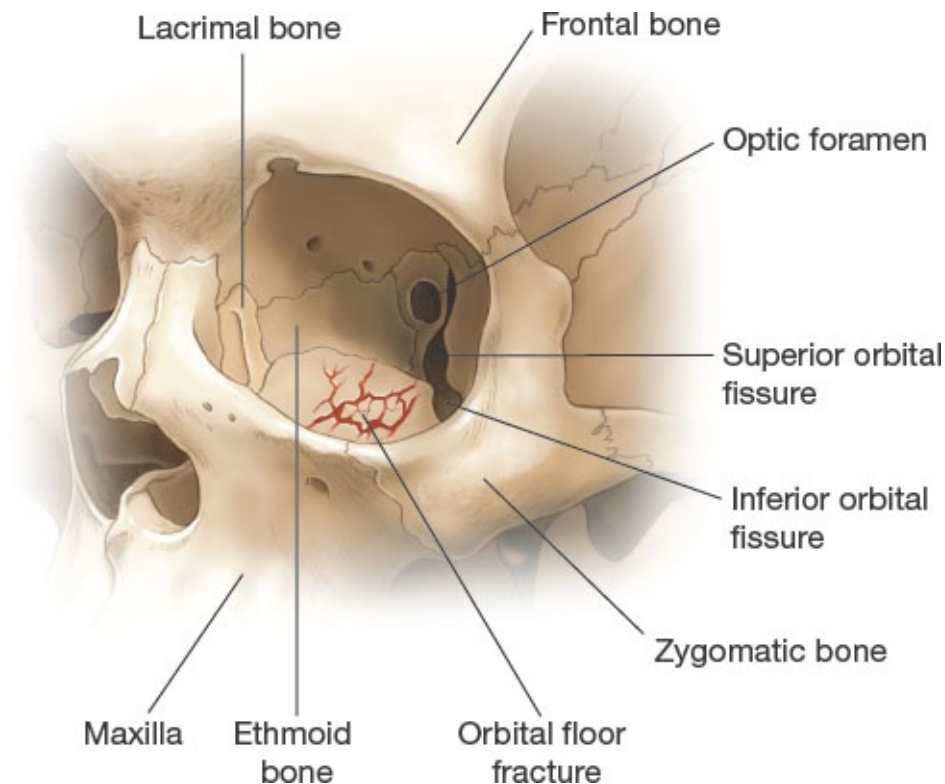


FIG 1 • Anatomy of the left orbit.

NATURAL HISTORY

- Untreated fractures generally result in enophthalmos. Depending on the volume increase associated with orbital fracture, it will range from minimally to significantly noticeable. Enophthalmos can be identified clinically with 2 mm of posterior displacement of the globe.² A 5% increase in orbital volume is sufficient for a clinical diagnosis of enophthalmos.² An important part of informed surgical consent is to discuss the anticipated natural history of untreated defects. Hypoesthesia in the distribution of a second branch of the trigeminal nerve generally resolves over several months. Diplopia may improve if it is secondary to muscle contusion.
- If an entrapped muscle is not treated promptly, permanent ischemic injury to the extraocular muscle will result in diplopia. It is the only emergency associated with orbital floor fractures. Our experience, as previously reported, is that it is more common in children than in adults.
- Retrobulbar hematoma that results in optic nerve compression is an emergency; however, in a blow-out fracture, there is typically an expanded volume that alleviates the pressure on the orbital apex.

- Patients with large orbital floor defects are generally treated acutely secondary to obvious enophthalmos. Patients with more subtle findings may be observed initially and surgically treated when/if they develop enophthalmos. These are generally patients with smaller defects on computed tomography (CT) scans.³
- The decision of whether or not to operate can generally be made within the first 6 weeks following injury. Longer follow-up may be recommended in patients managed nonoperatively.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Specific trauma-related history helps elucidate the amount of force transmitted to the globe and orbit.
- Previous eye surgery, eye injury, or pathology should be documented as well as the use of prescription glasses or contact lenses.
- Physical examination often reveals
 - Periorbital ecchymosis and swelling
 - Subconjunctival hemorrhage
 - Enophthalmos, most easily identified by both a worm's eye and a bird's eye view; may be masked by edema early after injury
 - Diplopia, often in upward gaze
 - Hypoesthesia in the distribution of the second branch of the trigeminal nerve, involving the cheek, nose, upper lip, gingiva, and upper teeth in various distributions
- Visual acuity, extraocular movements, and pupil examination need to be assessed
- Preoperative consultation with ophthalmology may be beneficial, especially in patients with decreased visual acuity or retrobulbar hemorrhage.

IMAGING

- Orbital or maxillofacial CT scan with 1 to 2 mm axial cuts and coronal and sagittal cuts will help understand the size and location of the defect, as well as soft tissue herniation. It will help determine the length and width of the bone graft or implant required for adequate repair⁴ (Video 1).



Video p2-c053_01

- A three-dimensional (3D) reconstruction is often beneficial in patients with multiple associated facial fractures. It is not essential for isolated orbital floor fractures.

DIFFERENTIAL DIAGNOSIS

- Medial orbital wall fractures may result in similar findings.
- Medial orbital wall defects should be identified preoperatively.
- Surgical treatment of orbital floor fractures that do not address associated medial floor fractures will result in only partial correction of enophthalmos.

NONOPERATIVE MANAGEMENT

- Small defects without herniation of orbital contents and without entrapment may be managed conservatively with close follow-up.

SURGICAL MANAGEMENT

- The primary objective of surgical intervention is to recreate normal anatomy with restoration of the orbital floor integrity and reduction of herniated soft tissue into normal position. Restoration of orbital shape and volume should help rebalance extraocular muscles and correct diplopia.
- Indications to correct orbital floor fractures include the following:
 - Enophthalmos
 - Large orbital floor defects with herniation on CT scan. Some authors mention that a 1 to 2 cm² defect or 50% of the orbital floor surface will result in enough orbital volume increase to result in clinically significant

enophthalmos.^{2,3}

- Diplopia associated with entrapment
- Entrapment with positive forced duction test. Extraocular muscles recover better if surgically released within 48 hours.
- Persistent oculocardiac reflex may be associated with soft tissue entrapment. Patients who benefit from early surgical intervention are those presenting with nausea, vomiting, and bradycardia, exacerbated with upward gaze.²

Preoperative Planning

- Complete review of the chart including medications is important, particularly anticoagulants.
- If long-acting dilating eye drops are used by ophthalmology, it is generally recommended to wait before taking the patient to the operating room. Pupil diameter is assessed preoperatively. If a pupil dilates intraoperatively, it is often secondary to excess retraction. This phenomenon cannot be observed in patients with pupils pharmacologically dilated.
- If the patient has a retrobulbar hematoma, clearance from ophthalmology prior to surgery is recommended.
- A thorough eye examination should be performed by the plastic surgeon and documented in the chart preoperatively.⁵
- Clearance from trauma team, neurosurgery, and other consultants is obtained prior to surgery.
- Timing of surgery depends on associated injuries. It may be beneficial to wait a few days and operate after periorbital swelling improves.
- CT scans are reviewed. The decision to proceed with bone grafts and titanium or resorbable implant is often made preoperatively. Other types of implants have been associated with complications such as extrusion³ (Video 1).
- Informed consent is obtained. Risks, goals, and benefits are explained to the patient or family members. Risks include bleeding, infection, scar, ectropion, diplopia, residual enophthalmos, hypoesthesia, need for additional surgery, and blindness.

Positioning

- Patient is in supine position, operating room table rotated 90 or 180 degrees.
- Vertex should be aligned with the head of the bed. This will help decrease surgeon fatigue and discomfort.

- In patients without cervical injury, the head of the bed could be slightly extended to better visualize the orbital floor.
- In patients with cervical injury, the cervical collar is left in place and the whole table can be placed in Trendelenburg to help visualize the orbital contents.
- A headlight is essential. Battery-powered headlights provide more freedom, allowing the surgeon to review the CT scan if necessary and to evaluate the patient in worm's eye and bird's eye views alternatively.
- Loupe magnification is based on preference.
- Operating room monitor with ability to project CT scan is also helpful.
- Sequential compression devices and body warmers are applied to all patients unless contraindicated.

Approach

- Subtarsal incision or transconjunctival incision provides adequate exposure.
- The subciliary incision carries a higher risk of ectropion and should be avoided.³
- The subtarsal incision is rapid, reliable, and easy to learn. It is also easier if one has to reoperate in a complex panfacial fracture patient. The key step is to preserve a strip of pretarsal orbicularis muscle to decrease the likelihood of postoperative ectropion.
- When using a transconjunctival incision, a modified lateral canthotomy^{6,7} is helpful. This gives better exposure than does a regular transconjunctival approach and avoids a lateral canthotomy. Entropion is a rare complication associated with the transconjunctival approach.⁸
- With either incision, the surgeon must visualize all edges of the floor defect.

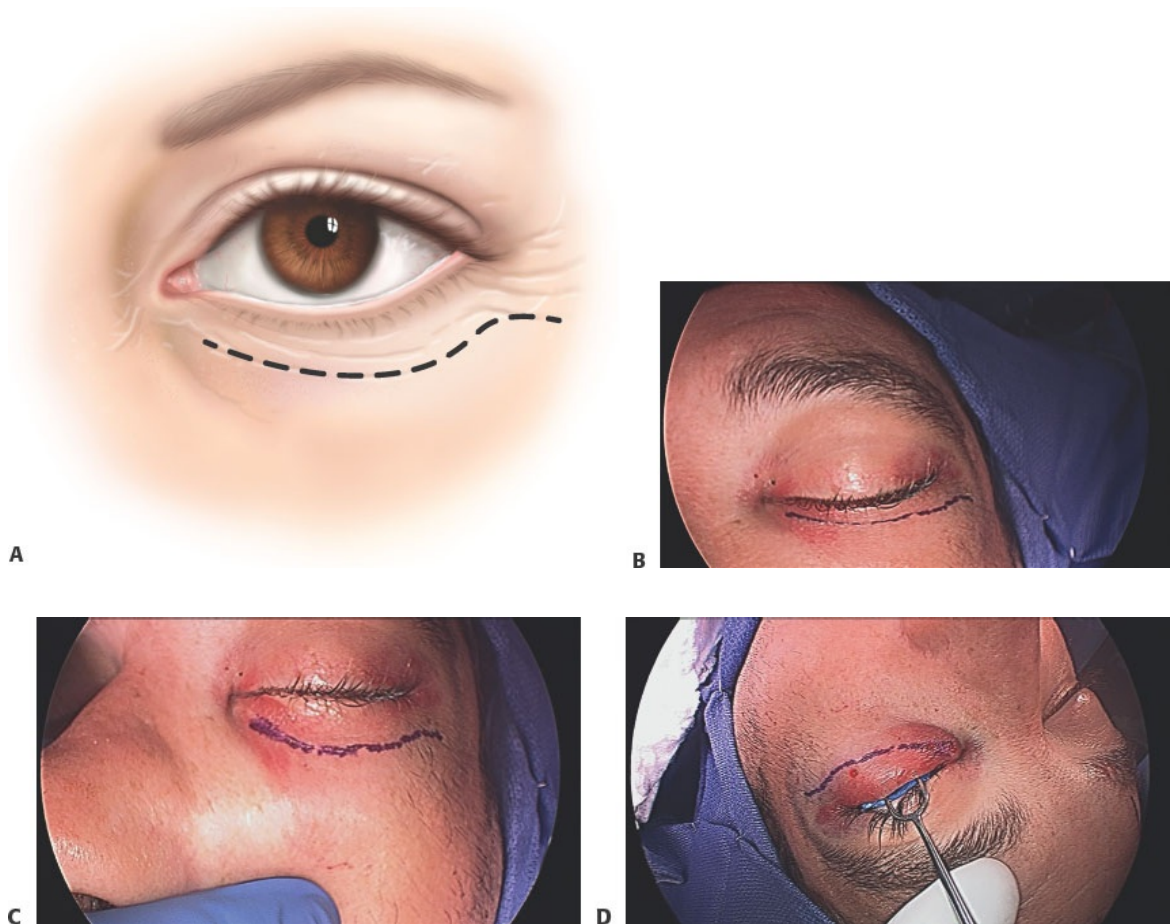
TECHNIQUES

■ Markings and Preparation

- Marking is made in the preoperative holding area in a natural eyelid skin crease for subtarsal approach (**TECH FIG 1A–C**).
- General anesthesia with an oral RAE tube improves surgical access compared to a regular orotracheal tube. If a regular tube is used, it is taped to the chin. For patients with multiple facial fractures, the orotracheal tube is

often wired to a permanent bicuspid or molar. If the patient has maxillary and/or mandibular fractures requiring intraoperative assessment of occlusion, a nasal RAE tube is used and secured to the nasal septum with a 0-silk suture.

- Infiltration of lidocaine 1% with epinephrine 1:100 000 on the lower lid and over the infraorbital rim prior to prepping and draping allows enough time for effective vasoconstriction.
- After prepping and draping, the eyes are thoroughly irrigated with balanced salt solution. Normal saline solution is generally avoided because the pH may not be balanced.
- Forced duction test is performed as a baseline.
- Corneal protector and ocular lubricant are applied.
- Tension is applied on the lower lid through either traction sutures or a double-pronged skin hook pulling superiorly and away from the globe (**TECH FIG 1D**).

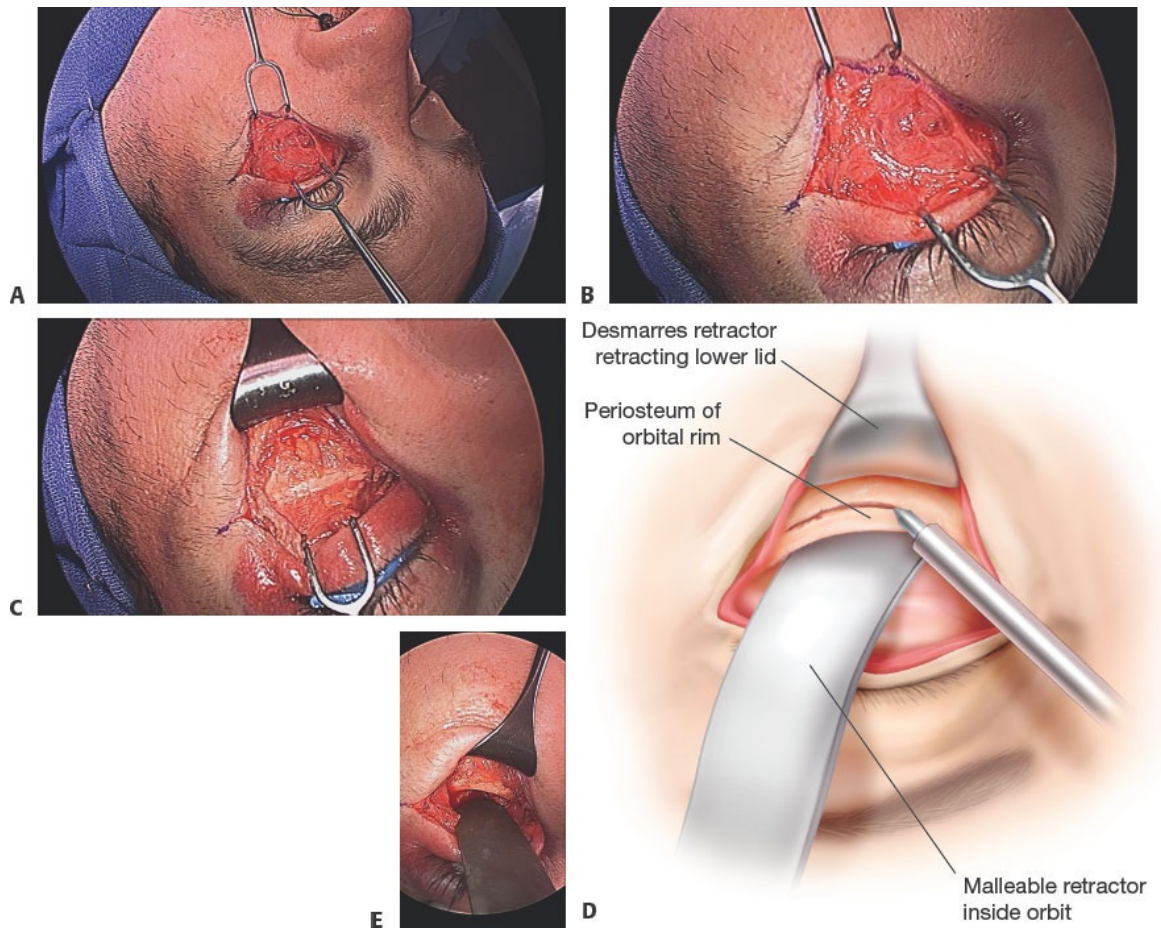


TECH FIG 1 • A. Planned incision in a natural skin

crease, below the level of the tarsal plate and below the pretarsal orbicularis muscle. It can be extended laterally in the crow's feet to provide better exposure. **B.** The incision is drawn in a natural skin crease and extends laterally and downward in the crow's feet. **C.** By pulling downward on the eyelid, it is easy to see that the pretarsal portion of the orbicularis oculi muscle will be preserved. **D.** The surgeon is standing at the head of the bed. This will allow better access to the orbital floor. Once a corneal protector is in place, the double hook is used to apply tension upward on the lower lid while the assistant pulls downward to apply countertraction while the incision is made through skin only. The blade is then placed tangential to elevate skin from the orbicularis muscle. An incision through the orbicularis muscle is made lower than the skin incision with the tenotomy scissors.

■ Exposure

- Subtarsal skin incision with no. 15 blade
- The blade is turned tangential to the skin to elevate skin over the underlying orbicularis oculi muscle for a few millimeters.
- Curved iris scissors are used to split the orbicularis muscle parallel to fibers, exposing the underlying preseptal plane. This is a stepped approach with orbicularis oculi incision slightly below the level of the skin incision.
- Meticulous hemostasis is provided with electrocautery through an insulated needle tip at a low setting or with bipolar cautery.
- Blunt dissection is performed with a finger down to the infraorbital rim in an avascular plane. Good exposure of the infraorbital rim is provided (**TECH FIG 2A–C**).



TECH FIG 2 • A. Suborbicular dissection proceeds to the infraorbital rim. Gentle traction with skin hooks provides excellent exposure. **B.** This plane is relatively bloodless, following areolar tissue. **C.** The inferior orbital rim is exposed. Corneal protectors are always used when skin hooks are used to retract tissue around the eye. **D.** Once the inferior orbital rim is exposed, the malleable retractor is placed over the orbital contents and a Desmarres eyelid retractor is used to retract the lower lid. Electrocautery is used to incise the periosteum. **E.** An assistant holds the Desmarres retractor while the surgeon holds the malleable and periosteal elevator to expose the defect.

- Infraorbital rim periosteum at the anterior edge is incised with electrocautery (**TECH FIG 2D**).
- Subperiosteal dissection is initiated over the anterior edge of the infraorbital rim, from medial to lateral, followed by intraorbital subperiosteal dissection. Wide subperiosteal dissection, often well beyond the fracture site,³ is required to provide adequate exposure of the defect.
 - An orbital retractor or malleable retractor is used to gently retract the orbital contents away from the floor (**TECH FIG 2E**).
 - A graduated orbital retractor helps determine how far into the orbit the dissection extends. The orbital apex is typically 45 mm from the infraorbital rim. This distance should be kept in mind as one dissects from anterior to posterior. Most orbital floor fractures will be within 30 to 35 mm from the infraorbital rim. This should have been measured preoperatively on the CT scan.
- Bradycardia may be encountered if too much pressure is applied to the globe. If this occurs, retractors are removed until the heart rate normalizes. Ongoing communication with the anesthesia team is essential.
- The corneal protector is removed to assess whether the pupil has dilated secondary to retraction/pressure on the globe. If this is the case and there are no medical contraindications, intravenous dexamethasone may be used intraoperatively and postoperatively for 24 to 48 hours.
- Dissection also includes reduction of all herniated soft tissue. There is generally an areolar plane over the infraorbital nerve. Avoid grasping the nerve while reducing orbital contents.
- Hematoma inside the maxillary sinus is aspirated. Irrigation of saline or bacitracin solution is also helpful in draining maxillary sinus hematoma.
- Use of 1 × 3-in. neuropledgets can help hold intraorbital fat and assist with exposure. They can be soaked in epinephrine solution to aid in hemostasis.

■ Implant Placement and Completion

- The orbital floor defect is measured. It should correlate with preoperative measurements based on CT scan. An implant slightly longer and wider than the defect is chosen. It may have to be cut to the desired size.
- The bone graft or implant is carefully applied (**TECH FIG 3A**; Video 2), making sure that it rests over the posterior ledge of the defect and does not

prolapse into the maxillary sinus. It should extend 1 or 2 mm beyond the posterior ledge. A longer implant or graft may impinge on the posterior aspect of the inferior rectus muscle or orbital apex structures.

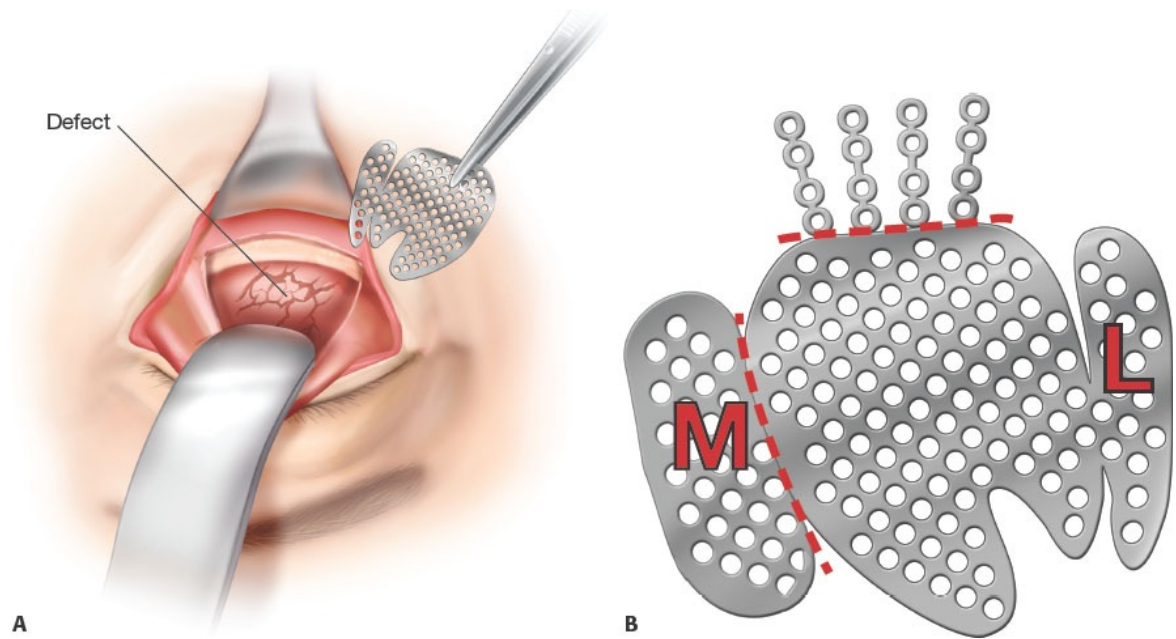


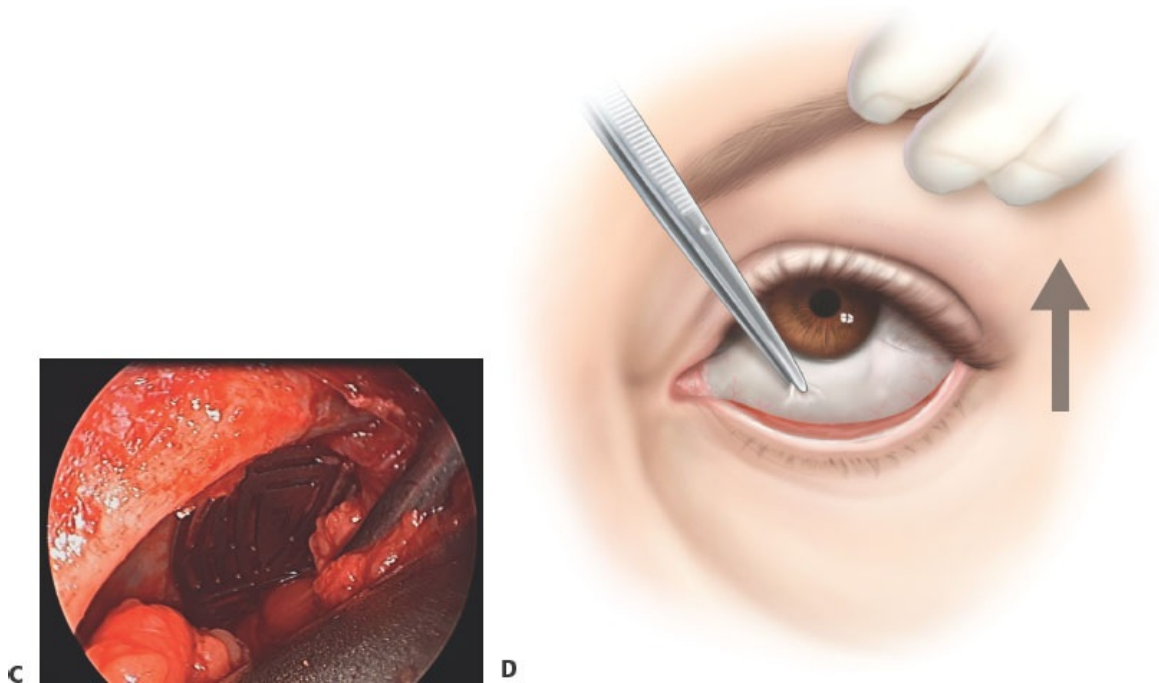
Video p2-c053_02

- The graft or implant must be properly positioned (**TECH FIG 3B,C**). This is the most critical portion of the procedure.
- Enophthalmos should be corrected. The globe position will appear slightly overcorrected because of intraoperative swelling.
- A forced duction test is repeated to be certain there is no entrapment (**TECH FIG 3D**; Video 3). The globe is rotated upward to make sure that there is no inferior rectus muscle entrapment. The globe is also moved laterally to make sure that there is no medial rectus muscle entrapment in the case of associated medial orbital wall fractures. The corneal protector is removed to perform this test and reapplied afterward.



Video p2-c053_03





TECH FIG 3 • A. Once the defect is completely exposed, a bone graft or titanium implant is placed to bridge the defect. **B.** Titanium orbital floor implant similar to the one used in surgery. The medial extension “M” and the anterior four extensions are cut prior to inseting. **C.** Titanium orbital floor implant in place; left orbit with suction tip in medial position and malleable retractor holding the orbital content. The anterior edge of the implant is behind the inferior orbital rim. Note that the plate has been trimmed to cover the defect. **D.** A forced duction test is performed after the implant or bone graft is placed on the orbital floor. It is better to perform a forced duction test before surgery, as a baseline, to be able to better appreciate changes following the procedure.

- Irrigation with bacitracin solution
- Closure of the periosteum with resorbable suture such as 3-0 or 4-0 Vicryl suture
- Hemostasis is re-evaluated.

- The orbicularis muscle is redraped.
- Orbicularis muscle may be resuspended laterally to the periosteum of the lateral orbital rim to provide support.
- Skin can be closed with a running 5-0 Prolene suture or with 6-0 interrupted fast-absorbing gut suture.
- Corneal protector is removed. Eyes are irrigated again with balanced salt solution.
- Temporary tarsorrhaphy may be applied through the gray line, lateral to the lateral limbus with 6-0 Vicryl or 5-0 plain gut suture in patients on whom postoperative chemosis could be a concern.
- Eyes are thoroughly irrigated with balanced salt solution.
- Lacri-Lube or ophthalmic ointment is applied in the eye and over the suture line.
- Frost suture is applied to provide gentle traction to the lower lid. It is removed 48 to 72 hours after surgery, after swelling improves.
- At the completion of procedure, communication with the anesthesia team is essential in order to avoid Valsalva, traumatic emergence from anesthesia and perioperative hypertension.

PEARLS AND PITFALLS

Physical findings

- Enophthalmos may not be obvious initially because of swelling. Decreased range of motion of extraocular muscles does not mean entrapment. Entrapment is rare. Oculocardiac reflex should raise the suspicion for entrapment. A forced duction test can be used in selective cases to rule out entrapment. Visual acuity should be assessed preoperatively.

Technique

- It is important to dissect the orbital floor to expose the entire defect to make sure that anatomic repair is achieved. Placement of plate or bone graft should be done under direct vision to make sure that it covers the posterior ledge of the defect without going too far posteriorly. An intraoperative forced duction test helps ensure that there is no entrapment after the plate or bone graft is applied.

Postoperative care

- Failure to recognize and address a retrobulbar hematoma may result in decreased visual acuity.

POSTOPERATIVE CARE

- Patients are generally observed overnight, with the head of the bed elevated 30 degrees. Most patients without concomitant injuries are discharged the morning after surgery.
- Extraocular movements and visual acuity need to be evaluated soon after surgery.
- If a Frost suture or a tarsorrhaphy suture is placed, it is generally removed after 48 to 72 hours, when swelling starts to resolve.
- Periorbital edema is expected as well as blurred vision secondary to ocular edema. If there is any significant decrease in visual acuity, the patient may have a retrobulbar hematoma. This is a surgical emergency, requiring decompression of the orbit in order to prevent blindness.
- Patients should avoid nose blowing early after surgery because there is a risk of pneumo-orbit with air extending to the soft tissue envelope. Over-the-counter nasal spray is recommended postoperatively.
- Lacri-Lube is recommended for patients who cannot completely close their eyelids.
- A postoperative CT scan may be indicated if there is any question about residual enophthalmos (Video 4). Diplopia is often seen early postoperatively and usually gets better over a few weeks, sometimes a few months. Patients should do range-of-motion exercises. If diplopia persists, ophthalmology consultation is indicated.



Video p2-c053_04

- If the patient develops ectropion, massaging the eyelid is recommended.

OUTCOMES

- With anatomic repair, there should not be residual enophthalmos. Extraocular movements should be intact unless there has been injury to the infraorbital portion of the oculomotor nerves or extraocular muscles, as a result of either trauma or surgery.
- Extraocular movements are often limited postoperatively and generally improve with time. If diplopia persists beyond a few weeks after surgery, ophthalmology consultation is indicated.
- Scars heal nicely following transcutaneous incision or transconjunctival approach. Although ectropion can be seen following transcutaneous approaches, entropion can be seen following a transconjunctival incision.⁶

COMPLICATIONS

- Hematoma may involve the lower lid, in the area of dissection. It can also be located in a retrobulbar location, leading to increased pressure around the optic nerve. This emergency needs to be recognized early and addressed surgically with lateral canthotomy to decompress the orbit. Lower lid hematoma can be aspirated once the hematoma liquefies but generally reabsorbs on its own. Lower lid hematoma may increase the risk of postoperative lower lid retraction and ectropion.¹
- Cicatricial ectropion can be seen postoperatively even if the pretarsal muscle is preserved. Commonly, this will resolve with massage and time.
- If lagophthalmos develops, ocular lubricants and nighttime taping are essential to prevent corneal ulceration.

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Correction of Orbital Floor

54 Blow-out Fractures: Variation 2

CHAPTER

Henry C. Vasconez

DEFINITION

- The orbit is a paired structure of the upper craniofacial skeleton.
- It houses the globe, nerves, vessels, and surrounding soft tissue structures.
- The orbital floor consists of very thin bone and ligamentous structures and therefore is easily fractured when sustaining a significant force.
- Orbital floor fractures can be defined as pure blow-out fractures or impure blow-out fractures (**FIG 1**).¹

ANATOMY

- The orbit is a paired structure that has a conical shape and is separated in the midline by the interorbital structures consisting primarily of the ethmoid and frontal sinuses and the underlying nasal structures.
 - The cone or bony pyramid of the orbit is made up of a roof, floor, and medial and lateral walls.
 - At the apex of the cone posteriorly lie the optic nerve and other important nerves and vessels.
- The orbital floor forms the roof of the maxillary sinus, slopes upward and medially toward the apex of the cone, and has an AP distance of approximately 45 mm.
- The bony orbit volume is approximately 30 cc and the globe is approximately 7 cc.
- The anterior portion of the floor is concave; the posterior portion is convex and is the thinnest part of the floor and sustains most of the fractures.

PATHOGENESIS

- Orbital floor fractures are categorized as pure or impure blow-out fractures.²

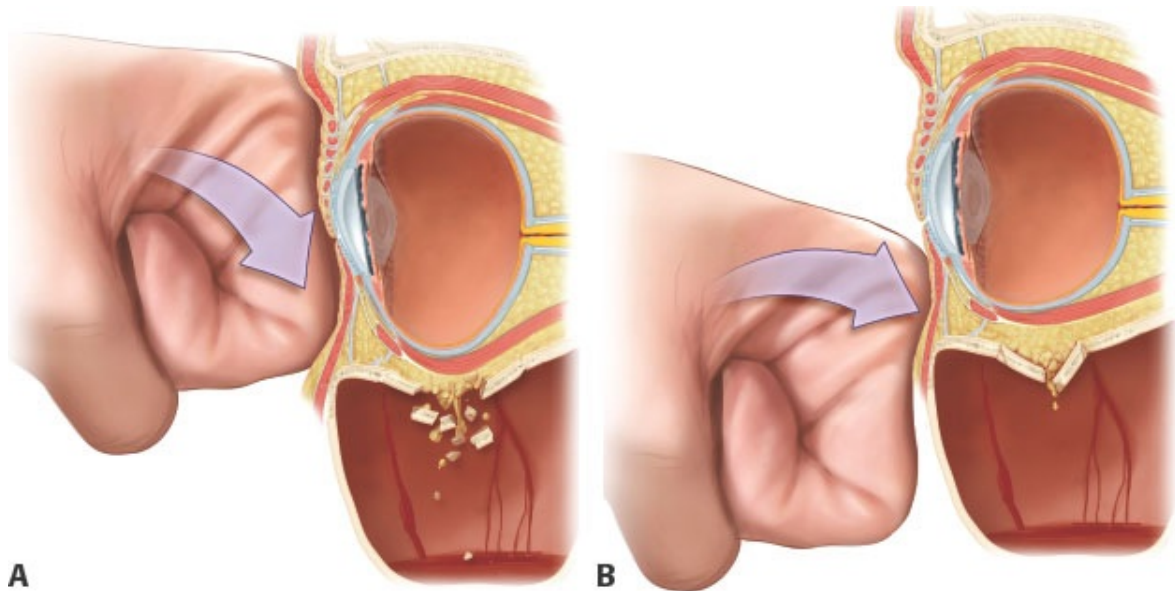


FIG 1 • Pure globe-to-wall blow-out fracture (**A**) vs buckling or impure blow-out fracture (**B**).

- There are also linear or cracked and trapdoor fractures as well as comminuted fractures of the floor.
- The type of fracture depends, in large measure, on the vector and amount of force applied to the orbit or surrounding skeletal structures.
- A pure blow-out fracture involves the thin floor and medial and/or lateral walls of the orbit.
- An impure blow-out fracture involves the disruption of the thick orbital rim and, many times, adjacent facial skeletal structures.
- A trapdoor orbital fracture is a pure orbital blow-out fracture, whereby a bony fragment is displaced inferiorly, into the maxillary sinus, while still being hinged. Orbital structures herniate through this defect and become entrapped.
- Orbital contents that can become entrapped include the periocular muscles, commonly the inferior rectus and inferior oblique. Muscle entrapment causes restriction of upward gaze and consequent diplopia.

NATURAL HISTORY

- Significant controversy remains regarding the indications for operative repair

of orbital floor fractures.

- Nondisplaced or mildly displaced orbital floor fractures will tend to do well after edema subsides and the brain adapts to the small visual field discrepancy.
- Diplopia secondary to enophthalmos, significant defects in ocular motility, and significant radiographic findings are all important indications for operative intervention.
- Entrapment of orbital contents, especially in the pediatric age group, can lead to significant, early symptoms, both visual and systemic (including nausea and vomiting), and should be addressed urgently.
- Significant orbital floor fractures that remain untreated can later present problems to the patient and can be very challenging to correct properly.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most orbital floor fractures result from blunt injuries, primarily from motor vehicle crashes or assaults.³
- Signs and symptoms of these fractures include edema and bruising, pain, diplopia, subconjunctival hemorrhage, sensory deficits mostly in the infraorbital region, and, at times, visual deficits.
- Ophthalmology should be consulted with any visual field deficits.
- The position of the globe, including cornea and pupil, is important to assess and compare with the contralateral, uninjured side.
- Extraocular muscle movements are then tested for any pain or deficits.
- In the unconscious patient, extraocular muscle movements can be assessed by performing a forced duction exam, testing for any restriction of muscles or associated structures (**FIG 2**). If possible, this result is compared with the contralateral side.
- Gentle yet thorough palpation of the orbit and its periorbital structures, is performed to identify obvious fractures or step-offs.
- Examination of the pupils is important to identify an optic nerve injury or other afferent pupillary defects. Consensual and accommodation reflexes are also evaluated.
- The oculocardiac reflex is particularly important in children with entrapment of orbital structures in the floor. An increase in vagal tone can lead to nausea and vomiting and ultimately cardiac disorders, including asystole. These cases should be managed emergently.
- Volume discrepancies of the orbit can lead to enophthalmos or dystopia of the

globe. Early evaluation can be difficult because of edema and should be carefully monitored over a 2-week period as the edema subsides and the displacement becomes more obvious.

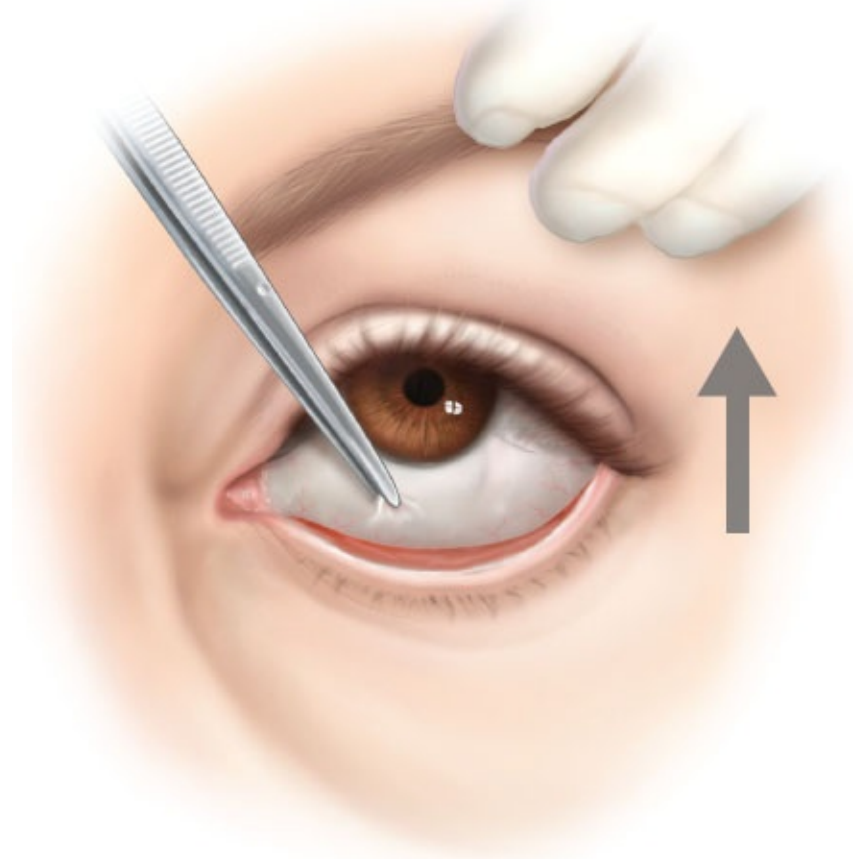


FIG 2 • The forced duction test.

- Delayed enophthalmos repair may be necessary even weeks after the injury if it is noted to be greater than 2 mm in an AP direction or is contributing to visual disturbances.

IMAGING

- CT scanning has revolutionized the diagnosis and treatment of orbital fractures.
- Coronal and sagittal reconstructions are most helpful for orbital floor fractures (**FIG 3**). They define the extent, size, and location of the injury, as well as associated injuries.
- 3D reconstructions can be helpful, especially in extensive injuries to outline

any other affected structures. This is very usual in nasoethmoidal orbital fractures, as well as associated zygomatic maxillary fractures.

- CT scan imaging distinguishes between a pure and an impure orbital floor blow-out fracture.

DIFFERENTIAL DIAGNOSIS

- Orbital roof fractures
- Medial orbit fractures
- Lateral orbital wall fractures
- Endocrine or systemic abnormalities affecting the orbit

NONOPERATIVE MANAGEMENT

- Significant controversy still remains regarding the operative vs nonoperative management of orbital floor fractures.
- As CT imaging technology has become more refined, a better evaluation and understanding of the injuries involved to the orbital floor permit better assessment and better selection of nonoperative candidates.
- Conservative management has become increasingly popular in recent years.
 - Some practitioners use a 1-cm defect in the floor as a cutoff for exploration as long as there is no evidence of herniation or clinical symptoms.
- After swelling and ecchymosis have resolved, if the patient is functionally intact, surgical correction may not be warranted. Delayed operative intervention after 2 or more weeks is also increasingly common among certain practitioners, especially ophthalmologists.
- Definite operative indications include significant enophthalmos, diplopia, ocular motility disturbances, and visual disturbances.

SURGICAL MANAGEMENT

Preoperative Planning

- A complete clinical assessment of the patient in particular of the orbit and periorbital structures.
- A good understanding of the mechanism of injury, of which structures are thought to be affected, and of the status of previous injuries to the area is vital.
- If any visual abnormalities are found or suspected, an ophthalmology consultation and a written assessment are crucial. If vision is normal, this should also be documented.

- CT scan images of the orbital floor fracture, including coronal and sagittal reconstruction from the axial images. The location and extent of the orbital floor fractures should be documented preoperatively.
- A forced duction test comparing the injured eye with the contralateral side.

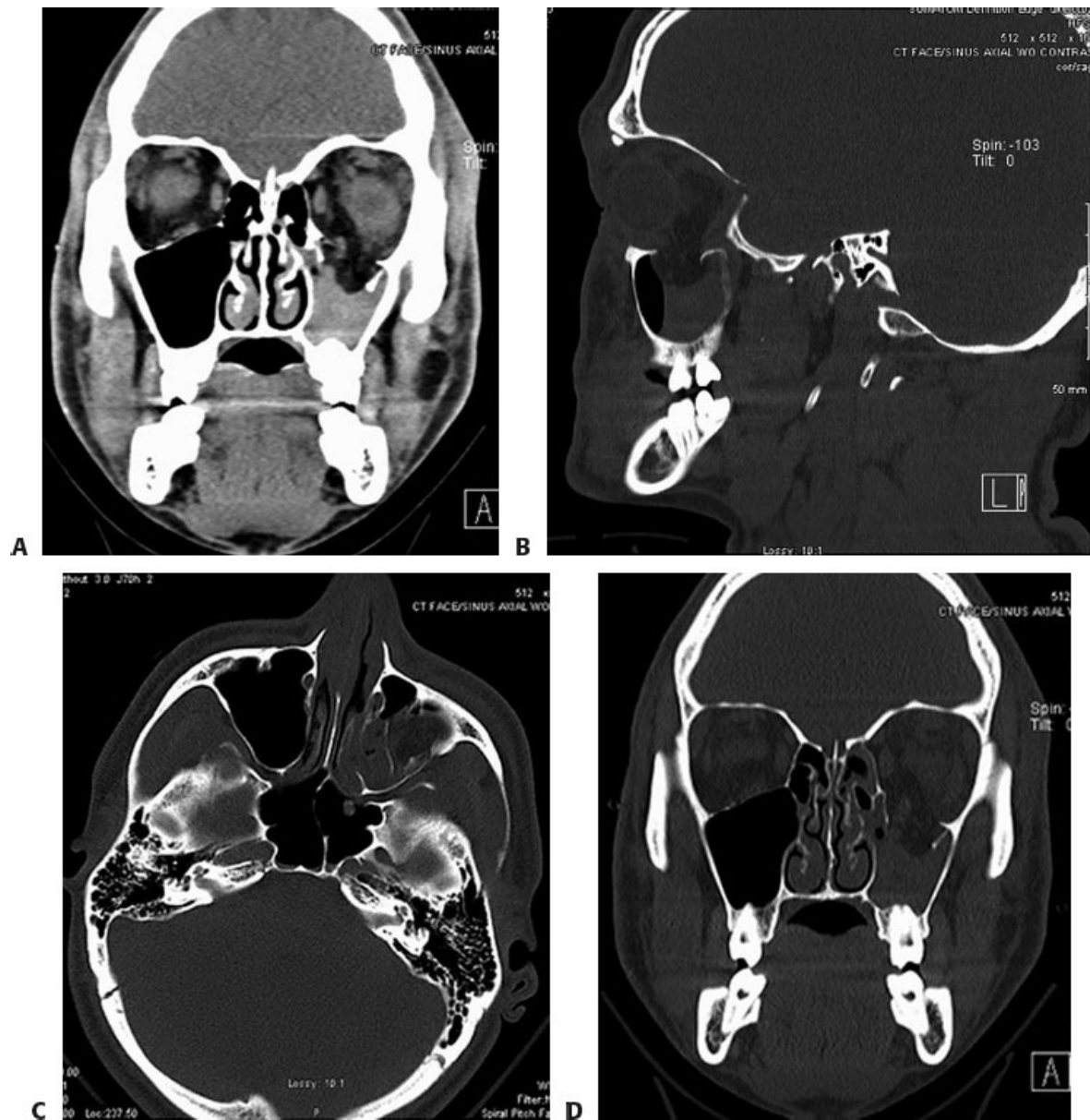


FIG 3 • **A.** Coronal CT scan image showing left orbital floor blow-out including opacification of maxillary sinus. **B.** Sagittal CT image of orbital blow-out fracture. **C.** Axial CT image showing fracture of left orbital floor.

Orbital rim is intact. **D.** Bone image CT showing left orbital blow-out fracture.

- Tetracaine 0.5% drops may be required for local anesthesia.
- There are many types of materials that have been used that include, but are not limited to, autogenous bone graft, titanium mesh, porous polyethylene, porous polyethylene incorporated into a titanium mesh, gel foam, supramid cartilage, dermal fat grafts, etc.
- Our choice, at present, in a noncomplicated orbital blowout fracture, is to use porous polyethylene-coated titanium mesh.
- The thickness of the orbital implant is also important to keep in mind. There are thinner and thicker orbital implants, depending on the amount of the disruption of the floor and the need to elevate the globe to a certain level.
- The implant should be curved and fashioned to conform to the shape of the orbital floor. If the fracture extends to the medial or lateral walls, the implant can be curved to fit those extensions.

Positioning

- The patient is placed in a supine position.
- A shoulder roll is placed under both shoulders for gentle hyperextension of the neck. Both eyes and midfacial structures are exposed for evaluation and comparison.
- A corneal protective lens is placed on the affected side and usually on the contralateral side. The lens can be removed to check globe position and to perform ocular motility exams.

Approach

- A subconjunctival approach provides good exposure for the orbital floor.
- A subciliary incision is preferred for more extensive fractures of the floor.
- A canthotomy can be used with a subconjunctival incision for improved exposure.

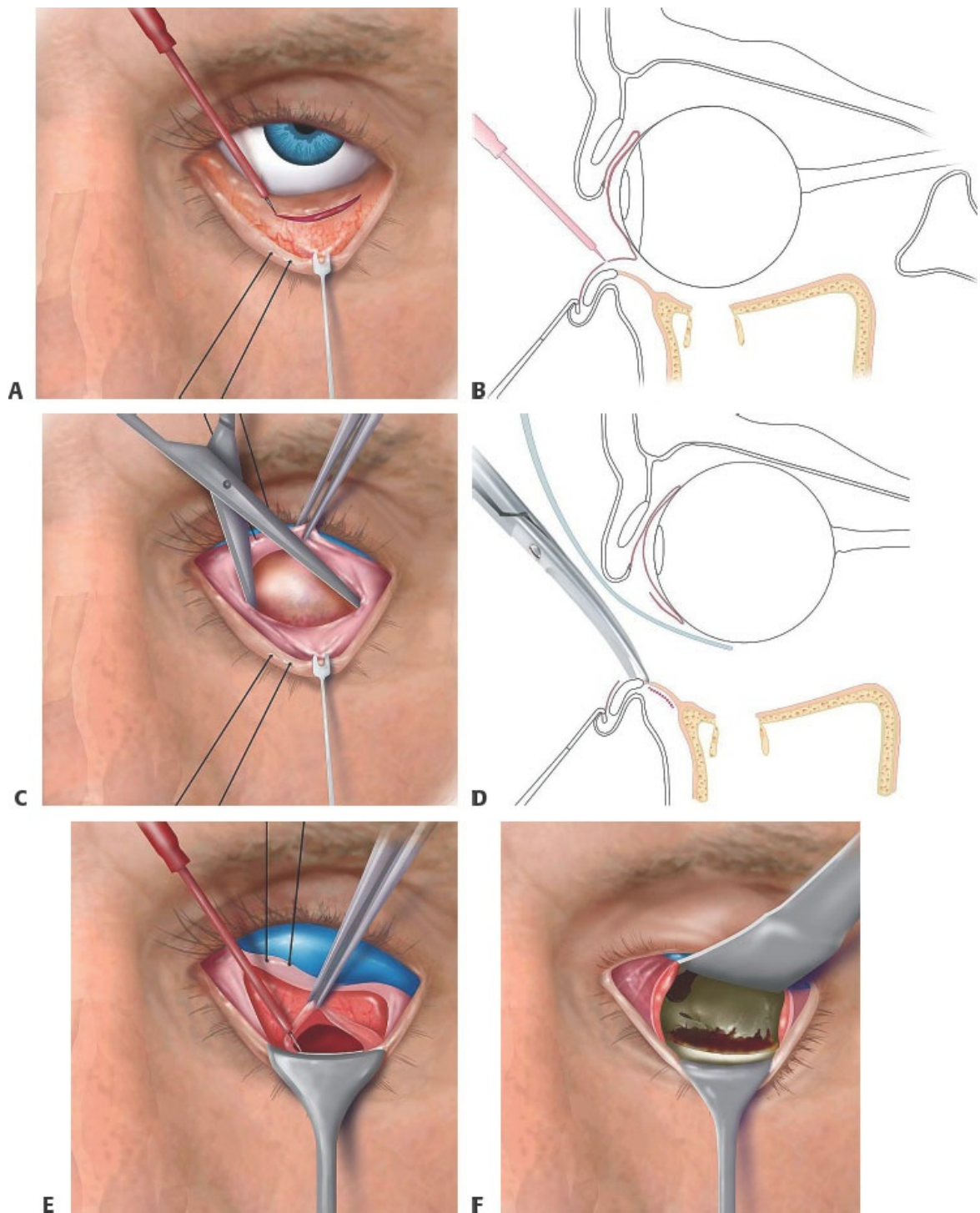
TECHNIQUES



Video p2-c054

■ Dissection of the Orbital Floor

- Inject the lower eyelid, extending to the orbital rim, with lidocaine 1% with epinephrine 100 000.
- Perform a forced duction test and tactically evaluate globe pressure for future reference.
- The subconjunctival incision—at least 4 mm below the internal subciliary margin—is made with a Colorado Bovie tip set at 12 (**TECH FIG 1A,B**).
- A preseptal dissection is used to reach the orbital rim without penetrating the orbital septum or the fat pockets (**TECH FIG 1C,D**).
- The orbital rim periosteum is incised with cautery (**TECH FIG 1E**).



TECH FIG 1 • **A.** Incision is made in the conjunctiva with Bovie tip. **B.** Lateral view of cauterization of the conjunctiva. **C.** The septum is exposed. **D.** Lateral view of preseptal dissection. **E.** The septum is

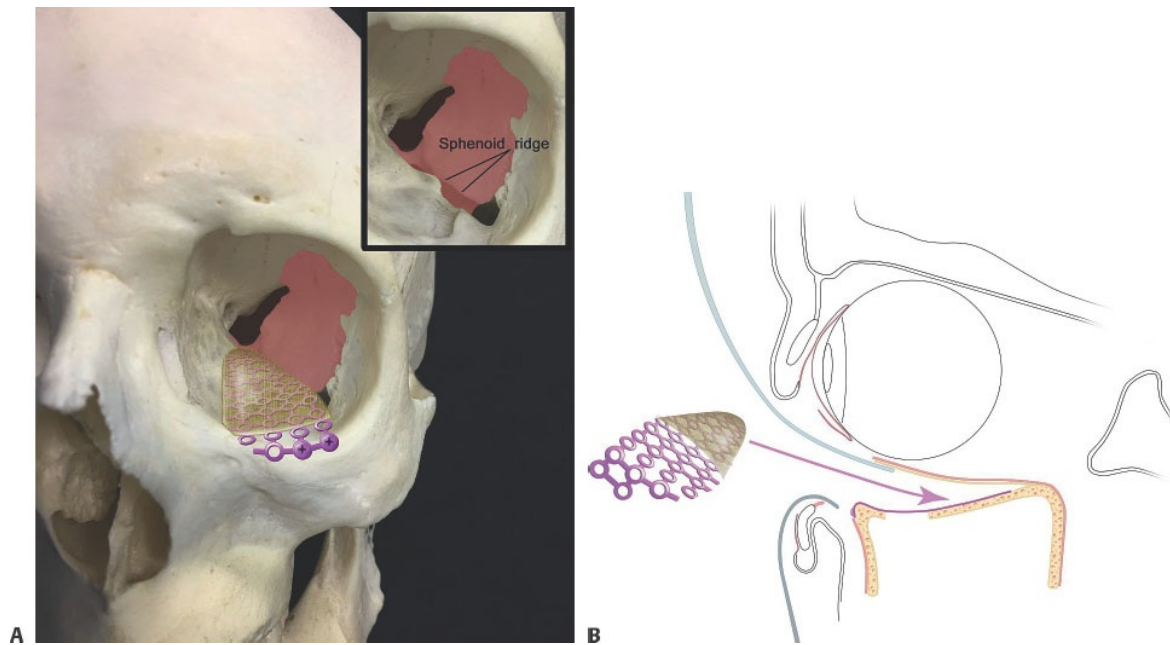
dissected and the periosteum is incised with cautery.

F. The fracture is exposed and the periosteum elevated.

- The orbital periosteum is dissected with a periosteal elevator.
- Avoid further disruption of the delicate orbital floor.
- Visualize the infraorbital nerve and keep it out of harm's way.
- Expose the fracture and tease out the herniated contents and retrieve them back into the orbit (**TECH FIG 1F**).
- Continue the dissection posteriorly, measuring the distance from the orbital rim every so often, in order to note how close to the orbital apex the dissection has proceeded.
- Dissect posteriorly until the hard, bony ledge of the posterior orbit.
- The synthetic or bone implant must rest on this area to avoid prolapse into the maxillary antrum.

■ Implant Placement and Completion

- When dissection of the floor is complete, with visualization of the fracture, a decision is made about the reconstruction material.
- The defect is measured and the implant is tailored to fit the defect.
- The implant must sit on the posterior orbital ledge with extension to the orbital rim for fixation (**TECH FIG 2**).
- Once the implant is positioned, another forced duction exam is conducted to determine any restrictions in globe mobility.
- Both globes are then compared for symmetry.



TECH FIG 2 • A. Implant is positioned on the posterior orbital ridge and fixated to the orbital rim. **B.** Lateral view of implant in place.

- The reconstructed globe may be higher than the normal globe due to swelling.
- The surgical site is irrigated with normal saline and hemostasis obtained.
- Closure consists of approximating periosteal layers over the implant.
- The conjunctiva is sutured with interrupted, buried 5-0 catgut sutures.
 - Some surgeons do not repair the conjunctiva; however, closure may avoid the risk of entropion.
- Ophthalmic antibiotic ointment is applied to the conjunctiva and eyelid.

PEARLS AND PITFALLS

Implant placement

- Check the position of the implant to be certain it has not been displaced prior to closure.
- Conduct a forced duction test after placement of the implant.
- Fixation of the implant at the orbital rim will prevent implant dislodging.

- Close the periosteum over the implant to minimize palpability and decrease exposure or infection.

Side-to-side comparison

- Compare the final position of the operated globe with the contralateral side. The operative site will have a more elevated globe position due to swelling.
- Digital palpation of both globes before and after completion of surgery will determine that both globes are soft and within normal limits.

Postoperative care

- Check vision, globe pressure, and degree of pain control in the early postoperative period in the recovery room.



FIG 4 • **A.** Postoperative CT scan showing repair of orbital floor fracture (*arrow*). **B.** Sagittal CT image showing floor reconstruction with titanium plate in position. **C.** 3D CT image showing left orbital floor repair. **D.** Axial CT image showing repair of orbital floor with titanium plate.

POSTOPERATIVE CARE

- Preoperative IV antibiotics are given and maintained for 24 hours postoperatively.^{4,5}
- The position of the implant needs to be verified by CT in the postoperative period (**FIG 4**).

OUTCOMES

- The use and incorporation of alloplastic materials in the orbit have been shown to be of great benefit (**FIG 5**).
- These implant materials have better results than autogenous bone grafting.
 - They maintain their shape, thickness, and size.
 - Their porous nature helps vascular integration and decreases the chance of infection.³

COMPLICATIONS

- Acute complications include retrobulbar hematoma, sudden blindness, increased pain, and pressure in the globe.
- These all require immediate attention with release of sutures and a return to the operating room for further evaluation.⁶

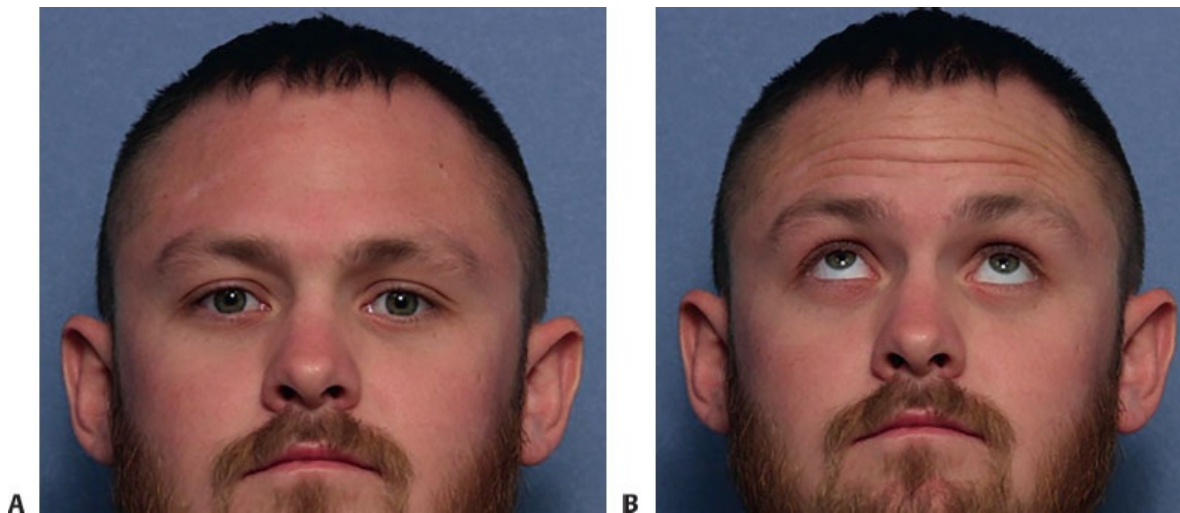




FIG 5 • Six-month postoperative views. **A.** Patient looking forward. Note symmetry of globes without dystopia. **B.** Patient looking up, showing good extraocular muscle function. **C.** Patient looking down. He describes no diplopia. **D.** Patient from below showing no evidence of enophthalmos.

- Long-term complications include infection, migration or displacement of the implant, exposure and palpability of the implant, residual enophthalmos, diplopia, dystopia, and ocular motility problems.³
- With any of these complications, a CT scan should be conducted in the early postoperative period.

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55 Correction of Lateral Orbital Wall Fractures

CHAPTER

Parit A. Patel

DEFINITION

- Of the seven bones that make up the orbit, the lateral orbit is composed mainly of the zygomatic bone.
- Fractures of the lateral orbit can result in expansion of the orbital volume with subsequent enophthalmos and orbital dystopia.
- Open reduction and internal fixation of the orbit restore the anatomy of the orbit and orbital volume. To restore the orbital volume successfully, the surgeon must have comprehensive understanding of the intricate anatomy of the orbit and surgical approaches to the orbit.

ANATOMY

- The orbit is a cone-shaped structure with a fixed volume.
- The seven bones that compromise the orbit include the sphenoid, maxilla, zygoma, frontal, ethmoid, lacrimal, and palatine.
- The contents of the orbit include the globe, extraocular muscles, cranial nerves II to VI, ophthalmic artery and other minor vessels, orbital fat, orbital septum, medial and lateral canthal tendons, check and suspensory ligaments, ciliary ganglion, lacrimal gland and sac, and nasolacrimal duct.
- The optic canal contains the optic nerve and ophthalmic artery. The superior orbital fissure contains cranial nerves III, IV, and VI. The inferior orbital fissure contains the infraorbital artery and vein and branches of the maxillary nerve.
- Orbital volume in the adult patient has been demonstrated to be $21.31 \pm 2.50 \text{ cm}^3$.¹
- Fractures of the lateral orbital wall can cause orbital volume expansion.

Fractures greater than 2.0 cm² can result in orbital expansion and clinically relevant enophthalmos.

- Fractures of the lateral orbital wall occur at the zygomatic sphenoid (ZS) suture, the greater wing of the sphenoid or the zygoma. The zygomatic portion of the orbit is the thickest bone of the orbit.
- Indications for treatment include clinically relevant expansion of the orbital volume with resulting enophthalmos and diplopia. Patients can also have blow-in fractures of the lateral orbit with associated proptosis.
- The lacrimal apparatus is important for tear production and drainage.
 - The lacrimal apparatus consists of the lacrimal gland, which is located in the superolateral aspect of the orbit and produces tears.
 - The lacrimal canaliculi, lacrimal sac, and nasolacrimal duct are important structures for draining tears into the nose (**FIG 1**).

PATHOGENESIS

- Lateral orbital fractures occur from significant force to the craniofacial skeleton due to trauma.
 - Impure fractures involve a fracture within both the orbit and the orbital rim.
 - Pure orbital fractures involve isolated fractures within the orbit.
 - The incidence of pure lateral orbital fractures is low, approximately 1% of all orbital fractures.²
- Lateral orbital fractures most commonly occur at the ZS suture and can be associated with zygomatic maxillary complex (ZMC) fractures.
- Fractures of the orbit can result in expansion of the orbital volume resulting in enophthalmos.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient usually presents with a history of significant facial trauma.
 - Associated signs and symptoms include periorbital pain, swelling, ecchymosis, dysesthesia, diplopia, and/or enophthalmos.

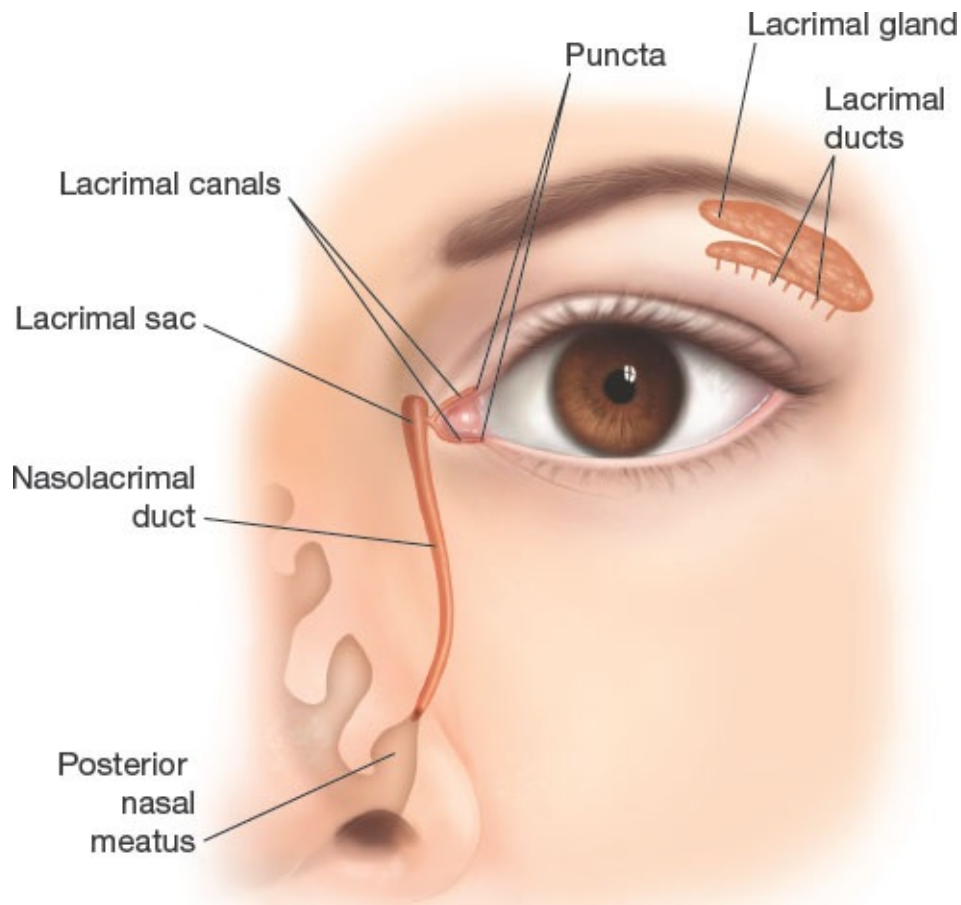


FIG 1 • Lacrimal apparatus.

- The patient can also have associated facial fractures that can be identified on physical examination with bony step-offs, gross facial asymmetries, and malocclusion.
- Enophthalmos can be identified using a Hertel exophthalmometer.
 - For every 1-cm³ volumetric increase in the orbital volume, enophthalmos increases by an increment of 0.89 mm.³
 - It can be difficult to assess enophthalmos in the acute setting because of periorbital swelling.
- The treating surgeon should be aware of surgical emergencies related to trauma to the orbit such as globe rupture, hyphema, entrapment, or a retrobulbar hematoma. In the setting of entrapment, there is restriction of movement of the globe.
- The clinical findings of a retrobulbar hematoma include severe ocular pain, visual acuity disturbance, and proptosis.

- There should be a low threshold for involving ophthalmology in situations of significant trauma to the periorbital region.
- Traumatic superior orbital fissure syndrome, although rare, can occur with lateral orbital wall fractures and is associated with ophthalmoplegia, proptosis, eyelid ptosis, a fixed and dilated pupil, and anesthesia in the ipsilateral ophthalmic branch of the trigeminal nerve. Orbital apex syndrome has a similar presentation; however, the patient additionally has visual loss from optic nerve injury.

IMAGING

- A CT scan of the face confirms clinical findings associated with facial fractures.
- The axial images will demonstrate the fracture of the lateral orbital wall and other related fractures, such as a ZMC fracture.
- The coronal images will demonstrate the size of the defect, which can be measured to assist in determining the indications for surgery.
- Sagittal images can help determine the posterior extent of the fracture and assist in sizing the implant or graft.

NONOPERATIVE MANAGEMENT

- If the fracture is less than 2.0 cm² and there are no signs of acute enophthalmos, the patient can be managed nonoperatively and monitored closely for development of enophthalmos and/or diplopia. There is approximately a 4- to 6-week window to treat the patient before the diplopia may require surgical correction.
- If the orbital fracture defect is marginal, the patient can be monitored until the swelling subsides to evaluate for enophthalmos.
- After resolution of swelling, if the patient has no signs or symptoms of enophthalmos or diplopia, surgery is not required.
- If there is a nondisplaced fracture of the zygomatic portion of the lateral orbital wall or at the ZS suture, the patient can be managed nonoperatively.
- Isolated fractures of the greater wing of the sphenoid, even with mild displacement, can be managed nonoperatively.

SURGICAL MANAGEMENT

- If the patient is stable, it is ideal to repair the orbital fracture in the first 24 to 48 hours.

- Beyond that time, there is maximal swelling that makes the operation and surgical approach more difficult.
- If the fracture is of marginal size and the patient does not have evidence of clinically relevant enophthalmos, the surgeon can wait 2 weeks to monitor and determine if surgery is indicated.
- Beyond 4 to 6 weeks, symptoms such as diplopia can be permanent and require strabismus surgery for correction.^{4,5}
- The objective of surgical intervention is to restore the anatomy of the orbit and the premorbid orbital volume. This prevents development of facial asymmetries related to enophthalmos or orbital dystopia. Furthermore, operative repair reduces the risk of developing strabismus and diplopia in the subacute phase or long term.
- Operative repair involves a surgical approach to the orbit through either a transconjunctival approach or a transcutaneous approach (ie, subciliary or midlid incision). Once in a subperiosteal plane, the periorbita is dissected free from the underlying bony orbit.
- Fractures of the lateral orbital wall occur most commonly at the ZS suture. The fracture can be comminuted and have an associated defect or be a linear fracture at the ZS suture or through the zygomatic bone.
- Depending on the extent of the fracture, the fracture can be repaired without bony fixation or with a titanium plate. If a sizeable defect is present, the lateral orbit can be reconstructed with an alloplastic orbital implant, mesh plate, or bone graft. If the fracture of the lateral orbit is associated with a ZMC fracture, the fracture at the ZS suture can be used to verify the reduction of the ZMC segment, with or without plate fixation.
- After open reduction and internal fixation, the lower lid is reconstructed appropriately to minimize the risk of ectropion, entropion, or lower lid malposition.
- All orbital fractures, including the lateral orbit, can be accessed through a transconjunctival approach to the orbit. A lateral cantholysis incision can be performed for additional access to the lateral orbital rim.

Preoperative Planning

- Risks and complications must be discussed with the patient and family. Risks include injury to the globe, postoperative enophthalmos, proptosis, orbital dystopia, persistent diplopia, visual acuity changes, postoperative entrapment, implant migration/infection, ectropion, entropion, and lower lid malposition.

- Orbital implants and an orbital/midface plating system should be available.
- Radiographic imaging should be available in the operating room for reference.

Positioning

- The patient is positioned supine with a shoulder roll in place.
- The operating table is positioned in Trendelenburg to maximize visualization of the orbit.

Approach

- The author recommends a transconjunctival approach to the orbit due to the ability to avoid external scars on the skin, ease of additional access to the lateral orbital rim with a lateral cantholysis from the same surgical field, and reduced rates of ectropion compared to other approaches.⁶

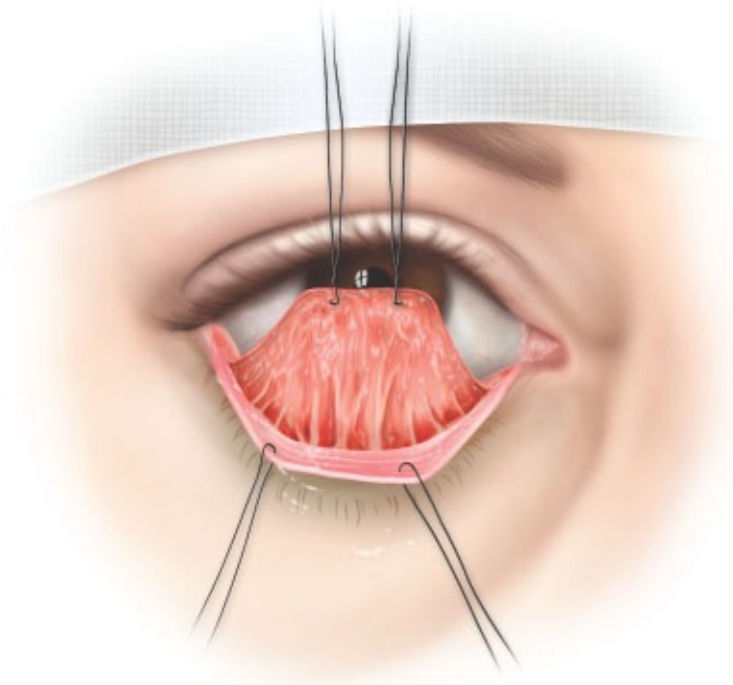
TECHNIQUES

■ Markings

- Needle-tip electrocautery is used to mark the conjunctiva 2 to 3 mm below the caudal aspect of the tarsal plate with a dotted line.
- The medial aspect of the marking should be lateral to the punctum.
- If a lateral cantholysis is needed, a marking is made at the lateral aspect of the palpebral fissure.
- Corneal shields are placed to protect the globe, and retraction sutures are placed in the lower eyelid at the gray line.
- With gentle traction, the lower lid is everted and pulled away from the globe.
- Local anesthetic, 50:50 mix of 1% lidocaine with epinephrine 1:200 000 and 0.5% Marcaine plain, is infiltrated into the lower lid conjunctiva and advanced deep to the orbital rim.

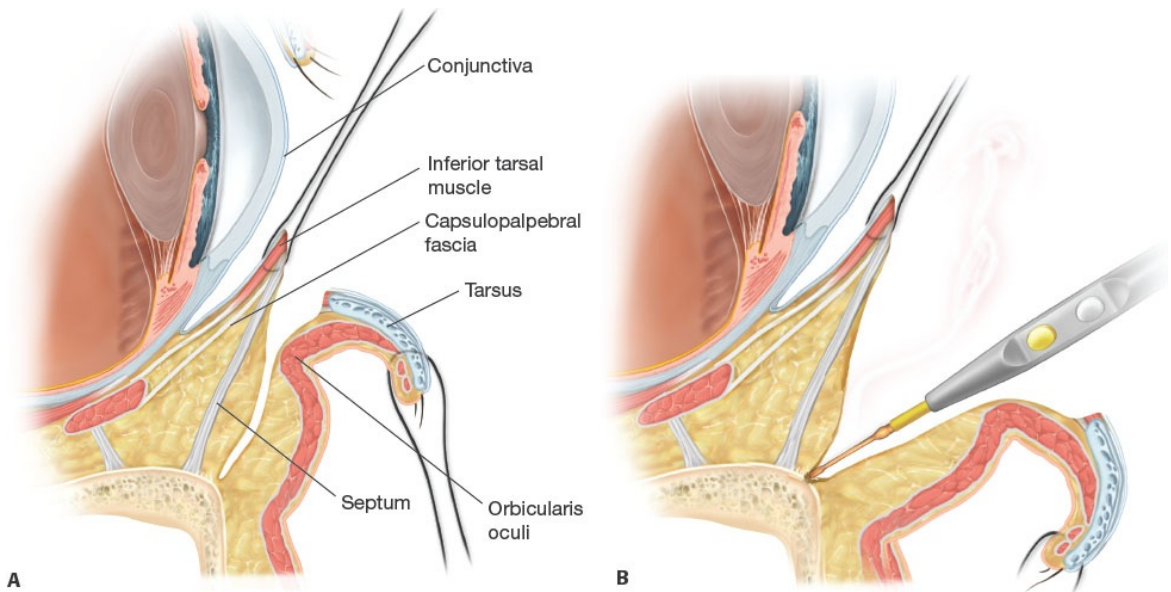
■ Exposure

- The conjunctiva and lower lid retractors are incised with needle-tip electrocautery on the pure-cut setting.

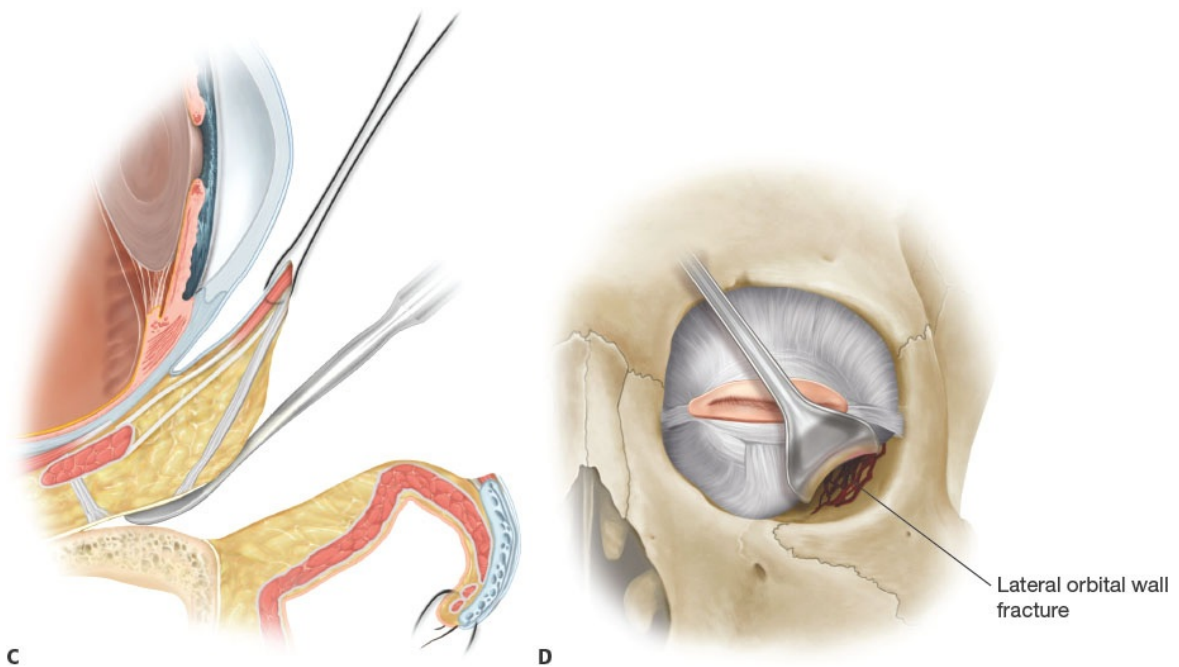


TECH FIG 1 • Surgical markings for the transconjunctival approach.

- With countertraction, the conjunctiva and lower lid retractors are pulled away from the lower lid (**TECH FIG 1**).
- The dissection continues caudally in the areolar plane between the lower lid retractors and the orbicularis oculi muscle (**TECH FIG 2A**).
- The dissection continues sharply in the preseptal plane to the arcus marginalis (**TECH FIG 2B**).
- The arcus marginalis is incised; in a subperiosteal plane, the periorbita is elevated from the orbital rim and orbital floor.
- A periosteal elevator is used to continue the dissection posterior into the orbit. The periorbita is dissected free from the fracture (**TECH FIG 2C**).
- Orbital retractors, including a Desmarres retractor (shown in **TECH FIG 2D**) and malleables are used for continued exposure of the orbital floor and lateral orbital wall.



- The dissection needs to continue into the orbit to identify the posterior ledge of the lateral orbital wall fracture (**TECH FIG 2D**).

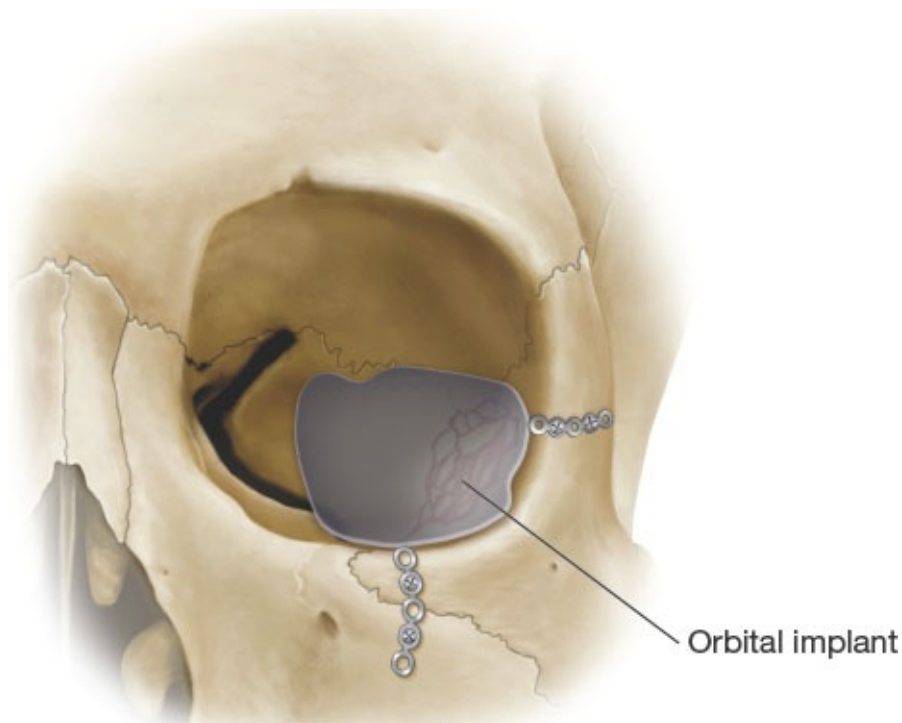


TECH FIG 2 • A. Dissection between the lower lid conjunctiva and lower lid retractors. **B.** Anatomy of the arcus marginalis of the orbital rim and needle-tip Bovie incising the arcus marginalis. **C.** A periosteal elevator is used to dissect the periorbital free from the fracture

in a subperiosteal plane. **D.** Desmarres retractor is used in combination with malleables to retract the periorbital contents to visualize the lateral orbital wall fracture and posterior fracture edge at the level of the zygomatic sphenoid suture.

■ Fracture Repair

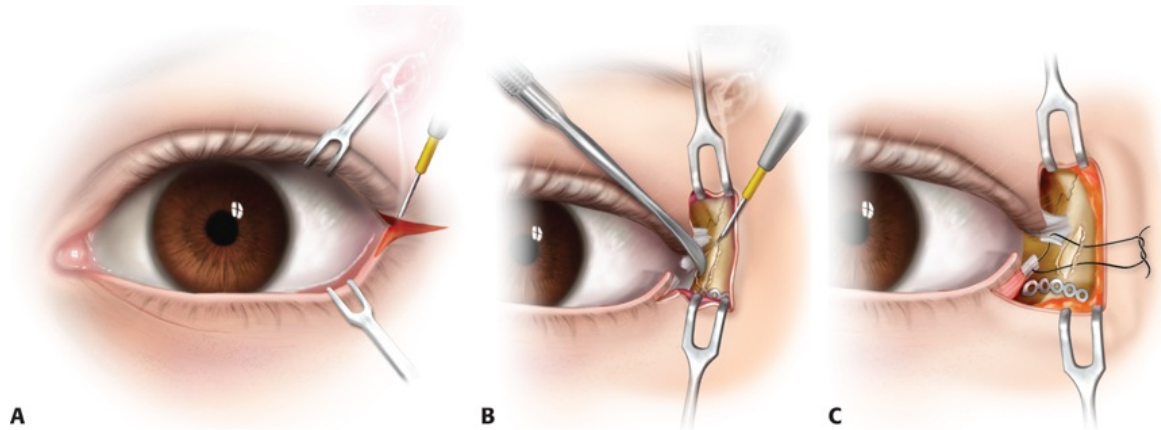
- If there is a comminuted fracture and a defect of the lateral orbital wall, a template is made of the defect, which is used to contour the orbital implant or mesh plate.
 - The implant can be fixated to the lateral orbital rim with a plate and or screw (**TECH FIG 3**).
- If the lateral orbital wall fracture is associated with a ZMC fracture, the fracture at the ZS suture can be used as a reference point for adequate reduction of the ZMC fracture.
 - A mini-titanium plate can be placed at the ZS suture.
- Ensure hemostasis and irrigate with saline.
- The globes should be assessed for symmetry and to rule out enophthalmos, proptosis, hyperglobus, or hypoglobus.
- Perform a forced duction test to verify that the implant is not entrapping tissue and restricting eye movement.
- The pupils should be evaluated throughout the case to verify that there is no compression on the optic nerve.



TECH FIG 3 • Orbital implant contoured and placed over the bony defect and secured in place with two screws at the orbital rim.

■ Lateral Cantholysis and Completion

- If the lateral orbital rim is involved, a lateral cantholysis can be performed for additional access.
- The lateral palpebral fissure is incised sharply down to the lateral canthal tendon.
 - The inferior limb of the tendon is incised sharply until the lower lid is dissected free and mobile (**TECH FIG 4A**).
- The periosteum is incised sharply, and with a periosteal elevator, the soft tissue is elevated from the lateral orbital rim (**TECH FIG 4B**).
 - If there is a fracture of the lateral orbital rim and displacement, the fracture fragments require reduction and fixation with plates and screws.
- If a lateral cantholysis is performed, the lateral canthal tendon will require reconstruction.



TECH FIG 4 • A. Lateral cantholysis incision at the lateral palpebral fissure and through the inferior limb of the lateral canthal tendon. **B.** Needle-tip electrocautery incising the periosteum of the lateral orbital rim. **C.** Reconstruction of the lateral canthal tendon with plating.

- A 4-0 Polydek suture is used to suture the lower lid to the superior limb of the lateral canthal tendon and periosteum on the inside of the lateral orbital rim (**TECH FIG 4C**).
- The conjunctival incision is closed with buried simple interrupted 6-0 fast gut suture.
- The corneal shields are removed and the globes irrigated with balanced salt solution.
- A Frost stitch is placed in the lower lid and secured to the forehead to support the lower lid postoperatively.
- In the postanesthesia care unit, visual acuity and the extraocular muscles are evaluated.

PEARLS AND PITFALLS

Physical findings

- It can be challenging to determine when to operate on marginal orbital wall defects.
- For defects larger than 2.0 cm², operative repair is indicated.

	■ For defects less than 2.0 cm², the patient can be monitored for signs of enophthalmos, and operative repair can be delayed for up to 4–6 weeks after injury.
Technique	■ The transconjunctival approach is the author's preferred technique due to the ability to avoid a scar on the face and the lower incidence of ectropion or lower lid malposition.⁶ ■ During the lower lid dissection, avoid entering the septum to minimize herniation of orbital fat into the operative field. The inferior oblique muscle can be injured if the septum is violated. ■ Perform a forced duction test after placement of the implant and examine the pupils periodically throughout the operation.
Postoperative care	■ Evaluate visual acuity and the extraocular muscles. ■ Support the lower lid with a Frost stitch or temporary tarsorrhaphy stitch to avoid lower lid malposition.

POSTOPERATIVE CARE

- Remove the Frost stitch on postoperative day 5.
- Ophthalmic bacitracin to the lateral cantholysis incision if performed.
- Lower lid and scar massage can be started at 4 weeks as needed.

OUTCOMES

- The incidence of postoperative enophthalmos has been reported to be as high as 27.5% and the incidence of postoperative diplopia, 42.5%. Operative repair before 2 weeks reduces the incidence of postoperative diplopia.⁷
- The incidence of infraorbital nerve dysfunction or hyperesthesia has been noted in 55% of patients postoperatively.⁷
- The highest rates of lower lid ectropion and revision surgery are associated with the subciliary approach (19.9%). Moreover, the lower lid scar was noticeable and found to have an unacceptable result in 43% of patients.⁶
- Of the three surgical approaches to the orbit, the subtarsal incision has the second highest complication rate and the transconjunctival approach has the lowest.^{6,8}
- Hardware extrusion, malposition, or infections related to orbital fractures are exceedingly rare.⁷

COMPLICATIONS

- Persistent diplopia after surgical repair can occur and may require further

revision surgery.⁹

- Postoperative enophthalmos can occur due to expansion of orbital volume, prolapse of tissue into the orbital defect, and fat atrophy. This situation requires revision surgery if clinically evident. Orbital dystopia can also occur postoperatively if there is inadequate reduction of the lateral orbital wall fracture when associated with a ZMC fracture.⁷
- Infraorbital nerve dysesthesia can occur from traumatic injury secondary to the fracture or by iatrogenic means.⁷

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56 Medial Orbital Wall Fractures

CHAPTER

Brad M. Gandolfi, Reena Bakshi, and Reza Jarrahy

DEFINITION

- Medial orbital wall fractures are traumatic injuries of the orbit that compromise the integrity of the medial orbital wall.
- These typically occur at the *lamina papyracea*, the thin central portion of the medial orbital wall, and may involve herniation of periorbital soft tissues into the adjacent ethmoid sinuses.

ANATOMY

- The anatomy of the orbit represents a complex interplay between bony structures and their associated soft tissues.^{1–5}

Bony Anatomy

- The overall configuration of the bony orbit is pyramidal, with walls that are curvilinear.
 - The height of the orbit averages 35 mm, with an average width of 40 mm.
 - The distance from the midpoint of the inferior orbital rim to the orbital apex measures approximately 45 mm.
- The medial orbital wall is the thinnest wall of the orbit. It is primarily composed of the lacrimal bone anteriorly and the orbital plate of the ethmoid bone posteriorly.
 - These structures are closely related to the orbital processes of the frontal, sphenoid, maxillary, and palatine bones.
- Ethmoid bone:
 - The orbital plate of the ethmoid bone accounts for the largest portion of the medial orbit wall. It is also the thinnest portion of bony orbit.

- The thin curved central area of this bone is referred to as the lamina papyracea. Due to its thin nature, most medial orbital wall fractures occur through the lamina papyracea, as opposed to the thicker anterior and posterior portions of the medial orbit.
- An extensive labyrinthine network of honeycomblike pneumatized air cells forms the ethmoid sinus medial to the lamina (**FIG 1A**).
- Frontal bone:
 - The orbital process of the frontal bone articulates with the ethmoid bone in the superior and posterior portion of the bony orbit.
 - The frontal bone is thicker than the lamina papyracea, providing protection to adjacent intracranial structures.
 - The roof and medial wall of the orbit meet at the frontoethmoidal suture. The anterior and posterior ethmoidal arteries, branches of the ophthalmic artery, enter the orbit through their respective foramina in the frontoethmoidal suture (**FIG 1B**).
 - The anterior ethmoid foramen is located approximately 15 mm posterior to the medial orbital rim and the posterior foramen is located approximately 10 mm further posteriorly.
 - Disruption of the anterior and/or posterior ethmoid arteries contributes to hemorrhage in the setting of medial orbital wall fractures.
- Lacrimal bone:
 - The lacrimal bone is related to the anterior and inferior aspects of the ethmoid bone.

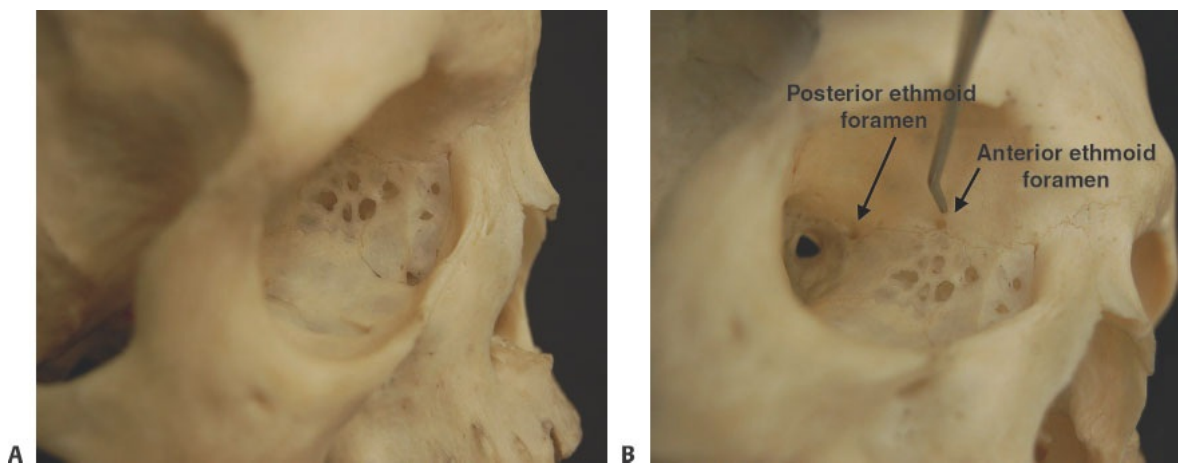


FIG 1 • A. Skull model demonstrating the thin nature of the lamina papyracea and the network of ethmoid air

cells lying medial to the orbit. **B.** The anterior and posterior ethmoid foramen are located on the frontoethmoidal suture.

- The central portion of the lacrimal bone is characterized by a depression—the lacrimal fossa—that contains the lacrimal sac. This central recessed portion of the lacrimal bone is surrounded by the anterior and posterior lacrimal crests.
- The medial canthal tendon inserts onto the anterior and posterior lacrimal crests.
- Sphenoid bone:
 - The sphenoid bone abuts the posterior edge of the orbital plate of the ethmoid bone.
 - It delineates the most posterior portion of the medial orbital wall and defines the optic foramen in the orbital apex.

Soft Tissue Anatomy

- Knowledge of the soft tissue anatomy of the medial orbit is necessary to safely and effectively manage medial orbital wall fractures without inadvertently injuring surrounding critical structures.
- Lacrimal caruncle and plica semilunaris (semilunar fold):
 - The lacrimal caruncle sits at the medial corner of the eye between the upper and lower eyelids, in close proximity to the medial canthal tendon. It is a fleshy nodule that contains sebaceous and sweat glands that help maintain normal ocular physiology.
 - It serves as a useful anatomical landmark for surgical approaches to the bony orbit.
 - The plica semilunaris is a fold of conjunctiva that sits between the caruncle and medial sclera. The plica assists in normal tear function and facilitates movement of the globe (**FIG 2A**).
- Medial canthal tendon:
 - The medial canthal tendon is associated with the orbicularis oculi muscle and defines the shape and position of the medial poles of the upper and lower eyelids.

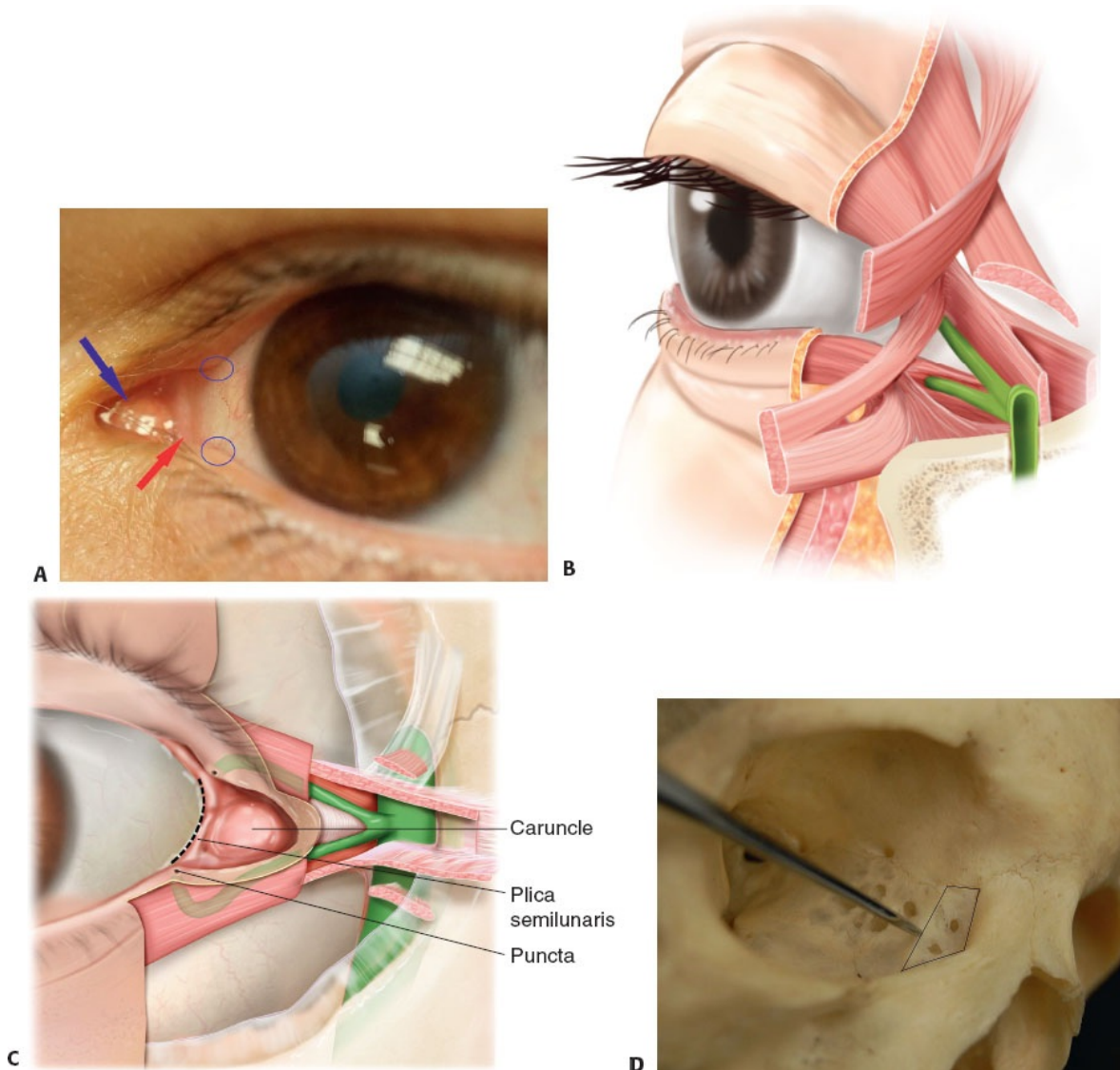


FIG 2 • A. The caruncle (*blue arrow*) and plica semilunaris (*red arrow*) help regulate normal ocular physiology and globe movement. The puncta on the upper and lower lids (*circled*) drain the eye. **B.** Sagittal section at the level of the attachment of the medial canthal tendon to the lacrimal crest. The medial canthal tendon splits into anterior and posterior components, enveloping the lacrimal sac and canaliculi. **C.** Relationship between the caruncle (C), puncta (P), the lacrimal apparatus, and the plica semilunaris. The medial canthal tendon has been removed to show the

anatomy. The lacrimal fossa (outlined in **D**) houses the lacrimal sac, which drains through the nasolacrimal duct (**E**).



- The tendon originates from fascial extensions of the upper and lower tarsal plates and divides into three limbs that insert in a fanlike fashion onto the medial orbital wall.
- Disruption of the medial canthal tendon from its bony insertions can have a significant deleterious effect on ocular function and aesthetics (**FIG 2B**).
- Anterior limb:
 - The anterior limb of the medial canthal tendon inserts onto the anterior lacrimal crest and forms the bulk of the tendon.
 - The pretarsal, preseptal, and orbital orbicularis fibers insert onto the anterior limb.
- Superior limb: The superior limb of the medial canthus extends over the lacrimal sac and covers its anterior and superior portions.
- Posterior limb:
 - The posterior limb of the medial canthal tendon inserts onto the posterior lacrimal crest.
 - Although not as robust as the anterior limb, its posterior vector is integral in maintaining apposition of the upper and lower lids to the globe.
 - It is closely related to the Horner muscle, a slip of the lacrimal portion of the

orbicularis oculi muscle, which contributes to regulation of normal lacrimal flow.

■ Lacrimal system:

- Puncti: The superior and inferior puncti serve as the primary site of drainage for the eye. They are located approximately 5 to 7 mm lateral to the medial canthal angle (circled in **FIG 2A**). The upper lid punctum is usually positioned 1 to 2 mm more medial than the lower lid punctum. The majority of tear volume is drained through the lower lid.
- Canaliculi: The canaliculi connect the puncti to the lacrimal sac. The ampullae are the vertical components of the canaliculi and are located directly beneath the puncti. The ampullae measure 2 mm in length on average. The canaliculi then turn sharply and extend medially along the border of the eyelid. They merge into a single duct before entering the lacrimal sac (**FIG 2C**).
- Lacrimal sac: The lacrimal sac is located within the lacrimal canal of the lacrimal bone between the anterior and posterior lacrimal crests and the anterior and posterior limbs of the medial canthal tendon (**FIG 2C–E**). It is partially covered by the superior limb of the medial canthal tendon and extends 5 mm superior to this structure. The sac continues into the nasolacrimal duct at the base of the lacrimal fossa, which continues through an intraosseous tunnel to drain into the nose lateral to the inferior nasal turbinate through the inferior meatus.
- Medial rectus muscle: The medial rectus muscle originates at the annular tendon, a fibrous ring surrounding the optic canal at the orbital apex. It inserts onto the medial surface of the globe and is innervated by the inferior division of the oculomotor nerve. Its primary function is to medially adduct the eyeball. Due to its location in the medial orbit, the medial rectus muscle is vulnerable to entrapment in a blow-out fracture through the medial orbital wall.

PATHOGENESIS

- Medial orbital fractures typically result from direct blunt trauma to the orbit. Mechanical energy transmitted to the medial orbital wall and/or hydraulic retropulsion of the globe into the orbit can cause structural damage to the medial orbital wall, particularly at the thin lamina papyracea.⁶
- Fractures of the medial orbital wall can play a protective role: absorption of energy by bone limits energy transfer to the orbital soft tissues, decreasing the

likelihood of traumatic globe rupture.

NATURAL HISTORY AND PHYSICAL FINDINGS

- Symptoms of medial orbital wall fractures include pain with extraocular muscle movement, ecchymoses, and periorbital edema. Physical examination findings include diplopia, enophthalmos, crepitus, visible or palpable medial orbital rim irregularities, and telecanthus.
- Cerebrospinal fluid leakage and epistaxis can also be seen in severe orbital injuries that involve adjacent intracranial or nasal structures.
- A formal ophthalmological evaluation should be performed to assess baseline ocular function. The ophthalmologist should document a complete examination, including assessment of visual acuity, pupillary reactivity, anterior and posterior ocular chambers, and extraocular muscle function. In the setting of medial rectus muscle entrapment, restriction of extraocular movements may be observed.

IMAGING

- Plain film radiography is of limited value in the assessment of medial wall fractures, although disruption of the medial orbit and opacification of the ethmoid sinus can sometimes be detected on x-ray.
- Fine-cut axial CT scan with multiplanar reconstruction has great sensitivity and specificity for identifying medial orbital wall fractures. Two-dimensional axial and coronal views can accurately image the disruption of the medial orbital wall and demonstrate herniation of periorbital soft tissues into the ethmoid sinuses (**FIG 3A,B**).
- Three-dimensional (3D) reconstructions of orbital CT scans are generally not helpful in diagnosing medial orbital wall fractures. The algorithms used by most 3D imaging software programs currently do not provide adequately detailed renderings of the surface anatomy of the thin curved medial orbital wall⁷ (**FIG 3C,D**).

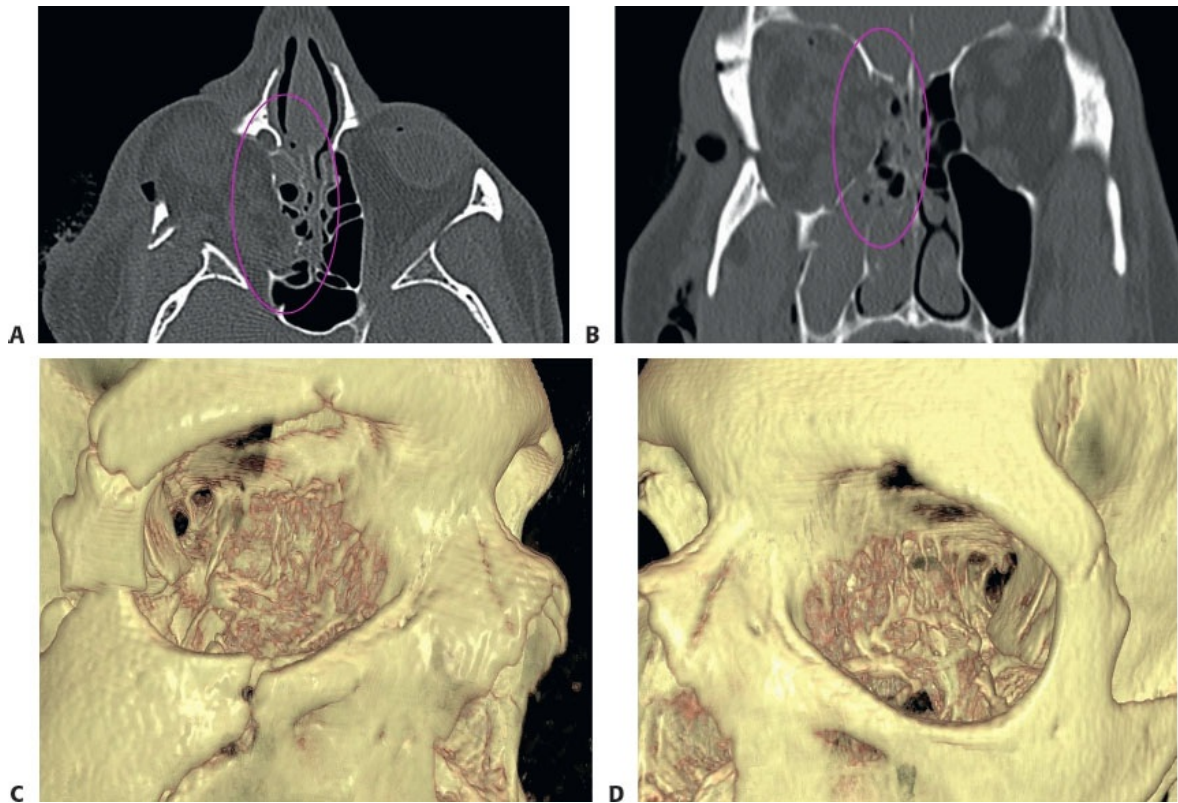


FIG 3 • Axial (**A**) and coronal (**B**) computed tomography (CT) imaging of the orbit demonstrating fracture of the (*right*) medial orbital wall with herniation of periorbital soft tissues into the ethmoid sinus (*circled*). **C,D**. 3D rendering of the same injury does not provide a detailed anatomic picture.

DIFFERENTIAL DIAGNOSIS

- Direct trauma to the eye resulting in medial orbital wall fractures can also cause injury to other parts of the orbit. Orbital floor fractures and, more rarely, orbital roof fractures can present with edema, ecchymosis, enophthalmos, and diplopia.
- Injuries to surrounding structures may also present in similar fashion, including fractures of the nasal bones, anterior cranial base, frontal sinus, and naso-orbitoethmoidal (NOE) complex.
- The pain and ophthalmoplegia of superior orbital fissure syndrome can mimic the discomfort and restriction of gaze associated with medial rectus entrapment.

NONOPERATIVE MANAGEMENT

- In some circumstances, medial orbital wall fractures can be managed nonoperatively. In the setting of a small defect without diplopia, significant enophthalmos, or medial rectus entrapment, observation is a reasonable option.
- Principles of nonoperative management include head elevation, application of ice cold compresses, and minimizing increased intraorbital pressure by avoiding nose blowing and other Valsalva maneuvers for 4 to 6 weeks following the injury.

SURGICAL MANAGEMENT

- Open repair of medial orbital wall fractures is indicated in the setting of large bony defects, early or persistent enophthalmos with associated diplopia, or medial rectus muscle entrapment.
- The goals of surgical management are release of any entrapped orbital soft tissues, replacement of periorbital into the bony orbit, restoration of orbital domain, and correction of enophthalmos and diplopia.
- A variety of approaches to the medial orbit have been described, each with its specific advantages and disadvantages^{6,8} (Table 1). Similarly, there are a variety of materials that may be used to repair the medial wall defect⁹ (Table 2). These are discussed in detail elsewhere in this text. The authors' preferred technique is a transcaruncular approach to the medial orbit with autologous split calvarial bone graft repair. Autologous bone harvest adds little additional time, cost, or morbidity to the operation. In skilled hands, harvesting autologous bone should be quick, straightforward, safe, and cost efficient.¹⁰
- Split calvarial bone grafts are taken from the parietal region. Here, the diploic space is well formed and the calvarial bone is consistently thick, particularly in the central 8 × 10 cm of the parietal bone.

Preoperative Planning

- The patient should be thoroughly informed of risks, benefits, and expected outcomes of the procedure, including the possibility of persistent diplopia, postoperative enophthalmos, or loss of vision.
- Preoperative CT scans should be used to plan the surgical intervention and should be available for review during the procedure.
- Surgery should be performed after resolution of acute postinjury inflammation and edema. Early intervention has been previously recommended, but recent

evidence has shown that delayed repair of orbital fractures can be equally effective.¹¹

- Fine ophthalmological instruments are helpful in manipulating the soft tissues of the eyelids and medial orbit.

Positioning

- The patient is placed on the operating room table in the supine position. A shoulder roll is placed to obtain slight neck extension. This is deferred if the patient is under cervical spine precautions.

Table 1 Approaches to the Medial Orbital Wal

Approach	Advantage	Disadvantage	Major Indication
Coronal	Full exposure of the superior and medial orbit	Higher level of invasiveness; extensive external scar; risk to temporal nerve; significant postoperative edema	Complex fractures involving orbit and surrounding structures; NOE fractures
Medial transcutaneous (Lynch incision)	Direct and wide exposure of entire medial orbital wall	Risk of injury to medial canthal tendon and lacrimal structures	Resection of large lesions involving the nose and ethmoid sinus
Transcaruncular	No skin incision	Limited access to larger defects involving the orbital floor	Isolated medial orbital injuries
Transconjunctival with transcaruncular extension	Wide exposure of the orbital floor and medial orbital wall	Larger incision with greater risk of conjunctival scarring and ectropion/ectropion	Orbital wall injuries involving both the floor and the medial orbital wall
Transnasal endoscopic	No incisions	Requires endoscopic equipment and	Small to medium-sized isolated medial orbital

		expertise; potentially difficult reduction of soft tissues; limited reconstructive options; no direct access to orbit	fractures
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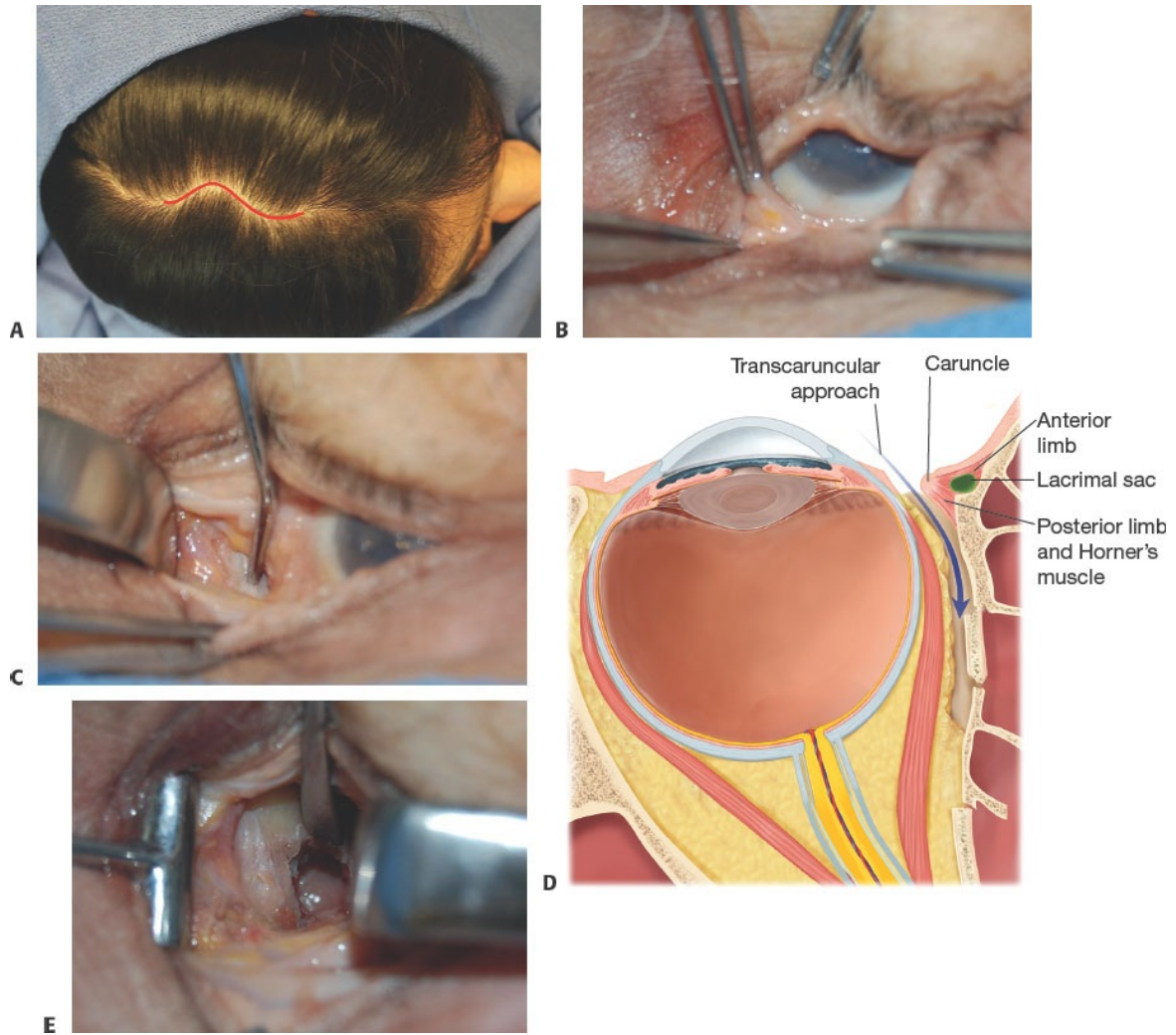
Table 2 Comparison of Commonly Used Reconstructive Materials for Orbital Wall Repair

Implant Type	Advantages	Disadvantages
Split autologous bone graft (calvarium, rib, iliac)	Readily available; osteoconductive; minimal scarring in revision setting; radiopaque; most cost-effective	Unpredictable resorption; added donor site morbidity; not advisable with intracranial injury or thin bones (eg, elderly patients)
Porous polyethylene	Moldable; soft tissue ingrowth stabilizes position	Difficult to remove (dense adhesions to orbital soft tissues); possible higher infection rate; high cost
Titanium	Moldable; easy to use; low infection rate	Difficult to remove (dense adhesions to orbital soft tissues); high cost; unclear safety profile in children
Absorbable plates	Easily moldable; minimal infection rate; low adhesion profile in revision setting	Cost; less applicable to large defects
Custom 3D-printed implant	Custom design for most accurate fit over defect	Cost; requires presurgical virtual surgical planning session; infection risk unclear; long-term outcomes unclear

TECHNIQUES

■ Medial Orbit Exposure

- The procedure is performed under general endotracheal anesthesia via an oral RAE tube secured in the facial midline.
- A dose of intravenous cephalosporin antibiotic (cefazolin) is given following the induction of anesthesia and prior to incision.
- In anticipation of cranial bone graft harvest, a planned zigzag incision is marked with ink behind the temporal hairline between the midline of the skull and the temporal crest. This location avoids the sagittal sinus in the midline and the temporalis muscle laterally during bone graft acquisition. The hair overlying this area is clipped (**TECH FIG 1A**).
- The scalp and face are prepped in standard fashion, and the head is wrapped with sterile surgical drapes. A corneal protector may be placed for protection of the surface of the globe.
- 0.25% bupivacaine with 1:200 000 dilute epinephrine is used to infiltrate the conjunctiva, plica semilunaris, and caruncle.
- The upper and lower eyelids are gently retracted and a needlepoint cautery tip is used to incise the conjunctiva and bisect the caruncle (**TECH FIG 1B**). The initial incision is 15 mm in length. It can be extended in crescentic fashion either superiorly or inferiorly for increased exposure.
- Retractors are repositioned under the medial and lateral cut edges of the caruncle to expose the medial orbital septum. Using cautery, sharp scissor dissection, Freer elevator, or a cotton-tipped applicator, dissection proceeds in a preseptal plane toward the medial orbital wall (**TECH FIG 1C**).



TECH FIG 1 • A. Positioning the incision for cranial bone graft harvest between the midline and temporal crest provides direct access to the thick parietal bone while avoiding the midline sagittal sinus and the temporalis muscle. **B.** The caruncle is bisected and conjunctiva incised and retracted. Cautery and sharp or blunt dissection are used to perform preseptal dissection to the medial orbital wall as seen here. **C.** The dissection continues posterior to the posterior lacrimal crest along the bone or whatever remnants of bone exist. **D.** The dissection extends through the caruncle in a subperiosteal plane if available. The

dissection is lateral to the lacrimal apparatus and medial to the orbital fat pads. **E.** The entire defect is exposed in a subperiosteal plane, and stable surrounding bone is identified for anticipated bone graft placement.

- Once the medial orbital wall is exposed, the posterior lacrimal crest must be identified, and dissection must proceed posteriorly to avoid injury to the medial canthal tendon (**TECH FIG 1D**).
- Needlepoint cautery is used to incise the periosteum posterior to the lacrimal crest. A Freer elevator is used to obtain wide subperiosteal elevation around the entire circumference of the bony defect (**TECH FIG 1E**).
- During the dissection, all orbital contents should be reduced back into the orbit, including any entrapped tissues such as the medial rectus muscle. Malleable retractors are effective in retaining the periorbita within the bony orbit while periosteal elevators are used to elevate the periosteum.
- If the anterior or posterior ethmoid arteries are identified during the dissection and found to be intact, they should be carefully cauterized using a bipolar cautery device.
- Dissection should proceed until stable bone to support a bone graft is identified around the entire periphery of the defect.
- After the medial wall defect is completely exposed, a template can be made to guide sizing of the bone graft or implant to be used in the repair. A 1- × 3-cm cotton sponge is placed over the medial wall defect and used to keep the orbital contents within the orbit while the bone graft is procured.

■ Graft Harvest

- 0.25% bupivacaine with 1:200 000 dilute epinephrine is infiltrated into the zigzag scalp incision site.
- The scalp is incised with a beveled blade so that the plane of dissection lies parallel to the hair follicles. The size of the incision varies according to the size of bone graft needed.
- Once the dermis and subcutaneous tissues are sharply incised, electrocautery is used to open the galea. Care is taken to avoid cauterizing the dermis and

hair follicles.

- Blunt subgaleal dissection with a subperiosteal elevator is performed to mobilize the overlying scalp. The loose areolar subgaleal plane can be dissected rapidly and the scalp retracted to expose the underlying parietal bone with its adherent periosteum.
- Based on the size of the medial wall defect and template, the margins of the desired bone graft are marked by incising the periosteum with needle tip cautery. A graft measuring 2×3 cm to 3×4 cm is usually adequate. The graft should be designed to allow for circumferential overlap with the intact medial orbital wall surrounding the fracture site.
- A sharp curved osteotome and heavy mallet are used to harvest the graft. The bone graft is harvested in a superficial plane above the level of the deep diploe.
- The depth of the osteotome must be precisely controlled at all times. Avoid driving the osteotome through the inner table and injuring the intracranial structures.
- The graft is harvested from an anterior to posterior direction. The osteotome is used to shave the bone graft from the outer table of the cranium by continuously moving between the anterior and lateral edges of the graft and staying superficial. The graft is elevated with its overlying pericranium, which serves to keep the graft intact.
- If the bone graft begins to flake or fracture due to excessively superficial positioning of the osteotome, it should be reoriented to engage a deeper layer of the outer table. Similarly, if there is excessive bleeding from trauma to the deep diploic space, the osteotome should be redirected to a more superficial plane.
- When an adequate length of bone graft has been raised, the osteotome is directed superficially to release the graft from the skull. Sharp scissors are used to cut the adherent posterior periosteum, and the graft is delivered from under the scalp flaps.
- Hemostasis of the skull donor site and scalp is obtained using bone wax and cautery as needed.
- The galea is closed with interrupted buried 3-0 Monocryl suture. The superficial layer of the scalp is closed with a running locking 4-0 plain catgut suture.
- (Note: An alternative technique that yields a full-thickness outer table bone

graft can be employed as well. Using a high-speed cutting bur, the margins of the bone graft can be drilled down to the level of the diploic space. The graft can then be removed from the underlying diploe using the osteotome or a reciprocating saw, again with great attention to the depth of these instruments. This full-thickness graft is more stiff and brittle than the partial-thickness outer table shave and may be less amenable to shaping and contouring for precise coverage of the medial wall defect.)

■ Fracture Repair

- Once the graft is harvested, attention is turned to the orbit to complete the repair of the medial wall fracture. Prior to placement in the orbit, the bone graft can be cut and contoured as needed *ex vivo* using bone-cutting instruments and Tessier bone-bending forceps.
- The cotton patty that was previously placed in the orbit is removed as a malleable retractor is again placed to retract the orbital contents laterally and expose the medial wall fracture.
- The bone graft is placed over the defect. If appropriately sized and designed, the graft should rest on the surrounding intact bone with stability, and there should be no need for fixation (**TECH FIG 2**).
 - (Note: If the medial wall is severely comminuted and there is a paucity of stable bone on which the graft can rest, it can be rigidly fixed to stable anterior bone using 1.3-mm titanium miniplates and screws. In such cases, the fixation plate can be screwed to the bone graft *ex vivo* and the graft can then be placed into the orbit in the desired position. It can then be secured to the anterior orbit. Great care must be taken to avoid injury to the medial canthal tendon and the lacrimal apparatus if rigid fixation is implemented.)
- Once the graft is in place, the retractors are removed and the soft tissues are released.
- A forced duction of the eye is performed by gently grasping the medial and lateral sclera with toothed ophthalmic forceps and moving the globe in all directions. Free motion of the globe confirms that no entrapment of the orbital soft tissues has taken place during positioning of the bone graft.
- The caruncular incision is closed with buried interrupted 6-0 plain catgut sutures, using the bisected caruncle as a landmark for accurate wound alignment.

- If there is significant soft tissue edema of the orbital tissues causing exophthalmos, and postoperative corneal exposure is a concern, a temporary lateral tarsorrhaphy suture is placed using 5-0 silk suture.



TECH FIG 2 • The bone graft is placed over the defect. The surrounding intact bone supports the graft.

PEARLS AND PITFALLS

Corneal protection

- Once the patient is anesthetized, communicate with the anesthesiologist regarding corneal protection. Many anesthesiologists like to place lubricating ointment on the surface of the globe to prevent intraoperative corneal desiccation and may do so without informing the surgeon. However, the presence of this thick gelatinous ointment can complicate the initial caruncular incision and dissection. A corneal protector avoids this issue.

Incision placement

- Care must be taken to identify the puncta before incision and to preserve them throughout the dissection. Careless manipulation of the eyelid can result in inadvertent injury to the puncta requiring additional reconstruction.

Enophthalmos

- Perform a physical examination immediately prior to beginning

	surgery with the patient in the supine position. Note the degree of enophthalmos by examining the patient from superior and inferior perspectives, and use these observations as indices to judge your correction once the bone graft is placed.
Anesthesia	■ Local anesthesia may be used to infiltrate the periorbital soft tissues prior to surgery. Epinephrine injected into the conjunctiva may cause dilation of the pupil and lower intraocular pressure.
Cautery	■ When using cautery within the orbit, be attentive to the current settings. Thermal energy from the cautery device can dissipate throughout the orbit and damage the periorbital soft tissues. Within the orbit, use bipolar cautery to limit inadvertent heat transfer.
Soft tissue dissection	■ Once in the preseptal plane, a back-and-forth sweeping motion with a cotton-tipped applicator is very safe and effective in rapidly dissecting the soft tissues down to the level of the orbital wall.
Anatomic landmarks	■ The vertical level of the anterior and posterior ethmoidal arteries within the orbit approximates the level of the cranial base. Be aware of the location of these anatomic landmarks to identify any potential involvement of intracranial structures in the medial orbital injury.
Orbital safe zone	■ A medial orbital safe zone of dissection exists up to 30 mm posterior to the orbital rim. Dissection in this zone can be performed without fear of injury to structures that occupy the orbital apex.
Pressure on the globe	■ Pressure on the globe may elicit an oculocardiac reflex with resultant bradycardia and hypotension. Alert the anesthesiologist during the surgery if you need to place pressure on the globe and be prepared to release your retraction if there are any physiological consequences to your manipulation.
Bone grafts	■ In complex fractures that involve extensive injury to the ethmoid air cells, multiple bone grafts may be stacked to restore integrity to the medial orbital wall.
Intraoperative navigation	■ Intraoperative navigation may assist in defining the medial orbital defect, confirming accurate placement of the bone graft, and avoiding injury to critical structures in the orbital apex (FIG 4).

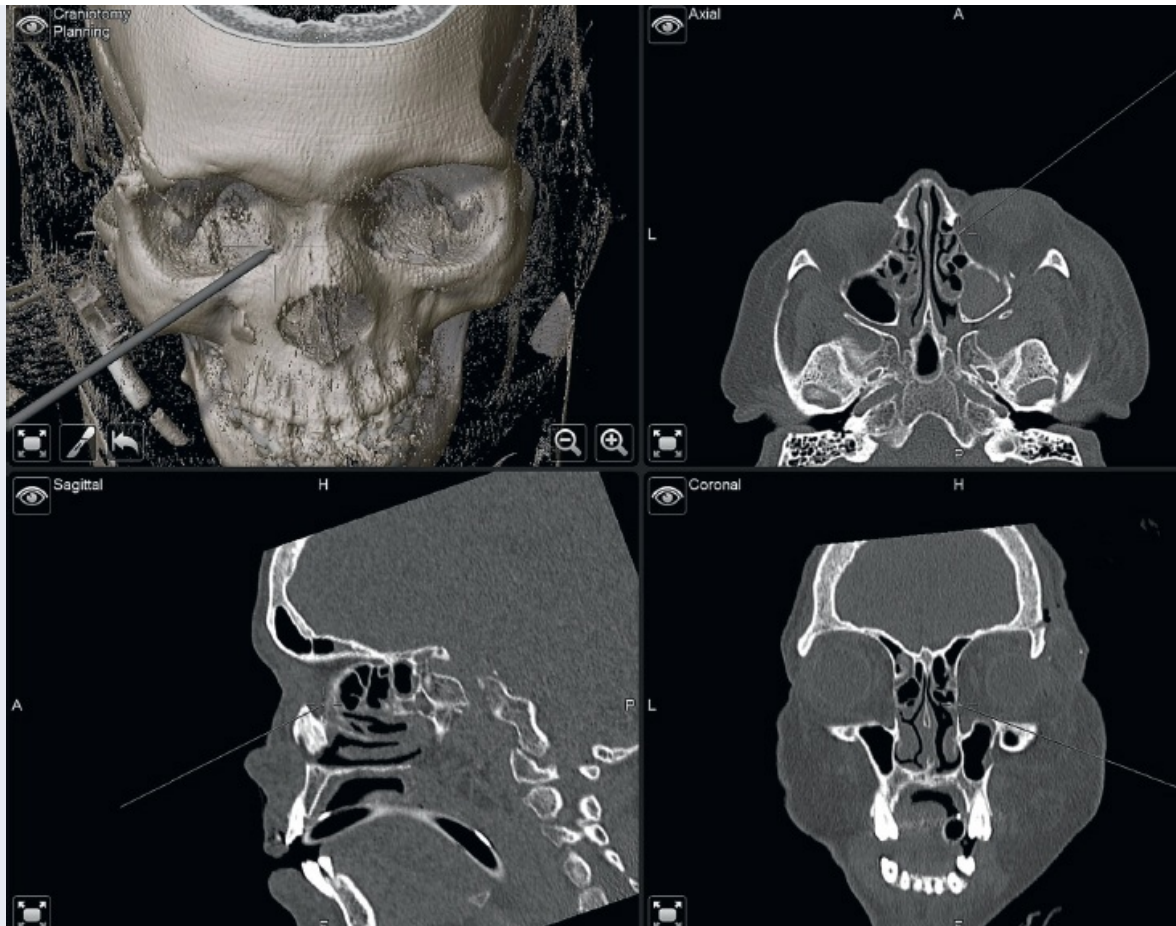


FIG 4 • Intraoperative navigation systems may help avoid injury to critical structures and confirm accurate graft placement.

POSTOPERATIVE CARE

- Cold compresses are placed on the eye continuously for the first 3 to 5 days following surgery; the first compresses are applied before the patient leaves the operating room. The patient's head is elevated during this time as well.
- Postoperative visual acuity examinations should be performed every 1 to 2 hours for the first 24 hours postoperatively. Even if the eyelids are swollen shut following surgery, light perception adequately confirms afferent optic nerve function.
- If a temporary tarsorrhaphy stitch is placed at the end of the operation, it is removed on the first postoperative day if there is no evidence of actual or threatened corneal exposure.

- The patient is counseled to not blow his/her nose for 6 weeks and to sneeze with an open mouth during that time to minimize elevation of intraocular pressure.

OUTCOMES

- If the medial orbital wall defect is well visualized and the bone graft is appropriately positioned, success rates are high, as defined by correction of enophthalmos, resolution of diplopia, release of any entrapped soft tissues, and preservation of the function and aesthetics of the medial canthal tendon and upper and lower eyelids.

COMPLICATIONS

- When using this technique in the treatment of medial orbital wall fractures, complications are rare. When they do occur, however, they can be severe.
- Blindness is the most severe and devastating complication that can result from any intraorbital surgery. Patients must be counseled that this is a possible outcome of surgery, albeit extremely rare. Knowledge of the surgical anatomy of the orbit and avoidance of aggressive surgical dissection in the orbital apex mitigate the chances of vision loss.
- Persistent or new-onset diplopia may be seen in the postoperative period. This can be due to iatrogenic injury to the rectus muscles, postoperative muscle fibrosis, or undiagnosed muscle injury sustained at the time of original trauma. True medial rectus entrapment warrants urgent intervention and release to prevent ischemia of the muscle and permanent muscle damage.
- Corneal injury, either due to iatrogenic abrasion or perioperative exposure, can lead to visual deficits.
- Conjunctival scarring can lead to cicatricial entropion or ectropion, both of which can be very difficult to correct.
- Injury to the medial canthal tendon during fracture repair may result in telecanthus that may require medial canthopexy repair.
- With any orbital surgery, and particularly with procedures that involve exposure of nonvascularized bone graft to sinus flora, the risk of infection is not insignificant.

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57 Correction of Orbital Roof Fractures

CHAPTER

Samita S. Goyal and James Jensen

DEFINITION

- Orbital roof fractures may occur in isolation but more often are a part of a larger pattern of traumatic injury.
- Classification¹:
 - Nondisplaced fractures
 - Isolated blow-in fractures
 - Orbital roof displaced inferiorly into orbit
 - No involvement of supraorbital rim or frontal sinus
 - Due to sudden increased intracranial pressure and shift of the cranium and intracranial contents; usually associated with severe brain injury
 - Leads to decreased volume of orbit and possible displacement of globe
 - Most likely injury type to require surgical intervention
 - Isolated blow-up (blow-out) fractures
 - Orbital roof displaced superiorly into anterior cranial fossa
 - No involvement of supraorbital rim
 - Due to increase in intraorbital pressure, hydraulic force, or shear strain
 - Leads to increased volume of orbit
 - Roof (blow up or blow in) and supraorbital rim

ANATOMY

- The orbital roof is a thin, slightly concave bone that separates orbital contents and the anterior cranial fossa.
- Includes the lateral extent of the floor of the frontal sinus
- Consists primarily of the orbital plate of the frontal bone; lesser (posterior)

contribution is from the greater and lesser wings of the sphenoid bone (**FIG 1**)

- The endocranial surface is characterized by multiple ridges and thin bones that may have a role in fracture patterns.
- The orbital surface is smooth and thin and includes the lacrimal fossa, a depression in the anterolateral orbital roof that contains the lacrimal gland.
- The supraorbital rim confers rigidity to the superior orbit.
- Structures in proximity to the orbital roof include the following:
 - Orbital septum
 - Lacrimal gland
 - Superior rectus muscle
 - Superior oblique muscle
 - Levator palpebrae superioris muscle
 - Supraorbital and supratrochlear nerves
 - Superior division of the oculomotor nerve
 - Globe

PATHOGENESIS

- Orbital roof fractures make up 1% to 9% of all facial fractures.
- Likely to have craniofacial, intracranial, ophthalmic, or other bodily injuries (isolated orbital roof fractures in adults are rare)
- In adults, most commonly seen in men 20 to 40 years of age (89%–93%).²
- More commonly seen in pediatric patients under 7 years of age³:
 - Children older than 7 years are more likely to sustain orbital floor fractures.
 - Young children have a high cranial:orbital ratio, incompletely pneumatized frontal sinus makes less likely shock absorption than in older children/adults; in high-energy impact situations, energy is more efficiently transmitted through the orbital roof.
- Most commonly due to high-energy impact injuries to the face
- Etiology
 - Mechanical vapor compression (MVC) (high energy): higher risk of comminution³
 - Fall: more likely linear pattern³
 - Assault
- Commonly seen at the junction of middle and medial thirds of orbital roof

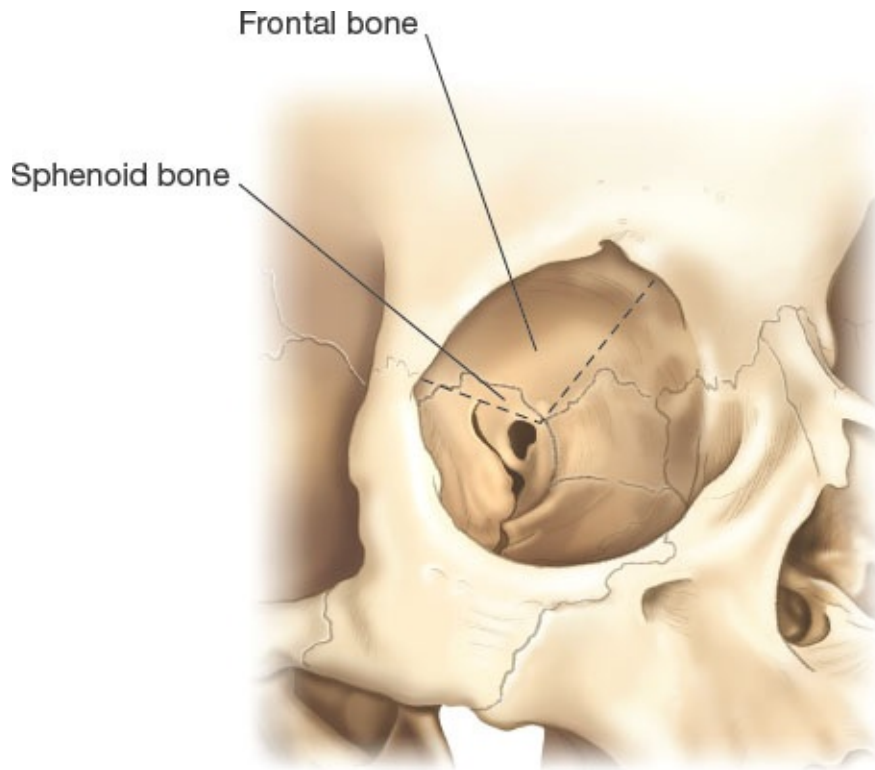


FIG 1 • Submental view of orbital skeletal anatomy demonstrating that the majority of the roof is frontal bone.

- Concomitant facial fractures²:
 - Frontal sinus (95%)
 - Orbital rims (60%)
 - Naso-orbital-ethmoidal region (33%)
 - Orbital wall fractures (33%)
 - Le Fort fractures (27%)
 - Also associated with fractures of the cribriform plate, lateral orbital wall, squamous portion of the temporal bone, and planum sphenoidale
- Concomitant soft tissue injuries: 25% of all fractures involving orbit have ocular injuries.⁴

NATURAL HISTORY

- In pediatric fractures, orbital roof fractures may develop into growing fractures³:
- Growing skull fractures—cranial fracture combined with dural tear and brain

herniation in a growing brain—can lead to progression of osseous defect with growth.⁵

- Frontal and parietal regions more commonly affected
- More likely to be seen in children less than 3 years of age (period of rapid brain growth)
- Suspect risk for development into growing fracture if imaging suggests herniation of intracranial contents into orbital region
- Isolated orbital roof “blow-in” fractures may autoreduce with resolution of cerebral edema if the dura is reasonably intact and apposed to the bone.⁶

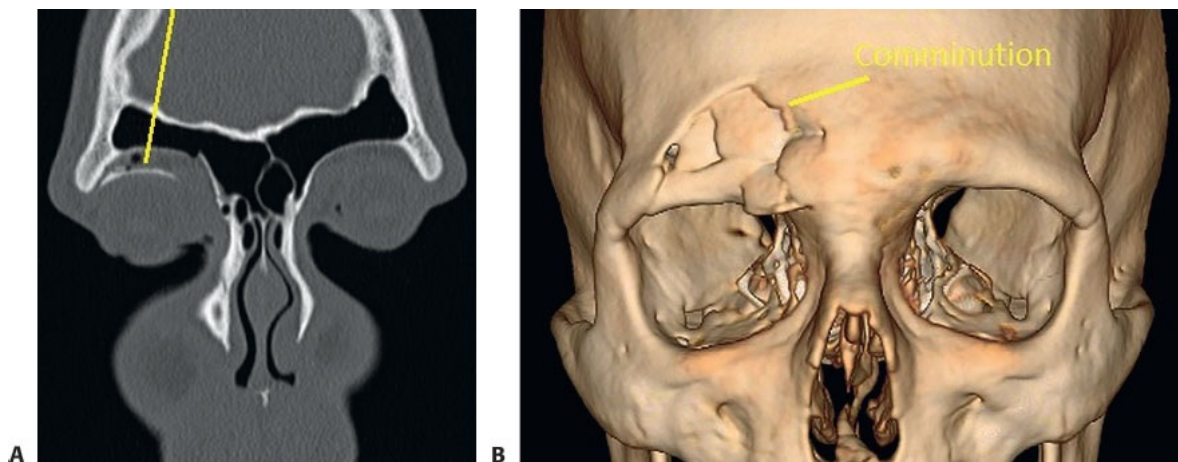
PATIENT HISTORY AND PHYSICAL FINDINGS

- History
 - Blunt or penetrating facial trauma
 - Diplopia
 - Eye pain
 - Diminished visual acuity
 - Blindness
- Physical findings
 - Superior orbital rim contour deformity
 - Periorbital or conjunctival ecchymosis and edema
 - Epiphora
 - Hypesthesia/paresthesia of supraorbital and/or supratrochlear nerves
 - Orbital emphysema
 - Soft tissue lacerations
 - Enophthalmos/hyperglobus (blow-out fracture)
 - Exophthalmos/hypoglobus/proptosis (blow-in fracture)
 - Extraocular muscle entrapment or imbalance (superior rectus muscle) with disconjugate gaze
 - Blepharoptosis due to injury to the levator palpebrae
 - Afferent pupillary defect
- Neurological comorbidity
 - Dural injury with cerebrospinal fluid (CSF) leak (clear rhinorrhea)
 - Intracranial hemorrhage
 - Pneumocephalus (implies dural disruption)
 - Meningitis
 - Brain injury
- Ophthalmic comorbidity

- Optic nerve compression or laceration
- Detached retina
- Retrobulbar hematoma
- Globe rupture
- Ptosis or lagophthalmos
- Intraorbital foreign bodies
- Extraocular motor nerve palsies
- Orbital encephalocele/intrusion

IMAGING

- Standard of care imaging modality: thin-slice (1 mm) computed tomography (CT) scan¹:
 - Axial, coronal, and sagittal views essential to provide complete assessment of degree of displacement and impact on surrounding structure.
 - 3D views not essential, but can be helpful in badly displaced/comminuted fractures, especially if utilizing a limited access approach
 - Advantages: rapid, available, provides ability to assess intracranial content/injury
- Magnetic resonance imaging (MRI): impractical as it is an insensitive exam of the bone and some foreign objects; contraindicated in situations where metallic foreign objects (bullet fragments) may be present in soft tissues (**FIG 2**).



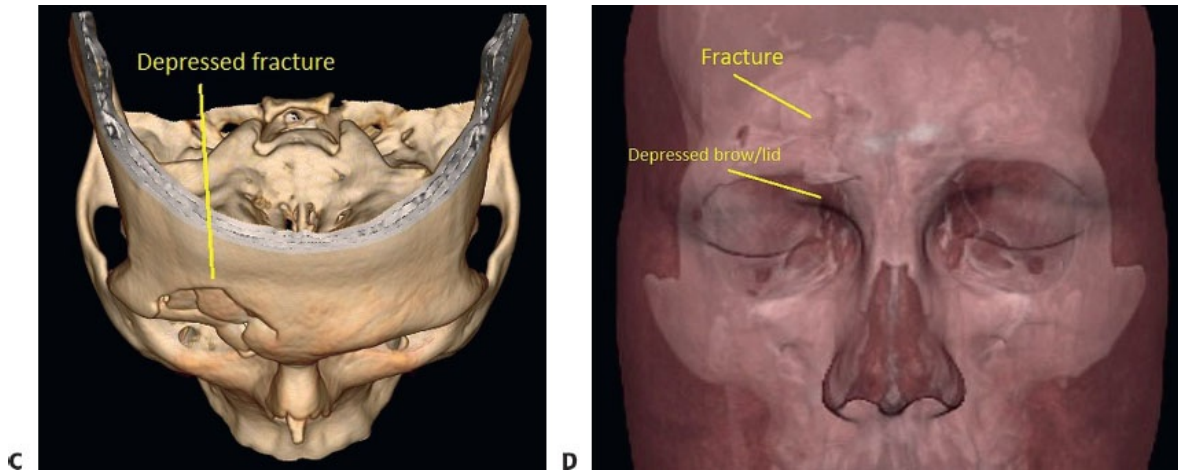


FIG 2 • Comminuted orbital roof/frontal sinus fracture with rim involvement in a 19-year-old following blunt force trauma (baseball). The patient had a ptotic upper lid secondary to inferior displacement of orbital roof (indicated by leader in **(A)**). **B.** 3D CT scan demonstrating the comminuted fracture. **C.** 3D CT bird's eye view of the fracture. **D.** Soft tissue envelope demonstrating the depressed eyebrow associated with the fracture.

NONOPERATIVE MANAGEMENT

- Conservative, nonoperative management is often appropriate in orbital roof fractures and indicated in
 - Isolated, nondisplaced, or minimally displaced orbital roof fractures
 - Initial nonoperative course in “blow-in” fractures associated with intracerebral edema; observe for reduction of fracture fragment with resolution of cerebral edema⁶
 - Children without signs of functional deficit (eyelid position/function, extraocular muscle mobility) or significant displacement
- Higher threshold to operate in children (more likely to tolerate conservative management) but certain fracture patterns may have potential for growing skull fractures (significant displacement and dural injury⁵).
- Treatment:
 - Head of bed (HOB) elevation

- Sinus precautions: employ techniques to minimize pressure within sinuses (no nose-blowing, no sneezing with mouth closed, etc.)
- Antibiotic course not proven to be necessary, but should be considered with obvious evidence of sinus contamination of intraorbital or intracranial space
- Pain management

SURGICAL MANAGEMENT

- Initial assessment includes standard advanced trauma life support (ATLS) protocol and appropriate prioritization of treatment plan.
- Appropriate coordination of other surgical procedures
- Emergent intervention warranted with: visual/neurological compromise, retrobulbar hematoma, extraocular muscle entrapment, globe rupture, severe brain injury (ie, herniation)
- Indications for surgery:
 - Injury and functional compromise of orbital contents, including the levator complex
 - Associated dural tear with prolapse of brain tissue into the orbit
- Consider deferring procedure until edema mostly resolved, if isolated fracture and no functional compromise is present.
- Titanium or resorbable mesh fixation may be considered.

Preoperative Planning

- Comprehensive ophthalmological assessment
- Careful review of CT scan, preferably with scans displayed in the OR and easily seen from the operating position
- Careful clinical examination on table prior to surgery, to establish morbid state to provide for comparison after reduction/fixation.
- Forced duction test to establish the presence/absence of entrapment
- Place corneal protectors with thickly applied ophthalmic ointment to be able to assess correction of globe malposition and comparison to contralateral side.
- Standard perioperative IV antibiotic dose
- Infiltrate planned incisions and dissection planes with local anesthesia with epinephrine (1:1 to 400 000).
- Consider intraop radiographic imaging (CT O-arm) to evaluate reduction, especially if limited access incisions are pursued.
- Headlight helpful, especially in limited access approaches

Positioning

- The table is turned sufficiently away from the anesthesia station to provide access to each side and the head of the bed (usually 90 degrees).
- Standard HOB elevation to minimize venous pressure
- Prep and drape the entire upper face and midface (ie, both sides for intraop comparison of contours following reduction).
- Anchor drapes in hair-bearing scalp with staples.

Approach

- Four approaches are described here. The first three are “limited access” and applicable essentially to isolated orbital roof/superior orbital rim fractures largely confined to the anterior orbit or lateral frontal sinus anterior table without concomitant intracranial injury.
- Lateral brow approach (**TECH FIG 1A**):
 - For limited fractures: Gives access to orbital surface of the roof and superior orbital rim
 - Advantages: Quick, avoids unnecessary dissection, and tissue disruption
 - Disadvantages: Limited access, nerve traction injury, crush injury to orbicularis oculi muscle, and subcutaneous atrophy from retraction, postoperative brow malposition/asymmetry, risk for unfavorable scar, and inability to safely reduce roof fractures with intrusion of intracranial contents
- Supratarsal approach (**TECH FIG 1A**):
 - Similar to lateral brow approach in indication, advantages, and disadvantage, except the added risk for levator damage and brow ptosis and the improved mobility of the thinner tissue of the upper lid in translating the overlying skin/subcutis to align with the fracture
- Translaceration approach:
 - Used with associated laceration in open fractures
 - May consider extending laceration in one or more directions to provide adequate exposure
 - Advantages: Speed, minimal unnecessary disruption of the tissue
 - Disadvantages: May disrupt frontalis, sensory innervation; limited exposure and inability to safely reduce intracranial material in “blow-in” fractures
- Coronal approach (**TECH FIG 1B**):
 - The standard approach for complex or comminuted orbital roof fractures associated with intracranial injury and frontal sinus fractures

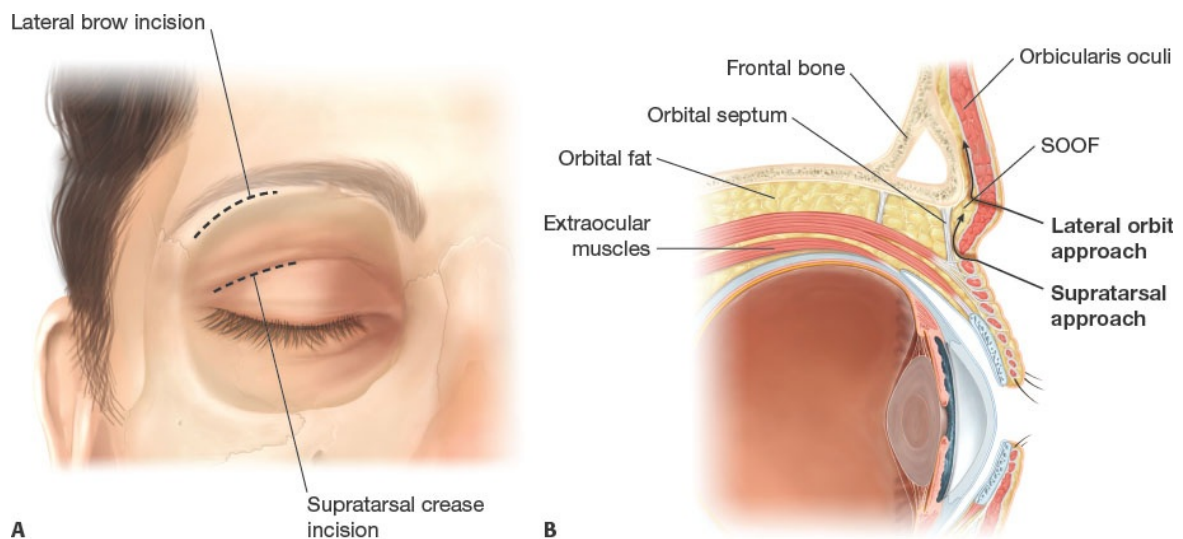
- Necessary for transcranial approach to orbital roof beyond anterior third
- Safe access for posterior orbital decompression
- Safe access to address dural injury and reduction of cranial contents
 - Advantages: Provides the widest exposure, least risk for sensory nerve damage, facilitates more accurate and faster reduction, and allows flexibility of simultaneous access to adjacent injured anatomy necessary for collaborating services, including split calvarial graft harvest if necessary
 - Disadvantages: Extensive scar, time-consuming, risk for motor nerve injury (frontal branch of CN VII), risk for temporal hollowing, discomfort, and longer recovery
- If the fracture is extensive or comminuted or involves disruption of the barrier between the brain and orbit, including dural injury, a conventional open approach via some version of a coronal incision is indicated (most cases that require operative intervention in collaboration with neurosurgical and/or ophthalmological colleagues).
- Surgical correction of the orbital roof per se may or may not require immediate attention depending on the comorbidity and the urgency therein.

TECHNIQUES

■ Lateral Brow Approach

- Place incision on the lower border of the eyebrow if the skin is completely intact to limit dissection through subcutis containing sensory nerves as they emerge from the superior orbital rim (**TECH FIG 1A**):
 - Position incision laterally to limit transection of sensory nerves.
- Distract skin/subcutis to center dissection vector on superior orbital rim.
- Continue sharply through subcutis and orbicularis muscle to the periosteum of orbital rim; if orbital septum is encountered, remain superficial to it, and redirect dissection plane superiorly toward its insertion in the orbital rim (**TECH FIG 1B**).
- Identify periosteum, and locate any traumatic laceration to serve as edge from which to dissect.
- Dissect the periosteum from underlying bone fragments to provide sufficient exposure of a periphery of intact, uninjured bones, 5 to 10 mm.

- Document, whether by photography or a quick intraoperative sketch, the configuration of fractured fragments to ensure correct reconstruction if fragment removal is necessary to achieve anatomic reduction.
- Reduce impacted fractures with fine dissector or elevator; may require removal of small, centrally located fragment to provide for optimal leverage of impacted fragments.
- If a portion of the orbital roof is displaced, removal of fragments in the superficial dissection to afford exposure necessary for adequate and stable reduction may be required.
- Reduction of multiple fragments may require stepwise approach; begin with the most distal or obscured edge, and work toward the center of dissection pocket.
- Contour plate(s) appropriately.



TECH FIG 1 • Location of skin incisions **(A)** and correct plane of dissection **(B)** in lateral brow and supratarsal approaches.

- Apply internally fixated plates and screws (titanium, primarily; resorbable plating material may be considered in these fractures as they are not prone to disruption by muscle action).
- Irrigate thoroughly.
- Perform careful layered closure of the periosteum if possible, muscle, and dermis with resorbable suture, and fine nonabsorbable suture for a precise,

tension-free superficial layer closure.

■ Supratarsal Approach

- Incision is placed in supratarsal crease, which may be difficult to find in very edematous eyelids (see **TECH FIG 1A**).
- Incise the skin and orbicularis concomitantly, encounter superficial tissue (preseptal fat or SOOF), sharply dissect through this as well, and dissect superiorly in the preseptal plane until the rim and/or fracture is encountered.
- Distract the skin/subcutis to center dissection vector on superior orbital rim.
- Continue sharply through the subcutis and orbicularis muscle to the periosteum of orbital rim; if orbital septum is encountered, remain superficial to it, and redirect dissection plane superiorly toward its insertion in the orbital rim (see **TECH FIG 1B**).
- Identify periosteum, and locate any traumatic laceration to serve as edge from which to dissect.
- Dissect periosteum from underlying bone fragments to provide sufficient exposure of a periphery of intact, uninjured bones, 5 to 10 mm.
- Document, whether by photography or a quick intraoperative sketch, the configuration of fractured fragments to ensure correct reconstruction if fragment removal is necessary to achieve anatomic reduction.
- Reduce impacted fractures with fine dissector or elevator; may require removal of small, centrally located fragment to provide for optimal leverage of impacted fragments
- If a portion of the orbital roof is displaced, removal of fragments in the superficial dissection to afford exposure necessary for adequate and stable reduction may be required.
- Reduction of multiple fragments may require stepwise approach; begin with the most distal or obscured edge, and work toward the center of dissection pocket.
- Contour plate(s) appropriately.
- Apply internally fixated plates and screws (titanium, primarily; resorbable plating material may be considered in these fractures as they are not prone to disruption by muscle action).
- Irrigate thoroughly.
- Perform careful layered closure of the periosteum if possible, muscle, and

dermis with resorbable suture, and fine nonabsorbable suture for a precise, tension-free superficial layer closure.

■ Translaceration Approach

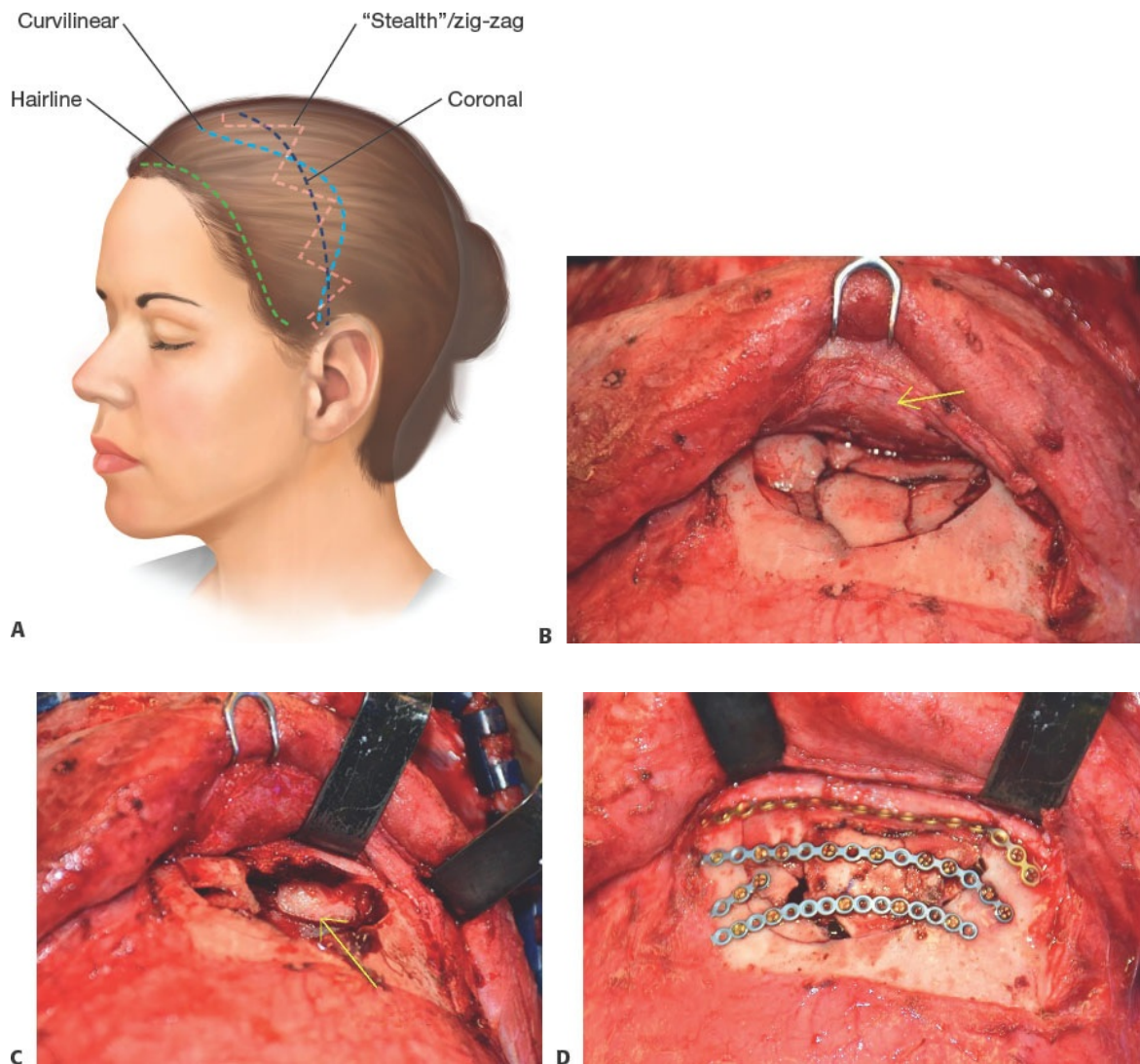
- Remove any temporarily placed sutures.
 - Explore wound to identify frontalis, corrugator, and procerus musculature; identify supraorbital/supratrochlear nerves for gentle retraction.
 - If necessary, dissect length of sensory nerves to enable safe retraction.
 - Identify periosteum, and locate any traumatic laceration to serve as edge from which to dissect.
 - Dissect periosteum from underlying bone fragments to provide sufficient exposure of a periphery of intact, uninjured bones, 5 to 10 mm.
 - Document, whether by photography or a quick intraoperative sketch, the configuration of fractured fragments to ensure correct reconstruction if fragment removal is necessary to achieve anatomic reduction.
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 - Contour plate(s) appropriately.
 - Apply internally fixated plates and screws (titanium, primarily; resorbable plating material may be considered in these fractures as they are not prone to disruption by muscle action).
 - Irrigate thoroughly.
 - Perform careful layered closure of the periosteum if possible, muscle, and dermis with resorbable suture, and fine nonabsorbable suture for a precise, tension-free superficial layer closure.
-

■ Coronal Approach

- Select incision pattern (**TECH FIG 2A**):
 - Zigzag or “stealth” incisions change direction and permit hair to more effectively camouflage scar; also, provide for greater stretch of the scalp to more easily evert.
 - Straight or slightly wavy incisions are faster but ultimately more visible.
- Select incision placement:
 - Anterior hairline incision facilitates flap elevation and reduces visibility of scar but may become visible with hairline recession.
 - Placement within hair-bearing scalp likely will provide best long-term cosmetic result.
- Hair grooming with clips or rubber bands vs shaving (not with a razor blade).
- Map (with palpation) course of superficial temporal artery.
- Begin incision superior to temporal crest to avoid confusion of superficial and deep temporal fascia.
- If only a limited pericranial flap is necessary, incise the skin with scalpel through the galea in relatively short segments (5–10 cm) with immediate blunt (or sharp with scalpel) dissection in subgaleal plane anteriorly and posteriorly.
- Cauterize arteries or large galeal veins; avoid cauterization of the dermis or subcutis to minimize risk of alopecia.
- Apply Raney clips as soon as possible to stop dermal bleeding.
- Extend incision through superficial temporal fascia with care to avoid the superficial temporal vessels. In adults, well-developed periauricular musculature will be encountered that will have to be divided.
- Continue blunt dissection in the subgaleal plane anteriorly, using cautery as necessary for any transcranial emissary vessels encountered, both superiorly and laterally, leaving the deep temporal fascia and temporalis musculature undisturbed and apposed to the cranium.
- Continue in the subgaleal plane until the fracture becomes detectable, then incise the pericranium with a 5- to 10-mm margin of intact bone, and continue the dissection in the subpericranial plane over the fracture fragments, with care taken to note the position of any fragments that become dislodged during this maneuver.
- Continue subpericranial dissection as necessary past the superior orbital rim (**TECH FIG 2B**), but avoid if possible complete disruption of this plane with

respect to orbital roof fragments to maintain blood supply and optimize healing.

- If a large pericranial flap is likely to be necessary (eg, to provide lining of disrupted dura/CSF leak over the orbital roof), then dissect in the subpericranial plane between the temporal crests from the beginning, incise the pericranium at the temporal crests, and continue scalp flap dissection laterally in the subgaleal plane (again, leaving the temporalis muscle in place if temporal bone access is not necessary).
- If orbital roof is too comminuted, consider split calvarial bone graft to restore structural integrity to the orbital roof (must have vascular bed and no continuity with sinus cavity to succeed).
- Once the fracture pattern is exposed, document, whether by photography or a quick intraoperative sketch, the configuration of fractured fragments to ensure correct reconstruction if fragment removal is necessary to achieve anatomic reduction.
- Reduce impacted fractures with fine dissector or elevator; may require removal of small, centrally located fragment to provide for optimal leverage of impacted fragments.
- If a portion of the orbital roof is displaced, removal of fragments in the superficial dissection to afford exposure necessary for adequate and stable reduction may be required (**TECH FIG 2C**).
- Reduction of multiple fragments may require stepwise approach; begin with the most distal or obscured edge, and work toward the center of dissection pocket.
- Contour plate(s) appropriately.
- Apply internally fixated plates and screws (titanium, primarily; resorbable plating material may be considered in these fractures as they are not prone to disruption by muscle action; **TECH FIG 2D**).
- Irrigate thoroughly.
- If fragments of the roof are not amenable to fixation, consider titanium or other alloplastic materials to restore physical barrier between orbital tissue and anterior cranial fossa.



TECH FIG 2 • A. Different options of coronal incision placement. **B.** Surgical exposure of patient in **FIG 2**, demonstrating biplanar approach (subgaleal converted to subpericranial at level of fracture) and displacement of fracture fragments into frontal sinus, which essentially occupied the entire width of the orbital roof fracture (no intracranial extension). The *arrow* indicates the pericranial flap. **C.** Removal of fragments reveals orbital roof fracture (arrow), confined to orbital sinus cavity. **D.** Internal fixation with transversely oriented contoured low-profile titanium

plates.

- If a pericranial flap is necessary to inset intracranially at the anterior cranial base/orbital roof, then a small cranial defect of 3 to 5 mm in vertical dimension and variable width will need to be provided close to the level of the roof (see technical description of cranialization of frontal sinus).
- Anchor the pericranium with suture with or without fibrin glue.
- Closure of the scalp is over a single-closed suction-fluted drain, emerging postauricularly, and consists of interrupted resorbable suture in the pericranium over the fracture repair, then interrupted resorbable sutures every 1 to 2 cm in the galea, and then running permanent suture or staples in the skin.
- Bolster dressing is optional.

PEARLS AND PITFALLS

Coronal approach: temporal hollowing

- Avoid disinsertion of temporalis musculature or exposure of temporal fat pad.

Coronal approach injury to frontal branch of CN VII

- Begin dissection in subgaleal/subsuperficial temporal fascia plane, progress with blunt dissection in this plane in the frontotemporal region, and convert to subpericranial well superior to the course of the nerve.

Raising the pericranial flap

- Some find it easier to raise the pericranium off the already-raised scalp flap than to raise it intact off the bone following subgaleal scalp elevation because of desiccation; be sure to keep all tissues well irrigated during the prolonged exposure with the coronal approach.

Plate orientation

- One could argue in favor of orienting fixation plates to follow relaxed skin tension lines, but low-profile miniplates are difficult to palpate over the superior orbital rim and forehead.

Resorbable

- Appropriately applied when strength is not necessary, but may

plating material	cause seroma formation and bony resorption; not proven to be as effective as titanium or porous polyethylene implants for orbital roof restoration.
Change of approach	■ Even if planning for a limited approach, always be prepared (and prepare patient) for a coronal approach. ■ Have a full set of instruments available.

POSTOPERATIVE CARE

- Immediate evaluation of vision in recovery room as soon as the patient is able to be examined.
- Elevation of the head of the bed
- Sinus precautions: Employ techniques to minimize pressure within sinuses (no nose-blowing, no sneezing with mouth closed, etc.).
- Avoidance of contact activities (sports, gym, recess, etc.) for 6 weeks
- Begin scar massage after incisional edema resolved (about 2 weeks postoperatively).
- Extraocular muscle exercises as needed
- Consider a short course of prophylactic antibiotics to decrease risk for postoperative infection (devitalized bone fragments).
- Postoperative imaging is entirely dependent on the intra- and postoperative courses.

OUTCOMES

- Level 1 evidence in treatment of orbital roof fractures is lacking.
- In children, roof fractures smaller than 2 cm² are unlikely to lead to globe malposition or development of encephalocele.³
- Early intervention of orbital roof fractures with ophthalmological sequelae decreases morbidity.⁵
- That two-thirds of orbital roof fractures are associated with traumatic brain injury underscores need for multidisciplinary approach.⁷

COMPLICATIONS

- Globe displacement⁸
- Retrobulbar hematoma
- Meningitis
- Persistent CSF leak due to inadequate repair of dural tear

- Eyelid ptosis from injury to levator palpebrae superioris muscle
- Injury to orbital structures: extraocular muscles, nerves, arteries, veins, and globe
- Blindness

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58 Secondary Correction of Enophthalmos

CHAPTER

David C. Matthews, Samer Abouzeid, and Edward W. Kubek

DEFINITION

- Enophthalmos refers to the posterior position of one eye relative to the contralateral eye.¹
- Secondary post-traumatic enophthalmos refers to the persistence of enophthalmos after attempted correction during the primary operation and is a common sequela to orbital trauma.
- Hypoglobus describes a vertical discrepancy in globe position.
- Secondary post-traumatic enophthalmos is the most common secondary facial deformity following primary surgery for facial trauma.²
- Until the 1970s, enophthalmos was not considered correctable.
- Tessier's work demonstrated that both acute and late enophthalmos were correctable.
- In 1982, Kawamoto first reported his technique to correct long-standing post-traumatic enophthalmos with osteotomies and bone grafting.³
- These techniques were then repeated by Manson, Wolfe, and Gruss.⁴

ANATOMY

- The bony architecture of the orbit forms two basic components, the orbital frame (comprising the rim) and the orbital pyramid with its apex pointed posteriorly (comprising the floor, roof, lateral wall, and medial orbital wall).
- The optic nerve enters the orbit at the apex of an asymmetric pyramid where the apex is oriented posteromedially and superiorly.
- General dimensions of the bony orbit are 50 mm deep, 35 mm wide, and 40 mm high.¹

- Each of the pyramid's four walls has a unique shape that contributes to globe position.¹
- Four structures of surgical importance¹:
 - The Hammer's "key area," or posterior part of the medial orbital wall (**FIG 1**).
 - S-Curvature of the posterior one-third of the orbital floor—any graft, synthetic or autologous, must sit atop the ledge created by the palatine bone posteriorly.
 - Greater wing of the sphenoid—anatomic reduction indicates proper alignment of the lateral wall and rim with the zygoma.
 - Orbital rim position—failure to anatomically reduce a displaced orbital rim (ie, the frame) prevents restoration of normal orbital shape and volume.
- Four measurements of surgical importance denote safe distances of dissection beyond key structures. Note that dissecting posteriorly to these distances will still be insufficient for secondary correction of enophthalmos, if the posterior margin of the defect is not defined.
- Dissection should be limited to:
 - Medial wall—36 mm of the anterior lacrimal crest
 - Orbital floor—35 mm of the infraorbital foramen
 - Orbital roof—30 mm of the supraorbital notch
 - Lateral wall—25 mm of the frontozygomatic suture

PATHOGENESIS (OPTIONAL)

- Post-traumatic, secondary enophthalmos occurs when the fracture pattern expands the volume of the bony orbit and is either uncorrected (**FIG 2A**) or reduced in the wrong position (**FIG 2B**):
 - As a result, the globe occupies a smaller percentage of the total space and assumes a more posterior position.
- The most common cause of secondary enophthalmos during the primary operation is inadequate posterior dissection for fear of injuring the optic nerve or globe,² followed by inadequate reduction of medial wall fractures (**FIG 3**).⁵
- Failure to re-establish the anatomic form of Hammer's key area and/or the S-curve of the posterior orbital floor can also lead to secondary enophthalmos, even in cases where the orbital floor is intact.¹

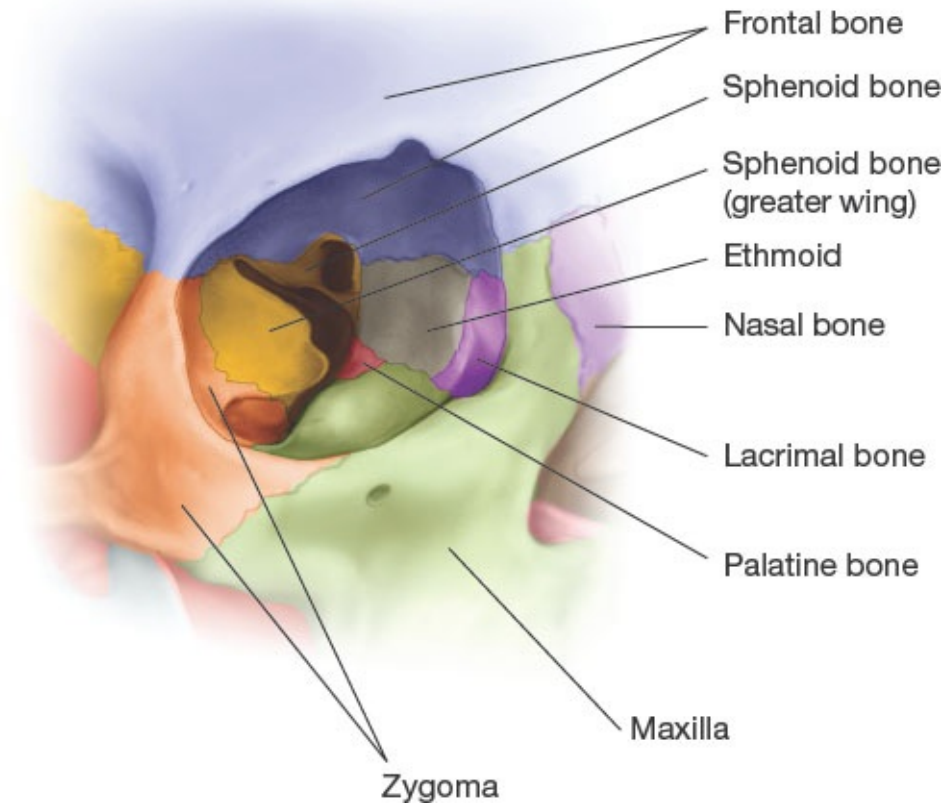


FIG 1 • Key areas of the orbit include the junction between the zygomatic bone and greater wing of the sphenoid. The palatine bone should be used as a support shelf for the bone graft.

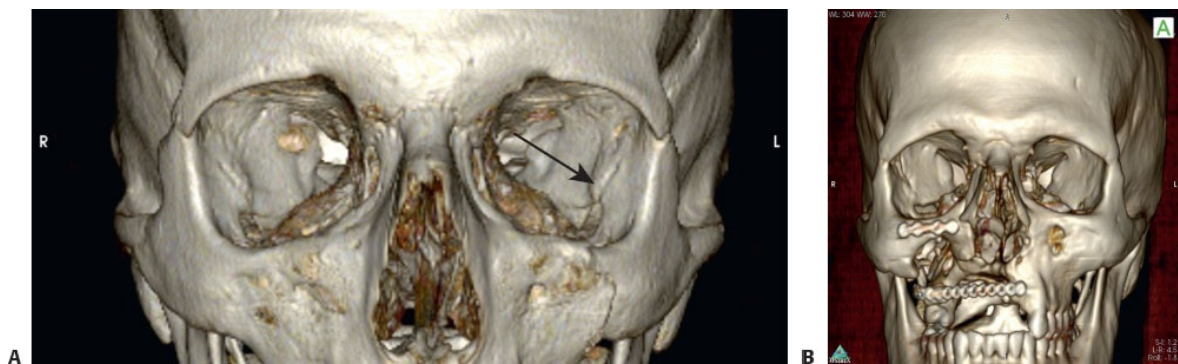


FIG 2 • **A.** Absent reduction of the orbital floor (see *black arrow*) results in increased orbital volume leading to enophthalmos. **B.** Inadequate reduction after remote zygoma fracture demonstrates the ledge between the

zygomatic bone and the greater wing of the sphenoid.

- Late atrophy of orbital fat is rarely demonstrated and is not a cause of secondary enophthalmos⁵; furthermore, it should be the goal of the surgeon to reduce all malpositioned orbital fat noted during the workup for secondary correction.

NATURAL HISTORY

- In the early postinjury period, clinical enophthalmos is usually masked by swelling.
- As edema subsides, postsurgical patients, or those who did not seek acute care, may present with enophthalmos, in the presence or absence of diplopia.
- Globe position and healing after the primary operation or injury is considered stable at 6 months.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- Normal physiologic anteroposterior variance between eyes is ≤ 2 mm.¹
- Discrepancies ≥ 3 mm can be evident to untrained observers.¹
- Normally, the globe functions as the fulcrum for the levator. Enophthalmia displaces this fulcrum causing the upper lid to appear ptotic (**FIG 4**).
- Patients may complain of eyelid thickening and impaired ability to fully open the eye.
- Preoperatively, the surgeon must document any numbness in the infraorbital and zygomaticofacial nerve distributions.



FIG 3 • Orbital floor dissection should reach the palatine bone (designated by the *arrow*).

- Hertel exophthalmometry is a noninvasive way to measure globe position. Normally, the cornea is 16 mm anterior to the lateral orbital rim. The Hertel technique is not applicable in the acute setting and inaccurate when the lateral orbital rim is displaced. In such cases, measurement relative to the ear canal may be useful.⁵

IMAGING

- A craniofacial computed tomography (CT) scan with 0.5-mm cuts should be obtained and formatted for 3D reconstructions (see **FIG 2**).
- The scan defines defects in the orbital floor, walls, and zygoma.
- CT-guided volumetric analysis can be used but is limited by an inability to predict bone resorption depending on type of bone graft (calvarial bone has less resorption than iliac bone). This analysis may be more beneficial when using preformed synthetic implants that do not resorb.⁶

SURGICAL MANAGEMENT

Preoperative Planning

- CT scan should be studied well to evaluate the dimensions of the bone that

should be harvested to reconstruct the orbital floor.

- Ophthalmologic examination should be documented preoperatively. A bedside Snellen eye chart is helpful for documenting the examination at bedside.
- Note any history of upper lid surgery for ptosis caused by enophthalmia because secondary correction of enophthalmos in this setting requires reversal of the prior upper lid operation.
- Consider a coronal incision for secondary operations to reduce large medial wall defects and old displaced zygomaticomaxillary complex fractures.
- The choice between autologous, alloplastic, metal, and bioceramic implants is guided by surgeon preference. Costlier prefabricated implants are typically reserved for secondary operations.⁷
- General principles for surgery
 - Wide subperiosteal exposure of the orbit is required to visualize the entire defect.
 - A subtarsal lower lid incision extended laterally increases exposure.

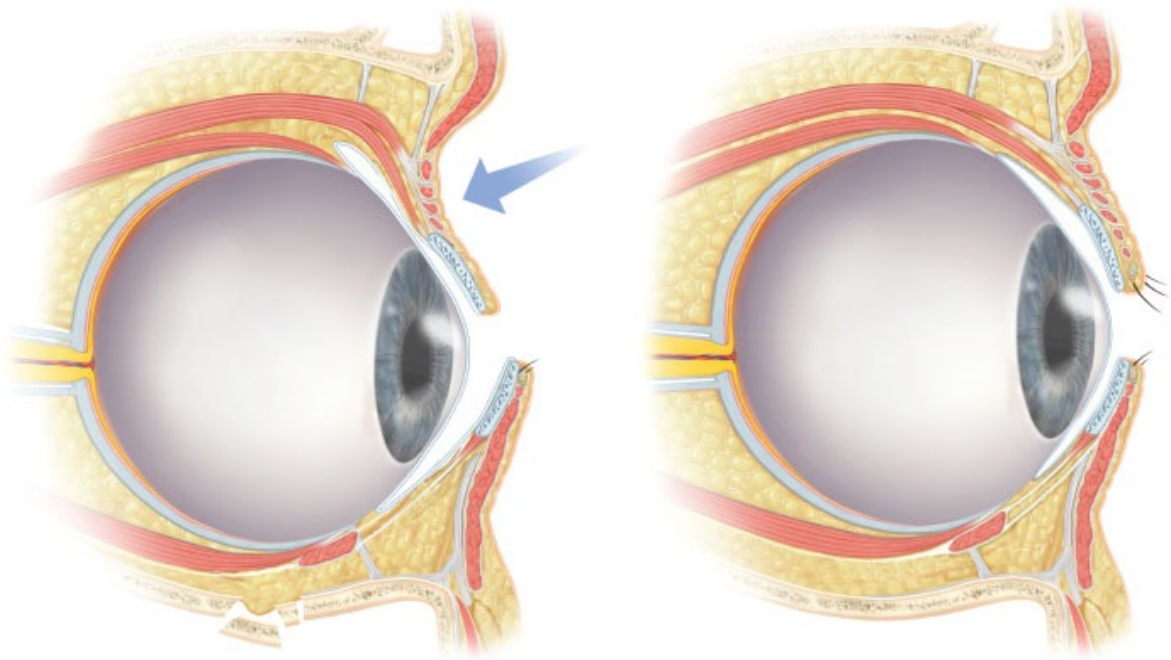


FIG 4 • When the globe is in a posterior and inferior position, the upper eyelid has no support, giving the impression of ptosis.

- Make an attempt to correct the entire defect with bone grafts.

- If necessary, the periosteum of the anterior maxilla is elevated so that orbital periosteum can be sutured to this layer to support the lower lid.
- Orbicularis ocularis is closed as well as the skin.
- In severe comminuted orbital fractures, remember that the infraorbital nerve is the key for dissection of the floor.
- Severe medial defects are approached through a coronal approach.

Patient Positioning

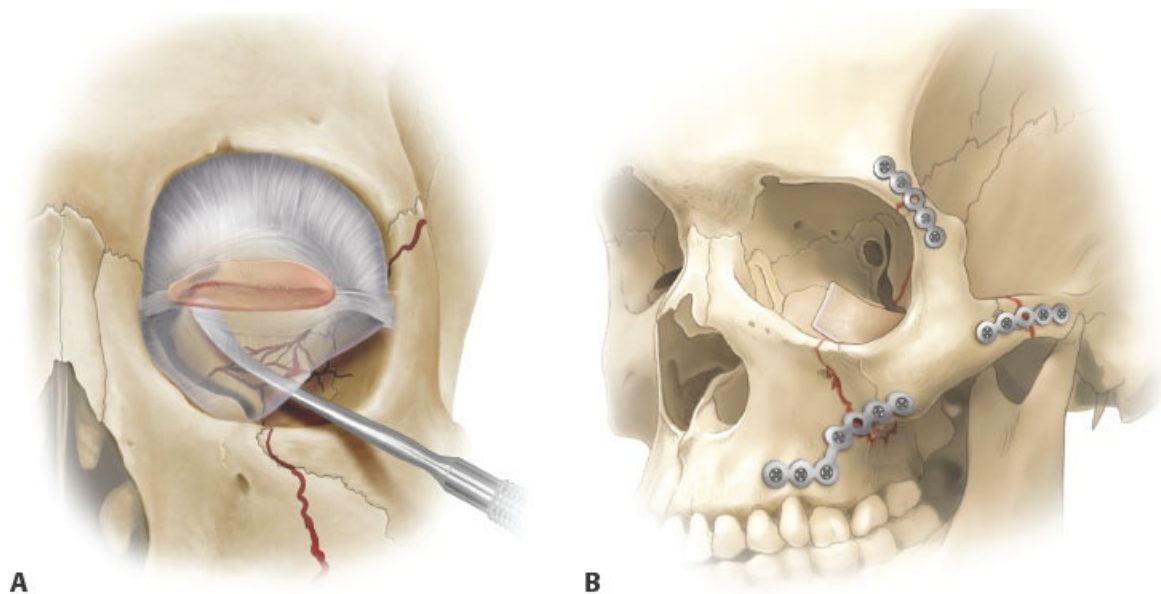
- The patient should be in the supine position.
- The endotracheal tube should be in the midline.
- The eyes should be closed with ophthalmic ointment.
- The face and upper shoulders will be scrubbed with Betadine and then the eyes irrigated with balanced salt solution (BSS).
- The head is draped, leaving the entire face in the surgical field.

TECHNIQUES

■ Periorbital Repair

- A transconjunctival or an infraorbital approach is made.
 - The transconjunctival approach:
 - Infiltration of local anesthetic with epinephrine
 - Incision is made posterior to the orbital septum; the incision should extend to the orbital rim.
 - The infraorbital approach:
 - Choose the highest subtarsal groove and make the skin incision.
 - Separate subcutaneous tissue until reaching the orbicularis muscle.
 - Incise the orbicularis transversely onto the orbital rim.
- A periosteal elevator dissects in the subperiosteal plane, moving from the fixed (unfractured) bone to the fracture site.
 - Periosteal elevation beyond 35 mm posteriorly endangers the optic nerve (**TECH FIG 1A**).
- After exposing the fractured area (including separation of the infraorbital nerve from the periorbital fat), the bony defect should be fully visualized.
- An autologous calvarial bone graft is taken from the parietal bone.

- After exposing the parietal skull, the graft is outlined with ink based on measurements from preoperative imaging.
- A cutting bur is used to follow the outline through the outer table.
- Bleeding from the diploe indicates proper depth.
- The graft is harvested using thin osteotomes to circumferentially free the outer table graft.
- The bone graft should be placed without fixation to span the defect.
- Ensure bony contact posteriorly, and stabilize the bone to the medial and lateral shelves of the defect.
- The graft should not extend beyond the inferior orbital rim anteriorly.
- Multiple layers of bone can be stacked until the eyes are at the same level and the “two thumbs pressure test” is similar bilaterally (**TECH FIG 1B**).
- Though bone grafts are the preferred method of treatment, synthetic implants can be used according to surgeon preference and availability of preoperative imaging with 3D modeling.
- To lessen the risk of ectropion, the malar periosteum should be resuspended.
- Before closing the skin, examine the globe’s mobility with a forced duction test.
- Two to three stitches with Vicryl 5-0 should be used to approximate orbicularis oculi edges.
- Closure is performed in one skin layer with nylon 6-0 for the infraorbital incision and Vicryl 6-0 Rapide to reapproximate conjunctivae for the transconjunctival approach.

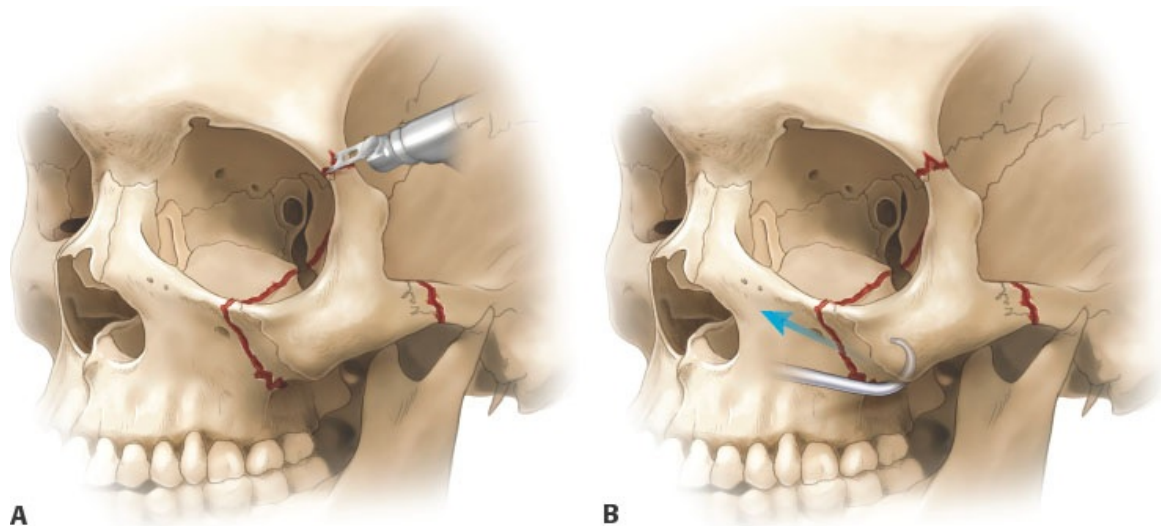


TECH FIG 1 • A. Elevation of the periorbital soft tissue is performed from regions of normal bone toward the previous site of fracture. The elevator should not be used to dissect further than 35 mm from the orbital rim. **B.** Plates are placed on the buttresses, and any gap is covered with bone graft.

■ Zygoma Repair

- A coronal incision should be used to access the zygomatic arch.
- The temporal fascia is elevated from the zygomatic arch toward the muscle to protect the facial nerve.
- The orbital contents can also be elevated from this approach.
- The masseter muscle insertion on the zygoma is released with an elevator.
- The zygomatic arch osteotomy is made in an oblique fashion.
- The zygomaticofrontal fissure should also be cut or mobilized depending on whether the fracture site is healed or not. (Usually, the fracture is along the fissure.)
- An osteotomy is made through the old orbital rim fracture (**TECH FIG 2A**).
- A heavy bone hook—Ginestet hook—is used with a steady forward force to mobilize the zygoma, and then lateral movements are made to free it completely (**TECH FIG 2B**).

- The landmark for placing the hook is at the intersection between a vertical line passing through the lateral canthus and a horizontal line passing through the tragus.
- The zygoma is anatomically reduced.
- Anatomic alignment of the lateral orbital wall and greater wing of the sphenoid is a useful indicator of proper reduction.
- The osteotomized and reduced zygoma is fixed with titanium plates and screws (2.0 or 1.5 mm).
- Plating should be performed to the orbital rim, frontozygomatic suture, and zygomatic arch. Stable fixation at the lateral buttress must withstand the inferior pull of the masseter.



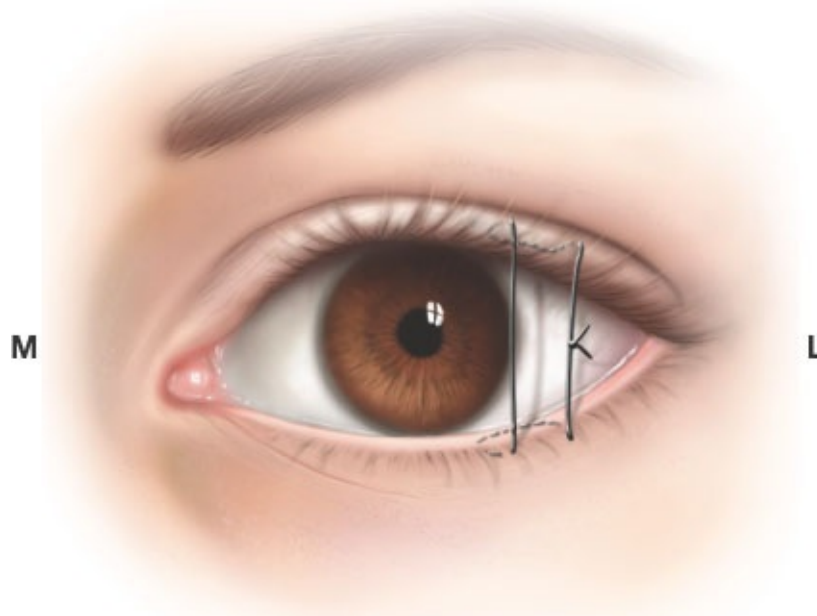
TECH FIG 2 • A. Using either a mechanical saw or a piezo saw, cuts are made along the frontozygomatic suture, the temporozygomatic suture, and lateral to the infraorbital nerve. **B.** A Ginestet hook should be used to mobilize the zygoma by pulling steadily forward, then outward, and inward.

■ Orbital Floor Repair

- Evaluation of the orbital floor bony defect should be made; a size-matched bone graft is harvested from the parietal skull.
- Multiple layers of bone can be placed to achieve symmetric positions of the

globes.

- A pseudotarsorrhaphy is performed at the end of the procedure:
 - A 5-0 Prolene horizontal mattress suture that involves the tarsus is placed between the upper and lower eyelids for temporary closure (**TECH FIG 3**).



TECH FIG 3 • The pseudotarsorrhaphy stitch should be lateral to the pupil, along the free edge of the eyelid.

PEARLS AND PITFALLS

Physical findings

- Normal physiologic anteroposterior variance between eyes is ≤ 2 mm.
- Discrepancies ≥ 3 mm can be evident to untrained observers.

Technique

- Temporalis fascia should be elevated posteriorly along the arch to protect the facial nerve.
- Oblique bone cuts should be made to allow greater bony contact and stability.
- All muscles should be freed from the zygoma for greater mobility

of the segment.

- Alignment of the lateral orbital wall and greater wing of sphenoid ensures reduction is optimal.
- Reapproximate the periosteum to avoid ectropion.
- The malar periosteum should be resuspended.
- Cautery should not be used on the orbicularis ocularis.

Postoperative care

- Eye examination should be performed when the patient is awake after surgery.
- Diplopia and eye position are assessed at 2 wk and 6 mo after surgery.

POSTOPERATIVE CARE

- An eye examination should be performed when the patient is fully awake.
- Antibiotic ointment and eye drops are applied for several days.
- Pain medications and antibiotics are given orally for 1 week.
- The patient may shower 2 days after surgery but should avoid contacting the incision line.
- A CT scan may be performed 1 week postoperatively.
- Removal of nylon stitches after 1 week.
- Eye exercises should be done immediately after edema resolution.
- Diplopia and eye position are assessed 2 weeks after the procedure and allowed 6 months to stabilize.

OUTCOMES

- Prepare patients for the possibility of subtle imperfections after secondary operations.
- Persistent diplopia from orbital trauma may not resolve with secondary correction.
- Final results will take 6 months to stabilize.
- Repeat bone grafts can be performed if the correction is insufficient.

COMPLICATIONS

- Optic nerve injury resulting in blindness
- Infraorbital nerve injury and facial numbness
- Infection or scarring of synthetic implants
- Exposure or inflammatory reaction to synthetic implants
- Nonresolution of the diplopia:

- Consider muscle injury as the cause.
- Strabismus surgery may be warranted in such cases.
- Proptosis from postoperative retrobulbar hematoma is a medical emergency requiring immediate exploration, lateral canthotomy, and immediate evacuation.
- Nonresolution of orbital dystopia.
- Ectropion (more common with subciliary approach) and upper lid malposition.
- Resorption of cranial bone graft with late recurrence of enophthalmos.^{8,9}

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Section VIII: Nasal Fractures

59 Closed Nasal Fracture Correction

CHAPTER

Benjamin C. Wood

DEFINITION

- Nasal bone fracture is the most common type of facial fracture.¹
- The combination of the central positioning and anterior projection of the nose, with the delicate nature of the thin nasal bones, increases the risk of fracture from traumatic injury.

ANATOMY

- The pyramidal shape of the nose is composed of skeletal and cartilaginous structural components supporting the overlying skin and soft tissue (**FIG 1**).
- The bony structure of the nose is composed of the paired, wedge-shaped nasal bones in the midline, which articulate with the frontal process of the maxilla, the nasal process of the frontal bone, and the ethmoid and vomer.
- The cartilage structures of the nose include the paired upper lateral cartilages and lower lateral cartilages and the septum, which is composed primarily of the quadrangular cartilage.

PATHOGENESIS

- The most common cause of nasal fractures is blunt trauma, typically due to motor vehicle accidents, physical altercations, or sports-related injuries.²

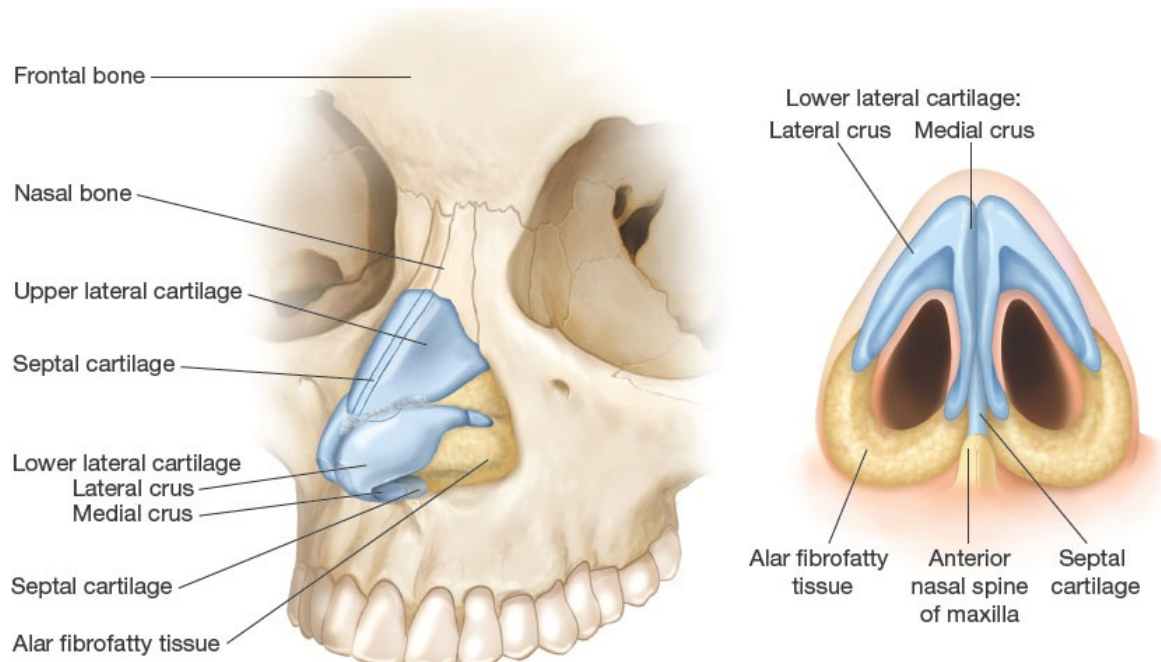


FIG 1 • Nasal structural anatomy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Delineate pertinent patient history, including mechanism of injury, time since injury, and any pre-existing nasal deformity or previous nasal surgery.
- Establish any prior history of nasal breathing difficulty, obstruction, or sleep apnea, including use of allergy medications, nasal sprays, or inhalers.
- External examination should focus on the severity of nasal deformity, lacerations, epistaxis, cerebrospinal fluid drainage, and pain or step-off on palpation.
- It is important to determine whether there is suspicion of a naso-orbital ethmoid (NOE) fracture on examination, which may warrant further evaluation with imaging.
- Internal examination using a nasal speculum to identify any mucosal lacerations, septal deviation, or the presence of a septal hematoma.
- Vasoconstrictive agents and topical anesthetic should be used to control bleeding and facilitate a proper internal nasal examination.
- Pediatric patients less frequently fracture the nasal bones but are more susceptible to failure to identify a septal hematoma on examination.³

IMAGING

- Nasal fractures are generally a clinical diagnosis, so radiographic imaging is of minimal utility unless there is suspicion of a more complex facial fracture pattern.

NONOPERATIVE MANAGEMENT

- Patients with minimal nasal symmetry distortion and patent nasal airways may be managed expectantly with observation and reassessment following resolution of soft tissue edema.

SURGICAL MANAGEMENT

- The timing of surgical management is dependent on the time since the injury occurred.
- Patients presenting within hours of the injury before substantial edema develops may be amenable to immediate closed nasal reduction.
- Patients presenting more than 3 or 4 hours after injury should have operative intervention deferred until sufficient time has passed to allow for resolution of edema to facilitate full visualization of the deformity.
- The decision for closed vs open nasal reduction depends on the severity of the injury.
- Simple, unilateral or bilateral, fractures are generally amenable to closed nasal reduction.
- Comminuted, closed or open, fractures may be better addressed with an open reduction.
- Septal hematomas always require immediate evaluation to avoid septal cartilage resorption and formation of a secondary nasal deformity.⁴

Preoperative Planning

- Determine whether the procedure should be performed under a local vs a general anesthetic.
- Consider patient age, compliance, medical comorbidities, and expectations.
- It is important to establish realistic patient expectations prior to surgery, as it is not uncommon to have a residual minor deformity following closed nasal reduction.
- Should an unsatisfactory deformity persist after closed nasal reduction, the patient may elect to have an open reduction and rhinoplasty in the future.

Positioning

- The patient is placed in the supine position with arms tucked.
- A shoulder roll may be placed for neck extension if necessary.

Approach

- Placement of topical and injectable anesthetic agents is performed first to allow for adequate time for the vasoconstrictive effect prior to beginning the procedure.

TECHNIQUES

■ Administration of Local Anesthetic

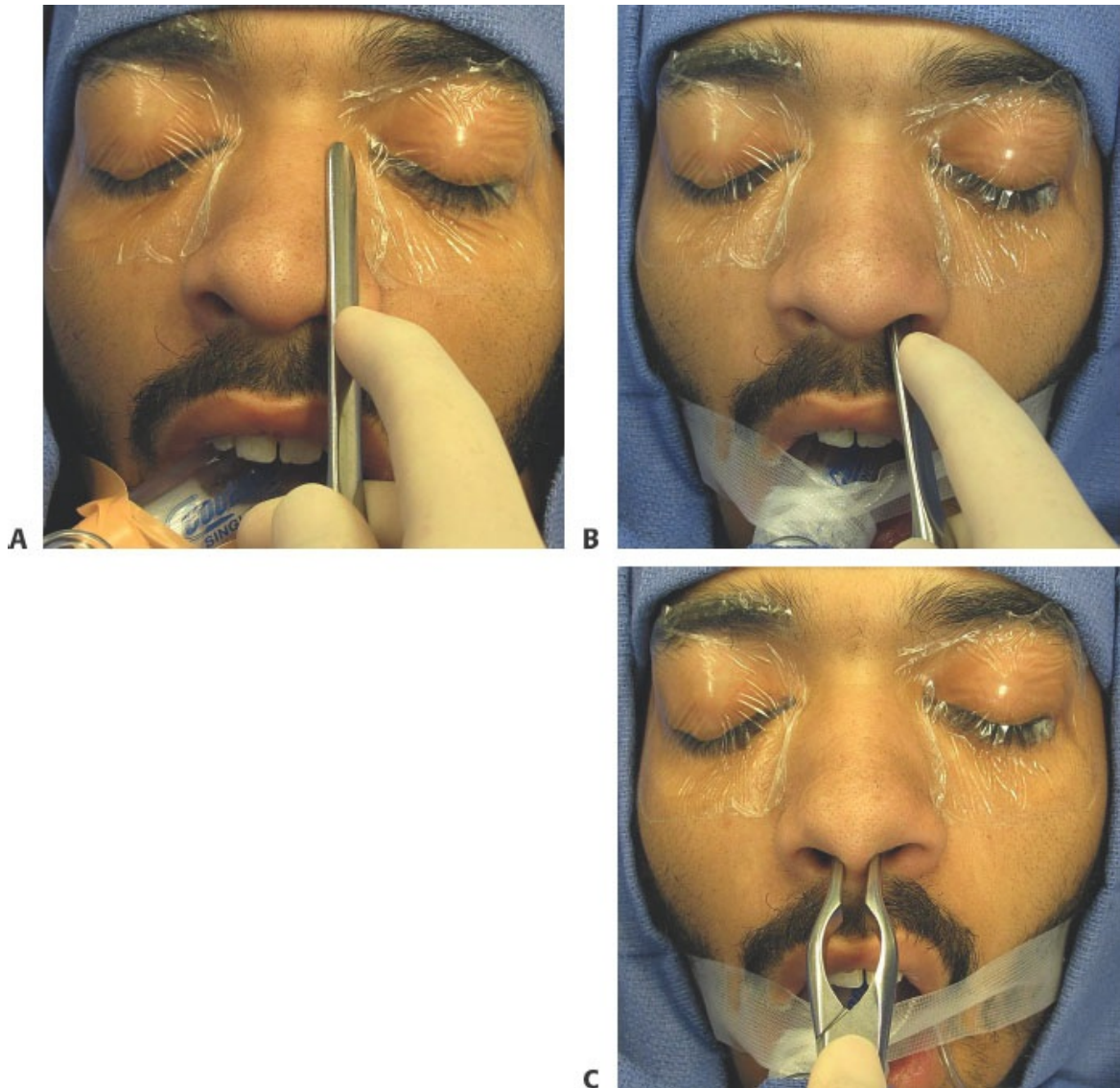
- Typically, both topical and injectable anesthetics are administered.
- Topical anesthetic is applied via pledgets soaked in either 4% lidocaine with oxymetazoline (Afrin) or phenylephrine hydrochloride (Neo-Synephrine) (**TECH FIG 1A**):
 - Place along nasal septum, middle turbinate, and nasal floor (**TECH FIG 1B**).
 - Leave in place for at least 7 to 10 minutes for the vasoconstrictive effect.
- Inject 1% lidocaine with epinephrine submucosally along the septum and the undersurface of the nasal bones and as a dorsal nasal and infraorbital nerve block bilaterally.
- Limit the volume of anesthetic injected so as not to obscure the deformity and results of the reduction.



TECH FIG 1 • A. Application of topical anesthetic via pledgets. **B.** Pledgets with topical anesthetic in place (7–10 minutes).

■ Reduction of Bony Nasal Pyramid and Septum

- First, measure the distance from the alar rim to the nasion of the medial canthus by placing the Goldman or Boise elevator externally along the nose (**TECH FIG 2A**):
 - This maneuver prevents advancing the elevator too far into the nasal vault in the event that there is an injury to the cribriform plate.
- Insert the elevator to the predetermined distance underlying the in-fractured nasal bone, and apply upward and outward pressure (**TECH FIG 2B**):
 - Use the combination of external digital pressure with intranasal elevator manipulation to assess adequate reduction of the nasal bone fracture.
- The nasal septum is then reduced using direct, blunt pressure to the displaced portion of the septum:
 - Alternatively, Asch or Walsham forceps may be used to straighten the nasal septum with gentle manipulation of the septum into proper alignment (**TECH FIG 2C**).

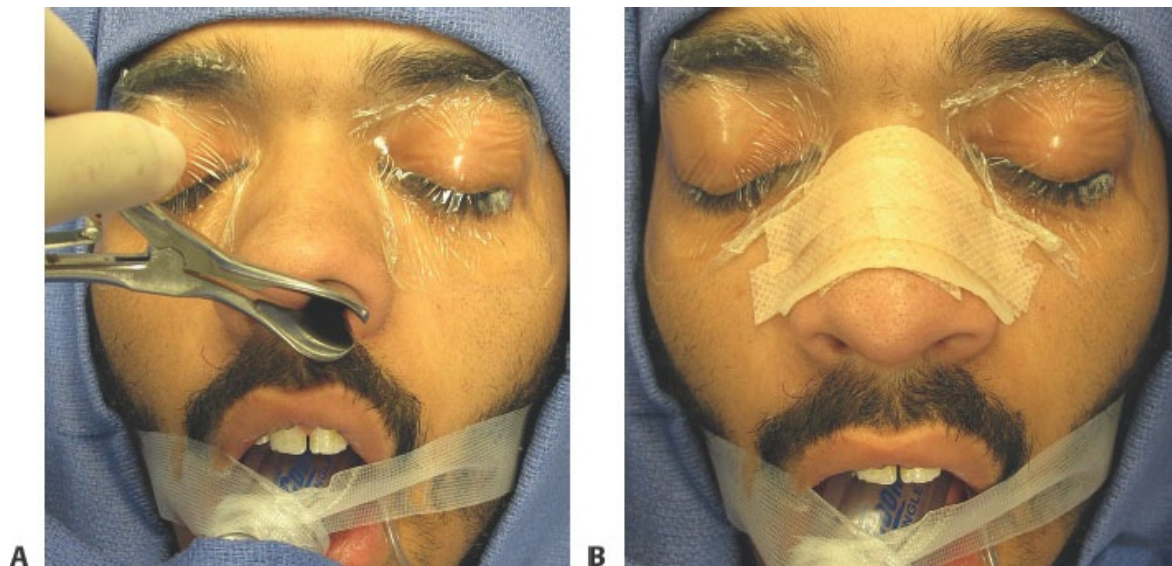


TECH FIG 2 • A. Measurement of the distance from the alar rim to the nasion. **B.** Outfracture of the nasal bone using a Boise elevator. **C.** Septal alignment using Asch forceps.

■ Nasal Airway Assessment and Splint Application

- Advance the elevator along the nasal floor to ensure that it passes to the nasopharynx without difficulty.
- Perform a nasal speculum examination to ensure patency and symmetry of the nasal airways (**TECH FIG 3A**).

- Apply a thermoplastic (Denver) external nasal splint to support and protect the reduced nasal fracture (**TECH FIG 3B**).
- Leave in place for at least 1 to 2 weeks depending on severity of fracture and patient compliance.



TECH FIG 3 • **A.** Nasal speculum examination to confirm symmetry and patency of nasal airway. **B.** Thermoplastic external nasal splint in place.

PEARLS AND PITFALLS

Physical examination

- Identify whether a septal hematoma is present, and perform hematoma evacuation immediately if needed, in order to prevent development of a late deformity.

Timing of surgery

- Defer surgical intervention until edema has fully resolved (generally 7–10 days) if the patient presents greater than 3–4 hours after injury in order to allow for optimal visualization of deformity and reduction.

Anesthetic administration

- Allow adequate time for the vasoconstrictive effect of the topical and injectable anesthetics to minimize bleeding with fracture reduction.

Nasal bone reduction	■ Measure distance from alar rim to medial canthus to prevent advancement of the elevator too far into the nasal vault.
External splint	■ Leave in place at least 1–2 weeks or longer depending on severity of fracture, patient activity level, and compliance.
Follow-up	■ Reassess patient after edema has fully resolved postreduction to determine whether there is a persistent deformity that may require open reduction and rhinoplasty.

POSTOPERATIVE CARE

- Patients should maintain the external nasal splint in place for at least 1 to 2 weeks.
- Apply ice for the first 24 hours and head elevation for the first 48 to 72 hours to facilitate faster resolution of bruising and edema.

OUTCOMES

- The goal of closed reduction is to minimize the nasal deformity in the least invasive manner possible.
- Although most patients experience significant improvement in nasal symmetry, complete correction of the nasal deformity is unlikely in the closed approach.

COMPLICATIONS

- Persistent nasal deformity due to an undiagnosed septal hematoma or unsatisfactorily corrected nasal deformity on closed reduction may result in the need for open reduction, generally within 7 to 14 days.
- Formal rhinoplasty may be performed, typically at 1 year, if necessary.

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60 Open Treatment of Nasal Fractures

CHAPTER

Jeyhan Wood

DEFINITION

- Open treatment of nasal fractures involves making an incision to provide direct visualization of the fractures and achieve reduction or use of lacerations that are already present.
- The nose sits prominently on the central face and as such is the most commonly fractured facial bone, compromising up to 50% of all facial fractures¹:
 - Nasal bone fractures can occur in isolation or be associated with other facial fractures, such as those of the orbits, frontal bone, or midface.

ANATOMY

- Nasal anatomy is complex, made up of the bony vault, cartilaginous vault (paired upper lateral and lower lateral cartilages), bony septum, and cartilaginous septum (**FIG 1**):
 - The nasal bones decrease in thickness caudally; therefore, most fractures occur in the lower half of the bone.²
 - The “keystone area,” made up of the caudal aspect of the nasal bones, the cranial aspect of the upper lateral cartilages, the perpendicular plate of the ethmoid, and the cartilaginous septum, maintains support for the nasal dorsum (**FIG 1A**).

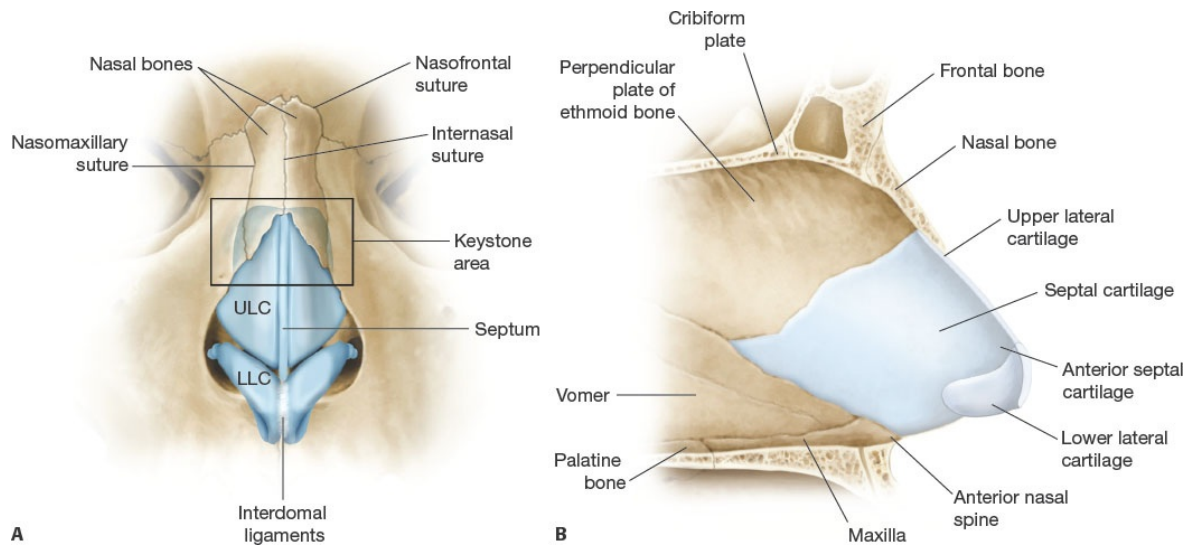


FIG 1 • AP (**A**) and lateral (**B**) view of nasal anatomy. ULC, upper laberal cartilage; LLC, lower lateral cartilage.

- The nose receives its rich blood supply from branches of both the external and internal carotid arteries. Because of this, nasal fractures are almost always associated with epistaxis, which most often stems from the Kiesselbach plexus of the anteroinferior septum.²
- Fractures can involve any of the above structures and in any combination, leading to obvious external deformity and/or functional compromise with difficulty breathing.

PATHOGENESIS

- Nasal fractures are most often the result of motor vehicle accidents, falls, altercations, and sports injuries.^{1,3}
- Nasal fractures are most often seen in males 15 to 30 years of age.
- There is no single consensus for nasal fracture classification; however, nasal fractures are often classified as lateral oblique vs frontal per the Stranc classification.^{1,3} Higuera et al. have more recently proposed a clinical classification system based on soft tissue vs bony injury, unilateral vs bilateral involvement, and simple vs comminuted fractures.²

NATURAL HISTORY

- Patients with untreated nasal fractures may experience an undesirable appearance, chronic nasal obstruction, and chronic sinusitis. This is especially

true if a septal injury is not adequately addressed.²

- With septal trauma, blood can accumulate between the mucosa and cartilage of the septum (septal hematoma), which if left undrained can eventually lead to fibrosis and resorption of the septal cartilage. This is demonstrated clinically as a saddle nose deformity.

PATIENT HISTORY AND PHYSICAL FINDINGS

■ Patient history:

- Assess the mechanism of injury (including the vector and magnitude of the force),² timing of injury, and preoperative state regarding the ability to breathe out of each nostril.
- Does the patient complain of a different appearance of the nose?
- Does the patient have a history of previous nasal trauma or nasal surgery?
- For significant maxillofacial trauma, the patient may need a complete trauma workup and appropriate precautions taken (cervical spine immobilization).
- Consider reviewing a photograph of the patient, such as a driver's license, to determine the patient's premorbid appearance.²

■ Physical examination:

- Perform an external exam looking for obvious nasal deformity (note caudal and dorsal deformity),⁴ tenderness, epistaxis, edema, periorbital ecchymoses, instability of nasal bones on palpation, step-offs, and crepitus:
 - Depending on the timing of presentation, obvious deformity may be masked by edema.
- Note any lacerations or canthal disruption, which would indicate a naso-orbital-ethmoid (NOE) fracture.
- Perform an intranasal examination with a nasal speculum and adequate light source, evaluating for septal hematoma, mucosal injury, septal deviation, airway obstruction, and clear rhinorrhea, which could be a sign of a cerebrospinal fluid (CSF) leak. Internal exam may be facilitated by using a topical decongestant.
- Assess for other facial fractures and consider nasolacrimal duct injury if the medial orbit is injured.
- Assess for uncontrollable hemorrhage. Nasal fractures may cause significant bleeding, which usually stops with manual pressure. However, persistent epistaxis may require nasal packing with Vaseline gauze or a Pope pack for anterior bleeds or intranasal placement of a Foley catheter for posterior bleeds:

- If bleeding is uncontrollable with these measures, consider interventional radiology for embolization.
- If the patient is unstable without other obvious sources of hemorrhage, consider ligation of the external carotid artery.

IMAGING

- Imaging for isolated nasal fractures is often not indicated, as treatment is based on physical exam findings.
- Plain films miss cartilaginous injury and often cannot clearly identify bony injury, with one study finding only 82% of nasal fractures successfully identified on plain film⁵:
 - Waters view (occipitomeatal) (**FIG 2A**) and lateral nasal views (**FIG 2B**) are the plain film examinations of choice, with demonstration of the orbits, maxillae, zygomatic arches, and the nasal pyramid, sidewalls, and septum.
 - If nasal bones are found to be displaced on x-ray, then those patients are at higher risk for long-term nasal deformity, and reduction is highly recommended.⁴
 - The internasal suture, nasomaxillary suture, and even the coronal suture can be mistaken for fractures on plain film.
- Computed tomography (CT) with or without 3D reconstruction has largely replaced all other modalities as far as clinical use (**FIG 2C,D**):
 - For maxillofacial CT scans, three views are ideal (axial, coronal, and sagittal) for complete evaluation of the facial skeleton.

DIFFERENTIAL DIAGNOSIS

- Nasal bone fracture/dislocation
- Cartilage injury
- Septal fracture/dislocation
- Contusion

NONOPERATIVE MANAGEMENT

- Indications:
 - Nondisplaced or minimally displaced fractures.
 - The patient desires no intervention.
- Options for conservative treatment:
 - A splint for external protection
 - Elevation of the head of the bed to decrease edema

- Ice application
- Nasal saline irrigation and/or Afrin (oxymetazoline) for nasal congestion
- Intranasal packing for epistaxis as needed

SURGICAL MANAGEMENT

- Indications include severely displaced fractures and/or dislocations of the nasal bones and/or cartilaginous vault (more than half the bridge width of the nose), fracture/dislocation of the caudal septum, open septal fracture, persistent deformity after attempted closed reduction,³ nasal fracture with substantial soft tissue injury,² or those with a delayed presentation (over 2 weeks since the injury):
 - If presenting more than 2 weeks after the initial injury, consider delaying open approach approximately 3 months to allow resolution of edema and healing of fractures.
 - Some surgeons advocate open reduction as soon as the early edema has resolved.²
- It is important for patients to have realistic expectations of outcomes. Discuss operative goals: fracture reduction and establishment of premorbid form and function vs altering the appearance of the nose with a cosmetic rhinoplasty.
- Discussion should also address the possible need for future nasal procedures.⁴

Preoperative Planning

- Review patient history and imaging studies. Define patient goals and set realistic expectations.

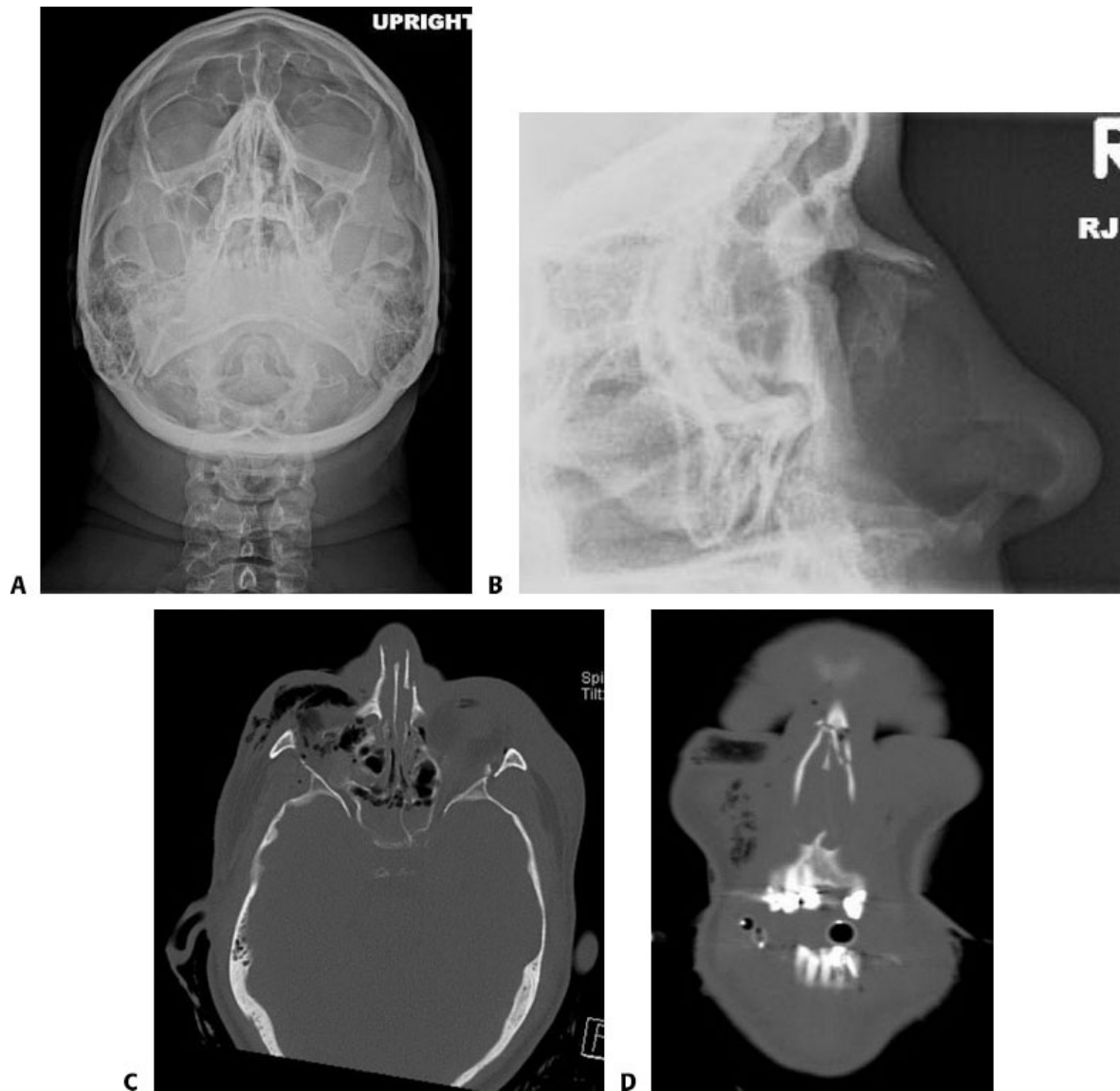


FIG 2 • A. Waters view of a patient with nasal trauma. No definitive fracture was identified by radiological exam; however, by clinical exam, the patient had obvious nasal deformity with deviation of the dorsum to the right. **B.** Lateral radiograph of the same patient demonstrating no definite fracture. Nonspecific irregularity of the tip of the nasal bone was noted. In a different patient, axial **(C)** and coronal **(D)** CTs demonstrate a displaced left nasal bone fracture.

- Based on the nasal injury and surrounding injuries, plan the incisions that will provide optimal exposure.
- For significantly comminuted fractures with loss of dorsal support, reconstruction beyond fracture reduction and fixation may be required (bone or cartilage grafts, suturing techniques, osteotomies for incomplete fractures).

Positioning

- The patient is positioned supine on the operating table with a shoulder roll placed for gentle extension of the neck.
- Cervical spine precautions are implemented as needed.
- Arms are tucked.
- The table is turned 90 to 180 degrees, based on surgeon preference.

Approach

- Open treatment of nasal and septal fractures can be achieved through a variety of incisions, including pre-existing adjacent lacerations, a coronal incision if other facial fractures are present (such as frontal bone) that necessitate wide exposure, an “open-sky”/glabellar approach, or an open rhinoplasty technique:
 - Advantages to the open approach include maximal surgical exposure contributing to a more accurate anatomic diagnosis, the opportunity for precise tissue handling, suturing, and grafting if needed.⁶
 - Wider exposure obtained with the open-sky approach is particularly valuable in fractures of the cribriform plate with associated CSF rhinorrhea.⁷
 - Disadvantages of the open rhinoplasty approach include the need for a transcolumellar incision, with wide dissection potentially leading to loss of support, and prolonged nasal tip edema.⁶
 - The advantage to using a coronal incision is that the surgical scar is hidden within the hairline.

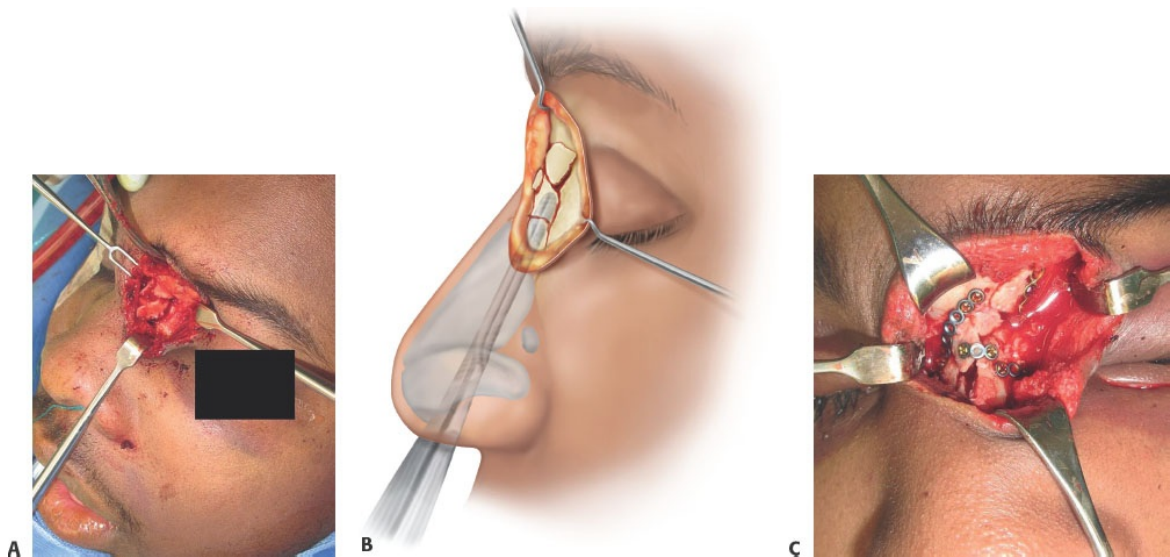
TECHNIQUES

■ General Fracture Management

- For each approach, fracture management is similar.
- Expose the fractures in the subperiosteal and subperichondrial planes

(**TECH FIG 1A**). Address septal fractures/dislocations first.

- Septal fractures/dislocations may require a hemitransfixion incision for full exposure:
 - If the septum requires excision of the fractured area, leave at least a 1-cm dorsal and caudal L strut for support. Resection of the part of the vomer and perpendicular plate of the ethmoid may be necessary in severe septal fracture.³
 - The caudal septum may need to be reduced to the midline and reattached to the anterior nasal spine using 5-0 polydioxanone as a figure-of-eight suture.
- Reduce fractures using a Boies elevator intranasally and manual manipulation (**TECH FIG 1B**). If the fractured segments of nasal bone remain unstable, consider internal fixation using low-profile miniplates (0.3-mm thickness) with 1.2×4 -mm screws. For fractures with significant displacement, larger plates (0.6-mm thickness) with 1.7×4 -mm screws may be used (**TECH FIG 1C**):
 - Use the intact frontal bone or maxilla as an anchor for plating severely comminuted fractures.²
 - If using wires for internal fixation, 26- to 30-gauge wires are recommended in order to prevent palpable sharp edges.²
 - Stabilization of the fracture fragments may also be accomplished using thick absorbable sutures in figure-of-eight fashion.²
- Do not strip small bony fragments of periosteum, as this may devascularize the bony segments.



TECH FIG 1 • A. Fractures are exposed in the subperiosteal and subperichondrial planes using a periosteal elevator or freer elevator. **B.** Fractures are reduced by a combination of internal manipulation with a Boies elevator and external manual pressure. **C.** Low-profile miniplates are used for internal fixation.

■ Approaches

- For each approach, surgical preparation of the patient is similar.
- Prep the face in standard sterile fashion using Betadine. Clean inside each nostril with a Betadine-soaked cotton-tipped applicator.
- Inject local anesthetic with epinephrine around the laceration, if present, into the septum and circumferentially as a ring block around the nose.
- Insert three Afrin-soaked pledgets into each nostril.

Use of Existing Lacerations

- Open the existing laceration if it has been previously repaired (**TECH FIG 1A**).
- Irrigate the wound with saline irrigation. Debride any nonviable tissue, and remove any foreign bodies.
- Address the fractures.
- Close lacerations with monofilament absorbable suture in the deep dermis and permanent monofilament suture in the skin (**TECH FIG 1B**).
- Evaluate the nose for obvious residual deformity. Feel the dorsal nose with a wet finger for any step-offs or irregularities, and address as needed.
- Apply nasal splints.

Coronal Approach



Video p2-c060

- Place the patient's head on a Mayfield headrest.
- Temporary tarsorrhaphies are placed to maintain corneal protection throughout the procedure (**TECH FIG 2A**).



TECH FIG 2 • A. For the coronal approach, temporary tarsorrhaphy sutures are placed for corneal protection using 5-0 Prolene. **B,C.** A curvilinear incision is marked within the hairline, extending from ear to ear. The adjacent hair is clipped. **D.** The periosteum is

incised at the nasofrontal suture using Bovie needle-tip electrocautery on the cut function to allow further release of the scalp flap and improve exposure of the fractures. The supraorbital bundles are visualized and preserved. **E.** The fractures are stabilized using low-profile miniplates. The plate is anchored to the stable frontal bone. **F.** The scalp is closed with 3-0 absorbable suture in the deep dermis/galea and 4-0 absorbable suture in the skin. A Blake drain is placed through a separate stab incision in the scalp.

- Mark a curvilinear incision that extends from ear to ear. Clip the hair adjacent to the incision (**TECH FIG 2B,C**).
- Prep the scalp and face and within each nostril using Betadine. Inject local anesthetic with epinephrine around the coronal incision, into the nasal septum and circumferentially as a ring block around the nose.
- Elevate the scalp flap in the subgaleal plane anteriorly. Lateral dissection should proceed just superficial to the superficial layer of the temporalis fascia.
- The periosteum is incised approximately 2 cm superior to the supraorbital rims, and the dissection continues to the supraorbital rims and the nasal bones in the subperiosteal plane.
- If the scalp flap will not sufficiently evert, then, laterally, incise the superficial layer of temporalis fascia from the root of the temporomandibular joint along a line running at a 45-degree angle toward the supraorbital subperiosteal incision. This exposes the superficial temporal fat pad:
 - Continue the dissection using Metzenbaum scissors just deep to the superficial layer of the temporalis fascia, until the zygomatic arch is reached. Avoid dissection within the fat pad, as this may lead to unwanted temporal hollowing.
 - Incise the periosteum along the superior aspect of the zygomatic arch. This should allow sufficient eversion of the scalp flap for complete exposure of the nasal fractures (and other facial fractures that require reduction).
- Once the nasofrontal suture is exposed, longitudinal incision of the periosteum in this region may allow further release of the flap for ease of

retraction. Preserve the supraorbital bundles (**TECH FIG 2D**).

- Dissection may proceed along the dorsum to the nasal tip in the subperiosteal and subperichondrial plane, using an elevator, if desired.
- Address the fractures with fixation plates as needed (**TECH FIG 2E**).
- Close the scalp incision with 3-0 absorbable suture in the deep dermis/galeal layer and 4-0 absorbable suture for skin approximation (**TECH FIG 2F**):
 - Leave a Blake drain within the scalp wound.
 - Apply nasal splints.

“Open-Sky” or Glabellar Approach

- Mark a transverse incision within a glabellar rhytid, connecting either to a vertical incision within the nasal sidewall (open-sky) or to an upper and lower eyelid incision (horizontal Y) (**TECH FIG 3**):
 - This approach is especially useful for providing direct visualization of NOE fracture fragments needing open reduction and internal fixation.⁷
- Skin incisions are made and the fractures addressed.
- Close the glabellar incision with monofilament absorbable suture in the deep dermis and a permanent monofilament suture in the skin (**TECH FIG 4B**). Apply nasal splints.

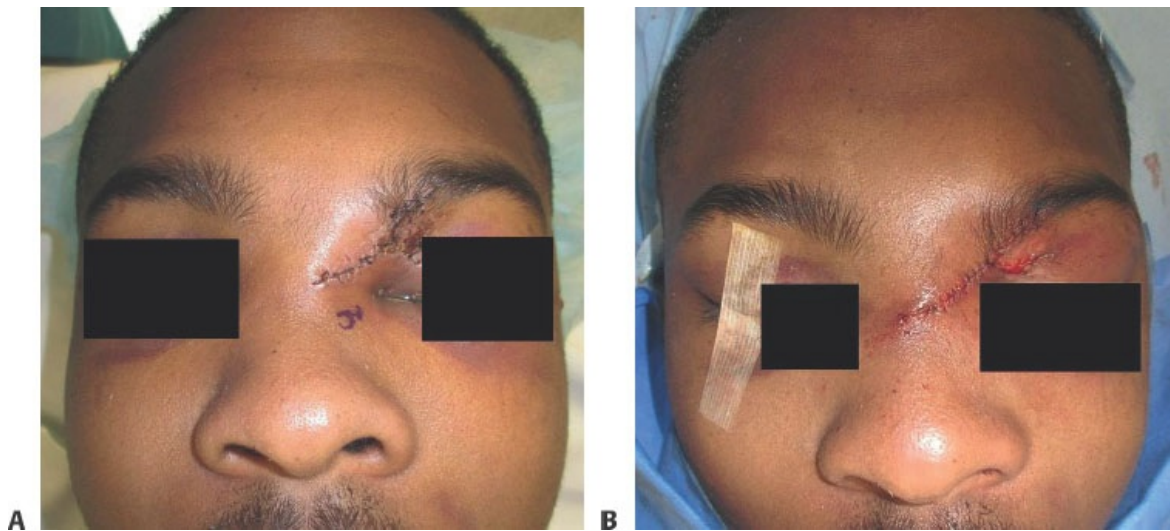


TECH FIG 3 • A transverse incision is made within a glabellar rhytid and may either be connected to a curvilinear vertical incision within the nasal sidewall or

may bifurcate into an upper and lower eyelid incision. The vertical incision is known as the “open-sky” approach, while the upper and lower eyelid incisions are known as the “horizontal Y” or extended glabellar approach.

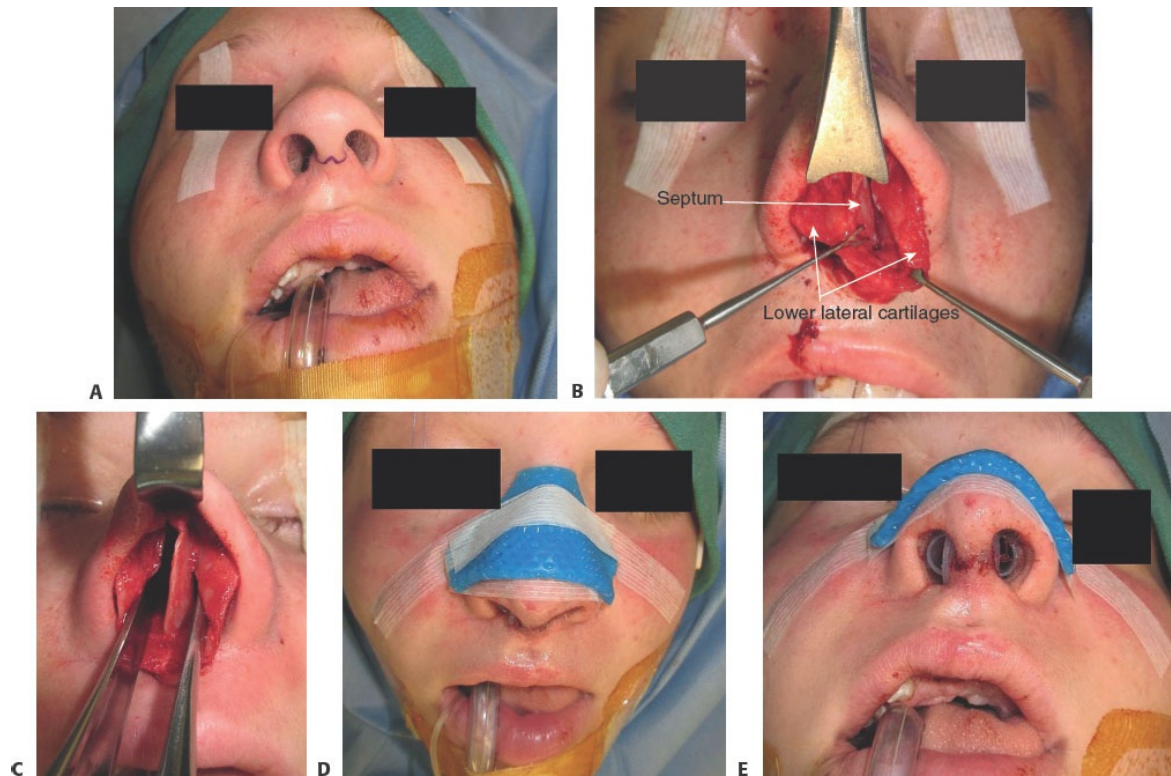
Open Rhinoplasty Approach

- Transcolumellar incision is marked along with marginal incisions within each nostril prior to injecting with local anesthetic (**TECH FIG 5A**).
- Skin incisions are made and the nose degloved in the subperichondrial and subperiosteal planes, as described in greater detail in “Rhinoplasty” chapters.
- If needed, expose the septum by dissection through the interdomal ligaments between the medial and middle crura of the lower lateral cartilages, using tenotomy scissors. Incise the mucosa of the caudal septum using a no. 15 blade, and then elevate the mucoperichondrium bilaterally with a Cottle elevator (**TECH FIG 5B**).
- Insert a nasal speculum for wide exposure of the septum (**TECH FIG 5C**).
- Address the fractures.
- Close transcolumellar incision with fine nylon or polypropylene suture and the marginal incisions using 5-0 absorbable suture.
- Apply nasal splints (**TECH FIG 5D,E**).



TECH FIG 4 • A. The laceration is opened if previously

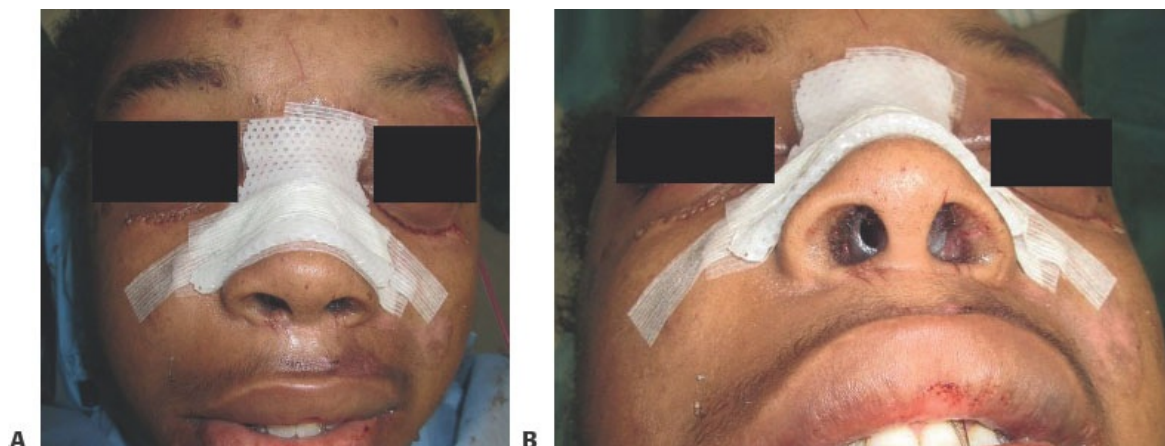
repaired. **B.** The laceration is closed with absorbable suture in the deep dermis and permanent suture in the skin.



TECH FIG 5 • A. A transcolumnellar (inverted V or stairstep) incision is marked along with marginal incisions into each nostril, following the caudal border of the lower lateral cartilages. **B.** The septum is exposed through dissection of the interdomal ligaments between the lower lateral cartilages. Starting at the anterior septal angle, mucoperichondrial flaps are elevated bilaterally using a Cottle elevator. **C.** A nasal speculum is inserted to provide wide exposure of the fractured or dislocated septum. **D,E.** An Aquaplast splint and Doyle splints are applied for stabilization of the nasal dorsum and septum, respectively.

■ Dressings

- For each approach, dressing application is similar.
- Apply Mastisol and Steri-Strips to the dorsum of the nose in a triangular fashion. Trim the Aquaplast splint to overly the Steri-Strips. Soak the splint in a hot water bath until malleable. Place the Aquaplast splint on the Steri-Strips, and gently conform the splint to the contour of the nose. Add additional Steri-Strips to reinforce the splint as needed (**TECH FIG 6A**).
- Trim Doyle splints as needed, and then place within each nostril after lubricating them with Bacitracin ointment. Secure the internal splints to the caudal septum with a 3-0 chromic suture (**TECH FIG 6B**).



TECH FIG 6 • **A.** A thermoplast splint (Aquaplast) is placed for external stabilization. **B.** Internal (Doyle) splints are covered with antibiotic ointment and then secured to the caudal septum with absorbable sutures.

PEARLS AND PITFALLS

- | | |
|--------------------|--|
| Indications | ■ The surgeon should have a clear understanding of patient history, physical exam, imaging studies, and the pathology to be addressed. |
| Approach | ■ For internal fixation of open fractures, use low-profile miniplates |

(0.3-mm thickness) with 1.2 × 4-mm screws. Placement of a fixation plate where glasses rest on the nose will lead to potential plate exposure.²

Approach ■ Use the incisors as a midline reference when nasal bones are mobile and displaced.²

Approach ■ Address septal deformities first.

Technique ■ The surgeon must assess and address persistent nasal deformities (either cosmetic or functional) during the initial surgical procedure; if these are not addressed, the patient will require repeat rhinoplasty.

POSTOPERATIVE CARE

- Patients are discharged immediately after surgery with narcotic pain medication.
- Antibiotics are often prescribed while nasal packing is in place to minimize the risk of infectious complications, such as toxic shock syndrome; however, recent literature reviews indicate that routine antibiotic prophylaxis after elective nasal surgery is likely not necessary if nasal packing is to be left in place for less than 48 hours^{8,9} or for simple revision rhinoplasties.⁹
- External and internal splints are removed at 1 week. If permanent suture was used for skin closure, sutures are removed at this 1-week postoperative visit.
- Elevate the head of the bed to prevent edema.
- Apply cold compresses as tolerated for the first 24 hours to help with edema.
- No nose blowing for 4 weeks.
- Patients may use nasal saline irrigation, Afrin (oxymetazoline) or Sudafed (pseudoephedrine), as needed for congestion.

OUTCOMES

- Current management techniques for reduction of nasal fractures result in a high incidence of persistent nasal deformity, with revision rates of 14% to 50% reported in the literature.⁴
- Patients with untreated or unrecognized septal deviation or injury are likely to require a septorhinoplasty in the future, as the septum is the keystone of the correction.²
- Discrepancies remain throughout the literature regarding timing of nasal reduction, the method of reduction, and postoperative management of these patients.⁴

COMPLICATIONS

- Persistent deformity requiring repeat rhinoplasty, for both aesthetic concerns and functional problems.
- Infection: use antibiotics for intranasal packing and CSF rhinorrhea.
- Open-sky incision may heal with scar contracture, causing medial canthal webbing.
- Septal hematoma: drain urgently to prevent the late complication of saddle nose deformity, which results from fibrosis and distortion or complete necrosis of the septum.⁴
- Epistaxis: control with direct pressure and/or intranasal packing. If unusual bleeding occurs, consider coagulation studies.

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Section IX: NOE Fractures

61 Naso-Orbital-Ethmoid (NOE) Fractures

CHAPTER

Craig Birgfeld and Joseph Gruss

DEFINITION

- Naso-orbital-ethmoid (NOE) fractures are fractures of the bones of the central face between the orbits involving the nose, the orbits, and the ethmoid sinuses.

ANATOMY

- The NOE region is comprised of the confluence of the nasal bones, the frontal process of the maxilla, the internal angular process of the frontal bone, the lamina papyracea of the ethmoid bone, and the lacrimal bone (**FIG 1A**).
- The NOE framework defines the nasal dorsum, the volume of the orbits, the shape of the medial orbits, and the support of the central face.
- Fractures tend to extend across the nasofrontal junction, down the medial orbital wall, across the inferior orbital rim, and across the medial buttress into the pyriform aperture (**FIG 1B**).
- NOE fractures include the complex anatomy of the medial canthal tendon attachments and nasolacrimal apparatus (**FIG 1C**).

PATHOGENESIS

- NOE fractures generally occur from blunt force trauma to the central face between the eyes, such as hitting the steering wheel or dashboard during an MVC.
- They frequently occur from self-inflicted gunshot wounds across the temple and orbits.
- NOE fractures are often components of more complex fracture patterns such

as frontal sinus fractures and panfacial fractures.

NATURAL HISTORY

- Without treatment, patients can suffer upper airway obstruction from impaction of the pyriform aperture and/or loss of nasal support resulting in a saddle nose deformity (**FIG 2**).
- Impacted and comminuted NOE fractures can change orbital volume leading to enophthalmos, dystopia, and diplopia.
- Damage to the nasolacrimal apparatus can lead to epiphora.
- Disruption of the nasofrontal outflow tract with an impacted NOE fracture can lead to frontal sinus congestion and mucocele formation.
- Untreated NOE fractures can significantly alter physical appearance.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients generally present with a history of blunt force trauma to the central upper face between the orbits.
- They may report airway obstruction, epiphora, diplopia, and alteration of physical appearance.
- Physical exam should focus first on vision, extraocular muscle involvement, and globe position.
- Patients may display telecanthus (an increased distance between the medial canthal tendons that is greater than 35 mm in adults) and hence a shortened palpebral fissure.
- The loss of dorsal nasal support leads to a saddle nose deformity with loss of nasal bridge, upturned nasal tip, and an increased nasolabial angle (normal = 90–100 degrees; **FIG 3**).
- A speculum exam should be performed to assess impaction of the lateral nasal sidewall and rule out septal fracture and/or hematoma.

IMAGING

- Fine cut (0.3–0.5 mm) maxillofacial CT scans with, at a minimum, axial and coronal views are necessary for accurate diagnosis (**FIG 4A,B**).
- Three-dimensional reconstructions are helpful to delineate anatomy and plan reduction maneuvers (**FIG 4C**).
- Sagittal views can be helpful if orbital floor fractures are also present.

DIFFERENTIAL DIAGNOSIS

- Isolated nasal bone fracture
- Isolated medial orbital wall fractures

NONOPERATIVE MANAGEMENT

- Nondisplaced NOE fractures can be managed conservatively with activity precautions and protection of the nasal dorsum with a splint.

SURGICAL MANAGEMENT

- Surgical intervention is reserved for displaced NOE fractures.
- The complexity of the intervention is determined by the amount of displacement and comminution of the segments.

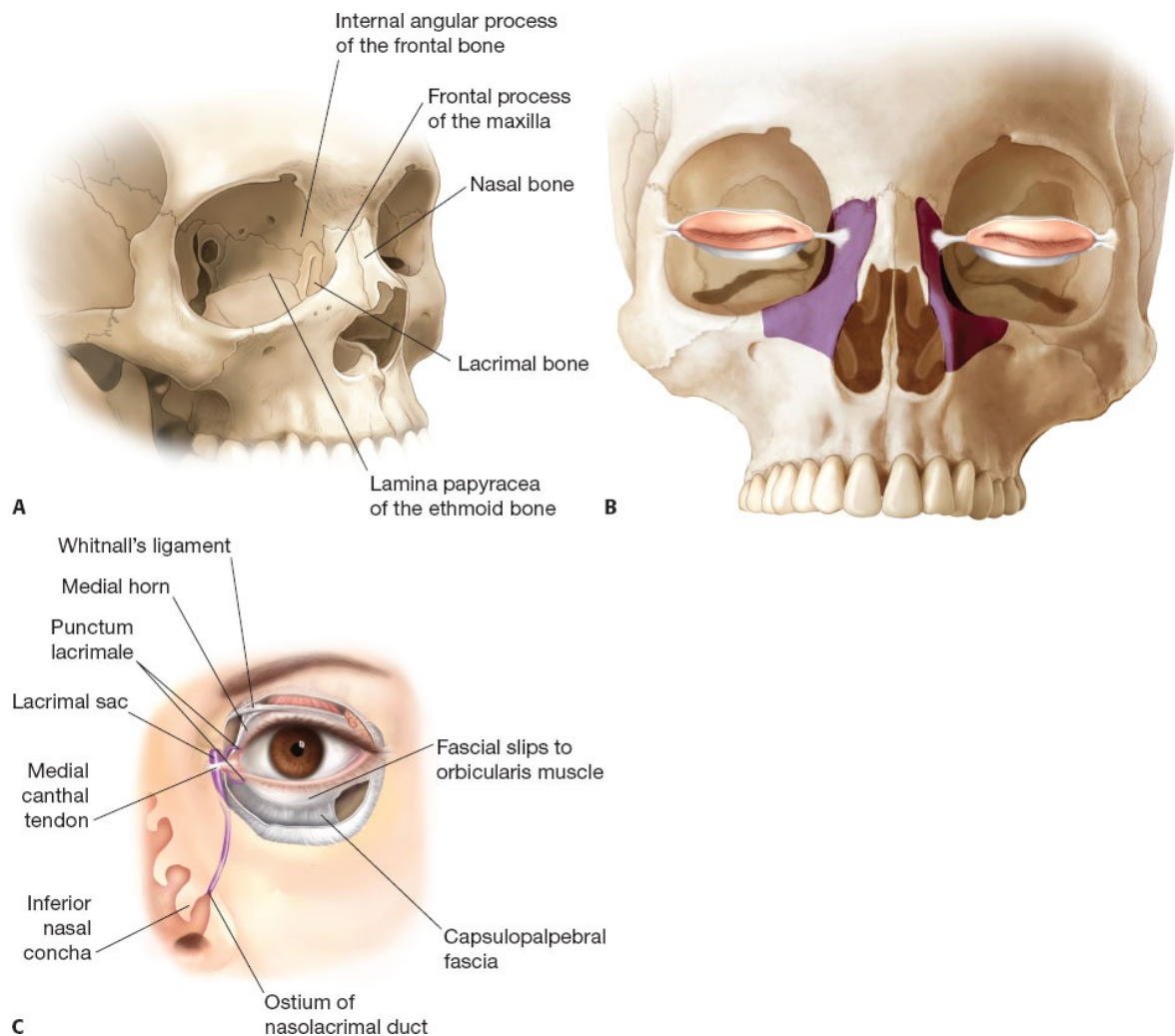


FIG 1 • A. The Naso-orbital-ethmoid complex is formed by the confluence of the nasal bones, the frontal

process of the maxilla, the internal angular process of the frontal bone, the lamina papyracea of the ethmoid bone, and the lacrimal bone. **B.** Typical fracture locations of a noncomminuted bilateral NOE fracture. **C.** NOE fractures involve the complex attachments of the medial canthal tendon and the nasolacrimal apparatus.

- The goal of surgical management is to restore facial harmony by focusing on the following features:
 - Establish dorsal nasal support
 - Ensure airway patency
 - Restore normal orbital volume
 - Return the intercanthal distance to within normal range



FIG 2 • Loss of dorsal nasal support frequently occurs with NOE fractures.

Preoperative Planning

- Review of CT scans will allow planning of surgical approaches necessary to restore normal anatomy, the maneuvers necessary for reduction, and the amount and placement of rigid fixation needed for a stable framework.
- Two classification systems aid in preoperative planning:

- Manson (focus on central segment and canthal attachment):¹
 - Type 1: single segment (**FIG 5A**)
 - Type 2: comminuted (**FIG 5B**)
 - Type 3: comminuted into the canthal insertion (**FIG 5C**)



FIG 3 • Untreated NOE fractures can lead to a “saddle nose” deformity.

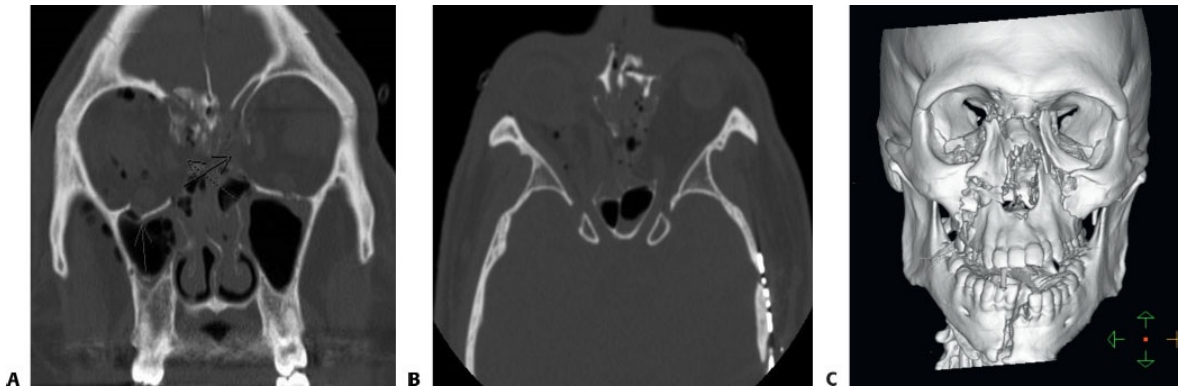
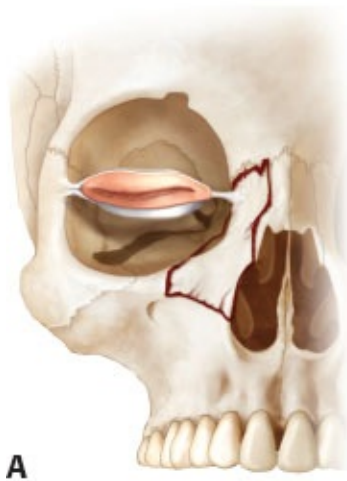


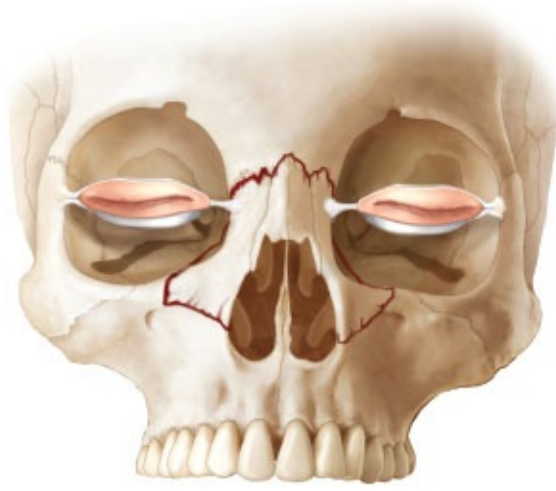
FIG 4 • **A,B.** Axial and coronal CT scans demonstrate a comminuted bilateral NOE fracture. **C.** NOE fractures are often associated with other upper and midface fractures such as demonstrated in this CT scan of a panfacial fracture.

- Gruss (with a focus on central face stability and associated fractures; **FIG 6**):²

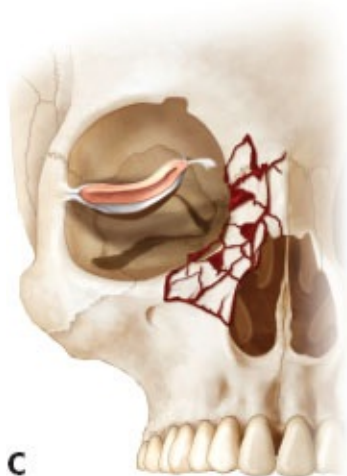
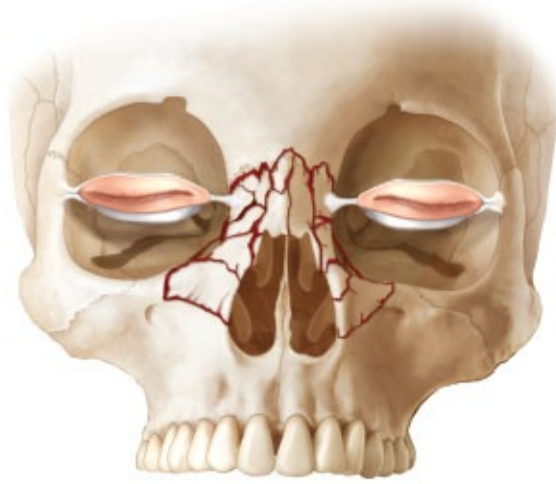
- Type 1: isolated to the bony NOE region



A



B



C



FIG 5 • The Manson Classification of NOE fractures demonstrates progressive comminution of the bony segment containing the medial canthal attachment. (**A.** Type 1. Single Segment. **B.** Type 2. Comminuted. **C.** Type 3. Communitied into the canthal insertion.)

- Type 2a: bony NOE and central maxilla with loss of nasal support
 - Type 2b: bony NOE and one lateral maxilla
 - Type 2c: bony NOE and bilateral lateral maxilla
 - Type 3a: frontobasilar injury (frontal sinus involvement)
 - Type 3b: Le Fort II and Le Fort III fractures
 - Type 4a: NOE with ocular/orbital displacement
 - Type 4b: NOE with ocular/orbital displacement including orbital roof
 - Type 5: NOE fractures with loss of the bone
- The use of these classification systems also allows planning for primary bone grafting and the need for transnasal wiring and medial canthoplasty. Upon induction of anesthesia, the surgeon should place traction on the medial canthal tendon with forceps to assess its stability and determine whether wiring is required.

Positioning

- Patients are placed supine on a gel donut for a limited approach and on a Mayfield headrest for a coronal approach.
- An oral airway secured with a wire can be used for isolated NOE fractures.
- If maxillary fractures (Gruss type 3, 4, or 5) or mandibular fractures requiring intermaxillary fixation are present, a nasal airway should be avoided, and either a submental airway or tracheostomy is preferred.

Approaches

- Increasingly complex NOE fractures require greater exposure.
- Central segment (type 1) fractures impacted only at the pyriform aperture can be approached through a single gingivobuccal sulcus incision.³
- If the inferior orbital rim is also displaced; then a lower eyelid incision can be added.
- If there is also displacement at the nasofrontal junction, a Lynch incision

(semicurved incision placed in the superomedial eyelid near the glabella) can be added, or a serendipitous laceration can be utilized.

- For increasingly comminuted fractures (type 2 and above) and those requiring immediate bone grafting, a coronal incision is generally preferred.
- Though the gull-wing or open sky approach has been described, it should generally be avoided.

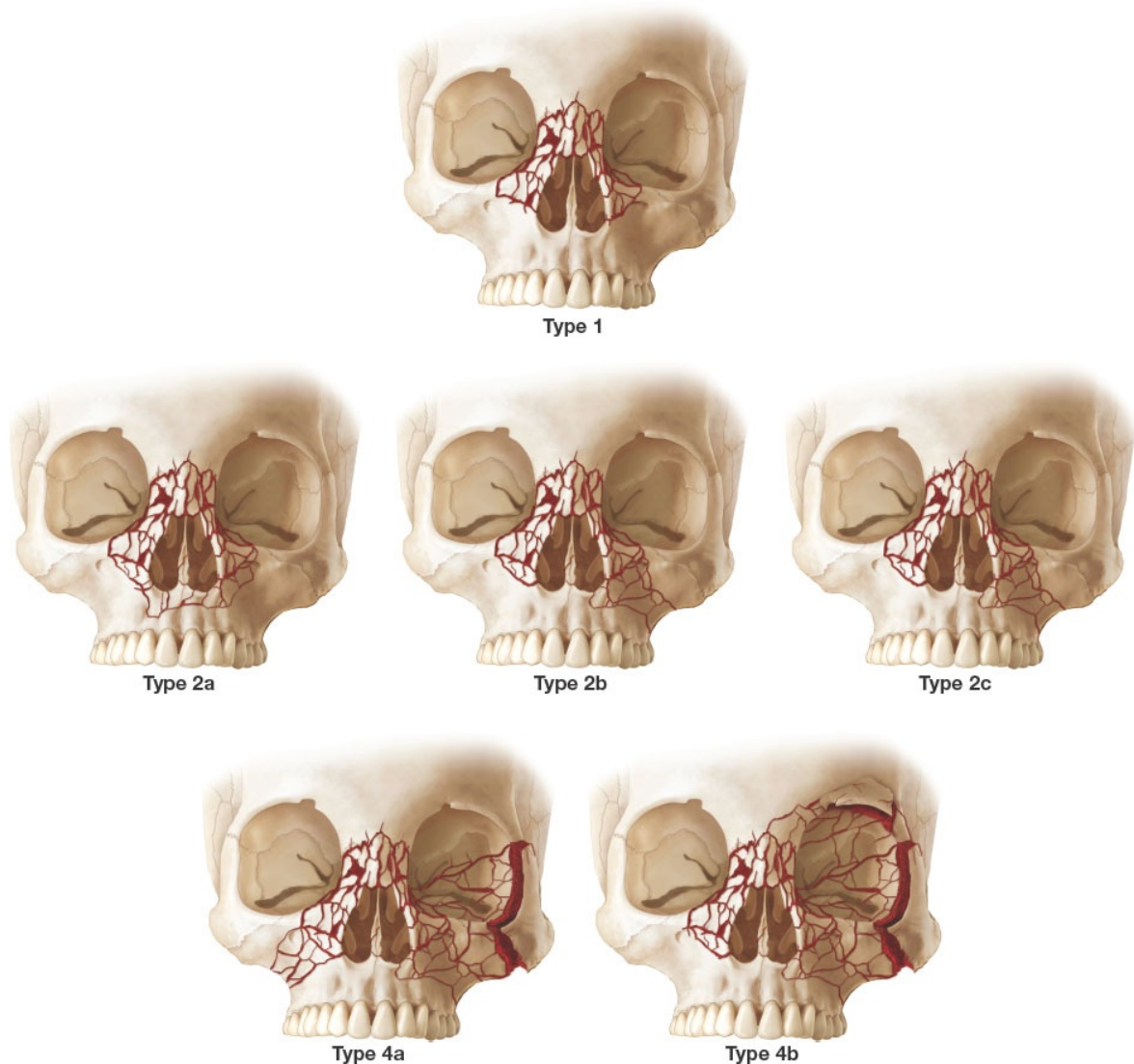


FIG 6 • Gruss types 1, 2, and 4 NOE fractures.

TECHNIQUES

■ Open Reduction Internal Fixation of NOE Fractures

Exposure

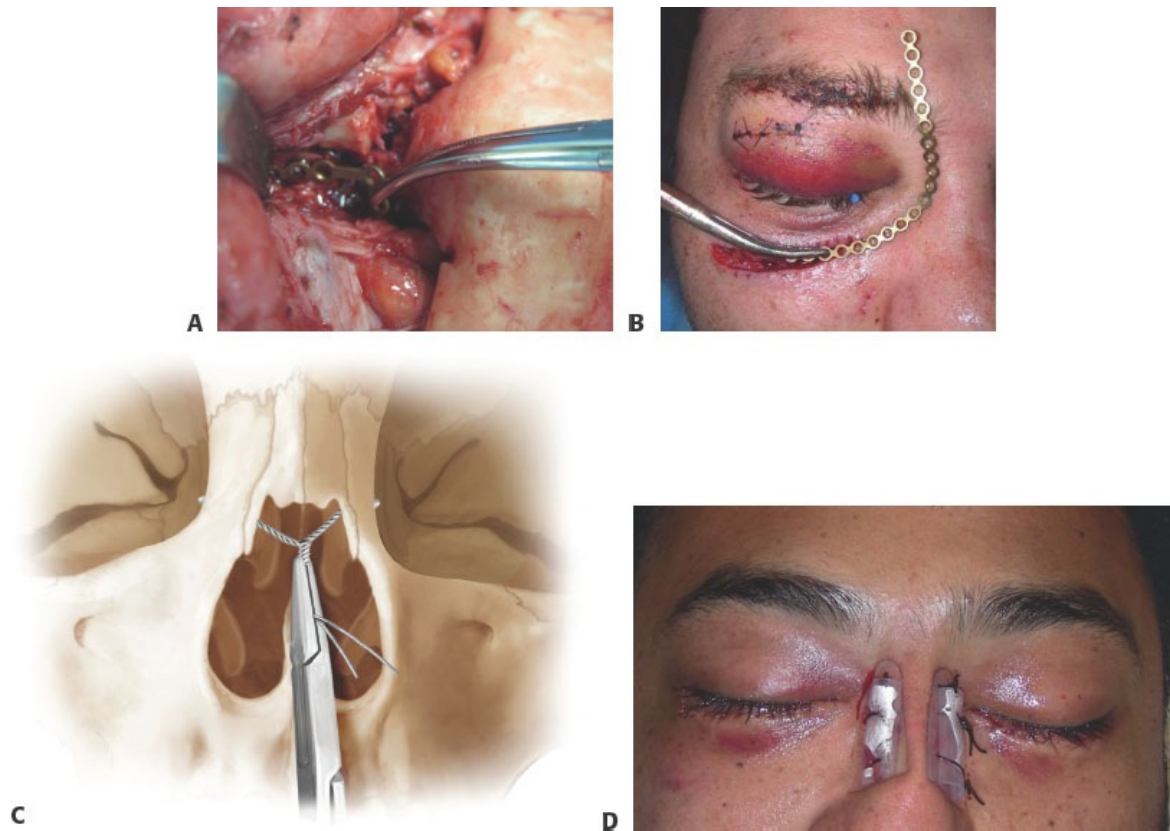
- Begin with exposure of all fracture sites starting with the lower eyelid approach.
- Incise sharply through the skin and orbicularis oculi muscle; then dissect bluntly in the submuscular, supraseptal plane down to the orbital rim. Incise through the arcus marginalis, and use a periosteal elevator to expose the fractured inferior orbital rim.
- Perform the coronal incision using a zigzag technique beginning within the hairline of the temple 1 cm superior and 1 cm posterior to the root of the helix. The use of microtip cautery can avoid the use of Rainey clips and subsequent alopecia. Dissect in the subgaleal plane until approximately 1 cm cephalad to the superior orbital rim; then transition to the subperiosteal plane to approach the nasofrontal junction. Carefully dissect down and around the insertion point of the medial canthal tendon attachment to join the previous lower eyelid dissection.
- Perform the gingivobuccal sulcus incision leaving a 1 cm cuff of mucosa attached to the gingiva to aid in closure. Dissect along the medial buttress to meet the lower eyelid dissection.

Fixation and Completion

- Once the fractures are exposed, place a Dingman elevator or Ash forceps into the nose, and disimpact the NOE segment to restore airway patency.
- With type 1 NOE fractures, place a miniplate along the cephalad margin of the NOE segment via the coronal incision (**TECH FIG 1A**).
 - Apply cephalad traction to the plate to reduce the fracture at the nasofrontal junction (video); then fixate the fracture.
 - The segment can then be rocked laterally with the intranasal Dingman elevator until the fractures are reduced at the orbital rim and medial buttress.
 - These are then fixated with a thin (0.5 mm) plate at the orbital rim and a thicker plate at the medial buttress (0.7–0.8 mm).
- With comminuted type 2 and type 3 NOE fractures, multiple bony fragments require reduction and fixation.
 - It is paramount to include the fragment that holds the medial canthal

attachment to restore normal intercanthal distance.

- A carefully bent 0.5-mm daisy chain plate mimicking the normal contour of the medial orbit can be used to reduce and fixate the comminuted fragments (**TECH FIG 1B**).
- If the tendon is avulsed or the bony fragment is too small to allow plate fixation, then either transnasal wiring (**TECH FIG 1C**) or a medial canthal barb can be used to re-establish normal canthal position. Overcorrection is the rule.⁴
- Next perform a nasal speculum exam to ensure patency of the airway and to assess septal integrity. If there remains inadequate dorsal nasal and tip support, then a cantilevered bone graft is placed through the coronal incision and an external rhinoplasty incision; centralize the lower lateral cartilages over top of the cantilever bone graft.
- Before closure, inspect the medial orbital wall. If there remains significant displacement of the orbital contents into the ethmoid sinuses or loss of the ethmoid contour bulge, then the medial orbital wall should be reconstructed with autograft or alloplast to prevent enophthalmos.
- After soft tissue closure, splints are applied. If the septum has been fractured, Doyle splints are placed intranasally. External compression splints are then placed along the lateral nasal sidewalls in the region of the medial canthal attachment to prevent edema and to redrape the soft tissue, recreating the normal concavity (**TECH FIG 1D**).⁵



TECH FIG 1 • **A.** In situ placement of fixation plate allows caudal traction on the displaced NOE segment and reduction of the fracture at the nasofrontal junction. **B.** A periorbital spanning plate allows fixation of the NOE fracture at the inferior orbital rim and the nasofrontal junction while maintaining medial reduction of the NOE segment, thus correcting telecanthus. **C.** Transnasal wiring technique. **D.** Placement of external splints to promote redraping of pericanthal soft tissue after narrowing of the underlying NOE segments.

PEARLS AND PITFALLS

Indications

	■ It can be helpful to compare current appearance to a preinjury photo. ■ An ophthalmology consult should be obtained to rule out concomitant injury to the globe.⁶ ■ Edema early after injury can mask the severity of enophthalmos and saddle nose deformity.
Approach	■ If a Lynch incision is used, carefully dissect around and preserve the supratrochlear neurovascular bundle.
Concomitant frontal sinus injury	■ If a concomitant frontal sinus injury requires either obliteration or cranialization, the NOE segment should be reduced and rigidly fixed first. Disimpacting the NOE fracture can reopen the frontonasal outflow tract, which needs to be obliterated.
Telecanthus	■ For type 1 NOE fractures, ensure the segment is not rotated outward before fixation. ■ For type 2 NOE fractures, be sure to capture the canthal bearing bony segment with the fixation plate. The surgeon can manually bend the plate medially to restore normal width. ■ For type 3 NOE fractures, transnasal wires or canthoplasty barb may be used to fixate the medial canthal position. ■ Overcorrection is key as the tendon tends to drift laterally.
Medial canthal webbing	■ Place external compression splints to redrape the soft tissue after fracture reduction and fixation.
Persistent enophthalmos	■ Be sure to recreate the ethmoid bulge when reconstructing the medial orbital wall fracture with either autograft or alloplast.
Nasolacrimal injury	■ Routine probing of the canalicular system is not recommended. However, if an obvious laceration involves the ducts, then they should be repaired over a Crawford tube.

POSTOPERATIVE CARE

- Tobacco avoidance and soft diet are recommended until the intraoral incisions have healed.
- Patients should avoid strenuous activity and nose blowing for 2 weeks postoperatively to prevent periorbital hematoma.
- Patients should avoid contact sports for 3 months postoperatively to ensure stable bony healing.
- The patient should be seen within 2 weeks after surgery to ensure normal

incisional healing.

- The external nasal splints and Doyle splints are removed at this clinic visit.
- It is common for patients to report transient diplopia for the first few weeks after surgery due to edema.
- It is also common for patients to exhibit epiphora after surgery due to edema that collapses the nasolacrimal apparatus.⁷
- If diplopia persists for 3 to 6 months, then referral to ophthalmology should be considered.⁸
- If epiphora persists greater than 6 months, then probing of the canalicular system and possible dacryocystorhinostomy (DCR) should be considered.

OUTCOMES

- Lack of treatment or inadequate treatment can leave permanent deformities such as telecanthus, shortened palpebral fissure, and saddle nose deformities, which are difficult, if not impossible, to correct secondarily.
- Herford et al. presented ten consecutive patients with Manson type 3 NOE fractures treated with ORIF. Of these, two patients were found to have asymmetry between the medial canthi and two had overprojection of the nasofrontal region.⁹
- Gruss et al. presented 46 consecutive patients with severe NOE fractures, 8 of whom had persistent nasolacrimal duct dysfunction and epiphora requiring DCR.⁷

COMPLICATIONS

- Complications can result from inadequate reduction of fracture segments and include:
 - Persistent telecanthus
 - Enophthalmos
 - Persistent epiphora
 - Airway obstruction
 - Saddle nose deformity
- Complications can result from surgical intervention:
 - Lower eyelid malposition
 - Scar alopecia
 - Visible scarring

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Section X: Maxillary Trauma

62 Closed Reduction of Zygomatic Arch Fractures

CHAPTER

Oluwaseun A. Adetayo

DEFINITION

- The zygoma bone has four skeletal articulations—the maxilla, frontal, temporal, and sphenoid bones.
- The zygomatic arch plays a prominent role in facial skeletal profile by establishing malar projection (“cheek bones”).
- Fractures of the zygomatic arch can occur in isolation. In such cases, the tetrapod articulations are usually not violated and the remainder of the complex is stable.
- This chapter focuses on closed reduction and treatment options for isolated zygomatic arch fractures.

ANATOMY

- The zygomatic arch is a part of the zygomaticomaxillary complex (ZMC). The bone and its articulations are shown in (**FIG 1A**).
- Although the term “arch” is used to describe the bone, it is more anatomically flat in configuration for the majority of its length and is curved posteriorly.
- The zygoma is also an important landmark for the muscles of mastication.
- The zygomatic arch furnishes attachments for portions of the superficial muscular aponeurotic system (SMAS), the temporoparietal fascia (TPF), and origins for some of the muscles of facial expression and mastication.
- The highly powered masseter muscle has superficial and deep components that

take their origin from the zygomatic arch and insert into the buccal surface of the mandibular angle, ramus, and body. Portions of the deep fibers of the muscle also radiate to the anterior capsule and the articular disk of the temporomandibular joint (TMJ), thus helping to stabilize the capsule of the TMJ.

- Fractures of the zygomatic arch may disrupt the origin of the masseter and potentially affect elevation and protrusion of the mandible, resulting in pain, trismus, and occlusal problems.
- The temporalis muscle is located deep to the zygomatic arch as it inserts onto the coronoid process. Depression of an isolated arch fracture can contribute to trismus or malocclusion, via an indirect impingement on the temporalis.
- The relationship of the masseter and temporalis muscles to the zygomatic arch are depicted in **FIG 1B**.

PATIENT HISTORY AND PHYSICAL FINDINGS

- All trauma patients should undergo appropriate evaluation to rule out any concomitant facial fractures or other life-threatening injuries.
- Physical findings in patients with zygomatic arch fractures may include facial asymmetry, loss of malar projection, trismus, pain, and decreased maximum incisal opening (MIO).
- Trismus and decreased MIO can occur due to direct pull of the masseter on the arch, impingement of a displaced arch on the temporalis muscle as it inserts into the coronoid, or more directly via its compressive effect on other muscles of mastication.

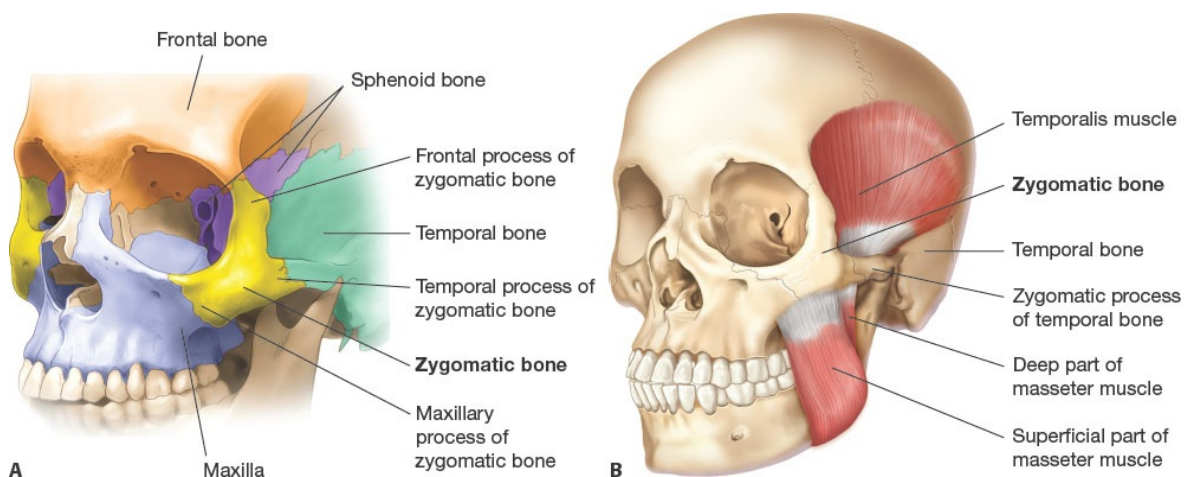


FIG 1 • A. The zygoma bone and its articulations. **B.**

The relationship of the masseter and temporalis muscles to the zygomatic arch.

- Facial asymmetry may result because of actual displacement of the arch or disruption of the origin of the zygomaticus muscles, which contribute to facial expression.

IMAGING

- Various modalities including x-rays, ultrasounds, and computed tomography (CT) scans have been described for evaluation of zygoma fractures.¹⁻³
- CT scans are the most commonly utilized diagnostic tools in patients with facial fractures and provide excellent detail for the evaluation of zygomatic fractures.
- CT scan using fine cuts with axial, coronal, and 3D reconstruction are particularly helpful to evaluate the degree of displacement, impingement, malrotation, and associated fractures.

NONOPERATIVE MANAGEMENT

- Nonoperative management of isolated zygomatic arch fractures is the treatment choice in patients with the following:
 - Nondisplaced or noncomminuted arch fractures
 - Lack of trismus
 - Lack of facial or malar asymmetry
 - Normal MIO
 - Preservation of facial width and projection

SURGICAL MANAGEMENT

- Operative intervention should be considered in patients who are medically stable with sequelae of arch fractures such as trismus, malar flattening, facial asymmetry, difficulty with mouth opening, and presence of concomitant fractures.
- The goals of treatment are:
 - Anatomic restoration of three-dimensional anatomy of the zygoma with articulation and muscular complexes
 - Restoration of facial width and malar projection
 - Resolution of symptoms due to fracture
 - Restoration of orbital volume and anatomy in cases of orbitozygomatic

fractures

Preoperative Planning

- A complete history and physical examination should be performed on every patient and all concomitant injuries identified.
- Obtain imaging of choice. Most commonly used are craniomaxillofacial CT scans with fine cuts (range of 0.625- to 1.25-mm cuts at most institutions) and includes axial, sagittal, coronal, and 3D imagings as needed.
- Isolated arch fractures have been estimated to occur in 5% to 10.4% of patients with zygoma fractures, of which 59.3% are displaced or comminuted.^{2,4}

Positioning

- The patient is positioned supine on the operating table with exposure of the head and neck to facilitate access. CT scan images are displayed intraoperatively.

Approach

- The following approaches have been described for treatment of isolated zygomatic arch fractures:
 - Percutaneous approach
 - Gilles approach
 - Keen approach
 - Others

TECHNIQUES

■ Percutaneous Approach

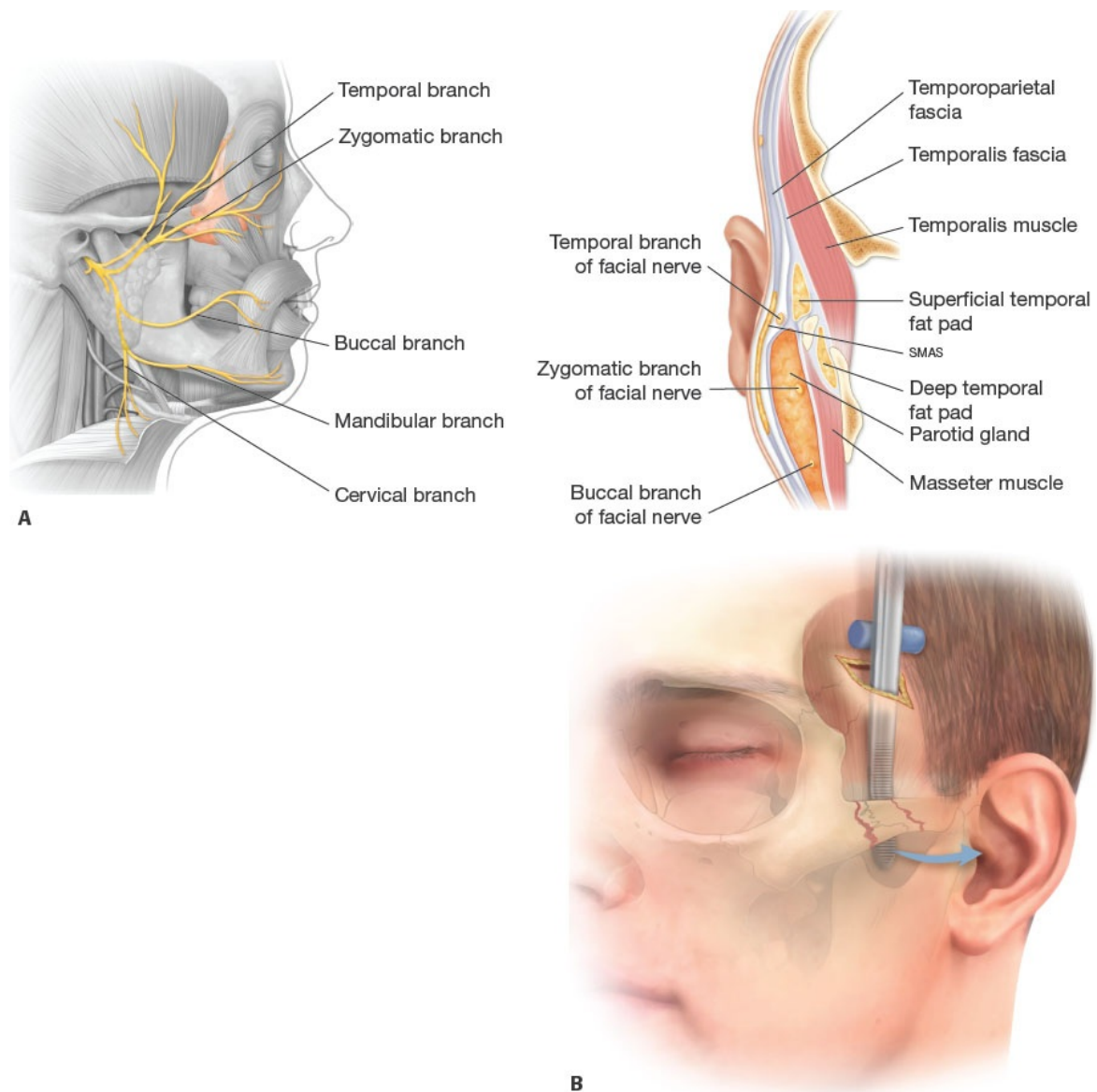
- A 0.5- to 1-cm cutaneous incision is made directly overlying the zygoma, and a reduction instrument such as a bone hook or a Carroll-Girard T-bar screw is inserted into the body of the zygoma.⁵
- Lateral traction is placed on the isolated zygomatic arch fragment and external manual palpation is performed to guide the reduction, which is denoted by the sound of the fragment clicking back into place.
- The contralateral hand is placed at the maxilla-zygomatic arch interface on

the face and used to guide the fragment during reduction into the appropriate axial projection and skeletal relationship.

- Advantages include the minimal access incision.
- Disadvantages include presence of a facial scar and the possibility of inadequate reduction or loss of reduction.

■ Gilles Approach

- This approach was described in 1927 by Gilles, and it involves the use of a scalp incision to access the zygomatic arch fracture.
- A 2-cm incision is made in the temporal hairline 4 cm superior to the helix and extended to the superficial temporal fascia (STF), which is incised.
- This exposes the deep temporal fascia (DTF), which has two layers—the superficial layer and the deep layer—that enclose the temporalis muscle.
- Next, the superficial layer of the DTF is incised, and the surgeon gains entry into the plane between this superficial layer and the temporalis muscle.
- Dissection is performed between these layers, staying below the superficial layer of the DTF and above the temporalis muscle, thus leading to the zygomatic arch.
- The frontal branch of the facial nerve, which crosses the zygomatic arch and is enclosed within the STF, is protected.^{6,7}



TECH FIG 1 • A. Relationships of the frontal branch of the facial nerve, superficial temporal fascia, deep temporal fascia, and the zygoma. **B.** Gilles approach.

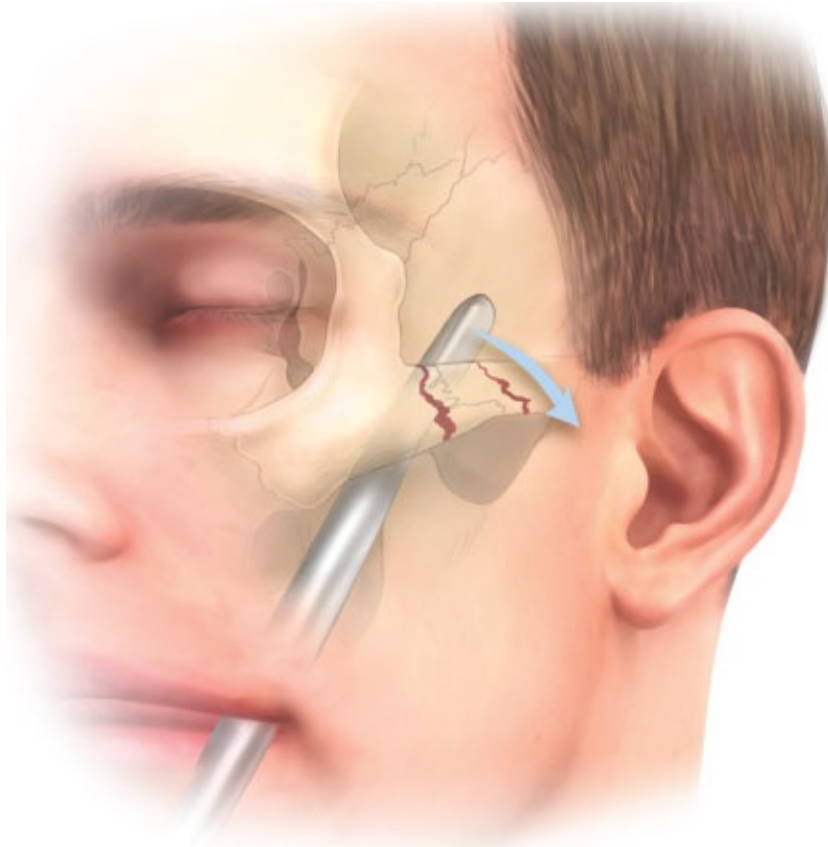
- Above the zygomatic arch at the fascial transition zone, the frontal branches of the facial nerve course on the undersurface of the STF before terminating in the frontalis and orbicularis oculi muscles. The fascial transition zone runs 1.5 to 3 cm above the superior aspect of the zygomatic arch.^{6,8} **TECH FIG 1A** illustrates the anatomic relationship in this region.
- A reduction forcep, such as a Rowe zygomatic elevator or a periosteal elevator, is placed beneath the zygoma, and lateral traction is performed to

reduce the fracture, while the contralateral hand can be used to guide reduction of the zygoma to re-establish malar projection (**TECH FIG 1B**).

- The adjunct use of fluoroscopy may be employed to guide reduction, although this practice is not routinely necessary or widespread. Fluoroscopy may aid in proper fracture reduction with closed reduction.⁹
- Reduction is usually completed by a palpable reduction into anatomic position and/or sound of the fragment clicking into position.
- Hemostasis is achieved and the incision is closed with reapproximation of all anatomic layers.
- Advantages include a camouflaged scar within the hair without facial scarring.
- Disadvantages include risk of alopecia, possibility of injury to the frontal branch of the facial nerve and the temporal fat pad, and inadequate or unstable reduction.

■ Keen Approach

- This approach was described by Keen in 1909 and utilizes an intraoral approach.
- The upper gingivobuccal sulcus of the affected side is infiltrated with local anesthetic of choice, and a 2- to 3-cm gingivobuccal sulcus incision is made running from the lateral incisor to the mesial aspect of the first molar.
- Subperiosteal dissection is performed over the maxilla to expose the zygoma and the zygomaticomaxillary buttress.
- A reduction forcep, such as a Boise or zygoma elevator, is placed deep to the zygomatic arch while palpating the malar eminence with the contralateral hand. This allows for elevation and reduction of the depressed arch with the application of a steady reduction force (**TECH FIG 2**).
- Completion of reduction is usually heralded by a palpable reduction into anatomic position and/or sound of the fragment clicking into position.
- Following reduction, the area is irrigated and the incision is closed.
- Advantages include a camouflaged scar in the oral cavity, and prevention of a temporal scar, alopecia, or facial scar.
- Disadvantages include the risk of inadequate or unstable reduction.



TECH FIG 2 • Keen approach.

■ Other

- Additional approaches for access to the fractured zygomatic arch have been described, including endoscopic approaches to assist visualization, hemicoronal incision for more direct access, fluoroscopic guidance, intraoperative ultrasonography to aid reduction, etc.^{1,3,4,7,9–12}
- The exact details of these additional techniques or adjuncts are beyond the scope of this chapter, and the reader is referred to the literature for additional information.

PEARLS AND PITFALLS

Indications

- Evaluate for concomitant fractures.

	■ Comminuted, malrotated, impinged, and unstable fractures may require open reduction and internal fixation.
Surgical technique	■ Respect the anatomic layers to avoid injury to the frontal branch of the facial nerve or atrophy of the temporal fat pad. ■ Avoid extensive stripping of the soft tissues to prevent premature midface descent secondary to soft tissue ptosis. ■ If any of the surgical techniques fail to achieve or maintain a stable reduction, then open reduction and internal fixation of the zygoma should be performed.
Failure of treatment	■ Patients whose fractures remain unstable after the various approaches described above should undergo open reduction and internal fixation of the fractures to restore normal anatomy and function.
Postoperative care	■ It is critical to identify or mark the site postoperatively. ■ A tape, sticker, or note serves as a good external reminder. ■ Monitor the patients to ensure compliance and that the reduction is stable. If any of the techniques fail, then proceed with open reduction and internal fixation with or without osteotomies.

POSTOPERATIVE CARE

- It is the author's practice to inscribe "No pressure" on a piece of wide tape, which is then gently secured to the patient's operated side over the malar eminence prior to extubation. This serves as a visual reminder to the patient, surgeon, anesthesiologist, and nursing staff caring for the patient postoperatively.
- Patient should be monitored to avoid pressure during sleep or activity on the operated side of the face while recovering from anesthesia.
- Nursing staff, treating personnel, and the patient should be educated on positioning and activity restrictions.
- Place the patient on a soft diet to avoid significant loading of the masticatory muscles during bony healing. Practices vary anywhere from 2 to 6 weeks depending on surgeon preferences, patient factors, degree of comminution, symptoms, etc.
- Maintaining good oral hygiene is key.
- There are no standardized recommendations regarding antibiotic use.

OUTCOMES

- Patients with successfully reduced zygomatic arch fractures have excellent

outcomes with the various techniques described above with minimal sequelae.

- Patients in whom reduction cannot be achieved or maintained should be considered for open reduction and internal fixation.

COMPLICATIONS

- Complications associated with each technique are described in the accompanying sections.
- General complications include:
 - Scar
 - Inability to achieve reduction
 - Inability to maintain reduction
 - Alopecia
 - Persistence of occlusal problems and facial asymmetry¹³

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63 Open Correction of Zygomatic Fractures

CHAPTER

Warren Schubert and Yeshaswini Thelekkat

DEFINITION

- Zygomatic fractures are fractures of the zygomatic bone together with any one or all of its four processes—maxillary, frontal, orbital, and temporal (**FIG 1**).
- When the fracture involves only the temporal process, it is referred to as an isolated zygomatic arch fracture.
- More often, fractures involve the adjacent bones through the other processes, and the term zygomatic complex or zygomaticomaxillary complex (ZMC) fracture is more appropriate.
- ZMC fractures are also referred to as fractures of the zygoma, malar complex, quadripod, quadramalar, tetrapod, trimalar fractures, and orbitozygomatic fractures.

ANATOMY

- The zygoma maintains points of articulation with the maxilla at the zygomaticomaxillary buttress (ZMB or lateral column of the midface) and at the inferior orbital rim (IOR), the frontal bone at the zygomaticofrontal (ZF) suture, the greater wing of the sphenoid at the zygomaticosphenoid (ZS) suture, and the temporal bone at the zygomaticotemporal (ZT) suture.
- The ZS component makes up the lateral component of the orbital wall.

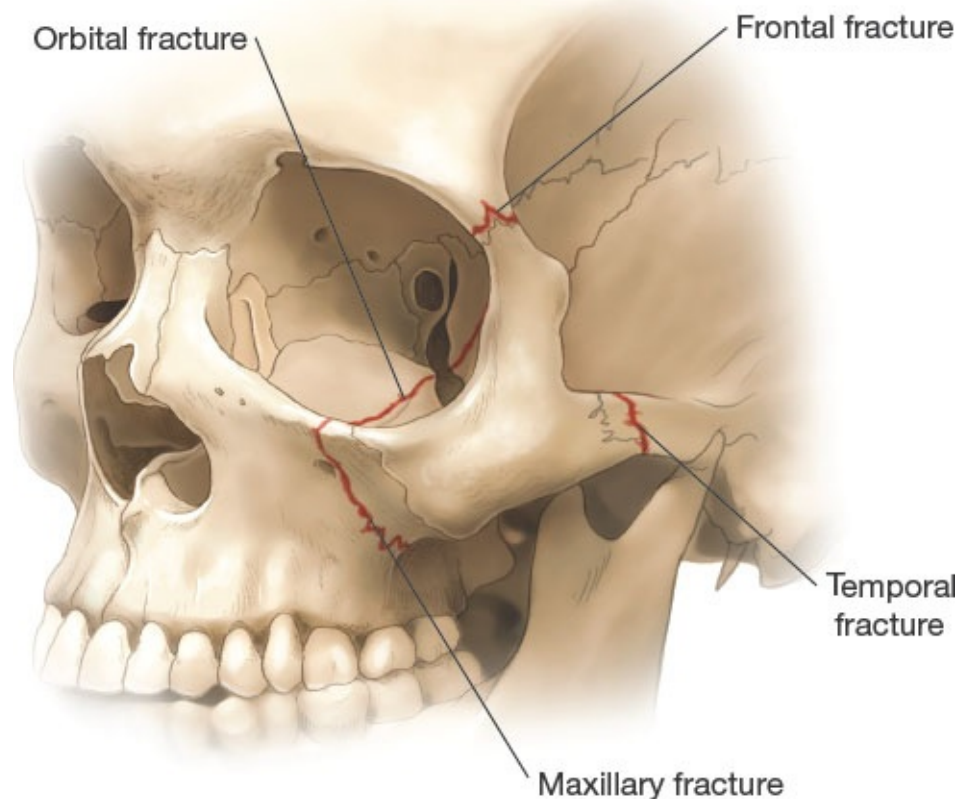


FIG 1 • ZMC showing fracture of four processes of the zygoma—maxillary, frontal, orbital and temporal.

- The zygoma also forms a major component of the maxillary sinus, contributing partially to the roof and to the posterolateral wall of the sinus.
- The zygoma serves as an attachment for a major portion of the masseter along the body and the zygomatic arch. The arch also serves as an attachment for both the superficial and deep portion of the deep temporal fascia along the zygomatic arch and posterolateral edge of the temporal process. The masseter muscle has a significant role in causing intrinsic deformations of the body and arch¹ (**FIG 2A**).
- The zygoma also provides attachment to the muscles of facial animation. These main muscles include the levator labii superioris along the infraorbital rim and the zygomaticus major and minor muscles along the malar eminence.¹
- The Whitnall tubercle lies on the medial aspect of the zygomatic bone, about 9 mm inferior to the ZF suture and 4 mm posterior to the lateral orbital rim (**FIG**

2B).^{2,3} This tubercle provides attachments to the lateral palpebral ligaments and the suspensory ligament of Lockwood, which forms the inferior hammock of the globe.

- This may cause a downward slant of the eyelids when there is an inferior displacement of the zygoma following trauma.^{3,4}
- A key to a successful reduction of the ZMC fracture is the alignment of the zygomaticosphenoidal suture in the lateral wall of the orbit, as this area is least likely to be comminuted.⁵
- Though it is referred to as the zygomatic “arch,” this structure is anatomically closer to being a relatively straight structure in the AP direction, rather than a curvilinear arch.
- A fracture of the ZMC is indeed complex as the zygoma helps to define the degree of midface projection and width, as well as contribute to the anatomy defining orbital volume, including the lateral orbital wall and part of the orbital floor (OF).
- Malposition of the ZMC can have a significant impact on the function of the eye as well as sensation to the infraorbital nerve.
- The various techniques that are described depend on how many points of fixation the surgeon feels are necessary for adequate reduction and fixation.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The clinical presentation of the patient is dependent on the direction and strength of the force striking the midface. The patient often presents with a blunting of the malar eminence, which is commonly displaced posteriorly.

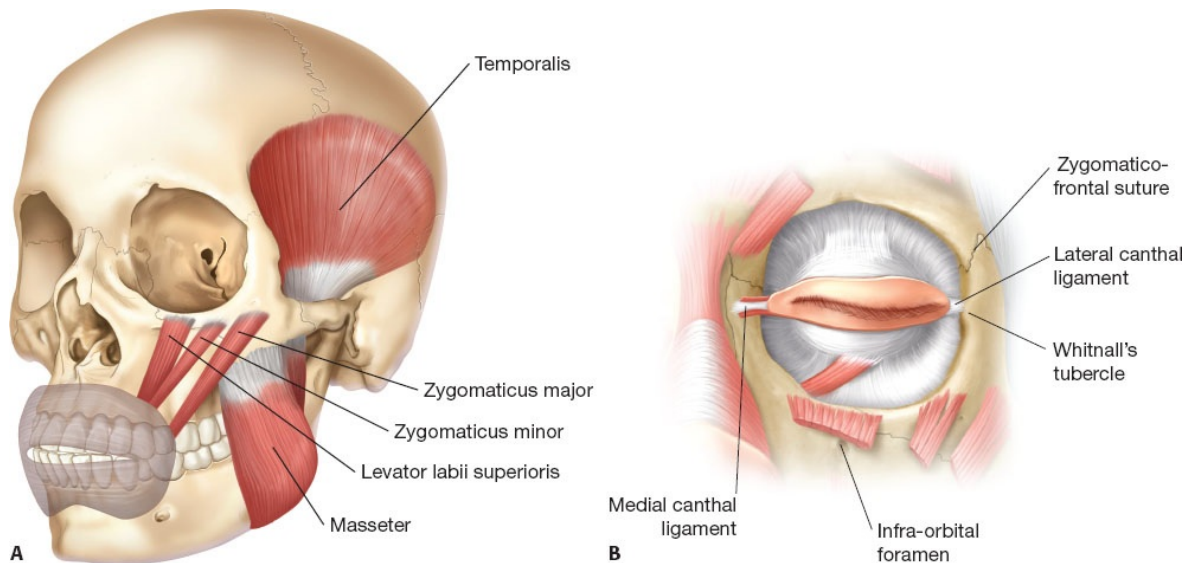


FIG 2 • A. Muscles that attach to the zygoma. **B.** Position of the Whitnall tubercle relative to the zygomaticofrontal suture with the lateral canthal ligament attached.

- Unless the fracture is a pure fracture of the zygomatic arch, all zygomatic complex fractures also result in orbital fractures, commonly of the OF and lateral orbital wall. As the orbit is involved, a complete orbital exam is required to confirm that the patient's globe and vision have not been compromised.
- The surgeon should confirm that the extraocular muscles are functioning, without evidence of entrapment of the extraocular muscles or other periorbital soft tissue.
- Diplopia may be due to entrapment or due to other malfunctions of the extraocular muscles or nerves to those muscles.
- A forced duction test may be needed to discern the difference between entrapment and malfunction of the extraocular muscles.
- Many have claimed to be able to perform a forced duction test adequately under topical anesthesia. We have generally found it necessary to have the patient completely relaxed and sedated to rule out entrapment in the acute phase of facial trauma.
- Trapdoor orbital fractures are more common in the pediatric and very young adult skeleton owing to the increased elasticity of the bone. In response to an acute periorbital impact following trauma, the floor fractures, and temporarily

bends, resulting in a linear crack. On the release of the force, the floor snaps back into its original position. There may be entrapment of the extraocular muscles and periorbita restricting the movements of the eyeball. There may be minimal signs of edema or ecchymosis externally, and CT imaging may be unremarkable when the volume of tissue entrapped is minimal. These fractures were referred to as “white-eyed blowout fracture” by Jordan et al.⁶

- The patients often present with severe pain on attempted eye movement associated with nausea and vomiting due to an unresolving oculocardiac reflex, which may be misinterpreted as being a primary intracranial injury.
- This form of entrapment requires emergent intervention, both for the comfort of the patient and to prevent prolonged muscle ischemia, which can result in a persistent diplopia.
- ZMC fractures and the associated OF fractures are commonly associated with impingement on the infraorbital nerve and numbness in that distribution of the midface.
- This should be recorded prior to any intervention to avoid postoperative concerns of an iatrogenic injury.
- A depression of the zygomatic arch medially may be associated with impingement of the coronoid process, thereby interfering with the movements of the mandible.
- This limits the patient’s ability to open or close his mouth, depending on the position of the patient’s mouth at the time of the impact and fracture of the arch and the degree of medial displacement of the arch.
- Contact of the arch with the coronoid process may also limit the excursion of the mandible from side to side (**FIG 3**).

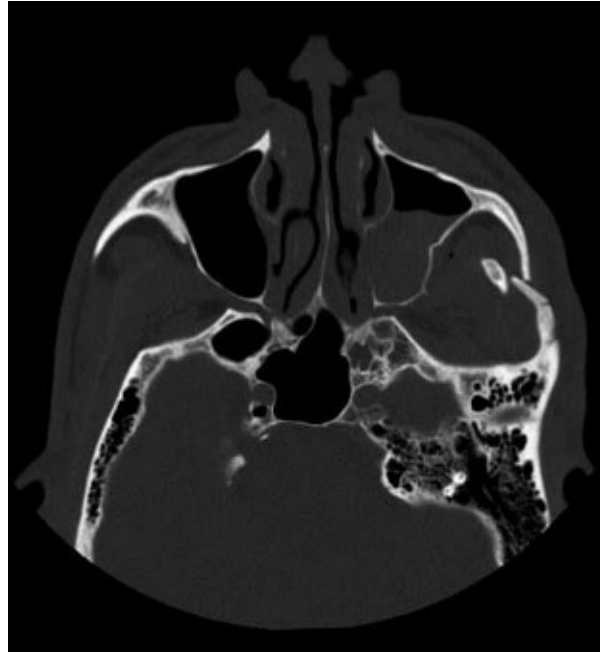


FIG 3 • Impingement of zygomatic arch on coronoid process.

IMAGING

- The appropriate radiologic workup requires fine-cut CT.
- The ideal workup includes axial cuts, reformatted coronal cuts, and sagittal cuts through the orbit.
- For our sagittal reformatting, we prefer oblique parasagittal cuts through the orbit that follow the axial line of the optic nerve.
- In special cases of complex or comminuted fractures, a 3D reformatting may also be very useful.

NONOPERATIVE MANAGEMENT

- If the zygoma is fractured, but not displaced, surgical intervention is usually not needed.
- In isolated arch fractures, if there is no coronoid impingement or significant cosmetic deformity in the form of a depression on the cheek posterior to the malar eminence, no intervention is usually required.

SURGICAL MANAGEMENT

- Steps involved in an appropriate open reduction and internal fixation (ORIF) of a complex zygoma fracture are variable, depending on the clinical findings,

CT findings, degree of comminution, and instability of the zygoma.

- The technique first described for fixation of a ZMC fracture is that of a standard three-point fixation of the zygoma.
- The number of points of fixation needed depends on the degree of instability of the zygoma following fracture reduction.

Preoperative Planning

- An exam documenting the patient's visual acuity, movements of the globe in all directions, presence or absence of diplopia, and infraorbital nerve anesthesia/paresthesia should be included in the preoperative exam.
- Adequate preoperative axial fine cuts and coronal and oblique parasagittal reformatted CT of the midface fractures should be part of the routine preoperative workup.
- Oblique parasagittal reconstructions in the plane of the optic nerve offer the best single global view of the degree of displacement of the OF (and roof) and can present the surgeon an estimate of the length of material needed if an OF reconstruction is required.

Positioning

- Positioning should be supine.
- A decision should be made preoperatively as to whether it is necessary to perform a coronal approach, as this will affect the position of the endotracheal tube. For a pure ZMC fracture, a coronal approach is seldom needed.
- Availability of intraoperative imaging or navigation also affects patient positioning on the table and the position of the operating table relative to anesthesia providers.
- We usually prefer to have the operative table at 90 or 180 degrees from the anesthesia source.

Approach

- Fractures of the ZMC can be accessed using various transcutaneous, transconjunctival, transoral, and coronal approaches.
- The ZF suture is commonly approached transcutaneously using an upper eyelid/lateral blepharoplasty incision.
- Although a lateral brow incision is popular with surgeons in other parts of the world, the access attained is not superior to the lateral brow and results in scar alopecia in the hair of the eyebrow, which can often be quite apparent. The

lateral blepharoplasty incision is a more direct approach to the ZF fracture and leaves a scar that is barely perceptible.

- The ZF can also be accessed with a transconjunctival lateral canthotomy incision, but requires considerable traction of the soft tissues in the cephalad direction, and may result in considerable postop edema.
- The infraorbital rim (IOR) and the OF can be accessed transcutaneously using a subciliary or subtarsal (midlid) incision.
 - Alternatively, the transconjunctival incision with or without a lateral canthotomy and a transcaruncular or retrocaruncular incision (for medial orbital wall fractures and medial floor fractures) will provide excellent aesthetic exposure to the IOR and medial and lateral OF.
- The ZMB can be accessed transorally using a maxillary vestibular incision.
- The zygomatic complex and the arch can be indirectly reduced using a transoral vestibular incision (Keen approach) or an extraoral, temporal incision (Gillies approach).
- For extensive fractures, a coronal approach can be contemplated through which the lateral and medial orbital walls and supraorbital rim can be accessed in one incision. The coronal incision provides direct exposure of the zygomatic arch for reduction and plating.
 - Visualization of the arch can offer an additional landmark for achieving the proper AP projection of the malar eminence, particularly in cases where other key landmarks have been destroyed, such as when the lateral wall of the orbit is comminuted.
 - The coronal incision will have to be combined with other incisions of choice to access the IOR and ZMB.
- The specific indication for each approach is discussed in the techniques section.

TECHNIQUES

■ Three-Point Fixation of a ZMC Fracture

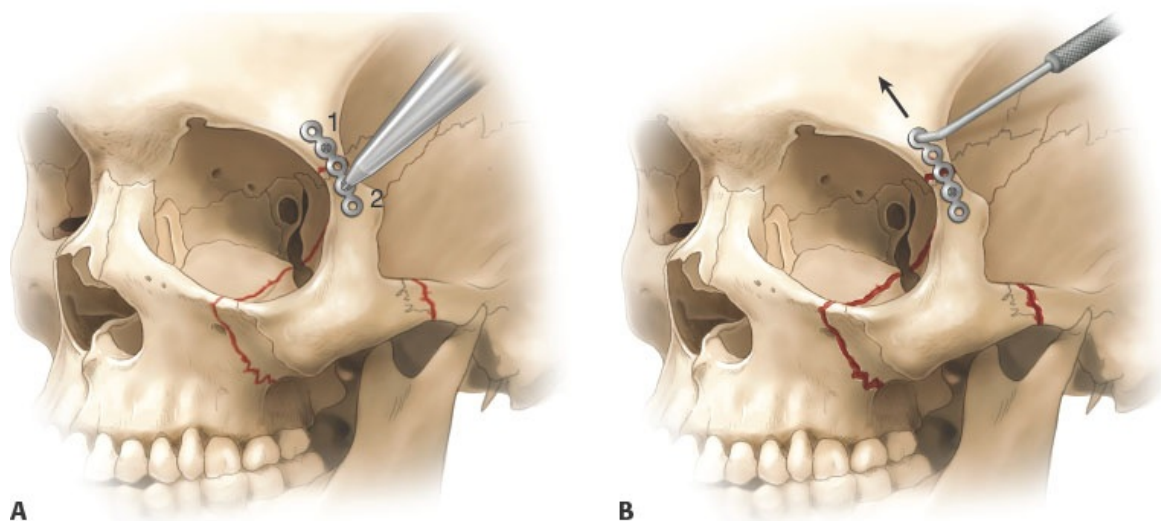
Approach

- In a severely displaced zygoma, the patient will require a lateral blepharoplasty incision (upper eyelid) and periorbital approach (subciliary,

midlid, or conjunctival incision).

- If there is significant displacement of the zygoma, especially with comminution of the lateral wall of the orbit, some surgeons advocate using a coronal incision to expose and plate the zygomatic arch to obtain the proper AP position of the zygomatic complex.
- It is the authors' opinion that the coronal approach often creates worse cosmetic results than the deformity it is meant to correct, including scalp scar alopecia, temporal hollowing, and the risk of injury to the frontal branch of the facial nerve.
 - We would seldom advocate including the coronal incision to address the arch unless there are additional reasons a coronal incision has to be made, such as a frontal sinus fracture or extremely comminuted landmarks of the other key reference points addressed below.
- Exposure of the ZF suture can be achieved by performing a lateral canthotomy/conjunctival incision without a blepharoplasty incision.
 - The degree of extreme pull on the soft tissues in the cephalad direction results in both a struggle of retraction intraoperatively and more postoperative periorbital edema than including an additional lateral blepharoplasty incision and heals with a minimal scar when done properly and is well concealed.
- The authors do not recommend the use of the lateral brow incision, which does not provide any better exposure to the ZF suture than a blepharoplasty incision and commonly results in an obvious permanent alopecia and what appears as a part in the hair of the eyebrow that can be noted from across the waiting room.

Not Recommended



TECH FIG 1 • A. Poor technique, with screw first placed in the frontal bone. **B.** Preferred technique, in which the first screw is placed in the zygoma so that the gap in the ZF suture can be further reduced by pulling the plate and fractured segment in the cephalad direction before placing the second screw in the frontal process.

- A ZMC fracture where there is separation of the ZF suture and comminution of the orbital rim is approached using a blepharoplasty and periorbital incision at the minimum.

First Plate

- We recommend first to plate the ZF fracture, initially with a single screw placed on each side of the fracture.
 - The ZF fracture is the poorest landmark of the various sites that will be plated to confirm the three-dimensional reduction of the zygoma.
- By using only one screw on each side of the fracture, the zygoma is still mobile and later can be swiveled into position for alignment of the orbital rim and lateral column of the midface in the area of the ZMB.
- The screw holes that are recommended to be used first should be the plate holes that are the nearest to the ZF fracture site (**TECH FIG 1**).

Reduction

- Once the initial stabilization of the ZF fracture has been done with just one screw on each side of the fracture, the zygoma is reduced.
- The authors prefer the Keen or intraoral approach. With this Keen approach, a significant force can be used to elevate the ZMC into its proper position using an appropriate zygoma elevator.
- The landmarks of the lateral orbital wall, the orbital rim, and the zygomaticomaxillary suture are used to confirm the proper alignment and reduction of the zygoma (**TECH FIG 2**).
- Some surgeons prefer the Gillies approach for elevating and repositioning the zygomatic complex.
- This approach requires an additional incision in the scalp, resulting in scar alopecia, and provides a far more indirect approach to the zygomatic arch, with several opportunities to end up in the wrong plane of dissection.



TECH FIG 2 • Intraoral (Keen) approach, with an instrument placed deep to the zygomatic arch to mobilize the ZMC.

- With a fractured zygomatic arch using a Keen approach, the surgeon can often insert a digit to actually palpate through the incision to confirm if the reduction has been achieved. This direct digital confirmation is not possible with the Gillies approach.
- Other methods of elevating the zygoma have been popularized, including using a hook under the zygomatic arch, a screw in the malar prominence to pull on, and a Carroll-Girard instrument.

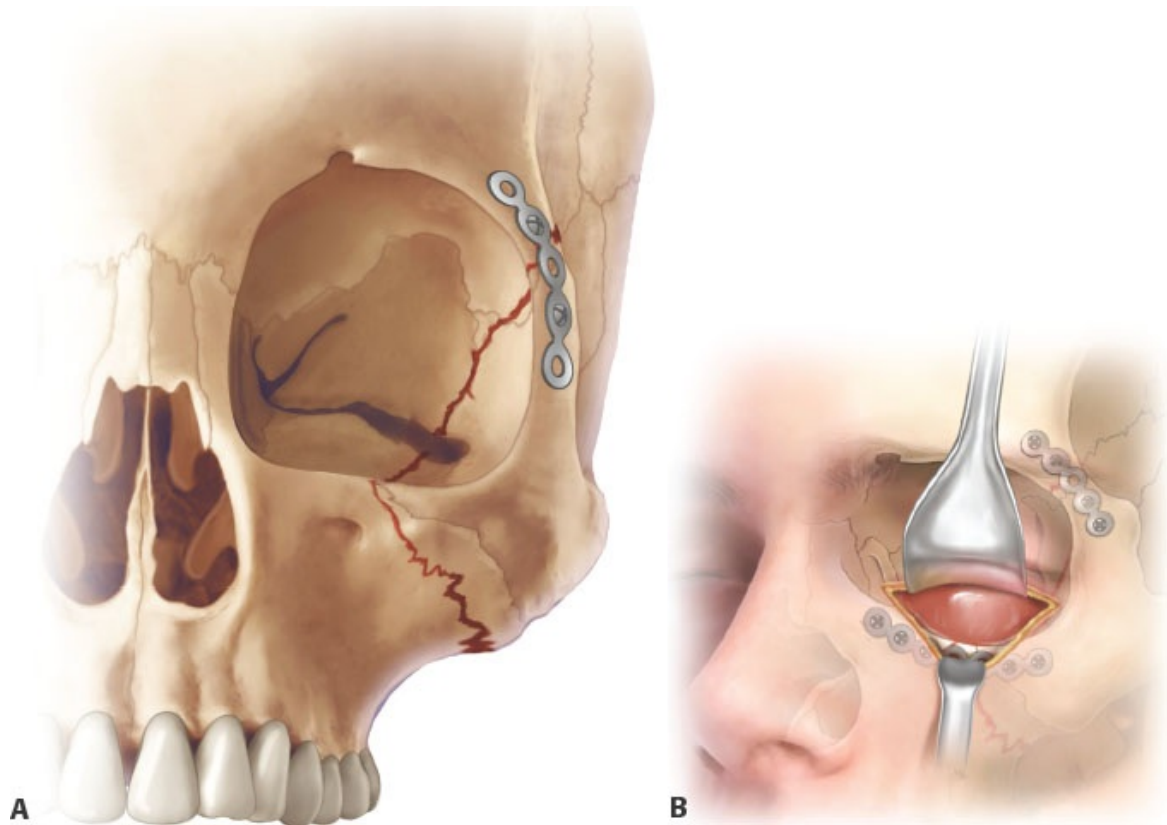
Second Plate

- If three plates are required, the authors recommend plating the IOR next, after plating the ZF suture. The goal is to have the orbit and orbital rim as perfect as possible.
 - A small deformity of the lateral column of the midface is more forgivable than not having the orbit perfectly aligned (both the lateral wall and the orbital rim).
 - After plating the ZF fracture and before placing a plate on the orbital rim or the lateral column of the midface, it is key to examine the lateral wall of the orbit to confirm an adequate reduction (**TECH FIG 3A**).
- The lateral wall of the orbit commonly fractures in the area of the junction between the zygoma and the greater wing of the sphenoid. We have found that in 60% of cases, this is not comminuted, and the ZS suture is an excellent landmark for confirmation of the proper reduction of the zygoma.⁵
 - After various landmarks have confirmed the proper reduction of the zygoma, the orbital rim is plated using the surgeon's preferred periorbital approach. There are great differences in comfort and experience level using various periorbital approaches.
 - We recommend using the kind of approach with which the surgeon has the most experience (**TECH FIG 3B**).

Third Plate

- The last plate commonly used in the three-plate technique is an L-plate on the lateral column of the midface.

- The plates used at the ZF suture and the orbital rim are generally smaller (1.3 mm or smaller plates) so that the patient will not be able to palpate and complain of the plate's prominence. The L-plate is a much larger plate and offers significant stability.



TECH FIG 3 • A. Initially, the ZF plate is placed with only one screw on each side of the fracture. It is important to align the fracture along the lateral wall of the orbit, which commonly occurs at the junction of the greater wing of the sphenoid and the zygoma, prior to the placement of additional plates. **B.** Inferior orbital rim plate is placed after the ZF plate and after confirmation of the proper reduction of the ZMC, including visualization of the lateral orbital wall.

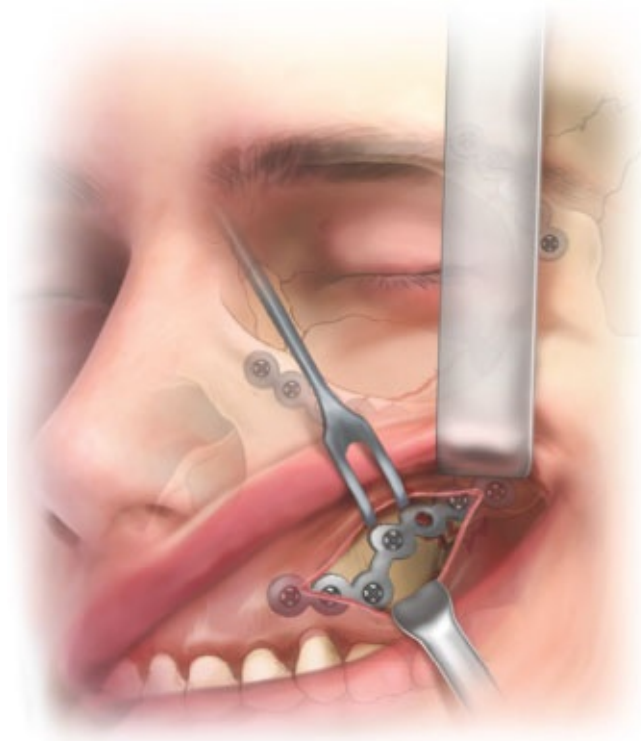
- As there is commonly significant comminution of the lateral column of the midface with these patients, we prefer a 2-mm L-plate that offers many

hole options to capture comminuted segments in variable locations (**TECH FIG 4**).

- Only after all of the other plates are placed are the final two holes of the plate at the ZF suture filled.

Other Concerns

- If reconstruction of the OF is required, this should be addressed after reduction and plating of the ZMC are complete.
- Every effort should be taken to protect the eye during the case.
 - Corneal protectors are useful.
 - A forced duction test should be performed at the end of the case to confirm that there has not been any entrapment, even in cases where a ZMC repositioning is performed without a reconstruction of the OF.
- Numbness in the infraorbital distribution is common both pre- and postoperatively. If the fracture segments appear to be impinging the nerve at the infraorbital foramen, it may be worth considering disimpacting the foramen.



TECH FIG 4 • The last plate to be placed in the three-

plate technique is the L-plate. After the placement of this plate, the final two (or more) remaining holes in the ZF plate are placed.

■ Alternative Treatments

- Various forms of intraoperative imaging are having a dramatic impact on previous traditional methods of treatment.
 - Many once thought that zygomatic arch fractures were unstable and if reduced would not hold their reduced position without plating.
 - We found that with intraoperative confirmation of a proper reduction of pure arch fractures, nine of nine consecutive fractures maintained their reduction after using the Keen approach.⁷
- In the past, it was often routine to explore the OF and reconstruct it as part of the reduction of a complex zygomatic fracture where the floor was involved or the malar eminence was telescoped posteriorly.
 - With the advent of intraoperative imaging, Wilde et al.⁸ have found that 81% of their patients did not need further surgery of the OF, the lateral wall, or the arch after a proper reduction of the zygoma, without exploration of these structures, having intraoperative visualization of an adequate reduction of the orbital walls.
 - The key is being able to visualize with radiographic imaging intraoperatively what has happened to all of the parts following the reduction of the zygoma. Once the zygoma is reduced to its proper three-dimensional projections, if the periorbita (specifically the periosteum of the orbit) has not been violated and explored, the floor will often resume its proper alignment in repositioning the ZMC due to ligamentotaxis.
- Navigation may be used intraoperatively in a similar way that intraoperative imaging is used if this technology is available to the surgeon.
 - With navigation, obtaining a preoperative CT with a fiducial guide may be necessary. With this technique, the surgeon is able to perform a virtual correction of the proper placement of the ZMC on the injured side by mirroring the proper position of the ZMC from the contralateral uninjured side.⁹
 - At the time of the surgery, the malpositioned ZMC is moved into its proper position as visualized in the virtual image.

- Rarely, a ZMC fracture will snap into reduction and be perfectly stable. There is no reason to use any plates or screws in these cases.
- If on the preoperative CT there is a fracture, but no displacement of the ZF suture, this portion of the fracture is often attached to the periosteum and hinged in a way that the surgeon may begin by only making an intraoral incision.
 - The dissection can often be carried up to the orbital rim through this intraoral incision.
 - If all of the key landmarks can be aligned and there is no (or little) comminution, a single 2-mm L-plate may be sufficient for stabilization of the ZMC fracture at the buttress.
- Every zygomatic fracture is unique. Good judgment should be used to determine how many surgical approaches are required and how many areas need to be plated. Though the authors originally supported the policy of exposing all fractures before plating, it is possible that with intraoperative imaging, fewer exposures and fewer plates and screws may be required.



TECH FIG 5 • The maximum number of plates (four-

point fixation) that might be used for a ZMC fracture. The authors would seldom find it necessary to plate the zygomatic arch, as a coronal incision would be needed. If a coronal incision is required, the plate on the arch would commonly be the second plate placed after the plate on the ZF fracture. If the arch is not plated, the orbital rim plate would commonly be the second plate placed. If there is a significant orbital floor defect, the floor would be the last part of the reconstruction after all of the other plates have been placed. Following placement of the orbital floor plate, a forced duction of the globe would be performed to confirm that the reduction of the zygoma or reconstruction of the orbital floor did not result in entrapment of the extraocular muscles or other soft tissues of the periorbital area.

- In the same way that a few fractures may attain stability without any fixation, some fractures may attain adequate stability (especially if there is no gap at the ZF fracture) with simpler one- or two-point fixation. In these noncomminuted fractures, one- or two-point fixation of the lateral wall of the midface with the possible addition of an IOR plate may be a consideration.
- In many cases in which the preoperative CT confirms a simple fracture of the IOR, this area may be adequately visualized using the intraoral approach only, without needing a periorbital incision.
- In cases of severe comminution of the multiple landmarks with significant displacement of the ZMC and a comminution of the lateral wall of the orbit, four-point fixation with exposure and fixation of the arch may be considered using a coronal incision, combined with other incisions (**TECH FIG 5**).

PEARLS AND PITFALLS

Adequate reduction and stabilization	■ Address all of the key landmarks for proper reduction, including the ZF suture, the lateral wall of the orbit, the orbital rim, and the lateral column of the midface. Make certain that the zygomatic arch is not laterally displaced, thus widening the midface, or medially displaced and impinging on the coronoid process of the mandible. Based on the degree of comminution and displacement found both on CT and intraoperatively, a decision must be made whether to use one-, two-, three-, or four-point fixation.
Intraoperative imaging	■ Availability of intraoperative imaging may help confirm an adequate reduction and possibly reduce the number of approaches that have to be used.
Navigation	■ Navigation may be used intraoperatively in the same way that intraoperative imaging is used.
Injury to the eye	■ Protect the eye by all possible means during the case. Corneal protectors are useful. A forced duction should be performed at the end of the case to confirm that there has not been entrapment of orbital soft tissue.
Injury to the infraorbital nerve	■ Numbness of the infraorbital distribution is common both pre- and postoperatively. If it appears that fracture segments are impinging on the nerve at the infraorbital foramen, it may be worth disimpacting the foramen by removal of a small amount of bone or fractured segment using an intraoral approach.

POSTOPERATIVE CARE

- Confirming that the patient's vision has not been compromised because of work in the periorbital area in the postoperative period is important.
 - Red color desaturation is also an important test as red color perception is first to be lost in optic nerve compromise.¹
- Both preoperatively and postoperatively, it is important to keep the head of the bed maximally elevated to decrease facial and, in particular, periorbital edema.
 - The use of nonsteroidal anti-inflammatory medications should be encouraged.
 - Many surgeons use steroids in the perioperative phase to help with inflammation, pain, and edema.
 - The growing dangers of excessive use of narcotics in North America need to be addressed.
 - Antibiotic use in the perioperative phase is common. Use of antibiotics is usually the surgeon's prerogative, but there is little evidence on its need and

the ideal duration of use.

- The use of ice packs may also be beneficial for pain and swelling in the immediate postoperative period.
- When conservatively treating zygomatic arch fractures by elevation alone (without plating), it is important to instruct the patient not to lie on the side of the fractured arch.
- Some surgeons advocate the use of aluminum eye shields or protectors or some other external splints to be sutured to the lateral aspect of the zygomatic arch, with the suture being driven deep to the arch. This may serve as a buttress to prevent a reduced arch fracture that has been displaced, from collapsing medially. Others argue that it also reminds the patient not to sleep on that side. Our study suggests that if the arch is properly reduced, it remains stable.⁷ Generally, if the patient is having pain, he does not lie on the fractured side of his face.

OUTCOMES

- If proper reduction is achieved and care is taken with the surgical approaches, excellent results are achieved with the anteroposterior projection and the transverse dimension of the face.

COMPLICATIONS

- Complications can include blindness, entrapment of the periorbital contents, orbital dystopia, widening of the midface, or other sequelae from an improper reduction.
- Numbness of the infraorbital nerve distribution is common but often resolves with time.
- Many surgeons have suggested a resuspension of the soft tissues after degloving the midface to prevent sagging of the tissues. Others feel an adequate layered closure of the various periorbital approaches or a more limited degloving of the soft tissue may avoid the problem of soft tissue sag.

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Addressing Late Malpositioning of the Zygomaticomaxillary Complex

64

CHAPTER

Warren Schubert and Yeshaswini Thelekkat

DEFINITION

- Late malpositions of the zygomaticomaxillary complex (ZMC) result when fractures either were not addressed at the time of the original trauma or were opened and internally fixated but not properly reduced.
- The term late in this chapter refers to fractures that have healed in a malposition and require an osteotomy to mobilize and reposition the zygoma.
- The term OIF (opened and internally fixated, but not reduced) has been popularized by Joseph Gruss to suggest that rather than have a proper ORIF (open reduction and internal fixation) the patients have been opened and internally fixated but not properly reduced, resulting in a malposition of the ZMC.
- The authors have been impressed that elderly and malnourished patients with ZMC fractures—even 6 weeks after initial trauma—can occasionally be replicated and mobilized using an osteotome without a saw and then fixated using methods outlined in the chapter on primary fixation of acute ZMC fractures.
- Osteotomies in a potentially new plane should always be avoided if the exact positions of the previous fractures can be replicated.

ANATOMY

- The key is attaining proper repositioning and stabilization of the zygomatic processes and buttresses.

- Though not absolutely required, the surgeon may consider a coronal approach when addressing a late malposition. As a result, a plate on the zygomatic arch to restore the AP position of the zygoma is more likely to be considered when addressing a late malposition than in routine acute ZMC fractures.
- The goal is to re-establish the alignment and proper position of the zygomaticofrontal (ZF) fracture, the lateral wall of the orbit (junction between the greater wing of the sphenoid and the zygoma), the orbital floor, the inferior orbital rim, the lateral maxillary column of the midface, and the zygomatic arch (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient may present with a variety of deformities including blunting of the malar eminence, enophthalmos, diplopia, dystopia of the eye, lateral canthal malposition, widening of the midface or depression of the zygomatic arch, and numbness in the infraorbital nerve distribution.

IMAGING

- As with an acute ZMC fracture, the appropriate radiologic workup requires fine-cut computed tomography (CT) slices.
 - The ideal workup includes axial cuts, reformatted coronal cuts, and oblique parasagittal cuts through the orbit. 3D reformatting of the midface may also be useful (**FIG 2**).
- Because the surgeon is faced with issues of remodeling of the bony fragments, exact repositioning of the osteotomized segments may present a challenge.
 - The surgeon may choose to use intraoperative CT to ensure the proper reduction of the osteotomized segments in the same way that surgeons have used this technique for acute fractures.¹
- Navigation may be used intraoperatively in a similar way that intraoperative imaging is used if this technology is available to the surgeon.²
 - With navigation, obtaining a preoperative CT with a fiducial guide may be necessary.
 - The surgeon is able to perform a virtual correction of the proper placement of the ZMC on the injured side by mirroring the proper position of the ZMC from the contralateral uninjured side.
 - At the time of surgery, the malpositioned ZMC is moved into its proper position as visualized in the virtual image.

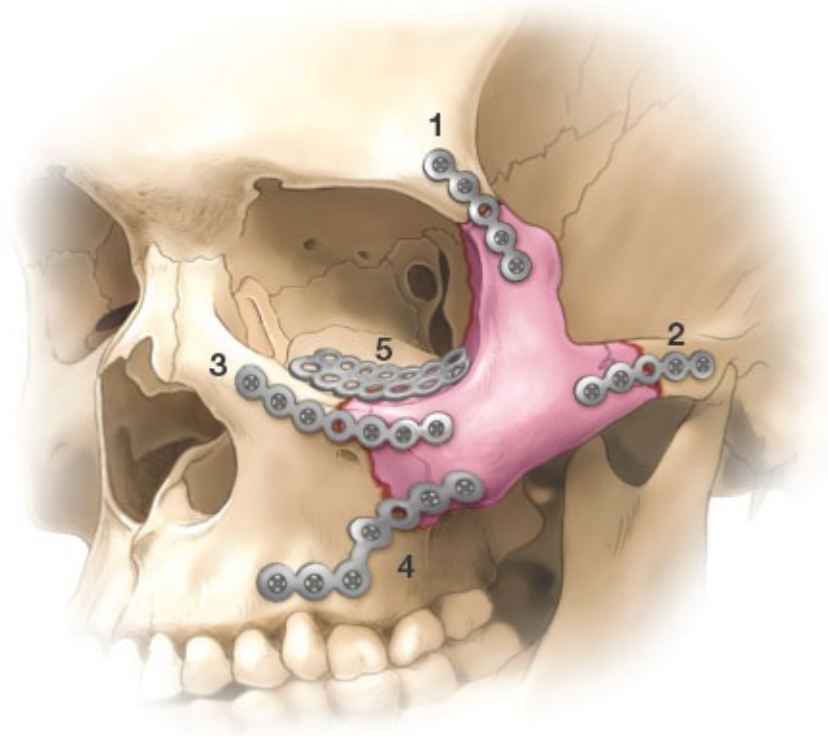


FIG 1 • Key anatomic points that need to be realigned and fixated: (1) Fronto-zygomatic suture; (2) Zygomatic arch; (3) Infraorbital rim; (4) Zygomatico-maxillary buttress; (5) Orbital floor.

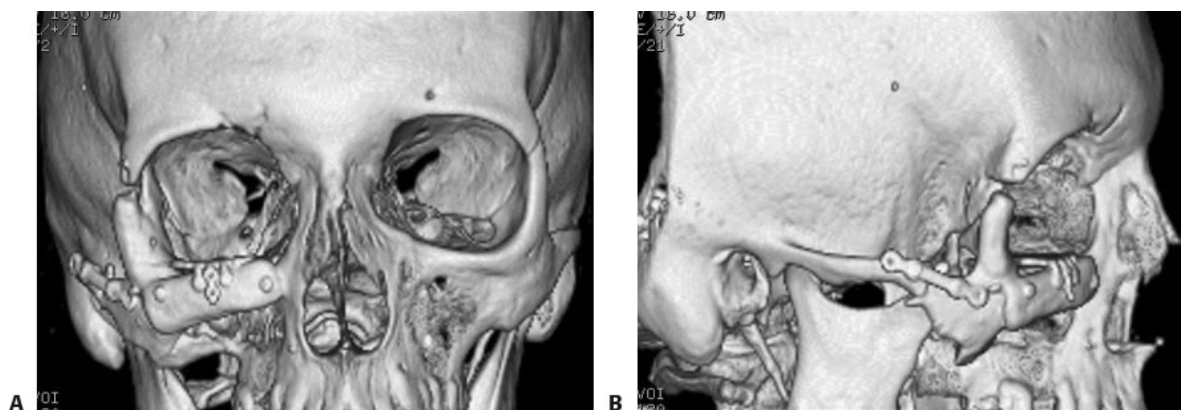


FIG 2 • **A.** AP CT of a late malposition of the ZMC in a patient who has had multiple past procedures, including a bone graft of the inferior orbital rim. It is clear that the ZMC was fixated without reduction (OIF). **B.** Lateral CT shows that a proper reduction of the ZF suture and the

zygomatic arch was never achieved.

NONOPERATIVE MANAGEMENT

- Nonoperative management is always an option.
- The authors' only experience with blindness with a ZMC repositioning occurred after an osteotomy was performed for correction of a late malposition. Our impression is that addressing a chronic deformity with enophthalmos has a significantly higher associated risk of blindness, possibly due to an orbital compartment syndrome, than does repositioning of an acute ZMC fracture.

SURGICAL MANAGEMENT

Preoperative Planning

- A complete ophthalmic examination should be performed by documenting the canthal and lid positions, identifying if there is a superior sunken sulcus of the upper eyelid, full movement of the extraocular muscles, diplopia, dystopia, and field defects.
- Exophthalmometric measurements of the degree of enophthalmos may be useful.
- As the lateral aperture of the orbit is often displaced, we prefer using a Naugle exophthalmometer over a Hertel and resting the Naugle on the frontal bar (**FIG 3A**). This assumes that the fractures being addressed do not include a displaced frontal bar.
- A McCoy facial trisquare is useful in measuring the relative location of the medial and lateral canthi to the contralateral lateral canthi (**FIG 3B**). An analysis of canthal positioning in photographs can be useful as well.
- Using either a photo or a trisquare, a horizontal line is drawn through the medial canthi to determine the relative positions of the lateral canthi.
- Our recommendation is to compare with the position of the contralateral (uninjured lateral canthi) with the eyes both open and closed.
- A complete neurologic examination including assessment of sensation of the infraorbital nerve distribution and the function of the motor branches of the facial nerve should be included in the workup.
- Preoperative photographs and high-quality CT imaging with the cuts mentioned previously, possibly with fiducials (if navigation is available), should be obtained for all patients.

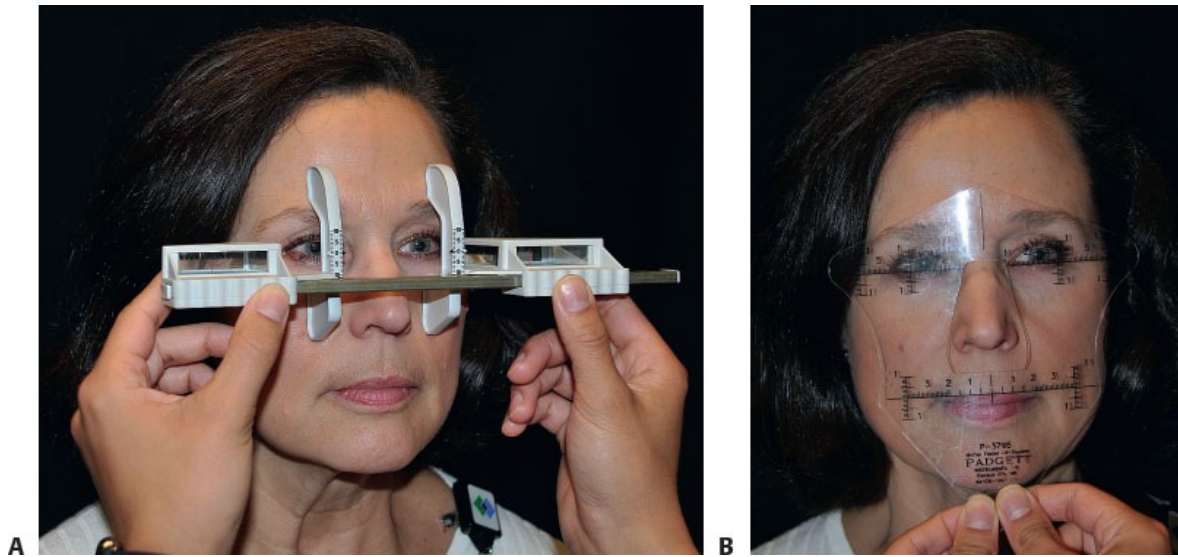


FIG 3 • A. Demonstration of a Naugle exophthalmometer for measuring globe protrusion. The advantage of this exophthalmometer is that unlike the Hertel, it does not rest on the lateral orbital aperture. If the malar eminence is involved with the trauma, it is possible to slightly tip the device up so that it is resting on the frontal bar. Though the absolute measurements may be slightly distorted, the surgeon is able to gain a good idea of the relative degree of globe protrusion (or enophthalmos) compared to the uninjured side. **B.** Demonstration of the use of the McCoy facial trisquare to examine the relative position of the medial and lateral canthus.

Positioning

- Positioning of the patient should allow the surgeon access for a coronal incision.
- Because we commonly use intraoperative imaging, we position the OR table 180 degrees from the anesthesiologist, with a straight oral tube for intubation.
- If intraoperative imaging is not available, positioning the table at 90 degrees from the anesthesiologist is adequate.

Approach

- It may be a difficult decision, depending on the complexity of the case, to determine the number of surgical approaches required to perform the osteotomies and obtain an adequate reduction of the zygoma.
- A further determinant may be the exact location of the previous fractures and the required locations of the osteotomies. It may be possible to use the same surgical approaches as with the acute ZMC.
- This would include an upper blepharoplasty incision to approach the ZF suture; a periorbital dissection to expose the lateral orbital wall and floor of the orbit, as well as the inferior orbital rim; and an intraoral approach to recreate the zygomaticomaxillary fracture and to perform the osteotomy through the zygomatic arch (**FIG 4**).
- In many cases, the surgeon may determine that the safest approach (and possibly easiest) is to perform a coronal incision for access to the ZF suture, lateral orbital wall, and the zygomatic arch.

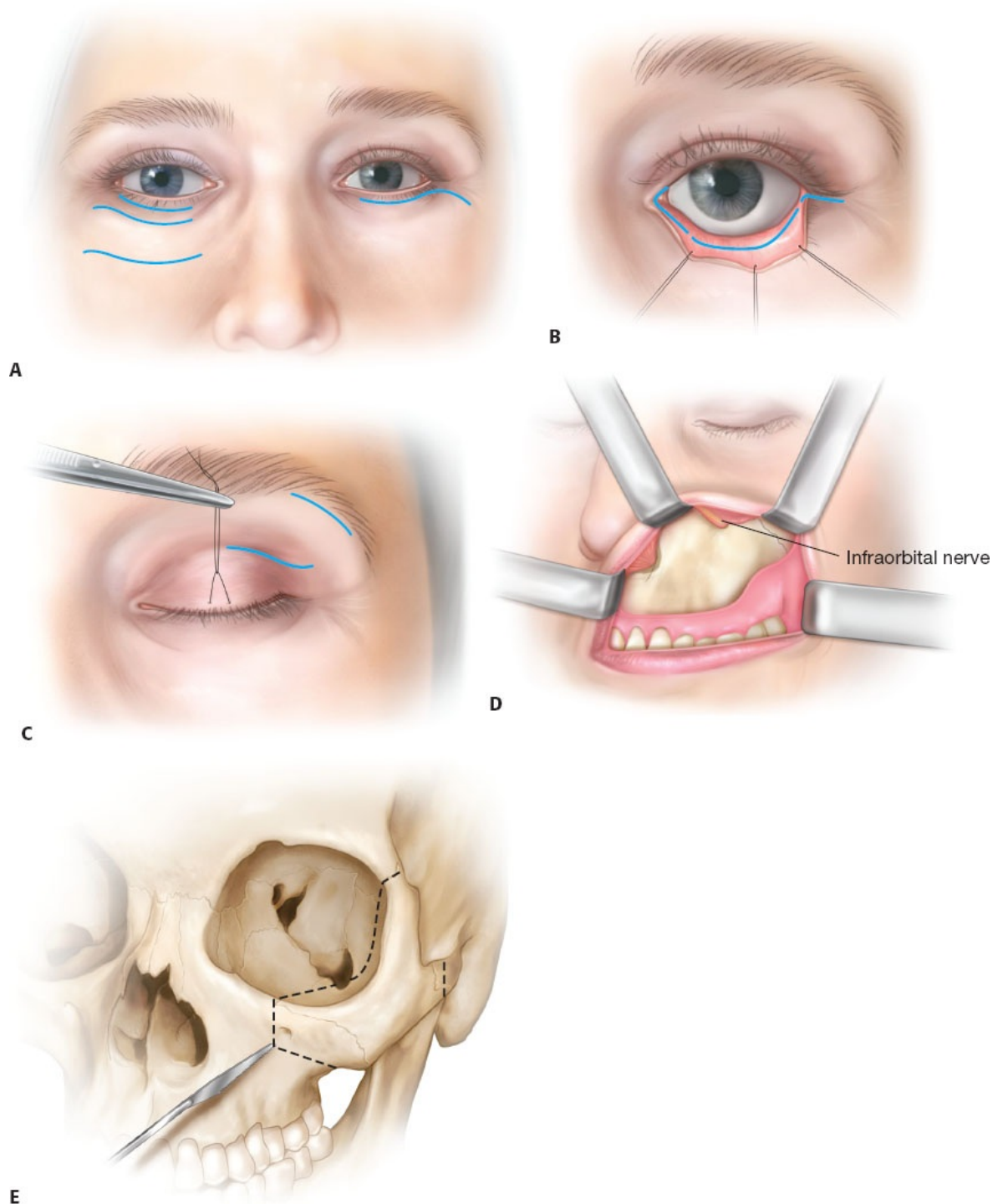


FIG 4 • Incisions: periorbital (subciliary, midlid, and orbital rim; **A**), conjunctival-lateral canthotomy (**B**), upper eyelid (blepharoplasty and brow; **C**), and intraoral (**D**). We do not recommend the orbital rim and brow

incisions due to unfavorable scars. **E.** Osteotomy of the zygomaticomaxillary segment made through the periorbital and intraoral approaches and the osteotomy of the zygomatic arch made through the intraoral incision using a Keen type of approach.

TECHNIQUES

- The first item the surgeon must address with the patient is the aspect of the deformity that bothers the patient most and the risks of various treatment options.

■ Camouflage Corrections

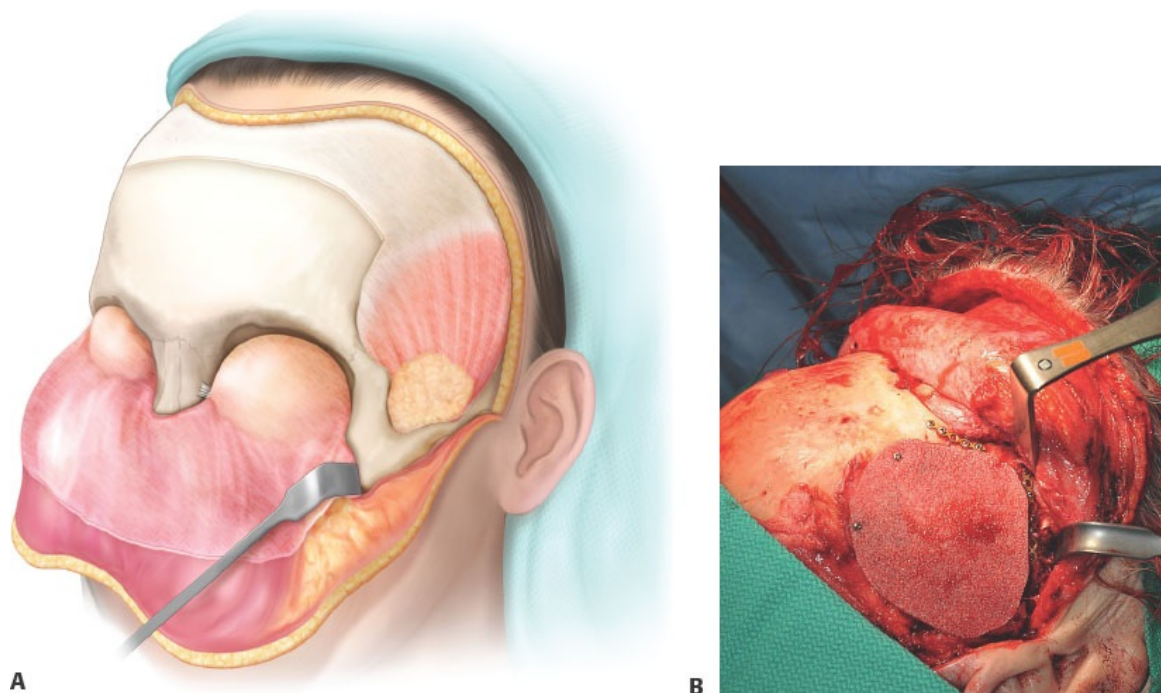
- The patient may choose more conservative methods of treatment or camouflage procedures to cover the deformity, without osteotomies to reposition the zygoma.
- Enophthalmos or dystopia may be adequately corrected with the use of bone grafts, cartilage, or porous polyethylene (PPE) or the use of some other filler in the orbit.
 - Posterior displacement of the malar eminence may similarly be addressed with a PPE malar implant or a bone graft.
 - In the past, methyl methacrylate and silicone implants were commonly used.
- A superior sunken sulcus of the upper eyelid can be addressed with fat grafting to camouflage the degree of the deformity.
- A malposition of the lateral canthus can be addressed by repositioning of the canthus.

■ Correction Requiring Osteotomies

- Assuming the most difficult case in which the patient prefers an osteotomy and complete correction of a healed OIF of the ZMC, at the minimum, periorbital and intraoral exposures are required.
 - Exposure of the ZF suture can theoretically be achieved by performing a

lateral canthotomy/conjunctival incision without a blepharoplasty incision. The degree of pull on the soft tissues in the cephalad direction results in both a struggle of retraction and more postoperative periorbital edema than including an additional lateral blepharoplasty incision.

- The blepharoplasty incision heals with a well-concealed scar.
- The authors condemn the use of the lateral brow incision, which does not provide any better exposure to the ZF suture than does a blepharoplasty incision and results in an obvious permanent alopecia and part within the eyebrow that can be permanently noted from across the waiting room.
- Through the periorbital incision, the globe can be retracted medially to expose the lateral wall of the orbit and superiorly to expose the orbital floor and perform the appropriate osteotomies.
 - Similarly, the orbital and intraoral exposure can be used to osteotomize the inferior orbital rim and the zygomaticomaxillary portion of the midface.
 - Using a Keen-type approach, the intraoral approach can also be used to perform the osteotomy of the zygomatic arch (see **FIG 4E**).
- Patients commonly present with an OIF and multiple problems. A coronal incision will often facilitate access for the various osteotomies and allows the surgeon to better visualize when adequate reduction is achieved.
 - In these cases, when a coronal incision is made, a blepharoplasty incision is not needed.
 - The periorbital incision and intraoral incision are still required.
 - The coronal incision also facilitates the exposure and osteotomy of the zygomatic arch (**TECH FIG 1A**).
 - In this case, the patient had significant temporal hollowing from previous procedures, and PPE has been placed to correct the temporal defect (**TECH FIG 1B**).



TECH FIG 1 • A. The coronal approach provides excellent exposure to much of the zygoma. **B.** Late malposition has been repositioned, using a coronal approach to facilitate exposure of the ZF suture, the lateral orbital wall, and the zygomatic arch (A PPE implant has been placed to correct temporal hollowing.).

■ Reconstruction and Fixation

- As with a traditional repair of an acute ZMC fracture, following the osteotomies and repositioning of the zygoma with fixation, a decision needs to be made as to whether the orbital floor or lateral orbital wall needs to also be reconstructed using titanium mesh, bone, cartilage, PPE, titanium mesh plus PPE, bioabsorbables, Silastic sheeting, and/or other less popular materials.
- The periorbita often must be mobilized to correct for enophthalmos. Controversy exists as to the extent of mobilization required to achieve adequate correction of globe protrusion.
 - In his original publication describing this procedure, Kawamoto³

recommended a complete 360-degree dissection and mobilization of the periorbita. In a later publication, Longaker and Kawamoto⁴ suggested that only the portion of the periorbita attached to the displaced ZMC needed to be mobilized. The extent of required mobilization remains controversial, and a perfect esthetic result in a patient with chronic exophthalmos remains a challenge.

- The challenges facing the surgeon include scarring of the periorbita.
- Even with a perfect reduction of the ZMC, it is possible that foreshortening of the soft tissue of the orbit and the extraocular muscles may prevent the surgeon from achieving proper globe projection.
- Although one- or two-point stabilization with plates and screws may be adequate in acute ZMC repair, because of the degree of scarring and foreshortening of the soft tissues, three- or four-point fixation is generally needed for malpositioned ZMC.
- Navigation and intraoperative imaging may also be very helpful in these cases, if the technology is available.

PEARLS AND PITFALLS

Preoperative clinical documentation

- Complete eye examination with documentation of limitations and asymmetries

Preoperative radiologic documentation

- Midface CT with reformatting and 3D reconstruction. Fiducials if navigation techniques are being considered

Camouflage alternatives

- Alternatives to osteotomies should be discussed: camouflage procedures, alternatives for correction of enophthalmos, and malar augmentation to correct asymmetry.

Mobilization of the periorbita

- The periorbita often must be mobilized to correct for enophthalmos. Controversy exists as to the extent of the mobilization that must be performed to achieve an adequate correction of globe protrusion.

Intraoperative assessment

- Use of intraoperative imaging or navigation, if available

POSTOPERATIVE CARE

- Postoperative care after addressing a late malposition of the ZMC is similar to that of acute treatment of the ZMC, with greater concern to ensure that the patient does not develop an orbital compartment syndrome.
- Performing a forced duction test at the end of the case and confirming that the patient's vision has not been compromised in the postoperative period is important.
- Keep the head of the bed maximally elevated to help decrease edema.
- The use of nonsteroidal anti-inflammatories should be encouraged. Many surgeons also use steroids in the perioperative phase to help with inflammation, pain, and swelling.
 - The growing danger of excessive use of narcotics in North America needs to be addressed.
 - Antibiotic use in the perioperative phase is common but with little evidence.
- The use of ice packs may be beneficial for pain and swelling in the immediate postoperative period.

OUTCOMES

- An improved or perfect repositioning of the zygoma is the goal. However, a perfect correction of enophthalmos and other chronic soft tissue asymmetries may be impossible to correct perfectly.

COMPLICATIONS

- Failure to adequately correct the malpositioned ZMC
- Failure to adequately correct soft tissue asymmetries
- Postoperative diplopia, dystopia, and blindness

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65 Correction of Le Fort I Fracture

CHAPTER

Ananth S. Murthy

DEFINITION

- The maxilla forms most of the middle third of the facial skeleton. It is attached to the zygomatic bone and nasoethmoid area.
- There are a series of vertical and horizontal buttresses to absorb energy during impact by alternating thick and thin structures of the bones.
- Le Fort I fractures occur above the apices of the dental roots, continue across the base of the maxillary sinus, and extend to the pterygoid process.

ANATOMY

- The maxilla forms portions of the orbit, nasal cavity, and oral cavity.
- It contributes to the stability of the face by interacting with the cranium to form buttresses (**FIG 1**).
 - Nasofrontal buttress: Medially with nasal bones and glabella (frontal bone)
 - Zygomatic buttress: Laterally with the zygoma, which further articulates with the frontal bone, sphenoid, and temporal bone
 - Pterygomaxillary buttress: Posteriorly with sphenoid
- Four processes: Frontal, zygomatic, palatine, and alveolar
- During childhood, the maxilla acts as a tooth bank. As permanent teeth erupt and sinuses form, the anterior wall becomes thin and the alveolar segment becomes thick. With aging, as permanent teeth exfoliate, the alveolar segment resorbs and recedes.
- The infraorbital nerve passes through the infraorbital canal in the anterior maxilla and supplies sensation to the upper lip and lateral portion of the nose.
- Fractures of the maxilla are caused by direct impact; pattern and distribution vary depending on magnitude and direction of force.

- Le Fort I fractures usually occur in combination with other maxillary and/or facial fractures (**FIG 2**).

PATHOGENESIS

- The most common cause is a frontal impact.
- The victim is usually thrown forward, striking the midface against an object, for example, the dashboard or steering wheel of a car.
- Displacement of the maxilla is generally posterior and inferior. Pterygoid musculature aids in this direction of displacement.
- Because of this displacement, premature contact of molars often results in an anterior open bite.
- Untreated fractures will result in maxillary retrusion and decreased facial height and malocclusion.

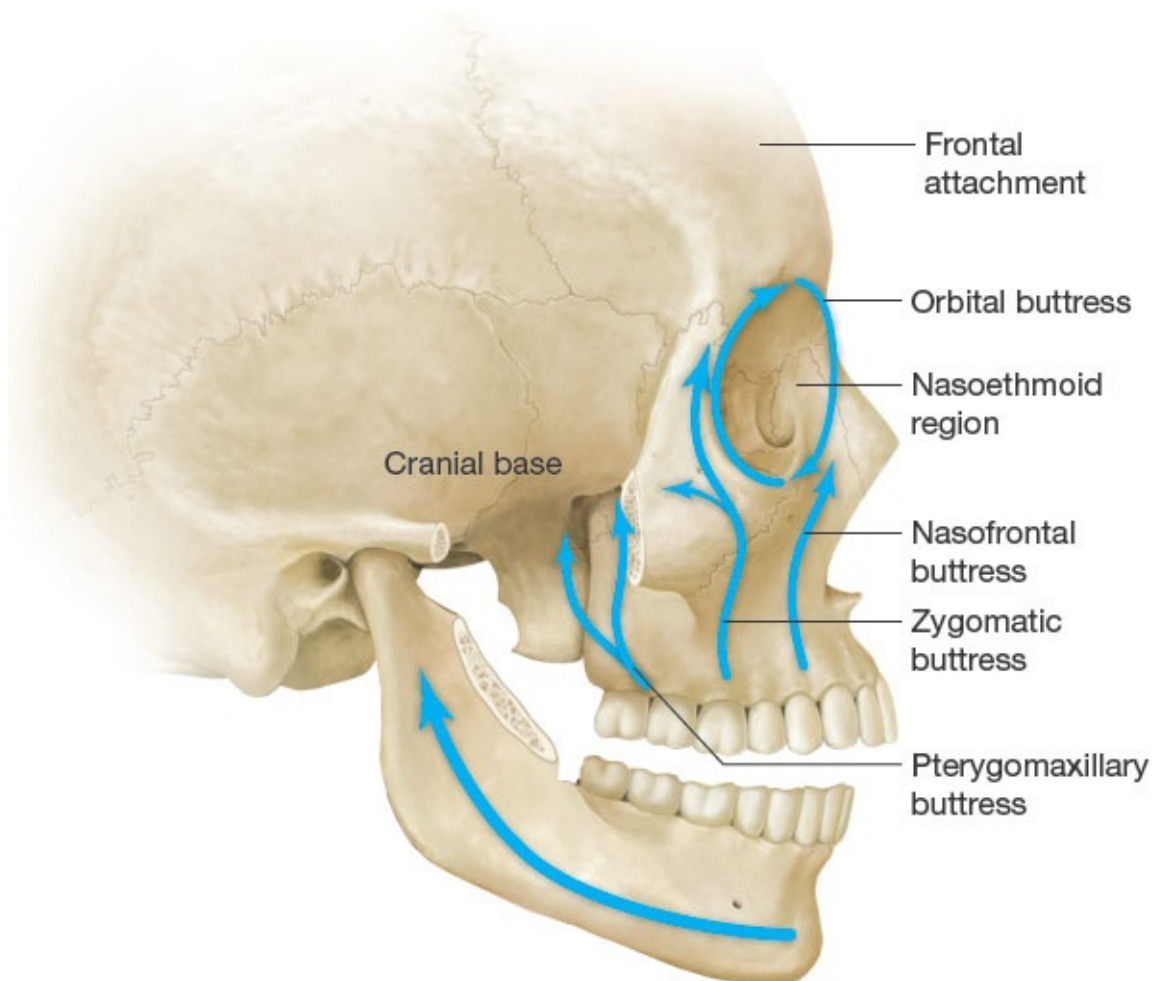


FIG 1 • A series of vertical and horizontal buttresses

(alternating thick and thin structures of the bones) that absorb energy during impact.

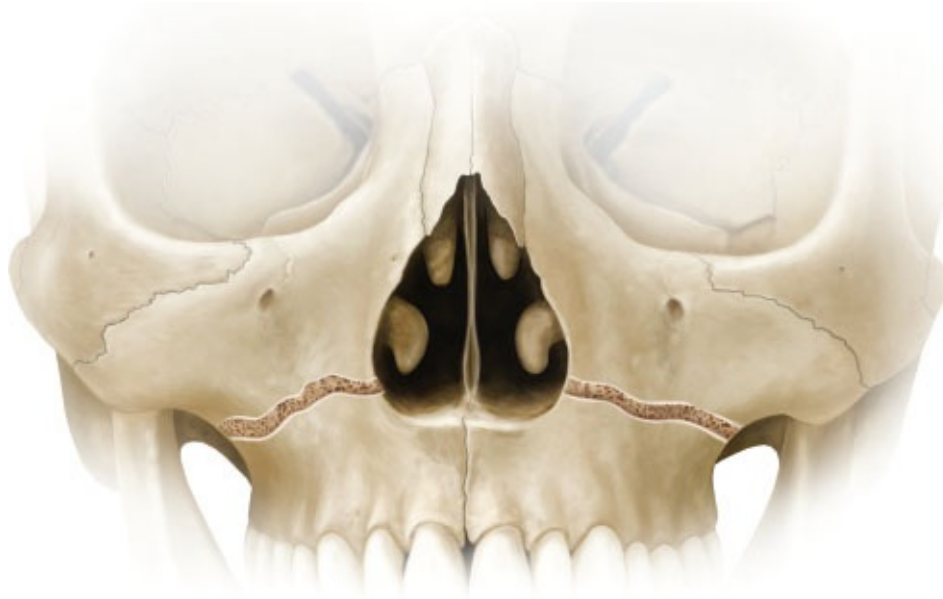


FIG 2 • Le Fort I fractures occur above the level of the dental apices, across the maxillary sinus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Mobility of maxillary dentition is the hallmark of a maxillary fracture.
 - Force applied by grasping the anterior portion of the maxilla with the thumb and index finger elicits mobility of the maxilla. Integrity of the palate should be assessed in cases of segmental or split palatal fractures.
- Epistaxis, ecchymosis, and edema are seen.
 - There is midface retrusion, and malocclusion is present.
 - There may be hematoma and lacerations of the buccal mucosa.
- Evaluation for other fractures of the face, especially nasal fractures, should be performed, as isolated fractures of the maxilla are rare.

IMAGING

- Computed tomography (CT) scan is required for diagnostic examination of the maxilla. Axial cuts are best to demonstrate fractures of the maxilla.
- Three-dimensional (3D) reconstructions aid in assessing symmetry and displacement of the maxilla (**FIG 3**).

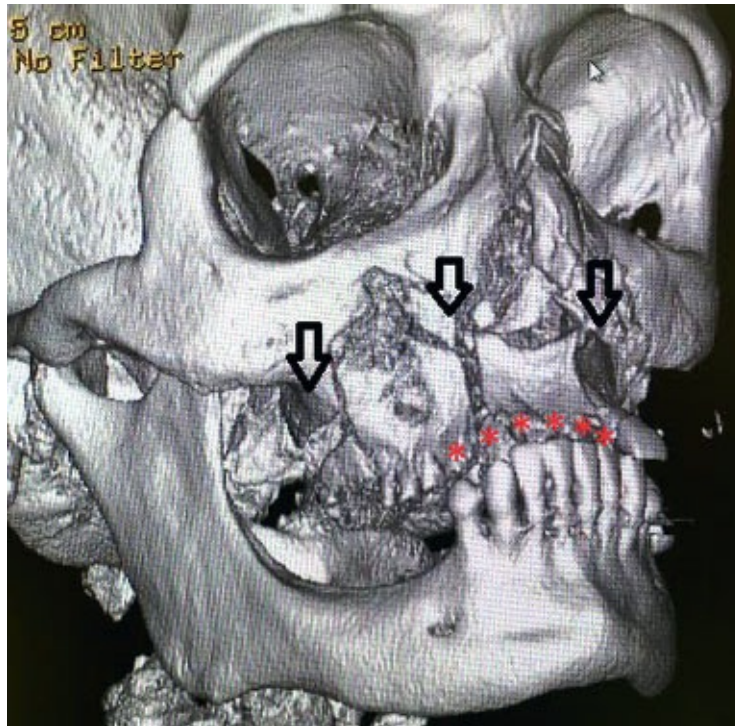


FIG 3 • CT scan showing Le Fort I maxillary fractures. Note the posterior impaction of the maxilla due to the trauma. Often segmental fractures (*arrows*) and loss of dentition (*asterisks*) are also seen.

SURGICAL MANAGEMENT

- Timing of surgery depends on the severity of injury.
 - Open, unstable fractures with hemorrhage will need emergent care.
 - Closed fractures with displacement and malocclusion should be treated within a week of injury.
- Initial treatment should be directed toward airway control, hemostasis, and maxillomandibular fixation.
- When comminuted fractures are present along with oronasal hemorrhage, and unstable midface, then, tracheostomy should be performed to obtain airway control.
- If endotracheal intubation is done, it should be converted to a nasotracheal airway so MMF can be pursued.
- The simplest and most effective way to reduce a maxillary fracture is to place the patient in occlusion with maxillomandibular fixation.

- Arch bars are useful because Le Fort fractures are usually accompanied by dentoalveolar fractures.
- Interdental wiring, dental bonding, and use of occlusal splints with quick-curing acrylic resins are also helpful in cases of displaced or missing teeth.
- The goals of treatment should be to re-establish midfacial height and projection, along with occlusion.
- Critical buttresses should be visualized, and the maxilla reduced for accurate alignment of these buttresses.
- Plate and screw fixation is necessary for control of fractures and fracture fragments.

Preoperative Planning

- Risks of tooth loss and malocclusion should be discussed with the patient. Preoperative occlusion should be determined by questioning patient or caretaker.
- Preoperative CT scans are imperative for diagnosis and planning. Intraoral exam to determine any dentoalveolar injury is important.
- If severe malocclusion is present with multiple fractures of the maxilla, then preoperative dental impressions along with model surgery and an occlusal splint may assist in obtaining maxillomandibular fixation.
- Arch bars/MMF systems, 26-G stainless steel wires, lidocaine with epinephrine, periosteal elevators, intraoral retractors, Rowe forceps, bone hooks, and 1.0 to 1.5 mm midface titanium plating systems will be needed.
- Loupe magnification with headlight assists with visualization.

Positioning

- Supine positioning with the head toward the anesthesia team allows access from both sides of the patient to the buccal sulcus and maxilla.
- Nasotracheal intubation is necessary, as MMF will be required. If fractures are unstable with oronasal hemorrhage, a tracheotomy should be considered.

Approach

- A buccal sulcus approach is the best way to visualize the maxilla.
- Preoperative injection with a local anesthetic plus epinephrine assists in hemostasis.
- A lip retractor, such as an Orringer retractor, aids with the exposure.

TECHNIQUES

■ Exposure and Reduction

- A lip retractor is placed and occlusion is assessed. A throat pack is placed.
- A buccal sulcus incision is made with a 10-mm cuff above the gingival border. When making the incision, avoid injury to the parotid duct, which is usually present at the level of the maxillary first molar.
- Using cautery, perpendicular dissection is directed toward the maxilla.
- Subperiosteal dissection is then performed with a Joseph elevator.
- The maxilla is exposed from the piriform/anterior nasal spine medially to the orbital rim superiorly (the infraorbital foramen and contents are visualized), the maxillary tuberosity laterally, and the zygoma superolaterally.
- A curved periosteal elevator can be used to dissect around the maxillary tuberosity hugging the bone until the pterygomaxillary fissure is reached by the tip of the elevator.
 - Avoid disrupting the buccal fat pad with lateral dissection; fat within the operative field becomes a nuisance during the case.
- All fractures are visualized. If vertical fracture lines are present between tooth roots, or alveolar fractures present, these are addressed first.
- Interdental wires can help align the vertical fractures.
- Rowe disimpaction forceps can be used to position the maxilla (**TECH FIG 1**).

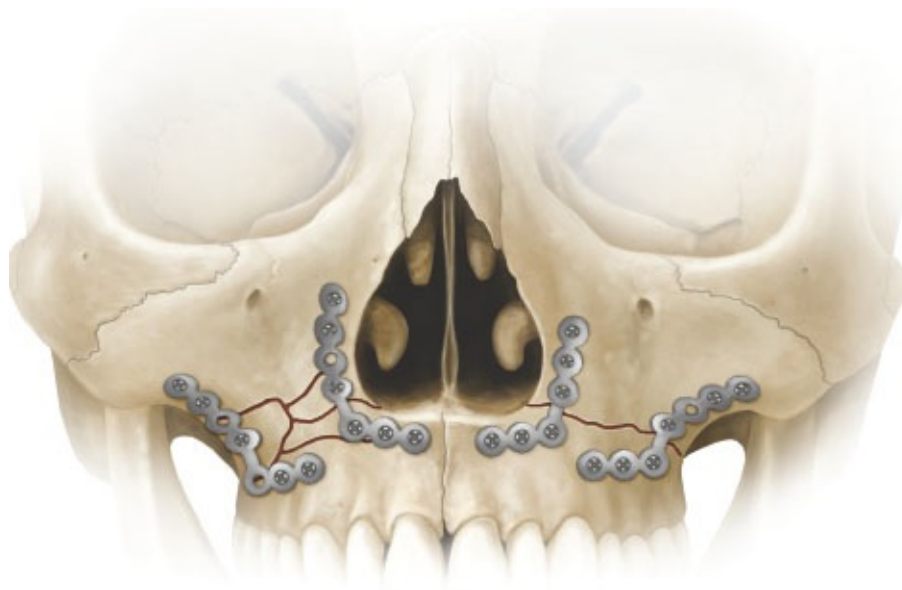


TECH FIG 1 • A and B. The use of Rowe forceps to

reduce maxillary fractures.

■ Maxillomandibular Fixation

- Arch bars are then placed on the maxillary and mandibular dentition; 26-gauge stainless steel wires are preferred.
- MMF is achieved by placing wire loops around the arch bars.
- After MMF, attention is turned to the maxilla. The fractures along the nasomaxillary and the zygomaticomaxillary buttresses are visualized. These are aligned. If there are greater than 5 mm gaps, they should be filled with a bone graft.
- Six-hole L-shaped plates work well for fixation.
 - Monocortical drilling at 8000 RPM with copious irrigation is needed.
 - Screws of 4 to 5 mm are typically adequate for fixation.
 - Three screws on each side of the fracture are optimal.
- The horizontal portion of the L-plate is affixed just above the dental roots (or between them), and the vertical portion is used to secure it to the stable portion of the maxilla or zygoma (**TECH FIG 2**).
- After medial and lateral buttresses are secured bilaterally, MMF should be released and occlusion tested. If normal occlusion and range of motion are present, then closure can be commenced.



TECH FIG 2 • Plating schema for Le Fort I fractures. It

is important to reduce the fractures and fixate them. Plates must be bent to accommodate the curvature of the buttresses.

- After thorough antibiotic irrigation, the buccal sulcus is closed from a lateral to medial progression. Interrupted 4-0 Vicryl sutures are placed in a composite fashion so that the muscle and mucosa of the buccal sulcus are closed together in a watertight fashion.
- After removal of the throat pack, an orogastric tube is placed and suctioned, prior to extubation.

PEARLS AND PITFALLS

Dissection	■ Gentle dissection near the maxillary tuberosity prevents piercing into the buccal fat pad and the nuisance of subsequent fat herniation into the surgical field.
MMF	■ If fractures are segmental and/or severely displaced, expose the fractures, followed by open reduction and pre-emptive alignment using wire. Then, MMF can be pursued successfully followed by internal fixation. ■ Leave MMF bars/screws for a few weeks after confirmed functional occlusion.
Malocclusion	■ If malocclusion is noted (initially as lack of cuspid contact), elastics should be instituted.
Gaps	■ Gaps in the critical buttresses larger than 5 mm should be grafted with bone.

POSTOPERATIVE CARE

- If used alone, MMF should be instituted for 4 weeks. If internal fixation is performed, MMF is not required.
- A nonchew diet is instituted until the bone is healed. Typically, this means liquids for the first week, followed by blended food for 6 to 8 weeks.
- Oral hygiene is critical. Chlorhexidine mouthwash helps maintain good oral hygiene.

- Nasal cleansing with saline sprays assists in clearing clot and exudate after surgery. Nose blowing is prohibited for 3 weeks, as the increased pressure may lead to epistaxis.
- Perioperative antibiotic for 24 hours is recommended, along with postoperative pain management.
- Orthodontic referral is recommended for guided elastics if malocclusion is suspected.
- Physical therapy for jaw mobilization aids in recovery of function.

COMPLICATIONS

- Hemorrhage can be managed with ligation, packing, and MMF.
 - If hemorrhage is not controlled with these measures, interventional radiology referral for embolization may be necessary.
- Airway can be managed based on severity.
 - Intubation postoperatively may be indicated, especially if MMF is maintained.
 - Tracheostomy may be necessary if nasal intubation is not possible due to extensive trauma.
- Anesthesia of the cheek. This is usually secondary to traction and should return over the first 8 to 12 weeks.
 - If the infraorbital nerve has been severed or avulsed, permanent anesthesia will result if not repaired.
- Dehiscence of buccal sulcus incision may occur. Meticulous oral care is necessary.
 - If plates are exposed, continue oral care till bone healing is noted.
 - Hardware may be removed after healing is confirmed radiographically.
 - Instability, not exposure, causes infection and malunion.
- If multiple lacerations are noted along the gingiva, be careful to preserve a vascular cuff at the buccal sulcus incision.
 - The mucosa should be preserved centrally and not incised to preserve vascularity.
 - If compromised, gingival necrosis/retraction can be noted postoperatively.
- Postoperative infections are rare despite the continuity and involvement of oral/nasal cavities and maxillary sinuses. Infections may occur in the face of pre-existing sinusitis, or dental infection.
 - If sinusitis is suspected, traditional methods of treatment are recommended.

- If dental abscess is suspected, tooth extraction may be required.
- Malocclusion may present at several time points. If malocclusion is seen after release from MMF and with articulation of the mandible, it is necessary to remove and replace internal fixation.
- If normal occlusion is obtained intraoperatively, and malocclusion is seen within the first 4 weeks postoperatively, then MMF can be reinstituted.
- After 4 weeks, guided elastics are recommended.
- After 8 weeks, when union across the fracture is expected, reosteotomy at the Le Fort I level and fixation is necessary.

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66 Correction of Le Fort II Fracture

CHAPTER

Nataliya Biskup and John van Aalst

DEFINITION

- Le Fort II is a midface fracture pattern that classically involves the critical vertical facial buttresses:
 - Nasofrontal
 - Zygomaticomaxillary
 - Pterygomaxillary (pathognomonic component of all Le Fort fractures)

ANATOMY

- The fracture starts at the zygomaticomaxillary buttress, extends through the inferior orbital rim and orbital floor to the nasofrontal buttress, and then travels posteriorly to involve the pterygomaxillary junction (**FIG 1**).
- The level of fracture across the nose is variable, ranging from as high as the nasofrontal suture to as low as the nasal cartilages.

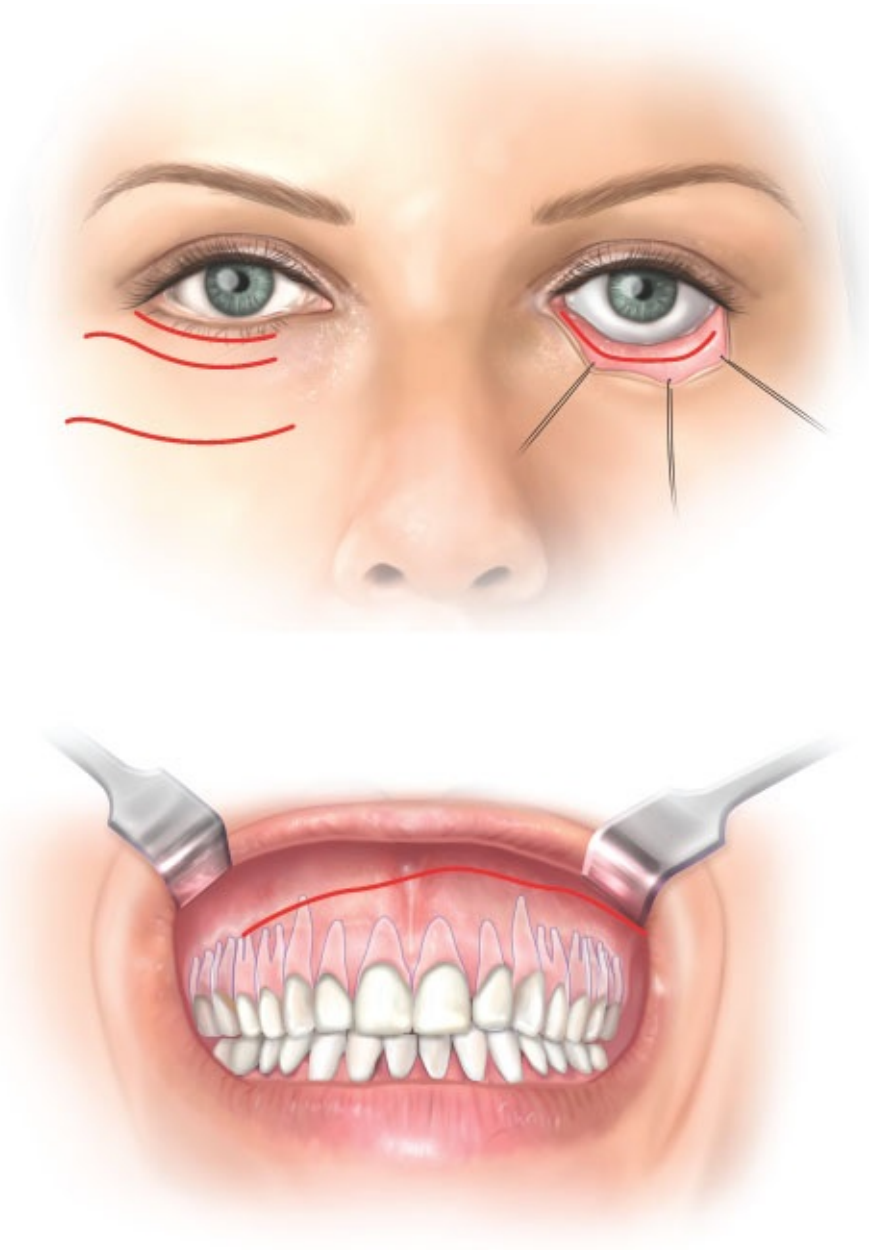


FIG 1 • Approaches for exposure of the maxilla for reduction and plating for Le Fort II fracture.

- The attached pterygoid muscles exert a posterior and downward pull on the maxilla leading to an anterior open bite with class III occlusal relationship.
- Fractures may be bilateral or unilateral, may be combined with other Le Fort fractures, and often may be a component of a pan-facial injury.
- Medial and inferior orbital walls and nasoethmoid fractures are commonly associated fractures. If the fracture traverses the lacrimal fossa, it may involve

the lacrimal system.

PATHOGENESIS

- Le Fort II fractures result from high-velocity, blunt trauma, such as motor vehicle collisions.
- Patients will often report being thrown forward striking the midface against an object such as a steering wheel.

PATIENT HISTORY AND PHYSICAL FINDINGS

- In addition to diffuse facial edema, malocclusion, periorbital ecchymoses, and epistaxis are often present.
- Mobility of the maxilla is a hallmark clinical finding.
- Step-offs along the inferior orbital rim may be palpable.
- The key points of examination are as follows:
 - Rule out cervical spine injury.
 - Evaluate ocular/orbital injury (vision, pupils, extraocular movement).
 - Assess cranial nerve V2 (sensation over cheek, lateral nose, and upper lip).
 - Evaluate occlusion. The expected occlusion is class III with an anterior open bite with premature posterior tooth contact.

IMAGING

- Maxillofacial CT with 3D reconstruction is the standard for diagnosis and preoperative planning. Fluid in the maxillary sinus is the most reliable indicator of maxillary fractures.

EPIDEMIOLOGY

- Most patients are males in their 30s involved in motor vehicle collisions.¹
- Among patients with maxillary fractures, the incidence of Le Fort I, Le Fort II, and Le Fort III fracture is 16% to 55%, 14% to 24%, and 13%, respectively.
 - Over half (57%) of the Le Fort fractures are combinations of the three; 89% coexist with other fractures in the maxillofacial region.²
- The incidence of associated serious eye injury is 9% and traumatic optic neuropathy 20%, and the rate becomes significantly higher for more complex fractures.^{2,3}
- Patients with Le Fort II fractures have higher injury severity scores and are more likely to need intensive care unit admission and immediate operative intervention (similar to patients with Le Fort III fractures and unlike patients

with Le Fort I injuries).^{4,5}

NONSURGICAL MANAGEMENT

- Observation is indicated in:
 - Patients with nondisplaced fractures, premorbid, unchanged occlusion, and willingness to comply with strict soft, no-chew diet
 - Edentulous patients with minimal displacement
 - Unstable patients
- Closed treatment with arch bars and guiding elastics is indicated in patients with minor malocclusion who can be reduced by closed maxillary disimpaction and manipulation.

SURGICAL MANAGEMENT

- Open treatment is indicated in patients with displaced fractures or malocclusion or those unable to comply with diet modification.

Preoperative Planning

- Rule out cervical spine injury prior to surgical correction of the facial fracture.
- Obtain ophthalmologic evaluation to rule out globe/retinal injury as intraoperative manipulation may exacerbate the injury.

Positioning

- Use nasotracheal intubation to facilitate verifying occlusion during fracture reduction.
- If nasotracheal intubation is contraindicated, place the endotracheal tube through retromolar space; if this is not possible and other lacerations are present, use submental or submandibular intubation.⁶

Approach

- Make an upper gingivobuccal sulcus incision from first premolar to first premolar, leaving a residual cuff of mucosa for final closure.
- Apply cautery directly onto maxilla the full length of the incision (**TECH FIG 1**).
- Use a Freer elevator to develop subperiosteal plane. Avoid injury to the infraorbital nerve, which exits the maxilla 1 to 2 cm below the inferior orbital rim.
- If needed, open the orbital rim via eyelid incision, either transconjunctival or

transcutaneous. If transconjunctival approach is chosen, make an incision with Bovie along the inferior fornix, well away from the tarsus. Use Bovie cautery directly onto the bone. If fracture extends medial along the rim, use a transcutaneous incision. Make an incision in the lower lid crease with a no. 15 blade. Raise a skin and orbicularis flap until arriving at the inferior orbital rim.

- Develop a subperiosteal plane to expose the infraorbital rim. Extend this approach medially via a transcaruncular approach to expose medial wall fractures if present.
- Use glabellar or coronal incisions for exposure of the nasofrontal junction, if needed.
- Close the gingivobuccal sulcus incision with 3-0 Vicryl simple interrupted. Close transcutaneous eyelid incision with 5-0 Prolene or 5-0 fast gut. Transconjunctival incisions do not need to be closed. If a lower lid incision is made, apply Frost stitch for 5 to 6 days postoperatively.

TECHNIQUES

■ Reduction

- Restore the fractured midfacial buttresses: the zygomaticomaxillary (ZM), pterygomaxillary, and nasomaxillary (NM).
- Apply Erich arch bars with 26-gauge wire.
- Expose fractures and debride callus with small curette or rongeur.
- Reduce fractures.
 - Muscular attachments to the pterygoid plates and posterior maxilla distract the maxilla posteriorly and resist reduction and fixation.
 - Use Rowe disimpaction forceps, “Stromeyer” hook, Tessier retromaxillary mobilizers, or channel retractors to passively mobilize the maxilla (**TECH FIG 1**).
 - If maxilla cannot passively be mobilized, placement of maxillomandibular fixation (MMF) can unseat the condyles such that when MMF is released, the condyles seat back into fossa, and a class III malocclusion occurs.

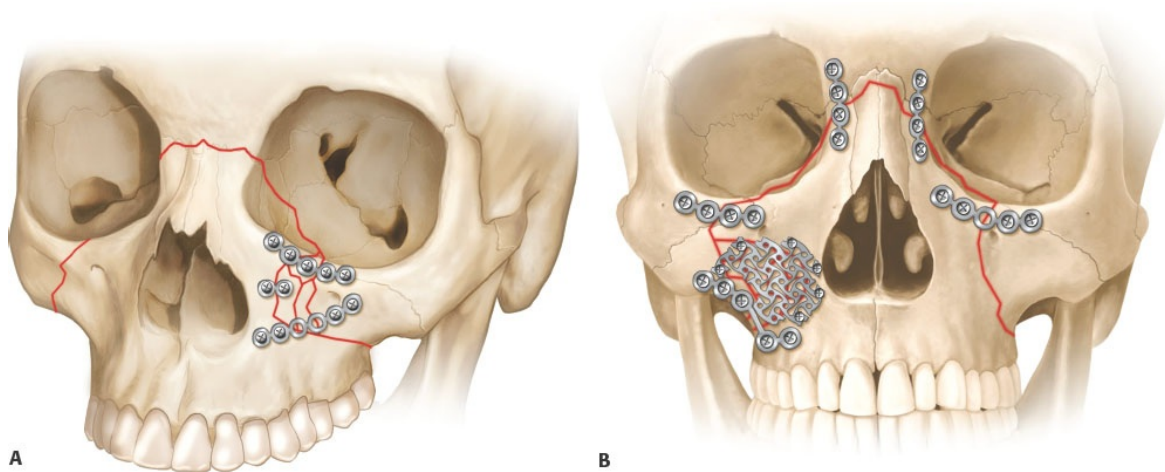


TECH FIG 1 • Instruments used in reduction of maxilla. From *left to right*: Rowe disimpaction forceps, Stromeyer hooks, Tessier retromaxillary mobilizer, channel retractors.

■ Fixation

- Once adequate reduction is obtained, fixate the maxilla.
- Two points of fixation are most common; however, the number of fixation points can vary from one to three depending on the degree of comminution and displacement of the fractures.
- Start plating at the most reliably reduced buttress (**TECH FIG 2A**).
- At the zygomaticomaxillary buttress, the greatest masticatory force is exerted; thus, use a larger caliber 1.5 or 2.0 mm L or straight plate.
 - Some Le Fort II fractures can be adequately reduced and plated at the ZM buttress only.
 - Place leg of plate along the most lateral portion of the ZM buttress as it has the thickest bone.
 - Place foot of plate along the alveolar bone taking care to avoid tooth roots.
 - In comminuted fractures, use longer plates in addition to smaller, shorter plates to reduce small fragments.
- At the inferior orbital rim, the forces are weaker and soft tissue is thinner; use a lower profile plate, such as a 1.2 mm, to avoid palpability.

- Rarely is plating at the nasofrontal area needed, as closed reduction of this fracture is often adequate.
 - If plating is deemed necessary, use low-profile straight, Y, or X plates.
- Use additional plates or mesh in comminuted fractures (**TECH FIG 2B**).



TECH FIG 2 • A. Most common plating configuration for noncomminuted Le Fort II fractures, includes plating of nasomaxillary/orbital rim and zygomaticomaxillary buttresses. **B.** Plating configuration used for comminuted Le Fort II fractures; shorter low-profile plates or a single sheet can be used to bridge bone defects.

■ Completion

- Following fracture fixation, release MMF and verify occlusion.
 - Passively open and close the mandible to see whether maximal intercuspation occurs and whether wear facets of the maxillary/mandibular dentition reference one another.
- Given that the maxilla is reduced by referencing its occlusion with the mandible, accurately reduce any mandible fractures and restore the posterior mandibular height and width.
 - Recognize any simultaneous palatal fractures, as this is critical to restoring accurate facial width.
- Reapply MMF depending on stability of reduction and restoration of

occlusion.

- Explore the orbital floor and medial orbital wall, if indicated, as Le Fort II fractures often involve fractures of these areas.
- Depending on degree of fracture displacement, reduction and fixation of these fractures may be indicated after plating the Le Fort II fracture.

PEARLS AND PITFALLS

Preoperative

- Evaluate ocular/orbital injury.
- Rule out cervical spine injury.

Technique

- Passive mobilization of maxilla is critical to prevent class III malocclusion.
- Rowe disimpaction forceps should be used with caution to avoid significant shear at the skull base and orbit and to prevent injury to the anterior maxillary dentition.
- Following surgery, immediately evaluate globe mobility and rule out entrapment with a forced duction test and check pupil symmetry.

POSTOPERATIVE CARE

- Vision and light perception should be monitored for 24 hours after reduction.
- Patient should elevate head of bed, apply ice, and avoid nose blowing for 4 to 6 weeks.
- Strict oral hygiene with gentle tooth brushing and non-alcohol-based mouthwash should be performed. Patients should have soft no-chew diet for 4 to 6 weeks.
- Postoperative antibiotics are recommended for 1 day after surgery. Antibiotics beyond this have not been shown to decrease infection rates.⁷
- Smoking and alcohol use should be avoided.
- Duration of MMF is variable from 2 to 6 weeks, depending on fracture stability after reduction, establishing occlusion, and amount of fracture comminution.

OUTCOMES

- Patients with more complex comminuted Le Fort fractures report more limitations due to physical and emotional problems.

- Approximately 70% of patients with Le Fort II fractures are able to return to work.
- Commonly, these patients report dissatisfaction with facial appearance and score higher on Social Avoidance and Distress scales.^{8,9}
- Other self-reported symptoms include visual problems, alteration in smell, difficulty with mastication, breathing, diplopia, and epiphora.¹⁰

COMPLICATIONS

- Early
 - Midface fractures may result in significant bleeding, which can be controlled by nasopharyngeal packing, manual fracture reduction, and/or angiographic embolization.¹¹
 - Airway obstruction may occur due to edema and posterior displacement of fracture fragments.
 - Though more rare than in mandible fractures, infection can occur, especially in patients with pre-existing sinusitis or obstruction of the maxillary sinus drainage tract.
 - Extreme care must be exercised with reduction of the maxilla as excessive force and down fracture may propagate fractures and lead to blindness. Cerebrospinal fluid leak, though rare, can also occur.
 - If the maxilla cannot be passively repositioned into appropriate reduction, consider a Le Fort I osteotomy to restore premorbid occlusion.¹²
- Late
 - The most common long-term complications include persistent infraorbital nerve paresthesias (22%); malocclusion (20%), most of which resolved with application of MMF; and orbital complications including diplopia (8%) due to extraocular muscle injury and epiphora due to nasolacrimal duct injury.¹⁰
 - Others include devitalization of teeth, nonunion, malunion, plate exposure, changes in facial appearance, and nasal airway obstruction. Delayed union is more likely to occur in comminuted fractures. Malunion often requires Le Fort I osteotomy to correct.¹⁰

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67 Correction of Le Fort III Fractures

CHAPTER

Joseph Lopez and Amir H. Dorafshar

DEFINITION

- Le Fort III type fracture lines classically transverse the horizontal and vertical buttresses of the face, separating the face from the base of the skull.
- Also known as *craniofacial disjunction*, Le Fort III type fracture lines extend specifically from the lateral and medial orbital walls to the nasofrontal region and the zygomatic arches (**FIG 1**).

ANATOMY

- The facial skeleton is composed of several bones: maxilla, mandible, lacrimal, nasal, palatine, vomer, zygomatic, and inferior nasal concha bones.
- The maxilla constitutes the middle third of the face and contains the maxillary sinus.
- The maxilla and the surrounding bones compose an important system of buttresses that provide mechanical support to the face.
- These buttresses include the lateral orbital wall, zygomatic arch, nasofrontal, and lateral and medial maxillary buttresses.
- The medial and lateral maxillary buttresses are better known as the nasomaxillary buttress and zygomaticomaxillary (ZMC) buttress, respectively (**FIG 2**).
- These buttresses (ie, nasofrontal, zygomatic arch, zygomaticofrontal, lateral orbital wall) are *critical* for bony alignment and stabilization after fractures.
- The main fracture line of Le Fort III type fractures extends from the bridge of the nose through the nasofrontal process, the medial and lateral walls and floor of the orbits, the zygomaticofrontal processes, and the zygomatic arches.
- The nasal septum is also fractured, and the maxilla is separated from the

pterygoid plates.

- The maxilla is highly vascularized. The largest branch of the external carotid artery, the internal maxillary artery, supplies the midface.
- Sensation to the maxillary teeth, nasal cavity, sinuses, and facial skin overlying the maxilla is supplied by the second branch of the trigeminal nerve (infraorbital nerve).
- The infraorbital foramen is located 5 to 10 mm below the infraorbital rim in line with the medial limbus of the pupil.

PATHOGENESIS

- All maxillary fractures, including Le Fort III type, are a result of high-energy frontal or lateral impacts to the face.
- When force is exerted on the maxilla and the surrounding bones, the force is dissipated in such a way that the globe and brain are protected from injury, resulting in characteristic fracture patterns.
- Maxillary fractures are categorized using the Le Fort system.
- Le Fort I and II type fractures are less complex maxillary fractures (and are not discussed here). Le Fort III type fractures are the most complex maxillary fractures and are often the result of high-energy facial injuries.
- Le Fort III type fractures usually present in a mixed pattern with other Le Fort type fractures often present (eg, Le Fort I and II).
- Le Fort III type fractures often present with other facial fractures such as mandible, ZMC, or naso-orbital-ethmoid (NOE) fractures.
- Le Fort III type fractures are often also associated with cervical spine and skull base fractures. These fractures may be associated with airway compromise, facial bleeding, and neurological injuries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- All initial trauma evaluations should consist of an assessment of airway, breathing, and circulation (ie, A, B, Cs).
- A proper primary and secondary survey should be performed in all patients with suspected facial trauma.
 - Because Le Fort III type fractures are the result of high-energy trauma, patients can often present with other life-threatening injuries such as intracranial bleeding or penetrating trauma.
- After the patient is stabilized, a complete history should be obtained (often from a family member or witnesses given that Le Fort III type fractures are

associated with neurological injuries or loss of consciousness). The following questions should be considered:

- When and where did the accident occur?
- What are the specifics of the injury (ie, object, speed, direction)?
- Was there loss of consciousness?
- Does the patient have the following symptoms:
 - Loss of vision?
 - Hearing changes?
 - Malocclusion?
 - Altered sensation?
 - Difficulty moving eyes?
 - Pain with jaw movement?
- A complete review of system should be obtained including allergies, medications, previous surgeries or medical conditions, and tetanus immunization history.
- A thorough history can be instrumental in guiding the CMF surgeon to specific injury patterns.

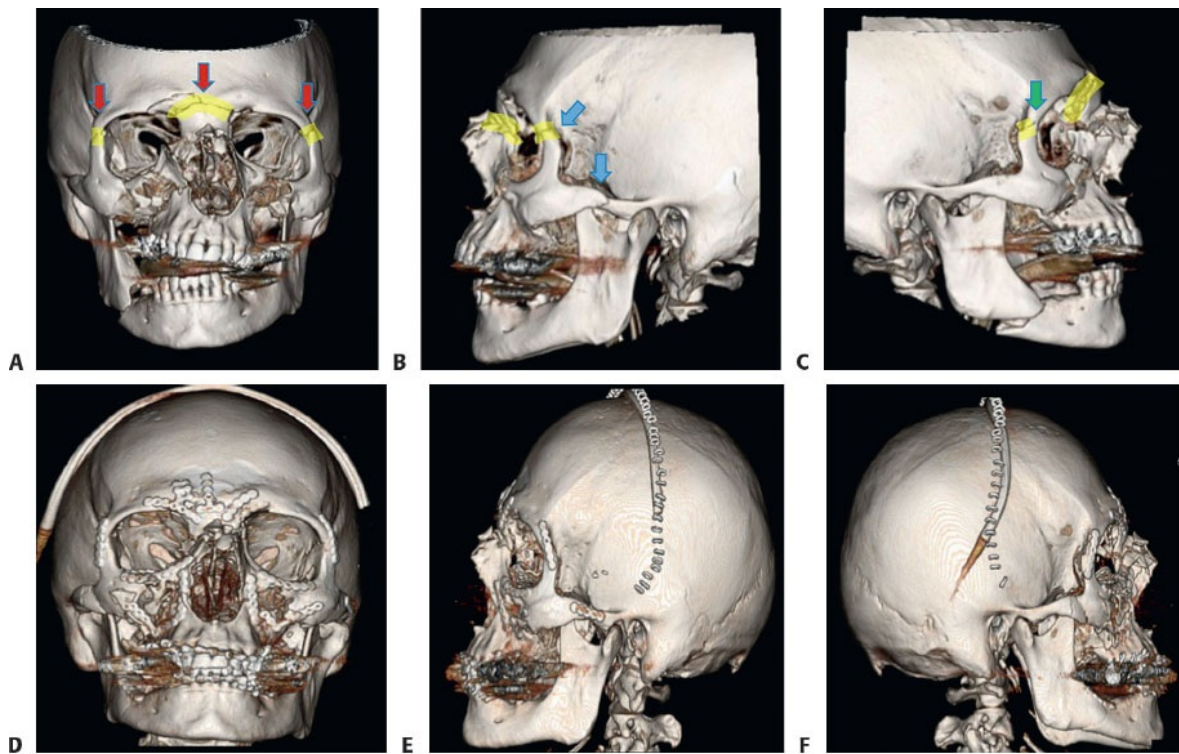


FIG 1 • Craniofacial disjunction/Le Fort III type fracture

in a 28-year-old healthy male after a high-impact motor vehicle collision. **A.** Le Fort III type fractures are typified by fracture lines across the bilateral lateral orbital walls and nasofrontal junctions (*red arrows*). **B.** Left zygomatic arch and zygomaticofrontal suture fracture (*blue arrows*). **C.** Right zygomaticofrontal junction fracture (*green arrow*). **D.** Stabilization achieved by reduction and fixation of the nasofrontal junction, bilateral orbital walls, and zygomaticofrontal junctions. **E,F.** Fixation of bilateral zygomaticofrontal fractures.

- Assess the head and neck region for the following:
 - Soft tissue asymmetry or skeletal deformities: Le Fort III patients often present with elongated faces or malar depression.
 - Ear canals and tympanic membrane for traumatic injuries (ie, hemotympanum, etc.) or CSF leaks
 - Nasal area for epistaxis, CSF rhinorrhea, swelling, septal deviation or hematoma, and nasal airway obstruction
 - Orbit for entrapment, ecchymosis, edema, or subconjunctival hemorrhage
 - Dentition for malocclusion, mobility of teeth, prosthetics, or mandibular/maxillary displacement during teeth contact: Le Fort III type fractures can present with malocclusion.

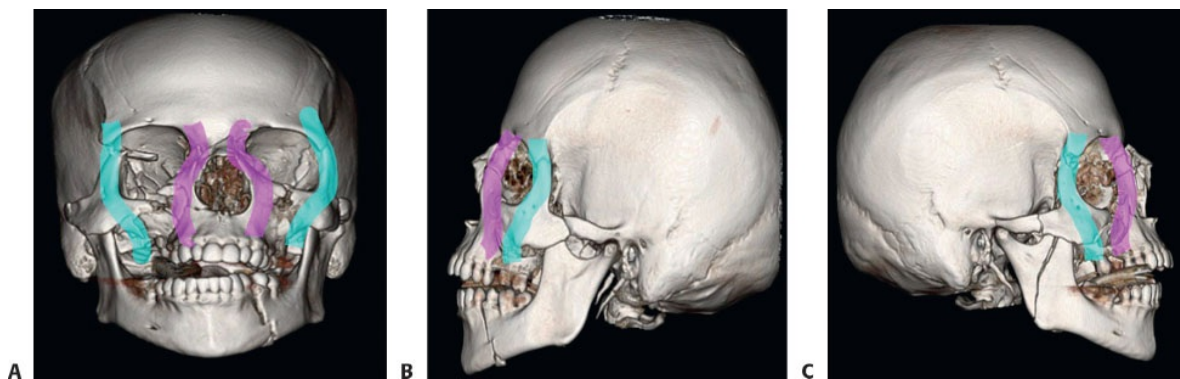


FIG 2 • 3D reconstructions created from CT maxillofacial coronal (**A**), axial (**B**), and sagittal (**C**) images of a 19-year-old healthy man with a Le Fort III

type fracture pattern after falling 15 ft. The *purple lines* display the nasomaxillary buttresses, and the *aqua lines* display the zygomaticomaxillary buttresses.

- Oral mucosa for swelling, lacerations, open fractures, or other pathology
- Occlusion for overjet, overbite, or open bite
- Neurovascular examination
 - Cranial nerves
 - Assess for paresthesia in the distribution of the infraorbital nerve.
- Palpation of the head and neck region for:
 - Step-offs, crepitus, clicking, or popping of the midface, nasal, frontal, and mandibular regions
 - Swelling or tenderness along buttress lines
 - Instability of the midface or maxillary mobility
 - Stability of the canthal attachments

IMAGING

- Patients suspected of having Le Fort III type or other maxillary fractures should undergo computed tomography (CT) to evaluate the fracture patterns and the need for treatment:
 - CT scans should be reviewed in the coronal, axial, and sagittal planes with particular attention to the buttresses to determine severity and types of fracture lines.
 - 3D reconstructions can often be useful for teaching purposes and for virtual surgical planning (**FIG 2**).

SURGICAL MANAGEMENT

- The two most important indications for surgical intervention of maxillary fractures are malocclusion and instability:
 - Given the complexity of Le Fort III type fractures, almost all Le Fort III type fractures present with malocclusion or instability that require surgical management.
- Other relative indications for Le Fort III type surgical management include uncontrolled bleeding and airway stabilization:
 - Because Le Fort III type fractures are associated with extensive soft tissue injury and swelling, nasal and oral airflow can be compromised.

- The main goal of operative management is to re-establish proper occlusion.
- Timing of surgical management is dictated largely by concomitant injuries.

Preoperative Planning

- CT scan should be reviewed to determine the correct combination of approaches.

Positioning

- The patient is positioned supine on the operating table with a shoulder roll to facilitate neck extension.
- Neck extension is contraindicated if the patient is suspected to have or has a spine injury.
 - In these situations, we prefer to defer surgical correction until the neck has been clinically or radiologically cleared. In extenuating circumstances when the neck cannot be cleared, or if there is indeed a cervical neck fracture, we will ask permission from the spine team to proceed with caution by either using an adapted silicone headrest or two 3-L intravenous solution bags taped on either side of the patient's head, to keep the neck in a neutral position throughout the duration of the surgery.

Approach

- Because of the complexity of Le Fort III type fractures, exposure often is achieved with multiple approaches including coronal flaps, lower eyelid incisions, and upper buccal incisions.

TECHNIQUES

■ Repair With Coronal Flap, Miniplate Fixation, and Intermaxillary Fixation

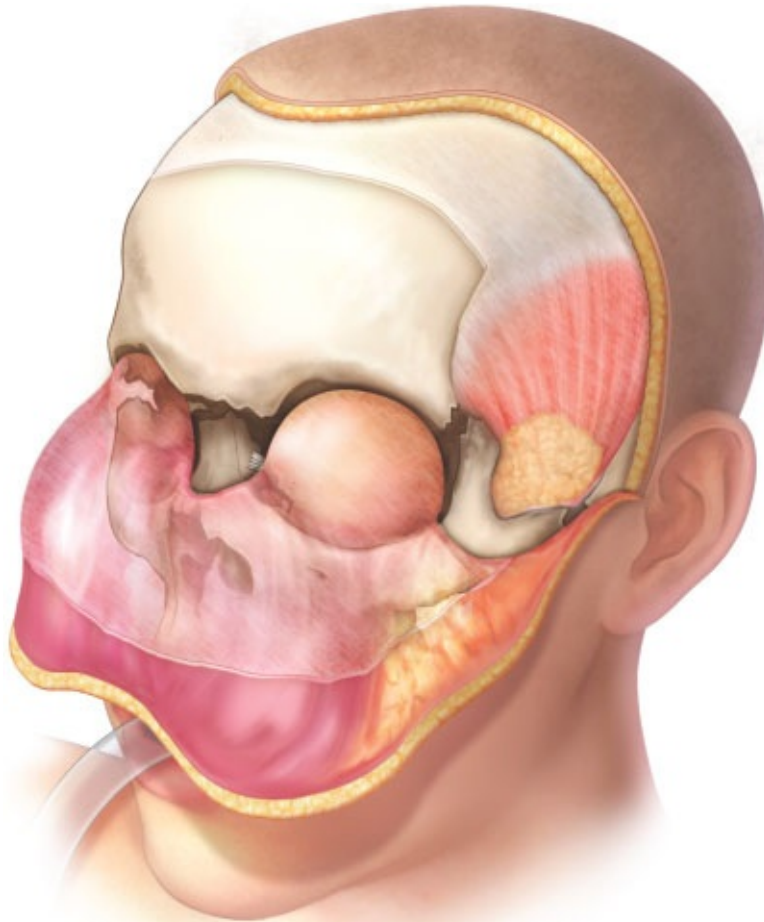
Airway Establishment and Exposure

- After a thorough discussion with the trauma and anesthesia team, the best method for airway management is determined.
 - Nasal intubation can be accomplished with a standard endotracheal tube or a nasal RAE tube which is longer and can be more easily secured.

- Careful attention to skull base fractures is mandatory when using nasal intubation.
- If postoperative airway compromise is of great concern, a tracheostomy must be considered.
- The face is prepped and draped in sterile fashion.
- Intermaxillary arch bars or screws should be applied at the outset of the case to assist with achievement of satisfactory occlusion with anatomical fracture reduction.
- A coronal incision is made from the preauricular crease above the pinnae across the temples to form a gentle curve behind the hairline.
- 1% lidocaine with 1:100 000 epinephrine can be injected to the incision line to control bleeding.
- Raney scalp clips can be applied at the incision for hemostasis. These clips can cause severe alopecia if left in place for a prolonged period of time, however. The authors prefer not to apply Raney clips and prefer to obtain hemostasis of the scalp during the incision.
- Hair can be held out of the way with elastic bands covered with towels attached to the scalp.
- Branches of the superficial temporal artery are clamped and ligated with suture.
- A subperiosteal plane is developed, and the scalp and forehead are elevated over the supraorbital rim (**TECH FIG 1**).
- Laterally, the dissection should be developed in the plane just superficial to the temporalis muscle fascia.
- The dissection is continued once one reaches the supraorbital rim with careful attention to preserve the supraorbital and supratrochlear vessels.
- While the flap is elevated, the periosteum is incised along the zygomaticofrontal buttress.
- If the zygomatic arch needs to be exposed, the supratrochlear and supraorbital vessels and nerves can be released by making osteotomies at the supraorbital foramina.
- The nasal bridge fracture can be exposed by elevating the periosteum from the frontal process of the maxilla and nasal bones. At times, the periosteum needs to be incised to better expose the nasal bones.
- To expose the infraorbital rim and lower maxilla, an upper gingival buccal incision can be made.

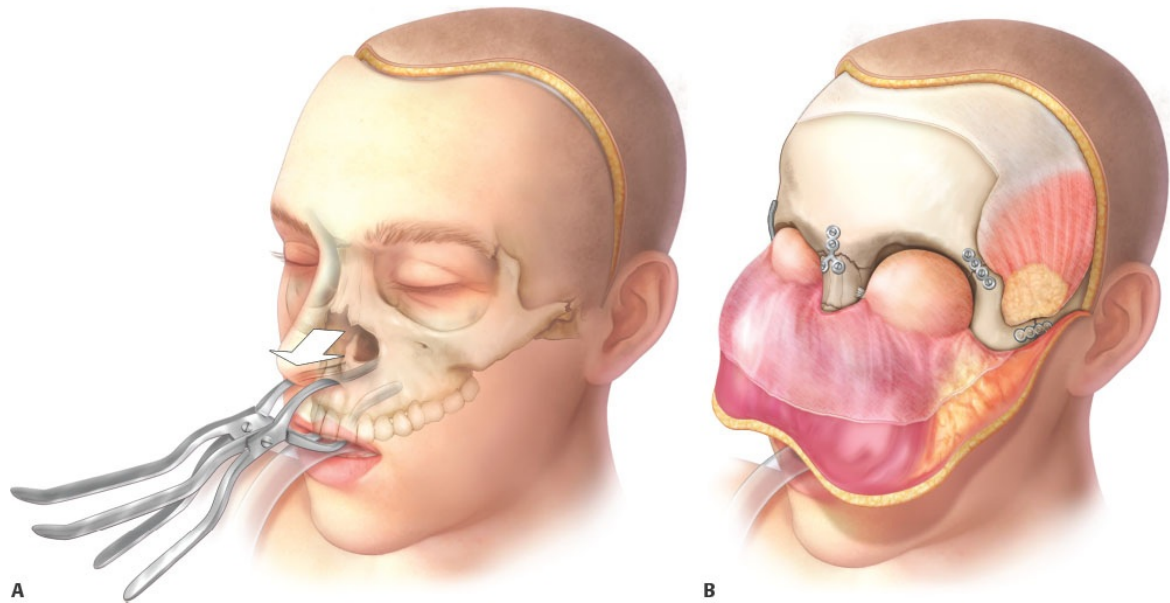
Fracture Reduction and Fixation

- Once all fractures are exposed, the Le Fort III fracture can be reduced with Rowe disimpaction forceps as needed. However, osteotomies may be needed to fully mobilize the fractured segment if the midface is impacted and cannot be disimpacted using the Rowe disimpaction forceps (**TECH FIG 2A**).



TECH FIG 1 • A coronal incision is made and a subgaleal (or subperiosteal) plane is developed. The scalp and forehead are elevated over the supraorbital rim. Near the supraorbital rim, a subperiosteal plane is developed (or continued) with careful attention to preserve the supraorbital and supratrochlear vessels. Laterally, the dissection should be developed in the plane just superficial to the temporalis muscle fascia.

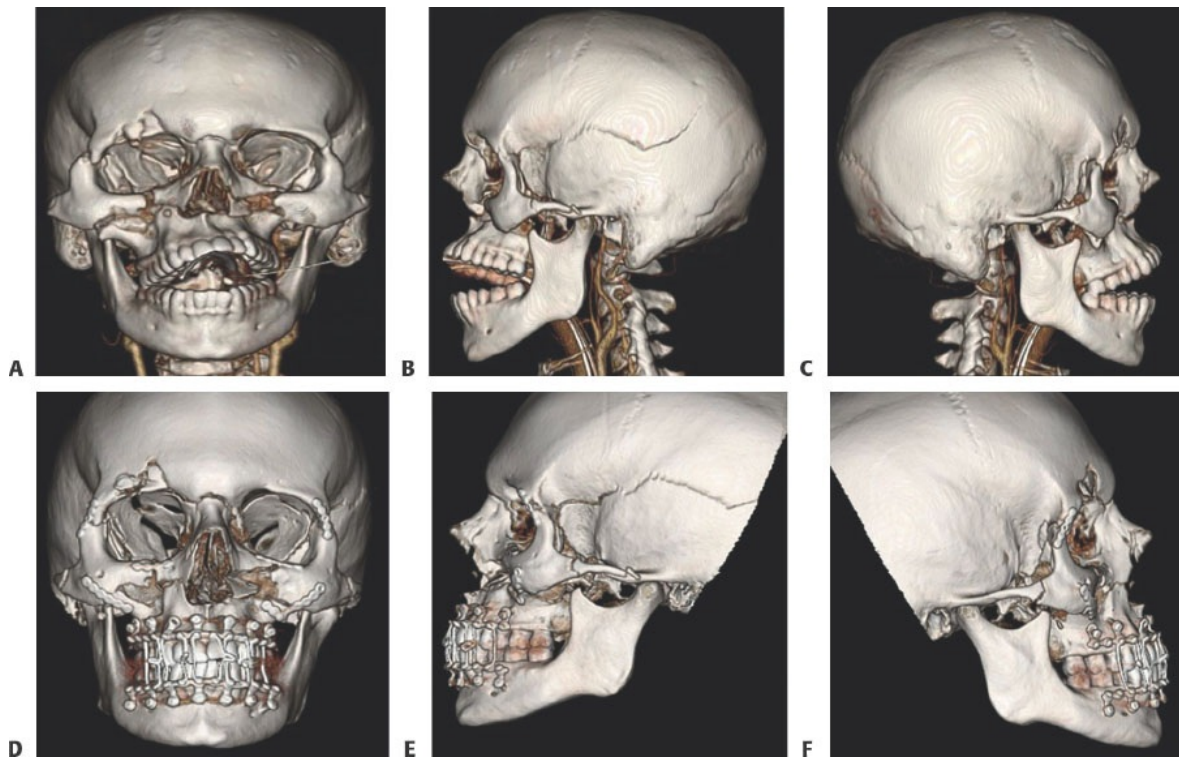
While the flap is elevated, the periosteum is incised along the zygomaticofrontal buttress down to the zygomatic arch.



TECH FIG 2 • A. Once all fractures are exposed, the Le Fort fracture can be reduced with Rowe disimpaction forceps as needed. However, osteotomies may be needed to fully mobilize the fractured segment if the midface is impacted and cannot be disimpacted using the Rowe disimpaction forceps. **B.** Once pretraumatic occlusion is achieved with intermaxillary fixation and all the buttress fractures are aligned, plating can proceed.

- Once pretraumatic occlusion is achieved with intermaxillary fixation (IMF) and all the buttress fractures are aligned, plating can proceed (**TECH FIG 2B**).
- Large bone gaps (5–10 mm) should be treated with bone grafts.
- The most important suture to fixate the lateral orbital walls is at the zygomaticofrontal junction. A miniplate with at least two holes on each side of the fracture must be placed with the bone in an adequately reduced position (**TECH FIG 3**).

- If the nasofrontal process is unstable, fine 0.5-mm plates, small interosseous wires, or 2-0 PDS sutures can be placed to approximate all the fragments.
 - If the orbital rim needs repair, an eyelid exposure can assist in fixating the reduced orbital segments. The authors' preferred eyelid approach is the transconjunctival incision.
 - The coronal flap, upper gingivobuccal, and eyelid incisions are closed in layers.
 - The patient is placed on perioperative antibiotics for 24 hours and imaging obtained as needed.
-



TECH FIG 3 • Le Fort III type fracture in a 25-year-old man who presented after an assault. **A–C.** Preoperative imaging revealed Le Fort III and I type fractures. **D–F.** Once pretraumatic occlusion was achieved with intermaxillary fixation, all the buttress fractures were aligned, and fixation via plating was performed.

PEARLS AND PITFALLS

Indications	■ Surgical indications for Le Fort III type fractures are instability and malocclusion.
Goals	■ Restore normal occlusion. ■ Restoration of facial height, width, and projection.
Approach	■ Given the complexity of Le Fort III type fractures, multiple approaches are necessary to reduce all fractures lines: these include the coronal flap, upper gingivobuccal incision, and lower eyelid incisions.
Technique	■ Place IMF arch bars or screws, expose all the fractures adequately, disimpact the Le Fort III segment using Rowe forceps or perform osteotomies to reduce fractures anatomically, place the patient into IMF, align the zygomaticosphenoid sutures, and fixate at the zygomaticofrontal and nasofrontal buttresses as required.
Postoperative diet and care	■ Patients should be placed on a soft diet while in IMF, and use chlorhexidine mouthwash 3 times per day.

POSTOPERATIVE CARE

- Following fracture repair, resolution of facial edema may occur quite slowly. Therefore, postoperative airway compromise is of great concern. A tracheostomy may be considered preoperatively in severe clinical scenarios.
- Studies have demonstrated that Le Fort III type fractures, when compared to other facial fractures, are more likely to require a surgical airway.¹
- IMF is the most common cause of frustration in patients. Proper hardware management to improve patient compliance and comfort is necessary.
- During surgery and before discharge, intraoral wires should be examined to prevent irritation or pressure sores.
- Arch bar care should be initiated with the use of chlorhexidine mouthwash 3 times per day to prevent bacteria over-colonization.
- The patient should be placed on soft/puree diet until removal of arch bars. A scheduled antiemetic regimen can be useful as well.
- IMF should be kept in place for 1 to 3 weeks.² IMF can then be replaced with two elastic bands per side for a total of 6 weeks of treatment. Occlusion should be monitored throughout this period, and the patient should be placed

in IMF if malocclusion develops.

- At the end of the 6-week treatment, arch bars can be removed, and intraoperative assessment of occlusion can be performed at that time.
- Recently, several studies have examined the course of antibiotics needed after surgical management of facial fractures. All these studies have demonstrated that a short course of perioperative and postoperative antibiotics (less than 24 hours) is needed to prevent postoperative infections.^{3,4}
- Follow-up varies depending on surgeon preference. However, the patient should not be discharged from follow-up until at least 3 to 6 months postoperatively to allow adequate assessment of surrounding structures (ie, dental, ocular, or lacrimal system functions).

OUTCOMES

- Currently, there is a paucity of data exploring outcomes in patients with Le Fort III type fractures:
 - However, the handful of studies that have examined outcomes in this unique patient population indicate that Le Fort III type fractures are highly debilitating fractures that cause significant morbidity to patients.
- Bagheri et al.¹ examined over 60 patients with Le Fort I, II, and III types who presented to a single institution over a 13-year period.
 - They found that higher Le Fort injuries are associated with greater severity of trauma as measured by injury severity scores and have a more frequent need for surgical airways.
 - Additionally, Le Fort III type patients are more likely to require neurosurgical interventions and experience vision-threatening ocular trauma.
- Girotto et al.⁵ compared the long-term general health status and psychosocial well-being of patients who suffered Le Fort fractures to patients who presented to a general emergency ward:
 - These investigators found that increasing Le Fort complexity is associated with emotional problems and physical impairment secondary to altered social interaction as a result of the facial trauma.
 - Patients with increasingly complex Le Fort type fractures reported difficulties with vision, smell, mastication, breathing, and epiphora.
- These studies suggest that Le Fort III type fractures cause significant morbidity and limit patient's potential to achieve productive and active lives.

COMPLICATIONS

- Immediate complications after Le Fort type fractures involve airway compromise or bleeding:
 - High-energy facial trauma can result in significant soft tissue swelling that can obstruct the nasopharynx or oropharynx.
 - Deep or superficial vessel damage can occur secondary to high-energy maxillary fractures. Ligation or nasal packing can often control the bleeding, but manual reduction with IMF may also be needed.
- Subacute complications after Le Fort type fractures typically involve damage to the surrounding structures such as skull base (or cribriform plate) producing CSF leaks or lacrimal duct injuries causing orbital cellulitis or dacryocystitis.
- Infections are prone to occur in patients who present with facial soft tissue injuries and/or contaminated wounds. Although less common than mandibular fractures, infections can result in plate exposure and bone graft loss.
 - Infections can often be treated with antibiotics only. However, if associated with plate exposure or failure, plates and grafts may have to be removed.
- Nerve injuries can occur as well.
 - Forehead paresthesia can occur with injuries to the supraorbital nerve during retraction of the orbital tissue or during reduction and fixation of the medial or lateral orbital rims.
 - Weakness of the forehead or upper eyelid can occur with injuries to the frontal branch of the facial nerve. This often occurs when applying traction on the forehead flap.⁶
 - Blindness can occur following Le Fort II type fractures and results from severe swelling within the optic canal.⁷
- Nonunion or malunion are rare long-term complications following correction of Le Fort type fractures. They are often secondary to suboptimal surgical management (ie, fixation) or delayed treatment.
 - Facial asymmetries such as long vs short face, increased width, inappropriate projection, and malocclusion can occur following improper management.
 - If symptomatic, the fracture sites must be explored and corrected with possible osteotomies, bone grafts, plates, alloplastic or dental implants, or further orthognathic surgery.
- Plates can occasionally be visible or palpable in thin-skinned patients. This can be avoided by using low-profile plates or using interosseous wires.

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Section XII: Panfacial Trauma

68 Maxillomandibular Fixation of Mandible Fractures

CHAPTER

Joseph Baylan and Dana Johns

DEFINITION

- Maxillomandibular fixation (MMF) can be used independently for closed reduction or in combination with open reduction and internal fixation (ORIF) for treatment of mandible fractures.

ANATOMY

- An understanding of dental anatomy and normal occlusal relationship is important when planning treatment with MMF.
- Incisor and canine teeth have a conical shape, whereas premolars and molars have a square shape.
- Normal occlusion is defined when the mesiobuccal cusp of the maxillary first molar occludes in the buccal groove of the mandibular first molar (**FIG 1**).
- The mandibular arch is lingual to maxillary arch.

PATHOGENESIS

- Two most common causes of mandible fractures are assault and motor vehicle collisions.
- Additional causes include gunshot wounds, falls, and sports injuries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Focused history and physical examination
 - Mechanism of injury

- Full intraoral and dental examination
 - Evaluate for anterior or posterior open bite in centric occlusion.
 - Evaluate for dental trauma and overall state of dental health.
 - Evaluate areas of wear on the teeth (“wear facets”) to determine which teeth and where teeth made daily contact prior to the injury. These wear patterns can give an idea of preinjury occlusion, as the occlusion may not have been normal.

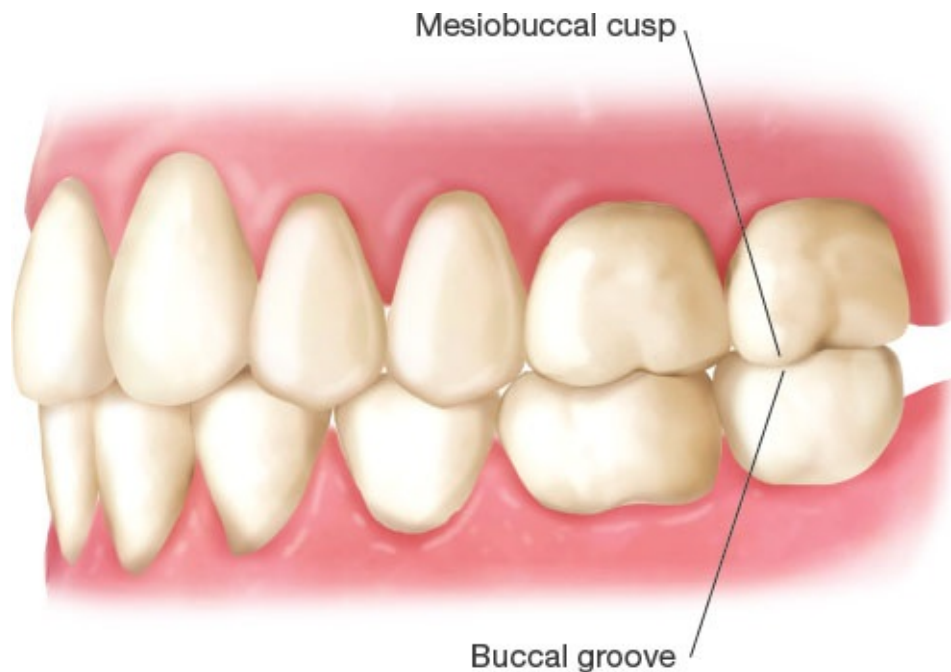


FIG 1 • Normal occlusion.

- Tips
 - Use tongue blade intraorally for complete soft tissue and dental evaluation.
 - Previous dental imaging and molds can be used to determine preinjury occlusion.

IMAGING

- Panorex plain films may be used to diagnose mandible fractures and can be used easily for postfracture follow-up.
- CT imaging is superior to plain films for diagnosing and evaluating mandibular fractures.
- Noncontrast maxillofacial CT, with 3D reconstruction if available, is useful for

determining fracture patterns, identifying concomitant injuries, and planning repair.^{1,2}

SURGICAL MANAGEMENT

■ Indications for MMF³:

- Temporary fragment stabilization as bridge to ORIF
- Conservative treatment
- Alveolar crest fractures
- Tension band in conjunction with rigid internal fixation
- Control of occlusion in the posttraumatic/postoperative period

Preoperative Planning

- Nutrition optimization is important for postoperative healing.
- For edentulous patients, consider intraoral prosthesis to maintain maxillary-mandibular relation.
- Appropriate preoperative evaluation of cardiopulmonary status is always indicated prior to any surgical procedure.
- Equipment
 - Erich arch bars and either 24- or 26-gauge dental wire (surgeon preference).
 - MMF set should include heavy needle drivers, wire cutting scissors, a pickle fork, and intraoral retractors (ie, Weider adult cheek tongue retractor, Minnesota, etc.).
 - Optional: MMF screws
- Anesthesia
 - General anesthesia via nasotracheal intubation is preferred.
 - Orotracheal intubation with ETT posterior to the retromolar trigone and submental intubation are other alternatives if nasotracheal intubation is not possible.
 - Tracheostomy should be performed if there are contraindications to the above-mentioned methods of anesthesia.

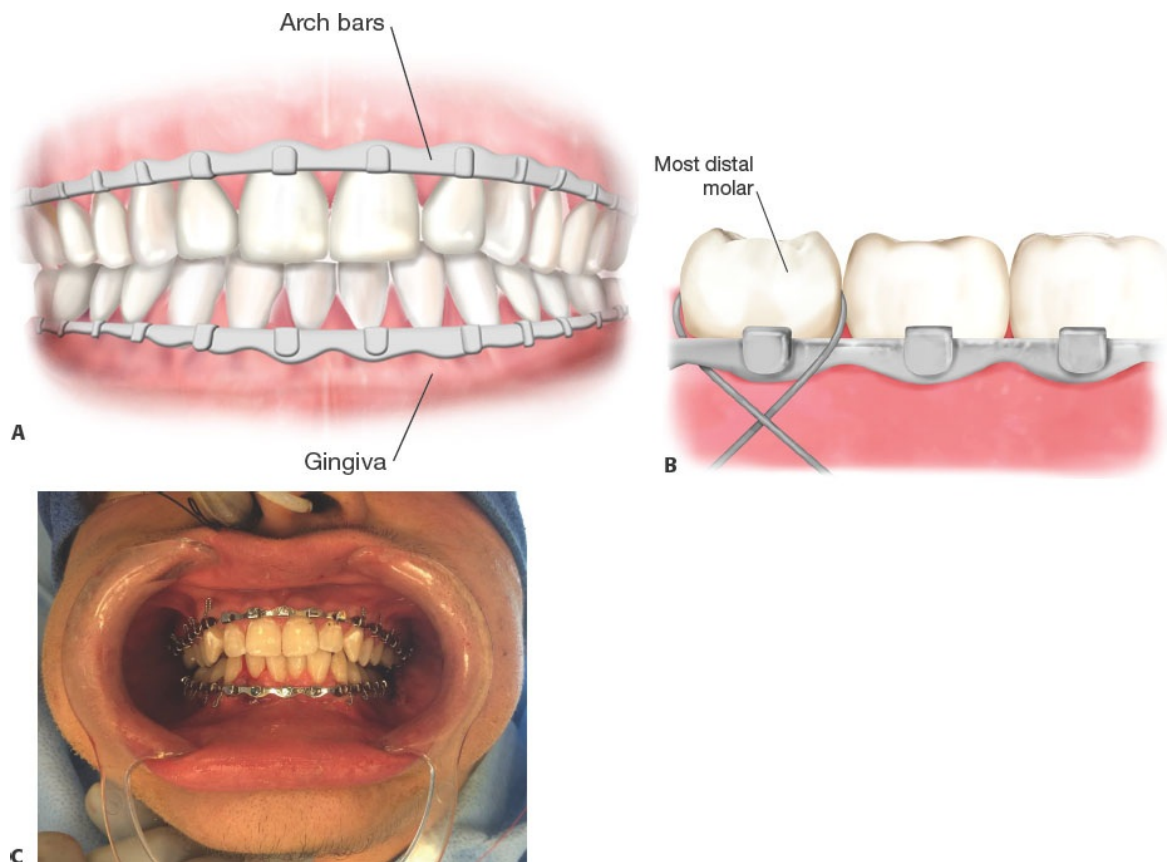
Positioning

- The patient is placed in the supine position with a shoulder roll and arms tucked.

TECHNIQUES

■ Arch Bars

- Check occlusion, paying attention to avulsed teeth and wear facets, to obtain preinjury occlusion.
- If possible, obtain prior dental records; however, this is often not possible in the acute trauma setting.
- Measure and cut appropriate length of arch bar required to span left second molar to right second molar.
- The arch bar should sit occlusal to the gingiva along the dental equator so as to avoid damage to the gingiva. Furthermore, the arch bar hooks should lie apical and symmetrical in the mandible and maxilla (**TECH FIG 1A**).
- A 24- or 26-gauge dental wire is passed around each side of the most distal molar with one end of the wire above and one end below the arch bar so that when the wire is twisted down it will secure the arch bar in place (**TECH FIG 1B,C**).
- Make sure the arch bar is correctly positioned prior to twisting the ends of the wire in a clockwise direction with a heavy needle driver:
 - Gently, pull up on the wire in a perpendicular direction to the arch bar during the twisting process to remove all slack from the wire. This is necessary to ensure the wire is tightened adequately.
 - Cut the wire, leaving 8 to 10 mm of the length to allow fold of the wire inward away from the gingiva, and place it along the arch bar to avoid gingival irritation.



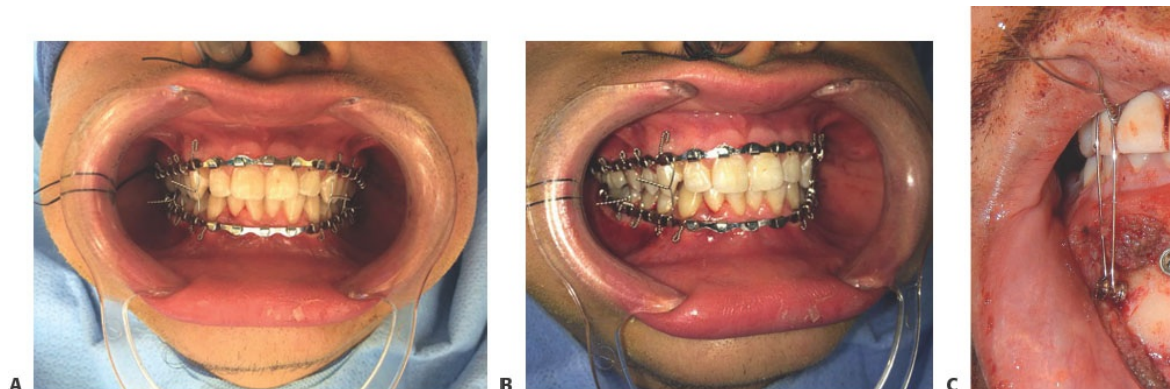
TECH FIG 1 • A. Arch bar relationship to the teeth and gingiva. **B.** First step in application of arch bars. **C.** Completed application of arch bars.

- Apply wires to the next tooth in a sequential fashion to span the arch bar from left second molar to right second molar to prevent redundancy and possible malocclusion:
 - Wires are placed in the interproximal spaces and apical to the widest diameter of the crown.
 - Wires are placed around all molar and premolars due to stability of tooth roots.
 - Wires can be placed around the canines and incisors; however, recommendations are to include two teeth in each wire pass to disperse the force of the MMF over both teeth.
- After all wires are placed, check the stability of the arch bar by grabbing it with an empty needle driver and seeing if it can be mobilized in any direction:

- If the arch bar is mobile, check all wires for tightness, and add additional clockwise twisting as needed until the arch bar is immobile.
- MMF is achieved by taking a looped wire and placing it along a minimum of two hooks on each arch bar (upper and lower) and securing it in place with a twist knot in the clockwise direction. Tight dental elastics can be wrapped around upper and lower hooks and utilized for MMF instead of wire loops:
 - The benefit of elastics is ease of removal in case of emergent airway issues.
 - Their disadvantage is less rigid MMF, but this can be overcome with tight placement.

■ MMF Screws (TECH FIG 2)

- Primarily indicated in emergency cases, simple fracture patterns, and when standard arch bars cannot be applied.
- Contraindications include comminuted/displaced/unstable, mobile teeth, and children, if tooth buds are present at the planned location of screw placement.
- Check occlusion, paying attention to avulsed teeth and wear facets, to obtain preinjury occlusion. If possible, obtain prior dental records.
- The self-drilling and self-tapping screws are placed apical and in between the canine tooth roots of the maxilla and mandible bilaterally.
- Ensure screw head grooves are lying in same line to pass wire for MMF.
- A total of four screws are used, with two located on the mandible and two on the maxilla.
- MMF is achieved with 0.4 mm wires passed through head grooves on the screws in the maxilla and mandible and tightened in a clockwise direction with a heavy needle driver:
 - Repeat for contralateral side.



TECH FIG 2 • A,B. Placement of MMF wires. **C.** MMF screw in the mandible with wire loop to MMF screw in the maxilla (upper screw not shown). Wire is passed through channel in the screw head.

■ Rapid Fixation Hybrid MMF Systems

- Multiple rapid fixation hybrid MMF systems are available for use.
- These systems combine elements of both arch bars and MMF screws and can be used to secure patients in MMF.
- These systems are an additional option in patients with poor dentition.

■ Special Considerations in Edentulous Patients

- Fracture stabilization with existing dentures, Gunning splints, or MMF screws can be used in patients with edentulous mandibles.¹

PEARLS AND PITFALLS

Wire application

- Proper occlusion and fracture reduction must be established before complete tightening of the circumdental wires in the area of the fracture in order to prevent malreduction by the arch bar.
- When applying wires for arch bars, start in a sequential fashion from distal molar to distal molar. An alternative is to start mesial and work distally. This sequence prevents redundancy and possible malocclusion.
- When twisting wires to arch bar, start each strand length equidistant from the twist to the crown. This helps reduce wire fracture due to overtwisting.
- Wires generally change from shiny to dull color just prior to breakage. Learning to recognize the color change helps reduce wire fracture.
- While passing wires through the interproximal space during arch bar application, pay careful attention not to injure the gingiva. Also, care must be taken to prevent inadvertent needle injury to the surgeon.

POSTOPERATIVE CARE

- Patients will be on a full liquid diet and should have nutrition counseling and close monitoring of nutritional intake, with supplementation as needed.⁴
- Oral hygiene can be poor during MMF, and, therefore, Peridex mouth rinse is imperative in maintaining good oral hygiene.⁴
- Dental wax can be used to protect oral mucosa from injury by wires and arch bar hooks.
- Routine follow-up at 2 and 4 weeks after surgery to evaluate healing and assess occlusion.
- Wire fixation can be released at 2 weeks after surgery, and the patient can be transitioned to dental elastic band fixation for the remainder of MMF to permit early motion of the TMJ joint.^{2,4} If there is a concern for adequate healing, a panorex film can be obtained prior to switching from wire to dental elastic fixation.
- Fixation should be removed intraoperatively or 4 to 8 weeks postoperatively pending fracture healing.

COMPLICATIONS

- Overall, there is an increased risk of anesthetic complications in patients with mandible fractures who are treated with MMF compared to those who are not.⁵
- Additional complications include^{1,2,5}
 - Aspiration
 - Gingival trauma and recession
 - Difficulty with oral hygiene
 - Delayed temporomandibular joint mobility
 - Malocclusion⁶⁻⁸

ACKNOWLEDGMENTS

We would like to acknowledge Paul Mittermiller and Peter Lorenz in preparing this chapter.

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69 Open Treatment of Mandible Fractures

CHAPTER

Joseph Baylan and H. Peter Lorenz

DEFINITION

- Mandible fractures are one of the most common facial bone fractures.
- Without adequate treatment, fractures of the mandible can lead to malocclusion, condylar resorption, and poor functional and cosmetic outcomes.¹

ANATOMY^{2,3}

- The mandible is a U-shaped bone composed of thick buccal and lingual cortices with a thin medullary canal.
- The mandible is divided into paired condyle, coronoid, ramus, angle, body, parasymphysis areas with a single midline symphysis, and tooth-bearing alveolus (**FIG 1**).
- Blood supply to the mandible comes from the inferior alveolar artery and direct muscular attachments.
- The inferior alveolar nerve traverses the mandible in the medullary canal, exiting at the mental foramen which is located inferior to the second premolar.
- Muscles inserting on the mandible (**FIG 2**):
 - Muscles of mastication
 - Masseter
 - Temporalis
 - Medial pterygoid
 - Lateral pterygoid:
 - Suprahyoid muscles
 - Digastric

- Stylohyoid
- Mylohyoid
- Geniohyoid

PATHOGENESIS

- Two most common causes of mandible fractures are assault and motor vehicle collisions.
- Additional causes include gunshot wounds, falls, and sports injuries.
- Most common location of fractures^{2,3}:
 - Condylar (36%)
 - Body (21%)
 - Angle (20%)
 - Symphysis (14%)
 - Alveolar ridge (3%)
 - Ramus (3%)
- Coronoid fractures (2%)
- Displacement of fracture segments commonly occurs from differing forces of inserting muscles³:
 - Muscles of mastication displace posterior segments superiorly.
 - Suprahyoid muscles displace anterior segment inferiorly.
- The lateral pterygoid displaces condylar head medially.
- Favorable mandible fractures³:
 - Nondisplaced by muscular pull.
- Most rami fractures.

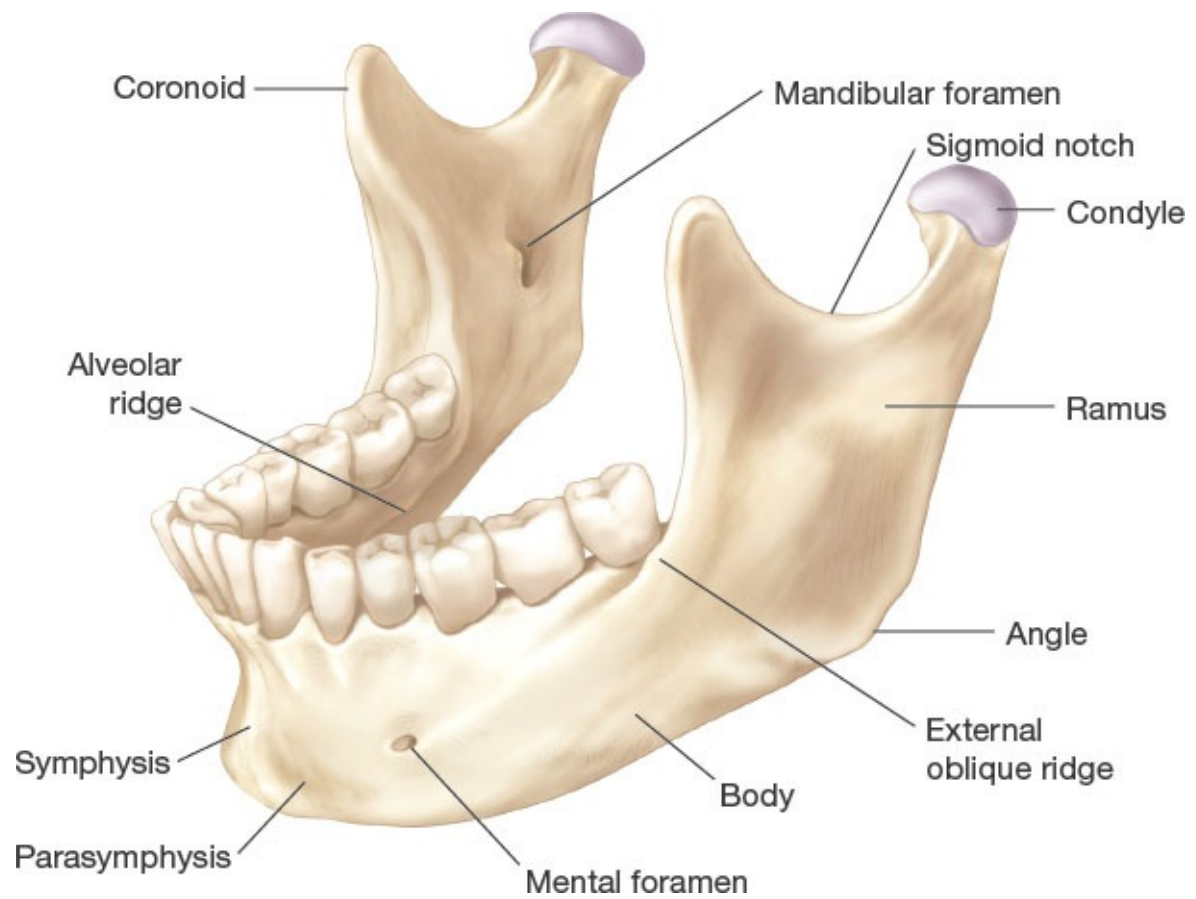


FIG 1 • Bony anatomy of the mandible.

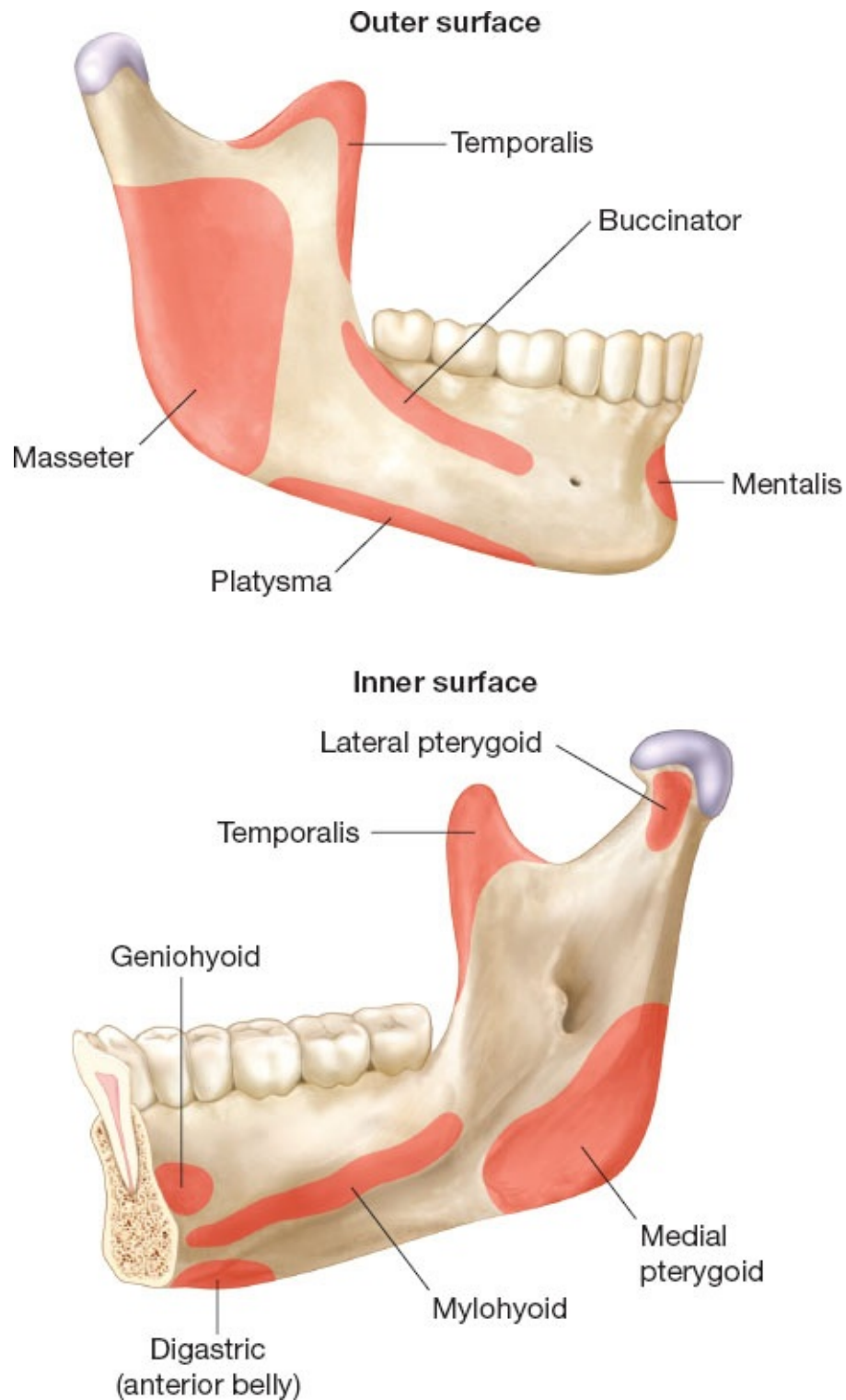


FIG 2 • Muscle attachments of the mandible.

■ Unfavorable mandible fractures³:

- Horizontal angle fractures that extend posteriorly and downward tend to be displaced by muscles of mastication.
- Vertical symphyseal and parasymphyseal fractures are displaced downward by suprahyoid muscles.
- High condylar fractures are displaced medially by the lateral pterygoid muscle.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Focused history and physical exam:
 - Mechanism of injury.
 - Full intraoral and dental examination.
 - Evaluate for anterior or posterior open bite in centric occlusion.
 - Evaluate for deviation of the mandible upon opening.
 - Palpate condyles in preauricular area and external auditory canal during opening to assess translation and tenderness.
 - Evaluate for mental nerve paresthesias.
 - Tips.
 - Use tongue blade intraorally for complete soft tissue evaluation.
 - Gingival lacerations are typically present at fracture sites.
 - Ecchymosis on the floor of the mouth is indicative of mandible fracture.
 - Chin deviation suggests condylar fracture.
 - Concomitant injury evaluation:
 - 2.6% of patients with facial fractures will have cervical spine injury.³

IMAGING

- Panorex plain films may be used to diagnose mandible fractures.
- CT imaging is superior to plain films for diagnosing and evaluating mandibular fractures.
- Noncontrast maxillofacial CT, with three-dimensional (3D) reconstruction if available, is useful for determining fracture patterns, identifying concomitant injuries, and planning repair.^{2,3}

NONOPERATIVE MANAGEMENT

- The majority of mandible fractures will require operative intervention.
- Nondisplaced, stable fractures with normal occlusion can be treated with soft diet and close follow-up.

- Greenstick-type fractures or minimally displaced fractures in children with normal occlusion can also be treated nonsurgically.^{3,4}
- In the case of edentulous mandibles, minimally displaced fractures can be treated nonoperatively.³

SURGICAL MANAGEMENT

- The main goal of operative intervention for mandible fractures is to restore preinjury occlusion and restore mandibular form and function.²
- Timing of surgery has no correlation to complication rates.^{2,5}
- Antibiotics:
 - All patients with mandible fractures should receive prophylactic antibiotics from the time of injury until the fracture is treated.
 - This practice has been shown to reduce postoperative infection from 50% to 6%.²
 - Penicillin-based antibiotic is preferred or clindamycin for patients with penicillin allergy.
- Postoperative antibiotics have been shown to have no effect on infection rates.²
- Fracture patterns to consider:
 - Symphysis and parasymphysis: fracture is located in the anterior mandibular portion between the canine teeth.
 - Body: fracture is located between canine and distal last molar.
 - Angle or ramus: fracture is located posterior to the second molar and triangle between the horizontal and ascending ramus and often involving the third molar.
- Condylar and subcondylar fracture: fracture is located superior to the ramus and is classified according to levels.
- Indications for open reduction and internal fixation (ORIF):
 - Severely displaced fractures
 - Bilateral fractures
 - Open fractures
 - Comminuted fractures
 - Multiple fracture sites
 - Panfacial fractures
 - Infected fractures
 - Uncooperative patients

- Patients with relative contraindication to MMF secondary to medical conditions (seizures, malnutrition, etc.)
- Indications for external fixation⁶:
 - Bridge until ORIF
 - Large segmental defect
 - Severe comminution
- Infection present
- Indications for removal of the teeth:
 - Grossly mobile teeth with periapical pathology or advanced periodontal disease
 - Teeth preventing fracture reduction
 - Fractured tooth root
 - Exposed root apices

Preoperative Planning

- Nutrition optimization is important for postoperative healing.
- For patients with edentulous mandibles, consider the creation of an intraoral prosthesis to help establish maxillary-mandibular relation.^{2,3}
- Appropriate preoperative evaluation of cardiopulmonary status is always indicated prior to any surgical procedure.
- Equipment:
 - MMF: Erich arch bars, 22- to 26-gauge wire.
 - Craniofacial mandibular plating system of preference. Different manufacturer's systems are similar, and vendors include Stryker, DePuy Synthes, and KLS Martin mandible plating sets. Choosing between systems is by surgeon preference, which is generally based on comfort/familiarity of use and availability at institution.
- Power bur and drill system.
- Anesthesia:
 - General anesthesia via nasotracheal intubation is preferred.
 - Orotracheal intubation with endotracheal tube (ETT) posterior to the retromolar trigone and submental intubation are other alternatives if nasotracheal intubation is not possible.
 - Tracheostomy should be performed if there are contraindications to the above-mentioned methods of anesthesia.

Positioning

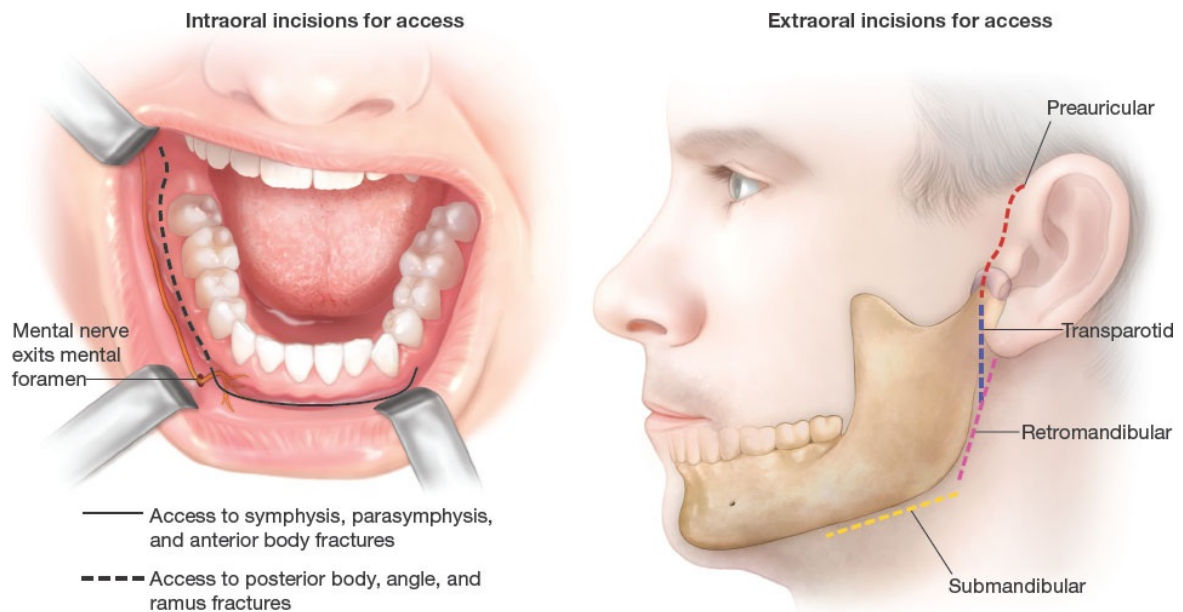
- The patient is placed in the supine position with a shoulder roll and arms tucked.

TECHNIQUES

■ General Considerations

Fracture Exposure

- Local anesthetic with epinephrine should be injected into incision sites prior to making incisions.
- Begin with lower buccal sulcus incision over the area of the fracture leaving at least 10 to 15 mm gingival cuff at the unattached gingiva.
- Use existing extraoral lacerations for additional exposure if needed.
- Submental and submandibular approaches are alternatives to improve reduction and access for complex fractures of the body and angle.
- Expose fracture site in a subperiosteal plane paying careful attention to avoid injury to the mental nerve with wide exposure (**TECH FIG 1**).



TECH FIG 1 • Incisions for access.

Initial Approaches to Fracture Reduction

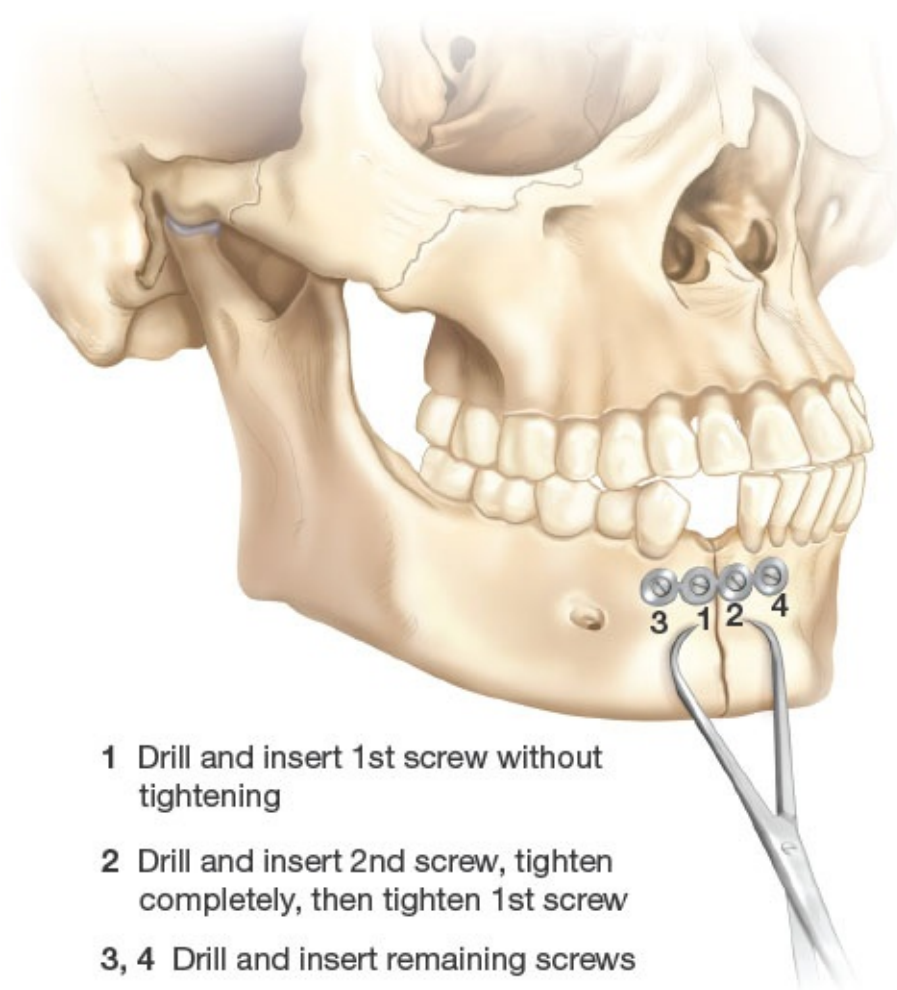
- Place patient in temporary MMF to help obtain preinjury occlusion.
- If fracture is displaced, manipulate segments until anatomic reduction is achieved.
- Consider the use of bone hooks or screws as adjuncts to achieve reduction.
- For comminuted fractures:
 - Realign fragments in a systematic fashion; superior to inferior, anterior to posterior, etc.
 - Temporary miniplates can be used to help hold reduction during realignment of fragments, but ensure plate location does not interfere with placement of reconstruction plate.
- Confirm mandibular condyles are seated.
- Ensure reduction is held with predrilled holes and reduction forceps placing clamps perpendicular to fracture line.
 - Alternative options include suture, wire, forceps, and an assistant.
 - The tendency is for splaying of the inner cortex of the mandible. Thus reduction is often applied with a medial force on the gonial angle in addition to a cephalad force to achieve reduction.

Plate Application (**TECH FIG 2**)

- Ensure the length of plate is adequate to span the fracture site and allow for a minimum of two screws on each side of the fracture site.
- Prior to plate application, confirm reduction is held appropriately and anatomically.
- Ensure mandibular condyles are well seated to prevent an anterior open bite.
- Plates should be contoured with plate bending pliers to fit flush with the underlying bone.
- Drill and insert the first screw without completely tightening it down for adjustment of plate position.
- Place the second screw on the other side of the fracture site, and then tighten the first screw completely.
- Fill remaining plate holes with screws.
- Consideration of a reconstruction plate may be necessary in cases of panfacial fractures or concomitant subcondylar fractures.
 - The superior border plate (tension band) will be monocortical to avoid

damage to the tooth roots.

- The inferior border plate (compression band) will be bicortical and often requires the use of a depth gauge to determine length of screw required.
- For comminuted fractures:
- Contour template to span the fracture and for flush placement of inferior mandibular border, paying careful attention to avoid injury to the mental nerve.
- Contour reconstruction plate using the template as a guide by torquing, in-plane bending, and out-of-plane bending, as necessary.
- Release MMF and ensure occlusion is appropriate. If concern for stability of fracture fixation is present, replace the patient in MMF with wires or dental rubber bands.



TECH FIG 2 • General plating technique.

■ Symphysis/Parasympysis

Nondisplaced and Simple Displaced Fractures

- The fracture should be stabilized with a minimum of two points of fixation.
- See general considerations for initial approaches to fracture reduction.
- After contouring, place two four-hole miniplates, 2.0 mm, at the fracture site, superiorly and inferiorly at the mandibular border.
- Apply monocortical screws below the apices of the tooth roots.
- Apply bicortical screws a few millimeters superior to the inferior border.
- See general considerations for plate application.

Comminuted Fractures

- The fracture should be stabilized with a minimum of two points of fixation.
- See general considerations for initial approaches to fracture reduction.
- Length of plate is dictated by a minimum of two screws on each side of the fracture to ensure load-bearing fixation.
- Mobile fragments can be held in place by screws through the reconstruction plate.
- Remove temporary plates if interference with reconstruction plate is present.
- Apply appropriate screws to reconstruction plate ensuring plate is flush with the mandible.
- See general considerations for plate application.

■ Body Fractures

Nondisplaced, Simple Displaced, and Oblique Fractures

- The fracture should be stabilized with a minimum of two points of fixation.
- See general considerations for initial approaches to fracture reduction.
- For nondisplaced fractures, place two four-hole 2.0-mm miniplates at the fracture site, superiorly and inferiorly at the mandibular border.
- For displaced and oblique fractures, place a 2.0-mm miniplate superiorly and a 2.4-mm compression plate inferiorly. An overbend of the compression plate is typically useful to ensure lingual cortex approximation at the fracture site.
- Apply monocortical screws below the apices of the tooth roots.
- Apply bicortical screws a few millimeters superior to the inferior border. To

protect the mental nerve, the plate must lie below the mental foramen. The use of retractors or transbuccal approach can ensure proper screw orientation.

- See general considerations for plate application.

Comminuted Fractures

- The fracture should be stabilized with a minimum of two points of fixation.
- See general considerations for initial approaches to fracture reduction
- Length of plate is dictated by a minimum of two screws on each side of the fracture to ensure load-bearing fixation.
- Mobile fragments can be held in place by screws through the reconstruction plate.
- Remove temporary plates if interference with reconstruction plate is present.
- Apply appropriate screws to reconstruction plate ensuring plate is flush with the mandible.
- See general considerations for plate application.

■ Angle and Ramus Fractures

Nondisplaced, Simple Displaced, and Oblique Fractures

- Consideration of plate placement should be either a plate along the external oblique ridge (Champy plate) or two miniplates along the superior and inferior border of the mandible.
- See general considerations for initial approaches to fracture reduction.
- Champy plate placement (**TECH FIG 3**):



TECH FIG 3 • Champy plate placed on the external oblique ridge of the mandible through intraoral approach.

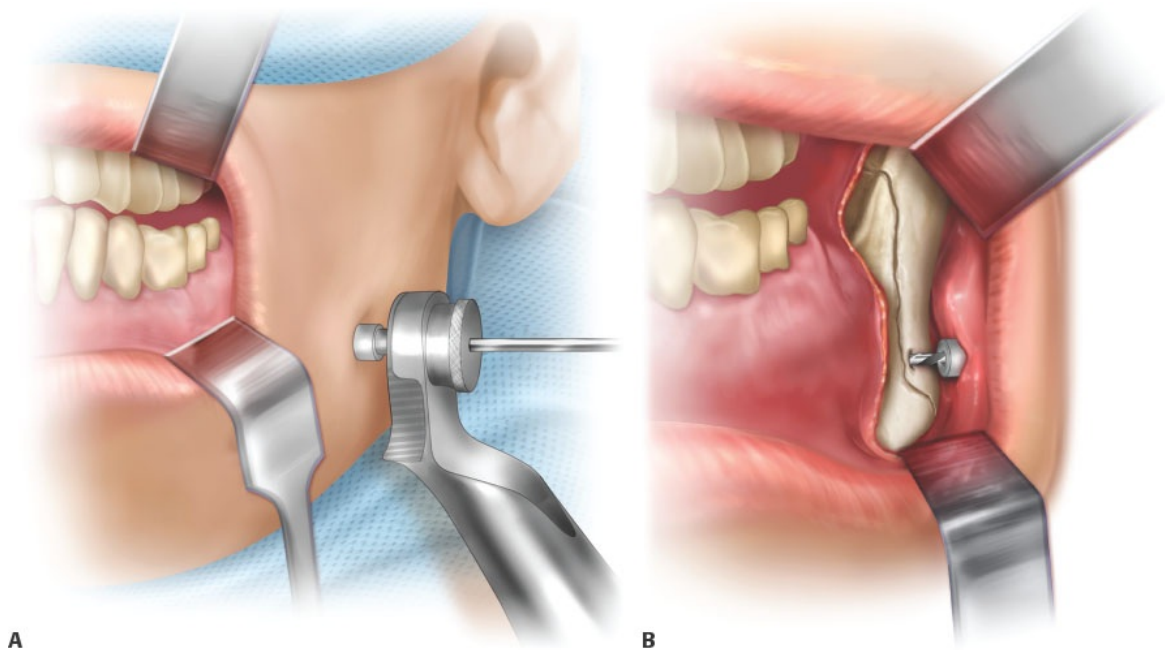
- Plate should be twisted 90 degrees to sit flush with the superior border of the mandibular angle along the external oblique ridge.
- Apply monocortical screws below the apices of the tooth roots and place plate to sit flush against the underlying bone.
- Two miniplate placement (**TECH FIG 4**):
 - The superior miniplate can be contoured to sit along the external oblique ridge or along the superior border of the fracture.
 - After contouring, place a 2.0-mm miniplate superiorly with monocortical screws.
 - A stab incision is made on the skin overlying the fracture to allow for

transbuccal trocar devices.

- Apply bicortical screws a few millimeters superior to the inferior border.
- The first screw should be placed posterior to the fracture site through the transbuccal trocar.
- The second screw is then placed anterior to the fracture site through the transbuccal trocar ensuring adequate reduction.
- Remaining screws are then placed.
- See general considerations for plate application.
- Do not hesitate to make an additional skin incision to aid in fixation.

Comminuted Fractures

- See general considerations for initial approaches to fracture reduction.
- To fully realign fragments, transbuccal trocar devices can be used.
- Due to difficult location, a submandibular incision can be utilized by avoiding injury to the marginal mandibular branch of the facial nerve.
 - Incision is made 2 to 3 cm below the inferior border of the mandible.
 - Divide platysma muscle 2 to 3 cm below mandibular border, and dissect in a subplatysmal plane.
 - Below the mandibular border, the marginal mandibular branch lies anterior to the facial vessels in subplatysmal plane. Identify with the nerve stimulator or other nerve identification system.



TECH FIG 4 • Transbuccal trocar approach for inferior border plate.

- Identify and ligate facial vein, and retract vessel superiorly to also retract marginal mandibular branch.
- Divide pterygomasseteric sling, and incise the periosteum over the fracture site.
- Use temporary miniplates to help hold reduction during realignment of fragments, but ensure plate location does not interfere with placement of reconstruction plate.
- Mobile fragments can be held in place by screws through the reconstruction plate.
- Remove temporary plates if interference with reconstruction plate is present.
- Apply appropriate screws to reconstruction plate ensuring plate is flush with the mandible.
- Close pterygomasseteric sling and remaining layers of the wound.
- See general considerations for plate application.

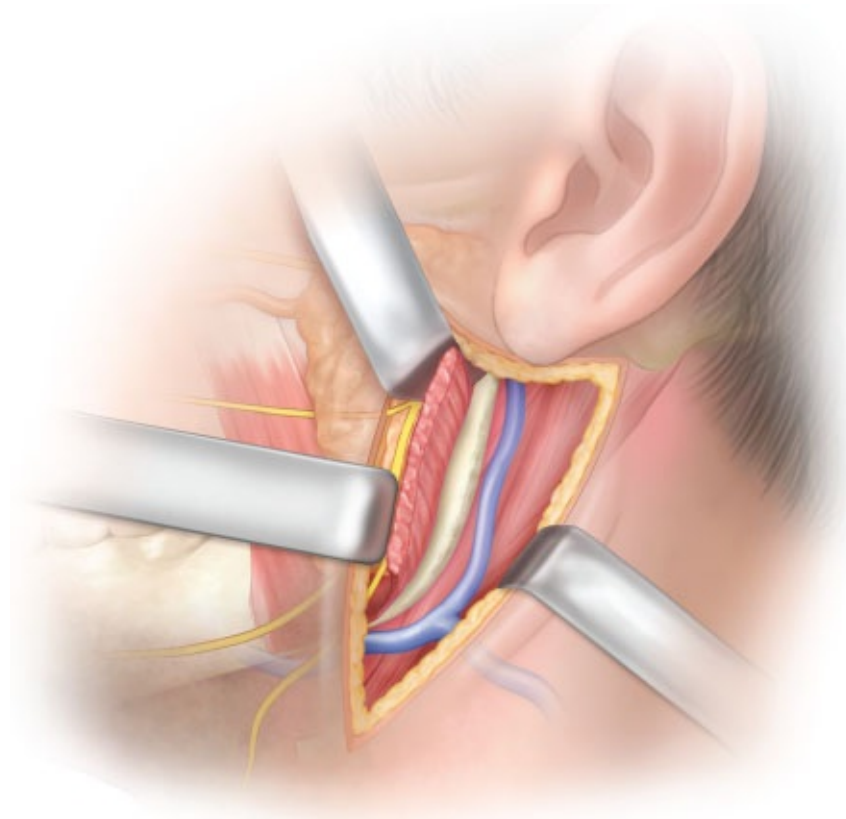
■ **Condylar and Subcondylar Fractures**

- Condylar fracture lines are within the temporomandibular joint and capsule. Subcondylar fractures are located below the temporomandibular joint capsule.
- Subcondylar fractures are generally treated conservatively due to potential risk of necrosis of the condylar head from disruption of blood supply during open reduction repair. Furthermore, because of the location, application of plates and screws is difficult.
- Treatment primarily consists of MMF for a minimum of 2 weeks when nondislocated.

ORIF

- Absolute indications for ORIF: (a) displacement of the condyle into the middle cranial fossa; (b) difficulty in obtaining adequate occlusion by closed reduction; (c) lateral capsular displacement of the condyle; or (d) invasion of the condylar neck by a foreign body.⁷

- An intraoral approach can be considered with incision over ascending ramus, but this exposure can often be difficult to expose the fracture.
- A retromandibular, retroparotid approach is advocated for exposure of the condylar/subcondylar process. An alternative is a retromandibular, transparotid approach (**TECH FIGS 1 and 5**).



TECH FIG 5 • Retromandibular, retroparotid approach for exposure of the condylar/subcondylar process. An incision has been made through the SMAS and the parotid gland dissected off the masseter. The pterygomasseteric sling has been incised for subperiosteal access to the condylar/subcondylar process posteriorly.

- Incision is made from the mastoid process to the angle of the mandible. The use of local anesthetic with epinephrine may impair facial nerve function and limit the use of a nerve stimulator and nerve identification.

- An incision is made through the superficial musculoaponeurotic system, and the parotid gland is identified.
- Dissection is carried posteriorly, and the masseter is identified behind the parotid gland.
- The pterygomasseteric sling is incised, and a subperiosteal dissection is carried out to expose the area of fracture.
- See general considerations for initial approaches to fracture reduction.
- Manipulation of the fragment for reduction may also be achieved with the jaw open.
- Due to the lateral pterygoid forces, medialization of the condylar fragment occurs. This must be overcome by lateralizing the segment.
- A plate is then placed along the long axis of the fragment to hold the condylar segment in place, but the screw is not completely tightened.
- The mandible is pulled out to length in an anterior/inferior direction with reduction held by an assistant or bite block.
- With anterior traction applied to the plate, secure the remainder of the plate ensuring it is flush with the underlying bone.
- If possible, apply the second plate for fixation. However, this is often difficult due to limited exposure of the fracture.
- Close the pterygomasseteric sling and remaining layers of the wound.

■ Special Considerations

Fractures of Atrophic/Edentulous Mandible^{2,3}

- Often seen in patient with poor hygiene, malnutrition, immunosuppressed, and elderly.
- Closed reduction: achieved with wiring patients in dentures or Gunning-style splints, which are acrylic splints that take form of modified dentures.
- ORIF for displaced or comminuted fractures:
 - The procedure is often performed with a reconstruction plate through either a submandibular or intraoral approach. The extraoral approach is technically easier.
 - A locking plate must span from angle to angle with a minimum of two screws in all bone fragments. Generally, three or more screws are placed in all fragments, and all plate screw holes over intact bone are utilized due to

the poor bone stock.

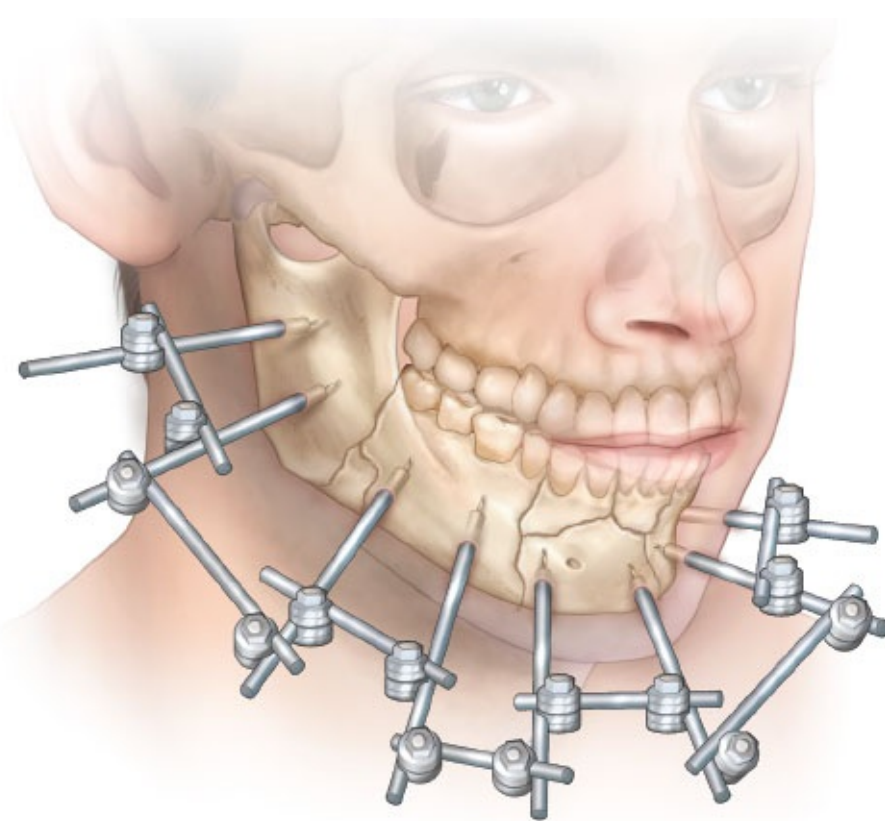
- Screws are generally placed in the symphysis and angle due to better bone quality.
- Autogenous bone graft may be added to fracture site to facilitate healing as malunion/nonunion is common in these patients.
- External fixation: can be considered for temporary stabilization as a bridge until ORIF is possible.

External Fixation

- Approach considerations:
 - Observation indicated with significant comorbid medical conditions
 - Closed reduction achieved by wiring
- Application (**TECH FIG 6**):
 - Safe zones are located along lower and posterior portions of the mandible. Avoid the condylar neck so as to prevent damage to the facial nerve trunk. Other areas to avoid are the mental foramen and mandibular canal containing the inferior alveolar nerve.
 - Place patient in MMF to help align major fragments.
 - Via small stab incisions, blunt dissection to bone is performed.
 - Through a trocar, bicortical pins are placed with two pins through each major fragment.
 - Rods are placed at the two pins for each fragment followed by rod-to-rod clamps.
 - Achieve reduction and tighten rod-to-rod clamps.
 - Alternatively, a bow-shaped rod can attach directly to the pins.
 - Release MMF and check occlusion.

Coronoid Fractures

- Coronoid fractures account for less than 1% of all mandible fractures.
- They are often associated with zygomaticomaxillary fractures and can present as trismus.
- Fractures are often observed and managed with soft diet only.
- If persistent trismus or interference with mouth opening is present, coronoid removal is considered without significant sequelae.
- Consider ORIF vs removal in cases of panfacial fractures.



TECH FIG 6 • External fixation application technique.

PEARLS AND PITFALLS

Reduction	■ Insufficient reduction can lead to a higher rate of postoperative complications.
Fixation	■ Number of plates and screws should be limited, and avoid temptation to over treat with too large or too many plates. ■ Poor screw positioning can result in nerve or root damage. ■ Compression in comminuted areas should be avoided, and reconstruction plate should be used. ■ At least two screws should be placed on each side of defect for comminuted fractures.

POSTOPERATIVE CARE

- Adult patients who have undergone ORIF will be on a soft, nonchew diet for 4

weeks minimum.

- Patients who have been placed in MMF will be on a full liquid diet and should have nutrition counseling and close monitoring of nutritional intake, with supplementation as needed.⁶
- Peridex mouth rinse is imperative for maintaining good oral hygiene.⁶
- Routine follow-up at 2 and 4 weeks after surgery to evaluate healing and assess occlusion is recommended.
- Normal bony union takes 4 to 8 weeks, depending on the age of the patient.³
- Arch bars should be removed 4 to 6 weeks after surgery.

COMPLICATIONS

- Complication rates are directly related to the type of injury and location of fracture.^{1,3}
- Angle fractures have the highest rate of complications.^{1,3}
- Infection is the most common complication after repair of mandible fractures.¹⁻³
- Less common complications include³:
 - Nonunion.
 - Malunion.
 - Malocclusion.
 - Tooth loss.
 - Trismus.
 - Ankylosis.
- Broadening of the face especially with condylar and subcondylar fractures.
- Paralysis of marginal mandibular and/or mental nerves is generally transient.¹

ACKNOWLEDGMENTS

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70 Open Treatment of Condyle Fractures

CHAPTER

Michael A. Lypka

DEFINITION

- Condyle fractures of the mandible refer to a group of fractures involving the condylar head, neck, and base (**FIG 1**).¹
- There have been many classification schemes for mandibular condyle fractures; which classification system is best is debatable.
- Important concepts relating to complexity of surgical repair would be the cranial-caudal position of the fracture (condylar head fractures are complicated), medial or lateral displacement of the proximal segment relative to the ramus (medially displaced are more difficult), and degree of displacement of the proximal segment from the mandibular fossa.

ANATOMY

- Knowledge of the anatomy of the temporomandibular joint (TMJ) and surrounding structures is critical if open treatment of condyle fractures is entertained. The decision to operate must be balanced with the potential risks of surgery, most importantly the risk to the facial nerve (**FIG 2**).
- Temporomandibular joint (TMJ)
 - The TMJ is a symmetrically paired synovial articulation, which is the interface between the mandible and the base of skull.
 - The condylar head, with a lateral and medial pole, rests in the mandibular fossa, separated from the middle cranial fossa cephalad by a thin margin (approximately 1 mm) of bone. Anteriorly, the TMJ rests on the articular eminence of the zygomatic arch and translates along its slope with oral opening.
 - An ovoid biconcave avascular disk is interposed between the mandibular

condyle and temporal bone, separating the TMJ into superior and inferior joint spaces, in which translation and rotation occur, respectively. The superior head of the lateral pterygoid muscle inserts into the anterior aspect of the disk, whereas the inferior head inserts onto the mandibular condyle. The disk transitions into an innervated network of connective tissue and blood vessels posteriorly, known as the bilaminar zone.

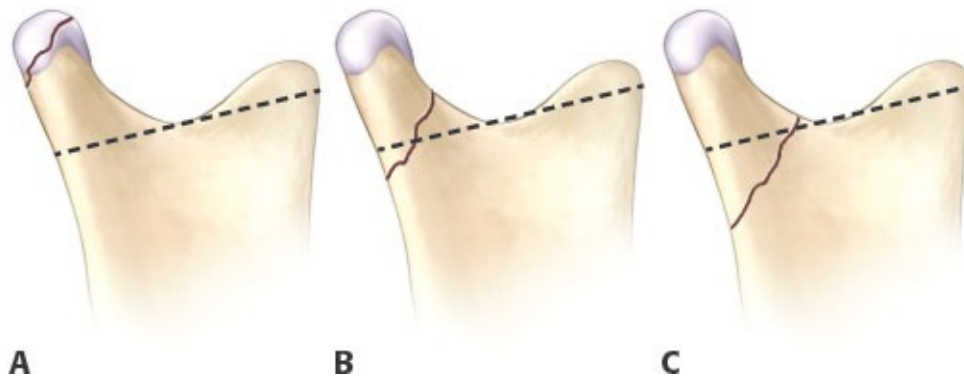


FIG 1 • Classification of mandibular condyle fractures. The sigmoid notch line (Loukota's line) differentiates neck and base fractures. **A.** Condylar head fracture: fracture of the medial or lateral pole of the condyle. **B.** Condylar neck fracture: the fracture runs above the line for greater than half its length. **C.** Condylar base fracture runs below the line for greater than half its length.

- The joint capsule that surrounds the eminence and fossa blends with the periosteum of the zygomatic arch and condylar neck. It is thickened laterally to form the temporomandibular ligament or lateral ligament.
- Vascular/nerve supply
 - The external carotid artery bifurcates into two terminal branches within the parotid gland; the superficial temporal artery, which ascends vertically along the posterior border of the condyle and forms anterior and posterior branches above the zygomatic arch, and the maxillary artery, which traverses the condylar neck on its deep surface toward the pterygopalatine fossa.
 - The auriculotemporal nerve provides sensory innervation to portions of the auricle, external auditory canal, tympanic membrane, and temporal skin, and

runs parallel and posterior to the superficial temporal artery.

- The superficial temporal vein lies superficial and posterior to the artery and then drains into the retromandibular vein, which runs posterior to the ramus of the mandible.

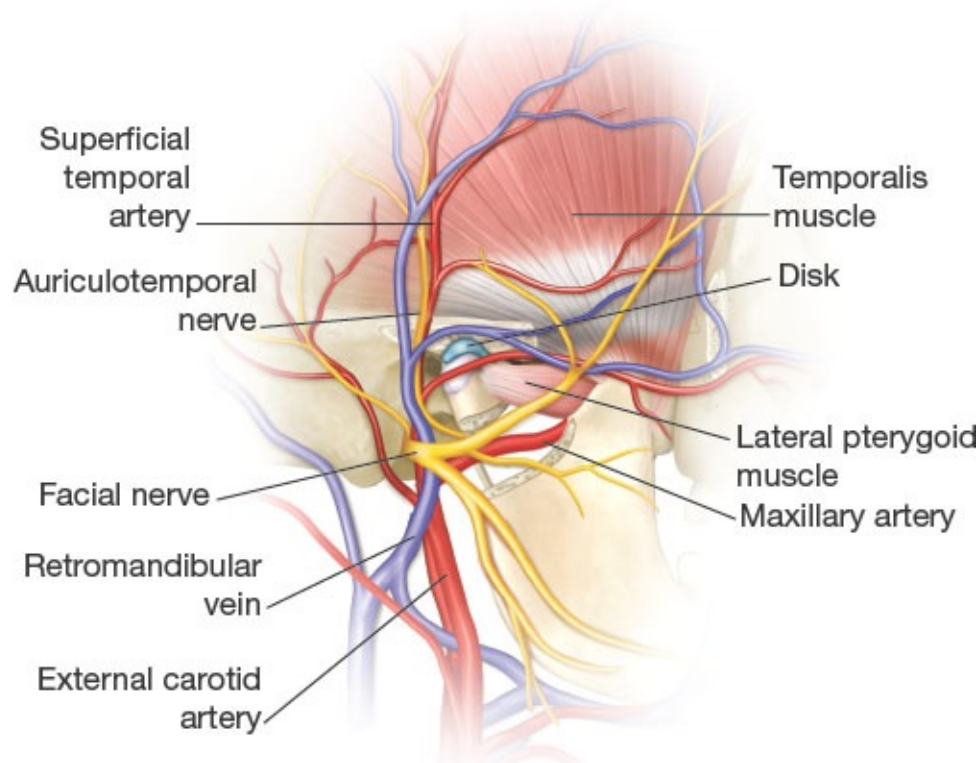


FIG 2 • Complex anatomy overlying mandibular condyle.

- Parotid gland
 - The parotid gland, encapsulated by the parotidomasseteric fascia (parotid capsule), lies directly over the TMJ capsule.
 - The gland contains facial nerve branches coursing through it, as well as the superficial temporal artery and retromandibular vein.
- Relevant fascial layers (**FIG 3**).
 - Deep to the skin, in the temporal region, lies the temporoparietal fascia (TPF) or superficial temporal fascia. Anteriorly, this layer is continuous with galea/frontalis. The TPF is continuous caudally in the parotid region with the superficial musculoaponeurotic system (SMAS). In the neck, the SMAS is continuous with the platysma muscle.

- A layer deeper, in the temporal region, is the innominate or subgaleal fascia. The temporal branch of the facial nerve lies in this plane, deep to the TPF. The parotidomasseteric fascia in the parotid region is continuous with the innominate fascia above and the superficial layer of the deep cervical fascia in the neck. The marginal mandibular branch lies within or just deep to this cervical fascia.
- The temporalis fascia overlying the temporalis muscle, splits into superficial and deep layers above the zygomatic arch, containing the superficial temporal fat pad, before inserting onto the zygomatic arch.
- Facial nerve
 - The facial nerve emerges from the stylomastoid foramen and curves anteriorly into the parotid gland. It bifurcates within the parotid gland into temporofacial and cervicofacial branches, ultimately giving rise to five terminal branches: temporal, zygomatic, buccal, marginal mandibular, and cervical. There are many interconnections between buccal and zygomatic branches but not the temporal and marginal mandibular branches, thus requiring special attention during surgical exposures involving these branches.

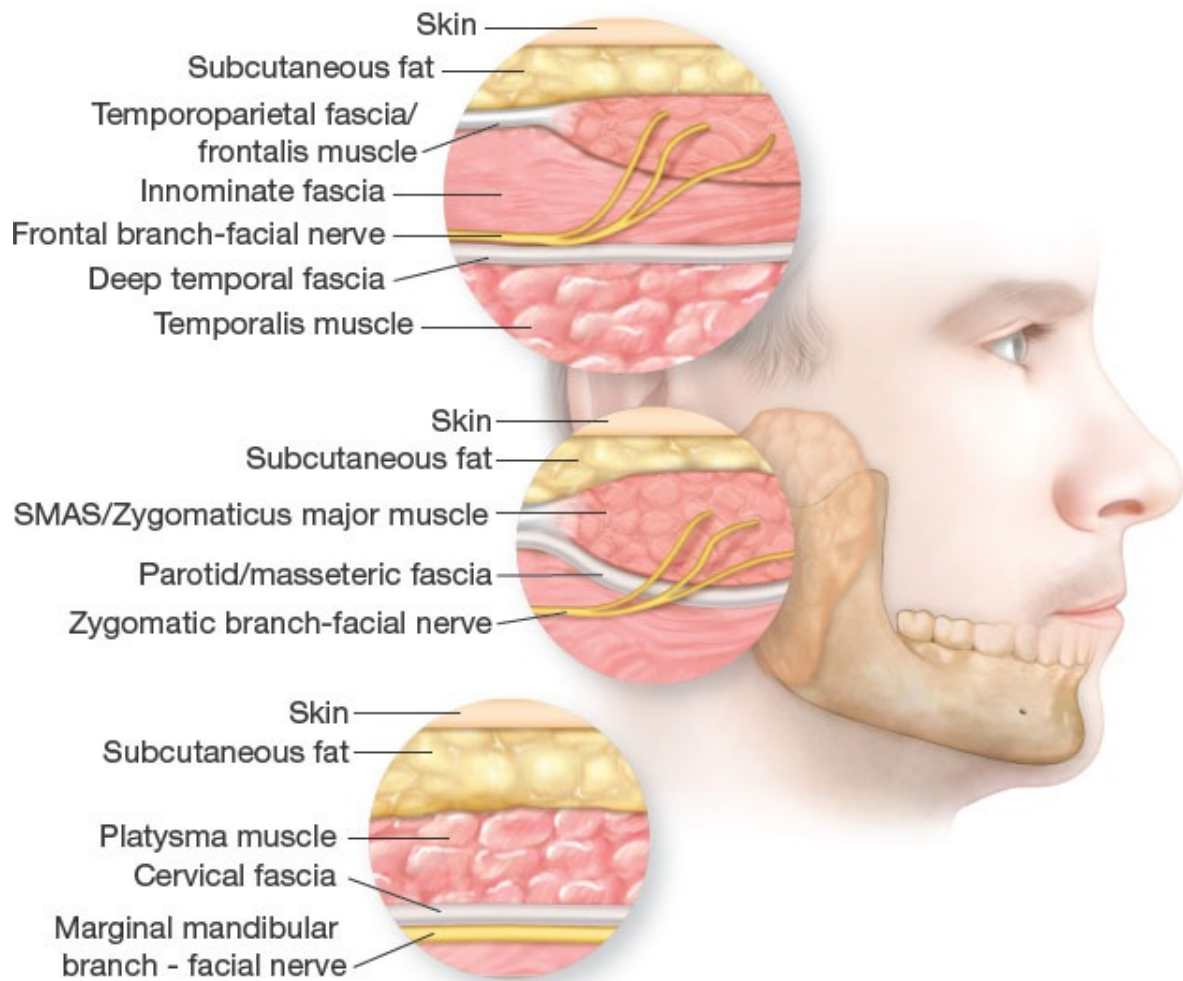


FIG 3 • Relevant fascial layers in the area of the mandibular condyle.

- The temporal branch runs deep to the TPF, crosses the zygomatic arch, and lies anywhere from 8 to 35 mm anterior to the external auditory canal.²
- The marginal mandibular branch, of significance in the Risdon approach, lies in or deep to the superficial layer of the deep cervical fascia. It may course below the angle of the mandible (upwards of 1.2 cm). Anterior to the facial vessels, the marginal mandibular nerve is almost always above the inferior border.^{3,4}

PATHOGENESIS

- Condyle fractures are sustained from either an axial load or a lateral impact.
- A patient who sustains an impact to the chin transmits forces to the base of

the skull resulting in bilateral condyle fractures, often with a concurrent symphysis fracture.

- A lateral impact results in ipsilateral condyle fracture and concurrent contralateral body fractures.

NATURAL HISTORY

- Untreated condyle fractures typically will heal without treatment (meaning that bony union will occur), but sequelae such as malocclusion, TMJ pain, or rarely ankylosis (less than 0.5 per 1000)⁵ can occur.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The mechanism of injury should be ascertained. An impact to the chin, as in a fall directly onto the chin, should elicit suspicion for bilateral condylar fractures with possible symphyseal fracture. A lateral impact (punch to the face) may result in a condyle fracture on the side of impact.
- Change in occlusion, preauricular pain, concussive symptoms, and limitations of mouth opening are important historical data.
- Physical findings
 - Limited mouth opening: deviation to the side of fracture on opening
 - Change in occlusion
 - Premature molar contacts on the side of fracture or lateral open bite on the opposite side.
 - Anterior open bite in bilateral condyle fractures due to loss of vertical height
 - Occlusal canting
 - Facial asymmetry due to loss of height on the fractured side
 - Tenderness to palpation over the fracture sites in preauricular area

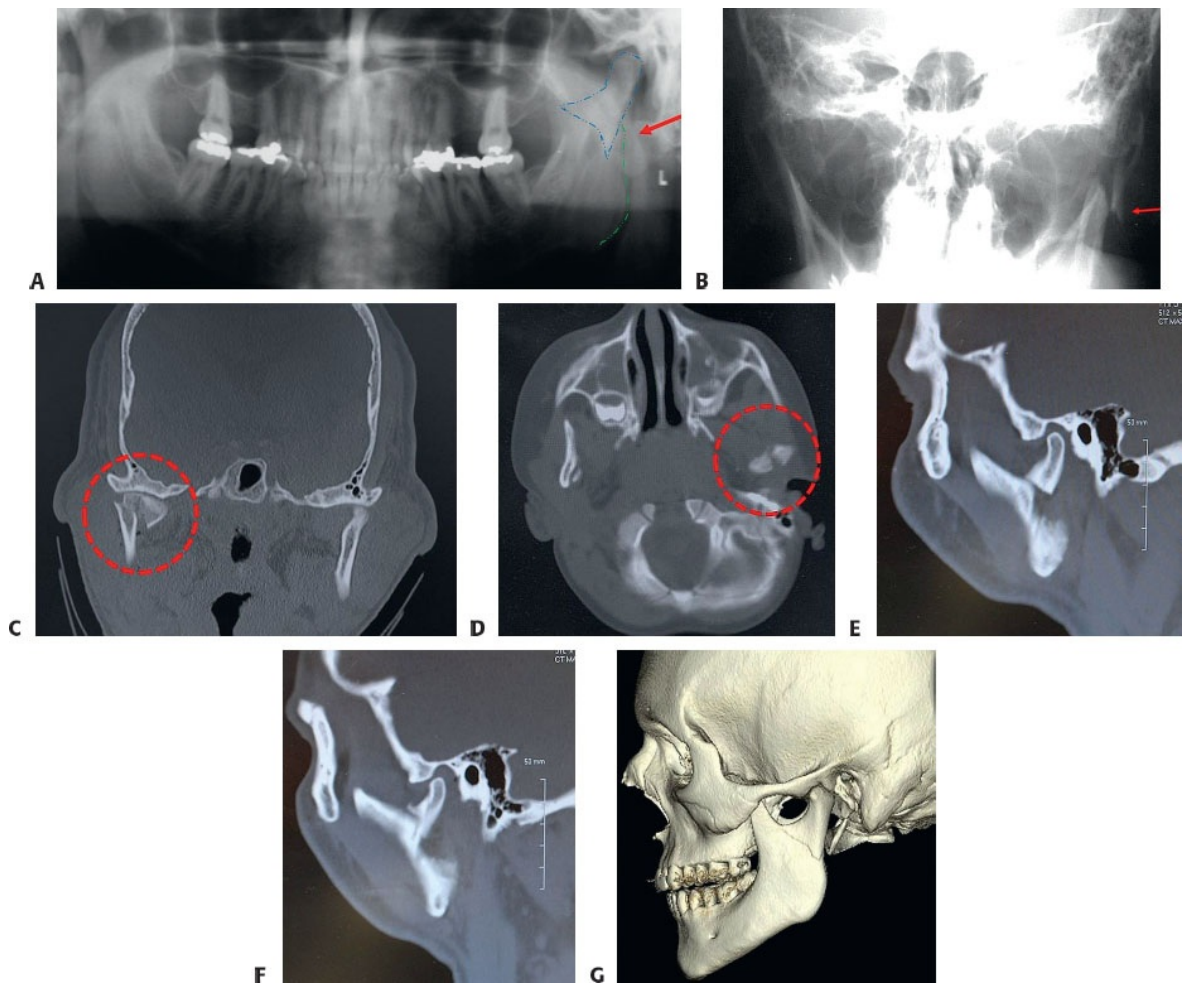


FIG 4 • **A.** Orthopantomogram of left condylar base fracture. **B.** Towne's view showing laterally displaced fracture. Coronal (**C**) and axial (**D**) CT scans of condylar head fractures in two different patients. (The author would not approach these surgically, although some would.) **E,F.** Sagittal CT sections of right and left condylar neck and base fractures. **G.** 3D CT scan of condylar base fracture.

- Blood in external auditory canal—signifies fracture of cartilaginous wall of EAC
- Submental lacerations
- Cervical spine tenderness (concomitant injury in approximately 5% of mandible fractures)

IMAGING

- Orthopantomogram is a useful x-ray that identifies most condyle fractures and provides an overview of teeth and bony structures, often giving additional information about occlusion (**FIG 4A**).
- Reverse Towne's view: This plain film, taken from posterior to anterior with the neck flexed, is a useful adjunct to the panorex to identify condyle fractures (**FIG 4B**).
- CT scans have become the standard for imaging of the maxillofacial skeleton in facial trauma and are indispensable in diagnosing and treatment planning for various types of condyle fractures.
- Coronal, axial, and sagittal views (**FIG 4C–F**), in addition to the 3D reconstruction (**FIG 4G**), will identify and characterize any fracture.

NONOPERATIVE MANAGEMENT

- In select cases with nondisplaced fractures on one or both sides, with a stable occlusion and limited pain, nonoperative management with a soft diet and progressive range of motion is appropriate.

SURGICAL MANAGEMENT

Indications/Contraindications

- According to Zide and Kent,⁶ absolute indications for open treatment include the following:
 - Displacement into the middle cranial fossa
 - Impossibility of obtaining adequate occlusion by closed reduction
 - Lateral extracapsular displacement
 - Invasion by foreign body
- The indications for open treatment of condyle fractures are relative, given the satisfactory outcomes of most fractures by closed means. Nonetheless, the decision to open condyle fractures is based on identifiable factors, including patient age, general health and mental state, concomitant panfacial fractures, and most importantly the surgeon's comfort level with opening condyle fractures. Common reasons for open treatment include the following:
 - Unilateral condylar fractures (fractures of the neck and base) with significant displacement or loss of vertical height
 - Bilateral condylar fractures (fractures of the neck and base) with significant displacement—to restore vertical height and projection

- Contraindications to open treatment include the following:
 - Condyle fractures in children
 - Fractures of the condylar head, including bilateral fractures. Although controversial, the author prefers managing postoperative malocclusions with orthognathic surgery rather than permanently disrupting the vascular supply to the condylar head, which often results in unsatisfactory results.

Preoperative Planning

- Combining history and physical findings, with a detailed radiographic evaluation, a decision is made to perform open reduction of the condyle fracture with the optimal surgical approach.

Positioning

- The patient should be positioned supine with the head in a horseshoe, allowing head rotation during surgery.

Approach

- There are three standard extraoral approaches to the mandibular ramus and condyle.
 - Retromandibular approach⁷ is the most used approach.
 - For fractures either just above, at, or below the sigmoid notch, this transparotid approach allows direct access to the fracture for efficient reduction and application of rigid fixation.

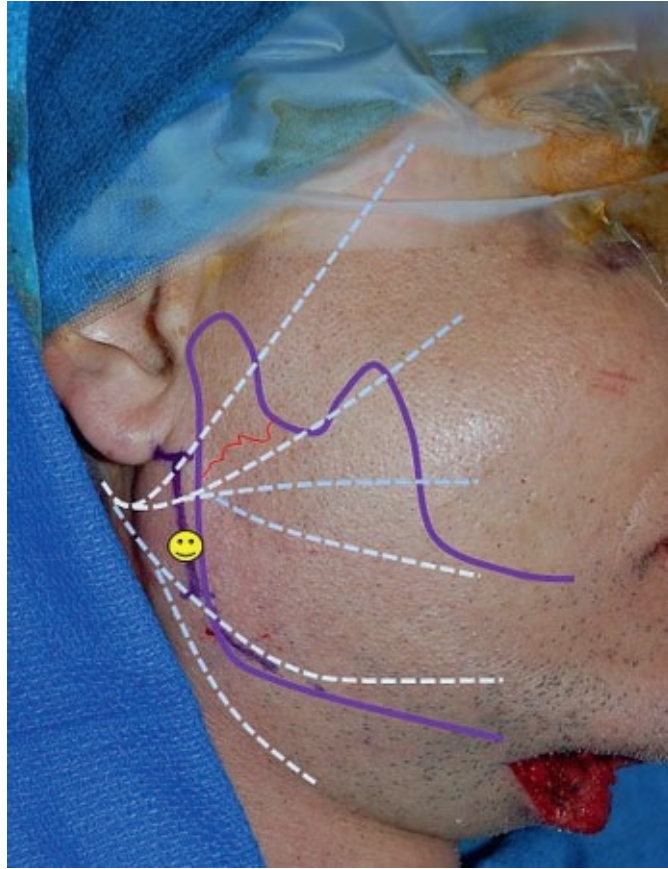


FIG 5 • Retromandibular incision relative to facial nerve branches.

- This approach is positioned between the buccal branches and the marginal mandibular branch, resulting in less traction on the nerve (**FIG 5**).
- Access is limited, however, because typically, only a small “window” can be created through the parotid gland.
- Risdon (submandibular)⁸ approach is the standard approach to the mandible.
 - This approach “from below” gives access to the entire ramus and condyle but requires significant soft tissue retraction, potentially resulting in traction injury to the marginal mandibular branch. A limited Risdon approach with the aid of an endoscope limits the need for extensive soft tissue retraction.⁹
 - Useful for fractures below the sigmoid notch or condylar head fractures in which a vertical ramus osteotomy is performed, and the condylar head disarticulated, with fixation of the segments on the back table and replacement with rigid fixation of the devascularized ramus/condylar unit (not advocated by this author).

- Preauricular approach allows access for condylar head fractures.
 - Access given by this approach is often too cephalad for most fractures and must be combined with another more inferior approach.
 - Useful to reduce a condyle fracture displaced into the middle cranial fossa.
- An intraoral approach to the condyle through a mandibular vestibular incision with or without endoscopic assistance, with extraoral trochar stabs or a special angled drill to apply fixation, is well described but will not be discussed here.¹⁰
- Open treatment of condyle fractures from an extraoral approach is already technically difficult, and it is the author's opinion that the intraoral-endoscopic technique, requiring special equipment and significant skill and training, should not be used by novice surgeons.

TECHNIQUES

■ Retromandibular Approach

Markings and Exposure

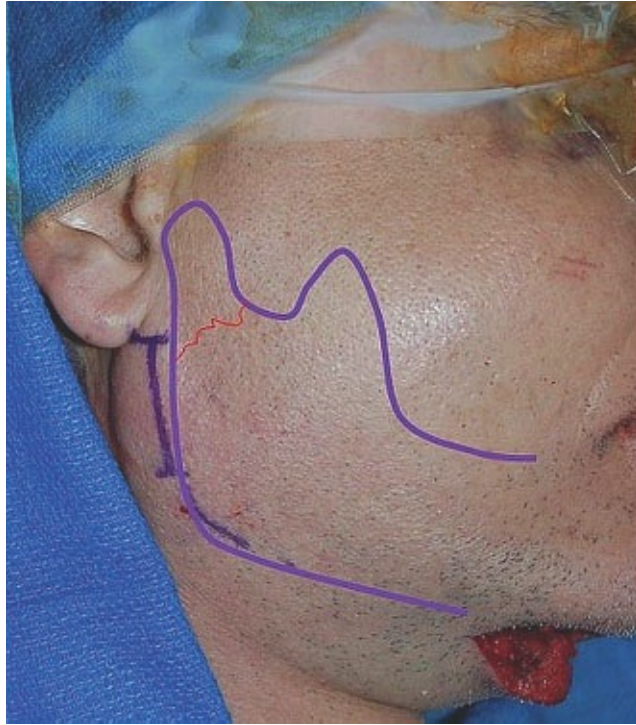
- Marking is made approximately a half centimeter below the earlobe paralleling the posterior border of the mandible, extending toward the angle (**TECH FIG 1**).
 - The incision can usually be limited to 2 to 3 cm.
- Local anesthetic with vasoconstrictor is administered. Avoid paralytic agents at this point so facial nerve monitoring is possible.
- The skin incision extends through the subcutaneous tissues and superficial musculoaponeurotic sling (platysma is thin in this region) to the parotid capsule.
- Vertical incision is made in the parotid capsule, entering the substance of the gland.
 - Blunt dissection is then performed through the gland, spreading in the direction of the facial nerve branches, in a horizontal or slightly oblique direction.
 - Toe-in retractors can be used to create a “window,” through the gland down to the mandible. Space is limited and will increase slightly with retraction. Typically, the window is between the buccal and marginal mandibular branches of the facial nerve. No attempt is made to isolate these branches,

but they may be encountered during dissection through the gland.

- Dissection through the pterygomasseteric sling is performed, with either a scalpel blade or Bovie cautery along the posterior border of the ramus. Subperiosteal dissection of the ramus, including the sigmoid notch and angle, then ensues, exposing the fracture cephalad.
- A toe-out retractor is placed behind the posterior ramus, protecting the retromandibular vein.
- A toe-in retractor is placed cephalad to locate the fracture line and displaced proximal segment.

Reduction and Fixation

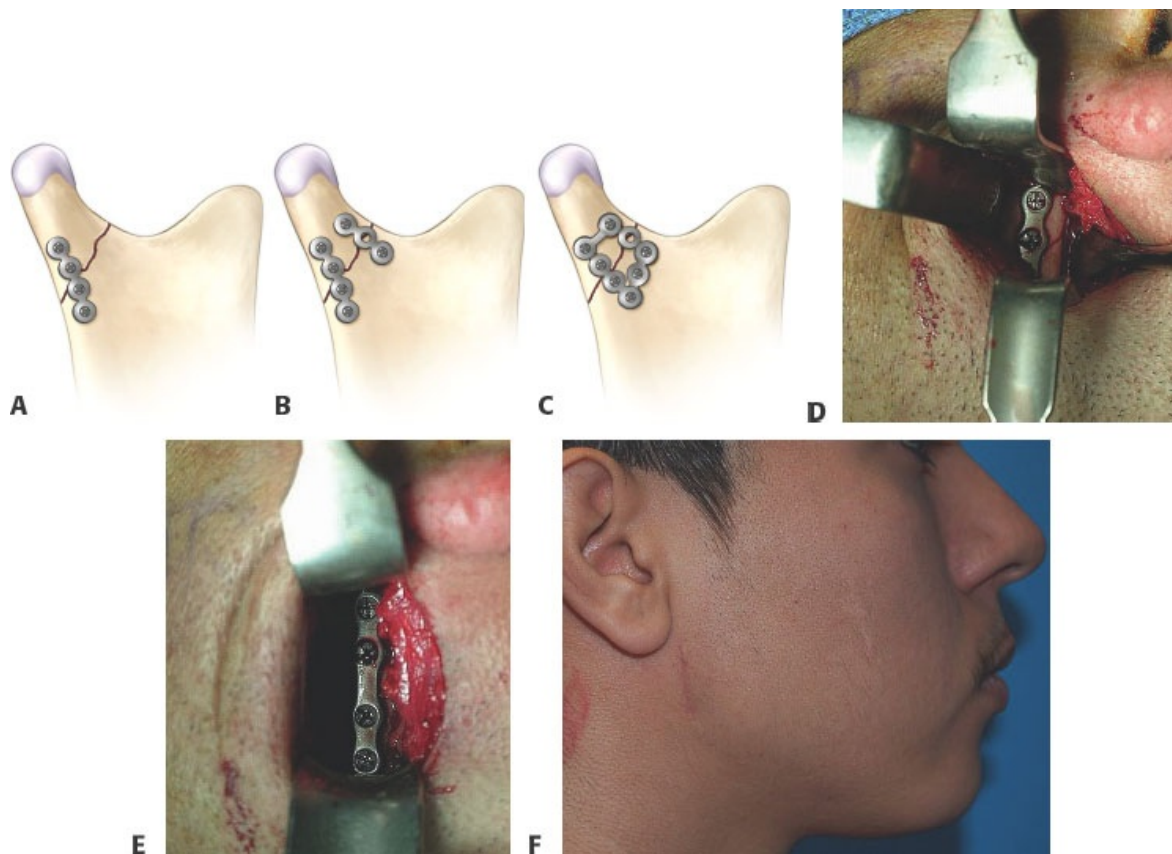
- Fracture reduction is the difficult part.
 - Laterally displaced proximal segments, and those below the sigmoid notch, are the easiest to locate and reduce, whereas medially displaced, high condylar neck fractures are the most difficult.
 - Although not always feasible, it is best not to strip all the periosteal attachments from the proximal segment (dissect only the parts closest to the fracture site as necessary); otherwise, the segment will be devascularized, but more importantly, will become a floating target, making successful reduction difficult.
- Typically, the ramus has lost vertical height due to overlap of fracture segments. To re-establish height and achieve reduction, the angle of the mandible needs to be pulled caudally, thus stretching the sling. Paralytic agents may now be useful to accomplish this task.



TECH FIG 1 • Retromandibular incision preoperative marking (with mandible overlay).

- Two options exist to pull the angle caudally. A wire can be used to lasso a screw placed at the angle by using a spinal needle to enter the dissection pocket from below percutaneously. Another option is to open the posterior occlusion with a bite block. This may contaminate a sterile approach; however, external approach to the condyle is often combined with an intraoral approach if other fractures require reduction and fixation.
- Ideally, the fracture is reduced, and if stable, fixation is applied, with any one of three options: a four-hole plate at the posterior border; two plates, one at the posterior border and the other at the sigmoid notch; or a specifically designed plate for the condyle (**TECH FIG 2A–E**).
- Stable reduction prior to fixation is rarely achieved. Often, it is useful to apply the fixation plate with one screw in the proximal segment and use it as a handle to control the segment and reduce the fracture.
 - With the fracture reduced, another screw is placed in the distal segment, followed by the remaining screws.
 - Alternatively, a K-wire can be used as a joystick for the proximal segment to control its movement.

- After fracture reduction and fixation, the posterior border of the ramus should naturally flare posteriorly.
 - If it does not, re-evaluate fixation.
 - Check occlusion after reduction.
- Irrigate surgical site and begin closure.
- Repair of the pterygomasseteric sling can be attempted but is not performed by the author.
- The key to this approach is a watertight closure of the parotid capsule, to prevent sialocele formation.
- Skin closure is accomplished according to surgeon preference (**TECH FIG 2F**).



TECH FIG 2 • Three different options for fixation of the reduced condyle fracture: one four-hole plate (**A**), two plates (**B**), custom plate (**C**). **D,E**. Plate fixation through retromandibular approach. **F**. Typical postoperative appearance of scar.

■ Submandibular (Risdon) Approach

- Marking is made 1.5 to 2 cm below the inferior border of the mandible, either paralleling the inferior border of the mandible or following a natural skin crease of the neck (**TECH FIG 3**).
- If a natural skin crease is used, the incision will tend to diverge from the mandible anteriorly, requiring a longer incision for the same access relative to an incision paralleling the inferior border.
- Local anesthetic with vasoconstrictor is administered. Avoid paralytic agents so facial nerve monitoring is possible.
- Skin incision is made and dissection continues through the platysma muscle to the superficial layer of the deep cervical fascia. The marginal mandibular nerve is in this layer, or just deep to it.
- Blunt dissection continues through the deep cervical fascia over the submandibular gland but inferior to the inferior border of the mandible. A prominent lymph node (Node of Stahr) will be encountered, heralding the location of the facial artery and vein (artery lies anterior and deep to the vein).
- The artery and vein may be ligated at this time if exposure of the body of the mandible is necessary. The marginal mandibular nerve lies superficial to the vessels; if dissection ensues deep to them, the nerve is protected.
- With retraction of the soft tissue cephalad, an incision is made in the pterygomasseteric sling. Subperiosteal dissection of the ramus and condyle is performed with this approach.
- Fracture reduction and fixation ensues as described in the retromandibular approach. Direct access to the angle allows the mandible to be tractioned inferiorly by this approach. The fracture segments can be lag screwed via this approach.
- The pterygomasseteric sling is approximated, followed by the platysma, and skin layers.



TECH FIG 3 • Preoperative markings for preauricular and Risdon (submandibular approaches).

■ Preauricular Approach

Exposure

- The simplest approach is through the preauricular crease, extending from the superior helix to the lobule.
 - A cephalad extension can be made for improved access, either straight vertically into the hairline or anteriorly, in a hockey stick fashion, either at the anterior hairline junction or just above the junction.
 - Modification: Transitioning the marking along the margin of the tragus (endaural) is a common modification to conceal the incision. A retroauricular crease incision has been described but requires transection of the external auditory canal with later reapproximation (see **TECH FIG 3**).
- Local anesthetic is injected. Paralytic agents should be avoided, so facial nerve monitoring is possible.
- The skin incision proceeds through the TPF (cephalad) and SMAS

(caudally). If an endaural incision is used, avoid transecting the tragal cartilage after skin incision.

- The superficial temporal vein will be encountered first and ideally retracted anteriorly.
- Below the zygomatic arch, dissection proceeds along the border of the tragal cartilage or external auditory canal, in this avascular plane.
- If dissection proceeds too far anteriorly, away from the cartilage, the superficial temporal artery will be encountered.
- Bleeding from this source may be difficult to control.
- Above the zygomatic arch, dissection proceeds to the temporalis fascia.
- An oblique incision is made in the temporalis fascia, extending from the root of the zygomatic arch, exposing the superficial temporal fat pad.
- Veins within the fat pad, close to the area of dissection, may be cauterized with bipolar cautery.
- Inferiorly from this oblique incision, a periosteal incision is made on the root of the zygomatic arch, which transitions into the caudal dissection along the border of the external auditory canal.
- The zygomatic arch is exposed in a subperiosteal plane, unveiling the TMJ capsule below.
- The soft tissues are retracted anteriorly, protecting the temporal branch of the facial nerve, which is contained within the flap.
- A periosteal incision is made on the posterior border of the condylar neck; the joint space is not entered.
- A tunneling-type subperiosteal approach is then employed from above to access the condylar head and neck, exposing the sigmoid notch anteriorly. Remember that the main trunk of the facial nerve is just caudal to this area of dissection.
- This dissection can be connected with a subperiosteal dissection from an alternative approach (Risdon or retromandibular) from below (**TECH FIG 4**).

Reduction and Fixation

- The displaced fracture segments are located, reduced, and fixated. Hooks can be used to stabilize small fragments. Overly aggressive stripping of the periosteal attachments will devascularize bony segments and make fracture reduction more challenging.
- Condylar head fractures are usually fixated with small lag screws or

miniplates (1.5 or 2.0).

- Deep layer closure is not necessary in this approach, and skin closure can be performed based on surgeon preference.



TECH FIG 4 • Intraoperative view of exposure to TMJ.

PEARLS AND PITFALLS

Decision-making

- Select appropriate cases (evaluate CT scan carefully).
 - Fractures of the condylar neck and below
 - Avoid fractures in children and condylar head fractures.
- If not comfortable with regional anatomy, do not use an open approach.

Anesthesia

- Avoid paralytic agents in order to monitor facial nerve during dissection.
- Use paralytic agents after dissection is complete to facilitate fracture reduction.

Technique

- The posterior border of the ramus/condylar unit should curve gently posteriorly after reduction.
- Avoid excessive periosteal stripping to maintain blood supply and facilitate fracture reduction.
- Check occlusion after reduction and fixation.
- Assure good closure of parotid capsule to avoid sialocele formation in the retromandibular approach.

Postoperative care

- A short period of MMF or guiding elastics is a good idea to prevent occlusal disharmonies and avoid discomfort.

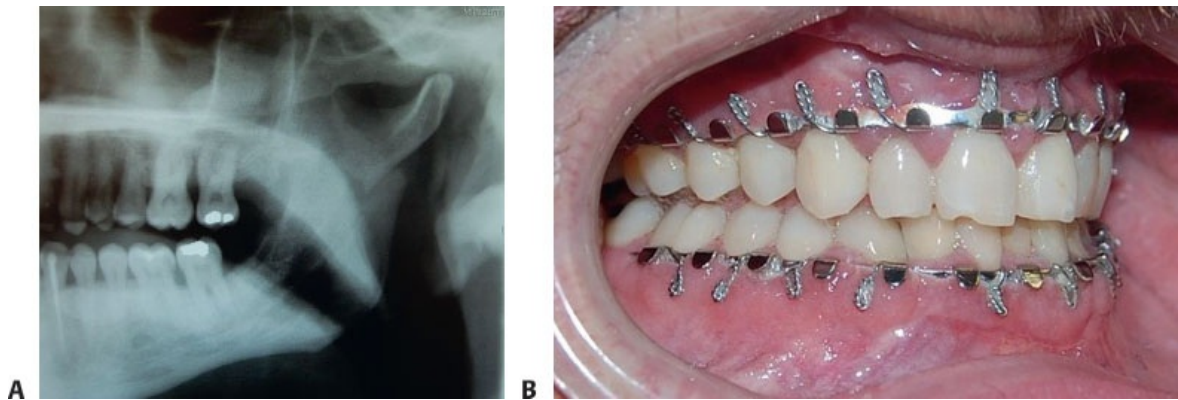


FIG 6 • A, B. Slight lateral posterior open bite due to loss of vertical height on the side of the fracture in a patient treated with a short period of maxillomandibular fixation. Patient refused open reduction.

POSTOPERATIVE CARE

- To avoid subtle occlusal discrepancies in the postoperative period (a result of swelling in the TMJ fossa from manipulation of the condyle), a short period (1 to 2 weeks) of maxillomandibular fixation or rubber band guidance is warranted.

OUTCOMES

- Most patients with condyle fractures, with either appropriate open or closed therapy, have excellent outcomes.
- The ability of the condyle to remodel and the stomatognathic system to adapt explain these good outcomes, even when the fracture is not reduced in closed treatment and when anatomic reduction is not precisely achieved in open

treatment.

- When treated ineffectively, however, certain sequelae may develop:
 - Malocclusion (most common) (**FIG 6**)
 - Long-term degenerative changes in the TMJ, with or without pain.
 - TMJ ankylosis (uncommon)—especially in the pediatric population when a fracture is unrecognized and range of motion is not established after the injury.
 - Iatrogenic facial nerve injury from open treatment approaches.

COMPLICATIONS

- Facial nerve injury. Typically, a traction injury resolves with time, but will be permanent if the nerve branches are transected or tractioned too aggressively.
- Poor scarring. Hypertrophic or unaesthetic scars are possible sequelae of extraoral approaches.
- Malocclusion. May be the result of:
 - Incorrect occlusion at fracture reduction
 - Improper fracture reduction (malunion)
 - Early failure of fixation
 - Loss of vertical height from resorption of the condylar head, leading to contralateral posterior open bite.
- Sialocele: Leakage of salivary fluid from parotid gland after the retromandibular approach. Prevented by careful closure of the parotid capsule. Treated with compression and antisialagogues.
- Malunion/nonunion
- Failure of fixation
- Facial widening/asymmetry

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71 Management of Mandibular Coronoid Fractures

CHAPTER

Raja Naddaf

DEFINITION

- Mandibular coronoid process fracture is extremely uncommon. In the anatomical distribution of mandibular fractures, coronoid process fractures account only for 0.2% to 2% of all mandibular fractures.¹⁻³

PATHOGENESIS

- Etiology of coronoid fractures: motor vehicle accidents, interpersonal violence, sport injuries, and falls. Less commonly, fractures are caused during mandibular third molar extraction and bad split during mandibular sagittal split osteotomy.¹⁻³

ANATOMY

- The zygomatic arch protects the coronoid process along its lateral aspect. The temporalis muscle attaches to the lateral surface of the coronoid process.
- Fracture of the zygomatic arch with medial displacement of fragments can often impinge on the coronoid process of the mandible and cause trismus.^{1,3,4}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Clinical exam demonstrates several symptoms, most commonly a limitation in mouth opening and in lateral movement of the mandible.
- In some cases, swelling and hematoma can be present; occlusion disturbance is less common and is usually related to other mandibular fractures.^{1,3,4}

IMAGING

- Plain radiographs or panoramic radiographs can be helpful, but the standard is computed tomography (CT) scans (**FIG 1**).

DIFFERENTIAL DIAGNOSIS

- Considering anatomical and functional relations, when facing a coronoid process fracture, the surgeon must take into consideration the probability of concomitant zygomatic arch fracture.

NONOPERATIVE MANAGEMENT

- Treatment of coronoid process fractures can be divided into three categories:
 - Nonoperative management
 - Conservative treatment
 - Open reduction and internal fixation (ORIF)
- Nonoperative management is advocated in cases of minimally displaced coronoid process fractures, absence of mouth opening limitation or trismus, and usually when the fracture is solitary.

SURGICAL MANAGEMENT

- In cases of concomitant zygomatic arch fractures, one should consider closed reduction of the arch fracture only.
- Several authors advocate the removal of the fractured coronoid process via an intraoral incision (coronoidectomy) in order to prevent fibrosis or ankylosis between the coronoid and the surrounding structures.^{1,3,4}
- ORIF is indicated in cases of significant displacement of the coronoid process or when there are other associated mandibular fractures (body, angle, condylar process).^{1,3,4}
- In cases of multiple mandibular fractures, there is an indication for ORIF of the coronoid fracture.

PREOPERATIVE PLANNING

- Imaging to visualize the coronoid fracture can be either x-rays, including panoramic radiography, or CT scans.

POSITIONING

- Nasal intubation is the preferred method, unless there are contraindications due to midface fractures or the need for tracheostomy.
- The patient should be placed in the supine position, with the head on a headrest to enable head manipulation during the operation.

APPROACH

- ORIF can be performed via an intraoral approach (less favored) or a modified

retromandibular approach or via submandibular approach through a Risdon incision (more favored).

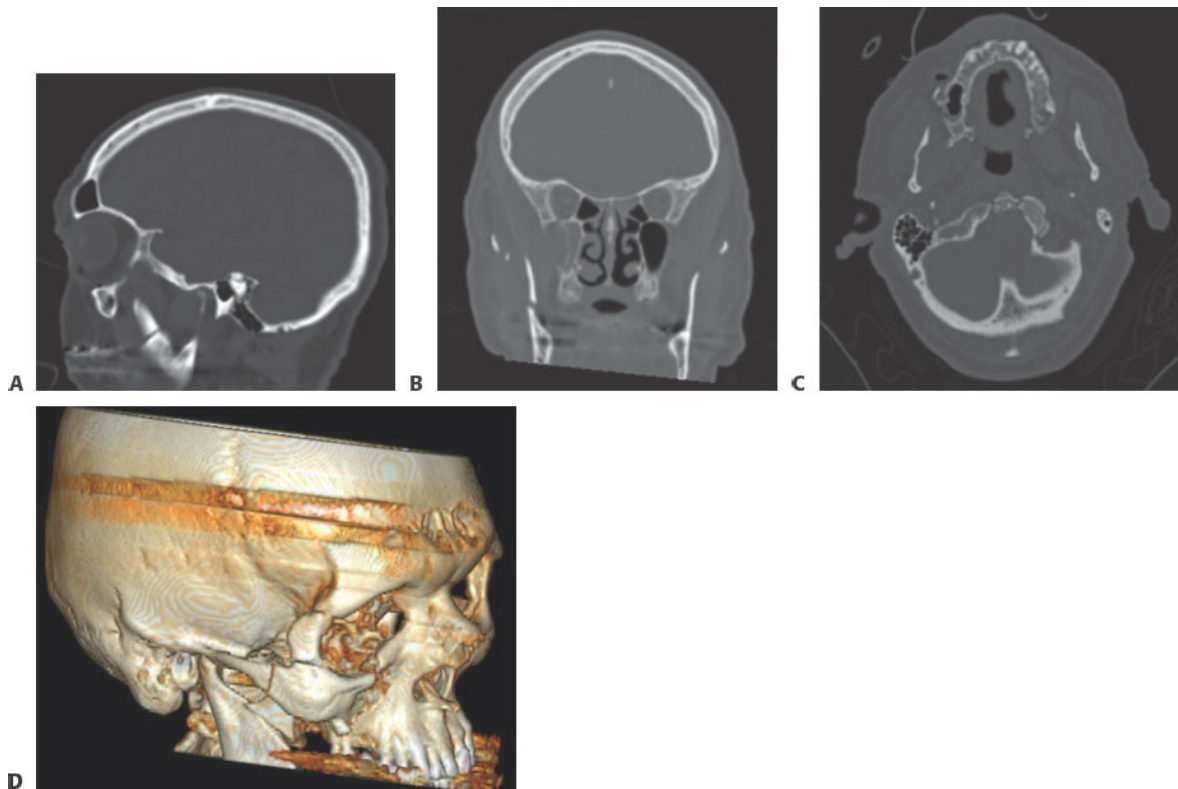


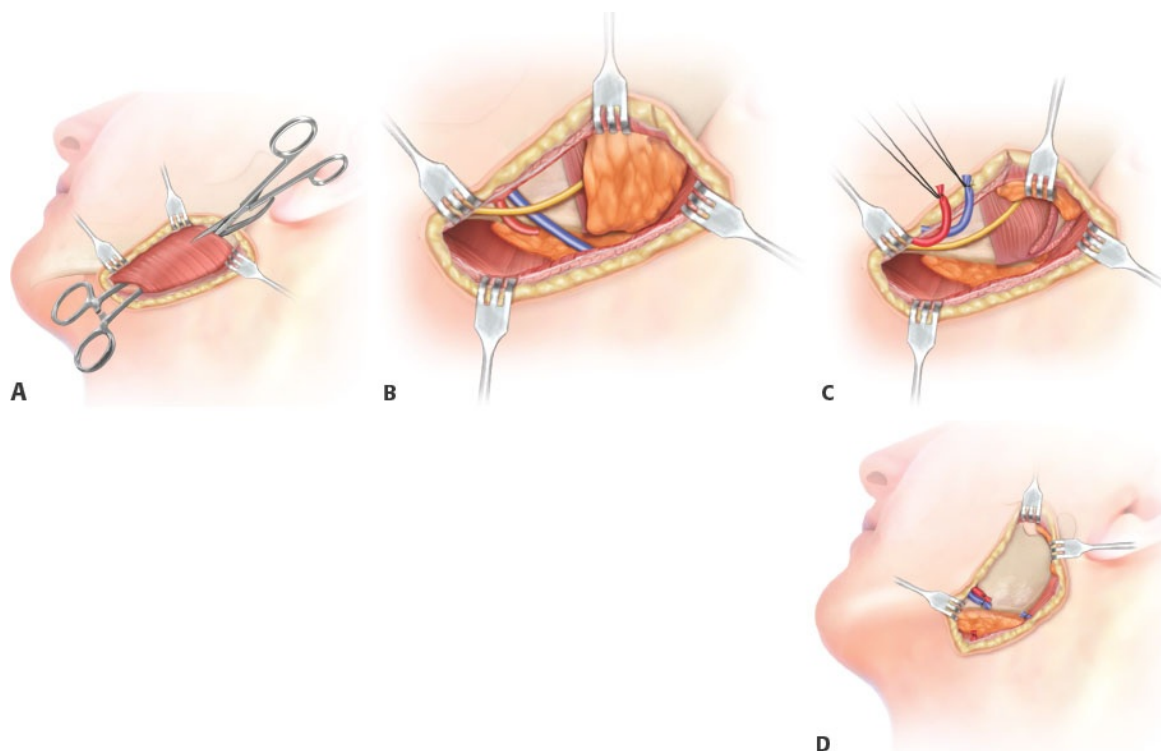
FIG 1 • Coronoid fracture as shown on sagittal (A), coronal (B), and axial (C) CT scans. D. 3D reconstruction demonstrates a coronoid fracture with a concomitant zygomatic complex fracture.

TECHNIQUES

■ ORIF via Modified Retromandibular Approach

- Begin by marking the inferior border of the mandible.
 - The skin incision should be 2 cm inferior to the lower border of the mandible (or two fingerbreadths).
 - The lips should be exposed to see if the marginal mandibular nerve is stimulated during dissection.

- Vasoconstrictor with lidocaine can be injected subcutaneously but not deep to the platysma so the marginal mandibular branch is not anesthetized.
- The incision can be extended according to the location of the fracture. Posteriorly, it can be extended to the mastoid.
 - The incision is extended to the platysma. Then blunt dissection should be performed through the platysma and to the superficial layer of deep cervical fascia. This dissection should be extended to the full extent of the skin incision (**TECH FIG 1A,B**).
- Avoid injury to the marginal mandibular branch of the facial nerve, which is usually inferior to the lower border of the mandible and superficial to the facial artery and vein.
 - The facial artery and vein can be ligated, and once retracted superiorly, this ensures protection of the marginal mandibular branch (**TECH FIG 1C**).
- Continue the dissection until reaching the pterygomasseteric sling and then make a sharp incision through the sling.
 - Subperiosteal dissection is performed on the lateral surface of the body and ramus of the mandible and superiorly toward the coronoid process of the mandible (**TECH FIG 1D**).
- When exposing the fractured coronoid process, anatomical reduction and fixation is done by appropriate plates and screws.
 - Usually, two 2.0 miniplates are needed (conventional mandibular plates); when the reduction is gained, use a 1.5-mm drill and 2-mm screws.
 - At least two screws are required on each side of the fracture line.
 - In some cases, a single miniplate is sufficient to properly reduce the fracture.
- After completing ORIF, ensure hemostasis.
 - Close by approximating the pterygoid and the masseter muscles, preferably with continuous resorbable sutures.
 - Continue suturing the superficial layer of the deep cervical fascia and the platysma.
 - Close the skin incision with interrupted nylon sutures. These sutures are to be removed after 7 days.
 - Directions for wound care management are given prior to patient's discharge.

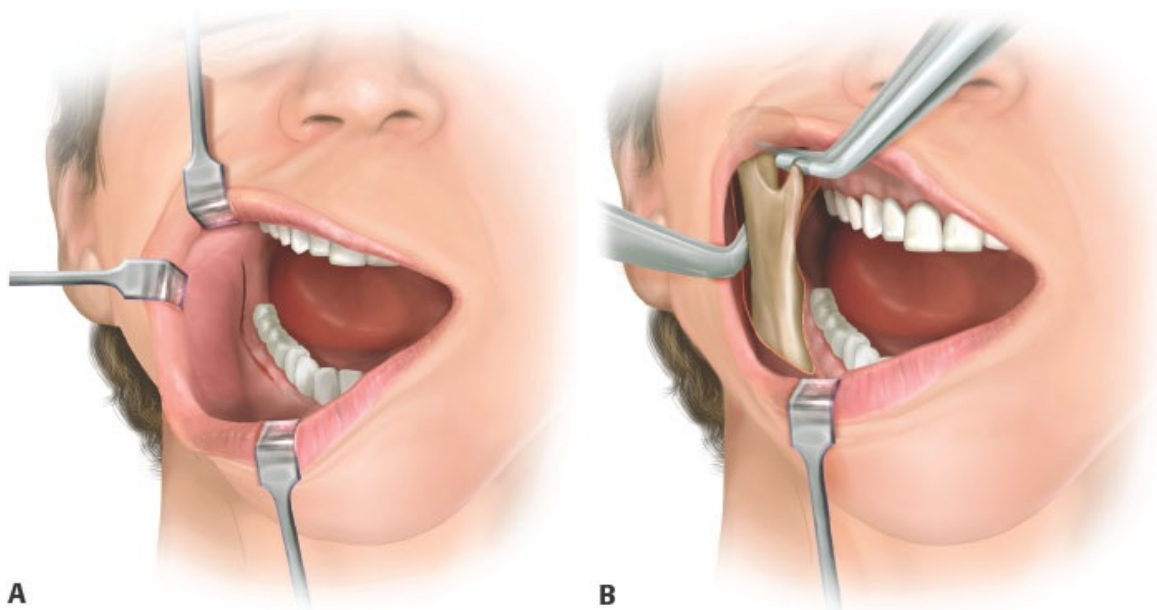


TECH FIG 1 • A. Hemostats have been used to bluntly dissect under the platysma. With the hemostats in place, the platysma is divided sharply. **B.** The marginal mandibular branch of the facial nerve is superficial to the facial artery and vein. **C.** After dissection through the superficial layer of the deep cervical fascia, the facial artery and vein are ligated and retracted superiorly. Then sharp dissection is performed on the pterygomasseteric sling. **D.** Subperiosteal dissection on the lateral surface of the body and ramus of the mandible and superiorly to the coronoid process.

■ Coronoidectomy by an Intraoral Approach

- Infiltrate lidocaine with vasoconstrictor.
- Make a vestibular incision through the mucosa, keeping a distance of 5 mm from the mucogingival line (**TECH FIG 2A**).

- Extend the incision to the external oblique ridge.
- Expose the ramus and the angle of the mandible with subperiosteal dissection (**TECH FIG 2B**).
 - The coronoid process is usually located in a more coronal position, because of persistent temporalis muscle attachments.
- After exposing part of the coronoid subperiosteally, grasp the coronoid with a large hemostat and pull while dissecting the coronoid subperiosteally until it is free from soft tissue.
- To close, suture the soft tissue with continuous resorbable sutures.



TECH FIG 2 • A. The vestibular incision is extended superiorly to the ascending ramus. **B.** Subperiosteal exposure of ascending ramus, lateral surface of the mandible, and the coronoid.

PEARLS AND PITFALLS

Physical findings

- Most coronoid fractures are treated conservatively.
- When a coronoid process fracture is present, consider the presence of associated zygomatic arch fractures, mandibular ramus, or body

	fractures.
Technique	■ A proper extraoral dissection using an electric nerve detector can aid in minimizing injury to the marginal mandibular branch of the facial nerve.
Postoperative	■ Short- or long-term limitation of mouth opening can be managed with physiotherapy.

POSTOPERATIVE CARE

- Antibiotics and corticosteroids can be administered.
- Soft diet should be given for the first few days after the operation.
- Chlorhexidine-containing mouthwash is used for 2 weeks.
- Postoperative panoramic and submentovertex x-rays can be performed postoperatively.
- If limitation of mouth opening is persistent 2 weeks postoperatively, the patient should receive physiotherapy.

OUTCOMES

- Patients with isolated coronoid fractures should generally have no long-term sequelae.
- Complications are much more likely to result from other associated facial fractures.

COMPLICATIONS

- Hematoma
- Limitation of mouth opening
- Trismus
- Wound infection
- Extraoral scars
- Malunion
- Nonunion
- Infection due to loose hardware
- Damage to the marginal mandibular branch of the facial nerve

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72 Surgical Correction of Nonunion of Mandible Fracture

CHAPTER

Howard D. Wang, Arthur J. Nam, and Amir H. Dorafshar

DEFINITION

- Nonunion of a mandible fracture occurs when there is a failure of the fracture to heal within an adequate amount of time.
- Nonunion of a mandible fracture usually leads to pain, malocclusion, and inability to masticate.
- Haug and Schwimmer defined this time period as 8 weeks after surgical management or 4 weeks without treatment.¹
- Mandibular nonunions are uncommon complications after mandible fractures with a reported incidence of 2.8% to 3.9%.^{1–3}

ANATOMY

- The mandible consists of two hemimandibles fused at the midline symphysis, and injuries can be classified based on the location of the fracture.
- The most common location of nonunion is the body, followed by the angle region of the mandible.²

PATHOGENESIS

- Nonunion of mandible fractures generally occurs as a result of inadequate fracture stabilization, inaccurate reduction, infection, or delayed treatment.
- Other risk factors associated with nonunion include injury characteristics, such as teeth in the fracture line or presence of multiple mandible fractures, and patient characteristics such as edentulous mandible, tobacco use, alcohol abuse, immune deficiency, diabetes mellitus, or patient noncompliance.²

PATIENT HISTORY AND PHYSICAL FINDINGS

■ History

- A thorough history should include the patient's chief complaint and symptoms such as pain, trismus, fever, and drainage.
- Reviewing all preoperative, intraoperative, and postoperative data from previous surgical treatments related to the initial mandibular trauma is critical in identifying the etiology of nonunion.
- Patient comorbidities including diabetes mellitus, immunosuppression, or polysubstance abuse should be elicited as these factors can contribute to the ultimate outcome.

■ Physical examination

- Patient's facial height, width, and symmetry are assessed.
- The mandible is palpated for tenderness, bony deformities, presence of abscess, and instability.
- Intraoral examination is performed with a focus on the occlusion, dental decay, oral hygiene, presence of purulent drainage, and condition of the oral mucosa.
- Any existing deficits in the sensory distribution of the inferior alveolar nerve and motor innervation of marginal mandibular branch of facial nerve are documented.

IMAGING

- Plain x-ray films (facial series, panoramic) can be used for postoperative evaluation to identify an enlarging gap in the fracture line, presence of irregular radiolucency, and/or hardware loosening (**FIG 1A, B**).
- Maxillofacial computed tomography (CT) with three-dimensional formatting has become the imaging modality of choice for evaluation of the fracture site, extent of soft tissue infection, and associated osteomyelitis (**FIG 1C–F**).

NONOPERATIVE MANAGEMENT

- Mandibular nonunions are often associated with infections of the soft or bony tissue, which require antibiotic therapy.
- Choice of antibiotics should focus on coverage of Gram-positive and anaerobic organisms with subsequent culture-directed antibiotics.

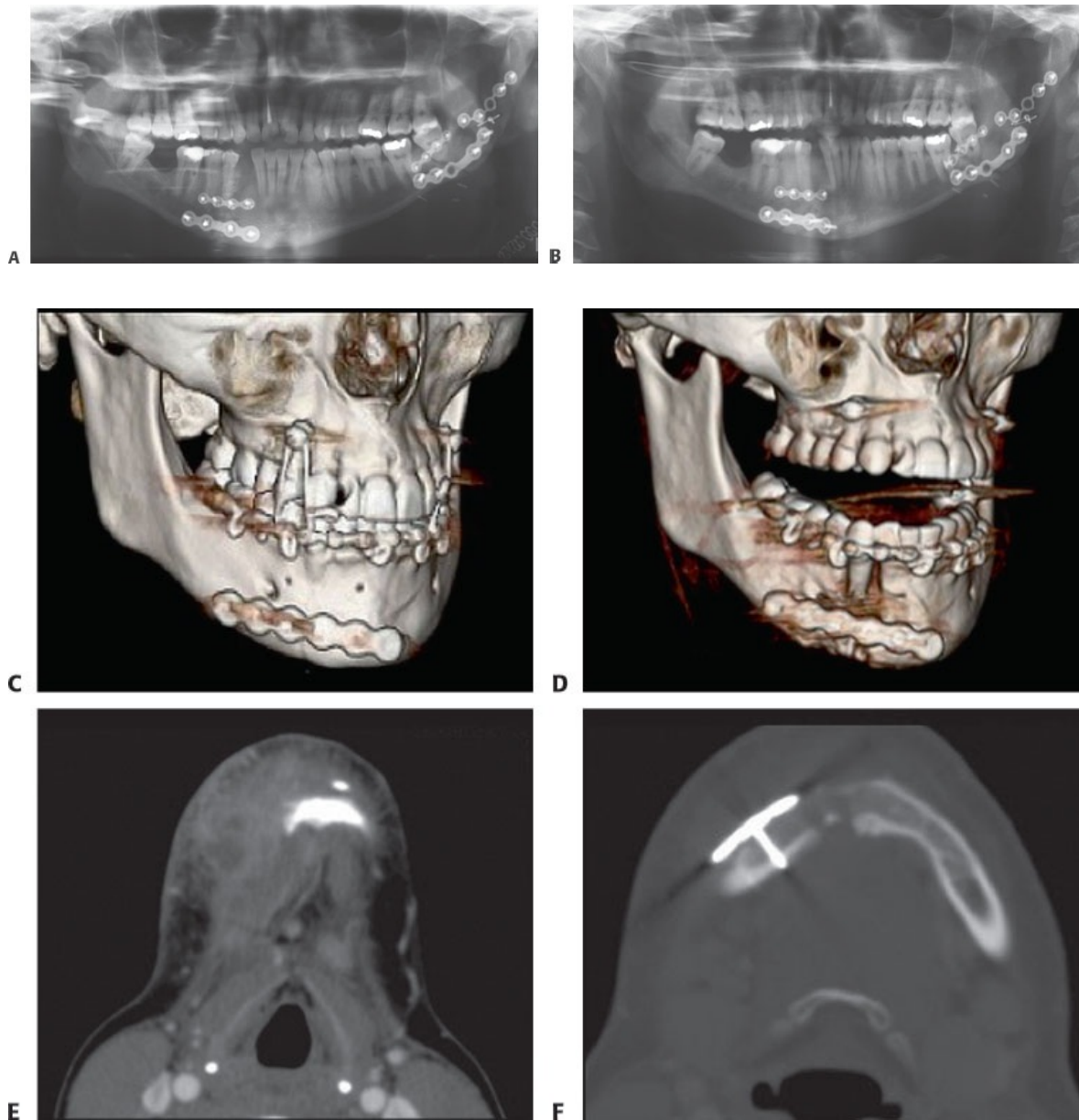


FIG 1 • **A.** Immediate postoperative panoramic plain radiograph after ORIF of multiple mandible fractures. **B.** Follow-up panorex demonstrating hardware loosening and nonunion of the left mandibular angle fracture. **C.** A 3D reconstruction of CT images demonstrating right parasymphyseal fracture immediately after open reduction and internal fixation. **D.** Repeat CT imaging showing evidence of nonunion at 4 weeks after surgery. **E.** Soft tissue window revealing evidence of abscess

formation near the site of the nonunion. **F. Bone window** showing the presence of bone gap.

- The duration of treatment will depend on whether the infection affects the soft tissue alone or if osteomyelitis is present, which may require 4 to 6 weeks of intravenous treatment.

SURGICAL MANAGEMENT

- The general algorithm for management of nonunion of mandible fractures includes debridement of nonviable bone to establish fresh bony edges, bone grafting when there is a lack of bone-to-bone contact, and rigid fixation to achieve proper stabilization.
- Occlusion should first be established with maxillomandibular fixation (MMF). It is important to ensure that the condyles are well seated superiorly in the glenoid fossa.
- Although the presence of infection does not always necessitate removal of existing hardware, mandibular nonunions generally result due to inadequate stabilization, and existing hardware will usually need to be removed.
 - Any evidence of hardware loosening or fracture instability is a clear indication for hardware removal.
- Debridement of devitalized or infected bone back to healthy, bleeding bone is critical for both clearance of infection and achieving bony union.
 - Teeth in the line of fracture should be extracted, especially in the presence of infection.⁴
 - A bone biopsy should be performed to diagnose and guide treatment of osteomyelitis.
- Traditionally, management of infected mandibular nonunions was performed with prolonged MMF or external fixation to control occlusion while the infection is treated and the soft tissue is healing. This was done to avoid placement of hardware in an infected field.⁵
 - More recent work suggests that instability is a primary contributor to the development of infected mandible fractures and that the use of rigid internal fixation after adequate debridement is a viable treatment option to achieve resolution of infection and bony union.⁶
- Therefore, rigid internal fixation has become the preferred method and should be performed using a load-bearing reconstruction plate with at least three

bicortical locking screws on each side of the fracture.

- The closest screw should be placed at a minimal distance of 7 to 10 mm from the fracture edge.⁷
- If the bone gap is small, bony union can be achieved with improved rigid fixation. However, larger gaps with inadequate bone contact will require autogenous bone grafting.
- Cancellous bone grafts packed tightly into the defect area have a high success rate by improving osteogenic potential.⁸
- Vascularized bone flaps (with or without associated skin paddle) are indicated in cases where a critical-sized defect greater than 6 cm is present, when previous bone grafting has failed, or when severe soft tissue contracture is present.⁹
- Potential options include free fibula flap or deep circumflex iliac artery (DCIA) flap.
- The choice of donor site depends on the location and size of the mandibular defect.
- The DCIA flap is often preferred for mandible defects involving the dentoalveolar region because it provides ample bone stock for osteointegrated dental implants, and the fibula flap is preferred for long defects or when multiple osteotomies are required, such as for anterior mandible defects.¹⁰
- There are two schools of thought in terms of timing of reconstruction.
- The delayed approach involves treatment of infected mandible with long-term antibiotics (6 weeks) after debridement to allow for resolution of infection and healing of intraoral incisions and teeth extraction sites. Repeat imaging can then be obtained to ensure there is no evidence of infection. Autogenous bone grafting is then performed as a second stage.
- More recently, Alpert popularized the immediate approach in which autogenous bone graft is performed at the time of initial debridement.¹¹ The major advantage of this approach is avoiding a subsequent operation; however, soft tissue closure may be more challenging in these circumstances.

Preoperative Planning

- Careful review of imaging is performed to assess the need for teeth extraction and the extent of bony debridement.
- The need for autogenous bone graft or vascularized bone flaps is determined

prior to the operation.

Positioning

- The patient is positioned supine with nasotracheal intubation, so proper occlusion can be checked intraoperatively.
- If an iliac crest bone graft is needed, a bump should be placed under the gluteal region to elevate the iliac crest, and the lateral hip area should be prepped.

Approach

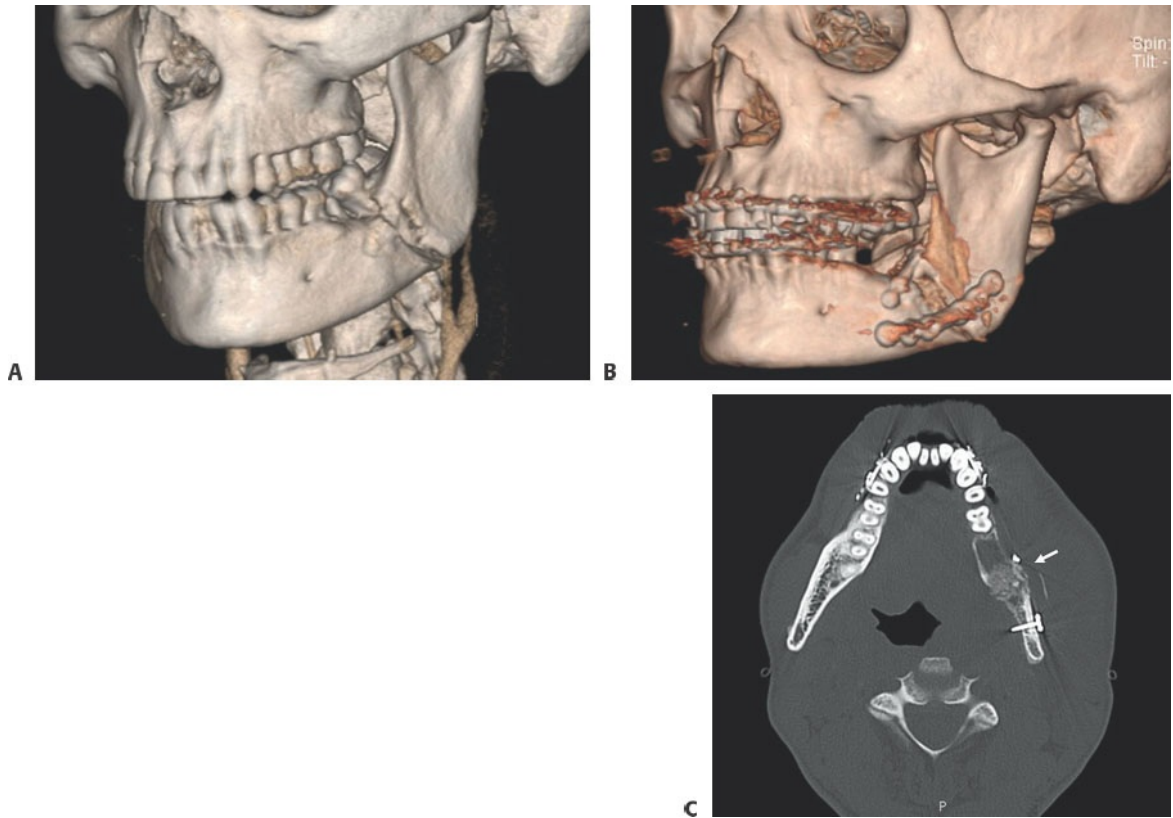
- Surgical management of mandibular nonunion can be performed via either an external transfacial approach or an intraoral approach.
- The major advantages of the intraoral approach are avoidance of an external scar and risk of injury to the marginal mandibular branch of the facial nerve.
 - However, the intraoral approach alone should be attempted only if there is sufficient healthy oral mucosa tissue for closure after debridement and fixation.
- Otherwise, an external approach is usually preferred after the intraoral wound has healed to avoid intraoral contamination of the surgical site. Furthermore, an external approach provides wide exposure for direct visualization of the fracture site, for obtaining sterile cultures, and for easier placement of bicortical screws while avoiding injury to the inferior alveolar nerve.
- The Risdon (submandibular) approach is frequently used to gain access to the body or angle region.

TECHNIQUES

■ Single-Stage Operation With Iliac Crest Bone Grafting via an Intraoral Approach

- Loose teeth within the fracture line are extracted (**TECH FIG 1A**).
- An intraoral incision is made to expose the fracture segment.
- Debridement of all nonviable bone is performed, usually with a cutting rotating bur.
- Patient's premorbid occlusion is then established with MMF.

- With the condyles seated properly in the glenoid fossa, the fracture segments are then placed into rigid fixation.
- In this case, a Champy plate and a lower border plate were applied (**TECH FIG 1B**).



TECH FIG 1 • A patient presented with a left mandibular angle fracture 4 weeks after initial injury. **A.** Maxillofacial CT demonstrating a nonunion of the left mandible angle fracture with the presence of a loose molar in the fracture line. **B.** Postoperative CT showing rigid fixation of the fracture with Champy plate and lower border plate. **C.** CT showing cancellous bone graft packed into the fracture gap.

- Three locking bicortical screws are inserted on each side of the fracture line to secure the lower border plate.
- Autogenous bone graft may be required in cases where a bone gap exists

after debridement of unhealthy bone at the site of the nonunion and can be harvested from a number of donor sites including the iliac crest, anterior tibia, or calvarium.

- The authors' preferred donor site is the iliac crest.
 - Once sufficient cancellous bone graft material has been harvested, it is packed tightly into the bone gap (**TECH FIG 1C**).
 - The intraoral incision is then closed tightly with absorbable sutures.
-

■ Two-Stage Operation With Osseous Free Flap

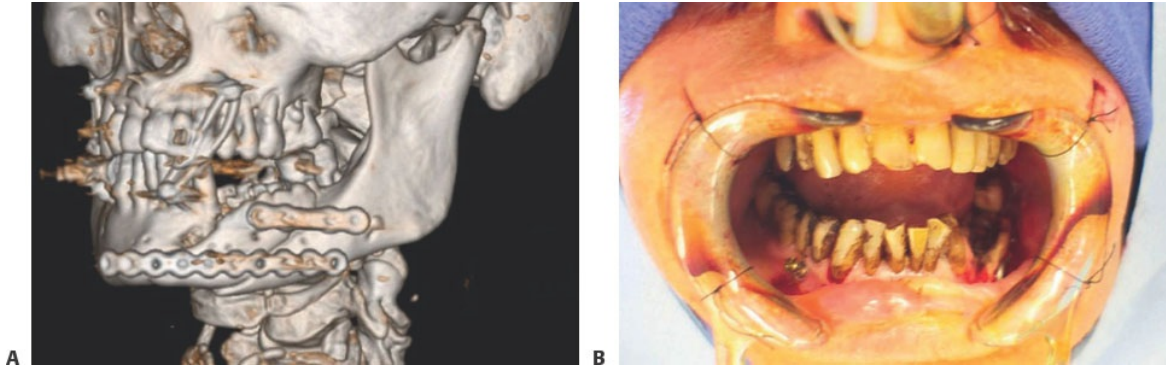
- The goal of the first stage is to remove all nonviable bone and allow healing of the intraoral soft tissue (**TECH FIG 2A**).
- Reconstruction of the mandible is performed in a subsequent operation via an external approach.

Stage 1: Debridement of Nonviable Bone and MMF

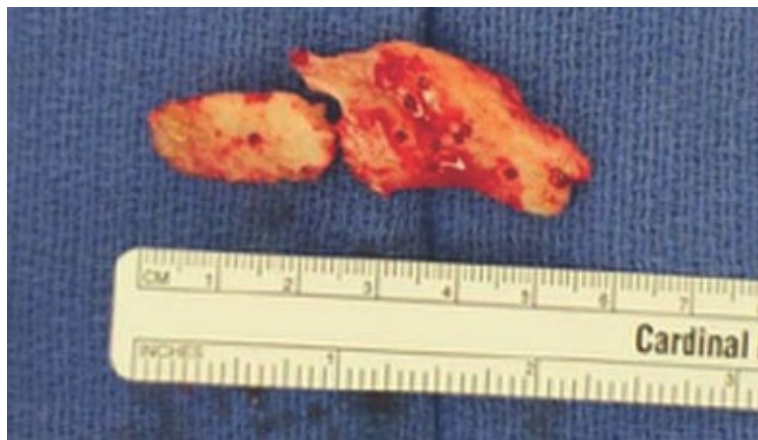
- Debridement of all nonviable bone is performed via an intraoral approach (**TECH FIG 3**).
- Patient's premorbid occlusion should be established with MMF.
- The intraoral wound is then allowed to heal over the course of 6 to 8 weeks.

Stage 2: Vascularized Free Osseous Flap Reconstruction via a Risdon Approach

- An osseous free flap such as the free fibula or DCIA flap may be required in cases when the size of the mandibular defect exceeds 6 cm.
- A two-team approach should be used whenever possible to reduce operative time.
- An external incision is made in a relaxed skin tension line approximately 2 cm caudal to the inferior border of the mandible. The length of the incision depends on the extent of the fracture (**TECH FIG 4A**).
- The platysma is divided after incision through the skin and the subcutaneous tissue (**TECH FIG 4B**).
- The marginal mandibular branch of the facial nerve lies deep to the platysma and may lie up to 2 cm below the ramus of the mandible; therefore, the platysma should be incised at least 2 to 3 cm below the inferior border of the mandible to avoid nerve injury.



TECH FIG 2 • A patient presented with nonunion of the left mandibular body fracture 8 weeks after open reduction and internal fixation at an outside facility. Because of the significant intraoral soft tissue deficiency, a two-stage treatment plan was selected. **A.** CT demonstrating evidence of nonunion of the left mandibular body after previous fixation. **B.** Exposed left mandible fracture with significant intraoral soft tissue deficiency.

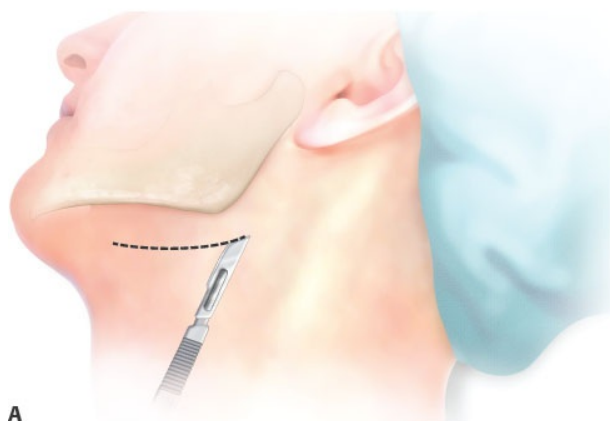


TECH FIG 3 • Nonviable bone is removed using the existing intraoral exposure.

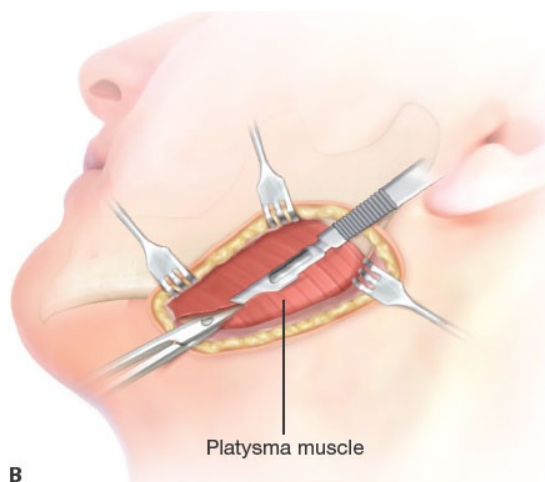
- The facial vessels lie deep to the marginal mandibular nerve in a craniocaudal direction. The vessels are ligated and reflected superiorly to protect the marginal mandibular nerve in the superior flap (**TECH FIG 4C**).
- The inferior border of the mandible is exposed by dividing the

pterygomasseteric sling and incising through the periosteum (**TECH FIG 4D**).

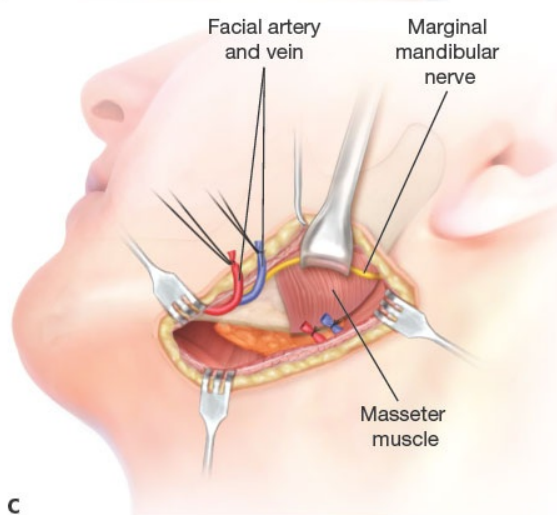
- Any unhealthy bone should be removed, and the fracture edges are burred until new bleeding edges are visualized (**TECH FIG 4E**).
- The recipient vessels should be identified in the neck for microvascular anastomosis. Options include the facial vessels, superior thyroid vessels, external carotid artery, and external and internal jugular veins.
- A DCIA flap is harvested along with a cuff of the internal oblique muscle (**TECH FIG 4F**).
- Once the flap has been harvested, a reconstruction plate is then adapted and applied to the bone flap.



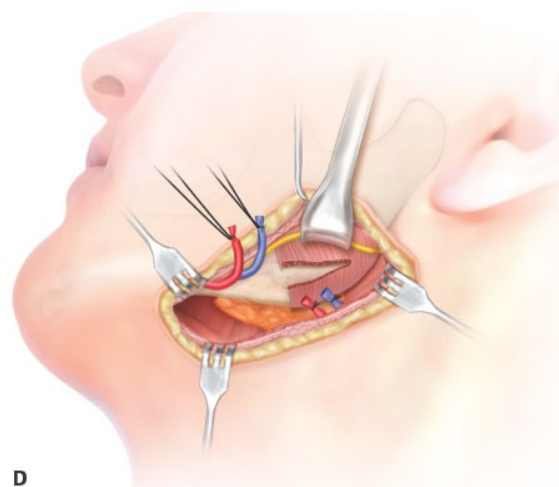
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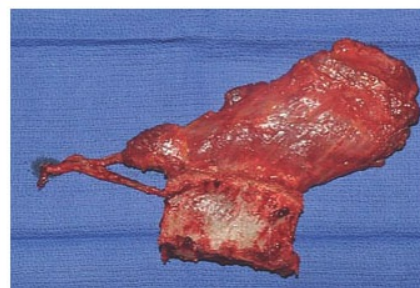
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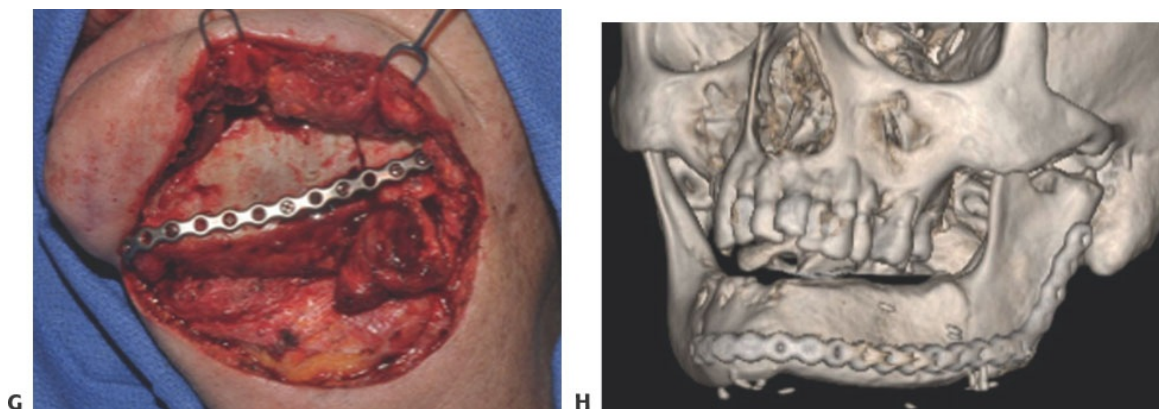
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F



TECH FIG 4 • A. Risdon (submandibular) approach to the mandible. The skin incision is made approximately 2 cm caudal to the inferior border of the mandible. **B.** The platysma muscle is then divided at 2 to 3 cm below the inferior border of the mandible. **C.** The facial artery and vein are identified and ligated. The marginal mandibular branch of the facial nerve runs superficial to the facial vessels. Reflecting the ligated facial vessels superiorly protects the nerve in the superior flap. **D.** Incision through the pterygomasseteric sling and the periosteum to expose the inferior border of the mandible. **E.** Excision of any remaining unhealthy bone. **F.** DCIA bone flap is harvested with a cuff of the internal oblique muscle. **G.** Flap inset into the defect and fixation with a reconstruction plate. **H.** Six-month postoperative CT demonstrating bony union.

- Flap inset is then performed with three locking screws placed on either side of the defect (**TECH FIG 4G**).
- Unicortical screws should be used on the flap to avoid injury to the vascular pedicle.
- Next, the microvascular anastomosis is performed to the recipient vessels.
- Closure of the incision should be performed in layers, approximating the pterygomasseteric sling, platysma, and skin. A suction drain can be left

depending on surgeon preference.

- Successful bony union can be seen on a follow-up CT scan (**TECH FIG 4H**).

PEARLS AND PITFALLS

Debridement	■ Aggressive debridement of pseudoarthrosis or infected bone stock is necessary for bony union.
Fixation	■ Rigid fixation with load-bearing construct is necessary to improve the chances of union.
Timing of bone grafting	■ Primary bone grafting can often be performed at the time of debridement. ■ If there is concern about the quality of soft tissue, bone grafting can be delayed and performed at a later stage.

POSTOPERATIVE CARE

- A 4 to 6-week course of postoperative antibiotics is usually administered for treating osteomyelitis.⁶
- The decision for use of postoperative MMF after rigid fixation is frequently surgeon-dependent.
 - Although some surgeons advocate that MMF is not required with rigid fixation, others prefer short-term (1 to 2 weeks) fixation with wires or elastics.
- The patient is started on a liquid or wired-jaw diet and progressed to a soft diet.
- Early physiotherapy is initiated to maintain maximum interincisal jaw opening and avoid complications of ankylosis of the temporomandibular joint.
- Patients with intraoral wounds are instructed to use chlorhexidine oral rinses at least 3 times a day.

OUTCOMES

- Studies on mandibular fracture nonunions are limited to small case series with short follow-up time.
- Benson and Alpert¹¹ retrospectively reviewed 43 patients with 50 infected mandibular fractures who were managed with debridement, rigid internal

fixation, and immediate autogenous particulate bone grafting.

- They reported that 94% achieved bony union and 86% required only one operation.
- Mehra et al.⁷ retrospectively reviewed 44 patients with infected mandibular fractures and divided them into those with soft tissue infection vs osteomyelitis.
 - Their treatment protocol of incision and drainage, debridement, fracture reduction, and stabilization with rigid internal fixation achieved 100% success rate for soft tissue–infected mandibular fractures and 92% success for those with osteomyelitis.
- Yamamoto et al.¹² reported that only 1 of 10 patients with mandible nonunion who were treated with removal of hardware and new fixation with 2.4-mm reconstruction plate required an additional operation to achieve union.

COMPLICATIONS

- Recurrent infection (ie, osteomyelitis)
- Nonunion
- Malunion
- Facial nerve injury (marginal mandibular branch) with external incision
- Inferior alveolar nerve injury
- Malocclusion
- Scarring
- Hardware exposure
- Trismus

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Section XII: Panfacial Trauma

73 Surgical Correction of Panfacial Fractures

CHAPTER

Detlev Erdmann and David Powers

DEFINITION

- The facial skeleton is composed of four subunits: frontal, upper midface, lower midface, and mandible.
- Panfacial fractures are defined as any fracture pattern that involves at least three of these four segments.¹

ANATOMY

- The face consists of 14 bones, 12 of which are paired (inferior nasal concha, lacrimal bones, nasal bones, maxillae, palatine bones, zygomatic bones) and 2 of which are not (mandible and vomer).
- The frontal bone constitutes the major component of the forehead and forms the superior part of each orbital rim.
- Zygomatic process of the frontal bone projects inferiorly to form the upper lateral orbital rim.
- The zygomatic bone forms the lower lateral and part of the inferior orbital rim.
 - Malar surface: Convex shape, contains the zygomaticofacial foramen
 - Temporal surface: Concave, articulates with maxilla (articular surface) and contains the zygomaticotemporal foramen
 - Orbital surface: Contains the zygomatic orbital foramen
- The nasal bones articulate with each other at midline as well as the frontal bone superiorly and the frontal process of the maxillary bone laterally.

- Maxillae lie in between the orbit and the upper teeth and consist of a body, zygomatic process, frontal process, alveolar process (contains the teeth of the upper jaw), palatine process (forms 75% of the hard palate), infraorbital foramen, and maxillary sinus.
 - Forms the inferior and medial orbital rims
 - Articulates with the frontal, zygomatic, ethmoid, nasal, and lacrimal bones
- The mandible consists of a body (anterior) and ramus (posterior).
 - The body of the mandible is further subdivided into the base and the alveolar portion, which contains the teeth of the lower jaw.
 - The ramus consists of two clinically significant superior projections:
 - The more posterior projection is called the condyle (which contributes to the formation of the temporomandibular joint).
 - The more anterior projection is called the coronoid process (which is the site of attachment for the temporalis muscle).

PATHOGENESIS

- Facial fractures occur in the setting of trauma, with assault and motor vehicle collisions (MVC) as the most common etiologies (36% and 32%, respectively, of all facial fracture cases presenting to a representative US institution).¹
- MVC and gunshot wounds (GSW) have been specifically shown to be significant predictors of panfacial fracture patterns.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- Once the patient has been appropriately stabilized, obtaining as complete a history as possible is integral to assess for specific injury patterns even prior to performing imaging studies.
- The following questions are most important when performing a systematic exam of the patient:
 - How and when did the accident occur?
 - What are the specifics of the injury?
 - What symptoms does the patient currently have (pain, altered sensorium, loss of consciousness, malocclusion)?
- Certain subjective complaints can substantiate the presence of specific craniomaxillofacial injuries; for example, new-onset anesthesia of the cheek/maxillary teeth may be a result of zygomaticomaxillary fractures resulting in injury of the infraorbital nerve.
- Physical examination

- Cranium/cranial base: Note any lacerations, swelling, ecchymoses, and contour irregularities.
- Frontal region: Inspect for any lacerations, depressions, or crepitus.
- Orbits: Examine for edema, ecchymoses, enophthalmos (possible zygomaticomaxillary complex fractures), emphysema, and limited upward gaze (possible inferior rectus muscle entrapment).
- Nasal region: Check for signs of naso-orbital-ethmoid (NOE) fracture, such as septal deviation or hematoma and telecanthus.
- Maxillary region: Assess for infraorbital nerve paresthesia or malar depression, trismus secondary to impingement on the coronoid process, and maxillary mobility.
- Ear region: Examine for hematoma and integrity of auditory canal/tympanic membrane.
- Mandible: Note the presence of external lacerations, ecchymosis or gingival tears (a possible sign of mandibular body or symphyseal fracture), step-off deformities, paresthesia along the distribution of the inferior alveolar nerve (an indication of fractures distal to mandibular foramen), periauricular pain, or malocclusions.
- Additionally, a thorough intraoral, ocular, and neurological exam should be conducted to rule out dental malocclusions, ophthalmological emergencies, and focal neurological defects.

IMAGING

- Computed tomography (CT) has largely replaced other imaging modalities as the standard for evaluation of facial trauma.
- Axial, coronal, and sagittal cuts are utilized to visualize specific fracture patterns and reformatted to generate three-dimensional (3D) images (**FIG 1A–C**).
- A standard head CT is better used as a screening tool, given its limited ability to visualize the zygomatic arch as well as the complete maxilla and mandible (**FIG 1D,E**).
- A more complete craniomaxillofacial CT should extend from the vertex of the skull to the symphysis of the mandible.
- 3D CT imaging affords additional understanding of the spatial relationship of fracture fragments but does not provide information about soft tissue deformities.

NONOPERATIVE MANAGEMENT

- Although most panfacial fractures are severe enough to warrant surgical treatment, facial fractures that are stable, nondisplaced, or asymptomatic may be managed conservatively with follow-up.²

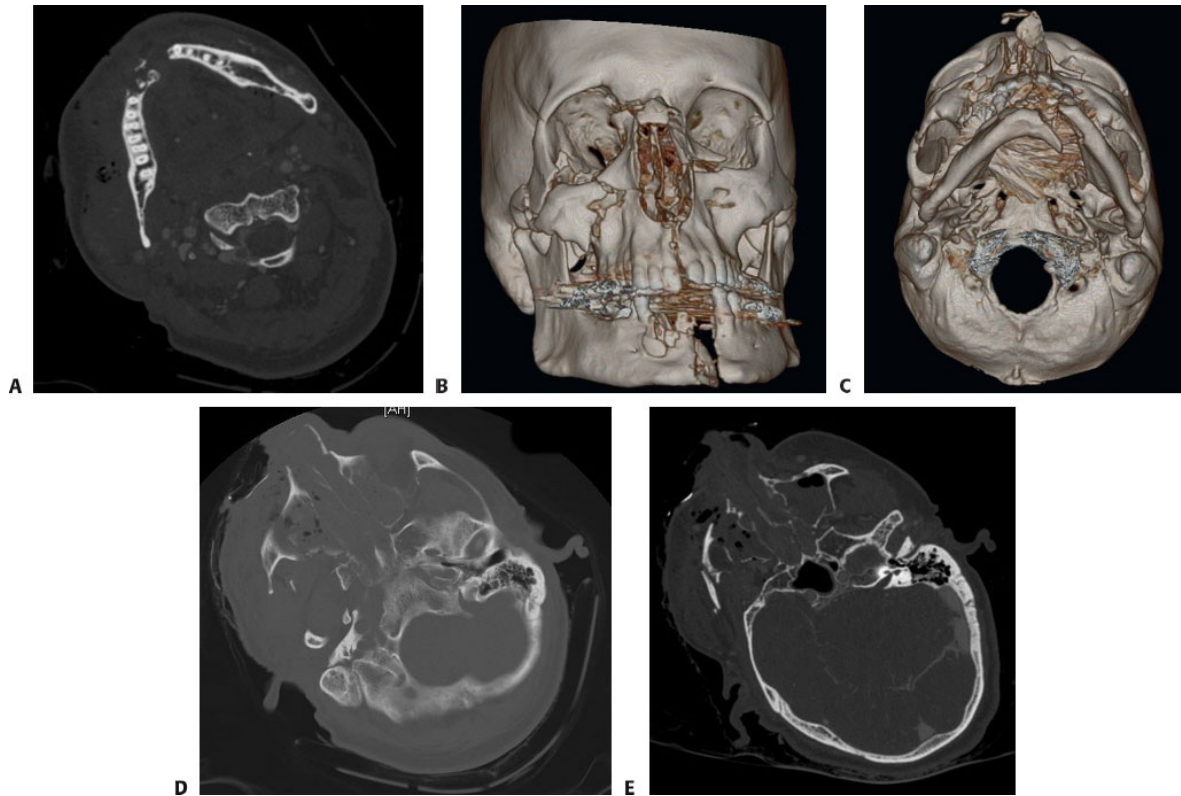


FIG 1 • **A.** Axial CT imaging can be used to visualize specific fracture patterns. **B,C.** CT imaging can be reformatted into three-dimensional images that are useful for preoperative planning. **D.** Craniomaxillofacial CT imaging provides a more comprehensive view of the zygomatic arch as well as the maxilla and mandible. **E.** Comminuted midface fractures.

SURGICAL MANAGEMENT

- The primary goal of panfacial trauma management is to establish an anatomically reduced platform from which to base the remainder of the reconstruction.

Preoperative Planning

- Review of preoperative radiographs with 3D reconstruction is necessary.
- Written sequencing of surgical approaches and goals for each section
- Confirmation of necessary surgical instrumentation and plating hardware to reconstruct the defects

Positioning

- The patient should be prepared and draped widely to allow for any and all needed exposures.
- A horseshoe head frame may be used for coronal exposure.

Approach

- One of the more common techniques for addressing midfacial fractures, often referred to as “outside-in” technique, focuses on first repairing the zygomatic arch to correct facial width.
- Zygomaticomaxillary complex fractures are usually repaired with open reduction and internal fixation.³
- The “bottom-to-top” approach focuses on reconstruction of the mandible first—generally accomplished as the mandibular bone is less prone to comminution in most causes of panfacial trauma—which results in larger bone fragments that are technically easier to repair.
- The “top-to-bottom” approach initiates repair at the forehead before working down to the maxilla and mandible (**FIG 2**).
 - This approach focuses on reconstruction of the “outer facial frame.” The orbital rims are used as a landmark to align the nasofrontal structure before reduction of the zygomatic arches and realignment of the maxilla and mandible.^{4,5}
- The “bottom-to-top-to-middle” approach focuses on reconstruction of the mandible first—generally accomplished first because the mandibular bone is less prone to comminution in most etiologies of panfacial trauma—which results in larger bone fragments that are technically easier to repair.
 - Attention is then directed toward the zygomatic arches/frontal bar regions and the NOE/orbit, correcting any discrepancy at the Le Fort I level as the final intervention.
- Possible incisions for gaining access to the mandible include the following:
 - Anterior degloving (**FIG 3A**)

- Intraoral degloving (**FIG 3B**)
- Posterior degloving (**FIG 3C**)
- Hinds incision/posterior ramus approach (**FIG 4**)
- Preauricular incision (**FIG 5**)
- Risdon incision (**FIG 6**)
- Submental incision (**FIG 7**)
- Transcervical incision (**FIG 8**)



FIG 2 • The “outside-in” technique focuses on repairing the zygomatic arch first in order to correct facial width.

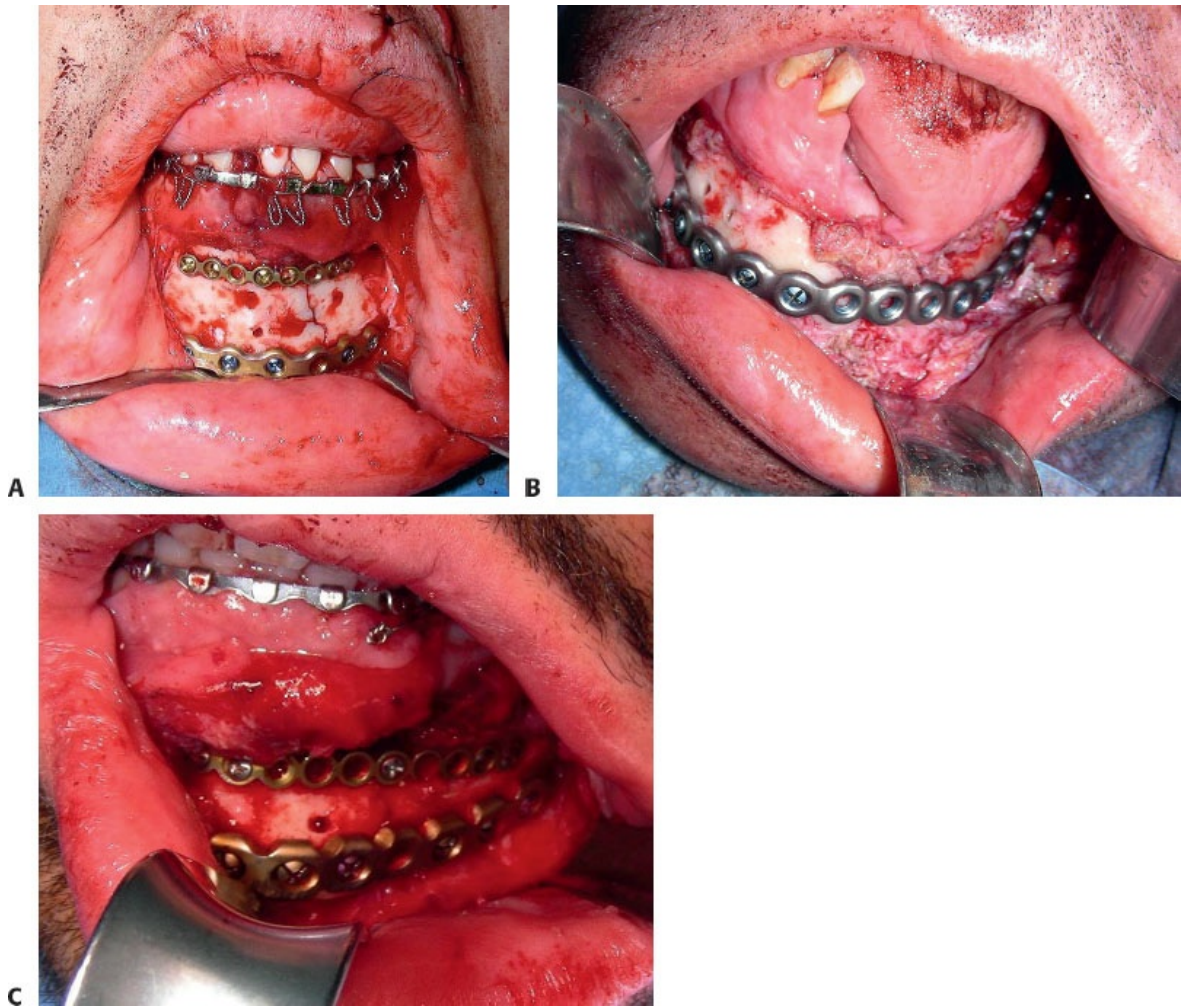


FIG 3 • Anterior (A), intraoral (B), and posterior (C) degloving incisions are made about 3 to 5 mm above the mucogingival junction and carried down through the mucosa, submucosa, facial muscles, and periosteum.



FIG 4 • The Hinds incision is particularly helpful for injuries involving the ramus, neck, or head of the mandible. Avoid the superior and inferior divisions of the facial nerve as well as the retromandibular vein. The incision can be made parallel to the ramus or over the posterior border of the ramus toward the mandibular angle.



FIG 5 • Preauricular incisions can be utilized to expose the TMJ. Given the location of the superficial temporal vessels and the auriculotemporal nerve relative to the TMJ, injury to these structures is possible and must be avoided. The incision is made to the superficial layer of the temporalis fascia. An anterior flap is then raised above the zygomatic arch and the superficial layer of the temporalis fascia is incised. The periosteal elevator is then shifted posteriorly and incised vertically. Retraction will then expose the TMJ capsule.

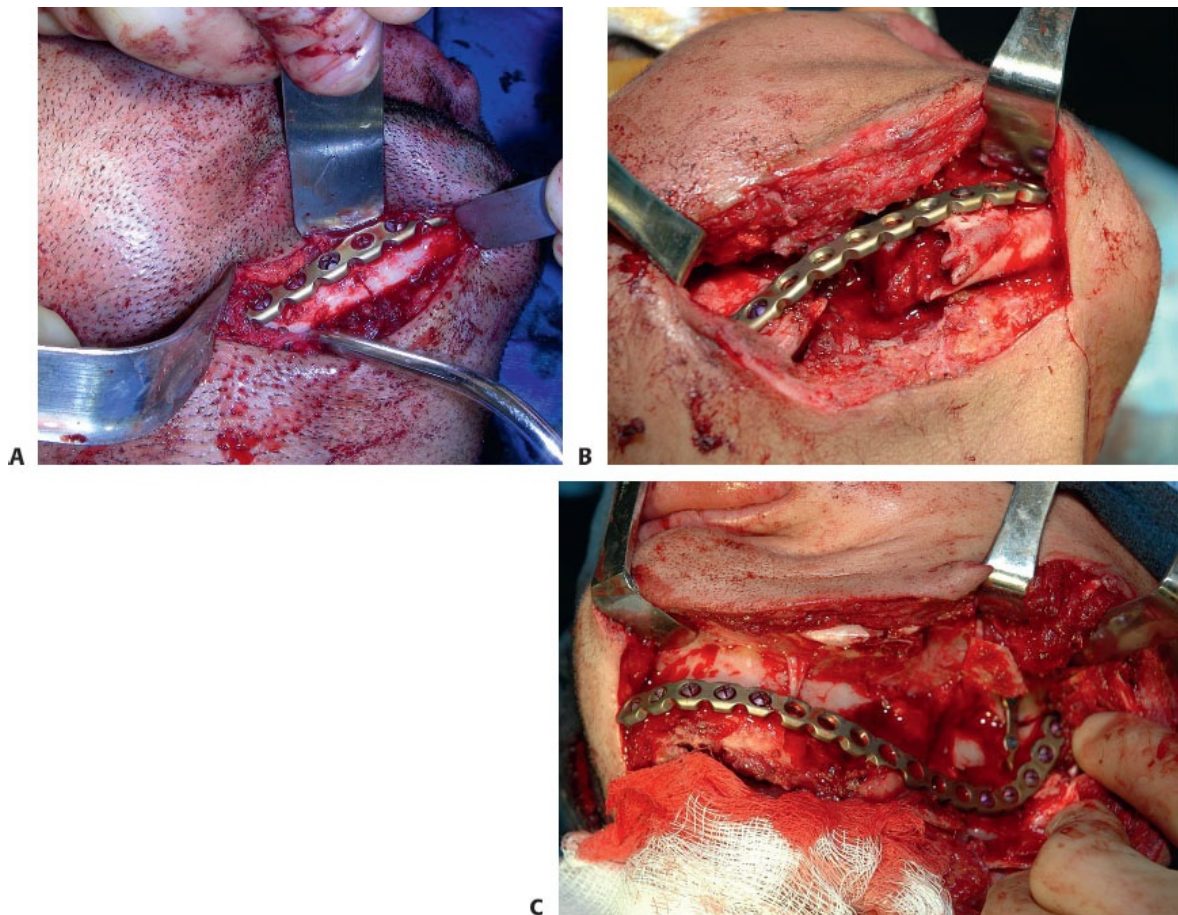


FIG 6 • **A.** The Risdon incision can be used to expose the mandibular angle, ramus, condyle, and TMJ. The incision is made 2 cm inferior and parallel to the inferior border of the mandible of the neck and to the level of

the platysma. **B.** Dissection is continued to the deep cervical fascia and submandibular salivary gland, with eventual incision of the superficial layer of the deep cervical fascia. Great care must be taken to avoid injury to the facial artery and vein as well as the marginal mandibular branch of the facial nerve. **C.** During anterior dissection, the mental nerve must be avoided.



FIG 7 • The submental incision, used in repair of mandibular symphysis fractures, can be made to follow the anterior curve of the mandible or can be hidden within a skin crease. The incision is made to the platysma. Dissection is carried out to the inferior border of the mandible and the periosteum is incised sharply.

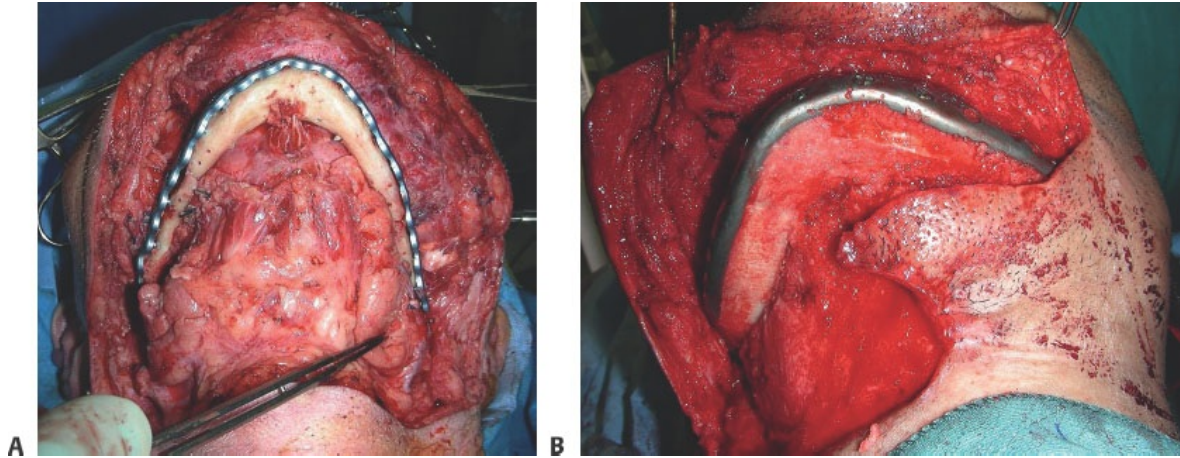


FIG 8 • A. The transcervical incision is made above the thyroid cartilage from the midline toward the angle of the mandible bilaterally and carried down to the superficial layer of the deep cervical fascia. **B.** A flap is then raised toward the inferior border of the mandible anterolaterally. Identify the cervical and mandibular branches of the facial nerve as well as the facial artery and vein to avoid injury. The periosteum is then incised at the inferior border of the mandible from midline to the mandibular angle bilaterally.

TECHNIQUES

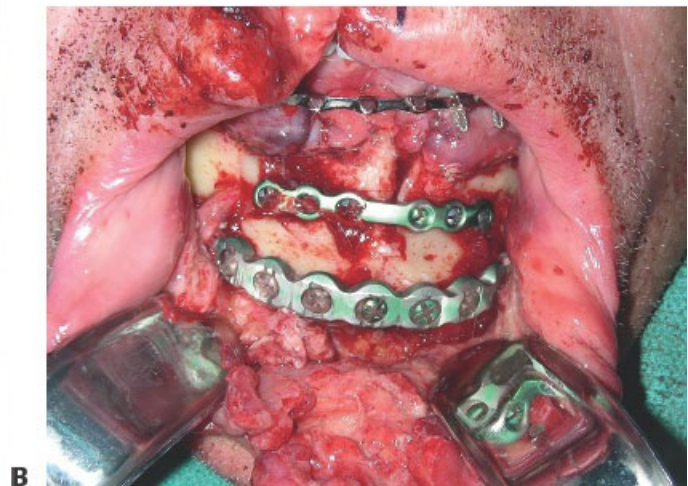
■ Bottom-to-Top Approach

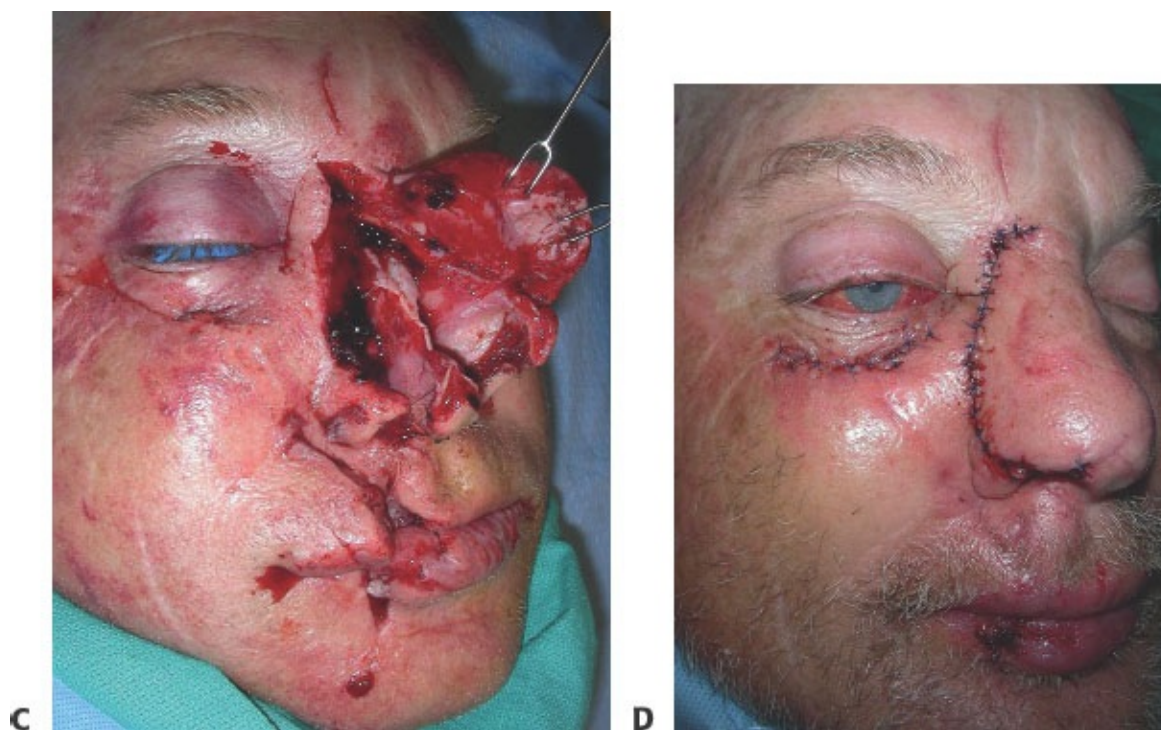
- Erich arch bars are adapted to the maxilla and mandible and secured with 24-gauge stainless steel wires.



Video p2-c073_01

- Placement of the arch bars should only begin on one side and progress laterally by incorporating all of the dentition.
- The arch bars are malleable, and simultaneous placement of the arch bars from the bilateral posterior region results in “excess” material, which classically prevents incorporation of the anterior dentition.
- Bone-anchored arch bars can be considered for dental arches that do have? disruption of the dentoalveolar tables (**TECH FIG 1A,B**).





TECH FIG 1 • A. Preoperative appearance. **B.** Arch bar placement. **C.** Resuspension of soft tissue. **D.** Closure of incisions.

- Access to the mandible is achieved with a combination of a no. 15 scalpel (see **FIGS 3 to 8**) and Colorado-tipped Bovie electrocautery to address the regions of the mandible requiring fixation.
- Anatomically reduce and stabilize the mandible with the appropriately sized surgical reconstruction kit placed in a bicortical manner to avoid vital structures.
 - The use of monocortical screws and a “simplification” plate may be necessary to assist with temporary stabilization of the mandibular fracture.
 - Impressions for dental splints should be accomplished only after the establishment of a stable dentoalveolar table of at least one dental arch.
- Access to the maxilla is achieved with a combination of a no. 15 scalpel and Colorado-tipped Bovie electrocautery.
 - The incision is made approximately 5 to 7 mm superior to the junction of the attached gingiva and alveolar mucosa to reduce maxillary fractures for the establishment of a functional occlusion.
- The patient’s occlusion is established with intermaxillary/maxillomandibular

fixation.

- Stabilization of the maxillary fractures is then performed.
- A coronal incision is performed with a no. 15 scalpel and Colorado-tipped Bovie electrocautery to gain access to the zygomatic arches/frontal bar bilaterally.



Video p2-c073_02



Video p2-c073_03

- Reduction/stabilization of the zygomatic arch fractures is accomplished, as well as any frontal bar/frontal sinus fractures.



Video p2-c073_04

- Repair of orbital floor fractures is accomplished.
- Repair of NOE fractures is accomplished.
- Intraoperative CT scanning (if available) is obtained at this time to evaluate reduction and fixation.
- Facial soft tissues are resuspended (**TECH FIG 1C**).
- Closure of incisions (**TECH FIG 1D**)

■ Top-to-Bottom Approach

- A coronal incision is performed with a no. 15 scalpel and Colorado-tipped Bovie electrocautery to gain access to the zygomatic arches and frontal bar bilaterally.
- Reduction with stabilization of the zygomatic arch, zygoma, and any frontal bar and frontal sinus fractures is completed.
- Repair of NOE fractures is accomplished.
- Repair of orbital floor fractures is performed.
- Erich arch bars are adapted to the maxilla and mandible and secured with 24-gauge stainless steel wires.
 - Placement of the arch bars should begin on one side and progress laterally, incorporating all of the dentition.
 - The arch bars are malleable, and simultaneous placement of the arch bars from the bilateral posterior region results in “excess” material, which classically prevents incorporation of the anterior dentition.

- Bone-anchored arch bars can be considered for dental arches that do not have disruption of the dentoalveolar tables.
- Access to the mandible is achieved with a combination of a no. 15 scalpel and Colorado-tipped Bovie electrocautery to address the regions of the mandible requiring fixation (see **FIGS 3 to 8**).
- Anatomically reduce and stabilize the mandible with the appropriate-sized surgical reconstruction kit placed preferably in a bicortical manner to avoid vital structures.
 - The use of monocortical screws and a “simplification” plate may be necessary to assist with temporary stabilization of the mandibular fracture.
 - Impressions for dental splints should be accomplished only after the establishment of a stable dentoalveolar table of at least one dental arch.
- Access to the maxilla is achieved with a combination of a no. 15 scalpel and Colorado-tipped Bovie electrocautery via an incision approximately 5 to 7 mm superior to the junction of the attached gingiva and alveolar mucosa.
 - This is to address the regions of the maxilla requiring reduction of maxillary fractures for establishing a functional occlusion.
- The patient’s occlusion is established with intermaxillary/maxillomandibular fixation.
- Stabilization of the maxillary level fractures is performed.
- Intraoperative CT scanning (if available) is obtained at this time to evaluate reduction/fixation.
- Facial soft tissues are resuspended.
- Closure of incisions

■ Bottom-to-Top-to-Middle Approach

- Erich arch bars are adapted to the maxilla and mandible and secured with 24-gauge stainless steel wires.
 - Placement of the arch bars should only begin on one side and progress laterally incorporating all of the dentition.
 - The arch bars are malleable, and simultaneous placement of the arch bars from the bilateral posterior region results in “excess” material that classically prevents incorporation of the anterior dentition.
 - Bone-anchored arch bars can be considered for dental arches that do not have disruption of the dentoalveolar tables.

- A no.15 scalpel and Colorado-tipped Bovie electrocautery can be used to access the regions of the mandible requiring fixation (see **FIGS 3 to 8**).
- Anatomically reduce/stabilize the mandible with the appropriate sized surgical reconstruction kit placed preferably in a bicortical manner should this avoid vital structures.
 - The use of monocortical screws and a “simplification” plate may be necessary to assist with temporary stabilization of the mandibular fracture.
 - Impressions for dental splints should be accomplished only after the establishment of a stable dentoalveolar table of at least one dental arch.
- Access to the maxilla is achieved with a combination of a no. 15 scalpel and Colorado-tipped Bovie electrocautery via an incision approximately 5 to 7 mm superior to the junction of the attached gingiva and alveolar mucosa. This treats the regions of the maxilla requiring reduction of maxillary fractures for the establishment of a functional occlusion.
- The patient’s occlusion is established with intermaxillary/maxillomandibular fixation.
- A coronal incision is performed with a no. 15 scalpel and Colorado-tipped Bovie electrocautery to gain access to the zygomatic arches/frontal bar region bilaterally.
- Reduction/stabilization of the zygomatic arch fractures is accomplished, as well as any frontal bar/frontal sinus fractures.
- Repair of orbital fractures is accomplished.
- Repair of NOE fractures is accomplished.
- Maxillary level fractures are stabilized.
- Intraoperative CT scanning (if available) is obtained at this time to evaluate reduction/fixation.
- Facial soft tissues are resuspended.
- Layered closure is undertaken, including interrupted absorbable suture material for deep and dermal layers and nonabsorbable interrupted closure for skin.

PEARLS AND PITFALLS

Preoperative radiology

- Comprehensive CT scans with 3D reconstruction

	should be obtained for presurgical planning on all panfacial trauma patients.
Exposure	■ Adequate exposure for visualization of all fractures is critical for anatomic reduction.
Subunit principle of repair	■ Repair the cranio-orbital subunit independent of the lower face and the maxillomandibular subunit independent of the upper face.
Ptosis of soft tissues	■ Lack of resuspension of the facial soft tissues after skeletonizing the calvarium for access to the fractures results in ptosis of the fat pads of the face and premature facial aging.
Reliance on dental splints without a stable skeletal foundation (either anatomically reduced maxilla/mandible)	■ Because of normal variability in dental occlusion, the lack of a stable arch form for reconstruction frequently results in loss of AP projection of the face and the classic appearance of a flat, wide midface.
Interval/intraoperative CT scans	■ Critically determine the proper alignment and stabilization of the facial structures during complex reconstruction.
Postoperative review of radiology	■ 3D CT scans should be evaluated in the immediate postoperative period to determine the need for potential early intervention to correct issues of enophthalmos, inadequate reduction, or poor stabilization.

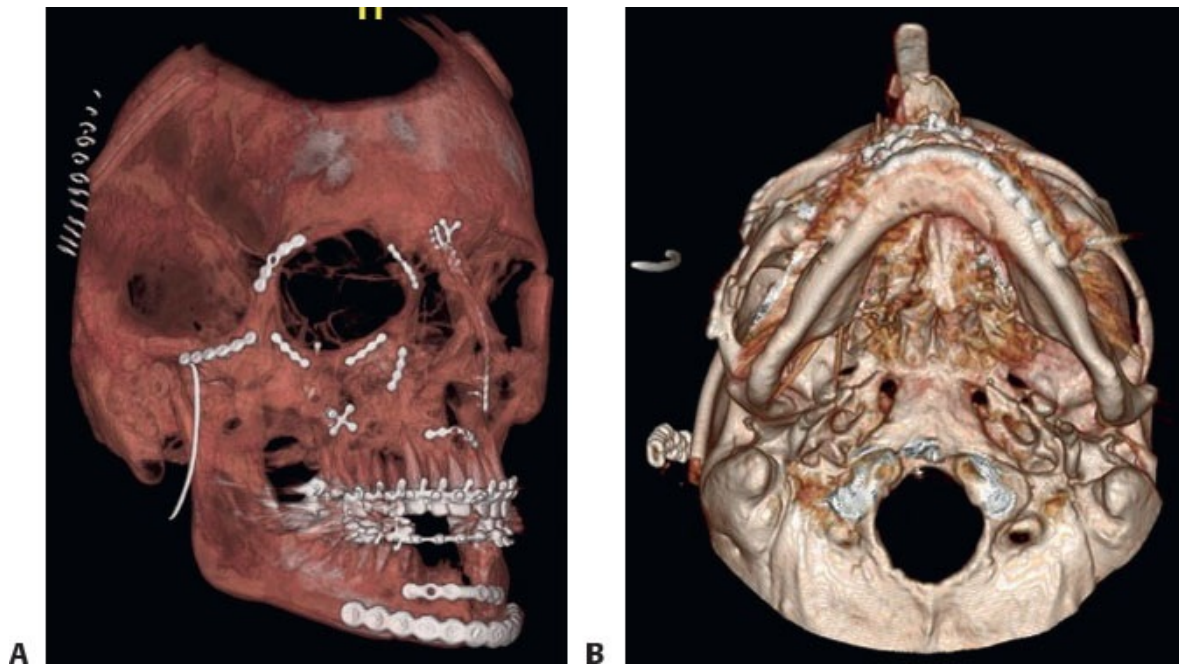


FIG 9 • Postoperative review of midfacial **(A)** and mandibular **(B)** reconstruction.

POSTOPERATIVE CARE

- If intraoperative CT scanning was not accomplished to review the reduction and fixation of fractures, comprehensive radiographic evaluation is performed in the immediate postoperative period in order to determine any potential need for revision (**FIG 9**).
- Daily checks are necessary while the patient is hospitalized; weekly outpatient checks should be performed until intermaxillary/maxillomandibular fixation has been discontinued and arch bars have been removed. Continue to reinforce the importance of oral hygiene.
- Physical therapy for active range of motion is frequently needed.
- Upon optimization of skeletal alignment and scar maturation (typically after 1 year), revision of soft tissue injuries may be undertaken.

OUTCOMES

- Gutta et al.⁶ performed a 5-year analysis of postoperative outcomes in patients who received treatment for mandibular fractures:
 - In a cohort of 363 patients, the overall complication rate was 26%, with hardware failure and infection being the two most common complications.

- Patel et al.⁷ found that methods of fixation, such as the Champy technique and use of reconstruction plates, were associated with higher rates of bony union and patient comfort.
- Extraction vs retention of teeth in the line of fracture has not been shown to significantly impact the outcome of reconstruction.
- A critical review of the literature, coupled with an internal review of more than 1200 facial fracture cases managed at our institution over a 6-year period, suggests that most complications encountered are secondary to operator error, either in decision-making/judgment or in technical performance.
- Rigidly stabilizing a fracture in a nonanatomic position resulting in malocclusion is not a failure of the hardware, nor should the surgeon expect the malocclusion to spontaneously correct.
- Selecting an inappropriate type/size of surgical plate for fracture repair without an understanding of the functional load the plate is subjected to should not be considered hardware failure if the plate loosens or breaks.
- Inadequate intraoral/extraoral closure of the surgical access or wound, with resulting exposure of the surgical hardware, is not truly a hardware complication.⁸
- In a single-center retrospective review of 359 patients who underwent surgical management of facial fractures, specific mechanisms of injury (such as MVC) and concomitant tobacco, alcohol, and/or tobacco use were associated with higher rates of surgical site infections.⁹

COMPLICATIONS

- Nonunion
- Malocclusion
- Asymmetry/soft tissue ptosis
- Soft tissue scarring
- Narrowing or overwidening of the face
- Lid malposition

ACKNOWLEDGMENT

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Section XIII: Pediatric Trauma

74

CHAPTER Pediatric Orbital Fractures

James Y. Liao

DEFINITION

- Fractures of the inferior and/or medial orbital wall

ANATOMY

- The orbit consists of seven bones; however, the ones that are involved are invariably the maxilla and ethmoid bones. Operative repair focuses on re-establishing the appropriate volume of these components (**FIG 1A**).
- Other pertinent anatomy includes optic nerve and superior fissure, which contains CN III to CN VI. These structures are located in the superior medial aspect of the orbit (**FIG 1B**).
- Soft tissue anatomy is relevant. This includes the palpebral fissure, gray lash line, septum, canthus, and caruncula (**FIG 1C**).
- Usually, orbital growth is complete by 6 to 8 years of age.

PATHOGENESIS

- Inferior orbital floor fractures occur with facial trauma, which entails a blow to the globe resulting in increased orbital pressure. This pressure fractures the thinner maxillary portion of the orbital floor causing a blow-out fracture into the maxillary sinus.

NATURAL HISTORY

- Diplopia that is self-limiting
- Enophthalmos can occur if the orbital volume is not corrected with floor reconstruction or soft tissue volume atrophy from trauma.

- Entrapment results in muscle fibrosis and permanently impaired conjugate gaze.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- Because of immediate post-traumatic swelling, enophthalmos is usually not appreciated clinically until swelling has decreased, unless the orbital blow-out fracture is quite large. Then enophthalmos and dystopia may be immediately appreciated.
- With blow-out fractures, extraocular movements are usually decreased due to the trauma and swelling, but there is usually some degree of movement.
- With entrapment, there is no voluntary extraocular movement due to pain. Attempted upward gaze will result in intense pain, and nausea; bradycardia can also occur.

IMAGING

- CT scan is the modality of choice. All three views are essential.
 - Axial views elucidate whether there is medial wall involvement, and the size.
 - Coronal views elucidate the width of floor fracture, medial wall, inferior rectus muscle involvement, and inferior orbital nerve involvement.
 - Sagittal views elucidate the length of the floor fracture and inferior rectus muscle involvement and helps delineate the depth of the dissection before encountering the posterior shelf.

DIFFERENTIAL DIAGNOSIS

- Need to diagnose other concomitant facial fractures. Most commonly involved are
 - Medial wall
 - Zygomatic maxillary complex
 - Le Fort 2
 - Le Fort 3

NONOPERATIVE MANAGEMENT

- Conservative treatment runs a higher risk of enophthalmos depending on the size of fracture. Amblyopia in pediatric population is generally self-limiting due to the adaptable plasticity of the brain.

SURGICAL MANAGEMENT

Preoperative Planning

- Performing CT scan of axial, coronal, and sagittal planes will help clarify anatomy such as orbital content or inferior rectus entrapment (**FIG 2**).
- Forced duction test under anesthesia if concerned about entrapment. This is difficult to do in an awake patient due to pain despite topical anesthetic drops. I usually defer to CT scan and clinical physical examination of pain and nausea with or without bradycardia upon upward gaze.

Types of Implants

- Synthetic
 - Polyethylene
 - Pros: No donor site and easily cut to size
 - Cons: Does not “grow” with the child, extrusion if not secured adequately, can become infected, and does not have rigidity for adequate support required in extensive orbital floor fracture
 - Titanium
 - Pros: Easily obtainable, retains shape, and easily cut to size, excellent rigidity required for extensive orbital fractures
 - Cons: Does not grow with child, extrusion if not secured adequately, concerns of soft tissue tethering into the openings of the implant^{1,2}

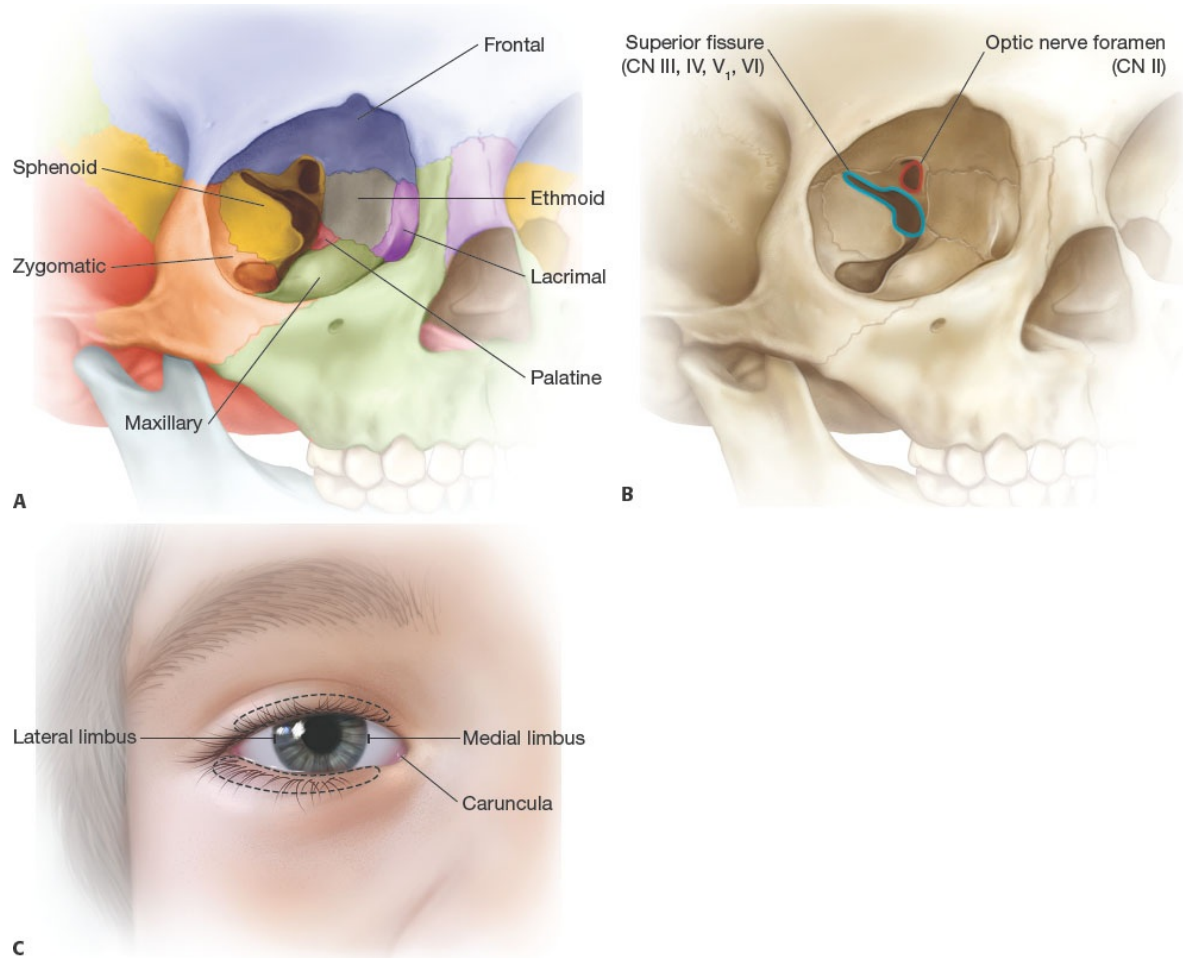


FIG 1 • A. Pediatric skull demonstrating the size of the orbit and forehead compared to the rest of the body. Orbital bones are labeled demonstrating the complexity of the orbital cone. **B.** Pediatric skull demonstrating the size of the superior fissure and the optic foramen in relation to the rest of the orbital cone. Note the size of the superior fissure in proportion to the rest of the orbital cone, as well as its location superomedially. This needs to be taken into account when dissecting on the floor. **C.** Pediatric eye demonstrating the soft tissue anatomy relevant for orbital fracture surgical exposure.

■ Mixed

- Pros: Easily obtainable and has both rigidity and minimal risk of tethering at

implant/soft tissue interface

- Cons: Does not grow with child; risk of extrusion if not secured adequately

■ Autologous

■ Bone

- Pros: Autologous; can be easily shaped
- Cons: Donor-site morbidity; requires time for harvest

■ Cartilage

- Pros: Autologous; can be easily shaped
- Cons: Donor-site morbidity; requires time for harvest

Positioning

- Need to be able to stand at head of bed allowing 270-degree access to the head. Usually turning the bed 90 degrees or 180 degrees provides this access (**FIG 3A**).
- Shoulder roll extending the head to give better visualization of the orbital floor (**FIG 3B,C**).

Approach

- Surgical treatment of orbital fracture can be separated into two different stages. Stage one is the soft tissue exposure and closure, and stage two is the orbital bone repair. Meticulous attention to detail is needed for the soft tissue handling during the exposure and closure because inadequate soft tissue handling can result in severe complications potentially worse than nontreatment. In fact, the actual soft tissue approach can be more morbid than the injury; refined handling of soft tissue is essential for favorable outcomes.³

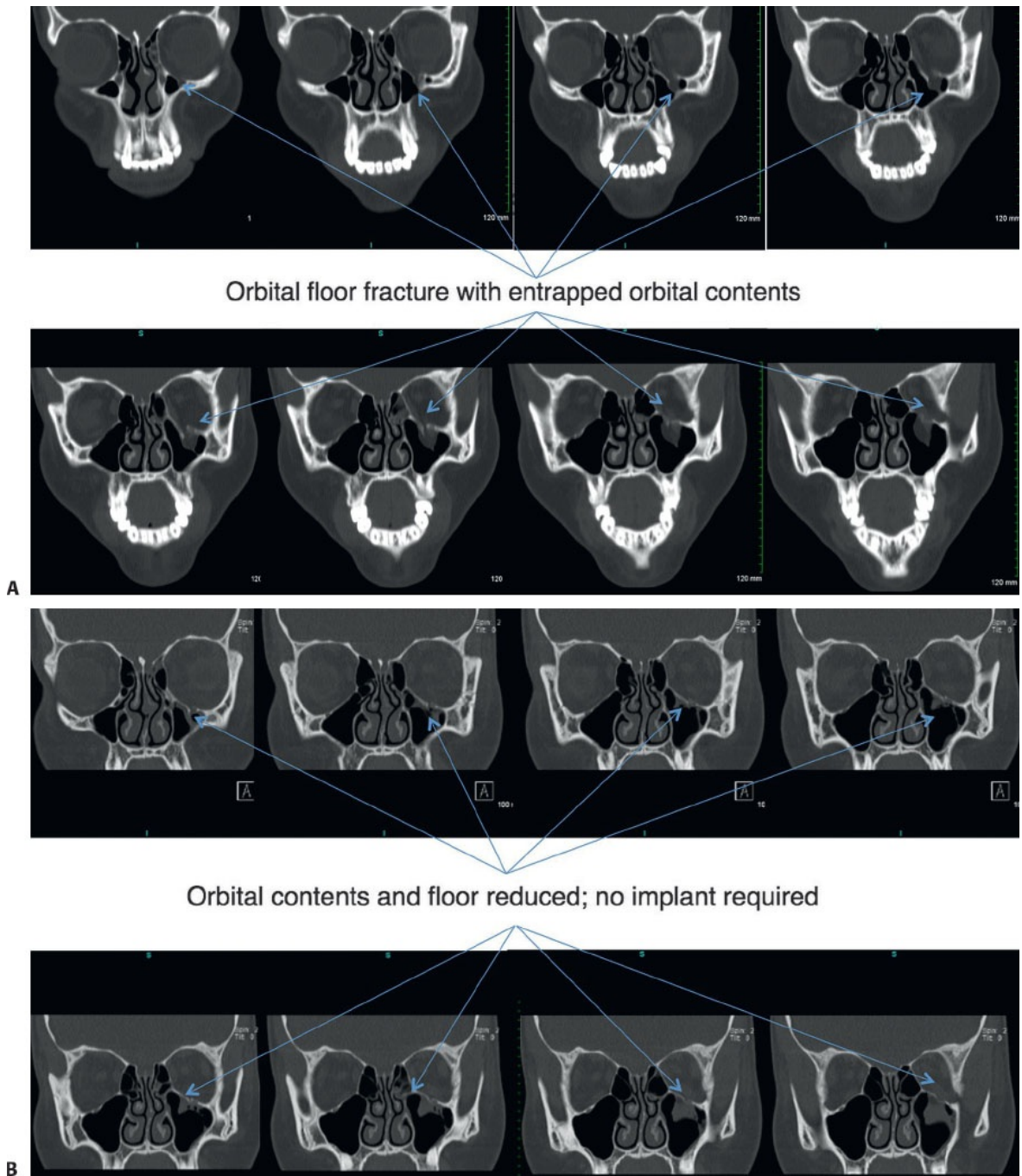


FIG 2 • A. Preoperative imaging showing orbital floor fracture with entrapped orbital contents. **B.** Postoperative imaging showing orbital contents and floor reduced. No implant was required.

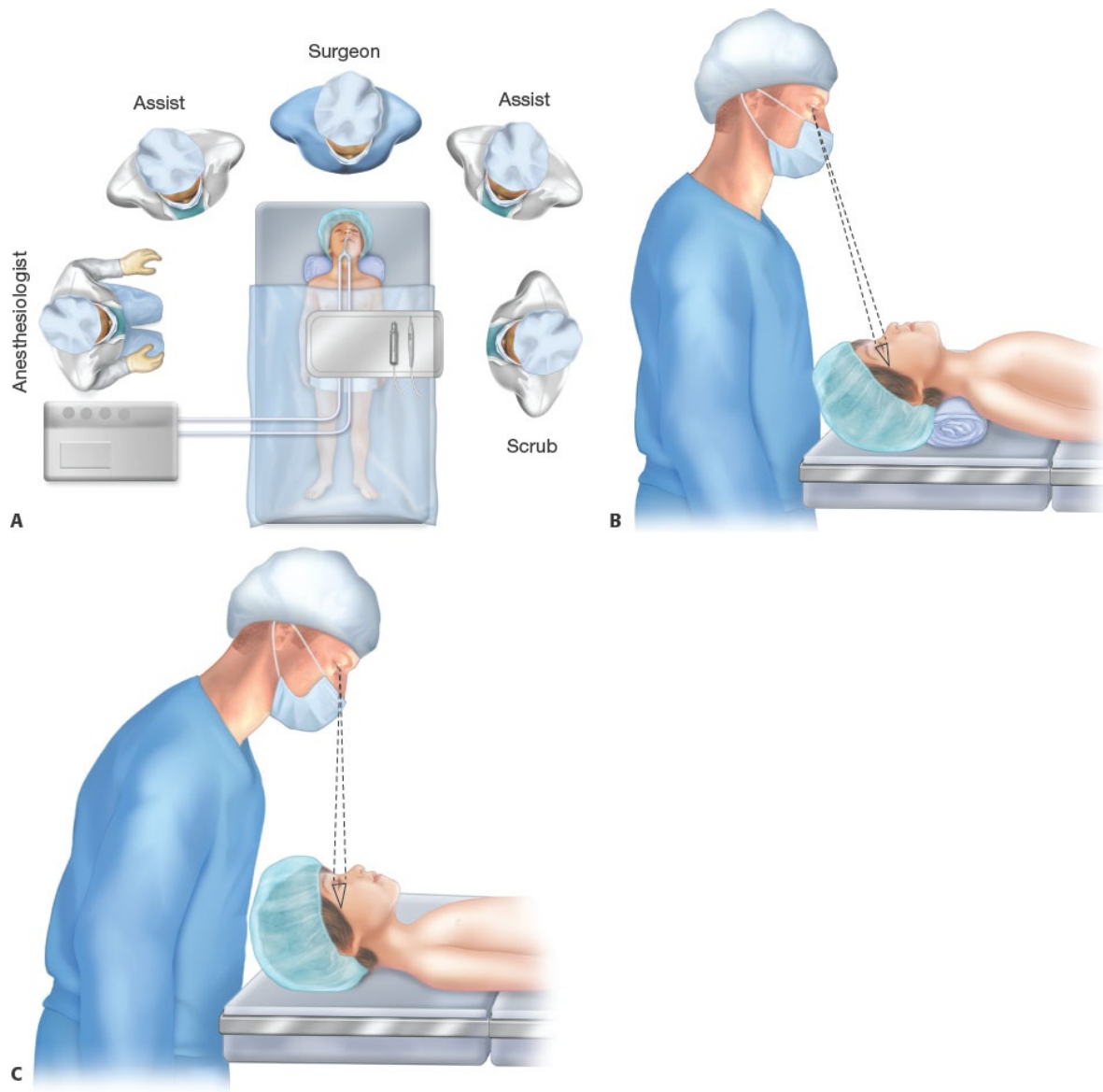
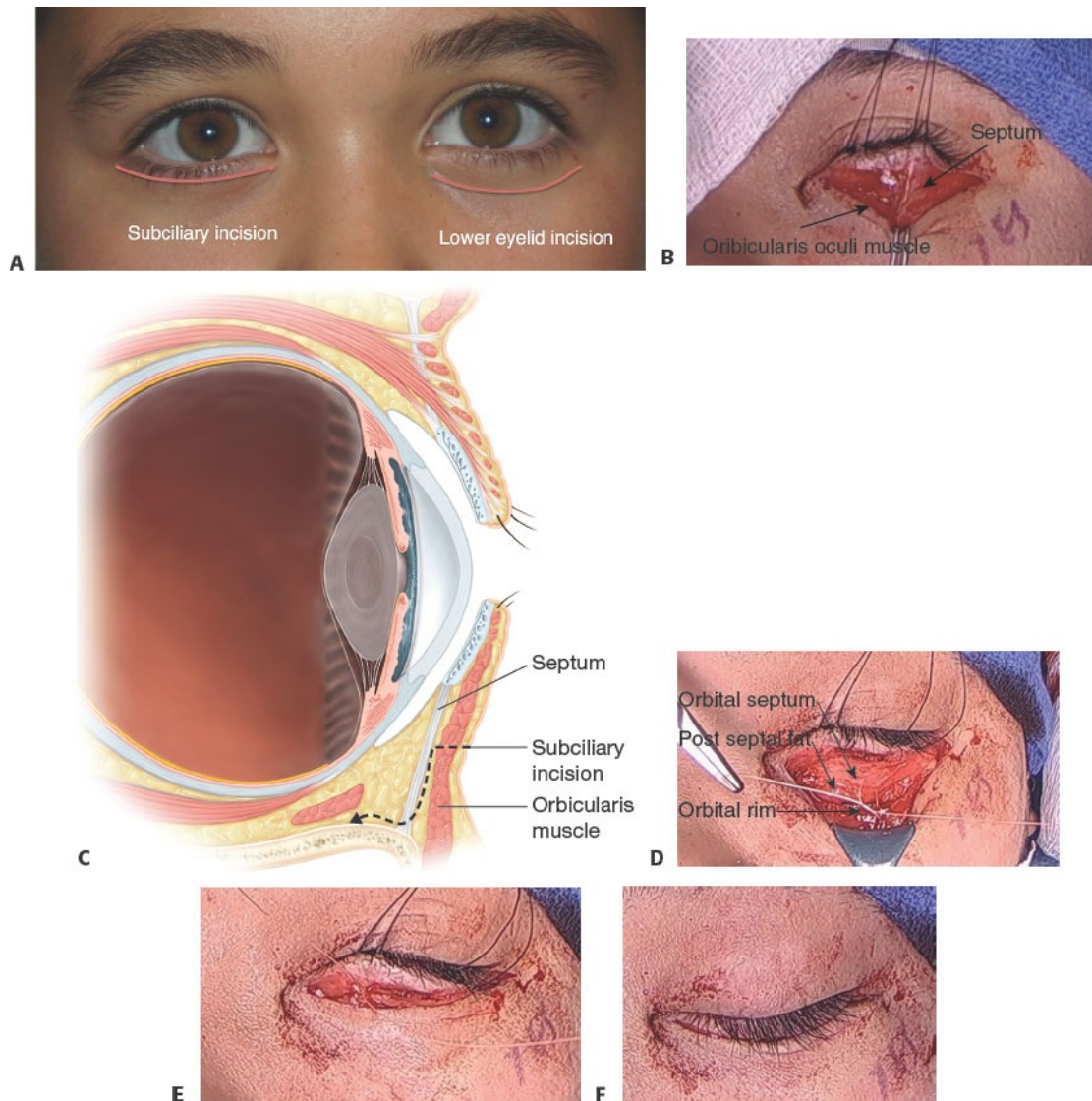


FIG 3 • A. Operating room setup. **B.** Having the patient's neck extended allows an easier angle of viewing into the patient's orbital cone and visualization of the orbital floor. **C.** If the patient's neck is flexed or neutral, the surgeon must lean over to visualize the orbital floor, which is ergonomically more difficult and tiring.

TECHNIQUES

■ Subciliary Approach

- I prefer this approach because it allows a much wider exposure of the rim and floor, as well as provides easier placement of implants onto the floor. Children and young adults have no lid laxity, and this incision avoids retraction on the actual tarsal sling. (Video demonstrates subciliary approach in a case of orbital entrapment.)
- Placement of corneal shield (optional)
- Retention sutures in the lower eyelid. The surgeon can place two sutures, one on each side of the limbus. I like to place the retention suture from the superior eyelid down to the lower eyelid and then back through the upper lid as a horizontal mattress. This protects the cornea and globe, as well as provides retraction during dissection.
- Incise at the lateral corner of the eye of the palpebral crease and plan for incision to be 2 to 3 mm below lash line (**TECH FIG 1A**) extending to the medial lash line to achieve adequate exposure.
- Dissect with tenotomy scissors under the skin in front of the septum but underneath the orbicularis oculi. Using scissors, cut at a bevel to raise a skin and muscle flap (**TECH FIG 1B**).
- Using traction of the lower eyelid retention stitch, spread transversely along the plane to expose the natural plane between the septum and orbicularis oculi (**TECH FIG 1C**). This is continued to the orbital rim. Gentle retraction with a Desmarres retractor while gently pressing down the orbital contents exposes the orbital rim. Avoid making this incision too posteriorly as this will violate the septum; an incision too anteriorly placed will incise the orbicularis oculi muscle.
- Incise the periosteum of the orbital rim with either needle-tip cautery or knife.



TECH FIG 1 • A. Eyelid incisions for approach to the orbital floor. The subciliary incision is preferred as it provides a discreet incision yet allows full exposure of the orbital floor. The lower eyelid incision is much more obvious in patients with youthful skin, such as pediatric and young adults. **B.** Demonstrates the tissue plane between septum and orbicularis oculi allowing an avascular plane of approach to the rim. **C.** Sagittal depiction of the subciliary approach. Note the septum posteriorly and muscle anteriorly. The dissection plane traverses between these two

structures. **D.** Closure of the orbital septum to its anatomic position assists in decreasing ocularis oculi tethering to the orbital rim, thus decreasing risk of ectropion. **E.** Muscle closure of lower eyelid orbicularis oculi to lower eyelid flap orbicularis oculi. **F.** Skin approximated without any gapping. If there is gapping, readvance the lower eyelid flap in order to decrease ectropion.

- Subperiosteal dissection allows improved exposure and avoids the fat of the orbital contents.
- After reconstruction of the orbital floor, handling of the soft tissue is important to prevent ectropion.
- Reapproximation of the periosteum with either 4-0 or 5-0 Vicryl depending on the amount of soft tissue dissected during exposure. An adequate periosteal bite is required to support the soft tissue of the cheek. This is especially important if there is also a ZMC fracture as this area is completely degloved. If the weight of this deep layer is not supported, the risk of ectropion is extremely high.
- Closure of the septum with resorbable suture such as 5-0 Vicryl (**TECH FIG 1D**).
- Reapproximation of the orbicularis oculi with a resorbable suture such as a 5-0 Vicryl. After this layer is closed, the skin should simply be opposing without any gap of the eyelid in comparison to the contralateral side (**TECH FIG 1E,F**). In fact, a little overlap of the lower eyelid over the incision is ideal. If there is gapping between the skin edges after muscle reapproximation, ectropion will most likely occur. Recheck to be certain that the periosteum is reapproximated appropriately by providing adequate support of the overlying soft tissue. The lower lid muscle and skin flap must be advanced adequately superiorly.
- Final skin closure can be completed with either 6-0 monofilament or 6-0 plain gut. I prefer to run a 5-0 fast or 6-0 fast gut. I also place a 6-0 fast tarsorrhaphy at the lateral limbus to assist in keeping the lower eyelid elevated during postoperative swelling. Patients can raise their upper eyelid enough to see. This suture can be removed at day 5 to 7; however, I usually

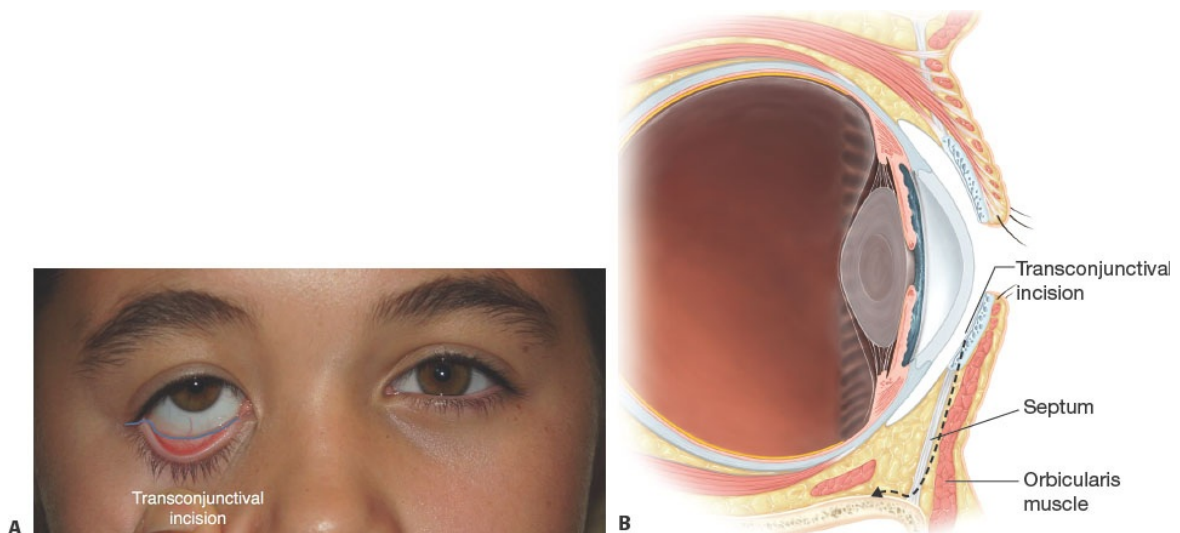
just let it degrade, which is usually around 5 to 7 days. This prevents patient discomfort.

■ Transconjunctival Approach

- I prefer not to use this approach in children and younger adults as there is no lid laxity. It can be difficult to assess the whole orbital floor, as well as place the implant. Also, oftentimes, “bowstringing” of the lower lid can occur after reconstructing the inferior canthus, which increases the chance of ectropion or entropion.
- Placement of corneal shield: optional
- Place two lower eyelid traction sutures on each side of the limbus right below the lash line.
- Using a sharp pair of tenotomy scissors, make a lateral cut right at the corner of the lateral palpebral fissure. This transects the lateral canthus separating the inferior limb from the superior limb (**TECH FIG 2A**).
- Reorient the scissors 90 degrees so that they are following the curve of the face, and then incise only the inferior limb of the lateral canthus.
- This should release the canthus to pull the lower eyelid out, thus exposing the inferior fornix. The cascade of vessels behind the tarsus and the transition to only the conjunctiva can be visualized. Make an incision with needle-tip cautery underneath this cascade of vessels. This should be a full-thickness conjunctival incision (**TECH FIG 2B**).
- This allows placement of another traction suture as a horizontal mattress from the upper eyelid skin down to the conjunctival flap, back through the flap to the eyelid, and then a loose knot. This provides tension on the conjunctival flap for easier dissection and keeps the corneal shield secure.
- Dissection plane is the same as before, which is between the orbicularis oculi muscle and the septum. Entering the septum allows fat to herniate out and can make retraction more difficult but does not affect overall exploration and floor reconstruction.
- After floor reconstruction (see below for this procedure), closure consists of 4 steps:
 - Reapproximation of SMAS layer to the periosteum of the orbital rim
 - Reapproximation of the orbicularis oculi
 - The conjunctiva does not necessarily need to be closed. Run a 6-0 fast gut

with wide spacing between bites.

- It is essential to reapproximate the inferior canthal tendon to Whitnall tubercle. One can either take a bite through the periosteum or, if there is no periosteum there, can drill a hole in the bone. The key is to make sure to “redrape” the lid against the globe; otherwise, there will be inadequate opposition of the lower lid against the globe.



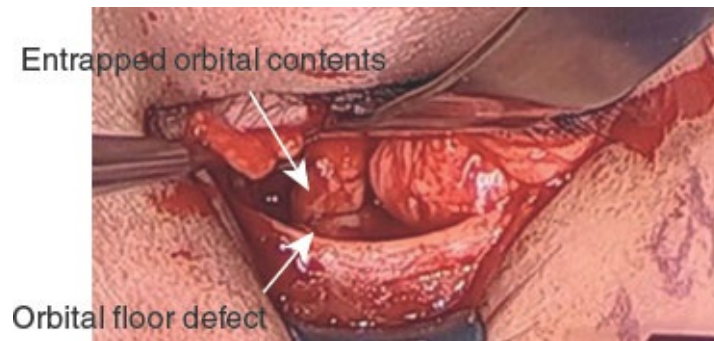
TECH FIG 2 • A. Transconjunctival approach to the rim. It can be difficult to get full exposure of a fracture unless the inferior canthal tendon is released, and even then, the exposure is limited without forceful retraction of the lower lid. Although there is more elasticity in a youthful/pediatric lower lid, it is also much tighter requiring more extensive retraction, increasing risk of entropion. **B.** Sagittal depiction of the transconjunctival approach.

■ Lower Eyelid Incision

- This is not an ideal approach for the pediatric population or the young adult, unless there is already a laceration (see **TECH FIG 1A**). In the older adult population, the scar is quite acceptable. If one does use this approach, the patient must be aware that there may be a lid edema superior to this incision for a prolonged time postoperatively.

■ Orbital Floor Dissection

- Subperiosteal dissection posteriorly provides a cleaner dissection plane to expose the fracture and herniated orbital contents (**TECH FIG 3**).⁴
- In larger fractures, it is common to encounter the inferior orbital nerve and this must be separated inferiorly. Removal of comminuted bone fragments will help delineate path of the nerve.
- Sweep laterally and medially to help find the posterior shelf. Using either a malleable or orbital content retractor, retract the orbital contents superiorly allowing the edge of the retractor to rest on the posterior shelf. During this maneuver, let the anesthesiologist know there may be vagal stimulation causing bradycardia. This should provide a clear view of the orbital floor defect to help shape the implant.
- CN II and the superior fissure are located superomedially. Be cautious when dissecting toward the fissure. Having an exact idea of the length of your dissection tool is mandatory; the distance from the rim to the apex of the orbital cone ranges will vary according to the patient's age and can be premeasured in the sagittal window preoperative CT scan.
- Shape the orbital plate, and while gently retracting superiorly, place the plate into position.
- When looking down at the surgical site, the surgeon must be able to see the plate. If the plate cannot be visualized, then the placement is not appropriate and the plate is in the maxillary sinus.



TECH FIG 3 • Amount of exposure capable with a subciliary incision. Orbital floor is easily visualized, including the entrapped orbital contents in this particular case.

- Secure the plate to prevent any form of movement because movement can cause migration and extrusion. One can simply secure the plate with a 4-mm screw in the orbital floor.
- If there is a trap door injury, simply reducing the trapped orbital contents is enough to reduce the orbital floor anatomically. The very elastic nature of the pediatric orbital floor bone causing the trapdoor mechanism is also what allows the bone to reduce, thus obviating the need for an implant. Using a small nerve hook can help reduce the orbital floor into its anatomic location, but one must be careful not to completely fracture the floor. This will turn a greenstick fracture into a complete orbital floor defect requiring reconstruction.

PEARLS AND PITFALLS

Preoperative preparation	■ Judicious infiltration of vasoconstrictive local anesthetic.
Adequate exposure	■ Optimal positioning can improve the ease and efficiency of the procedure. Extension of the head allows better visualization of the orbital floor. ■ Although technically either transconjunctival or subciliary incisions can give adequate exposure, subciliary incision can be more easily extended medially for full exposure of floor and medial wall.
Implant placement	■ Need to have adequate exposure and visualize or palpate the posterior shelf ■ Visualize the implant when looking straight down into the orbit (see FIG 3C)
Soft tissue	■ Resuspension and “no tension” closure will help prevent ectropion and entropion.
Postoperative care	■ Obtain postoperative imaging (either CT scan or skull films). ■ Steroid ophthalmic drops to assist in keeping lower eyelid elevated during postoperative period where swelling can cause “bowstringing” of the lower eyelid

POSTOPERATIVE CARE

- Repeat x-ray; lateral films are adequate to demonstrate appropriate placement. If there are other facial fractures, repeat CT scan. In pediatric patients, avoid unnecessary radiation.
- Temporary tarsorrhaphy
- Steroid ophthalmic ointment or drops
- Head of bed elevated
- Visual checks
- Sinus precautions

COMPLICATIONS

- Diplopia
- Enophthalmos
- Ectropion
- Entropion
- Reconstruction malposition
- Palpebral fissure discrepancy

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75 Surgical Correction of Pediatric Midface Fractures

CHAPTER

Eric Lowry Cole and Shelby R. Lies

DEFINITION

- Le Fort fracture
 - Le Fort I dentoalveolar separation including pterygoid plates
 - Le Fort II bilateral pyramidal fracture including pterygoid plates
 - Le Fort III craniofacial separation involving the frontonasal articulation, traversing the orbital walls with disjunction of pterygoid plates and zygomatic arch (**FIG 1**)
- Nasal bone fracture
- Naso-orbitoethmoid fracture
- Zygomaticomaxillary complex fracture
- Frontal bone fracture

ANATOMY

- The zygoma articulates with the frontal bone, maxilla, temporal bone, and sphenoid. All fractures of the zygoma affect the orbital floor or lateral orbital wall.
 - The zygomaticosphenoid junction is the key anatomical articulation in the reduction of these fractures (**FIG 2**).
- Naso-orbitoethmoid (NOE) fractures are defined as a comminuted fracture of the nose and orbit involving the medial orbital walls, ethmoid sinus, and bony and cartilaginous structures of the nose.

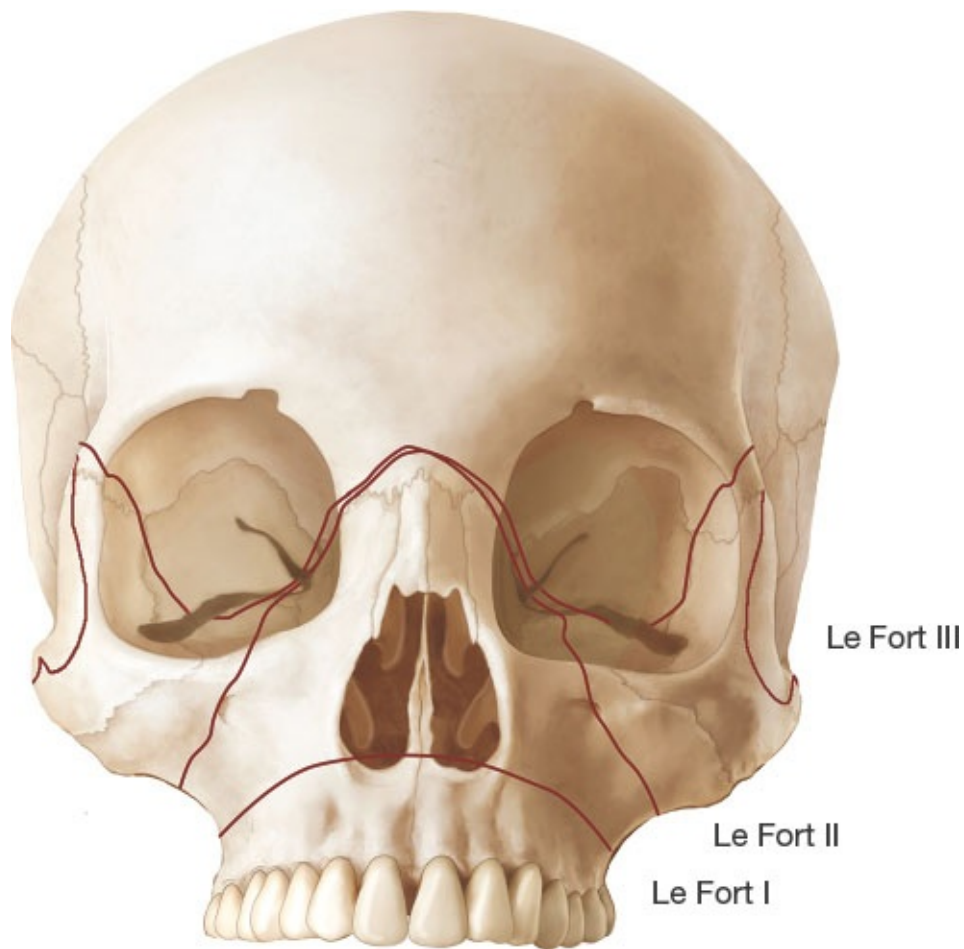


FIG 1 • Le Fort fracture classifications.

PATHOGENESIS

- Motor vehicle collisions and assault are the most common causes of facial fractures in children.¹
- Consider possible nonaccidental injury if the history does not match the injury or if there are multiple emergency room visits.
- The prominent cranium and mandible in children make isolated midface fractures uncommon, and their presence should prompt a search for associated intracranial and cervical spine injuries.²
- Pure Le Fort fractures are rare and oblique hemi-Le Fort patterns are more common in children.
- Relative underdevelopment of the maxillary sinus allows the zygomaticomaxillary buttress to resist classic Le Fort I level fractures, and instead, force is transferred to dentoalveolar segments causing alveolar and

dental injuries.

- Le Fort II and Le Fort III level injuries often present with NOE fractures combined with zygomaticomaxillary complex and orbital wall fractures.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Blunt trauma causes fractures at articulations.
- Direct impact to the lateral face may cause an isolated depressed zygomatic arch fracture.

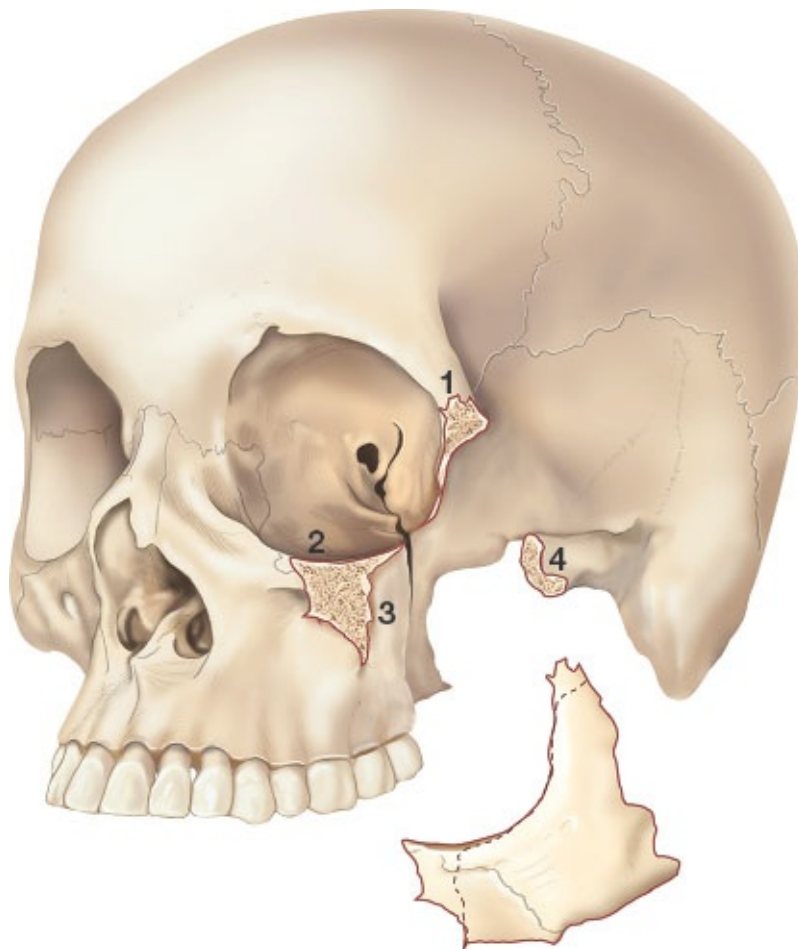


FIG 2 • Zygomaticomaxillary complex articulations.

- Significant medial displacement may result in the loss of lateral facial width or trismus through impingement on the coronoid.
- Higher-velocity injuries often cause comminution and deformity in facial width, orbital rim step-offs, flattening of malar prominence, and globe malposition.

- Assess facial symmetry and occlusion; palpate to determine integrity of frontal bones, orbital rims, and malar eminence of zygomatic arch.
- Check stability of the maxilla including dentoalveolar segments by stabilizing the head and attempting to mobilize the dentition. Ecchymosis may be present in the gingivobuccal sulcus.
- Visual acuity and globe integrity must be documented. Examine extraocular movement and pupillary response.
- Enophthalmos. Lateral and/or inferior displacement of the zygoma may increase orbital volume and lead to enophthalmos. Greater than 3 mm change in globe position compared to contralateral eye appears clinically significant. Relation of the corneal surface to the lateral orbital wall can be measured with a Hertel exophthalmometer device.
- Diplopia. Symptoms occur mostly in upward gaze due to hypotropia where the focus is on the eye with a visual axis lower than the contralateral fixating eye, most commonly with injury to the inferior rectus muscle.
- Traumatic optic neuropathy can present with subtle findings of diminished color perception. Consult an ophthalmologist.
- Oculocardiac reflex involves classic triad of bradycardia, nausea, and syncope. If symptoms occur in any phase of treatment, suspect periorbital entrapment, which necessitates release. Pediatric patients are more prone to sustain a trapdoor deformity of the orbital floor, leading to entrapment and persistent nausea (**FIG 3A,B**).
- Cheek numbness as a result of infraorbital nerve injury.
- NOE fracture deformity includes loss of nasal bridge projection, upturned nose, and telescoping nasal length (**FIG 3C,D**).
- The varying degree of loss of canthal attachment creates an increase in intercanthal distance with blunting of the palpebral fissures. A bowstring test can assess for tendon avulsion.
- Intranasal speculum examination for epistaxis and septal hematoma
- Rule out CSF leak with a tilt test for halo sign and/or beta-transferrin analysis.

IMAGING

- Plain occipitomeatal views demonstrate distraction of articulations and zygomatic arch anatomy.
- Computed tomography (CT) max-face is the diagnostic study of choice to evaluate the characteristics of fracture patterns. Considerable information can

be obtained from CT imaging.

- Manson's classification according to degree of displacement/comminution is useful based on CT³:
 - Minimal displacement, no comminution
 - Moderate displacement, mild comminution
 - Severe displacement, major buttresses comminuted in multiple locations
- Three dimensional (3D) reconstruction offers interpretation of complex fractures (**FIG 4**).



FIG 3 • Restriction of the left eye (**A**) correlating with

radiographic evidence of snapback entrapment **(B)**.
C,D. Preoperative photographs of a patient with hemi–Le Fort II and NOE fracture demonstrate loss of nasal bridge projection, upturned nose, and telescoping nasal length.

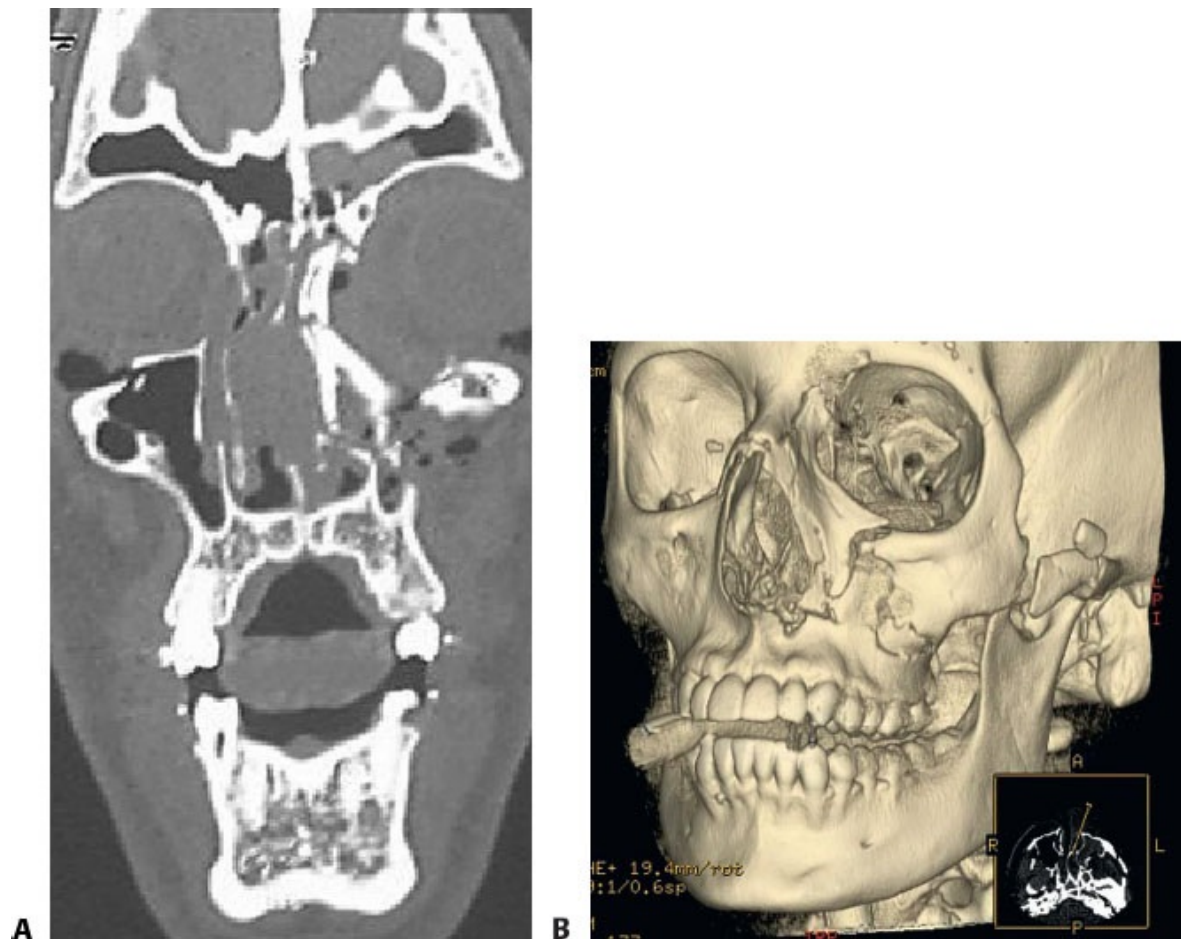


FIG 4 • A. Coronal CT hemi–Le Fort II NOE fractures.
B. CT 3D Reconstruction hemi–Le Fort III.

DIFFERENTIAL DIAGNOSIS

- Skull fractures from frontal impact are more common in young children, and older teens have a higher probability of facial fractures.²
- Intracranial abnormalities
- Cervical spine injury
- Nasal bone

- Mandible, particularly the subcondylar region
- Frontoethmoid region
- Orbit, most frequently involving the orbital roof in children under 7, as compared to the floor in adults

NONOPERATIVE MANAGEMENT

- In the pediatric patient, rigid skeletal fixation can do more harm than good. Children have significant capability of bony remodeling and dental compensation.
- Fractures should be managed conservatively whenever possible.
 - Nondisplaced and minimally displaced fractures, in the absence of orbital dysmorphism or malocclusion, may be treated with nonoperative care.
 - Close follow-up and a soft diet for 4 weeks are recommended.
- Bone fragment displacement can be caused by muscles of mastication; therefore, parents should be advised to provide appropriately “mushy” meals that can be squeezed between the fingers and instruct children to avoid force while eating.

SURGICAL MANAGEMENT

- Many of the same principles in the treatment of adult midface fractures apply to children.
 - Notable exceptions include the avoidance of implants in tooth-bearing areas to prevent damage to tooth buds and the use of resorbable plates.
- Resorbable plating systems composed of polylactic and polyglycolic acids are readily available and preferred when possible.
 - The plates are usually resorbed within a year and are of adequate strength for fixation of thin bones.⁴
- The goals of reconstruction include obtaining pretraumatic occlusion along with re-establishing the buttresses (medial nasomaxillary and lateral zygomaticomaxillary) to restore the width and projection of the midface.
- The indications for surgical treatment of fractures include malocclusion, trismus, and significant displacement causing enophthalmos or a noticeable contour deformity.
- Treatment involves open reduction and fixation with miniplates, preferably resorbable.
 - Le Fort I displaced fractures require MMF and ORIF of the medial nasomaxillary and lateral zygomaticomaxillary buttresses.

- Le Fort II fractures are often unilateral (hemi) and can present with NOE fractures. Treatment of displaced fractures requires fixation of the medial and lateral buttresses and the orbital rim. A coronal incision may be necessary to address the nasofrontal region.
 - NOE fractures are particularly difficult to manage in children.
 - Complete avulsion of the medial canthal tendon is the strongest indication for surgery.
 - Avulsion of the canthal tendon is best managed with open transnasal canthoplasty.
 - Cantilever bone graft should also be considered during primary reconstruction.
- Le Fort III fractures are often unilateral with multiple fragments and present with NOE combined with zygomaticomaxillary complex fractures.
 - Synchronous ORIF of each subunit fracture through existing lacerations, a coronal approach, or a glabellar incision.
 - Lower lid incisions are needed to assess and treat orbital rim and floor defects if present.

Preoperative Planning

- CT scans and 3D reconstructions should be carefully reviewed and available for display intraoperatively.
- Pediatric dental and orthodontic evaluation should be considered especially if impressions and models were taken before injury.
 - A palatal splint can be fabricated to treat palatal fractures without open reduction internal fixation.
- Occlusion and fracture site mobility should be examined.
 - The bowstring test and inserting a clamp intranasally with the index finger externally palpating medial canthus can assess for instability.
- Evaluation of occlusal relationship requires nasotracheal intubation in most cases.
 - Depending on patient's condition, a submental intubation or tracheostomy might also be considered.

Positioning

- The child is placed in the upper corner of the operating table with a shoulder roll, donut cushion under the head, and arms tucked.

- Minimize blood loss with slight head-up position, controlled blood pressure, and local infiltration with epinephrine.
- A Mayfield head ring attachment to bed may facilitate exposure with coronal approach.

Approach

- Incision selection is based on the desired exposure of displaced articulations.
- Surgical approaches include using existing lacerations; the maxillary vestibule; the lower and upper eyelid to expose the infraorbital rim and zygomaticofrontal sutures, respectively; the glabellar approach; the coronal approach; and the temporal Gillies approach for zygomatic arch reduction.
- The ethmoidal approach is not recommended due to potential scar contracture.
 - Le Fort I: Maxillary vestibule
 - Le Fort II: Maxillary vestibule, lower eyelid, with or without coronal
 - Le Fort III: Eyelid, coronal, or glabella
 - Comminuted NOE fractures: Coronal approach

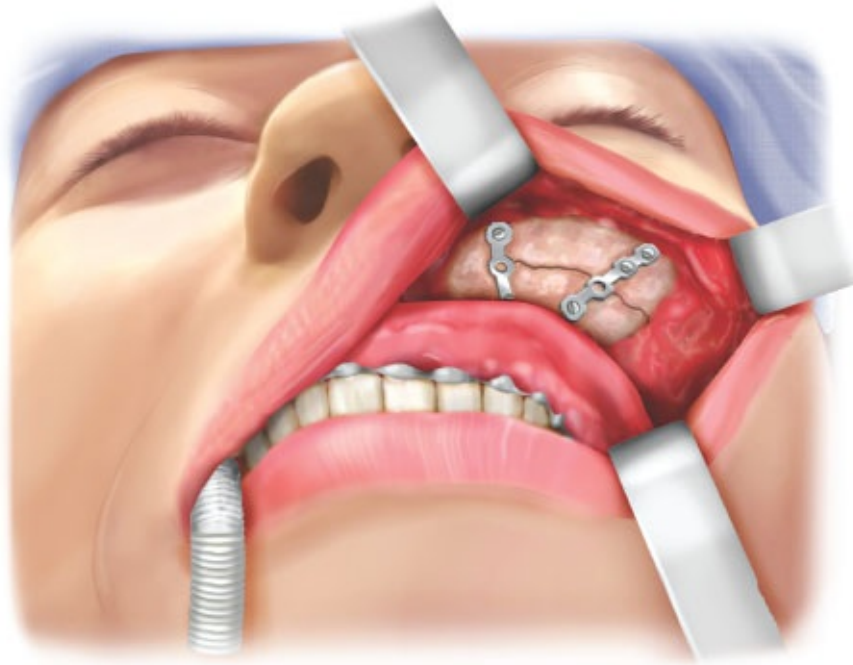
TECHNIQUES

■ Le Fort I Open Reduction Internal Fixation

- Nasotracheal intubation is necessary. An oropharyngeal pack protects the upper aerodigestive tract from blood and debris. First, arch bars are secured to dentition. Developing dentition requires adjustment in securing maxillomandibular fixation.⁵
 - If the patient is less than 2 years old, higher-energy injuries can be managed with closed reduction and acrylic splints secured with circum-mandibular or piriform drop wires.
 - If the patient is 2 to 5 years old, arch bars can be secured to the deciduous teeth.
 - If the patient is 6 to 12 years old with mixed dentition, stable teeth vary by age. From 6 to 7 years, the deciduous molars are relatively stable.
 - At 8 to 10 years, the permanent first molars and central incisors appear.
 - By age 10, adequate permanent teeth allow arch bar placement.
- Local anesthetic with epinephrine is injected in the gingivobuccal sulcus for

hemostatic effect.

- Incise perpendicular to the mucosa with needle-tip electrocautery or scalpel in gingivobuccal sulcus with care to leave a myomucosal cuff for closure.
- Proceed with dissection through the periosteum of the maxillary bone. Perform subperiosteal dissection with malt elevator to expose the fracture site. Identify stable bone above and below the medial and lateral buttresses.
- Reduction of the maxilla may be difficult due to telescoping and impaction and may be complicated if healing has commenced because of significant time between injury and treatment. Rowe disimpaction forceps may be needed to obtain adequate repositioning of the maxilla. A Stromeyer hook can also be placed in the piriform aperture and used for manipulation.
- After the fracture has been mobilized, remove the throat pack and secure MMF with wires.
- Ensure the condyles are properly seated, and reduce the maxilla for optimal bone contact. Five-millimeter or smaller gaps may be tolerated⁶; however, for comminuted fractures with a larger bony defect, a bone graft may be required for complete osteosynthesis.
- Resorbable plates may be used to decrease the risk of growth disturbances and injury to tooth buds.⁷ The plate is contoured and secured across the zygomaticomaxillary buttress. An additional plate is fixed to the nasomaxillary buttress (**TECH FIG 1**).
- After internal fixation, MMF is released and occlusion is determined. If an open bite or class III occlusion is present, the condyles may not have been seated appropriately in the glenoid fossa. This requires plate removal and repositioning for proper positioning of the condyles.
- The wound is irrigated. The gingivobuccal incision is closed with a 4-0 Vicryl running suture.



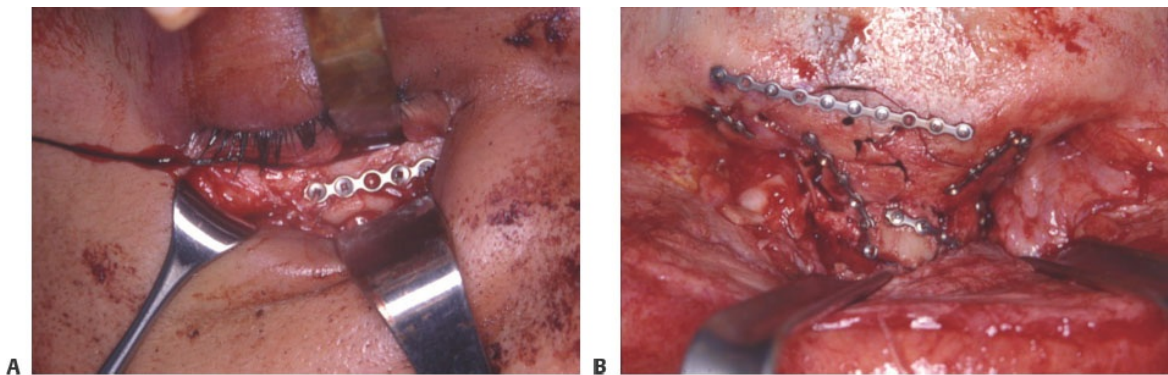
TECH FIG 1 • Vestibular approach plating medial and lateral buttresses.

■ Le Fort II Open Reduction Internal Fixation

- Preoperative markings include an existing subtarsal lower eyelid skin crease for orbital rim exposure.
- After nasotracheal intubation and throat pack placement, arch bars are secured to the dentition.
- The fracture segments are exposed through a maxillary vestibular approach.
 - The fracture fragments are mobilized and disimpacted by forceps or bone hooks.
- After adequate reduction, MMF is secured. Reduction and fixation of Le Fort fractures should occur before addressing the orbital wall.
 - A resorbable L-shaped plate is applied to the zygomaticomaxillary buttress. The foot of the plate should be placed in a manner to avoid damage to the tooth roots with screw placement.
- The orbital rim should then be explored. Subtarsal incision is made with a no. 15 blade scalpel and extended through orbicularis oculi preseptally to the orbital rim with a needle-tip electrocautery.
 - Using a Desmarres for retraction, subperiosteal dissection is performed

using an elevator and a curved malleable retractor to widely expose the orbital floor and the orbital wall.

- A contoured plate is applied to the infraorbital rim and secured (**TECH FIG 2A**).
- If the Le Fort II segment is stable, the MMF wires are removed and occlusion is checked.
- Depending on the fracture pattern, an inverted Y-plate or multiple miniplates are used for securing the nasofrontal fracture (**TECH FIG 2B**).
- If there is a defect of the maxillary sinus wall, it may be bridged by resorbable mesh.
- The periosteum is resuspended near the arcus marginalis.
 - The eyelid incisions are closed with 6-0 fast-absorbing gut suture and surgical glue.
 - The gingivobuccal incision is closed with 4-0 Vicryl running suture.



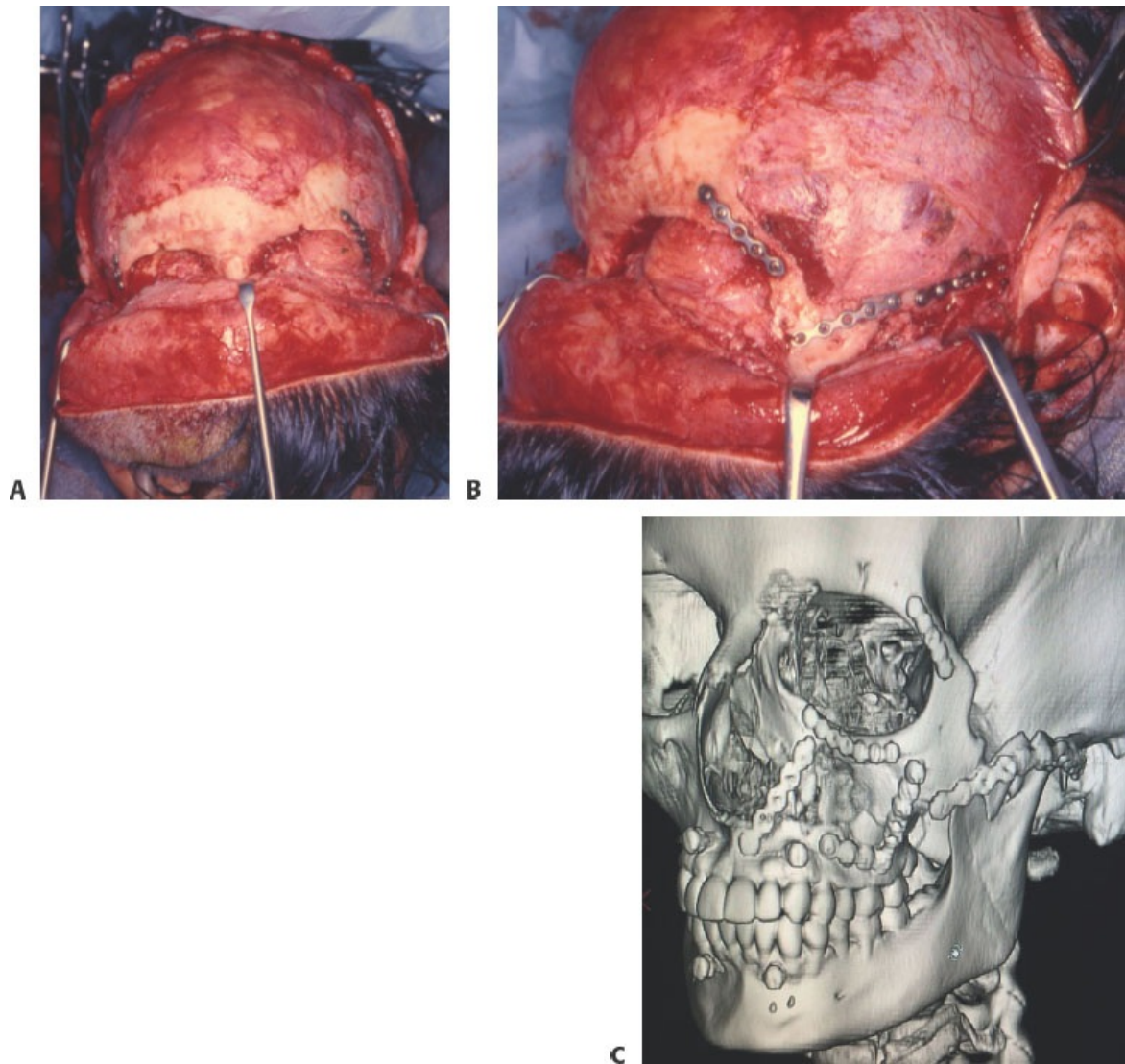
TECH FIG 2 • A. Subtarsal approach infraorbital rim plate. **B.** Plating of a comminuted NOE fracture.

■ Le Fort III Open Reduction Internal Fixation

- Preoperative markings include an existing subtarsal lower eyelid skin crease for orbital rim exposure.
 - Nasotracheal intubation is required to assess occlusal relationship. If not possible, submental intubation should be considered.
 - The hairline can be clipped if a coronal or bitemporal approach is planned.
- Arch bars are secured to dentition.
- The coronal incision is made with a graduated subperiosteal plane, leaving

the pericranium intact superiorly and incising deep through the periosteum several centimeters above the orbital rims (**TECH FIG 3A**).

- If a pericranial flap is planned for frontal sinus injury, however, begin the incision in a subperiosteal plane to raise the skin and pericranial flaps together.
- When approaching the zygomatic arch, to avoid injury to the temporal branch of the facial nerve, transition to incising the deep temporal fascia several centimeters above the arch and dissect within the intermediate fat pad to complete exposure.
- A reduction hook can be used for manipulating the Le Fort complex and zygoma.
 - The tip of the Stromeier hook can be inserted percutaneously 4 cm below the lateral canthus below the arch for repositioning.
 - A threaded reduction tool such as Carroll-Girard might also prove helpful to align the midface in three dimensions.
- Generally, plate fixation is applied to fractures at the zygomaticofrontal suture, the zygomatic arch, and the nasofrontal junction.
- The zygomaticofrontal fracture site can often be palpated. If not exposed through a coronal incision, a 1-cm incision is made directly over the suture site parallel to the lateral orbital rim for exposure.
 - A low-profile resorbable plate may be used for fixation.
- Nasofrontal plates are secured if needed in the appropriate configuration.
- Plates are then applied to the zygomatic arch to reestablish the sagittal buttress (**TECH FIG 3B**).
- After internal fixation, MMF is released and occlusion checked.
- The incisions are closed in layers.
- **TECH FIG 3C** demonstrates a postoperative CT 3D reconstruction with plates in situ.



TECH FIG 3 • A. Coronal exposure graduated plane. **B.** Coronal approach plating zygomaticofrontal articulation and zygomatic arch. **C.** Hemi–Le Fort III postoperative CT 3D reconstruction with zygomaticofrontal, infraorbital rim, nasomaxillary, zygomaticomaxillary buttress, and zygomatic arch plate fixation as well as posts for MMF.

■ **Zygomaticomaxillary Complex Fracture Open Reduction Internal Fixation**

- Preoperative markings include an existing subtarsal lower eyelid skin crease for orbital rim exposure.
- The course of the superficial temporal artery can be palpated and marked to confine the area of the planned Gillies incision within the temporal hairline.
- Surgical approaches typically include the marked lower eyelid, directly over the zygomaticofrontal suture, the Gillies, and the gingivobuccal sulcus to expose displaced articulations. General endotracheal anesthesia is administered.
- The planned areas of dissection are infiltrated for hemostatic effect.
- The zygomaticofrontal fracture site can often be palpated. A 1-cm incision is made directly over the suture site parallel to the lateral orbital rim for exposure.
- The orbital floor should be explored before and after reduction to ensure the fixation did not alter orbital volume or floor stability.
 - Subtarsal incision is made with a no. 15 blade scalpel and extended through orbicularis oculi preseptally to the orbital rim with Colorado tip Bovie electrocautery.
 - Using a Desmarres for retraction, subperiosteal dissection is performed using a Molt no. 9 elevator and a curved malleable retractor to widely expose the orbital floor and the lateral orbital wall to precisely assess anatomic alignment after reduction.
 - Anatomic reduction is largely based on the lateral orbital wall, specifically the relationship of the zygomatic bone and the greater wing of the sphenoid.
 - The zygomaticosphenoid junction is the most accurate assessment of proper reduction.
- The Gillies incision is made and an elevator inserted deep to the temporal fascia superficial to the temporalis muscle to lever the zygomatic arch and obtain restoration of the malar eminence.
 - A Carroll-Girard screw may also prove beneficial to allow manipulation of fragments as a joystick.
- The gingivobuccal sulcus incision is made and subperiosteal dissection performed to expose the zygomaticomaxillary buttress.
- Each fracture line is inspected to assess the correct position at the exposed articulations.
- While holding reduction with a hook on the zygomatic body and the elevator

under the arch, an L-shaped miniplate is used to fixate the ZMB.

- A small resorbable miniplate is used to fixate the ZF suture.
- The orbital floor is again inspected, and if a defect remains, a resorbable mesh implant is placed. A forced duction test is performed.
- The periosteum is resuspended near the arcus marginalis.
 - The eyelid incisions are closed with 6-0 fast-absorbing gut suture and surgical glue.
 - The Gillies is reapproximated with 4-0 Monocryl deep dermal and gut suture.
 - The gingivobuccal incision is closed with 4-0 Vicryl running suture.

PEARLS AND PITFALLS

Proper reduction

- Rowe disimpaction forceps and/or a Stromeyer hook are useful instruments to obtain adequate repositioning of the maxilla. Le Fort I osteotomy may be required if conventional methods are unsuccessful. Zygomaticosphenoid articulation is key to prevent future deformity with regard to orbit volume and facial symmetry.

Conservative management

- Avoid internal fixation for stable or nondisplaced fractures. Use the least invasive approach for manipulation of displaced fragments to obtain acceptable reduction. Good bone remodeling allows satisfactory long-term results.

Implant choice

- Avoid implants in tooth-bearing areas due to the risk of damaging tooth buds. Resorbable fixation decreases the risk of growth disturbances and injury to developing teeth.

Malocclusion

- Check occlusion for open bite or class III tendency. The condylar heads need to be positioned correctly in their respective glenoid fossae when securing MMF.

POSTOPERATIVE CARE

- Visual acuity and extraocular motions are examined in the postanesthesia care unit upon awakening.
- Wire cutters should always be available postoperatively for emergent MMF release.
- Elevate the head of bed, keep incisions clean and dry for 36 hours, and then resume bathing. Allow surgical glue applied to skin incisions to fall off on its

own.

- Chlorhexidine swish and spit TID for 1 week
- Liquid diet for 48 hours
 - Soft diet at least until adequate healing of maxillary vestibular incision
 - Patients in MMF will remain on high-protein liquid diet until MMF release.
 - The duration of MMF is dependent on fracture complexity and stability of fixation.
- For NOE fractures, soft tissue support stressed with compressive dressings and splinting for careful postoperative molding of epicanthal folds during the healing process.
- Oral antibiotics for 3 to 5 days. Analgesics as needed
- Follow up serial physical examination to assess globe position and symmetry as edema subsides

OUTCOMES

- Fortunately, pediatric facial fractures are rare; however, when faced with the challenge of reconstruction, it is important to consider potential future growth deformities while planning restoration of pretraumatic anatomy.
- Cephalometric follow-up shows clinically significant impairment in growth in horizontal and vertical planes.
 - Mean deficiency in growth for all landmarks was 3.7 mm in the x axis and 2.9 mm in the y axis.⁸
- Employ conservative management when possible because children have great capacity for bony remodeling.
- Contour deformities are usually mild. Aesthetic outcome is also dependent on soft tissue involvement (**FIG 5**).
- Orbital function is generally restored fully with proper repair of floor defects.
- Nonunion and malunion are rare.
- Interference with nasal growth and distortion of the medial canthal areas are observed in pediatric NOE fractures if not managed appropriately.



FIG 5 • Postoperative photographs of the patient in **FIG 3C,D** after repair of hemi–Le Fort II and NOE fractures.

COMPLICATIONS

- Complications associated with specific pediatric facial fracture can be classified as intrinsic, secondary to intervention, or resulting from growth and development.⁹
- Malocclusion, TMJ decreased motion, pain
- Facial asymmetry can be caused by inadequate reduction, or ptosis of the malar fat pad, which can be prevented by periosteal suspension of the soft tissue.
- Diplopia can occur initially in 10% of patients with a ZMC fracture; up to 5% may have permanent diplopia.
 - Diplopia occurs most commonly with injury to the inferior rectus muscle.
 - Follow up with scans, and if no improvement is seen in 4 to 6 months, the patient may need rebalancing of extraocular muscles.
- Enophthalmos is defined as posterior displacement of the globe within the orbit due to changes in the volume of the orbital vault relative to its contents.
 - There is approximately 1 mm of enophthalmos for every cubic centimeter increase in orbital volume. Greater than 3 mm change in globe position compared to contralateral eye appears clinically significant.
 - Approximately 20% of patients with orbital fractures have globe malposition.

It is most commonly associated with incomplete zygomatic reduction.

- Etiology of enophthalmos includes fractured medial wall composed of thin lamina papyracea, fat atrophy, extraocular muscle atrophy, and scar contracture.
- Mild to moderate deformity can be corrected with orbital floor implants.
- Available options to fill appropriate volume include bioresorbable mesh, biocompatible porous polyethylene, and/or titanium implants; bone graft is preferable for the pediatric patient. Convert every 1.5 cc of graft material to get 1 mm of globe position advancement. The corrected eye should look proptotic compared to the contralateral eye on the table.
- Severe enophthalmos requires osteotomies and repositioning of the zygoma.
- Traumatic optic neuropathy can occur in 1% to 2% with ZMC fractures. This condition can present with subtle findings of diminished color perception.
- Consult an ophthalmologist, treat with steroids, and assess for improvement or stabilization of visual deficit *prior* to surgical intervention.
- Bradycardia: The oculocardiac reflex involves classic triad of bradycardia, nausea, and syncope. The reflex is mediated by the ophthalmic division of the trigeminal nerve, which passes through the reticular formation to the vagus visceral motor nuclei. The efferent limb message is carried by the vagus nerve to the heart.
- If symptoms occur in any phase of treatment, suspect periorbital entrapment, which necessitates release.
- Inadequate reduction of the zygomaticomaxillary complex causes loss of midface projection, increased facial width, and enophthalmos, which should be avoided by proper planning and assessment of alignment throughout the operation.
- NOE: Complications of untreated NOE fractures include nasolacrimal duct obstruction, telecanthus, and saddle nose deformity. Repair includes ORIF and cantilever bone graft.
- Nasal and septal deformities may require secondary rhinoplasty after completion of midfacial growth.

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76 Management of Pediatric Mandible Fractures

CHAPTER

Nataliya I. Biskup and Brian S. Pan

DEFINITION

- The pediatric facial skeleton is largely protected from fractures due to larger facial fat pads, more malleable bone, and a larger head-to-face ratio compared to that of adults.¹
- Mandible fractures are one of the most common pediatric facial fractures.²
- Proper management of the pediatric mandible fracture is critical to limit disruptions in growth and dental development that can ultimately impact occlusion and function.

ANATOMY

- The mandible is a unique bone composed of vertical and horizontal elements that form a U-shaped construct.
- The growth pattern of the mandible occurs in a superior and posterior direction, resulting in a concomitant downward and forward displacement of the mandibular body and symphysis.³
- From early childhood through adolescence, the inferior alveolar nerve changes in position as the canal migrates cephalically from the lingual inferior border of the mandible to a more superior position.
- The preadolescent mandible has high osteogenic potential due to its rich blood supply from the inferior alveolar artery.
- Following permanent tooth eruption, the medullary center of the mandible becomes more thickened and calcified.

PATHOGENESIS

- The most common cause for facial injuries in children is motor vehicle

collisions.

- Sports-related injuries are the second most common cause of facial fractures.
- These injuries occur more commonly in older children and in adolescence.
- Childhood falls and assault/nonaccidental trauma are the least common causes.
- Assaults occur most commonly in adolescence.
- Males are twice as likely to sustain facial fractures compared with females.⁴
- Condyle fractures are considered the most common type of mandible fractures followed by the symphysis, the body of the mandible, the angle, and lastly the ramus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Depending upon the age of the child, an accurate history may not be available.
- If patient compliance for an adequate exam is not possible, proceed with imaging and consider an exam under sedation.
- Physical exam findings may include pain on palpation over the fracture site, malocclusion, decreased maximal incisive opening, jaw deviation with opening, loose teeth, and intraoral lacerations or ecchymosis.
- Assess for paresthesia or anesthesia caused by injury of the inferior alveolar and mental nerves.
- Chin abrasions and lacerations, coupled with blood in the external auditory canal, should raise suspicion for a condylar fracture.⁵

IMAGING

- Although a panorex and plain films of the mandible can be obtained, a computed tomographic (CT) scan is the standard for imaging in the setting of facial trauma.
- Cone beam CT (CBCT) scans are another means for accurately diagnosing facial fractures and have the advantage of exposing the child to less radiation.

NONOPERATIVE MANAGEMENT

- Most pediatric mandible fractures are treated conservatively. Minor malocclusions will self-correct by the ability of the pediatric mandible to remodel and with minor orthodontic manipulations at skeletal maturity.
- Children with deciduous and mixed dentition have a capacity for spontaneous occlusal readjustment after injury and treatment, as deciduous teeth are shed and permanent teeth erupt.⁶
- Observation is indicated for:

- Patients with condylar and subcondylar fractures
 - Mild malocclusions may be treated with soft diet and/or maxillomandibular fixation (MMF).
 - Moderate to severe malocclusion may be treated with closed reduction and MMF. Open reduction is rarely indicated, especially in intracapsular fractures. Open reduction risks vascular compromise to the condyle, which is a growth center for the mandible with high remodeling capacity.^{7,8}
- Minimally displaced fractures in the tooth-bearing mandible, namely, parasymphysis, body, angle. These areas are filled with developing tooth follicles, and thus operative intervention should be avoided if possible.
- Start the patient on a mechanical soft diet, rigorous physiotherapy, avoidance of rigorous physical contact, and symptomatic pain control for 4 to 6 weeks. Arrange long-term follow-up to closely monitor mandibular growth.

SURGICAL MANAGEMENT

Position

- Place the patient supine under anesthesia with nasotracheal intubation.
- May consider sedation-only anesthesia, if only closed reduction is to be performed without MMF or with minimal MMF (such as an Ivy loop or lingual splint).

TECHNIQUES

■ Closed Reduction and Maxillomandibular Fixation Options

Reduction

- Reduce fractures manually as appropriate depending on fracture pattern and direction of displacement.
- Verify adequate reduction by assessing occlusion while the patient is in centric relation. The pediatric mandible can tolerate a greater degree of variability in fracture reduction than the adult patient.

IMF Bone Screws

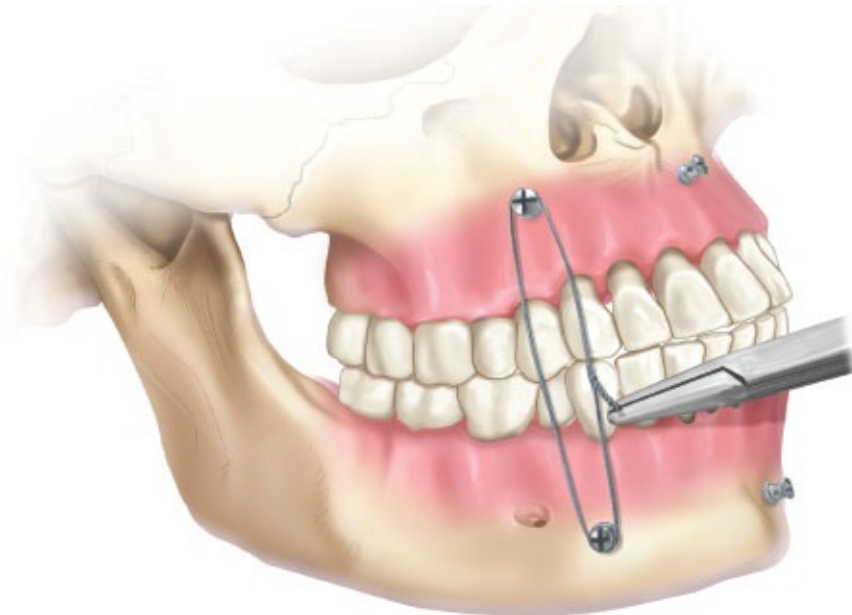
- Obtain preoperative imaging (either CT scan or panorex) to identify

positions of permanent and deciduous dentition.

- Place screws in appropriate locations to avoid injury to dental structures:
 - Verify CT scan (ideally one with 2-mm cuts) to accurately identify location of tooth roots to avoid during screw placement.
- Use self-drilling, self-tapping bone screws, placing at minimum two within the mandible and two within the maxilla (**TECH FIG 1**):
 - Consider placement of a single midline screw in the mandible and one in the maxilla as this can often be adequate for fixation and ideal to avoid tooth roots.
- Secure centric occlusion with 25-gauge wire loops.⁹

Arch Bar Application

- Measure and apply the Erich arch bars of appropriate lengths to the maxilla and mandible to allow for all teeth to be wired.
- Secure the arch bars with prestretched stainless steel 26-gauge wire, passing one end of the wire through the buccal gingiva above the arch bar:
 - The wire is then captured on the lingual side and passed through the lingual gingiva, capturing the wire on the buccal side of the tooth (**TECH FIG 2A**).
 - The ends of the wire are then twisted clockwise until the bar is tightly coapted to the tooth (**TECH FIG 2B**).



TECH FIG 1 • Place at minimum two screws within the mandible and two screws in the maxilla.

- Repeat this process until the majority of the dentition is secured and the arch bars are stable.
- Check the stability of the anchoring teeth with bimanual palpation.
- Cautiously apply wires around deciduous teeth because they are more prone to extraction by wire tightening:
 - Note that primary teeth have short conical roots, wide cervical margins without a well-defined cingulum that makes securing the wire more technically challenging. Ideally, apply arch bars in patients older than 9 to 11 years of age.¹⁰
 - Cautiously, apply wires around erupting secondary teeth; periodontal ligaments are not well attached to the bone, and, therefore, the teeth can be extruded by the wire.
- Use rigid wires or elastics to secure occlusion. Elastics may be better tolerated in children with equivalent outcomes as far as fracture healing and mandibular function (**TECH FIG 2C**).¹¹

Interdental Wiring (Bridle Wire, Ivy Loops)

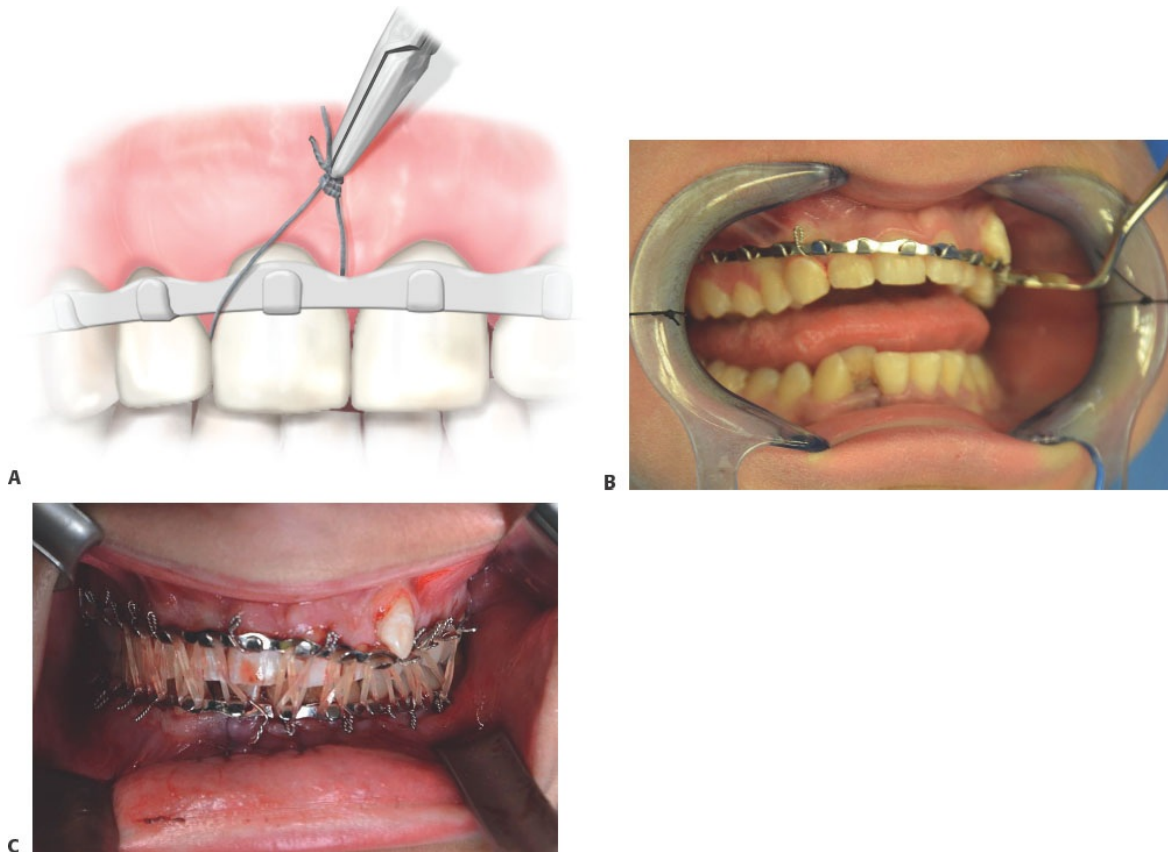
- Consider Ivy loops in younger patients who are not good candidates for arch bars as interdental wiring is less prone to tooth avulsion.
- Apply Ivy loops or bridle wire using prestretched 26-gauge wire (**TECH FIG 3A**).
- Make an eyelet with the wire and insert between the teeth (step 1).
- Bring the wires around the contralateral side of the teeth (step 2).
- Insert dorsal wire through loop (step 3), and twist the wire until secure (step 4) (**TECH FIG 3B**).
- Apply loops to the mandibular and maxillary dentition.
- Use a 25-gauge wire to secure the eyelets from maxillary dentition to the mandibular dentition.

Circum-mandibular and Drop Piriform Wires

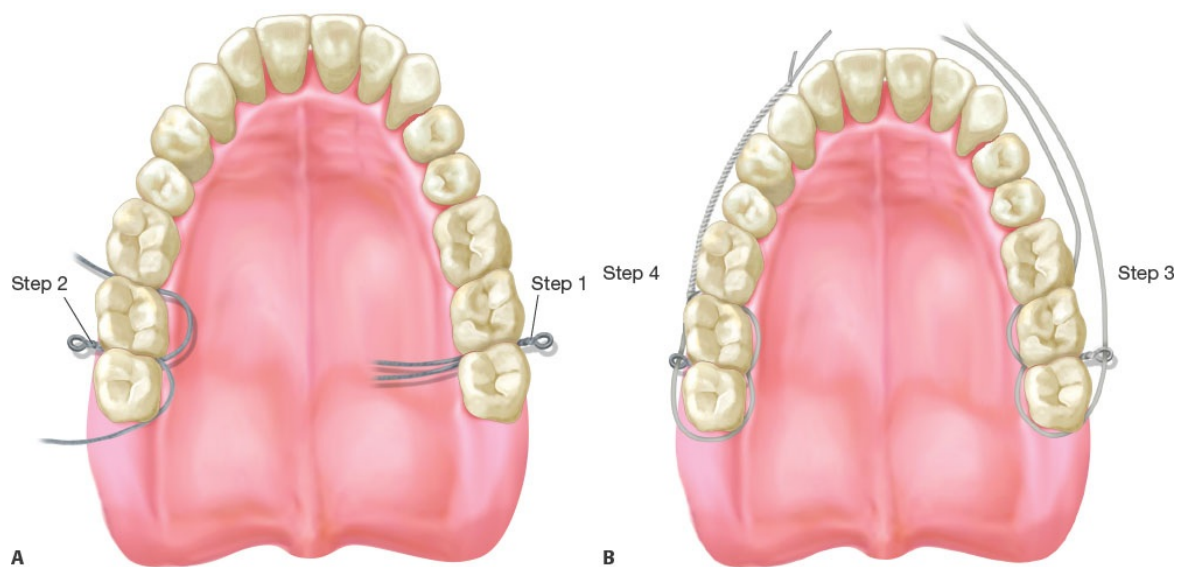
- This form of MMF avoids the risk of damaging tooth buds by penetrating the mandible, avulsing existing teeth with interdental wiring, and

inaccuracies of splint fabrication. Efficacy of this technique may be limited in fractures of the non-tooth-bearing mandible, and these wires can often loosen.

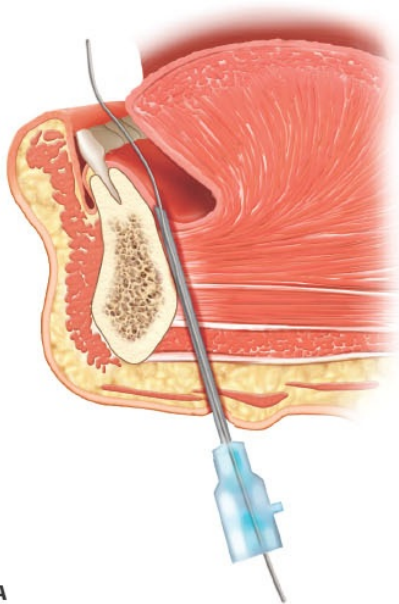
- For a single fracture, place three total wires: two wires mesial (or anterior) to the fracture and one wire distal (or posterior) to the fracture:
 - For double fractures, place four total wires: two wires mesial (anterior) to the fractures and one wire distal (posterior) to each fracture.
- Avoid injuring the mental nerve, which is located at the level of the primary first molar in the deciduous dentition, and the permanent first premolar in permanent dentition:
 - Do not engage the fracture line with the wires.
- To place circum-mandibular wires, pass a 16-gauge intravenous catheter stylet (IVCS) percutaneously from the submandibular region, hugging the lingual cortex, and exit on the lingual side close to the alveolus.
- Pass a 26-gauge wire through the lumen of the IVCS. Clamp wire intraorally to avoid pulling through (**TECH FIG 4A**).



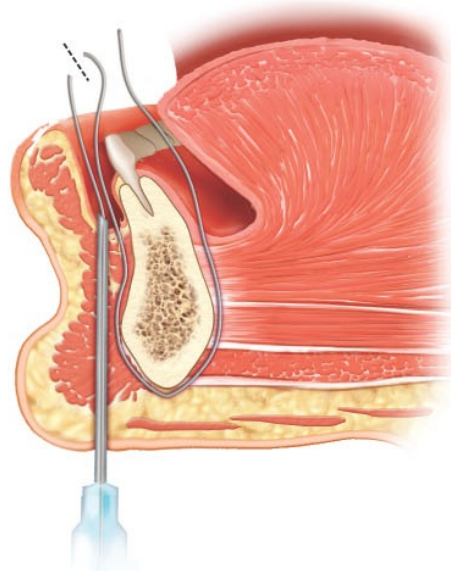
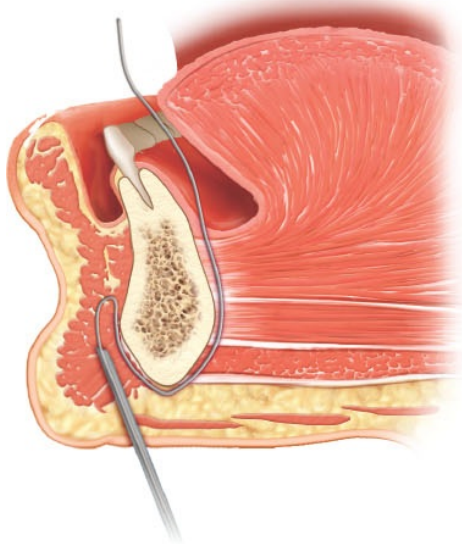
TECH FIG 2 • **A.** Pass one end of the wire through the buccal gingiva above the arch bar. The wire is then captured on the lingual side and passed through the lingual gingiva, capturing the wire on the buccal side of the tooth. **B.** The ends of the wire are then twisted clockwise until the bar is tightly coapted to the tooth. **C.** Place elastics around the arch to securely coapt the dentition.



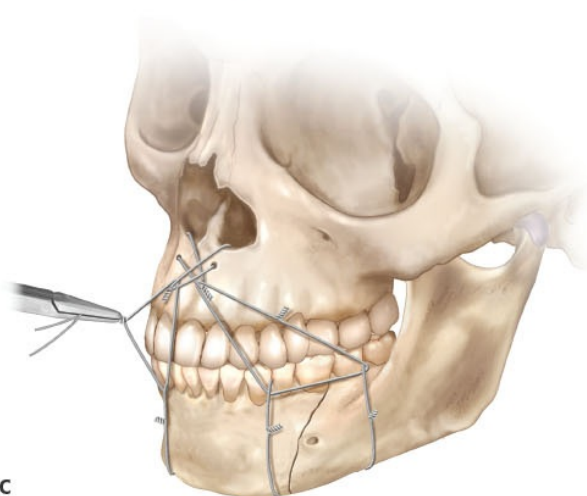
TECH FIG 3 • **A.** Step 1: Make a loop with the wire and insert between the teeth. Step 2: Bring the wires around the contralateral aspects of the teeth. **B.** Step 3: Insert dorsal wire through loop. Step 4: Twist the wires until secure around the dentition.



A



B



C

TECH FIG 4 • A. Pass a 16-gauge intravenous catheter stylet percutaneously from the submandibular region exiting on the lingual side close to the alveolus. Then pass a 26-gauge wire through the lumen of the IVCS. **B.** Guide the IVCS around the inferior border of the mandible onto the buccal surface, passing the needle and wire through the gingivobuccal sulcus, and recapture the wire. **C.** Use a 1-mm drill to make a hole on each side of the piriform rim, and pass a 26-gauge wire through each side. Twist each wire down.

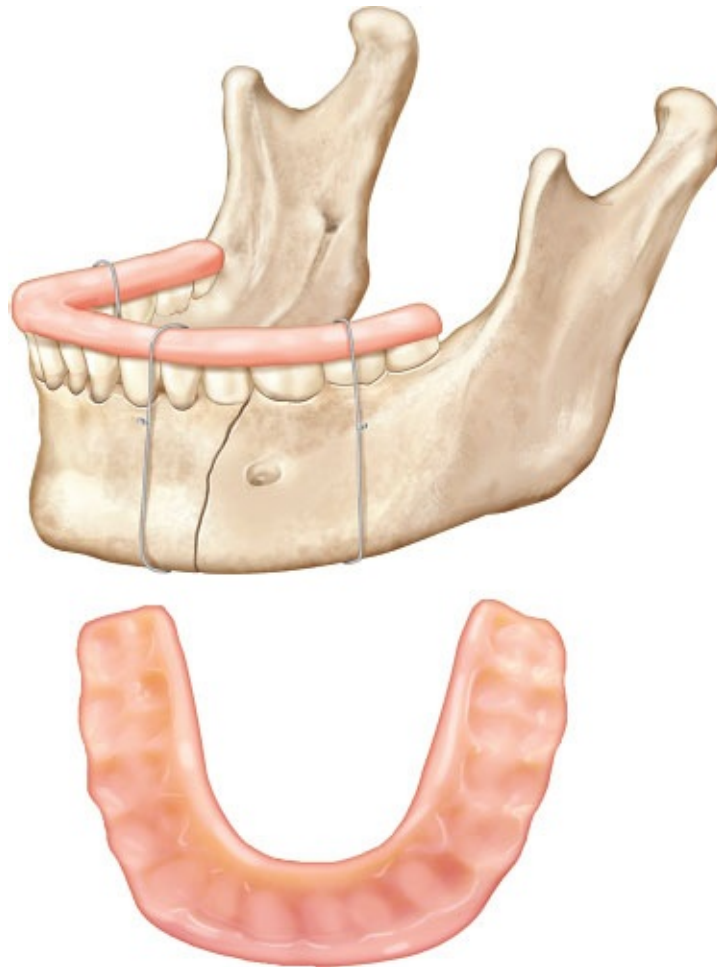
- Guide the IVCS around the inferior border onto the buccal surface of the mandible, hug the buccal cortex, rotate the IVCS such that the bevel is on the leading side and the wire on the nonleading side. Then, pass the needle and wire through the gingivobuccal sulcus, and recapture the wire, twisting it down between an interdental space (**TECH FIG 4B**)¹²:
 - Twist wires down with enough tension to reduce fractures but not so much tension as to damage the growing bone.
 - These wires may be twisted down over an arch bar.
- Alternatively, an awl may be used to place wires.⁸
- To place drop piriform wires, make a high circumvestibular incision around the piriform aperture, and use a Freer elevator to develop a subperiosteal plane around the rim of the piriform:
 - Release attachments of the anterior nasal spine.
 - Elevate floor of the nose and lateral piriform rim in a subperiosteal plane.
- Use a 1-mm drill to make a hole on each side of the piriform rim, and pass a separate 26-gauge wire through each side (**TECH FIG 4C**):
 - Create a loop of wire by twisting the wire down on an instrument outside the mucosal surface to facilitate future lateral wire removal.
- Use an intermediate wire to engage the two circum-mandibular wires and the piriform drop wire in a triangular arrangement (see **TECH FIG 4C**).¹³

Splint Application

- This form of MMF is especially useful in patients less than 3 years of age

who have few stable dental structures.

- Obtain maxillary and mandibular impressions using alginate impression material.
- Prepare the casts.
- Cut mandibular cast into two pieces at the fracture line and reassemble to articulate with the maxillary dentition in the best occlusion. Affix the two pieces with hot glue:
 - Construction of a well-fitting splint via model surgery is technically challenging and may result in occlusal inaccuracy.
- Construct a lingual splint with an acrylic material. Drill holes in the splint at each interdental space to facilitate the insertion of circumdental wires or apply circum-mandibular wires.



TECH FIG 5 • Mold splint to the reduced mandible and dentition, allow to set, and secure to the mandible with

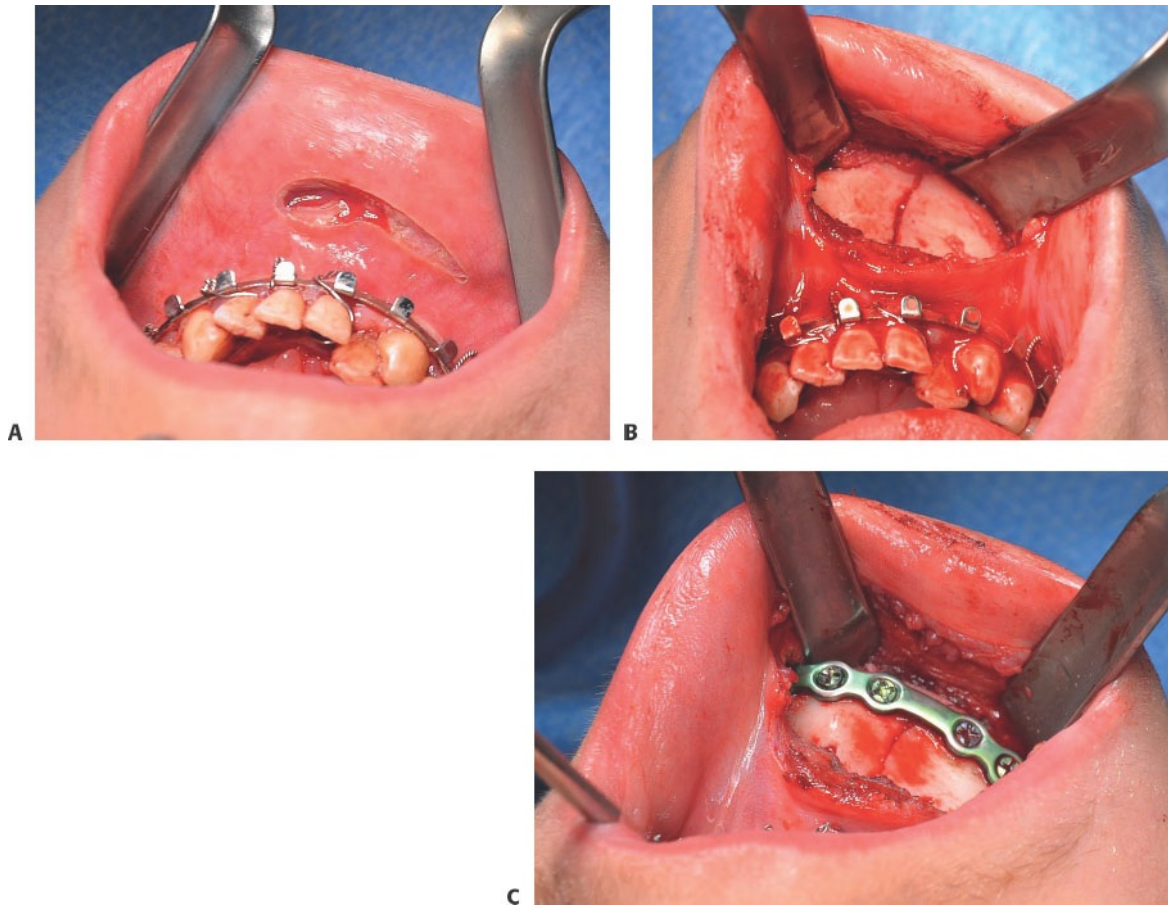
interdental or circum-mandibular wires.

- Reduce fracture, and insert the splint on the lingual aspect of the mandible:
 - Pass 25-gauge wires from the splint holes to the corresponding interdental spaces and then around each erupted tooth.
 - Alternatively, manufacture the splint in one stage in the operating room:
 - Reduce fracture manually and secure reduction with interdental wiring or monocortical bone wires.
 - Apply catalyst-activated acrylic material to mold splint, allow to set, and then secure to the mandible with interdental or circum-mandibular wires¹⁰ (**TECH FIG 5**).
 - Remove the splint at 2 to 3 weeks if the occlusion is stable.¹⁴
-

■ Open Reduction and Internal Fixation

- Apply Erich arch bars.
- For patients without dentition, use circum-mandibular wiring, or drop piriform aperture suspension wires.
- For patients with deciduous dentition (3–6 years old), tooth roots are strong enough to withstand interdental wiring.
- For patients with mixed dentition (6–12 years old), apply MMF carefully (refer to adult mandibular MMF) as deciduous roots may be undergoing resorption by permanent dentition:
 - Consider obtaining a panorex to verify root status of each tooth. If many unstable and resorbing roots are present, use circum-mandibular wiring, acrylic splints, or drop piriform wires.
- For patients with adult dentition, apply MMF as one would for an adult.
- Employ the least invasive surgical approach to access the fracture and allow stable reduction.¹⁵
- Inject fracture sites and proposed incision sites with 0.25% lidocaine with epinephrine 1:400 000.
- Use needle-point cautery to incise:
 - In gingivobuccal sulcus for parasymphysis or body fractures (**TECH FIG 6A**)
 - Along external oblique ridge for angle and ramus fractures

- Use a Freer elevator to expose fractures.
 - Limit exposure to only what is needed to reduce and fixate the fracture.
- Expose inferior border clearly as this is the safest place to plate and apply screws, especially in patients less than 9 years of age (**TECH FIG 6B**).



TECH FIG 6 • **A.** Incise along the gingivobuccal sulcus over the fracture site (parasymphysis fracture). **B.** Expose the fracture and the inferior border of the mandible. **C.** Place plate along the inferior border of the mandible, and adapt the plate to site passively along the bony surface.

- Curette the fracture site to debride the callus. Do so conservatively to avoid tooth root and tooth bud injury.
- Reduce fracture. Avoid bone reduction clamps as these require deep purchase and can migrate through the bone.

- Place the patient into MMF.
- Apply preferred plating system. May consider resorbable plates, as they have been shown safe and effective in pediatric fractures^{16,17}
 - Consider application of MMF concurrently with resorbable fixation.
 - Resorbable systems require a large plate and larger screws to provide similar stability as a titanium plate, thus increasing the risk of root injury during tapping and plate application.
- May use titanium plates; however, these should be removed in 3 to 6 months after fracture healing has occurred, especially in patients less than 10.
 - When applying titanium plates and screws, place 1.0- to 1.3-mm plates in those under 3 years, 1.3 to 1.5 mm in 4 to 9 years, and 2.0 mm in preadolescents and adolescents.
 - Place the plates along the inferior-most portion of the mandibular border.
 - Adapt the plate to sit passively along the bony surface (**TECH FIG 6C**).¹⁰
- Use monocortical screws almost exclusively.
 - Reserve bicortical screws for patients older than 11 years of age.
 - Apply plates along the inferior-most position of the mandibular border, and direct screws posteromedially, not superiorly.
- If fixation of the superior mandibular border is required, do so with interdental wiring and splinting to avoid tooth root injury.
- Test occlusion by releasing the patient from MMF, and gently lift the mandible by grasping the lower lip:
 - If the patient's occlusion is appropriate, replace MMF with wires or elastics.
- Close incision with resorbable suture.

PEARLS AND PITFALLS

Preoperative

- Rule out cervical spine injury given that the force to produce a fracture of the pediatric mandible is significant.
- Conservative management should be strongly considered in nondisplaced and minimally displaced fractures.

Physical findings

- Malocclusion is the most sensitive finding for diagnosis of a mandible fracture.

	■ If compliance during examination is an issue, repeat exam under sedation or anesthesia.
Technique	■ Avoid injuring teeth, tooth roots, and tooth buds. The patient's dentition will determine the technique for MMF. ■ Pediatric fractures have a higher tolerance for variability in reduction due to restitutional remodeling, but gross malocclusion is unacceptable.
Postoperative	■ Follow these patients long term as the child's growth needs to be monitored until after the pubertal growth spurt. ■ Consider involving an orthodontist for long-term care. Occasionally, functional appliances or corrective jaw surgery may be necessary in the setting of asymmetric growth secondary to condyle fractures. ■ Shorten the period of immobilization and MMF to 2 to 3 wks.

POSTOPERATIVE CARE

- If MMF is utilized, the patient is discharged home with wire cutters and/or scissors to release the elastics holding the dentition in occlusion.
- In the setting of open reduction with internal fixation, consider releasing MMF if the child is cooperative and close supervision is possible.
- If MMF is applied, do not leave on for longer than 2 to 3 weeks as pediatric fractures heal quickly:
 - Temporomandibular joint (TMJ) ankylosis may result from prolonged immobilization.
 - Guiding elastics may be used especially in the setting of a condyle fracture.
- Liquid/pureed diet is indicated postoperatively.
 - A soft diet is initiated at 3 weeks, and a regular diet is resumed at 6 weeks following surgery.
- Chlorhexidine mouthwash is recommended after meals accompanied by gentle tooth brushing.

OUTCOMES/COMPLICATIONS

- Available data suggest that appropriately managed fractures have good long-term functional outcomes.
 - Fractures managed with ORIF with or without MMF were more likely to have adverse outcomes related to dental trauma and TMJ clicking.²
- The impact of mandible fractures on growth is another highly debated topic:

- Multiple studies have suggested that condyle fractures, and those limiting TMJ movement, are prone to causing growth abnormalities.¹⁸
- Other potential complications mirror those encountered in adult patients including dental injuries, hardware infections, and need for subsequent surgery.
- Long term follow-up is indicated especially for patients who have suffered fractures prior to adolescence.

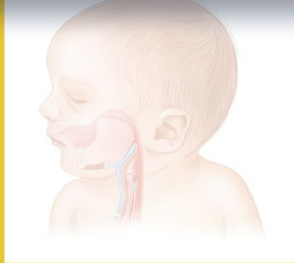
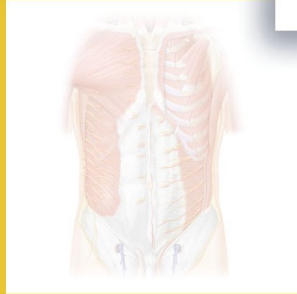
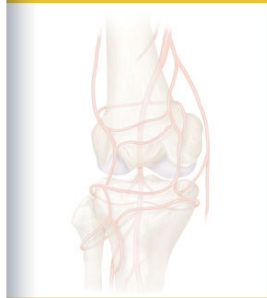
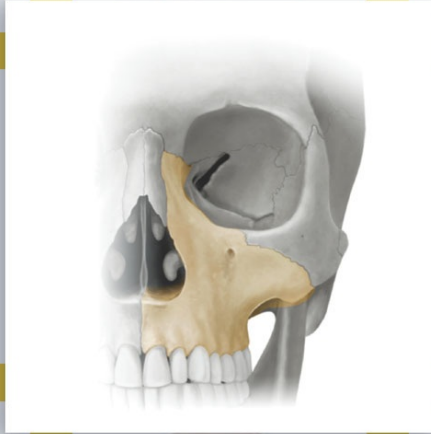
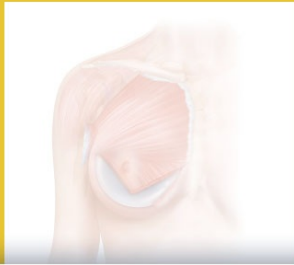
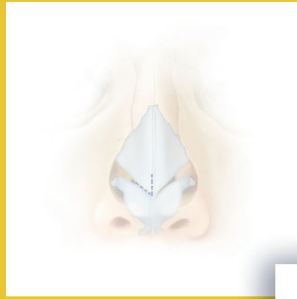
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PART 3

Head and Neck Reconstruction



Section I: Anesthesia

1 Local Anesthesia of the Face

CHAPTER

Cerrene N. Giordano and Anthony M. Rossi

DEFINITION

- Local or regional anesthesia involves the injection or application of a medication to a specific area of the body to minimize procedural-related pain.
- Various types of local anesthesia exist including topical, infiltrative, nerve block, and tumescent.
- The number of office-based procedures utilizing local anesthesia continues to rise, particularly in the dermatologic setting.
- In-office procedures performed under local anesthesia have reduced recovery time, decreased cost, and improved safety relative to those performed under general anesthesia or intravenous sedation.

ANATOMY

- Effective local anesthesia for the face, particularly with peripheral nerve blocks, requires a complete understanding of the underlying nervous anatomy.
- The 11 branches of the trigeminal nerve (cranial nerve V) and 2 branches of the cervical plexus (C2, C3) are primarily responsible for the cutaneous sensory innervation of the face and neck (**FIG 1**).
- The trigeminal nerve is divided into three main components—V1 (ophthalmic nerve), V2 (maxillary nerve), and V3 (mandibular nerve) with further smaller divisions.
- V1 is composed of the supraorbital, supratrochlear, infratrochlear, external nasal, and lacrimal nerve branches and is primarily responsible for the sensory innervation of the upper eyelids, glabella, forehead, dorsal nose, and anterior

portion of the scalp.

- V2 is composed of the zygomaticotemporal, zygomaticofacial, and infraorbital branches and supplies innervation to the central face including the lower eyelids, medial cheeks, temples, lateral nasal sidewall and alar rim of the nose, and the upper cutaneous and mucosal lip.
- V3 is composed of the auriculotemporal, buccal, and mental nerves and innervates the lateral and lower halves of the face including the preauricular region, portions of the anterior ear, jawline, chin, and lower lip.
- The supraorbital, infraorbital, and mental nerves exit their respective foramen all located in the midpupillary line.
- Cervical nerves C2 and C3 form the great auricular and lesser occipital nerves that complete the innervation of the lateral and anterior neck, the ear, and the postauricular scalp.

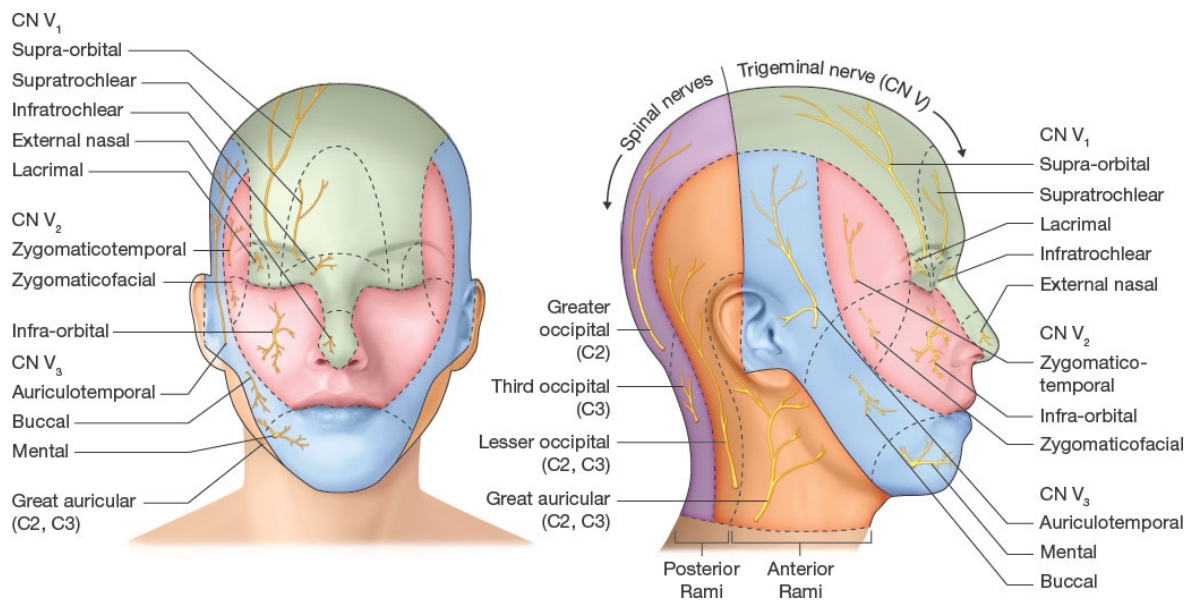


FIG 1 • Trigeminal and cervical plexus nerve distribution.

- The great auricular and lesser occipital nerves emerge from Erb point in the posterior cervical triangle, located approximately at the midpoint of the posterior border of the sternocleidomastoid muscle.
- The greater occipital (C2) and third occipital (C3) nerves supply the posterior scalp and neck.

MECHANISMS OF ACTION

- All local anesthetics share a similar molecular structure composed of a hydrophilic amine and a lipophilic aromatic ring linked together by an intermediate chain that classifies the agent as an ester or amide.
- Both esters and amides cause reversible inhibition of voltage-gated sodium channels within affected nerves, thereby blocking depolarization and inhibiting action potential propagation and ultimately sensation.¹
- Esters, such as tetracaine, procaine, and chlorprocaine, are hydrolyzed by plasma cholinesterases and excreted by the kidneys (Table 1).
- In contrast, amides such as lidocaine, mepivacaine, and bupivacaine are metabolized by microsomal enzymes in the liver.²
- The structural components of the local anesthetic agent determine various parameters for clinical efficacy.
 - The lipid solubility of the aromatic ring influences the diffusion and potency of the product, with more lipid-soluble molecules possessing greater diffusion through the nerve cell membrane resulting in higher potency.
 - Agents that are highly protein-bound have a longer duration of action as they possess a stronger affinity for the sodium-gated ion channels.
 - Speed of onset is determined by the drug dissociation constant (pKa), defined as the pH at which the ionized and nonionized forms of the drug are present in equal amounts.
 - All local anesthetics have a pKa higher than physiologic pH.
 - The closer the pKa is to physiologic pH, the more nonionized form of the medication is present, and the more rapidly the drug penetrates the nerve cell membrane creating its clinical effect.
- Ropivacaine is a newer amide anesthetic that has been shown to have a rapid onset and longer duration of action compared to lidocaine.

NATURAL HISTORY

- The Inca populations were the first to discover the pain-reducing property of the *Erythroxylum coca* plant.²
- In the late 1880s, cocaine was isolated from the plant and used initially in ophthalmologic surgeries.
- Safer alternatives were developed early in the 20th century followed by widespread acceptance within the medical community.
- Lidocaine was the first amide anesthetic to undergo clinical testing in the 1940s, with a faster onset, longer duration, and lower toxicity compared to the

ester formulations available at the time.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Eliciting relevant patient history and performing a physical exam prior to the use of any anesthetic agent are crucial to ensure patient safety and minimize complications.
- Patient history
 - Determine medication allergies and prior exposure to injectable or topical anesthetics.
 - Obtain an up-to-date list of the patient's medications including over-the-counter herbs and agents to avoid potential interactions, particularly with drugs metabolized through the liver.
 - A detailed medical history should be elicited, with particular attention to cardiac, renal, liver, and neurologic diseases.
- Relative contraindications
 - Hypersensitivity to the agent (particularly esters)
 - Application of a topical agent to the skin with impaired barrier function
 - G6PD (glucose-6-phosphate dehydrogenase) enzyme deficiency with the use of EMLA (eutectic mixture of local anesthetics)
 - Significant cardiac or hepatic disease
 - Use of class I antiarrhythmic (tocainide, mexiletine)

Table 1 Anesthetics Used for Local Infiltration

		Duration (min)		Max Recommended Dose (Adults)	
		Without Epinephrine	With Epinephrine	Without Epinephrine	With Epinephrine
Anesthetic	Onset (min)				
Amides					
Articaine	2–4	30–120	60–240	5.0 mg/kg or 350 mg	7.0 mg/kg or 500 mg
Bupivacaine	2–10	120–240	240–480	2.5 mg/kg or 175 mg	3.0 mg/kg or 225 mg
Etidocaine	3–5	200	240–360	4.5 mg/kg or 300 mg	6.5 mg/kg or 400 mg
Lidocaine	<1	30–120	60–400	4.5 mg/kg	7.0 mg/kg

				or 300 mg	or 500 mg
Mepivacaine	3–20	30–120	60–400	6.0 mg/kg or 400 mg	7.0 mg/kg or 550 mg
Prilocaine	5–6	30–120	60–400	7.0 mg/kg or 400 mg	10.0 mg/kg or 600 mg
Esters					
Chloroprocaine	5–6	30–60	N/A	11.0 mg/kg or 800 mg	14.0 mg/kg or 1000 mg
Procaine	5	15–90	30–180	10.0 mg/kg	14.0 mg/kg
Tetracaine	7	120–240	240–480	2.0 mg/kg	2.0 mg/kg

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- Use of EMLA in infants under 1 month of age (increased risk of methemoglobinemia)
- Lidocaine is pregnancy category B; however, *lidocaine is excreted in breast milk*; therefore, caution is advised for use in breast-feeding mothers.
- Ocular exposure with EMLA should be avoided due to the presence of sodium hydroxide and the potential for alkaline injury.
- Caution is advised with concomitant use of EMLA and certain methemoglobinemia-inducing medications such as acetaminophen, anesthetics (prilocaine and benzocaine), anticonvulsants, antimalarials, nitrates, sulfonamides, and aniline dyes.
- Physical examination
 - Ensure there is no skin breakdown or signs of infection or inflammatory lesions in areas where the agent will be applied/injected.
- Selection of agent
 - Based on the anticipated procedure, the anesthetic is selected by taking into account the need for topical vs injectable modality, duration of the agent, and location of the procedure.
 - The level of preprocedure patient anxiety should also be assessed and may determine the agent and application type used.

SURGICAL MANAGEMENT

- Facial anesthesia is necessary for a variety of different cutaneous procedures, including skin biopsies, excisions, Mohs micrographic surgery, surgical

reconstruction, and laser and light-based therapies for facial resurfacing, scar revision, or lesion ablation.

- The decision to use an anesthetic and the selection of the agent is dependent partially on the type of procedure performed and the anticipated degree of discomfort.
- Facial nerve blocks are commonly implemented for ablative laser resurfacing of the entire face; however, there are reports of regional cutaneous nerve blocks for larger pigmented or vascular facial lesions as well.
- Regional nerve blocks hold the advantage of minimizing significant tissue distortion, using less total volume of medication, and less patient discomfort, but they are more challenging to administer.
- Tumescent anesthesia is a form of local anesthesia using large volumes of highly dilute anesthetic delivered subcutaneously, first described by Dr. Jeffrey Klein in the 1980s.
 - It can be used alone or with various levels of sedation based on the intended procedure.
 - While there is a wide range of usages for tumescent anesthesia, face and neck uses generally include liposuction, face and neck lifts, dermabrasion, and full-face laser resurfacing.
 - Lower volumes of fluid are infiltrated into the face (100–150 mL per side) when compared with body infiltration, so the concentration of lidocaine may be higher for facial procedures.³

Preoperative Planning

- Obtain an accurate patient weight to calculate the maximum allotted anesthetic dose especially for procedures requiring larger volumes.
- Lidocaine toxicity is dose dependent, and it is critical to remain below the calculated maximum dose.
- It is also important to take into consideration individual patient characteristics as frail, elderly patients or those with underlying liver malfunction may require lower dosages.
- The maximum allotted dose of plain lidocaine for an adult patient is 4.5 mg/kg for whom the addition of epinephrine allows for up to 7 mg/kg⁴ (see Table 1).
- The WiMP formula may also be used for ease of calculating maximum allotted dosages as long as the patient's weight, maximum dosage, and percentage concentration of the agent are known.⁵

- $V \text{ (mL)} = (\text{weight (kg)} \times 0.1 \times \text{maximum dose (mg/kg)}) / \text{percentage concentration}$

Positioning

- Positioning is key to establishing both patient and provider comfort during the procedure.
- Ideally, the patient should be comfortably seated on the exam table with the table leaning back and the feet propped up to minimize a vasovagal reaction.
- The patient's head should be firmly rested against the back of the table to allow for stabilization and minimize sudden movements when the needle is injected.
- It is best when injecting if the patient's eyes are closed so they do not unintentionally pull away if they visualize the needle.
- For the surgeon, the table needs to be at an appropriate height, and the patient needs to be positioned closer to the surgeon's side of the table to avoid excessive bending or reaching.
- The patient's skin is held taut by either the surgeon's nondominant hand or an assistant.
- The surgeon's nondominant hand may be used to stabilize the dominant hand during the injection. Alternatively, the surgeon may rest a few fingers of his or her dominant hand on other parts of the patient's face to stabilize self.
- If an assistant is present, care must be taken to ensure the assistant is far enough from the anticipated injection target to avoid accidental needlestick injury should a sudden movement occur.
- Additionally, the surgeon should be positioned so the needle is facing away from critical anatomic structures such as the globe of the eye to avoid an accidental puncture with unanticipated patient movement.

Approach

- Topical agents
 - The topical anesthetic agents encompass a wide variety of noninvasive, painless products, which are commonly used prior to minimally invasive cosmetic procedures.
 - Topical lidocaine and EMLA (eutectic mixture of local anesthetics) are the two most commonly used topical agents.
 - Lidocaine is available in many formulations including cream, viscous

solution, jelly, ointment, spray, and patches.

- Due to its unique liposomal delivery system to enhance penetration through the stratum corneum, lidocaine 4% cream (LMX-4, Ferndale Laboratories, Ferndale, MI) has the advantage of ease of application without occlusion, more rapid onset compared to EMLA (Astra Pharmaceuticals, Westborough, MA), and availability without a prescription.
- EMLA is a eutectic mixture of 2.5% lidocaine and 2.5% prilocaine hydrochloride. EMLA is applied to intact skin, under occlusion, for a minimum of 1 hour to facilitate absorption.
- The depth of anesthesia is directly proportional to the duration of time the product is left in place, with maximum clinical anesthesia achieved at 2 to 3 hours and clinical effect remaining around 1 to 2 hours post removal of product.⁶
- EMLA is safe for use in pediatric and adult populations, and the dosing is largely based on weight and surface area. The manufacturer recommends a dose of 2 g of EMLA per 10 cm² for 2 hours. The maximum recommended dose is 60 g applied to 400 cm² of normal skin.
- Caution with either product should be exercised with use over large surface areas as prolonged application, large surface area, occlusion, and high concentrations increase the risk for cardiotoxicity and central nervous system toxicity.
- **Injectable agents**
 - Lidocaine and bupivacaine are the two most commonly used injectable agents. Lidocaine has a rapid onset of action, generally less than 1 minute, and lasts on average from 30 to 120 minutes, longer with the addition of epinephrine.⁴
 - Bupivacaine is a slower-acting agent, with a 2- to 10-minute onset; however, it has one of the longest durations of action, lasting 120 to 240 minutes without epinephrine. Because of the longer duration of action, bupivacaine is commonly used in lengthy surgical procedures, but its risk of cardiac and neurologic toxicity remains a concern.
 - Ropivacaine and levobupivacaine are two newer amide anesthetics that have a similar duration of action to bupivacaine with fewer cardiotoxic and central nervous system effects and less pain on injection when compared to lidocaine with epinephrine.
- Infiltrative anesthesia may be combined with other forms of anesthesia such as topical, nerve block, or tumescent for larger or more complex cutaneous

procedures.

- Smaller needle sizes, such as 30 or 32 gauge, should be used, and needles should be replaced frequently to reduce pain on injection.
- Additions to injectable anesthetics such as epinephrine, hyaluronidase, and bicarbonate that can enhance efficacy and/or improve patient comfort will be discussed in another section.

TECHNIQUES

■ Local Infiltration

- Prep the surrounding skin with an antiseptic agent such as alcohol, Betadine, or chlorhexidine immediately prior to injection.
- Stretch the surrounding skin and stabilize the needle with the nondominant hand.
- Quickly pierce the skin with the tip of the needle at a 90-degree angle (**TECH FIG 1**).
 - Injection through an enlarged pore or follicle may minimize patient-perceived pain.
- Aspirate the needle prior to product infiltration to avoid intravascular injection and minimize risk for toxicity.⁴



TECH FIG 1 • Piercing the skin at a 90-degree angle irritates fewer nerve fibers, thereby reducing injection pain.

- Advance the needle tip deep/subdermally first and deposit about 0.5 mL of anesthetic agent.
- Be sure to inject slowly as rapid infiltration and cutaneous distention contribute to increased pain.
- Pause for about 30 seconds, and move the needle more superficially while injecting more volume.⁷

- The needle may be slightly withdrawn and advanced subcutaneously in a fanlike fashion to continue anesthetizing while minimizing the number of painful injection points.
 - Once that region is complete, the needle may be fully withdrawn from the skin and reinserted within 1 cm of the blanched border to continue injecting along the established area.⁷
 - Anterograde injection is recommended to keep the wheal before the needle tip to minimize further pain of the needle.⁷
 - For larger excisions, it is generally recommended to perform a ring block with infiltrative anesthesia around the outside of the ellipse, and supplemental anesthesia may be added centrally only where needed upon testing of the area.
 - Using a longer needle to inject deep into the fascial plane or having additional syringes on hand intraoperatively may be necessary for supplementation based on the depth of the procedure planned.
 - The lowest possible dose to achieve an anesthetic effect should be used to avoid toxicity.
-

■ Facial Nerve Blocks

- There are a number of facial nerve blocks that can be performed, including supraorbital, supratrochlear, infraorbital, infratrochlear, mental, zygomaticofacial, zygomaticotemporal, and external nasal. The most commonly used are supraorbital, supratrochlear, infraorbital, and mental.
- Many authors cite the use of 4% articaine hydrochloride with epinephrine as the preferred agent for facial nerve blocks, but 1% lidocaine with or without epinephrine or mixtures of 1% lidocaine and 0.25% bupivacaine may also be used.
- Generally, 3-mL syringes with small-gauge needles such as 25 or 30 are used to reduce pain. Occasionally, longer needles such as 30 mm may be used to ensure product deposition at the targeted foramen.

Supraorbital and Supratrochlear Nerves

- The supraorbital foramen is located in the mid-pupillary line and is palpated along the orbital rim.
 - The needle is inserted perpendicular to the skin above the foramen and

advanced until contact is achieved with the supraorbital ridge, with care not to enter the foramen and cause damage to the nerve (**TECH FIG 2**).

- The supratrochlear nerve can be blocked with periosteal injection at the medial eyebrow and nasal root junction, about 1 cm medial to the supraorbital foramen.
- About 0.5 to 3 mL of anesthetic solution is deposited periosteally to each location after negative aspiration.

Infraorbital Nerve (Video)



Video p3-c001

- The percutaneous approach for the infraorbital nerve involves palpation of the infraorbital foramen, located in the mid-pupillary line about 1 cm lateral to the ipsilateral nasal ala.⁸ The patient may feel a slight discomfort with palpation, which assists in identification.



TECH FIG 2 • Supraorbital nerve block.

- The injection is placed 1 cm inferior to the foramen, and the needle is tangentially directed and slowly advanced upward until the approximate location of the foramen is reached.
- A small wheal (approximately 0.2 mL) of anesthesia can be placed subdermally prior to advancing the needle to minimize pain.
- Alternatively, topical anesthetic agents can be used to reduce injection-related pain.
 - After negative aspiration, a 0.5- to 2.5-mL bolus of anesthetic solution is very slowly deposited just outside of the foramen.
 - It may be helpful for the injector to leave a finger of the nondominant hand pressed over the foramen for ease of location/identification.
- Extreme caution is advised to avoid needlestick injury.
 - The infraorbital nerve has a slower onset of anesthesia, so it is recommended that this nerve is anesthetized first.⁸
- The intraoral approach to the infraorbital nerve (**TECH FIG 3**) involves first

locating the foramen by gentle palpation of the overlying skin as described above.

- The area is then marked and/or the injector's finger is kept in place as a guide.
- A small wheal (approximately 0.2 mL) of anesthesia is placed in the mucobuccal fold over the second premolar.
- The needle is then advanced further upward toward the marked foramen, remaining parallel to the long axis of the second premolar until the foramen is reached.
- After negative aspiration, a 0.5- to 2.5-mL bolus of anesthetic is slowly placed just outside of the foramen.



TECH FIG 3 • Intraoral approach to infraorbital nerve block.

Mental Nerve

- The mental nerve may be reached percutaneously as well, with identification

of the foramen about midway between the upper and lower edges of the mandible in a direct line with the second bicuspid.

- A small wheal of anesthesia can be injected subdermally and then the needle tip advanced until bone is reached.
- A 0.5- to 2.5-mL bolus of anesthesia is injected just outside of the foramen after careful negative aspiration to avoid intravascular injection.
- The intraoral approach for a mental nerve block is more commonly used (**TECH FIG 4**).
 - Identify landmarks for the mental foramen, which is caudad to the second premolar about midway between the tooth and the inferior mandibular border.
 - While retracting the lower lip, the needle is inserted at the gingival-buccal border at the base of the first bicuspid and directed parallel to the bicuspid in the direction of the foramen.
 - After negative aspiration, a 0.5- to 2.5-mL bolus is injected just outside of the foramen.



TECH FIG 4 • Intraoral approach to mental nerve block.

■ **Tumescent Anesthesia**

Dosing

- Because of the wide variability in the volumes used as well as lidocaine and epinephrine concentrations, specific recommendations for tumescent anesthesia are challenging.³
- Lidocaine is the most commonly used anesthetic agent; however, bupivacaine or a combination of the two has also been described.
- The typical compositions for tumescent anesthesia per 1000 mL of normal 0.9% saline or lactated Ringer solution are shown in Table 2.³
 - Some sources recommend higher concentrations in a smaller volume (250 mL) specifically for facial procedures: 600 to 1000 mg lidocaine (0.24%–0.4%), 1 mg epinephrine, and 5 mEq bicarbonate in 250 mL solution.⁹
- The maximum allotted dose is 55 mg/kg of lidocaine in tumescent solution, though some sources claim that lower dosages such as 35 mg/kg should be used in patients taking medications that potentially interfere with lidocaine metabolism.⁹
- The physician should remain on high alert for a minimum of 24 hours after the procedure, as tumescent anesthesia has a delayed peak of activity and therefore the potential for delayed systemic adverse events.
- Tumescent infiltrate is ideally warmed to 37°C to 40°C to avoid hypothermia.⁹

Procedure³

- Tumescent fluid is injected with either an 18-gauge-long spinal needle or a blunt infiltration cannula depending on the size of the case. Either a large syringe or pneumatic pressure device may be used.
- Intradermal or subdermal blebs of 1% lidocaine and 1:100 000 epinephrine are created at the incision sites.
- A no. 11 blade is used to create 2- to 3-mm incisions. Fluid is infiltrated at a low rate (50 to 200 mL/min) and is adjusted for patient comfort. Infiltration is stopped when the infiltrate is about 5 cm beyond the planned procedure site

or when the subcutaneous tissue is firm.

- Wait about 7 to 10 minutes prior to initiating the procedure.
- Supplementary lidocaine with epinephrine may need to be injected intra-/subdermally along incision lines for complete cutaneous anesthesia.

Table 2 Common Tumescence Analgesia Fluid Formula

Medication	Dose Range	Commonly Used Dose (per 1000 mL 0.9% Normal Saline or Lactated Ringer Solution)
Lidocaine	10 mL of 1% to 60 mL of 2%	50 mL of 1% (500 mg)
Epinephrine (1:100 000)	0.5–2 mL of 1:100 000	1 mL of 1:100 000 (1 mg)
Sodium bicarbonate (8.4%)	10–12.5 mL	10 mL of 8.4% (840 mg)

From Gutowski KA. Tumescence analgesia in plastic surgery. *Plast Reconstr Surg*. 2014;134:50S-57S.

■ Additives

- Certain medications can be added to the main anesthetic agent in order to optimize efficacy and minimize patient discomfort during the procedure.
- Epinephrine is often added to local anesthetics for its vasoconstrictive property to minimize systemic absorption, reduce potential for toxicity, increase anesthetic duration at the target nerves, and minimize bleeding at the operative site.
 - 1:100 000 is commonly used in clinical practice, with recent evidence suggesting that a concentration of 1:200 000 is as effective for facial procedures.
 - Epinephrine is pregnancy category C and is secreted in breast milk and, therefore, should be avoided in this group.
- Sodium bicarbonate is added to some anesthetic solutions because lidocaine solutions are often acidic, contributing to the pain upon injection. Bicarbonate increases the pH and reduces the pain associated with product infiltration. A buffered solution is generally prepared by adding 5 mL of 8.4% sodium bicarbonate to a 50-mL bottle of 1% lidocaine with 1:100 000

epinephrine, which is an approximate 10:1 dilution.

- The concentration of epinephrine decreases more rapidly in a buffered solution; therefore, most practices recommend mixing only minutes to hours prior to use and avoid storing pre-prepared buffered solution. However, there was no reduced lidocaine effectiveness after storage for 1 week.
- In addition, the FDA mandates that sodium bicarbonate is a single-use vial making stock preparation less feasible.
- Warming the solution to 98.6°F to 130°F, particularly when combined with buffering, has been shown to reduce injection-related discomfort.
- Hyaluronidase promotes diffusion of the anesthetic through digestion of the extracellular matrix. Analgesic efficacy is improved over a larger surface area with a mixture of lidocaine and hyaluronidase when compared to lidocaine alone; however, no increase in onset or duration was observed. This may be particularly useful in delicate areas such as the eyelid where much lower volumes of anesthesia are needed to minimize tissue distortion.
- The mixture is prepared with 0.5 mL (75 IU) of bovine testicular hyaluronidase added to 0.5 mL of aqueous 0.5% lidocaine hydrochloride solution.
- This addition to local anesthesia is safe and does not appear to retard wound healing.
- Although allergy to hyaluronidase is exceptionally rare, a preliminary skin test for hypersensitivity is generally recommended in nonemergent situations. In addition, it is recommended that patients with known hypersensitivity to hymenoptera stings avoid hyaluronidase due to potential cross-reactivity.

■ Behavioral and Communication Techniques

- Often, the only pain a patient perceives during a procedure surrounds the anesthetizing process and is not related to the actual procedure itself.
- In addition to the many techniques described above, many behavior or communication techniques have also been proposed.
- Distraction or “talkesthesia” is a popular modality that involves talking with the patient about his or her occupation, hobbies, family, etc. to focus their mind elsewhere.
- Physical distraction is another method, such as vibration, slight pinching of

the skin, and tapping alternate body areas in order to activate nearby “touch” nerve fibers and reduce spinal cord transmission of signals produced by “pain” fibers.^{7,10}

- Application of cold or topical anesthesia to the area can reduce the pain of the needlestick.
- Always alerting the patient prior to injection is crucial to minimize sudden movements and improve safety.

PEARLS AND PITFALLS

Assessment	■ Obtain a detailed medical history, medical allergies, and a current list of medications prior to the use of any anesthetic agent. ■ A complete understanding of facial anatomy is essential in performing successful peripheral nerve blocks.
Techniques	■ Proper patient positioning is key to minimize chances of a vasovagal reaction. ■ Surgeon comfort and patient stabilization during injection minimize risk of unintended needlestick injuries. ■ Injection at a 90-degree angle and into a follicular opening or pore can minimize needle discomfort. ■ Patient distraction is an essential tool to reduce pain perception.
Additives	■ Epinephrine 1:200 000 has been shown to be as efficacious as 1:100 000 concentration with lower toxicity risk. ■ Epinephrine causes vasoconstriction to prolong anesthesia duration, minimize systemic absorption, and reduce intraoperative bleeding.
Toxicity	■ Calculating the weight-based maximum allotted dosage of the anesthetic agent prior to a large procedure is crucial to avoiding toxicity. ■ The surgeon must be very familiar with signs and symptoms of early toxicity so appropriate intervention may take place. ■ Stabilizing the patient and initiating basic life support are the first actions needed if toxicity is suspected.

POSTOPERATIVE CARE

- Most of the postoperative care is going to be dependent on the type of procedure that was performed and the anesthetic agent that was used (see Table

1).

- However, it is important to inform patients that there may be some bruising and swelling partially due to the infiltration of the anesthesia, particularly in sensitive regions such as the eye or lips.
- Patients may need to sleep upright for a few nights to allow downward drainage with gravity and minimize further pressure/swelling. They can be reassured that it will improve within a few days.
- If epinephrine is used with the anesthetic solution, there is a chance of bleeding once the epinephrine vasoconstrictive effect wears off. Patients should hold firm continuous pressure for 30 minutes at a time, and pressure dressings immediately postoperatively are crucial in preventing this complication.
- If the area around or within the mouth was anesthetized, patients will need to avoid hot liquids for a few hours until the anesthetic dissipates to avoid unintentional thermal burns.

COMPLICATIONS

- Common side effects for topical anesthetic agents²:
 - Pallor
 - Erythema
 - Edema
 - Pruritus
 - Dermatitis
 - Alterations in temperature sensations
- Common local injection side effects:
 - Pain
 - Erythema
 - Edema
 - Vasovagal reaction
 - Bruising
- Temporary nerve paralysis: If epinephrine is added, the patient may experience a “shaky” or “jittery” feeling or palpitations.
- Toxicity
 - Local anesthetic systemic toxicity (LAST) largely occurs with inadvertent overdose, intravascular injection, and abnormal product metabolism and can be largely avoided with a thorough history and safe injection techniques.
 - Signs and symptoms of lidocaine toxicity are dose dependent and occur as

follows:

- Above 3 g/mL: nonspecific dizziness and drowsiness
- Above 5 µg/mL: perioral paresthesias, tinnitus, muscle fasciculation
- Above 9 µg/mL: fatal, seizures, coma, respiratory and cardiac arrest
- To minimize toxicity, the correct weight-based dosage should be calculated prior to the procedure either using the maximum recommended dosages for lidocaine based on additives (see Table 1) or by using the WiMP formula (discussed in the Preoperative Planning section).
- The maximum lidocaine dose in tumescent anesthesia is 55 mg/kg.
- Using the lowest recommended dosage and continuous communication with the patient is imperative as early recognition of the signs and symptoms of lidocaine toxicity is crucial to initiating care.
- Needle aspiration prior to injection minimizes the risk of inadvertent intravascular injection.
- The following may be done should inadvertent toxicity occur:
 - Administration of the anesthetic should stop immediately, and if topical, it should be removed.
 - Initiate basic life support and contact emergency services if indicated.
 - Vital signs should be established, and the patient should be closely monitored with regular assessment of airway, breathing, and circulation for at least the following 12 hours as cardiovascular depression can persist or recur even after treatment.
 - Benzodiazepines may be administered should seizures occur; however, propofol must be avoided.²
 - An intravenous lipid emulsion has been used with success in treating LAST. The mechanism remains largely unknown; however, the emulsion preferentially partitions the lipophilic anesthetic from the cardiac tissue, thereby improving cardiac conduction.
- Allergy
 - Many patients will report an “allergy” to the anesthetic or the epinephrine with symptoms of palpitations, sweating, light-headedness, or syncope.
 - This is not a true allergy but either a vasovagal reaction to the injection or effects from the epinephrine.
 - True allergies are exceedingly rare (less than 1% of all adverse reactions) but more common with the ester class of anesthetic agents due to the production of para-aminobenzoic acid (PABA) during hydrolysis.²

- Cross-reactivity between ester and amide agents is extremely uncommon, but amides may contain methylparaben as a preservative, which can result in PABA production and cause complications for PABA-sensitive individuals. Therefore, preservative-free formulations are recommended in this population.
- If an allergy is suspected, patch testing (type IV reaction) or prick testing (type I reaction) can be performed.
- Allergic contact dermatitis is an increasing concern with topical anesthetic agents.
- For patients with true anesthetic allergies, alternatives such as 1% diphenhydramine or bacteriostatic saline (0.9% benzyl alcohol in normal saline) may be used for injection.⁴

ACKNOWLEDGMENTS

We thank Drs. Kishwer Nehal and Erica Lee for their contributions to this chapter.

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Section II: Facial Lacerations

2 Management of Facial Lacerations

CHAPTER

John G. Fernandez

DEFINITION

- Facial lacerations are a common emergency room encounter for a plastic and reconstructive surgeon.
- Nearly 7 million patients require treatment for traumatic lacerations per year in the United States.¹
- Approximately 1.5 to 2 million patients present to the ER with facial lacerations.
- According to a study by Singer et al., nearly 28% of all patients visiting the ER with lacerations had facial lacerations.²
- Most complex injuries require layered closure to decrease tension and improve overall results, although single-layered closure is sufficient in small linear wounds. In select patients, topical skin adhesives are gaining acceptance.¹
- Complex wounds involving the eyelids, nose, lips, and ears may require layered closure. Facial lacerations are often associated with more severe injuries to vital structures; therefore, one needs to be suspicious of more severe underlying injuries.
- Facial lacerations may involve tissue loss and may require skin undermining to achieve tension-free closure.
- Composite tissue loss may require more complex reconstruction to restore lining, support, and coverage.

ANATOMY

- There are several vital structures on the face that impact wound closure and/or reconstruction. These include the parotid duct, lacrimal system, white roll of the lips, eyelid margin, facial nerve, and transverse facial artery (**FIG 1**).
- The face has an abundant blood supply and rich network of lymphatics in the dermis and subdermal areas.

PATHOGENESIS

- There are many causes of facial lacerations including penetrating trauma, blunt trauma, and blast injury. Occasionally, multiple mechanisms may be present (eg, penetrating trauma in the setting of a motor vehicle accident).
- The etiology of the facial laceration should be elicited in the history and physical examination; concomitant injury to musculoskeletal (eg, cervical spine injury) or soft tissues should be ruled out.
- Suspicion for other injuries should be high in patients with high-speed blunt trauma and those with penetrating injuries where the entry and exit wounds are not readily identified.

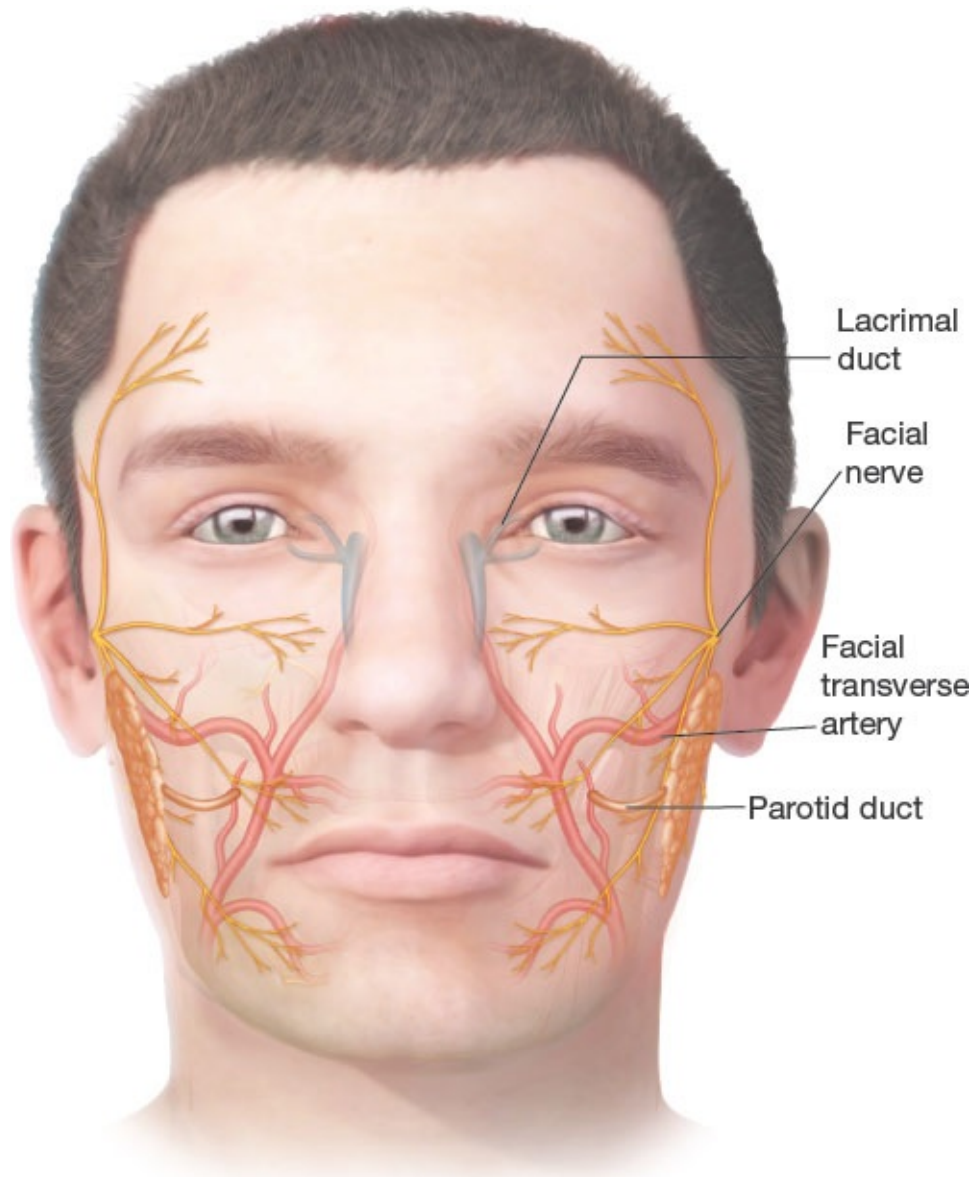


FIG 1 • Vital structures of the face.

- Clean wounds can be repaired expeditiously. However, contaminated wounds or wounds with a significant amount of devitalized tissues may require debridement and delayed closure.

NATURAL HISTORY

- Most routine facial lacerations that are repaired surgically heal rapidly and without difficulty.
- These wounds, perhaps due to the rich vascular supply of the head and neck, rarely become infected or necrotic.

- Superficial wounds that do not warrant closure heal rapidly by secondary intention often with excellent cosmetic results.
- Delayed revision surgery is possible but in many cases not necessary.
- Occasionally, facial lacerations, particularly those in the periorbital area, may result in prolonged swelling. This is usually managed conservatively with scar massage and, less frequently, compression.
- Trapdoor scarring can occur in rounded lacerations leading to contour deformities and a noticeable scar. These scars can usually be successfully revised by undermining and occasionally with Z-plasty or W-plasty.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for patients with facial lacerations includes a detailed assessment of the mechanism of injury, the etiology of the laceration and timing of injury, and the determination if loss of consciousness was associated with the trauma. In addition, physicians should:
 - Document timing of most recent tetanus immunization
 - Elicit history of keloid or hypertrophic scarring
- Patient factors that may lead to wound healing complications such as diabetes, tobacco use, poor nutritional status, steroid therapy, radiation history, and immunosuppression should be documented.
- Concomitant injury to the facial skeleton should be ruled out either by careful history and physical examination or with radiographic imaging as necessary. In addition, injury to other vital structures in the head and neck should be evaluated.
- Significant periorbital lacerations, particularly those that occur as a result of blunt trauma or projectile injury, require funduscopic and visual acuity examination to assess for globe injury. In addition, extraocular muscle movement should be assessed, if entrapment, muscle injury, or nerve damage is suspected.
- The location, size, depth of wound, tissue loss, and level of wound contamination should be assessed.
- Facial nerve function and sensory changes to the skin should be evaluated. Penetrating injury to the cheek may result in laceration of the facial nerve, parotid duct, or both. Cannulation of the parotid duct and irrigation may be needed to identify the area of injury.

IMAGING

- Imaging studies are not routinely necessary for assessment of simple lacerations.
- If there is a suspicion of skeletal injury or injury to underlying vital structures, however, radiologic evaluation is helpful.
- Noncontrast CT scans of the maxillofacial bones with thin slice axial, coronal, and sagittal views are useful for evaluating facial bone fractures.

DIFFERENTIAL DIAGNOSIS

- Partial-thickness wound
- Full-thickness wound
- Complex soft tissue injury including bone involvement
- Underlying vital structure injury

NONOPERATIVE MANAGEMENT

- Healing by secondary intention is an option for superficial lesions or wounds that are contaminated.
 - In some cases, these wounds heal nicely and require no additional intervention.
 - Revision surgery, laser, or dermabrasion, and other techniques may be necessary, however, for depressed or hypertrophic scars.
- Multiple nonsurgical closure techniques such as adhesive tapes, tissue adhesives, etc. have been described.
 - These options are a useful and cost-effective strategy for simple lacerations that are easily closed without tension, particularly in children for whom anesthesia and suture removal may be traumatic.

SURGICAL MANAGEMENT

- The main indications for surgical repair of facial lacerations are
 - Full-thickness wounds (particularly those that may benefit from a multilayer closure)
 - Complex wounds that include trauma to underlying skeletal structures necessitating operative repair
 - Lacerations that injure the facial nerve or parotid duct
 - Wounds that require debridement of devitalized tissues and/or washout of contaminated wounds
- Lacerations to the underlying facial musculature may also require operative exploration and repair to prevent functional and aesthetic complications.

Preoperative Planning

- Patients should be counseled about the length of time necessary for complete wound healing, the potential need for revision surgery, and the risk of hypertrophic or keloid scarring.
 - Additional procedures that may be helpful, such as dermabrasion, steroid injections, or laser therapy, may also be useful information for the patient.
- Detailed history and physical exam should be completed and relevant radiographic studies should be reviewed.
- Tetanus immunization should be provided if outdated (greater than 10 years since the last immunization).
- Oral or intravenous antibiotics may be useful for contaminated wounds or in patients with comorbid conditions that increase the risk of infections. Lacerations of the ear or exposed cartilage, particularly if the perichondrium is injured, may also benefit from preoperative antibiotics.
- Facial nerve function should be documented and confirmed.
 - High-powered loupes or microscope may be needed for repair and should be available to the surgeon.
- Injuries that may involve the lacrimal drainage system should be examined with magnification, and a Jones test can be used to assess integrity of the duct.

Positioning

- Simple lacerations can be repaired in the emergency room setting if proper instruments and lighting are available.
 - More complex lacerations or the need for sedation may require management in the operating room or in a more monitored setting.
- The patient is positioned in a comfortable setting on the operating room table.
 - The head of bed is slightly elevated and turned 180 degrees from anesthesia and centered under the lights.
 - Pressure points are inspected and protected.
 - Sequential compression devices are placed bilaterally if necessary.

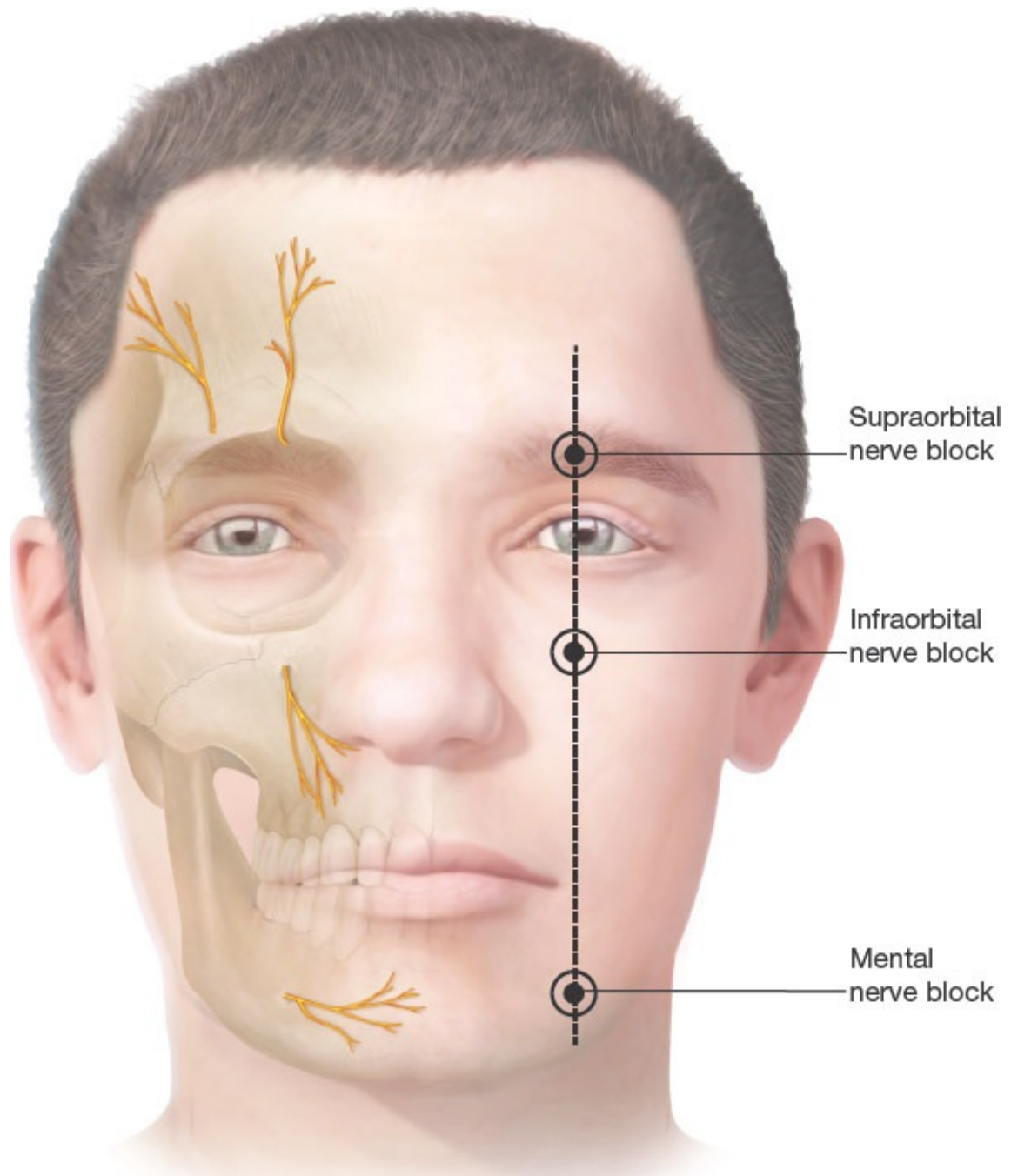
Approach

- The approach is straightforward for laceration repair:
 - Decide if the wound is amenable to layered closure.
 - All wounds are cleaned, irrigated and hemostasis is assured.
 - Debridement is conservative and only planned for devitalized tissue.

TECHNIQUES

■ Administration of Local Anesthetic

- Inject along the wound edges for small wounds.
- Nerve blocks work best for larger or more complex wounds (**TECH FIG 1**; see also chapter on Local Anesthesia of the Face). These blocks are particularly useful for
 - Mental nerve block
 - Infraorbital nerve block
 - Supraorbital or supratrochlear nerve block



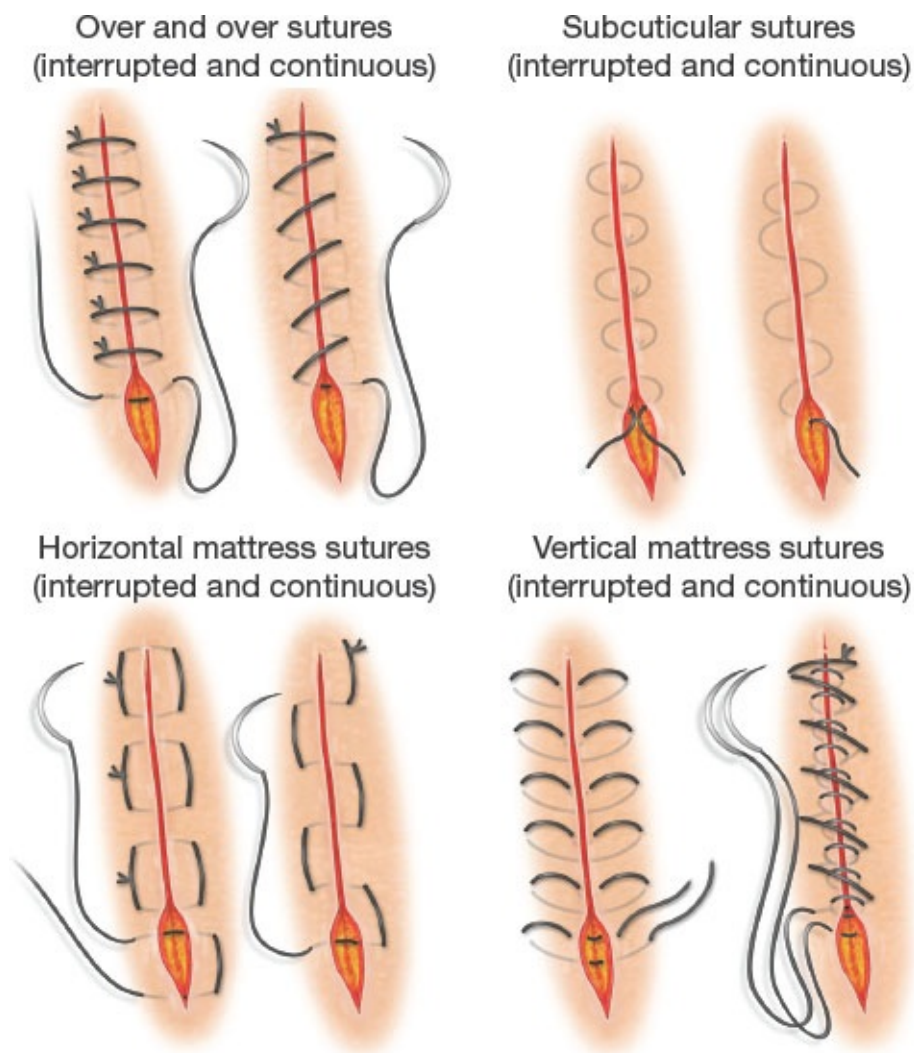
TECH FIG 1 • Regional nerve blocks.

■ Wound Irrigation and Preparation of Wound

- The wound is irrigated with normal saline to remove debris and clean the bed prior to closure.
- The goal is to reduce gross contamination and remove foreign bodies such

as glass, large debris, or dirt.³

- Additional sterilization steps can also be performed with dilute Betadine (10%) after irrigation.
- Devitalized tissues are debrided to establish the true size of the defect.
- Overly aggressive debridement of partially ischemic areas can be staged to allow complete demarcation.
- Given the excellent blood supply of the face, some ischemic areas may overcome the initial insult and survive.



TECH FIG 2 • Suture techniques.

■ Primary Wound Closure, Including Underlying

Structures

- Handle all tissues gently and with care to avoid excess trauma.
 - Minimal pressure of the wound edges leads to decreased crush injury and local edema and faster healing time.
 - Undermining of subcutaneous tissue as needed facilitates tension-free closure.
 - Repair of underlying muscle with absorbable suture such as Vicryl or PDS suture can also take tension off of the wound and improve functional/cosmetic outcomes (**TECH FIG 2**).
 - Care should be taken to avoid distortion if large portions of the muscle have been damaged.
 - For skin approximation, place sutures approximately 1 cm from the skin edge, making an effort to evert skin edges and avoid tension.
 - Space the sutures approximately 3 to 5 mm apart from each other.
 - Use multilayered closure with absorbable sutures for deep layers and dermis and 6-0 fast absorbing or 5-0 or 6-0 monofilament for skin reapproximation.
-

■ Repair of Specific Injuries

Parotid Duct Injuries

- Unrepaired parotid duct injuries may lead to development of a sialocele or salivary fistula.
- Be suspicious if laceration is between the external auditory canal and the commissure of the lip. The duct exits intraorally in the region of the second maxillary bicuspid.
- Diagnose the injury by using a small-gauge catheter or angiocath to cannulate the distal orifice, and inject normal saline for retrograde filling of the duct to identify subsequent injury in the wound.
- If the duct is injured, it should be debrided to clean edges and repaired with microsurgical technique using 8-0 monofilament nylon.

Facial Nerve injuries

- Facial nerve injuries are common with penetrating trauma to the face.
 - Injury of buccal branch frequently occurs with parotid duct injury because this facial nerve branch travels near the parotid duct.
- If a clean, sharp laceration to the facial nerve is identified, prompt primary

repair is indicted. The goal is a tension-free repair.

- If no significant nerve gap exists (less than 1 cm), proceed with minimal nerve mobilization and precise epineurial reapproximation.
 - Either the epineurium or perineurium should be reapproximated with 9-0 or 10-0 monofilament.
- If the nerve has been crushed or otherwise damaged, the nerve ends should be sharply debrided and the nerve gap should be assessed.
- If the injury cannot be repaired without tension, nerve grafts harvested from the ansa cervicalis or the sural nerve can be used to bridge the gap.
- These repairs should be done with high-power loupe or microscope magnification to obtain excellent nerve coaptation.

Lacrimal System or Eyelid Injuries

- If an underlying lacrimal injury is detected, the wound should be copiously irrigated and any foreign bodies should be removed.
 - The eyelid is extremely well vascularized, so do not debride unless completely devitalized.
- Next, a silicone stent is placed to prevent stricture formation, as well as repair of the overlying lid laceration.
- For anterior lamella lacerations, a multilayered, tension-free closure is best.
- The orbicularis is repaired with 7-0 absorbable suture, and the skin is reapproximated with 6-0 fast-absorbing suture in running or interrupted fashion.
- Full-thickness lid margin lacerations are repaired in layers, with a buried deep tarsus suture first, followed by realignment of the lash line.
 - It is important to evert this tissue and avoid knots abutting the cornea.

PEARLS AND PITFALLS

Assessment

- Determine vital structure injuries during preoperative assessment and operative exploration.
- Be suspicious of other injuries depending on location and mechanism of injury.

Wound preparation

- Wound irrigation with normal saline decreases bacterial load and is essential for wound preparation in contaminated wounds.
- Antibiotics are not necessary unless the wound is grossly

	contaminated or a bite wound.
Technique	■ Hold the body of the needle with needle driver, where it is flat. ■ Deep layers, including muscle fascia and dermis, should be closed with taper needle and skin closed with a cutting needle. ■ Make sure suture bites are at the same level of tissue, and evert the skin edges to prevent depression or notching during wound contracture.
Postoperative care	■ Keep wound dry for 48 hours. ■ Keep head of bed elevated to minimize edema. ■ Sutures are usually removed in 5–10 days, and the incisions can be bolstered with paper tape to prevent scar separation.
Scar management	■ Starting 3 weeks after repair of laceration, massage incision line twice daily for 2–5 min. ■ Consider micropore taping or using silicone sheets for hypertrophic scars. ■ Laser, dermabrasion, or local steroid injection may be helpful for some patients.

POSTOPERATIVE CARE

- Apply triple antibiotic ointment for the first 24 hours (ophthalmic if periorbital).
- Oral or parenteral antibiotics are generally not necessary for clean wounds; however, these interventions may be useful in contaminated wounds, open facial fractures, and bite injuries. Multiple studies show prophylactic antibiotics do not protect against infection of nonbite wounds.
- Patients may shower 48 hours after repair when epithelialization over the incision line has occurred.
- The head of the bed can be kept elevated 30 to 40 degrees to decrease edema.
- Ice packs are also helpful in the first 24 hours but should be avoided if there is evidence of ischemia or skin flap formation.
- Sutures are removed on postoperative day 5 to 10.

OUTCOMES

- Proper handling of wound edges along with tension-free closure will lead to a low incidence of keloids and hypertrophic scarring.

COMPLICATIONS

- Poor cosmetic outcome including poor scarring

- Infection
- Wound breakdown
- Changes to the local sensation
- Dehiscence
- Parotid duct stricture
- Lacrimal duct stricture
- Mass movement or nerve-related complications

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Section III: Scalp and Calvarium

3 Scalp Reconstruction With Rotation Flaps

CHAPTER

Finny George and Evan Matros

DEFINITION

- The scalp serves as a protective layer for underlying deep structures including the calvarium and brain.
- It plays an equally important aesthetic role in providing hair coverage.
- Rotation or local flaps can be useful in reconstructing defects up to 5 cm and can be utilized first, before ascending the reconstructive ladder.
- Replacing like tissue with like tissue results in superior results both aesthetically and functionally, particularly with regard to the presence or absence of hair.
- Adequate scalp compliance and pliability is necessary to effectively rotate adjacent scalp tissues.
 - Patients with tight scalp tissues or those with radiation- or surgery-induced fibrosis will have less pliability and rotation potential. The use of scalp flaps in these patients, as well as those with locally aggressive pathology, exposed hardware, and potential exposure of underlying tissues, may be limited.

ANATOMY

- The layers of the scalp are the skin, subcutaneous network (contains blood vessels, lymphatics, and nerves), galea aponeurotica, areolar plane, and pericranium.¹
 - The skin of the scalp is the thickest of all the skin on the body.

- Vertical septa connecting the galea to the skin minimize shearing.
- The galea is a fibromuscular central tendinous confluence of the occipitalis and frontalis muscles. It is contiguous with the superficial temporal fascia and the SMAS.
- The loose areolar plane is the layer in which separation of the scalp from the cranium occurs during trauma. This property can be used during reconstructive surgery to obtain soft tissue advancement.
- The parietal scalp has the greatest mobility and can be helpful in local tissue recruitment.
- Vascular supply
 - The principal blood supply is the supraorbital, supratrochlear, superficial temporal, occipital, and posterior auricular vessels.
 - The vascular supply is derived from both the internal and external carotid systems and forms a rich collateral network. For example, an entirely avulsed scalp can be replanted after repair of only one major blood vessel.
- Sensory
 - The trigeminal nerve contributions are as follows:
 - Supraorbital and supratrochlear nerves supply the forehead, anterior hairline, and frontoparietal regions.
 - Zygomaticotemporal and auriculotemporal nerves supply the temporal region.
 - The occipital and greater occipital nerves supply the occipital region. These originate from the cervical spinal nerve and plexus.

PATHOGENESIS

- Defects of the scalp often result from trauma, malignancy, or congenital disease.
- Radiation damage creates two potential reconstructive dilemmas. Radiation can cause chronic wounds. It also limits soft tissue compliance for defect closure.
- Underlying calvarial reconstruction with a cranioplasty introduces a foreign body and hardware, which can be a chronic wound source.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pertinent history must include information on:
 - Circumstances surrounding injury
 - If the pathology is secondary to tumor excision, then margin status, potential

for local or systemic dissemination, should be documented. Ideally, reconstruction should be delayed until negative margins are obtained; however, this is not always possible when vital structures or hardware is exposed.

- Prior treatment or operations that were done, including failed treatments
 - Underlying presence of hardware or implants
- History of radiation or chemotherapy, immunosuppression, or connective tissue disorders.
- History of smoking, alcohol abuse, weight loss, diabetes, or bleeding disorders should be documented.
- Physical examination should gather enough knowledge to prepare an accurate preoperative plan.
 - Look for prior incisions, evidence of poor wound healing, and radiation changes (eg, woody, discolored skin with telangiectasia).
 - Examine the skin laxity.
 - Available remaining blood supply to the scalp especially in the setting of prior surgery
 - Areas of numbness should be documented.
 - Doppler examination may be helpful to document course and integrity of arterial supply.
- Chronic wounds should be biopsied to rule out recurrent, residual, or new malignancy.

IMAGING

- Diagnostic studies are typically not needed for reconstructive surgery planning; however, these may be necessary for oncological analysis.

NONOPERATIVE MANAGEMENT

- In poor surgical candidates, nonoperative or conservative management may be possible so long as there is no direct communication with the brain.
- This option is best reserved for patients in whom the calvarium is intact and has not been previously injured by radiation or surgery.

SURGICAL MANAGEMENT

Preoperative Planning

- Prior operative reports should be reviewed to ensure vascularity to the proposed rotation flap.

- Risks specific to this operation should be discussed with the patient:
 - Partial or complete flap loss
 - Alopecia
 - Dog ears
 - Asymmetry
 - Abnormal hair growth pattern
 - Need for further or revisionary surgery
- Preoperative antibiotics are administered.
- Temporary markings should be placed with good lighting and exposure by taking into consideration skin laxity, previous incisions, and hair growth patterns.
- A Doppler probe may be used to identify vessels supplying the proposed flap.
- The flap should be planned so that the secondary defect can be closed either primarily or with the use of a skin graft.
- Local anesthetic can be used to minimize bleeding; however, real-time assessment of flap vascularity may not be possible in the presence of vasoconstrictors such as epinephrine.

Positioning

- Depending on the location of the defect, the patient may need to be supine, prone, or in decubitus position to properly expose the defect and proposed donor scalp.
- Generally, the entire scalp needs to be prepped into the surgical field.
- The leg should be prepped as well in case a skin graft is needed.
- It is generally not essential to shave the scalp prior to surgery, but this may be helpful in patients with multiple previous incisions.

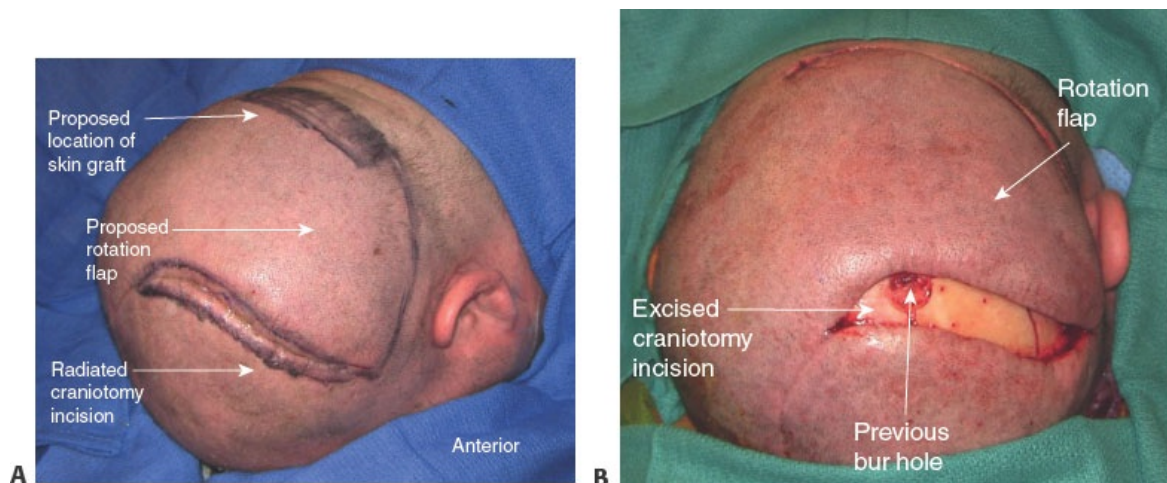
TECHNIQUES

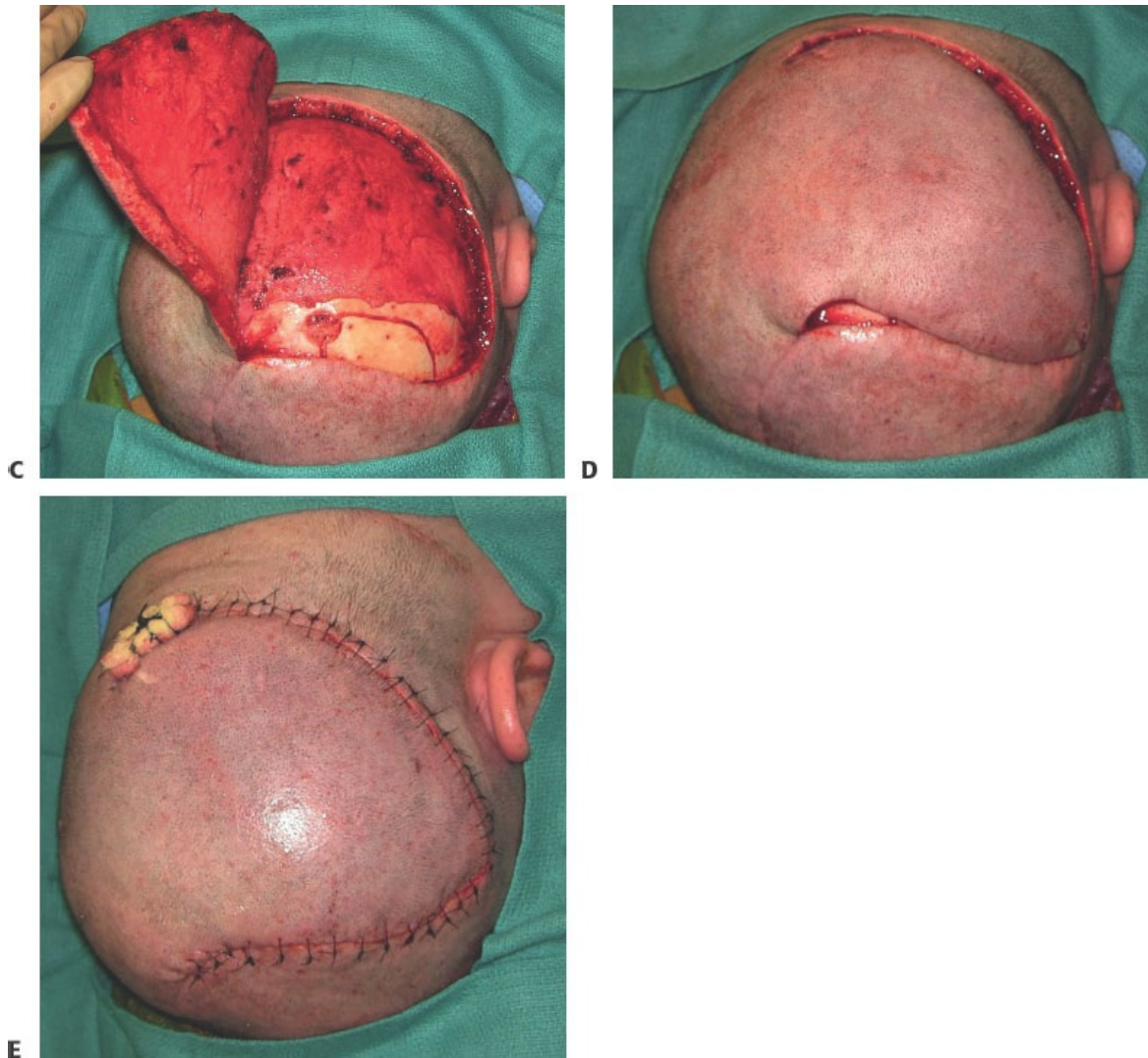
■ Rotation Advancement Flap

- Using a marking pen, the proposed rotation flap should be drawn utilizing a long, curvilinear incision that incorporates at least one named vessel mentioned earlier (**TECH FIG 1A**).
- The length of the rotation flap should be much larger than the diameter of

the defect (approximately five times as big) so that tension is minimized along the flap closure (**TECH FIG 1B**).

- Incision should be made parallel to hair follicles so they are not disrupted.
- The dependent parts of the incision (if any) should be made first so that bleeding does not obstruct visualization of subsequent steps.
- The incision is carried through the galea into the loose areolar plane.
- The flap is extensively undermined within the loose areolar plane. This is the principal plane of dissection. The pericranium needs to be carefully preserved especially if a skin graft is needed (**TECH FIG 1C**).
- The flap is advanced and rotated to close the defect and reapproximated in layers.
 - Any tension should be placed at the base of the flap, not the tip (**TECH FIG 1D**).
- A limited amount of galeal scoring may help tissues advance further; however, this can disrupt vascularity and should be done with care.
- Skin graft placement at the flap donor site should be considered if there is too much tension (**TECH FIG 1E**).
- Drain placement in the subgaleal plane should be considered.
- The resultant dog ear at the pivot point of the flap can be left alone or excised as a Burow triangle.





TECH FIG 1 • A. This patient experienced breakdown of a prior craniotomy incision (left temporoparietal region) after he received radiation treatment. **B.** The dehisced, chronic wound is debrided and excised. The flap dimensions are generous compared to the relatively small defect because of the noncompliant radiated nature of the tissues. **C.** The scalp flap is elevated superficial to the pericranium. The pericranium is necessary to support the skin graft at the flap donor site. **D.** The scalp flap is rotated and advanced into the defect. **E.** The flap is inset, and the defect is completely covered. The donor site was

unable to be closed primarily, necessitating a skin graft, shown here covered with a Xeroform bolster.

PEARLS AND PITFALLS

Planning

- At least one main blood vessel must be included in the flap.
- Use large flaps with wide bases.²

Technique

- The scalp is not as compliant as other soft tissues on the body; as a result, large flaps are generally necessary for even modest defects.
- The need to skin graft the flap donor area must be considered preoperatively and discussed with the patient as it introduces an area of alopecia.
- Leaving the pericranium intact is essential for skin graft survival.
- Although scoring the galea is often done to increase advancement, it should be done with caution because vessels are immediately superficial to the galea.

Avoid

- V-Y local flaps should not be designed on the scalp. Their blood supply comes from beneath so would be disrupted with wide subgaleal undermining.
- Avoid placing the suture line over a critical area.²

POSTOPERATIVE CARE

- Care must be taken to avoid compression of the blood supply to the chosen flap.
- Drains are removed when drainage is less approximately 30 mL/d.
- Bolsters for skin grafts are removed 4 to 10 days after surgery.
- Sutures are removed after 7 to 10 days. In patients with tight skin or history of radiation, sutures may be left in place for longer periods of time (4–6 weeks).

OUTCOMES

- In a large series of 139 patients, Janis et al. retrospectively reviewed scalp reconstruction for oncologic defects ranging from 0.7 to 35 cm in width and found that 18.8% of patients who underwent local flaps developed complications.³

- Newman et al. demonstrated fewer complications with uncomplicated defects measuring less than 150 cm² were closed using local flaps in combination with skin grafts.⁴

COMPLICATIONS

- The most common complications with rotation flaps are bleeding, hematoma, seroma, infection, alopecia, flap necrosis/flap loss, and chronic wound development.

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4 Scalp Reconstruction With Free Flaps

CHAPTER

Finny George and Evan Matros

DEFINITION

- Free tissue transfer using microsurgical techniques is considered the highest rung on the reconstructive ladder and is generally reserved for complex and/or large wounds.
- Free flaps should also be considered in situations in which tissue with robust blood supply is needed to optimize healing such as in patients with prior radiotherapy treatment or underlying cranioplasty.
- Unlike adjacent tissue transfer in the form of a scalp flap, any free flap will introduce non-hair-bearing tissue into the region.

ANATOMY¹

- The principal blood supply to the scalp is through the supraorbital, supratrochlear, superficial temporal, occipital, and posterior auricular vessels.
- The most commonly used recipient vessels for free tissue transfer to the scalp are the superficial temporal vessels.
- Alternatively, the occipital vessels are large in size and have been described.
- If regional vessels are unavailable, a vein graft may be necessary to reach the neck vessels.

PATHOGENESIS

- Defects of the scalp often result from trauma, malignancy, or congenital disease. Occasionally, chronic wounds develop after radiation therapy.
- Full-thickness defects exposing the brain are especially problematic because of the risk of cerebrospinal fluid leak and infection.
- Calvarial reconstruction with devascularized bone flaps or foreign material

also increases the risk of infection and wound healing complications.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pertinent history must include information on
 - Circumstances surrounding injury
 - Prior treatment or operations, including failed treatments and presence of hardware or implants
 - History of radiation or chemotherapy, immunosuppression, or connective tissue disorders
 - History of smoking, alcohol abuse, weight loss, diabetes, or bleeding disorders
- Physical examination should gather enough knowledge to prepare an accurate preoperative plan.
 - Look for prior incisions or evidence of radiation damage to determine patency of recipient vessels (**FIG 1**).
 - Previous coronal incisions may extend into the preauricular area, causing damage to the superficial temporal artery and vein.

IMAGING

- Diagnostic studies are typically not needed.
- In the setting of prior surgery, however, one can evaluate potential recipient vessels with Doppler studies or angiography.

SURGICAL MANAGEMENT

Preoperative Planning

- Prior operative reports should be reviewed.



FIG 1 • This patient had been treated with excision, Medpor cranioplasty, and adjuvant radiation for squamous cell cancer on the scalp. **A.** Hardware exposure necessitated definitive flap reconstruction. **B.** Previous rotation flaps and skin grafts can be seen.

Table 1 Free Flap Graft Sources

Pros	Cons
Anterolateral thigh	
• Thin and pliable in patients with suitable body habitus • Supine position for harvest • Primary donor-site closure possible for smaller defects • Potential for two-team surgery • Chimeric flaps can provide both skin and muscle coverage if necessary. • Vascularized fascia can be harvested with the flap and inset below the native skin flap, providing a “second layer” closure. This is helpful in patients with radiation-damaged scalp skin that may result in delayed healing with a simple skin-to-skin closure.	• Large thigh donor-site defects may require skin grafting. • Unpredictable pedicle length
Latissimus dorsi	
• Broad muscle with large surface area. The flap can be placed beneath the remaining scalp skin in patients with a history of irradiation. This “two-layer” repair decreases the risk of wound complications that may arise from dehiscence of the flap to the native scalp skin that may occur when skin-to-skin closure is obtained with skin flaps. This flap is considered by many as the optimal choice for large scalp defects because of its surface area.³	• Lateral repositioning • Lengthy scar with high incidence of donor-site seroma formation • May require scalp skin grafting, thus limiting potential for hair

• Long, large-caliber pedicle • Can be harvested with serratus anterior muscle for even greater surface area • Can be harvested as a myocutaneous flap to provide durable coverage in the posterior scalp for total scalp reconstruction	reconstruction
Rectus abdominis myocutaneous flaps (vertical or transverse rectus flaps)	
• Large skin paddle • Long, large-caliber pedicle • Potential for two-team surgery	• Donor-site hernia • Can be too thick relative to the scalp, making inseting difficult • Limited potential for “two-layer” closure • Ischemic complications in large flaps that extend across the midline

- Risks specific to this operation should be discussed with the patient:
 - Partial or complete flap loss
 - Alopecia
 - Need for further or revisionary surgery in addition to donor-site morbidity
- The patient must be aware that he or she will require a potentially lengthy operation and hospital stay.
- Patients must be informed that flap compromise requires urgent re-exploration, possibly the use of anticoagulants, transfusions, and the need for vein grafting from different portions of the body.
- Long procedures in the decubitus or prone position are at risk for development of pressure sores even despite proper positioning and padding.
- Preoperative antibiotics are administered.
- Temporary markings should be placed with ideal lighting and exposure to delineate areas of laxity, hair growth patterns, and prior surgical incisions.

- A Doppler probe can be used to identify arterial supply of the remaining scalp flap and recipient vessels.
- In addition, during the planning phase, consider the following:
 - The estimated pedicle length necessary to reach the defect.
 - Backup plans for recipient vessels should be anticipated in case of size discrepancy or other potential issues. This may include the use of vein grafts.
- In choosing a free flap, considerations should include thickness of tissues to be replaced, surface area for coverage, desire for full-thickness skin-to-skin closure (as opposed to a skin graft, which may take an extended period to epithelialize).² A variety of flaps are available (Table 1).

Positioning

- One of the goals should be to limit the number of times the patient needs to be repositioned and redraped once asleep. This should therefore be coordinated with oncologic teams if a combined procedure is planned.
- Anterolateral thigh (ALT) flap
 - The patient is placed in a supine position, and the whole lower extremity—from 5 cm above the hip—is included in the operating field.
 - A skin graft donor site should also be prepped and is generally harvested from the same thigh.
- Latissimus dorsi flap
 - The patient is positioned in the lateral decubitus position with padding placed between the shoulder and the neck on the contralateral side to prevent impingement of the brachial plexus by the clavicle.
 - An axillary roll is also used between the inner arm and the lateral thorax.
 - The ipsilateral arm is included in the operating field to allow for free movement.
- Rectus flap
 - The patient is placed in the supine position so that the area from midchest to midthigh is exposed.
 - The skin island of this flap is oriented vertically or transversely along the axis of the rectus abdominis muscle.
- A horseshoe underneath the scalp or cranial pins may facilitate scalp exposure for easy inseting.

TECHNIQUES

■ Superficial Temporal Artery Preparation

- The location of the artery is confirmed by Doppler, and the incision is marked 5 mm medial to the tragus to a point 2 cm above the helical rim.⁴
- The incision is marked 3 to 5 mm medial to the artery to avoid cutting directly on the vessel with skin incision.
- In most cases, the vein is located lateral to the artery and dives deep into the parotid gland dividing into the deep and superficial branches.⁴
- If the vessels are small, then dissection can be continued proximally, and the superficial portion of the parotid gland is divided for exposure. Consider the operating microscope for this dissection to reliably visualize the facial nerve. At this level, the vein is usually 3 to 4 mm in diameter, and the artery is 1.5 to 3.0 mm.⁴
- Avoid injury to the auriculotemporal nerve, which runs parallel to the vessels in the preauricular area.

■ Specific Donor-Site Dissections

Anterolateral Thigh Flap

- The dominant perforator is predictably found within a 3-cm radius at the midpoint of a line between the anterosuperior iliac spine and the superolateral border of the patella.⁵
- However, it should be recognized that the perforator anatomy is variable and in a small minority of cases even absent.
- Using a marking pen, the proposed flap skin island is drawn.
 - The medial aspect of the flap is planned over the rectus femoris muscle such that the lateral intermuscular septum where the perforator emanates is included in the flap center.
 - The medial incision is made first, full thickness, to the level of the fascial plane.
 - Dissection continues in the subfascial plane to identify the dominant skin perforator(s).

- The rectus femoris and vastus lateralis muscles are separated from each other once the intermuscular septum is incised. The rectus femoris muscle is retracted medially until the descending branch of the lateral circumflex femoral vessel comes into view.
- The perforator can be dissected anterograde or retrograde until it joins the lateral circumflex femoral pedicle. If septocutaneous perforators are not found, myocutaneous perforators that come through the vastus muscle will be present, as is the case in many patients.
- The descending branch of the lateral circumflex femoral vessel is traced proximally to its origin with the profunda femoris system. Femoral nerve branches should be preserved if possible.
- The lateral aspect of the skin island is then incised to complete the dissection with care taken to avoid injury to the perforator.

Latissimus Dorsi Myocutaneous Flap

- A skin island can be harvested with the flap to use as a flap monitor postoperatively or to cover the posterior scalp area to decrease the effects of compression. This skin island can be removed later if necessary.
- The proposed skin island can be oriented obliquely or horizontally as necessary. The incision is carried down to the muscle and skin flaps are elevated to expose the anatomic margins of the latissimus muscle.
- The muscle is elevated from the chest wall by finding the loose areolar plane on its undersurface and dissecting in a posterior-to-anterior direction. This is done by dividing the origin at the vertebral column and separating it from the paraspinous muscle fascia and lumbosacral fascia.
- The anterior edge of the latissimus muscle toward the axilla is reflected by identifying the vascular pedicle on its deep surface. The thoracodorsal pedicle gives off a serratus branch, which can be divided if the serratus muscle is not needed for reconstruction.⁶⁻⁸
- The muscular attachments to the humerus are divided.
- If maximum pedicle length is needed, the thoracodorsal pedicle can be traced high into the axilla to the subscapular system with division of the circumflex scapular branches. This may require an additional incision length to improve exposure.

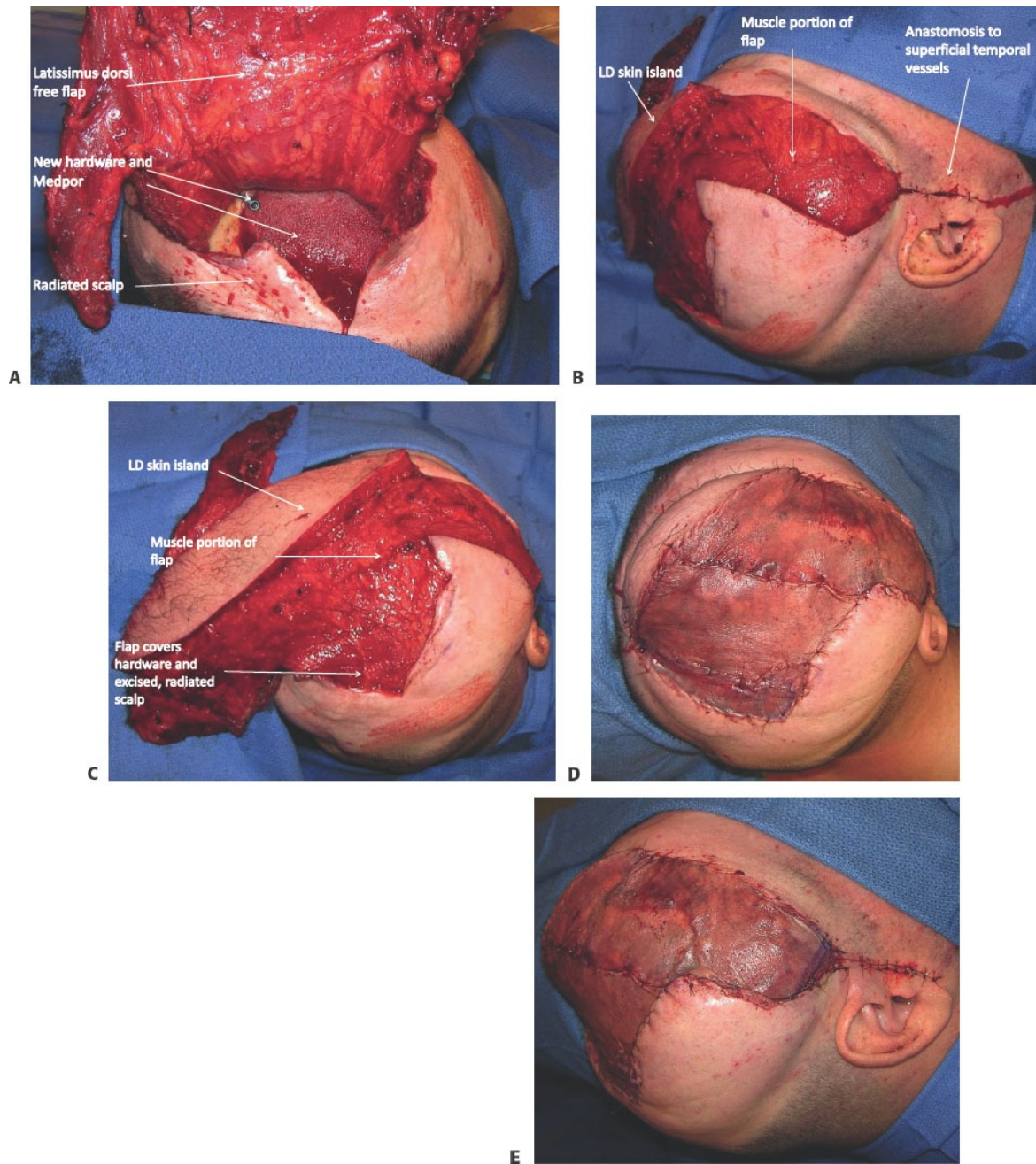
Vertical or Transverse Rectus Abdominis Myocutaneous Flap

- The incision is marked either vertically or transversely on the rectus muscle.

- The incision is made and carried down to the level of the abdominal fascia. The medial and lateral rows of perforating vessels are identified.
 - The flap can be harvested with muscle or as a perforator flap as dictated by reconstructive needs and donor-site anatomy.
 - Care must be taken at the level of the inscriptions because the pedicle can be superficial in these locations.
 - As the undersurface of the muscle is slowly elevated, care is taken to identify the pedicle and prevent shearing forces.
-

■ Microsurgery for Scalp Flaps

- Routine microsurgical repair is performed on any of the flaps listed.
- Vessel size discrepancy can be accommodated using a variety of approaches, including the use of couplers for the vein, interrupted suture technique, and running sutures.
- The vein can be repaired with an anastomotic coupling device or hand sewn based on the surgeon's preference.
- Flap inseting requires soft tissue or muscle placement well beyond the borders of any hardware or cranioplasty to keep incisions away from these areas (**TECH FIG 1**).
- Double-layer closure with placement of the flap muscle or vascularized fascia below the native skin is helpful to prevent exposure of the calvarium or hardware, particularly in patients who have been previously irradiated.



TECH FIG 1 • A. Insetting a latissimus dorsi (LD) flap. **B.** The flap is inset and anastomosed to the right superficial temporal artery and vein. The muscle of the flap is inset well beyond the skin edges. **C.** The LD flap covers the hardware and mesh. The skin paddle is useful in these defects for both skin coverage and flap monitoring. **D.** The muscle portion of the flap is

covered with skin graft. **E.** The final inset and closure.

PEARLS AND PITFALLS

Technique

- ALT flap: Preserve the vascular branch arising from the descending branch of the lateral femoral circumflex artery to the rectus femoris muscle when possible to prevent potential ischemic complications in this muscle.
- LD flap: A skin flap can be used to facilitate postoperative monitoring or avoid pressure on the skin graft in the posterior portions of the flap.
- Rectus flap: Flaps that extend beyond the midline may have ischemic issues leading to partial flap loss and delayed wound healing. Vertically oriented flaps have better blood supply but can be too narrow or too thick in some patients.
- Insetting the flap muscle or skin island on the temple or cheek will effectively lengthen the flap reach if the pedicle is unpredictably short. This may create cosmetic issues requiring correction in a secondary procedure.
- Using a “two-layer” closure with muscle or vascularized fascia below the native scalp skin can decrease severity of wound separation, particularly in patients who have been previously treated with radiation.
- The STA vessels are useful because of their proximity to most scalp defects; however, they are thin walled and require careful dissection. Dissection can be continued into the superficial lobe of the parotid to increase recipient vessel size.

POSTOPERATIVE CARE

- Patient position must be optimized to prevent flap compromise from compression on the vascular pedicle and allow for proper postoperative monitoring.
- Flap monitoring should follow a protocol and be standardized. Given that most thrombotic events occur in the first 24 to 48 hours, more frequent clinical assessments are required during this time period.
- Postoperative anticoagulation should be discussed with ablative teams as risk

of intracranial bleeding may be a relative contraindication. Although there is no consensus on the need for or type of anticoagulation that should be used, we routinely use postoperative antiplatelet therapy for 5 days if not otherwise contraindicated.

- Once it is safe to do so, patients should be encouraged to ambulate.
- Drains are usually removed when the output is less than 30 cc/d.
- Sutures are removed when adequate healing has occurred depending on the quality of the recipient tissues.

OUTCOMES

- There is a 98% success rate using free tissue transfer for complex scalp defects.^{9,10}
- STA/V is available and suitable for microvascular tissue transfer in oncologic scalp reconstruction in most patients. Halvorson et al. found no statistical difference in outcome between using superficial temporal vessels and neck vessels.⁴
- Debulking of the skin paddle can improve the appearance of the protuberant grafts (**FIG 2**).



FIG 2 • **A,B.** Postoperatively, the skin paddle is protuberant and bulky. **C,D.** Debulking of the skin paddle greatly improves appearance and contour.

COMPLICATIONS

- Complication rates were similar between ALT and LD flaps in a 15-year study by Fischer et al.⁹
- Some of the complications from free flap reconstruction include
 - Vascular thrombosis
 - Donor-site morbidity

- Wound complications and infection, related to defect size, age, and smoking⁹
- Flap loss
- Partial flap loss
- Exposed underlying hardware

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5 Scalp Reconstruction With Tissue Expansion

CHAPTER

Finny George and Evan Matros

DEFINITION

- Tissue expansion is the process by which an external force is applied to recruit the viscoelastic properties of the scalp to increase the size of the available healthy tissue.^{1,2}
- Restoration of the scalp to its prealopecia state is the primary goal of tissue expansion of the scalp. It is a crucial tool in the restoration of hair-bearing scalp.³
- By expanding normal, healthy, hair-bearing scalp tissue, defects up to 50% of the total surface area of the scalp can be resurfaced.
- There are three commonly used tissue expander shapes: round, crescent, and rectangular. The tissue expander shape used is not critical.
- For large defects, multiple tissue expanders can be used simultaneously.
- The base diameter of the expander should be approximately 2 to 2.5 times the size of the defect.

ANATOMY

- The layers of the scalp are the skin, subcutaneous network (contains blood vessels, lymphatics, and nerves), galea aponeurotica, areolar plane, and pericranium.⁴
- The galea is a fibromuscular central tendinous confluence of the occipitalis and frontalis muscles.
- The loose areolar plane, deep to the galea, is the layer in which natural plane of separation of the scalp from the cranium occurs.
- The parietal scalp has the greatest mobility and so can be helpful in local tissue recruitment. This quality can be used in tissue expansion.

- During the process of expansion, predictable changes occur histologically^{1,2,5}:
 - The epidermis thickens, dermis thins, muscle thins, quantity of myofibroblasts increases, 30% to 50% of fat is permanently lost, high density of blood vessels grow, and a collagen/fibroblast capsule forms around the expander.
 - This increased angiogenesis that occurs in expanded flaps allows for improved survival and reliability.
- Expanders are placed in the subgaleal plane, superficial to the pericranium.

PATHOGENESIS

- Alopecia of the scalp often results from trauma, burns, radiation, malignancy, or congenital disease (**FIG 1**).
- Irradiated scalp may not expand well or may be associated with higher complication rates.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pertinent history must be gathered from the patient and will include information on:
 - Circumstances surrounding development of scalp alopecia
 - Prior treatment or operations that were done, including failed treatments
 - Prior use of hardware or implants
 - History of radiation or chemotherapy
 - History of smoking, alcohol abuse, weight loss, diabetes, or bleeding disorders
- Physical examination should gather enough knowledge to prepare an accurate preoperative plan.
 - Look for prior incisions.
 - Examine the skin quality and laxity.
 - Note unusual hair growth patterns including cowlicks.

SURGICAL MANAGEMENT

Preoperative Planning

- Prior operative dictations should be reviewed to ensure that vascularity to the proposed area of expansion has not been disrupted or the area has not been irradiated.
- The patient must be aware that he or she will have an abnormal appearance

during the expansion process and that they will have multiple office visits to undergo the expansion.



FIG 1 • This patient had scalp closure with a skin graft following excision of an adnexal tumor. After a disease-free interval, she requested skin graft removal.

- They must be informed that at least two operations will be needed for this type of procedure.
 - Tissue expander placement
 - Tissue expander removal, scalp flap elevation, and closure with removal of alopecia areas
- Risks specific to this operation should be discussed with the patient. They include alopecia along areas of new incisions, exposed tissue expander or inflation port, dog ears, partial or complete scalp flap loss, asymmetry, abnormal hair growth pattern, and the need for further surgery.
- Preoperative antibiotics are administered.
- Temporary markings should be placed on the patient in the preoperative area where there is ideal lighting and exposure, areas of laxity can be assessed, and hair growth patterns can be noted.

Positioning

- Depending on the location of the defect, the patient may need to be supine or prone to properly expose not only the defect but also the proposed donor scalp.
- Generally, the entire scalp needs to be prepped into the surgical field.
- It is not essential to shave the scalp prior to surgery.

Approach

- The tissue expander can be placed immediately adjacent to an area of alopecia or through a remote incision. There are pros and cons to each approach that must be carefully considered.
- A marginal incision can be made approximately 1 cm beyond the area of alopecia or skin graft.
 - A reliable closure needs to be ensured so there is no dehiscence once expansions are initiated.
 - This incision will become the leading edge of the subsequent scalp flap.
- Remote incisions to place the expander away from the area of alopecia will have a more reliable closure; however, the placement of new incisions needs to be along the same line as the future scalp flap. This can be difficult to anticipate.

TECHNIQUES

■ Insertion of Tissue Expander

- Using a marking pen, the proposed incision should be drawn a minimum of 1 cm from the edge of the defect or prior skin graft (**TECH FIG 1A**).
 - This will allow for reliable suture purchase in healthy tissues away from prior skin grafts.
 - Incisions should be made parallel to the defect margin.
- The proposed incision is infiltrated with 1% lidocaine with epinephrine.
- Incision should be made parallel to hair so that follicles are not disrupted.
- The incision is carried through, full-thickness, to the subgaleal plane.
- Adequate undermining is done so as to accommodate the size of the expander with additional laxity to close the incision without tension.
 - An additional 2-cm remote incision is required to place the port of the

expander.

- The expander is irrigated with bacitracin solution and evacuated of all air.
 - The expander is tested with 60 mL of injectable saline to satisfactorily demonstrate competence without leaks. This fluid is then evacuated.
- The expander is placed in the pocket, and the tubing is positioned away from any potential inadvertent puncture (**TECH FIG 1B**).
- The port is secured with two 5-0 Prolene sutures so that it does not flip in the postoperative period, making location and port access difficult.
- A drain is placed in the same pocket as the expander and is brought out through a separate stab incision.
- The scalp incisions are closed in layers (**TECH FIG 1C**).
- Capillary refill is checked throughout the flap making sure that there is no unfavorable tension on the skin or the incision.

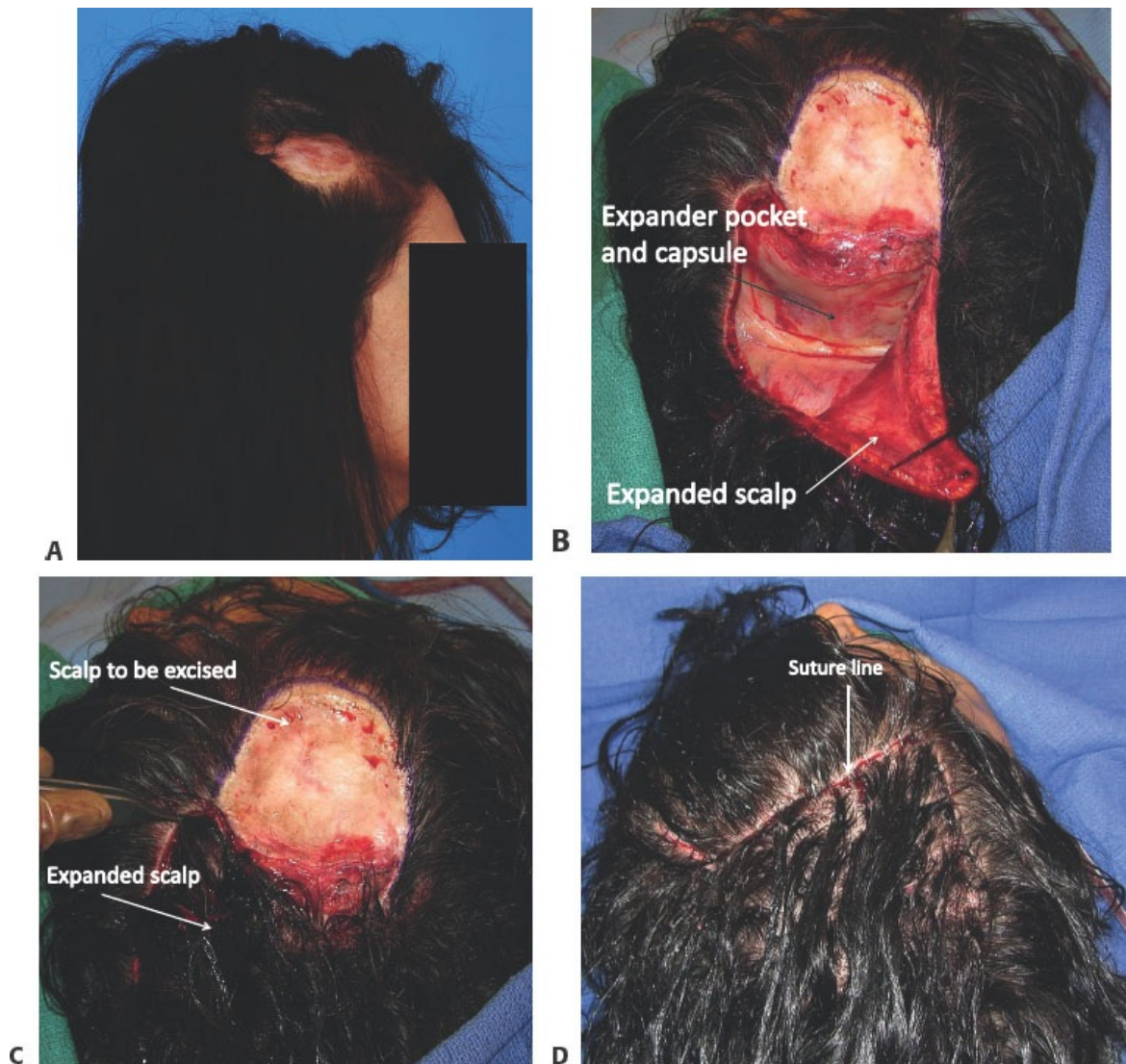


TECH FIG 1 • **A.** The uninvolved scalp posterior to the alopecia (bottom of photo) is proposed for expansion and recruitment. The incision should be placed in healthy scalp to facilitate reliable healing of the suture line. **B.** The tissue expander (crescent shaped) and the remote port for filling access. **C.** Placement of the suture line posterior to the injured tissue and skin graft is crucial for healing.

■ Advancement of Flap

- The tissues should ideally be overexpanded at least 20% larger than the size of the defect for tension-free closure after tissue recoil (**TECH FIG 2A**).

- After the expansion process, the patient is brought back to the operating room for removal of the expander and rotation/advancement of the flap.
- As previously mentioned, the incision used to insert the expander was placed 1 cm posterior to the prior skin graft or original defect. During this operation, this intervening bridge of skin is excised, as its blood supply is presumed to be compromised.
- The capsular pocket is entered and the expander is removed (**TECH FIG 2B**).
- The old incision that was made to place the port is also opened and the port is removed.
- A proposed rotation advancement flap is drawn with a marking pen and blood supply to the flap confirmed prior to committing to the incision.
- The incision is made and the scalp elevated in the areolar plane.
 - A Burow triangle may need to be excised in order to equalize the two sides of scalp along the incision.
- Once the scalp is incised, the advancement is checked to ensure that the defect will be adequately covered prior to excision of any skin graft (**TECH FIG 2C**).
 - The periosteum under the skin graft is left intact.
- A drain is placed in the former capsular pocket and brought out through a separate stab incision.
- Hemostasis is achieved, and the incision is closed in a layered fashion (**TECH FIG 2D**).



TECH FIG 2 • A. The scalp has been expanded. **B.** The expander is removed through the previous incision. The expanded scalp is elevated and the capsule is scored if necessary to allow for advancement. **C.** The expanded scalp is draped over the defect to be excised. The skin graft is not excised until it is ensured that the scalp flap is sufficient in dimension. **D.** The defect is excised, and the expanded scalp is advanced over the defect and closed, healthy tissue to healthy tissue. A drain is left in place.

PEARLS AND PITFALLS

Planning	■ At least one main blood vessel must be included in the flap. ■ Prior incisions should be noted.
Technique	■ The tissue expander shape is not as important as its size. It must be significantly larger than the defect to ensure a flap large enough to excise all areas of alopecia. ■ It is more straightforward to place the expander adjacent to areas of alopecia. This approach does not burn any bridges.
Avoid	■ Avoid additional incisions for placement of the expander that could compromise subsequent scalp flap design. ■ Rapid expansion can lead to higher extrusion rates.

POSTOPERATIVE CARE

- Inflation of the expander is started after the incisions have healed and continued until enough soft tissue has been recruited.
 - Expansions are initiated 2 weeks after placement.
 - Inflation is done weekly.
 - The end of the expansion process can be difficult to determine clinically.
 - The amount of tissue available for rotation/advancement is approximately equal to half the circumference of the inflated expander.
- Drains must be left in place until less than 30 mL/d drainage.
- Once the scalp has been sufficiently expanded, approximately 1 month is waited before the second surgery.
- The entire process of expander placement, expansion, and scalp flap takes approximately 3 months.

OUTCOMES

- The reported incidence of complications in scalp reconstruction with tissue expansion is 6% to 25%.⁶
- Governa et al. reported their study of 157 patients with 262 expanders. Complete scalp coverage was obtained in only 62% of the patients.⁷
- Postoperative result is shown in **FIG 2**.

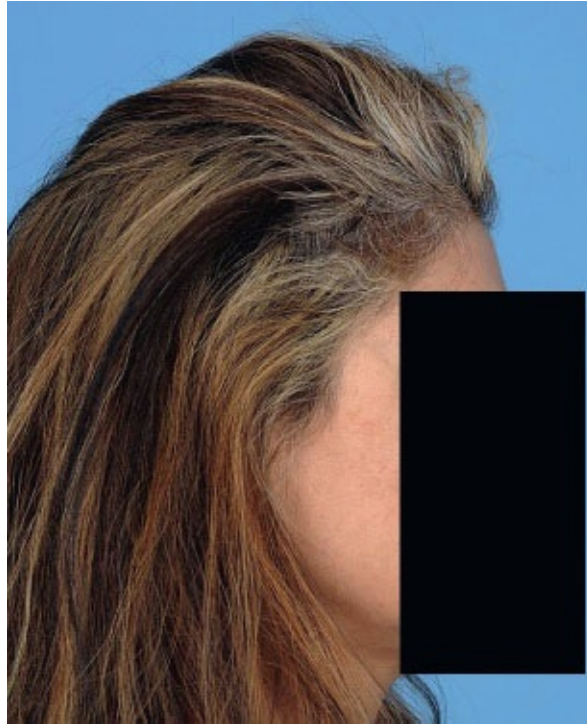


FIG 2 • Six months postoperatively, the patient has normal hair coverage on the scalp.

COMPLICATIONS

- The most common complications with tissue expansion are
 - Pain
 - Scar widening
 - Expander or port exposure
 - Infection
 - Hematoma
- Children under the age of 3 should not have scalp expansion because of unfavorable effects on open cranial sutures.
- Higher complications are associated with expansion in children under age 7 and in patients who have been radiated or burned.
- Rarely, it may be possible to continue expansion if the port or expander itself becomes exposed as long as there are no signs of infection.
- Manders et al. detailed their experience with 41 expanders in 35 burn patients with alopecia. In this review, 25% of patients had major complications requiring alterations in the treatment plan, while 17% had minor problems.⁸

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6 Calvarial Reconstruction With Split Rib Grafts

CHAPTER

David A. Staffenberg and Gerald J. Cho

DEFINITION

- The rib cage is made up of paired ribs, sternum, and thoracic vertebrae acting to protect and stabilize the chest cavity.
- Because the rib cage is comprised of 24 ribs and resection of as many as 2 ribs is well tolerated (ie, does not cause chest wall instability), the rib cage is an abundant source of bone graft material.

ANATOMY

- The rib cage or the thoracic cage consists of bone and cartilage.
 - Normally, there are 12 ribs on each side. Each rib articulates with the thoracic vertebral column posteriorly, and the first 10 ribs articulate with the sternum via the costal cartilage.
 - The caudal two ribs are “floating ribs” and lack corresponding costal cartilages (**FIG 1**).
- Rib grafts are technically easier and safer to obtain than split calvarial grafts in children below the age of 8 because the diploe of the calvarium at this age is poorly developed. Moreover, unlike the iliac crest donor site, rib graft harvest is less painful and does not affect growth potential of the pelvis.
- The rib is circumferentially surrounded by cortical bone and has a cancellous core. The rib can be split into two mirror images to increase the surface area.

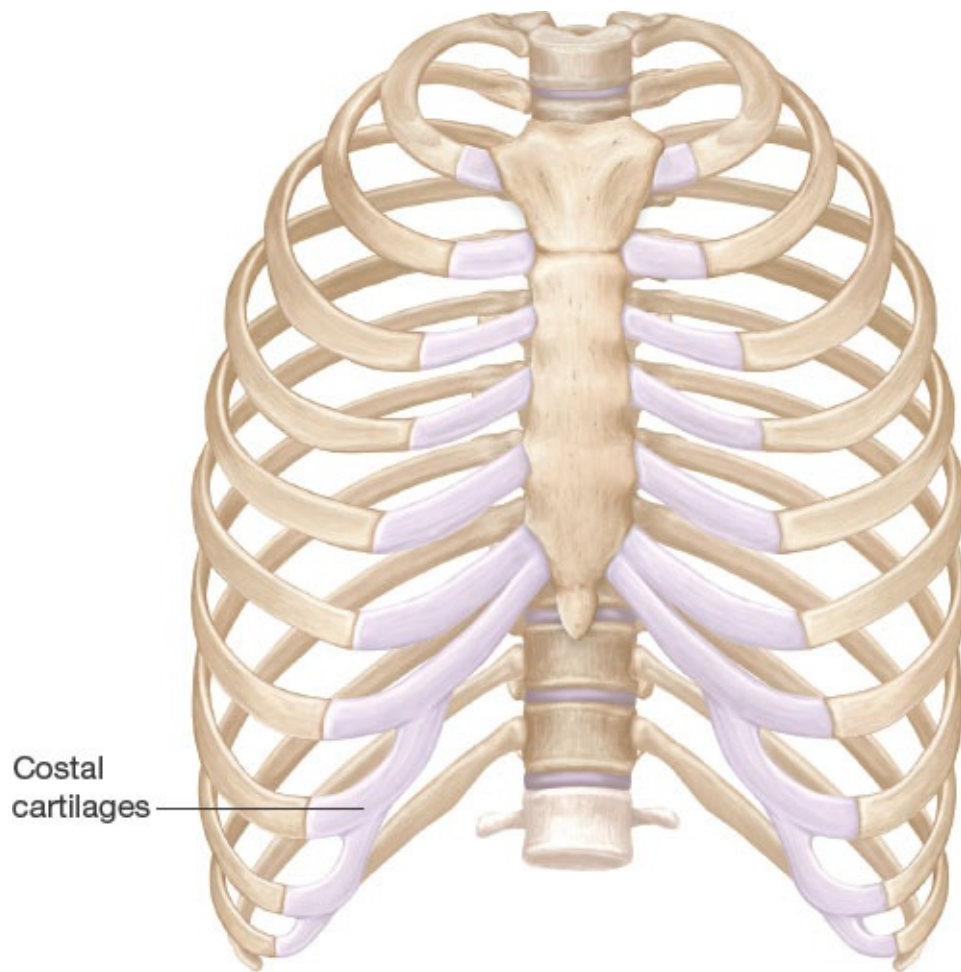


FIG 1 • The rib cage. Normally, there are 12 ribs on each side. The caudal two ribs are “floating ribs” and lack corresponding costal cartilages.

- Splitting the bone also makes it more malleable to match the cranial contour.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history and physical exam should document prior history of chest surgery or trauma particularly previous scars and their location, as well as history of prior rib graft harvest.

IMAGING

- Preoperative chest x-rays are rarely necessary prior to harvesting of rib grafts unless there is an unusual finding on physical exam.
- Similarly, postoperative chest x-rays are usually unnecessary even if there is a small violation of the parietal pleura as this rarely leads to a clinically

significant pneumothorax. If there is suspicion of injury to the visceral pleura or lung parenchyma, then a chest x-ray and close clinical observation may be warranted.

SURGICAL MANAGEMENT

Preoperative Planning

- Skin incisions are marked along the relaxed skin tension lines to minimize postoperative scarring.
 - In females, an inframammary fold incision may be used and is located at approximately the level of the fifth rib.
- Incisions are placed lateral to the costochondral junction to avoid harvesting of the costal cartilage, which is not useful for calvarial reconstruction.
- The length of the incision is related to the amount of bone that is necessary. Nevertheless, it is possible to minimize the length of the incision with the use of angled Horsley rib cutters.
- Harvesting of more than two adjacent ribs should be avoided to minimize the risk of flail chest and respiratory compromise.

Positioning

- The patient can be positioned prone or supine as rib harvest is possible from both the anterior and posterior chest.
- The choice for positioning depends largely on the cranioplasty defect to be treated and aiming to avoid repositioning during surgery.

TECHNIQUES

■ Rib Graft Harvest

- The skin is incised and dissection is carried down to the anterior rectus fascia for the anterior approach. The fascia and muscle are split along the underlying rib using careful palpating as a guide (**TECH FIG 1A**).
- The periosteum of the rib is elevated along the length of the bone using Freer or Joseph elevators.
- Care is directed at the inferior border of each rib where the neuromuscular bundle lays under a small overhang. The neuromuscular bundle is carefully

preserved.

- A Doyen elevator (available in pediatric and adult sizes) is used to continue periosteal dissection under the rib and extend the dissection laterally.
- It is most advantageous to first separate the bony rib from the costal cartilage (in the anterior approach) or to use a scalpel to divide the cartilage just medial to the junction while a malleable retractor protects the underlying periosteum and pleura (**TECH FIG 1B**).
- A wet gauze is wrapped around the medial end of the rib being harvested and a Kocher is used to cinch the gauze snugly around the rib. This will prevent unwanted split ends (**TECH FIG 1C**).
- The surgeon's index finger can then gently provide additional length of the graft by sliding it laterally along the rib separating additional periosteal attachments.
- The Horsley rib cutter is carefully placed in position. The surgeon's index finger confirms placement by palpating along the rib and the rib is cut.
 - Some surgeons will ask the anesthesiologist to decrease the tidal volume during the harvest.
- The rib graft is placed in saline, and attention is directed to the harvest site.

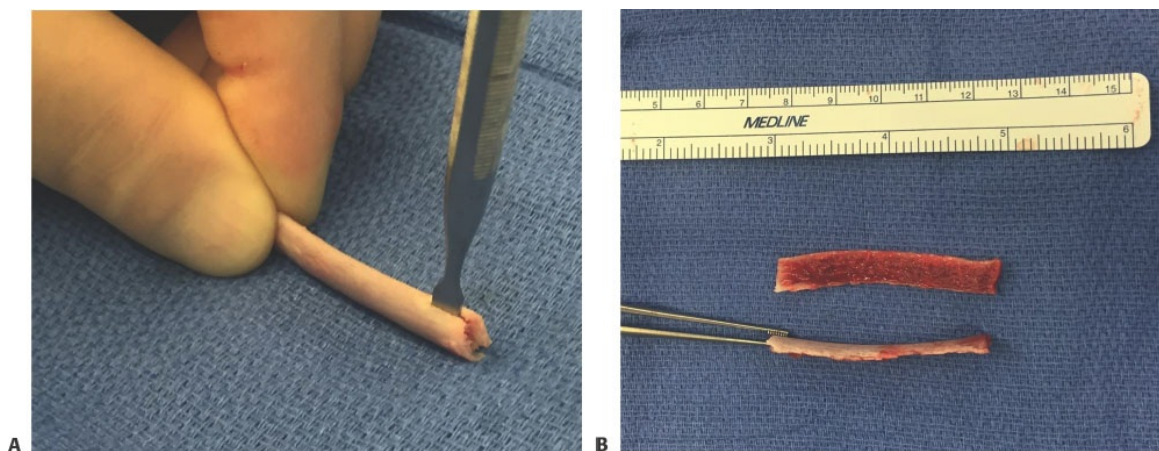


TECH FIG 1 • **A.** Surface anatomy. Note prior incision. The regenerated rib can be harvested again, split, and used. **B.** For the anterior approach, the bony rib is first separated from the costal cartilage by using a scalpel to divide the cartilage just medial to the junction, while a malleable retractor protects the underlying periosteum and pleura. **C.** A wet gauze is the wrapped around the medial end of the rib being harvest and a Kocher is used to cinch the gauze snugly around the

rib. This will prevent unwanted split ends.

■ Checking the Harvest Site and Completion

- The harvest site is filled with saline and the anesthesiologist is asked to provide 40 mm Hg pressure to the airway and hold it while the surgeon observes for persistent bubbling.
 - After a suitable period of observation (usually 5–10 seconds), the anesthesiologist resumes normal ventilation.
- Initial but nonsustained bubbling indicates that the parietal pleura has been transgressed, whereas persistent bubbling indicates that both parietal and visceral pleura are injured.
 - In the former scenario, the donor site can be closed without additional attention.
 - In the latter scenario, the surgeon must attempt to identify an obvious rent in the parietal pleura and place a red rubber catheter through it, leaving the wide end above the level of the skin. The donor site is then closed around the catheter. Because the lungs are ventilated with positive pressure, suction does not need to be applied to the red rubber catheter. The catheter is removed after the donor site is closed.
- Closure is performed in layers using resolvable sutures to reapproximate the periosteum. In infants and young patients, the harvested rib may regrow (we have been able to reharvest ribs years later because of this phenomenon).
- Additional anesthetic may be injected into the donor site for postoperative comfort (0.25% Marcaine is frequently used). The surgeon may also make use of commercially available systems to deliver pain medicine to the donor site via a catheter.
- A chest x-ray may be obtained postoperatively to rule out a pneumothorax or hemothorax. When suspicion of a pleural rent is minimal, an x-ray may be avoided.
- The harvested rib is inspected. Any cartilage remnant is removed.
- In children, thin spatula osteotomes are ideal for manually splitting the ribs in a sagittal plane without use of a mallet (**TECH FIG 2**).
 - In infants, a scalpel blade will frequently suffice, whereas in adults, a Frehofer with a mallet will work well.



TECH FIG 2 • **A.** A thin spatula osteotome is used to split the rib. **B.** Splitting rib effectively doubles the surface area.

PEARLS AND PITFALLS

Indications	Split rib grafts are indicated for cranioplasty particularly in children who are less than 8 years old.
Splitting rib graft	Doubles effective surface area, grafts are more malleable to better match contour.
Prior rib harvest	Regenerated rib can be harvested again, split, and used.
Damage to pleura	Rarely clinically significant if limited to parietal pleura.
Amount of rib harvested	It is not recommended to harvest more than two adjacent ribs to minimize the risk of respiratory compromise from a flail chest.

POSTOPERATIVE CARE

- Intercostal nerve blocks and infiltration of surrounding soft tissue with local anesthetics can help reduce postoperative pain at the rib donor site.

- Patients can resume their regular activities/return to school after 2 weeks postop.

OUTCOMES

- Reliable grafts that incorporate well into the adjacent calvarium and accommodate the growing skeleton.^{1,2}
- Split rib grafts contour well and maintain their shape over time.^{3,4}

COMPLICATIONS

- Pneumothorax/hemothorax: If a pneumothorax is present, a small red rubber catheter is placed into the pleural cavity. The overlying muscle is reapproximated and the catheter withdrawn while the anesthesiologist applies positive pressure ventilation.
- Hypertrophic scarring of chest wall incision: Transverse incisions parallel to the resting skin tension lines typically heal more favorably than oblique incisions.
- Chest wall deformity: Rarely, a problem when perichondrium is left intact as there is usually complete regeneration of the donor rib in children. Avoiding violation of the sixth rib margin can prevent outward flaring of the rib as the child grows. Chest wall deformity is more noticeable in extremely thin patients.⁵
- Resorption of graft: Rib grafts have a higher rates of resorption clinically and in animal studies as compared to calvarial bone grafts.⁶

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7 Calvarial Reconstruction With Split Calvarial Grafts

CHAPTER

David A. Staffenberg and Gerald J. Cho

DEFINITION

- Split calvarial grafts are cortical bone grafts harvested from the skull.
- These grafts can be either partial-thickness grafts where only the outer cortex is removed or full-thickness grafts that are then split along the diploic space to separate the bicortical graft into two pieces.

ANATOMY

- The calvarium (skull) consists of separate bone plates encasing the brain. Each named bone plate adjoins the adjacent bone plates at the cranial sutures.
 - Paired frontal bones
 - Paired parietal bones
 - Occipital bone (occasionally with an accessory suture or mendosal suture)
- The skull consists of three layers of variable thickness:
 - Outer table (cortical bone)
 - Middle layer (cancellous bone)
 - Inner table (cortical bone)
- These three layers are not present at the cranial sutures.
- The entire calvarium can serve as a donor site for split calvarial grafts. There are two main danger zone, however:
 - The midline, where the sagittal sinus resides subcortically
 - Below the temporal crest, where the bone tends to be thinner, increasing the risk for inadvertent intracranial entry
- Frontal bone can also be used when this is the site of surgery (eg, a frontal craniotomy is performed by the neurosurgeons for tumor access).
 - The craniotomy bone flap can be split, during the neurosurgical portion of the

procedure, if additional bone will be required for repair).

- The thickest bone resides in the parietal and occipital bones.¹ Parietal bone is the most common donor site because it is the thickest.
- Transcortical emissary veins can cause brisk bleeding during the osteotomy. This can usually be controlled with bone wax.
 - Subcortical vessels can cause thinning, and thus, weaken the inner cortex.
- The split calvarial graft may be a superior alternative to other bone graft donor sites.
 - It offers a hidden scar if placed within the hair-bearing scalp.
 - It is frequently a painless donor site, particularly when compared with iliac crest and rib.
- Split calvarium will typically provide cortical bone grafts that have the following advantages over iliac crest and rib:
 - Smooth surface
 - Able to hold screws
 - Able to bear load
 - Warp resistant
- In experienced hands, a large quantity of cortical bone can be harvested.
- Splitting the calvarium is easiest when the diploe is well-developed.

PATIENT HISTORY AND PHYSICAL FINDINGS

- When a donor site is being selected, note the patient's handedness. This is to decrease potential morbidity in case there is inadvertent intracranial entry and damage to the motor cortex.
 - A left-handed patient will have a left side donor site.
 - A right-handed patient will have a right side donor site.
- When there has been previous surgery, the surgeon must take note of:
 - Previous scars, their condition and location
 - Mobility of the scalp: An adherent scalp may indicate loss of the intermediate layers of the scalp and therefore the potential for subsequent wound healing problems.
 - Palpable bony defects or hardware

IMAGING

- Imaging may be useful to determine the characteristics of available sites.
- CT scanning with bone windows is currently the most useful imaging

modality.

- CT is particularly helpful when there are palpable bony defects or hardware present.
- The thickness of the inner and outer tables of the calvarium, as well as the thickness of the diploe, should be noted by the surgeon.
- Imaging is recommended until the surgeon has gained suitable experience.

SURGICAL MANAGEMENT

Preoperative Planning

- If coronal incision is being used, the scalp flaps can be retracted to expose the graft donor site.
- The coronal flap is elevated in a subperiosteal plane if a full outer cortical graft is being harvested down to diploe.
- If a split-thickness (partial thickness outer table) calvarial graft is being harvested, a subgaleal plane is elevated to preserve the periosteum.
- If a coronal incision is not being used, we recommend a sigmoid-shaped incision over the donor site for wide exposure.
- The flaps are elevated in a subperiosteal plane if a full outer cortical graft is being harvested down to diploe.
- If a split-thickness (partial thickness outer table) calvarial graft is being harvested, a subgaleal plane is elevated to preserve periosteum on the intended bone graft.

Positioning

- The patient can be positioned supine or prone.
- The patient's head should be secured and on a firm surface (ie, avoid cushions) to minimize "bouncing" while the osteotomes are driven with a mallet.

Approach

- Ex vivo calvarial split is a useful technique when neurosurgeons are performing a craniotomy for an intracranial procedure and additional cortical bone is required at the completion of the procedure.
- In situ split calvarial is a reasonable option for adult patients and is useful when a craniotomy is not necessary for the surgery at hand. However, there is a greater learning curve than ex vivo technique because inadvertent injury to the inner table may cause dural tears or intracranial injury.

TECHNIQUES



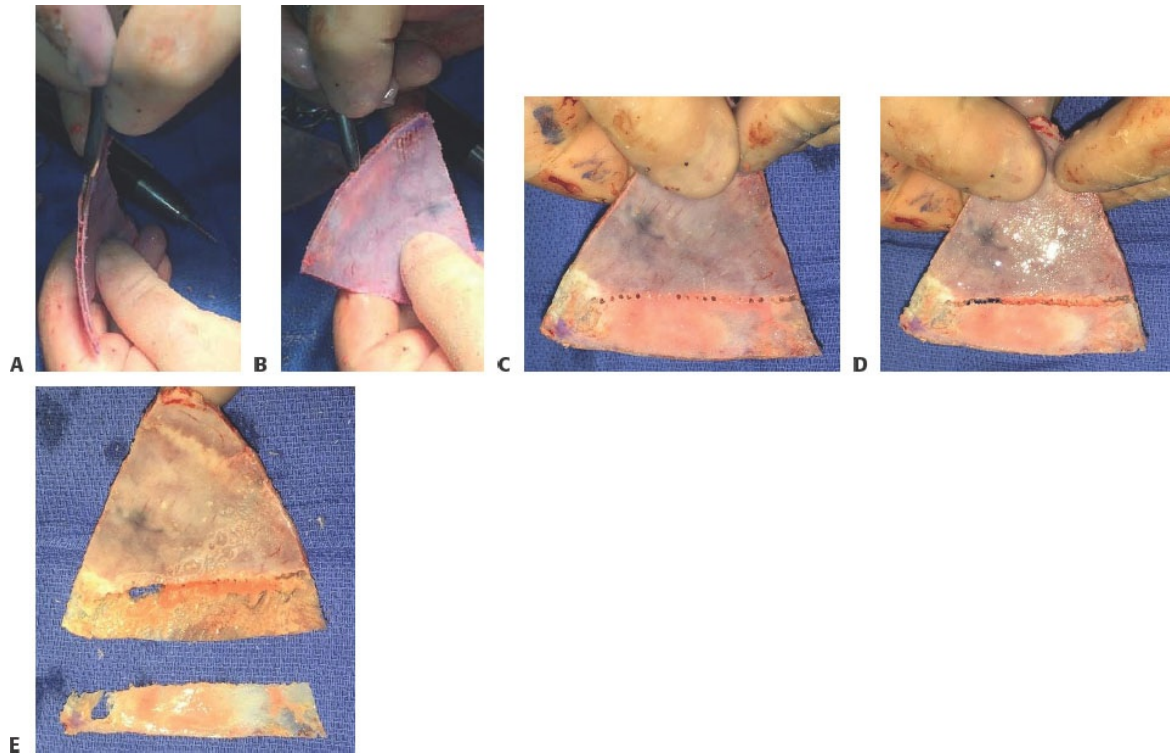
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■ Ex Vivo Split Calvarial Graft From Craniotomy Bone Flap

- The craniotomy bone flap is placed in saline on a sterile back table.
- We use a table with a drill/saw system secured to a pole because this allows efficient use of the time while the neurosurgery team is working.
- Bone is kept in saline when not being used.
- Instruments are selected based on the age of the patient and the characteristics of the bone to be split.
 - In infants as young as weeks of age, a no. 15 scalpel blade may be an efficient tool for splitting bone through the diploe. A sterile vise applied to the side of the back table is helpful to minimize injuring the surgeon's nondominant hand.
 - In infants from a few months old, a series of spatula osteotomes can be used to gently split the calvarium along the diploe (**TECH FIG 1A,B**).
 - After roughly 6 months of age, a C-1 side-cutting bit on a Midas Rex can be used to create a series of adjacent drill holes while applying copious saline irrigation to prevent thermal necrosis. The C-1 bit can then be used to gently connect each hole (**TECH FIG 1C-E**).
- Several of the popular saw systems have developed flexible saw blades as

thin as 0.3 mm. I prefer using the reciprocating saw for this purpose. Again, use caution to avoid injury to your own hands or those of your assistants.

- While working with the saw, a vise or Kocher clamp can be used to reduce vibration.



TECH FIG 1 • A,B. C-1 side-cutting bur on Midas Rex is used to separate the inner cortex from the outer cortex along the diploic space. Note that the maximal width of bone graft obtained is dictated by the length of the drill. **C.** The drill is used to perforate the inner cortex in a “postage stamp” manner. **D.** The perforations are connected using the drill. **E.** Split calvarial graft is obtained.

■ In Situ Split Calvarial Graft

- The desired donor site is exposed in a subperiosteal plane.
- The desired graft is marked with a sterile pencil, bonny blue, or the like.
- A saline-cooled bur is used to create a trough around the border of the

desired graft; the trough is continued into the diploe. The depth is noted when cancellous bleeding is seen (**TECH FIG 2A**).

- Plan to drive the osteotome toward the floor. Use the bur to bevel the upper margin to make the proper position and angle of the osteotome easier.
 - A selection of slightly curved osteotomes is used along the diploe. Care is exercised to avoid directing the osteotome into the inner table. An assistant secures the patients head to avoid bouncing, while the mallet drives the osteotomes. Rapid light taps are safer and allow frequent correction and adjustment of the osteotome (**TECH FIG 2B**).
- Once the outer table is harvested, the inner table integrity is confirmed. Compromise of the inner table should prompt consideration of a neurosurgical consult intraoperatively.
 - Judicious use of bone wax can control bleeding from the diploe.
- The saline-cooled bur is used to bevel the edges of the donor site to minimize palpability of the step-off.
 - Filling the donor site with an alloplastic “bone paste” may be considered in the hairless, or shaven, patient.
- The scalp is closed in layers. A drain may be used based on the surgeon’s preference. I favor a craniofacial dressing over the use of a drain.



TECH FIG 2 • A. A cutting bur is used to make a trough through the outer cortex and into the diploe. The outer edges are contoured and feathered

peripherally. **B.** The outer cortex is removed using a right-angled oscillating saw, or alternatively, it can be chiseled off using a curved osteotome.

■ Thin Split-Thickness In Situ Calvarial Bone Graft

- Periosteum attached to the intended graft is imperative.
 - An incision is made around the desired dimensions of the graft (scalpel or cautery is acceptable).
 - A wide, sharp osteotome is selected and oriented at about 45 degrees off the outer table with the surgeon's nondominant hand.
 - The surgeon's dominant hand is used to strike the osteotome with a mallet with light but rapid contact. This will "shave" a thin split calvarial bone graft, which is comminuted but held together by the periosteum.
 - The comminution allows the graft to curl, which makes it ideal for repair of an orbital floor defect, ie, acute pure orbital blow-out fracture.
-

PEARLS AND PITFALLS

Patient age	■ Patients at the extremes of age pose a technical challenge and experience is even more critical to minimize morbidity in these patients. Neonates may have an undeveloped diploe, whereas elderly patients lose the diploe, which may present a technical challenge. In situ split-thickness harvesting in these two groups is not recommended.
Intracranial pressure	■ Patients with even subclinical increased intracranial pressure (eg, syndromic craniosynostosis, some nonsyndromic craniosynostosis) may lose the inner table and simply manifest with a monocortical calvarium. Splitting is increasingly more difficult or impossible in areas where the calvarium has thinned.
Know your instruments	■ Know the capability of your instruments (saws, osteotomes, burs, etc.)
Know your own	■ Practice. <i>There is a real learning curve.</i>

POSTOPERATIVE CARE

- Limited exposure and smaller grafts can be managed with simple compressive dressings, which can be removed after a few days.
- Wide exposure for large grafts may require a closed suction drain.

OUTCOMES

- Calvarial bone grafts are considered the standard for autogenous craniofacial reconstructions.^{1,2}
- No controlled human studies currently exist that characterize the volume or rate of absorption. However, numerous clinical studies demonstrate excellent graft stability along the entire craniofacial skeleton. Animal studies have shown calvarial grafts to be superior to rib and iliac crest bone grafts.
- Donor-site complications are rare across all studies.³

COMPLICATIONS

- Dural exposure
 - If small (less than 1 cm²), there is no need for calvarial reconstruction
 - Larger (greater than 1 cm²) defects can be reconstructed with another split calvarial graft or alloplastic mesh.
- Dural tear
 - This complication requires prompt neurosurgical intervention. Injured dura should be adequately exposed and the brain evaluated for injury. In the absence of brain parenchyma damage, the dura should be closed primarily when possible. Larger dural tears may require dural grafts.
- CSF leak
 - Small CSF leaks can be managed with bed rest.
 - Larger CSF leaks may require external drainage.
- Donor-site contour deformities
 - Rarely, a cosmetic problem (widened scar) when donor site is in hair-bearing scalp.
 - Burring down sharp edges of graft site can help camouflage defect.

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Section IV: Skull Base and Midface

8 Free Fibula Flap for Midface Reconstruction

CHAPTER

J. Rodrigo Diaz-Siso and Eduardo D. Rodriguez

DEFINITION

- Composite midface defects, involving skin, bone, and mucosa, are commonly the result of oncologic resection, high-energy trauma, inflammatory diseases, or congenital anomalies.
- Unreconstructed midface defects may lead to impaired speech, oral incompetence, and limited masticatory, deglutitive, orbital, and respiratory functions, in addition to facial disfigurement and associated decreased quality of life.
- The free fibula is a versatile flap that can include a long segment of vascularized bone, which can be shaped as needed through multiple osteotomies.
 - The flap can include muscle, fascia, and/or skin, making it an ideal reconstructive option for composite defects.
- The reconstructive goals are to replace the facial buttresses, resurface internal and external soft tissue lining, separate the oral and nasal cavities, and restore the alveolus, resulting in a patent nasal airway, adequate midfacial projection and ocular globe position, and allowing for endosseous dental rehabilitation.

ANATOMY

- The skeletal foundation of the lower leg is composed of the tibia (medial) and fibula (lateral), parallel long bones connected by an interosseous membrane,

which divides the leg into anterior and posterior compartments (**FIG 1**).

- The anterior compartment is bordered laterally by the anterior intermuscular septum. The anterior tibial vessels and deep peroneal nerve are directly anterior to the interosseous membrane.
- The lateral compartment, which includes the peroneus longus and peroneus brevis muscles, is bordered posteriorly by the posterior intermuscular septum, which contains the perforator vessels that perfuse the lateral skin of the lower leg, and thus the skin island of the flap when applicable.

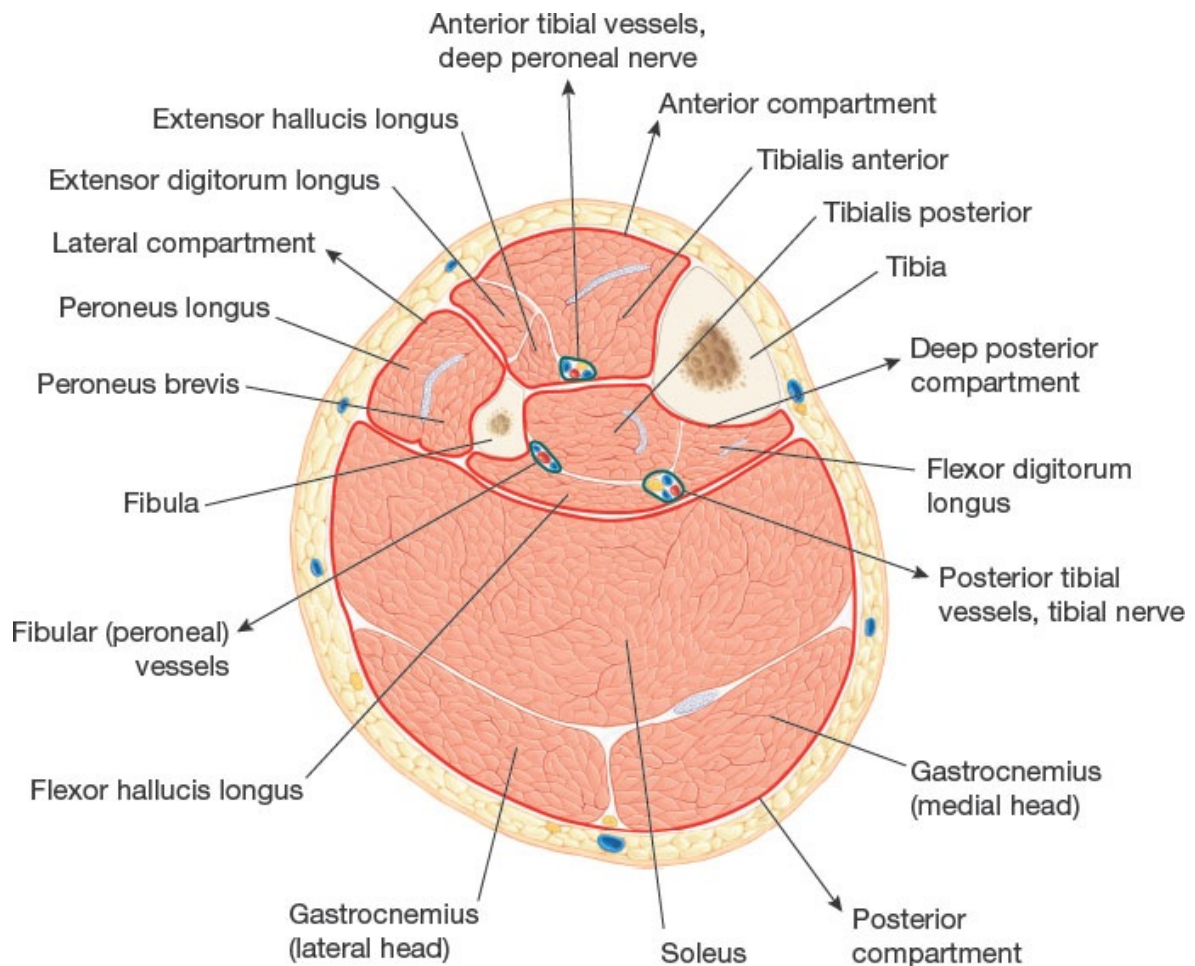


FIG 1 • Cross section of the middle leg showing fascial compartments and relevant anatomical structures.

- The deep posterior compartment includes, from medial to lateral: flexor digitorum longus, tibialis posterior, and flexor hallucis longus muscles; the fibular vessels run between the latter two. The posterior tibial vessels and

tibial nerve are found lateral to the flexor hallucis longus, posterior to the tibialis posterior muscle, and anterior to the transverse intermuscular septum.

- The posterior compartment includes the soleus and gastrocnemius muscles.
- The fibula is nonweight bearing, but the proximal and distal epiphyses are crucial to the integrity and stability of the knee and ankle joints, respectively.
- The common fibular nerve wraps around the neck of the fibula before dividing into the deep and superficial fibular nerves, limiting proximal dissection and procurement. Even after epiphyseal preservation, approximately 25 cm of vascularized bone can be harvested.
- The fibular artery provides the dominant blood supply to the fibula, supplemented by periosteal and muscular branches; the vascular pedicle can be considerable, yielding up to 15 cm. The well-defined vascular supply allows the division of the free fibula into segments as small as 2 to 3 cm.
- The two venae comitantes of the fibular artery are responsible for venous drainage.
- The lateral sural nerve supplies the sensory innervation of the lateral leg skin; sensory nerve coaptation is possible, but not routinely performed.
- Muscles commonly included in a free fibula flap include the flexor hallucis longus and the tibialis posterior, located in the deep posterior leg compartment. The soleus, located directly posterior to the posterior and transverse intermuscular septa, can also be included.
- The midface contains three vertical and two horizontal skeletal buttresses¹ (**FIG 2**).

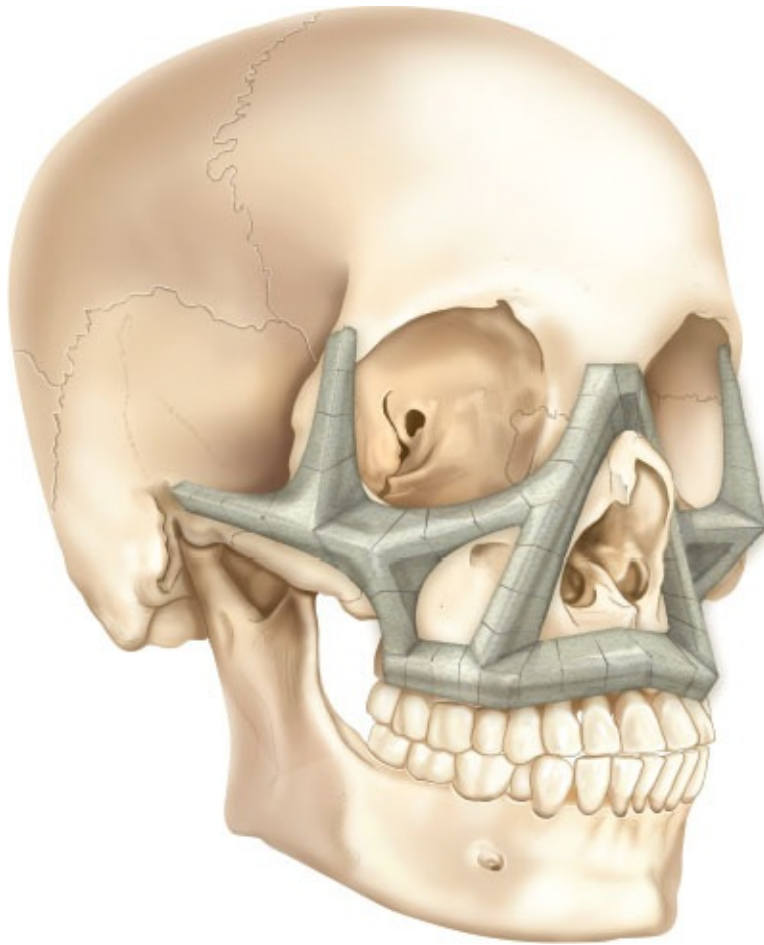


FIG 2 • Illustration of the horizontal and vertical skeletal buttresses of the midface.

- Vertical: The nasomaxillary, zygomaticomaxillary, and pterygomaxillary buttresses maintain facial height and resist occlusal load.
- Horizontal: The inferior orbital rim maintains the position of the ocular globe, and together with the maxillary alveolus and the malar prominence, it is responsible for maintaining the facial profile and width, respectively.
- A classification of skeletal midface defects focuses on the absence of these essential functional subunits of the maxilla² (**FIG 3**):
 - Class I: unilateral dentoalveolar defect
 - Class II: unilateral dentoalveolar and orbital rim defect
 - Class III: bilateral dentoalveolar defect
 - Class IV: bilateral dentoalveolar and orbital rim defect
- Depending on concomitant skin deficits, and/or pterygoid injury, which affects

the complexity of the posterior fixation of the flap, this classification is designed to determine flap selection for microsurgical reconstruction.²

- Important: instead of attempting to recreate the absent curvilinear structures of the facial skeleton, segments of vascularized bone are strategically placed to serve as girders that are capable of (and necessary for) preserving function and maintaining aesthetic facial proportions and contour.³

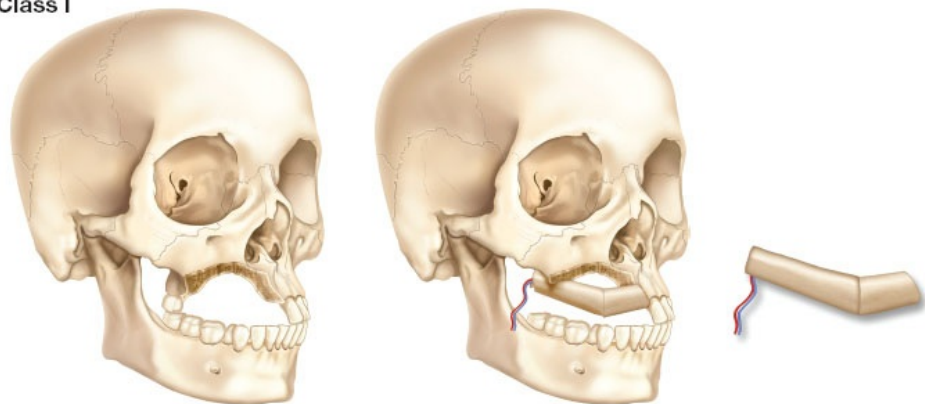
PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed medical history must be performed to identify patients with current or prior peripheral vascular disease, deep vein thrombosis, vasculitis, or lower leg trauma, which may increase the risk of an unreliable fibular vascular pedicle.
- The popliteal, dorsalis pedal, and posterior tibial pulses are examined.
 - Lower extremity Allen test can be performed to ensure that both the dorsalis pedis and posterior tibial arteries perfuse the distal lower extremity.
 - Anatomic variations, like peronea magna (hypoplasia or absence of anterior and posterior tibial arteries), must be identified⁴ (**FIG 4**).
- The range of motion and stability of the knee and ankle joints are assessed.
- Facial anthropometrics are assessed, including horizontal thirds and vertical fifths.
- Dental/facial midlines, dental show at rest and smiling, and maxillomandibular occlusal relationships are recorded when applicable.

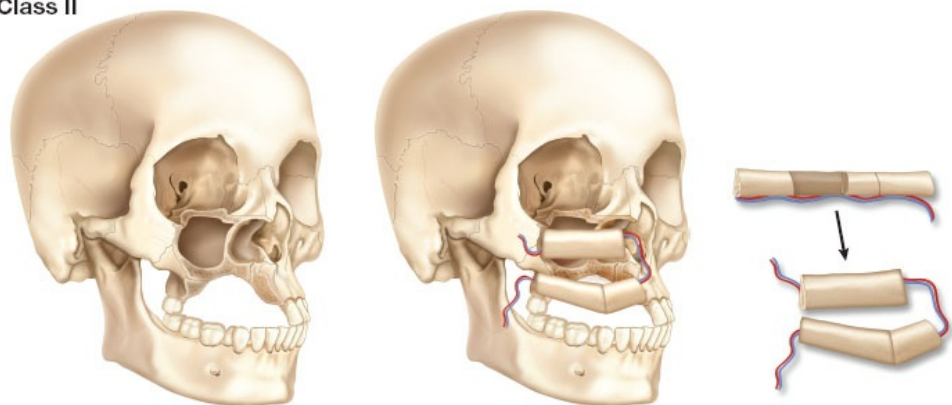
IMAGING

- Angiography is not routinely performed but can be considered if history is positive for possible tibial artery damage or injury, and/or if distal pulse assessment is abnormal or suspicious.
 - Other imaging modalities (CT or MR angiography) are also effective alternatives.
- In traumatic defects, three-dimensional maxillofacial CT will allow precise analysis of the missing bone that will be reconstructed, in addition to soft tissue analysis.
- When computerized surgical planning (CSP) is employed, three-dimensional lower leg- and maxillofacial CTs are performed to aid the design of the flap, which is based on an existing traumatic defect or the predicted absent maxillary bone that will result from planned ablative surgery.

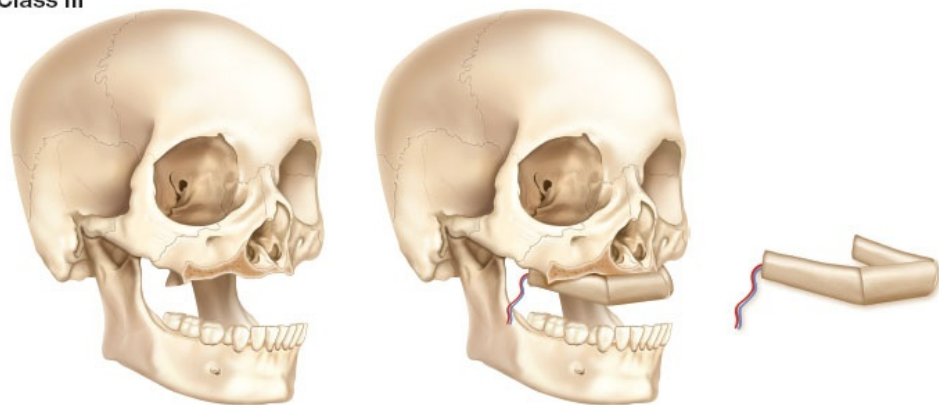
Class I



Class II



Class III



Class IV

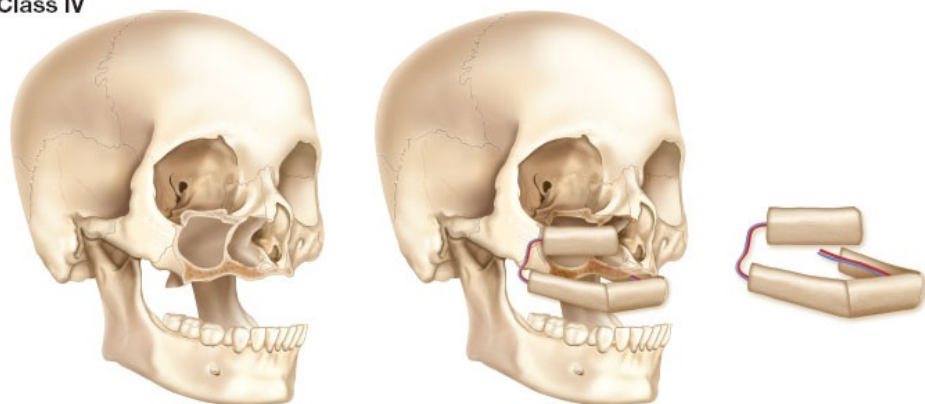


FIG 3 • Classification of midface skeletal defects in ascending order of reconstructive complexity, and illustrations of possible free fibula flap reconstruction of each defect. Class I: Unilateral dentoalveolar defect. Class II: Defect involves inferior orbital rim and ipsilateral maxilla. Class III: Bilateral dentoalveolar defect. Class IV: Defect involves bilateral dentoalveolar loss and at least one orbital rim.

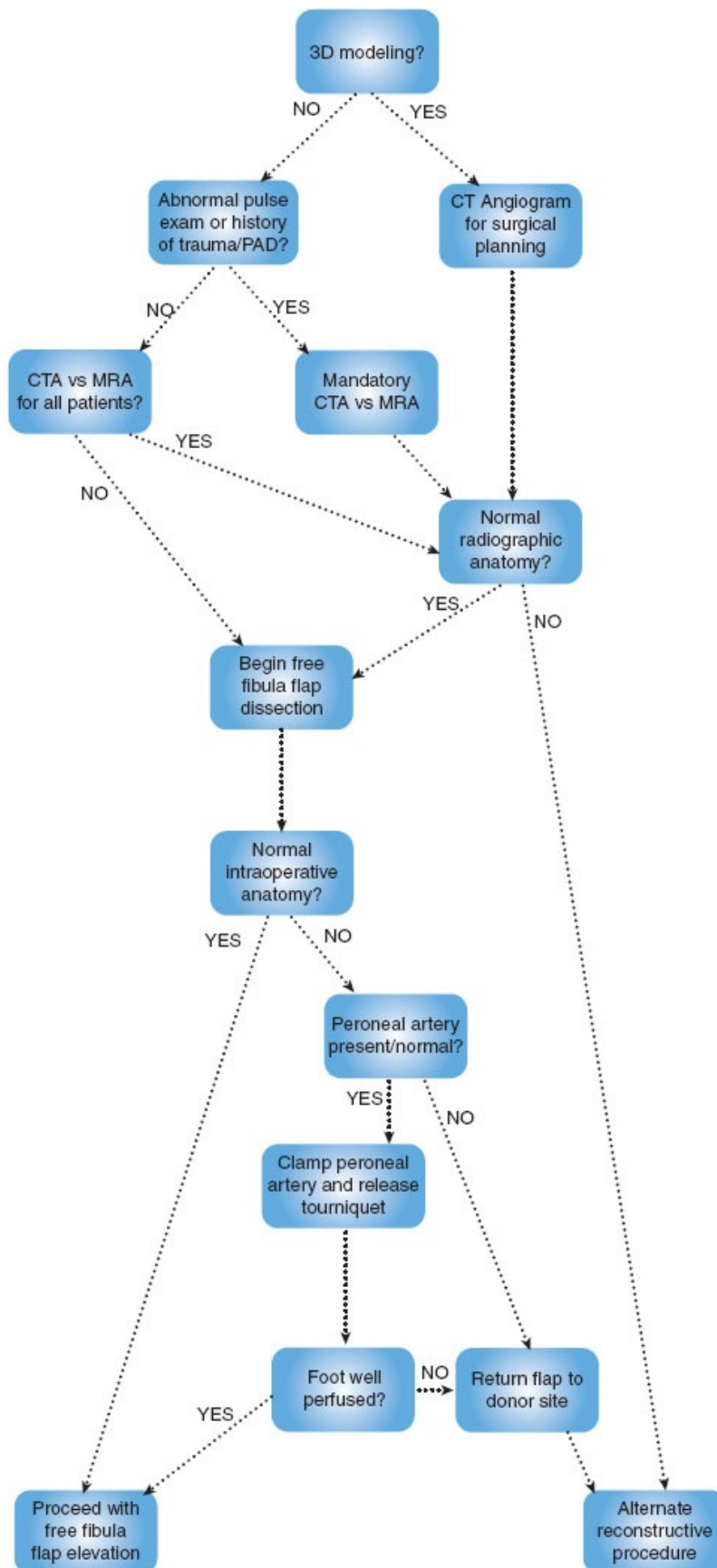


FIG 4 • Algorithm to rule out aberrant lower extremity vascular anatomy in a free fibula flap reconstruction candidate.

NONOPERATIVE MANAGEMENT

- Prosthetic obturation is among the earliest techniques developed to reconstruct facial defects.
- Midfacial prostheses can be considered in patients who are poor candidates for—or unwilling to pursue—free tissue transfer.
 - Advanced age, medical comorbidities, smokers, contaminated wounds, etc.
- In pediatric patients, prosthetic obturation can serve as a temporary reconstructive solution during growth.
 - Permanent free flap reconstruction can be revisited once the patient reaches skeletal maturity.

SURGICAL MANAGEMENT

- Reconstruction of composite midface defects may not be possible in a single stage; surgical plans and patient expectations must be managed with this in mind.
 - Phase 1 goals: restore skeletal anatomy, eliminate dead space if necessary, and deliver soft tissue volume in slight excess for future refinement.
- Consider early involvement of dental colleagues:
 - Close collaboration and detailed planning of osseointegrated implant placement is essential to optimizing dental rehabilitation and long-term outcomes.

Preoperative Planning

- VSP can accurately predict and facilitate fibular osteotomy and flap inset sites based on 3D reconstructions of CT data (**FIG 5**).
 - 3D-printed osteotomy guides ensure maximal precision during separation of the fibular segment from the lower leg, division of the bone flap into multiple segments, and fixation of the resulting segments to accommodate a desired flap shape.
- VSP also identifies the best point of fixation on the midface, in addition to aiding the design of recipient-site osteotomies that may be required prior to

optimal flap inset and fixation.

- A 3D-printed model of the patient's skull and the desired shape of the bone segment(s) help preoperative contouring of a 2.0-mm titanium miniplate, minimizing ischemia time. If required, minor adjustments in the shape of the plate can be made prior to flap inset.
 - Alternatively, stereolithographic models of the patient's facial skeleton and remaining dentition can be used intraoperatively for this purpose.
- Preferred recipient pedicles are the superficial temporal and facial vessels.
 - Unilateral defects: whenever possible, ipsilateral vessels are preferred.
 - Bilateral defects: less relevant; will depend on quality of local tissues; may determine recipient site selection.
 - Class IV defects (bilateral dentoalveolus and inferior orbital rim): multiple free flaps may be indicated; bilateral recipient vascular pedicles will likely be necessary.
- When choosing between ipsilateral and contralateral donor fibula, consider the following:
 - The fibular vessels are located on the medial surface of the fibula, and the flap's vascular pedicle extends superiorly from the proximal end of the procured bone segment.
 - Thus, the fixation plates will be screwed onto the lateral surface of the fibula, which will become the anterior surface of the reconstructed midface bone (flap vasculature will run on posterior surface).
 - Recipient vessel selection may be limited in extensive defects, and vascular compromise of one leg may force the surgical team to procure the flap from the opposite side. Nevertheless, fibula flaps can be rotated 180 degrees to reach ipsilateral or contralateral recipient vessels depending on reconstructive needs.
 - A fibula flap ipsilateral to the chosen recipient vessels may be oriented more easily so that, upon inset, the donor vascular pedicle does not cross the midline to reach the recipient vessels.

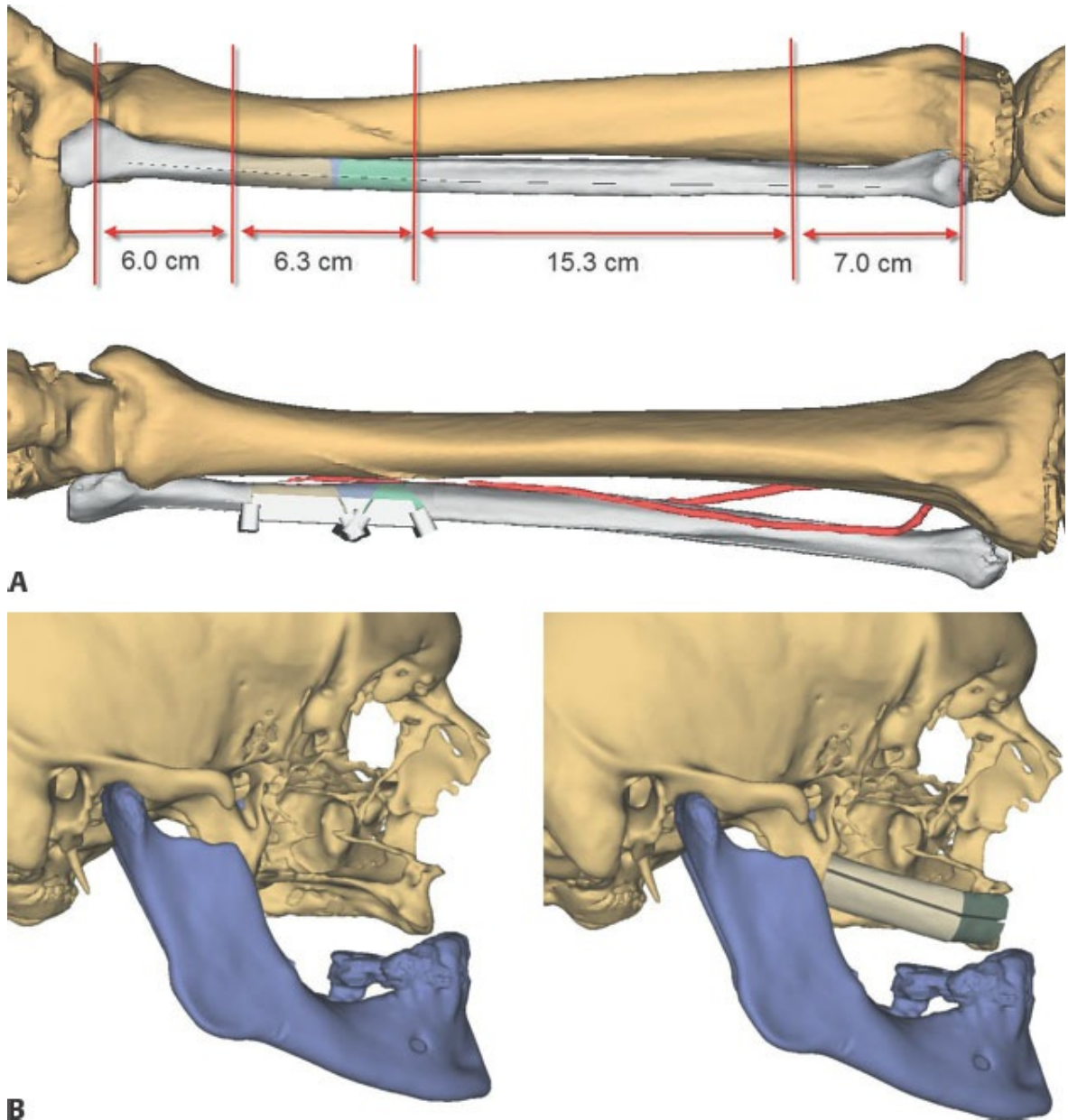


FIG 5 • Computerized surgical plan to reconstruct a midface defect that resulted from the resection of a right maxillary oncologic deformity in a 58-year-old man. **A.** Synthes ProPlan software was used to calculate the overall length of the fibula segment to be elevated, as well as the length of each fibula segment to be osteotomized and reshaped before flap inset. **B.** Patient's preoperative anatomy showing the right

maxillary defect, and the virtually planned postoperative result with the fibula segments recreating the horizontal maxillary buttresses.

- This limits interference with anesthesia and decreases the required length of the flap's vascular pedicle.
- For unilateral soft tissue defects, determine/anticipate the extent of absent skin vs floor of mouth.
 - If more external skin is required, the skin paddle from an ipsilateral fibula flap may lie more favorably upon inset.
 - If more floor of mouth tissues are required, a contralateral fibula flap may be more favorable by extending the skin paddle resection posteriorly.

Positioning

- The patient is positioned supine, with the knee of the donor leg flexed, the pelvic girdle rotated internally, and with towels or a sandbag elevating and stabilizing the heel.

Approach

- A two-team approach to reconstruction is used whenever possible.
 - One team elevates the flap while the other explores the midfacial defect.
- Early reports describe a posterior approach,⁵ but lateral surgical approach has proven simpler and quicker.

TECHNIQUES

■ Preparation of Midface Defect

- The mechanism of injury will determine the extent and complexity of defect preparation.
- Mass resection: the defect is created by the ablative surgery team.
 - Reconstructive team must precisely assess the resulting skeletal and soft tissue requirements before finalizing and/or adjusting previous flap design if necessary.
- High-energy trauma: early reconstruction is advocated.

- Aggressive debridement of nonviable tissues is necessary to determine the eventual defect.
 - Reconstruction before scar formation and contracture (within 2 weeks) facilitates dissection, precise skeletal alignment, and maintains adequate volume of the soft tissues.
 - Delayed reconstruction is approached as a secondary reconstruction, requiring defect recreation, scar tissue removal, skeletal realignment, and soft tissue reexpansion.
 - Necessary corrective osteotomies or skeletal realignments are performed at this time to streamline bone inset.
 - VSP dental positioning guides are fixated to determine and maintain occlusion during surgery.
 - VSP osteotomy guides are fixated onto applicable bone sites.
 - Osteotomies are performed using an oscillating saw.
 - Guides are removed.
-

■ Free Fibula Flap Harvest: Lateral Approach

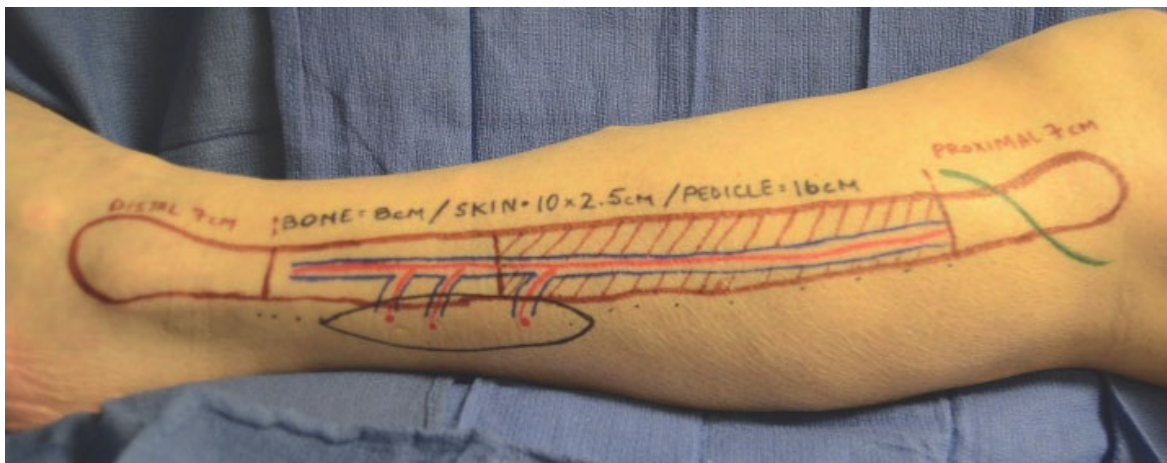
Donor Site Marking

- Once the donor site has been selected, as described in Preoperative Planning, the fibula is outlined and marked by palpating the fibular head, the lateral malleolus, and the anterior and posterior fibular borders on the lateral leg (**TECH FIG 1**).
- The most proximal 5 to 7 cm of the fibula is marked; this segment is usually not be included in the flap to avoid injury to the common peroneal nerve during dissection and to prevent postoperative knee instability.
- The distal-most 5 to 7 cm of the fibula is also measured, marked, and excluded from the flap to avoid ankle instability.
- The fibular segment that will be included in the flap is marked as distally as possible to maximize (proximal) pedicle length.
- A Doppler pencil probe is used to identify skin perforators within the posterior intermuscular septum, located in close proximity to the posterior border of the fibular outline.
- The skin paddle is designed and marked on the distal two-thirds of the lateral leg, ensuring that a perforator emitting a prominent signal is located in the center of the flap area.

- Flap procurement is performed after partial exsanguination and placement of a thigh tourniquet, which is inflated to 100 mm Hg higher than the patient's systolic blood pressure.

Incision and Skin Paddle Dissection

- A mid-lateral incision is made posterior to the palpable fibula and skin flap is elevated above the fascia.
 - The superficial peroneal nerve lies in this layer, and care is taken to avoid injury.
- The anterior border of the skin paddle marking is incised; dissection proceeds in a posterior direction until the posterior intermuscular septum is identified (**TECH FIG 2**).
- The fasciocutaneous perforators that perfuse the flap are located in the posterior intermuscular septum, which is thin and fragile and must be dissected cautiously.



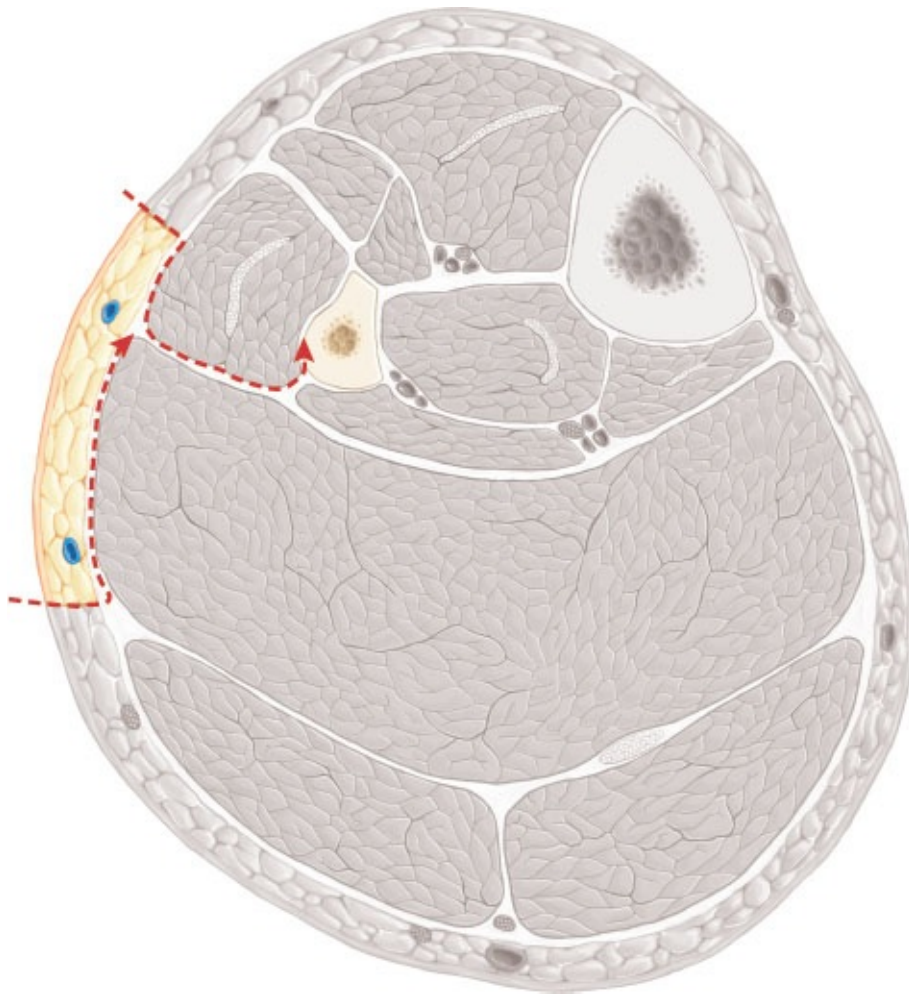
TECH FIG 1 • Surgical markings for free fibula flap elevation. Location of perforators is identified, and skin paddle marked accordingly. Proximal and distal 7 cm of the fibula are also marked and excluded from the flap.

- Dissecting medially, the peroneus longus and peroneus brevis muscles are sharply separated from the posterior intermuscular septum until the fibula is identified.

- The posterior margin of the skin paddle is incised and elevated anteriorly above the fascia until reaching the posterior intermuscular septum.

Lateral and Anterior Compartment Dissection

- Anterior to the perforators, the superficial muscular fascia is incised. Beginning inferiorly, the peroneal muscles are sharply dissected off the fibula.
 - To maintain periosteal circulation, a small cuff of peroneus brevis muscle is preserved on the fibula.
 - Superiorly, the common peroneal nerve is identified and preserved.
- The peroneal muscles are reflected anteriorly, and the anterior intermuscular septum is incised, accessing the anterior compartment.



TECH FIG 2 • Path of dissection of a free fibula flap that requires a skin paddle. The posterior

intermuscular septum is separated from the lateral compartment until the fibula is identified.

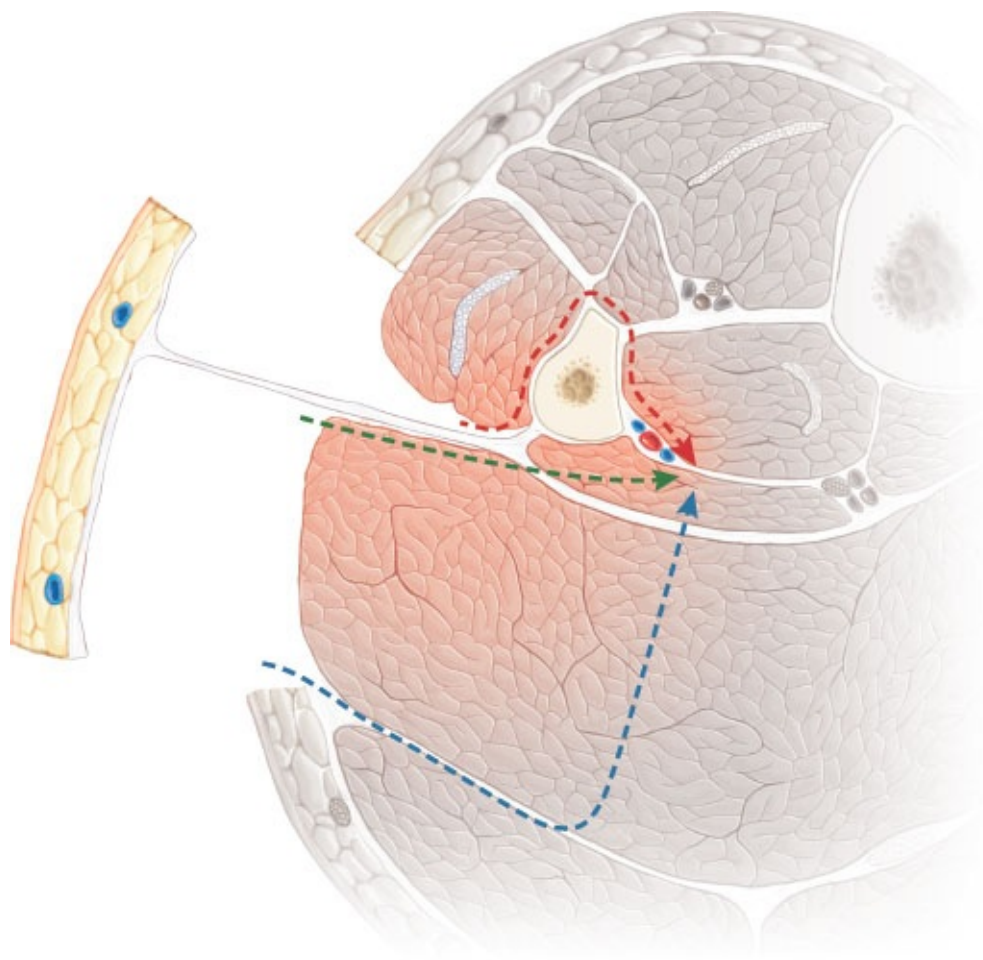
- The extensor digitorum longus and extensor hallucis longus are elevated from the fibula until the interosseous membrane is identified.
 - The anterior tibial artery and deep peroneal nerve lie anterior to the interosseous membrane.
 - Medial retraction of the lateral and anterior compartment musculature helps visualize and protect the neurovascular pedicle during dissection.
- The interosseous membrane is incised, resulting in anterior access to the deep posterior compartment and visualization of the tibialis posterior muscle (**TECH FIG 3**).

Posterior Compartment Dissection and Distal Osteotomy

- If soleus muscle is included in an osteomyocutaneous flap design, the lateral half of the soleus is separated posteriorly from the lateral head of the gastrocnemius.
 - When the midline of the soleus is reached, the dissection veers anterolaterally toward the fibula until the transverse intermuscular septum is identified.
 - Based on a separate muscular perforator, the lateral half of the soleus muscle can be elevated as part of a chimeric osteomyocutaneous flap design.
- If the soleus muscle is not included in the flap design, proceeding medially, the soleus muscle is bluntly separated from the posterior intermuscular septum until reaching the transverse intermuscular septum.
- In all cases, the transverse intermuscular septum is incised, resulting in posterior access to the deep posterior compartment and visualization of the flexor hallucis muscle (see **TECH FIG 3**).
- The custom osteotomy guide is fixated onto the lateral surface of the fibula.
 - Depending on individual patient needs and flap design, efforts are made to position the osteotomy guides favorably in relation to dominant skin perforators.
- The distal osteotomy is performed using an oscillating saw.

Deep Posterior Compartment Dissection and Proximal Osteotomy

- Anteriorly, the distal posterior tibialis muscle is transected at the chevron-shaped decussation of its fibers.
- Dissection proceeds in a proximal direction by exposing the peroneal vessels on the medial surface of the fibula and the flexor hallucis longus muscle posteriorly (see **TECH FIG 3**).
 - The amount of posterior tibialis muscle elevated with the flap can also be adjusted depending on recipient site soft tissue requirements, but at least a small cuff is preserved on the fibula to maintain periosteal circulation.
 - Gentle lateral retraction of the fibula can facilitate dissection and ligation of perforators emerging from the fibula.
 - The posterior tibial vessels and the tibial nerve can be visualized medially and avoided during dissection.
- The flexor hallucis longus muscle is carefully separated from the fibula in a proximal direction, exposing perforator branches.
 - To maintain periosteal circulation, a small cuff of flexor hallucis longus muscle is preserved on the fibula.
 - A larger lateral portion of the flexor hallucis muscle can also be elevated with the fibula if necessary.
- Perforator branches are cautiously dissected, ligated, and traced proximally to identify the proximal fibular vessels and the common peroneal nerve.
- The proximal osteotomy is performed, allowing mobility of the flap and excellent visibility of the proximal fibular pedicle, which is dissected until visualizing its branching point from the proximal posterior artery.



TECH FIG 3 • The path of dissection during elevation of a free fibula flap. *Red arrow* shows dissection of the lateral and anterior compartments and through the interosseous membrane. *Green arrow* demonstrates posterior compartment dissection in cases where additional muscle is not necessary. *Blue arrow* shows the path of dissection when soleus muscle procurement is warranted for coverage or soft tissue bulk.

Completion

- When applicable, osteotomies to reshape the elevated fibula are performed once the flap has been dissected in situ (**TECH FIG 4**).
- The proximal fibular vascular pedicle is ligated, and the flap can be

transferred to the back table for further customization.

- The tourniquet is removed and meticulous hemostasis is obtained.
- The skin flap donor site is skin grafted.
- Skin incision proximal and distal to skin paddle are closed primarily.



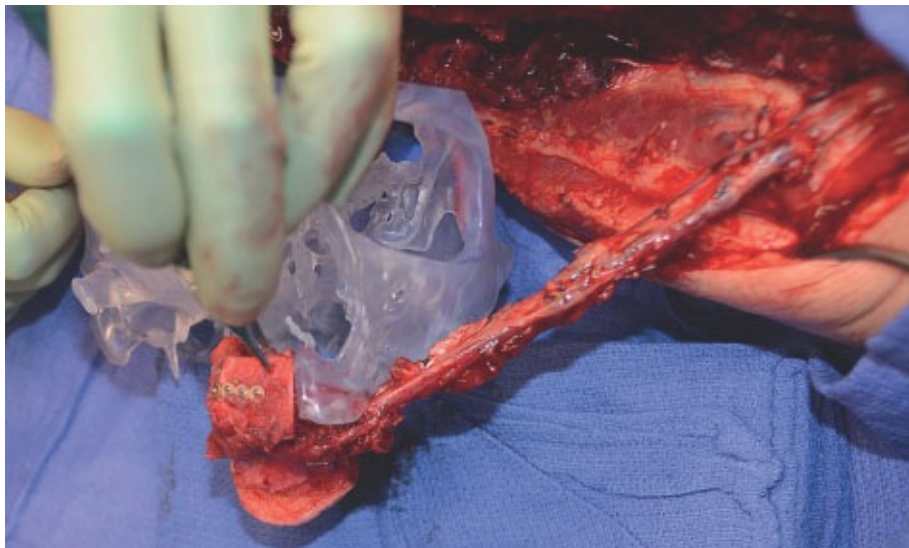
TECH FIG 4 • Elevated, osteotomized, and reshaped fibula flap with vascular pedicle still attached.

■ Free Fibula Flap Customization, Skeletal Fixation, and Inset

- The free fibula flap's versatility makes it applicable to different defect types (see **FIG 3**).
 - Small defects: can be reconstructed using a single linear bone segment (Class I).
 - Multiple osteotomies: the fibula can be fixated into a polygonal chain of bone segments that can be shaped to accommodate contoured defects (Class I, II, III, IV) or increase the vertical height of the flap (Class II, IV).
 - Soft tissue adaptability: multiple skin paddles based on individual

septocutaneous perforators can be created.

- Dead space obliteration: the flexor hallucis longus, tibialis posterior, or soleus muscle can be included with the flap.
- Mock bony inset can be performed in custom 3D-printed/stereolithographic model of recipient site skeletal anatomy, with adjustments made as needed (**TECH FIG 5**).
- The reshaped fibula is inset and fixated onto the recipient site bone using 2.0-mm miniplates using monocortical screws.
 - The skin paddle (with or without a muscular component) can be gently rotated based on the main perforator to achieve proper orientation.
- Donor and recipient vascular pedicles are approximated and length is trimmed to prevent kinking.
 - Anastomoses are preferably performed end-to-end with interrupted 9-0 nylon sutures. Venous couplers can also be used at the surgeon's discretion.
- Soft tissue inset
 - Internal or external points of compression to the anastomosis sites must be avoided.
 - Open or closed drains are used to avoid restrictive fluid collection.
 - Meticulous hemostasis is performed at recipient site to avoid active bleeding or hematoma formation.
 - Soft tissues and skin are closed.



TECH FIG 5 • Prior to full elevation, the fibula flap is inset onto a 3D-printed model of the patient's

craniofacial skeleton and maxillary defect, allowing the surgical team to verify that size and shape of the flap conform to the operative plan.

■ Anticipated Secondary Surgeries

- Phase 2+ goals: contour bone and/or soft tissues, and address position of adjacent subunits when applicable (eyelids, nose, etc.) using reconstructive surgery armamentarium.
- Neomaxilla may require distraction or stabilization.
- Flap soft tissues may require debulking procedures.
- Cheek soft tissues may require augmentation via fat grafting or additional free tissue transfer.
- Maxillary defects involving the dentoalveolus and the inferior orbital rim (Class II and IV) may require additional soft tissue augmentation in the periorbital and malar regions.

PEARLS AND PITFALLS

Indications

- Anticipate the need for multiple stages and incorporate secondary surgeries into reconstructive plan
- The full extent of the defect and precise composite tissue requirements must be defined before initiating flap elevation
- Early intervention is essential in high-energy traumatic defects

Flap design

- The ample bone can be osteotomized and reshaped to reconstruct a variety of composite midfacial defects
- Focus on functional structural support, not exact replication of absent bone
- Muscle can be included to obliterate dead space
- Generous skin paddle can be elevated based on septal perforators

Approach

- Employ efficient two-team approach
- Protect the common peroneal nerve proximally
- Exclude proximal and distal fibular segments to prevent knee and ankle instability

Computerized surgical planning	■ Facilitates precise design of the bone segment ■ Predicts corrective osteotomies at recipient site for snap fit ■ Streamlines bone inset and fixation ■ Reduces ischemia time
Watertight soft tissue closure	■ Avoid communication with oral cavity
Postoperative management	■ Avoid restrictive dressings in head and neck ■ Administer DVT prophylaxis if not otherwise contraindicated ■ Close monitoring of hemodynamic stability and flap viability ■ Open communication with postanesthesia and/or ICU team to avoid vasopressor therapy or compression whenever possible

POSTOPERATIVE CARE

- Patients often remain intubated up to 48 hours after surgery to prevent early respiratory complications due to airway secretions or edema.
 - This expedites emergent returns to the operating room.
- Strict monitoring of hemodynamic status, urine output, and fluid balance is mandatory.
 - Vasopressors are avoided unless other interventions such as fluid boluses, etc. have failed to stabilize the blood pressure.
- Deep venous prophylaxis is useful in most patients. However, concomitant injuries or intracranial surgery may be a relative contraindication and should be coordinated with anesthesia and the other surgical teams.
- Dressings and other restrictive materials are preferably avoided in the head and neck.
- Assessment of the flap's skin island must be aggressive to increase the likelihood of salvage in the case of vascular compromise, particularly in the first 24 to 48 hours.
 - Clinical monitoring of color, temperature, and capillary refill.
 - Doppler pencil probe monitoring at the site of anastomosis or available exposed surfaces.
 - First 24 hours: every 30 to 60 minutes.
 - Postoperative day 2 to 3: every 60 minutes.
 - Subsequent days until discharge: every 6 hours.
- Donor site:
 - The donor leg is placed in a boot or posterior splint with the ankle at 90

degrees, a monitor for signs of vascular insufficiency or compartment syndrome.

- Suction drains are evaluated daily and removed once less than 30 mL of serum is collected in 24 hours.
- There will be no ambulation initially, and the leg will remain elevated until the skin graft is fully healed.
- Upon ambulation, partial weight bearing will gradually transition to full weight bearing.
- Bone union and position can be assessed with serial CT scans (**FIG 6**).

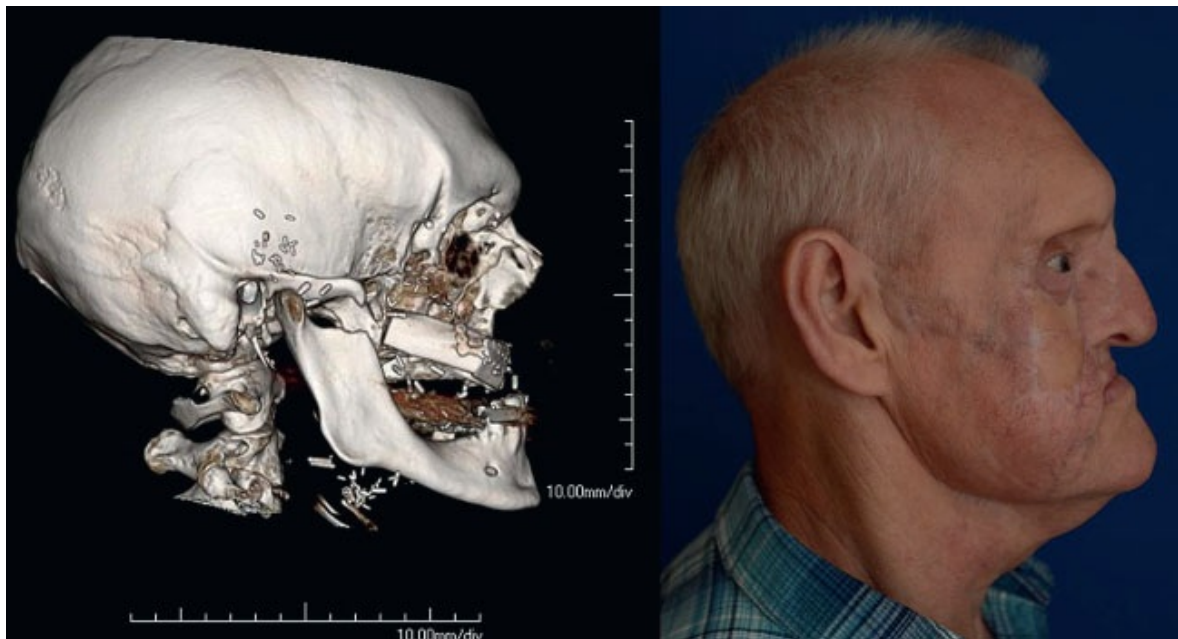


FIG 6 • Postoperative CT and photograph of the patient in **FIG 5**. CT image shows that the operation has been performed according to the virtual plan, resulting in successful restoration of midface contour.

OUTCOMES

- In Chang et al.'s series of 116 free fibula flaps, increased rates of partial flap loss and total complications were recorded for ischemia times exceeding 5 hours (tourniquet plus microvascular clamp).⁶
- Marre found a higher risk of vascular compromise after 1.5 to 2 hours of ischemia time in a series of 182 deep inferior epigastric perforator flaps.⁷

- Seruya et al. compared CSP-assisted (10) vs conventional (58) free fibula flap craniofacial reconstruction.⁸
 - Short- and long-term outcomes were comparable.
 - Total ischemia time was significantly shorter in CSP group; total operative time was shorter but not significant.
- Avraham et al. reported high rates of dental rehabilitation, increased reconstructive complexity, and decreased total operative time in a series of 54 CSP mandibular reconstructions.⁹
- Ch'ng and colleagues described a series of 54 patients receiving a free fibula flap to reconstruct the maxilla or mandible and subsequent osseointegrated implant dental rehabilitation after oncologic resection.¹⁰
 - Of 243 implants, 91.8% were retained at median 3-year follow-up.
 - Risk of implant failure without radiation was 5.1%.
 - Failure when implants were placed after radiation was 13%.
 - Failure when implants were placed before radiation was 18.6%.

COMPLICATIONS

- Up to 30% overall donor site morbidity has been reported.
 - Infection
 - Wound dehiscence
 - Skin graft failure
 - Paresthesias distal to donor site
 - Great toe flexion contracture
 - Tibial curvature/valgus deformity in children
- Recipient site complications:
 - Infection
 - Hematoma
 - Lower eyelid ectropion (delayed reconstruction)
 - Nonunion of the neomaxilla
 - Arterial or venous thrombosis requiring return to the operating room
 - Partial or total free flap failure

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9 Soft Tissue Flaps for Maxillary Reconstruction

CHAPTER

Ahmed M. Hashem and Brian R. Gastman

DEFINITION

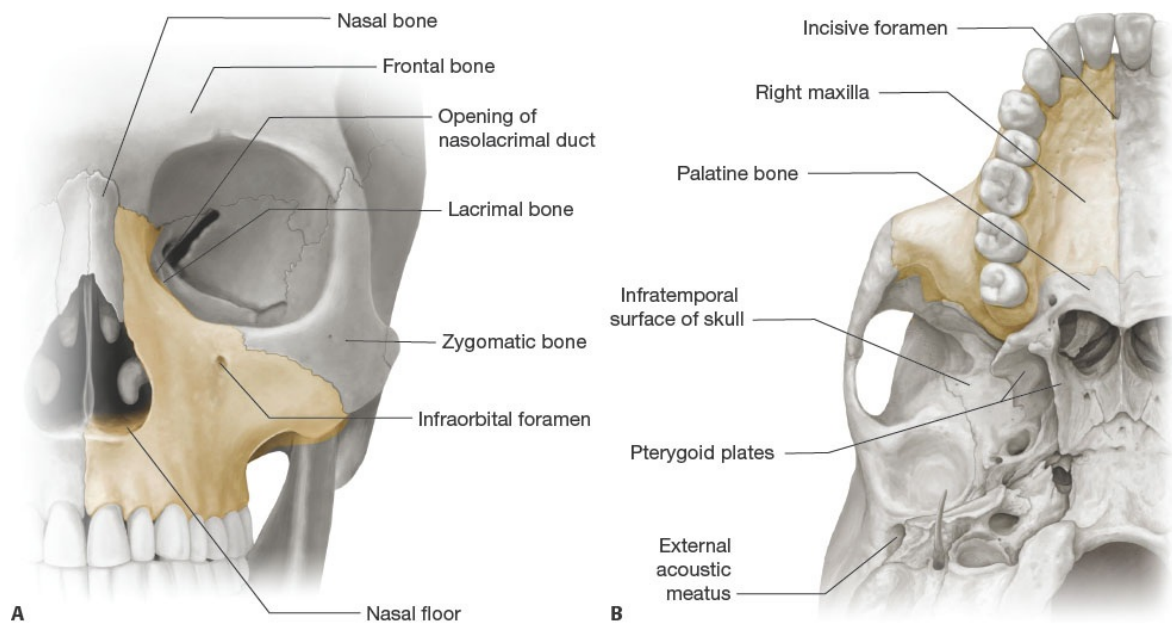
- Maxillary reconstruction is the process of rebuilding and coverage of midface and cheek defects.
- Tissue loss often results from oncologic resections but can also occur secondary to blunt or penetrating trauma and, less commonly, from necrotizing infections.
- The loss of critical soft tissue components such as the lower eyelid, the nose, the upper lip, and oral commissure adds significant complexity to the reconstruction.
- The functional implications involve speech, mastication, and deglutition.

ANATOMY

- The maxilla is a complex structure occupying the midface.
- Conceptually, it is a six-walled construct (hexahedron) bounded by the orbit superiorly, the palate and oral cavity inferiorly, the nasal airway medially, and the infratemporal fossa and cranial base posteriorly.
 - Anteriorly and laterally, it forms the contour of the cheek (**FIG 1A,B**).¹
- The maxillary sinus is a mucosa-lined air cavity in the maxillary process that drains into the middle meatus of the nose.
 - The sinus is rudimentary at birth but undergoes rapid expansion 6 to 7 years after puberty.
- The skeletal framework consists mainly of the maxillary and zygomatic bones, which articulate with parts of the pterygoid, palatine, lacrimal, ethmoid, and sphenoid bones (see **FIG 1A**).
- The vertical maxillary buttresses and the horizontally oriented alveolar process

define the contour of the midface, contribute to vertical facial height, carry the dental elements of the upper jaw, and support the upper lip.¹

- The soft tissues comprising the skin, lining mucosa, and intervening facial musculature constitute the lower eyelid, the cheek, the upper lip, and oral commissure.¹
- From a reconstructive standpoint, it is critical to appreciate that the maxilla forms the floor of the orbit, the roof of the mouth (the palate), and the lateral nasal wall including the lacrimal system.¹
- From a functional perspective, its integrity is critical for normal speech, mastication, and deglutition.¹



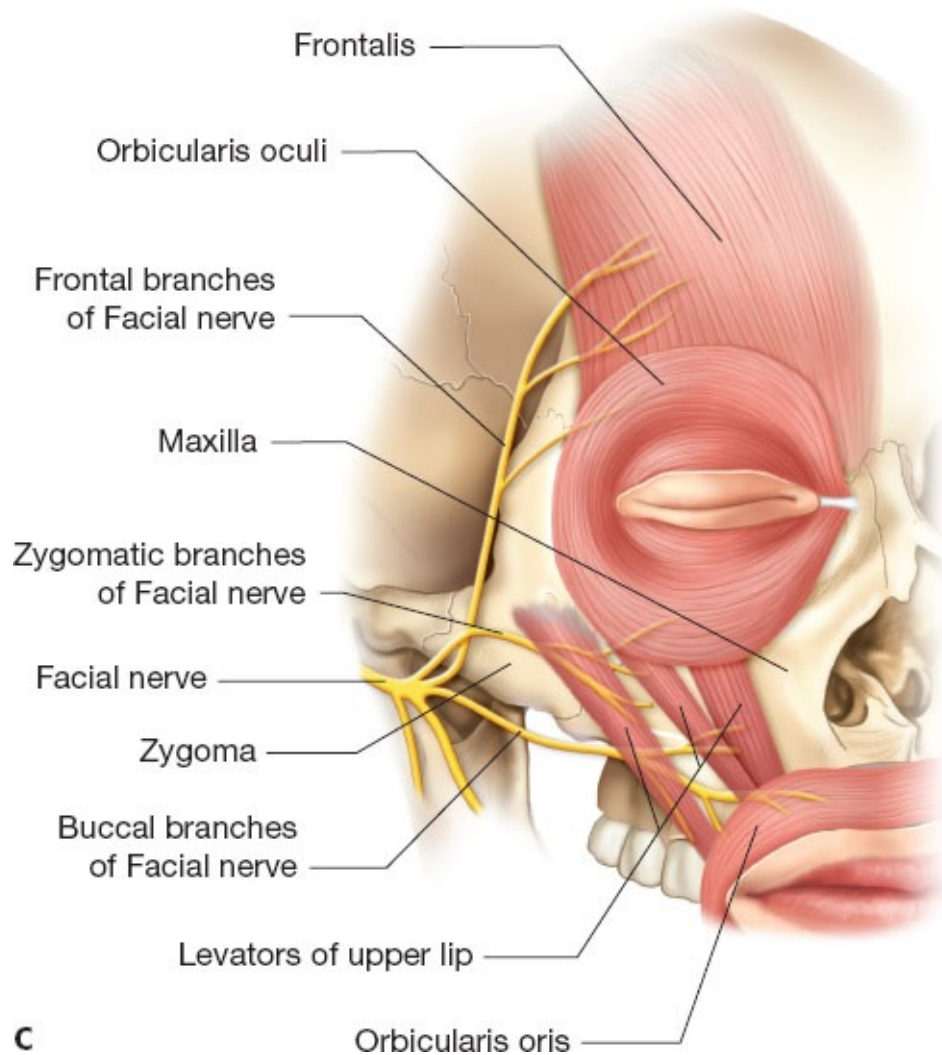


FIG 1 • A. Left maxilla (frontal view). Bony articulations of the maxilla. The maxilla shares in the formation of the orbital floor and forms the lateral nasal wall. **B.** Right maxilla (inferior view). The maxilla forms the roof of the mouth (the palate) and is related posteriorly to the infratemporal fossa and cranial base. **C.** Right maxilla. The maxilla is related to the critical facial muscles (orbicularis oculi, orbicularis oris, levators of the upper lip) and the frontal, zygomatic, and buccal rami of the facial nerve.

■ Anteriorly, it is related to the facial and angular arteries, whereas posteriorly, it

is in close proximity to the internal maxillary artery, the pterygoid venous plexus, and the last four cranial nerves.

- The zygomatic and buccal branches of the facial nerve ramify in the sub-SMAS plane of the cheek to supply the orbicularis oculi, the orbicularis oris, and the levators of the upper lip (**FIG 1C**).
- The infraorbital nerve travels in the floor of the orbit to emerge on the cheek through the infraorbital foramen and provide sensation to the midface. The zygomaticofacial nerve also appears anteriorly through a foramen inferior to the lateral part of the inferior orbital rim.

PATHOGENESIS

- Maxillary defects occur in many cases secondary to tumor extirpation of malignancies originating in the paranasal sinuses, the nasal cavity, the palate, or the orbit.
- In other cases, aggressive malignancies arising from the intraoral mucosa, the cheek skin, or the salivary glands may invade the maxilla and require extensive composite tissue excisions.¹
- High-energy traumatic injuries (eg, gunshot wounds) constitute another cause of challenging maxillary defects.²
- Necrotizing inflammations like noma (cancrum oris)³ and malignant pyoderma in association with granulomatosis with polyangiitis have also been described.⁴
- Composite resections where lining, support, and external skin are missing can pose a significant reconstructive challenge.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete history should be obtained to identify comorbid conditions that may be optimized preoperatively.
 - A personal or family history of clotting/bleeding abnormalities should be elicited.
 - History of prior surgery, neck dissection, or radiation therapy of the head and neck should be noted.
- Physical examination of the head and neck should evaluate dentition, speech and swallowing, facial nerve function, and sensory innervation.
 - Changes in skin texture and quality, eyelid function and support, and mouth opening should be assessed.
- The expected resection should be envisioned and soft tissue and bony requirements estimated. Close collaboration with the ablative surgeon is crucial

in this regard.

- Assessment of potential local and distant tissue donor sites should be undertaken (eg, temporalis, pectoralis major, radial forearm, rectus abdominis, anterolateral thigh [ALT] flap).
- Allen test is useful for evaluation of the palmar arch in patients who may require a radial forearm flap.
- Assessment of soft tissue thickness and previous scars/surgery is important to identify first-line and second-line choices for reconstruction.

IMAGING

- Imaging modalities like CT scan and MRI are useful preoperatively to determine the size and extent of the tumor and understand the potential resulting defect. These studies are also useful in patients with acquired defects of the maxilla resulting from trauma or infections.
- A 3D CT scan helps with preoperative virtual surgical planning and manufacturing of custom-designed models, templates, osteotomy guides, and prebent plates and selection of optimum screw size and site especially if dentoalveolar reconstruction and functional occlusion are contemplated. However, these options are most useful for osseous reconstruction of maxillary defects.
- Duplex examination or CT angiography with 3D reconstruction is occasionally required to evaluate the neck vessels in difficult cases with prior neck dissection or radiotherapy.
- Postoperatively, positron emission tomography (PET) and CT scan will be of benefit to assess the operative bed for tumor recurrence if a free flap was employed.

NONOPERATIVE MANAGEMENT

- Custom-made obturators can be used to manage maxillary defects and can provide support for facial structures and separate the oral cavity from the maxillary sinus.
- Obturators restore intelligible speech, prevent nasal regurge, and provide aesthetic contours.
- Obturators may be useful in patients at high risk for complex reconstructive procedures or, on occasion, as salvage of a failed reconstruction.
- They may also be useful for small defects of the palate (<50% of the hard palate), providing rapid rehabilitation with no donor-site morbidity.

- In general, obturators are best for small defects in the hard palate and are more difficult to secure in larger defects that involve the hard and soft palate.
- Larger defects are more easily managed with free flaps resulting in superior restoration of speech and swallowing^{5,6}
- The use of an obturator requires close preoperative, intraoperative, and postoperative collaboration between the oncologic surgeon, reconstructive team, and a prosthodontist. The steps necessary for obturator creation include:
 - Fabrication of dental casts, analysis of occlusion, and preoperative modeling
 - Creation of a temporary obturator manufactured from heat-processed polymethylmethacrylate, which is strong enough to provide a stable and functioning construct but is still adjustable intraoperatively using a bur or drill to fit the surgical defect
 - Split-thickness skin grafting of the buccal surface of the cheek flap and bolstering with the temporary obturator, which is fixed with screws or wires
 - Postoperative evaluation and adjustments
 - Fabrication of a permanent prosthesis fashioned from durable cast metal base (eg, titanium) after maturation of the surgical cavity and conclusion of radiotherapy
- Use of obturators carries the advantage of visual inspection of the surgical site for tumor recurrence. This benefit, however, remains theoretical because reoperation is infrequent and modern imaging enables early detection. Nevertheless, many patients have been successfully served with these devices.
- Disadvantages of obturators include leakage and nasal regurgitation due to imperfect fitting, the need for frequent cleaning and successive refinements as the tissues remodel.

SURGICAL MANAGEMENT

- The development of microsurgical techniques enabled successful autogenous tissue reconstruction of complex maxillary and midface defects.
- The approach is largely dictated by the extent of the defect and the functional requirements.
- Simple defects can be closed with local soft tissue flaps and bone grafts when necessary and rarely pose a problem.
- Complex composite defects involving external skin cover, structural support, and lining require planning for restoration of orbital floor support, lining of the nasal airway, palatal reconstruction, and resurfacing of surface defects that may include the upper lips, eyelids, and nose. In addition, dental restoration is

necessary in most maxillary resections that involve the hard palate.

- In this context, the classification system described by Cordeiro and Santamaria¹ is useful to stratify maxillary/midface defects and evaluate their functional requirements. The resultant analysis is able to guide appropriate treatment strategies.¹ Based on this schema, maxillectomy/midface defects can be categorized as follows:
 - Type I defect (limited maxillectomy): Only one or two walls—*excluding the palate*—of the hexahedron are missing. Usually, there is an absence of the anterior wall in conjunction with either the medial wall or the floor of the orbit (**FIG 2**).¹
 - Type II defect (subtotal maxillectomy): The whole lower maxilla is absent (the dentoalveolar arch, the anterior, medial, and lateral walls, in addition to the palate), while the orbital floor is intact.
 - These are further subdivided into type II-A when less than half of the transverse hard palate is missing and type II-B when more than half of the transverse hard palate is resected (**FIG 3**).
 - Type III defect (total maxillectomy): The whole maxilla including the orbital floor is deficient. Type III defects are additionally split into type III-A if the orbital contents are preserved and type III-B if they are exenterated (extended maxillectomy) (**FIG 4**).¹
 - Type IV defect (orbitomaxillectomy): The orbit and maxilla are removed while sparing the palate. This may include resection of the anterior cranial fossa leaving the dura or brain exposed (**FIG 5**).¹
- The advent of vascularized composite allotransplantation (ie, facial transplantation) refined midface and maxillary reconstruction by replacing “like” with “*exact* like,” thus achieving a closer aesthetic match in terms of soft tissue and skeletal components.
- The risks of lifelong immunosuppression nevertheless limit the use of this modality, which is still considered experimental, to a highly select group of patients (eg, trauma).
- Gastman et al. published an extension of Cordeiro and Santamaria classification system¹ to address the added specific needs in evaluating patients presenting for facial vascularized composite allotransplantation.⁷

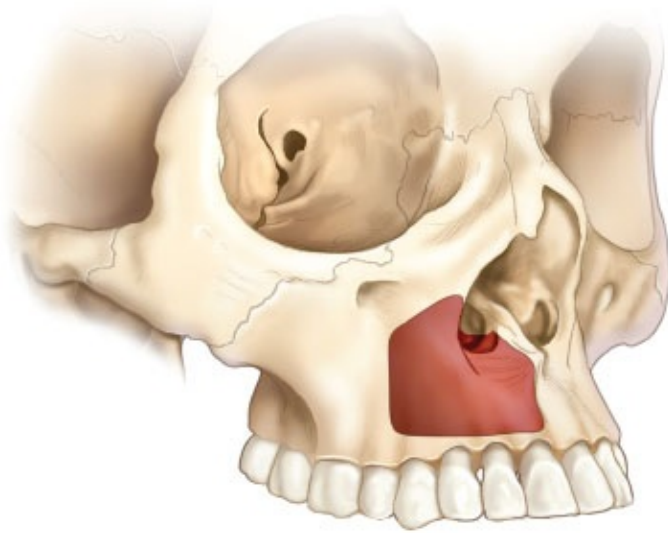
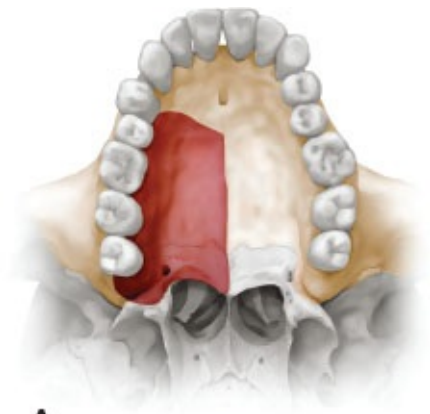
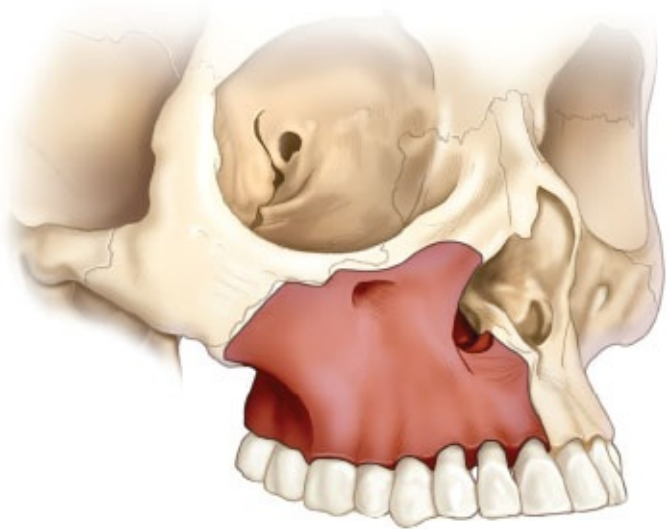
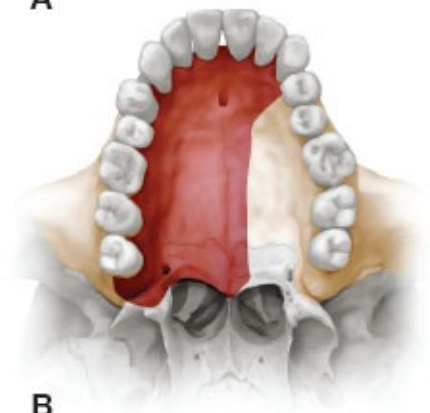


FIG 2 • In a type I (limited maxillectomy) defect, the anterior and medial walls are missing and occasionally the orbital floor; the palate is intact.



A



B

FIG 3 • Type II (subtotal maxillectomy) defect involves the lower maxilla including the palate. In type II-A, less than half of the transverse palate is missing. In type II-B, more than half of the transverse palate is resected.

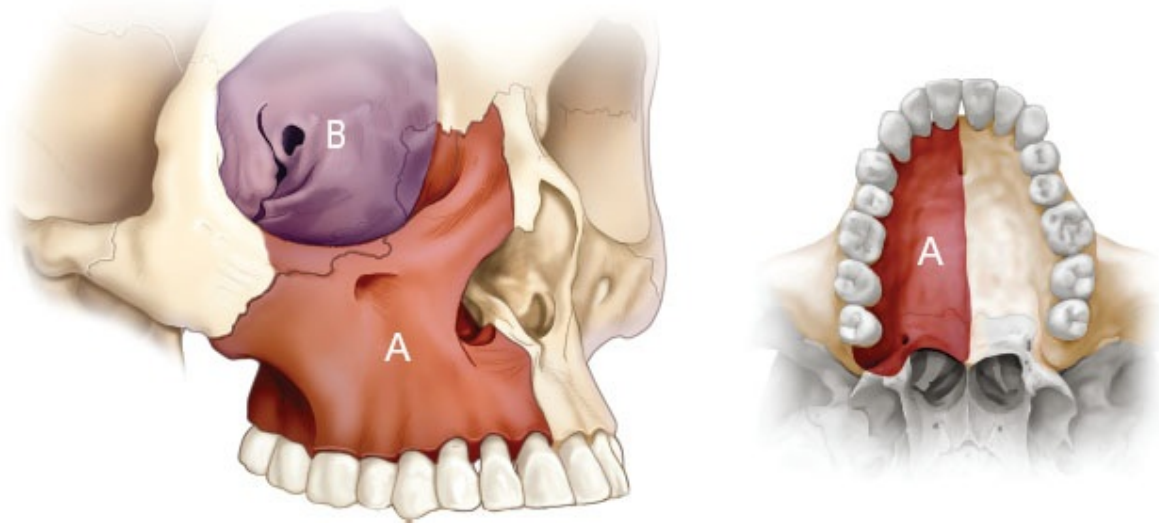


FIG 4 • Type III (total maxillectomy) defect. In type III-A, orbital contents are preserved. Type III-B is associated with orbital exenteration (extended maxillectomy).

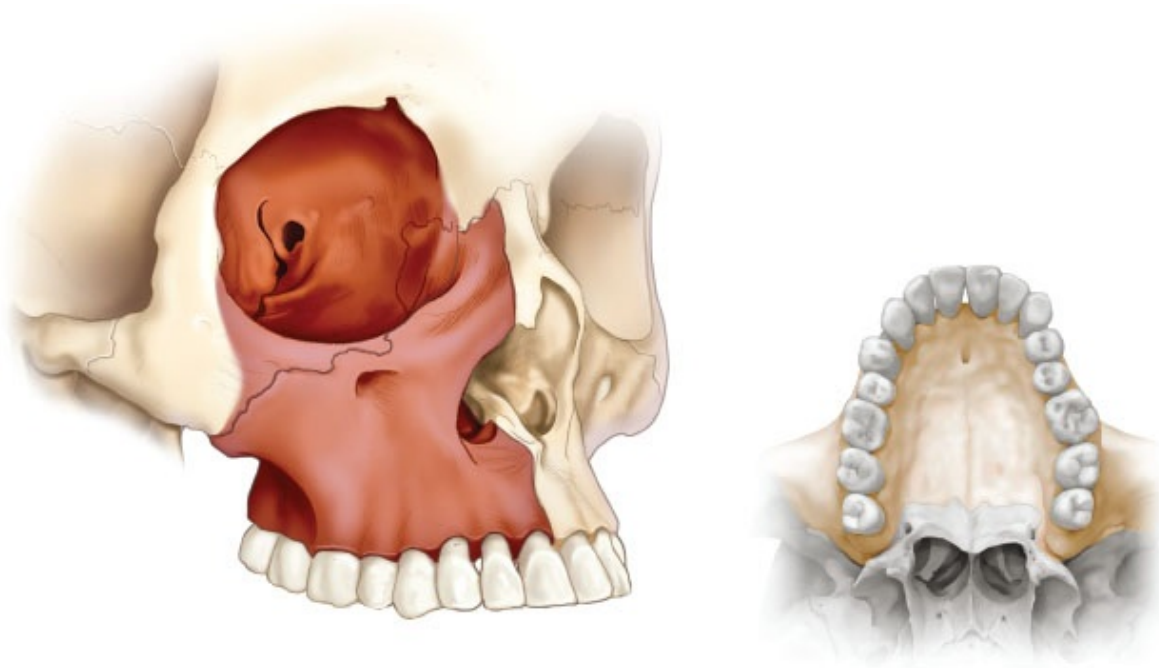


FIG 5 • In a type IV (orbitomaxillectomy) defect, the upper maxilla and orbit are missing, while the palate is intact.

Preoperative Planning

- Oncologic resections are by far the most common cause of maxillary defects. Consequently, adequate tumor clearance and tumor-free margins assume the highest priority in management. Close collaboration with the ablative surgeon is thus critical.
- Resections may involve functional impairment of speech and oral intake in addition to loss of globe support and eyelid cover.
- The reconstruction is best accomplished in a multidisciplinary setting with input from surgical oncology, medical oncology, radiotherapy, speech, nutrition, ophthalmology, and dentistry, in addition to reconstructive surgery.
- Complex defects are often composite and require three-dimensional planning to reconstruct lining, cover, and provide structural support. Accurate analysis of the functional needs is hence crucial. Accordingly, precise assessment of the extent of prospective resection based on clinical and imaging data should be undertaken.
- Adjacent critical soft tissue components including the eye, lip, oral commissure, and nose are evaluated.
- The neck is examined for previous scars and the availability of ipsilateral suitable recipient vessels.
 - Supplementary Doppler examination can be helpful. In case of any doubt, a CT angiogram with 3D reconstruction can clarify the vascular status in the cervical region.
 - Occasionally, the superficial temporal vessels are spared and can serve as recipient vessels near the defect, which facilitates the microsurgery.
- Potential donor sites are evaluated for vascularity and adequacy, the pedicle length is measured, the skin paddle is determined, and the potential for primary donor-site closure is gauged.
 - Allen test is essential if a free radial forearm flap is contemplated.
 - CT angiography is occasionally necessary to assess donor vessels for other soft tissue flaps such as the ALT or rectus flap.
- In type II and III resections, the quality of dentition is assessed, the occlusion is analyzed, and impressions of the maxillary dental arch and palate can be

taken to create stone casts.

- Alternatively, computer-aided virtual surgical planning and 3D printing can provide computer-generated templates. These guides are helpful for osseous reconstruction of maxillary defects but are less useful in soft tissue reconstruction.

Positioning

- The resection is usually accomplished in supine position with the head rotated to provide greater access.
- A shoulder roll can be placed between the spine to extend the neck and facilitate dissection of recipient vessels.
- Flaps harvested in this position (eg, free radial forearm flap, free rectus abdominis flap, free ALT flap) are advantageous for a two-team approach to conserve operative time.

Approach

- Ideally, donor-site dissection is started at the same time as the ablative procedure. If there is uncertainty regarding the extent of the disease, it is wiser to wait until the margins are clarified. The technical details for each flap donor site are described elsewhere.
- In dentoalveolar defects, simultaneous insertion of osseointegrated dental implants at the time of osseous free flap reconstruction will optimize chewing, speaking, and swallowing at an earlier date.^{8,9} Patient selection however is crucial because subsequent radiotherapy can result in a high failure rate with this approach.¹⁰

TECHNIQUES

■ Limited Maxillectomy for Type I Defect

- In these defects, the anterior and medial walls of the maxilla with or without the orbital floor have been resected and require reconstruction (note that palatal involvement converts the condition to either a type II or type III maxillary defect) (see **FIG 2**).
- Functionally, the lower eyelid and occasionally the upper lip and portions of

the lateral aspect of the nose are also missing and need reconstruction.

- These are usually small-volume defects with large surface area requirements.
- The bony needs are limited to orbital floor to provide globe support and avoid dystopia. This does not necessitate vascularized bone nor a biomechanically high load construct. Thus, a bone graft enveloped in the free flap tissue is usually sufficient.
- The free radial forearm fasciocutaneous flap is generally suitable in this setting. It supplies relatively less bulky tissue and can harbor two skin islands (one for external cover and the other for nasal lining). The flap can be de-epithelialized to provide matching contour and envelope bone grafts for orbital floor support.
 - Alternatively, an osteocutaneous design can be used to supply vascularized bone and minimize bone resorption.
- The reconstruction proceeds with analysis of the defect after oncologic resection and planning of the flap taking care to estimate the length of the pedicle necessary to reach recipient vessels as well as the size of the internal and external skin paddles.
- Recipient vessels in the neck or superficial temporal vessels are dissected and made ready for microanastomosis.
- If orbital floor reconstruction is required, a template of the defect is created using a cardboard or foil material (the wrapper for chromic sutures is ideal).
- This template is then used to harvest an iliac crest or split calvarial graft.
 - The inner table of the iliac crest is preferable in most cases due to its increased thickness and natural curve.
 - However, if a calvarial bone flap has been raised by neurosurgery during the resection, a bone graft can also be easily harvested from the inner table.
- The bone graft is used to repair the orbital floor defect and fixed into place using miniplates (preferably self-tapping) or wires.
- A subcutaneous tunnel is created to pass the pedicle for the flap to the recipient vessels.
- The radial forearm flap is dissected as outlined in the flap harvest section and allowed to reperfuse for 20 to 30 minutes once the tourniquet is taken down.
 - The pedicle vessels are marked with blue dye to facilitate tunneling of the vessels and prevent twisting or kinking in this process.
- Once the pedicle length, suitability of recipient vessels, and hemostasis are

ensured, the flap is disconnected and brought up to the head and neck.

- The pedicle vessels are carefully passed through the tunnel taking care to avoid twisting.
- The flap is then carefully inset into the defect (either completely or partially) to set the length of the pedicle.
- Microsurgical anastomosis is performed in the standard fashion.

■ Subtotal Maxillectomy for Type II Defect

- This defect involves the lower maxilla, including the palate (see **FIG 3**).
 - Defects of the hemipalate in which the anterior projection of the maxilla is maintained (ie, resection is posterior to the contralateral canine) can be reconstructed with soft tissue flaps. These are moderate-volume defects and, when using soft tissue flaps, in general require more tissues than a radial forearm flap (although this is possible in obese patients).
 - Defects of the anterior palate that result in loss of facial projection are best reconstructed with osteocutaneous flaps¹¹ or an obturator.
- The vertical rectus or ALT flaps are good options for soft tissue reconstruction of type II maxillectomy defects.
 - The donor site should be selected based on the anatomic features of the flap (thickness of the soft tissues) as well as volume requirements of the defect.
 - The ALT flap can be harvested with a portion of the vastus lateralis muscle that is used to obliterate the maxillary sinus. Similarly, a portion of the rectus muscle can be used in the same manner.
 - In general, the use of adipose tissues for volume restoration is preferred over muscle due to the loss of facial volume that will occur when the muscle atrophies.
 - Similarly, the use of a muscle flap alone in obese patients should be avoided if possible due to the expected atrophy of the muscle and loss of facial volume. In these cases, a radial forearm flap may be a better option.
- Passing the flap pedicle medial to the mandible (ie, behind the soft palate) is the shortest route to the recipient vessels in the neck. The superficial temporal vessels can also be used; however, this orientation can make the inset of the flap more difficult.
 - It is easiest to pass the pedicle through the tunnel prior to inseting the flap.

- The rectus or ALT flaps are usually oriented vertically to repair the palatal defect.
 - Usually, a skin paddle measuring 4 to 5 cm in width is needed for hemipalatal reconstruction.
 - The use of a very wide flap should be avoided as this results in a convex palate that complicates postoperative eating and dental rehabilitation.
 - The goal is to recreate the concavity of the palate; however, this is not always feasible with soft tissue flaps and may require secondary revision.

■ Total Maxillectomy for Type III Defect

Total Maxillectomy with Orbital Preservation for Type III-A Defects

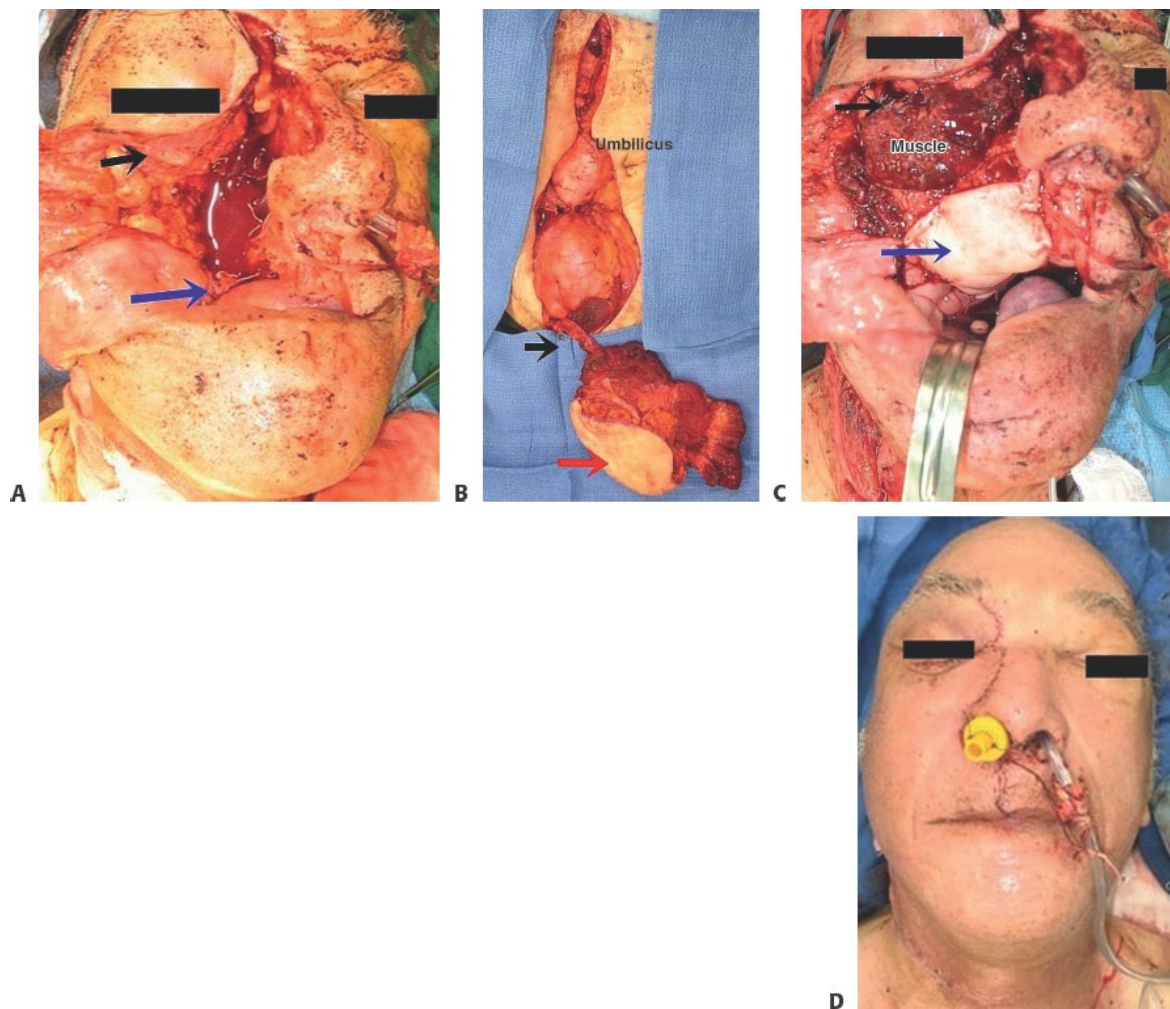
- In this category of maxillary defects, the whole maxilla is missing including both the palate *and* the orbital floor (see **FIG 4**). The orbital contents are spared, however, and thus orbital floor reconstruction is necessary to avoid orbital dystopia and diplopia and preserve binocular vision.
- The reconstructive goals include orbital floor reconstruction, obliteration of orbitonasal and orbito-oral communication, palatal resurfacing, and restoration of malar contour and in some cases external skin cover.
- The orbital floor can be reconstructed using split calvarium or iliac crest grafts as outlined above.
 - These bone grafts are sandwiched between the preserved orbital contents cranially and a free flap caudally.
 - Alternatively, an ipsilateral temporalis muscle flap can be used to cover the inferior border of the bone graft and separate it from the maxillary sinus, while an obturator is used to manage the oronasal communication.^{1,12} This approach is probably best reserved for patients who are not suitable free flap candidates and who will not require postoperative radiation therapy.

Total Maxillectomy with Orbital Exenteration or Extended Maxillectomy for Type III-B Defects

- This defect includes the whole of the orbit and the maxilla in continuity (see **FIG 4**).
 - The anterior cranial fossa/roof of the orbit may be deficient with resultant brain or dural exposure requiring urgent coverage.

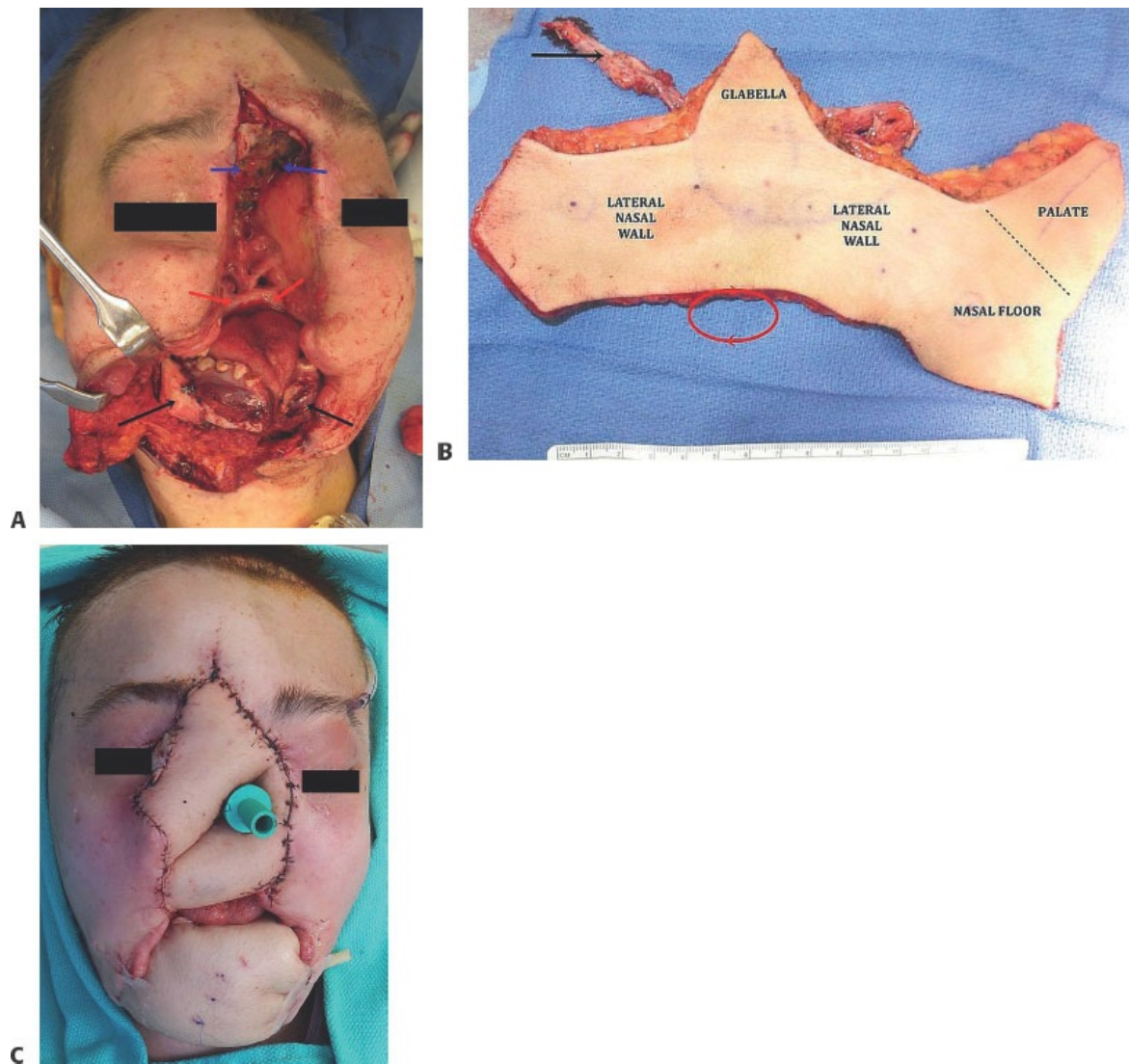
- The external soft tissue loss is often extensive and may encompass the eyelids, lateral nose, upper lip, and oral commissure.
- The reconstructive goals comprise restoration of nasal and palatal lining, coverage of brain or dura, and external skin cover if necessary.
- In type III defects, the malar projection will be maintained if the malar eminence is spared.
 - Otherwise, the soft tissue of the flap can be used to provide projection; however, this may atrophy with radiation and require revision surgery.¹
- To reconstruct the through-and-through defects and seal the orbit, single free flaps can be folded onto themselves to provide both external cover and internal lining.
- The selected free flap should fill the cavity of the maxillary antrum, obliterate any dead space, and possess multiple skin islands to provide nasal and palatal lining in addition to external skin cover.
- The free rectus abdominis myocutaneous flap has a robust and dependable blood supply.
 - The abundance of skin perforators permits versatility and yet reliability in designing multiple skin islands to address palatal and nasal lining in addition to external skin cover.¹² The pedicle length is usually sufficient to reach the ipsilateral neck and can be extended in select cases with more cranial defects to reach the neck without the need for vein grafts.¹³
 - The main drawback of this flap is the excess bulk in some patients that requires secondary debulking procedures.
 - Moreover, the flap does not provide vascularized bone to restore orbital floor support or allow dental implants (**TECH FIG 1**). Nevertheless, nonvascularized bone can be used for orbital floor reconstruction, and dental prostheses (eg, dentures) can be designed to optimize function.^{14,15}
- Lateral circumflex femoral artery–based flaps can also provide ample soft tissue and a long pedicle.
 - Multiple skin islands and muscle can be harvested on a single vessel using the transverse and descending branches.
 - Excess adipose tissue can create a bulky reconstruction, however.¹⁶
 - Like the rectus abdominis myocutaneous flap, this is a soft tissue flap, and nonvascularized bone grafts will need to be used (**TECH FIG 2**).
- The ALT flap based on the descending branch of the lateral circumflex femoral artery is particularly versatile in midface/maxillary reconstruction.

- To achieve sufficient pedicle length, it is necessary to dissect the vessel up to its takeoff from the lateral circumflex femoral artery.



TECH FIG 1 • **A.** Type III-A right maxillary defect following total maxillectomy with orbital preservation. The orbital floor (*black arrow*) and the palate (*blue arrow*) are missing and will need to be reconstructed. **B.** Elevation of a vertical rectus abdominis myocutaneous flap based on the inferior epigastric vessels (*black arrow*). The skin island (*red arrow*) is designed to fit the palatal defect. **C.** Showing the flap inset. The skin paddle was used to reconstruct the palate (*blue arrow*). The orbital floor was restored with

a titanium mesh (*black arrow*) that is sandwiched between the orbital tissue cranially and the free flap caudally. The muscle was used to fill in the dead space. **D.** Postoperative picture after closure of the skin incision.



TECH FIG 2 • A. Central face high-energy avulsive injury involving the mandible, the alveolar process, and the palate, in addition to the nose and cranial base. The *black arrows* point to the remnants of the mandibular arch, the *red arrows* point to the remaining

part of the posterior palate, and the *blue arrows* point to the cranial base. **B.** Harvesting of a free ALT flap designed to be tubed and folded to reconstruct the lateral nasal wall, the nasal floor, and the palate. The *black arrow* points to the vascular pedicle. The red dotted line denotes the axis where the flap will be folded to form the nasal floor on one side and the palate on the other. The red ellipse indicates the border that will be tubed to create a nasal passage. **C.** Early postoperative appearance after reconstruction. The lower lip and lower jaw were restored with a free osteocutaneous fibula flap.

- With a perforator design, it is usually possible to achieve enough length to reach the facial artery in the neck.
- If the superficial temporal vessels are intact and preserved, they constitute a reasonable alternative recipient. This simplifies the microsurgery.
- Prior to surgery, it is prudent to evaluate the thickness of the subcutaneous tissue of the lateral thigh, which is variable in different age groups, among both sexes, and according to body habitus and fat deposition.
- This is critical in maxillary/midface reconstruction, which frequently requires folding of the flap to accommodate the complex multiwalled nature of the maxilla (hexahedron).
- The design of the flap should consider the location of the pedicle in relation to the recipient vessels. Errors in design can render the reconstruction more challenging.
 - The flap can be easily folded upon itself to provide cover and lining of multiple surfaces (**TECH FIG 2B**).
- A suprafascial dissection can result in less bulk and is not much more challenging in harvesting the flap.
 - The advantage is a better thigh contour at the donor site especially if grafting is necessary.
 - On the other hand, inclusion of the deep fascia can be useful to substitute for absent dura in respective defects.
- The reconstruction with the ALT is often bulky and requires secondary

revisions to optimize appearance.

- The donor site rarely causes a problem even if a complex design is used.
- Free iliac crest with internal oblique muscle based on the deep circumflex iliac artery can provide vascularized bone to reconstruct the orbital floor and simultaneously provide sufficient bone stock for dental implants.
 - The internal oblique muscle tissue can obliterate the dead space and seal the oral and nasal communication.
 - Subsequent epithelialization of the muscle surface restores a near-normal lining.
 - Harvesting can be more difficult than other flaps, however, and the pedicle length is limited.⁵
- Flaps based on the subscapular/thoracodorsal axis constitute another alternative.
 - The latissimus dorsi, the serratus anterior, and the teres major can be harvested in conjunction with parts of the scapula nourished by the circumflex or angular branch, thus supplying plenty of muscle in addition to vascularized bone.
 - The skin can be included as a musculocutaneous or perforator-based flap.
 - Bone stock is less robust compared to the iliac crest free flap, but the pedicle is longer.
 - Although dissection is less challenging than the iliac crest free flap, the main drawback is that a two-team approach is not feasible. Furthermore, shoulder motion can be problematic in the early postoperative period.^{5,17,18}

■ Orbitomaxillectomy for Type IV Defects

- In these defects, the upper maxilla and orbit are missing while the palate is intact (see **FIG 5**).
 - Again, the brain or dura may be exposed and may need urgent coverage.
- The reconstructive goals include sealing of the anterior cranial fossa (to manage oronasocranial communication), restoring the nasal airway, reconstruction of the palate, obliteration of the maxillary sinus, and, in some cases, external skin cover.
- A multi-island free flap with large volume is needed to achieve these goals and fill the resultant dead space.
- The free rectus abdominis myocutaneous flap has several advantages as

described above.

- Most relevant is the potential to extend the pedicle length to reach the neck vessels in these more cranial defects.
- Lateral circumflex femoral-based flaps (eg, free anterolateral thigh flap) constitute a reasonable alternative since they possess a long pedicle, can include additional muscle and fascia, allow versatility in design, and supply plenty of soft tissue with limited donor-site morbidity.
- The rectus flap is oriented in the vertical fashion as described for type II defects, and the pedicle is passed medial to the mandibular border to the neck vessels.

■ Critical Soft Tissue Component of the Face

Upper Lip and Oral Commissure

- The upper lip and oral commissure can be involved in all types of maxillary defects.
- Reconstruction of the oral sphincter is extremely important from a functional standpoint to preserve oral competence and avoid drooling, which can be extremely disturbing.
- Currently, there is no satisfactory method to recreate the oral sphincter mechanism using tissues other than the lip itself.
- Use of the remaining tissue to reconstruct the oral sphincter in form of a lip switch procedure (Estlander flap or the Karapandzic flap) is therefore indicated in all these defects unless the defect involves greater than 80% of the lip.^{1,14,14}
- Incorporating the free flap tissue into the oral aperture will lead to oral incompetence, drooling, and worse functional outcomes.¹
- Microstomia is generally less disturbing than the sequelae of oral incompetence.¹

Eyelids

- The eyelids can be involved in type I, type III, or type IV defects.
- In type III-B and type IV defects, this will be part of the orbital exenteration procedure. Eyelid reconstruction in these cases would only serve to cover a prosthesis and generally yields poor results.
 - A glue-on type of prosthesis can provide a reasonable alternative.¹

- In other categories of maxillary defects, the eyelids are usually preserved, but ectropion is a common complication following free flap reconstruction. In these cases, a secondary tarsal strip, skin grafting, and canthopexy are required.

Nose

- Loss of nasal tissue to different degrees can be encountered in a variety of maxillary defects.
- Functional restoration of the airway is independent of aesthetic reconstruction of the external nose.
- Ipsilateral local tissues (eg, nasolabial flap, mucoperichondrial septal flaps) may not be available.
- Concomitant nasal reconstruction at the time of maxillary coverage may lead to poor outcomes.
- Either a prosthesis or alternative surgical procedures, such as contralateral forehead flaps or even a second free flap, can be employed in a delayed fashion.

PEARLS AND PITFALLS

Oral competence

- Maxillary defects that involve a significant excision of the lips or oral commissure risk the development of oral incompetence with poor function and constant drooling. If less than 80% of the upper or lower lip is missing, it is better to restore the oral sphincter by way of a lip switch procedure (Estlander flap or the Karapandzic flap) rather than simply incorporating the free flap into the lip, which will result in oral incompetence and worse functional outcomes. Microstomia is a risk though following a lip switch procedure especially if a large portion of the lip was excised and postoperative radiotherapy is administered. Nevertheless, microstomia is less problematic than constant drooling.¹⁹

Intraoral lining

- In composite defects extending to the oral cavity, restoring the intraoral lining is essential to a successful maxillary reconstruction. Using the more proximal tissue that is nearest to the vascular pedicle and has the most reliable blood supply for this purpose is advisable.¹² First, it sets the length of the pedicle for microvascular

	anastomosis, and second, it lowers the risk of major oral leakage. This permits early oral intake and avoids contamination near the microsurgical anastomosis with attendant risks of secondary hemorrhage. It is easier to manage loss of external coverage and employ a secondary flap than to treat a situation of major oral leak due to necrosis of intraoral lining with obligatory cessation of oral feeding, infection, and pending risks of secondary hemorrhage.
Dental rehabilitation	■ Preservation of the ipsilateral canine and at least one molar can be extremely useful for dental rehabilitation to allow the alignment and fixation of dentures. ■ Reconstruction of the palate to provide a concave surface facilitates dental rehabilitation and preparation of a denture in patients who undergo soft tissue reconstruction of the palate. Secondary revision with liposuction and skin excision is sometimes necessary to facilitate this process.
Ectropion	■ Providing sufficient skin for cheek reconstruction and anchoring the flaps to bone can help minimize this complication. A concomitant canthopexy or canthoplasty may also be helpful. ■ Secondary procedures such as skin grafting, a tarsal strip, or canthopexy/canthoplasty can ameliorate cases of postoperative established ectropion.
Orbital dystopia	■ Accurate reconstruction of the orbital floor at an appropriate clinical level and for optimum depth is mandatory to support the globe and avoid this complication. The inner table of the iliac crest and outer table of the calvarium have matching curvature and are sufficiently strong to avoid dislodgement during mastication. Fixation to the remaining bone can be challenging, and a tongue in groove technique can be helpful in this regard.¹⁴
Palatal lining	■ It is crucial to accurately measure the skin inset into the palate. The palatal skin should be smaller or equal to the defect to avoid prolapse of skin into the oral cavity and speech impairment. Suspending the flap to the cranial base can be a useful adjunct to avoid this complication.

POSTOPERATIVE CARE

- Free flap monitoring using clinical examination, Doppler, and infrared spectroscopy is mandatory since early intervention will maximize flap salvage.
- Care must be taken to avoid compression of the pedicle in the neck or in the preauricular area. Pillows should be used carefully (or not at all) to avoid wrapping around the neck and compressing the pedicle vessels. Similarly,

tracheostomy ties and other circumferential neck dressings should be avoided.

- Patients should be kept in a head-up posture and hemodynamic stability monitored.
- General tracheostomy care if applicable and nutritional support are essential.
- Speech, dental, and nutritional evaluation should ideally commence in the preoperative phase and rehabilitation started immediately postoperatively to optimize patient outcomes.

OUTCOMES

- Cordeiro and Chen retrospectively reviewed 100 flaps used for midface reconstruction following oncologic resections performed at the Memorial Sloan Kettering Cancer Center.¹⁴
 - Generally satisfactory outcomes were achieved in most patients with autogenous free flaps.
- Intelligible speech was restored in most patients who required palatal resection (43 of 44), especially when less than half of the palate was lost. They noted that preservation of the soft palate maximized speech outcomes and prevented velopharyngeal dysfunction.
 - When more than half of the palate was sacrificed, they recommended the substituting skin island to be accurately measured equal to or smaller than the defect to avoid intraoral prolapse. If needed, it can be anchored to the cranial base.^{1,14}
- Most patients (47 of 50) resumed an unrestricted or soft diet postoperatively.
 - Oral competence was preserved or restored in most maxillary defects requiring lip resection (11 of 12 patients) using a lip switch procedure.
 - Microstomia was encountered in 3 of 12 patients.¹⁴
- Mild vertical and horizontal diplopia was observed in 1 and 4 of 12 patients, respectively, following orbital floor reconstruction but led to minimal functional disturbances.^{1,14}
- Ectropion occurred in 10 of 21 patients but was usually mild or moderate (70% of cases).
 - Severe cases (30%) were improved with skin grafting, a tarsal strip procedure, or a canthopexy/canthoplasty.¹⁴
- Of 70 patients evaluated for aesthetic outcome, 41 were rated excellent (58.6%), 25 were judged as good (35.7%), and 4 were evaluated as fair (5.7%).
 - Aesthetic outcomes were largely dependent on the extent of outer skin

resection and whether eyelid, lip, or globe removal was necessary.¹⁴

COMPLICATIONS

- Free flap loss will usually require a secondary free flap.
- Ectropion
- Ocular dystopia
- Enophthalmos
- Velopharyngeal dysfunction
- Unintelligible speech
- Nasal regurgitation of fluid
- Drooling
- Microstomia
- Color and texture mismatch of external skin
- Bulky reconstruction

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Section V: Mandible

10 Mandible Reconstruction With Fibula Free Flap Using CHAPTER CAD/CAM Techniques

Jamie Levine, David Hirsch, and Lawrence Brecht

DEFINITION

- Recent advances in imaging, computer-aided design/computer-aided modeling (CAD/CAM) software, and 3D printing technology have enabled virtual planning of complex 3D osseous reconstruction of head and neck defects.¹⁻⁵
- Using these methods, we can now prepare exact models and customized surgical devices that facilitate and simplify reconstruction. Virtual surgical planning and customized surgical templates decrease the learning curve for osseous reconstruction of head and neck defects while simultaneously improving the precision of reconstruction.⁶
- This is important because traditional methods for surgical planning of these reconstructions have a steep learning curve and even small errors can lead to poor outcomes.
- CAD/CAM virtual surgical planning also increases collaboration with oncologic and dental colleagues leading to a more unified plan. This approach allows development of more creative solutions for complex defects that ordinarily would be difficult to visualize preoperatively.^{7,8}
- This chapter will provide step-by-step planning for mandible reconstruction using the fibula flap with CAD/CAM planning. This approach can easily be modified for use with other osseous sources (eg, iliac crest, scapula, etc.) or for reconstruction of other osseous defects of the head and neck (eg, maxilla).

ANATOMY

■ Mandible

- The mandible is a complex 3D structure with two symmetric points of articulation at the skull base forming the temporomandibular joint (**FIG 1A**).
- The mandibular body and the curved mental protuberance contain 16 sockets to hold the lower teeth. The ramus and condyle form the articulation points with the skull base.
- The mandible has two foramina.
 - The mandibular foramen is located on the internal surface of the ramus and serves as the entry point for the inferior alveolar nerve.
 - The mental foramen is on the external surface of the mandibular body, below the second premolar. The inferior alveolar nerve exits the mandibular canal at this location and then becomes the mental nerve.
- The mandible serves as the attachment point for multiple muscles, including the muscles of mastication that help coordinate movement of the mandible with chewing.
- The blood supply of the central mandible is derived from multiple sources including the inferior alveolar artery and periosteal branches from the surrounding musculature.

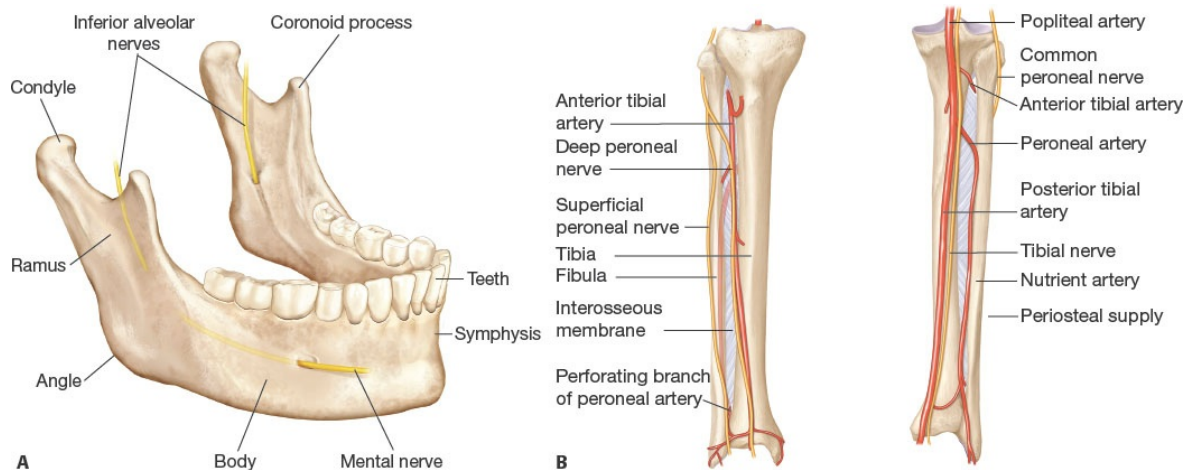


FIG 1 • A. Anatomy of the mandible. **B.** Anatomy of fibula flap.

■ Fibula flap

- The fibula is the preferred choice for mandible reconstruction in most

patients^{7,9} because of the following characteristics: the bone has a dual blood supply (periosteal and axial) enabling complex shaping of the bone; there is a large amount of bone available (20–25 cm) enabling reconstruction of subtotal mandibulectomy defects; the vascular supply is consistent and large caliber; the bone stock is sufficient for dental rehabilitation; and finally, because the fibula can be harvested simultaneously with the oncologic resection.

- The dual blood supply of the fibula enables surgeons to perform multiple osteotomies to achieve the complex shape of the mandible. However, in general, segments are planned.
- The blood supply for the fibula is derived from the peroneal artery and vein (**FIG 1B**).
 - The pedicle length is variable and depends primarily on the amount of bone that is needed and anatomic variability in the take off of the peroneal artery/vein from the tibioperoneal trunk. In general, the length of the pedicle can be planned preoperatively using virtual surgical planning and angiography.

PATHOGENESIS

- CAD/CAM virtual surgical planning can be used for acquired and congenital defects of the mandible. The most common cause of mandibular defects necessitating vascularized bone transfer is oncologic resection of the mandible for malignant tumors (**FIG 2**).
- These tumors include primary bone tumors (eg, osteogenic sarcoma) or more commonly, metastatic spread from squamous cell cancer of the soft tissues of the head and neck (eg, floor of mouth or tongue).
- Osteoradionecrosis is a common complication of radiation therapy of the head and neck and in some cases results in late defects of the mandible. These patients present with nonhealing wounds or pathologic fractures of the mandible and in some cases, benefit from resection of the necrotic bone and reconstruction with free flaps.
- Benign lesions such as ameloblastoma, giant cell tumors, odontogenic mandibular cysts, and odontogenic tumors (ie, ameloblastoma) also require resection and reconstruction. These lesions do not metastasize but can be locally aggressive and have a high risk of recurrence if not resected with appropriate margins.
- Traumatic injuries, and less commonly infectious etiologies (eg, refractory

osteomyelitis), resulting in bone loss or complex lesions with nonunions also require osseous reconstruction in select cases.

- Congenital defects of the mandible in rare cases require free tissue transfer with bone flaps. More commonly, these defects are treated with bone grafting or distraction osteogenesis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history and findings will depend mainly on the cause of disease process.
- For all patients, bone donor sites should be carefully assessed for blood supply, quality of soft tissues, and bone stock.
- Similarly, the anticipated defect in the mandible should be assessed for osseous and soft tissue needs and recipient vessels for microsurgery. Mouth opening, mastication, and swallowing should be examined.
- The quality and quantity of the teeth should be assessed and dental consultation should be obtained as needed.
- Dental rehabilitation (bone implants at the time of surgery or in a delayed fashion versus dentures) should be considered if feasible and discussed with the dental team.
- Medical comorbidities, prior treatments, planned treatments postoperatively, and prognosis should be assessed and noted whenever feasible.
- Patients with osteoradionecrosis or osteomyelitis may need to be optimized for treatment preoperatively using hyperbaric oxygen treatment, debridement, and antibiotic treatment as needed.

IMAGING

- Fine cut (1-mm-thick sections) CT scans of the mandible and fibula with 3D reconstruction is the best option for examining the bone and for planning of the reconstruction. MR imaging may also be useful in some cases to evaluate the surrounding soft tissues but is not useful for developing 3D bone models (**FIG 3**).^{1,2}
- The mandibular CT scan is usually performed as a noncontrast study because the primary need is to evaluate the bone anatomy and anticipated defects.

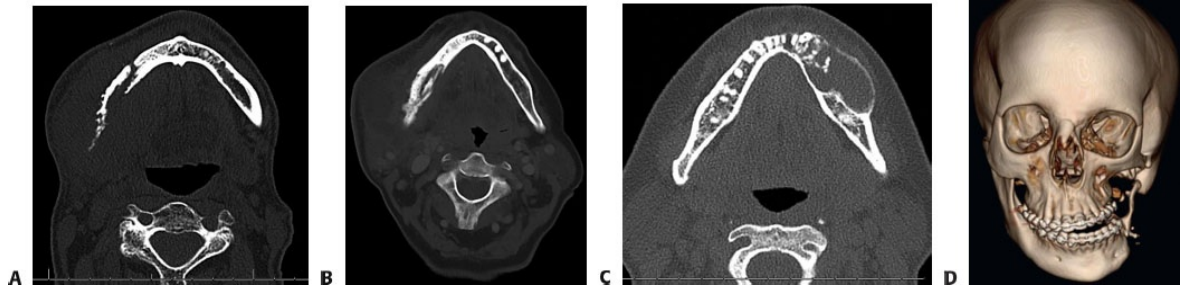


FIG 2 • Common causes of mandibular defects. **A.** Right mandibular osteoradionecrosis with surrounding infection. **B.** Squamous cell carcinoma of the right hemimandible. **C.** Left mandibular ameloblastoma. **D.** Treacher Collins syndrome with resorbing left mandibular rib graft.

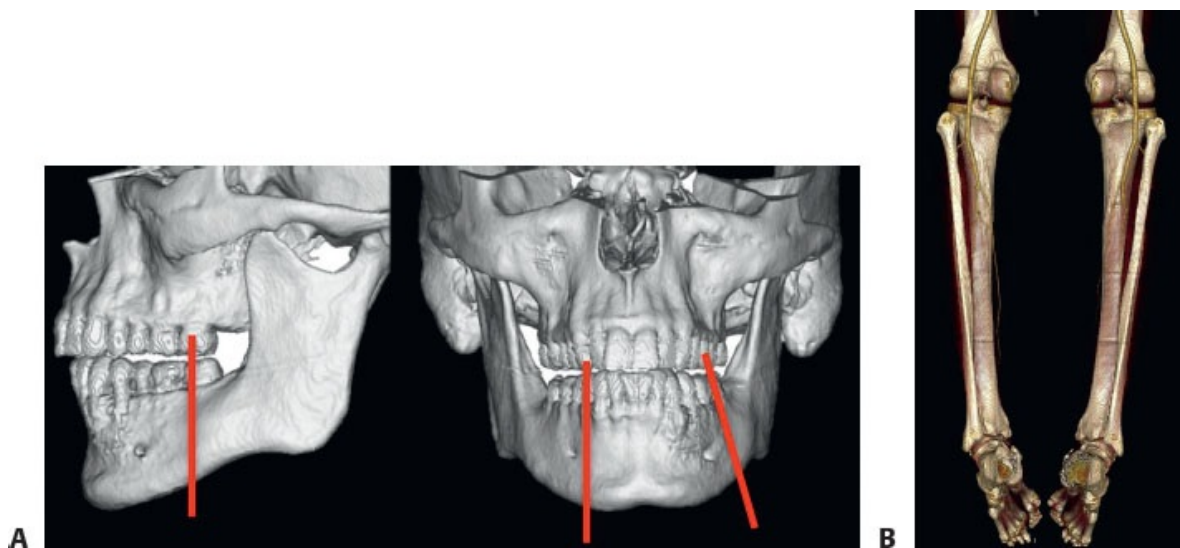


FIG 3 • **A.** Three-dimensional model of the mandible derived from thin cut CT scans demonstrating area to be resected (*red bars*). **B.** CT angiogram of the lower extremity and fibula anatomy.

- Imaging of the fibula flap is typically done with a CT angiogram to evaluate the osseous anatomy as well as the vascular blood supply. The angiogram is used to evaluate the vascular anatomy of the lower extremity (three vessel runoff, abnormal vascular anatomy), and the perforator anatomy of the skin paddle. This imaging helps with planning the placement of the osteotomies and

skin paddles.

- Although standard models of the fibula are available and may be used for planning, in our hands, CT scans of the patient's own fibula is more accurate since because is some variability in the shape of the bone that may alter the angles needed for shaping of the fibula.

SURGICAL MANAGEMENT

Preoperative Planning

- The CT scans of the mandible and fibula are used for preoperative virtual surgical planning with the oncologic surgeons, dentists (if necessary), and the reconstructive team.
- It is important for the ablative surgeon to be involved in the planning session to accurately plan surgical margins. In cases where there is doubt about the surgical margins, two separate plans can be prepared. This approach enables intraoperative modification of the virtual surgical plan depending on anatomic or oncologic findings. Thus, a “narrow” margin resection plan may be created as the initial plan; however, if intraoperative findings dictate larger resection, then the backup “wider” resection plan can be executed instead. This approach creates two separate cutting guides for the head and neck and fibula harvest plans (**FIG 4A**).

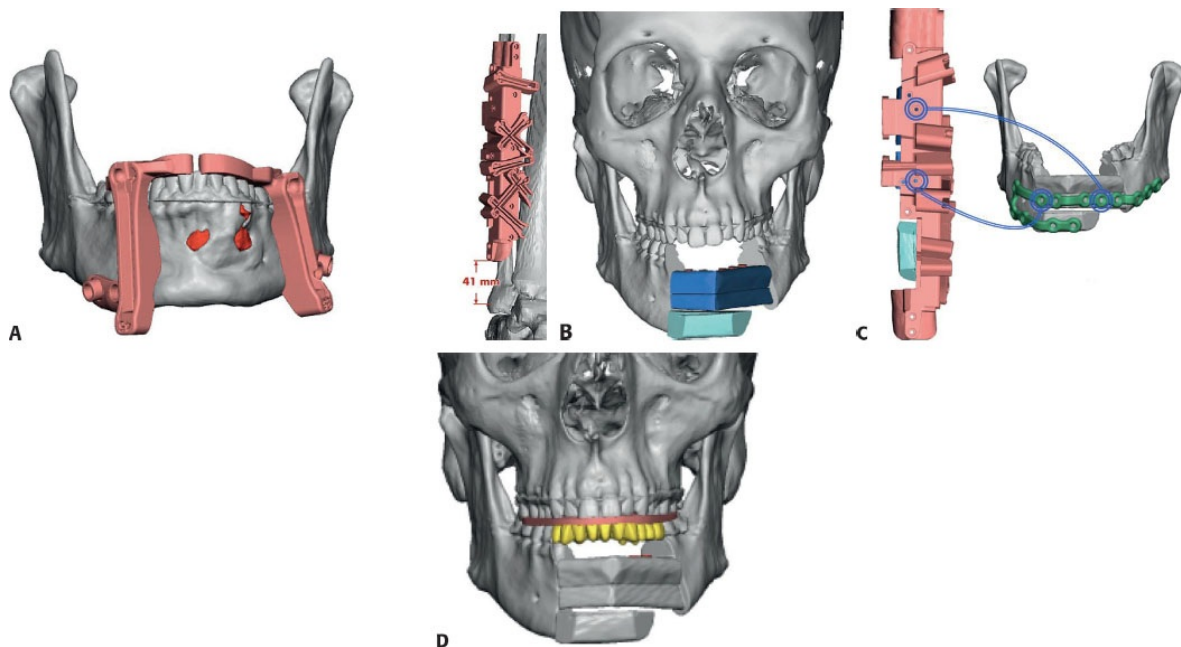


FIG 4 • A. Virtual surgical planning and design of

mandibular (*left*) and fibula (*right*) cutting guides. **B.** Top-down plan for mandible reconstruction. Double barrel fibula flap reconstruction is planned with positioning of the mandibular segment along the upper border of the mandible to facilitate dental implant placement. **C.** Fibula cutting guide with predictive holes for placement of prebent plates and positioning of double barrel segment. **D.** Final placement of dental implants with double barrel fibula flap reconstruction.

- We used to be concerned only with the position of the bone reconstruction, now we plan from the top down. We start with the jaws in occlusion during the virtual meeting, then the noninvolved jaw is removed, and we plan the surgical cuts (**FIG 4B**).
- Finally, if dental implants are planned, we position them with the dental team at this point. In general, we try to place our implants under opposing teeth. If creating a bridge, then we evenly spread out the implants to equilibrate forces (**FIG 4C,D**).

Positioning

- The patient is positioned supine with the neck extended using a shoulder roll.
- A roll (bump) is affixed on the OR table to position the lower leg at a 90-degree angle at the knee (**FIG 5**). A hip roll may be needed to shift the patient slightly away from the surgeon and facilitate positioning of the lower leg.
- Bony prominences and soft tissues are padded appropriately.
- The OR table may be rotated to facilitate positioning of the surgical, anesthesia, and nursing teams.

Approach

- In most cases, the fibula flap is harvested simultaneously with the head and neck resection. This approach decreases the surgical time and improves outcomes. However, in some cases, this is not feasible (eg, complex reconstructions, or cases in which it is not clear if the tumor is resectable). In these cases, fibula flap harvest is performed after the resection is completed.



FIG 5 • Placement of the bump on the OR table to help position the fibula intraoperatively.

- In general, it is possible to use the fibula flap from either side (ie, the flap that is ipsilateral or contralateral to the anticipated mandibular defect).
- The ipsilateral fibula flap will position the flap vessels laterally in the neck by simplifying the microsurgical anastomosis. In addition, because the septum is under the bone (ie, posterior to the fibula) in this flap orientation, the skin paddle may be easily used for extraoral reconstruction. The skin paddle in an ipsilateral flap can also be placed intraorally; however, because the septum needs to go up and over the mandible, the amount of skin available for intraoral reconstruction is more limited.
- The contralateral fibula flap (in relation to the mandible defect area) places the flap vessels medially in the neck by facilitating crossing over to the contralateral neck if necessary. In addition, in this flap orientation, the septum is above the bone thus facilitating intraoral placement of the skin paddle.
- With the right planning, either leg can be utilized for most cases.

TECHNIQUES

■ Fibula Flap Harvest

Design

- The bone and posterior septum are marked and a Doppler is used to localize skin perforators in the middle and distal thirds of the bone.
 - The position of these skin perforators can be checked with the preoperative CT angiogram.
- The size and shape of the skin paddle is marked to plan for intra- or extraoral reconstruction.
- Orient the skin paddle to incorporate the signal and the area designed for coverage either intraorally or otherwise. This should be done carefully because the fibula skin paddle has limited mobility in relation to the bone.
- Although not necessary in all cases, we almost always design and harvest a skin paddle. This can be used as a backup in case additional soft tissues are resected or the quality of the remaining soft tissues is questionable. In addition, the skin paddle can be used for postoperative monitoring.
 - In some cases, the vascularized fascia and de-epithelized skin paddle may be used to augment soft tissue defects to improve contour or to cover the fixation hardware and decrease the potential for erosion/exposure.
- A tourniquet is applied to the upper thigh and padded with Webril or gauze. We usually use a sterile tourniquet that is applied once the patient is prepped and draped.
 - The tourniquet is set to a pressure that is about 100 mm Hg higher than the systolic blood pressure.
 - The leg is elevated and partially exsanguinated using an Esmarch bandage (personal preference) or without a full exsanguination.
- Generally, 2 hours of ischemia are well tolerated. If longer periods are needed for flap harvest, the circulation can be re-established for 20 to 30 minutes and the tourniquet can be reapplied.

Incisions and Flap Elevation

- The lateral approach to the fibula is used. The anterior skin incision is performed, and the fascia is incised. The skin is elevated off of the underlying musculature taking care to avoid injury to the superficial peroneal nerve.
- The peroneus longus and brevis muscles are cut while applying tension on the muscles leaving a 5-mm cuff of muscle on the anterior surface of the fibula. Care should be taken in the upper part of the leg to avoid injury to the anterior tibial vessels and tibial nerve.
- The intermuscular septum is then incised.

- The posterior skin incision is performed, and the skin and fascia are elevated off of the musculature.
 - The septum is identified and perforating vessels in the septum are preserved.
 - Branches to the soleus muscle are ligated.
- The fibula is carefully separated from the soleus muscle and the perforating branches from the peroneal artery/vein to the soleus muscle are identified and divided.
- The flexor hallucis longus muscle (FHL) is identified and divided.
 - The amount of FHL that is harvested with the flap can be modified depending on the reconstructive needs. In some cases, very little FHL is needed (eg, anterior defects) and therefore the FHL muscle is carefully dissected away from the fibula.
 - In other situations, vascularized muscle can be used to obliterate soft tissue defects (eg, posterior defects of the mandible or patients with osteomyelitis). In these cases, the majority of the FHL muscle is harvested with the flap.
- The fibula is then osteotomized inferiorly and superiorly using an oscillating electric saw, taking care to avoid injury to the tibioperoneal trunk proximally.
 - This can be done by passing a right angle from below the fibula while directly visualizing the vascular trunk.
 - A malleable retractor or army-navy type retractor can then be placed around the bone to avoid inadvertent injury to the vessels.
 - Leave about 6 cm of fibula bone proximally and distally, and take slightly more if needed but leaving less than 4 cm of bone proximally or distally, may result in instability and require screw fixation.
- Bone clamps placed distally are used to pull the muscle out, and the distal peroneal vessels are identified and ligated.
 - The posterior tibialis muscle is then carefully incised taking care to avoid injury to the peroneal vessels that run deep to the muscle.
- The peroneal vessels are then dissected away from the tibial nerve and posterior tibial vessels.
- At this point, the tourniquet is deflated, and hemostasis is ensured.

■ Mandibular Osteotomy

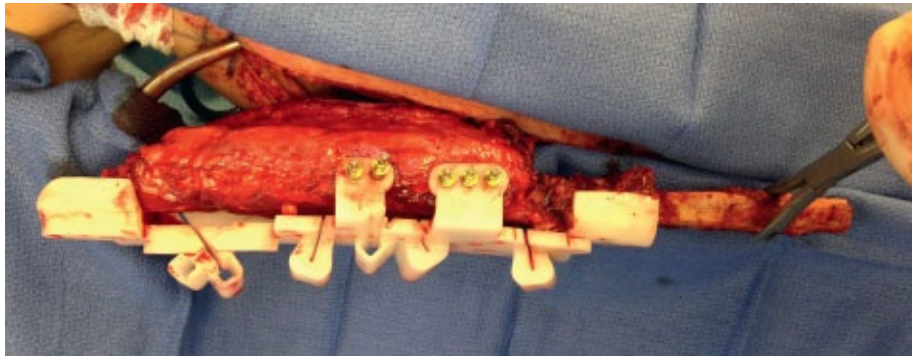
- The ablative surgeons perform their exposure of the mandible, and the custom mandible cutting guides are applied and fixed in place.
 - The resection is then performed using the cutting guides.
- Frozen section margins are evaluated if necessary.
- Recipient vessels in the neck are exposed. Commonly, we use branches of the external carotid artery (facial, lingual, superior thyroid) and branches of the internal or external jugular veins.

■ Fibula Flap Osteotomy

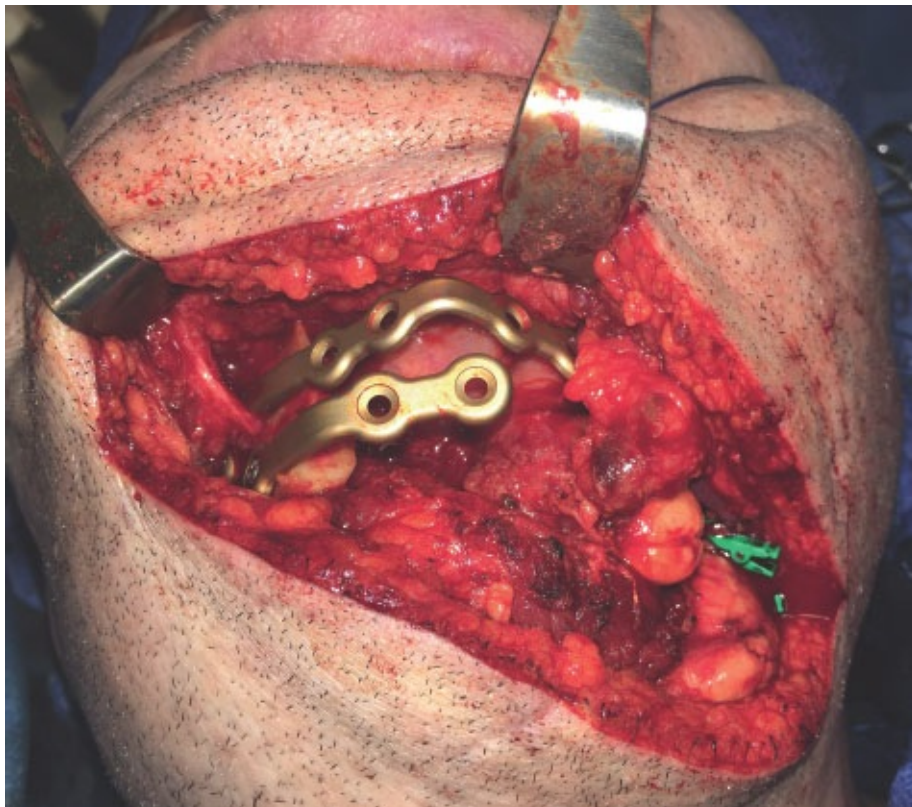
- Place the personalized fibula cutting guide to the preplanned location on the fibula and mark the area of the osteotomies and dental implants (if planned).
 - The cutting guide is attached to the fibula with two monocortical screws in each segment to avoid movement/rotation. This is very important, particularly if simultaneous dental implant placement is planned (**TECH FIG 1**).
- If dental implants are planned, clear a landing point on the fibula with a freer elevator or cautery through the periosteum below the implant drilling guide.
 - All the holes and implant positioning should have been meticulously planned in the online sessions and printed into the guide.
 - We place the implants before any osteotomies are made because precise orientation and positioning of the implants is critical for their long-term success.
- Once the dental portion of the procedure is completed, a subperiosteal dissection is performed at the area where the fibula osteotomy is planned to protect the pedicle.
- Wedge osteotomies are then performed using an oscillating saw. The osteotomies may be fixated at this point using miniplates.
 - Alternatively, the flap may be transferred to the head and neck area and the osteotomies fixated with a reconstructive bar.
- We prefer to do all of this preparatory work while the flap still attached to the vascular pedicle in situ in order to minimize flap ischemia time. For less complex defects, however, osteotomies can also be performed on the back table after pedicle ligation.

Insetting the Fibula Flap Into the Mandibular Defect

- The flap pedicle is divided and the flap is transferred to the head and neck area.



TECH FIG 1 • Positioning of the cutting guide on the fibula and placement of dental implants prior to fibula osteotomies.



TECH FIG 2 • Submental view of customized reconstruction plate and fixation of the fibula flap to the mandible.

- The pedicle vessels can be dissected in a subperiosteal manner to position the vessels optimally for microsurgical anastomosis.
 - Care should be taken to avoid devascularization of the fibula.
- In most cases, we use a prebent reconstructive plate that has been customized for the patient.
 - This plate is applied to the mandibular defect based on the cutting guide (**TECH FIG 2**).
 - The fibula is then inset into the defect and fixated to the plate. Minor burring of the bone may be necessary to achieve an optimal fit.
 - Monocortical screws are used on the fibula and each segment is usually fixated with two screws to prevent movement. We generally avoid bicortical screws since this may result in pedicle injury or weakening of the bone.
- If a prebent plate is not available, then a 2-mm-thick reconstructive plate can be bent to the defect (ideally prior to mandibular resection) or based on 3D model.
 - Guiding elastics may be needed in these cases to precisely fixate the mandible and ensure proper alignment of the teeth.
- If we are planning a double barrel segment to increase the vertical height of the mandible, we resect a 2-cm periosteal sleeve between bone segments to prevent kinking of the vascular pedicle.
- Inset the skin flap (usually the posterior or deep portions) prior to revascularization to stabilize the vascular pedicle because bleeding may obscure visualization of this closure.

■ Microsurgical Anastomosis and Flap Inset

- Microsurgical anastomosis is performed using a microscope or loupes, and reperfusion is monitored.
- The remainder of the flap skin paddle is performed and the flap is trimmed as needed. Meticulous intraoral closure is critical to avoid complications like salivary leaks and complex infections.
- Skin monitoring sutures are placed for postoperative evaluation using a Doppler. In cases where the flap is buried or no skin perforator is available, an implantable Doppler may be used.

■ Dental Implants

- If dental implants are placed at the time of reconstruction, we generally unroof and expose these implants 4 to 6 months postoperatively, when the bone has undergone appropriate osteosynthesis.³
- In the rare case of a benign tumor in which most or all of the mucosa is being spared, we can contemplate a single-stage reconstruction with fibula, placing the implant, then direct prosthesis placement.¹⁰
 - These cases require good soft tissue so that we can cover around the implant abutments and under the prosthesis to protect against salivary leakage. If we are not able to do this with well-vascularized mucosa or fascia, then prosthesis placement may not be possible and a well-vascularized skin paddle should be put in place.

PEARLS AND PITFALLS

Imaging timing

- When planning a resection, the preoperative CT scan should be obtained relatively close in time to the planning session and the surgery to avoid changes in the resection plan.

Planning session¹¹

- The tumor or disease process should be outlined by the modeling team and generous margins should be planned. It is best to do this with the ablative team involved during the online meeting so that they agree with this plan. If there is a question about margin safety and need for further intraoperative resection, an alternate guide can be made to accommodate for these potential changes.

Soft tissue planning

- Take into account your soft tissue needs when planning these procedures. Take as much skin as you need from your primary flap or choose alternative flaps if a complex resection is planned and there is a large intra- and extraoral soft tissue need. Do not leave yourself short of tissue.

Planning maneuvers to minimize soft tissue need

- In cases with significant tissue loss or lack of tissue flexibility such as in radiation injury, the bony reconstruction can be deprojected slightly to minimize strain on the overlying soft tissue and decrease the complexity of the reconstruction.

Plan approval

- Each team should evaluate the plan that is created by the engineers. This includes the ablative, dental, and reconstructive teams if dental prosthetic is planned.

Customized plates	■ As the reconstruction becomes more complex with multiple segments, predesigned plates can play an important role in obtaining very precise reconstruction results.
Primary implant consideration	■ Consider primary osteointegrated implants in benign cases and isolated malignant cases where the intraoral soft tissues are healthy and enable watertight closure around dental implants.
Bone size	■ Bone segments should remain at least 2 cm in length to maintain appropriate periosteal circulation.
Perforator location	■ Use the virtual planning to appropriately position your bone segments. Imaging can note 3D variations in the bone and perforator location, which can assist in the soft tissue design. Place skin where needed intra- or extraorally.
Fibula position and side decision	■ As a guideline, if both fibulas are available, when we have a need for an intraoral skin paddle and ipsilateral blood supply, we choose the contralateral fibula for orientation purposes. When skin is needed extraorally, with ipsilateral vessels, then the ipsilateral leg is planned. This arrangement can be adjusted based on the need of the situation. This is also the case with anterior defects, the location of the cutaneous defect and side of vascular supply will help determine which fibula will fit best.
Accuracy strategies	■ When using multiple segments or have critical positional requirements such as needed for primary implant placement, make intermediary splint devices to help confirm the position of the reconstruction as you advance through each step. Also, predictive hole guides and customized plating can help with this accuracy significantly.
Vessel dissection	■ Maximize peroneal vessel length as needed up to the attachment to the posterior tibial vessels.
Double barrel	■ When planning a double barrel segment, we find that a 2-cm (or greater if needed) periosteal sleeve allows for appropriate rotation.
Implant planning	■ Planning for implants should be performed from the top down. Need to plan the position based off of the maxillary dentition. If bone is not planned out appropriately, then implant position may also not be appropriate.
Implant placement	■ If placing primary implants, we place the guide and the implants first prior to performing the osteotomies. This helps to maintain accuracy.

POSTOPERATIVE CARE

- Postoperative care monitoring depends on the underlying health of the patient. In most cases, ICU observation is not necessary and may delay ambulation and tracheostomy decannulation.
- Head movement usually limited to less than 25 degrees first week postoperatively. The head is maintained in the neutral position and external compression of the vascular pedicle is avoided.
- Monitoring is preferred with physical assessment of the skin paddle color and pencil Doppler. The skin paddle may also be stuck with a needle and bleeding evaluated directly. In patients with implantable Dopplers, the skin paddle (if available) is still evaluated for color and refill. Monitoring protocol is in place with q1h flap checks for the first few days postoperatively and then decreasing to q2h and q4h thereafter.
- The ankle is splinted at the conclusion of the procedure in neutral position with a plaster or fiberglass splint.
 - Alternatively, a preordered walking type of ankle-foot orthotic (AFO) can be obtained so the patient can ambulate early in the postoperative period. Physical therapy consultation is useful in most cases to improve movement and stabilize early ambulation.
- If a skin graft is placed for the skin donor site, we usually use a VAC as a bolster for 5 days. Patients may ambulate with the VAC in place. Once the VAC is removed, ambulation is limited until the skin graft has completely taken.
- Compression wrapping with ACE bandage and elevation is usually needed for 1 to 2 months postoperatively.
- Feeding tubes are placed transnasally in the operating room and the position is confirmed radiologically. Tube feeds are usually started postoperative day one on and can be maintained until healing has occurred. Long-term tube feeds may require gastric tube placement.
- Swallowing function may be assessed if necessary in patient who have undergone floor of mouth resection. In these cases, speech/swallow evaluation may also be necessary.
- Once intraoral healing has been confirmed and the tracheostomy has been removed, oral feeds can be started and advanced as necessary.
- Most patients who undergo mandible reconstruction require tracheostomy. The timing of decannulation is dependent on the patients' recover. In most cases,

we downsize the tracheostomy by 3 to 4 days postoperatively once the intraoral and tongue swelling is decreased. Then from there advance to decannulation within another 1 to 2 days.

- Care must be taken to avoid tracheostomy ties to prevent compression of the pedicle. In these cases, tracheostomies are usually sutured or stapled into place.
- Most patients are discharged home by 7 to 14 days postoperatively.
- Some patients, depending on their preoperative condition, benefit from a short stay in a subacute rehabilitation center.

OUTCOMES

- Patients usually do very well postoperatively.⁴
 - By 6 to 8 weeks, ambulation is usually back to normal and the facial aesthetics are stabilized.
 - If chemotherapy or radiation is necessary postoperatively, this can usually be performed safely by 6 to 8 weeks postop.
- Oral function should be normalized by 2 to 4 weeks postoperatively especially if the tongue was left intact.
- Bone healing between the osteotomy sites should be well integrated by 3 to 4 months.
- If a patient is treated with radiation postoperatively, then dental implant placement requires careful consideration because the bone is at high risk of breakdown and implant failure.
- The reconstruction plates can be left in place unless there is hardware failure, exposure, pain, screw loosening, or palpability.
- Dental implants result in an excellent reconstruction (**FIG 6**).

COMPLICATIONS

- Typical complications include infections, bleeding, salivary leaks, malocclusion, pain, and nerve complications (sensory impairment, or more rarely, motor difficulties). Medical complications including pneumonia, aspiration, and cardiovascular morbidity may also occur. Donor site complications may include impaired healing, skin graft loss, pain, and neurovascular injury. Vascular complications from the donor site are rare but possible in patients with atherosclerotic disease.



FIG 6 • Postoperative view of the final reconstruction with dental implants in place.

- Long-term problems may include trismus, pain, and speech/swallowing problems. In addition, patients may have nonunion or implant-related complications.
- Airway risks are particularly worrisome in the early postoperative period especially if there is a large anterior or floor of mouth resection.

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Mandible Reconstruction With Fibula Flap With Templates

CHAPTER 11

Eric G. Halvorson

DEFINITION

- Mandible reconstruction is most commonly indicated following tumor extirpation, although it is also indicated for posttraumatic defects of the mandible. Less common indications include osteoradionecrosis and infection.
- The fibula flap remains the standard for microvascular mandible reconstruction.
- Although many descriptions of surgical technique exist, the closing wedge osteotomy remains a “black box” for learners.
 - In this chapter, a simple and reliable technique to create anatomic wedge osteotomies is presented, using preoperative templates based on the patient’s native anatomy.

ANATOMY

- The anatomy relevant to fibula flap harvest is presented in Chapter 10 of this section, as well as techniques for neomandible creation using CAD/CAM osteotomy jigs.
- This chapter focuses exclusively on how to create a neomandible using traditional templates and closing wedge osteotomies.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Risk factors for wound healing complications should be assessed, including radiation exposure, smoking, diabetes, steroid use, poor nutrition, and obesity.
- Prior neck dissection can make reoperation and recipient vessel exposure difficult. A history of lower extremity trauma, surgery, or peripheral vascular

disease may preclude use of the fibula flap.

- The oral cavity is examined and the expected defect analyzed for quantity of bone and lining required.
 - Patients with poor dentition who will require adjuvant radiotherapy may benefit from dental extraction.
 - Occlusion is assessed and carefully noted, as one goal of surgery is to maintain native occlusion.
- Distal lower extremity pulses and skin texture are examined.
 - Patients with potential vascular disease should undergo preoperative imaging to evaluate three-vessel runoff.
 - Patients with taut or thin skin will likely require a split-thickness skin graft for donor-site closure.

IMAGING

- Craniofacial CT scans are performed to assess the extent of disease (tumor, traumatic defect, osteoradionecrosis, infection).
 - Three-dimensional renderings are helpful but not necessary.
- Lower extremity angiography is commonly performed (CTA or MRA) to assess three-vessel runoff. If these studies are inadequate, conventional angiography is performed.
 - Patients must have at least a patent anterior tibial or posterior tibial artery (in addition to the blood supply of the flap derived from the peroneal artery) to be candidates for fibula flap harvest.

SURGICAL MANAGEMENT

Preoperative Planning

- Excellent communication between the extirpative and reconstructive surgeons is necessary to coordinate perioperative planning, including staging of disease, imaging, labs, and clearance for surgery.
- In delayed reconstruction, eg, in patients treated for traumatic defects, it is helpful to have two surgeons involved (one to recreate the defect and expose recipient vessels and the other to elevate the flap). However, this is not an absolute requirement.
- A secure airway is required in the perioperative period, as flap swelling, abnormal deglutition, and secretions can compromise the airway. In addition, emergent reintubation may compromise microsurgical reconstruction and

disrupt the repair. As a result, a tracheostomy is almost always indicated until adequate healing has occurred to allow decannulation.

- Adequate nutrition is important in the perioperative period.
 - A flexible nasogastric or nasoduodenal tube is often placed at the end of surgery for early initiation of tube feedings.
 - If patients are malnourished prior to surgery, a percutaneous endoscopic gastrostomy tube may be considered.

Positioning

- Patients are placed in supine position with a bump under the shoulders and the neck extended.
- A folded towel or blanket is placed under the hip to facilitate internal rotation when the hip and knee are flexed.
- A padded roll or IV bag is secured to the table so the foot can rest on it with the hip and knee flexed (and internally rotated). This facilitates exposure and dissection.
- The heels and lower extremity are padded to avoid pressure sores during these long procedures.
- The entire lower extremity is prepped and a sterile tourniquet is used so the thigh can later be used as a donor site for a split-thickness skin graft if needed.

Approach

- If the defect is truly central, and both necks are available for recipient vessels, then either extremity can be utilized to harvest a fibula flap.
 - The left is preferable as most patients use their right leg for driving, etc., but angiographic findings may also dictate which side to use.
- An ipsilateral flap (with respect to the location of the defect in the jaw) is typically used. This approach places the septum carrying the cutaneous vessel/s externally and inferiorly.
 - This allows the septum and skin to be brought over the hardware and into the oral cavity for standard gingiva/floor of mouth defects.
 - In addition, using the ipsilateral flap places the pedicle vessels laterally on the fibula flap thus localizing the vessels in optimal position for microsurgical anastomosis to the neck vessels.
- A contralateral flap will place the septum and skin island internally and superiorly, which may be preferable when there is a large intraoral defect that

extends beyond the gingiva/floor of mouth.

- A two-team approach is preferable to reduce operative time.
- The flap can be elevated during extirpation, provided there is good communication between the two operative teams and an accurate estimate of the defect is made.
- It is prudent to take more flap than you think you might need.
- The neomandible can be created in situ on the leg, further reducing both operative and ischemic time.

TECHNIQUES

■ Maintaining Native Condyle Position and Occlusion

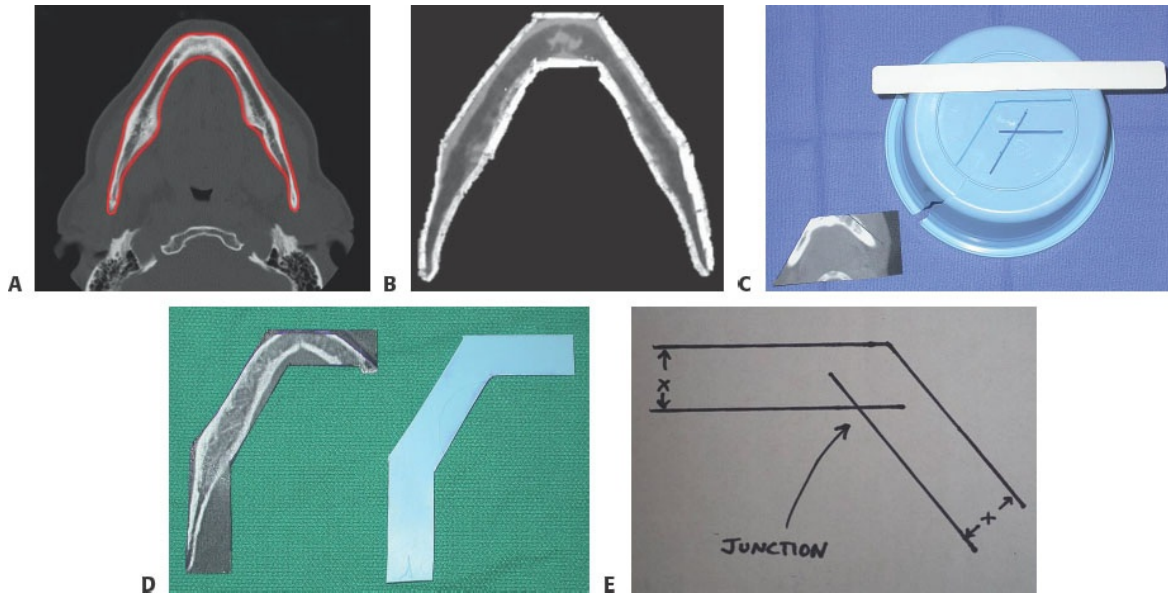
- Mandibular discontinuity leads to abnormal condylar positioning and malocclusion, as the muscles of mastication contract each segment unopposed. Significant distortion of native condylar positioning when re-establishing mandibular continuity can lead to malocclusion and/or abnormal movement when chewing.
- If the disease process has not distorted the outer border of the mandible, *prior to resection* a reconstruction bar can be appropriately bent and secured to it using two screws on the nonpathologic side of each planned extirpative osteotomy.
 - Following resection, the bar is replaced and the fibula flap can usually be secured to it, provided it maintains occlusion and there are not large gaps (greater than 3 mm) between the bar and fibula.
 - Locking screws are required when gaps exist, to prevent distortion of the bony segments and gaps between bone and bone (worse than gaps between bone and hardware).
- If necessary, a new bar can be appropriately bent (using osteotomy templates) and secured, although it may be necessary to place the patient in temporary mandibulomaxillary fixation (MMF) to maintain occlusion during the revised osteosynthesis.
- If the disease process has grossly distorted the external surface of the mandible, placing the patient in temporary MMF after resection will maintain

condylar positioning and proper occlusion for bony inset of the fibula flap.

- For edentulous patients, a reconstruction bar can be bent around the tumor and secured to the normal segments of the bone as above. This bar can be replaced with a new bar that is bent using the osteotomy templates. In this case, the initial bar should be secured to the normal segments using holes that are not near the cortex designated for final osteosynthesis.
- The author's preference is to avoid postoperative MMF if the teeth easily come into good occlusion following final flap inset.
 - It is unlikely that significant malocclusion following osteosynthesis of the neomandible will be corrected with MMF. Adjusting how the bony segments are secured to the hardware may be necessary to optimize native occlusion.
 - For edentulous patients, occlusion is not a factor and anatomic inset is not as critical.

■ Creating Anatomic Templates

- The lowest axial cut of the mandible on preoperative CT is printed and the outer surface traced and cut to create linear segments separated by distinct angles (**TECH FIG 1A,B**).
- Mandibular angle templates are based on the appropriate sagittal image.
 - Although it is possible to print 1:1 ("life size") images of the CT, the osteotomy angles are the same regardless of magnification.
- A template is created for each osteotomy by tracing the printed CT onto a plastic sheet (eg, a sterile plastic bowl) that is sterilized with Betadine or chlorhexidine (**TECH FIG 1C,D**).
- It is critical to draw the inner (lingual) lines parallel to the outer (buccal) lines and the exact same distance from them (ideally 1 cm).
 - The junction of these lines forms a point that is critical in subsequent steps (**TECH FIG 1E**).



TECH FIG 1 • The lowest axial cut of the mandible on preoperative CT is printed **(A)** and the outer surface traced **(B)** and cut to create linear segments separated by distinct angles. **C,D**. A template is created for each osteotomy by tracing the printed CT onto a plastic sheet (eg, a sterile plastic bowl) that is sterilized with betadine or chlorhexidine. **E**. It is important to draw the inner (lingual) lines parallel to the outer (buccal) lines and the exact same distance from them (ideally 1 cm). The junction of these lines forms a point that is critical in subsequent steps.

■ Fibula Flap Elevation

- Doppler interrogation along the septum between the lateral and superficial posterior compartments (2 cm posterior to the fibula) at the junction of the middle and distal thirds of the lower extremity should reveal several signals.
 - An appropriate skin paddle is designed centered on the septum and marked Doppler signals.
 - The incision should extend proximal to the skin island to facilitate exposure of the tibioperoneal trunk.
- The leg is elevated and exsanguinated with manual compression or an

Esmarch bandage. The sterile thigh tourniquet is inflated to 250 to 350 mm Hg.

- The anterior incision is made and dissection is carried down to the fascia with cautery.
 - Is it prudent to bevel out several centimeters and then make the fascial incision, to ensure that the septum is incorporated into the flap.
- During the anterior dissection, it is important to try and avoid injury to the superficial peroneal nerve.
- Following the fascial incision, Allis clamps are placed on the fascial edges, and the flap is elevated off the underlying peroneus longus using blunt dissection and cautery.
 - The septum will be present on the posterior surface of the peroneus longus, and a septocutaneous branch of the peroneal vessel should be visualized.
- The lateral compartment musculature is then pulled away from the fibula and elevated off the bone, leaving a small (2 mm) cuff of muscle on the bone to avoid thermal injury to the periosteum.
 - The septum between the anterior and lateral compartments will be encountered and should be incised carefully to avoid injury to the anterior tibial vessel and deep peroneal nerve.
- Retractors are placed to elevate the anterior tibial vessel and deep peroneal nerve, and the anterior compartment musculature is elevated off the fibula as above.
 - The interosseous membrane is next encountered and is incised along its length by preserving roughly 6 cm of fibula proximally and distally.
- The critical structures to avoid are the peroneal vessels and nerve proximally and the ankle syndesmosis distally.
 - Preserving 6 cm proximally and distally typically accomplishes this, but dissection should follow individual anatomic landmarks and not static measurements.
- The anterior incision is temporarily stapled and the posterior incision is made. As above, beveling out several centimeters at the level of the fascia will ensure the septocutaneous branch of the peroneal vessel is preserved.
- It is prudent to avoid injury to the sural nerve during the superficial posterior dissection.
- The fascia is incised and grasped with Allis clamps, and the skin paddle is elevated off the underlying soleus muscle. This should isolate the skin paddle

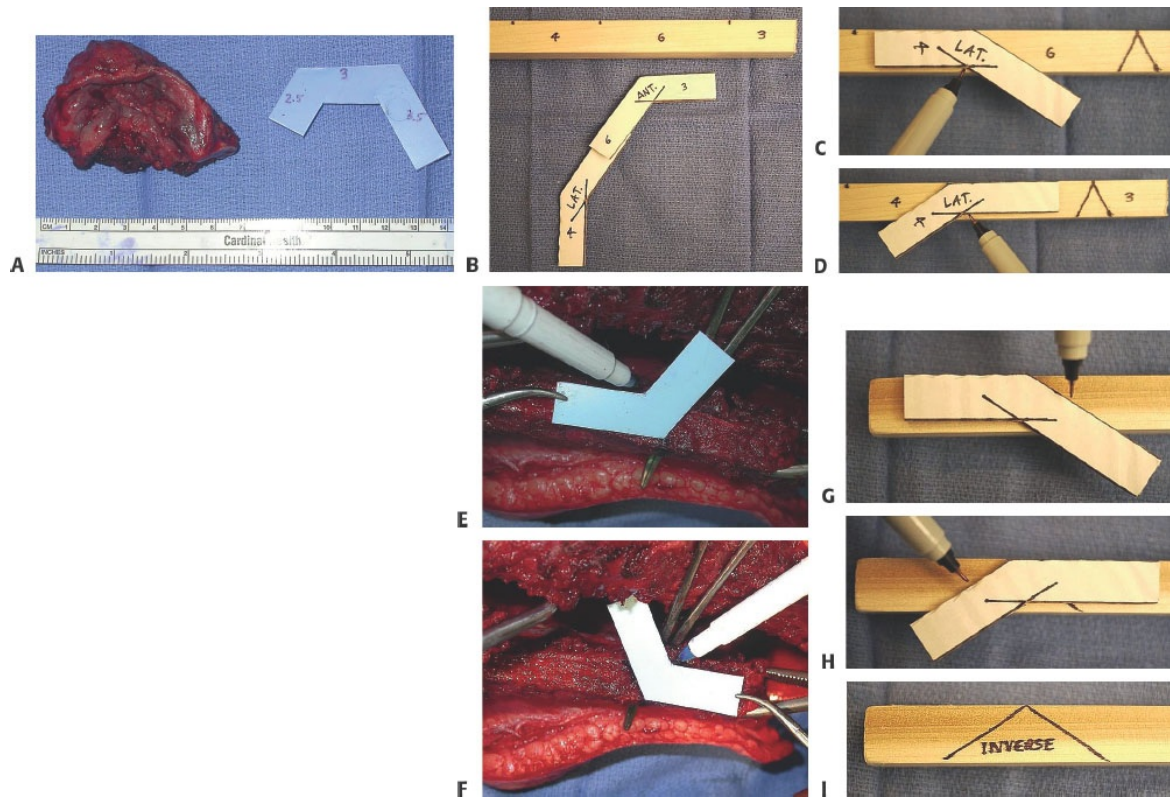
on the septum.

- The attachments of the soleus muscle to the fibula are taken down with blunt dissection and cautery, exposing a potential space between the soleus muscle and flexor hallucis.
 - Multiple large branches of the peroneal pedicle to the soleus muscle are typically observed proximally and ligated.
- A right-angled clamp is placed around the fibula proximally and distally, taking great care not to injure the peroneal neurovascular bundle proximally.
 - The clamp is used to bluntly dissect a space that will accept an Army-Navy retractor, which is then used to protect the soft tissues as the proximal and distal osteotomies are performed with a sagittal saw.
- The distal bone is gently grasped with a bone clamp and pulled out of the wound, which should expose the distal peroneal pedicle to be ligated.
 - The epimysium of the flexor hallucis is incised via the posterior approach, which allows easier retraction of the flap.
- The author's preference is to transect the flexor hallucis distally and include it with the flap.
 - If the muscle is left behind, it is avascular and has no origin. This can result in a hammertoe deformity due to contracture.
 - Most patients do not notice its absence, except young athletes or dancers.
 - With an ipsilateral flap, the muscle will hang below the neomandible, buttressing the floor of mouth repair and filling in the soft tissue defect from lymphadenectomy. If the cutaneous pedicle is injured, the muscle can serve to close floor of mouth and other defects.
- While retracting the distal flap out of the wound, the tibialis posterior will be visible from the anterior approach, with its characteristic chevron fiber orientation.
 - This muscle is divided from the fibula leaving a 1-cm cuff to avoid injury to the flap.
 - Posterior to this muscle lies the septum between the superficial and deep posterior compartments. This septum is carefully incised, to avoid injury to the peroneal pedicle immediately below.
- The flap is elevated from distal to proximal, where the peroneal vessels are identified and dissected to their origin off the tibioperoneal trunk. The veins often have multiple branches, necessitating careful dissection.
- The tourniquet is let down, and hemostasis is achieved.

- During flap inset, it is helpful to have a second surgeon perform donor-site closure.
 - The wound is irrigated and hemostasis achieved.
 - A drain is placed and the skin is closed with interrupted deep dermal and running subcuticular absorbable suture.
 - It is critical to avoid compartment syndrome and therefore surgeons should have a low threshold to place a split-thickness autograft if primary closure is too tight.
 - Sterile dressings and a well-padded posterior splint is applied.
 - Patients may get out of bed to a chair with their leg elevated but do not ambulate until postoperative day 5.
-

■ Marking the Osteotomy Sites

- The length of each segment is estimated by measurement of the defect and/or specimen, and osteotomy sites are marked on the fibula (**TECH FIG 2A,B**).
 - It is possible to use the template in determining segment length, but only if it is printed out as a 1:1 image and not overly affected by the disease process (in which case the contralateral mandible may be used as a mirror image).



TECH FIG 2 • A,B. The length of each segment is estimated by measurement of the defect and/or specimen and osteotomy sites are marked on the fibula. **C–F.** The outer point of the template is lined up with the point of osteotomy and one edge of the template is held parallel to the anterior surface of the fibula. The point formed by the junction of the two inner (lingual) borders of the template is used to mark one side of the closing wedge osteotomy, then the other edge of the template is held parallel to the outer surface of the fibula and the marking for the closing wedge is finalized. **G–I.** It is important to recognize that the inner angle of the template is used, and not the outer borders; otherwise, an inverse angle osteotomy will be formed.

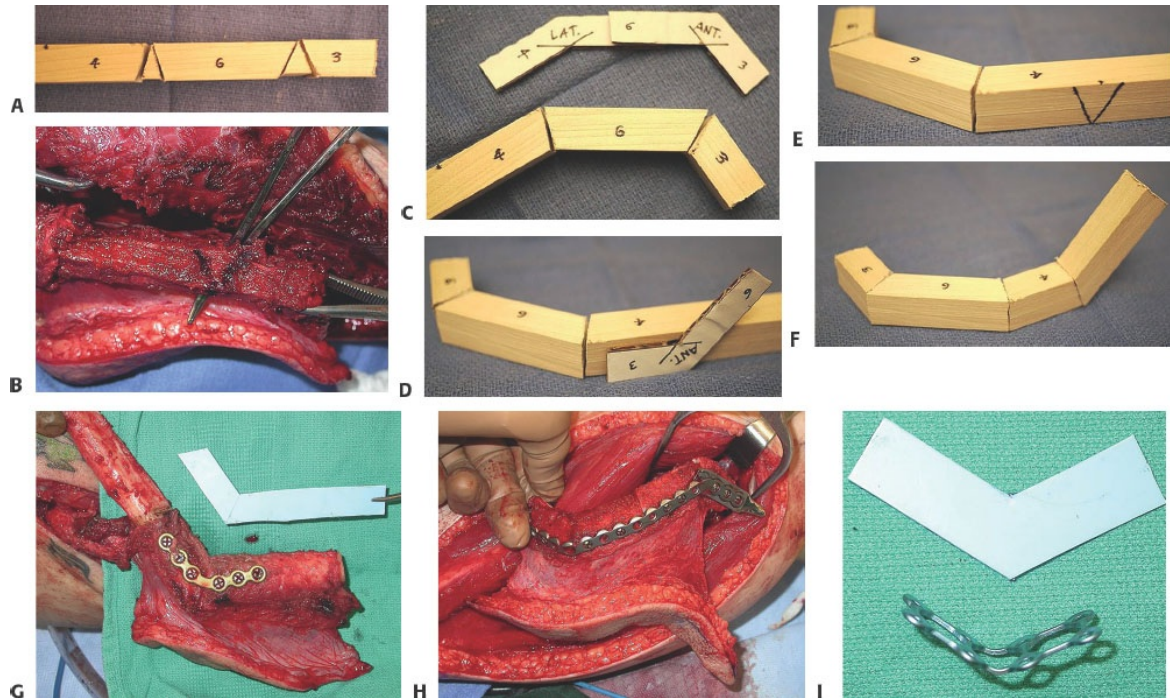
- The outer point of the template is lined up with the point of osteotomy and

one edge of the template is held parallel to the anterior surface of the fibula.

- The point formed by the junction of the two inner (lingual) borders of the template is used to mark one side of the closing wedge osteotomy, then the other edge of the template is held parallel to the outer surface of the fibula, and the marking for the closing wedge is finalized (**TECH FIG 2C–E**).
 - It is important to recognize that this inner angle is used, and not the outer borders of the template, or else an inverse osteotomy will be formed (**TECH FIG 2F–I**).
 - It is critical not to design an osteotomy where the septocutaneous branch of the peroneal vessel emerges.
 - This can be avoided by moving the planned osteotomy 1 cm to either side of the vessel to avoid injury during osteotomy.
-

■ Closing Wedge Osteotomies

- Closing wedge osteotomies are then performed using a reciprocating pneumatic or electric saw, protecting the peroneal vascular pedicle by passing a snap under the bone to place it between the periosteum and vascular pedicle.
 - The osteotomies created should match the template with a high degree of accuracy (**TECH FIG 3A–C**).
- Reconstruction of the mandibular angle can be performed in the same manner (**TECH FIG 3D–G**).
- Osteotomies can be performed with the raised fibula flap in situ by using the measurements and templates (**TECH FIG 3H**).
- Miniplates or reconstruction bars can be bent using the template for even more accuracy in constructing the neomandible (**TECH FIG 3I**).¹
 - Although it is potentially more accurate to use miniplates, it is often easier and faster to use a reconstruction bar. This typically yields a similar result. However, in the event of an infection, it is far easier to remove miniplates than a reconstruction bar.
 - The important thing is that occlusion and aesthetics are optimized.
- For three or more osteotomies, a virtually planned osteotomy jig should be considered to create three-dimensional osteotomies.
- Osteotomies can be performed in situ on the leg (to reduce operative and ischemic time) or during flap inset.



TECH FIG 3 • A–C. Closing wedge osteotomies are performed using a reciprocating saw, protecting the peroneal vessels by passing a snap under the bone to place it between the periosteum and vascular pedicle. The osteotomies created should match the template with a high degree of accuracy. **D–G.** Reconstruction of the mandibular angle can be performed using a closing wedge osteotomy on the outer surface of the fibula in the same manner as described above. **H.** Osteotomies can be performed with the raised fibula flap in situ utilizing the measurements and templates. **I.** Miniplates or reconstruction bars can be bent using the template to optimize accuracy in constructing the neomandible.

- To facilitate inset of the skin island, the septum can be incised if needed, if the septocutaneous branch of the peroneal vessel is preserved and not overly twisted.
- The skin island is appropriately trimmed and inset using interrupted

absorbable suture, and the remainder of the surgical wounds are closed over drains after irrigation.

- To test intraoral closure, gauze can be placed in the neck under the closure and the mouth irrigated with dilute methylene blue solution.
- If the gauze has blue staining, then the closure is not tight enough.

PEARLS AND PITFALLS

Preoperative planning

- Review the patient's exam findings and imaging with the extirpative surgeon to anticipate the location and size of the defect.
- Careful physical examination is more important than imaging, which may include lower extremity angiography.
- Consider placing a reconstruction bar prior to resection, to maintain native condylar positioning and dental occlusion.

Approach

- An ipsilateral flap is typically used, which optimizes inset for the microsurgical anastomosis to the ipsilateral neck vessels and closure of the floor of mouth and gingival defects.
- A two-team approach is helpful for both immediate and delayed reconstructions to reduce operative time.

Positioning

- A hip bump (eg, folded towel) and secured/padded foot rest allow the donor extremity to be positioned with hip/knee flexion and internal hip rotation, thus facilitating exposure.

Creating a template

- The lowest axial cut of the mandible on CT is printed and the outer surface traced and cut to create linear segments separated by distinct angles. This forms the basis for plastic templates specific to each osteotomy.

Closing wedge osteotomies

- Templates are used to mark each closing wedge osteotomy. Use the inner angle of the template, not the outer surface.
- Protect the peroneal pedicle with a snap during each osteotomy.

POSTOPERATIVE CARE

- Patients are admitted to an intensive care unit for ventilator management and hourly flap checks.
- The author's preference is to use clinical exam to monitor most flaps, reserving internal Dopplers or tissue oximeters for difficult cases where the

pretest probability of flap failure is higher, thus increasing the positive predictive value of the monitoring device.

- For buried flaps, an internal Doppler is usually used if the microanastomosis proved difficult.
- Tube feeds are initiated on postoperative day 1 or 2, and oral care with chlorhexidine solution is provided every 8 hours.
 - The head of bed is maintained in an elevated position, with no pillows or circumferential neck ties to prevent kinking or compression of the pedicle.
 - The donor leg is kept elevated on pillows.
- Antibiotics are typically discontinued after 24 hours. However, longer course of treatments can be considered in high-risk patients (eg, those with a preoperative history of radiation, heavy smokers, compromised skin, or preoperative infection).
 - Subcutaneous heparin or enoxaparin is given preoperatively and postoperatively until discharge.
- Drains are removed when output is less than 30 mL/d.
- A formal swallow study is rarely performed unless a leak is suspected. A bedside swallow evaluation is performed to guide diet advancement.

OUTCOMES

- This technique is a very simple way to create anatomic closing wedge osteotomies. For most patients requiring one or two osteotomies, this technique is successful in restoring preoperative occlusion and facial aesthetics (**FIG 1**).
- For patients without good dentition, this technique reliably restores condylar positioning. For patients requiring three or more osteotomies, or osteotomies in multiple planes (eg, subtotal mandibulectomy), a more accurate reconstruction is likely to be achieved using a custom three-dimensional osteotomy guide created preoperatively based on the patient's CT scan.^{2,3}



FIG 1 • This technique is a simple way to create anatomic closing wedge osteotomies that restore preoperative occlusion and facial aesthetics.

COMPLICATIONS

- Complications are similar to other head and neck microvascular reconstruction cases and can include flap necrosis, orocutaneous fistula, wound dehiscence, and functional problems with speech and swallowing (that usually improve with time and therapy).
- Malunion or nonunion of the bony segments is rare, although late hardware infection can occur. This usually manifests as an intraoral wound with hardware exposure or an external sinus tract with granulation tissue.
- Donor-site complications include wound dehiscence, exposure of peroneus longus tendon, hammertoe, skin graft loss (if used), compartment syndrome, and functional problems with gait.
- Young patients tolerate fibula harvest well. Older patients may require use of a walker or cane, at least initially.
- It is common for patients to have pain and swelling late in the day, which persists for months after surgery.

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12 Mandible Reconstruction With Scapula Flap

CHAPTER

Mouchammed Agko and Hung-Chi Chen

DEFINITION

- Reconstruction of the mandible requires bone to replace osseous defects and soft tissues to reconstruct the floor of mouth, tongue, soft palate, and/or external skin. This combined soft tissue and osseous reconstructive needs, in combination with vascular anatomy and other patient factors, determine the optimal donor site. In specific circumstances, the subscapular system of flaps can be employed for this purpose.
- The subscapular vascular system is one of the most versatile and reliable donor sites with consistent anatomy that can provide a multitude of skin, fascia, muscle, and osseous flaps combinations.
- Saijo and dos Santos laid the anatomic foundations for the scapular flap leading to the first successful microsurgical transfer by dos Santos, Gilbert, and Teot.^{1–3} Nassif subsequently described the parascapular flap.⁴
- In 1981, Teot et al. reported use of an osseous scapular flap based on the circumflex scapular artery (CSA).⁵ Later, Swartz et al. popularized the use of the osteocutaneous scapular flap for mandibular reconstruction.⁶
- Historically, it is interesting to note that although Ignio Tansini is credited for the first description of the latissimus dorsi flap, his initial depictions of the flap have been actually determined to be consistent with that of a parascapular flap.

ANATOMY

- The subscapular artery (SSA) arises at the distal border of the subscapularis muscle from the third portion of the axillary artery.
 - It measures 2 to 4 mm in diameter and courses for 2 to 3 cm prior to dividing into the CSA and thoracodorsal artery (TDA).

- The CSA, which is 1.5 to 3.5 mm in diameter, courses for 3 to 4 cm before it gives off the branches to the lateral border of the scapula.
- It enters the triangular space (omotricipital triangle) that is formed by divergence of the teres muscles from the lateral scapula (teres minor superiorly, teres major inferiorly) and the long head of the triceps laterally.
- At this level, it sends branches to the subscapularis muscle and numerous musculoperiosteal branches to the lateral border of the scapula.
- Subsequently, it gives off branches to the infraspinatus and teres muscles.
- It is the musculoperiosteal branches between the anterior subscapularis muscle and the posterior teres muscles that provide the vascularization of the upper two-thirds of the lateral scapula and have to be preserved during harvest of the lateral osseous flap.
- The distance from the axillary artery to these branches (effectively the pedicle length of the flap) is 6 to 8 cm.
- After emerging through the triangular space, the CSA is encased in the dorsal thoracic fascia.
- An areolar space separates this from the underlying deep muscle fascia.
- The CSA courses caudally for 2 to 3 cm before it divides into its terminal branches: ascending, transverse, descending, and anterior.
- Although all these can serve as the source for axial flaps overlying the specific branch, the two most commonly used are the scapular and parascapular flaps based on the main transverse and descending branches, respectively (**FIG 1**).

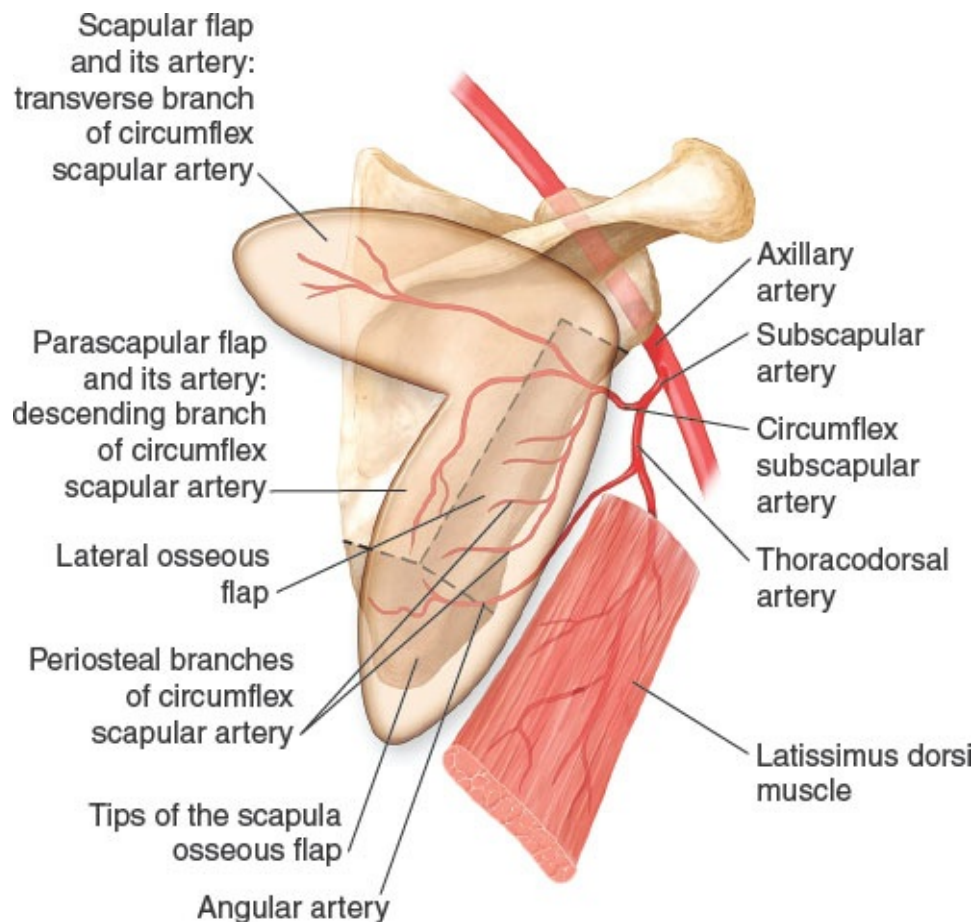


FIG 1 • The vascular supply of the scapular/parascapular skin paddles and the lateral edge/tip of the scapula osseous flaps are shown. After giving off musculoperiosteal branches to the lateral border of the scapula (lateral osseous flap), the circumflex scapular artery emerges through the triangular space and divides into its terminal branches. The transverse and descending branches supply the scapular and parascapular skin paddles, respectively. The tip of the scapula receives its blood supply from the angular artery that is a branch of the thoracodorsal artery itself or its serratus anterior branch.

- The circumflex scapular system has two veins of disparate size that coalesce before joining the single vein of the thoracodorsal system to form the

subscapular vein (SSV) (2.5–4 mm in diameter).

■ Anatomic variations:

- Double CSA (8%–14%)
- Double circumflex scapular vein (CSV) (14%)
- CSA originating separately from the axillary artery (4%–8%)
- CSV originating separately from the axillary vein (12%)
- Descending branch of the CSA (parascapular flap pedicle) coursing anterior to the teres major muscle (TM) and emerging between the inferior border of the teres minor muscle (Tm) and the superior border of the latissimus dorsi muscle (7 of 30 cases)
- SSA and thoracoacromial arteries sharing a common origin from the axillary artery (2–47 cases)

PATIENT HISTORY AND PHYSICAL FINDINGS

- The shoulder and axillary area is carefully examined. Range of motion of the shoulder joint and strength of the parascapular muscles are determined.
- Previous injuries and surgical interventions in the vicinity are scrutinized to assess potential damage to the vascular structures precluding safe harvest.
- Although scars involving just the skin do not preclude harvesting the cutaneous portion of the flap, deeper scars (eg, previous thoracotomy incision, previous axillary lymph node dissection) may have injured the pedicle or the flap.
- Special attention is paid to identify spinal accessory nerve injury by examining trapezius muscle bulk and function. Further compromise of parascapular muscles may exacerbate winging of the scapula.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- No preoperative studies are required.
- In cases of previous injury or surgery, angiography (conventional, computed tomography, or magnetic resonance) can be employed to confirm intact vascular anatomy.
- Theoretically, x-rays of the scapula or computerized tomography with 3D reconstruction could be used for preoperative planning.
- For the purposes of photographic documentation, preoperative photos of the donor site and shoulder function are obtained.

SURGICAL MANAGEMENT

- The available reconstructive options for mandibular defects are as follows:
 - Osteocutaneous fibula flap
 - Vascularized iliac crest flap
 - Osteocutaneous scapula flap
 - Osteocutaneous radial forearm flap
 - Vascularized rib with blood supply from the latissimus dorsi muscle
 - Vascularized medial femoral condyle corticoperiosteal flap for short defects of the mandible
 - Reconstruction plate covered with pedicle or free myocutaneous flap
 - Delayed repair with nonvascularized bone graft
- Anterior, sagittal, or hemimandibular defects can be restored with the osteocutaneous scapula flap.
- Specific indications for the use of the osteocutaneous scapular flaps in mandibular reconstruction include the following:
 - Composite defects of the mandible with large soft tissue requirements for intraoral lining, external coverage, and/or soft tissue augmentation.
 - The soft tissue defect is not directly adjacent to the osseous defect and relative independence is required between the bone and soft tissue component for optimum inset.
 - Fibula is not available due to vascular disease, aberrant anatomy, injury, or previous harvest.
 - Patient wants to avoid the morbidity of vascularized iliac crest harvest.
- Medical status prohibiting lengthy procedures under general anesthesia would preclude the use of this flap.
- Relative contraindications include the following:
 - Osseous defect larger than 14 cm in men or 10 cm in women
 - Need for multiple osteotomies that could endanger viability of the osseous flap
 - Pre-existing shoulder disorders limiting range of motion and periscapular muscle strength
 - Damage to the vascular pedicle due to injury or procedure (eg, lymphadenectomy)
 - Skin of the back too thick (obese patients)
- There are numerous advantages of this flap compared to other options for mandibular reconstruction.
 - The hairless nature of the scapular skin flap closely resembling the texture

and sometimes color of the facial skin.

- The vascular pedicle can be dissected to the appropriate length and diameter to match the recipient vessels.
- Additional flaps can be carried on a single arterial and venous anastomosis except in cases of anatomical variations.
- The soft tissue elements can be spatially oriented independently of each other or the bone enabling coverage of complex composite defects.
- Primary closure of large skin flaps is possible providing more skin than other osteocutaneous flaps.
- Limited morbidity with minimal loss of shoulder function if no preoperative limitation exists.
- The vascular pedicle is reliable even in patients with diabetes or arteriosclerosis.
- Scapular osteocutaneous flaps also have some limitations.
 - Some authors have described flap harvest in a modified semilateral position to avoid redraping. However, most surgeons prefer to reposition the patient before and after flap harvest.
 - Two-team approach is not possible. Mandibular resection/recipient site preparation has to be completed prior to proceeding with the flap harvest.
 - Revascularization of the flap can only be performed after donor-site closure.
 - If undue tension is present at closure, the donor-site scar may be widened. However, patients rarely complain as the scar is not easily visible to them.
 - If skin grafting becomes necessary, this is an inherently unfavorable site.
 - Dissection of the CSA pedicle through the triangular space can be tedious and time-consuming.
 - Because the sensory branches from the 3rd to 5th intercostal nerves are divided during elevation of the flap, primary sensory innervation is not possible. However, when transferred to the head and neck region, the flap may regain satisfactory sensation without nerve repair through spontaneous regeneration from the tissue bed.
 - Bone stock may be limited in women precluding dental rehabilitation.

Preoperative Planning

- For preoperative marking and flap design, the patient is seated or stands comfortably with the arms resting at the sides.
- The borders of the scapula and its spine are marked.
- The triangular space is identified by palpating the lateral border of the scapula

at 2/5th of the distance between the center of the spine and the inferior angle of the scapula.

- The posterior axillary fold formed by the teres major (TM) is pinched between the thumb and the remaining fingers to identify the upper border of the muscle.
- The emergence point of the CSA from the triangular space can be located at area where the upper border of the TM meets the lateral border of the scapula.
 - A pencil Doppler can confirm the location of the CSA and the course of its branches.
- Scapular fasciocutaneous flap
 - The axis of the scapular flap is a line parallel to the spine of the scapula extending from the emergence point of the CSA to the posterior midline.
 - The flap itself is marked from the posterior axillary line to the posterior midline in a lenticular fashion with the medial end extending over the triangular space. The design is limited superiorly by the spine of the scapula and inferiorly by the inferior angle.
 - An additional 2 cm passing across the midline can be included as an extension based on random perfusion.
 - Usual flap dimensions allowing primary closure are 20 cm × 10 cm, with the length ranging from 6 to 25 cm and the width from 4 to 16 cm.
- Medial osseous flap
 - The scapular fasciocutaneous flap can carry an osseous segment from the medial border of the scapula (10–12 cm × 3 cm × 0.71–1.5 cm) through its fascial attachments to the bone.
- Parascapular fasciocutaneous flap
 - The axis of the flap corresponds to the lateral border of the scapula when the arm is in adduction.
 - The flap is marked from the posterior axillary crease superiorly and can extend to the 12th rib or midway between the inferior angle of the scapula and posterior superior iliac spine.
 - The width that would allow primary closure is confirmed by pinching the skin and subcutaneous tissue.
 - Usual flap dimensions allowing primary closure are 24 cm × 12 cm, with the length ranging from 6 to 32 cm and the width from 8 to 20 cm.
- Lateral osseous flap
 - The length of the lateral scapular bone that can be reliably elevated on the periosteal branches of the CSA depends on number of planned osteotomies.

- Usually up to 10 cm in women and 14 cm in men can be harvested, when one proximal osteotomy is planned.
- The bone can be up to 3 cm wide with variable thickness (1.5–3 cm) along the length of the flap.

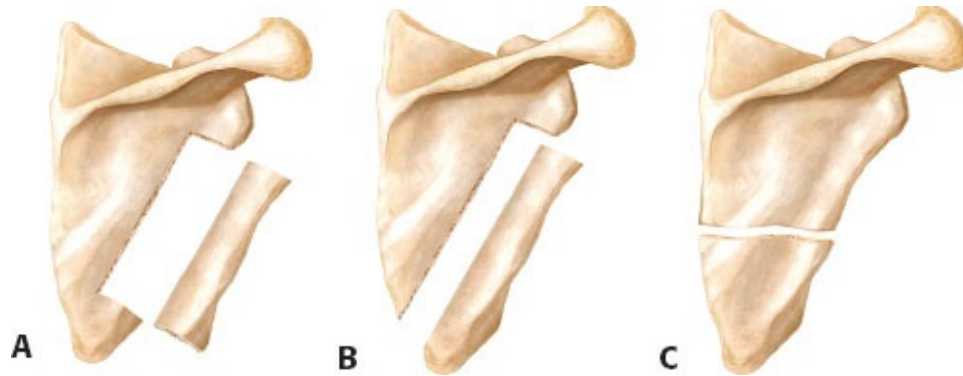


FIG 2 • Bone flaps that can be harvested. **A.** Lateral osseous flap based on the periosteal branches of the circumflex scapular artery (CSA). **B.** Extended lateral osseous flap including the tip of the scapula where both the periosteal branches of the CSA and the angular artery are preserved. **C.** Tip of the scapula osseous flap based on the angular artery only.

- If more and/or distal osteotomies or longer bone is needed, the scapular tip (an additional 3 to 4 cm of bone) can be safely and simultaneously harvested based on the angular artery. Alternatively, the tip of scapula can be harvested as a separate vascularized bone segment (**FIG 2**).⁷
- The angular artery branches off the TDA or the serratus branch and travels on top of the serratus muscle beneath the TM.
- Because of the dedicated periosteal branches from the CSA, the lateral osseous flap is not dependent on the overlying skin for its vascular supply. Therefore, depending on the soft tissue defect, it can be elevated with a scapular or parascapular fasciocutaneous flap, or a combination of them (either combined in an L-shaped bilobed configuration or as separate skin paddles).

Positioning

- Although prone and modified lateral decubitus positioning has been suggested, the lateral decubitus position with the arm fully prepped in the operative field allows optimal access (**FIG 3**).

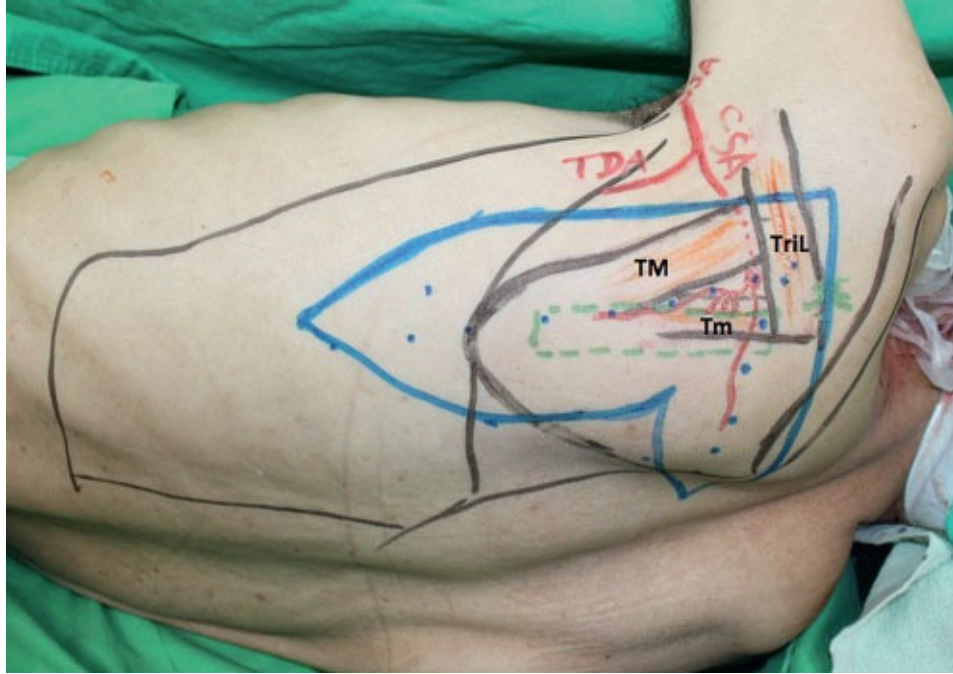


FIG 3 • The patient has been placed in right lateral decubitus position with the left arm abducted at 90 degrees. The scapular and parascapular skin paddles have been delineated in *blue*. The subscapular artery (SSA) is shown branching into the thoracodorsal (TDA) and circumflex scapular arteries (CSA). The CSA is shown emerging through the triangular space bound superiorly by the long head of the triceps (*TriL*), medially by the teres minor (*Tm*), and laterally by the teres major (*TM*). After giving musculoperiosteal branches to the lateral osseous flap (marked in *light green*), the CSA gives off a descending branch coursing caudally and a transverse branch coursing medially that supply the parascapular and scapular skin paddles, respectively. The outline of the latissimus muscle is also shown in *black*.

- During harvest of the skin paddle and bone, the arm is best kept in abduction for easy identification of the teres muscles.
- During harvest of the pedicle at the depths of the triangular space and exposure of the subscapular pedicle in the axilla, manipulation of the arm will allow easy exposure.
- An axillary roll and appropriate padding of pressure points are important to prevent brachial plexus injury and decubitus ulcer, respectively.

Approach

- Two different approaches exist for the harvest of the skin component of the flap, whether it is a scapular or parascapular one.
- In the medial approach, the skin paddle is elevated peripherally prior to dissection of the CSA.
- On the contrary, with the lateral approach, the pedicle is identified first through a limited incision followed by dissection of the skin island.

TECHNIQUES



Video p3-c012

■ Preparation of Recipient Site

- Prior to flap harvest, the recipient site should be examined to determine location, configuration, and size of the different components of the defect.

- The viability of remaining tissues should be assessed. If necessary, any tissue of questionable viability should be trimmed further.
- Recipient vessels should be exposed and prepared for expeditious revascularization after closure of the donor site and repositioning of the patient.
- After careful assessment of the defect and the recipient vessels, the following decisions on the specific flap design can be made: length of the osseous component, osteotomy sites and number, number and size of skin paddles, additional muscle flaps, optimal pedicle length, and inset of the flap.
- The axillary hair is clipped.
- The ipsilateral arm is fully prepped and included in the operative field as is the shoulder, axilla, and lateral torso from sternum and umbilicus anteriorly to spine posteriorly.
- The ipsilateral thigh should be prepared separately for possible skin graft harvest.

■ Skin Flap Harvest

- The skin flap can be harvested through either a medial or a lateral approach.

Medial Approach (Retrograde, Distal to Proximal)

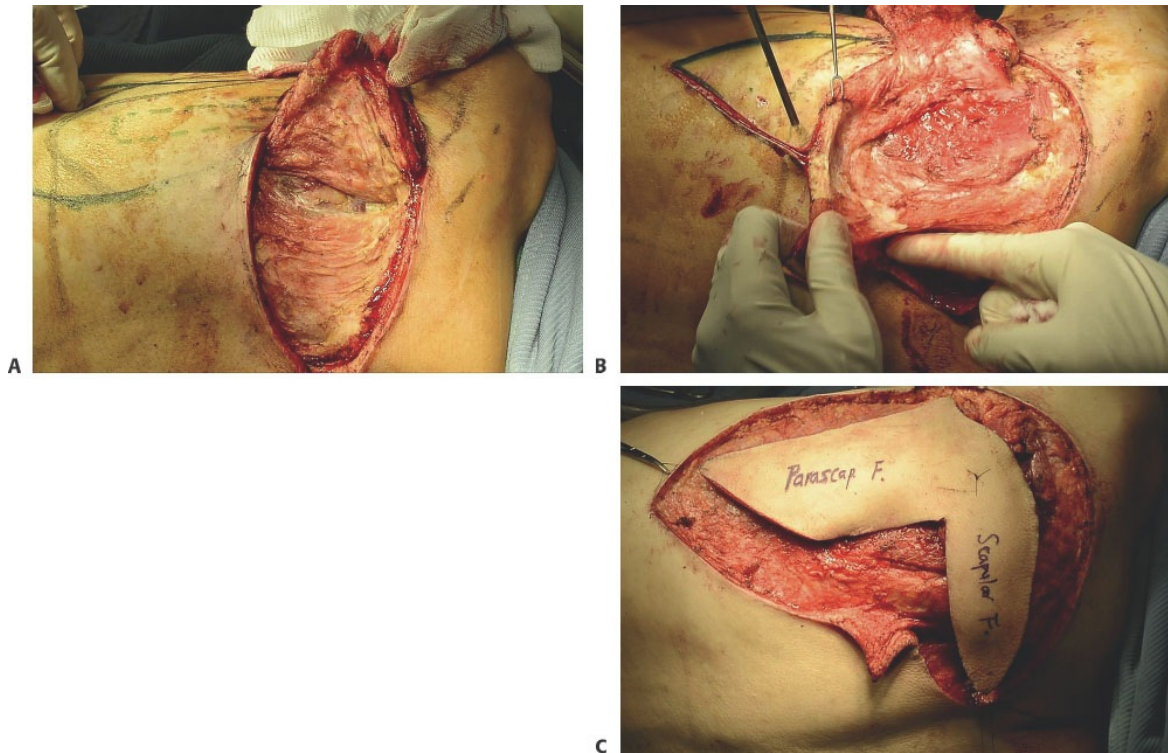
- The course of the terminal branches of the CSA, transverse or descending, can be reliably estimated using anatomic landmarks and confirmed with a Doppler.
- The skin flap design is centered over this vascular axis by marking the triangular space and using a pencil Doppler to map out the vessel (see **FIG 3**).
- At the distal end of the flap, an incision is made through the skin down to, but not including, the deep muscle fascia (**TECH FIG 1A**).
- The dissection proceeds expeditiously in an areolar plane between the deep thoracic fascia, which carries the pedicle, and the underlying deep muscle fascia. Dissection over the latissimus muscle is done rapidly as the skin perforator in this area is in the flap (**TECH FIG 1B**).
- The skin incisions are extended proximally on both sides of the pedicle that is clearly visualized on the undersurface of the flap.
- Once the lower border of the teres major is identified, a more careful

dissection is required to safely expose the pedicle exiting the triangular space between the teres major inferiorly and the teres minor superiorly.

- The pedicle gives off small branches to the teres major and minor that require care for ligation.
- After the pedicle is shown entering the flap, the remaining proximal incisions are completed to create a flap island (**TECH FIG 1C**).
- Separating the teres major and minor with a self-retaining retractor and abduction of the arm facilitates dissection of the flap.

Lateral Approach (Antegrade, Proximal to Distal)

- Proximal flap incisions are made first in the vicinity of the triangular space along the preoperative markings. The deltoid, triceps, and teres muscles are exposed.
- The deltoid is retracted cephalad and the CSA is identified at the hiatus between the teres major and minor.
- The direction of the transverse and descending branches is confirmed.
- The skin paddle can then be adjusted if necessary and centered over the vascular pedicle under direct vision as the dissection proceeds from proximal-to-distal direction.
- Once the distal incisions are made, the skin island is isolated on the CSA pedicle.
- The pedicle is completely dissected and the vessels are separated in anticipation of flap harvest. It is important to complete pedicle dissection *prior* to osteotomies because the bleeding from the cut bone edges will complicate this process.



TECH FIG 1 • **A.** The scapular skin paddle has been partially elevated and retracted laterally with a skin hook. **B.** The scapular skin paddle has been reflected laterally. The skin hook is retracting the parascapular skin paddle to be elevated next. **C.** Both scapular and parascapular flaps have been completely islandized.

■ Inclusion of Latissimus Dorsi Muscle

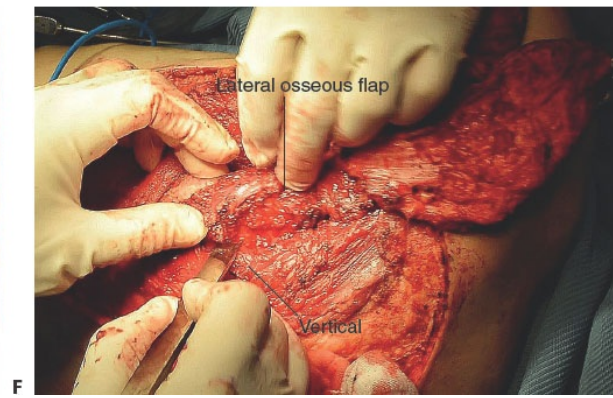
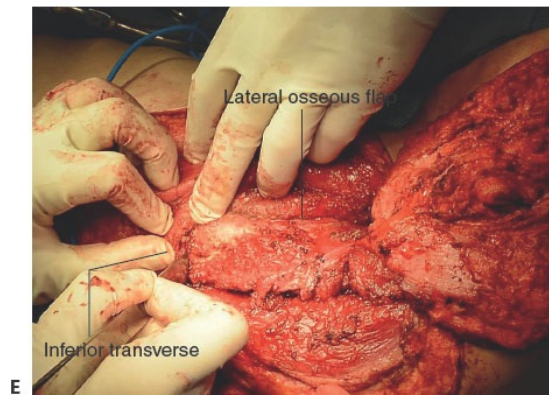
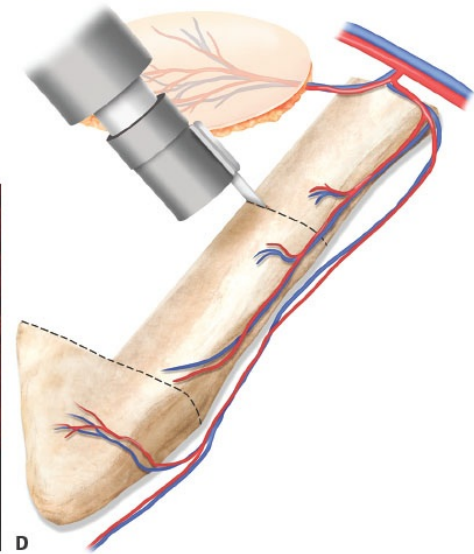
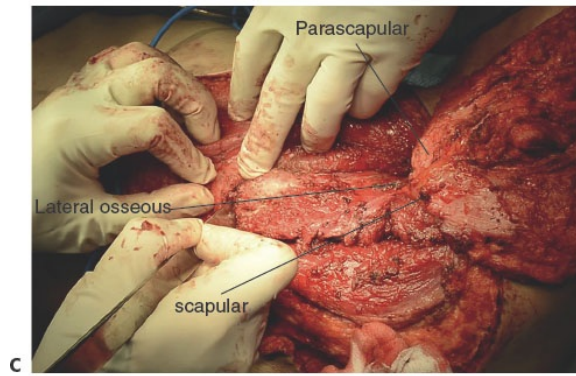
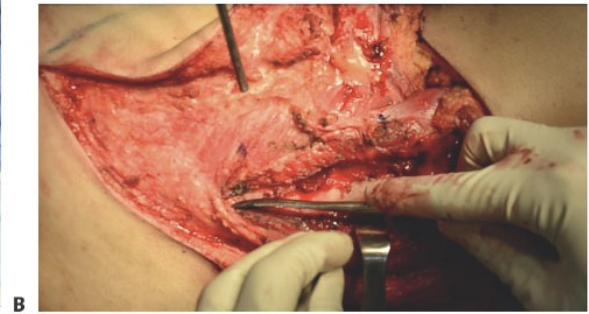
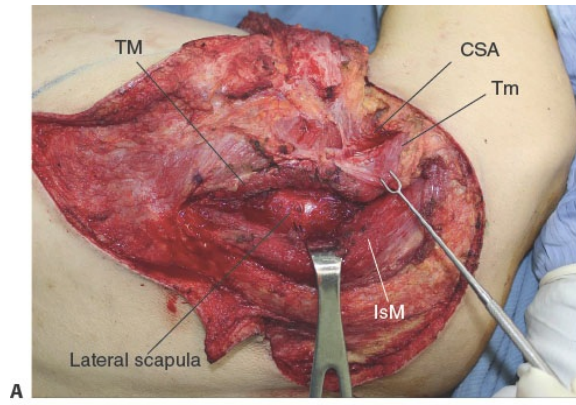
- A portion of the latissimus or serratus anterior fascia can be included in the flap based on the shared blood supply of these structures with the flap.
- Dissection of the pedicle to include the takeoff of the TDA and the serratus anterior branches is performed.
- This dissection enables transfer of a large soft tissue component that can be used to repair complex defects of the head and neck.

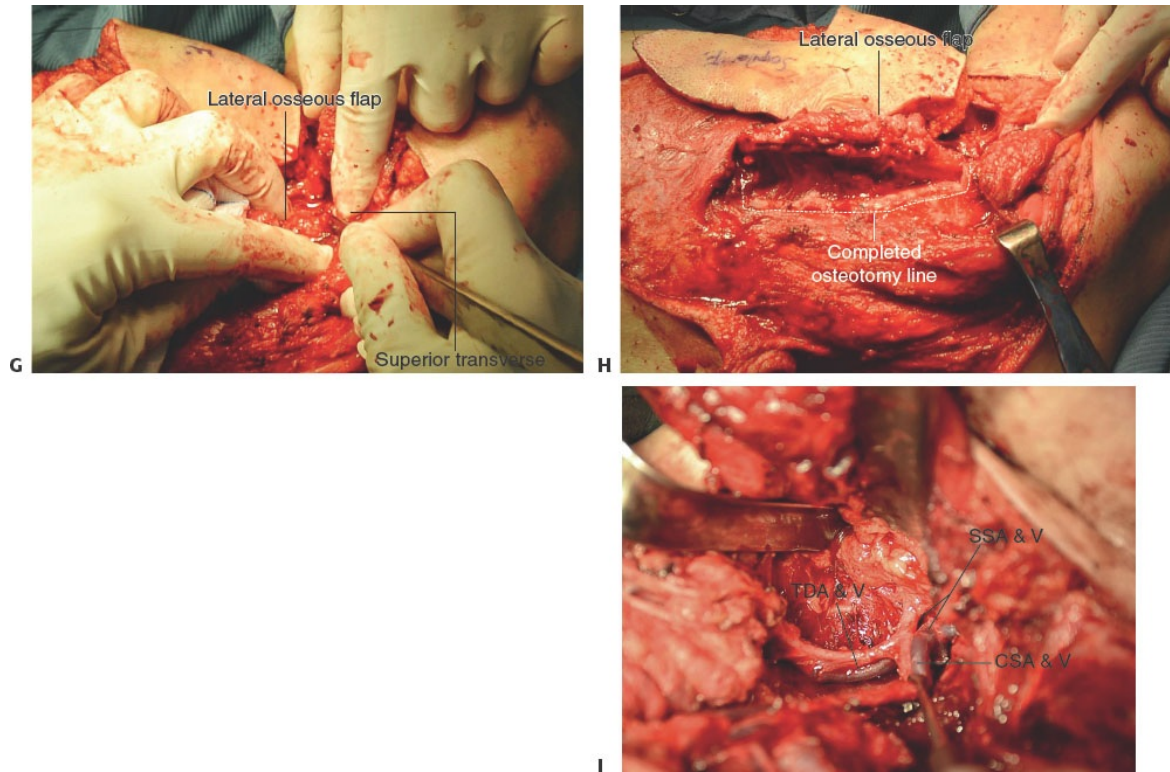
■ Bone Harvest

- Bone harvest continues in a similar fashion with both the lateral and medial

approaches to skin flap harvest.

- The multiple muscle branches from the CSA are carefully divided as the dissection continues into the triangular space.
- It is important to avoid dissection between the CSA and lateral border of the scapula.
- The teres muscles and the infraspinatus muscle are divided 2 to 3 cm medial from the lateral border down to the scapular bone along the intended vertical osteotomy line (**TECH FIG 2A**).
- The muscles are then elevated off the lateral scapula leaving a muscular cuff to avoid injury to the periosteal blood supply (**TECH FIG 2B**).
 - This is especially true as the lateral border of the scapula is approached where 1 cm of muscle cuff is left attached to bone.
- The divided teres muscles are reflected laterally.
- The vascular branches to the lateral border of the scapula are identified and preserved (**TECH FIG 2C**).
- The periosteum is sharply divided along the vertical osteotomy line and elevated medially. A saw or an osteotome is used to cut through the bone (**TECH FIG 2D**).
- The inferior transverse osteotomy is made first (**TECH FIG 2E**).
- The vertical osteotomy is parallel to the lateral border and extends from 1 to 2 cm below the glenoid fossa/shoulder joint superiorly to the planned distance inferiorly (**TECH FIG 2F**).
- During the superior transverse osteotomy between glenoid fossa superiorly and the CSA inferiorly, great care is taken to avoid injury to these structures (**TECH FIG 2G**).
- The bone is then everted laterally to allow easy detachment of the underlying subscapular muscle by similarly preserving a muscular cuff on the bone (**TECH FIG 2H**).
- If the tip of the scapula is to be included, the angular artery is identified, preserved, and traced to its junction to the serratus branch or the TDA itself. The serratus anterior insertion to the tip is divided leaving a muscle cuff.
- Any bleeding from the muscle cuff of the bone flap is controlled with bipolar cautery.
- The CSA and its comitant veins are traced proximally toward their junction with the thoracodorsal artery and its accompanying vein (**TECH FIG 2I**).





TECH FIG 2 • A. Both scapular and parascapular skin paddles have been reflected laterally exposing the circumflex scapular artery (CSA). The origins of teres major (*TM*) and teres minor (*Tm*) muscles from the lateral border of the scapula have been divided to expose the underlying bone (lateral scapula). Please note the infraspinatus muscle (*IsM*) retracted medially. **B.** The periosteum is elevated along the planned vertical osteotomy line. **C.** An osteotome is used to perform the inferior horizontal osteotomy. The scapular and parascapular skin paddles have been reflected superiorly to expose the underlying lateral osseous flap. The lines point to the vascular supply of the flaps—musculoperiosteal (lateral osseous), descending (parascapular), and transverse (scapular) branches, respectively. **D.** Due to the periosteal vascular supply, the osteotomies should be performed with great care. The periosteum should be minimally

stripped at the planned osteotomy site. Multiple contouring osteotomies might jeopardize the blood supply to the bone. Inclusion of the angular artery would “supercharge” the osseous flap allowing more than one osteotomy. The osteotomies are performed in the following sequence: inferior transverse (**E**), vertical (**F**), and superior transverse (**G**). **H**. After the osteotomies (*dashed line*) are completed, the lateral osseous flap is elevated to allow division of the subscapular muscle attachments. **I**. A closeup view of the subscapular artery and vein (SSA&V) branching into the thoracodorsal artery/vein (TDA/V) and circumflex scapular artery/vein (CSA/V). Note the very short length of the subscapular vein. In this case, two separates venous anastomosis might be required, especially if there is a valve at the short segment of the subscapular vein.

- The subscapular pedicle is then followed proximally to the axillary vessels, and any remaining branches are ligated.
- It is important to preserve the nerves to the surrounding muscles during this dissection.
- The pedicle is divided at an appropriate length.
- The donor site has to be closed, before the flap can be inset.
- In the meantime, if available, a second surgeon can prepare the flap at the back table (osteotomy, vessels). This will allow more expeditious inset and revascularization.
- After division of the pedicle, the donor-site closure begins with reattachment of the divided muscles to the remaining scapular bone.
 - Two or three drill holes allow suture fixation of the cut muscle ends to the edge of the scapula.
- Large-bore suction drains are placed in the axilla and the back.
- With adequate undermining, most defects can be closed primarily in two layers. Otherwise, skin grafts are used as necessary.

■ Preparation and Inset of the Flap

- The osseous component of the flap is cut to appropriate length and osteotomized as necessary to match the mandibular defect.
- Because the blood supply of the scapula flap is based on periosteal perforators, care should be taken to avoid stripping the bone for osteotomies. In addition, the number of osteotomies should be minimized as much as possible to avoid bone necrosis.
- In addition, because the periosteal blood supply is critical, the periosteum should be maintained in continuity during the osteotomies by careful, limited elevation.
- Osteotomy is made with a small reciprocating saw or fine burs while shielding the periosteum.
- If a prebent and appropriately marked reconstruction plate is available, this can be done even before the division of the pedicle.
- Alternatively, the flap can be prepared either by a second surgeon at the back table while the donor site is being closed or immediately before inset.
- However, it is best done before revascularization to avoid tension to or accidental avulsion of the pedicle. Plating is best done at the time of the inset.
- If the defect is small or access to it is limited, the flap destined to provide intraoral lining can be completely or partially inset prior to bone fixation.
- Osteosynthesis with the native mandible can be achieved with a single reconstruction plate spanning the entire defect. Alternatively, small plates or interosseous wires can be used.
- Microvascular anastomosis is completed in the standard fashion.
- Finally, soft tissue inset is completed.

■ Flap Variations

Medial Osseous Flap

- An osteocutaneous flap can be harvested from the medial border of the scapula between the scapular spine and the inferior angle. The corticocancellous segment is 10 to 12 cm long and 2 to 3 cm wide.
- The blood supply is provided from fascial attachments of the dorsal thoracic fascia on the undersurface of the scapular flap to the underlying bone.

- Nevertheless, the bone is thinner on the medial border of the scapula (1.5 cm as compared to 3 cm on the lateral aspect) providing less bone stock.

Inframammary Extended Circumflex Scapular (IMECC) Flap

- It is yet another option of skin paddle design that can be combined with the lateral osseous flap to better disguise the scar in women.
- The flap is centered over the anterior branch of the superficial CSA that arises from the descending branch a few centimeters below the triangular space and turns toward the ipsilateral inframammary fold.

Isolated Angular Bone Segment

- The inferior angle of the scapula can be harvested as an isolated bone segment in combination with any of the skin paddle options to reconstruct composite mandibular defects of appropriate size.
- The angular branch can arise from the TDA itself, the serratus branch, or the latissimus dorsi branch. It reaches the scapula on top of the serratus muscle and beneath the TM.

Additional Options

- Several additional flaps can be elevated with the osteocutaneous flap on the same subscapular pedicle:
 - Latissimus dorsi muscle
 - Latissimus dorsi myocutaneous flap (**TECH FIG 3**)
 - Latissimus dorsi muscle with rib
 - Dorsal thoracic fascia flap
- Simultaneous elevation of serratus flaps is discouraged, as it is an important muscle for shoulder stability.



TECH FIG 3 • A. All the components of a composite osteomusculocutaneous flap are shown. **B.** Another patient is shown in right lateral decubitus position with both the scapular and latissimus dorsi skin paddles islandized. The scapular osteocutaneous flap will be used for mandibular reconstruction and intraoral lining. On the other hand, the fleur-de-lis skin paddle and underlying latissimus dorsi muscle (latissimus dorsi musculocutaneous [LDMC] flap) will provide external coverage of the lower jaw and allow release of a neck contracture. **C.** On the same patient, the scapular skin paddle is reflected to expose the underlying lateral osseous component of the flap.

Axillary incision	■ A counter incision in the axilla or extension of the existing incision toward the axilla, though not necessary, will allow identification and dissection of the subscapular vessels in a safer and more rapid manner.
Skin over the triangular space	■ The triangular space should be included in all skin flap geometries to ensure optimum blood supply.
Skin island configurations	■ When the scapular flap is combined with a parascapular flap, they can be raised in continuity in a reverse L-shaped configuration (with de-epithelialization performed as necessary) or as two separate skin islands.
Pedicle length	■ The effective maximum pedicle length for the lateral osseous flap is 4–6 cm (subscapular artery plus CSA up to the periosteal branches). Lateral osseous bone to scapular or parascapular skin paddles 2–3 cm.
Lengthening the pedicle	■ When suitable recipient vessels are found only on the contralateral neck: ■ The TDA is harvested distally to an appropriate length and used as the donor artery to provide blood supply in a reverse flow fashion. ■ For venous outflow, either the SSV with a vein graft (reversed thoracodorsal vein is readily available) can be used or the cephalic vein can be transposed.
Simultaneous recipient vessel dissection	■ In the lateral decubitus position, a second surgeon could explore ipsilateral neck vessels simultaneously.
Additional soft tissue	■ Subcutaneous dissection beyond the skin border can provide additional soft tissue, if facial contouring is necessary.
Tissue expansion	■ Pre-expansion can allow primary closure of larger than usual flaps. Otherwise, postoperative expansion of the surrounding skin can allow resurfacing of a previously grafted area.
Primary closure of large parascapular defect	■ A pedicled TDA perforator flap has been described for closure of a large parascapular flap defect in an attempt to avoid skin grafting.

Scapular vs parascapular skin island	■ If only one skin paddle is required, parascapular flap can be preferred over the scapular flap as it facilitates the axillary exposure for dissection of the pedicle and allows placement of the scar in a less conspicuous area.
Skin grafting	■ Skin grafting at the donor site invariably results in poor graft take, significant contour irregularity, and conspicuous scar.
Flap thickness	■ The flap may be thick in obese individuals. This should be taken into consideration during planning of flap dimensions.
Dental rehabilitation	■ If osteointegrated implants are planned for dental rehabilitation, careful planning of the inset is necessary. The graft orientation should be such that the bone segment with the optimum height and width is placed at the area of interest.
Anatomic variations	■ In case of double CSA or CSA/CSV that do not join the SSA/SSV, additional recipient vessels are required if any additional tissue is to be carried on the TDA. ■ If the pedicle of the parascapular flap (CSA descending branch) courses behind the TM, the TM has to be divided during the harvest of the skin island.

POSTOPERATIVE CARE

- The shoulder/arm is kept immobilized for 1 week to allow healing and minimize pain.
- First, range-of-motion exercises are carefully initiated followed by shoulder girdle muscle strengthening exercise 2 to 3 weeks after surgery.
- The donor site requires 3 to 4 weeks to heal completely.

OUTCOMES

- Although shoulder function limitation has been reported in the literature, adhering to a meticulous technique and postoperative rehabilitation regimen can prevent this complication.⁸
- In large series of 105 patients undergoing osseous scapular flap harvest, Gibber reported no such complication.⁹
- For various reasons, still only a minority of patients eventually undergo placement of osteointegrated implants irrespective of the implantability of the reconstructed bone segment.
- Anatomic studies have demonstrated bone stock amenable to implantation in 78% to 95% of specimens.¹⁰
- Potential complications include

- Hematoma
- Seroma
- Wound infection or dehiscence
- Widened scar at the donor site
- Limitation of shoulder movement and strength
- Nonunion of mandibular reconstruction
- Brachial plexus or long thoracic nerve injury

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Lateral Mandible Reconstruction With Soft Tissue Flaps

13

CHAPTER

Afshin Mosahebi, Evan Matros, and Babak J. Mehrara

DEFINITION

- The mandible provides contour to the posterior lower third of the face and plays a key role in mastication and maintenance of oral competence.
 - As a result, mandibular function is necessary for swallowing, speech, and aesthetic contour of the face.
- The most common indication for mandibular reconstruction is segmental bone loss resulting from cancer ablation, trauma, osteoradionecrosis, and infection.
- Defects of the lateral mandible are defined as those that extend posteriorly from the mental foramen and can include the ramus or condyle.
- Lateral mandibular defects that are most suitable for soft tissue–only reconstruction defects include not only osseous defects but also extensive soft tissue injury including the floor of the mouth, tongue, palate, pharynx, and external skin. Mandibular defects that result in the complete loss of the temporomandibular joint and the surrounding soft tissues may also benefit from soft tissue–only reconstruction because inseting of bone flaps in these defects may be difficult and associated with poor function.

ANATOMY

- The mandible is anatomically divided into one horizontal component and two vertical components.
 - The horizontal component comprises the symphysis and the body on each side, forming a U-shaped arch that connects the two vertical segments.
 - Each vertical segment is composed of the angle, ramus, coronoid process and condylar process. The vertical segment serves as the insertion site for the

muscles of mastication and forms the articulation of the mandible with the skull.

- The arterial supply of the mandible is derived from branches of the lingual, facial, and inferior alveolar arteries.
- The inferior alveolar nerve is the largest branch of the mandibular nerve. It enters the mandible through the mandibular foramen on the medial surface of the mandibular ramus and gives two terminal branches: the mental nerve and the incisive nerve.
- The mental nerve innervates the skin of the chin as well as the skin and the mucosa of the lower lip.
- The incisive nerve continues to travel in the mandible and provides sensory innervation to the premolar, canine, incisor teeth, and their associated gingiva.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history should include careful assessment of the pathology of the anticipated mandibular defect and the previous treatments that have been administered.
- History of prior surgery, particularly those that may involve the vascular supply of the mandible, should be obtained. This information is important in surgical planning because damage to the ipsilateral neck vessels may require the use of contralateral neck vessels or alternative plans.
- Surgical plans should be reviewed with the head and neck surgeons (if they are involved in the procedure).
- History of radiation to the area should also be obtained because this treatment may impede healing of soft and bony tissues, decrease availability of recipient vessels, and increase the potential need for external skin coverage.
- Past medical history, medical comorbidities, and risk factors for cardiovascular disease (eg, hypertension, coronary artery disease, hyperlipidemia, history of smoking, obesity, diabetes, etc.) should be reviewed.
- This is common in patients with head and neck cancers because many of these individuals have a history of smoking and ethanol use.
- Patients with long-standing history of cardiovascular disease require medical consultation for preoperative clearance and optimization.
- Preoperative speech and swallowing should be documented and assessed because these functions may be significantly affected by tumor invasion and surgical ablation. In addition, preoperative mouth opening should be recorded as interincisal distance.

- Oral hygiene and dentition should be assessed because patients with poor oral hygiene and dentition are at much higher risk of postoperative infections and complications. Severe compromise of dentition or oral hygiene may also require preoperative dental consultation.
- The presence or absence of pain with mouth opening, chewing, swallowing, or eating should be obtained.
- The patient's general nutritional status should be assessed by physical examination and laboratory tests.
- Personal and family history of bleeding abnormalities should be elicited.
- The physical examination should also include assessment of the head and neck area, anticipate the planned resection in the case of oncologic patients, assess availability of recipient vessels, quality of intraoral and extraoral soft tissues, and available donor sites for reconstruction.
- A pulse examination of the extremities is necessary to document the potential for peripheral vascular disease.
- The quality (ie, thickness, pliability, etc.) of soft tissue donor sites should be addressed, and alternative plans should be developed.

IMAGING

- Preoperative computed tomography (CT) or magnetic resonance imaging (MRI) may be helpful in assessing osseous defects and potential involvement of the soft tissues.
- Preoperative angiography may also be helpful in assessing availability of recipient vessels in the head and neck area, although this is rarely necessary.
- Preoperative imaging of donor sites may also be useful for assessment of blood flow. However, this is rarely necessary for assessment of soft tissue flaps such as the anterolateral thigh or rectus abdominis flaps commonly used in soft tissue only reconstruction of complex lateral mandible defects.

SURGICAL MANAGEMENT

- Lateral mandible defects that involve primarily the bone with limited resection of the soft tissues are best reconstructed with bone flaps (eg, fibula, scapula, iliac crest).
- Soft tissue reconstruction of lateral mandible defects is indicated in patients with an intact anterior mandibular arch (ie, bone resection is lateral to the incisors) in combination with complex soft tissue defects involving the floor of the mouth, tongue, palate, pharynx, or, in some cases, external skin.

- It is useful in cases in which the temporomandibular joint is widely excised, leaving a large defect at the base of the skull where bone flaps cannot be adequately seated.
- It may be needed in patients who do not have osseous donor-site options (eg, severe peripheral vascular disease). However, this is less common because multiple options for bone donor sites exist (eg, scapula may be a good choice in these cases).
- Of the variety of soft tissue flaps useful for reconstruction of complex lateral mandibular defects, the vertical rectus abdominis myocutaneous flap and the anterolateral (ALT) flap are most commonly used for the following reasons:
 - They provide large amounts of soft tissues and muscle that can be tailored to complex defects.
 - They enable harvesting of multiple skin paddles that can facilitate combined intraoral and extraoral defect reconstruction.
 - They have long pedicles that can easily reach neck recipient vessels even if it is necessary to use vessels contralateral to the site of the defect.

Preoperative Planning

- The defect is evaluated for reconstruction, taking into consideration the volume of tissues necessary to maintain the remaining mandible in anatomic position.
 - The need for intraoral and extraoral (if necessary) tissue reconstruction is assessed.
- Factors that are important in planning reconstruction of lateral mandibular defects:
 - Medical comorbidities, functional and nutritional status, and oral hygiene
 - Extent of the mandibular defect
 - Anticipated soft tissue defects
 - Prior surgical procedures and availability of recipient vessels
 - The need for postoperative adjuvant therapies that may be necessary
 - Planned or anticipated secondary/tertiary reconstructions

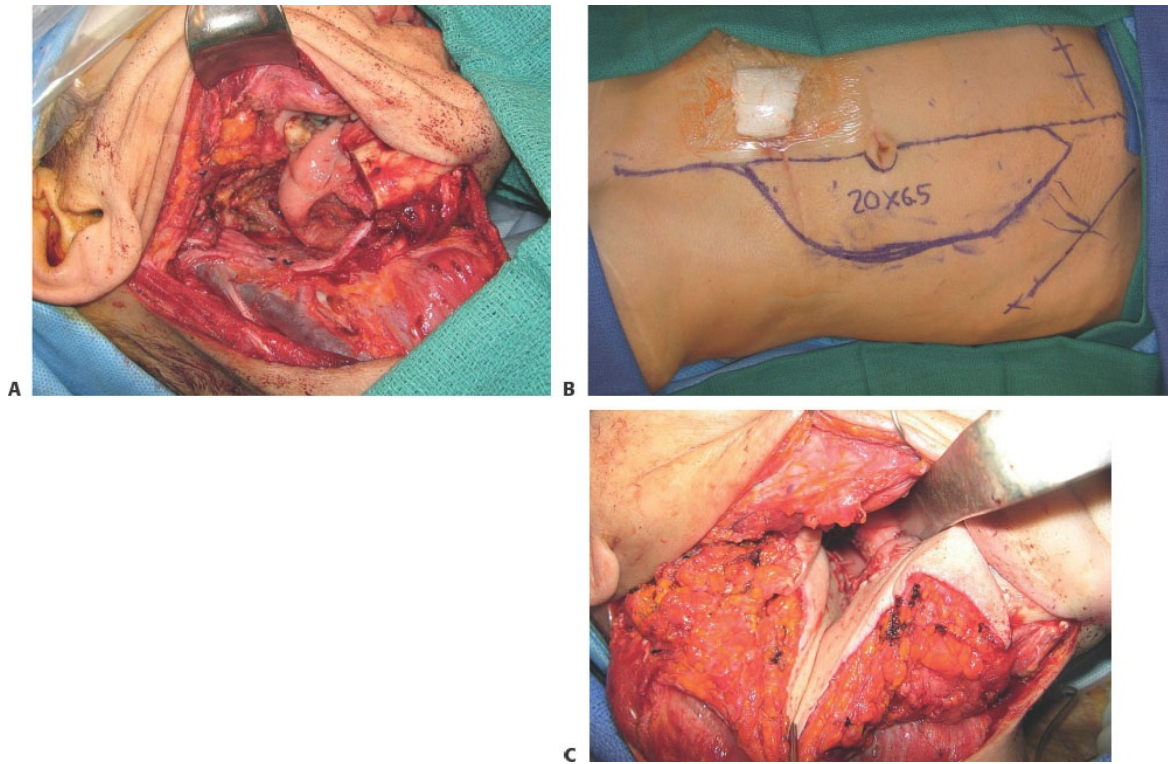
Positioning

- The patient is positioned in supine position.
- In most cases, a tracheostomy is also performed because emergent reintubation of a patient with an extensive reconstruction involving the lateral mandible may be challenging and may result in iatrogenic injury to the free flap.

TECHNIQUES

■ Horizontally Oriented Flaps

- It is generally simplest to orient the flap horizontally along the axis of the defect thus interposing the soft tissue flap between the cut end of the mandible and the infratemporal fossa.
- This orientation results in optimal positioning of the vascular pedicle with respect to the neck vessels.
 - If the ipsilateral neck vessels are used, the flap is oriented with the vessels exiting the flaps posteriorly.
 - Conversely, if it is necessary to use the contralateral neck vessels, the flap is oriented with the vessels exiting the tissues medially (thus decreasing the distance necessary to reach the contralateral vessels).
- The patient shown in **TECH FIG 1A** has undergone a radical resection of the right hemimandible, retromolar trigone, floor of the mouth, and partial tongue for a recurrent squamous cell cancer involving the retromolar trigone area.
 - Because the temporomandibular joint was resected, and the patient had a paucity of recipient vessels preventing double free flap reconstruction, the defect was reconstructed with a vertical rectus abdominis myocutaneous (VRAM) flap (**TECH FIG 1B**).
 - The flap has been inset into the defect in the horizontal plane, thus obliterating the defect in the mandible and maintaining normal positioning of the remaining bone and, at the same time, obliterating the intraoral soft tissue defect (**TECH FIG 1C**).
 - Rigid fixation with plates is rarely necessary in this type of reconstruction. Plates placed in this manner routinely fail (necessitating additional surgery) and complicate flap inset resulting in compression or pressure on the flap.
 - Microsurgical anastomosis was performed to the right superior thyroid artery (end to end) and the internal jugular vein (end to side). In general, the inset is performed at least partially to stabilize the flap followed by microsurgical anastomosis.



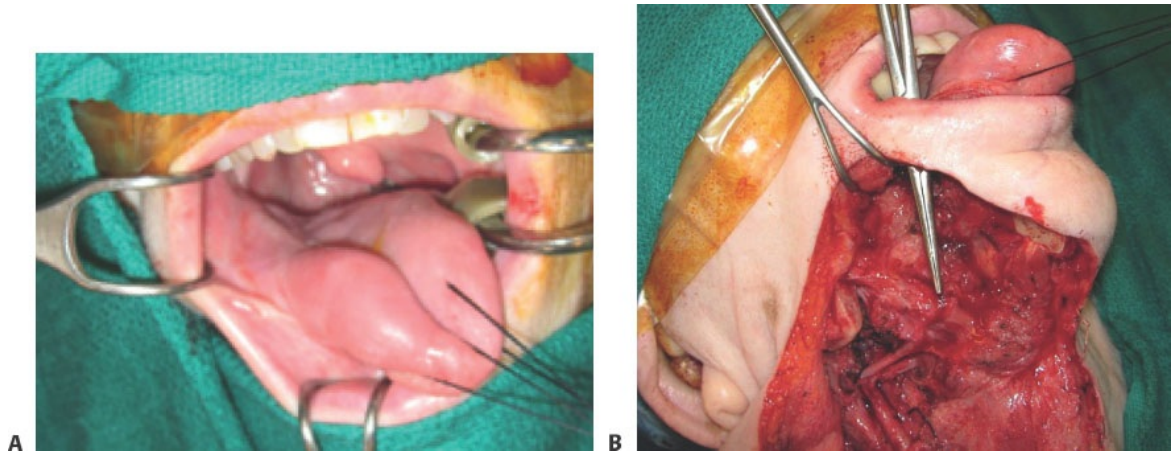
TECH FIG 1 • **A.** Extensive lateral mandible defect (lateral mandible, floor of the mouth, lateral tongue, retromolar trigone, and temporomandibular joint) in a patient treated for a recurrent squamous cell cancer. **B.** Markings for a large VRAM flap. **C.** Flap inset demonstrating horizontal orientation of the flap to reconstruct the floor of the mouth, retromolar trigone, and mandibular defect.

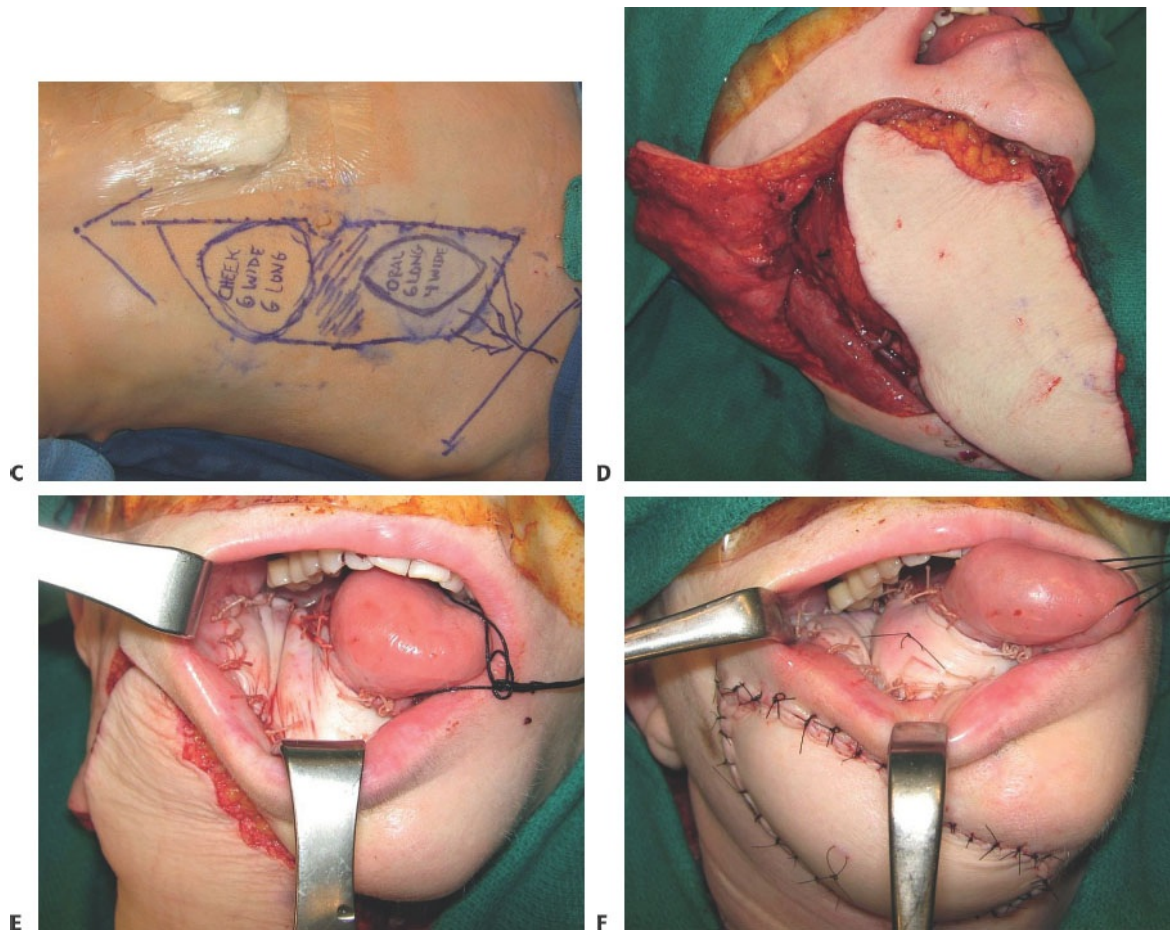
■ Nonhorizontally Oriented Flaps

- It may be necessary to orient the flap slightly off axis or in a more vertical direction. This most commonly happens when there is a combined intraoral and extraoral defect.
- The patient shown in **TECH FIG 2A** had a recurrent squamous cell cancer of the right hemimandible with regional metastasis to the lateral cheek, floor of the mouth, and retromolar trigone.
- Resection of this recurrence resulted in an extensive intraoral and extraoral defect involving the lateral mandible, floor of the mouth, buccal mucosa,

retromolar trigone, and external cheek skin (**TECH FIG 2B**). A fibula flap alone would not be suitable for this reconstruction and would necessitate a double free flap, which, given this patient's medical comorbidities and nutritional deficits, was not advisable.

- A VRAM flap with a double skin island was designed to reconstruct all the defects with one flap (**TECH FIG 2C**).
- The flap was inset in a primarily vertical orientation with the skin paddle and muscle obliterating the mandible defect and the inferior skin paddle inset into the intraoral defect (**TECH FIG 2D-F**).
- Note watertight closure of the defect.





TECH FIG 2 • A. Recurrent squamous cell cancer of the lateral mandible involving the cheek and retromolar trigone. Note abnormal adherence of the tongue to the buccal mucosa and the preoperative absence of the right marginal mandibular nerve function. **B.** An extensive resection resulting in a complex intraoral and extraoral defect has been performed. **C.** Double-island VRAM flap is planned and drawn in place with approximate measurements of the skin paddles needed for reconstruction. **D.** Flap positioning prior to inset. Note almost vertical orientation lining up the inferior portion of the flap intraorally. **E.** Flap has been inset into the intraoral defect. **F.** Final flap inset demonstrating closure of both intraoral and extraoral defects.

PEARLS AND PITFALLS

Planning	■ The plan should be discussed with the ablative surgeon preoperatively because preservation of the anterior mandibular arch is necessary. ■ Dental consultation is helpful in patients with carious teeth. ■ Preoperative imaging may be necessary to assess the extent of the expected defect and availability of recipient vessels.
Recipient site preparation	■ Recipient vessels should be preserved during resection and prepared prior to flap transfer. ■ The defect should be carefully analyzed to design the optimum flap and the best combination of skin, muscle, and fat to meet the volume and soft tissue requirements of the defect.
Flap inset	■ Flap can be inset vertically or horizontally to best obliterate the intraoral and extraoral (if present) defects. ■ Orientation of the flap with respect to recipient vessels should also be considered.
Donor-site closure	■ A two-team approach allows flap inset and donor-site closure simultaneously, thus cutting down time under anesthesia.
Postoperative care	■ The head should be kept neutral to minimize stress on the closure. ■ Drains should be kept away from the anastomoses. ■ Circumferential tracheostomy ties are strictly avoided as they can compress the pedicle.

COMPLETION

- The neck wound is copiously irrigated with warm saline or antibiotic solution and the position of the vessels is confirmed with gentle ranging of the neck to ensure that the vessels do not become kinked with patient motion.
- One or two closed suction drains are placed in the neck with care taken to avoid compression of the vein or suction near the anastomosis.
- Skin wounds are closed after loose approximation of the platysma (if possible) and skin closure with nylon sutures (4.0).

POSTOPERATIVE CARE

- Tube feedings are begun within 48 hours of the conclusion of the procedure. Irrigation of the oral cavity for hygiene is generally begun after 3 days.
- The tracheostomy is left in place for 10 to 14 days, or until wound healing is assured and it is clear that additional surgery is not needed.
- Extensive defects, particularly those involving reconstruction of the pharynx or retromolar trigone may benefit from swallow studies to ensure that there is no leak into the neck and that the patient does not aspirate oral feeds. These are usually done approximately 2 weeks postoperatively.
- Patients who have extensive surgery in combination with a prior history of radiation may benefit from longer recovery times (eg, 6 weeks) with swallow assessment performed as an outpatient. In these cases, oral feeds are maintained with nasogastric or, more commonly, gastric tubes.

OUTCOMES

- The use of soft tissue reconstruction alone for extensive defects allow patients to return to an oral diet relatively quickly.¹
- Mosahebi et al. evaluated 76 patients who underwent soft tissue reconstruction of extensive posterolateral mandibular defects.
 - VRAM was used most commonly (89%) and mean length of stay was 18 days.
 - Most patients (54%) were able to tolerate oral feeds at discharge, and 60% had normal or near normal speech.
 - Aesthetic outcomes were good in 49%, fair in 21%, and poor in 30%.
 - Salivary fistulas developed in 6.6% of patients and healed spontaneously in over 80% with conservative management.
- Kroll et al.² reported on 21 patients treated in a similar manner with most patients achieving good to excellent aesthetic outcomes, and excellent speech and swallowing in 33%.
 - Most patients required secondary revisions to address neck fullness.

COMPLICATIONS

- Potential complications are related to flap failure (generally less than 5%), infections, hematoma, intraoral wound dehiscence (which may lead to orocutaneous fistula formation), or functional complications (eg, impaired speech, swallowing, mastication).
- Flap donor-site complications may also be problematic in this patient population.

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14

CHAPTER Maxillomandibular Fixation

Cherry L. Estilo, SaeHee Kim Yom, and Joseph Randazzo

DEFINITION

- Maxillomandibular fixation (MMF), also called intermaxillary fixation, involves fixation of fractures or residual components (following surgical resection) of the mandible or maxilla by applying elastic bands or stainless steel wire between the maxillary and mandibular arch bars.
- Occlusion is the relationship between the maxillary and mandibular teeth as they contact one another. In this chapter, the term “occlusion” refers to the occlusion when the jaw is closed.

ANATOMY

- MMF serves two purposes:
 - To stabilize and align the jaws into appropriate occlusal relationship to maintain preoperative occlusal status
 - To assist in maximizing the precision of the reconstruction
- Presence of full or near-full complement of healthy dentition (especially, in the posterior region) is ideal for successful MMF.

PATIENT HISTORY AND PHYSICAL FINDING

- A thorough oral and dental clinical examination is completed.
- The periodontal status of the teeth and the condition of existing restorations or fixed prosthesis are evaluated to determine the ideal teeth for fixation.
- The occlusal relationship and any mandibular deviation are noted.

IMAGING

- Along with clinical examination (**FIG 1A**), a panoramic radiograph (and selected dental radiographs, if necessary) examination is completed to assess

the overall health and stability of the patient's dentition.

- When indicated, selected dental (periapical or bite-wing) radiographs are obtained (**FIG 1B**).

SURGICAL MANAGEMENT

- Equipment (**FIG 2**)
- Erich arch bars

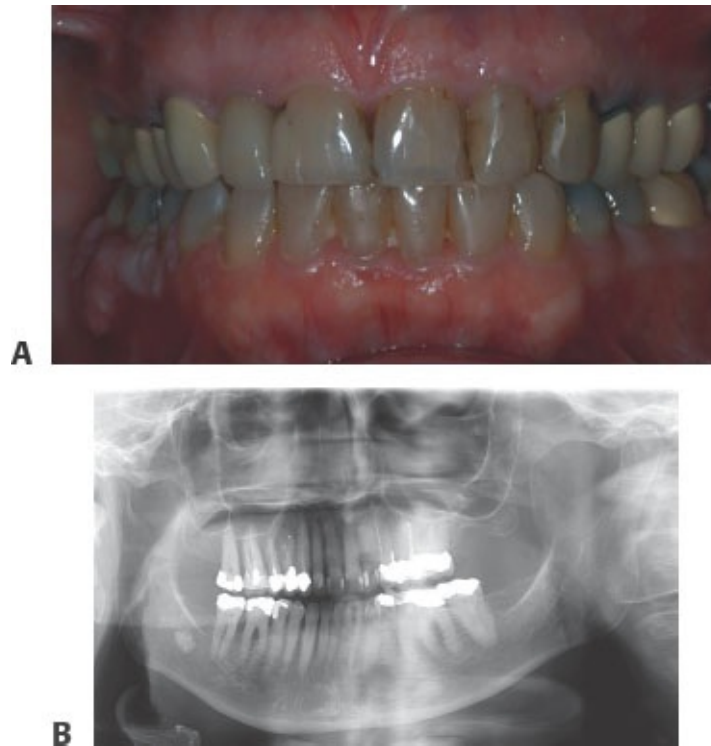


FIG 1 • A. Occlusion prior to mandibular resection. **B.** Periapical radiograph.

- Stainless steel ligature wire (24 gauge)
- Wire cutters
- Needle holders
- Band pusher
- Elastics (red rubber whistle tip catheter size 14 French, cut in 3-mm thickness)



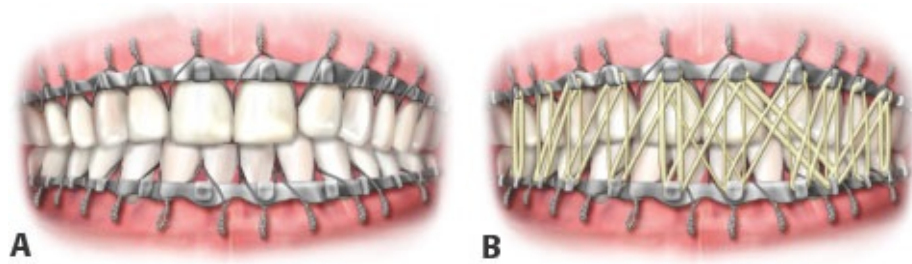
FIG 2 • Tools necessary for MMF.

TECHNIQUES

■ Intermaxillary Fixation

- The patient's preoperative occlusal relationship is confirmed.
- The preoperative imaging is reviewed.
- The Erich arch bars are measured and cut to fit the contour of the remaining dentition of the maxilla and mandible.
- The ligature wires are cut to approximately 15 cm (for posterior and 1–2 cm shorter for anterior teeth) and stretched to prevent loosening after placement.
- The arch bar is placed on the maxilla and mandible with the lugs positioned apically (**TECH FIG 1**).
- The arch bar is anchored to periodontally sound teeth by passing the ligature wire through the interproximal space and circumferentially fixed by twisting the two ends together in a clockwise direction until tight.¹
- A band pusher is used to assist in placing the ligature wire as apically as possible on the lingual/palatal aspect to ensure a secure fit.
- The excess length is cut leaving the terminal segment (approximately 1.5 cm), which is then curved to form a rosette to prevent trauma to the adjacent soft tissue.
- Following application of the arch bars, the bars are tested for stability. At least three wire loops are usually employed to ensure proper fixation.
- Elastic bands are placed on the opposing lugs of the maxilla and mandible to

complete the fixation in appropriate occlusal relationship.



TECH FIG 1 • A. Placement of arch bars on the mandible and maxilla. Note apical and opposite orientation of the lugs. **B.** Placement of bands on arch bars completing MMF.

PEARLS AND PITFALLS

Indication	■ To maintain preoperative occlusal status
Technique	■ Arch bars are cut to the appropriate size and bent to the shape of the mandible and maxilla. ■ Arch bars should be securely affixed to the mandible and maxilla. Loose bars can be uncomfortable and may result in loss of alignment. ■ Band pushers are helpful for this. ■ Wires are cut short and capped with bone wax or other material to avoid injuring/irritating the lips.
Postoperative care	■ Topical anesthesia is very helpful and facilitates removal of the bars. ■ Radiographic evaluation may be performed to confirm proper alignment and healing. ■ Oral hygiene is important to avoid infections and pain.

POSTOPERATIVE CARE

- The Eric arch bars are removed approximately 1 week following placement (or when fracture healing has been confirmed in cases where the mandible fracture

is not repaired with plates/screws, and MMF is used as the primary means of repair).

- Dental x-rays may be obtained to confirm proper alignment of the mandible (**FIG 3A**).
- Prior to removal of the Erich arch bars, topical anesthetic may be applied to the gingival area or local anesthesia provided via gingival infiltration for patient's comfort.
- The ligature wires are cut with either a wire cutter or high-speed handpiece and removed with a needle holder.
- The arch bars are released and removed from the maxilla and mandible.
- The oral cavity is carefully inspected to ensure that it is free of debris and materials (**FIG 3B**).
- The oral cavity is carefully irrigated using saline and suctioned.
- Postoperative panoramic radiograph is obtained.
- Following removal of MMF, the patient is advised to maintain a soft diet and to chew on the contralateral side.

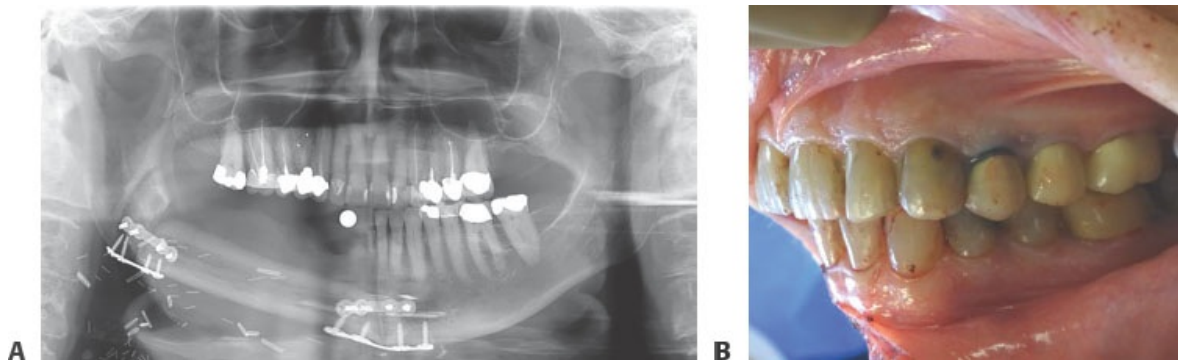


FIG 3 • A. Postoperative panorex image demonstrating fibula flap for reconstruction and restoration of occlusion. **B.** After removal of arch bars, occlusion is maintained.

- Oral hygiene instructions are provided to include brushing all remaining teeth after meals and at bedtime using an ultrasoft toothbrush.

OUTCOMES

- In most cases, MMF has excellent outcomes and patients recover satisfactorily. Irritation and discomfort are common and should be treated symptomatically;

in most cases, the bars are removed in a week.

- MMF may decrease ventilatory capacity and should be used with caution in patients with reduced pulmonary function particularly if the airway is not secured.²

COMPLICATIONS

- The technique of MMF is safe and, in general, well tolerated.
- Complications related to MMF are relatively rare and include pain, gingivitis/periodontitis, and irritation of the buccal mucosa.
- Malocclusion is a potential complication but is more commonly related to the techniques used for mandibular stabilization. If MMF alone is used for the treatment of mandibular fractures, then malocclusion may occur particularly in poorly aligned comminuted fractures.

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Section VI: Lip

15 Repair of Lip Commissure Defects with Estlander Flaps

CHAPTER

Simon G. Talbot and Julian J. Pribaz

DEFINITION

- Defects of the lips may occur from malignancy (most frequently squamous cell carcinoma followed by basal cell carcinoma), trauma, vascular malformations, or infections.¹
- There is disagreement in the literature about terminology.
 - Here, we refer to a lip switch flap *not* involving the commissure (either lower to upper lip as originally described or vice versa) as an Abbe flap.
 - We refer to a lip switch involving the commissure (either upper to lower or vice versa, as both were described in the original paper) as an Estlander flap.
 - We have chosen to not use the terms “reverse Abbe” and or “Abbe-Estlander,” which are sometimes used elsewhere to refer to upper to lower flaps excluding the commissure.

ANATOMY¹

- The lips include multiple layers of tissue: skin/subcutis, muscle, submucosa, and mucosa.
- The vermilion forms a wide boundary between the mucosa and skin. Meticulous repair of the white roll (the external border of the vermilion and skin) is critical as defects in this border are easily noticed.
- Lip function is controlled by the orbicularis oris muscles (sphincteric function) and numerous muscles of facial expression (elevation and depression functions).
 - Elevators include levator labii superioris, levator anguli oris, zygomaticus

major and minor, levator anguli superioris, and mentalis muscles.

- Depressors include depressor anguli oris, depressor labii inferioris, and platysma muscles.
- Key external landmarks of the lips include Cupid's bow, the philtral columns, the central tubercle, the white roll, and the commissure.
- Arterial supply is through the facial artery branching into the superior and inferior labial arteries. These run just deep to the mucosa in the submucosal layer just deep to the orbicularis oris muscle, at the level of the mucosal-vermilion junction (**FIG 1**).
- Venous drainage does not follow the arterial pattern, but a dense plexus exists in the lips.
- Sensation is supplied by the infraorbital branch (upper lip) and mental branch (lower lip) of the trigeminal nerve.
- Motor function to the orbicularis oris is supplied by the buccal branches of the facial nerve.
 - Additional muscles of facial expression are supplied by the zygomatic and mandibular branches.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Because of the unique anatomy and appearance of the lips, when defects involving the lips are too large to close directly, local flaps using the similar-appearing “like tissue” from the opposite lip are ideal.
- Estlander flaps are suited for patients presenting with a full-thickness defect of the lateral lip up to and including the commissure.
- Defects up to a quarter of the upper lip and one-third of the lower lip can usually be closed directly.
 - Flap closure is more appropriate for defects of half to three-quarters of the upper or lower lip (**FIG 2**).
 - Larger defects may require additional or distant flaps.
- Similar to an Abbe flap, the Estlander flap is a cross-lip flap. However, whereas the Abbe flap can rotate clockwise or anticlockwise based on either labial artery, the Estlander flap rotates around the commissure and can be based only on the contralateral labial artery as the ipsilateral vessel has usually been removed with the tumor extirpation.
- A second-stage procedure to divide and inset the flap and re-establish the commissure is required, and this can be safely done at 3 to 4 weeks.

- Estlander flaps can be used to reconstruct either upper or lower lip defects.²

Cross-section of lip showing labial artery

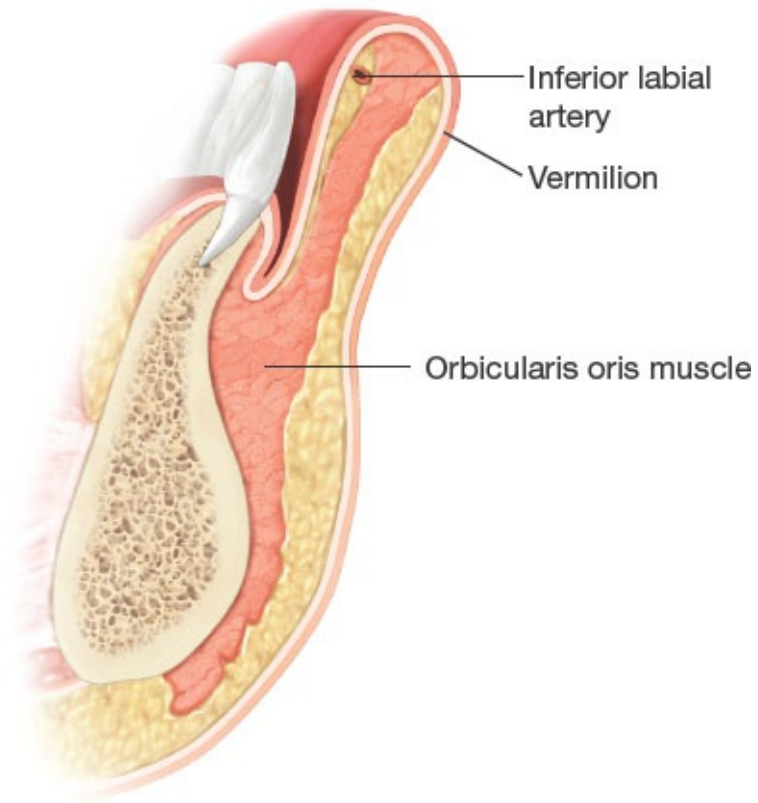


FIG 1 • Cross-sectional anatomy of lower lip.



FIG 2 • Defect after Mohs resection of infiltrating basal cell carcinoma.

IMAGING

- Imaging may be required for oncologic workup or as indicated by trauma. However, for operative planning, no imaging is necessary.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative markings may be aided by the use of a template (a sterile Esmarch is ideal for this purpose).
- Unlike with an Abbe flap, markings for an Estlander flap should not traverse the vermillion, as this will subsequently form the new oral commissure.

Positioning

- A nasal intubation is preferred with the tube secured to the nasal septum using an absorbable suture.
- The operating table is turned 90 degrees away from the anesthesiologist with the operative side of the mouth toward the center of the room. A standard head drape is used.

Approach

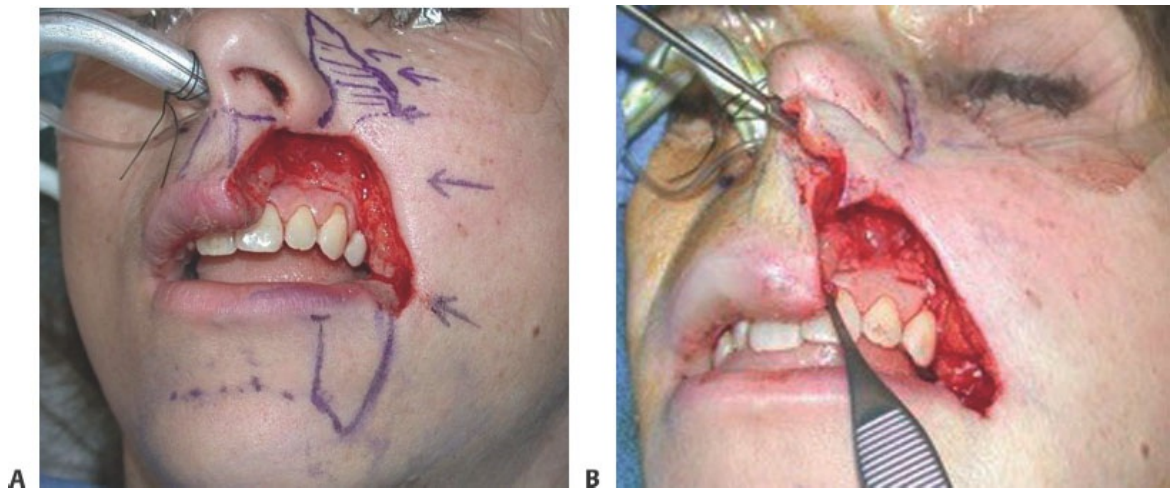
- A superiorly or inferiorly based flap can be performed depending on the location of the defect.

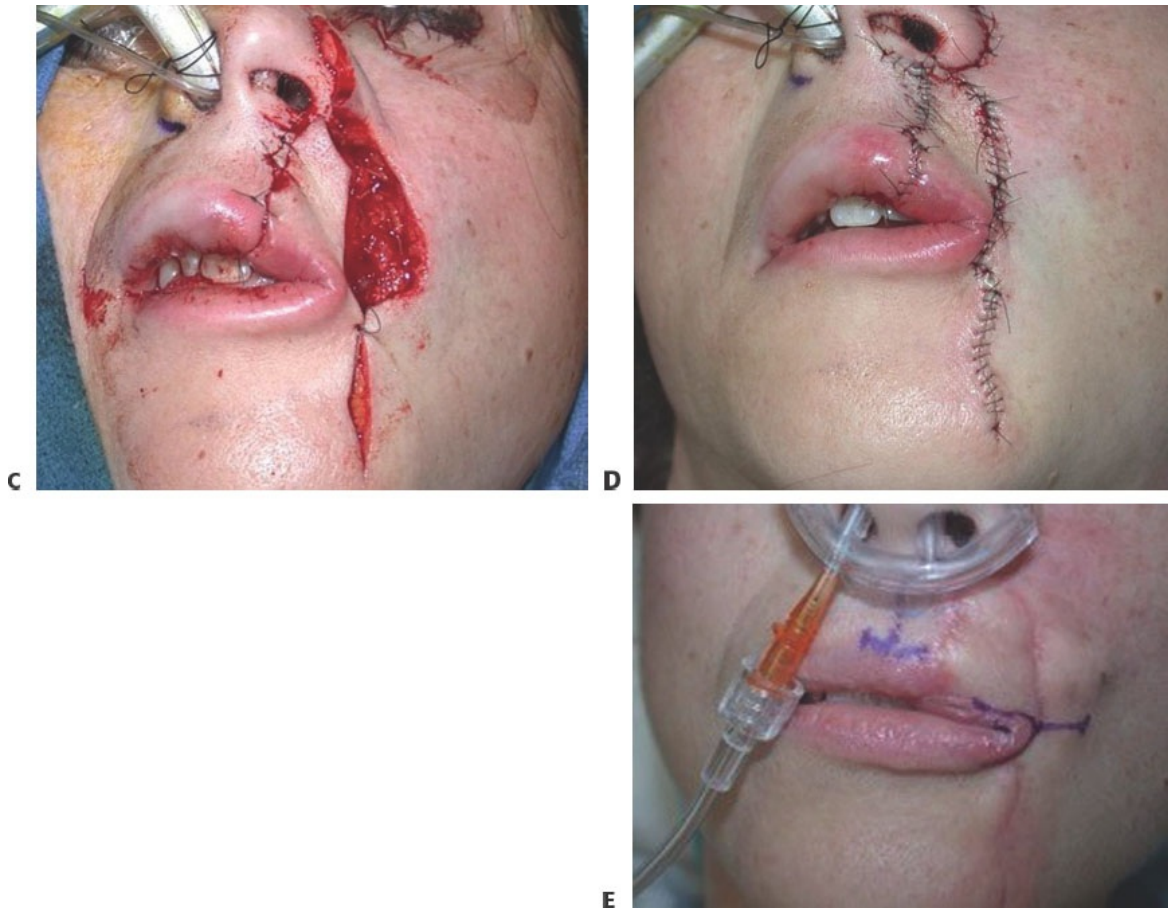
TECHNIQUES

■ Estlander Flap for the Upper Lip

- Incisions should use natural skin creases, such as the mental crease where possible.
- The triangular flap should be marked and should be the same height and half the width of the defect (to share the horizontal deficiency between the upper and lower lips).

- A concurrent cheek advancement flap (and a Burow triangle resection from the lateral alar/medial cheek) reduces the defect and size of flap/donor site required (**TECH FIG 1A**).
- Often, the Burow triangle is not resected but used as an inferiorly based flap that is advanced medially with the cheek flap and can be useful to repair the nostril sill (**TECH FIG 1B**).
- Needlepoint cautery allows precise dissection.
- The labial artery must be preserved. This should not be skeletonized to preserve a sufficient plexus of veins for drainage.
- The flap is rotated about the commissure and sutured in place.
- A layered closure is performed taking care to approximate the orbicularis oris and precisely close the vermilion at the white roll (**TECH FIG 1C,D**).
- Later, a commissure-plasty in which the base of the flap is divided and inset and the commissure re-established is required (**TECH FIG 1E**).

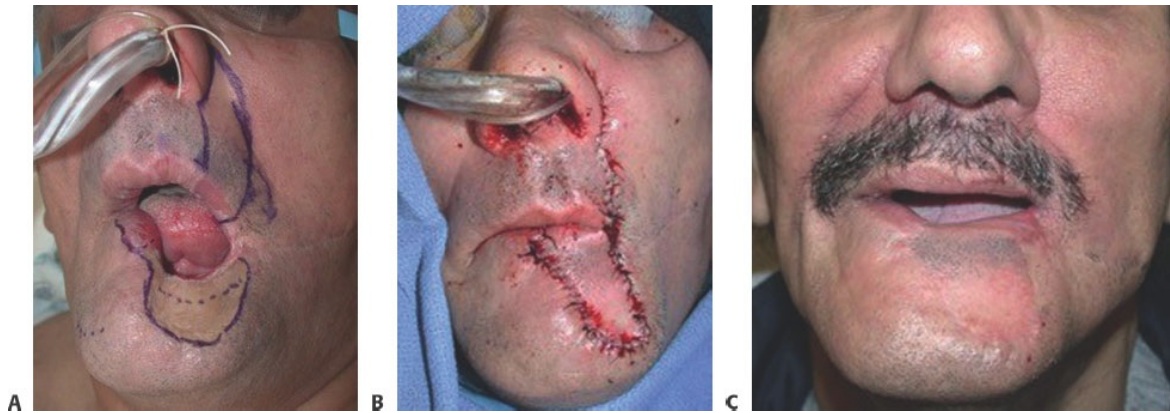




TECH FIG 1 • **A.** Operative markings. **B.** Advancement of Burow flap. **C.** Estlander flap elevation and transposition. **D.** Final flap inset. **E.** Division and inset of flap with commissure-plasty.

■ Estlander Flap for Lower Lip

- A case showing Estlander flaps used for the lower lip is shown in **TECH FIG 2**.



TECH FIG 2 • A. Patient with loss of lower lip post necrotizing infection. **B.** Upper lip-to-lower lip Estlander flap. **C.** After commissure-plasty.

PEARLS AND PITFALLS

Hemostasis	■ Good hemostasis is critical to prevent this highly vascular area from ongoing bleeding.
Pedicle	■ The labial artery must be preserved and not skeletonized; maintenance of adequate mucosa aids with venous drainage.
Technique	■ If congestion occurs, the flap inset can be taken down and a delayed inset performed when choke vessels have opened.
Technique	■ A concurrent cheek advancement flap can reduce the size of the defect and flap/donor site required.
Technique	■ A Schuchardt advancement using an incision in the labiomental fold can additionally help with closure of a lower lip defect.
Caveats	■ Smoking can severely impair vascularity of the flap and should be strictly avoided both preoperatively and postoperatively.

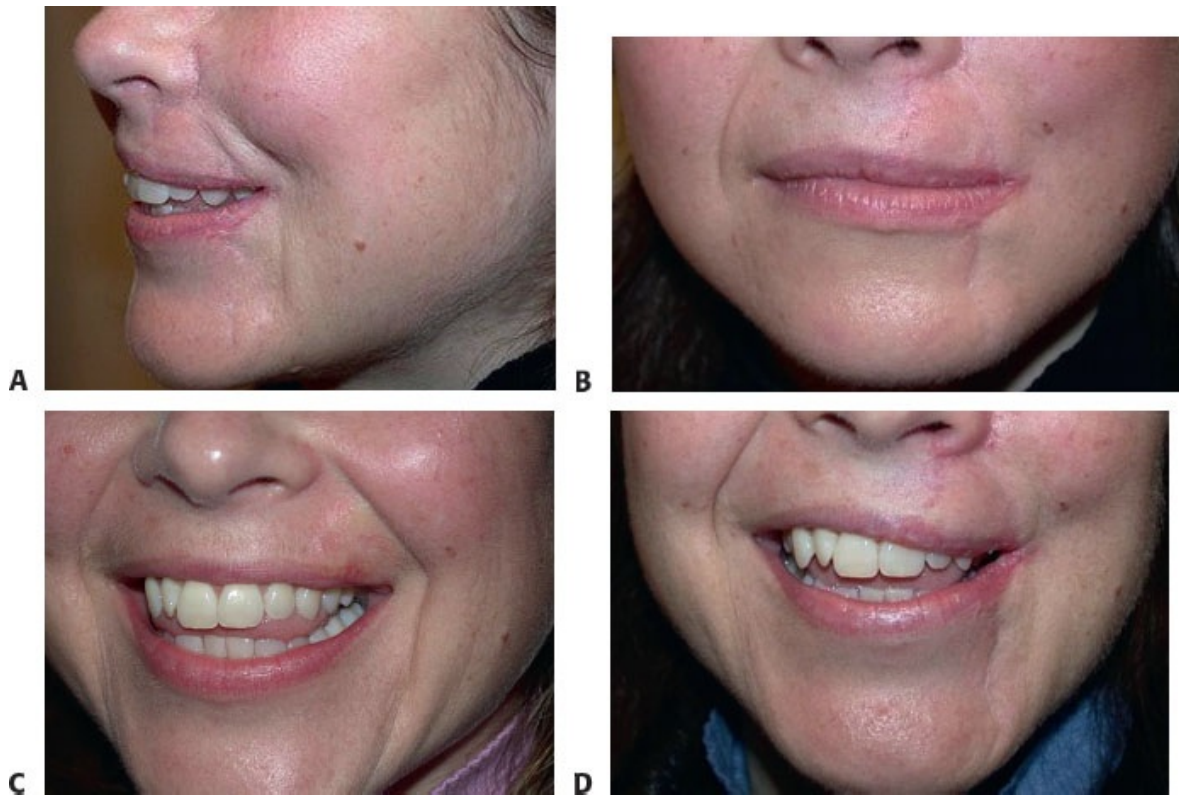


FIG 3 • A,B. Postoperative appearance of the patient in **TECH FIG 1** after division and inset with commissure-plasty. **C.** Preoperative smile. **D.** Postoperatively, she has elevator weakness due to loss of levator labii superioris during tumor excision.

POSTOPERATIVE CARE

- Bacitracin ointment is applied to suture lines.
- Sutures are removed at 7 to 10 days.
- Stretching of the mouth is avoided until full healing.

OUTCOMES

- The Estlander flap provides a relatively simple reconstruction of large defects of the lateral upper or lower lip involving the commissure (**FIG 3A,B**).
- Minor revisions may be required, including resuspension and tightening of lip elevators and revision of any contractures at the commissure to improve symmetry and widen the aperture.
- Sensory and motor recovery occurs over months in the order of pain, touch,

and temperature.³

- Because of rearrangement of the surrounding muscles of facial expression, animation may be altered (**FIG 3C,D**).

COMPLICATIONS

- Arterial compromise or venous congestion may occur if vascularity is not maintained.
- When more than half the width of the lip requires reconstruction, this flap may not be large enough to prevent significant microstomia.

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16 Repair of Lip Defects With Karapandzic Flaps

CHAPTER

Simon G. Talbot and Julian J. Pribaz

DEFINITION

- Defects of the lips may occur from malignancy (most frequently squamous cell carcinoma followed by basal cell carcinoma), trauma, vascular malformations, or infections.
- A Karapandzic flap is either a single/unilateral or a paired/bilateral innervated musculocutaneous rotation flap used to reconstruct subtotal lower lip defects.
- A reverse Karapandzic flap can be used to reconstruct an upper lip defect. Combined upper and lower lip defects have been reconstructed with simultaneous upper and lower flaps.
- Midline defects are preferred for this method of reconstruction; lateral or commissure defects may result in significant asymmetry.

ANATOMY

- The unique anatomy of the lips make the use of adjacent “like” lip tissue ideal for reconstruction.
- The lips include multiple layers of tissue: skin/subcutis, muscle, submucosa, and mucosa.
- Karapandzic flaps maintain continuity and innervation of the orbicularis oris muscle. This is an advantage over flaps that replace a lip defect with cheek tissue excluding the orbicularis.
- The vermilion forms a wide boundary between the skin and mucosa. Meticulous repair of the white roll (the external border of the vermilion and skin) is critical as defects in this border are easily noticed.
- The original description of the Karapandzic flap references the robust labial artery circulation.¹

- In the very old, irradiated, or those requiring bilateral flaps, the labial artery alone may be insufficient, hence the benefit of keeping an intact mucosa for additional vascularity when designing Karapandzic flaps.
- The modiolus can be thought of as a circle, and a defect in this circle may be closed by rotating the remaining edges around the circumference to close the defect.
- Reapproximation of the orbicularis oris and preservation of the buccinator along with maintenance of nerves allows for early intrinsic muscle function (**FIG 1**).
- Some authors recommend the use of a nerve stimulator to help protect native innervation.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients will present with a large, subtotal, or total lip defect.

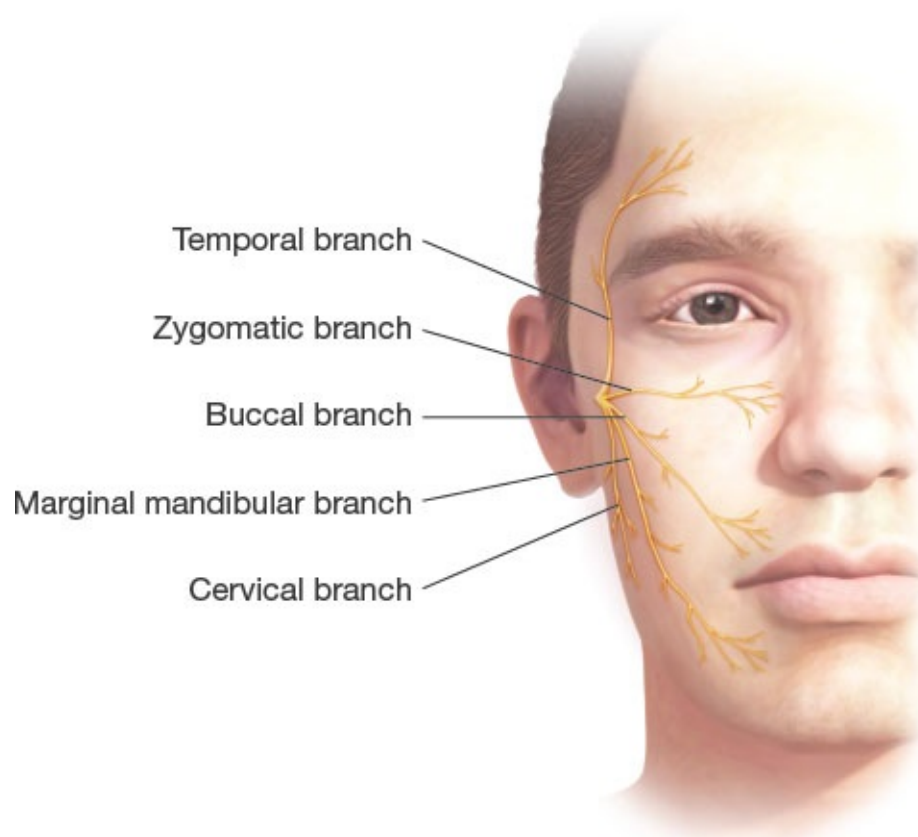


FIG 1 • Facial nerve anatomy and distribution of perioral facial nerve branches to be preserved in Karapandzic flap.

IMAGING

- Imaging may be required for oncologic reasons but is not routinely required for flap planning.

SURGICAL MANAGEMENT

Preoperative Planning

- Markings include a skin incision parallel to the lip margin; the vertical dimension of the flap is determined by the vertical dimension of the lip defect (**FIG 2**).



FIG 2 • Preoperative appearance and markings for unilateral Karapandzic flap.

- The flaps are extended laterally and vertically. Where possible, incisions are hidden in the melolabial folds and/or mental crease.

Positioning

- A nasal intubation is preferred to prevent distortion of the lips. The endotracheal tube should run vertically upward to avoid interference with the operative field.
- The operating table is turned 90 or 180 degrees from the anesthesiologist. A standard head drape is placed.

Approach

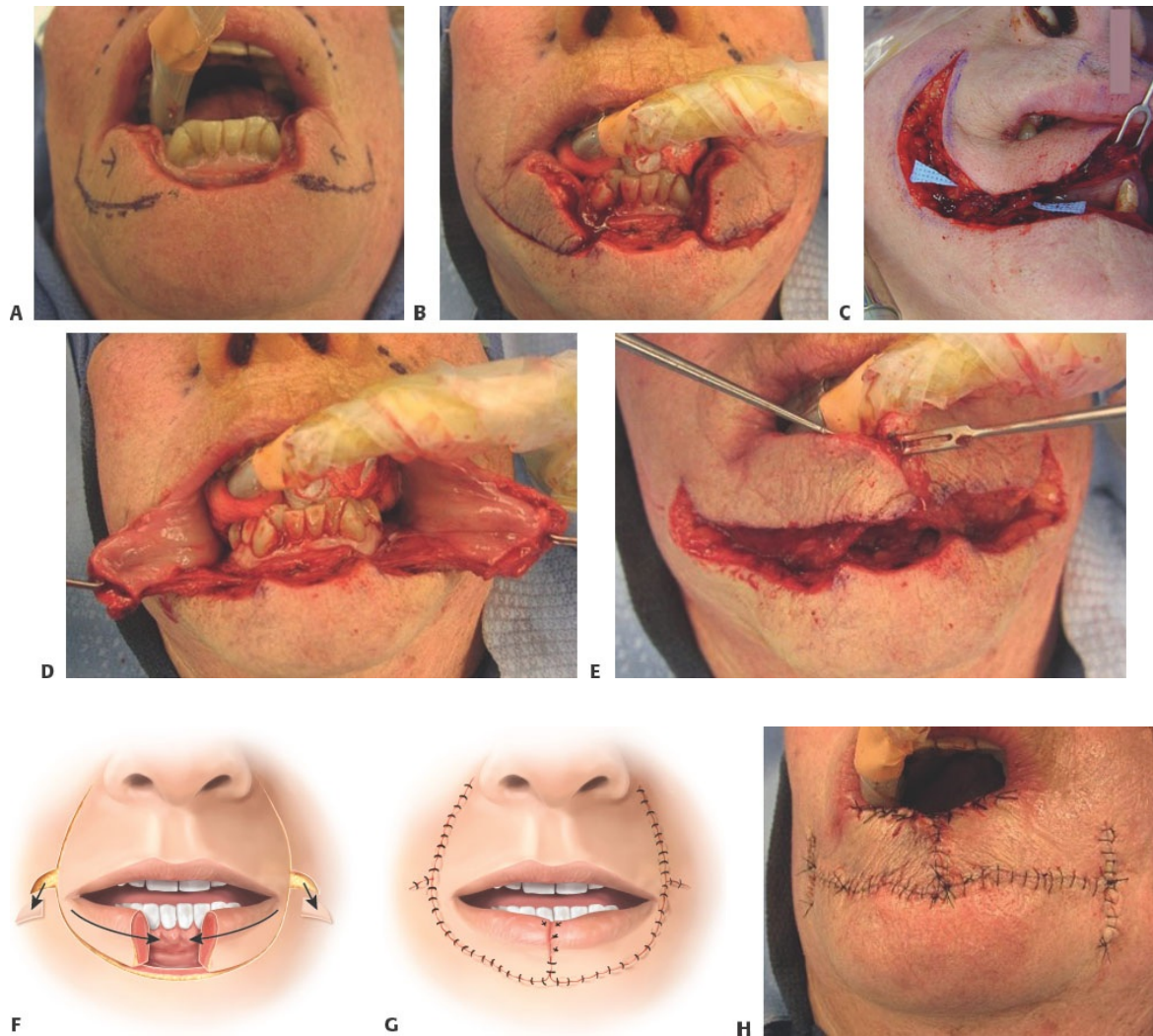
- A single or bilateral Karapandzic flap may be sufficient for medium to large lip defects.
- Where this is inadequate, combinations of Karapandzic flaps and an Abbe flap may be needed.
- Extended Karapandzic flaps may also facilitate larger defects to be reconstructed. This technique uses medial cheek elements (as an extension of the primary flaps) to form the central lower lip elements with a mucosal advancement forming the vermillion.³

TECHNIQUES

■ Bilateral Karapandzic Flaps for Closure of Large Midline Lower Lip Defect

- Markings are drawn as described (**TECH FIG 1A**).
- Judicious local anesthesia with epinephrine can be used to aid hemostasis but should be kept away from the facial artery pedicle.
- Marked incisions are made, and dissection proceeds carefully through the subcutaneous fat (**TECH FIG 1B**).
- The facial artery is located deep to the facial muscles and enters the skin from below. Similarly, the branches of the facial nerve are located deep to the musculature. These branches are dissected bluntly (often with a mosquito) preferably with loupe magnification.
 - In this manner, the skin, subcutaneous tissues, and facial muscles are incised, but the nerves and vasculature beneath the muscle are preserved (**TECH FIG 1C**).
 - Blunt dissection may be possible in the deeper and more superior aspects of the cheek incisions to easily maintain these structures (**TECH FIG 1D**).⁴
- Although the facial and labial arteries will stretch significantly, if sacrifice is needed, flap vascularity may be maintained on an intact, large mucosal pedicle (**TECH FIG 1E**).
- Only the advancing 2 to 3 cm of the mucosa is incised but the rest is left intact, to help with perfusion and venous drainage.

- Mucosa, muscle, and skin are closed in layers.
- For the donor area, the skin incision is repaired but the incised muscle is left free, thus preventing tension on the closure of the flap.
- An intrinsic discrepancy between the cheek and flap lengths can be minimized with excision of the Burow triangles (**TECH FIG 1F–H**).



TECH FIG 1 • **A.** Markings for bilateral Karapandzic flap. **B.** Bilateral flap incisions are made. **C.** Neurovascular bundles are preserved. **D.** Flaps are elevated on neurovascular pedicles, maintaining mucosa where possible. **E.** Flap transposition. **F.** Removal of the Burow triangles offsets the discrepancy between the cheek and flap lengths. **G,H.**

The incisions are closed in layers.

PEARLS AND PITFALLS

Hemostasis	■ Local anesthesia with epinephrine can be injected away from the pedicle.
Pedicle	■ Visible facial artery branches and nerves should be kept intact with careful blunt dissection using loupe magnification. ■ Perfusion and venous drainage is maintained by not dividing mucosa excessively, just the advancing edge.
Technique	■ Excision of the Burow triangles can help share length discrepancies while closing.
Caveats	■ Smoking can severely impair vascularity of the flap and should be strictly avoided both pre- and postoperatively.

POSTOPERATIVE CARE

- Bacitracin ointment is applied to external suture lines.
- Sutures are removed at 7 to 10 days.
- Stretching of the mouth is avoided until full healing.
- No specific therapy is required.

OUTCOMES

- In patients with large initial defects, this technique can lead to microstomia. However, this is relatively uncommon due to the elasticity of normal lip tissue.
- Using “like” lip tissue and intrinsic musculature for this reconstruction is typically superior functionally and esthetically to using distant flaps.
- There is tightness of the lower lip with lack of projection relative to the upper lip, which improves with time and with subsequent fat grafting and vermilion advancement (**FIG 3**).

COMPLICATIONS

- Microstomia may be corrected with a staged commissureplasty. This can be performed through a Y-to-V flap or through excising a lateral wedge and advancing mucosal flaps.

- Effacement of the gingivobuccal sulcus can occur and may be revised with a skin graft internally in the sulcus.²



FIG 3 • **A.** Early postoperative appearance. **B.** Appearance and function may be improved with fat grafting and mucosal advancement. **C.** Late postoperative appearance and function.

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17 Repair of Lip Defects With the Abbe Flap

CHAPTER

Robert Beinrauh and Joseph H. Dayan

DEFINITION

- A full-thickness portion of the lower lip, which includes the mucosa, orbicularis oris muscle, and skin with vermillion, based on the right or left inferior labial artery with mucosal venous attachments¹
- Used in reconstruction of defects of the upper lip (which do not involve the commissure) between one-third and one-half of the entire lip
- A reverse Abbe flap (Estlander-Abbe flap) is the exact same flap only taken from the upper lip to reconstruct lower lip defects not involving the commissure.
- We will use the technique for the traditional Abbe flap for this chapter, but recognize the reverse flap is the same technique based on the superior labial artery.

ANATOMY

- The lips are a sphincter composed of a concentric ring of mucosa, muscle, and skin, which form a tight seal to prevent liquid from escaping the oral chamber and also to produce the labial sounds used in speech.
- Orbicularis oris muscle:
 - A circumferential ring of muscle around the mouth that functions to compress and purse the lips together
 - The muscle fibers run horizontally on the upper and lower lips and begin at the modiolus.
 - There is an oblique extension of the muscle that runs from the commissure to the anterior nasal septum and nasal floor.
- The inferior labial artery branches from the facial artery at the angle of the

mouth.

- The artery runs inside the lip several millimeters inferior and anterior to the vermillion/mucosal junction of the posterior lip² (**FIG 1**).

PATHOGENESIS

- Lip deformities can be congenital or acquired.
- Congenital deformities are most commonly cleft lip defects.
- Acquired deformities are most commonly due to traumatic or neoplastic etiologies.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Abbe flap is an excellent choice for defects of up to approximately 50% of the upper or lower lip.
- Upper lip defects of 25% or less and lower lip defects of 33% or less can be closed primarily. However, the Abbe flap may be useful even in these relatively small defects if the philtral column is involved and requires reconstruction.

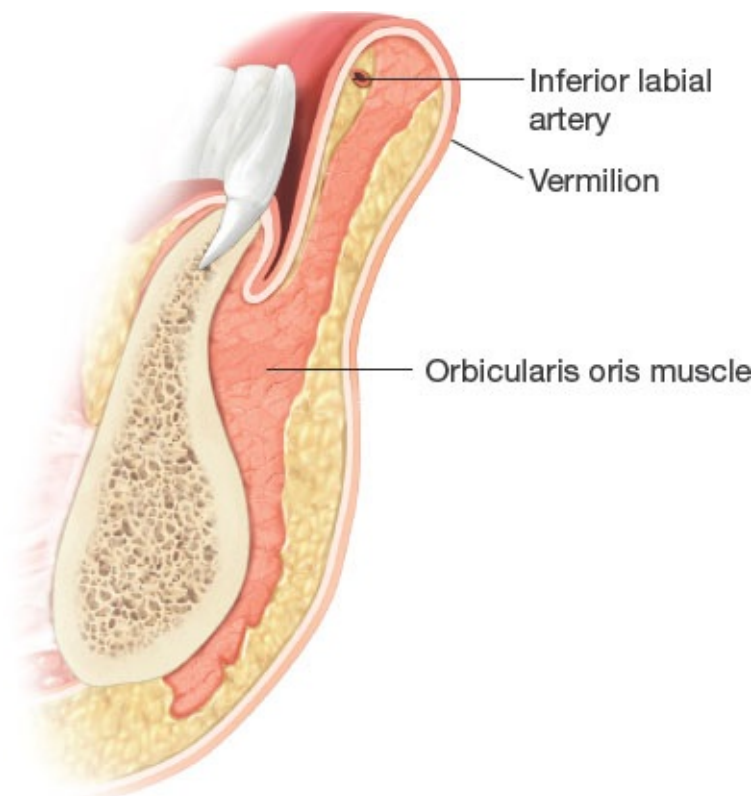


FIG 1 • Cross section of the lip showing inferior labial

artery.

- Lip defects larger than 50% of the lip may require either larger flaps, staged reconstruction, or a flap from a distant tissue site. However, there is some patient-to-patient variability in these size considerations due to anatomic considerations (ie, the baseline size of the lower lip) and the degree of skin laxity.
- The Abbe flap is used for defects that do not involve the lip commissure. The Estlander flap is more useful for more lateral defects that involve the commissure. Abbe flap is excellent for reconstruction of bilateral cleft lip patients with scarred or short philtrums.³

IMAGING

- No imaging is necessary for the Abbe flap. However, a pencil Doppler can be helpful to confirm position of inferior labial artery.

SURGICAL MANAGEMENT

Preoperative Planning

- Size of the defect and layers of lip involved must be assessed.
- The orbicularis oris muscle must be reconstructed to restore lip competence and avoid cosmetic deformities (eg, whistle deformity) with lip movement.
- In general, the size of the lower lip Abbe should be less than 30% of the width of the lower lip to avoid microstomia. However, as noted, there is some variability based on skin laxity and anatomic considerations.

Positioning

- Supine position and prep as for any facial procedure

Approach

- Measure defect and use template of the wound to design the resection size of the lower lip.
- The flap should be designed so that it will easily rotate into the defect without tension.
 - The flap should be located in an area with similar vermilion thickness as the edges of the defect.
- Make the horizontal size of the lower lip flap dimension 50% of the horizontal

size of the upper lip defect.⁴

- Do not make the inferior extent of the flap extend beyond the mental crease.
- Drive the incision laterally along the mental crease.
- Note position of inferior labial artery with Doppler prior to incision.

TECHNIQUES

■ Donor-Site Preparation

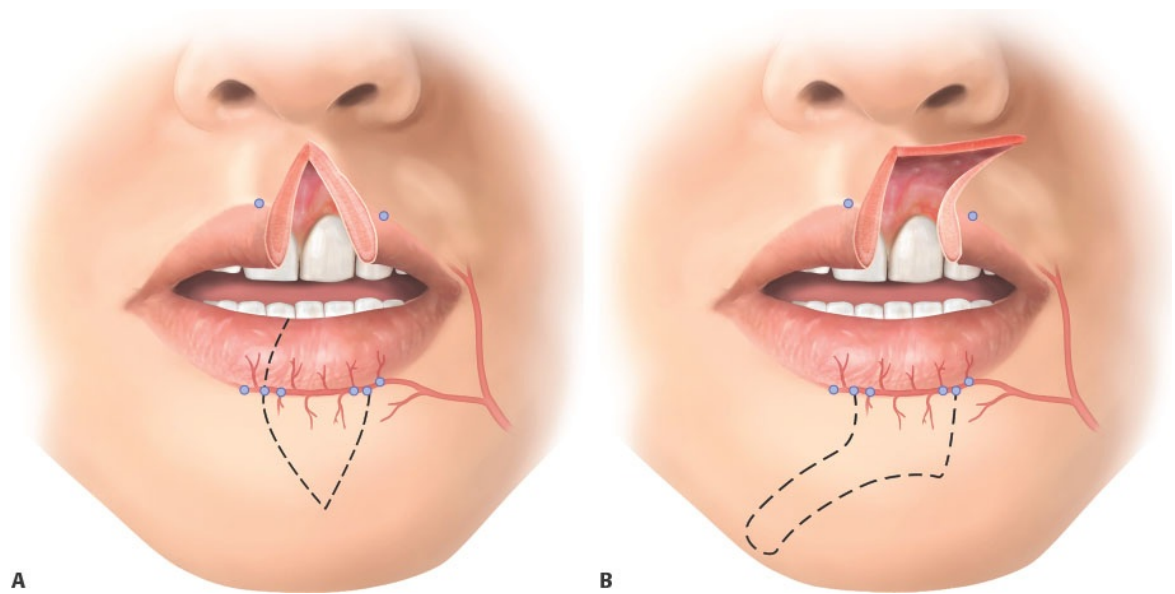
- Use of loupe magnification for the procedure is recommended.
- The donor site should be prepared first.
- Freshen the edges if needed with a no. 15 blade scalpel and create hemostasis with cautery.
 - Use a 25-gauge needle dipped in methylthioninium chloride to mark the white roll of your defect as well as of the lower lip.
 - The incision at the vermilion should be a perpendicular cut so that the Abbe flap will approximate into the vermilion in a straight line.
- Measure the recipient site width. The lower lip flap markings should be approximately half this diameter of the defect (**TECH FIG 1**). Avoid harvesting a very narrow (less than 0.5 cm) flap.
- The vertical extent of the defect should match the Abbe flap exactly.



TECH FIG 1 • Markings for Abbe flap donor site.

■ Recipient Site Preparation

- Mark out the Abbe flap to your specifications.
- Use a 25-gauge needle dipped in methylthioninium chloride to mark the white roll of your defect as well as of the lower lip.
 - Mark the white roll where you will incise with the methylene blue and then mark the white roll on either side of the incision so that you will have a guide to approximate the white rolls during the approximation of the Abbe flap into the defect as well as approximation of the donor site white roll following rotation of the flap (**TECH FIG 2A**).
 - Take care not to incise through the mental crease of the chin pad. Drive this incision laterally (**TECH FIG 2B**).
 - The donor flap should be located opposite the defect to facilitate easy rotation.
- Keep the pedicle as lateral as possible when the donor site is closed to allow the patient to eat and drink for 2 weeks while the pedicle is maintained.
- Doppler the artery on the side of the inferior lip at the site that will retain the pedicle.
- Use 2 to 3 cc of local anesthetic with epinephrine in the inferior portion of the flap to maintain a bloodless dissection.

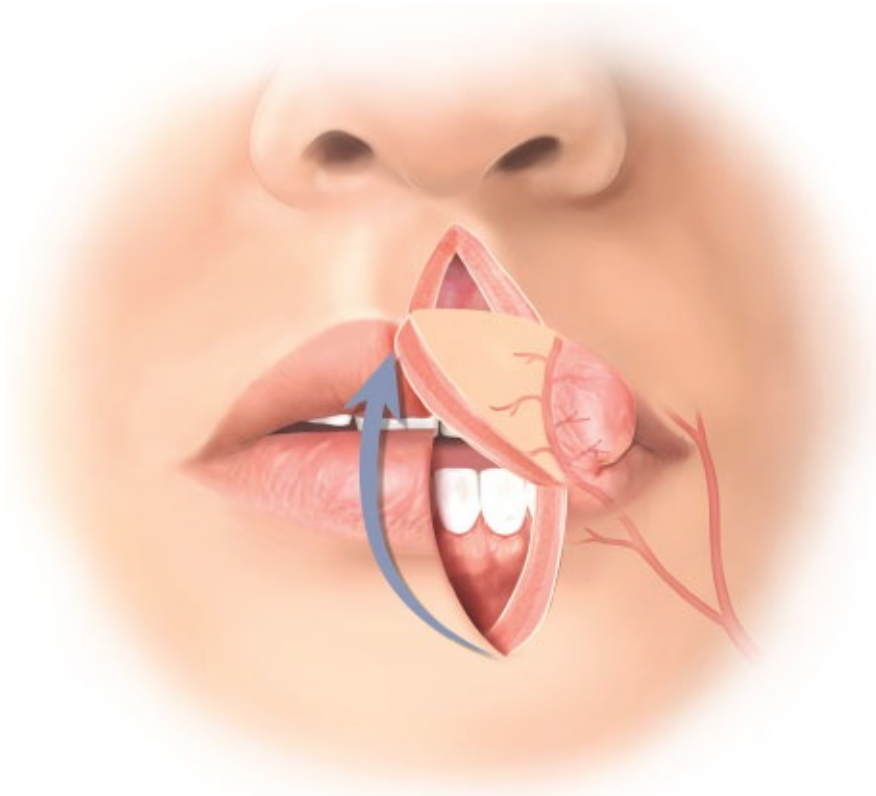


TECH FIG 2 • A. The white rolls are marked with methylene blue at both the donor and recipient sites to facilitate approximation. **B.** The scar should be driven laterally at the mental crease.

■ Raising the Flap

- Begin the dissection on the nonpedicle side of the lower lip flap.
- Compress the inferior labial artery with one hand and have the assistant hold the lip opposite to the mark to compress the other side of the inferior labial artery.
- Incise the skin and vermilion with a no. 15 blade scalpel.
- Use needle-tip cautery to cauterize each end of the inferior labial artery.
 - Use this opportunity to note the position of the artery to the mucosa and vermilion as it will be analogous to the more important contralateral pedicle side.
- Dissect the nonpedicled side through the muscle and the mucosa with the cautery to achieve a through-and-through separation of tissue.
- As you begin the incision of the pedicle side of the flap, make an incision through the anterior portion of the vermilion and white roll as well as the skin.
 - Do not incise too deep at this point.
 - Only through the skin and dermis

- Begin the dissection of tissue at the inferior aspect of the flap and work your way superiorly.
- As you near the pedicle, stop using cautery and begin to slowly spread the tissue in a horizontal direction with blunt tip tenotomy scissors.
- Release only the amount of orbicularis oris muscle that is needed to facilitate rotation at this time.



TECH FIG 3 • The posterior vermilion and mucosa are kept intact around the inferior labial artery for rotation.

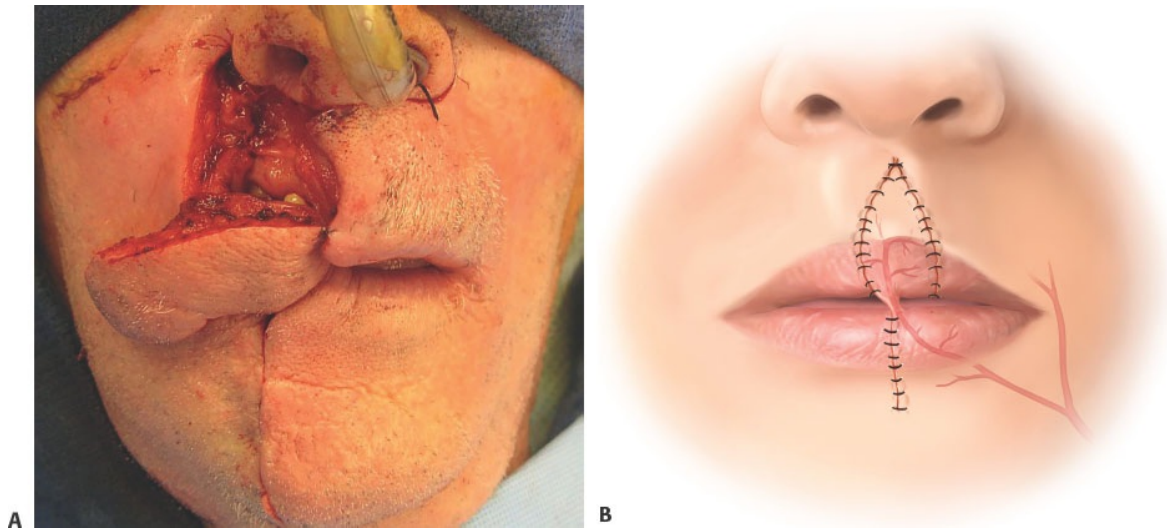
- Leave the posterior vermilion and mucosa intact around the inferior labial artery (**TECH FIG 3**).
- The artery does not need to be visualized.
- Use a Doppler to monitor position of the inferior labial artery as necessary.

■ Flap Placement and Closure

- We prefer temporary closure of the lower lip donor site with a 4-0 Vicryl

(Ethicon, Branchburg, NJ) to help facilitate the rotation (**TECH FIG 4A**).

- Replace this suture with the 5-0 Prolene (Ethicon, Branchburg, NJ) at final closure.
- Once the flap is rotated, suture the white roll together using 5-0 Prolene (Ethicon, Branchburg, NJ) suture.
 - This placement must be as exact as possible.
- Suture the vermillion of the flap to maintain its thickness and position.
- Suture the mucosa in horizontal mattress fashion.
 - The closure of the donor site mucosa is important to make watertight so as not to develop leakage of saliva.
- The orbicularis oris is closed next using 4-0 Vicryl suture.
- The dermal layer is closed using 5-0 Monocryl suture.
- The skin is then approximated using 5-0 Prolene suture in an interrupted fashion.
 - Dissolvable suture can be used for this step in small children who will not tolerate suture removal postoperatively.
- The lower lip donor site is closed in an identical fashion (**TECH FIG 4B**).



TECH FIG 4 • A. Rotation of the Abbe flap into the recipient site. The donor site has been temporarily closed. **B.** Final closure of both sites, showing the pedicle.

PEARLS AND PITFALLS

Patient selection	■ Abbe flap is not a good option if the defect involves the commissure or resection of the lower lip will exceed about 30% of the total lip as microstomia may result.
Design	■ The flap must be designed to facilitate rotation into the defect. Failure to do this will result in tension on the pedicle and ischemia.
Technique	■ Leave the inferior labial artery pedicle together with the posterior vermilion and mucosa to facilitate venous drainage as well as to avoid tension and kinking of the artery.
Closure	■ It is essential to approximate all of the lip elements as well as possible during the first procedure. ■ The second-stage surgery will have scar tissue and swelling to contend with, which will hinder achievement of a good cosmetic result.
Ischemia	■ If flap shows signs of ischemia upon rotation, place flap back into original position and treat it as a delay. Attempt rotation again in 10–14 days.



FIG 2 • Results 2 months postoperatively at rest (**A**) and with mouth open (**B**).

POSTOPERATIVE CARE

- There is no need to place additional fixation to keep the mouth shut.
- The patient may have a full liquid diet.
 - Start with a clear liquid diet postoperatively to avoid emesis.

- Use antibiotic ointment 3 times a day.
- Division of the pedicle should occur at approximately 14 to 21 days.
 - Restoration of white roll of vermillion of both upper and lower lip should be done at this time if it was not completed at the first stage.
 - Revision of the lower lip donor vermillion can be done at this stage.
 - Reserve revision of the upper lip Abbe flap until the future when a more adequate blood supply is established (**FIG 2**).

COMPLICATIONS

- Injury to the inferior labial artery pedicle
- Microstomia
- Ischemia of the flap upon rotation
- Infection
- Salivary leak
- Inadequate cosmetic restoration of vermillion lip elements
- Scarring of the donor site

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18 Lower Lip Reconstruction With the Nasolabial Flap

CHAPTER

George D. Xipoleas and Matthew S. Kilgo

DEFINITION

- The nasolabial flap is a versatile random pattern superiorly or inferiorly based flap that can be used to reconstruct defects of the lower lip.^{1–3}
- The nasolabial flap can be used to reconstruct defects spanning the entire transverse dimension (approximately 7 cm) of the lip.
- In most cases, the flap can be used to reconstruct the entire vertical dimension (approximately 2.0 cm) of the lower lip.

ANATOMY

- The lower lip is composed of the intraoral mucosa, vermilion, and skin/subcutaneous tissue extending inferiorly to the labiomental fold.
- The most distinguishing feature of the lip is the vermilion, a modified mucosa that covers the free margin of the lip and is adapted to external exposure.
 - There are relatively few salivary glands beneath the vermilion in contrast to the mucosa.
- Musculature of the lower lip (**FIG 1A**)
 - The body of the lower lip is predominantly composed of the orbicularis oris.
 - The primary muscle responsible for oral competence. It compressed and protrudes the lips and creates the oral sphincter.
 - The orbicularis oris muscle has two points of origin.
 - The peripheral fiber originates from the modiolus where they interdigitate with the fibers of the adjacent muscles of facial expression (buccinators, levator anguli oris, depressor anguli oris, levator labii superioris, depressor labii inferioris, zygomaticus minor, and zygomaticus major). This is

considered the peripheral portion of the muscle.

- The central fibers are restricted to the lip proper and are considered the labial portion of the muscle.
- The muscle fibers interdigitate in the midline and insert into the mucosa.
- The mentalis muscle elevates and protrudes the lower lip.
 - Originates from the incisive fossa of the mandible
 - Inserts into the skin of the chin
- The depressor labii inferioris muscle draws the lower lip downward and laterally.
 - It originates from the mandible adjacent to the mental foramen.
 - It inserts into the skin of the lower lip.
- Innervation of the lower lip (**FIG 1B**):
 - Motor innervation to the lower orbicularis oris is from the marginal mandibular and buccal branches of the facial nerve.
 - Motor innervation to the depressor labii inferioris and mentalis is from the marginal mandibular branch of the facial nerve (cranial nerve 7).
 - Sensory innervation of the lower lip is from the mental branch (V3—third division) of the trigeminal nerve (cranial nerve 5).
- Blood supply of the lower lip (**FIG 1C**):
 - Paired lower labial arteries that are branches of the facial artery
 - They course horizontally across the lip in the submucosal plane, posterior to the orbicularis muscle at approximately the same level as the anterior vermilion line.
- Lymphatic drainage (see **FIG 1C**):
 - Drainage occurs via the submandibular and submental lymph nodes.
- The nasolabial crease is an anatomic landmark created by the insertion of the superficial muscular aponeurotic system (SMAS) into the skin junction of the cutaneous lip and the cheek.
 - Marks the division of the cheek lateral to the fold and the lip and nose medial to the fold
 - Medial to the crease, the skin of the lip is tightly attached to the orbicularis oris muscle.
 - Lateral to the crease, the skin of the cheek is loosely attached to the deep muscular fascia, and there is an abundance of subcutaneous tissue and skin laxity.

PATHOGENESIS

- The majority of lip defects in adults are secondary to excision of malignant tumors. Other causes of lip defects include vascular malformations, congenital defects, and trauma.
- Neoplasms of the lip are primarily related to actinic changes.
- Upward of 90% of lower lip neoplasms are squamous cell carcinomas (SCCs) with the remainder being made up of basal cell carcinomas (BCCs), salivary gland carcinomas, and melanomas.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed history and physical examination are important to determine the type of lesion and intervention.
- The physical examination should be directed not only to the lips but to the oral mucosa and to the lymphatic drainage basins, ie, the submandibular and submental nodes.

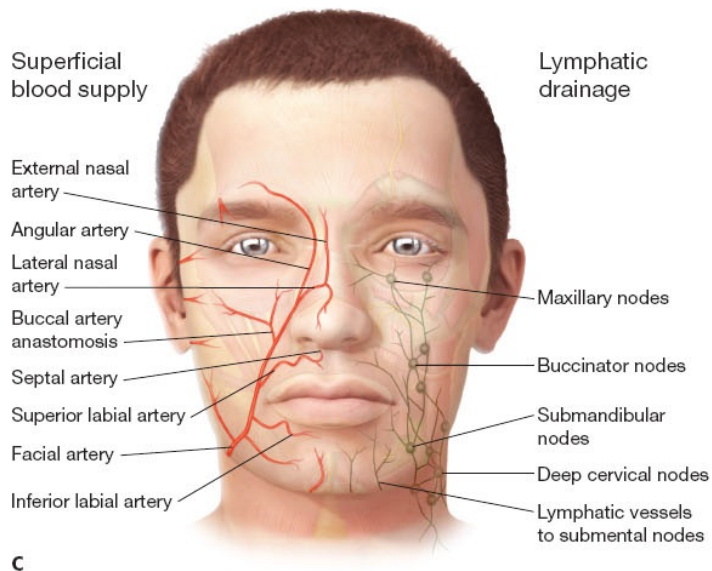
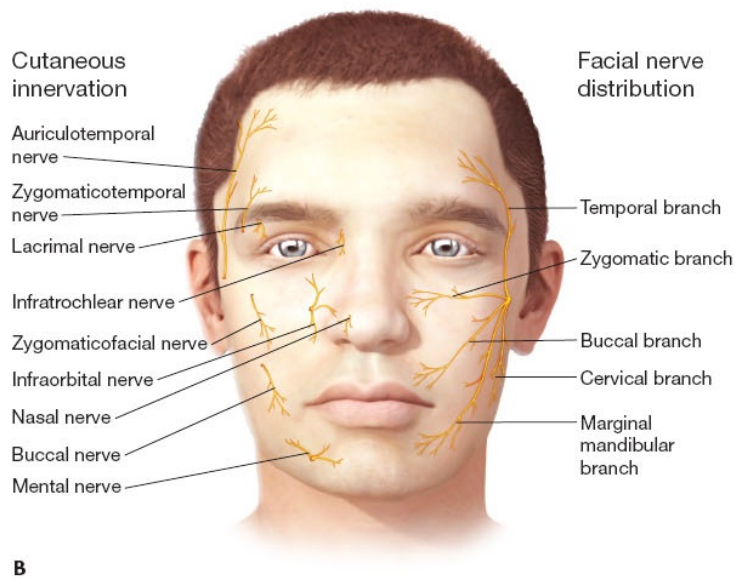
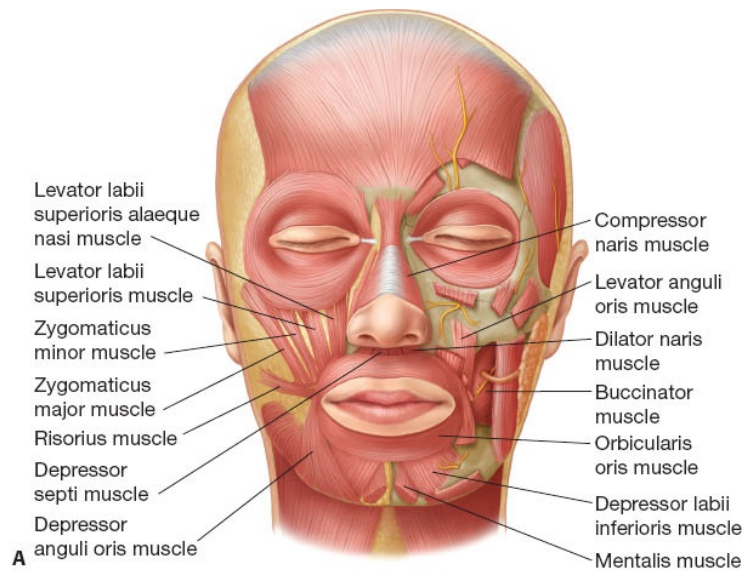


FIG 1 • A. Musculature of the face. **B.** Motor and sensory innervation of the face. **C.** Blood supply and lymphatic drainage of the face. The nasolabial flap is a random pattern flap and does not need a perforating blood vessel to be found for viability of the flap.²

- What is the patient's age, sex, and skin type?
 - Cancers of the lip are most common in lighter skin males in their sixth decade. There is a 6:1 ratio of SCC in males to females.
- Does the patient have a history of prolonged or repeated sun exposure?
 - Sun exposure is the most important risk factor in the development of skin cancers.
 - One-third of patients have outdoor occupations or outdoor pastimes.
 - The lip is susceptible to metaplasia because it lacks the pigmented layer for protection.
- How did the lesion present, how long has the lesion been present and how has the lesion changed?
 - Patients will typically report a history of a nonhealing "scabbed" or "crusted" lesion that bleeds when the scab is removed.
 - Long-standing lesions with no changes in size or characteristics are less likely to be malignant.
 - Long-standing nonhealing wounds are more likely to be malignant.
 - Increases in size, changes in color, consistency, and mobility may be an indication of malignant degeneration.
- Where is the lesion located? Is it mobile or fixed? Is there any associated adenopathy?
 - It is important to determine the location of the lesion and the structures involved:
 - That is, the vermilion, mucosa, or muscle
 - Most tumors grow slowly and may be freely mobile, whereas others will grow rapidly, infiltrating adjacent tissue.
 - In the lower lip, perineural spread along the mental nerve can also occur.
 - In the lower lip, SCC is much more common and will spread via lymphatic drainage to the submandibular or submental nodes.

IMAGING

- Imaging will be dictated by the pathology of the lesion. If the lesion is benign or a basal cell carcinoma, imaging is usually not necessary because it does not typically spread to distant sites. If the lesion is a more aggressive tumor, imaging may be appropriate.
- CT scan or MRI can be used to determine local/regional spread into the soft tissue and lymph node basins.
- A panorex can be undertaken if the tumor is felt to be fixed to the mandible or if there are paresthesias in the mental nerve distribution.

DIFFERENTIAL DIAGNOSIS

- Most lesions of the lower lips are malignant SCC. Biopsy should be undertaken to determine the identity of the lesion. The differential includes both benign and malignant lesions.
- Basal cell carcinoma
- Melanoma
- Sebaceous adenoma (benign)
- Hemangioma (benign)
- Venous lake (benign)
- Pyogenic granuloma (benign)
- Merkel cell carcinoma (malignant)
- Dermatofibrosarcoma protuberans (malignant)
- Microcystic adnexal carcinoma (malignant)

NONOPERATIVE MANAGEMENT

- Radiation therapy is a nonoperative treatment option for basal cell or squamous cell cancers that may be useful for patients who cannot undergo surgical excision of malignant lesions or are not suitable reconstruction candidates due to medical comorbidities or other factors.
- Radiation has an equivalent 5-year survival when compared to surgery in lesions that are less than 3 cm in diameter.
- Radiation, however, may result in local tissue changes that may complicate reconstruction if surgical excision is necessary.
- Cryotherapy or curettage may also be possible depending on the pathology of the lesion.

SURGICAL MANAGEMENT

- Basal cell carcinoma:
 - Nodular type BCC can be excised with 2-mm margins.
- Squamous cell carcinoma:
 - Lesions less than 1.5 cm in diameter can be excised with 10-mm margins.
- In both the cases of BCC and SCC, Mohs surgery can be employed.
- Melanoma:
 - In situ lesions—5-mm margins
 - Up to 1 mm depth—1-cm margins
 - 1- to 2-mm depth—1- to 2-cm margins
 - 2- to 4-mm depth—2-cm margins
- Definitive reconstruction of the lip should be delayed until the final margins are cancer-free.

Preoperative Planning

- The size of the defect should be evaluated.
- Facial examination should be performed to assess the laxity in the nasolabial crease and the amount of tissue in the nasolabial fold.
- Determination if a unilateral flap or bilateral flaps will be needed. Bilateral flaps can be used to reconstruct the entire width of the upper lip.
- If the patient has vascular compromise or is a smoker, then a delay procedure should be considered.
- The type of anesthesia should be discussed with the planning:
 - Local with sedation vs general anesthesia

Positioning

- The patient is positioned supine on the operating room table.
- The head is stabilized in a foam ring.
- The face is prepped with dilute Betadine.
- Eye shields or Steri-Strips are placed over the lids to protect the eyes.
- The face is draped bilaterally from tragus to tragus and from forehead to chin to visualize the entire face and provide access to both nasolabial folds.

Approach

- Care should be taken that the margins of the lip are negative for malignancy before definitive reconstruction be undertaken.
- Once definitive measurements are known, lower lip reconstruction can

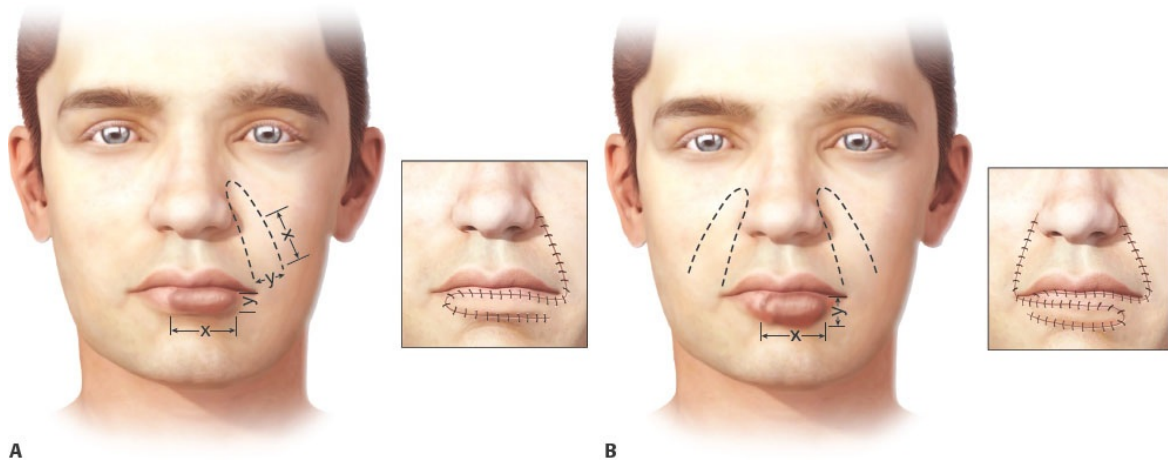
proceed with various techniques. Consideration should be given to the size of the defect and the types of tissue that needs to be replaced.

- Often, smaller lesions can be repaired primarily or with lip advancement flaps, without the use of local tissue flaps.
 - Defects less than 33% of the total lower lip width can be repaired primarily.
- If a local flap is necessary, usually for defects greater than 33%, care should be taken to consider what type of tissues are missing.
 - If the mucosal aspect of the lip has been violated, mucosal advancement flaps can be used to resurface the area of the wet/dry border of the lip.
 - Local cheek, lip, or nasolabial flaps can be used unilaterally or bilaterally to reconstruct large defects.³

TECHNIQUES

- A banner-shaped flap is designed in the nasolabial fold with the nasolabial crease serving as the medial border and superior border of the flap.
 - The width of the flap, at its widest point should not exceed 2.5 cm in middle-aged people (**TECH FIG 1**); however, the width can be increased to 3.5 cm in the elderly due to increasing skin redundancy and laxity.
 - The flap is based immediately superior to the lateral aspect of the defect to minimize the creation of a standing cutaneous deformity. Placing the flap base superiorly and laterally to the commissure prevents downward traction on the flap.
- The flap is injected with 1% lidocaine with epinephrine to aid in hemostasis and is elevated in the subcutaneous plane. The distal tip is tapered for ease of closure of the donor site.
 - Meticulous hemostasis is obtained with the bipolar electrocautery.
 - The donor site may be undermined for tension-free closure and is repaired in a layered fashion with deep absorbable sutures and cutaneous permanent sutures removed within 1 week.
 - A 0.5-cm portion of the donor site may be left open at the pivot point to reduce the amount of tension on the flap.
- The flap is transposed into the lip defect and sutured in place with deep absorbable sutures consisting of cutaneous absorbable sutures on the mucosal side of the defect and interrupted permanent sutures on the skin surface.

- If the commissure remains intact, the pedicle can be divided 10 to 14 days after the transfer. Longer time periods may be required for patients who have been previously treated with radiation or have scarring of the periorbital area.
- In defects that are vertically short, a single flap may suffice to adequately restore the full lip height.
- When larger vertical defects exist, bilateral flaps may be interposed to reconstruct the vertical dimensions of the lip, with one flap serving as skin coverage and the other as lining.



TECH FIG 1 • A. The width of the flap (y) should not exceed 2.5 to 3.5 cm, depending on the age of the patient. **B.** If the height of the defect (y) exceeds 2.5 to 3.5 cm, or if the length of the defect (x) exceeds 7 cm, bilateral nasolabial flaps should be used to cover the defect adequately.

PEARLS AND PITFALLS

Local anesthesia

- Use local anesthesia with epinephrine for vasoconstriction.

Blood supply

- The nasolabial flap has a robust subdermal blood supply. There is no need to incorporate a named vessel into the flap.

Delay the flap when necessary	■ If the vascularity of the flap is questionable, lay back down into the donor site and perform delay procedure.
Do not short-change yourself	■ The nasolabial flap has distinct dimensions. If the defect is larger than the unilateral nasolabial flap will accommodate, use bilateral nasolabial flaps.
Pathology	■ Proper pathology is needed for margins. Do not perform the procedure unless the margins are cancer free.
Hemostasis in the lip	■ Obtain meticulous hemostasis in the lip wound bed. A hematoma in the lip bed could compromise the flap.

POSTOPERATIVE CARE

- The procedure may be performed as an outpatient.
- The patient applies bacitracin BID to the suture lines.
- Normal oral hygiene is maintained.
- Chlorhexidine swish and spit is added as well to the oral regimen.
- Liquid diet is prescribed for 3 days followed by soft diet for 2 weeks after which the patient returns to a normal diet.

OUTCOMES

- Functional oral aperture without microstomia
- Normal oral hygiene and use of dentures
- Aesthetically acceptable results
- Normal speech

COMPLICATIONS

- Include
 - Oral incompetence
 - Drooling
 - Flap loss
 - Tight lower lip if flap is designed too small

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19 Lip Reconstruction With Radial Forearm Free Flap

CHAPTER

Vishal Thanik

DEFINITION

- Lip reconstruction is restoration of form and function after loss from a number of causes, the most common being oncologic resection and trauma.
- The lips are critical functional units in the processes of speech and alimentation and are one of the prime conveyors of emotion in the human face. They are also a focus of beauty in cultures worldwide.
- Reconstructive options in lip reconstruction are determined primarily by size and location of the defect; as defects become larger in more critical locations, functional outcome becomes paramount and aesthetic quality diminishes.
- Smaller defects typically can be addressed with local flaps, and in general, the use of free flaps is reserved for defects that cannot be reconstructed with local tissue alone.

ANATOMY

- The lips are a trilaminar structure containing mucosa, muscle, and skin.
- External anatomy (**FIG 1A**)
 - Upper lip—base of nose to nasolabial fold
 - Lower lip—mental crease to nasolabial fold
 - Corners of the lip referred to as commissures
 - Skin transitions to mucosa at the vermilion border, with the transition skin referred to as the white roll.
 - Midline of the upper lip has a curve referred to as the “Cupid’s bow.”
 - Cupid’s bow progresses vertically to the philtrum, a depression that is bordered on either side by the philtral columns.
 - The vermilion is a specialized mucosal surface that does not contain minor

salivary glands.

■ Internal anatomy (**FIG 1B**)

- Muscular anatomy of the lip functions as a specialized sphincteric system.
- Orbicularis oris forms a sphincteric ring and is the major muscle of the trilaminar structure.
- Major elevators of the lip are the zygomaticus major and levator anguli oris, with zygomaticus minor and levator labii superioris as secondary elevators.
- Major depressor of the lip is the depressor anguli oris, with contributions from the depressor labii inferioris, mentalis, and platysma.
- The modiolus is just lateral to the commissure and is the confluence of muscle fibers to the dermis, the functional insertion of the levator and depressor muscles.

■ Innervation

- Sensory innervation to the upper lip is provided by the maxillary branches of the trigeminal nerve, whereas the lower lip is supplied by the mandibular branches.
- Motor innervation is via branches of the facial nerve.

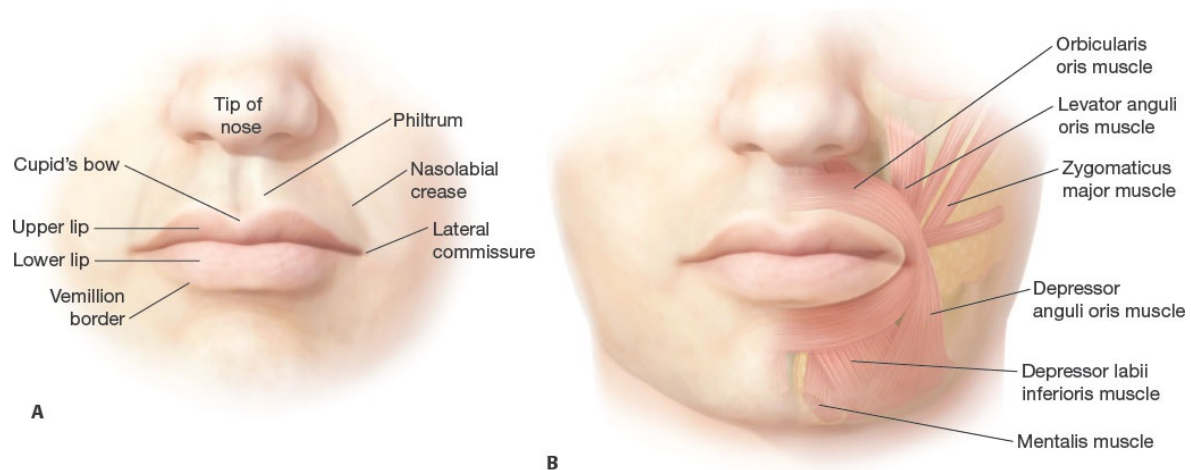


FIG 1 • A. External anatomy of the lip. **B.** Musculature of the lip.

■ Vascular supply

- The facial artery is the main blood supply to the lip and branch, diving and entering the lips laterally, becoming the superior and inferior labial arteries. These vessels can run between the mucosa and orbicularis muscle or through

the muscle depending on the patient.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Understanding the underlying etiology of the defect is paramount. Traumatic wounds can generally be reconstructed immediately after adequate debridement and ruling out of concomitant injuries that could delay treatment. With oncologic defects, margin status and need for further excision or adjuvant therapy should be assessed prior to reconstruction.
- A full history should be established, with particular attention paid to previous lip/facial reconstruction, smoking and comorbid status, and any history of radiation therapy of the head and neck.
- Physical examination requires assessment of the defect and the surrounding tissues.
 - Assessment of the size and location of the defect, as well as the size of the opposite, typically normal lip
 - Evaluation of the depth of injury, including status of the orbicularis oris
 - Evaluation of the opposite lip for concomitant injury, typically in trauma
 - Neurovascular examination, inventorying sensibility and perfusion of the remaining lip
 - Evaluation of donor sites if free flap reconstruction is warranted

IMAGING

- Imaging is typically unnecessary prior to lip reconstruction.
- In patients with traumatic lip defects, head CT and C-spine imaging may be performed to rule out concomitant injuries.

Surgical Management

- Operative management of lip defects depends on the location, size, and thickness of the defect.
- Partial-thickness defects of the lip and vermilion, if small (generally less than 30% of the lip), can be converted into full-thickness defects and closed primarily in a V-shaped manner.
- Larger partial-thickness defects of the vermilion that are not amenable to V-excision and closure are best managed with mucosal advancement flaps from the labial or buccal surface. Other options include mucosal V-Y advancement flaps or cross-lip mucosal flaps.^{1,2}
- Large, full-thickness defects of the lip are considered those that are 80% or

more. For defects of this size, free flap reconstruction is usually indicated. Another option in some patients, particularly those who are not free flap candidates, is bilateral nasolabial flaps or other local approaches.

- Lower lip defects are more common than the upper lip defects due to increased sun exposure.
- Full-thickness lower lip defects reconstructed with free flaps are difficult due to the potential for lip incontinence and benefit from suspension of the flap with a tendon or fascia graft. Upper lip defects typically do not require tendon grafting.
- The radial forearm flap is the workhorse flap in lip reconstruction because of its thinness and pliability, ability to easily integrate the palmaris tendon, and long pedicle length, which facilitates anastomosis in the neck or superficial temporal system.^{3,4}
- Other flap options include anterolateral thigh flap, parascapular flap, and lateral arm flap. In thin individuals, rectus abdominis and gracilis have also been described.⁵⁻⁷
- Innervation of the flap can be achieved by harvesting the lateral antebrachial cutaneous nerve with the flap and coapt to the mental nerve for sensory reinnervation.

Preoperative Planning—Radial Forearm Flap

- Evaluation of potential recipient vessel site should be performed, including assessment if any previous neck dissection has been performed.
- The size of the defect needs to be established. Typically, the remaining edges retract with the cheek, making the defect appear larger than it actually is. The lip edges should be pulled to resting tension, and the opposite lip can be used for confirmation.
- The width of the flap can be undersized somewhat to the size of the defect, but the height should be modestly oversized to compensate for tension by the palmaris as well as postoperative scarring.
- The height of the mucosal and skin defect should both be measured because they are not typically equal.
- Use of a template to size the defect is advised.
- Presence of palmaris tendon should be confirmed by physical examination.
- In the absence of the palmaris tendon, the plantaris tendon or fascia lata can be utilized through a separate site.

- Allen test should be performed on the forearm to ensure adequate perfusion of the first three digits with radial artery occlusion.

Positioning

- The patient should be placed supine. A foam donut is helpful for positioning of the head.
- The nondominant hand should be abducted on an arm board for radial forearm harvest.

Approach

- For radial forearm free flap, a two-team approach can be applied, with one team harvesting the flap while the other debrides and prepares the defect and recipient vessels.

TECHNIQUES

■ Radial Forearm Free Flap

- Based on the designed template, the radial forearm flap should be marked on the nondominant arm.
- Palmaris tendon should be centered at the junction between the mucosal and skin elements, ie, the fold-over point.
- The radial artery is placed on the side of the flap that will be the external skin.
- Cephalic vein is typically marked and included in the flap if possible.
- Flap is raised under tourniquet control after limb elevation.
- Circumferential incisions are made into the subcutaneous fat; care is taken to identify and preserve the cephalic vein and lateral antebrachial cutaneous nerve.
- Dissection begins on the ulnar border of the flap in a subfascial plane. Dissection proceeds radially in this plane with care taken to preserve the paratenon.
- When the palmaris tendon is encountered, its most distal portion at the palmar aponeurosis should be identified and divided, leaving a cuff of palmaris distal to the distal flap edge.

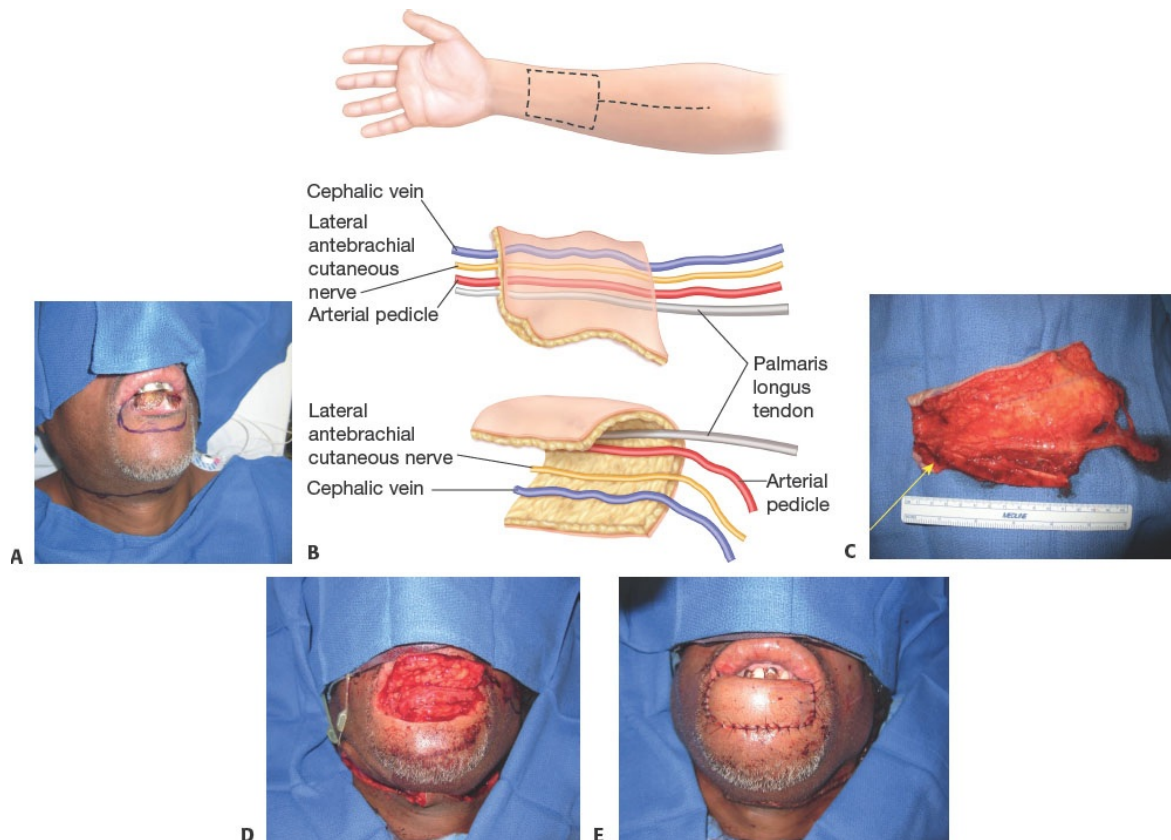
- Dissection proceeds in a deeper plane incorporating the palmaris and its sheath. Once radial to the palmaris, the previous plane can be re-established until the intramuscular septum and radial artery are encountered.
- Dissection now proceeds from the radial incision. The brachioradialis tendon is identified and retracted radially, giving exposure to the septum and radial artery.
- The cutaneous branch of the radial nerve should be protected.
- The distal portion of the radial artery pedicle can be clipped and divided and the septum can be elevated deep to the vascular pedicle. Branches to the periosteum of the radius and to flexor muscles of the forearm should be ligated and divided.
- A lazy-S incision is carried proximally along the ulnar border of the brachioradialis to the origin of the radial artery.
- Distal to proximal dissection continues along the vascular pedicle, cephalic vein, and lateral antebrachial cutaneous nerve.
- Once adequate pedicle length is obtained, the flap is harvested with either tie or double clip.
- Donor site is closed with unmeshed split-thickness skin graft. VAC dressing and splint are applied (**TECH FIG 1**).



TECH FIG 1 • Skin graft closure of the donor site. Note the slightly more proximal location of the skin paddle to allow for increased length of palmaris distally.

■ Recipient Site Preparation and Insetting

- A multitude of recipient vessels from branches of the external carotid system and jugular vein can be utilized.
- If concomitant nodal dissection has been performed, that exposure can be utilized.
- In the absence of neck incision, a transverse neck incision and exposure of the facial artery can be used (**TECH FIG 2A**).
- For inset of the flap, the flap should be folded along the axis of the palmaris tendon (**TECH FIG 2B–D**).
- Suspension of the palmaris sling is routed through the remaining orbicularis muscle and/or modiolus and sutured to itself, allowing for a dynamic suspension (**TECH FIG 2E**).
- Tension on the palmaris is critical, with a slight overcorrection performed.⁸
- Microneural anastomosis of the lateral antebrachial cutaneous nerve and the mental nerve should be performed if available.



TECH FIG 2 • A. Markings for resection and

transverse neck incision for recipient vessel exposure. Nodal dissection can also be performed through this incision, dependent on ablative surgeon preference. **B.** Schematic diagram demonstrating flap orientation for total lower lip reconstruction. **C.** Flap harvested demonstrating axis of fold along the palmaris longus tendon (*yellow arrow*). **D.** Appearance of the flap after mucosal inset and palmaris tensioning. **E.** Final inset and tensioning of flap.

PEARLS AND PITFALLS

Physical findings

- With oncologic defects, margin status and need for further excision or adjuvant therapy should be assessed prior to reconstruction.
- Assessment of the size and location of the defect, as well as the size of the opposite, typically normal lip.
- Evaluation of the depth of injury, including status of the orbicularis oris
- Evaluation of the opposite lip for concomitant injury, typically in trauma
- Ensure that palmaris is present preoperatively by physical examination.
- Preoperative Allen test

Technique

- Defining the defect width and height is critical. The lateral lip edges should be brought into physiologic tension prior to marking the width as to not oversize the defect. The skin and mucosal heights should be measured individually as they are typically different.
- Palmaris tendon should be centered at the junction between the mucosal and skin elements, that is, the fold-over point. The flap can be placed slightly more proximal than typical to increase the length of palmaris distally.
- For inset of the flap, the flap should be folded along the axis of the palmaris tendon (ie, along the width of the flap).

Postoperative	■ Early mobilization is encouraged. ■ Nasogastric or PEG tube should be used for feeding initially. ■ The donor site is typically covered with a split-thickness skin graft with bolster or VAC dressing. Addition of a splint for 7 days is helpful as well.
Complications	■ A watertight closure on the mucosal side is critical; good oral care and frequent examination minimize salivary leak. ■ The majority of complications arise at the donor site, typically the sequelae of loss of the paratenon during flap harvest. Exposed tendon often causes failure of the skin graft and tethering of the tendon with functional diminishment.

POSTOPERATIVE CARE

- Patients routinely stay in the hospital for 7 to 14 days.
- Flap monitoring is performed by experienced nursing and house staff by clinical examination and handheld Doppler. The authors prefer flap checks q 15 minutes × 2 hours, q 30 minutes × 1 hour, q 1 hour × 48 hours, and q 2 hours until day 4.
- Patients typically are out of bed by postop day 1 and ambulating either the same day or on postoperative day 2.
- Oral care with normal saline swish and spit begins on POD no. 3 along with clear liquid diet when sufficient healing has occurred with diet advancing to soft diet on days 5 to 7.

OUTCOMES

- Despite its shortcomings, the radial forearm remains the best option for reconstruction of subtotal lip defects.
- It allows for single-stage reconstruction or skin and mucosa and restores oral competence and adequate stomal size.
- Color match and lack of vermilion are long-term issues. Tattooing can be used to improve cosmetic outcomes by simulating the vermilion.

COMPLICATIONS

- The majority of complications are at the radial forearm donor site.
- Loss of the paratenon during flap harvest is the most common issue. Exposed tendon often causes failure of the skin graft and delay of wound healing. Secondary effects of this complication are tethering of the tendon with

functional diminishment.

- Care must be taken to evaluate the circulation of the hand with an Allen test preoperatively. Failure to recognize an incomplete arch can lead to catastrophic loss of blood flow to the digits.
- Major issues at the recipient site are early salivary leak or tensioning issues of the palmaris graft.
- Overtensioning of the palmaris can lead to bowstringing of the lip and difficulty with eating. Undertensioning can lead to issues with oral competence.

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Section VII: Eyelid

20 Direct Closure and Lateral Cantholysis

CHAPTER

Aaron Fay and John Nguyen

DEFINITION

- The primary objectives of eyelid reconstruction are to
 - Restore anatomic alignment and dynamic function of the eyelids
 - Create a stable eyelid margin with acceptable vertical lid height of both anterior and posterior lamellae
 - Maintain adequate eyelid closure
 - Optimize appearance and symmetry
- Full-thickness eyelid defects involving up to one-third of the margin can be repaired by direct closure, depending very much on the age of the patient, though sometimes the addition of a lateral cantholysis is required to allow adequate mobilization of the lateral lid.

ANATOMY

- The eyelids are conceptually considered as the anterior and posterior lamella (**FIG 1**). The anterior lamella consists of skin and orbicularis oculi muscle. The posterior lamella contains tarsus and palpebral conjunctiva.
- The gray line is an important landmark that separates these two lamellas. This line is important for eyelid margin repair and represents the superficial portion of the orbicularis oculi muscle known as the muscle of Riolan. From the eyelid margin to the superior (upper lid) or inferior (lower lid) edge of tarsus, the upper eyelid tarsal plate is approximately 10 mm tall centrally and tapers toward the medial and lateral canthal tendons, whereas the lower eyelid tarsal plate measures approximately 4 mm high and tapers slightly.

- Above the upper eyelid crease, eyelid anatomy is substantially different, where the concept of lamellae begins to break down. The posterior lamella in this anatomic region includes the conjunctiva, Mueller muscle, and the aponeurosis of levator palpebrae superioris. Most authors now consider a “middle lamella” that includes the preaponeurotic fat and orbital septum. This leaves the orbicularis oculi and skin to constitute the anterior lamella.
- The lateral eyelid also incorporates the palpebral lobe of the lacrimal gland. The lower lid contains analogous structures but notably contains a third fat pad laterally (whereas the lacrimal gland occupies that space in the upper lid). The canthal tendons suspend the eyelids medially and laterally and the lacrimal drainage system including the punctum, canaliculus, common canaliculus, and the medially located lacrimal sac.
- Vascular supply to the eyelids is provided by the marginal arcade, near the eyelid margins, and the peripheral arcades, coursing along the superior tarsal edge in the upper lid and along the inferior tarsal edge in the lower lid.
- Palpebral width, on average, measures 30 mm in adults. The lower lid typically rests at the inferior corneal limbus, with the lateral canthus 2 mm higher than the medial canthus. The upper lid rests slightly inferior to the superior corneal limbus with the peak of the upper lid between the medial corneal limbus and the medial border of the pupil.
- The skin of the eyelid is unique in that it is the thinnest skin found anywhere on the body and is devoid of subcutaneous fat, hence an intimate connection with orbicularis oculi, another thin layer covering the orbital septum from lid margin to brow.

PATHOGENESIS

- Eyelid margin defects can be partial thickness or full thickness, may occur at different positions on the eyelid, and most commonly result from trauma in young men.
- Lacrimal injury may concurrently exist, especially when the laceration is in the medial canthal region. This is more common in children.
- Mechanisms include tissue stretch, crush, avulsion, or tear. Tissue loss is rare, so direct closure without the need for cantholysis is typically performed.
- Resection of malignant eyelid tumors (most often basal cell carcinoma, squamous cell carcinoma, and sebaceous cell carcinoma) results in defects of various sizes. Because surgical margins are needed, these surgeries often cause large defects that may require cantholysis when closing primarily.

- Closure of larger eyelid defects requires local flaps such as Tenzel semicircular flap which is discussed in subsequent chapters.

NATURAL HISTORY

- Incomplete closure of eyelid defects can lead to eyelid notching, exposure, entropion, ectropion, trichiasis, corneal injury, eyeball rupture, and corneal blindness.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Assessment of the eyelid defect typically occurs after stabilization of life-threatening conditions in patients with traumatic injuries.
- History should include nature of the injury; type of trauma; the extent of trauma; prior ocular and periocular surgical history; visual changes; tetanus vaccination status of the patient and the assaulting animal in case of bites; recent food or liquid ingestion; and drug allergy. Bite, hook, or clawing trauma may be suggestive of canalicular laceration.

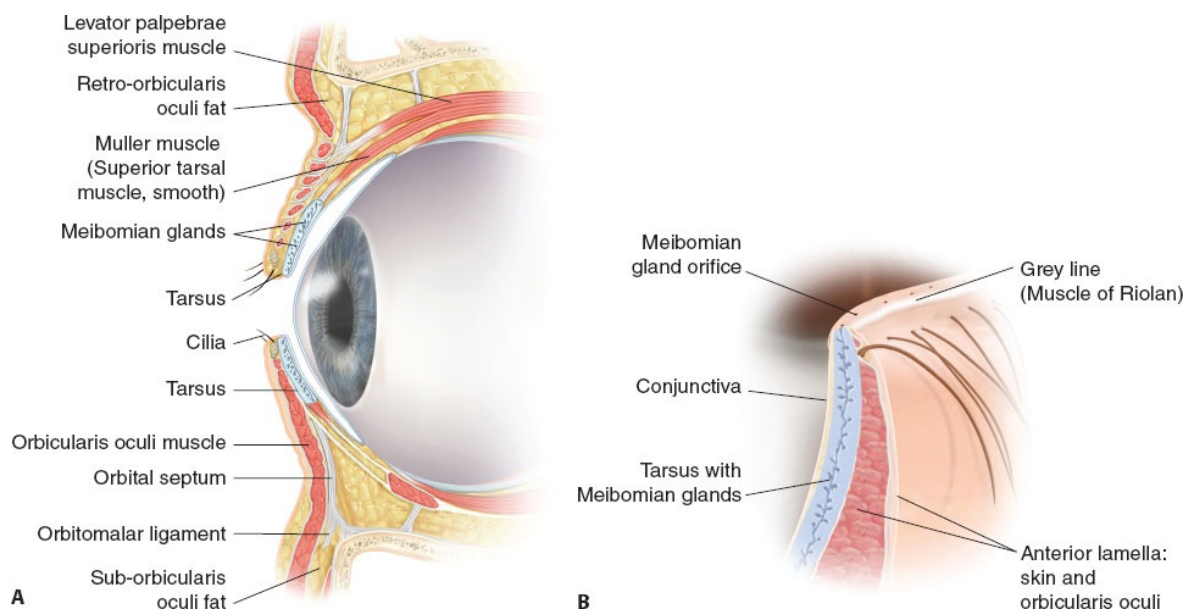


FIG 1 • A. Anatomy of the eyelid demonstrating the components of the anterior and posterior lamellas. **B.** Position of the gray line separating the anterior and posterior lamella.

- A detailed assessment of the defect must include the width, height, and eyelid

layers involved.

- A defect in the medial canthal region requires an additional examination for canalicular and medial canthal tendon integrity; complete eyelid eversion is indicative of loss of canthal tendon attachment.
- In many cases, the medial canthal tendon can be assessed quickly by distracting the upper and lower lid margins laterally and observing the degree of migration of the medial commissure.
- When a laceration appears to involve the medial eyelid, the punctum should be dilated and the canaliculus probed. Superficial-appearing lacerations in this region are notoriously misleading.
- The eyelid is also inspected for scarring or previous incision sites. Prior irradiation, burn injury, or skin conditions such as scleroderma and ichthyosis may limit the amount of skin stretching needed for primary wound closure.
- Laxity of the lid, especially in elderly patients, is also examined as it may facilitate closure and precluding the need for cantholysis.
- In cases of trauma, careful examination for debris or retained foreign bodies or eyeball laceration (“ruptured globe”) is important. Globe injuries typically dictate the timing of lid repair.

NONOPERATIVE MANAGEMENT

- Small eyelid margin defects involving the anterior lamella without lid laxity may heal adequately by secondary intention. Similarly, small lacerations involving only the anterior lamella without significant tension may be amendable to adhesive repair with cyanoacrylate.

SURGICAL MANAGEMENT

- Lid margin reconstruction is one rare instance in that near perfection can be achieved in many cases. Three months after repair, the surgical site can often be undetectable.
- This requires meticulous apposition of anterior and posterior lamellae.
- Horizontal tension should be maximized at the expense of the vertical tension.
- Parallel wound edges perpendicular to the lid margin are desirable, and minimal excision of wound edge tissues should be performed.
- At the completion of the repair, the lid margin should show a mild eversion at the fusion site in order to avoid notching as the healing wound contracts linearly.

- A delayed repair, whether due to late presentation or surgically planned, typically requires debridement of the epithelialized wound edges. In a defect with canalicular involvement, it is best to repair as soon as possible; however, canalicular repair can still be achieved up to 48 hours after initial injury.

TECHNIQUES

■ Wound Preparation

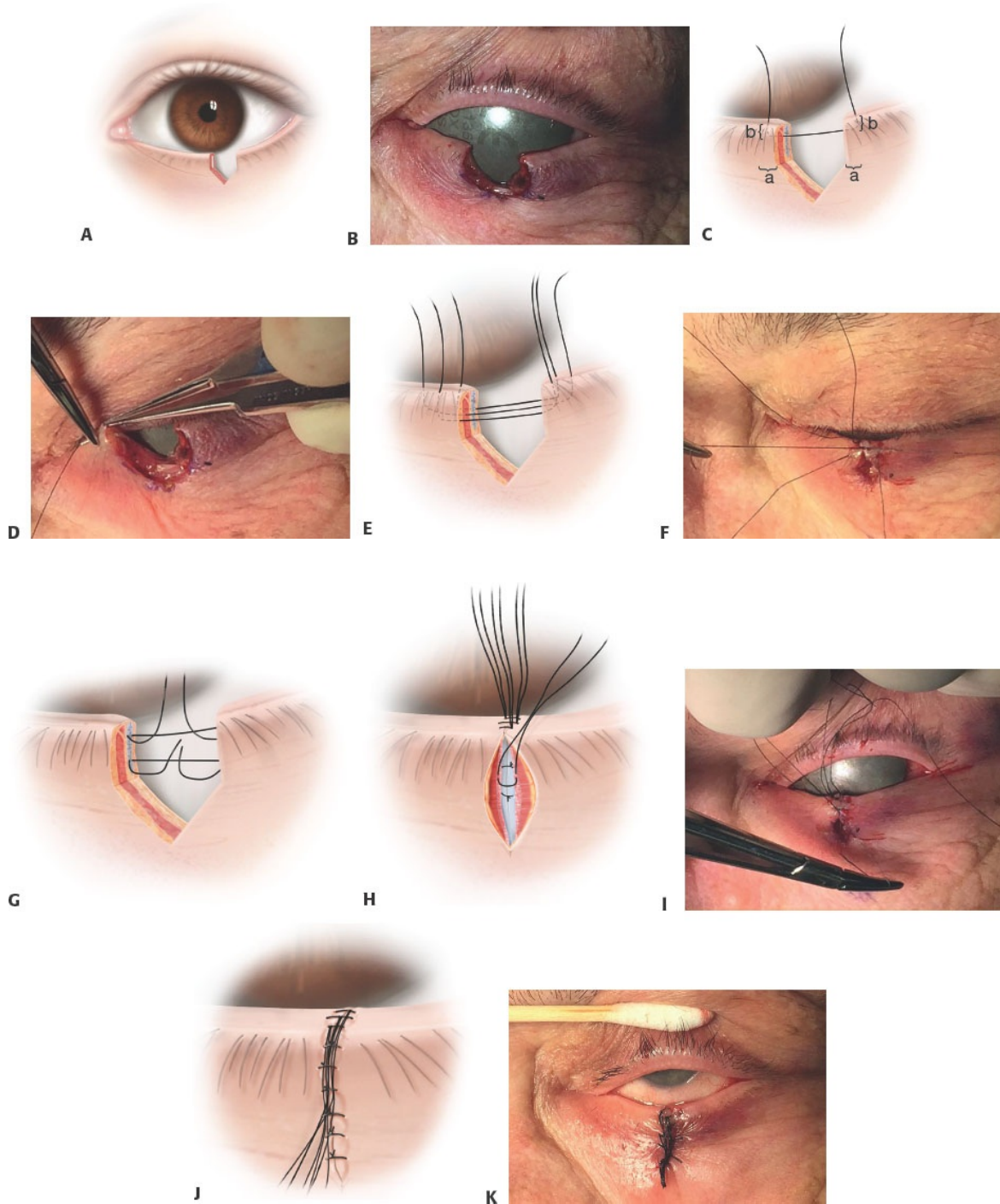
- The wounds and the lateral canthal region, if needed, are infiltrated with 2% lidocaine with 1:100 000 epinephrine.
- After cleansing with ophthalmic povidone-iodine (1:20 dilution), a scleral shell can be inserted for ocular protection.
- Apposition of the wound edges using two toothed Adson forceps will indicate the amount of tension and whether primary closure would require canthotomy and cantholysis.

■ Primary Wound Closure

- The eyelid margin is repaired using 6-0 silk sutures, which are left long and draped away from the wound awaiting incorporation into subsequent skin sutures. These more pliable sutures are less likely to cause corneal injury than a rigid monofilament. Three sutures are placed along the margin—the first through the gray line, second through tarsus, and third through the lash line.
- The suture bites should be equidistant from the wound on each side of the defect, and the vertical excursion of the bite should be longer than the horizontal excursion of the bite to facilitate wound eversion (**TECH FIG 1A–F**).
- The tarsal edges are then apposed and sutured with partial-thickness 6-0 polyglactin suture. In order to pass intratarsal sutures and to avoid the conjunctival surface, the S-14 spatulated needle is preferred. Precise alignment of the tarsal edges will maintain proper apposition of the posterior lamella (**TECH FIG 1G,H**).
- Minor to moderate amount of anterior lamella tension can be relieved with placement of interrupted 6-0 polyglactin sutures through the orbicularis oculi,

particularly at the level of the primary lid crease (**TECH FIG 1I**).

- The skin is closed with 6-0 nylon sutures. The long ends of the lid margin silk sutures are incorporated into the second nylon suture away from the lid margin (**TECH FIG 1J,K**).



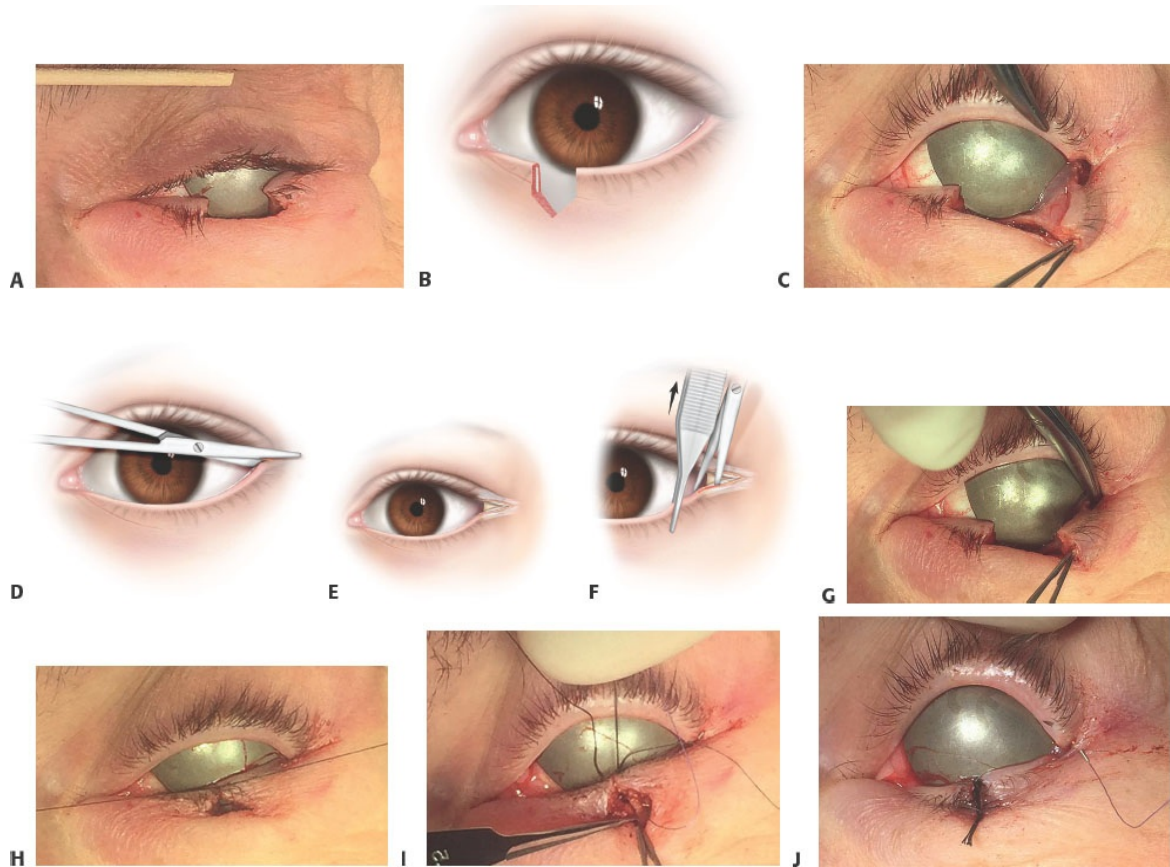
TECH FIG 1 • A,B. Full-thickness lower eyelid defect

measuring one-fourth to one-third the length of the lid margin. This type of defect can often be closed using the direct closure method alone. **C,D.** The cardinal suture is placed through the gray line (muscle of Riolan) symmetrical across the defect. The posterior lid margin edge is checked for alignment before accepting this suture. Silk is preferred because it is soft and well tolerated by the ocular surface. **E,F.** Three sutures are placed through the lid margin: the first through the gray line, the second through the tarsus, and the third through the lash line. Each suture is symmetrical as shown in **C**, but need not be equal in dimension. **G.** Lamellar sutures are placed through the tarsus to avoid the conjunctival surface. (Margin sutures not shown here.) **H.** Three silk sutures are tied along the lid margin. Two sutures are shown in the tarsus. **I.** Following tarsal approximation, orbicularis oculi is closed with buried polyglactin sutures. **J,K.** The long ends of the silk sutures are incorporated into the second skin sutures (nylon).

■ Canthotomy and Cantholysis

- A skin incision is made from the lateral canthus toward the lateral orbital rim, approximately 1 cm, running along a lateral canthal rhytide if possible (**TECH FIG 2A–C**).
- Curved Stevens scissors are then used to divide the lateral canthal tendon along its length by following the skin incision down to the lateral orbital rim (**TECH FIG 2D**).
- The scissors are then angled inferonasally to strum and then lyse the inferior crus of the lateral canthal tendon. The cantholysis can be performed progressively until the desired laxity is achieved (**TECH FIG 2E–G**).
- Following completion of the primary wound closure, the skin and orbicularis edges in the lateral canthal region can be closed with 6-0 fast-absorbing gut

sutures (**TECH FIG 2H–J**).



TECH FIG 2 • A. Full-thickness lower eyelid defect measuring one-third to one-half the length of the lid margin. This type of defect can often be closed using direct closure method provided the lateral canthal tendon is released. **B,C.** A linear incision is created with a no. 15 blade, extending 1.5 cm from the lateral commissure toward the orbital rim. **D.** This incision is extended through the lateral canthal tendon using curved Stevens tenotomy scissors to create a full-thickness canthotomy. **E.** Following lateral canthotomy, the tendon is divided into superior and inferior crura or rami. **F,G.** The lateral lid margin is secured with toothed Adson forceps, traction is placed on the inferior ramus of the lateral canthal tendon, and

Stevens scissors are introduced in the space between the myocutaneous flap and conjunctiva to perpendicularly transect the taut inferior ramus close to the orbital rim, which is called cantholysis. The scissors are directed downward (toward the tip of the nose) to approach the inferior ramus of the tendon. This is facilitated by manually distracting the lower eyelid away from the orbital rim in a perpendicular plane. **H.** The lid margin is closed using a series of 6-0 silk sutures. **I.** Tarsus is closed using 6-0 lamellar-style polyglactin sutures in order to avoid damage to the ocular surface. **J.** Following closure of the wound, the lateral canthal angle is reformed using 6-0 nylon or resorbable sutures.

PEARLS AND PITFALLS

Ophthalmic examination

- In trauma cases, a complete ophthalmic examination is critical to avoid missing a ruptured globe injury that would need repair first.
- Obtain a CT scan if there is concern for orbital injury or foreign body.

Technique

- Avoid excessive cantholysis that can cause ectropion or dehiscence.

Suturing

- When placing the cardinal silk suture through the gray line, cross the two ends of the suture and pull in opposite direction while observing the alignment of the posterior edge of the lid margin. If the edge is not perfectly aligned, the suture should be removed and replaced.

POSTOPERATIVE CARE

- Topical antibiotic ointment can be used 3 times per day until first postoperative visit at 1 week.
- Typical ointments are bacitracin ophthalmic preparation or erythromycin ointment.

- The lids may appear tight but will relax overtime with avoidance of manipulation of lid by patients.
- Nylon and silk sutures are typically removed 7 to 10 days after repair.

OUTCOMES

- A smooth lid margin resting at the inferior corneal limbus is desirable.

COMPLICATIONS

- Wound dehiscence may occur with excessive wound tension or when the tissues have been chronically inflamed.
 - Because of the friable nature of a dehisced wound, careful manipulation is required to resuture the already damaged tissue edges.
 - Canthotomy and cantholysis may be needed during dehiscence repair if there is significant tissue tension.
- Eyelid notching can be avoided by ensuring eversion of wound edges at the margin with silk sutures.
- Ectropion may occur as a result of aggressive cantholysis and would need repair with resuspension of the lateral canthal tendon.

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21 Tenzel Semicircular Rotational Flap

CHAPTER

John Nguyen and Aaron Fay

DEFINITION

- The Tenzel semicircular rotational flap was initially described by Dr. Richard Tenzel in 1978.¹⁻³
- It is conceptually similar to the classic Mustarde cheek rotation flap but provides better dynamic reconstruction of the various eyelid lamellae with less tissue rearrangement.
- The Tenzel flap utilizes the rotation of a semicircular musculocutaneous flap beginning at the lateral canthus, extending either downward (for upper eyelid reconstruction) or upward (for lower lid reconstruction) to close full-thickness defects of the eyelid ranging from one-third to two-thirds of the horizontal length of the eyelid margin.
- Both the anterior lamella (skin and orbicularis muscle) and the posterior lamellar (tarsus and conjunctiva) are addressed in a single-stage operation. The final postoperative appearance of the flap is superior to skin grafting or the larger Mustarde flap.⁴
- A large defect up to two-thirds of the horizontal length of the lower eyelid can be repaired with the Tenzel semicircular flap.

ANATOMY

- The upper and lower eyelids meet at the lateral canthus, a tendon-ligament complex that is firmly attached to Whitnall tubercle, 2 to 4 mm deep to the lateral orbital rim. The anterior eyelid lamella (skin and orbicularis oculi) is continuous in this region.
- The thin eyelid skin transitions to thicker facial skin that contains subcutaneous fat, and the orbicularis oculi extends approximately 2.5 cm

beyond the lateral orbital rim.

- Posteriorly, the suborbicularis oculi fat lies anterior to the periosteum of the zygomatic bone.
- The periosteum of the orbit (periorbita) and zygomatic bone condense at the orbital rim to form the *arcus marginalis*; the strong periosteum can be useful to provide elevation support for the flap (**FIG 1A,B**).
- Arterial supply is derived from the lacrimal artery, giving rise to the zygomaticotemporal artery, exiting the lateral orbital wall at midorbit, and to the zygomaticofacial artery, running inferolaterally to exit through a small foramen in the zygomatic bone.
- Both the zygomaticofacial nerve and the zygomaticotemporal nerve arise from the maxillary nerve.
- The zygomaticofacial nerve leaves the orbit inferolaterally through the zygomaticofacial foramen along with the artery and supplies the skin of the malar eminence.
- The zygomaticotemporal nerve similarly egresses the zygomatic bone superiorly to supply the anterior temple (**FIG 1C,D**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Eyelid defects occur most commonly from trauma or tumor resection. Other causes include burns and congenital abnormalities.
- Basal cell carcinoma is the most common eyelid malignancy (90%); squamous cell carcinoma, sebaceous cell carcinoma, and cutaneous melanoma are neoplasms that involve the eyelids in order of decreasing frequency.
- The biologic behavior of the tumor should be a key consideration in reconstructing a large eyelid defect as it can affect long-term prognosis.
- Factors such as the size and orientation of the defect, patient age, vascular supply to surrounding tissues, previous treatment (both surgical and radiation), and age of the wound should also be carefully assessed, as any of these can affect surgical plan and outcome.
- The Tenzel flap is most useful when there is sufficient lateral canthal skin laxity and there is at least a small portion of the full-thickness eyelid available on either side of the defect.
- It can be used when there is no tarsus on the lateral side of the defect, but optimal results will require a periosteal flap or tarsal replacement graft such as hard palate mucosa, auricular cartilage, nasal septal chondromucosal graft,

free tarsoconjunctival graft, allograft, or xenograft to provide the stability that is normally provided by the tarsus.

- Without proper structural support, the lateral portion of the eyelid is likely to roll inward, causing chronic ocular surface injury.
- In cases of irradiation or burn injury, the Tenzel flap is preferred over grafting as the flap provides its own vascular supply.

NONOPERATIVE MANAGEMENT

- In general, significant eyelid defects require surgical repair.
- Nonoperative management of large eyelid defect can lead to eyelid notching, scarring, entropion, ectropion, trichiasis, and lagophthalmos with corneal exposure causing corneal injury, infection, eyeball rupture, and blindness.

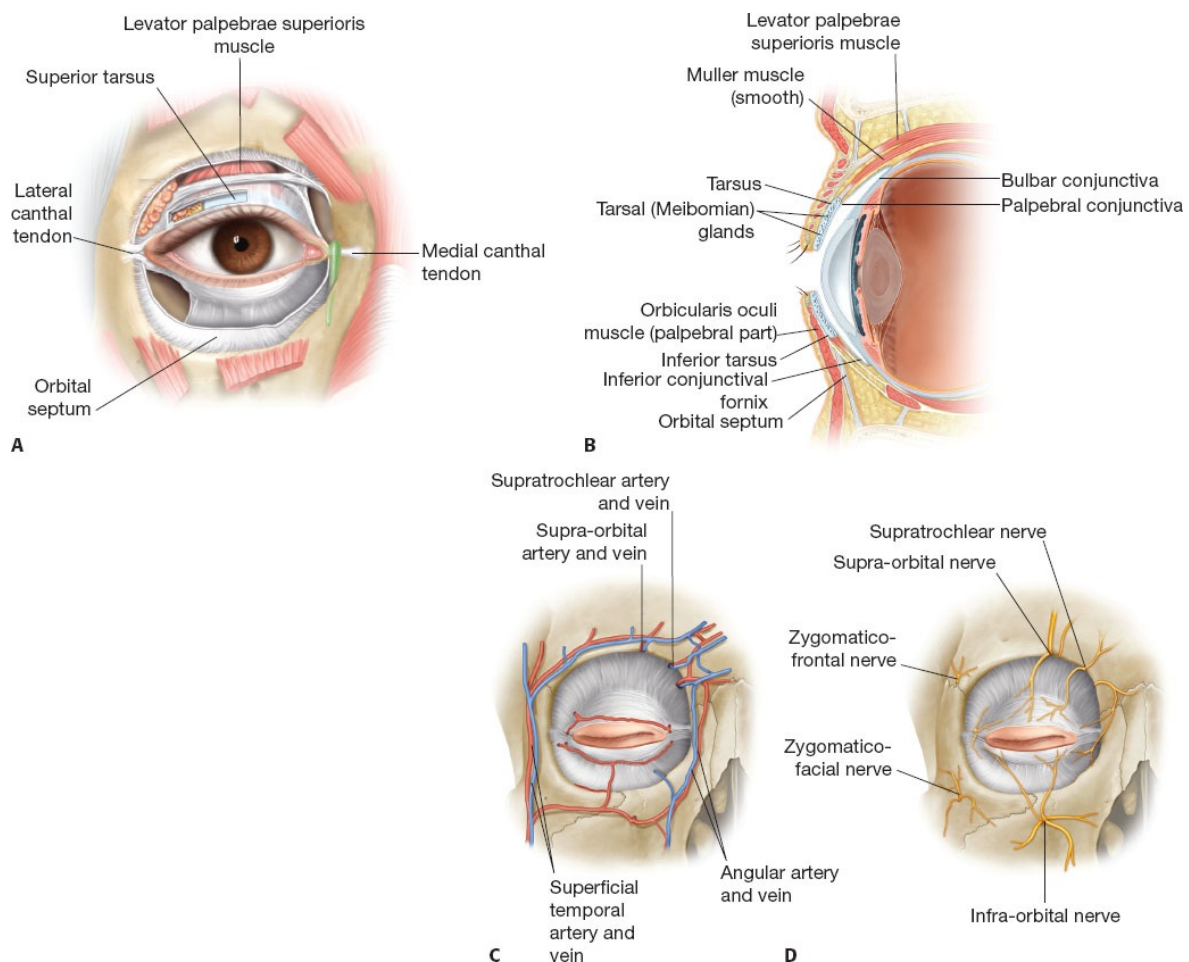


FIG 1 • Anatomy (A,B), blood supply (C), and sensory nerve innervation (D) of the eyelids.

SURGICAL MANAGEMENT

Preoperative Planning

- Initial analysis begins with estimation of the actual size of the defect by grasping both edges with toothed Adson forceps and pulling them together.
- If the edges are within 1 to 2 mm of one another, primary closure with lateral cantholysis may be all that is required.
- A larger defect up to two-thirds of the eyelid constitutes an excellent candidate for Tenzel flap for reconstruction (**FIG 2**).
- For larger defects, Hughes or Cutler-Beard flaps may be more effective (discussed in separate chapters).

Positioning

- The patient is positioned in the supine position and prepped with Betadine 5% Sterile Ophthalmic Prep Solution.
- A corneal shield is used to protect the eye.

Approach

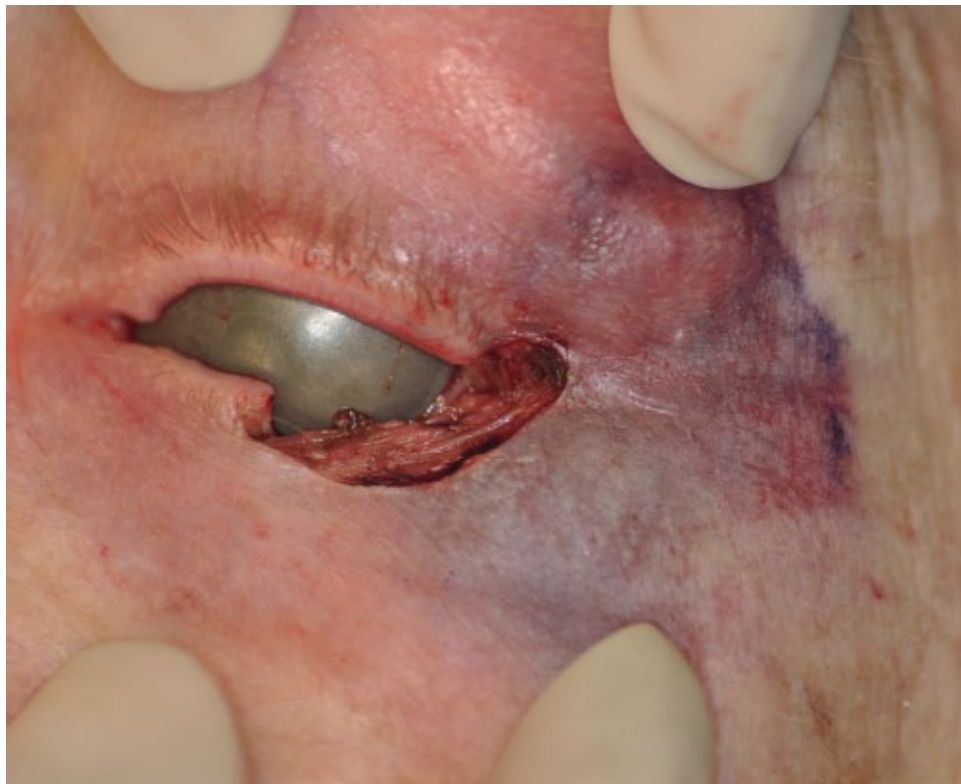


FIG 2 • Lower eyelid defect resulting from basal cell cancer excision that is suitable for Tenzel flap reconstruction.

TECHNIQUES

■ Tenzel Flap Reconstruction for the Lower Eyelid

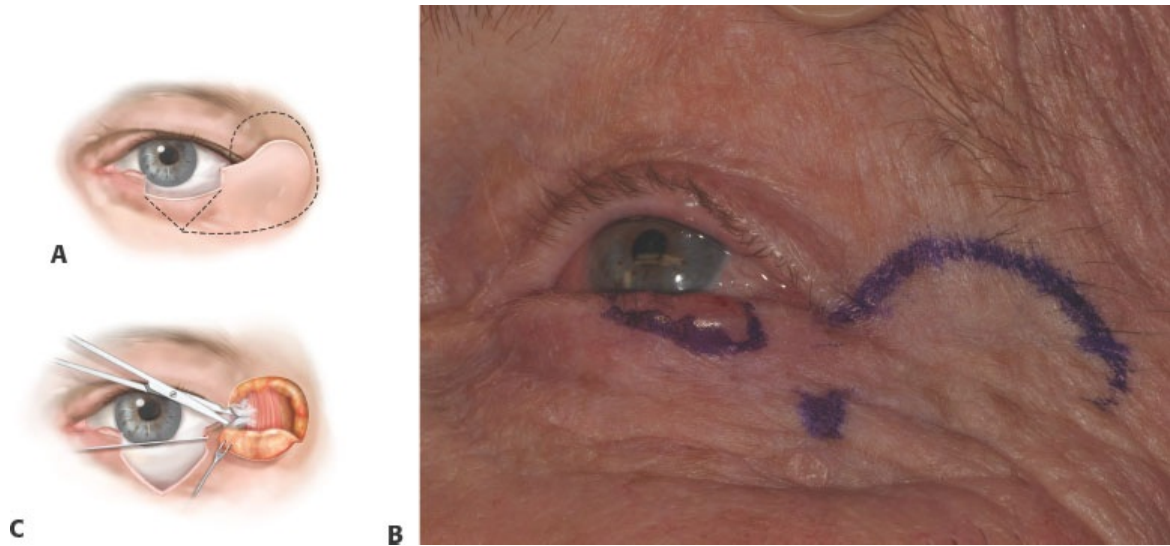
Design and Flap Elevation

- Beginning precisely at the lateral canthus, a semicircular superior arching line is drawn with a diameter of approximately 20 to 25 mm extending toward the lateral eyebrow line; the mirror image is used for the upper eyelid reconstruction (**TECH FIG 1A,B**).
 - The area is infiltrated with 2% lidocaine with 1:100 000 epinephrine.
- A no. 15 Bard-Parker blade is used for skin incision.
- Electrodissection using a monopolar electrode with an ultrasharp tungsten tip is performed to undermine and to develop the myocutaneous flap.
- A lateral cantholysis of the inferior crus of the lateral canthal tendon is made beneath the flap and is critical to the mobilization flap.
 - The flap is thoroughly undermined and advanced medially for closure of the eyelid defect (**TECH FIG 1C**).

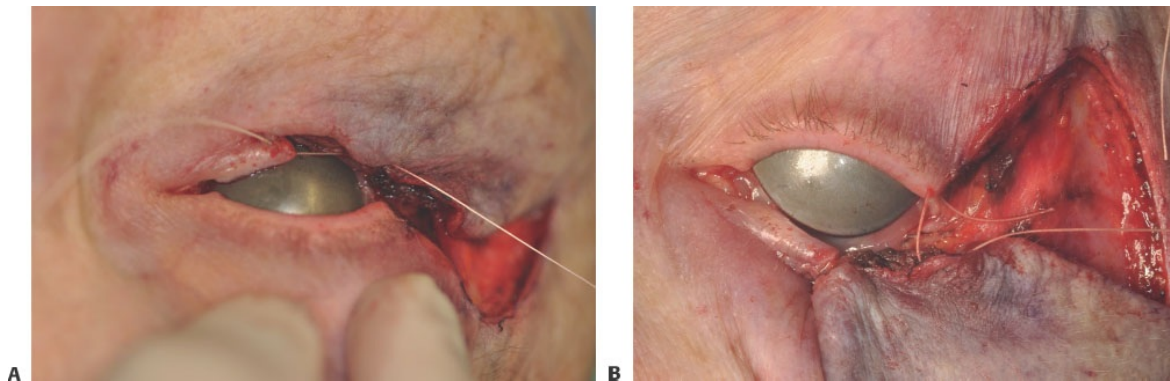
Tarsal Edge Repair and Flap Inset

- The tarsal edges should be incised anew as necessary so they are perfectly perpendicular to the lid margin, sacrificing as little tissue as possible.
 - The tarsal edges are then apposed and sutured with partial-thickness 6-0 polyglactin suture (S-14 spatulated needle) (**TECH FIG 2A**).
- The eyelid margin is repaired using 6-0 silk sutures, which are left long and draped away from the wound awaiting incorporation into subsequent skin sutures.
 - Three sutures are placed along the margin—the first through the gray line, second through the tarsus, and third through the lash line.
 - The suture bites should be equidistant from the wound on each side of the defect, and the vertical excursion of the bite should be longer than the horizontal excursion of the bite to facilitate wound eversion.

- Minor to moderate amount of anterior lamella tension can be relieved with placement of interrupted 6-0 polyglactin sutures through the orbicularis oculi, particularly at the level of the primary lid crease.



TECH FIG 1 • Schematic representation of the Tenzel flap for reconstruction of a lower eyelid defect. **A.** Flap markings. Circular areas shown with *dotted lines* are undermined to elevate flap in the submuscular plane. **B.** Flap markings in a patient with a lower eyelid basal cell cancer. **C.** Flap elevation and transection of the lower crus of the lateral canthal tendon.



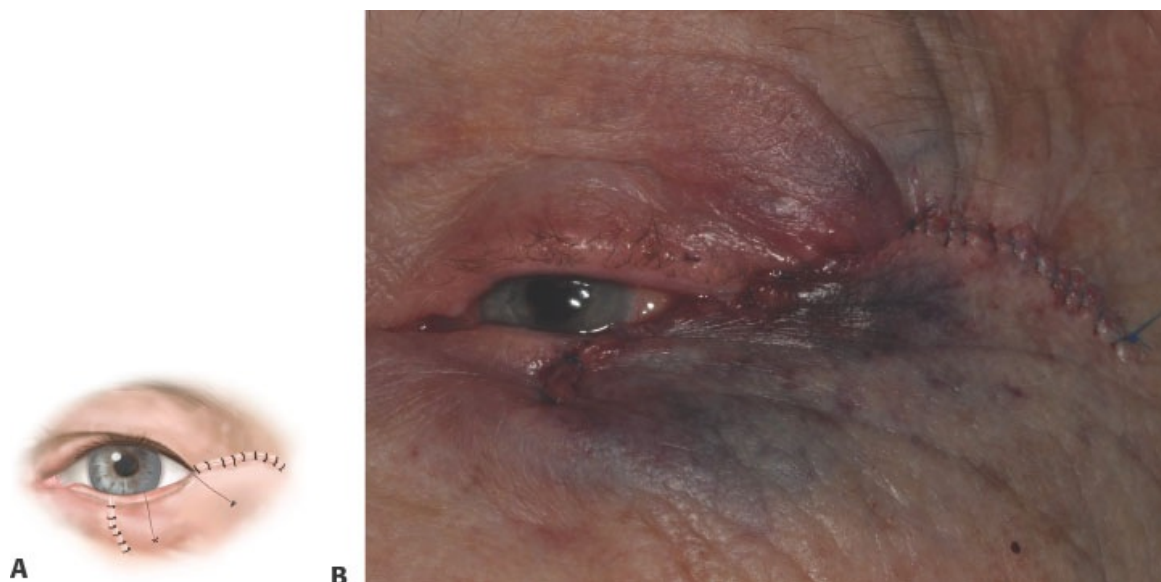
TECH FIG 2 • **A.** Suturing the tarsal edges after flap elevation and lateral canthal tendon transection. **B.** Lateral canthal fixation of the flap tissue is performed

to prevent lateral sagging and to minimize tension on the repaired defect.

- The skin is closed with 6-0 nylon sutures.
- The long ends of the lid margin silk sutures are incorporated into the second nylon suture away from the lid margin.
- To prevent lateral sagging and poor opposition of the lower eyelid to the globe and to minimize tension on the repaired defect, the lateral canthal fixation of the flap tissue is performed with placement of 4-0 polyglactin on a semicircular needle to secure the deep surface of the flap to the inner aspect of the superolateral rim periosteum (**TECH FIG 2B**).
- Improved eyelid contour can be obtained by incorporating a lateral orbital rim periosteal flap.
 - The flap is typically 8 to 10 mm wide, and the length is determined by measuring the distance from the rim to the lateral end of the tarsus on the flap.
 - It is hinged at the arcus marginalis, typically based at least midpupil, and angled superiorly 45 degrees to follow the eyelid contour and to provide upward pull on the lid.
 - It is sutured to the lateral tarsal edge of the mobilized flap.

Donor-Site Repair

- The semicircular donor site is closed in layers with 5-0 or 6-0 polyglactin sutures in a buried fashion for the muscles and 6-0 polypropylene sutures for the skin (**TECH FIG 3**).
- An excision of the Burrow triangle or extension of a skin incision may sometimes be necessary to prevent trapdoor deformity.



TECH FIG 3 • A,B. Flap advancement and final closure of the defect and donor site.

■ Posterior Lamellar Flap

- For larger defects or for those without the tarsus at the lateral edge, a posterior lamellar graft may be necessary to provide extra stability.
- Auricular cartilage, hard palate mucosa, nasal septal chondromucosal graft, free tarsoconjunctival graft, allograft, or xenograft can be used after harvesting in the usual manner.
- The tissue should be cut into rectangular fashion to snugly fit into the space between the lateral most tarsal edge and the lateral orbital tubercle.
 - 5-0 polyglactin sutures are used to secure the graft in place on both ends.
- If a periosteal flap or mucosal graft is used laterally, conjunctival advancement is unnecessary.
- Otherwise, the conjunctiva is advanced from the inferior fornix to the superior skin margin of the Tenzel flap, and it is secured with 7-0 chromic gut or polyglactin sutures.

PEARLS AND PITFALLS

Corneal protection	■ Protect the cornea during the procedure with a corneal shield. ■ Complete canthotomy and cantholysis are necessary to ensure sufficient mobilization of flap for wound closure. ■ Lateral canthal fixation is critical to prevent postoperative lid sagging or poor globe apposition. ■ Conjunctival lining of the posterior lamellar graft helps to prevent formation of symblepharon, adhesion of conjunctival/eyeball to the flap.
Hemostasis	■ Meticulous hemostasis is critical.
Dressing	■ Dressing contact lenses are useful in some cases to treat/prevent corneal epitheliopathy.

POSTOPERATIVE CARE

- Topical antibiotic ointment is used three times per day until first postoperative visit at 1 week.
 - Typical ointments are bacitracin ophthalmic preparation or erythromycin ointment.
- The lids may appear tight but will relax overtime with avoidance of manipulation of lid by patients.
 - Nylon and silk sutures are removed 7 to 10 days after repair.
- Temporary upper lid ptosis secondary mechanical dragging of the flap on the lateral upper lid tissue usually resolves after several weeks.

OUTCOMES

- A smooth lid margin resting at the inferior corneal limbus along with upward contour of the lid at the lateral canthus is desirable.
- Erythema along the eyelid margin in the area of the flap fades over time to give more normal appearance except for madarosis (loss of eyelashes).

COMPLICATIONS

- Wound dehiscence may occur with excessive wound tension especially with incomplete lateral canthotomy and cantholysis or when the tissues have been chronically inflamed.
 - Because of the friable nature of a dehisced wound, careful manipulation is required to resuture the already damaged tissue edges.
- Eyelid notching can be avoided by ensuring eversion of wound edges at the margin with silk sutures.

- Ectropion may occur in case without lateral canthal fixation to the orbital rim.

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22 Eyelid Reconstruction With the Hughes Flap or Cutler-Beard Flap

CHAPTER

Larissa Habib and Brian Marr

DEFINITION

- The Hughes flap was originally described in 1937 and has been modified to increase efficacy and minimize postoperative complications.
 - It is an effective vertical lid-sharing procedure that can achieve good functional and cosmetic results for lower eyelid greater than 50% defects resulting from trauma or cancer excision.
 - It involves a tarsoconjunctival advancement flap to recreate the lower lid posterior lamella.
 - The anterior lamella is recreated using a full-thickness skin graft or a local skin flap.¹
- The Cutler-Beard flap is a cutaneoconjunctival advancement flap from the lower lid that is used for very large (greater than 70%) defects in the upper eyelid.
 - Indications are tumor resection, trauma, and congenital defects.
 - The goal is to provide lid apposition to protect the eye, good aesthetic quality, and good mobility.²

ANATOMY

- The upper and lower eyelids meet at the medial and lateral canthus with the lateral canthus sitting 2 to 4 mm higher than the medial (**FIG 1**).
- The palpebral fissure is approximately 28 to 30 mm in length and 9 to 10 mm in height.
- The eyelid anatomy can be divided into anterior and posterior lamellae.
- The anterior lamella consists of the skin and the orbicularis oculi muscle.

- The eyelid skin is the thinnest in the body (less than 1 mm). The epidermis receives its nourishment from a deeper connective tissue layer as it lacks blood vessels and lymphatics. There is a sparse amount of fat in the preseptal and preorbital skin, and fat is absent in the pretarsal skin.
- The orbicularis oculi is loosely adherent to the skin and divided into orbital and palpebral portions. The palpebral is further divided into pretarsal and preseptal. The palpebral portion functions in blinking and voluntary winking. The orbital portion is for forced closure.
- The posterior lamella consists of the tarsus and the conjunctiva.
- The tarsal plate is composed of dense fibrous tissue. It is approximately 1 mm thick and provides the structural support of the eyelid. The upper eyelid tarsus extends from the punctum to the lateral canthus and is 30 mm long and 7 to 10 mm high, with the highest portion being centrally. The lower tarsus is only 3.8 mm wide. The ciliary border contains meibomian gland orifices that provide the lipid layer of the tear film. The medial and lateral ends are attached to the orbital rim by the medial and lateral palpebral ligaments.

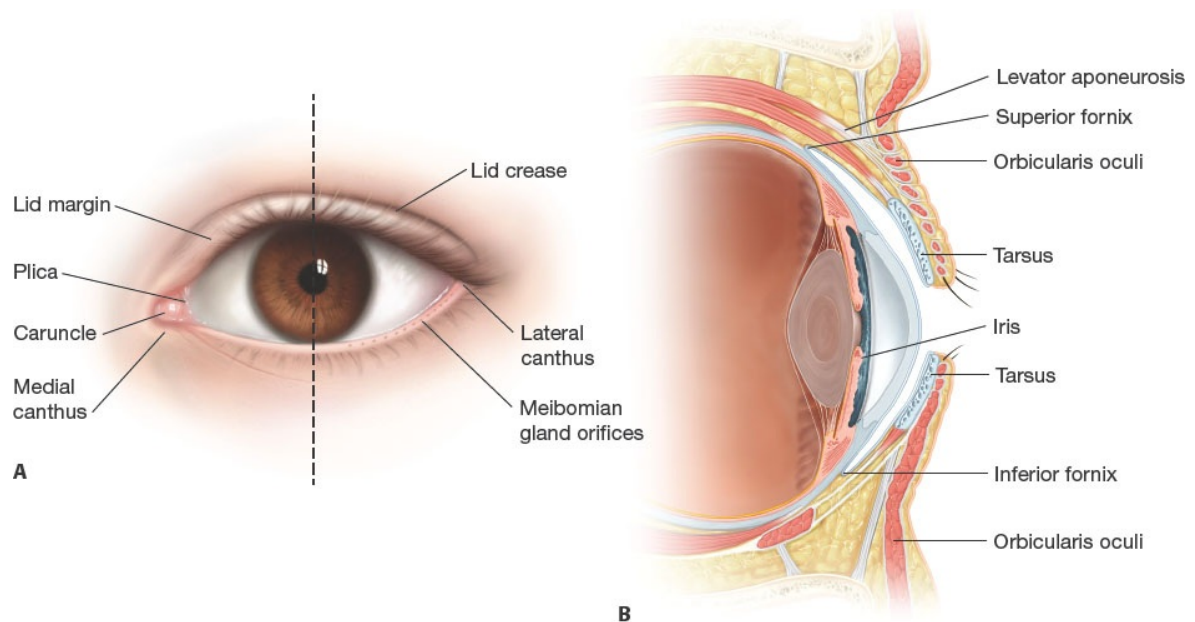


FIG 1 • A,B. External and sagittal section depicting the eyelid anatomy as well as surrounding structures.

- The conjunctiva is a mucous membrane that covers the sclera and the inner eyelids. The palpebral conjunctiva is adherent to the tarsus and then

continues as the orbital conjunctiva where there is a plane that allows dissection from the Mueller muscle. At the fornix, the conjunctiva reflects anteriorly to become the bulbar conjunctiva.

■ Upper eyelid retractors

- The levator palpebrae superioris arises at the orbital apex and courses anteriorly for 40 mm ending in the aponeurosis 10 mm behind the septum. At this junction, it changes direction to vertical and then inserts inferiorly onto the lower third of the tarsal plate. In addition, some fibers pass anteriorly to form the eyelid crease.

- The Mueller muscle originates from the undersurface of the levator at the muscular aponeurotic junction and then travels between the levator and the conjunctiva to insert on the superior border of the tarsus. It is innervated by the sympathetic nervous system.

■ The lower eyelid retractors are an extension of the inferior rectus muscle.

- They pass anteriorly and envelop the inferior oblique before joining the inferior transverse ligament to become the capsulopalpebral fascia and inserting at the inferior border of the tarsal plate.

- A small portion of the retractors joins with Tenon capsule at the inferior fornix and courses anteriorly to form the lower lid crease.

■ Blood supply is derived from both the internal and external carotid arteries.

- Medially, two palpebral branches (superior and inferior marginal arteries) arise from the ophthalmic to supply the upper and lower lid. These arteries then travel horizontally as the marginal arcades that lie on the tarsal plate (4 mm from the upper margin and 2 mm from the lower margin).

- Laterally, the lacrimal artery provides branches to both the upper and lower lids, which travel horizontally to anastomose with the marginal arcades.

■ The external carotid contributes through branches of the facial, superficial temporal, and infraorbital arteries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation includes a detailed examination of the extent of the lid defect, in particular, the extent of involvement of the anterior and posterior lamellae.

- The adjacent skin, contralateral upper eyelid, postauricular, and supraclavicular areas should be inspected for potential donor skin.

IMAGING

- Preoperative photos should be taken to document the extent of the defect.
- Imaging with CT or MRI can be considered based on etiology of the defect, in particular in trauma situations to assess other injuries or embedded foreign body.

SURGICAL MANAGEMENT

Preoperative Planning

- In determining whether a Hughes procedure is appropriate, one must consider the size and location of the defect as well as the status of the other eye.
 - An alternative procedure may be preferred if there is limited vision in the opposite eye as vision will be temporarily obscured by the vascular flap.
 - The extent of the posterior lamella defect and the anterior lamella defect must be determined to assess the size the flap as well as to determine the donor site for the skin graft.
- The extent of the posterior lamella defect and the anterior lamella defect must be determined to assess the size of the Cutler-Beard flap.
 - It is also important to assess the visual function of the contralateral eye as this procedure requires closure of the eye for up to 3 weeks.

Positioning

- For the Hughes flap, the patient should be supine with the postauricular area and contralateral eye exposed after draping.
- For the Cutler-Beard flap, the patient should be supine with both eyes exposed after draping.

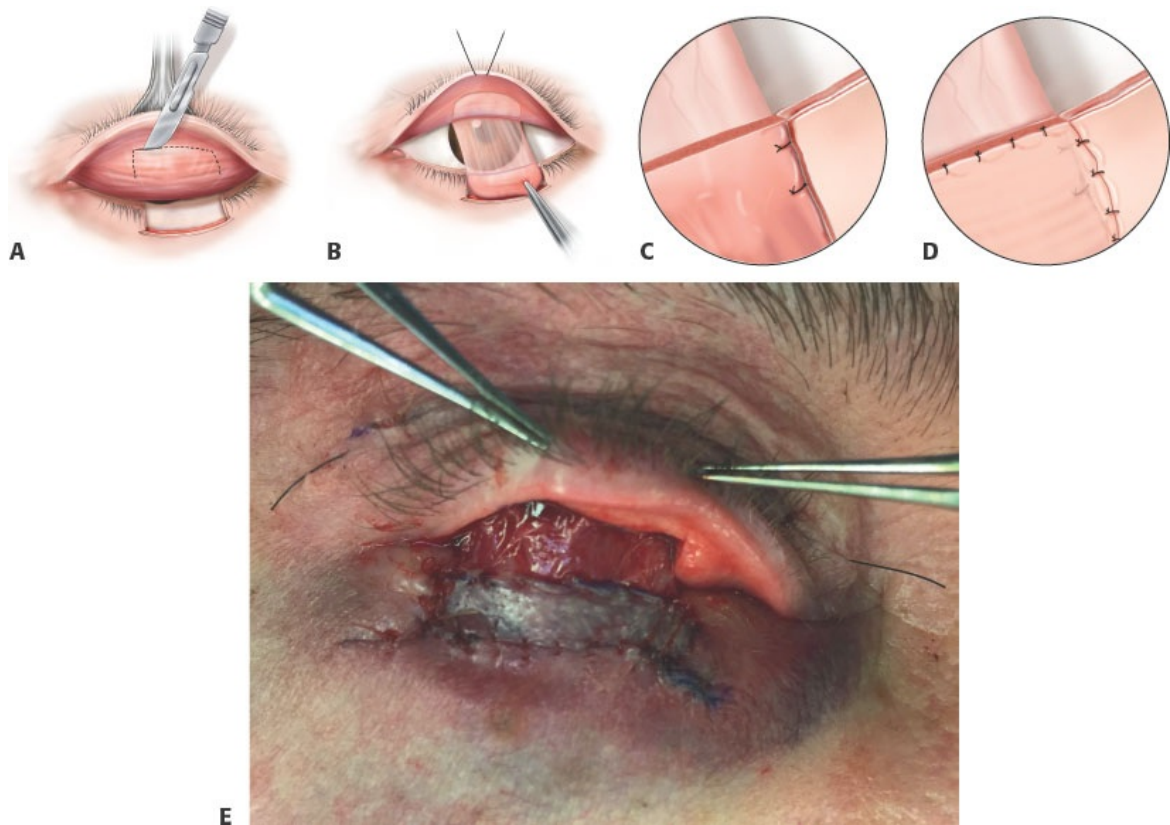
TECHNIQUES

■ Hughes Flap

Flap Creation

- Local anesthetic is injected into the pretarsal upper lid as well as subconjunctivally above the superior tarsal margin.
- The upper eyelid is everted using a Desmarres retractor to gain access to the conjunctiva and tarsal plate.

- A horizontal incision is marked 4 mm from the lash line to match the length of the posterior lamellar defect of the lower lid (**TECH FIG 1A**).
- The tarsus and conjunctiva are incised horizontally, and then the incision is extended vertically from both ends toward the fornix.
- The tarsus and conjunctiva are dissected away from the levator aponeurosis to the level of the Whitnall ligament so that the flap can be pulled downward to cover the defect without too much tension (**TECH FIG 1B**).
- The flap is then advanced to the lower lid and sutured to remnants of tarsus medially or laterally with 5-0 Vicryl on P-2 needle (**TECH FIG 1C,D**).
- To cover the flap and recreate the anterior lamella, an advancement skin flap or free skin graft can be considered depending on the size of the defect as well as the laxity of the skin (**TECH FIG 1E**).



TECH FIG 1 • A. The upper lid is everted on a Desmarres retractor, and an initial incision to match the length of the lower lid defect is made through conjunctiva and tarsus, 4 mm from the lash line. **B.** The tarsoconjunctival flap is dissected away from the

levator and the sutured into place in the defect. **C,D.** The free skin graft sutured over the pedicle flap. **E.** Photograph showing the vascular pedicle in place in the lower lid defect, with the overlying free skin graft.

Separation of Flap

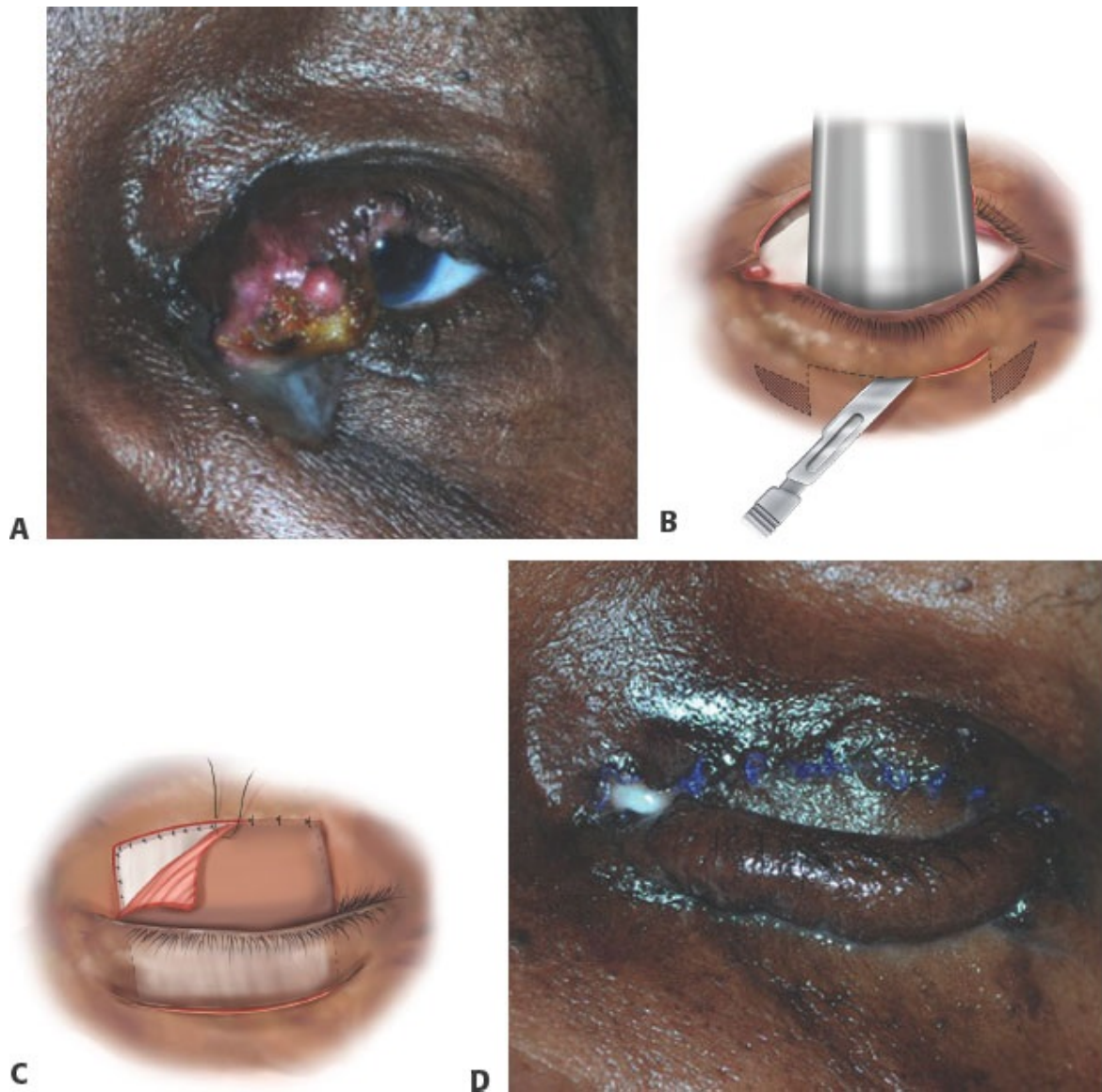
- The flap is separated 4 to 6 weeks postoperatively.
- A muscle hook is used to lift the flap from the conjunctiva, and Westcott scissors are used to separate the graft along the lower lid.
- The conjunctiva is sutured to the lower lid margin using 6-0 chromic gut.
 - The conjunctiva should be slightly higher than the skin surface to protect the cornea and to impart better appearance.
- Mueller muscle and levator aponeurosis are dissected away from the overlying skin and allowed to retract back.

■ Cutler-Beard Flap

Flap Creation

- The lower lid is measured and marked horizontally to match the upper eyelid defect. The mark is extended vertically to the fornix.
 - An attempt should be made to fashion the flap to fit the defect without much modification to preserve as much tissue as possible.
- Local anesthetic is injected into the upper eyelid defect and the pretarsal lower lid as well subconjunctivally.
- A full-thickness horizontal incision with a no. 15 blade is made 4 to 5 mm below the lash line, leaving the lower eyelid margin and tarsus intact.
 - This is important so as to avoid the marginal artery that provides essential blood supply to the remaining lower eyelid.
 - Westcott scissors are then used to extend the incision laterally and medially. The incision is then extending vertically to the fornix (**TECH FIG 2B**).
- The flap is divided into a conjunctivocapsular layer and a superficial skin and orbicularis layer.
- The deeper layer is sutured to the remaining conjunctiva of the upper lid superiorly, medially, and laterally with 7-0 Vicryl (**TECH FIG 2C**).

- The skin and orbicularis layer are then sutured to the margin of the upper lid with interrupted 6-0 chromic gut (**TECH FIG 2D**).



TECH FIG 2 • **A.** Patient with a sebaceous cell carcinoma of the upper eyelid prior to excision. **B.** An incision corresponding to the upper eyelid defect is made through the lower eyelid. **C.** The lower eyelid flap is sutured into the upper eyelid defect. **D.** Patient with Cutler-Beard flap in place.

Separation of Flap

- At 4 to 6 weeks, the flap is separated.
- A muscle hook is used to lift the flap from the conjunctiva and Westcott scissors are used to separate the graft.
- The conjunctiva is cut so that there is an extra 1 to 2 mm for some eversion after it is sutured to the skin. This improves long-term appearance and prevents rubbing of the corneal surface by the skin edge.
- The retracted portion of the lower flap is reattached to the bridged lower eyelid (**TECH FIG 3**).



TECH FIG 3 • Final result after flap separation.

PEARLS AND PITFALLS

HUGHES FLAP

Indication

- Lower lid defects $\geq 50\%$.

Technique

- Ensure 4-mm remaining tarsus in the upper lid. Consider free graft if sufficient anterior lamellae to support it.
- Ensure complete dissection from upper lid retractors to prevent

	postoperative upper lid retraction.
Postoperative care	■ Advise the patient the limitations of temporary monocular vision. ■ At stage 2 or when opening the flap, take care to contour a smooth line with the remaining eyelid margin for a good cosmetic result.
CUTLER-BEARD FLAP	
Indication	■ Upper lid defect greater than 70%.
Technique	■ Horizontal incision 4 mm below lash line to avoid compromise of donor eyelid blood supply. ■ Ensure 1–2 mm of redundant conjunctiva when separating graft to improve appearance. ■ In patients who may need more upper eyelid support, a second procedure can be done using AlloDerm, hard palate, or ear cartilage. ■ If the defect extends medially or laterally, the graft may not be sufficient, and additional revision may be necessary to reform the canthal angle. ■ When dividing the flap, take care to form or align the medial and lateral canthal angles with the divided flap edge.

POSTOPERATIVE CARE

- Antibiotic steroid ointment combination with patch for 48 hours.
 - The ointment should be continued twice a day for a week.
- The graft is separated at 4 to 6 weeks.

OUTCOMES

- In a series of 125 cases using the Hughes flap,³ 15.2% had minor perioperative complications including trichiasis (9.6%), pyogenic granuloma (1.6%), and corneal ulceration (4%).
 - Major perioperative complications included flap necrosis (0.8%) and flap dehiscence (1.6%).
 - Long-term consequences included ocular irritation (16%, 40% resolved at 6 months) and mucous discharge (2.4%).
 - Three cases needed reoperation for trichiasis, ectropion, and lower lid retraction.
 - Patient satisfaction was reported as 88% with appearance and 80% with ocular comfort.

- Most patients do very well after a Cutler-Beard flap, both functionally and cosmetically. There are, to date, no large case series to describe the outcomes.
- In a small case series by Carroll, 3 of 10 patients developed cicatricial entropion after this procedure.⁴

COMPLICATIONS

- Hughes flap
 - Complications can occur in the acute or chronic setting. Acute complications include the following:
 - Flap dehiscence
 - Skin/flap necrosis
 - Trichiasis or abnormal positioning of the eyelashes resulting in growth of the lashes into the eye resulting in irritation. Mild cases can be treated with topical medications until swelling resolves. More severe cases may require ablation of the eyelashes with laser or surgical removal.
 - Chronic complications include the following:
 - Entropion
 - Ectropion
 - Lagophthalmos
 - Upper lid retraction
- Cutler-Beard flap
 - Scarring and retraction of the lower lid
 - Upper eyelid entropion
 - Lid margin irregularity
 - Eyelash loss
 - Bridge flap necrosis
 - Lower eyelid margin necrosis

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23 Lower Eyelid Reconstruction With Palatal Grafts

CHAPTER

Farooq Shahzad, Babak J. Mehrara, and Aaron Fay

DEFINITION

- With proper case selection, lower eyelid reconstruction can be enhanced using hard palate grafts.
- Both horizontal deficiency and vertical retraction can be corrected using this technique.
- Palatal grafts are not suitable for upper lid reconstruction because the keratinized surface can abrade the underlying cornea.

ANATOMY

Eyelids

- For purposes of reconstruction, it is useful to consider the eyelids in three constituent layers, or lamellae: anterior, middle, and posterior (**FIG 1**). Below the lid crease in the region of tarsus, only anterior and posterior layers can be defined.
- The anterior lamella comprises skin and orbicularis oculi muscle. Eyelid skin is the thinnest in the body, entirely lacking subcutaneous fat. This makes skin matching difficult when placing full- or split-thickness skin grafts. Whenever possible, eyelid skin grafts are harvested from the contralateral or opposing eyelids.
 - The lashes arise in the anterior lid margin and project anteriorly and superiorly in the upper lid. In the lower lid, the lashes are less robust, projecting anteriorly and inferiorly. Lamellar disjunction can produce eyelash ptosis that interferes with vision.
 - Orbicularis oculi is a thin, circumferential striated muscle that can be

conceptualized in three regions: pretarsal, preseptal, and orbital. Pretarsal orbicularis extends all the way to the lid margin, where it can be visualized as the “gray line” separating anterior and posterior lamellae. This important landmark is known as the muscle of Riolan. Responsible for blinking, the preseptal orbicularis extends from the tarsal periphery (superior edge or inferior edge of tarsus in the upper or lower eyelids, respectively) approximately to the level of arcus marginalis around the orbital rim. When stimulated, this portion of orbicularis produces complete, intentional, mildly forceful closure with no radial rhytide formation, as used, for example, upon sleeping. Preseptal orbicularis stimulation is usually accompanied by a Bell phenomenon (upward rotation of the eyeball). The orbital portion of orbicularis oculi extends peripherally beyond the arcus marginalis and eventually interdigitates with frontalis and corrugator muscle superiorly. This portion of muscle produces tight, forceful eyelid closure accompanied by glabellar and lateral rhytide formation. Orbicularis oculi originates and inserts along the raphe near the medial and lateral canthi.

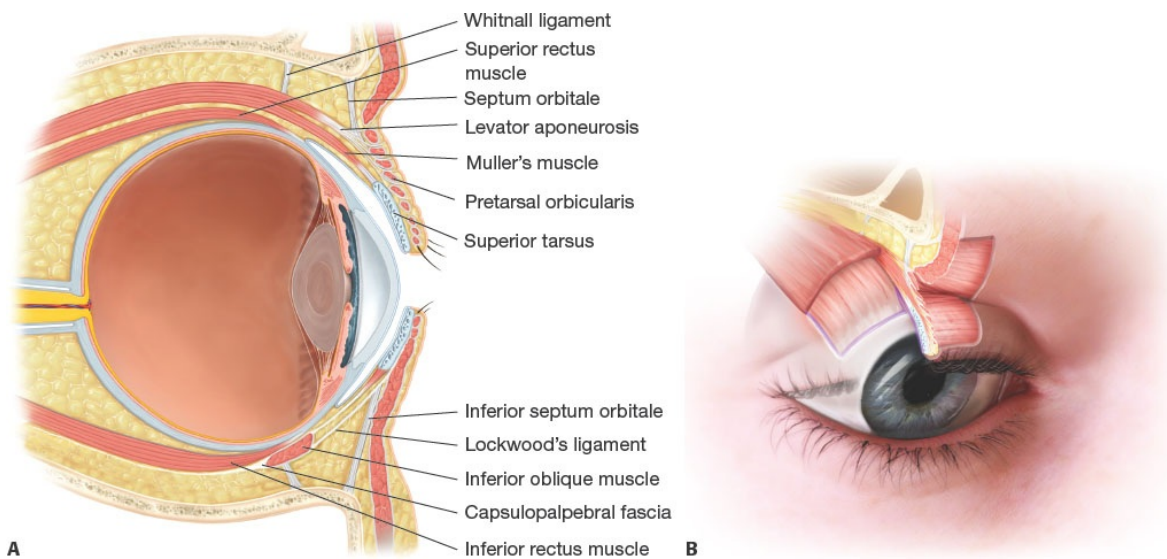


FIG 1 • A. Sagittal section through superior eyelid showing lamellar anatomy. Below the lid crease, the anterior and posterior lamellae are well defined. Anterior lamella consists of skin and muscle, while posterior lamella consists of tarsus and conjunctiva. Above the lid crease, three layers of lid are recognized: conjunctival and retractor muscles constitute the

posterior layer, orbital fat and septum constitute the “middle lamella,” and skin and muscle constitute the anterior lamella (extension of SMAS onto the eyelid). **B.** Anterior view of eyelids demonstrates the normal contour and resting position of the upper and lower lid margins. Note that the superior limbus and inferior limbus are concealed by the upper and lower lid margins, respectively.

- The middle lamella, distinguishable only superior to the primary upper lid crease (and inferior to the tarsus in the lower eyelid), consists of a fibrous orbital septum and orbital fat. The orbital septum originates at the arcus marginalis along the superior orbital rim and inserts onto the distal aponeurosis of levator palpebrae superioris. This plane defines the anterior limit of the orbit; the skin and orbicularis represent the terminal extension of the frontal SMAS, whereas retroseptal tissues (levator muscle, Muller muscle, and conjunctiva) originate deep within the orbit. These distinctly different planes fuse along the orbital septum, the “periosteum” of the eyelid.
- The posterior lamella consists of the conjunctiva, tarsus below the lid crease, and eyelid retractors above the lid crease. Levator palpebrae superioris (levator muscle) and Muller muscle (sympathetic eyelid muscle) form the upper eyelid retractors. In the lower lid, these muscles fuse more completely, the so-called capsulopalpebral fascia. All structures in the upper lid have analogues in the lower eyelid. Formed of collagen (not cartilage), the tarsal plates are the structural elements of the eyelid, lending rigidity, stability, and directionality especially to the lid margin regions. The center of the upper and lower lid tarsi are approximately 10 and 4 mm high, respectively. These structures taper laterally and medially where they fuse with medial and lateral canthal tendons. Because they taper quite significantly, direct closure of tarsal defects produces mismatched tarsal elements; the lid margin provides a template for reconstruction.
- The medial canthal tendon inserts on the medial orbit via two crura, along the anterior and posterior lacrimal crest. During reconstruction, it is important to reconstitute the posterior crus so that the lid hugs the ocular surface all the way to the caruncle. Without it, the lid can become distracted anteriorly, leaving a space between the lid margin and ocular surface. The lateral canthal tendon

inserts on the periorbita of the lateral orbital tubercle of Whitnall posterior to arcus marginalis. Here again, it is important to reattach the tendon posteriorly in order to draw the lid tightly against the globe all the way to the commissure, particularly in deep-set eyes and, less importantly, in relatively proptotic eyes.

- Upper eyelid contour forms a smooth, continuous arc with its apogee typically at the medial pupil. The upper eyelid margin typically conceals 2 mm of superior cornea, whereas the lower lid sits at or just above the inferior corneal limbus. These measures should be evaluated with the patient's head in neutral position, as chin-up or chin-down positioning will dramatically alter the lower lid position. Simultaneous unveiling of the superior and inferior limbus produces a "Walt Disney eye," characteristic of thyroid eye disease. An imaginary line segment connecting the medial and lateral canthi is slightly canted upward and outward in most patients, the positive canthal tilt. During reconstruction, the lateral canthus should be placed approximately 2 mm superior to a horizontal line drawn through the two medial canthi.
- The blood supply to the eyelid forms anastomoses between internal and external carotid artery circulations through the marginal and peripheral vascular eyelid arcades extending across the eyelids. The external carotid circulation progresses medially through the facial artery and then the angular artery and laterally through branches of the superficial temporal artery. Supraorbital, supratrochlear, and infraorbital branches from the ophthalmic artery form the internal carotid contribution.

Hard Palate

- The hard palate separates the oral and nasal cavities. The anterior three-fourths is formed from the horizontal process of the maxilla, whereas the posterior portion consists of horizontal portion of the palatine bone. The anterior and lateral periphery of the palate is known as the alveolar arch. Posteriorly, the hard palate is continuous with the soft palate.
- The mucosa of the hard palate is tightly bound to the periosteum by a surprisingly thick fibrous submucosa. The midline mucosal ridge is called the palatine raphe (**FIG 2**).
- The blood supply of the hard palate is via the greater palatine artery that exits the greater palatine foramen medial to the 3rd molar. This vessel travels anteromedially and enters the incisive foramen in the anterior palate. The greater palatine nerve travels with the artery.

PATIENT HISTORY AND PHYSICAL FINDINGS

■ History

- Historical visual acuity is obtained to help determine visual potential in the eye. History of dry eye or other ocular pathologies should be obtained, with ophthalmic consultation as indicated.
- The etiology of the defect and the need for any further treatments (eg, radiation, foreign bodies, residual or recurrent malignancy, thyroid disease, anticipated intraocular surgery) are noted.
- A history of previous eyelid surgeries or radiation may affect the type of reconstruction.

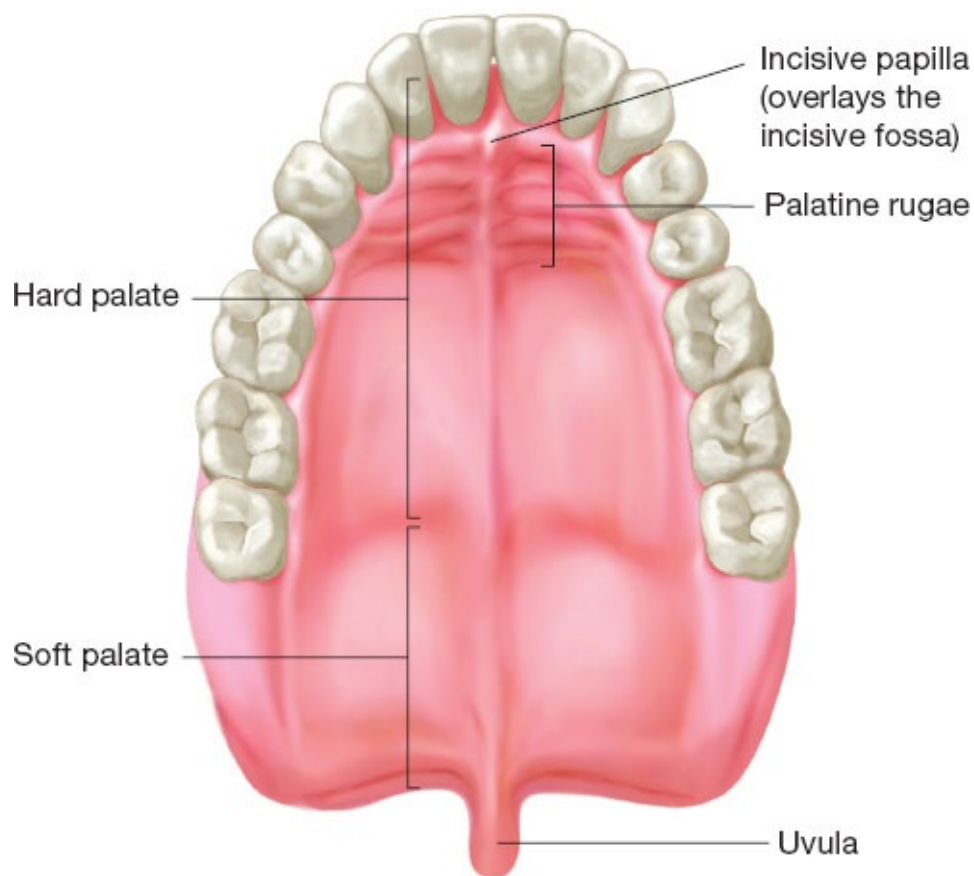


FIG 2 • Palatal anatomy.

- A history of previous palatal surgery is obtained. History of cleft palate is a relative contraindication.
- Physical examination
 - Ophthalmic examination should include visual acuity, extraocular muscle

function, presence or absence of Bell phenomenon, and eyelid function.

- A defect analysis is performed, looking at the following elements: anterior and posterior lamella, medial and lateral canthal tendons, and the lacrimal apparatus. Lacrimal involvement in the defect should prompt further evaluation with likely simultaneous lacrimal reconstruction.
- The eyelid and periorbital tissues are assessed for suitability for use in reconstruction. Pre-existing surgical scars and tissue laxity is noted.
- The palate is examined to ensure its adequacy as a donor site.

SURGICAL MANAGEMENT

- Hard palate grafts are useful primarily for reconstructing defects in the posterior lamella of the lower eyelid. Because the graft contains thick fibrous tissue as well as mucous membrane, it can be used to replace tarsus as well as conjunctiva. Only tarsoconjunctival grafts and flaps can provide this benefit, but they are in rare supply and often not available. However, because hard palate mucosa is keratinized, it can damage the cornea in the early phase before metaplasia to a nonkeratinized mucosa can take place.
- Because it is a free graft, the hard palate segment must be conjoined with an advancement or rotational myocutaneous flap or a temporary or permanent pedicle of muscle or fascia (eg, Mustarde).
- The hard palate graft can insert into a full-thickness defect to replace the horizontal length of the tarsus or in vertical continuity with the tarsus to correct eyelid retraction (more common).

Preoperative Planning

- Grafts require a healthy bed of vascularized tissue to survive. For isolated posterior lamellar defects, the graft can be placed on the intact anterior lamellar orbicularis muscle.
- If the eyelid defect is full thickness, anterior lamellar reconstruction needs to be performed with a vascularized flap.
 - Commonly used local flaps for upper eyelid anterior lamellar reconstruction include local orbicularis transposition or rotation, Tenzel semicircular, Fricke temporal transposition, glabellar transposition, and forehead flaps.
 - Commonly used local flaps for lower eyelid anterior lamellar reconstruction are local orbicularis advancement or rotation flaps, Tenzel semicircular flap, upper eyelid myocutaneous transposition flap (unipedicled [Fricke] or bipedicled [Tripiet]), nasolabial transposition flap, Imre rotation flap, and

Mustarde cheek rotation flap.

- A sandwich technique can also be used where the orbicularis muscle is used as a bed for anterior and posterior lamellar grafts. The orbicularis has a robust blood supply and can be mobilized into the defect. A skin graft is placed on its anterior surface and a posterior lamellar graft on its bulbar surface.

Positioning

- The operation is performed in the supine position.
- A shoulder roll extends the neck and facilitates visualization of the hard palate.
- Exposure of the palate is obtained with a Dingman mouth gag. Alternatively, a side-biting mouth gag and tongue retractor can be used.
- A lubricated corneal shield is used to protect the eye during surgery.
- The instruments for eyelid surgery and palatal graft harvest should be kept separately to minimize contamination of the eyelid wound with oral secretions.
- Gloves should also be changed when going from the mouth to the eyes to minimize infection.

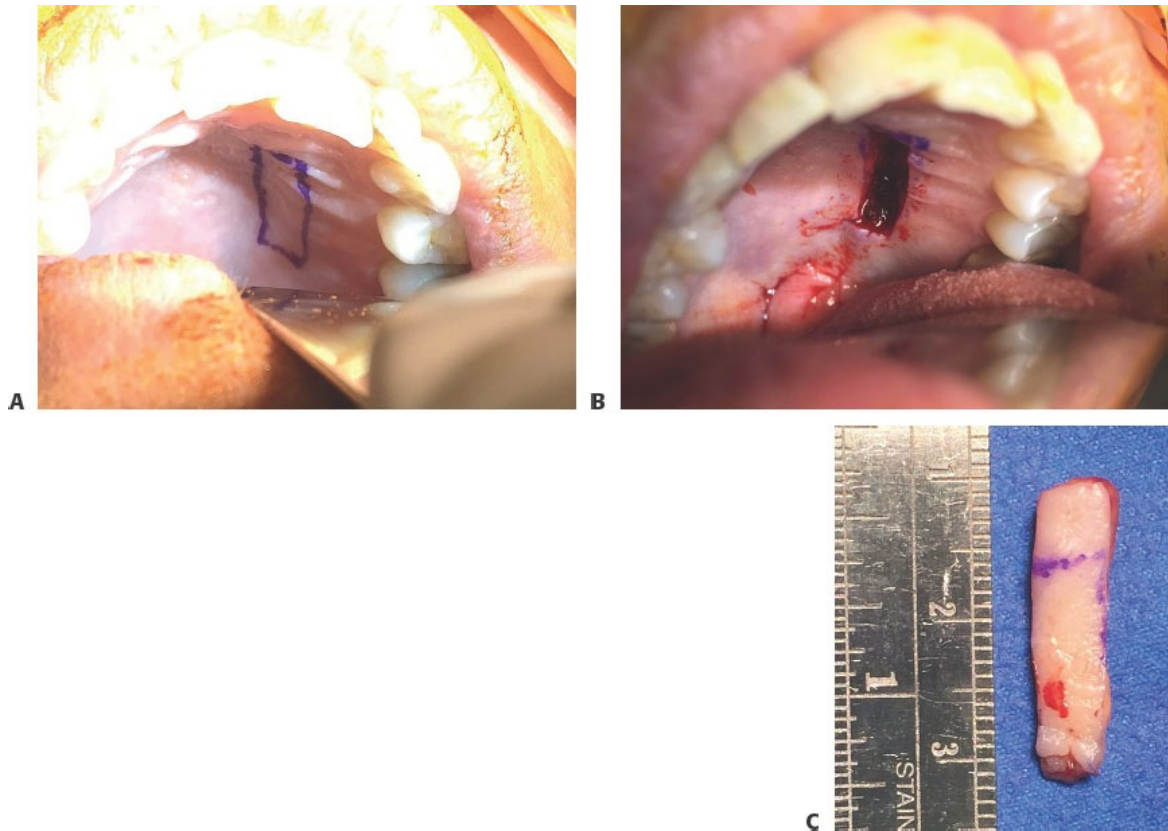
TECHNIQUES

■ Harvest of Hard Palate Graft

- The dimensions of the posterior lamellar defect requiring the palatal graft are noted.
 - A template of the defect made with a piece of rubber glove or sterile packaging can be very helpful.
- Markings are performed with methylene blue. Surface landmarks are marked to help with orientation.
 - The posterior edge of the hard palate and the palatal midline are marked.
 - The greater palatine vessel is palpated medial to the 3rd molar. Its location is marked with a dot.
- The graft can be harvested between the midline, the posterior edge of the hard palate, and the marginal gingiva. The greater palatine vessel is to be avoided.
 - The palatal mucosal thickness increases with increased distance from the marginal gingiva.¹ Staying at least 3 to 4 mm anterior to the posterior edge

of the hard palate and toward the midline will prevent inadvertent injury to the soft palate and the greater palatine neurovascular bundle (**TECH FIG 1A**).

- The template is positioned on the palate at the optimal location for harvesting.
- The graft is marked a few millimeters larger than the defect to account for the minor graft contraction that occurs during the first few postoperative months.²
- Local anesthetic consisting of bupivacaine with epinephrine is infiltrated into the mucosa.
 - The needle should not be pushed in up to the palatal bone as this will hydrodissect the periosteum off the bone.
- The hard palate incisions are made with a no. 15 blade.
 - Care is taken not to inadvertently push the knife against the palatal bone and thus incise the periosteum.
- The graft is then elevated in the submucosal plane using an angled beaver blade, Freer periosteal elevator (in the submucosal plane), and curved Stevens scissors (**TECH FIG 1B**).



TECH FIG 1 • Palatal graft harvest. **A.** The palate is marked close to the midline raphe in order to avoid the palatal artery and nerves. **B.** Harvest site can be dressed with processed cellulose fabric to help maintain hemostasis. **C.** Harvested graft can be trimmed to appropriate thickness to match recipient site tarsus and conjunctiva.

- The hard palate graft is stored on the back table in an antibiotic solution (**TECH FIG 1C**).
- Hemostasis is ensured with a bipolar electrocautery.
- If the greater palatine vessel is inadvertently injured, it may need to be tied off.
- Surgicel can be sutured onto the raw palatal surface. It controls the minor oozing from the wound and also covers the surface to decrease postoperative pain from irritation of the wound.

■ Inset of Hard Palate Graft for Posterior Lamellar Reconstruction

- The graft is inspected. If it is too thick, it is trimmed to appropriate thickness.
 - Any visible mucous glands on the posterior surface of the graft are excised.
- The graft is inset with its mucosal surface directed posteriorly.
- It is sutured to the margins of the posterior lamellar defect (ie, laterally to the remaining medial and lateral tarsal plates and inferiorly or superiorly to the tarsal remnant or the conjunctiva using 7-0 polyglactin sutures; **TECH FIG 2**).
- Suture knots are placed on the deep side of graft away from the ocular surface.
- Lateral canthal anchoring is performed if there is any pull on the eyelids or for lax eyelids.
 - Failure to do so in high-risk patients will result in postoperative ectropion.
- A bandage contact lens can be placed for corneal protection. This is especially useful in reconstruction of upper lid posterior lamella.
- A traction suture can be used to suspend the lower eyelid in cases of reconstruction of large posterior lamellar defects or when the graft is used as a spacer for reconstruction of severe lower lid retraction.
 - The suture is removed after 1 week.



TECH FIG 2 • Hard palate graft in recipient bed, in this case, used to augment lower tarsus for correction of lid retraction.

PEARLS AND PITFALLS

Graft harvest

- The posterior extent of graft harvest should be 3–4 mm anterior to the posterior edge of the hard palate and toward the midline. This is to prevent inadvertent harvest of soft palate mucosa, which can result in a palatal fistula or injury to the greater palatine vessels.
- A template of the defect aids in marking the graft at an optimal location on the palate. It should be marked a few millimeters larger to account for the minor graft contraction that occurs during the first few months postoperatively.

Corneal protection

- The cornea is protected during the procedure with a corneal shield. Postoperative corneal epitheliopathy can be prevented with a dressing contact lens, particularly in upper eyelid reconstruction.

Hemostasis

- At the end of the procedure, hemostasis must be obtained. The palatal donor site can also be covered by Surgicel cellulose fabric, which can decrease bleeding and sensitivity of the open wound.

Lateral canthal anchoring

- There should be a low threshold for lateral canthal anchoring in eyelid reconstruction. Eyelid laxity is usually managed by correctly sizing the interpositional graft but should be addressed at the time of reconstruction.

POSTOPERATIVE CARE

- Oral antibiotics can be used for 24 to 72 hours as needed.
- Oral hygiene is emphasized. Chlorhexidine gluconate 0.12% squish and spit after meals and at bedtime is used for 7 to 10 days.
- Topical lidocaine jelly can be used for pain control.
- In patients with severe postoperative discomfort, an obturator can be placed over the donor site to cover the open wound from irritation while it is healing.

COMPLICATIONS

- The hard palate donor site reconstitutes the mucosa over several weeks. The

time to heal increases with the size of the wound.

- Delayed healing can occur, usually due to infection.
- Bleeding is the most frequent complication of hard palate graft harvest, reported in up to 10% of patients.³
 - If local pressure does not control bleeding, electrocautery or suture ligation is required.
- Additional complications include keratin debris at the recipient site in the early postoperative period⁴, eyelid or palatal infection, palatal fistula, partial graft dehiscence, and graft failure.
- Late complications include lower lid retraction, ectropion, entropion, and corneal injury.

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24 Lateral Tarsal Strip Canthoplasty

CHAPTER

Richard H. Caesar

DEFINITION

- Any lower eyelid laxity or frank ectropion of the lower eyelid that results in a failure of the lower eyelid to sit smoothly against the globe can lead to symptoms of epiphora, discomfort, and poor appearance.
- Lower eyelid tightening is a crucial component of the treatment of lower eyelid ectropion of any cause.
- Any entropion of the lower eyelid (inversion of the lower eyelid) will usually have lower eyelid laxity as a component of the etiology. Lateral tarsal strip can be used to address this laxity with additional steps to reattach the lower eyelid retractors.
- Lateral tarsal strip canthoplasty is a powerful technique for lower eyelid tightening.¹

ANATOMY

- The lateral canthal tendon attaches the lateral ends of the tarsi to Whitnall tubercle, 2 mm posterior to the lateral orbital rim formed by the zygomatic bone.
- It is the origin of the palpebral and pretarsal orbicularis muscle fibers that pass to the medial canthal tendon.

PATHOGENESIS

- Common causes of acquired ectropion include age-related laxity and cicatricial changes resulting from iatrogenic causes, trauma, or burns.
- A paralytic ectropion results from a loss of innervation to the orbicularis muscle and facial elevators.

- Mechanical ectropions are rare and result from external forces such as eyelid tumors.

NATURAL HISTORY

- Acquired ectropion in most cases can only be corrected with surgery.
- Notable exceptions are temporary paralytic ectropion that can have full spontaneous recovery and mild cicatricial ectropion secondary to dry skin or dermatitis. Intensive treatment with emollients, anti-inflammatory agents, and massage can, on occasion, fully resolve the ectropion.
- Acquired entropion (lower eyelid inversion with abrading of the conjunctiva/cornea by the eyelashes) always requires surgery for a permanent solution.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Notable patient history and physical findings that should be assessed include appearance, epiphora, and pain/discomfort.
- Lower eyelid laxity with marginal eversion and conjunctival exposure should be assessed.
- Also assess secondary inflammation and thickening of the eyelid margin.
- Exclude tethering or cicatricial changes of the skin, lower eyelid retractors, or conjunctiva. Exclude mechanical cause and paralytic cause.

IMAGING

- Imaging is not usually required, but orbital MRI may be useful to identify the cause of unusual cicatricial changes to the lower eyelid retractors.

NONOPERATIVE MANAGEMENT

- Surgery may be avoided with a resolving paralytic ectropion and a treatable mild cicatricial ectropion.
- If the patient does not want surgery or is unable to have surgery, the eye can be kept comfortable by means of intensive ocular lubricants day and night. We recommend preservative-free hyaluronic acid-based lubricants during the day and white soft paraffin at night.
- Involutional entropion can be treated with injection of botulinum toxin to the lower orbicularis.²

SURGICAL MANAGEMENT

- Lower eyelid laxity and frank entropion and ectropion repair requires lower

eyelid tightening. This can be achieved by many different techniques to include wedge resection, skin-sparing wedge resection, lateral canthopexy and lateral tarsal strip.

- Concurrent lower eyelid blepharoplasty, skin grafting, heteropalpebral flap, medial retractor repair, central retractor repair, and surgery to the medial canthal tendon may also be required.
- The lateral tarsal strip remains one of the most powerful techniques to tighten the lower eyelid.

Preoperative Planning

- The surgeon should define the position of the incision, the degree of eyelid shortening required, and the angle of placement of the deep suture to the orbital rim.
- Concurrent additional procedures should be determined.
- The vast majority of patients are comfortable with local anesthesia alone, but sedation and general anesthesia should be available when required.

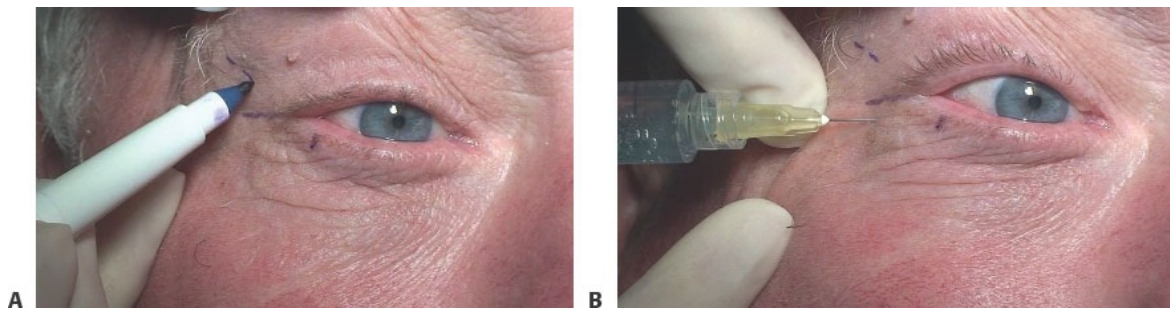
Positioning

- The patient is most comfortable lying reasonably flat with a cushion under the head and knees.
 - The surgery can be done with the patient sitting if required.
- The surgeon sits to the side of the patient.

TECHNIQUES

■ Markings and Anesthesia

- Mark the incision from the lateral canthal angle to extend 10 to 12 mm laterally and inferiorly following the most obvious rhytide (**TECH FIG 1A**).
- Mark the extent of the tarsal strip required.
- Mark the angle of fixation to the posterior orbital rim by following the curve of the lower eyelid.
- Instill local anesthetic drops (oxybuprocaine or tetracaine) to the conjunctival fornix.
- Injecting local anesthetic (**TECH FIG 1B**), 2 mL of 2% lidocaine with 1:200 000 epinephrine, superior and inferior to the lateral canthus, is effective and avoids the marginal arcades.
- Clean with povidone-iodine and drape the surgical field.



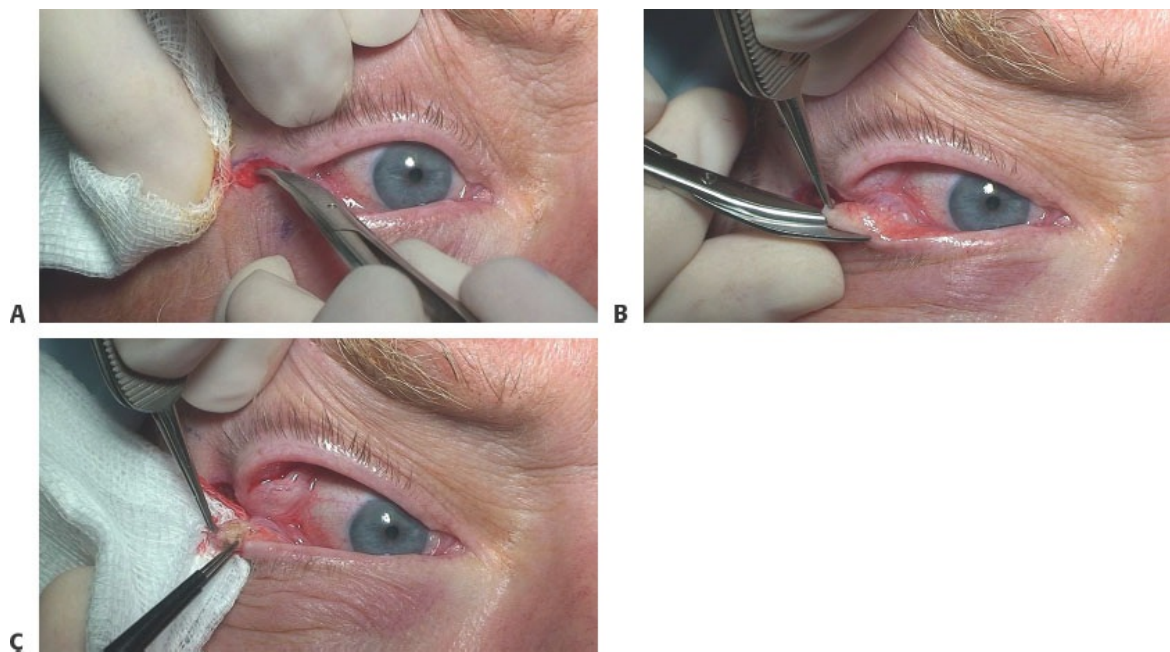
TECH FIG 1 • **A.** Mark the skin with the incision, the extent of the tarsal strip, and the position to suture to the rim. **B.** Inject local anesthetic at the lateral canthus superior and inferior to the marginal arcades.

■ Removing the Tarsal Strip

- With a no. 15 blade, make a primary skin incision, and then perform a lateral canthotomy and dissect to the orbital rim with blunt-tipped Westcott scissors (**TECH FIG 2A**).
- Expose the orbital rim with blunt dissection.
- Grasp the exposed lateral edge of the tarsal plate with toothed forceps and use the scissors to make a pocket anterior to the tarsal plate, between the

tarsus and the orbicularis.

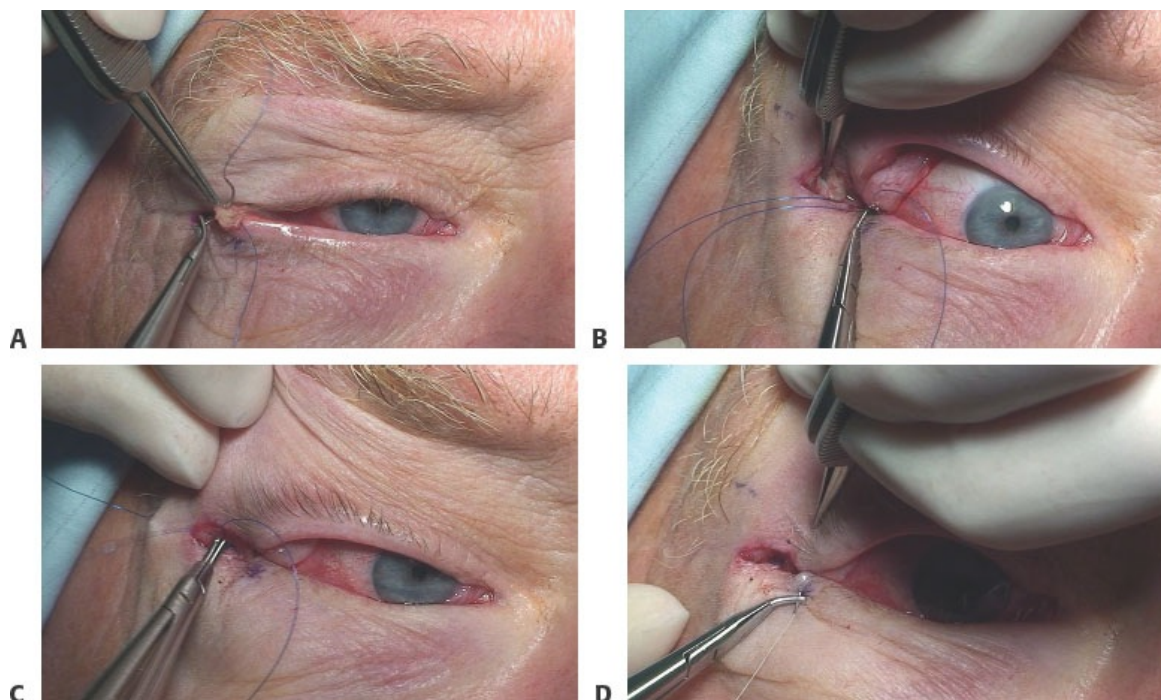
- Cut along the inferior border of the tarsal plate to release the conjunctiva and septum.
- Release the anterior lamella along the gray line to the preplaced mark of the extent of the strip.
- Remove the superior eyelid margin in a thin strip with the scissors (**TECH FIG 2B**).
- Excise any redundant anterior lamella as a small triangle.
- Remove the conjunctiva over the inner, posterior aspect of the tarsal plate with bipolar cautery (**TECH FIG 2C**). Compress the tarsus to release the meibomian contents.
- Trim off the most lateral portion of the tarsus to reveal the fully stripped lateral tarsus.



TECH FIG 2 • **A.** Incise the skin and use blunt-tipped Westcott scissors to perform a canthotomy to the orbital rim. **B.** Use the scissors to create the tarsal strip. **C.** Use cautery to remove the conjunctiva from the inner aspect of the tarsal strip.

■ Placing the Tarsal Strip

- Use a double-armed 5-0 Prolene suture or double-armed 5-0 Vicryl or equivalent (**TECH FIG 3A**).³
- First, pass the suture through the tarsus from superior to inferior, perpendicular to the eyelid margin.
- Then, pass one arm of the suture from posterior to anterior at the inferior border of the tarsal strip. Pass the second arm from posterior to anterior at the superior border of the strip.
 - The suture passed from posterior to anterior will place the strip in the best anatomical position on the inner aspect of the orbital rim once tied.
- Pass the superior suture through the periosteum at the orbital rim. This is most easily achieved by placing the suture on the rim, passing it backward until the tip trips inside the rim, and then passing forward to catch the periosteum on the inner aspect of the orbital rim.
- Check the eyelid and canthal position. Adjust the vertical position of the suture to the orbital rim if incorrect.
- Place the second inferior suture 2 mm lower on the orbital rim (**TECH FIG 3B**).
- If using 5-0 Prolene, tie five knots with the needles still attached. Then, bury the end of the suture by passing the needle posteriorly and laterally from the knot to exit (**TECH FIG 3C**). Trim at exit.
- If using 5-0 Vicryl, tie and cut as normal.
- Close the orbicularis with a deep 6-0 Vicryl suture if required.
- Close the lateral canthus and skin with two or three interrupted 6-0 Vicryl sutures (**TECH FIG 3D**).



TECH FIG 3 • **A.** Pass a double-armed suture posteriorly to anteriorly through the tarsal strip. **B.** Anchor the suture to the inner aspect of the orbital rim. **C.** Bury the ends of the suture. **D.** Close the angle and skin with interrupted sutures.

PEARLS AND PITFALLS

Granuloma formation	■ Discharge the contents of the meibomian glands within the tarsal strip.
Bruising	■ Avoid the marginal arcades when injecting local anesthesia and maintaining meticulous hemostasis.
Irritation from deep suture	■ Knot with needles attached and use the needle to pass the end of the suture flat and posteriorly.
Asymmetry	■ Careful preop marking and intraoperative adjustment of suture placement to the orbital rim.
Pulling the lower lid inferiorly on the globe	■ Beware negative vector patients with prominent eyes.

POSTOPERATIVE CARE

- Topical antibiotic ointment is applied daily to the eye and the sutures until sutures are removed or dissolve.
- Ice packs are used for the first 24 to 48 hours to reduce inflammation.

OUTCOMES

- Tarsal strip canthoplasty results in high patient satisfaction with effective outcomes in 87% to 96% of patients.^{4,5}

COMPLICATIONS

- Infection
- Chemosis
- Bruising
- Visible scar
- Asymmetry
- Suture granuloma
- Prolonged tenderness over deep suture

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Section VIII: Cheek

25 Cheek Reconstruction With Laterally or Medially Based Cervicofacial Flap

CHAPTER

Sammy Sinno and Barry M. Zide

DEFINITION

- Local tissue from the cheek and upper neck provide the best tissue for cheek reconstruction; several techniques have been described including submental and sternocleidomastoid flaps.^{1,2}
- Laterally, or posteriorly, based cervicofacial flaps are most useful for small to moderate full-thickness skin and subcutaneous defects of the anterior and inferior cheek. These flaps take advantage of the loose neck skin to provide a large amount of coverage with local/regional tissue borrowed from the lateral face, neck, and even chest. Laterally based flaps avoid incisions below the eyelid; however, crossing the anterior mandibular border may require a Z-plasty (**FIG 1**).
- Medially, or anteriorly, based cervicofacial flaps are also useful for moderate sized full-thickness skin and subcutaneous defects of the anterior and upper cheek. These flaps also take advantage of the loose preauricular and neck skin and avoid incisions on the mandible.



FIG 1 • Lateral-based and medial-based cheek flaps.

ANATOMY

- The cheek is a laminated structure consisting of skin, subcutaneous tissue, and the superficial musculoaponeurotic system (SMAS). These structures overlie the facial nerve, parotid gland, buccal fat pad, and mandible.
- The arterial supply to the cheek is provided by the facial, superficial temporal, and transverse facial arteries originating from the external carotid artery. Venous drainage may parallel the arterial system though variations are common (**FIG 2**).
- Techniques of deep-plane elevation or tissue expansion can be used to improve the blood supply and reliability of the flap.²⁻⁵
- The cheek can be subdivided into overlapping zones to categorize lesions and organize the reconstructive strategy (**FIG 3**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The cheeks are often exposed to trauma and sun damage leading to a frequent requirement for reconstruction.

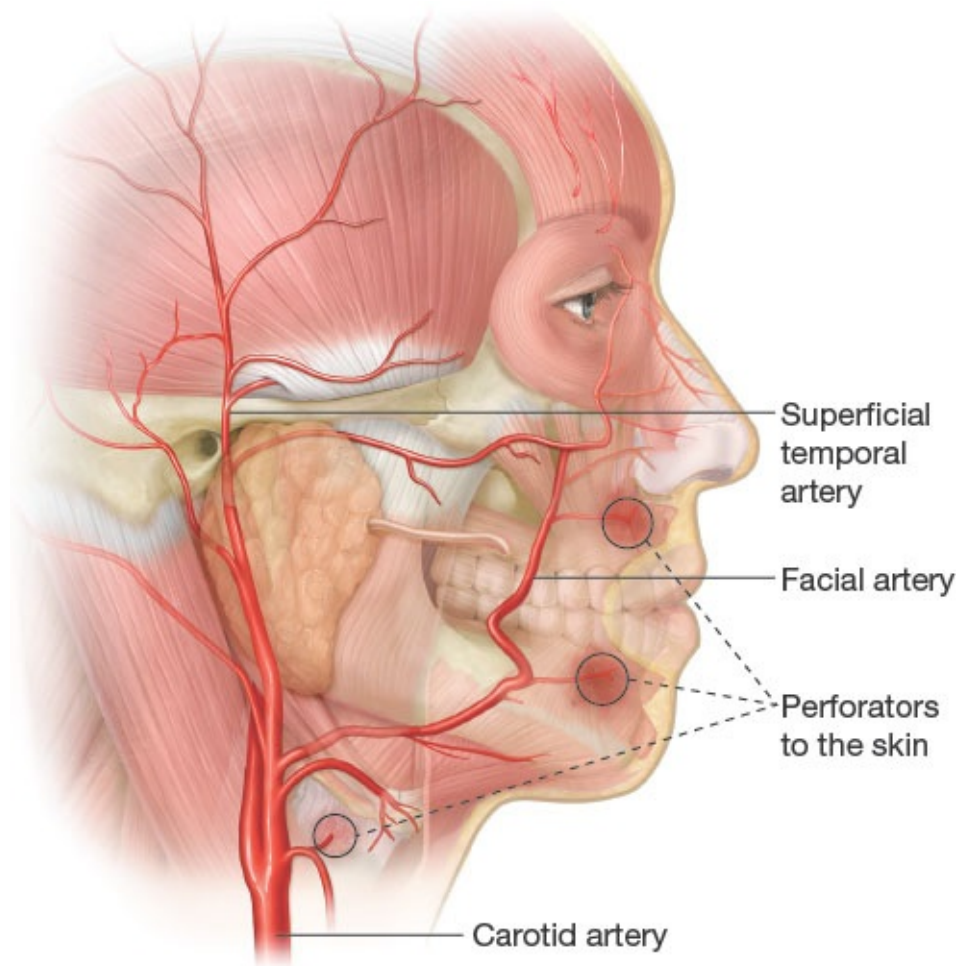


FIG 2 • Arterial blood supply of the cheek.

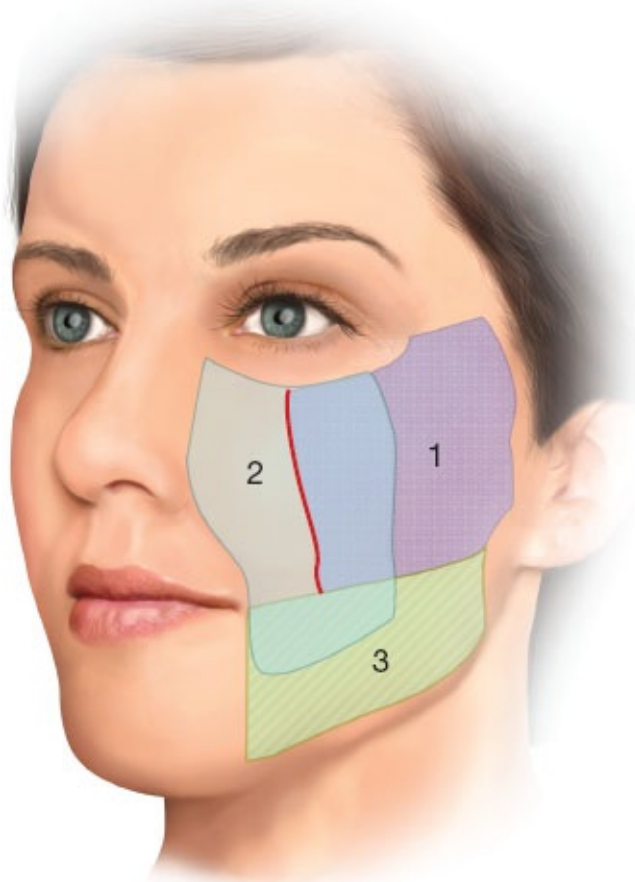


FIG 3 • The three reconstructive zones of the cheek. Red border between zones 1 and 2 marks a vertical line dropped from the midpupil. Zone 1, lateral cheek; zone 2, central cheek; zone 3, inferomedial cheek. Laterally (posteriorly) based cheek flaps work best for zone 3 defects. Medially (anteriorly) based flaps are best for zone 1 and 2 defects.

- The defect size, depth, and location must be evaluated in addition to the surrounding skin quality, tone, and texture.
- Hairlines should also be noted, particularly sideburns in women, as this will affect flap design due to the need to avoid hair transposition onto the cheek.
- Patients should be encouraged to stop smoking as this increases the risk of distal flap necrosis.
- For skin cancer defects, consider delaying the reconstruction until the

resection margins are proven clear by histological analysis.

- The effect of radiation therapy must also be taken into account when applicable.
- Ensure that the blood supply to the face is intact by evaluating neck and facial scars.
- Specifically evaluate the area where the facial and superficial temporal arteries are located. Pay particular attention to prior sentinel lymph node biopsy scars in the face and cheek.

IMAGING

- No imaging is required other than that indicated by a preoperative clearance workup.

SURGICAL MANAGEMENT

Preoperative Planning

- Smaller cervicofacial flaps may be performed under local anesthesia or deeper anesthetic techniques.
- Assess the mobility and laxity of the skin surrounding the defect and determine which facial structures may be distorted by flap movement.
- Scars should be positioned at the border of aesthetic units (nasal-facial junction, nasolabial fold, infraorbital rim) or along the hairline when possible, which may require sacrifice of additional tissue.
- If it is not possible to place the scar at the border of aesthetic units, scars should be aligned parallel to relaxed skin tension lines (these are curvilinear on the cheek).

Positioning

- Patient is positioned supine on the operative table with the head turned to the contralateral side from the defect.
- The ipsilateral face, neck, and chest are prepped into the field. Alternatively, the entire face may be prepped into the field to assess symmetry intraoperatively.

Approach

- Depending on the size and location of the defect, decisions must be made regarding plane of flap elevation (subcutaneous or sub-SMAS), extent of

posterior incision (preauricular, postauricular, chest), and need for preoperative tissue expansion.

- If the surgeon decides to go sub-SMAS, it is critical to spread obliquely so the nerves stay on the downside.
- The senior author rarely performs sub-SMAS dissection for posteriorly based flaps.
- Incisions should follow the nasolabial fold and can continue to the submental crease.
- Larger defects may require an incision that extends posteriorly toward the sternocleidomastoid muscle.
- Patients (especially nonsmokers) with smaller defects and significant skin laxity that allows for defect closure under minimal tension are good candidates for cervicofacial flaps elevated in the subcutaneous plane.
- Large defects, poor skin laxity/quality, and a positive smoking history are additional indications for tissue expansion or deep-plane elevation of the cervicofacial flap to minimize the risk of distal flap necrosis.
- Deeper defects may also benefit from deep-plane elevation (including the platysma muscle in the neck) as the greater flap tissue bulk prevents contour depression over the defect that may be seen with only skin and subcutaneous tissue coverage.

TECHNIQUES

■ Laterally Based Cervicofacial Flap

- The defect is outlined, and flap is drawn to place scars along the borders of aesthetic subunits (**TECH FIG 1A**).
- After completion of the flap design, dilute 0.5% lidocaine with 1:200 000 epinephrine is infiltrated in the subcutaneous plane.
- Using sharp and blunt dissection, the entire flap is elevated in a subcutaneous plane (**TECH FIG 1B**).
- Support of the flap may be required, and anchors, periosteal sutures, and sutures around the medial canthal tendon can aid greatly.
- After obtaining hemostasis, the flap inset begins anteriorly with buried deep dermal 5-0 PDS suture and rotating the flap superiorly and anteriorly.

- Working anteriorly, each advancement point is secured with buried deep dermal 5-0 PDS suture.
- Excision of any dog ear at this point is crucial. When the scar crosses the mandibular border, a Z-plasty or W-plasty is often required below the mandible.
- Scar placement should rest without excess tensions along the nasolabial fold.
- A drain is placed.
- The skin incision is closed with running and interrupted 6-0 Prolene sutures.



TECH FIG 1 • A. The defect is outlined, and the flap is marked. Note the incision along the nasolabial fold with, in this case, a posterior back cut. The inferior incision should be “cut as you go.” **B.** Flap elevation in the subcutaneous plane. Note that a deep plane can be used if there are concerns for flap ischemia.

■ Medially Based Cervicofacial Flap

Creating the Flap

- Similar to the laterally based flaps, the cheek defect is outlined and drawn to place scars along the borders of aesthetic subunits (**TECH FIG 2A**).
- The flap markings begin at the superior and lateral edge of the defect and, if possible, can be placed at the junction between the cheek and eyelid. In some

cases (**TECH FIG 2B**), the excision includes the lower eyelid skin in which case the flap incision is placed within the lower eyelid itself.

- It should be remembered, however, that the closer the incision is to the lid margin, the higher the risk of ectropion.
- The marking of the lateral portion of the apex of the flap is placed approximately 1 cm superior to the lateral canthus. This helps to suspend the cheek flap above the lateral canthus, thus decreasing the risk of ectropion.
- The flap edges are infiltrated with a dilute solution lidocaine with epinephrine as outlined above.
- Skin incisions are performed and the skin flap is elevated in the subcutaneous plane.
 - Care must be taken to avoid raising excessively thin flaps as this increases the risk of flap necrosis.
 - Similarly, care must be taken to avoid injury to the facial nerve with excessively deep dissections.
- The flap may be elevated using a no. 10 blade or with a fine-tipped electrocautery (eg, Colorado needle) at a low setting (15).
 - The dissection continues medially until the defect is reached.
 - The medial and inferior borders of the defect are similarly elevated in the subcutaneous plane.
- Flap dissection is then continued inferiorly down to the neck, taking care to avoid injury to the great auricular nerve over the sternocleidomastoid muscle (**TECH FIG 2C**).
- The extent of the dissection depends on the patient's skin laxity and the amount of excess skin in the neck. This can be judged by periodically gently pulling the skin flap over and analyzing the tension on the flap.
- Meticulous hemostasis is achieved with bipolar electrocautery.

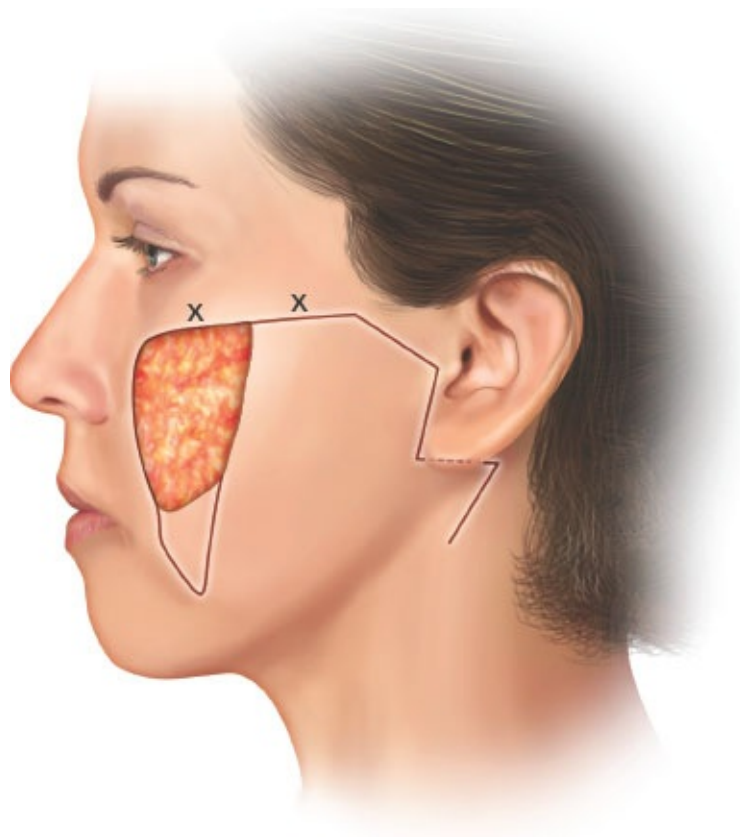
Insetting the Flap

- Once adequate dissection has been performed, a back cut on the flap is performed to decrease tension on it.



TECH FIG 2 • A. Melanoma in situ with 0.2-mm deep lesion in center. The wound is dressed after getting clear margins on step sections. The flap is elevated in the sub-SMAS plane with oblique spreading of scissors to avoid nerve injury. The flap design: the incision goes straight back or up slightly the distance of the width of the lesion removed. It then moves to the mid tragus and downward to the lobule. The incision goes straight back about 3.5 cm and an angle opened 60 to 70 degrees is marked in **B**. The incisions are well hidden and the sub-SMAS dissection guarantees reliability not found in the Mustarde-type flap. **C.** Final result.

- The patient's face/neck is then placed in the extreme lateral position to maximize the length of flap that is necessary to close the wound with no tension. Temporary sutures are placed in the superolateral portion of the defect (ie, the area that is at greatest tension) to the flap minimizing tension on the flap as much as possible.
- The remainder of the flap is inset with temporary sutures again aiming to minimize tension on the flap.
 - Particular attention should be placed in the preauricular area as closure of the flap defect at this area can result in excessive tension on the flap. If this is the case, a small triangular area in front the ear can be left open and skin grafted with a full-thickness graft harvested from the excess portions of the flap.
- The inferomedial portion of the flap usually has a small dog-ear from the flap rotation.
 - Excision of this dog-ear is marked in such a way to avoid narrowing of the flap base (**TECH FIG 3**).
 - In some cases, a secondary revision may be necessary.



TECH FIG 3 • Dog-ear excision in the inferomedial portion of the flap. Note angulation of the dog-ear to avoid narrowing of the flap base (*arrow*).

PEARLS AND PITFALLS

Incision placement

- Incisions should be placed along borders of facial aesthetic units whenever possible. This may require excision of additional tissue surrounding the defect.
- Avoid vertical incisions in the central cheek anterior to a line dropped down from the lateral canthus (Z-line).
- Dog-ears do not settle down no matter how long you look at them. The flap should be completely flat at the time of surgery. If flap viability may be jeopardized, tell the patient about the potential residual dog-ear before the first stage.
- Excise dog-ears in a manner that does not narrow the flap base.

Flap choice

- Laterally based cervicofacial skin flaps survive better than medially based flaps because the transverse branches of the facial and superficial temporal arteries are preserved.

Skin cancer

- Consider delaying the reconstruction until the margins of resection are proven clear by histological analysis.

Flap suspension

- Larger defects require longer incisions with wider elevation and undermining. Larger flaps frequently have tension at the cheek closure that may compromise blood supply and are vulnerable to flap ptosis.
- Suspend to the medial canthal tendon if required.
- Leave dog-ears if necessary.

Flap readvancement

- Similar to other rotational flaps, these may be readvanced for serial excisions, positive margins, or partial flap loss.

POSTOPERATIVE CARE

- Patients should rest with their head elevated for the first few days postoperatively.
- Skin sutures should be removed 5 to 10 days postoperatively.

- Large flaps with wide undermining extending onto the inferior neck may require placement of a closed suction drain.
- Postoperative antibiotic coverage is not necessary.

OUTCOMES

- Laterally and medially based cervicofacial flaps provide excellent color and texture match with the ability to camouflage scars in the cheek borders.
 - Proper patient selection, appropriate flap design, gentle tissue handling, and hemostasis minimize complication rates (**FIGS 4 and 5**).
- Two major drawbacks to cervicofacial flaps include unpredictable distal tip perfusion and anterior skin excess requiring excision as a vertical dog-ear.
 - Incidence of distal tip necrosis has been reported in 14.5% of cases; this is reduced with sub-SMAS elevation.⁶

COMPLICATIONS

- As noted, distal tip necrosis is a problem. However, the incidence of this complication can be minimized by avoiding tension on the flap, elevation of the flap in a thick subcutaneous or, in some cases, submuscular plane, and meticulous attention to hemostasis.
- Contour deformities, dog-ears, and scarring can occur particularly in large, deep defects. These may require revision surgery such as scar revision, dog-ear excision, or resurfacing.
- Hematomas occur commonly after facelifts and cheek flaps due to the excellent blood supply of the face. Meticulous hemostasis is therefore necessary.
 - In addition, if general anesthesia is used, it is important to have a calm emergence and avoidance of hypertension during extubation.
- Infection is rare but can occur and should be treated aggressively.
- Facial nerve injury is also rare but can occur in thin patients or in cases where submuscular dissection is performed.



FIG 4 • A. The melanoma just under 1 mm is removed full thickness. The anterior margin is moved to the nasojugal fold and along the nasolabial fold. The Schrudde designed flap is lifted sub smas preserving nerves by oblique spreading of scissors. The flap design goes straight back the width of the lesion and the distance to the nasojugal fold and then down to mid tragus. A 70-degree flap is designed under the ear. After closure, the ear lobule is left to auto tube to preserve correct lobule shape. **B.** The final result is well supported. The flap design does not require the usual upswing of the flap behind the defect as the Schrudde design already does this. The ear lobule has auto tubed.



FIG 5 • A. Preoperative image of patient who underwent

laterally based cervicofacial flap. Immediate **(B)** and 12-month **(C)** postoperative views.

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26 Cheek Reconstruction With Tissue Expanders

CHAPTER

John T. Stranix and Barry M. Zide

DEFINITION

- Tissue expansion is a proven technique for generating additional cutaneous tissue to reconstruct facial defects when local coverage options are otherwise inadequate.
- Skin adjacent to, or near, the surgical defect is stretched over time to produce adequate local tissue of similar color and texture for coverage without creation of a donor-site defect.
- Expansion is achieved through placement of a buried prosthesis that is gradually filled with saline via a distant port.
- As the volume of saline increases, the prosthesis enlarges and stretches the overlying tissue to cause expansion.

ANATOMY

- Skin expansion results from mechanical stress applied over time through both mechanical creep (cellular stretch) and biologic creep (increased cellular proliferation).
- Thickening of the epidermis occurs with concurrent thinning of the dermis and alignment of collagen fibrils.
- Angiogenesis occurs in response to ischemia generated by tissue expansion, increasing both the number and caliber of blood vessels in the expanded tissue. This is similar to the increased vascularity seen with the delay phenomenon and expanded flaps can be considered delayed flaps.
- Skin of the anterolateral neck shares essentially the same color, texture, and dermal appendages as the skin covering the majority of the cheek. This excellent match makes the neck an ideal donor site for cheek reconstruction

with tissue expansion.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Tissue expansion is performed over 3 to 4 months, requiring office visits 5 to 7 days apart. This requires a motivated, well-informed, and compliant patient and family. Sometimes, twice-weekly fills can expedite expansion.
- In some cases, parents and/or patients can do the fillings with proper instruction.
- Tissue expansion has a higher complication rate in children compared to adults.¹ Smokers also have an increased risk of complications.²
- Facial tissue expansion must take into account the location, size, shape, and type of defect (nevus, burn, trauma, oncologic).
- Expansion under scars or radiated tissue should not be done.
- Consideration should be given to the aesthetic subunits involved, adjacent specialized structures that may be disrupted/distorted, skin quality, pre-existing scars, and any additional areas with reconstructive needs.
- Available donor sites for expansion must be evaluated as this will determine the size and type of expander possible.

SURGICAL MANAGEMENT

- The increased vascularity of expanded lateral cheek and neck tissue enables the design of unique advancement, rotation, or transposition flaps specific to individual cheek defects.
- There are three general approaches to tissue expansion for coverage of cheek lesions:
 - Expansion of tissue immediately adjacent to the defect (which thins the skin)
 - Cervicofacial flap expansion and/or neck expansion for cervicofacial flap donor-site coverage
 - Direct expansion from below the lesion to allow excision and primary closure
- An expander placed in the upper neck (as opposed to an expander placed immediately adjacent to the defect) is preferred because this approach results in decreased skin thinning.
- Transillumination of the expander in situ is a helpful technique because this approach identifies the major blood vessels of the flap by enabling the surgeon to perform back cuts more accurately.
- The Schröder angle rotation flap adapts well to an expander placed in the

neck. This flap incorporates an angular subcutaneous flap below the ear and backward. When the flap is brought up and forward, it fills the area in front of the ear, which would have a defect otherwise.

- The size of the required expander can be calculated directly based on the length and width of the expected defect. When using a single expander, the length of the expander should be equal to or greater than the longest side of the lesion. The width of the expander should be the maximum possible according to anatomy.
- The timing required to reach full expansion and the amount of fluid needed for expansion vary based on the quality and quantity of skin. Similarly, the timing of transfer after adequate fill has been obtained varies based on the condition of the skin and the amount of expansion that has been done. However, in general, once full expansion has been obtained, the transfer can be safely scheduled after 1 to 2 weeks.

Preoperative Planning

- Careful flap planning should incorporate the expander placement incision(s) and align scars with borders of aesthetic units when feasible.
- For large expanders, multiple access incisions may be required to allow for adequate expander pocket dissection. Incisions are usually preauricular or open V shaped in the scalp or along the Schröder infra-auricular incision.
- If re-expansion and readvancement may be required for serial excisions, this should also be incorporated into flap choice and design. Serial expansions and excisions are associated with a higher extrusion rate during subsequent expansions.³ The author rarely re-expands the face.
- Actual or anticipated defect size must be determined to select the appropriate number, size, and orientation of tissue expander(s). Location of remote port placement should be distant from the expander and secured in situ.
- Donor-site selection plays an important role with the goal of providing a good soft tissue match in color, texture, and contour. For cheek reconstruction, the lateral cheek and neck provide an excellent match.

Positioning

- The procedure can be performed under sedation with monitored anesthesia care or full general anesthesia with the patient positioned supine on the operative table.
- The head is turned toward the contralateral side from the defect, and the

ipsilateral face, neck, and chest are prepped into the field.

- Administration of an antibiotic with skin flora coverage 30 to 60 minutes prior to incision is recommended.

Approach

- Size, shape, and number of the expanders
 - As stated earlier, in cases in which a single expander is used, the length of the expander should be longer than the length of the incision required to replace the intended area, whereas the width of the expander should be roughly equal to the width of the expected defect. In practice, we use the widest expander possible based on anatomic constraints.
 - Using the largest expander possible within the limitations of donor-site anatomy will reduce the number of expanders (and total expansion) required.
 - Compared to the expander base area, expander volume is less important due to the minimal risk of hyperinflation up to 10 times above the manufacturer's stated nominal capacity.⁴
 - Using multiple expanders allows more rapid expansion with fewer complications than single expanders and should be considered when feasible.²
 - Soft, flat, rectangular silicone expanders with rounded corners are recommended for expansion of head and neck tissue. In the face and neck, floppy bag expanders are avoided due to knuckling and extrusion problems.
- Port placement
 - Remote filling ports are preferred in the head and neck over integrated filling valves and are typically placed in the postauricular scalp or neck.
 - External filling valves may be helpful in children, but the port egress site must be dependent to allow for periprosthetic fluid drainage and should be far from the expander (greater than 6 cm) as they are associated with a higher infection risk.⁵
 - Ports must be secured to prevent drift.
- Incision placement
 - Incisions for expander placement should not interfere with subsequent flap advancement or compromise the blood supply to the expanded tissue. Ideally, placement incisions are either incorporated into the subsequent flap design (like the Schrudde infra-auricular V), placed within the area to be excised, or distant like the scalp.
 - Access incisions should be kept away from the expansion process (greater

than 2–3 cm) and never oriented parallel to expander edges as this increases exposure risk. Incisions should be either perpendicular to the expander or in the shape of a V or W with the broad base directed toward the expander.

■ Flap incisions and tissue transposition

■ Simply cutting around the advancing edge of the expander base does not take full advantage of the expanded tissue.

■ The following flap designs enable the most efficient use of expanded local tissue for coverage:

- The single back-cut flap is ideal for triangular defects. The single back cut allows the flap to be advanced and/or transposed and is a workhorse technique. The flap can be shaped or contoured in a way to recreate a side burn or exactly tailored to a defect.
- The double back-cut flap provides maximal gain of soft tissue advancement and is best for round or rectangular lesions. These flaps are amenable to re-expansion for serial excisions.
- Over-the-top advancement flap allows for simple calculation of the amount of soft tissue available in the flap. This type of advancement is used when the expander was larger than the square-shaped defect. It does require sacrifice of some adjacent normal tissue over the lateral edges of the expander, and the required dog-ear excisions cause the flap to narrow when advanced.

■ Expanded cervicofacial flap

■ A powerful technique for coverage of large cheek defects (greater than 3 cm) incorporates tissue expansion into the design of cervicofacial rotation/advancement flaps.

■ Benefits of cervicofacial flap expansion include the following:

- Improved flap vascularity, which may obviate the need for sub-SMAS flap elevation
- Allows coverage high onto the temporal area and farther medially and inferiorly
- Facilitates tension-free closure
- Transillumination demonstrates axial blood supply, enabling utilization of the maximal flap back cut to optimize rotation/advancement
- Remote expander placement away from the defect reduces exposure risk, with access incisions directly incorporated into flap design.

■ Direct expansion and closure

- For nonexpansile lesions of the cheek, direct expansion from underneath the defect itself enables excision and primary closure.
- This technique minimizes the degree of undermining necessary and has the benefit of resulting in a straight line scar that can be favorably oriented along resting skin tension lines.

TECHNIQUES

■ Tissue Expander Insertion

- Once the flap design and implant position are determined, mark out the access incision, remote port location, and planned expander pocket.
- Infiltrate a dilute solution of 1:200,000 to 1:400,000 epinephrine in a subcutaneous plane throughout the marked areas.
- After a period of 7 to 12 minutes for vasoconstriction, make the access incision (usually 2–3 cm long) into subcutaneous tissue.
- Develop the expander pocket with a combination of blunt and sharp dissection in the subcutaneous plane staying above the superficial musculoaponeurotic muscular system (cheek) and platysma (neck).
- Make sure the pocket is far enough away from the incision so the expander is about 2 cm from the access point.
- With the same technique, create a superficial pocket for the remote fill port that is separate from the expander pocket but accessible through the same incision.
- Hemostasis should be checked and the pocket should be irrigated.
- Prior to insertion, trim the port tubing to the appropriate length to avoid redundancy that may lead to kinking and check the expander for leaks.
- After rolling and inserting the expander into the pocket, attach a 16-gauge plastic angiocath to the expander tubing, completely deflate the expander, and then clamp the tube.
- The connector is placed and tied with two 3-0 Tevdek or Ethibond sutures on each side to prevent detachment. The port is also secured so it does not drift. The tubing to the expander must be on the down side.
- Make sure the skin overlying the port is loose and the tubing does not kink.
- When you are satisfied with port position and palpability, place a suture

around the tubing but under the skin adjacent to the dome to secure the port in place.

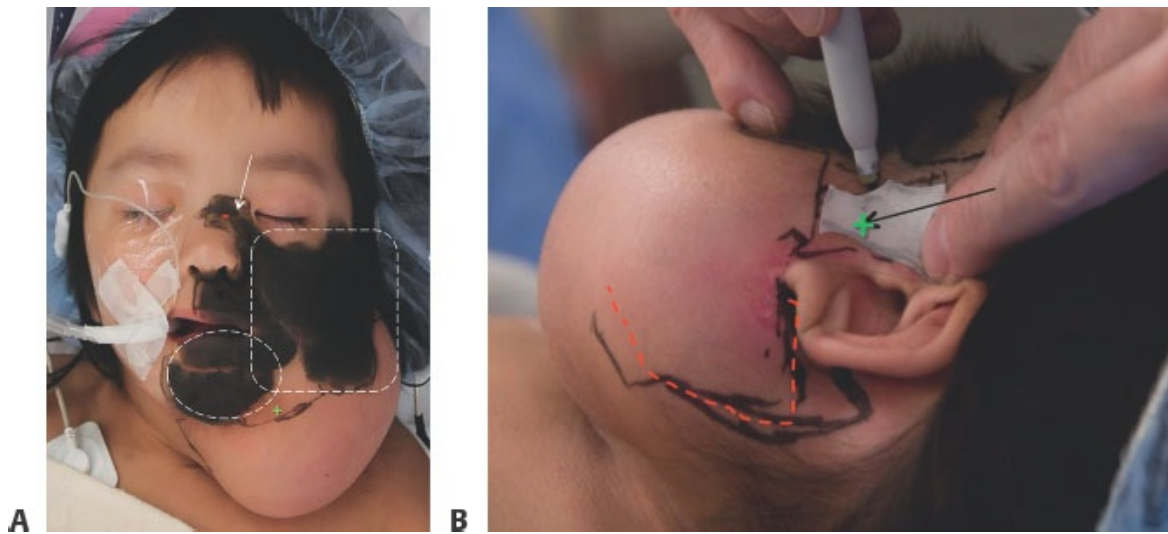
- The port tubing must be sutured in place to prevent drift into the larger pocket.
- Place a small closed suction drain that is tunneled to a separate, remote stab incision for egress.
- Use a 23-gauge needle to transcutaneously access the port and partially fill the expander with injectable saline (about 10% volume). This initial fill unfurls the expander, obliterates dead space caused by undermining the pocket, and allows assessment of the connection between the port and expander.
- Check to make sure the insertion of the port tubing into the expander is on the downside.
- Make sure the expander lies flat in the pocket after the partial fill by pushing on the overlying skin—no edges should be felt. If the pocket needs adjustment, pull out the expander first, or else, it may be cut in the procedure.
- Once adequate expander position is obtained, close the access incision(s) in layers.

■ Expanded Flap Elevation and Inset

- Following adequate expansion, design a flap that will provide defect coverage and draw it in marker over the expanded tissue (**TECH FIG 1A,B**).
- When designing the back cut, transilluminate the flap to identify and mark the location of axial blood vessels (**TECH FIG 1C**).
 - Division of these should be avoided and will determine the maximal extent of your back cut.
- Infiltrate a dilute solution of 1:2-400 000 epinephrine in a subcutaneous plane throughout the marked areas.
- Perform the marked incisions through the dermis.
- Using cautery, elevate the flap in a subcutaneous plane until the expander capsule is encountered.
- Cautery will not cut the expander and thus avoids a flood of saline into the field.
- Incise the expander capsule the entire length of the incision.
- Additional capsulotomy and subcutaneous undermining of this proximal

tissue should be performed as needed for adequate movement.

- Although the capsule edge may be removed if it prevents motion, significant capsulectomy should not be performed as this may compromise flap blood supply.
- If excessive tension is present, the back cuts may be extended up to the first axial vessels encountered on transillumination to provide additional rotation.
- Rotate and inset the flap (**TECH FIG 1D,E**).
- Place a small closed suction drain that is tunneled to a separate, remote stab incision for egress (can use the same stab incision previously used with expander placement).





TECH FIG 1 • **A,B.** Markings for a Schrudde design flap wherein a triangle placed under the ear allows the flap to move without worry of needing to fill the defect from flap movement. The flap should not go right under the eyelid unless the lid is supported by fascial slings. **C.** The expanded flap is transilluminated so the back cuts do not interrupt blood supply. With the lights out in the OR, the vessels are easily visible. **D.** The flap should be supported by sutures to periosteum or fascia, indicated by *arrows*. **E.** Completed flap inset.

■ Expanded Cervicofacial Flap

- Refer to the chapter Cheek Reconstruction With the Angle Rotation Flap for flap design. The flap is designed in exactly the same manner, except expansion is performed prior to elevation and advancement.

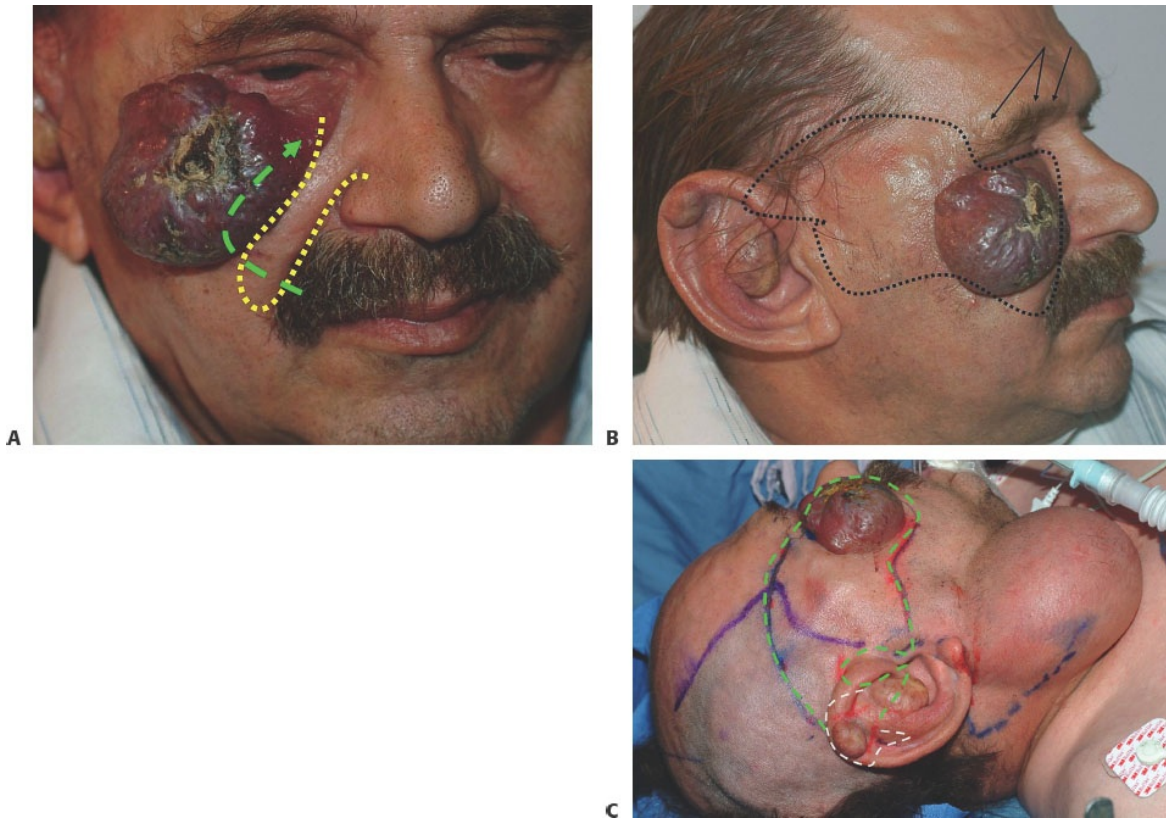
- Expansion of the cervicofacial flap is usually done with a neck expander and may avoid sub-SMAS flap elevation.
- A subcutaneous implant pocket is designed 1 cm larger in all dimensions. Expander insertion is performed through the preauricular flap incision, which may be extended cranially to facilitate exposure. A submental counterincision may also be helpful for pocket dissection.
- The remote fill port can be placed in the scalp or behind the ear.
- Perform the incisions and expander removal in the same manner as the subcutaneous flaps above.
- Additional subcutaneous dissection should be performed for complete flap elevation. Flap advancement, inset, and superomedial support should be performed according to the techniques detailed in the chapter Cheek Reconstruction with the Angle Rotation Flap.
- Take full advantage of the improved vascularity and quantity of soft tissue. Align planned incisions with aesthetic subunit borders, sacrificing some residual normal tissue from the medial cheek if necessary (**TECH FIG 2**).
- There is usually a vertical dog-ear medially that requires excision.
- In addition to the cutaneous inset of the above flaps, these larger flaps require suspension from periosteum, bone anchors, and temporal fascia.



TECH FIG 2 • A. An OR fire burned this woman. The graft to the lower eyelid was too small, the cheek had an expander attempt, and it became exposed. The red line indicates the delay incisions made at the time of expansion placement. The green line shows the incision for the final flap. **B.** Flap inset.

■ Neck Expansion for Donor-Site Coverage of Large Cervicofacial Flaps

- For larger cheek defects, deep-plane cervicofacial flap elevation may be performed in conjunction with neck soft tissue expansion for donor-site coverage (**TECH FIG 3A,B**).
 - This provides the maximum possible flap vascularity by combining the sub-SMAS elevation with tissue expansion delay phenomenon and enables primary donor-site closure with pliable neck tissue.
- The tissue expander is placed in the subcutaneous (preplatysmal) plane inferior to the mandibular border using the above technique (**TECH FIG 3C**).
- Following adequate neck tissue expansion, the cervicofacial flap is designed with transillumination used to identify axial vessel location and incorporate them into the backcut limitations.
- Removal of edge of expander scars and proper back cut will maximize the gain.



TECH FIG 3 • A large AVM extending from the superomedial cheek to the superior ear required excision down to deep temporal fascia. **A.** The flap (indicated in yellow) will go thinly under the lid, as shown by the *green arrow*. **B.** The AVM will be removed to deep temporal fascia. The ear will be reduced. The upper brow will be supported by anchors (*arrows*) as the frontal branches are removed. **C.** Flap design. The neck expander was placed via a preauricular incision to provide additional soft tissue and allow primary donor-site closure for the deep-plane angle rotation cervicofacial flap.

Incisions	■ Keep placement incisions at least 2–3 cm away from the expansion process. ■ Inverted V incisions work well for insertion and allow for expansion to begin at 10 d; must be kept away from base of the proposed flaps. ■ Use back cuts with transillumination to maximize tissue gain and avoid flap devascularization.
Expander selection	■ Rectangular expanders are preferred because you can figure out mathematically when the expander is close to ready. ■ Choose size according to base length dimensions that are slightly larger than the defect (not according to expander volume, as they can be significantly overinflated). ■ Avoid hard-backed, floppy bag, or integrated fill port expanders on the face and neck. ■ Multiple expanders may allow for more rapid expansion but also increase the chance of problems. Expanders, if multiple, should be chosen according to the shape/extent of the defect and what each expander will accomplish.
Expander placement	■ Infiltrate semitumescent dilute epinephrine prior to pocket formation. ■ Make sure the expander lies flat in the pocket after insertion, no edges should be palpable, and the port connection must be on the downside. ■ Make sure the remote port is loose in its pocket, or the overlying skin will necrose, and always secure the port in place. ■ Use a closed suction drain that egresses from a distant site.
Tissue expansion	■ Avoid trying to predict exactly how long expansion takes since this is highly variable. ■ In certain instances, teach appropriate family members to do the expansions at home. ■ Expand until you have approximately 20% more tissue than needed to cover the defect when possible.
Implant exposure/infection	■ Consider temporary deflation, drain any periprosthetic fluid, and start antibiotics if evidence of infection. ■ May save a seemingly infected implant. Drainage from the most dependent portion of the expander and Betadine irrigations can save the day... sometimes. ■ If almost fully expanded, try to incorporate the area of exposure into the back cut of the flap.

POSTOPERATIVE CARE

- Postoperative antibiotics are not required, and the drain is removed within 24 to 48 hours.
- Filling begins at the first postsurgical visit, typically at 7 to 10 days.
- If the expander was inserted through an incision that may be affected by the expansion, it will be necessary to delay filling for 3 weeks.
- Filling should be performed after sterilizing the skin over the port to prevent contamination.
- It is important to use a 23-gauge or smaller needle to prevent port leakage (although the companies say it will work with a 21-gauge needle). A butterfly needle is particularly useful as it allows for slight patient movement without dislodging.
- In children, it may be helpful to apply a topical local anesthetic 20 minutes prior to each filling session.
- Subsequent filling amounts vary but are usually about 5% of the nominal expander volume with intervals between fillings ranging from 4 days to 1 week.
- The expander should be compressible to 1 cm after filling.
- Frequent small-volume inflations are better tolerated, approximately every 5 days.
- When guardians or significant others can be trained or designated as fillers, they can usually fill every 5 days.
- Expansion is complete when the cutaneous tissue generated is able to cover a surface area approximately 20% greater than the defect itself to accommodate for primary flap contraction after expander removal.

OUTCOMES

- Follow-up patient photos are shown in **FIG 1**.

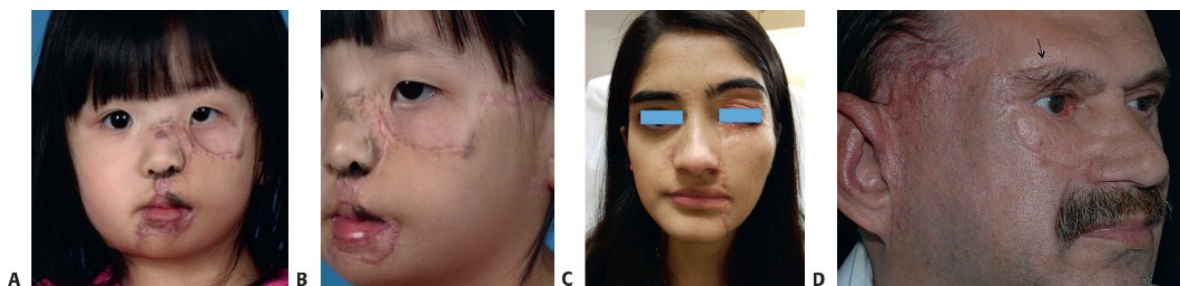


FIG 1 • A,B. Follow-up photos of the patient in TECH FIG 1. She will need additional work for the epicanthal fold, residual nevus on lip, and tightness around the commissure. **C.** Follow-up photo of the patient in TECH FIG 2. The lower lid position is excellent as a graft was used under the margin of the lid. The flap would be too heavy without support. The commissure was repaired later. **D.** Follow-up photo of the patient in TECH FIG 3. The anchor scar is indicated by an *arrow*.

COMPLICATIONS

- Complication rates with tissue expansion vary widely and are directly related to the experience of the individual surgeon.⁶
- Most complications that occur with tissue expansion are technique specific and do not interfere with completion of the planned multistage procedures.²
- Late infections are usually related to iatrogenic contamination during the course of inflation. These infections should be managed with port externalization, irrigation, and antibiotic therapy. Late infections may be salvaged with immediate intervention and antibiotic therapy.
- Implant exposure usually occurs through necrosis of the overlying skin, trauma, a dehiscence and malpositioned incision, or a fold in the implant. Inadequate pocket dissection or too rapid inflation can lead to implant extrusion as well.
- Major complications are rare but include the following:
 - Infection
 - Implant exposure
 - Flap ischemia and/or necrosis
 - Hematoma
- Minor
 - Transient pain with expansion
 - Seroma
 - Widening of scars
 - Dog-ears at donor site

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27 Cheek Reconstruction With Free Radial Forearm Flap

CHAPTER

John G. Fernandez

DEFINITION

- Cheek and face defects commonly occur secondary to trauma, burns, or tumor resection.
- Most cheek defects can be treated with primary closure, skin grafts, or local flaps.¹
- Less commonly, reconstruction of cheek defects requires free flap transfer. These defects are more complex, often involve a large area of the skin, or are composite defects involving the cheek skin and underlying tissues.
 - Free flap coverage is necessary owing to lack of local tissues from previous surgery or radiation.²
 - Some patients require free tissue transfer because the facial vessels are ligated during the course of concomitant neck dissection.
 - The radial forearm flap (RFF) is an excellent option in these situations due to its long pedicle, thin and pliable skin paddle, and the potential to transfer multiple skin paddles to line composite through-and-through cheek defects.
- Other flaps are also useful for cheek defects. These include the anterolateral thigh flap, scapular and parascapular flaps, lateral arm flap, fibula flap, and the rectus abdominis flap.
 - Flap selection is based on multiple factors including volume of tissue loss and subsequent functional and aesthetic reconstruction needs.
 - This process is individualized for the patient and the defect to be reconstructed.
- No clear evidence supports one flap over the use of another.
 - The flap must appropriately match the color and thickness of the surrounding

cheek soft tissue and have a reliable blood supply with adequate vessel diameter and length.

- The advantage of RFF is its flexibility in design and its ability to be fashioned as a fasciocutaneous flap, as an osteocutaneous flap involving unicortical short segment of radius, or as composite flaps, including palmaris longus tendon (for lip reconstruction), as well as its ability to be de-epithelialized and folded to reconstruct the intraoral lining and external skin defects.²

ANATOMY

- The borders of the cheek include laterally the preauricular crease, medially the nasal-cheek junction, nasolabial fold and lip, inferiorly the lower border of the mandible, and superiorly the orbital-cheek junction (**FIG 1A**).¹
- The main arterial supply to the cheek is from branches of the external carotid artery with the greatest contribution arising from the facial artery.
- The branches of the facial nerve lie deep to the SMAS.
- The RFF venous drainage is primarily from the venae comitantes, secondary drainage from the cephalic vein (**FIG 1B**).³
- RFF dominant arterial supply is the radial artery.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history should identify patient factors that may increase the risk of complications, including smoking history, hypertension, obesity, diabetes, and prior radiation therapy.
- Elicit personal or family history of clotting abnormalities, strokes, coronary artery disease, or cerebrovascular disease.
- A personal or family history of clotting abnormalities may warrant a hematology consult to rule out familial causes of hypercoagulability or bleeding diathesis.
- A directed physical examination of the head and neck includes a detailed assessment of the tumor or traumatic defect; nodal involvement; quality of the surrounding cheek skin including laxity, scars, and fine wrinkles; and assessment of facial nerve function.
- Preoperative plan for resection should be determined in consultation with the oncologic surgeons.
- Orbital-cheek junction and periorbital reconstruction may result in eye-related complications including ectropion, scleral show, dry eye, and chemosis.⁴

Therefore, a preoperative and postoperative visual field exam and periorbital assessment may be necessary for lesions that encroach on the eyelid.

- The preoperative evaluation for patients who will undergo cheek reconstruction with an RFF flap includes gathering pertinent patient history such as hand dominance, prior upper extremity surgery, history of trauma, or fractures.
- Consider the body habitus and thickness of the donor tissue and its potential effect on the overall aesthetic and functional outcome.
- An Allen test should be performed to assess ulnar and radial artery perfusion to the hand. Motor and sensory examination of the hand should be performed.
- Patients should be instructed to avoid blood draws or intravenous line placement in the arm to be used for RFF harvest.

IMAGING

- X-ray of the forearm and hand is indicated if an osteocutaneous flap is planned.



FIG 1 • A. Outlines of the zones of the cheek. Note overlap of zones. **B.** Arterial and venous anatomy of the forearm.

SURGICAL MANAGEMENT

- The goal of surgical management is to re-establish the normal anatomy of the face; provide stable soft tissue coverage; allow for normal speech and swallowing, thereby improving quality of life; and maximize aesthetics.
- An RFF is an excellent option for complex defects of the cheek and can be performed to provide external coverage or as a folded flap to repair through-and-through cheek defects.

Preoperative Planning

- Consider the size of the anticipated defect of the aesthetic subunit (suborbital, preauricular, and buccomandibular) and intraoral component (if any).
- Maxillectomy defects often result in periorbital skin defects, whereas mandibulectomies and buccal tumors often include the buccomandibular

subunit.

- Isolated tumors of the buccal mucosa or advanced/recurrent parotid gland tumors may also result in through-and-through defects.
- Melanomas involving the cheek, particularly desmoplastic melanomas, may result in large skin defects in combination with a unilateral neck dissection thereby limiting the potential for reconstruction using local flaps (eg, cervicofacial flap).
- A free RFF is a good option in these circumstances.
- Consider the reconstructive needs and goals to help decide the proper reconstructive technique.
- Perform an Allen test again in the preoperative holding room or operating room to confirm clinic findings. For most accurate results, use a pulse oximeter on the thumb while occluding the radial artery.
- Make sure no blood draws or IV lines are placed in the nondominant arm (use of limb alert bracelet is helpful).

Positioning

- The patient is placed supine on the operating room table with the arm extended 90 degrees on a hand table.
- The head of bed is turned 180 degrees and centered under the lights.
- All pressure points are inspected and protected, and preoperative antibiotics are given within 60 minutes of the incision.
- Corneal eye protectors and sequential compression devices are placed bilaterally.
- Alternatively, the eyelids can be sutured together after application of ointment using a fine nylon suture that is removed after the operation.
- The arm is prepped circumferentially to the level of the axilla. A sterile tourniquet is padded and inflated when the flap is ready to be harvested.

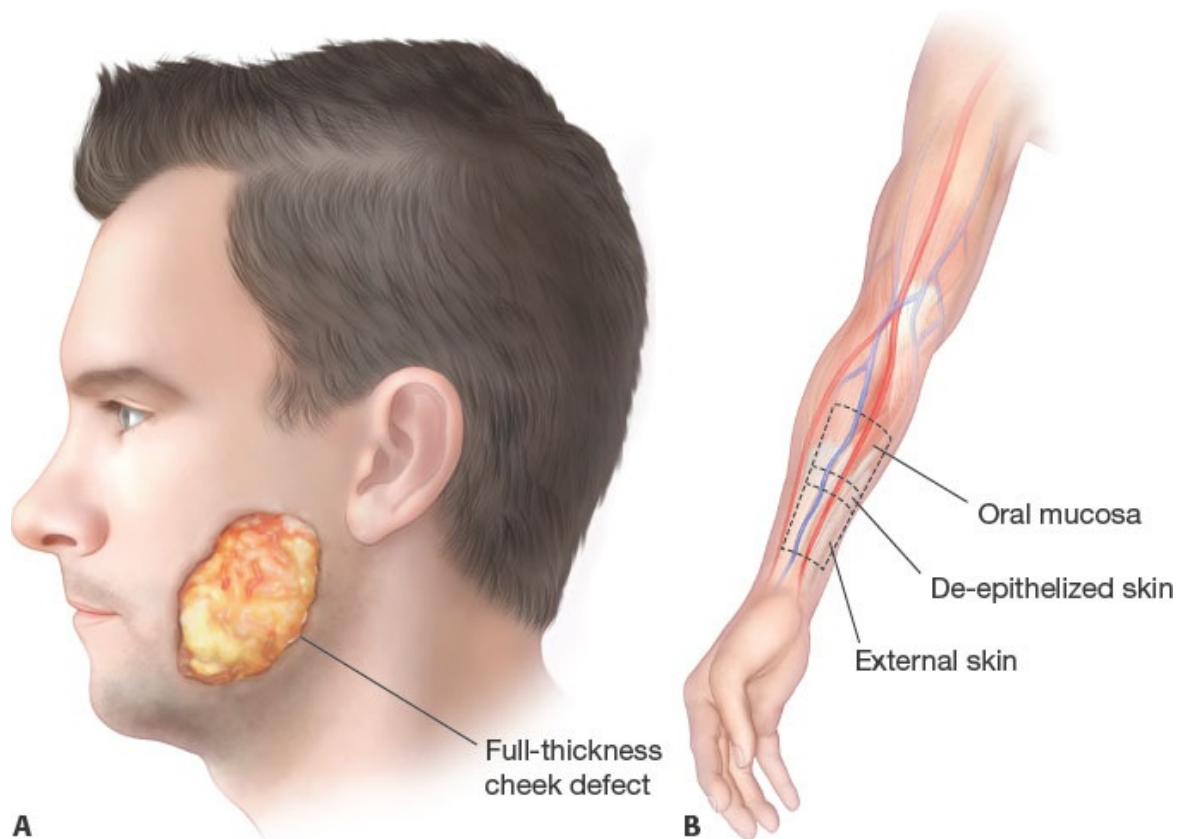
Approach

- The flap is raised under tourniquet control in a distal to proximal fashion.
- It can be raised either subfascial or suprafascial.
- If the fascia is included in the flap, care is taken to preserve the paratenon on the tendons to ensure skin graft take.
- The flap can safely be raised on the superficial venous system, the deep system,³ or both.

TECHNIQUES

■ Flap Design

- Evaluate the specimen and design the flap based on the postablative oral mucosa and/or skin defect measurements (**TECH FIG 1A**).
- Mark the radial artery, cephalic vein, palmaris longus tendon, and FCR.
- Design skin paddle centered over the radial artery and cephalic vein.
 - If a small flap is needed, the cephalic vein can be excluded from the initial design and the flap is centered over the radial vessels. In these cases, it is helpful to incise the distal aspect of the flap first and ensure that the vena comitans of the radial artery is of adequate size for microsurgical anastomosis (**TECH FIG 1B**).

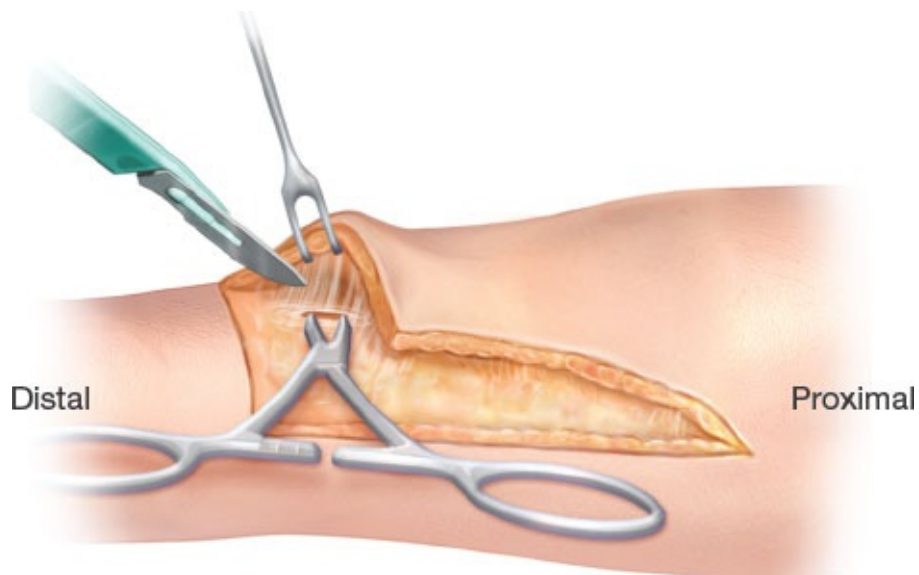


TECH FIG 1 • **A.** Evaluate the specimen and design the flap based on the postablative oral mucosa and/or

skin defect measurements. **B.** Design skin paddle centered over the radial artery and cephalic vein.

■ Flap Dissection

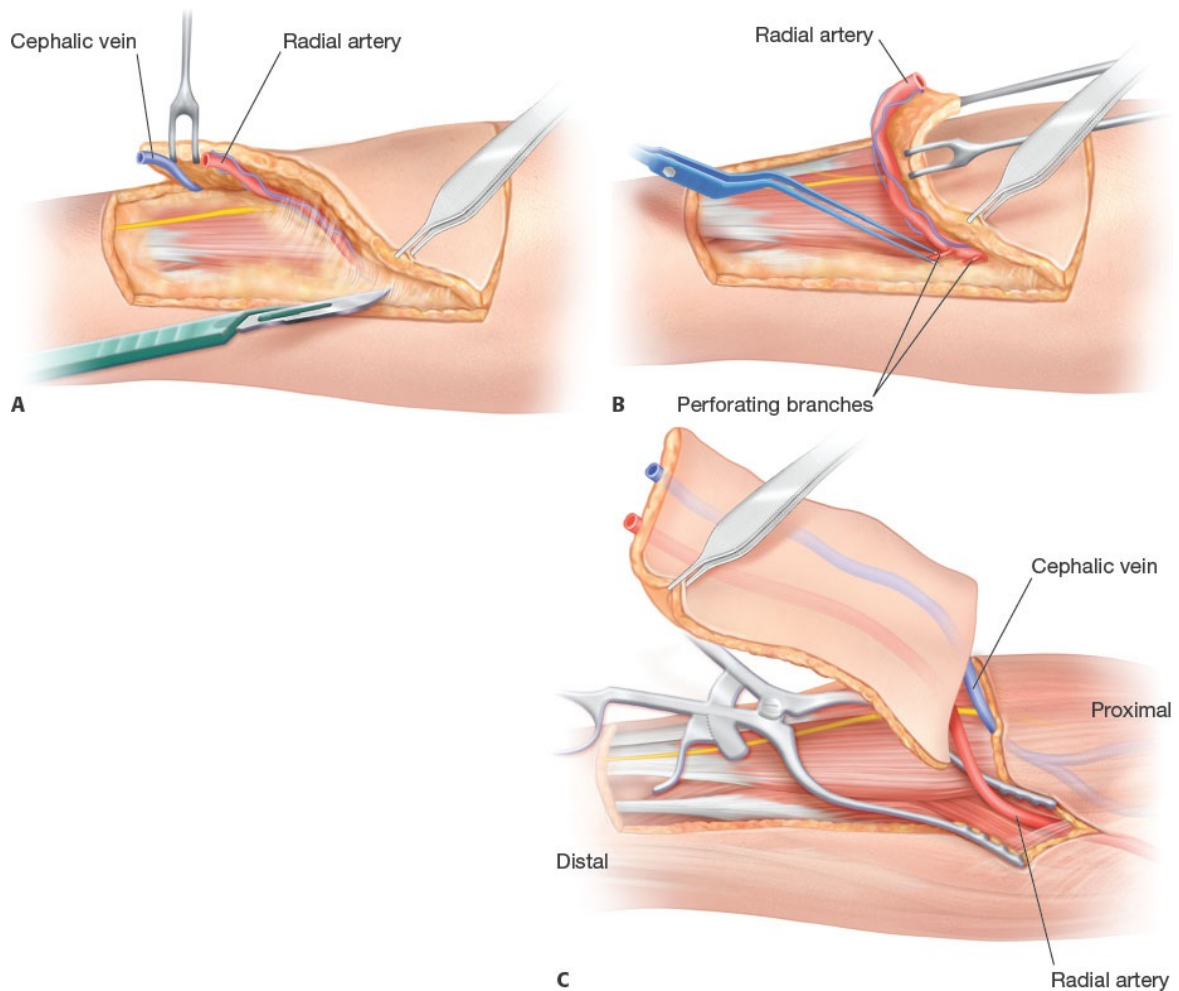
- Elevate the extremity and inflate the tourniquet.
- The flap is incised circumferentially.
 - When making the distal incision, care must be taken to avoid injury to the radial nerve branches as they are superficial in the distal region of the wrist.
 - Similarly, injury to the cephalic vein should be avoided when making the proximal incision (**TECH FIG 2**).
- Subfascial dissection is the safest approach to the flap vessels and can be performed expeditiously. However, care must be taken to avoid injury to the superficial radial nerve.
 - The simplest way to avoid this problem is to identify the radial nerve trunk as it exits below the brachioradialis muscle.
 - The branches can then be traced distally and dissected out of the flap.
 - Small branches entering the skin flap are sharply transected.



TECH FIG 2 • Incision is made with a 10 blade. Incise fascia with knife and raise edges using Adson forceps. Spread with hemostat in the direction parallel to nerves.

■ Subfascial Dissection

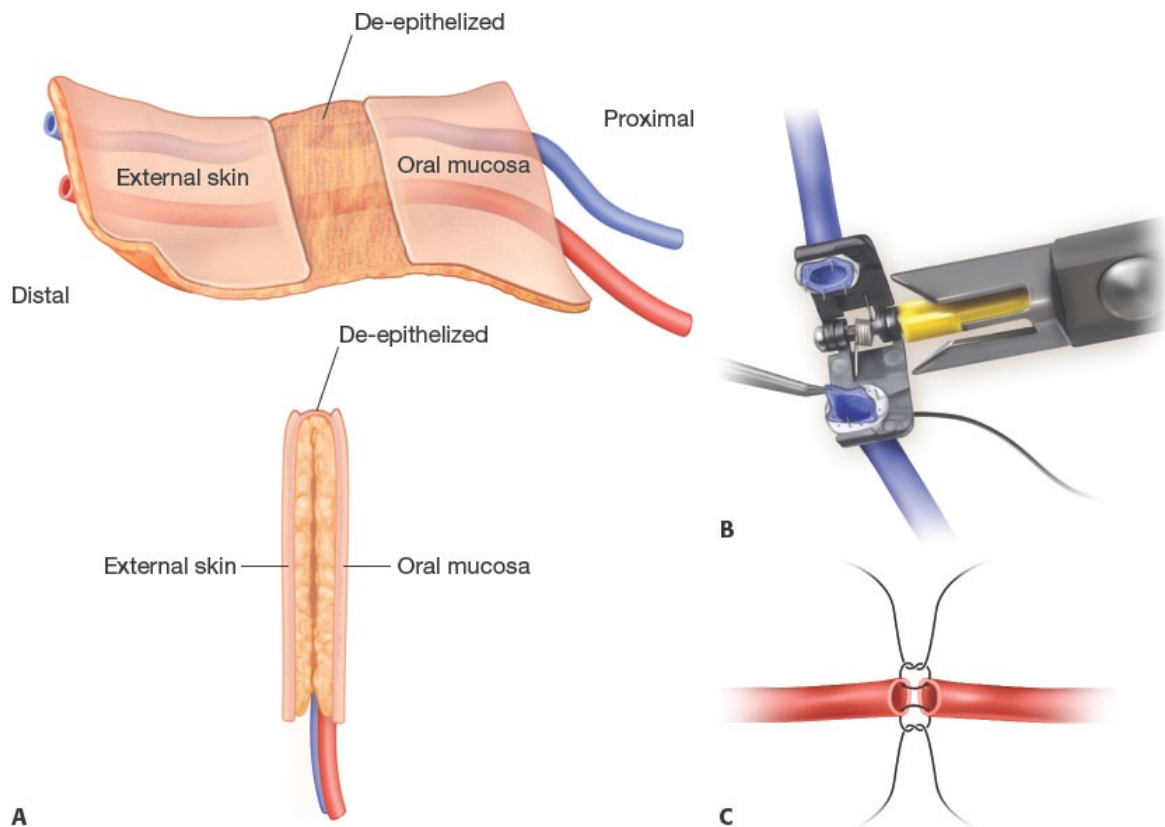
- The radial artery and vena comitans are identified distally and ligated.
- The radial vessels are dissected in a subfascial plane from distal to proximal, taking care to avoid injury to the skin-perforating vessels.
 - Small perforators to the muscles and radial bone are cauterized or suture ligated (**TECH FIG 3A**).
- Follow the pedicle as it dives under the brachioradialis tendon (**TECH FIG 3B**).
- Move back and forth between radial and ulnar sides to ensure circumferential view of the radial artery.
 - As you move proximally, use a blunt retractor like a Weitlaner to spread the brachioradialis and FCR (**TECH FIG 3C**).
- Dissect the cephalic vein proximally for additional venous outflow as necessary.
- Incise proximal skin last and be sure to dissect on top of the cephalic vein.
- Mark pedicle orientation with methylene blue or a marking pen.
- Deflate tourniquet and use bipolar cautery for hemostasis.
- Allow the flap to reperfuse for 20 to 30 minutes prior to harvesting for inset and microanastomosis.
- Donor site is closed with skin graft.



TECH FIG 3 • A. In subfascial plane, dissect with knife from distal to proximal. Using the no. 10 blade pointed away from the flap, dissect in subfascial plane staying on the sensory branches of the radial nerve. **B.** Spread under the pedicle perpendicular to the pedicle and bipolar cauterize the tissue. There are multiple perforating branches from the pedicle to the underlying muscle and bone. These small vessels are easily cauterized with a bipolar. **C.** Incise proximal skin last, and be sure to dissect on top of the cephalic vein. As you move proximally, use a blunt retractor to spread the brachioradialis and FCR. This maneuver exposes the radial artery and VC.

■ Flap Inset

- Divide flap pedicle to start ischemia time.
- Transfer flap to the defect and tunnel pedicle vessels to the neck.
- Inset flap at key points to set the pedicle length.
 - If a through-and-through defect is present, then inset the intraoral component first with absorbable sutures (eg, Vicryl) (**TECH FIG 4A**).
- De-epithelialize folded portion of flap with a no. 10 blade.



TECH FIG 4 • A. Transfer flap to the defect and inset flap with an absorbable suture such as 2-0 Vicryl interrupted sutures for the intraoral lining. De-epithelialize folded portion of flap with a no. 10 blade. Inset external skin to flap skin with 4-0 Vicryl for the dermis and 6-0 nylon for the skin. **B.** Vein anastomosis with a coupler device or hand sewn with 10-0 nylon. **C.** Arterial anastomosis is performed with

interrupted 9-0 nylon circumferentially.

- Microsurgical anastomosis is then performed.
 - The recipient arteries most commonly used in the neck are the facial, superior thyroid, or lingual artery, and the recipient veins are the internal jugular or branches of the internal jugular and the facial vein (**TECH FIG 4B,C**).
- The neck and wounds are irrigated with warm saline or antibiotic solution, and hemostasis is ensured.
- A neck drain is placed if necessary.
 - Care should be taken to avoid compression of the pedicle with the drain. This can be done by simply sewing the drain loosely to the sternocleidomastoid muscle.
- The neck skin and platysma, as well as the cheek skin, are closed in a layered fashion.

PEARLS AND PITFALLS

Indications	■ Free flap reconstruction is indicated for through-and-through cheek defects, requiring intraoral lining and external skin coverage. Free flaps are also useful for large defects of the cheek that cannot be closed with local options or skin grafts.
Flap selection	■ No evidence supports one flap over another flap. The flap must match tissue thickness and color and have a reliable blood supply and vascular pedicle.
Postoperative monitoring	■ Free flap survival for head and neck reconstruction is greater than 95%. Frequent clinical observation and Doppler checks are essential for early detection of compromised vascular flow.
Donor site	■ Volar resting splint and negative pressure therapy to skin graft for 5 days. Subsequently, Ace wrap and arm elevation for 3–6 weeks.

POSTOPERATIVE CARE

- The most important factor in flap salvage is thorough monitoring and early detection of compromised vascular flow.

- Clinical observation to assess skin color, temperature, and capillary refill and Doppler sonography are extremely effective in flap monitoring.
- Flap monitoring is performed most frequently in the first 6 hours after surgery (eg, every 1 hour) and gradually decreases over time (Q2 hours × 4 hours; Q4 hours × 48 hours).
- Postoperative antibiotics are generally not necessary and are used for a short duration (5 days).
 - A preoperative dose of antibiotics within 60 minutes of incision has been shown to reduce surgical site infections.
- Deep venous thrombosis prophylaxis includes early mobilization, bilateral sequential compression devices, and subcutaneous Lovenox daily.

OUTCOMES

- The free RFF is a highly reliable flap, able to be folded for intraoral lining and external skin coverage.
- Free flap success rates in head and neck reconstruction is higher than 95%.

COMPLICATIONS

- Donor site wound breakdown or skin graft breakdown leading to tendon exposure
- Poor donor site cosmetic outcome
- If bone is harvested, risk of fracture and potential functional loss
- Ischemic hand
- Partial or total flap loss
- Intraoral leak or fistula
- Infection

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28 Cheek Reconstruction With Skin Grafts

CHAPTER

Farooq Shahzad and Babak J. Mehrara

DEFINITION

- The cheeks are the largest aesthetic unit of the face.
 - The boundaries of the cheek are medially the nasofacial groove and nasolabial fold, inferiorly the mandibular border, laterally the preauricular crease, and superiorly the infraorbital rim and the line joining the lateral canthus to the helical root.
- The cheek is subdivided into three aesthetic subunits: suborbital, preauricular, and buccomandibular (**FIG 1**).¹
 - These subdivisions are useful for planning reconstruction.

ANATOMY

- The face has an abundant blood supply with a rich collateral network. The arterial supply to the cheek is via branches of the external carotid artery. The principal supply is via three sources (**FIG 2**):
 - Facial artery and its continuation, the angular artery
 - Transverse facial artery, which is a branch of the superficial temporal artery
 - Infraorbital artery, which is a branch of the internal maxillary artery
- The veins accompany the arteries.

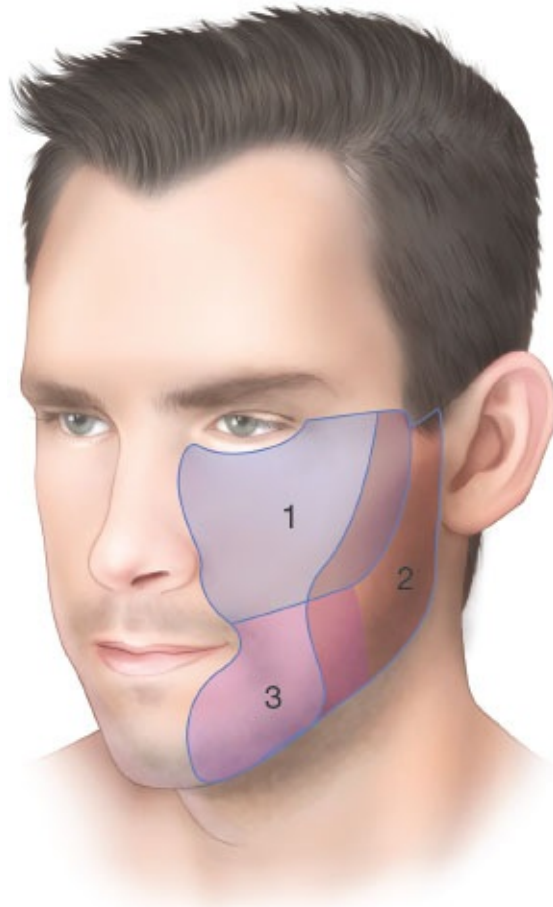


FIG 1 • Aesthetic subunits of the cheek: (1) suborbital; (2) preauricular; (3) buccomandibular.

- The lymphatics of the cheek drain to the parotid, submandibular, and submental nodes. Additional drainage occurs to the jugular nodes.
- Sensory innervation to the cheek is via three sources:
 - Maxillary division (V_1) of the trigeminal nerve via the infraorbital and zygomaticofacial nerves
 - Mandibular division (V_3) of the trigeminal nerves via the buccal, mental, and auriculotemporal nerves
 - Cervical plexus (C_2 , C_3) via the greater auricular and transverse cervical nerves

PATIENT HISTORY AND PHYSICAL FINDINGS

- Cheek defects occur most frequently following skin cancer resection but may also occur after trauma or other causes.

- Skin cancers on the cheek can be removed by conventional methods or using Mohs micrographic surgery.
- Assessment of margins is important and should be discussed with the patient.
- If margin status is in doubt, it is often more prudent to proceed with reconstruction only when the final pathology is reviewed and negative margins are assured.
- Many skin cancer excisions or traumatic injuries of the cheek may be repaired primarily. In other cases, local flap reconstruction or skin grafts are more appropriate.
- Skin grafts are useful in patients with significant comorbidities in whom facial flaps may be contraindicated, situations in which the blood supply to local flaps has been compromised, large defects that are not amenable to reconstruction with local tissues, or cases in which local flap closure may result in distortion of the adjacent structures such as the eyelid or nose.
- For example, skin grafts may be useful in young patients with large superficial cheek skin defects. These patients have tight skin without much redundancy, and thus, attempts to reconstruct larger defects with local flaps will cause distortion of contour or pull on adjacent structures like eyelids.
- Skin grafts are also helpful in some cases for men because facial flaps in these patients may change the distribution of hair growth resulting in a noticeable and difficult-to-treat problem.
- Infrequently, skin grafts may be useful for reconstruction of aggressive or recurrent tumors in which there is a high risk of local recurrence that is more suitable for applying skin grafts to facilitate surveillance.
- Finally, skin grafts may be used in combination with flap closures to extend the reach or avoid tension on the base of the flap or to provide coverage for adjoining anatomic regions (eg, eyelid).



FIG 2 • A. Arterial and venous anatomy of the cheek. **B.** Sensory and motor nerve anatomy of the face.

- The defect is analyzed for the following:
 - Location, size, and depth of the defect
 - Involvement of deeper structures (eg, facial nerve, parotid duct, and oral

mucosa)

- Proximity of the defect to lower eyelid, nasal ala, and lip
- Previous radiation and radiation changes. Heavily radiated or compromised wounds may not be amenable to local flaps or skin grafts and may require vascularized tissue transfer depending on the exposed structures and complexity of the wound.

NONOPERATIVE MANAGEMENT

- Areas of the face with a concave surface heal well with secondary intention healing.
- The cheek is convex, and therefore, secondary healing results in aesthetically displeasing results.
- Exceptions are small preauricular defects and very small medial defects at the alar groove that heal well with local wound care.

SURGICAL MANAGEMENT

- Patient selection for skin graft reconstruction is as discussed above.
- Full-thickness skin grafts taken from within the face and neck (cranial to the clavicles) will have better color and texture match.
 - Common donor sites are the preauricular or postauricular areas, neck, upper eyelid, and supraclavicular region.
- Scars are ideally placed at the borders of the cheek.
 - In general, however, subunit principle and excision of normal skin are not necessary or advised. In rare circumstances, the margins of the graft may be adjusted to blend into normal anatomic structures (eg, nasolabial fold or lower eyelid-cheek margin).

Preoperative Planning

- The condition of the wound bed is examined. Contaminated wounds or those with eschars will need debridement and dressing changes until an appropriate bed is available for skin grafting.
- If possible, skin grafting should be delayed until the wound has granulated enough to decrease contour deformities that may result from deep excisions. In practice, this is not always possible, however, because of contracture and deformity of adjacent structures.
 - One potential solution is the use of decellularized dermis or other material (eg, Integra) to promote wound filling and granulation, thereby avoiding

contour deformities.

- Anticoagulants or antiplatelet agents may be discontinued or bridged prior to the procedure; however, the risk of stopping these medications (eg, stroke, MI) should be weighed against skin graft loss and should be individualized.
- In most cases, consultation with the patient's primary care or medical team is needed to make this decision.
- The expected postoperative course should be discussed with the patient.
- Full-thickness skin grafts initially turn pale and then become hyperemic as they revascularize. They stay pink for several weeks before settling down to their final color. Often, these grafts initially look pin cushioned and fibrotic but soften up over a period of 2 to 3 months. These issues are minimized with optimization of the recipient bed and preservation of the full thickness of the dermis (and even a small amount of subcutaneous layer).
- Possible future revision procedures should also be discussed if necessary.

Positioning

- Patient is positioned supine, with the head at the edge of the bed.
- Small transparent dressings (Tegaderm) are used to tape the eyes closed for protection.
- Preoperative antibiotics are administered.

Approach

- Skin graft reconstruction of cheek defects can be performed with a full-thickness or split-thickness skin graft.
- Full-thickness skin grafts are generally preferred for the face as they have better color, texture, and thickness match. They cause less secondary contracture and are preferable if the defect is close to structures like eyelids or lips.
- Split-thickness skin grafts have a better take and may be needed for reconstruction of larger defects.

TECHNIQUES

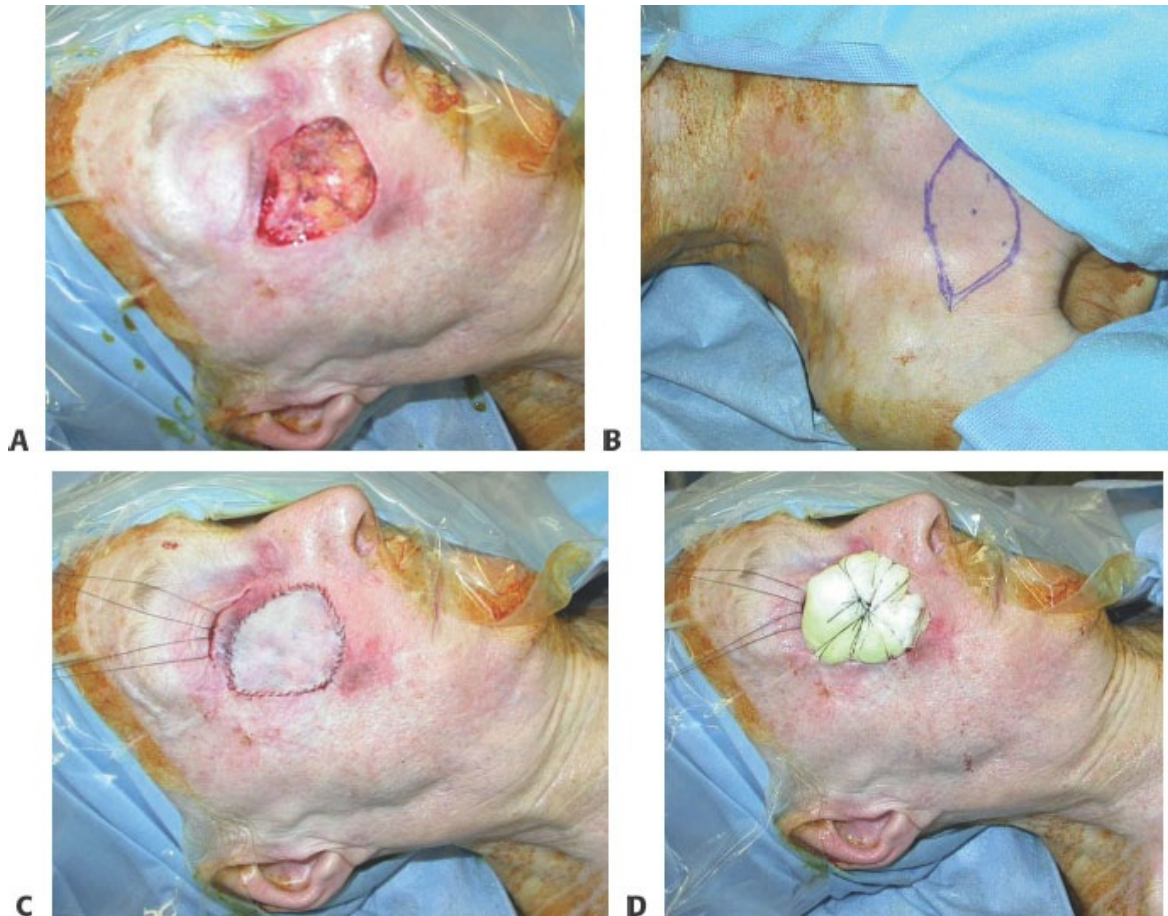
■ Cheek Reconstruction With Full-Thickness Skin

Graft

- The procedure can be performed under general or local anesthesia, depending on size of the wound, general medical condition, and patient preference.
 - Nerve blocks can enhance patient comfort.
 - The cheek can be anesthetized by injecting the infraorbital, zygomaticofacial, and mandibular branch of trigeminal (V₃) nerves.²
- The entire face and neck are prepped with a povidone-iodine solution and draped.
 - This wide exposure allows visualization of both sides of the face to check for symmetry and gives access to all donor sites.
- The wound bed is prepared.
 - If there is fibrinous material in the wound, it is cleaned down to healthy tissue (**TECH FIG 1A**). One simple way of doing this is by rubbing a dry piece of gauze in the wound, which will remove loose fibrinous material and nonviable debris.
 - A water-based device (eg, Versajet) can be used for more aggressive yet controlled debridement. For thick eschars (eg, burn wounds), a scalpel or Weck blade is used.
- A template of the defect is made with a sterile glove wrapper. An easy way to do this is to press the wrapper against the wound. The blood will stain the wrapper and outline the defect. This can then be cut with scissors and tailored to the shape of the defect.
- An appropriate donor site is then chosen. Donor sites within the face and neck have a better color match compared to more distal sites.
- The template is oriented on the donor site and marked (**TECH FIG 1B**).
 - Local anesthetic (0.25% bupivacaine with epinephrine) is infiltrated.
- The skin graft is harvested full thickness using a knife.
- The donor site is closed. Undermining of the edges can be done to help the closure.
- The skin graft is defatted on the back table.
 - This is performed by stretching out the graft using hemostats at four edges of the graft and placing of the nondominant finger.
 - A very thin layer of fat may be left in select cases with optimum recipient beds and can improve outcomes. This thin fat layer supports gliding of the

graft and may enable future revision with fat grafts to correct contour deformities if they arise.

- Care should be taken to avoid overthinning of grafts with removal of a portion of the dermis (in effect creating a split-thickness graft), as this will result in graft contracture and poor aesthetic outcomes.
- The graft may be pie crusted in a few small areas by making small slits with a no. 11 knife.
 - This allows egress of fluid during the initial few days when graft adherence to the wound bed is critical. This is not critical in all cases.
- The skin graft is then inset on the wound.
 - It is tacked in a few corners with 50 chromic sutures to anchor the graft (**TECH FIG 1C**).
 - Remainder of the skin graft can be sutured with a running technique. We often use 6-0 fast-absorbing gut sutures; however, nylon sutures may also be used.
 - A bolster dressing is created with Xeroform gauze or cotton balls soaked in mineral oil to fashion a tie over bolster (**TECH FIG 1D**).



TECH FIG 1 • **A.** Cheek defect after resection with negative margins. **B.** Full-thickness skin graft marked in the infraclavicular area. **C.** Full-thickness graft has been sutured in place and Frost sutures placed to support the lower eyelid. **D.** Bolster dressing sutured in place.

■ Cheek Reconstruction With Split-Thickness Skin Graft

- Split-thickness skin grafts are useful in patients in whom a full-thickness skin graft is not available or there are contraindications for full-thickness graft harvest (eg, massive burns, inadequate donor sites, medical contraindications).
- The face and neck are prepped and draped as above. The wound bed is

prepared.

- A template of the wound is made. This is used to mark the donor site.
- Split-thickness skin grafts can be harvested from any available donor site in the body.
 - Commonly they are harvested from the thighs due to easy accessibility.
 - Split-thickness skin grafts harvested from the scalp provide a better color match.
- The donor site is injected with 0.25% bupivacaine with epinephrine for pain control and hemostasis.
- The skin graft is harvested with a dermatome at a thickness of 0.012 to 0.014 inches.
- The donor site is then covered with an epinephrine-soaked gauze pad for hemostasis.
- Split-thickness skin grafts in the face are used as sheet grafts and are not meshed. Meshed grafts on the face are cosmetically unacceptable.
 - The graft is pie crusted by making small slits with a knife. This allows egress of fluid during the initial few days when graft adherence to the wound bed is critical.
- The skin graft is then inset on the wound.
 - It is tacked in a few corners with 50 chromic sutures to anchor the graft.
 - Remainder of the skin graft can be sutured with a running suture. We often use 6-0 fast absorbing gut sutures; however, nylon sutures may also be used.
 - A bolster dressing is created with Xeroform gauze or cotton balls soaked in mineral oil to fashion a tie over bolster.
- The donor site is dressed with alginate dressing and covered with a transparent membrane dressing (Opsite).

PEARLS AND PITFALLS

Graft thickness

- Full-thickness skin grafts are preferred for facial reconstruction. They have a better color, contour, and thickness match compared to split-thickness skin grafts.
- If split-thickness grafts are used, they should not be meshed if at

	all possible as this results in a cosmetically unacceptable appearance.
Wound bed	■ The wound bed should be well vascularized. It should be debrided to remove any fibrin or nonviable tissue that will impede graft take. ■ Hemostasis should be assured because blood under the skin graft will prevent graft adherence.
Donor site	■ Skin graft donor sites from the face and neck will have the best color match. Donor sites caudal to the clavicles have poor match. ■ A template of the defect should be created. This helps to accurately plan the skin graft harvest.
Appearance	■ Skin grafts may have a patchlike appearance. This is due to the difference in color, texture, and thickness between the donor and recipient sites (FIG 3). This becomes more obvious with sun exposure as the untanned skin grafted area becomes more visible compared to the tanned native skin. ■ Patch appearance can be minimized by selecting donor sites with a color match as close as possible to the defect (FIG 4). ■ Minimal thinning of the graft (and preservation of a thin layer of subcutaneous fat) improves the long-term appearance of the graft (FIG 5).
Postoperative care	■ Any fluid collections under the skin graft should be promptly evacuated with a needle or knife blade. ■ Infections can result in graft loss and should be treated early.
Revisions	■ Procedures like dermabrasion, laser, and dermal fat grafts can improve the final aesthetic result.

POSTOPERATIVE CARE

- The skin graft and bolster are kept dry and protected from trauma.
- The bolster is removed 5 to 8 days postoperatively.
 - If there is any accumulation of fluid under the skin graft, it is evacuated with a needle or small scalpel nick.
 - A thin layer of petrolatum jelly (Vaseline) is applied twice a day for approximately 3 weeks.
- Full-thickness skin grafts: The donor site can be washed in 24 hours.
- Split-thickness skin grafts: If the alginate dressing gets soaked, it can be changed in 24 to 48 hours. Otherwise, it is changed at the time of bolster removal.

OUTCOMES

- Dermabrasion can improve the appearance of skin grafts.³
 - This is done several months postoperatively, once the skin graft has completely healed. This helps smooth areas of contour irregularities.



FIG 3 • A. Split-thickness skin graft was used to treat a large cheek defect of an obese man with multiple medical comorbidities. **B.** 1 year postoperatively. **C.** Note shrinkage of graft with time and new biopsy site with dressing.

- Patients with large skin grafts or those at high risk for hypertrophic scar formation can be treated with facial pressure garments.⁴ Silicone sheeting can also be helpful.
 - There is some evidence, however, that pressure garments may cause disturbance of facial growth in children.⁵
- Laser therapy has been shown to help improve the appearance of facial scars.⁶
 - Pulse dye lasers can be used to improve the appearance of hypertrophic and erythematous skin grafts.
- Contour depressions that are unsightly can be improved with dermal fat grafts.⁷
 - This is done at least 6 months postoperatively or even longer if graft scar maturation has not occurred.
 - These grafts can be harvested from any part of the body, commonly around a pre-existing scar or the lower abdomen.

- The dermal fat grafts are contoured to the deformity and placed under the skin graft.

COMPLICATIONS

- Complete or partial skin graft loss can occur due to a blood or fluid collection under the graft or movement of the graft preventing graft adherence.
- Hemostasis at the wound bed should be assured prior to placement of skin graft.
- The graft should be bolstered securely to prevent graft movement.
- Infections can occur at the graft or donor site.
- Graft site infections can result in sloughing of the skin graft. Patients at risk are diabetics, immunocompromised, and smokers.
- Infections should be treated early with antibiotics.
- Secondary contracture of the graft can result in contour abnormalities and distortion of adjacent structures.
- Grafts close to the lower eyelid can result in cicatricial ectropion.



FIG 4 • A,B. This cheek defect was allowed to fill in by

granulation tissue over a 3-week period, and a full-thickness skin graft was harvested from the cervical area. **C,D.** Excellent contour and acceptable skin color match are seen postoperatively.

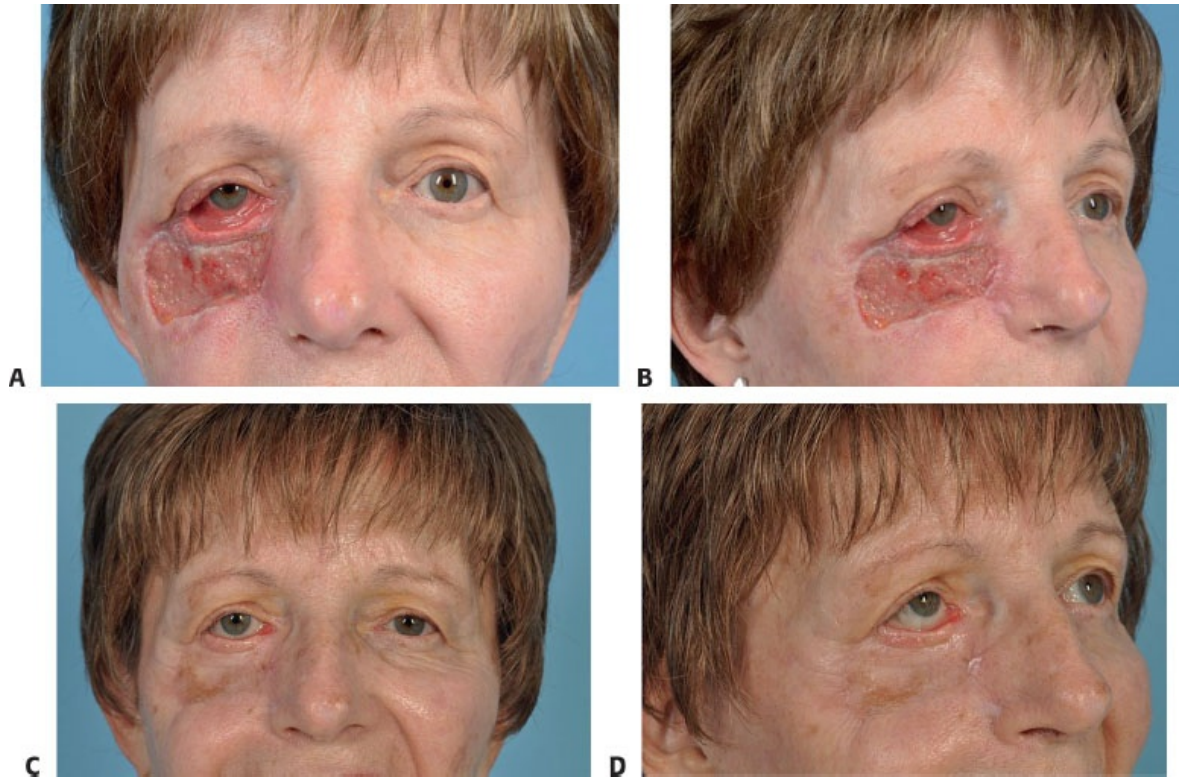


FIG 5 • A,B. Large defect in the upper cheek and lower eyelid area. A full-thickness skin graft was harvested from the upper chest area and thinned minimally after allowing the area to granulate and fill in for 2.5 weeks. **C,D.** Excellent contour and lack of graft shrinkage are seen postoperatively.

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Section IX: Ear

29 Antia-Buch Flaps for Ear Reconstruction

CHAPTER

Amir M. Ghaznavi and Brian R. Gastman

DEFINITION

- Antia-Buch flaps are best used for traumatic or postsurgical helical defects of the upper third and middle third of the ear that measure between 25% and 50% of length of the helix.¹

ANATOMY

- The ear is made up of delicate skin and soft tissues covering a cartilaginous framework and underlying muscles.
 - The cartilaginous portion of the ear includes the conchal bowl, antihelix, and helix.
 - The surrounding muscles of the ear can be divided into intrinsic muscles (muscles that originate and insert on the ear) and extrinsic muscles (muscles that originate in other regions of the skull and insert onto the ear).
- The intrinsic muscles include the helicis major, helicis minor, tragus, antitragus, transverse, and oblique muscles.
- The extrinsic muscles include the anterior, superior, and posterior auricular muscles.
- The arterial supply of the ear is derived from the posterior auricular artery and perforators arising from the superficial temporal artery.
- Venous drainage is provided by the posterior auricular veins that drain into the external jugular system as well as the superficial temporal and retromandibular veins.
- Lymphatic drainage of the ear is to the parotid, infraclavicular, mastoid, and

infraauricular cervical nodes.

- Sensory innervation of the ear is provided by:

1. Great auricular nerve (C2–C3)

- Auriculotemporal nerve (V3)
- Lesser occipital nerve
- Auricular branch of the vagus nerve (Arnold nerve)

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete history and physical exam of the head and neck should be performed to document the exact location of the defect within the ear (superior third, middle third, and lower third portions) and involvement of cartilage if present.
- The patient should also be examined for evidence of nodal metastases and secondary lesions in the head and neck region. Attention should be paid to the lymph node basins in the parotid and cervical areas.
- Comorbidities that can increase the risk of postoperative wound healing and bleeding complications should be evaluated and optimized if possible.

IMAGING

- No imaging is required for Antia-Buch flaps; however, imaging of the head and neck region may be necessary to evaluate tumor metastasis.

NONOPERATIVE MANAGEMENT

- Isolated skin defects of the helical rim with intact underlying cartilage and perichondrium can heal by secondary intention or full-thickness skin grafting.
- Full-thickness skin grafts can result in excellent outcomes in patients with preserved cartilaginous support. However, healing by secondary intention or skin grafting of more complex lesions that include full-thickness excision of the underlying cartilage may result in contour abnormalities and require more complex reconstructions.

SURGICAL MANAGEMENT

Preoperative Planning

- The contours of the ear are marked preferably before skin prep to avoid washing off.
- Patients who have large defects of the ear should be counseled that they may require contralateral reduction by wedge resection and/or setback of the

unaffected ear at a later time to obtain symmetry.

Positioning

- The patient is placed in a supine position with the entire ear exposed including the hairline.
- The bed is turned 180 degrees to allow unimpeded approach to the head and neck area.
- The contralateral ear may be exposed if planning on contralateral procedure and to evaluate symmetry.

Approach

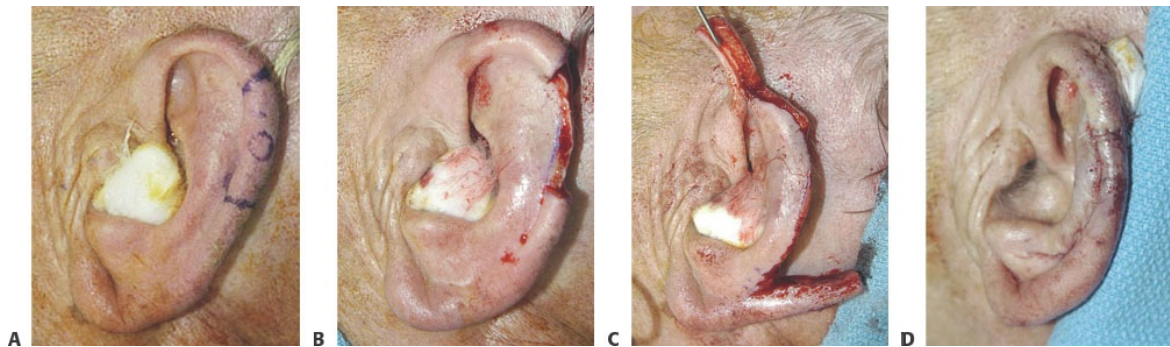
- Several surgical approaches have been described for Antia-Buch flaps including those for “classic” helix-only defects that are less than 25% of the total length of the helix, as well as modifications for longer defects and defects that include loss of the helix, scapha, and antihelix.
- Prophylactic antibiotics are administered by most surgeons particularly if the cartilage or perichondrium has been removed.
- Coverage with fluoroquinolones provides excellent cartilage penetration and provides coverage of common organisms that can cause infections of the ear (eg, *Pseudomonas aeruginosa*).
- Prolonged antibiotic treatment is usually not necessary unless the wound is contaminated or the patient is otherwise at risk for postoperative infections.

TECHNIQUES

■ “Classic” Helix-Only Defect¹

- The lesion and the proposed area of resection are identified and marked on the ear (**TECH FIG 1A**).
- The resection is performed with an incision in the helical sulcus to remove the lesion and separate the helical cartilage from the scapha (**TECH FIG 1B**).
- An incision is made in the helical sulcus (either inferiorly, superiorly, or both) extending through the anterior skin and cartilage taking care to avoid injury to the postauricular skin.

- The posterior skin is undermined superficial to the perichondrium to the level of the auricular cephalic sulcus, resulting in formation of a chondrocutaneous composite flap based on the posterior skin (**TECH FIG 1C**).
- If the defect is small (less than 10%), the inferior segment can be advanced, and the redundant Burrow triangle can be excised if necessary.
- For intermediate defects (10%–25%), both the superior and inferior portions need to be advanced for a tension-free closure (**TECH FIG 1D**).

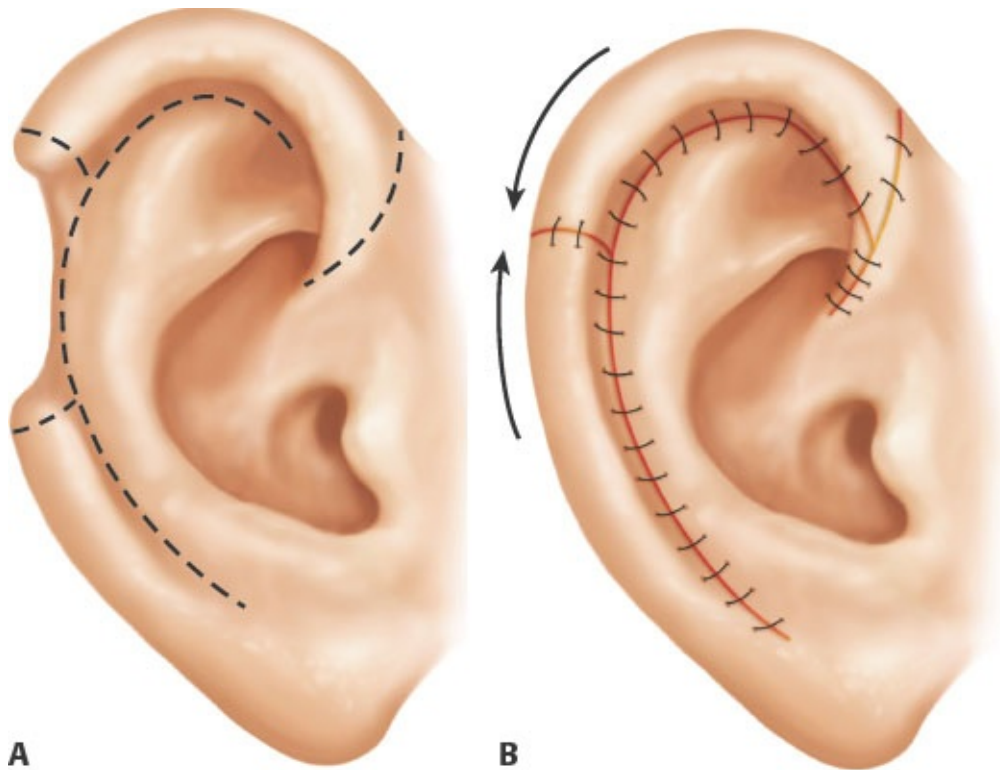


TECH FIG 1 • **A.** Helix defect marked. **B.** Helix freed from scapha. **C.** Formation of chondrocutaneous composite flaps superior and inferior. **D.** Composite flaps advanced and closed.

■ **Modification for Defects of More Than 25% of the Helix^{1,2}**

- Defects that are more than 25% of the total length of the helix may require a modification of the classic technique of closing the defect without tension.
- The superior and inferior incisions are performed as described above to elevate the chondrocutaneous composite flaps.
- Additional mobilization of the superior segment is obtained by performing a V-Y advancement flap of the root of the helix, thereby extending the reach of the superior flap (**TECH FIG 2**).
- If additional mobilization is necessary to avoid cupping of the ear or to obtain a tension-free closure, then the advancement of the superior flap can be increased with a wedge resection of the scaphal cartilage.

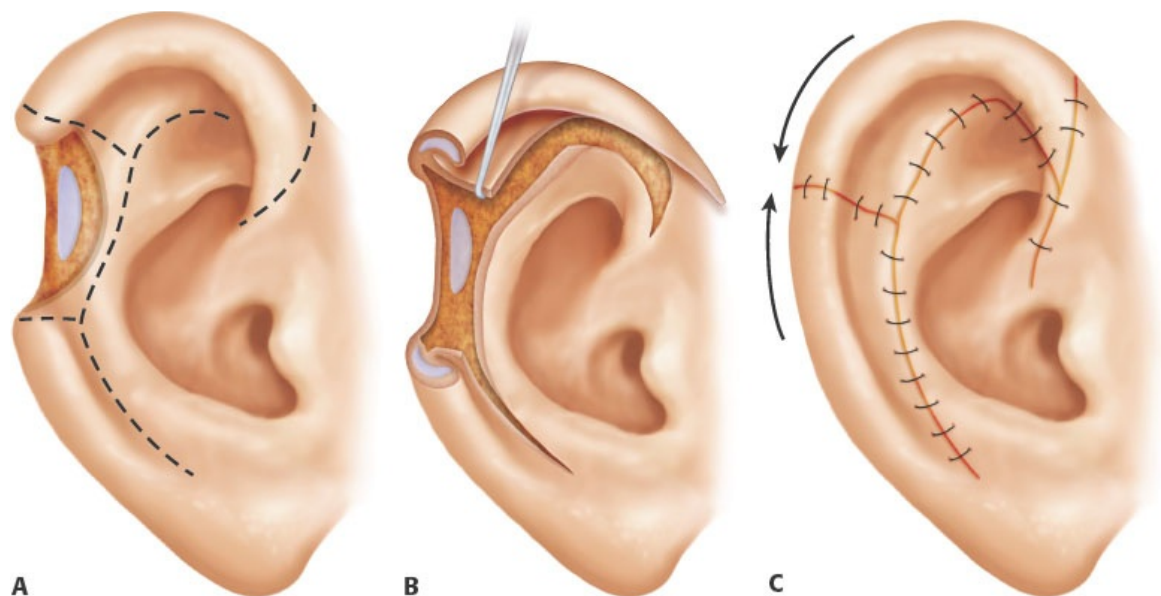
- Alternatively, the superior part of the scapha can be trimmed by a few millimeters to decrease the distance that the superior flap must advance.
- However, this modification will result in shortening the height of the ear.



TECH FIG 2 • A. Making a V cut into the root of the helix. **B.** Advancement of superior segments.

■ Modification for Defects Including the Helix and Scapha³

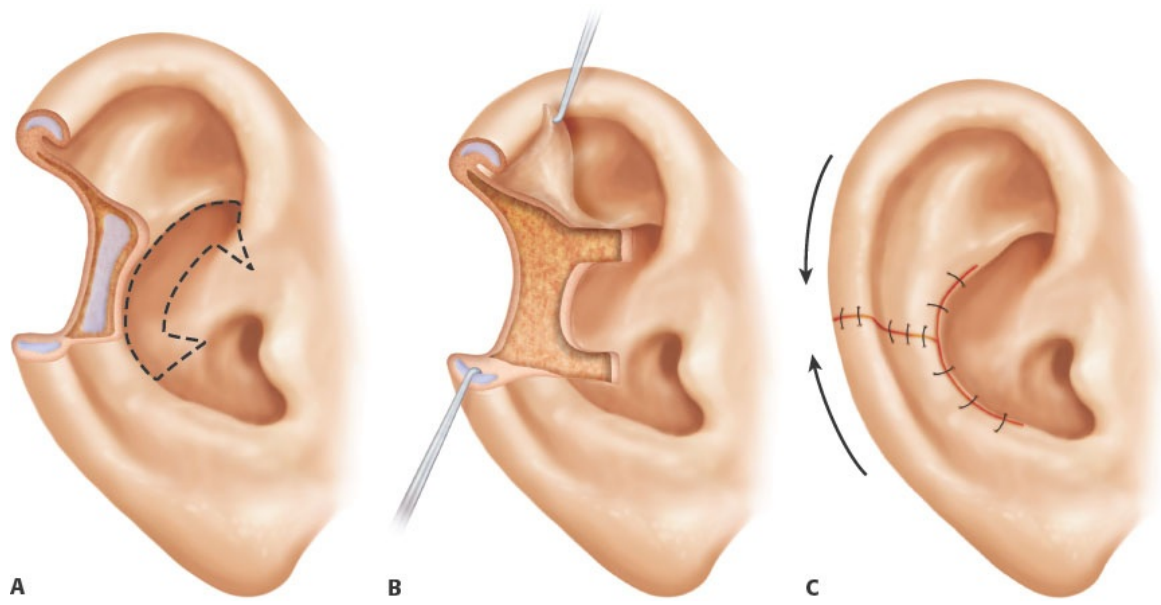
- In some cases, resection of tumors or traumatic lesions results in loss of the helix and a portion of the scapha.
- A modification of the Antia-Buch flap can be performed by excising a crescent-shape portion of the anterior chondrocutaneous tissues on either side of the defect (**TECH FIG 3A**).
- The superior and inferior segments are then advanced using the classic approach (with or without the helical root V-Y advancement flap) to close the resulting defect (**TECH FIG 3B,C**).



TECH FIG 3 • **A.** Helical-scapal defect. **B.** Helical-scapal defect with excision of the chondrocutaneous anterior tissue. **C.** Advancement of segments.

■ **Modification (C) for Helix, Scapha, and Antihelix^{4,5}**

- Resections of the ear that include the helix, scapha, and antihelix can also be closed with modification of the classic Antia-Buch flaps.
- In these cases, wedge excisions of anterior cartilage and skin of the superior and inferior poles of the concha are performed (**TECH FIG 4A**).
- A paring incision in the concha is performed to allow tension-free advancement of the superior and inferior segments (**TECH FIG 4B**).
- The superior and inferior segments are then advanced for wound closure (**TECH FIG 4C**).



TECH FIG 4 • A. Helical-scapal-antihelix defect. **B.** Paring incision in the concha and wedge resections. **C.** Advancement of segments.

PEARLS AND PITFALLS

Hemostasis	■ Meticulous hemostasis must be obtained.
Anesthetic	■ Avoid any epinephrine on anterior aspect of pinna to avoid possibility of skin necrosis.
Surgical technique	■ Care must be taken to avoid injury to the postauricular skin flap as it is the blood supply to the chondrocutaneous flaps. ■ The dissection should be performed superficial to the perichondrium.

POSTOPERATIVE CARE

- A noncompressive dressing can be applied for comfort.
- Topical antibiotic ointment can also be applied at the discretion of the surgeon once the dressing is removed.
- No postprocedure prophylaxis is required in most cases.
- Sutures are typically removed in 7 to 10 days.

- The patient should be advised to avoid pressure on the operated ear and should refrain from sleeping on the affected side.
- Patients who wear glasses should be advised to avoid wearing glasses or remove the stem from the affected side until healing has occurred.
- Patients should also avoid applying ice to the area postoperatively.

OUTCOMES

- Ramsey et al. reported 47 patients with chondrocutaneous helical rim advancement flaps of Antia and Buch. Indications were helical rim defects of 25% to 50%.⁶
- No necrosis was reported.
- Two patients had hematomas.
- Superior cosmetic results
- Noel et al. reviewed 15 retrospective patients after modified chondrocutaneous helical rim advancement flaps.⁷
- 2.5 cm mean defect size
- Upper flap changed to transposition flap rather than advancement flap thus eliminating resection of scapha
- No skin necrosis or hematoma

COMPLICATIONS

- Skin necrosis is a rare complication but may occur in smokers or patients who have untreated hematomas.
- It is generally managed conservatively if the area is clean but may require debridement and grafting or other reconstructive procedures for extensive skin/cartilage loss.
- Ear hematoma is more common and can be problematic if it is not managed expeditiously.
- Hematoma may cause cartilage growth/deposition (so-called cauliflower deformity) and may be very difficult to manage in a delayed setting.
- Large hematomas may cause skin and cartilage necrosis and infections. Hematomas should be drained either with a needle or more commonly by reopening the incision. Drains are rarely necessary.
- Infections are rare. Most respond quickly to oral antibiotics; however, more severe cases may require intravenous antibiotics and/or incision and drainage as necessary.

- Long-term edema is also uncommon but can be problematic when it occurs. Although the etiology of this is not known, this complication is likely related to impaired lymphatic drainage.
- Lymphatic massage and compression dressings may be helpful in these instances.
- Cancer recurrence and other causes of swelling should also be ruled out.

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30 Postauricular Flap for Ear Reconstruction

CHAPTER

Matthew M. Hanasono

DEFINITION

- Reconstruction of auricular defects arising from trauma or oncologic resection aims to restore the natural anatomic structures and landmarks of the ear and ideally should maintain balance and symmetry with the contralateral ear.
- Postauricular flaps are useful for reconstructing larger marginal defects of the upper and middle thirds of the auricle and are typically used in combination with cartilage grafts for reconstructing those defects that are too large for wedge or Antia-Buch chondrocutaneous advancement techniques.¹
- The postauricular flap is also known as the retroauricular flap or the Dieffenbach flap.
- Inferiorly based postauricular flaps can also be used for ear lobe reconstruction (see chapter on Reconstruction of the Ear Lobe).

ANATOMY

- The outer rim or helix creates the outer curvature of the ear and originates from the face at the root of the helix.
 - Concentrically, within the helix is the antihelix, which separates into two separate crura in the upper third of the ear that define the triangular fossa.
 - The scapha is the concave rim that separates the helix and antihelix.
 - The concha lies within the antihelix and is the structure that leads to the external auditory meatus.
 - The anterior border of the external auditory meatus is defined by the tragus.
 - In the lower third of the ear lies the lobule or ear lobe, which does not contain cartilage (**FIG 1A**).
- The blood supply to the auricle is through the posterior auricular artery and

superficial temporal artery.

- The posterior auricular artery runs in the sulcus between the auricular cartilage and the mastoid process of the temporal bone.
- This vessel supplies the posterior ear skin and posterior auricular muscle and sends perforating branches that pierce the auricular cartilage in the region of the triangular fossa, cymba conchae, cavum conchae, helical root, and ear lobe to supply the anterior ear skin (**FIG 1B**).^{2,3}
- The posterior auricular artery anastomoses with the superficial temporal artery through the superior auricular artery.
- Venous drainage is via the posterior auricular vein into the external jugular system and the superficial temporal and retromandibular veins.
- This rich anastomotic network of blood vessels is the basis for the postauricular flap.

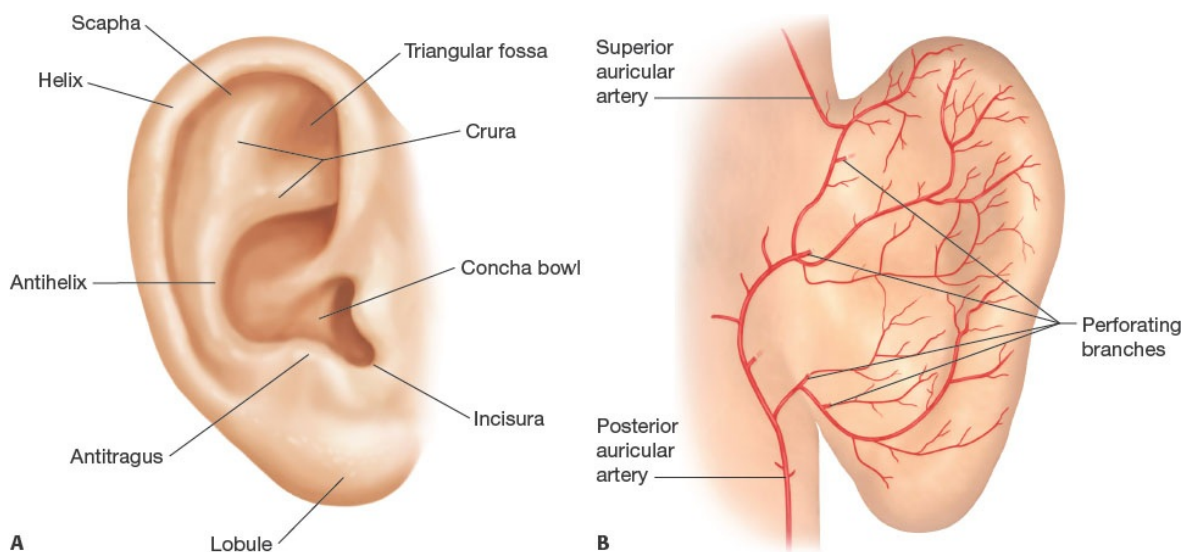


FIG 1 • A. Anatomy of the external ear. **B.** Arterial anatomy of the posterior ear. (The right ear is shown.) The posterior auricular artery provides the blood supply for the postauricular flap. It anastomoses with the superficial temporal artery via the superior auricular artery.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical should be obtained prior to any operation by

paying close attention to significant comorbidities, including smoking history, prior surgeries including scars in the postauricular area, and medications that may predispose the patient to bleeding.

- Patients who wear glasses should also be educated in postoperative care and management of incisions.
 - They may need to remove the earpiece of the glasses on the reconstructed side until adequate healing has occurred, and then replace the earpiece.
- Defects resulting from oncologic resection should consider documentation for clear margins or Mohs excision prior to definitive reconstruction.

IMAGING

- Patients who have undergone resection for aggressive cutaneous malignancies may require imaging studies or staging and to rule out metastatic disease.

SURGICAL MANAGEMENT

- Postauricular flaps used in ear reconstruction can be based in the superior, middle, or inferior postauricular and mastoid region.²
- They are indicated for marginal reconstruction, in combination with cartilage grafts to support and give definition to the helix, in a staged manner as originally proposed by Dieffenbach (**FIG 2**).

Preoperative Planning

- The extent of the defect should be evaluated prior to reconstruction.
 - Postauricular flaps are preferred over wedge resections and closure, eg, for defects that encompass more than one-fourth to one-third of the outer circumference of the ear.
 - The defect size should be compared to the amount and reach of available postauricular skin.
- Pathology should be reviewed to confirm that clear margins have been obtained prior to proceeding with reconstruction.
 - In the setting of melanoma and squamous cell carcinoma, it is important also that the sentinel lymph nodes are negative as well.
- If the patient is taking anticoagulants, these should ideally be discontinued before surgery to minimize risks of hematoma.
 - If the anticoagulation cannot be continued, the patient should be made to understand the increased risks of bleeding and hematoma as complications.

Positioning

- Proper patient positioning is critical to prepare for the reconstruction again to allow the reconstructive surgeon the best access, exposure, and approach to the ear.
- The patient is placed into the supine position, and the bed can be turned 180 degrees to give access to both ears.
- It is helpful to prep and drape the entire head again to give full access and exposure to both ears.
- Local anesthetic with epinephrine is useful, despite anecdotal reports of potential risks for inducing ischemia to the ear.

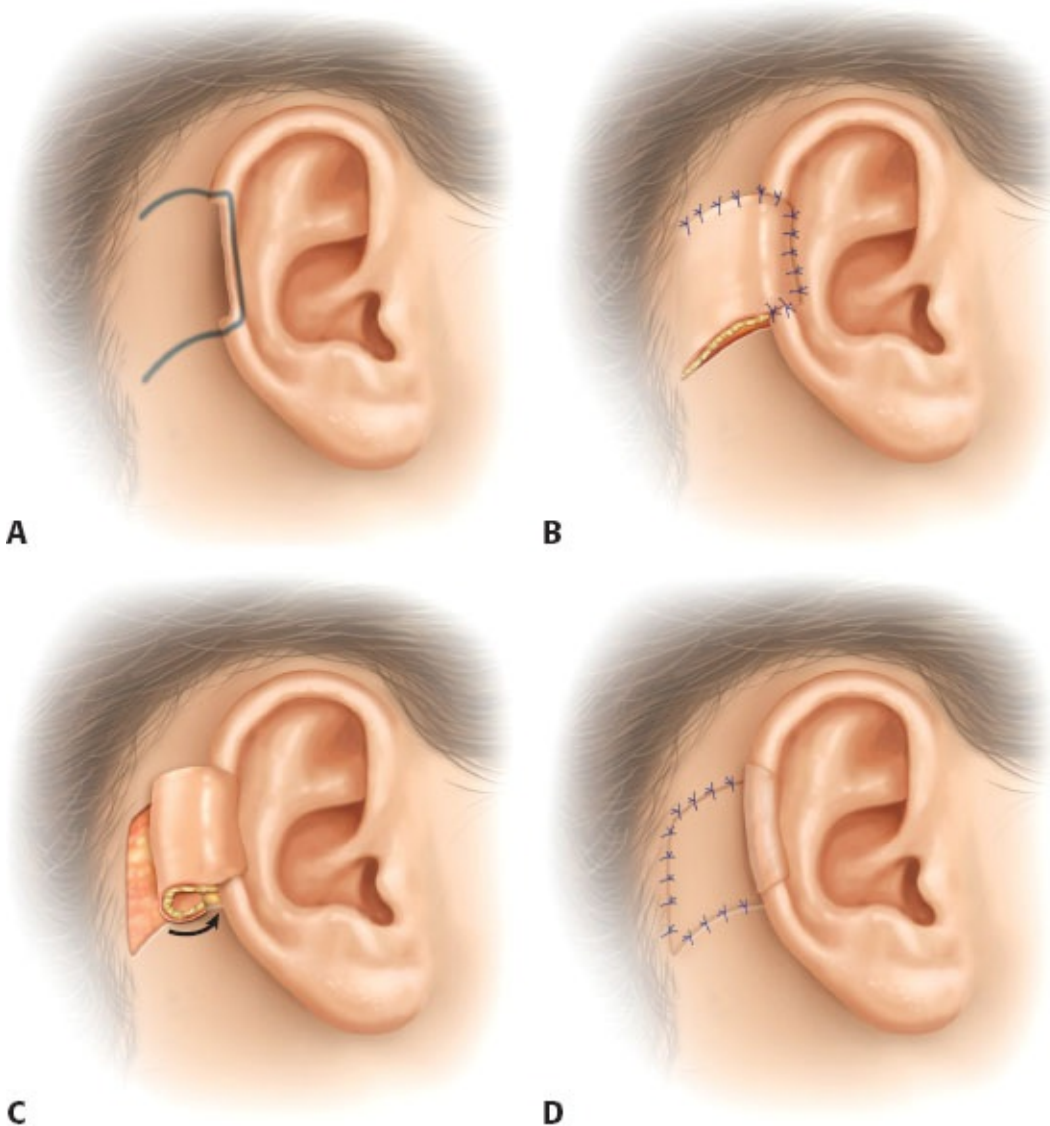


FIG 2 • Method of reconstructing marginal ear defects with the postauricular flap, as originally described by Dieffenbach. The postauricular flap is initially elevated **(A)**, and the flap is transposed from the posterior auricle to the anterior auricle during inset **(B)**. A helical cartilage graft is strongly recommended to preserve the shape of the ear and give definition to the helix, although not included in the original description by Dieffenbach. At a second stage, the base of the flap is divided **(C)**, and the flap donor site is skin grafted **(D)**.

TECHNIQUES

■ Postauricular Flap for Marginal Auricular Defects

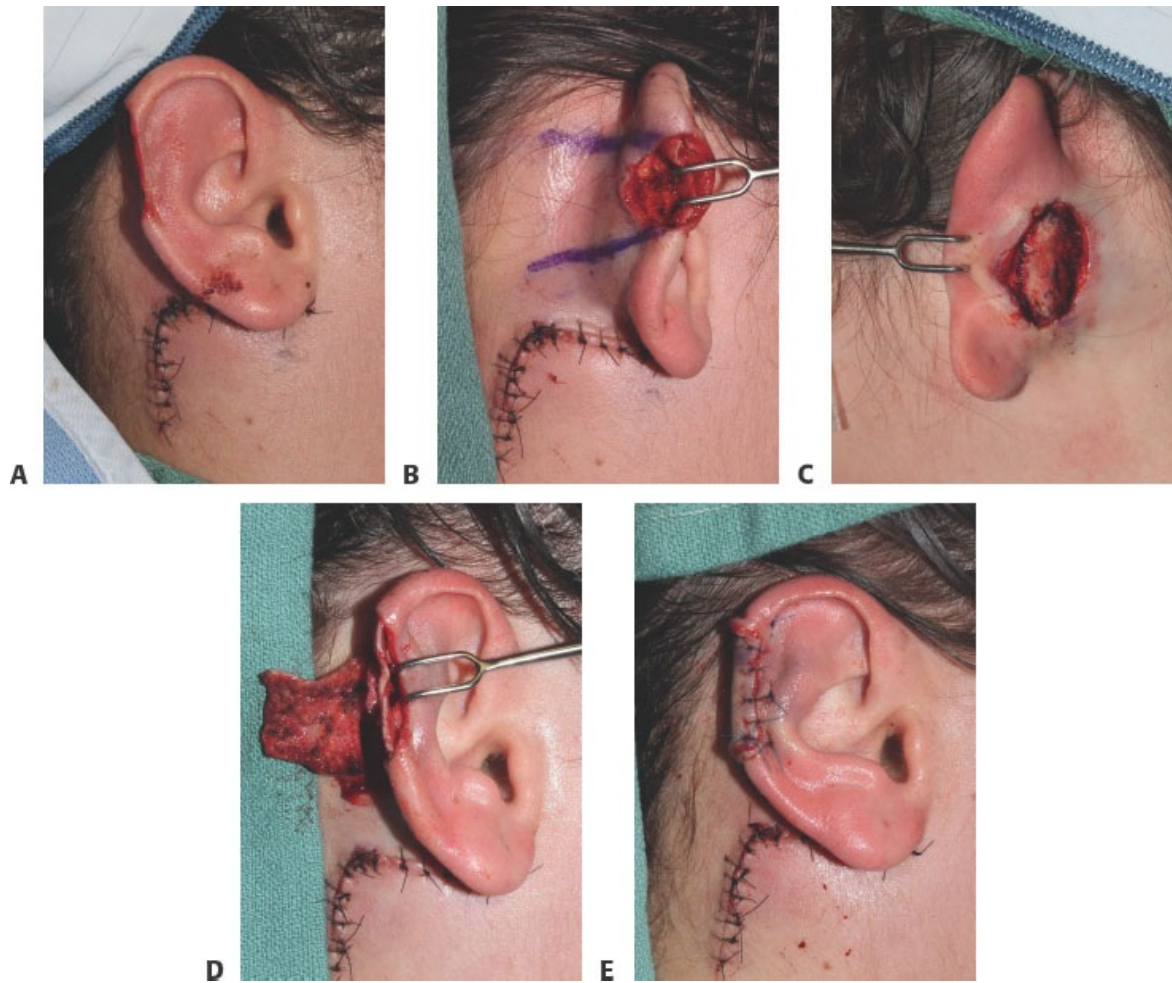
Stage 1

- The postauricular flap is used for reconstruction of marginal auricular defects that include the helix as part of a two-stage reconstruction (**TECH FIG 1A**).
- In the first stage, a posteriorly based flap is elevated and advanced anteriorly in a horizontal configuration (**TECH FIG 1B**).
 - The flap should include the subcutaneous fat but not the periosteum.
 - Although an extended retroauricular advancement flap that includes hair-bearing scalp skin has been described by Butler,⁴ in most cases, the base of the flap is in the mastoid region and the postauricular artery is not divided, if possible.
- Although the original description of the technique by Dieffenbach specified a skin flap only, a cartilage graft provides better definition of the helix and prevents collapse of the auricle as the flap heals and contracts.
 - The naturally curved cartilage from the contralateral conchal bowl serves as an excellent source of graft material.
 - Either a postauricular approach (**TECH FIG 1C**) or anterior incision made just inside the antihelical fold can be used to harvest the cartilage.

- The distal postauricular flap is used to resurface the anterior skin of the auricle (**TECH FIG 1D,E**).
 - Mattress sutures are used at the margin of the helix, to help prevent notching by providing skin eversion.
 - The auricle will be pinned back by the attachment of the flap to the mastoid region.

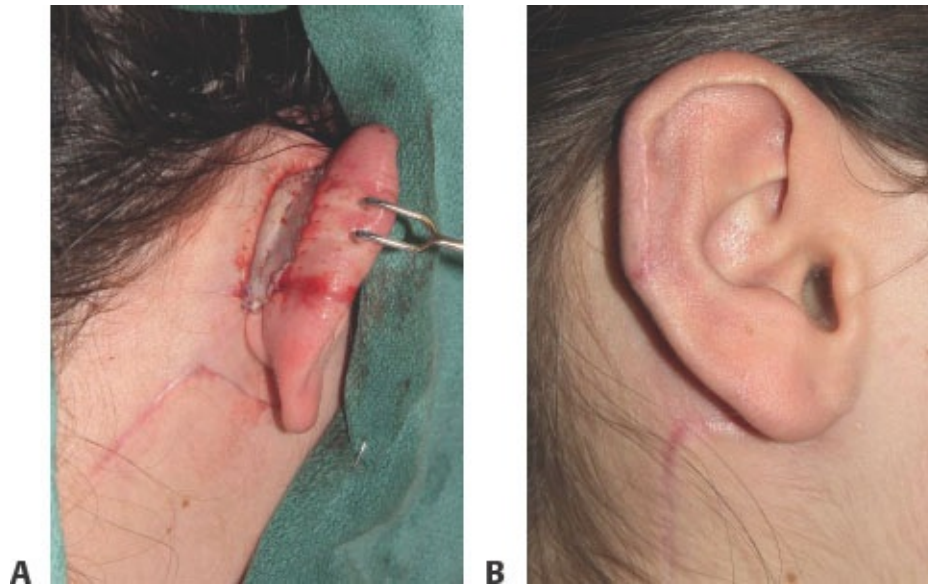
Stage 2

- Four to 6 weeks later, after secondary revascularization, the posterior aspect of the flap is divided.
- The ear can then be elevated, and the flap is advanced and inset into posterior surface of the auricle to complete the reconstruction.
- The mastoid donor site, which has periosteum at its base, is reconstructed with a full-thickness skin graft that is bolstered with a tie-over dressing for 5 days (**TECH FIG 2A**).
- The completed reconstruction is shown in **TECH FIG 2B**.
- A second example of a lower third auricular defect involving part of the lobule that was reconstructed with a more inferiorly based postauricular flap is shown in **TECH FIG 3**.

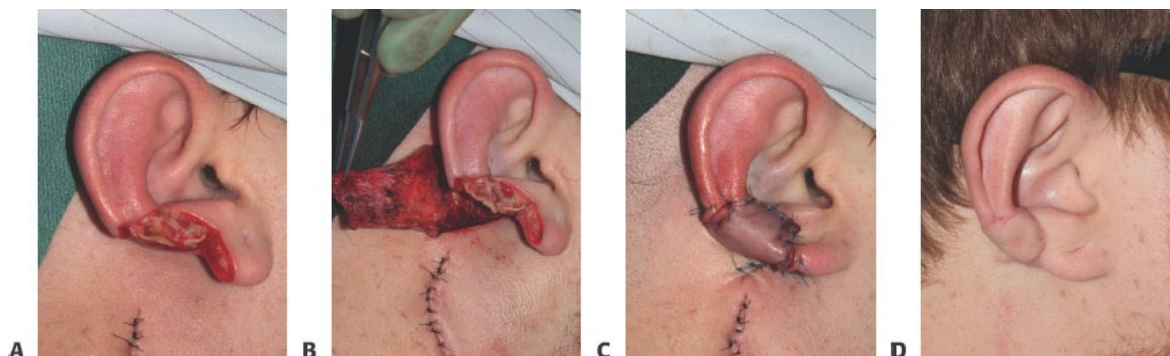


TECH FIG 1 • A. A helical rim defect of the central one-third of the ear. The lower incision, which has been sutured, is from a sentinel lymph node biopsy. **B.** A postauricular flap is designed, extending into the postauricular sulcus, but the postauricular artery is not divided. **C.** A contralateral conchal cartilage graft is harvested to provide support and definition to the helical rim. The graft may be obtained through an anterior or posterior (shown here) approach. **D.** The conchal cartilage graft has been secured in place with either permanent or long-acting absorbable sutures. The postauricular flap has been elevated. The plane of dissection is above the perichondrium of the ear cartilage and the periosteum of the mastoid process

bone. **E.** Completed flap inset. The edges of the flap at the margin of the ear are everted to help prevent notching at the helix.



TECH FIG 2 • A. At the second stage, 4 to 6 weeks later, the base of the flap is divided and the proximal flap is advanced onto the posterior auricle and sulcus. A full-thickness skin graft is then placed over the mastoid periosteum and secured with a bolster dressing. **B.** Postoperative results following postauricular flap and conchal cartilage graft reconstruction of a middle one-third auricular helical defect.



TECH FIG 3 • A. Lower one-third of the auricle marginal surgical defect. The auricular cartilage has been spared. **B.** Completed postauricular flap elevation, including the postauricular skin and subcutaneous fat with the flap, while preserving the perichondrium and periosteum of the donor site. **C.** Completed postauricular flap inset. **D.** Postoperative result following postauricular flap reconstruction and second-stage flap division and skin grafting of the donor site for a lower one-third auricular defect.

PEARLS AND PITFALLS

Preoperative care	■ The use of local anesthetic with epinephrine is not contraindicated in auricular reconstruction.
Technique	■ The defect should be assessed accurately to determine whether a postauricular flap reconstruction is feasible without creating a greater deformity and distortion of the ear. ■ Cartilage grafts are necessary to preserve the shape of the ear. An early result without cartilage may seem satisfactory, but without structural support, the flap will contract with time and the shape of the ear will be distorted.
Hemostasis	■ Hemostasis is critical as a hematoma can severely compromise the viability of the cartilage, distort the underlying structure, and adversely impact the final cosmetic result.
Postoperative care	■ Avoid any pressure or trauma to the reconstructed ear, including wearing of glasses and sleeping on the side of the reconstructed ear.

POSTOPERATIVE CARE

- Because permanent sutures are used to reapproximate the skin, the sutures will need to be removed in approximately 7 to 10 days.

- The incision should be cleaned regular with soap and water, paying careful attention to avoid trauma or pressure to the ear.
- Pressure dressing is usually not recommended.
- Antibiotic ointment can be used following surgery at the surgeon's discretion.
- Patients should avoid sleeping on the side of the ear that has been reconstructed.
- Patients should also refrain from wearing glasses.
 - If patients do not wear contacts and have to wear glasses, it is recommended that the earpiece on the reconstructed side be removed to avoid any potential trauma to the reconstructed ear.

COMPLICATIONS

- Infection of the ear and cartilage can be a serious complication that can lead to loss of additional cartilage and necrosis of the tissue. This can then result in a much more extensive ear defect, larger than the original defect.
 - Although extended prophylactic antibiotics are not generally recommended, a fluoroquinolone is considered the antibiotic of choice in the perioperative period due to good tissue penetration of cartilage and coverage for *Pseudomonas aeruginosa*.
- Bleeding can lead to significant distortion of the ear and underlying cartilage. Meticulous hemostasis is mandatory at the time of the operation.
- Notching of the helix is a common complication following reconstruction of marginal defects.
 - This can usually be revised satisfactorily several months later after primary healing of the cartilages and resolution of tissue edema.

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31 Reconstruction of the Ear Lobe

CHAPTER

Matthew M. Hanasono

DEFINITION

- Ear lobe defects can result following trauma or following resection of cutaneous malignancies.
- The simplest types of resection and reconstruction for skin cancers on the ear lobe are amputation-type resections. These can be carried out along a curved line to approximate the curvature of the lower border of the ear lobe. Most of the procedures will result in loss of volume or height (ptosis) of the lobule.
- The ear lobe is difficult to reproduce surgically because it has a characteristic protuberance that consists of fibrofatty tissue rather than cartilage.
- Many techniques have been described for ear lobe reconstruction.^{1–8}
 - Most require more than a one-stage operation.

ANATOMY

- Ear lobes (ear lobules) occur in the lower third of the ear. They consist of areolar and fibrofatty tissue and lack cartilage.
- The ear lobes are usually about 2 cm long and may or may not be attached to the cheek to a variable degree, a characteristic that is thought to be inherited.
- The ear lobe should lie roughly even at the level of the nasal ala, which is typically half the distance between the eyes and mentum.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical should be obtained prior to any operation paying close attention to significant comorbidities, including smoking history, and prior surgeries including scars in the area that may impact the design preauricular and postauricular flaps.

- Preauricular and postauricular skin laxity should be assessed to plan whether a single folded flap can be used or if double-opposing flaps will be required.
- For example, young patients and patients who have had a face-lift may not have adequate preauricular skin laxity to create a flap and still close the donor site primarily. Sentinel lymph node biopsy and neck dissection incisions may also preclude some local flaps.

IMAGING

- Patients who have undergone resection for cutaneous malignancies such as melanoma and squamous cell carcinoma may require imaging studies for staging and to rule out potential for metastatic disease.

SURGICAL MANAGEMENT

- Numerous reconstructive techniques have been described to restore the ear lobe, all based on single or double local flaps.
- Based on the availability of preauricular and postauricular tissue, a single folded flap or double-opposing flaps can be used for ear lobe reconstruction.
 - Single flaps are usually folded and may be designed as bilobed flaps.
- Use of an anteriorly based transverse folded flap is known as Gavello procedure.³
 - The advantage of this procedure is that it is usually a single-staged procedure. A cartilage graft may be added to give support and prevent contracture, and the donor site is usually skin grafted.
 - The negative is the long length of the flap and the possibility of a donor-site scar (**FIG 1A**).
- Folded preauricular or postauricular flaps usually need a thin cartilage graft to maintain ear lobe height (**FIG 1B**).
- Double-flap reconstruction with preauricular and postauricular skin flaps usually does not require grafts (**FIG 1C,D**).⁶
- The author's preferred technique is to use double-opposing preauricular and postauricular flaps for ear lobe reconstruction.

Preoperative Planning

- Pathology should be reviewed to confirm that clear margins have been obtained prior to proceeding with reconstruction. In the setting of melanoma, it is important also that the sentinel lymph nodes are negative as well.
- The extent of the defect should be evaluated prior to reconstruction. Partial

defects are more likely to be able to be managed with a single flap and less likely to need a cartilage graft to maintain ear lobe height.

- If earrings are to be worn postoperatively, a hole in the cartilage graft, if used, will likely need to be made by the surgeon.
- If the reconstructed ear lobe cannot be made to match the contralateral ear lobe in height, the contralateral ear lobe can be reduced by performing an amputation or posterior skin transverse wedge excision.
- For single-lobe reconstructions in which a cartilage graft is used, nasal septal cartilage or conchal cartilage can be used.

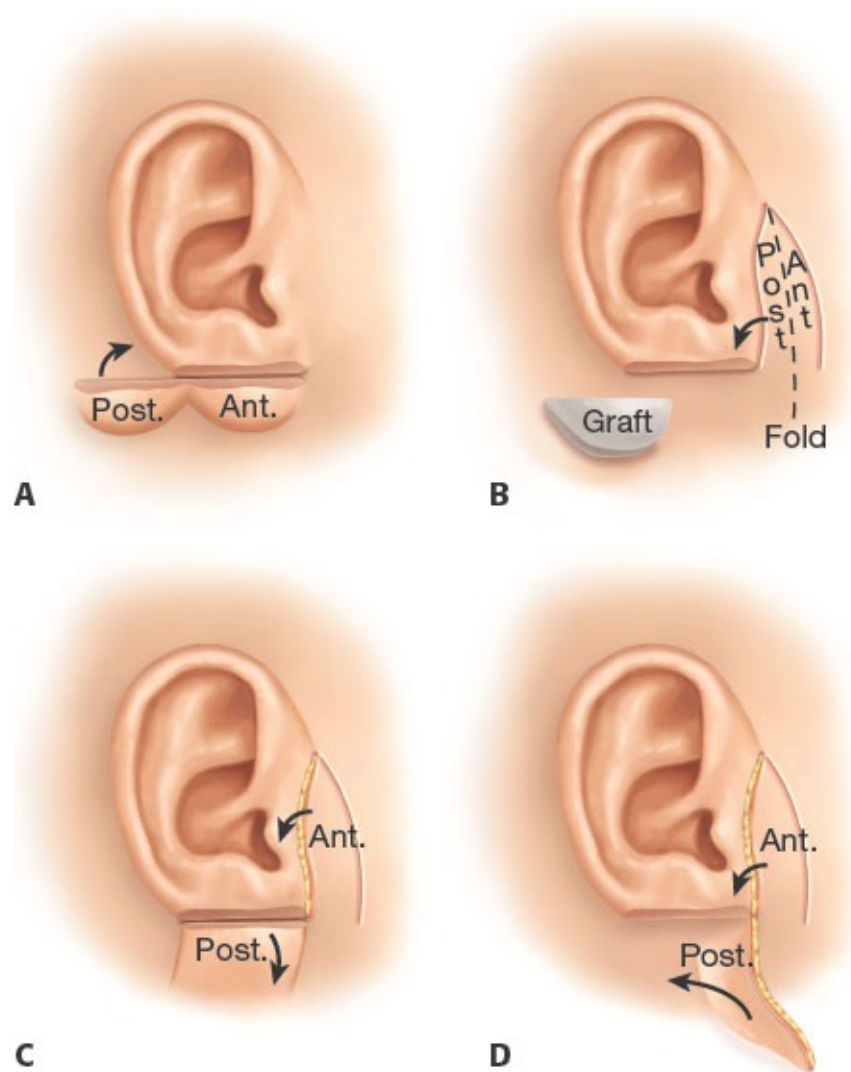


FIG 1 • Some methods of ear lobe reconstruction with local flaps. **A.** Transversely oriented, bilobe flap

originally described by Gavello. **B.** Inferiorly based preauricular flap that is folded longitudinally. A cartilage graft is needed to maintain ear lobe height. **C.** Double-opposing flap technique in which a postauricular flap becomes the posterior surface of the ear lobe and a preauricular flap becomes the anterior surface of the ear lobe. No cartilage graft is usually needed. The postauricular flap is divided at its base to release the ear lobe from the postauricular (mastoid) region, and the donor site is skin grafted at a second stage. **D.** Double-opposing flap technique in which a superiorly based postauricular (infra-auricular) flap becomes the posterior surface of the ear lobe and a preauricular flap becomes the anterior surface. The donor sites are closed primarily, and a second stage may not be necessary, although, in practice, a second stage is often needed to revise the anterior attachment of the reconstructed ear lobe.

Positioning

- The patient is placed into the supine position, and both ears should be prepped and draped to give full access and exposure to both ears.
- Additionally, if septal cartilage is to be used as a graft, the nose should be exposed and prepped.
- Local anesthetic with epinephrine is useful, despite anecdotal reports of potential risks for inducing ischemia to the ear. This can also be injected into the subperichondrial plane to assist with septal cartilage harvest, in addition to applying 4% cocaine-soaked pledgets against the septal mucosa.

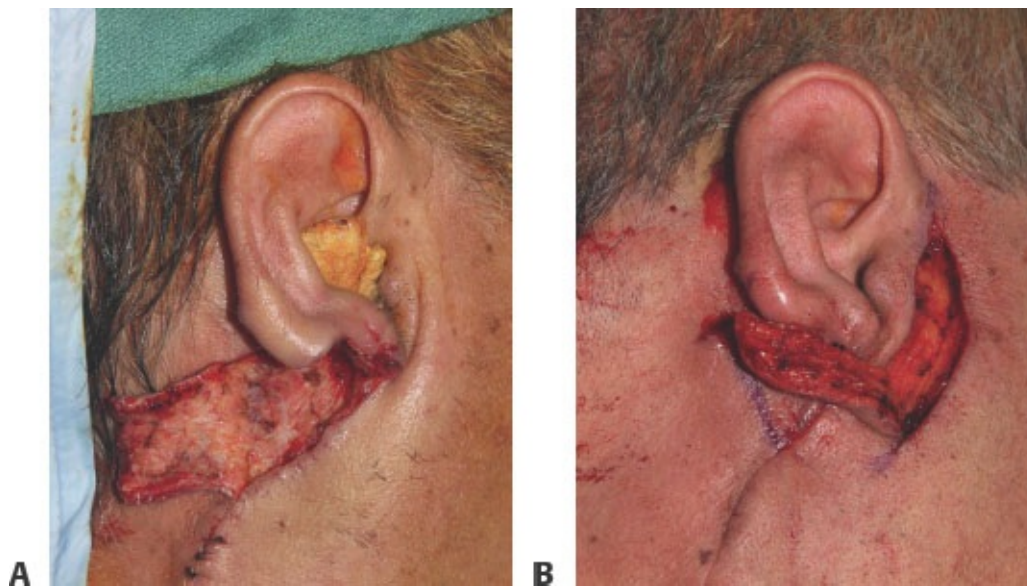
TECHNIQUES

■ Double-Opposing Preauricular and Postauricular

Flaps

Stage 1

- Although superiorly based postauricular skin flaps, extending into the infra-auricular neck, have been described,⁷ a more reliable postauricular skin flap is an inferiorly based one used to reconstruct the posterior surface of the ear lobe (**TECH FIG 1A**).
 - The flap is elevated from the mastoid process of the temporal bone, sparing the periosteum.
- An inferiorly based preauricular skin flap is designed (**TECH FIG 1B**).
 - The width of the flap should be at least the height of the ear lobe to be reconstructed, if possible.
 - Slight overcorrection is desirable in that the flap will contract slightly and, also, this allows the scar to be hidden posteriorly.



TECH FIG 1 • **A.** Right ear lobe defect to be reconstructed with double-opposing postauricular and preauricular flaps. The postauricular flap is elevated, leaving the mastoid periosteum intact. **B.** A preauricular flap is then elevated, leaving the parotid fascia intact. The width of this flap is ideally at least as large as the height of the original ear lobe.

- The flap should include the subcutaneous fat and be elevated above the parotid fascia.
- The flaps are opposed to each other.
- A cartilage graft is not necessary to prevent contracture in double-opposing flap reconstruction and will also make the ear lobe unnaturally stiff and bulky.
- Because the postauricular flap is still connected to the mastoid skin, the ear lobe will be pinned back temporarily until second-stage surgery.

Stage 2

- At a second stage, the postauricular skin flap is divided, releasing the reconstructed ear lobe from the mastoid region (**TECH FIG 2A**).
- The postauricular donor site is skin grafted.
- The base of the anterior flap can also be refined by partial division, if needed.
- The postoperative result is shown in **TECH FIG 2B**.



TECH FIG 2 • A. The preauricular and postauricular flaps have been joined, and at a second stage, the base of the postauricular flap has been divided, releasing the proximal flap and allowing it to be inset. The donor site is reconstructed with a full-thickness skin graft. **B.** Postoperative appearance showing good

ear lobe height and cosmesis.

PEARLS AND PITFALLS

Preoperative Care

- The use of local anesthetic with epinephrine is not contraindicated in auricular reconstruction and minimizes the need for cauterization.

Technique

- The choice of flap is made based on the laxity of the preauricular and postauricular skin.
- Single longitudinally folded flaps often contract and do not give adequate height (ptosis) unless they are very wide and a cartilage graft is added to maintain the ear lobe shape.
- Double-opposing flaps have less tendency to contract, even without cartilage grafts.
- Consider shortening the contralateral ear lobe if the reconstructed ear lobe does not match/cannot be made to match.
- Loss of ear lobe height can be avoided by not longitudinally folding a single flap or by using an anterior and a posterior flap (**FIG 2**).
- Alternately, loss of length can be avoided by placing a nonanatomic cartilage graft into a single folded flap.

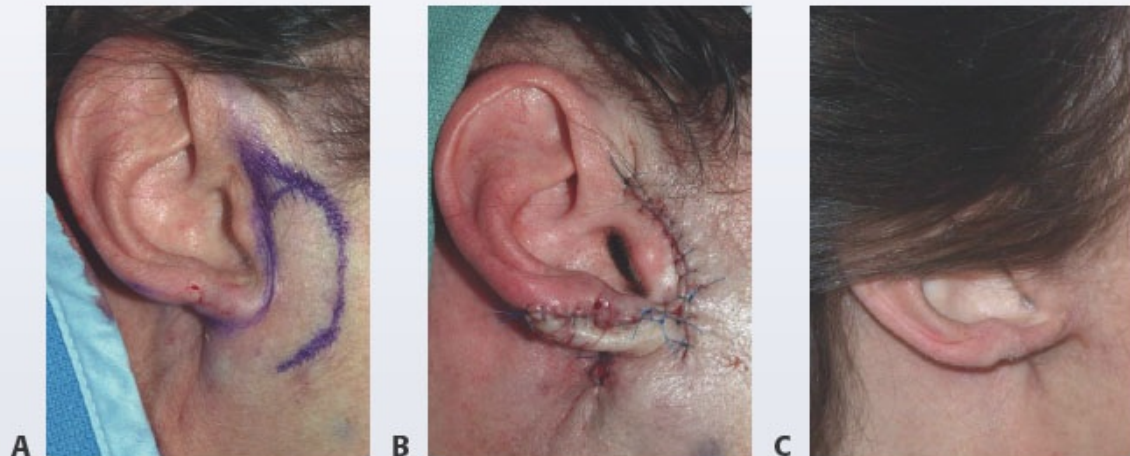


FIG 2 • A. A longitudinally folded preauricular flap is used for ear lobe reconstruction. **B.** Although the reconstructed ear lobe initially looks like it has good height, it will contract because no cartilage

graft was used. **C.** Postoperative appearance, showing loss of ear lobe height.

Postoperative Care

- Avoid any pressure or trauma to the reconstructed ear including wear of glasses and sleeping on the side of the reconstructed ear.

POSTOPERATIVE CARE

- Since permanent sutures are used to reapproximate the skin, the sutures will need to be removed in approximately 7 to 10 days.
- The incision should be cleaned regularly with soap and water, paying careful attention to avoid trauma or pressure to the ear.
- Pressure dressings are not recommended, because they may compromise blood flow to the flap.
- Patients should avoid sleeping on the side of the ear that has been reconstructed.

COMPLICATIONS

- If there is significant tension on the closure, there is a risk for dehiscence.
 - Again, the patient should avoid any trauma or displacement of the ear during the early recovery period to avoid any undue tension on the closure.
- Partial or total flap loss is a risk that can be minimized by keeping skin flaps thick, to maximize vascularity, and avoiding inset under tension.
 - In some cases, tight sutures must be released, even if it means needing to do a revision or delayed wound closure.
 - Medicinal leeches may also be useful for treating flap venous congestion.

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Wedge Reconstruction of Partial Auriclectomy Defects

CHAPTER

Edward I. Chang and Matthew M. Hanasono

DEFINITION

- Partial ear defects can result following trauma or more commonly following resection of cutaneous malignancies.
- Wedge resection and closure techniques are appropriate for defects up to one-third of the outer circumference of the ear occurring in the upper two-thirds of the ear.
- Reconstruction of such defects aims to restore the natural anatomic structures and landmarks of the ear and ideally should maintain balance and symmetry with the contralateral ear.^{1–3}

ANATOMY

- The ear is an important component both in the aesthetic balance of the face and in auditory function (it funnels sound into the external auditory canal and selectively amplifies sounds in the frequency range of human speech).
- The anatomic landmarks of the ear are defined by the underlying cartilaginous framework, which create the contours that should be restored as best as possible during wedge reconstruction of the ear.
- The outer rim or helix creates the outer curvature of the ear and originates from the face at the root of the helix (**FIG 1**).
- Concentrically within the helix is the antihelix, which separates into two separate crura in the upper third of the ear that define the triangular fossa.



FIG 1 • Anatomy of the auricle. Landmarks need to be precisely realigned in ear wedge resection and reconstruction.

- The scapha is the concave rim that separates the helix and antihelix.
- The concha lies within the antihelix and is the structure that leads to the external auditory meatus.
- The anterior border of the external auditory meatus is defined by the tragus. In the lower third of the ear lies the lobule or ear lobe, which does not contain cartilage.³⁻⁵
- The ideal proportions of the external ear are variable based on age and gender.
 - The length of the ear should be approximately twice the width and should project 1.5 to 2 cm from the head.⁴
 - The superior most part of the ear should be level with the position of the brow or just cephalad to the orbits, which are typically situated in the middle of the face.
 - The ear lobe should lie roughly even at the level of the nasal ala, which is

typically half the distance between the eyes and mentum.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical should be obtained prior to any operation paying close attention to significant comorbidities including smoking history, prior surgeries including scars in the area that may impact the design of the wedge resection, and medications that may predispose the patient to bleeding.
- Patients who wear glasses should also be educated in postoperative care and management of incisions.
 - They may need to remove the earpiece of the glasses on the reconstructed side until adequate healing has occurred before replacing the earpiece.
- Defects resulting from oncologic resection should consider documentation for clear margins or Mohs excision prior to definitive reconstruction.

IMAGING

- Patients who have undergone resection for cutaneous malignancies such as melanoma and squamous cell carcinoma may require imaging studies for staging and to rule out potential for metastatic disease.

SURGICAL MANAGEMENT

- Reconstruction of the ear using a wedge resection approach will result in an asymmetry compared to the contralateral ear.^{6,7}
 - The reconstructed ear will typically be smaller and may also have increased projection compared to the normal ear.
 - The anticipated result should be discussed with the patient prior to embarking on reconstruction using this technique.
- In the trauma setting, nonviable tissue should be debrided prior to definitive reconstruction.
- Topical sulfamylon can be helpful in preventing subsequent chondritis, given the effective bioavailability with cartilage penetration.
- After adequate healing and, in the case of cancer, a satisfactory surveillance period during which no recurrences are detected, wedge resection of the contralateral ear for symmetry can be offered to the patient.

Preoperative Planning

- The extent of the defect should be evaluated prior to reconstruction.
 - A wedge resection technique is appropriate for defects that encompass less

than one-third of the outer circumference of the ear.

- Larger defects will create significant projection and cupping of the ear.
- Pathology should be reviewed to confirm that clear margins have been obtained prior to proceeding with reconstruction. In the setting of melanoma and squamous cell carcinoma, it is important also that the sentinel lymph nodes are negative as well.
- Local anesthetic with epinephrine is useful, despite anecdotal reports of potential risks for inducing ischemia to the ear.

Positioning

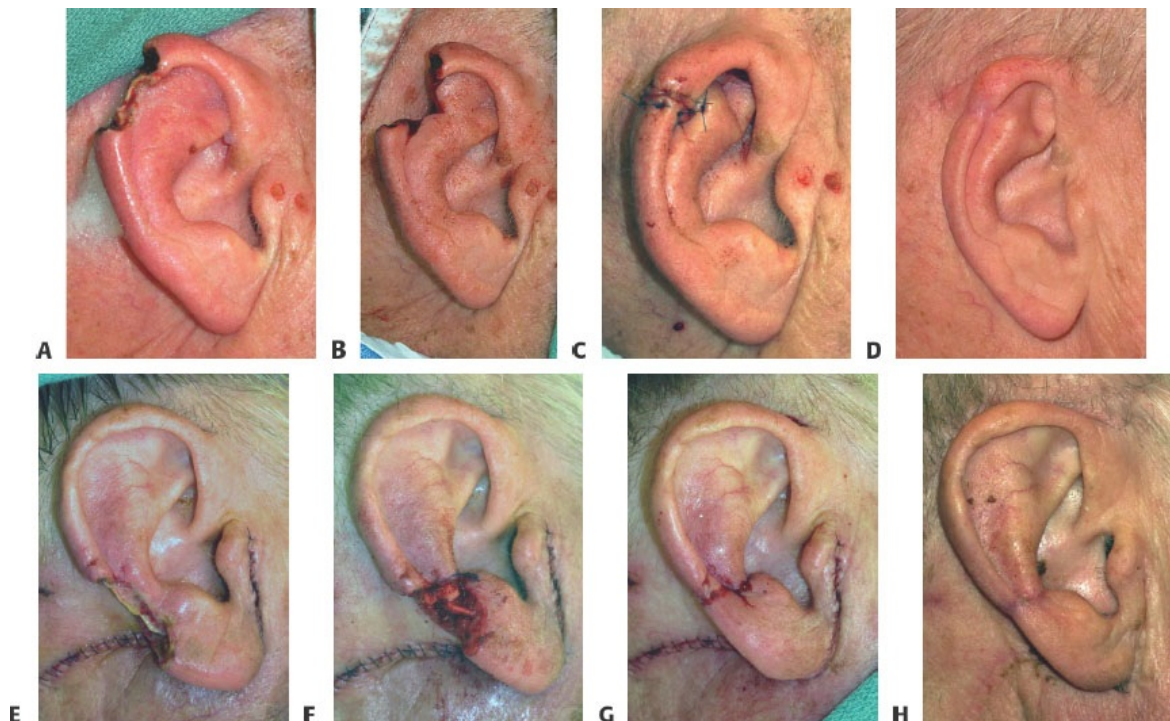
- Proper patient positioning is critical in preparation for the reconstruction again to allow the reconstructive surgeon the best access, exposure, and approach to the ear.
- The patient is placed into the supine position, and the bed can be turned 180 degrees to give access to both ears.
- It is helpful to prep and drape the entire head again to give full access and exposure to both ears.

TECHNIQUES

■ Wedge Resection of Helix

- The length of the curvature of the missing helix is measured, and the edges of the defect are approximated using forceps to assess whether a wedge resection approach will create an unacceptable deformity, asymmetry, or poor aesthetic result.
- The edges of the helix and antihelix should be marked to ensure precise alignment of these structures.
- Local anesthetic is then injected and several minutes are allowed to achieve the desired hemostatic effect.
- The wedge excision is marked that extends into the scapha and antihelix and potentially into the concha depending on the size of the defect.
 - A full-thickness wedge is resected from the remaining ear.^{8,9}
- The cut edges of the ear cartilages are repaired first, using monofilament suture on tapered needles.

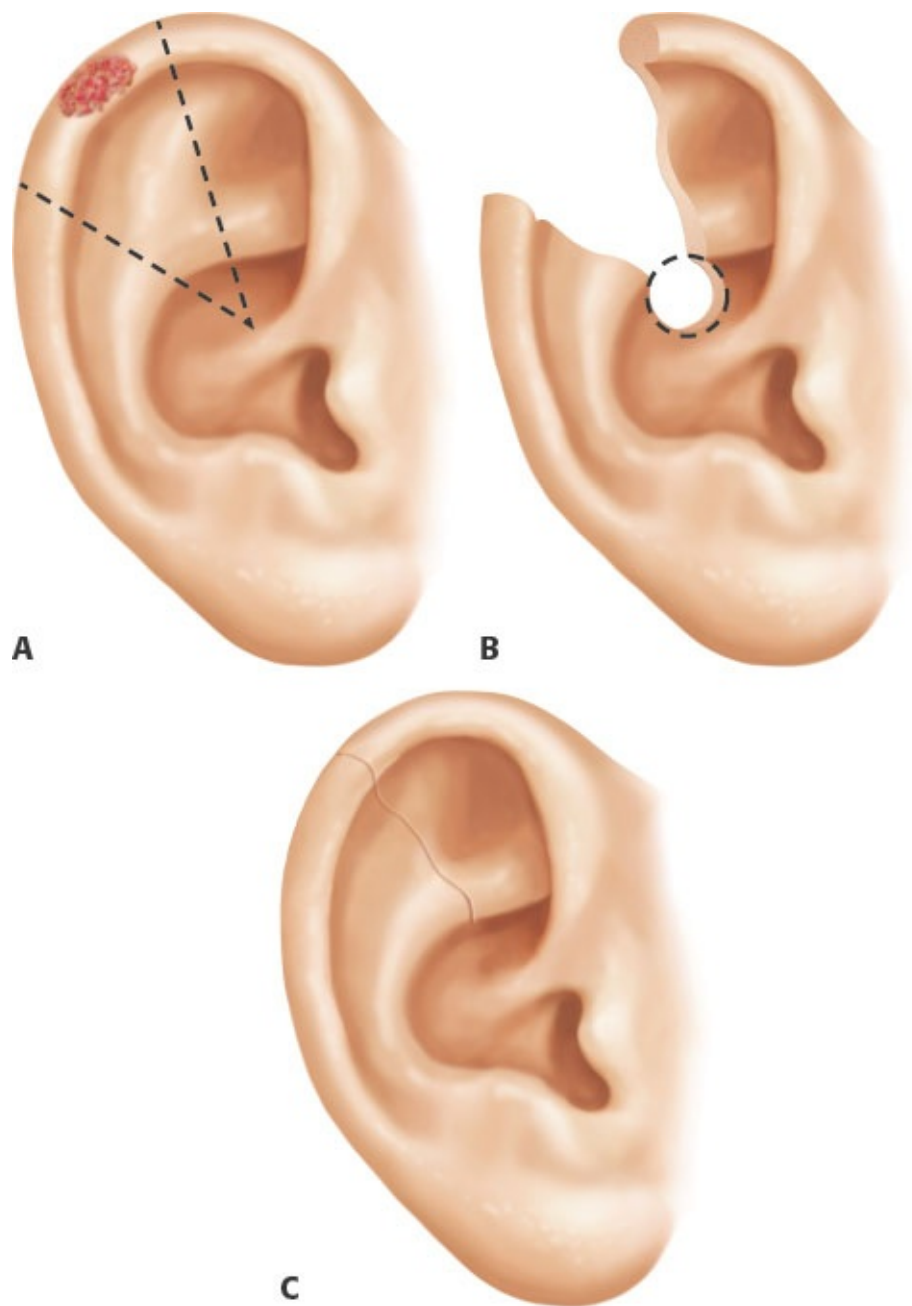
- Clinical examples of upper third and middle third wedge excision and reconstructions are shown in **TECH FIG 1**.



TECH FIG 1 • Wedge resection and reconstruction to repair partial auriclectomy defect in the superior (**A–D**) and middle (**E–H**) one-third of the ear following removal of skin cancer.

■ Variations

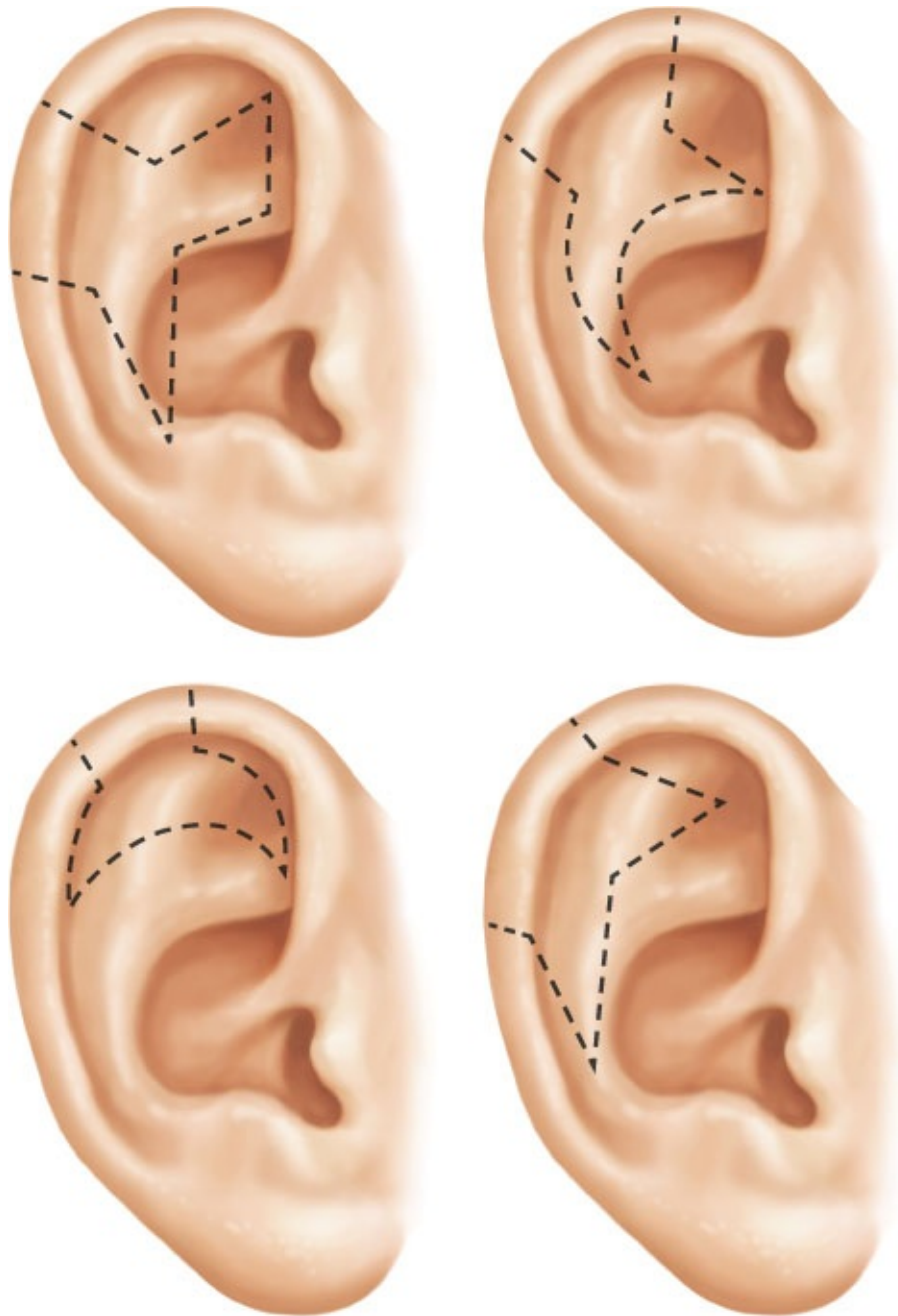
- A wedge-type excision and closure will typically result in a small redundancy of cartilage near the apex of the wedge, causing cupping of the reconstructed auricle.
 - This can be managed by a keyhole-type excision of cartilage (**TECH FIG 2**).
 - **TECH FIG 3** shows other wedge-type excisions.



TECH FIG 2 • Full-thickness wedge resection and reconstruction using “keyhole-type” cartilage excision to prevent redundancy of the cartilage at the apex of the wedge. Planned excision (**A**), removal of “keyhole” (**B**), and final result (**C**).

- The skin is then closed using permanent suture, everting the skin edges as much as possible.

- Mattress sutures are often helpful to maximize the eversion of the skin edges. The landmarks should be realigned based on the markings.
- The posterior skin is closed in an identical fashion using permanent sutures, again everting the skin edges as much as possible.



TECH FIG 3 • Variations of cartilaginous wedge resections to avoid redundancy of the cartilage at the

apex of the wedge and a cup deformity of the reconstructed auricle.

PEARLS AND PITFALLS

Preoperative care	■ The use of local anesthetic with epinephrine is not contraindicated in auricular reconstruction.
Technique	■ The defect should be assessed accurately to determine whether a wedge resection is even feasible without creating a greater deformity and distortion of the ear. ■ The structures of the ear should be realigned precisely with perfect skin eversion to avoid notching and a suboptimal aesthetic result. ■ A small keyhole or other type of subcutaneous cartilage excisions at the apex of the wedge can help avoid cupping of the ear.
Hemostasis	■ Hemostasis is critical as a hematoma can severely compromise the viability of the cartilage, distort the underlying structure, and adversely impact the final cosmetic result.
Postoperative care	■ Avoid any pressure or trauma to the reconstructed ear including wearing of glasses and sleeping on the side of the reconstructed ear.

POSTOPERATIVE CARE

- Because permanent sutures are used to reapproximate the skin, the sutures will need to be removed in approximately 7 to 10 days.
- The incision should be cleaned regular with soap and water, paying careful attention to avoid trauma or pressure to the ear.
- Pressure dressings are usually not recommended.
- Antibiotic ointment can be used following surgery at the surgeon's discretion.
- Patients should avoid sleeping on the side of the ear that has been reconstructed. Patients should also refrain from wearing glasses.
- If patients do not wear contacts and have to wear glasses, it is recommended that the earpiece on the reconstructed side be removed to avoid any potential trauma to the reconstructed ear.

COMPLICATIONS

- If there is significant tension on the closure, there is a risk for dehiscence. Again, the patient should avoid any trauma or displacement of the ear during the early recovery period to avoid any undue tension on the closure.
- Infection of the ear and cartilage can be a serious complication that can lead to loss of additional cartilage and necrosis of the tissue.
 - This can then result in a much more extensive ear defect, larger than the original defect.
 - Although extended prophylactic antibiotics are not generally recommended, a fluoroquinolone is considered the antibiotic of choice in the perioperative period due to good tissue penetration of cartilage and coverage for *Pseudomonas aeruginosa*.
- Bleeding can lead to significant distortion of the ear and underlying cartilage. Careful hemostasis is mandatory at the time of the operation.
- Notching of the helix is a common complication following reconstruction of the ear primarily using a wedge resection.
 - This can result from excess tension on the closure or potentially from poor technique in skin eversion but can usually be revised satisfactorily several months later after primary healing of the cartilages and resolution of tissue edema.

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Section X: Nose

33 Nasal Reconstruction With Banner Flaps, Bilobed Flaps, and Nasolabial Flaps

CHAPTER

Michael V. Chiodo and Pierre Saadeh

DEFINITION

- Banner and bilobed flaps are local rotation and transposition flaps that provide well-matched color and textured skin for small (0.7–1.2 and 0.5–1.5 cm, respectively) nasal cutaneous defects.
- When compared with banner or single transposition flaps, bilobed or “double transposition” flaps can move tissue over a longer distance from the mobile soft tissue of the upper nose to the nasal tip.
- Although full-thickness skin grafts may aid in reconstructing small defects of the upper two-thirds of the nose, they are often too thin to mimic the native contours of the nasal tip.
- The nasolabial crease is one of the most important boundaries in facial aesthetics. It is the delineation between the cheek and the lips and the cheek and the nose.
- Because of its proximity to the nose and lips, flaps from this region have a critical role in nasal and cutaneous lip reconstruction.
- Nasolabial flaps are cheek flaps harvested from the strip of prominent cheek fat just lateral to the nasolabial crease referred to as the nasolabial fold.
- These flaps are most useful for small to medium-sized full-thickness skin defects of the nasal alae, caudal nasal sidewall, and upper cutaneous lip.
- They take advantage of the redundant nature of the skin of the nasolabial fold and its reliable underlying blood supply to achieve transfer of sizeable

flaps and ability for primary closure of donor defects with favorable scar placement along aesthetic unit borders.

- Nasolabial flaps are largely classified as transposition, advancement, or interpolated flaps. By definition, the base of an interpolated flap is not continuous with the defect of question, so the pedicle must cross over or under intervening tissue. Therefore, interpolated nasolabial flaps ultimately require division and inset of the flap's pedicle in a second-stage procedure, whereas transposition and advancement flaps can be done as single-stage operations.

ANATOMY

- The nose can be divided into nine aesthetic subunits with three paired units (alar base, alar wall, dorsal sidewall) and three central subunits (tip, columella, and dorsum) (**FIG 1A**).
- These units are separated by nasal contour lines between areas of different skin texture and thickness.
- Additionally, the nose can be broken into thirds based on skeletal support: proximal third is supported by the nasal bones, middle third by the upper lateral cartilages, and distal third by lower lateral cartilages (**FIG 1B**).
- The nose should be thought of as a trilaminar structure with external skin and muscle (nasalis) supported by a skeleton of cartilage and bone and an internal lining.
- Banner and bilobed flaps are random pattern cutaneous flaps dependent on the subdermal plexus for blood supply.
- The nasalis muscle, which is often included in these flaps, consists of transverse and alar parts that overlie the nasal sidewalls with an aponeurosis extending across the nasal dorsum.
- The anatomic basis for the nasolabial crease is controversial. There are two prevailing theories: a muscular theory and a fascial theory.
- Supporters of the muscular theory discuss a "fold muscle," which originates from the upper lip elevators and progresses through the nasolabial fold and crease on its way to the upper lip vermillion.
- Proponents of the fascial theory suggest the nasolabial crease is not created by muscular insertion, but rather developed by the fascial insertion of the end portion of the superficial musculoaponeurotic system (SMAS) into the skin at the junction between the upper and lower cutaneous lips and the cheek.
- There is an abundance of subcutaneous fat directly lateral to the nasolabial crease, referred to as the nasolabial fold. The skin of the cheek in this area is

loosely adherent to the deeper fascia, allowing for excellent mobility.^{1,2}

- The arterial supply to this region of the cheek is provided by facial and angular artery perforating vessels.
- Venous drainage parallels the arterial system.
- The blood supply of this region is robust to support both superiorly and inferiorly based flaps.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Given its prominence, the nose is the facial structure most susceptible to trauma as well as photodamage, which can lead to cutaneous malignancies, making it a common site for reconstruction.
- The size, depth, composition (skin, skeletal support, internal lining), and location of the defect or anticipated defect must be evaluated in addition to the surrounding skin quality, tone, and texture.

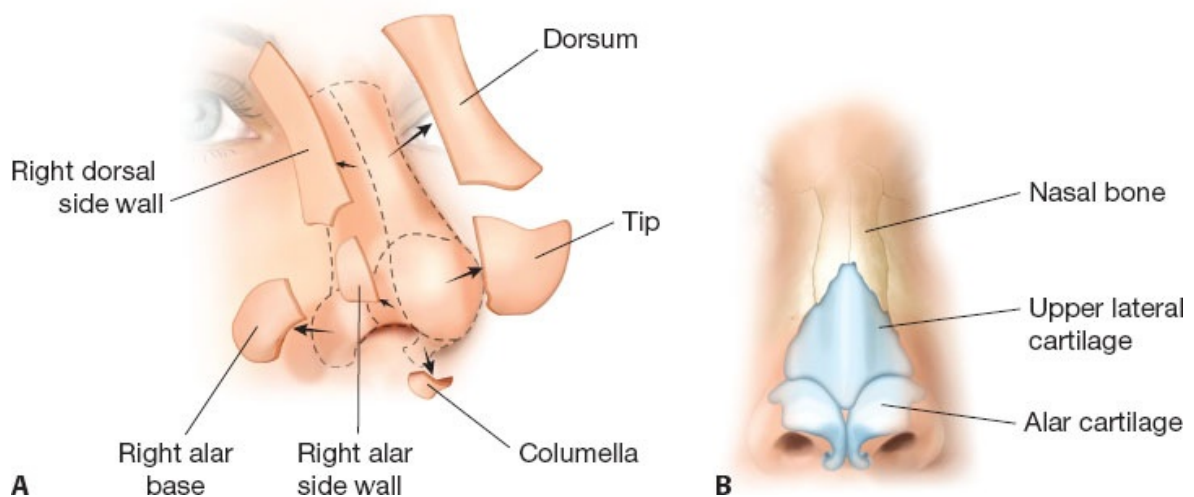


FIG 1 • A. Aesthetic subunits of the nose. **B.** "Thirds" of the nose.

- Defects caused by tumor extirpation are often the result of Mohs micrographic surgery; once margins are confirmed negative by frozen section (same day), reconstruction can proceed.
- Prior nasal operations, scars, and the effect of radiation therapy must also be taken into account when applicable.

SURGICAL MANAGEMENT

Preoperative Planning

- In the senior author's practice, nasal banner and bilobed flaps and nasolabial flaps are most commonly performed under local anesthesia. Patient preference should be considered regarding the method of anesthesia.
- Assess the mobility and laxity of the skin surrounding the defect. Cranial nasal skin is thinner and more mobile than the caudal skin and must be considered when planning flap choice and orientation.
- With proper flap planning of nasolabial flaps, scars will recreate the nasolabial crease.
- The alar facial sulcus is a crucial facial aesthetic boundary representing the convexity between the nose, cheek, and upper lip.
 - Preservation of this boundary is of critical importance in flap design and should be a primary focus during initial nasolabial flap planning.
 - Secondary revision of this region should be avoided as recreation of this convexity is challenging.¹

Positioning

- The patient is positioned supine on the operative table with their head turned to the contralateral side from the defect. Some reverse Trendelenburg with the neck in slight extension can be useful to decrease venous bleeding.
- The entire midface, at minimum, is prepped into the field to assess symmetry intraoperatively.

Approach

- Banner and bilobed flaps
 - The choice between banner and bilobed flaps is mainly dependent on defect size and location.
 - Smaller defects of the upper nasal sidewall and dorsum (0.5–1.0 cm diameter) are typically more amenable to banner flap closure. Donor-site scars are minimal, and medial canthus distortion is avoided. Banner flaps for nasal tip reconstruction often result in mismatched skin thickness resulting in unnatural topography. Larger banner flaps involve wider dissections and undermining, resulting in nasal distortion and significant standing cutaneous deformity at the pivot point.
 - Although bilobed flaps require a more extensive scar pattern, the geometrically precise design recruits mobile skin from the mid-dorsum and

sidewall to enable greater flap rotation. Better skin thickness match with less nasal contour distortion and standing cutaneous deformity is achieved at the pivot point. They are more useful for larger defects (1.0–1.5 cm diameter), particularly on the central or lateral nasal tip, ala, and caudal sidewall.

Defects on the upper half of the nose are typically not suited for bilobed reconstruction due to medial canthus distortion.

- Banner and bilobed flaps include skin, subcutaneous fat, and nasalis muscle elevated in the areolar tissue plane directly over the perichondrium (if flap is raised laterally over cartilage) or periosteum (if raised over the nasal bones). Including the nasalis makes both banner and bilobed flaps myocutaneous, adding reliable vascularity.
- Cutaneous nasal defects larger than 1.5 to 2 cm are best reconstructed with other modalities (forehead flap, dorsonasal flap, or nasolabial flap) as larger banner or bilobed flaps often leave scars that violate multiple aesthetic subunits and can result in nasal contour distortion.
- Nasolabial flaps
 - Depending on the size and location of the defect, decisions must be made regarding plane of flap elevation (cutaneous, subcutaneous, or fascial) and need for cartilaginous support for the nasal alae.¹
 - These flaps can be elevated as peninsular flaps in the cutaneous plane or island flaps when elevated in the subcutaneous plane.
 - We prefer elevation in the subcutaneous or fascial planes, taking advantage of the rich network of perforating vessels from the facial and angular artery in this area.

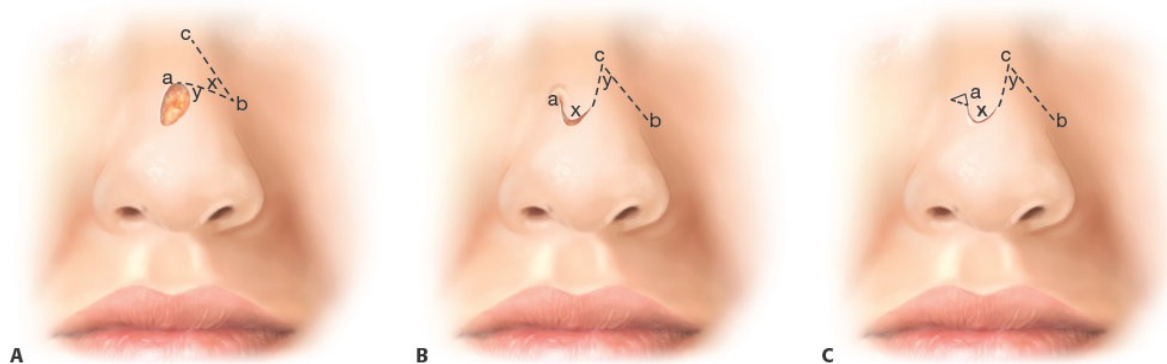
TECHNIQUES

■ Banner Flap

- The defect is outlined, with additional areas of excision determined in order to place scars along the borders of aesthetic subunits.
- Most often, the inferior border of the anticipated banner flap is marked tangential to the superior border of the defect and oriented in a horizontal fashion across the dorsum of the nose.
- The distance between *a* and *c* determines flap base width and can be

designed 1 to 2 mm smaller than the diameter of the defect (**TECH FIG 1**).

- Point *b* represents the tip of the flap, and when possible, this landmark is placed along a subunit border to help hide the donor-site scar.
- The length of raised tissue (*ab*) is longer than the defect size, making the flap a long and thin triangle, facilitating easy and primary closure of the donor site.
- After flap design is complete, dilute 0.5% lidocaine with 1:200 000 epinephrine is infiltrated in the subcutaneous plane.
- The flap is then raised in the areolar plane between the nasalis muscle and perichondrium/periosteum.
- The skin surrounding the flap and defect is undermined in the same areolar plane as the flap to facilitate tension-free closure.
- The flap donor site is closed first with 6-0 nylon, followed by flap transposition into the defect.
- The standing cutaneous deformity at the pivot point is assessed and removed, typically with a small Burrow triangle excised at point *a* to facilitate closure and prevent contour deformity.
- The flap is then trimmed to fit the defect precisely and inset with interrupted 6-0 nylon sutures.
- A thin layer of bacitracin is applied to the incisions twice daily until sutures are removed 5 to 7 days postoperatively.
- When sutures are removed, Steri-Strips can be applied for an additional week of support.



TECH FIG 1 • A. The flap is marked adjacent to the defect (*a*). The distance between *a* and *c* determines flap width or base and is made slightly smaller than

the diameter of the defect as the defect can be made smaller during closure. Point *b* represents the tip of the flap, and when possible, this landmark is placed in the alar crease to help hide the donor-site scar. The length of raised tissue (*ab*) is longer than the defect size, making the flap (*x*) a long and thin triangle (*b*), facilitating easy and primary closure of the donor site.

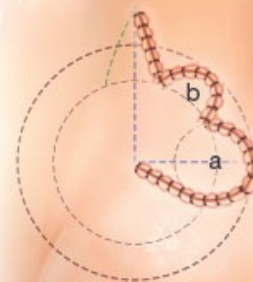
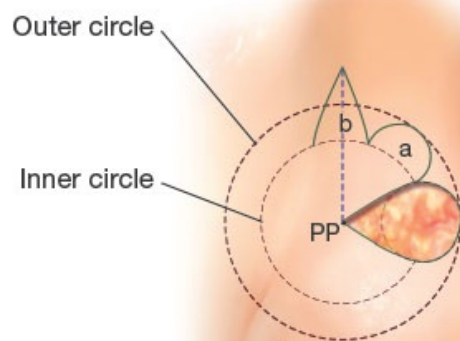
B. Flap *x* is then raised in the subnasalis plane and rotated into the defect and trimmed appropriately. **C.** A small Burow triangle can be excised at point *a*, the pivot point, to facilitate closure.

■ Bilobed Flap

- Although the original bilobed flap was designed to rotate tissue 180 degrees into a defect, this design created a large dog-ear at the point of rotation.
- Zitelli's modification of limiting total flap rotation to no more than 90 to 110 degrees decreases dog-ear formation and the risk of pincushioning.
- The flap consists of two lobes, *a* and *b*, which are used to cover the defect and close the donor site, respectively; *a* is the exact width of the defect, while *b* can be slightly narrower as tissue from the more proximal nose is more mobile and pliable.
 - The height of the second lobe is approximately 1.5 to 2.0 cm greater than the height of the first lobe.
- Markings and preoperative planning are paramount in technical execution and postoperative results.
- The planned defect is first marked and typically made circular in shape.
- The flap is designed with a pivot point located at a distance equal to the defect radius away from the defect margin. Pivot points farther away from the defect result in larger flaps, which can push each lobe off the nose, distorting either the eyelid or cheek.
 - When possible, a laterally based flap design is preferred due to improved vascularity and avoids scars over the nasal dorsum.
- We suggest using two concentric circles that share the same pivot point to aid in marking: the larger outer circle has a radius of three times the defect's

radius, whereas the smaller inner circle has a radius twice the length of the defect's (**TECH FIG 2A**).

- Premade bilobed flap templates of different sizes can be printed to provide reliable, easy, and fast bilobed flap design.
- A template of the defect is then made and placed just inside the circumference of the outer circle, adjacent to the defect, making lobe *a*.
- Lobe *b* is triangular in shape, adjacent to lobe *a*, and the farthest away from the defect; the base of this triangle is along the outside of the *inner circle* making it one defect's radius away from the circular defect.
- Lobe *a* can be curved slightly away from the defect, which includes a small Burrow triangle in its design, preventing dog-ear formation at the pivot point.
- After flap design is complete, dilute 0.5% lidocaine with 1:200 000 epinephrine is infiltrated in the subcutaneous plane.
- Incisions are made along the markings, and the flap is elevated in the areolar plane directly above the perichondrium or periosteum, always including the nasalis muscle to improve flap vasculature and maintain uniform thickness with the defect.
 - Undermining extends beyond the base and pivot point of the flap to improve mobility.
 - The skin around the flap and the defect is also undermined in the same areolar plane to facilitate tension-free closure.
- Inset begins with primary closure of the secondary donor site.
- Lobe *a* is then rotated 45 to 50 degrees into the defect and inset (**TECH FIG 2B–E**).
- The standing cutaneous deformity at the pivot point is excised and closed.
- Finally, the triangular lobe *b* is rotated into the primary donor site, trimmed to fit, and inset. Skin incisions are all closed with 6-0 interrupted nylon sutures.
- A thin layer of bacitracin is applied to the incisions twice daily until sutures are removed 5 to 7 days postoperatively.
 - When sutures are removed, Steri-Strips can be applied for an additional week of support.



A

B



C

D

E

TECH FIG 2 • A. Using two concentric circles that share the same pivot point aids in marking: the larger outer circle has a radius of three times the defect's radius, and the smaller circle's center is the defect's diameter away from the same shared pivot point (PP). **B.** The flap is undermined widely in the submuscular plane, beyond the base and pivot point of the flap, avoiding violation of neighboring aesthetic subunits when possible. Lobe *a* is then rotated 45 to 50 degrees into the defect, while the triangular lobe (*b*) is rotated into the primary donor site. Intraoperative

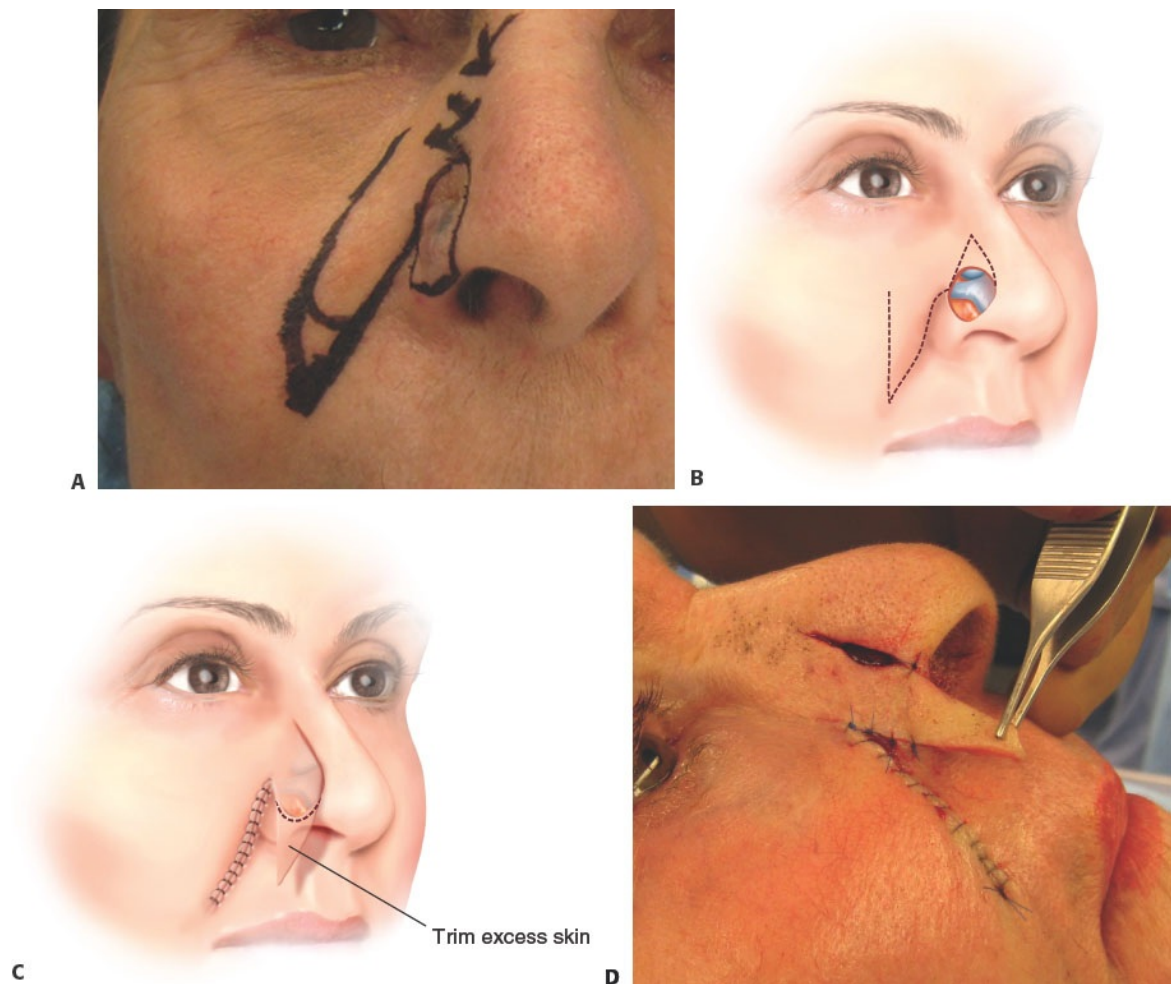
photographs show markings for a laterally based bilobed flap for an alar defect **(C)** that is raised in the subnasalis plane **(D)** and inset without tension or distortion of the nasal subunit **(D)**.

■ Superiorly Based Single-Stage Nasolabial Advancement Flap

- The defect is outlined, with additional areas of excision determined in order to place scars along the borders of aesthetic subunits.
- The flap is designed beginning at the medial portion of the lateral aspect of the wound.
 - A line is drawn running parallel to the nasolabial crease and should encompass a width equal to that of the wound.
 - The lateral aspect of the flap should stop at the level equal to the superior extent of the wound.
 - A 30-degree Burow triangle should be excised superior to the wound to prevent dog-ear formation (**TECH FIG 3A**).
- After completion of the flap design, dilute 0.5% lidocaine with 1:200 000 epinephrine is infiltrated in the subcutaneous plane.
- A no. 15 blade is used to complete the drawn incisions into the subcutaneous tissue (**TECH FIG 3B**).
- Using sharp dissection, the entire flap is elevated in a subcutaneous plane. The flap should be widely undermined in order to prevent a trapdoor deformity.
- The superiorly based Burow triangle is excised in a subcutaneous plane.
- After obtaining hemostasis, the flap inset begins by placement of buried deep dermal 5-0 PDS sutures. The first suture approximates the cheek skin to the periosteum in the nasofacial sulcus. The nasolabial crease is then reset by approximating the most superolateral aspect of the donor wound to the superior aspect of the alar crease.
- The flap is then thinned for flap concavity after final inset.
- The alar groove is recreated by placement of a buried deep dermal 5-0 PDS suture from the central portion of the flap to the center of the alar crease.
- The distal portion of the flap is then tailored to fit the contour of the defect

(**TECH FIG 3C,D**) with approximately 5 mm of overhang beyond the ala.

- The distal end of the flap is not inset into the defect; rather it is left open to self-tubularize around the inferior margin of the alar rim as it heals.
- The remaining incisions are closed in standard layered fashion. The author prefers deep dermal Monocryl sutures followed by a running nonabsorbable stitch.



TECH FIG 3 • A,B. Planned incisions for single-stage advancement nasolabial flap. **C.** Nasolabial flap after it has been undermined and brought into the defect. The distal aspect of the flap is tailored to fit the defect contour (*dashed line*) but left approximately 5 mm longer than the defect and left open to allow self-tubularization around the inferior margin of the ala as

it heals. The flap will be trimmed along the dashed line, and the triangular portion of transposed soft tissue will be discarded. **D.** The flap is partially inset by Prolene suture. The incision line along the nasolabial incision is closed as well as the lateral aspect of the portion of the flap filling the defect.

■ Two-Stage Interpolated Nasolabial Flap

- For subtotal nasal sidewall or alar defects, a template of the defect should be made using a pliable material such as foil.
 - If the entire nasal ala will be reconstructed, an exact template of the subunit should be made from the contralateral, normal side of the nose.
- The template is then reversed and placed along the nasolabial fold at a level superior to a horizontal line drawn through the ipsilateral oral commissure.
 - The medial border of the template should reside in the nasolabial crease, ensuring final scar closure will lie along the nasolabial crease (**TECH FIG 4A**).
 - An extra 1 mm of donor margin should be included to compensate for eventual flap contraction.
- Donor-site closure is facilitated by excision of a triangular dog-ear. The medial aspect of the flap should extend distally directly along the nasolabial crease ensuring donor-site scar camouflage.
- After completion of the flap design, dilute 0.5% lidocaine with 1:200 000 epinephrine is infiltrated in the subcutaneous plane.
- A no. 15 blade is used to complete the drawn incisions into subcutaneous tissue.
- Using sharp dissection, the entire flap is elevated in a fascial plane (**TECH FIG 4B,C**). The flap and, if possible, the recipient area should be widely undermined to prevent a trapdoor deformity.
- The proximal skin portion of the flap can be narrowed to allow for transposition, but care should be taken to encompass a broad subcutaneous flap base to preserve perforating blood supply.
- Subcutaneous fibrous bands can be carefully taken down as needed to afford adequate transposition.

- After hemostasis is achieved, flap inset begins (**TECH FIG 4D**). The most distal aspect of the flap is inset in a single-layer closure with fine, nonabsorbable, simple interrupted sutures.



TECH FIG 4 • A. Distal sidewall and superior alar defect with preoperative markings illustrating adjacent nasal subunits, proposed flap with triangular dog-ear excision placed along nasolabial fold, and arterial supply. Planned incisions are made **(B)**, and the flap is sharply elevated in the fascial plane and advanced into the defect **(C)**. **D.** The flap is then inset into the defect, with the distal aspect excised as tolerated to allow for primary closure of the donor site along the nasolabial fold. Three weeks after advancement, the patient returns **(E)**, and the flap is debulked and inset for better contour **(F)**. Pedicle division was not required in this case due to favorable orientation.

- Wide undermining of the donor site allows for tension-free closure within the nasolabial crease after excising the dog-ear at the most distal component of the donor site. The donor site is closed using a fine, nonabsorbable, running suture.
- After 3 weeks, the patient is brought back for pedicle division and flap debulking/inset (**TECH FIG 4E,F**).
 - First, the pedicle is sharply excised in an elliptical manner using a no. 15 blade, and the donor site is closed primarily. The author prefers this technique rather than proximal pedicle inset as it leaves the patient with a linear rather than V-shaped proximal end of the donor-site incision.
 - The flap is then conservatively trimmed, and final flap inset is completed using fine, nonabsorbable, simple interrupted sutures.

PEARLS AND PITFALLS

Incision placement

- Dog-ears do not settle. The flap should be completely flat at the time of surgery unless there is concern for flap viability.

Flap planning

- The choice between banner and bilobed flaps is dictated by size and location. Banner flaps are best suited for more cranial nasal

	defects under 1.0 cm. Bilobed flaps work well for caudal defects up to 1.5 cm. ■ Banner flaps crossing the midline of the nasal dorsum result in bilateral distortions that are symmetric and less obvious. ■ When truly unilateral, banner flaps may distort alar anatomy, possible narrowing the vestibule. ■ Both banner and bilobed flaps should be left completely on the nose because larger flaps can distort eyelid, cheek, and lip aesthetics. ■ The diameter of wound suitable for nasolabial flap coverage is usually less than 2.5 cm; however, this is ultimately determined by the extent of cheek laxity. ■ The convexity of the alar fascial sulcus is of particular importance when considering facial aesthetic boundaries. If the flap trajectory will cross over this region, a two-staged interpolated flap must be used. Advancement flaps crossing the alar fascial sulcus will blunt the convexity, and this deformity is very difficult to reconstruct.
Flap limitations	■ The nasolabial flap is most suitable for reconstruction of nasal alar and caudal nasal sidewall defects. Do not attempt to reconstruct the nasal tip with nasolabial flap. Such attempts are often complicated by tip necrosis and extensive trapdoor deformities.
Dermabrasion	■ Postoperative dermabrasion can even out small irregularities at suture lines and improve scar appearance.
Skin cancer	■ Consider delaying the reconstruction until the margins of resection are proven clear by histological analysis.

POSTOPERATIVE CARE

- Patients should rest with their head elevated for the first few days postoperatively.
- All facial skin sutures should be removed 5 days postoperatively.
- Drains should be removed 24 to 48 hours postoperatively.
- Postoperative antibiotic coverage is not routinely used

OUTCOMES

- In a series of 70 flaps, Elliott et al. reported only one partial flap loss, salvaged by a small revision.³
- Zitelli et al. found excellent color and texture match in all 20 patients treated with nasal bilobed flaps; the only complication was superficial epidermal necrosis in two patients.⁴

- Dog-ears, pincushioning, and donor-site concavity are the main contributors to suboptimal aesthetic outcomes.
- Nasolabial flaps provide excellent reconstruction options of the nasal ala and caudal nasal sidewall. The skin and subcutaneous tissue of the nasolabial fold provide a suitable color and texture match with the ability to camouflage scars in facial aesthetic boundaries. Proper patient selection, appropriate flap design, gentle tissue handling, and hemostasis minimize complication rates.^{5,6}
- For defects involving more than half of the alar subunit, a two-staged, interpolated nasolabial flap can provide results close to patient's normal. Full subunit reconstruction allows for camouflage of scars at subunit junctions.⁷
- A drawback of the nasolabial flap is that, in some instances, it requires a two-staged operation. Appropriate patient selection cannot be overstated.
- Need for revisional surgery is rare in the senior author's practice but should be discussed with the patient before the initial operation. Dog-ears should be excised at the time of initial operation unless there is concern for flap viability. If this is the case, it is appropriate to come back at a later date for dog-ear excision. Defects that violate the alar groove in certain instances will require a secondary operation for recreation of the alar crease.

COMPLICATIONS

- Flap necrosis
- Contour deformities, dog ears, pincushioning, and scarring
- Donor-site concavity
- Hematoma
- Infection

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34 Nasal Reconstruction With Paramedian Forehead Flap

CHAPTER

Robert D. Wallace and Petros Konofaos

DEFINITION

- Nasal defects can be caused by trauma (including burns) and the sequela of skin cancer treatment by excision or radiation. Nasal defects can be partial or through and through involving all the three layers of the nose.
- Nasal reconstruction involves the use of autologous tissues to repair nasal defects.
 - All of the affected or missing parts must be replaced to achieve both an aesthetic (normal-looking nose) and a functional (easy breathing) reconstruction.
- The paramedian forehead flap (PMFF) is an interpolated axial flap based primarily off the supratrochlear neurovascular system and is well suited for reconstructing complex defects of the nose.
 - This flap produces an excellent tissue color and texture match for nasal reconstruction.

ANATOMY

Nose

- The nose consists of a pair of nasal bones that extend from the frontal bone and caudally fuse with the dorsal septum forming a support structure that extends along the length of the nasal dorsum (**FIG 1A**).
- The caudal aspect of the nasal bones overlaps the cephalic portion of the upper lateral cartilages for a distance of 2 to 4 mm.
- The upper lateral cartilages constitute the distal nasal sidewalls and extend toward the tip of the nose (**FIG 1B**).

- At their caudal free edge, they are overlapped by the cephalic portions of the lower lateral cartilages.
- The lower lateral cartilages provide the structural support to the soft tissues of the lower third of the nose.
- The nasal septum is composed of three structures: the perpendicular plate of the ethmoid posteriorly and cephalically, the vomer posteriorly and caudally, and the quadrangular septum anteriorly (see **FIG 1A**).
- The septum functions as a support structure for the midportion of the nose, and it also constitutes the medial component of the internal nasal valve.
- The blood supply to the dorsal nose is derived from the dorsal nasal artery and the anterior ethmoidal artery (**FIG 1C**).
- The lateral nasal artery, branch of the angular artery, supplies the nasal sidewalls and the caudal nasal dorsum and tip. The columellar branches of the superior labial artery with the distal branches of the lateral nasal artery supply the nasal tip from below.
- The blood supply to the septum comes from the anterior and posterior ethmoidal arteries, the sphenopalatine artery, and the posterior septal artery.
- The sensory innervation to the nose is derived from the ophthalmic (V1) (upper half of the nose) and the maxillary (V2) (lower half of the nose) divisions of the cranial nerve V. The motor innervation is from the facial nerve (VII).

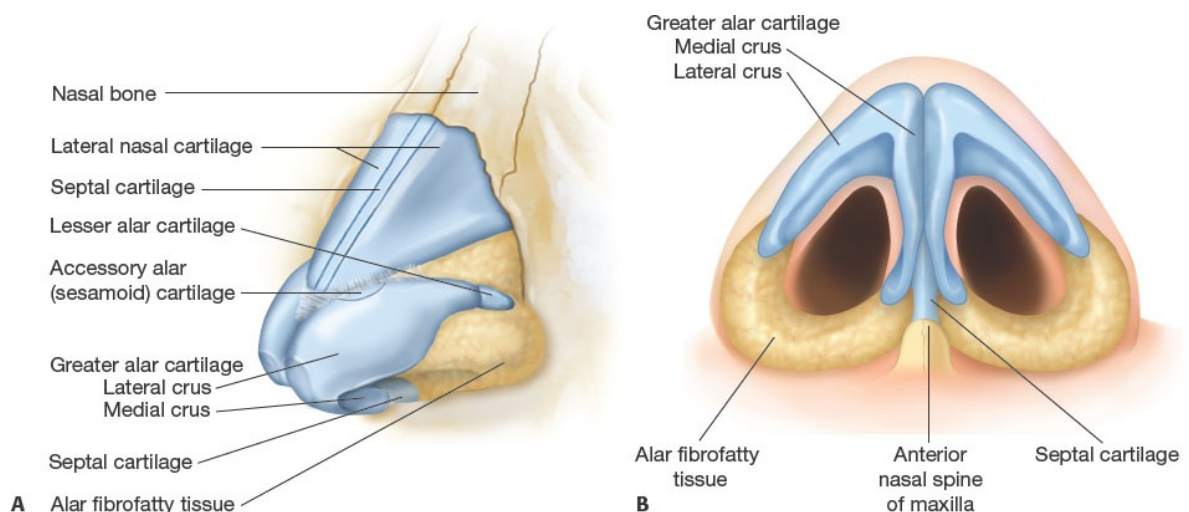
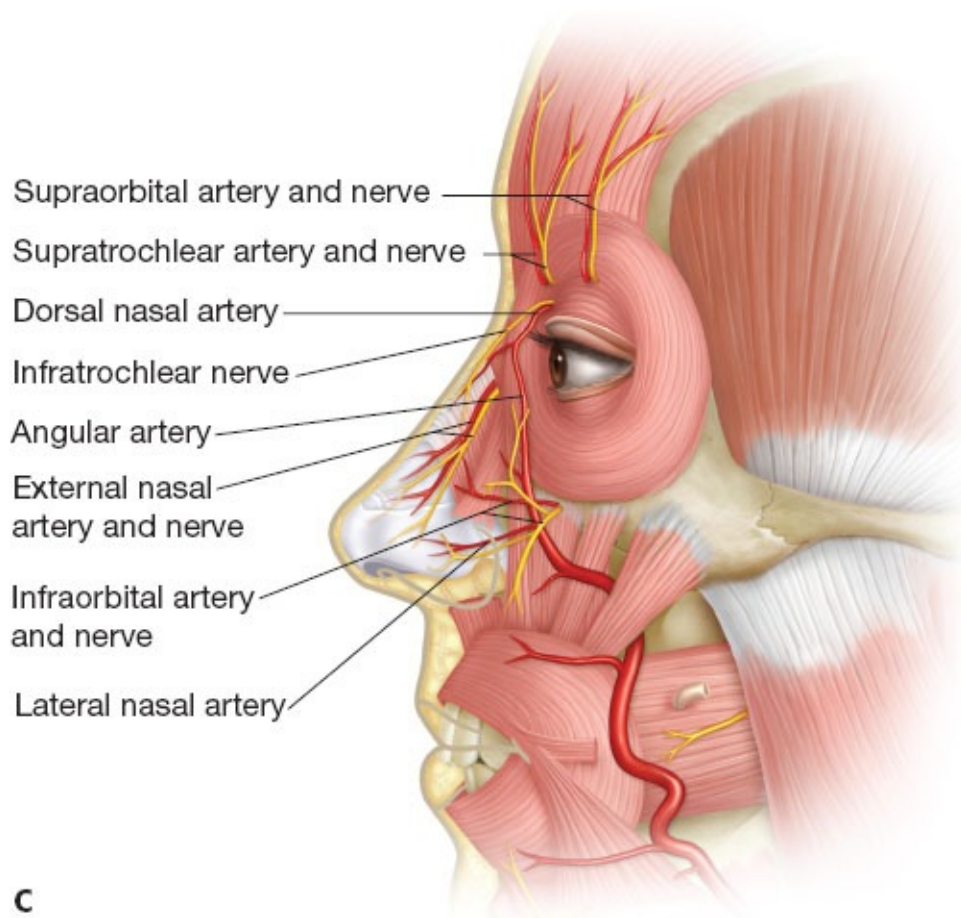


FIG 1 • A–C. Anatomy of the nose.



- There are three nasal vaults:
 - The bony vault consists of the paired nasal bones and the ascending frontal process of the maxilla.
 - The upper cartilaginous vault is outlined by the paired upper lateral cartilages.
 - The lower cartilaginous vault is made of the lower lateral cartilages.
- The skin envelope of the upper two-thirds of the nose consists of thin, loose, and mobile skin with few sebaceous glands.
 - The skin of the lower third of the nose is thick and less mobile, with aberrant sebaceous glands.

Paramedian Forehead Flap

- The forehead provides a source of skin with an excellent color and texture match with nasal skin.
- The PMFF is an axial pattern interpolated flap that is based on the ipsilateral or contralateral supratrochlear neurovascular system to exit the orbit

approximately 1.7 to 2.2 cm lateral to the midline, in a vertical vector, passing under orbicularis oculi and above corrugator supercilii muscles (**FIG 2**).

- The artery, 1 cm above the brow, runs in the submuscular plane, under the frontalis, to a more superficial, subcutaneous position at the middle of the forehead.
- The PMFF consists of frontalis muscle, subcutaneous fat, and skin, except its distal portion, in which the majority of subcutaneous fat and the frontalis are removed.

PATIENT HISTORY AND PHYSICAL FINDINGS

- During the process of taking the patient's medical and surgical history, emphasis should be put on the following:
 - Case of the nasal injury, disease remission, or cancer clearance
 - Tobacco and alcohol use
 - Previous surgeries on the nose, midface, and forehead regions



FIG 2 • Design of paramedian forehead flap. M, medial side of the flap; L, lateral side of the defect; A, ala; S, skin excess.

- History of radiation therapy and/or chemotherapy
- General health status of the patient and more specifically the existence of conditions affecting wound healing and flap viability
- Patient's ethnicity
- Active drug use
- Physical examination
 - The skin of the midface and the forehead regions is inspected for scarring and previous incision sites.
 - The patency of the nasal airway should be evaluated for constrictions and/or bulky obstructing tissue, for lateral nasal wall collapse, or external nasal valve deficiency.
 - Moreover, the nose and the forehead area should be inspected for variations from normal anatomical topography.
 - Evaluation of the primary defect includes¹
 - Wound dimensions, shape, and location
 - Identification of nasal and/or facial subunits involved
 - Wound inspection for infection, constrictions, and other deformities
 - Understanding the defect in terms of tissues involved, as complex nasal defects often involve loss of lining, support, and skin cover
 - Identification of the location of the supratrochlear artery can be achieved through palpation and/or using a handheld Doppler.
 - Preoperative photography is essential to document the defect, allow outcome review and comparison, and educate the patient regarding the indicated surgical treatment.

IMAGING

- No specific radiographic imaging studies are required.
- Facial radiograph, computed tomography, or magnetic resonance imaging is occasionally employed in cancer-related cases with high risk of recurrence or to clarify bony and soft tissue injury of the midface region.

SURGICAL MANAGEMENT

- Immediate nasal reconstruction after skin tumor extirpation is safe in selected patients.
- Reconstruction is delayed when the histologic margins are questionable, the tumor histology is aggressive, in case of perineural or deep bony invasion, and when radiotherapy is to be given.

- Factors governing the choice of nasal reconstruction include donor-site morbidity, facial scarring, and the complications associated with borderline vascularity.
- Function and appearance were considered of secondary importance. On the other hand, modern nasal reconstruction emphasizes the restoration of a normal appearance and function, not on simply obtaining a healed wound.
- Millard envisioned facial landmarks as “units” and suggested to replace them in their entirety with tissue of similar color and texture to avoid a patchlike repair.
- Burget and Menick² analyzed the nose as a facial unit with subunits, based on the skin quality, border outline, and 3-D contour of each region (**FIG 3**).
- They also introduced the nasal subunit principle, which holds that, if the defect is greater than 50% of the subunits, it is better to discard adjacent normal tissue within the subunit and resurface the entire subunit rather than merely “patching the hole.” Thus, depending on the extent of the defect, wounds should be altered in size, configuration, and depth to reconstruct an entire unit.
- The subunit principle finds its ideal application for defects of the tip and alar regions because these subunits are convex and can lead to a trapdoor effect following flap inset and healing, thereby augmenting the effect of recreating the convex shape of the subunit.
- For defects of the nasal dorsum and sidewalls, the subunit principle is less applicable, because these relatively flat subunits blend indistinctly.
- The principles of ideal nasal reconstruction include
 - The exact replacement of missing tissues in dimension, thickness, and outline
 - The use of the contralateral subunit as a template for reconstruction
 - The establishment of a support framework with primary and delayed primary cartilage and bone grafts
 - Flap edges blended to the recipient site

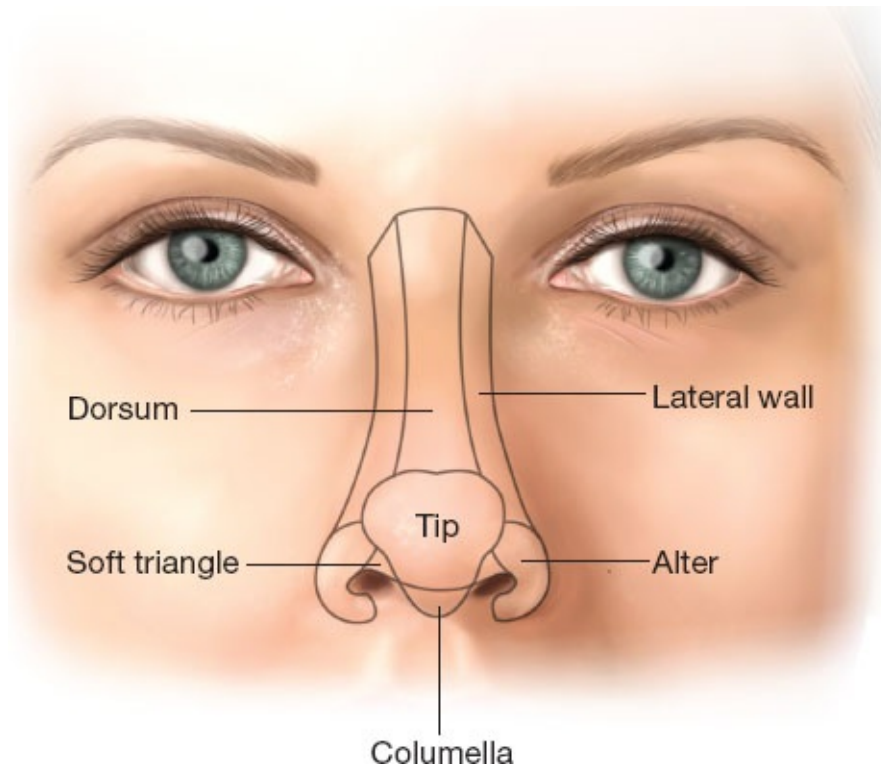


FIG 3 • Aesthetic subunits of the nose.

- Marginal scars braced by cartilage grafts
- Detailed subcutaneous sculpture
- It is imperative to educate the patient and outline the necessary steps that will be required to repair the defect. Moreover, the patient's preferences and needs must be considered by the surgeon at the planning of the indicated reconstruction.

Preoperative Planning

- Preoperative planning should be guided by the principles of aesthetic regional unit reconstruction: alter the wound in size, outline, depth, or position, if helpful, to improve the final result. After defining the defect by means of location and missing layers, the reconstruction can be broken down into component parts, with each part addressed in turn.
- Successful reconstruction is composed of thin, conforming cover that matches nasal skin in color and texture; thin, vascular, and supple lining that does not stuff the airway; and a hard tissue framework to support, shape, and brace soft tissue against gravity, tension, and scar contraction.
- When designing the selected flap, it is important to avoid either distorting

adjacent structures or making the flap too small. When substantial amounts of all three layers are lacking, however, the reconstruction becomes more complex and less predictable.

- The PMFF is the mainstay of reconstruction for a wide variety of nasal defects.
 - For subtotal or total nasal defects, a three-stage full-thickness PMFF (with an extension to supply missing lining or combined with a septal mucosal flap) and septal or ear support grafts are used.
 - The two-stage PMFF is best suited to resurface small defects that do not require contour recreation, complex support grafts, or lining replacement. All stages are performed under general anesthesia.
- If missing, the nasal midlayer support framework must be replaced, to prevent nose collapse.
 - The support grafts can be placed primarily if vascularized lining remains or is restored with intranasal lining flaps.
 - Otherwise, the structural grafts are placed during the second stage of reconstruction with PMFF.
 - Sources for support graft for cartilage can be septal or ear cartilage and for bone calvarial or rib bone grafts.
 - Whereas septal cartilage is especially useful as a single or layered onlay dorsal graft, a tip graft, a sidewall brace, or a columellar strut, the ear remains the workhorse of tip and alar repair.
- If deficits of the internal lining cannot be closed primarily, there are several options for reconstituting it.
 - If left unrepaired, the area will heal by secondary intention with significant wound contracture, alar distortion, and nasal obstruction.
 - Punctate defects can be closed primarily, whereas an independent flap is required to repair larger defects.
 - Most commonly used options include the folded PMFF, the ipsilateral septal mucosal flap, and a full-thickness skin graft (in combination with PMFF).
- In cases in which ischemic tissue is identified, prior to reconstruction, the wound should be debrided after it demarcates itself.
 - A contaminated or infected wound should be debrided and controlled with antibiotics prior to reconstruction.
 - Significant edema and wound tension are given time to resolve.
- In cases in which the defect extends/includes to the lip and/or cheek units,

reconstruction of these areas must be established, prior to nasal reconstruction.

- Options include cheek advancement flap with/without a nasolabial extension to resurface the cheek and/or lip, an Abbe flap (if the full thickness of the upper lip is absent), or a free flap depending on the dimensions and/or depth of the defect.

Positioning

- The patient is placed supine on the operating room table in 20 to 30 degrees of a reverse Trendelenburg position.
 - This position has the advantage of decreasing intraoperative blood loss by eliminating venous pooling and flap congestion.
- Bland ophthalmic ointment is applied to the globe. The patient's eyes are closed and protected with Tegaderm.
- The full face and scalp, from the midvertex to the submental area, are prepared with a sterilization solution of the surgeon's choice.
 - A sterile head drape is placed, and full-body draping is completed in the usual sterile fashion.
- After induction of general endotracheal anesthesia, the operating room table is rotated to position the anesthesiologist at the patient's right hip.
 - Pressure points on upper extremities are padded, and a pillow is placed under the patient's knees.
 - Alternating pressure devices are applied to the lower legs.

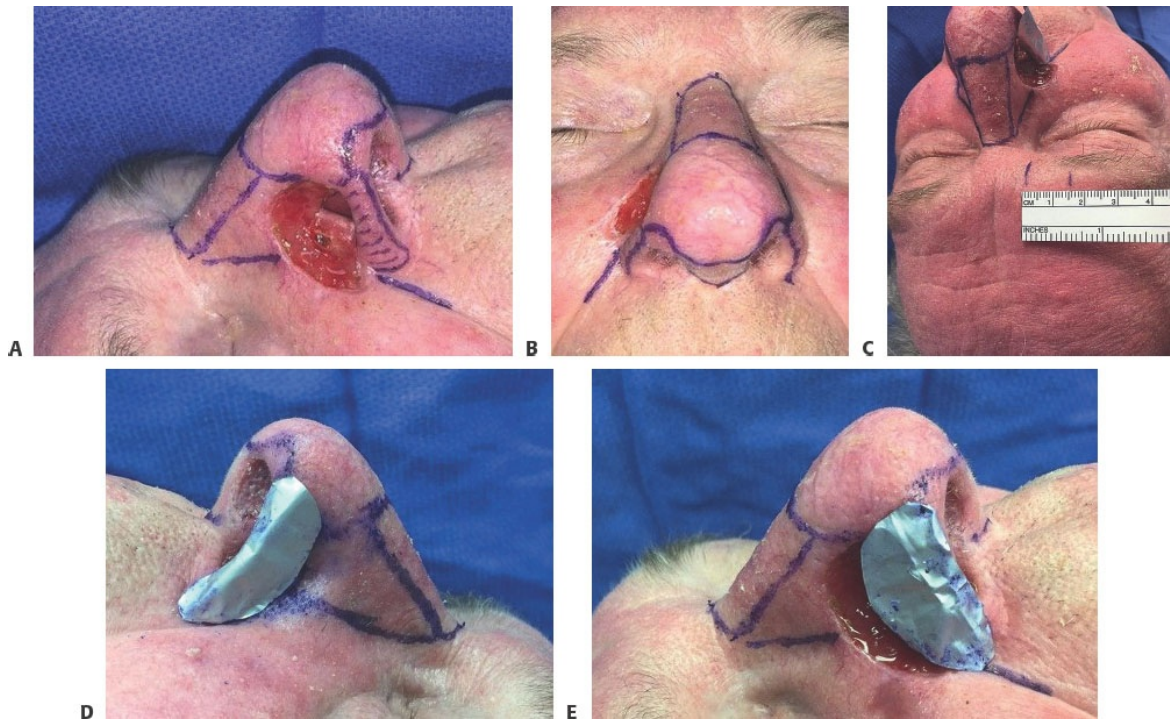
TECHNIQUES

■ Markings and Templating

- Using a marking pen, the hairline, frown lines, subunits of the nose and lip, old scars, grafts, flaps, the location of planned vascular pedicles, areas of soft tissue excess or deficiency, and facial landmarks are marked during all stages (**TECH FIG 1A,B**).
- The path of the supratrochlear artery can be mapped out using a Doppler probe, but the author has not found this to be necessary.
 - The base of the pedicle is usually centered over the supratrochlear artery on the same side, which corresponds to the medial border of the eyebrow in

the majority of patients.

- The pedicle portion of the PMFF can be as narrow as 1.5 cm, which allows for an easier primary closure over the inferior portion of the flap (**TECH FIG 1C**).
- Templates, based on the contralateral normal, are especially helpful to determine the dimension, outline, and contour required to restore the defect.





TECH FIG 1 • Lateral (**A**) and anterior (**B**) view of preoperative markings of the nasal aesthetic subunits. **C.** The pedicle portion of the paramedian forehead flap can be as narrow as 1.5 cm, which allows for an easier primary closure over the inferior portion of the flap. **D.** Using the foil of a suture pack, a template of the contralateral normal side can be created with the silver side exposed. **E.** The template is flipped and oriented properly into the defect with the colored surface outward. **F.** The length of the pedicle is measured by a length of suture/gauze extending from the distal end of the positioned template to the level of the medial eyebrow.

- Using the foil of a suture pack, a template of the contralateral normal side can be created with the silver side exposed (**TECH FIG 1D**).
- Then, the template is flipped and oriented properly into the defect with its colored surface outward (see **TECH FIG 1E**).
- The foil-based templates can be preserved, resterilized, and reused during

later operations.

- The template is used to design the flap on the forehead skin.
 - The upper border of the template is positioned at the frontal hairline unless the patient has a receding hairline or frontal balding.
 - If the PMFF is used for covering the lining defect, the lining template is positioned as a distal extension of the covering flap with a few millimeters of excess skin between the cover and lining flaps to ease its folding.
 - If necessary, the lining extension can carry a few hair follicles (see **FIG 2**).
 - The length of the pedicle is measured by a length of suture/gauze extending from the distal end of the positioned template to the level of the medial eyebrow.
 - Then, by stabilizing the suture/gauze at the eyebrow, it is rotated 180 degrees in the coronal plane toward the midline to the most distal recipient site on the nose.
 - This step is vital to determine the exact position of the template on the forehead.
 - The flap is then precisely outlined on the forehead with a skin marker, following the exact shape of the template (**TECH FIG 1F**).
-

■ Stage 1: Elevation and Placement of the Flap

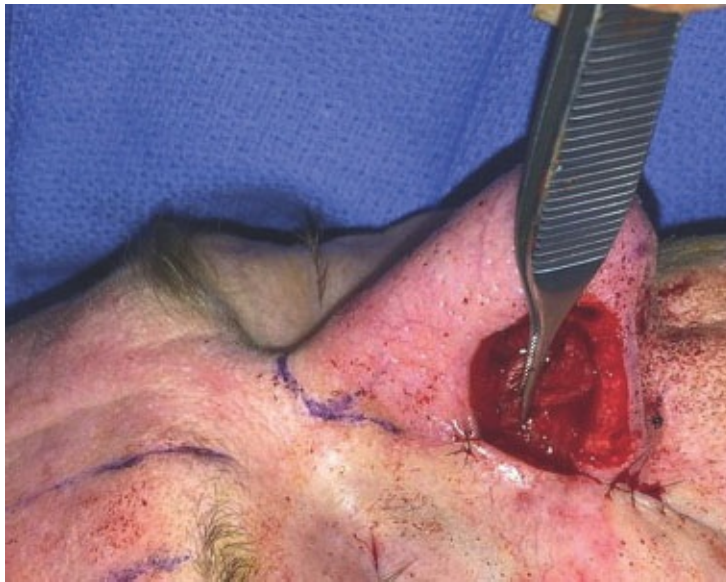
- After induction of general anesthesia and once the markings have been placed, local anesthetic (lidocaine 1% with epinephrine 1:100 000 concentration) is injected around the planned incision lines for hemostasis, sparing the lower part of the flap and the pedicle.
 - A prophylactic antistaphylococcal antibiotic of the surgeon's choice is administered intravenously.

Reconstruction of the Nasal Lining

- If a patient has a deficit of the internal nasal lining, this is repaired prior to inset of the PMFF.
- If the defect cannot be closed primarily, either an ipsilateral septal mucosal flap³ or a folded PMFF is commonly used.
- The ipsilateral septal mucosal flap is based on the septal branch of the superior labial artery.
 - Following injection of the septal mucosa with local anesthetic (lidocaine 1% with epinephrine 1:100 000 concentration), in the subperichondrial

plane along the entire length of the septum, two horizontal incisions extending from anterior to posterior are made with a scalpel on an extended handle.

- Both incisions should extend as far as posterior as possible (around 2 cm posterior to the bone-cartilage junction of the septum).
- A posterior vertical incision is then made between the ends of the dorsal and inferior septal incisions.
- The flap is dissected in the subperichondrial plane from above downward toward the floor of the nose and from posterior to anterior.
- Then, it is rotated laterally and inferiorly to line the vestibule and the lateral sidewall, with the mucosal surface facing toward the nasal passage, and is sutured in the defect.
- The exposed cartilage is left to heal by secondary intention or harvested for cartilage replacement (**TECH FIG 2**).



TECH FIG 2 • Repair of the nasal lining. After the ipsilateral septal mucosal flap is raised, it is rotated laterally and inferiorly to line the vestibule and the lateral sidewall.

- If a folded PMFF is selected for lining reconstruction, the distal lining extension of the PMFF is folded inward and sutured to the residual mucosal lining about the margin of the defect with 5-0 Vicryl Rapide interrupted

sutures.

- No primary cartilage support is placed within the folded flap at this stage.

Ala Cartilage Grafting

- Following lining reconstruction, the missing framework is substituted by means of cartilage grafts.
- For ala cartilage grafting, we use ear concha cartilage through an anterior incision.
 - The incision lies within the antihelix. It is barely visible and provides adequate exposure for harvesting the indicated amount of cartilage. In most cases, the entire concha is removed (**TECH FIG 3A,B**).
 - The incision is closed with interrupted 5-0 Vicryl Rapide sutures.
 - Quilting sutures approximate the anterior and posterior auricular skin (**TECH FIG 3C**).
- Based on the defect's size and geometry, the area that will best provide the appropriate contour and dimension is cut out from the harvested material.
 - The grafts are fixed with interrupted 5-0 chromic sutures to the residual normal skeleton, to each other, and to the underlying lining (**TECH FIG 3D**).

Flap Elevation and Donor-Site Closure

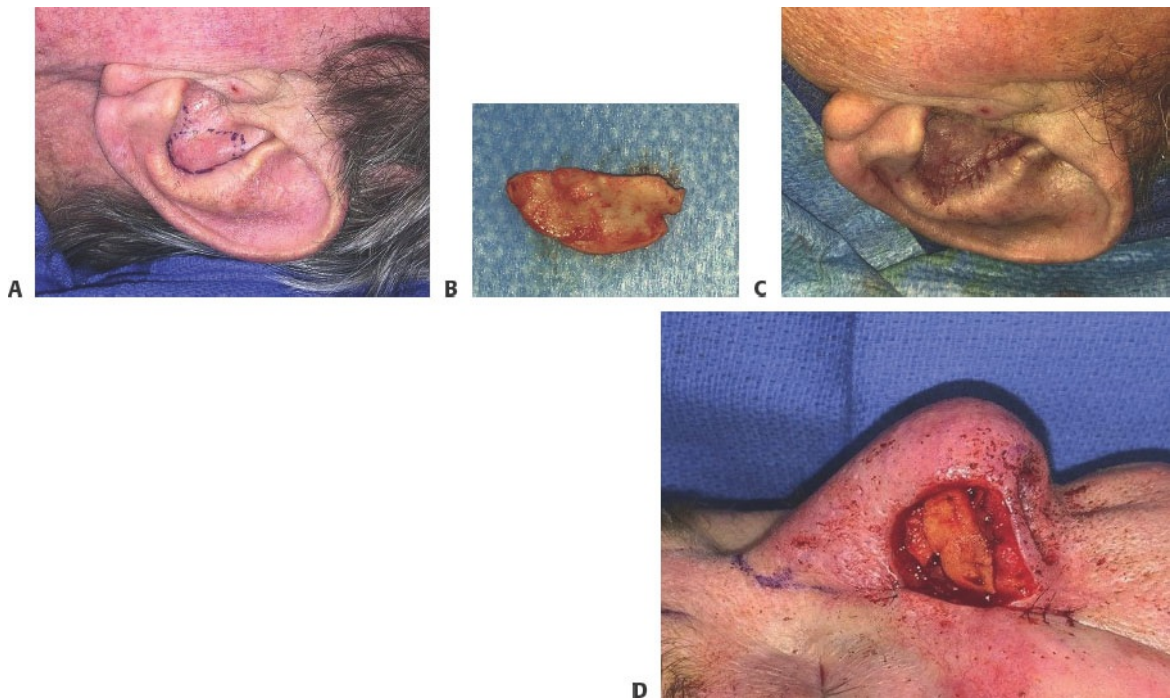
- The PMFF is incised through the skin, subcutaneous tissue, muscle, and fascia.
- Elevation of the flap is undertaken with blunt dissection in the subfascial plane, above periosteum, from superior to inferior fashion.
 - When the corrugator supercilii muscle is encountered, it is dissected from the underlying periosteum bluntly to allow greater mobility of the pedicle.
 - At this point, the supratrochlear artery may sometimes be visualized on the deep surface of the frontalis muscle just as it exits over or through the corrugator supercilii muscle.
- If the pedicle length is not sufficient, the incision is carried below the level of the eyebrow. This incision is made through skin and subcutaneous tissues.
 - Then, using blunt dissection, the pedicle is mobilized away from the medial bony orbit.
- Following flap elevation, hemostasis along the border of the flap is achieved with an electrocautery applied judiciously.
 - Donor-site closure is accomplished in layers after undermining, in the

subgaleal plane, of the skin borders up to 1 cm.

- As the wound edges are advanced, a dog-ear deformity of scalp tissue occurs at the superior apex of the flap donor-site defect. This is excised completely by extending an incision sufficiently superiorly in the scalp.
- The muscle and galea of the forehead are approximated as a single layer with simple 3-0 Monocryl sutures.
- The skin incision is repaired with simple sutures of 5-0 or 6-0 nylon. A drain is not employed.
- Any gap that cannot be approximated is allowed to heal secondarily, which takes approximately 6 to 8 weeks.

Defect Preparation

- Once it is clear that the previously raised PMFF has adequate rotation and vascularity, the defect is recreated by excising the residual skin (and scar) within the subunit, only if the defect encompasses more than half of a convex nasal subunit (the tip or ala).



TECH FIG 3 • Cartilage graft. **A.** Anterior approach for ear concha cartilage graft. **B.** The cartilage graft. **C.** The incision is closed with interrupted 5-0 Vicryl Rapide sutures. Quilting sutures approximate the

anterior and posterior auricular skin. **D.** The cartilage graft is fixed with interrupted 5-0 chromic sutures to the residual normal skeleton.



TECH FIG 4 • A. The paramedian forehead flap is rotated in the defect. **B.** Following cauterization along their entire length of the pedicle to control postoperative bleeding, the raw surface of the pedicle is dressed with Xeroform and antibiotic ointment.

- This does not apply for defects within the dorsal and sidewall subunits.
- If indicated, the remaining skin of the subunit is removed to the level of the perichondrium or periosteum.
- The skin around the nasal defect is undermined below the muscle layer for 1 cm, which helps with flap inset and prevents trapdoor deformity.

Handling of the Paramedian Forehead Flap Pedicle

- Thinning of the distal portion of the PMFF, through removal of the muscle and most of the subcutaneous fat, is important to be sufficiently supple and thin to conform to the nasal framework and manifest its contour.
- Further thinning of the PMFF is performed during the second and third stage of reconstruction.
- Following thinning, the flap is rotated into the defect and secured in place

with 5-0 nylon interrupted sutures for precise approximation of the skin edges.

- The raw borders of the pedicle of the flap are cauterized along their entire length to control postoperative bleeding, a common occurrence during the first 12 hours after surgery.
 - Some authors recommend the use of a full-thickness skin graft on the raw surface of the pedicle to avoid bleeding.
 - We have not found this step necessary and simply treat the raw surface of the pedicle with Xeroform and antibiotic ointment, thus avoiding the unnecessary use of a skin graft and the correlated donor-site morbidity (**TECH FIG 4B**).
-

■ Stage 2: Sculpture of the Nasal Repair

- Three to four weeks after the PMFF transfer into the nasal defect, sculpture of the nasal repair is performed (**TECH FIG 5A**).
 - The procedure is performed under general anesthesia to avoid the distortion created by local anesthesia or the chemical blanching of epinephrine.
 - Moreover, in cases where the folded PMFF is used, placement of cartilage grafts are also taken place at this stage.
- The nasal and regional units, the PMFF border scars, the ideal nostril rim and nostril aperture, and the excess between the cover and lining flaps are marked.
 - The ideal outline of the reconstructed ala is determined by remarking the correct rim position and outline, based on a template of the contralateral normal (**TECH FIG 5B**).
- An incision is made along the margin of right alar rim.
 - The forehead skin is easily elevated, with 2 to 3 mm of subcutaneous fat.
 - Flap elevation varies, depending on the extent of soft tissue excisional sculpture needed or the need to place additional delayed primary cartilage grafts.
 - The excess flap between the cover and lining must be eliminated (**TECH FIG 5C**).
- Following creation of an ideal subsurface shape, the forehead skin, of comparable thickness to the native nasal skin, is returned to the recipient site.

- The cover flap is secured with a single layer of 5-0 nylon interrupted sutures.
- Quilting sutures of 5-0 Vicryl Rapide are placed over the position of the alar crease in order to define the upper border of the ala (**TECH FIG 5D**).



TECH FIG 5 • **A.** Complete epithelialization of the raw surface of the pedicle is seen 2 weeks after the first

stage of reconstruction without the use of a skin graft.

B. The ideal outline of the reconstructed ala is determined by remarking the correct rim position and outline, based on a template of the contralateral normal. **C.** Elimination of the excess flap between the cover and lining. **D.** After the cover flap is secured with 5-0 nylon interrupted sutures, quilting sutures of 5-0 Vicryl Rapide are placed over the position of the alar crease in order to define the upper border of the ala.

■ Stage 3: Division of the Pedicle

- Three to four weeks later (6–8 weeks after flap transfer), the pedicle is divided.
- Lidocaine 1% containing epinephrine is injected into the base of the pedicle and circumferentially around the flap where it attaches to the nose, followed by the usual sterile preparation and draping.
- The pedicle is separated with a scalpel at the superior margin of the nasal defect.
 - An incision is made between the flap and adjacent nasal skin on either side of the pedicle to release the cephalic portion of the flap from the nose. This improves nasal contour through thinning and proper trimming and inset of the flap.
 - The incision is closed with 5-0 nylon interrupted stitches.
- The remnant of the pedicle is completely excised in a fusiform shape.
- The defect is closed along the line of the PMFF closure, thus returning the brow to its anatomic position.

PEARLS AND PITFALLS

Indications

- Reconstruction of complex post-traumatic and post-tumor excisional nasal deformities

Contraindications

- Patients with soft tissue loss, prior surgery/trauma, radiation therapy

at the forehead

- Patients unwilling or unable to tolerate multiple-stage operation

Planning

- Paramedian placement of the skin paddle leaves a more aesthetically pleasing scar and allows the potential of two PMF a single patient.
- The narrow pedicle design provides a greater arc of rotation with less chance of kinking of the vascular pedicle.
- In patients with vascular compromise, such as those with atherosclerotic disease, diabetes, or long-standing tobacco use, surgical delay of the PMFF is advised (**FIG 4**).

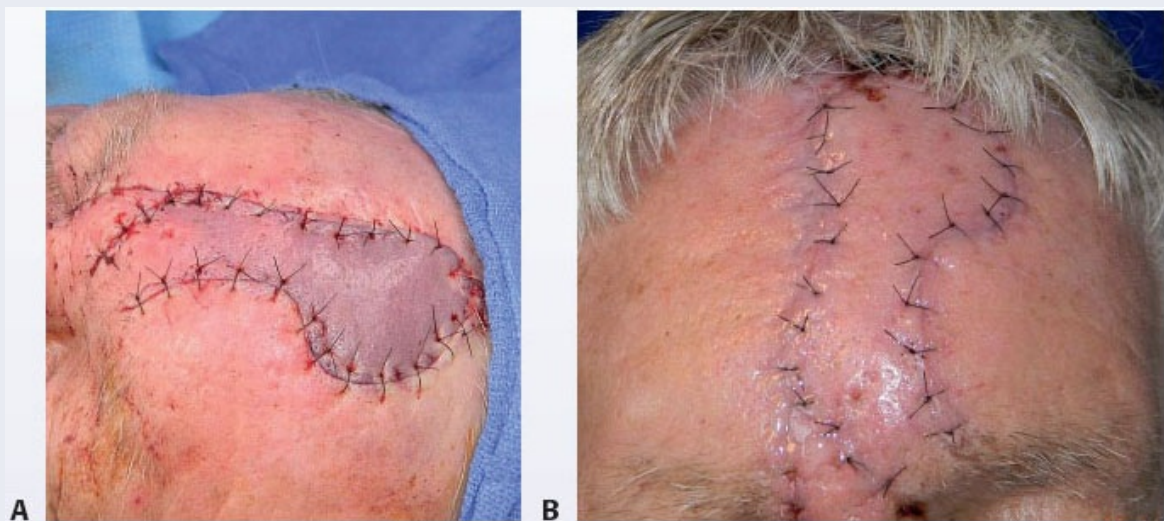


FIG 4 • A. Following raising of a paramedian forehead flap in an active smoker with a nasal defect, the flap showed signs of vascular compromise. Thus, a surgical delay of the flap was performed. **B.** The same flap 3 days later shows complete reversal of the vascular compromise.

Technique

- Aggressive thinning of the most distal part of the skin paddle down to the dermal plexus can be performed during the initial flap elevation or at an intermediate stage.
- Lining and structural support need to be addressed for complex nasal defects at the initial stage of PMMF elevation.
- Scars are re-excised during pedicle division, and meticulous approximation of flap edges is essential to restore optimal appearance.

POSTOPERATIVE CARE

- Postoperative care consists of cleaning the suture lines with soap and normal saline and application of antibiotic ointment twice daily for 3 days. Sutures are removed on the 7th to 10th postoperative day.
- The patient is advised to avoid excessive sunlight exposure to the forehead and face region for 6 months to prevent postinflammatory hyperpigmentation of the scars. Moreover, extremes of heat or cold may cause temporary color changes in the flap skin at the recipient site and are better avoided for several months.
- The Xeroform wrap around the raw surface of the pedicle is removed between the 3rd and 5th postoperative day, and then, it is treated with antibiotic ointment till complete epithelialization is achieved.
- The donor site of the PMFF, which cannot be closed primarily, is treated with Xeroform, antibiotic ointment, and eye patch till the 3rd to 5th postoperative day.

OUTCOMES

- Two patient examples are shown in **FIG 5**.
- Little et al.⁴ presented their experience with the use of PMFF in nasal reconstruction.
 - According to their results, the complication rate was 16.1%. Full-thickness defects and smoking were significantly associated with major complications.
 - On the other hand, age, vascular disease, or diabetes was not significantly associated with complications.
 - The authors suggested that for patients most at risk, a three-stage PMFF should be used for reconstruction.
- Paddack et al.,⁵ through a retrospective review study, studied the factors contributing to treatment failure with the PMFF in nasal reconstruction. Their study included 82 patients who underwent two-stage PMFF repair.
 - The overall failure rate was 6%.
 - No single comorbidity was noted to have a statistically significant effect on failure rates, although 83% of failures were observed in smokers.
- Kendler et al.⁶ assessed the aesthetic and functional outcomes and complications of PMFF in elderly patients with nonmelanoma skin cancer. There were 28 patients included with median age of 81 years (range, 75–95 years).
 - Although there were seven treatment-related complications, the authors

suggested that the PMFF procedure is a safe and low-risk procedure in patients 75 years of age or older with advanced nasal defects.



FIG 5 • A. This Caucasian male patient had a left ala defect following Mohs tumor excision. **B.** Long-term outcome (3 years) following a two-stage reconstruction with a PMFF. **C.** This Caucasian female patient had a

lower half nasal defect—including left ala, tip, and lower half of the dorsum—following Mohs tumor excision. **D.** First stage of reconstruction with a paramedian forehead flap. The donor site was healed by secondary intention. **E,F.** Long-term outcome (1 year) after a three-stage reconstruction with a PMFF.

- Rohrich et al.⁷ performed a retrospective analysis on 1334 patients who underwent nasal reconstruction. Three- or two-stage reconstruction was performed in 81% of the cases.
- The revision rate was 1.2%.
- The authors suggested the use of axial pattern flaps such as the PMFF for defects larger than 1.5 to 2 cm in diameter in more than two stages of reconstruction.

COMPLICATIONS

- The complication rate for PMFF is low. Hematomas, flap partial or total compromise, and poor aesthetic outcome are the most common complications.
- The development of small hematomas under the distal portion of the flap is the most common complication observed with PMFF. Hematomas develop at the time of initial flap transfer due to the rich vascularity of the flap, which creates a tendency for the undersurface of the portion of the flap thinned of its muscle and subcutaneous fat at the time of transfer to bleed postoperatively.
- To reduce the development of hematomas, careful hemostasis is needed over the entire raw undersurface of the thinned portion of the flap.
- Flap partial or total compromise is mainly due to venous congestion. This is avoidable in at-risk patients by taking the aforementioned precautions in design of the flap and use of surgical delay in indicated cases.
- Other options for salvaging a compromised PMFF include debridement followed by a second flap or graft.
- Poor aesthetic outcome include the appearance of the forehead scar, the ill-defined alar crease, the bulky nostril margin, the short nostril aperture, or an area of excess tissue.
- At 4 to 6 months, once wound maturation is complete, the alar crease can be defined by direct soft tissue excision; a hanging nostril margin trimmed by rim excision; the nasal aperture enlarged by local soft tissue excision, local

lining redistribution, or a composite skin graft, and the forehead donor scar can be revised by excision and readvanced, discarding any area of hypertrophy associated with secondary healing.

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35 Septal Flaps for Nasal Lining

CHAPTER

Jordan D. Frey, John T. Stranix, and Pierre Saadeh

DEFINITION

- Nasal defects are classified on the anatomical basis of the affected nasal layer: external nasal cover or skin, bony or cartilaginous nasal support, or internal nasal lining.
- Replacement of nasal lining is considered the most imperative and challenging aspect in all of nasal reconstruction.¹
 - Poor nasal lining replacement will lead to internal scarring and contracture that will compromise the aesthetic and function of native and/or reconstructed nasal cover and support.
- Intranasal septal flaps are often favored for nasal lining reconstruction because they provide thin, reliably vascular tissue upon which cartilaginous support establishes nasal shape and support.^{2,3}

ANATOMY

- Intranasal lining transitions from the stratified squamous epithelium of the ala and columella to the mucoperichondrium of the septum and mucosa of the nasal vault.⁴
- Laterally, internal nasal mucosa is supplied by the facial and angular arteries.
- Septal mucoperichondrium is supplied by the paired septal branches of the superior labial arteries and paired anterior ethmoidal arteries^{5,6} (**FIG 1**).
 - The septal branches of the superior labial artery arise anteriorly through the orbicularis oris muscle lateral to the nasal spine at the base of the columella.
 - The anterior ethmoidal vessels arise posteriorly passing below the nasal bones to supply the dorsal septum.
- A variety of septal flaps can be designed based on these vascular pedicles to

replace deficient nasal lining.

PATHOGENESIS

- Nasal lining defects may arise from a variety of mechanisms including traumatic, oncologic, infectious, autoimmune, iatrogenic, and drug-induced etiologies.^{3-5,7}
- Although oncologic resections or traumatic injury can result in more localized defects, autoimmune and infectious etiologies more often produce pan-mucosal insult.⁴
- Nasal lining deficiencies may occur in isolation or in the context of nasal support or cover deficiencies, including full-thickness nasal defects.
- Septal flaps can be utilized for primary nasal lining defects or to cover secondary defects after other intranasal flaps have been used to provide lining for the primary defect.

NATURAL HISTORY

- Significant isolated nasal lining defects eventually result in scar contracture that can circumferentially destroy the midvault and nasal floor.⁴
- This is followed by cartilage and bone necrosis leading to loss of midvault support, tip rotation, and central facial collapse toward the piriform aperture.⁴
 - Bony nasal vault collapse is prevented by the strength of the nasal bones.⁴
- Ultimately, if external nasal skin becomes devascularized, full-thickness necrosis can occur.⁴
- Therefore, expeditious reconstruction of nasal lining defects, before the onset of scar contracture, guided by defect etiology, is strongly favored to provide optimal aesthetic and functional results.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Upon initial presentation, nasal lining defect etiology must be determined.
- If an etiology is not determined or residual disease is apparent, appropriate investigative biopsies, cultures, laboratory tests, or referrals should be arranged.⁴
 - It is imperative that the inciting etiology of the defect is rendered quiescent prior to any intervention, lest the ultimate reconstruction be compromised by ongoing pathology.

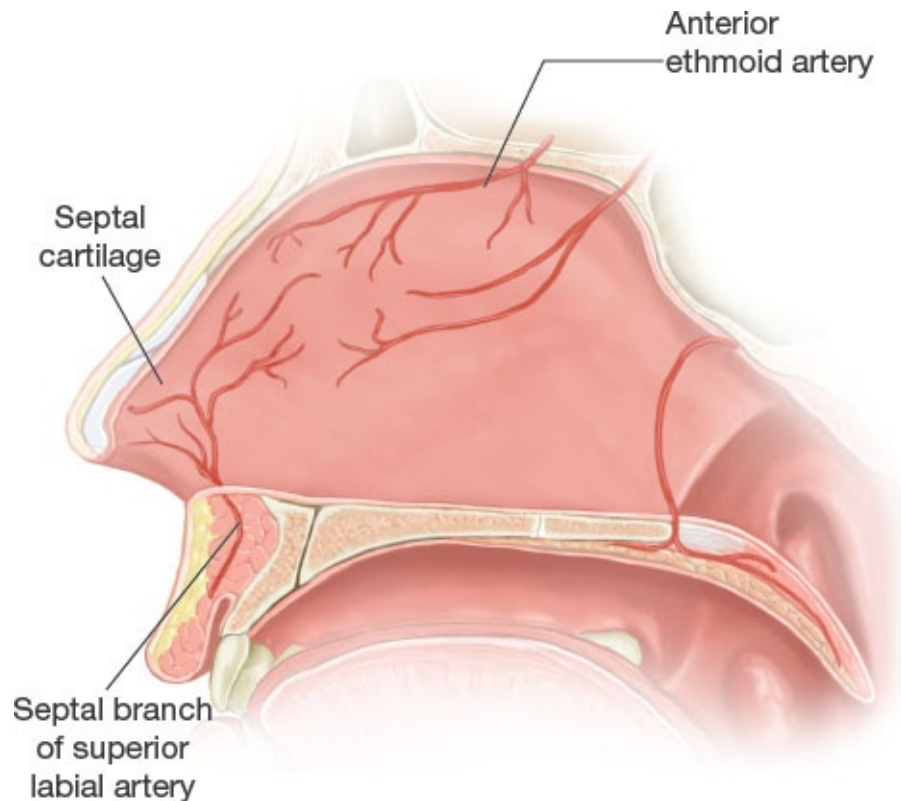


FIG 1 • The septal mucoperichondrium is largely supplied by the paired septal branches of the superior labial arteries anteriorly and paired anterior ethmoidal arteries posterodorsally.

- Possible symptoms of nasal obstruction should be elicited from the patient on history and examination because septal flaps may further compromise obstruction.
- A full extra- and intranasal physical examination should largely focus on defining the location, size, and extent of the nasal lining defect as well as any defects in nasal support or cover to guide the determination of the septal flap required.
- The subunit principle proposed by Burget and Menick is used to classify nasal cover defects and guide external nasal reconstruction.⁸
- The septal mucoperichondrium and its blood supply should be examined to ensure its integrity; injury along the nasal spine or posterior septum may indicate damage to the superior labial or anterior ethmoidal vessels, respectively.

IMAGING

- Traditional radiographic imaging is generally not necessary when planning for nasal lining reconstruction with septal flaps.
- Meticulous and standardized preoperative patient photography is mandated for both accurate operative planning and assessment of postoperative results.

DIFFERENTIAL DIAGNOSIS

- Trauma (facial fractures, foreign body)
- Oncologic (basal cell carcinoma, squamous cell carcinoma, melanoma, lymphoma)
- Infectious disease (syphilis, tuberculosis)
- Autoimmune disease (Wegener granulomatosis)
- Iatrogenic injury (septorhinoplasty, endotracheal tube pressure necrosis)
- Intranasal drug abuse (cocaine)

SURGICAL MANAGEMENT

- The use of septal flaps for nasal lining in any given defect is based on the size and location of the defect and the availability of septal mucoperichondrium; defect etiology and status of nasal cover and support are separate considerations.
- When needed, the septum proper may be harvested as graft for nasal support; care is taken to leave an adequate L strut to prevent dorsal nasal collapse.

Preoperative Planning

- Preoperatively, patient examination and photography help determine the full extent of the total nasal defect including the status of the nasal lining to develop a comprehensive operative plan.
- Patients are counseled preoperatively that multiple stages are typically required for complex nasal reconstruction and that the need for minor revisions postoperatively is likely, regardless of the type of reconstruction being pursued.
- Preparatory surgery includes debridement of necrotic or infected tissues and/or release of tethered scars at the time of or before definitive reconstruction.
 - These procedures may also take place at the time of flap delay, prelamination, or prefabrication per the reconstructive requirements.

Positioning

- Patients are positioned in the supine position with the neck in slight extension

to facilitate surgical access to the nose; this can be augmented with a shoulder roll.

- Slight reverse Trendelenburg can help decrease venous pressure and thereby bleeding.
- As required, the ears and/or chest is included in the surgical field to permit conchal cartilage or rib graft harvest for nasal support.

Approach

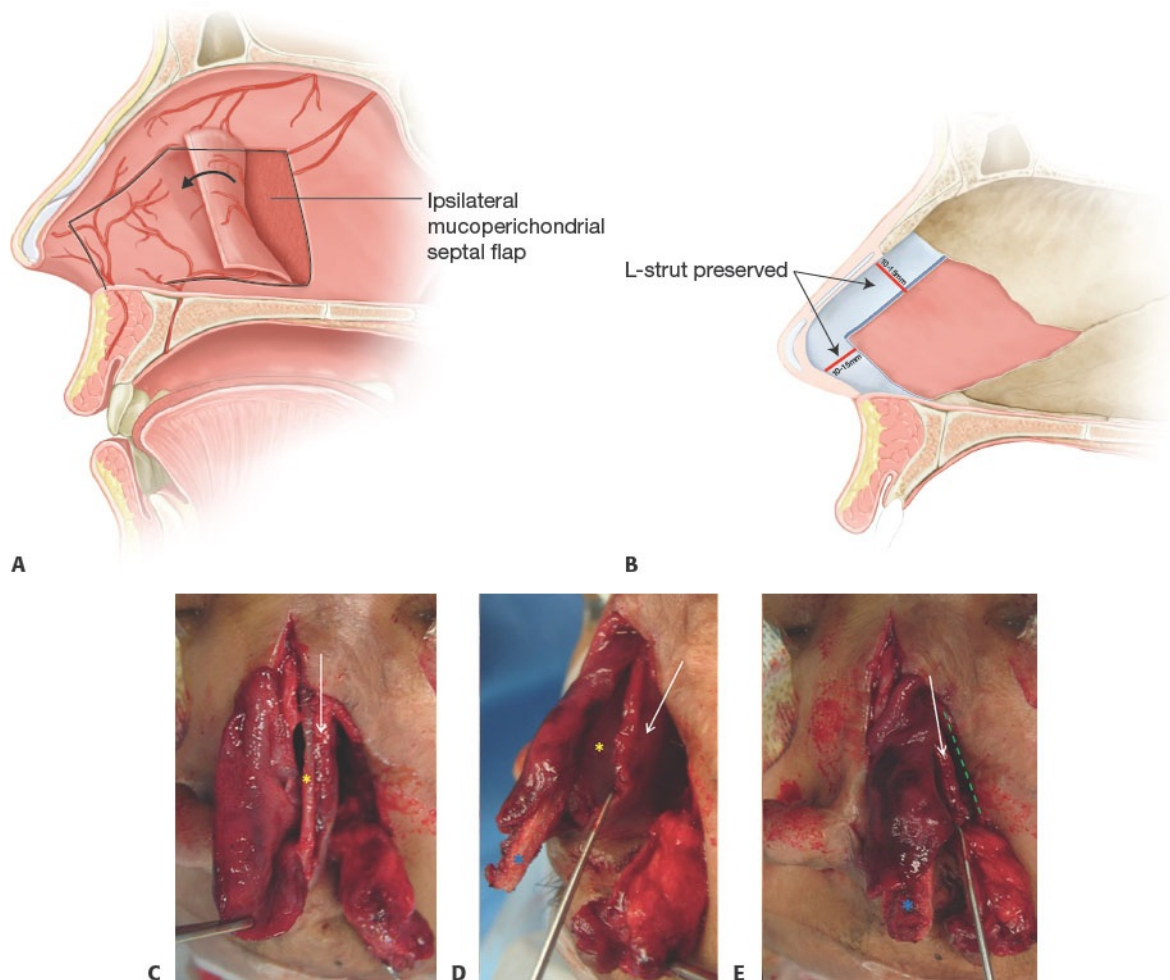
- If not performed in isolation, nasal lining reconstruction should precede reconstruction of nasal support and external coverage.
- The nasal lining defect is reincised to establish fresh defect edges and release any residual scar for accurate estimation of the amount of tissue required for reconstruction.
- Local hingeover or vestibular bipediced flaps with fixed sizes and less donor-site morbidity are performed first if multiple flaps are required with a septal flap for nasal lining reconstruction.
 - This allows for the harvest of the smallest possible septal flap that still provides adequate defect lining.

TECHNIQUES

■ Ipsilateral Mucoperichondrial Septal Flap

- An ipsilateral mucoperichondrial septal flap is raised based on one of the paired septal branches of the superior labial artery.
- This flap can be designed up to 3 cm in width by 3 cm in length and transposed laterally to provide lining for ipsilateral nasal vestibular and inferior sidewall defects.
- Superiorly, the flap can reach the medial canthus and, inferiorly, the nasal floor.
- To harvest the flap, an incision is made extending from the anterior area of the nasal spine upward toward the dorsum in a straight line (**TECH FIG 1A**).
- The incision travels posteriorly at a level of 6 to 8 mm below the nasal dorsum moving parallel to the dorsum and nasal bones after which it is taken inferiorly at a right angle toward the nasal floor.

- The incision continues anteriorly from the inferior aspect of the posterior vertical incision toward the nasal spine, leaving a cuff of tissue surrounding the pedicle.
 - 10 to 15 mm of cartilaginous L strut is preserved (**TECH FIG 1B**).
- The mucoperichondrium is carefully elevated off the septum.
- The flap is then transposed laterally and sutured to the edges of the defect without tension (**TECH FIG 1C–E**).



TECH FIG 1 • A. Creation of an ipsilateral mucoperichondrial septal flap begins by extending an incision from the anterior nasal spine upward toward the dorsum in a straight line; the incision carries posteriorly moving parallel along the dorsum and nasal bones before turning 90 degrees to extend

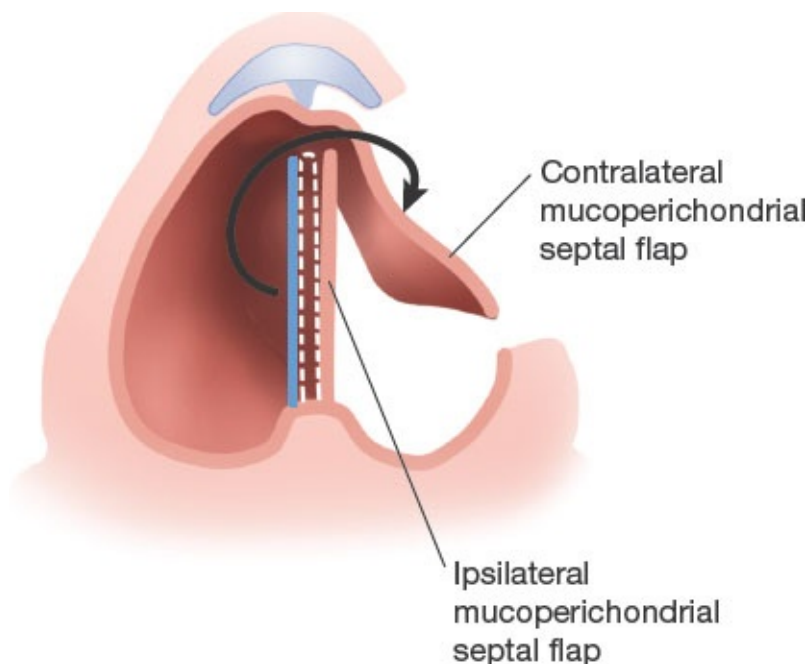
inferiorly to the nasal floor. The incision continues anteriorly toward the nasal spine, leaving a cuff of tissue surrounding the pedicle. This flap is supplied by a septal branch of the superior labial artery. **B.** Care must be taken to preserve 10 to 15 mm of cartilaginous L strut to avoid loss of structural integrity. **C–E.** This composite nasal defect required staged reconstruction. Left nasal lining was reconstructed with ipsilateral mucoperichondrial septal flap (*arrows*) that was elevated off the residual nasal septum (*yellow asterisks*) and inset laterally along the defect edge (*green line* in **E**). The nasal dorsum was reconstructed with a cantilever bone graft (*blue asterisks*), and the patient ultimately underwent external coverage that consisted of a paramedian forehead flap.

■ Contralateral Mucoperichondrial Septal Flap

- Contralateral mucoperichondrial septal flaps are utilized for moderately sized lateral sidewall nasal lining defects of the midvault that cannot be adequately covered by an ipsilateral septal flap.
- This flap is based dorsally off one of the paired anterior ethmoidal arteries.
- A contralateral mucosal flap is first designed with a width equal to the vertical height of the defect that must be covered; this width may span the entire dorsum if needed.
- Two vertical lines approximating the adequate width of the flap are drawn, extending vertically from the dorsum to the nasal floor.
- A ventral horizontal line is drawn connecting the vertical lines to complete flap design; no incision is made along the nasal dorsum.
- Once the contralateral mucosal flap is designed, a horizontal incision is made approximately 6 to 8 millimeters from the nasal dorsum on the ipsilateral mucoperichondrium.
- The ipsilateral mucosa is raised off the septum, and the septum is harvested

with care taken to leave an adequate L strut and to protect the contralateral mucoperichondrial flap.

- The contralateral flap is incised and passed through the slit in the ipsilateral mucosa after which it is transposed and sutured to the contralateral nasal lining defect (**TECH FIG 2**).
- The ipsilateral nasal bone or middle crura of the lower lateral cartilage may be resected or transected to facilitate superior or inferior flap transposition, respectively.
- The contralateral mucoperichondrial flap may be designed to extend onto the nasal floor; this will permit the flap to reach the lateral piriform aperture on the defect side.
- The ipsilateral septal mucoperichondrium must be preserved to prevent a significant septal fistula.

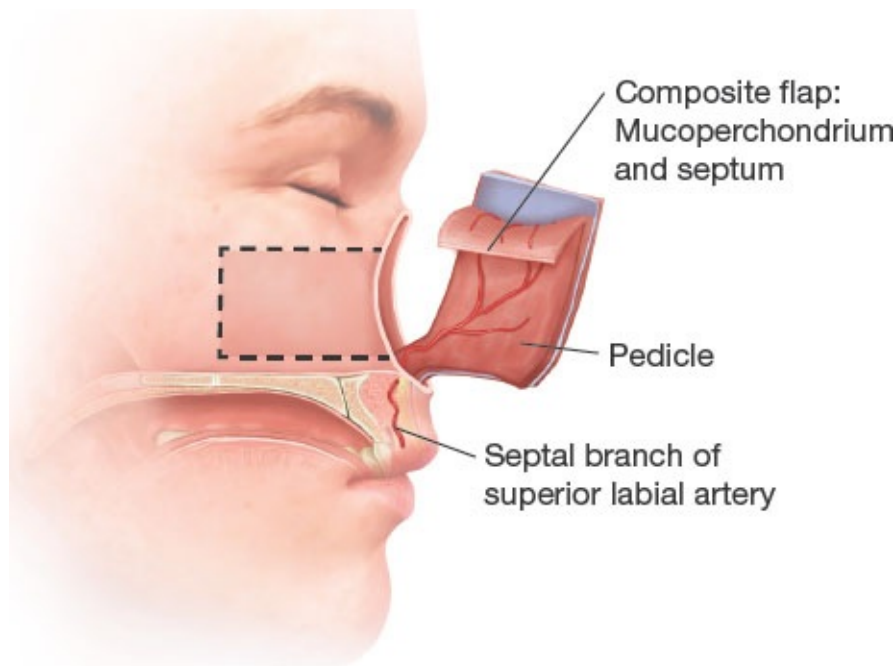


TECH FIG 2 • The contralateral mucoperichondrial septal flap is designed similarly to the ipsilateral septal flap. A slit is made along the nasal dorsum on the ipsilateral septal mucosa, which is then carefully lifted off the septum. The septum is harvested and may be used for nasal support as required. The contralateral septal flap may then be incised and transposed

through the slit in the ipsilateral septal mucosa into the defect. This flap is supplied dorsally by the anterior ethmoidal artery.

■ Septal Composite Hinge or Pivot Flap for Central Nasal Lining

- Cases requiring central nasal lining often coincide with subtotal or total defects of the nasal soft tissues, anterior septum, and nasal bones.
- In these circumstances, the total or remaining composite nasal septum can be elevated based on the bilateral superior labial arteries and “hinged” or “pivoted” anteriorly to provide both support and lining.
- The flap is created by making full-thickness incisions through the septum superiorly at a level approximately 1 centimeter below the dorsum and inferiorly along the nasal floor.
- A soft tissue cuff is left surrounding the pedicle in the region of the nasal spine and upper lip.
- The superior and inferior cuts are then connected with a posterior vertical cut (**TECH FIG 3**).
- The bilateral mucoperichondrium near the nasal spine is elevated off the septum, and a small piece of cartilage and bone is resected to facilitate flap transposition anteriorly.
- The superior edge of the transposed septum is secured to the remaining upper lateral cartilages or nasal bones.
 - In total nasal defects with loss of cartilaginous and bony support, bone grafting or other reconstruction of the nasal process of the frontal bone is required prior to securing the composite septal flap.
- Inferiorly based bilateral septal mucoperichondrial flaps can be raised either immediately or after delay to provide midvault and upper vault nasal lining.
- In total nasal defects, the septal mucoperichondrium will not reach inferiorly nor will it reach far enough laterally to completely line the middle and upper nasal vestibule; additional nasal lining reconstruction is required.



TECH FIG 3 • The septal composite hinge or pivot flap is created by making full-thickness cuts through the septum superiorly at a level approximately 1 centimeter below the dorsum and inferiorly along the nasal floor. A soft tissue cuff is left surrounding the pedicle similar to the ipsilateral septal flap. The superior and inferior cuts are then connected with a posterior vertical cut. Inferiorly based septal mucoperichondrial flaps can be raised bilaterally to provide nasal lining.

PEARLS AND PITFALLS

Patient history

- All patients should be assessed for smoking, which decreases intranasal septal flaps reliability.

Preoperative planning

- Templates of nasal lining defects are useful intraoperatively after all scarring has been released to help ensure the adequate septal flap design.

Flap technique	■ Septal flaps should be raised in the subperichondrial plane to protect blood supply, whether from the septal branches of the superior labial arteries or the anterior ethmoidal arteries.
Pedicle protection in anteriorly based septal flaps	■ In both the ipsilateral septal flap and composite septal hinge or pivot flap, an approximately 1.2-cm soft tissue cuff should be left intact in the area of the anterior nasal spine to protect the superior labial artery pedicle.
Combining ipsilateral and contralateral mucoperichondrial septal flaps	■ In cases of ipsilateral nasal lining defects extending from the nasal sill to the nasal bones, an ipsilateral septal flap can be combined with a contralateral septal flap for nasal lining reconstruction. ■ The ipsilateral flap covers the inferior vestibule while the contralateral flap covers the midvault and upper vault. ■ The pedicle of the ipsilateral septal flap may obstruct the external nasal valve and can be secondarily divided after the flap has healed.
Central nasal lining defects	■ The high arching nature of the midvaults and upper vaults often allows small central nasal lining defects to be closed primarily by mobilizing the medial septal and lateral sidewall mucosa.
Complications	■ Patients with severe scarring, multiple prior nasal surgeries, prior infections, or smoking history are predisposed to complications with septal flaps for nasal lining.

POSTOPERATIVE CARE

- Patients undergoing isolated nasal lining reconstruction with septal flaps may be discharged home on the same day.
- More complex nasal reconstructions requiring septal flaps in conjunction with more extensive local or microsurgical flap techniques require hospitalization.
- After discharge, patients should keep their heads elevated including at night for at least a few days to a week.
- Nasal stents may be placed at the conclusion of the procedure and generally remain in place for 3 to 4 weeks postoperatively.⁹
- Patients should avoid blowing their noses and can gently use a moist cotton-tip applicator to clean their noses as needed.
- Patients should be cautioned to expect drainage in the early postoperative period and variable nasal airway obstruction for up to 6 months after reconstruction is complete.

- Depending on the extent of the reconstruction, patients can usually quickly resume their normal daily activities but should be advised to avoid any activities that could result in injury to the face; extra care should be taken while asleep to ensure that inadvertent trauma to the nose does not occur.
- Smokers must refrain from smoking at least 1 month preoperatively and until reconstruction is completed.
- Patients should be reminded of the staged nature of most nasal reconstructions.

OUTCOMES

- Overall, patient satisfaction with nasal appearance after nasal reconstruction with septal mucoperichondrial flaps as part of overall nasal reconstruction is high (greater than 80%).^{1,4,6,7}
- Rates of objective and subjective nasal obstruction after septal flaps for lining coverage range from 0% to 31%.^{1,5,7}
- Isolated nasal lining defects undergoing reconstruction rarely result in functional nasal compromise.⁴
- Short-term postoperative nasal bleeding requiring nasal packing in this patient population is as high as 66%.⁵
- Rates of long-term nasal mucosal crusting and bleeding after nasal lining reconstruction with septal flaps range from 0% to 36% and from 0% to 6%, respectively.^{1,5,7}
- Infection and partial or complete flap necrosis are rare.^{1,5,7}

COMPLICATIONS

- Short-term complications include nasal bleeding, crusting, and obstruction.^{3,5}
- Nasal bleeding and crusting may persist long term.^{3,5,7}
- Persistent iatrogenic septal fistulae may develop after ipsilateral or contralateral septal flaps; when small, fistulae may cause whistling.¹
- Large septal fistulae from composite septal hinge or pivot flaps are inherent to flap design and generally well tolerated by patients.³
- Septal mucoperichondrial flaps inherently have little support, and if structural support is lacking, late scarring and contracture can cause late nasal distortion, stenosis, and obstruction.
- Overall, flap infection or necrosis is rare given the abundant vascularity of the face.^{1,5,7}
- Limited areas of flap necrosis can be managed conservatively and allowed to

heal secondarily if cartilage is unexposed.

- Cartilage exposure may necessitate debridement to avoid infection and local tissue necrosis.

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36 Radial Forearm Flap for Nasal Lining Reconstruction

CHAPTER

Robert L. Walton and Brent Robinson

DEFINITION

- Since its initial description by Yang et al. in 1978,¹ the radial forearm flap has been considered to be one of the most versatile flaps for nasal defect reconstruction.
- It provides for thin, well-vascularized tissue that is easily harvested, with acceptable donor-site morbidity.
- Unique to the radial forearm free flap (RFFF) is its ability to be partitioned into separate islands for restoration of specific nasal lining elements such as the nasal vestibule, floor, and columella.²
- The free radial forearm flap is properly defined as a fasciocutaneous flap that is primarily based on the radial artery and its venae comitantes (VCs).
- One or two of the cutaneous nerve branches of the forearm (ulnar, median, or lateral cutaneous nerves of the forearm) provide for sensibility of the flap if a neurosensory configuration is required.³
- The size of the flap can encompass any section of the skin and fascia from the crease of the volar wrist to the antecubital fossa including the circumferential forearm.

ANATOMY

Vascular Anatomy

- The vascular anatomy of the radial forearm flap has been well elucidated.⁴ As noted above, circulatory flow is provided by the radial artery and its associated VCs (**FIG 1A**). The basilic and cephalic veins of the forearm are usually included in large configurations of the flap, although the VCs provide for its

primary venous drainage.⁴ Its long vascular pedicle (8–12 cm) and generally consistent anatomy make the radial forearm flap particularly advantageous for nasal reconstruction.

Radial Artery

- The radial artery originates just distal to the bicipital aponeurosis where the brachial artery divides into the radial and ulnar arteries. In the proximal forearm, the radial artery lies beneath the brachioradialis muscle and becomes more superficial as it approaches the hand. The radial artery travels between the heads of the first dorsal interosseous muscle to create the deep palmar arch providing blood to the thumb and thenar side of the index finger. As the radial artery becomes more superficial in the distal forearm, it gives off small fasciocutaneous perforators that course superficially to supply the overlying fascia and skin. These fasciocutaneous perforators constitute the primary perfusion of the radial forearm skin.⁴ Saint Cyr et al. found an average of 24.6 radial artery perforators in the forearm, with the majority located distally and over 50% of these having a radial orientation.⁴ The presence of these two main clusters found along the distal and proximal thirds of the radial artery can significantly facilitate flap planning and harvest.⁴
- Although variations in radial artery anatomy are rare, its collateral communications with the ulnar circulation in the hand should be confirmed preoperatively by an Allen test at the wrist. In the most common configuration of the deep palmar arch (Type A), it is formed by the anastomosis between the deep volar branch of the radial artery and the deep inferior branch of the ulnar artery.⁵ The superficial palmar arch (type A) is formed by anastomosis between the superficial volar branch of the radial artery and the continuation of the ulnar artery.⁵
- The RFFF has two systems of venous drainage: a deep system composed of two VCs accompanying the radial artery and a superficial system composed of the cephalic vein and a series of subcutaneous veins (17). The profunda cubitalis vein serves as the primary connection point between the two systems (**FIG 1B**).⁶ The superficial system is based off the cephalic vein and a series of meandering, subcutaneous venules that drain into it.⁷ The superficial venous drainage is generally considered to have a consistent course and a favorable caliber for subsequent anastomosis ranging from 3 to 6 mm.⁶ The cephalic vein courses around the radial border of the forearm ascending along the ventral aspect of the forearm toward the antecubital fossa, where it joins the basilic

vein. The cephalic vein drains the radial portion of the dorsum of the hand. Deep venous drainage occurs with the paired deep VCs that travel along each side of the radial artery with communicating tributaries. The VCs send off paired branches at each ramification of the radial artery, reproducing a triplicate pattern of vessels.⁷

- Although widely studied, the controversy of one vs two venous anastomoses still exists.⁸ Even though the published success rates of RFFF approach 95%, a series of complicating factors still can lead to unpredictable venous compromise postoperatively.⁸ In a retrospective cohort study of 370 radial forearm free flaps, Selber et al. conducted a comparative analysis of the deep vs the superficial drainage systems. They found that problems of inadequate outflow are more commonly encountered when the cephalic vein is used to drain the flap. When of adequate caliber (greater than 1 mm), they advocate using the VCs as the sole venous outflow for the flap.⁷
- As noted by Gottlieb et al., the VCs coalesce into a single vein at the level of the brachial artery bifurcation. The profundus cubitalis vein (vena anastomotica) connects the coalesced VCs to the cephalic vein at the level of the cubital fossa.⁹ By dissecting the cephalic vein proximal to this point of coalescence, both the deep and superficial venous systems can be drained via one large anastomosis. Advantages of this technique include improved venous drainage of very large radial forearm flaps, rendering the venous anastomosis technically easier, due to its larger size, and more available versatility in designing the venous portion of the vascular pedicle where the deep and superficial systems join in the proximal forearm allowing for single outflow vessel anastomosis.⁹ As noted, this configuration is reserved for large flaps that wrap the radial forearm distally and extend the greater length of the forearm to the wrist.

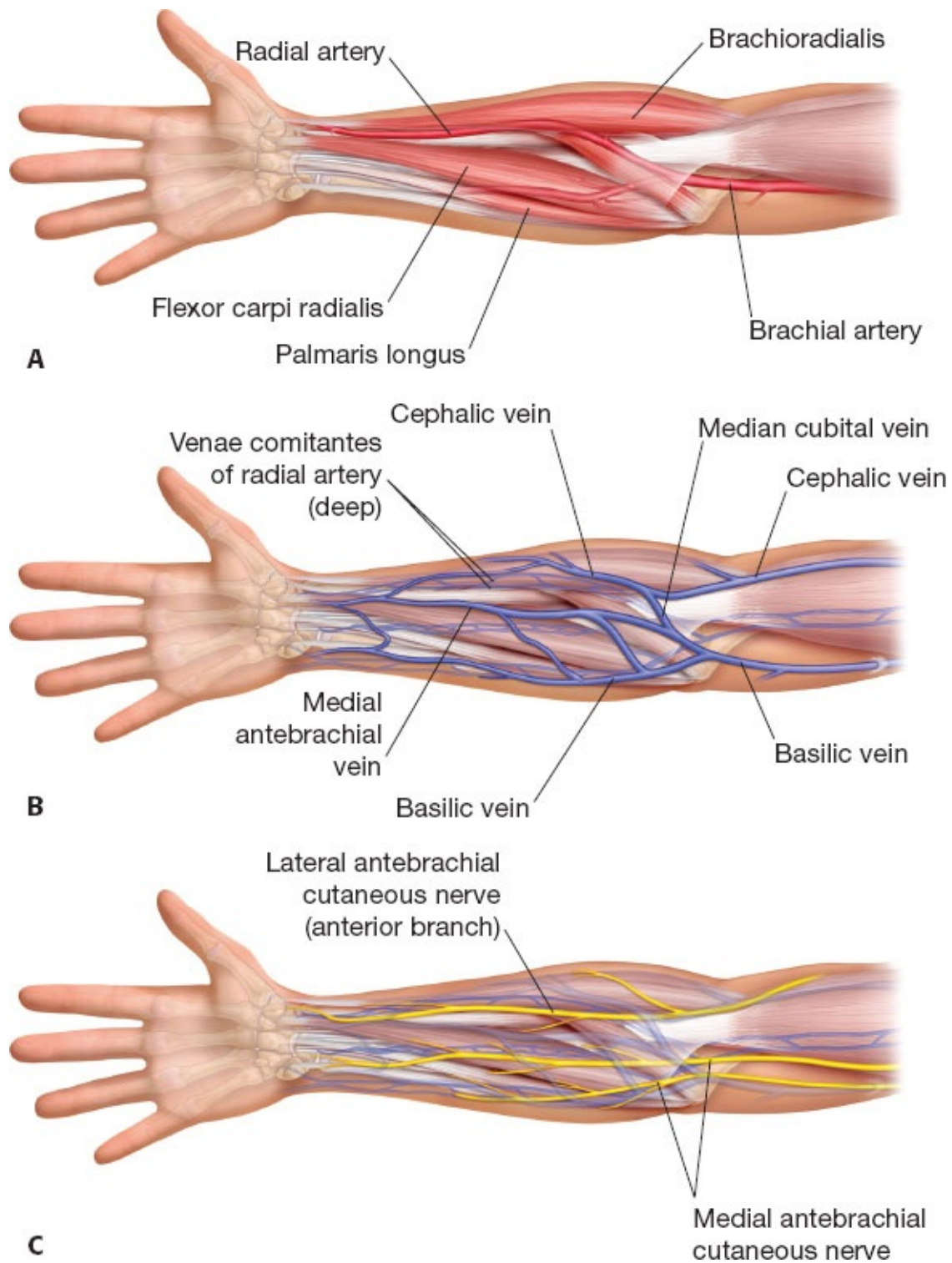


FIG 1 • Arterial **(A)**, venous **(B)**, and nerve **(C)**, anatomy of the radial forearm flap.

Nerve Supply

- The medial and lateral antebrachial cutaneous nerves of the forearm provide for cutaneous sensibility of the radial and volar forearm (**FIG 1C**). The lateral antebrachial cutaneous nerve is a continuation of the musculocutaneous nerve originating from C5 to C7 nerve roots and the lateral cord of the brachial plexus, and it innervates the greatest surface area of the flap's three overlapping nerve territories.⁹ The nerve arises between the biceps brachii and the brachialis muscles. It pierces the fascia radial to the biceps tendon in the cubital fossa, passes posterior to the cephalic vein, and divides into anterior and posterior branches. The larger anterior branch accompanies the cephalic vein into the forearm and supplies the skin of the radial half of the anterior surface as far as the thenar eminence. The smaller posterior branch supplies the skin of the radial border and posterior aspect of the forearm as far as the wrist. The medial antebrachial cutaneous nerve arises from C8 to T1 nerve roots. At the junction of the middle and distal thirds of the forearm, the nerve emerges from the brachial fascia running with the basilic vein and dividing into an anterior and ulnar branch. The anterior branch supplies the anterior medial surface of the forearm to the wrist; the ulnar branch passes anterior to the medial epicondyle and supplies the skin on the forearm on its posteromedial surface.
- An important attribute of the RFFF is its ability to provide restoration of sensibility in reconstruction as a neurosensory fasciocutaneous flap. Studies determining the long-term recovery of sensibility in flaps have shown increased sensibility and better functional results with reinnervated flaps compared to noninnervated flaps.¹⁰ The lateral antebrachial cutaneous nerve is the dominant nerve of the radial forearm flap, providing sensibility to over 62% of the potential flap area. It is most commonly employed for restoring sensibility in neurosensory configurations of the flap.¹⁰
- Of special note is the superficial branch of the radial nerve (SBRN), the branches of which are commonly encountered during elevation of the radial edge of the flap (**FIG 1C**). These branches are highly vulnerable to injury during flap elevation necessitating diligent care during this portion of the dissection. The SBRN courses under the brachioradialis and between the heads of the extensor carpi radialis longus just proximal to the radial styloid process.¹¹ When raising the flap, it is important to note the close relationship between the cephalic vein and SBRN. If harvest of the cephalic vein is undertaken by the surgeon during formation of the flap, an awareness of the precise anatomical location of the SBRN in relationship to both the radial artery and cephalic vein is essential to avoid neurologic injury.¹¹ Flap donor-

site morbidity arising from injury to the SBRN has been documented by Grinsell and Thiele (2005) to be between 9% and 18% depending on whether the VCs or cephalic vein were included in the elevation, as raising the cephalic vein doubled the risk of SBRN injury.¹²

PATIENT HISTORY AND PHYSICAL FINDINGS

- If an Allen test is positive but concern still exists on the patency of the radial artery, it is reasonable to obtain upper extremity arteriography for further evaluation.
- In a cadaver dissection of 650 cadaver arms, only 3.2% had no communication between the radial and ulnar artery, and 3% had an incomplete deep arch.¹³
- If both of these variations are present, the thumb will be dependent on the radial artery (approximately 1 in 1100).¹³ Vein graft reconstruction would be necessary in these cases.
- Other important components in the patient's history include hand dominance. It is preferable to harvest the flap from the nondominant upper extremity.
- Additionally, hair growth patterns on the forearm are important aesthetic considerations that may affect subsequent flap design and shape.
- A critical issue in the use of the radial forearm free flap is prior cannulation of the radial artery.
 - Arterial line catheterization traumatizes the intima, damaging vascular outflow to the perforating branches by subjecting the radial forearm flap to compromised perfusion and possible partial or complete loss.
 - Despite palpable radial pulses and a positive Allen test, flap perfusion may still be compromised.
 - History of prior arterial line catheterization should prompt consideration for use of a radial forearm flap from the opposite upper extremity or an alternate flap.

IMAGING

- Although the fine vascular perforators from the radial pedicle to the overlying skin islands can be identified using magnified contrast angiography preoperatively, we have not found such studies to be necessary owing to the plethora of fine perforating vessels emanating from the radial system in the distal forearm.
- The distribution of these vessels in the distal forearm has proved to be fairly

consistent in our experience with adequate physiologic flow provided in over 100 consecutive multi-island flaps without any perfusion issues.

SURGICAL MANAGEMENT

Preoperative Planning

- The first stage in reconstruction of total and subtotal nasal defects is restoration of the nasal lining and adjacent cheek and upper lip elements constituting the nasal base.¹⁴
- This is usually accomplished with the microsurgical transfer of a radial forearm flap to avoid compromising the local tissues and structures of the midface and airway.
- The nasal lining is composed of the floor, the nasal vestibules, and the membranous septal element (in which the columella is repaired or the midline septum is reconstituted).

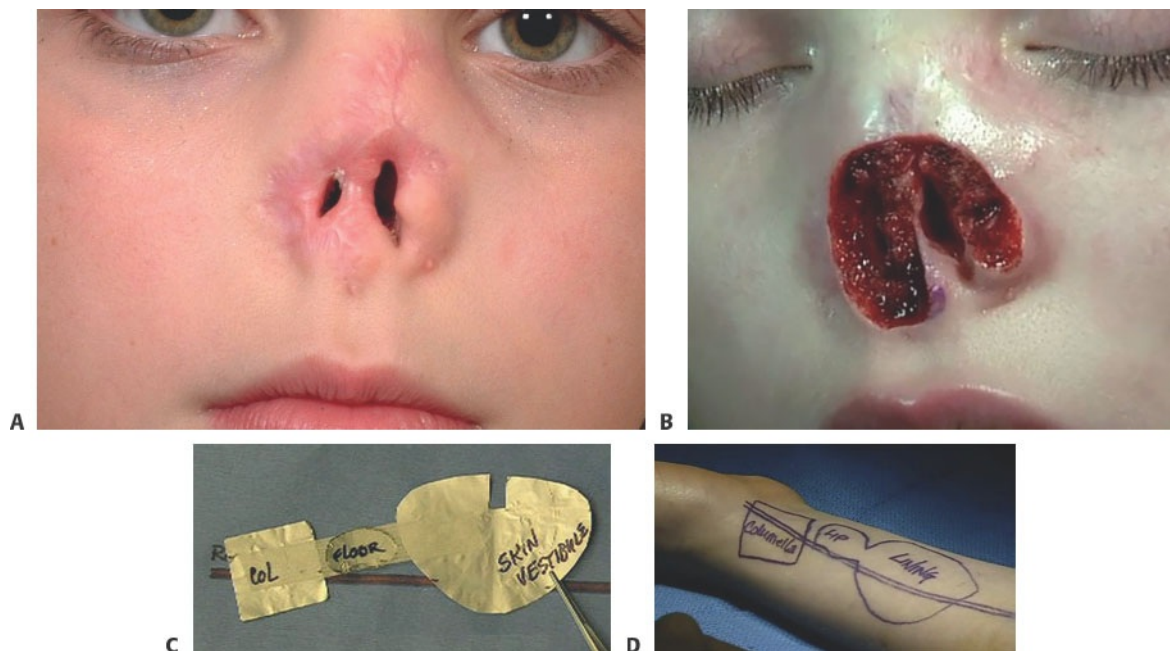
TECHNIQUES

■ Templating and Flap Design

- The nasal site is dissected first, with excision of the remnant scar and any skin grafts to recreate the original defect (**TECH FIG 1A,B**).
- Templates of each of the missing lining and adjacent lip and cheek defects are made of foil from surgical suture packets.
 - Care is taken to provide sufficient skin island separation so as to accommodate the three-dimensional, anatomic positioning of these elements at the nasal site.
 - We have found it useful to attach each of the foil templates with strips of paper tape beforehand to replicate the radial vascular pedicle and then determine the best three-dimensional configuration of the islands that allows for their anatomic positioning without kinking the vascular pedicle (**TECH FIG 1C**).
- The flaps are then transferred to the forearm, where they are aligned to the radial vascular pedicle as separate skin islands (**TECH FIG 1D**).
 - For the vestibular lining element, we have found it helpful to orient the vascular pedicle at its cephalic edge so as to allow access to the nasal tip

and vestibule for placement of the supporting cartilage grafts and for sculpting without injuring the vascular pedicle.

- The vascular pedicle proximal to the skin islands should be at least 8 to 10 cm in length to allow it to span the distance from the nasal defect site to the facial artery and vein at the inferior border of the mandible.
- This precise distance is measured intraoperatively so that adequate pedicle length is obtained during flap harvest. Although vascular repairs can technically be performed more proximal near the nasal site, the marked size variability and unpredictability of the venous anatomy at this level necessitates accessing the facial system at a more anatomically predictable site, ie, below the mandibular margin.



TECH FIG 1 • **A.** An 11-year-old girl had subtotal nasal loss following a dog bite. **B.** Surgical preparation of the nasal site involves excision of all scar tissue to approximate the dimensions of the original wound. **C,D.** Foil templates of the missing nasal elements are joined with tape and aligned to the radial pedicle on the volar forearm. (Reprinted from Walton RL, Burget GC Beahm EK. Microsurgical reconstruction of the nasal platform and lining. In: Nelligan PC, Wei FC,

eds. *Microsurgical Reconstruction of the Head & Neck*. New York: Thieme Publishers, 2010:547-589 with permission.)

■ Flap Harvest

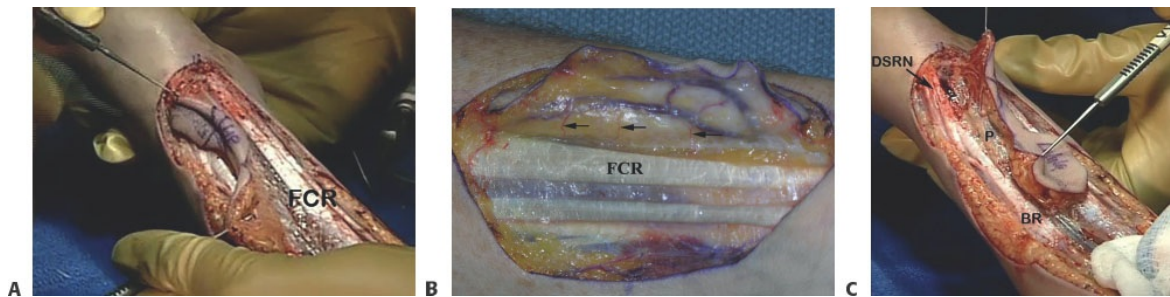
Confirmatory Dissection of The Radial Forearm Flap(s)

- Preoperatively, an Allen test is performed to assure adequate hand perfusion via the ulnar vascular pedicle.
- The 1 to 3 island radial forearm flaps are dissected under tourniquet control.
- The skin islands are kept attached at this stage of the dissection to facilitate elevation.
- The conjoined skin flap is dissected from its ulnar margin in a plane superficial to the level of the forearm fascia (**TECH FIG 2A**).
- The dissection terminates at the tendon of the flexor carpi radialis. Here, the dissection transitions to the subfascial plane.
- Small filamentous vascular branches emanating from the radial pedicle to the undersurface of the flap are easily identified and protected (**TECH FIG 2B**).
- On the radial side of the flap, the dissection proceeds through the subcutaneous tissue to the volar surface and the ulnar border of the brachioradialis tendon (**TECH FIG 2C**).
 - Care is taken here to identify and protect the dorsal sensory branches of the radial nerve and the musculocutaneous nerve.
- Occasionally, one or two small proximal branches of the radial sensory nerve may be found entering the radial forearm flap.
 - These are divided, and the proximal stumps are buried in the adjacent brachioradialis muscle to avoid painful neuroma formation.
- The dissection then proceeds deep to the radial vascular pedicle, where several relatively large branches emanating dorsally from the vascular pedicle will be encountered.
 - These are ligated with 6-0 PDS absorbable sutures and divided.
- At this point of the dissection, we have found it helpful to release the tourniquet and evaluate flap perfusion.
 - In the rare circumstance in which perfusion of the skin island is sluggish or

compromised, further flap elevation should be abandoned or delayed. The radial artery and venae comitantes (VCs) at this stage have not been divided, so little is lost.

Completion Dissection and Elevation of the Radial Forearm Flap(s)

- If the skin island demonstrates satisfactory perfusion, the tourniquet is reapplied and the flap elevation proceeds to completion.



TECH FIG 2 • A. The dissection commences on the ulnar border of the flap with elevation superficial to the deep fascia. At the radial edge of the flexor carpi radialis (FCR), the dissection is directed deep to include the radial artery and venae comitantes. **B.** Fine filamentous perforators emanating from the radial pedicle (*arrows*) to the overlying skin are preserved. **C.** On the radial side of the flap, the subcutaneous tissues are bluntly dissected to identify and preserve the dorsal sensory branches of the radial nerve (DSRN) and the distal sensory branches of the musculocutaneous nerve (MCN). At the ulnar margin of the brachioradialis tendon (BR), the dissection is directed deep to include the radial artery and its VCs (P). (Reprinted from Walton RL, Burget GC, Beahm EK. Microsurgical reconstruction of the nasal platform and lining. In: Nelligan PC, Wei FC, eds. *Microsurgical Reconstruction of the Head & Neck*. New York: Thieme Publishers, 2010:547-589, with permission.)

- Distal to the skin island, the radial artery and its two VCs are dissected out and ligated with fine 5-0 PDS absorbable suture and divided (**TECH FIG 3A**).
- A forearm incision is made over the course of the proximal radial vascular pedicle, and the vascular pedicle is dissected to its appropriate length with ligation and division of its multiple forearm muscular branches (**TECH FIG 3B**).
 - In certain situations, the microsurgical venous anastomoses can be simplified by dissection to the confluence of the VCs into a single vein just proximal to the profunda cubitalis branch joining the cephalic vein.
- After the flap has been isolated to the radial pedicle and the pedicle dissected to length, the tourniquet is released and the flap is allowed to reperfuse.
 - The pedicle and skin islands are examined under magnification to assess perfusion and to obtain final hemostasis (microbipolar and fine suture ligation of small branches).
- Separation of the skin islands and flap debulking are then performed.
 - The islands are dissected using loupe magnification, with care taken to preserve the fine, filamentous vascular branches emanating from the pedicle to each skin island.
 - Operative magnification is used to debulk selected areas of the flap (especially the vestibular element) (**TECH FIG 3C**). This is accomplished by incising the fibrous interstitium between the fat lobules and gently teasing and suctioning the fat away by a process dubbed “liposuction.” We have found this to be a very effective technique for performing the initial debulking of the acute flap without compromising its blood supply.

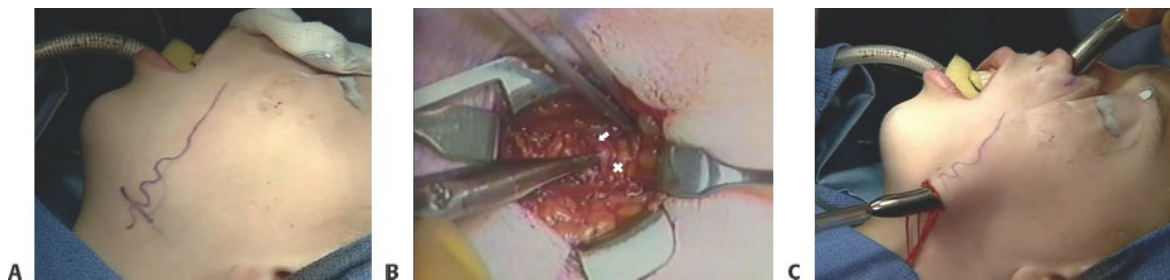


TECH FIG 3 • A. The radial artery and venae comitantes are ligated with fine sutures and divided after adequate flap perfusion has been verified. **B.**

The flap pedicle is dissected proximally with ligation and division of the multiple muscular branches. **C.** The flap can be debulked using operative magnification and selective excision of the fat globules peripheral to the pedicle.

■ Dissection and Exposure of the Facial Artery and Vein

- The facial vessels are exposed through a 2-cm incision made just below and parallel to the inferior mandibular border at the palpated notch or Doppler site of the facial artery pulse (**TECH FIG 4A,B**).
- The platysmal fibers are dissected apart longitudinally to expose the facial artery and vein.
 - The marginal branch of the facial nerve is identified and protected.
- A sub-SMAS tunnel connecting the nasal defect site with the facial vessel site is created using blunt dissection with progressive Hegar cervical dilators.
- The dilated tunnel is maintained with a 32 F chest catheter passed subcutaneously from the facial incision site riding the end of the retracting dilator for subsequent delivery of the vascular pedicle (**TECH FIG 4C**).

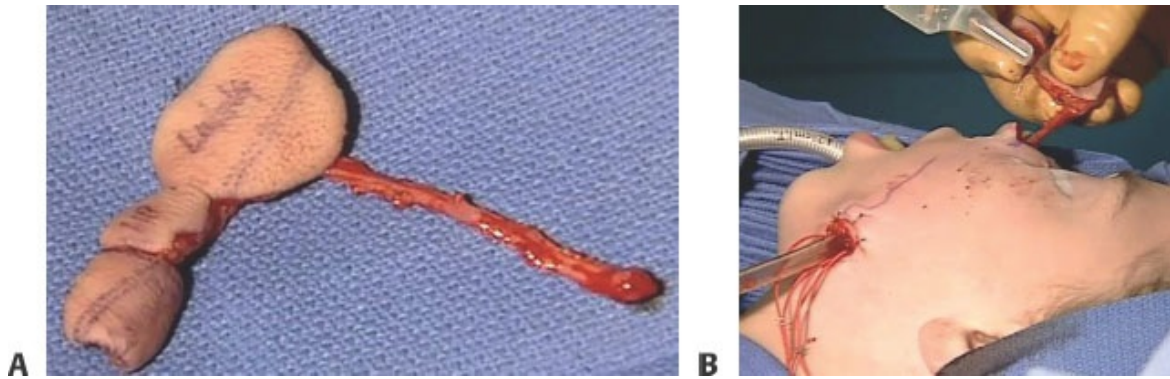


TECH FIG 4 • A. The facial vessels are accessed in the upper neck 1 to 2 cm below the lower border of the mandible. **B.** Dissection proceeds deep to the platysma with care taken to identify and preserve the marginal branch of the facial nerve. At this level, a large facial vein (3 to 4 mm external diameter; X) and facial artery (2 to 3 mm external diameter) (*arrow*) can

be identified. Occasionally, a large lymph node will be encountered that obscures access to the facial vein—dissection and removal of this lymph node will facilitate access to the facial vein. **C.** After the facial vessels have been dissected, a sub-SMAS tunnel is bluntly dissected for passage of the flap pedicle. This is progressively enlarged using cervical dilators. The dilated tunnel is maintained with a 32 F chest catheter that is passed in retrograde fashion behind the dilator. (Reprinted from Walton RL, Burget GC, Beahm EK. Microsurgical reconstruction of the nasal platform and lining. In: Nelligan PC, Wei FC, eds. *Microsurgical Reconstruction of the Head & Neck*. New York: Thieme Publishers, 2010:547-589, with permission.)

■ Transfer of Flap to Facial Site

- After the flap pedicle is divided, the flap is transferred to the nasal site where the vascular pedicle is gently directed through the subcutaneous tunnel in the cheek using the previously placed 32 F chest tube as a guide (**TECH FIG 5**).
- Gentle suction and a continuous drip of lactated Ringer solution for lubrication allow passage of the pedicle with avoidance of any vascular branch ligature avulsion or inadvertent twisting.
- Following delivery of the vascular pedicle through the cheek to the facial vessel site, the chest tube is then withdrawn, allowing the soft tissues to collapse around the unsullied pedicle.
- The flap is temporarily secured to the nasal site with 4-0 silk sutures.



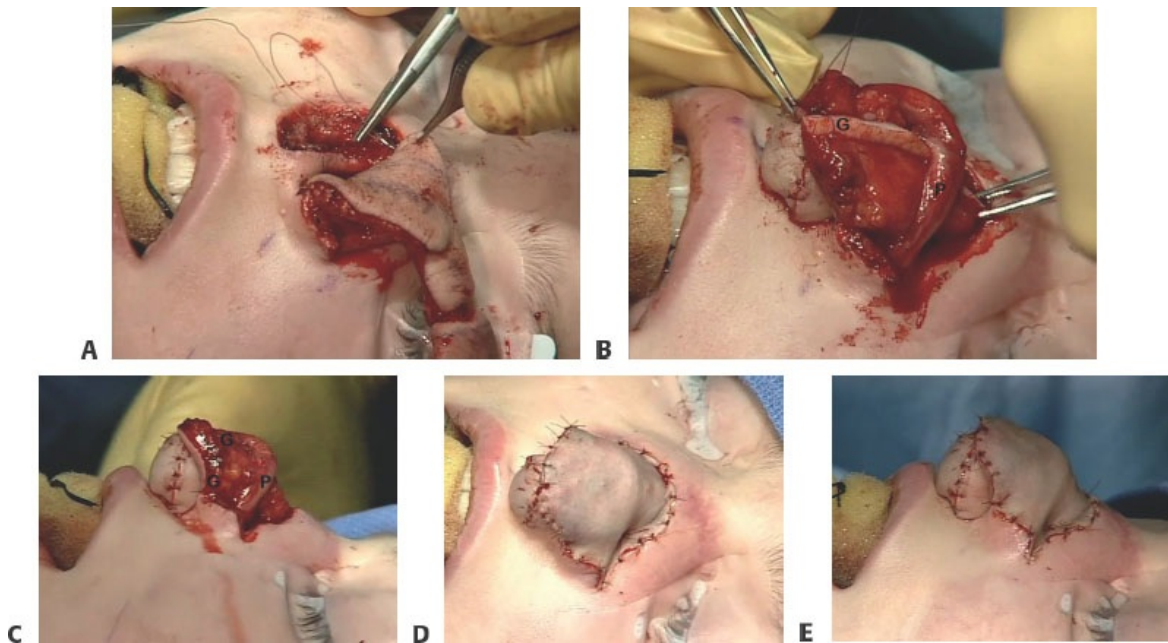
TECH FIG 5 • A. Detached flap reader for transfer. **B.** At the facial site, the flap pedicle is delivered through the cheek via the previously placed chest tube. Using saline drip irrigation as lubricant and gentle suction, the pedicle is delivered to the anastomotic site. This technique allows for accurate placement of the pedicle with minimal risk for twisting or shearing of side branch ligatures. (Reprinted from Walton RL, Burget GC, Beahm EK. Microsurgical reconstruction of the nasal platform and lining. In: Nelligan PC, Wei FC, eds. *Microsurgical Reconstruction of the Head & Neck*. New York: Thieme Publishers, 2010:547-589, with permission.)

■ Flap Inset

- The vascular repairs are performed end to end to the facial artery and vein. Although no systemic anticoagulation is used, we routinely employ high-concentration heparin irrigation (50 000 units heparin/100-cc lactated Ringer solution) while performing the vascular anastomoses.
 - Aspirin (81 mg) is also administered intraoperatively and for 21 days postoperatively for its prostacyclin and antiplatelet effects.
- Following re-establishment of vascular inflow, the flap islands are arranged anatomically at the nasal site and inset with fine sutures (**TECH FIG 6A**).
- To avoid contraction of the nasal vestibular lining elements, we have found it useful to brace the vestibular element with small grafts of cadaver allograft

cartilage placed in the midline and along the caudal edge of the vestibule and secured with 6-0 PDS suture (**TECH FIG 6B,C**).

- The undersurface of the vestibular element, which now lies externally, is closed with a full-thickness skin graft from the inguinal region (**TECH FIG 6D,E**).
 - When placed over the supporting cartilage allografts, the take of the full-thickness skin graft is not compromised, as a result of its excellent capacity for bridging.
- When the grafted area is large, a fine suction drain, fashioned from a 22-gauge butterfly intravenous needle, is placed beneath the skin graft to facilitate graft adherence and promote serous drainage.
- A simple petroleum jelly-impregnated gauze/mupirocin dressing is applied to the grafted vestibular element.
- No internal nasal packing or stents are employed.



TECH FIG 6 • **A.** Following re-establishment of vascular inflow, the flap islands are arranged anatomically at the nasal site and inset with fine absorbable (chromic) sutures. **B.** The vestibular element is temporarily stented with cadaver cartilage allografts to prevent shrinkage in the interim between

the microsurgical lining flap and the placement of permanent skeletal support (autologous cartilage grafts) and a forehead flap for external cover. The graft (G) is seen spanning the vestibular element and lying beneath the vascular pedicle (P). **C.** These cartilage allografts (G) are placed along the longitudinal axis of the vestibular element and at the nostril margins and secured with 6-0 PDS sutures. **D,E.** Following inset of the flap islands, the exposed undersurfaces of the flaps are closed with full-thickness skin grafts. Full-thickness grafts stifle contraction and are useful for bridging the cadaver cartilage allografts stents. During the second stage of reconstruction, the skin grafts and cadaver cartilage grafts are removed. (Reprinted from Walton RL, Burget GC, Beahm EK. Microsurgical reconstruction of the nasal platform and lining. In: Nelligan PC, Wei FC, eds. *Microsurgical Reconstruction of the Head & Neck*. New York: Thieme Publishers, 2010:547-589, with permission.)

■ Closure of the Forearm Donor Site

- We routinely employ a full-thickness skin graft harvested from the inguinal region, which provides very stable coverage for the distal volar forearm donor site.
 - It is pliable, exhibits minimal contraction, and is aesthetically quite acceptable (**TECH FIG 7**).
- A template of the forearm defect is transferred to the inguinal region where it is incorporated within the confines of an ellipse, the longitudinal axis of which is aligned with the inguinal fold.
- For large defects, the graft may need to be applied as articulated segments derived from the confines of the ellipse.
- The graft is inset using 4-0 silk sutures that are used to secure a sponge stent.

Following application of the stent dressing, the forearm and hand are wrapped in a light compression bandage composed of Kerlix fluffs, Reston foam, Kling wrap, and an Ace wrap secured with staples.



TECH FIG 7 • Full-thickness skin grafts are preferred for closure of the forearm donor site. Here a grafted forearm donor site is shown one year postoperatively.

PEARLS AND PITFALLS

Timing

- For complex flap shapes, we have found that delay of the radial forearm flap is advantageous for augmenting dermal perfusion, and we do this routinely 10–14 days prior to flap transfer. The flap is incised all around and elevated to a variable degree above the forearm fascia depending on the size and shape complexity of the flap island. For nasal lining–only defects, two delays are performed 3–4 weeks apart.

Tendon protection

- Prior to making the skin incision, the brachioradialis and flexor carpi radialis tendons are identified at the volar wrist and traced proximally. These structures will form the boundaries of the “no-fly zone,” defining the traverse of the radial pedicle and its perforators to the overlying skin paddle. In most cases, we prefer to harvest the flap in the suprafascial plane, preserving the deep fascia for coverage of the flexor tendons and nerves. This results in less donor-site morbidity and allows for selective thinning of the flap as necessary for nasal lining reconstruction.

Perforators

- When harvesting multiple islands, it is important to use magnification

(loupe or operating microscope) to identify the radial perforators to each island. After the islands have been dissected, care should be exercised to protect each island from shear or twisting forces that might injure the perforating vessels.

Flap thickness

- Do not underestimate the thickness of this flap despite its apparent thinness in situ. This is especially relevant when transferring the flap to the face for use in nasal lining reconstruction or external nasal cover. Direct debulking of the flap prior to transfer can be effectively accomplished by using operative magnification to visualize the fat globules allowing for their lysis and direct suction removal with care to avoid injury to the radial pedicle perforators and the subdermal vascular plexus. In obese patients, pretransfer debulking/delay of the flap is essential for avoiding the typical “meatball” appearance that results from transfer of the full subcutaneous thickness of the flap.
- In certain reconstructions in which the flap is tubed for reconstruction of the columella, it is important not to coapt the opposing edges under tension as this may compromise of the blood flow. In these cases, it is helpful to apply a small full-thickness skin graft between the folded edges of the flap to ease the tension. These grafts do quite well, provided adequate hemostasis is achieved prior to application of the skin graft. If necessary, they can be excised at the time of flap debulking and contouring usually 6–8 weeks following transfer.

POSTOPERATIVE CARE

- The flap reaches maximal swelling at 48 hours.
 - Close observation must be maintained to assure that this swelling does not interfere with flap perfusion especially if multiple islands are used.
 - If there is any concern about flap perfusion as the swelling ensues, release of several inset sutures may be all that is necessary to relieve the tension and improve flap perfusion.
 - Once the swelling subsides, and usually within 3 to 4 days, the sutures can be replaced.
- If the flap is transferred to the face, care must be taken to avoid the use of cool mist face masks or blow-by oxygenation as these may result in excessive cooling of the flap, which induces vasospasm and subsequent thrombosis.
 - To avoid this complication, insist on the use of warm (steam) humidification for all oxygenation adjuncts and be sure to personally check this to assure that no cool mist is contacting the flap.
- The forearm donor-site bandage is kept in place for 1 week. It is preferable to

not use arm slings as these tend to produce shoulder stiffness, especially in older patients; patients are instructed to carry their bandaged arm upright, with overhead elbow stretching on postoperative day 1.

- The stent dressing is removed and graft take is assessed at 1 week. The graft is redressed with a petrolatum dressing and a light gauze wrap and ace bandage.
- At 10 days postoperatively, the sutures are removed and moisturizing creams are applied.
- The forearm is kept wrapped with an ace bandage or Coban elastic bandage applied by the patient for 6 weeks to stifle hypertrophic scarring and promote contouring of the forearm donor site.

OUTCOMES

- Use of the radial forearm flap for restoration of the nasal lining elements has proved to be a very reliable approach for management of challenging total and subtotal nasal defects.
- In more than 150 such cases, we have experienced only one total flap failure and six partial losses. The total flap failure occurred in a patient with Wegener granulomatosis with protein C deficiency who exhibited flap necrosis on the 4th postoperative day despite normal Doppler signals. Three partial flap losses were associated with prior radial artery cannulation.

COMPLICATIONS

- Complications inherent to the radial forearm flap are few as this is a very robust flap with large-caliber vessels and an infinite assortment of configurations and applications.
- As noted above, be wary of using the radial forearm flap if prior catheterization of the radial artery has been performed, even if the Allen test demonstrates patent communication between the radial and ulnar systems. When using the flap around hardware, be cognizant of the fact that hardware can very quickly occlude the pedicle especially as the flap swells.
- In these cases, judicious placement of the pedicle away from any restricting hardware or bone graft will be good insurance against middle of the night phone calls. If the pedicle is oriented toward the edge of the flap, as in nasal reconstruction, it is often helpful to delay the flap to assure adequate perfusion of the skin island.
- Previous trauma to the forearm with visible scarring on its volar surface should raise caution about the potential for vascular perfusion problems. In these

cases, surgical delay or choice of a different flap (or arm) is warranted.

- Over the years, we have encountered several instances of vascular spasm induced by flap contact with cool moist humidified air provided by face mask or head tent devices by respiratory therapy.
- The small size of these nasal lining flaps makes them especially vulnerable to ambient air temperatures.
- If postoperative patients require supplemental oxygen, it is important to deliver this as a warm moist humidified flow to avoid temperature-induced vasospasm.
- Experience has shown that flaps incorporating previous forearm tattoos are at risk for vascular compromise and partial flap necrosis.
- For these small flaps, it is recommended that tattoo areas of the volar forearm be excluded from the flap design whenever possible.
- After flap healing, the second stage of nasal reconstruction involves removal of the skin graft cover, debulking of the vestibular lining element, placement of cartilage support grafts, and application of a paramedian forehead flap for external cover.
- Care must be taken during this stage to avoid creating any holes in the vestibular lining flap that might communicate with the nasal airway to avoid infection.
- If the radial forearm lining flap has been compromised during the dissection, these injuries should be meticulously repaired. We have found it useful to cover these repair sites with small dermis grafts as an added level of protection.

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Nasal Reconstruction With Skin Grafts and Composite Grafts

37

CHAPTER

Steven M. Levine and Daniel C. Baker

DEFINITION

- Nasal defects are frequently not amenable to primary closure without distortion of the underlying cartilaginous structure or obvious repositioning of the nasal tip or ala.¹
- Nasal defects are commonly treated with the local flaps or local regional flaps.
- The ideal reconstruction is skin of similar color, thickness, and texture.
- One-stage reconstruction is an attractive option to both patient and surgeon.
- Full-thickness skin grafts, for the purposes of this text, include the epidermis, dermis, and often adipose tissue.
- Composite grafts include both a component of skin as well as cartilage.

ANATOMY

- Nasal anatomy is often divided into aesthetic subunits.
 - These subunits are a useful guide but quite frequently can be ignored when reconstructing the nose with full-thickness skin grafts or composite grafts.
- Maximizing surface area for graft take is of primary concern when using full-thickness skin grafts or composite grafts.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Skin/subcutaneous defects on the nose may be treated in many cases with a full-thickness skin graft. However, if the defect includes missing cartilage or would benefit from extra-anatomical cartilage (such as an alar rim or tip), a composite graft should be considered.
- The defect must have an appropriate graft recipient bed to accept either graft.

- This means if the wound has been heavily cauterized during the resection portion of the procedure, excisional debridement and local wound care should be performed until a suitable bed is present.
- If the defect is contaminated as in the case of a dog bite or motor vehicle accident, debridement and local wound care should be performed until a clean recipient bed is present.
- Care should be taken to note the length, width, and depth of the defect.

SURGICAL MANAGEMENT

- Full-thickness skin grafting or composite grafting can be performed under local anesthesia, sedation, or general anesthesia, depending on the preference of the surgeon and the patient.

Preoperative Planning

- The primary consideration for preoperative planning is to define the extent of the defect and identify a suitable donor site.
- In general, color match is improved by selecting a donor site that is anatomically close to the nose (eg, the ear, preauricular skin).
 - These grafts have better color and texture match to the nose.
- The preauricular region is an ideal donor site and usually heals with an inconspicuous scar. Strong preference is given to this site vs the retroauricular site despite the natural inclination to use the more “hidden” skin behind the ear.
- Occasionally, the supraclavicular skin is good color and texture match for the nose.
- The surgeon should identify the components of the donor tissue required to optimize the aesthetic outcome.
 - Frequently, a thin layer of adipose tissue should be harvested with the grafts to allow for appropriate depth matching between the graft and the recipient site.
 - It is important to avoid overthinning of full-thickness skin grafts as this may result in late contracture or a cobblestone appearance of the graft that is difficult to address.
- The two most common donor sites for composite grafts used for nasal reconstruction are the anterior helical rim, which can be harvested along with a pennant of preauricular skin, and the conchal bowl, which can be harvested with either conchal skin or retroauricular skin.

Positioning

- The patient is either supine if under sedation or full anesthesia or sitting reclined or supine in an exam chair if performing the graft on an awake patient.

Approach

- The approach to the graft can be varied from surgeon to surgeon with a consistent emphasis on delicate handling of the graft both at the time of harvest and when securing it to the recipient site.

TECHNIQUES

■ Graft Repair of Nasal Defect

Site Preparation and Graft Harvest

- The donor site and recipient site are cleaned with alcohol and then prepped with Betadine.
- A small amount of eye ointment is placed on the sclera to protect the eyes if using anesthesia.
- First, the recipient site is defined. This means that any nonviable tissue is debrided and a fresh wound edge is created using a sharp knife to bevel the perimeter (**TECH FIG 1**).
 - Hemostasis should ideally be obtained using pressure and patience to avoid burning the recipient site and impeding graft take.
 - Very light cautery can be used if needed.
- After the recipient site is prepared, a foil template is made and transferred to the donor site.
- If a composite graft is planned for an alar defect with a lining deficiency that is greater than 8 mm, it will usually require a turndown flap.
- The authors prefer to use the adjacent sidewall skin as a turndown flap that is secured using 5-0 absorbable suture.
- Other surgeons prefer a septal hinge flap, but we find this flap to be flimsy and difficult to control.



TECH FIG 1 • Recipient site prepared.

- The graft is harvested entirely with a knife, and the edges are beveled.
- If the graft is a composite graft with cartilage, care is taken to not separate the cartilage from its attachments to the surrounding skin.

Graft Placement

- If alar reconstruction is being performed, a tongue in groove closure is performed with the composite graft cartilage and the recipient alar rim—in other words, extend the graft cartilage beyond the skin and use this additional cartilage to insert in both lateral recipient sites.
- 6-0 monofilament sutures are used to sew the grafts to the deep recipient bed to minimize potential space.
- The graft is secured usually using 6-0 nylon suture in the recipient bed (**TECH FIG 2**).
- Prior to finishing, a 20-gauge angiocatheter is used to irrigate beneath the flap with saline.
- If a bolster is used, it is secured to the flap with tape, not suture.
- The donor site is closed primarily, elevating tissue where needed to minimize tension on the closure.



TECH FIG 2 • Composite graft sewn in place with edges beveled and delicately approximated to surrounding tissue. Conchal skin was harvested with cartilage to add structure to avoid notching the alar rim.

PEARLS AND PITFALLS

Handle grafts with care

- Do not cauterize when harvesting the grafts. Do not inject local anesthesia through the graft, rather inject around the graft.

Graft take is a reflection of the health of the recipient bed

- Exercise patience when determining the appropriate timing for the graft. Fresh eschar is not a suitable recipient bed as in the case of a cauterized post-Mohs defect. Use local wound care principles to obtain a healthy granulation bed prior to grafting.

6-0 monofilament sutures to minimize potential

- These small monofilaments and accompanying small needles are an excellent alternative to through-and-through basting sutures.

space

Meticulous postgraft care

- See these grafts frequently over the first few days. Minor problems can be treated thereby avoiding major problems. Small collections can be rolled out from beneath the graft; Silvadene can be used in compromised regions. Often, epidermolysis heals and completely recovers.



FIG 1 • The patient in TECH FIGS 1 and 2 one year after composite graft for alar rim reconstruction.

POSTOPERATIVE CARE

- Tie-over bolsters have been abandoned in favor of either no bolster (for grafts smaller than 1 cm) or a small Xeroform bolster covered with nonstick gauze and tape.
- Cool packs are also used to reduce swelling and have reportedly been shown to improve graft survival by lowering the metabolic requirement of the grafted tissue.
- Patients are instructed to use cool compresses at home for the first 12 hours.
- Patients are seen back in the office the following morning, and any dressing over the graft is removed, and a cotton-tipped applicator is used to roll over the graft and express any collected fluid to avoid interference with graft imbibition. This is repeated daily for the first 2 or 3 days.
- Silvadene 1% is used TID on any compromised area of the graft.

OUTCOMES

- The surgeon should follow their first several grafts very closely to understand

the progression of healing so that they know what to expect and can convey to the patients the normal healing of the grafts.

- In the case of composite graft (or full-thickness grafts with significant adipose tissue), they are usually pale for the first day, then turn blue (congestion) for 2 or 3 days, but a small amount of pink hue is usually seen behind the blue and emerges dominant between days 5 and 6 (**FIGS 1 to 4**).
- Healing goes on for at least 1 year after grafting, and all revisions should ideally be considered only after this point.

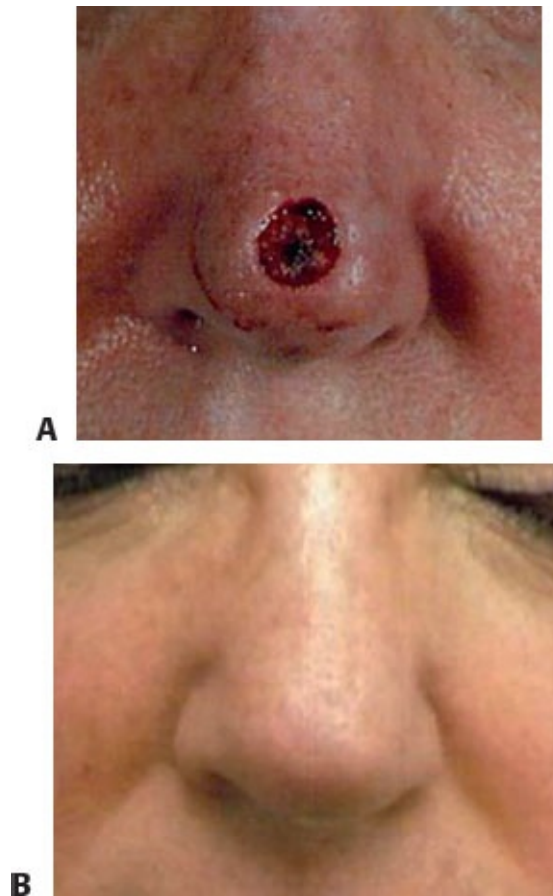


FIG 2 • Full-thickness skin graft with preservation of fat for nasal tip reconstruction. **A.** Preoperative. **B.** Eleven months postoperatively.

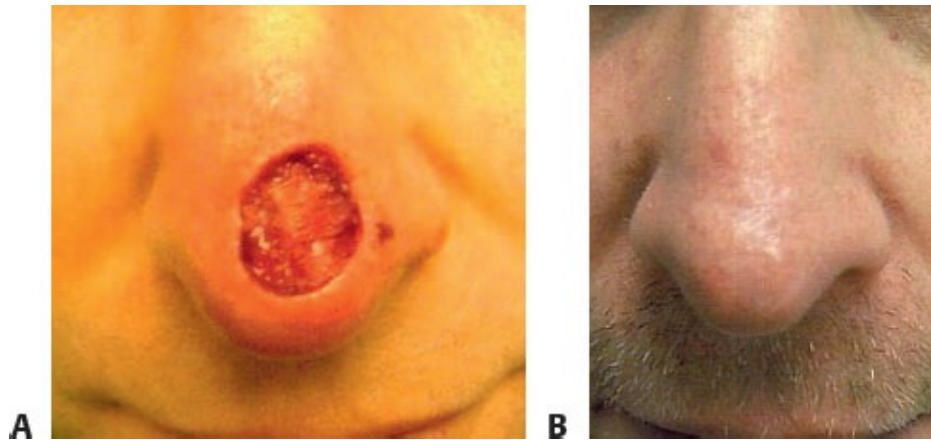


FIG 3 • Full-thickness skin graft with preservation of fat for nasal tip reconstruction. **A.** Preoperative. **B.** Eleven months postoperatively.

COMPLICATIONS

- The most feared complication is complete graft loss. This is exceedingly rare.
 - Partial graft loss can occur and is usually the result of an inadequate graft bed or retained fluid collection beneath the graft.
- Step-offs between graft skin and native skin can occur if appropriate beveling of the recipient site and graft are not carried out.
- Infections can occur but should be minimized with appropriate aseptic technique. The authors do not use routine postoperative antibiotics.
- Blood pressure control is important to prevent recipient site bleeding and graft loss.

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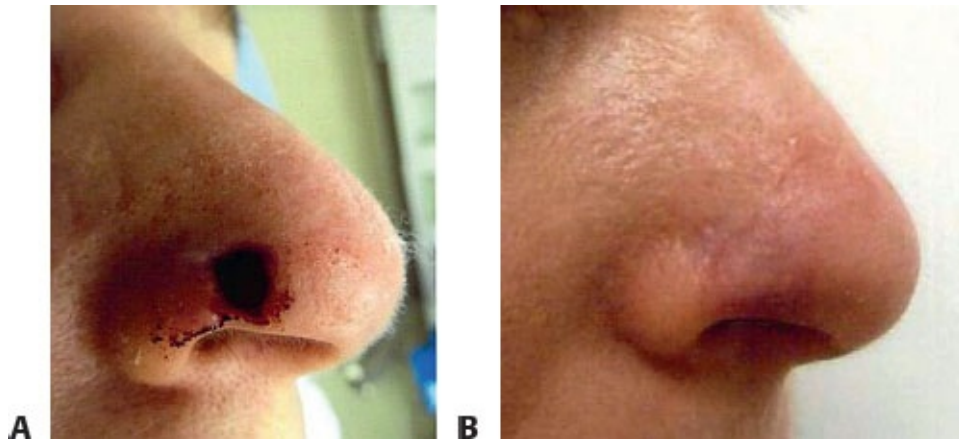


FIG 4 • Composite graft for alar rim reconstruction. Conchal skin was harvested with cartilage to add structure to avoid notching the alar rim. **A.** Preoperative. **B.** Five months postoperatively.

38 V-Y Advancement Flaps for Nasal Reconstruction

CHAPTER

Julian J. Pribaz and Simon G. Talbot

DEFINITION

- There are multiple different types of V-Y flaps. It is important to differentiate these especially with respect to their use in nasal reconstruction, as they must be applied correctly for successful outcome:
 - A *classic V-Y flap* refers to a triangle-shaped island flap designed at one edge of a defect with the tapering V part distal to the defect (**FIG 1A**).
 - It is based on a mobile subcutaneous pedicle.
 - As the triangular flap is advanced into the defect, the residual donor site is closed primarily, resulting in a Y-shaped scar.
 - It is essential that there is an adequate and mobile pad of subcutaneous fatty tissue to allow flap advancement.^{1,2}
 - The *extended V-Y flap* is a modification of the V-Y advancement flap, with the addition of an extension limb onto the advancing edge of the standard flap (**FIG 1B**).
 - The limb is located adjacent to the area requiring reconstruction and is elevated from its bed and hinged down as a transposition flap on the end of the V-Y advancement flap to close the most distal part of the defect.
 - A *double extended V-Y flap* is an even larger flap, with an extension limb on each side of the defect, so that both limbs are transposed onto the advancing edge of the V-Y flap, which itself is based on a mobile subcutaneous pedicle.³

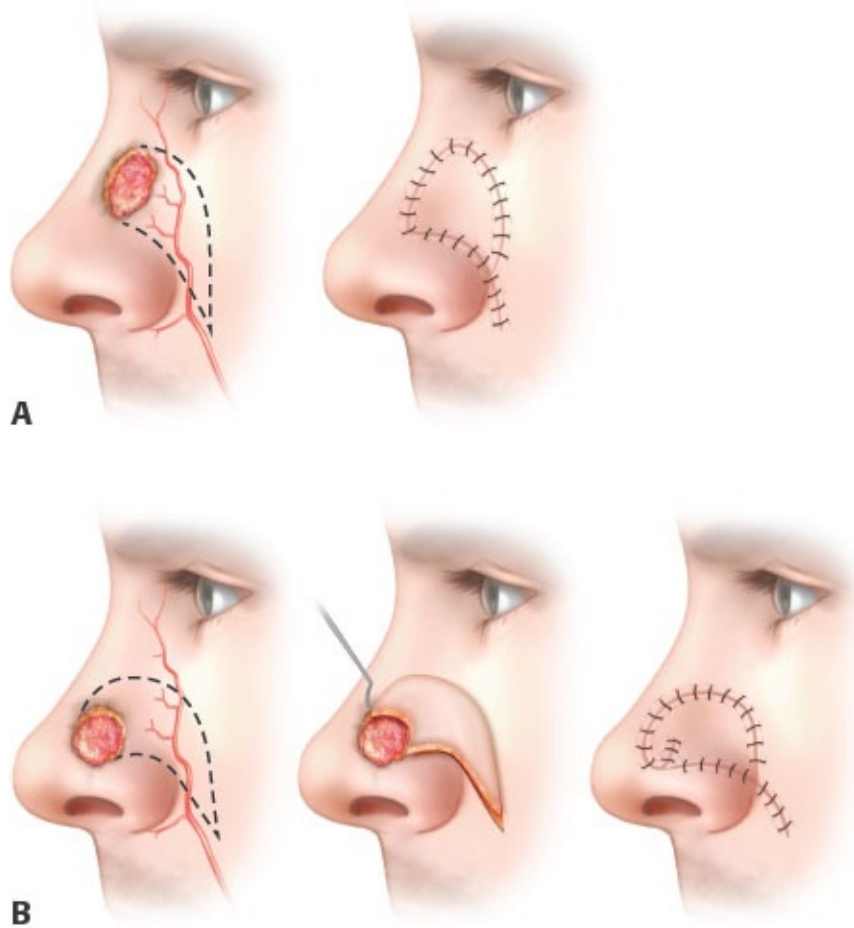


FIG 1 • Perforator V-Y flaps based on the angular artery, showing a regular V-Y design for a more vertically oriented defect **(A)** and an extended V-Y design for a more medial and circular defect **(B)**.

- The *V-Y perforator flap* is an entirely different concept, and the only similarity with the above is that the eventual donor-site closure goes from a V to a Y configuration.
 - Unlike the regular V-Y flaps, the perforator flaps are not based on a broad mobile subcutaneous pedicle but rather on specific perforating vessels that must be mobilized for flap advancement.

ANATOMY

- The cutaneous anatomy of the nose is not uniform.
- The skin in the upper half is thinner and has a variable amount of underlying subcutaneous fat, with the most mobility over the nasal bridge just below the

glabella.

- The lower half of the nose is thicker and more sebaceous and also much more adherent with very little mobility due to lack of subcutaneous fat.
- The blood supply is rich and comes from the paired angular arteries and accompanying veins.
- The angular artery starts at the alar base as a continuation of the facial artery and runs in the trough between the nasal side wall and adjacent cheek. It anastomoses with the infraorbital, infratrochlear, and dorsal nasal vessels and across the midline with corresponding vessels on the opposite side. It gives multiple small perforators that pass both medially onto the nose and laterally onto the cheek (**FIG 2**).⁴
- There is relatively loose areolar tissue with some fat around the pedicle, which provides flap mobility.
- The type of V-Y flap that can be used successfully will depend on the location of the defect on the nose.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients present with small, yet often challenging, defects of the nose that are usually the result of tumor excision.
- In many cases, these patients have undergone Mohs surgery involving complete excision of the tumor with clear microscopic margins, making it safe to proceed with immediate reconstruction.
- The location, size, shape, and orientation of the defect are important in determining the method of reconstruction.
- The goal is to restore the nose to as near normal as possible, especially with respect to the contour restoration with no distortion to the natural landmarks of the nose.
- Any surgery will produce scars, but contour restoration is more important because scars do settle and mature with time to becoming less conspicuous.
- Ideally, the use of adjacent local tissue will ensure that the best color and texture will be restored.

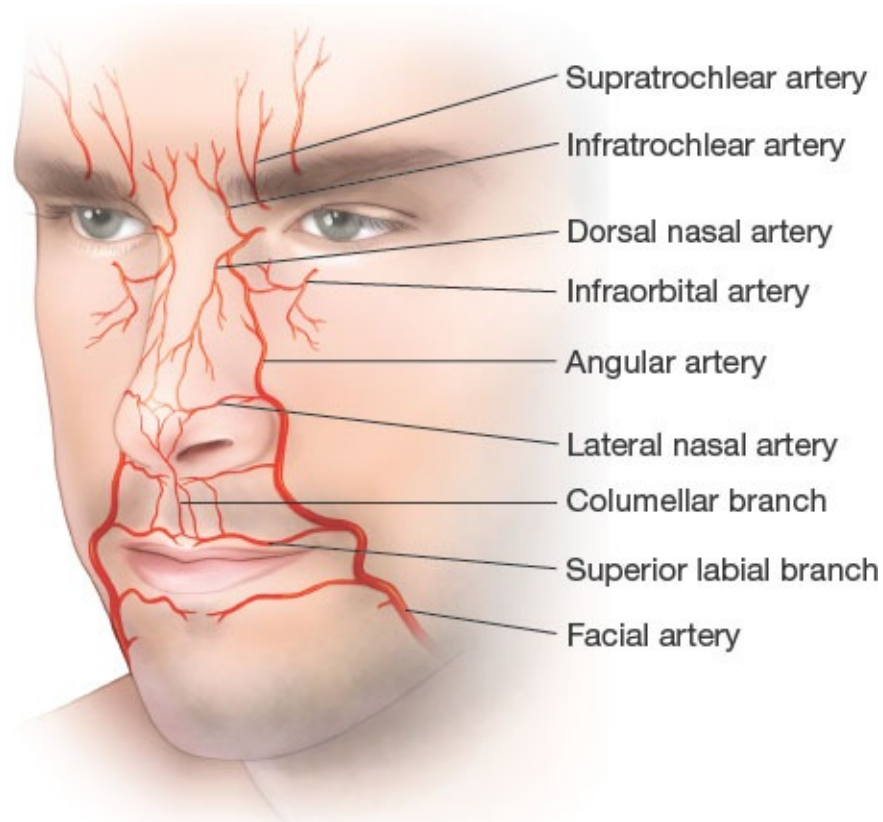


FIG 2 • Vascular supply to the nose. The angular artery starts at the alar base as a continuation of the facial artery and runs in the trough between the nasal side wall and adjacent cheek. It anastomoses with the infraorbital, infratrochlear, and dorsal nasal vessels and across the midline with corresponding vessels on the opposite side.

- The use of V-Y advancement flaps brings in local “like tissue” that causes a minimum distortion.
- The type of V-Y flap that is used depends on the site of the defect.
 - The classic V-Y flap is possible only in the proximal nose across the nasal bridge, where there is more subcutaneous tissue and the flap can be advanced effectively and expeditiously in a transverse direction.
 - For defects of the distal half of the nose, a perforator type V-Y flap is used. This may be extended or doubly extended for additional reach (see **FIG 1**).
 - For vertically oriented defects, a perforator flap without extensions will

suffice.

- For round, more transversally oriented defects or defects that are more medially located, an extended type of V-Y perforator flap is needed.

SURGICAL MANAGEMENT

Preoperative Planning

- For simple V-Y flaps across the nasal bridge, no special planning is needed other than assessing the mobility of the soft tissues and designing the transverse V-Y flap.
- For defects in the distal half of the nose, the beginner should use a Doppler ultrasound to map out the angular artery and perforators, but once experienced, this is not necessary because there are consistent, multiple perforators.
- The flap is designed adjacent and lateral to the defect, with the V component extending across the nasal-cheek junction to capture the perforators.
 - The orientation of the flap has a slight downward or oblique tilt, so that eventually once transferred into the defect, the flap is entirely on the nose and does not cross the nose-cheek junction.

Positioning

- The procedure is short and usually performed under local anesthesia in a day surgery setting, with the patient in supine position.
- The procedure could be done under MAC anesthesia or rarely under general anesthesia.
- It is best to inject the local anesthetic before prepping and draping the patient to allow the anesthetic and epinephrine to take effect.
 - We have not had any problems with the use of epinephrine with the local anesthetic.

Approach

- The approaches are different according to the type of V-Y flap as described above.
- Loupe magnification may be used for the perforator-type flap dissection, especially if inexperienced.

TECHNIQUES

■ Classic V-Y Flap for Proximal Nasal Defects

- The usual defect is on the lateral side of the nasal bridge and medial canthal area.
- A transversely oriented V-Y flap is designed and infiltrating with local anesthesia.
- Once this has taken effect, simple skin incision and minimal blunt dissection is adequate to mobilize the flap and complete the repair (**TECH FIG 1**).



TECH FIG 1 • Basal cell carcinoma of the left inner canthus marked to be excised and repaired with classic V-Y flap.

■ Perforator V-Y Flap for Defects of the Distal Half of the Nasal Side Wall and Supra-alar Region

Standard Perforator V-Y Flap

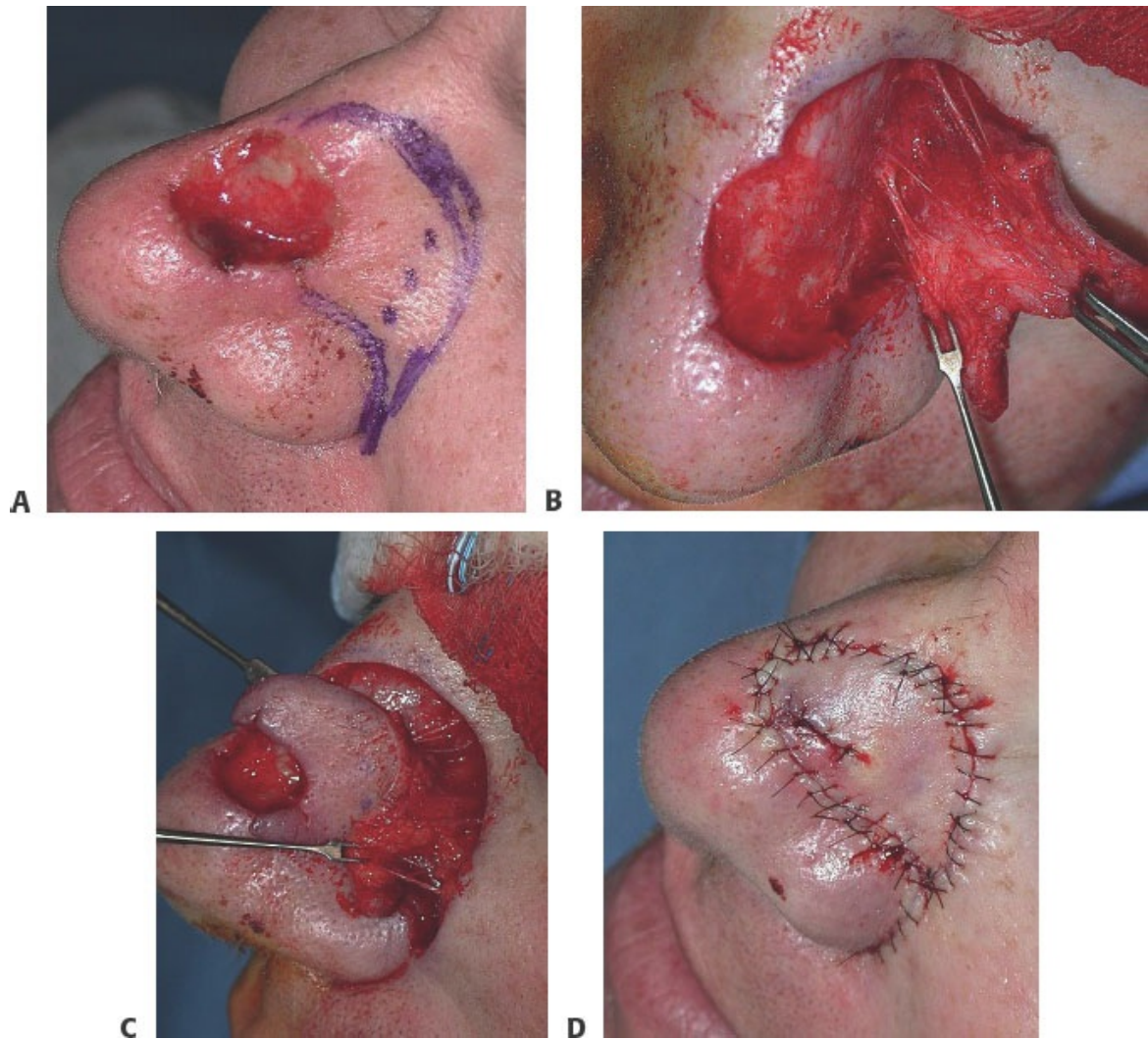
- The flap is marked as described above (**TECH FIG 2A**).
- Local anesthesia with epinephrine is infiltrated along the flap margins, including the nose-cheek junction where the perforators are located.
- The skin is incised, and the flap nearest the defect is completely elevated off the underlying tissue toward the nose-cheek junction.
- The lateral V aspect of the flap is incised down to the subcutaneous tissue

only, and then blunt, spreading type of dissection is performed with fine scissors, teasing out the deeper subcutaneous fatty tissue and the perforators.

- The perforators are readily visualized, but no attempt is made to isolate the flap on a single perforator (**TECH FIG 2B,C**).
- The mobilization is continued until adequate mobilization has been achieved to allow the flap to move into the defect with minimum tension.
- The inset is performed in a single layer, with nylon attempting to evert the wound edges for a better repair and help to minimize pincushioning due to scar contracture (**TECH FIG 2D**).
 - Deeper absorbable sutures are used to repair the donor site, with the repair falling along the nasolabial fold.
- The flap appears pink, well perfused, and not congested at the end of the operation despite the use of epinephrine with the local anesthetic.
- This is usually performed as a single-stage procedure, but secondary minor scar revisions may occasionally be required.

Extended Perforator V-Y Flap

- For more medially located defects, or more transversely oriented defects, an extended type of flap design is used, and the advancing extension wings are sutured together to increase the reach.
 - The suture line of the extension flap often falls along a natural crease line at the junction between the alar subunit and the lateral domal subunit, so it becomes less conspicuous with time (**TECH FIG 3**).
 - Perforator V-Y flaps are generally not indicated for defects involving the nostril margins.
- Although the V component of the flap starts on the cheek, after transfer, it should lie completely within the nose, with Y closure being made along the nasolabial fold.
- The V-Y perforator flap should not disrupt the alar subunit. Its lower border can be just along the supra-alar crease, but not cutting across it or distorting it.



TECH FIG 2 • A. Patient following Mohs surgery with a more circular defect medially located, with perforator flap design. Perforators marked as dots along nose-cheek junction. **B.** Perforator dissection medially. **C.** Perforator dissection laterally. **D.** Flap inset.



TECH FIG 3 • **A.** Patient with defect at domal/alar groove with flap marked curving over the alar subunit. **B.** Flap inset.

PEARLS AND PITFALLS

Indications and assessment

- Have a clear understanding of the different types of V-Y flaps that may be used for nasal reconstruction and where they can be applied.

Technique

- Cannot do a conventional V-Y flap in the distal half of the nose due to lack of mobile subcutaneous tissue.
- Where there is limited tissue mobility, a perforator-type flap is required. Do not skeletonize the pedicle.
- An extended perforator V-Y flap is required for larger, transversely oriented, and more medially located defects.
- Perforator V-Y flaps can “start on the cheek” but must “end up on the nose.” It should not span the nose-cheek junction.
- Inset flap with everting suturing to minimize pincushioning.

POSTOPERATIVE CARE

- Skin-colored Steri-Strips are usually applied as the only dressing.
- The Steri-Strips may need to be replaced in a day or so if they become blood

stained.

- The sutures are removed at a week and the usual scar management protocol followed.

OUTCOMES

- The V-Y flap provides a simple and reliable way of reconstructing small yet difficult nasal defects, either of the bridge of the nose with a simple V-Y flap or distal half of the nose with a perforator V-Y flap, both providing an aesthetic reconstructive outcome (**FIG 3**).^{5,6}

COMPLICATIONS

- Scar contracture and pincushioning can be minimized with careful and everting skin edge suturing.
- Minor scar revisions can be performed if needed once the scars have had a chance to mature.



FIG 3 • Postoperative appearances of the patients in TECH FIGS 1A, 2B, and 3C,D.

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Section XI: Cavity and Pharynx

39

CHAPTER Facial Artery Perforator Flap

Julian J. Pribaz and Simon G. Talbot

DEFINITION

- Perforator flaps are a relatively recent addition to our reconstructive techniques.
- They have evolved as a result of meticulous studies of vascular blood supply to the skin, which have demonstrated a rich network of perforator vessels arising from all major vessels, allowing for the elevation of safe and customized flaps based on these vessels.
- The facial artery is the major vessel supplying the lower half of the face. Multiple innovative flaps have been developed based on perforators arising along the course of the facial artery, including flaps in the perioral region, which is the subject of this chapter.^{1–6}

ANATOMY

- Arterial
 - The facial artery enters the face by hooking around the lower border of the mandible at the anterior edge of the masseter muscle. It follows a tortuous course through the cheek, passing upward and medially toward the oral commissure and then to the alar base, where it becomes the angular artery (**FIG 1**).
 - It passes deep to the muscles of facial expression and gives off two major named vessels—the inferior and superior labial arteries—as well as multiple perforators to all surrounding structures, including the superficial and deep muscles, skin, and mucosa.

- Hofer mapped out the perforators supplying the skin and found that these were multiple, with at least three perforators having an average diameter of 1.2 mm. His injection studies showed that a single perforator can supply a large area of facial skin, thus making it useful for perioral reconstruction.⁷

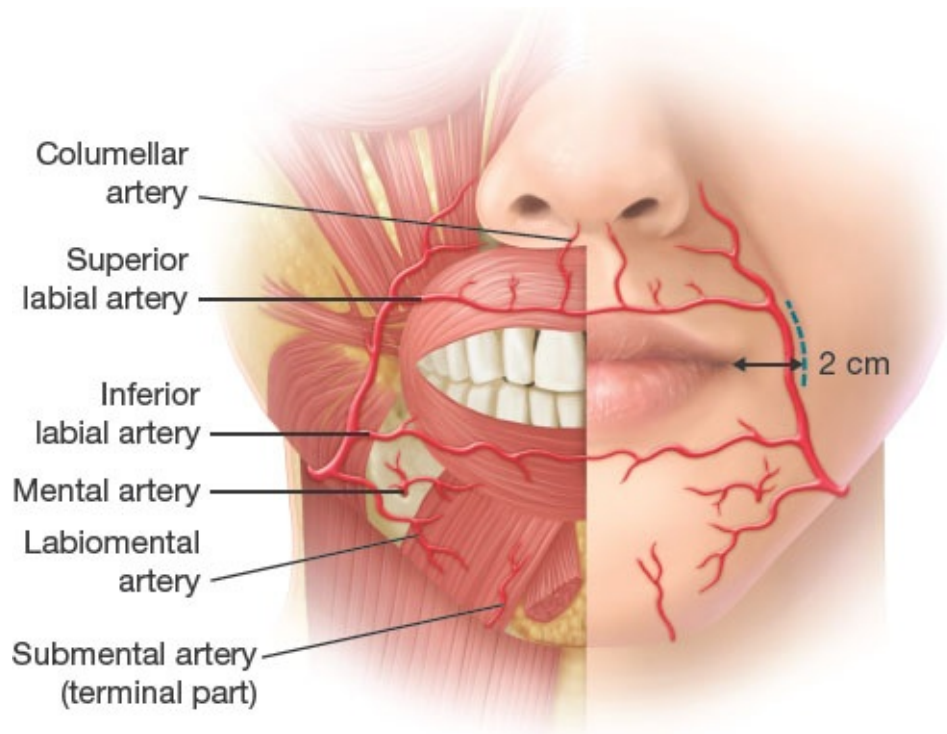


FIG 1 • Arterial supply of the lower face and mouth.

■ Venous

- The main facial vein does not run with the artery but is located more laterally in the cheek and approaches the facial artery near the angle of the mandible.
- There are multiple small venous channels in the soft tissues that provide adequate drainage to perforator flaps. However, it is important not to skeletonize the pedicle but rather leave a cuff of soft tissue to allow for venous drainage.
- This is an important distinguishing feature of facial artery perforator flaps compared with those harvested from other parts of the body in which the perforating vessels are routinely skeletonized to maximize flap reach and rotation. Because of the tortuous nature of the artery and the mobility of tissues in this region, it is still possible to rotate safely the flap up to 180 degrees.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The soft tissues making up the nasolabial fold and jowl area are lax and mobile. Fortunately (from the reconstructive point of view), these qualities increase with aging, when the need for flaps from this donor site also increases to deal with surrounding defects created after tumor extirpation. The tissue laxity facilitates primary repair of the donor site.
- In addition, this area of the skin lies directly over the course of the facial artery and its perforators, allowing for safe flap elevation and repair.
- Superiorly and inferiorly based pedicled nasolabial flaps with a skin bridge have been used successfully since ancient times. The inclusion of a skin bridge makes the flap bulky, limits its mobility, and distorts the surrounding anatomy. It also requires a secondary procedure to divide and inset the flap.
- A better understanding of the anatomy of perforators refined and developed island flaps supplied by one or more perforators devoid of skin bridge, which has made it easier to rotate the flap and perform more one-stage reconstructions.
- Perforator flaps based on the facial artery can be considered for all substantial defects of the perioral region, lips, distal nasal, and cheek (**FIG 2**).
- They have the advantage of using local “like tissue” adjacent to the defect, which results in aesthetically superior reconstructions. This includes the use of hair-bearing skin from the jowl area for mustache and beard reconstruction.
- As the facial artery is sandwiched between the superficial muscles of facial expression and the deeper buccinator and mucosa (which are all supplied by the facial artery), it is possible to raise a composite full-thickness cheek island flap if this is what is needed for reconstruction.



FIG 2 • A. Patient with nostril sill and upper lip defect after excision of basal cell carcinoma. **B.** Superiorly based island perforator nasolabial flap. **C.** After single-stage flap transfer.

- To avoid injury to the muscles of facial expression, the deep part of this flap can be harvested just inferior to the risorius muscle, where only the buccinator muscle is taken with the flap (**FIG 3**).

IMAGING

- A facial artery perforator flap is most often indicated for reconstruction after tumor excision, and imaging may be required for oncological assessment to ensure adequate resection. No special imaging is needed for operative planning, however.

SURGICAL MANAGEMENT

Preoperative Planning

- A careful diagnosis of the defect or deformity is required, and the suitability of facial artery perforator flap is assessed. This will be made based on the location, size, and depth of the defect as well as the subunits of the face, lip, cheek, and nose involved.
- Will a single facial artery perforator be adequate to complete the reconstruction?
- Is there adequate laxity in the surrounding tissues to allow closure of the donor site with minimal deformity?
- Can this be done in a single stage? If not, the patient needs to be counseled about possible revisions and secondary procedures, especially if the defect spans different subunits.
- The integrity and location of the facial artery and its perforators are assessed with a Doppler ultrasound.
- There are multiple perforators along the course of the facial artery, but it is best to choose the perforator closest to the defect to enable the flap to rotate into the defect with the least tension.
- Templates of the defect and subunits (using the contralateral side) are used to design the flap, which usually abuts one edge of the defect (**FIG 4**). A piece of sterile Esmarch bandage, aluminum foil, or DuoDerm can be used for the template.
- Such planning may lead to using other local flap rearrangement techniques to reduce the overall size of the defect, especially if it encroaches several different subunits.
- These measures can result in a smaller perforator flap with fewer demands on the donor site.
- The greatest degree of laxity is in the lower cheek and jowl area, which is the commonest site for flap harvest.

Positioning

- Smaller defects can be performed under local anesthesia with sedation, but it is more common to employ general anesthesia.
- A nasal or oral endotracheal tube can be used. It is best to secure this with suturing to the nasal septum or wiring to the dentition, to avoid tape and distortion to the perioral area to better appreciate the entire operative field to enable restoration of the best symmetry with the opposite side.

- The patient is supine and the operating table is turned 90 to 180 degrees away from the anesthesia team.

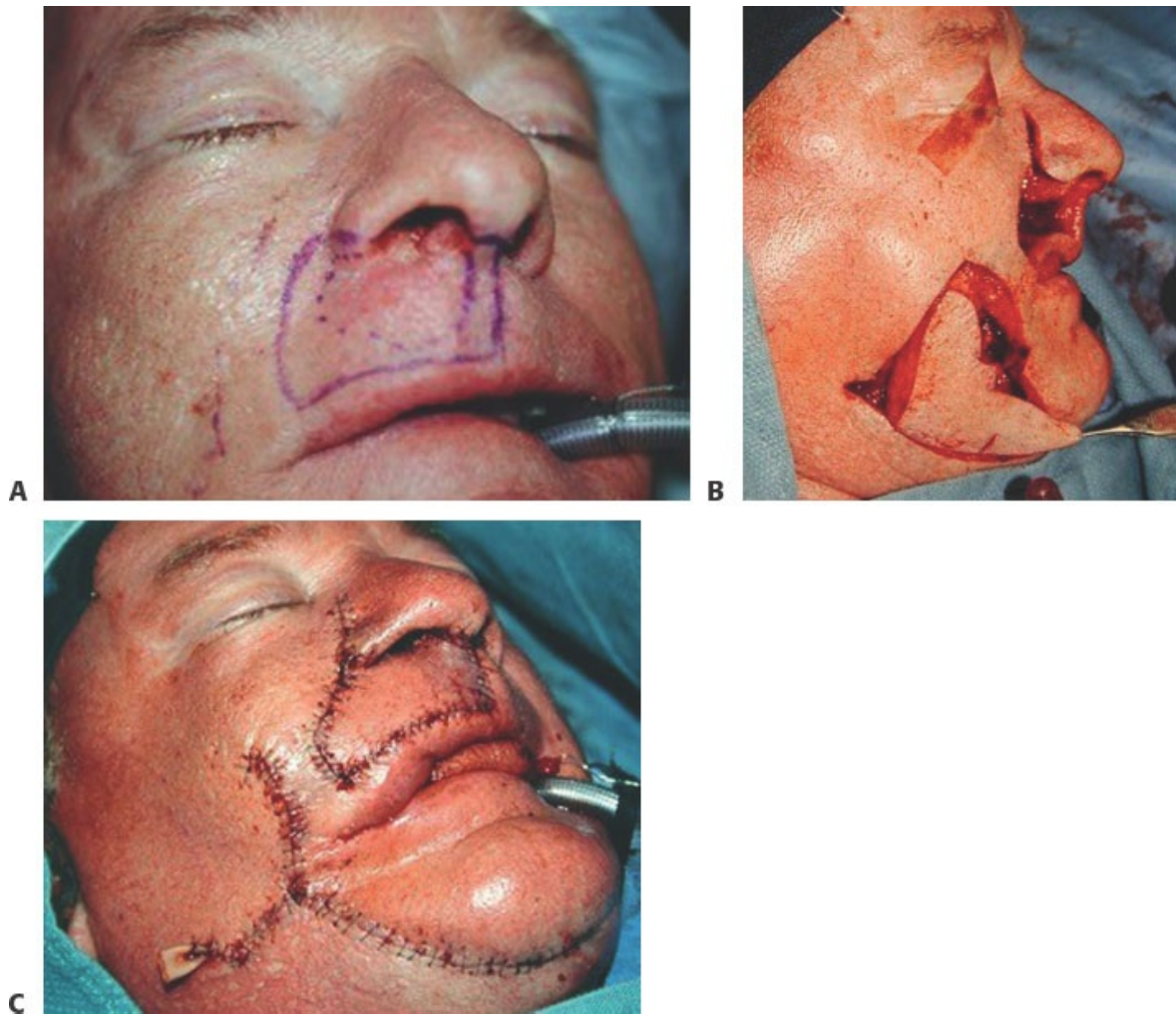


FIG 3 • **A.** Patient with full-thickness small cell carcinoma of the upper lip and nostril floor. **B.** Tailored full-thickness cheek perforator flap elevated. **C.** Flap inset onto defect.

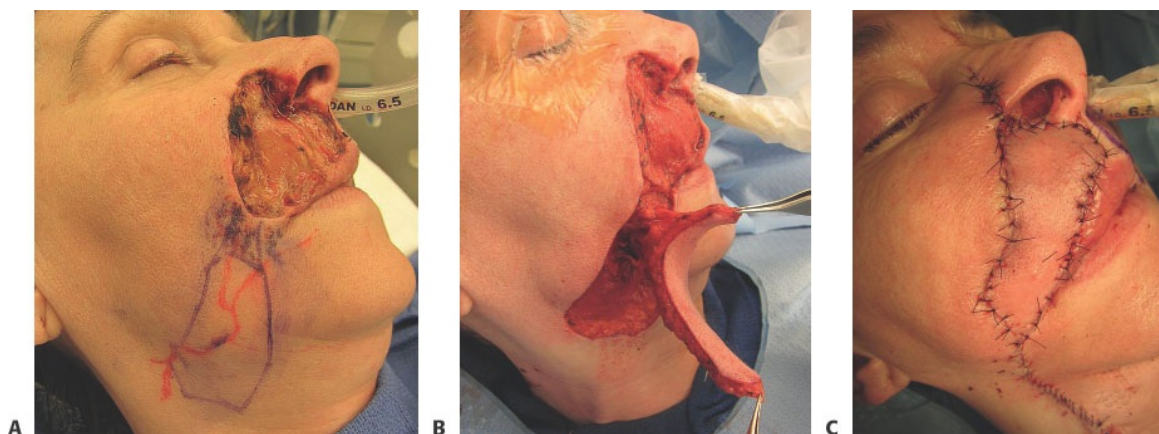


FIG 4 • **A.** A patient with extensive defect involving the right upper lip, cheek, and alar base. **B.** Template of defect.

TECHNIQUES

■ Facial Artery Perforator Flap to Repair Perioral Defect

- After the flap is marked (**TECH FIG 1A**) and the artery and perforator are identified with Doppler, a small amount of local anesthetic with epinephrine can be injected along the proposed incision line (well away from the perforators) and allow it to take effect, to minimize oozing for the initial flap dissection.
- Incisions are made along the previously marked lines.
- Low-voltage needle-tip cautery (set at 15) helps precise dissection.
- Unlike some other perforator flaps in which the perforator is identified first, with the facial artery perforator flap (where there are multiple perforators along the course of the vessel), it is best to start the dissection at the distal end of the flap and carry the dissection down to the SMAS and muscle layer and start elevating just above the muscles. The terminal branches of the facial nerve are deep to the muscles and thus protected.
- The dissection continues toward the facial artery, which is easily visualized at the inferior, distal end of the flap.
 - The smaller distal perforators are cauterized and divided, and the flap is dissected superiorly toward the superior perforator (previously identified by Doppler).
- No attempt is made to skeletonize the pedicle, but the dissection is continued until adequate mobility is obtained to allow the flap to rotate into the defect.

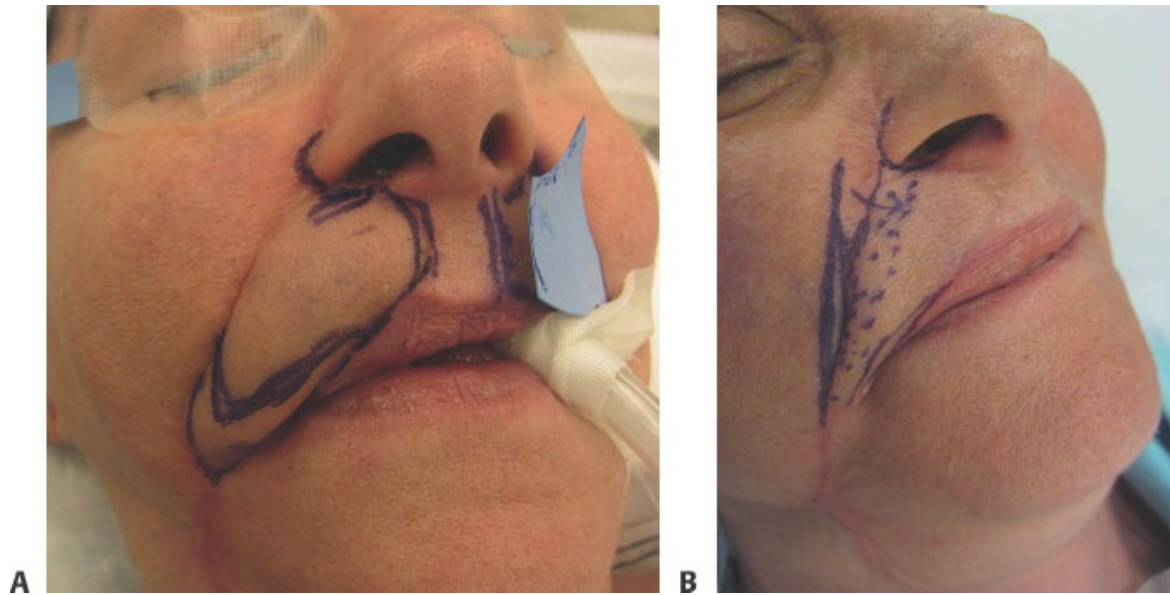


TECH FIG 1 • **A.** Design of perforator facial artery flap. **B.** Elevated perforator facial artery flap. **C.** Postoperative appearance showing bulky flap that extends beyond natural subunits of the lip and cheek and loss of right alar base.

- Because the perforators are multiple and close together, there may be more than one perforator in the base of the flap. In addition, a cuff of soft tissue is needed for adequate venous drainage.
- The facial artery perforator flap (as compared with perforator flaps elsewhere) has the benefit of excellent tissue mobility and a tortuous facial artery, which allow more mobility without skeletonizing or thinning the flap excessively (**TECH FIG 1B,C**).

■ Secondary Revision Surgery

- Small defects can be repaired in a single stage, but larger defects may need secondary revision (**TECH FIG 2**).
- Even though one of the benefits of this type of flap reconstruction is the use of “like” tissue, it may still be bulky, and secondary debulking to restore the natural contour may be required.
- In addition, scars may need to be revised, and restoration of the normal subunits of the cheek, lip, and nose may require secondary surgery.



TECH FIG 2 • Secondary revision surgeries to restore right alar base (A) and natural contours of the lip and cheek (B).

PEARLS AND PITFALLS

Diagnosis and suitability of facial artery perforator flap

- Assess defect's suitability for a facial artery perforator flap based on its location and size. For larger flap requirements, there is a need to assess adequacy of donor site to avoid deformity or distortion. May need preliminary tissue rearrangement at the site of the defect to reduce its size and to conform to subunit principles of repair.

Flap vascularity

- Assess vascularity of facial artery and perforators with Doppler ultrasound.

Flap design

- Use templates to design flap.

Pedicle

- Select perforators that are closest to the defect to allow tension-free repair.

Technique	■ Mobilize flap as much as needed without skeletonizing the pedicle. Essential to leave a cuff of soft tissue for adequate venous drainage.
Secondary procedures	■ Inform patient of possible need of secondary procedures to improve the contour and restore appropriate subunits for best aesthetic result.



FIG 5 • The patient in TECH FIGS 1 and 2 at 19 months postoperatively.

POSTOPERATIVE CARE

- Bacitracin ointment is applied to the suture lines.
- Sutures are removed at 1 week.
- Normal smile function is restored once the swelling subsides.
- Revision surgery, as described above, can be undertaken at 2 to 3 months postoperatively.

OUTCOMES

- The facial artery perforator flap is a relatively new addition to our surgical armamentarium and has the benefit of allowing reconstruction with adjacent, “like” tissue, giving the best possible aesthetic outcome (**FIG 5**).
- Minor revisions to further enhance the aesthetic outcome are generally required.

COMPLICATIONS

- Venous congestion may occur if the flap is inadequately mobilized and rotated and sutured under tension.
 - This can be rectified by additional judicious pedicle dissection, enough to

allow tension-free rotation.

- If congestion persists, the flap should be returned to its bed and allowed to equilibrate.
- Venous congestion can also occur if the pedicle is thinned excessively.
 - This is more difficult to rectify and may need pricking and chemical leeching.
 - If a congested vein is present at the margin of the flap, this can be cannulated, and 0.5 cc of blood can be intermittently allowed to drain. This is more effective than simple pricking, as the whole venosome is decompressed. This technique can be used for any congested flap, and typically after a few hours, the venous drainage equilibrates.

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40 Facial Artery Musculo-Mucosal (FAMM) Flap

CHAPTER

Julian J. Pribaz and Simon G. Talbot

DEFINITION

- The FAMM flap is an acronym for **f**acial **a**rtery **m**usculom**m**ucosal flap.
- It was derived based on the principles of combining a nasolabial and buccal mucosal flap, to create an intraoral axial flap, centered on the facial artery.¹
- It is very versatile and can be reliably based superiorly (retrograde flow) or inferiorly (antegrade flow), to reconstruct a wide variety of difficult defects within the oral and nasal cavities.

ANATOMY

- The FAMM flap is an axial flap containing the facial artery with its accompanying venous plexus, with a small amount of surrounding buccal fat, buccinator muscle, submucosa, and mucosa. It can be thought of as an intraoral and mirror-image version of an axial nasolabial flap.
- Arterial anatomy
 - The facial artery provides a rich blood supply to the lower central part of the face and neck.
 - It is a branch of the external carotid artery, and after giving off several cervical branches, it enters the face by hooking around the lower border of the mandible at the anterior edge of the masseter muscle (**FIGS 1 and 2**).
 - It follows a tortuous course through the cheek, passing upward and medially toward the oral commissure.
 - It traverses deep to the superficial muscles of facial expression—the risorius, the zygomaticus major and minor, and the superficial lamina of the orbicularis oris muscles.
 - It lies superficial to the buccinator, the levator angulioris muscle, and the

lateral edge of the deep lamina of the orbicularis oris muscle, and it has a variable relationship to the levator labii superioris muscle.

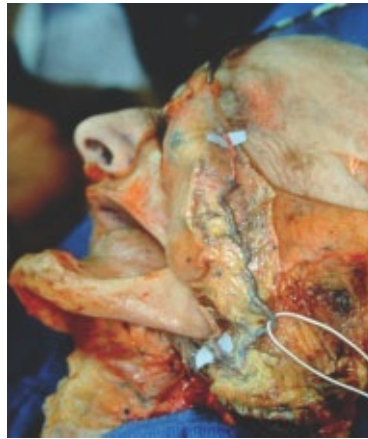


FIG 1 • Anatomy of facial artery.

- It gives off the inferior and superior labial arteries (through which it connects with the contralateral side), as well as multiple perforators to the cheek skin and mucosa. In the cheek, it also anastomoses with the buccal and transverse facial vessels.
- It continues superiorly as the angular artery, giving multiple perforators to the nasal alar and sidewall, and terminates near the medial canthus where it anastomoses with branches from the dorsal nasal, infratrochlear, and infraorbital vessels.²
- Venous Anatomy
 - The main facial vein does not run with the artery but is located more laterally in the cheek and approaches the facial artery near the angle of the mandible.
 - Nonetheless, the FAMM flap has an excellent venous outflow and rarely becomes congested due to a “syncytial” type of venous plexus within the submucosa, which connects not only to the facial vein but also to pterygoid plexus and maxillary vein.
- Due to its intraoral design, the FAMM flap spares the superficial and most important muscles of facial expression and their nerve supply, as well as the overlying skin, thus minimizing deformity.³
- The FAMM flap is usually 1.5 to 2 cm in width and can be 8 cm in length, but it is key that the facial artery traverses the entire flap. Although from the vascular point of view the flap could certainly be made wider, this would create

too large an intraoral defect, leading to contracture.

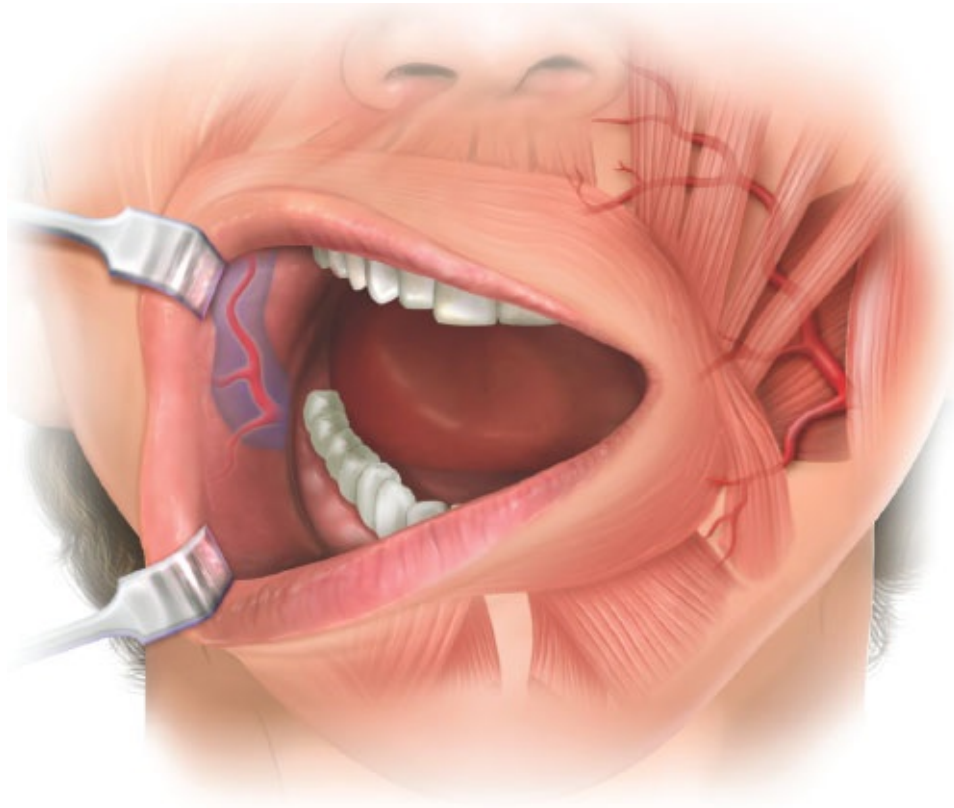


FIG 2 • Schematic of the course of the left facial artery through the cheek passing between the superficial muscles of facial expression and buccinators. Contralateral intraoral view of proposed right FAMM flap.

- The flap is designed anterior to Stensen duct.
- The FAMM flap can be based superiorly (where the blood flow is retrograde) or inferiorly (where the blood flow is antegrade), thereby increasing its versatility.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The FAMM flap may be indicated in patients with a wide array of relatively small (yet difficult to repair) defects and deformities within the oral cavity, including small defects in hard and soft palate, alveolus, buccal sulcus, floor of mouth, tongue, and tonsillar fossa. It can also be used to reconstruct defects of

the upper and lower lip vermillion. In addition, the flap has been used to reconstruct intranasal mucosal defects.^{4,5}

- The patient needs to be carefully evaluated and the problem in question accurately assessed according to its location and size to determine if a pedicled FAMM flap (with maximum size 2 × 8 cm) can be used for the reconstruction.
- An intact facial artery, detected by Doppler examination, is crucial, as is the lack of scars from previous procedures along the course of the flap.

Superiorly or Inferiorly Based FAMM Flap?

- A superiorly based FAMM flap is considered for defects involving the hard palate, upper alveolus, antrum, upper lip sulcus, and vermillion and for restoration of nasal lining (**FIG 3**).

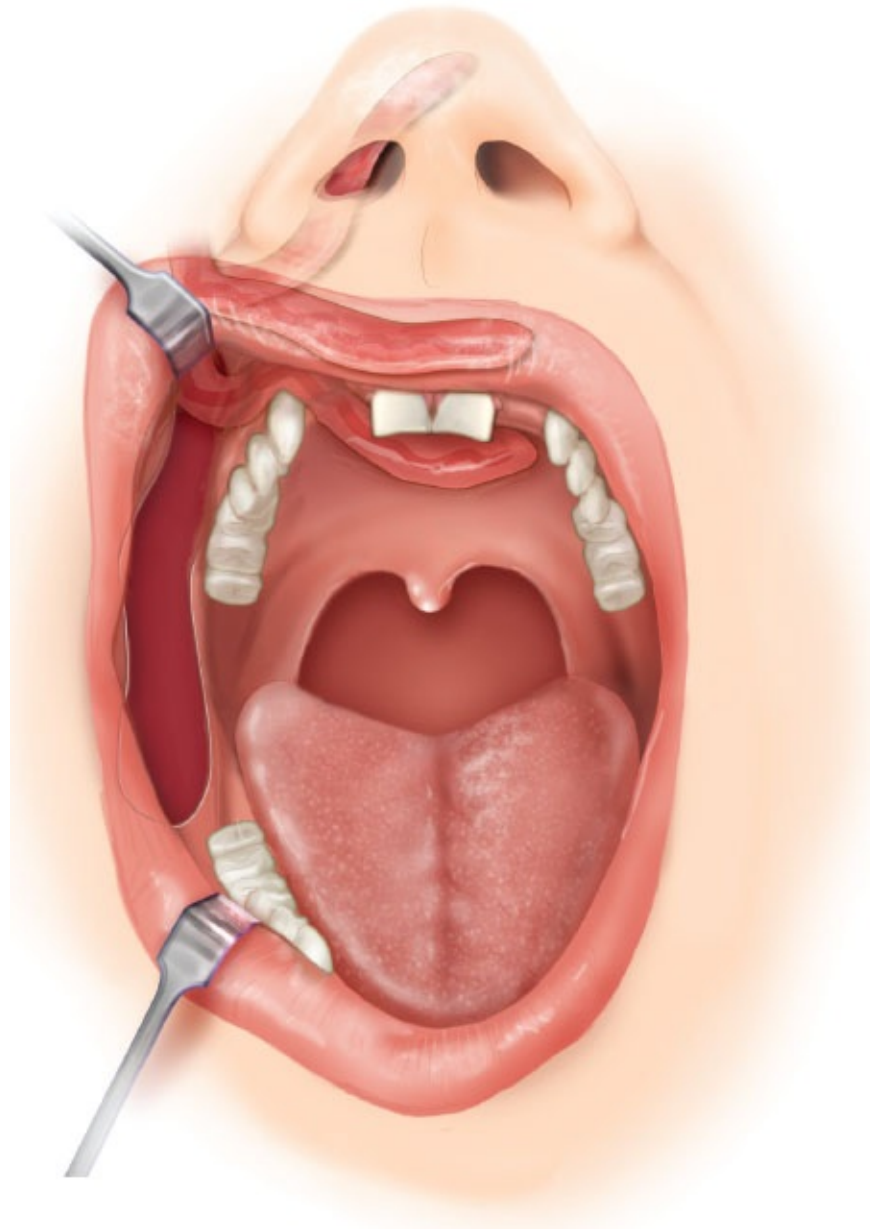


FIG 3 • Superiorly based FAMM flap may be used to repair defects of (1) the hard palate, alveolus, (2) maxillary antrum, upper lip sulcus and vermilion, (3) nasal lining.

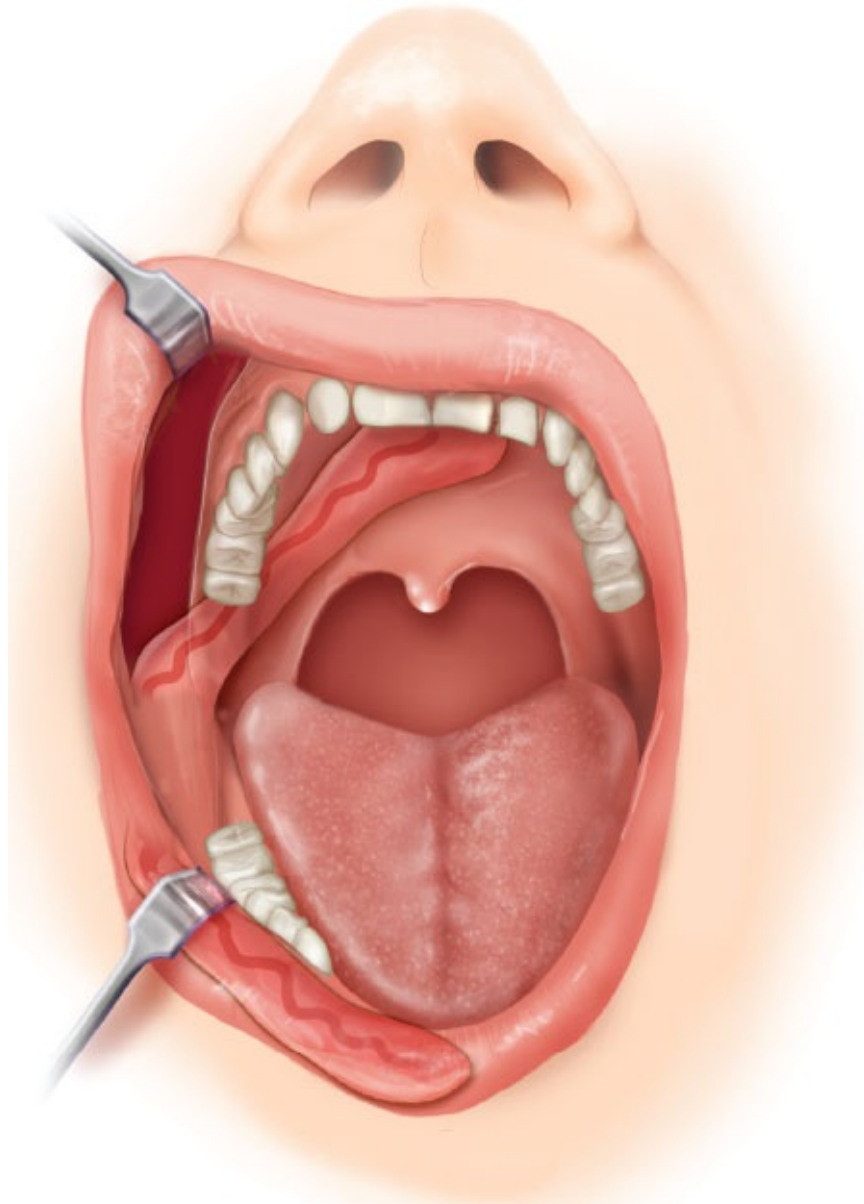


FIG 4 • Inferiorly based FAMM flap may be used to repair (1) floor of mouth, lower lip sulcus, and vermillion, (2) soft palate and tonsillar fossa, and (3) hard palate.

- An inferiorly based FAMM flap would be considered for defects in the floor of mouth, tongue, lower lip sulcus and vermillion, tonsillar fossa, and soft palate (**FIG 4**).

Intact Upper Jaw Dentition vs (Unilateral or Bilateral) Edentulous Alveolar Cleft Deformities?

- This will determine the type of FAMM flap that may be used; with an intact dentition, a superiorly based flap to repair a palatal defect cannot be used as the flap cannot traverse an intact dentition. However, it may be possible to repair a palatal defect with an intact dentition by using an inferiorly based flap, which is brought around the maxillary tuberosity.
- Reconstruction of fistulas and other through-and-through defects requires consideration of both lining and coverage requirements. The lining may be achieved with local turn-in flaps, but this may then make the defect too large for coverage with a FAMM flap. Occasionally, two FAMM flaps may be considered—one for lining and another for coverage.

SURGICAL MANAGEMENT

- Preoperatively, a careful assessment needs to be made whether the FAMM flap is appropriate for the needs of the repair based on the size and location of the defect within the oral or nasal cavity.
- A decision based on the problem being addressed will need to be made whether the FAMM flap will be superiorly or inferiorly based.
- Defects that are too large, or prior surgeries and scar, may preclude the successful use of the FAMM flap, and an alternative method of repair will be required.

Preoperative Planning

- It is essential to map out the course of the facial artery. The artery is easily palpated at the angle of the mandible, and then its course can be mapped out with a Doppler ultrasound, both extra- and intraorally.
- It is important to remember that the facial artery has a tortuous course through the cheek to allow for the tissue mobility for facial movement and expression.
- Its course is well anterior to the Stensen duct and has a roughly “boomerang-shaped” course, passing obliquely toward the oral commissure and then more vertically toward the alar base.

Positioning

- The procedure is performed under general anesthesia with the patient supine and the operating table rotated 90 to 180 degrees away from the anesthesia team.
- For intraoral work, a nasal endotracheal tube is best, but an oral endotracheal secured to the contralateral side of the mouth or with a Dingman retractor

securing the tube in the midline can also be used.

- Silk traction sutures are placed on the ipsilateral upper and lower lips and commissure (taking care not to injure the facial artery as it passes close to the commissure).
- The boomerang-shaped flap, which is 1.5 to 2 cm in width, is then marked out centered on the Doppler-identified facial artery.

Approach

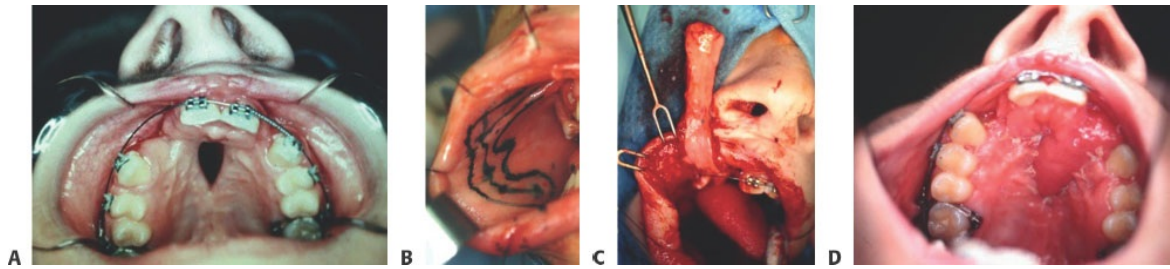
- As previously mentioned, the selection of a superiorly or inferiorly based flap will depend on the problem at hand.
- Local anesthetic with epinephrine may be injected, but *only* into the distal part of the flap for easier dissection of the facial artery. Vasoconstriction should be allowed to take effect before commencing the flap dissection.

TECHNIQUES

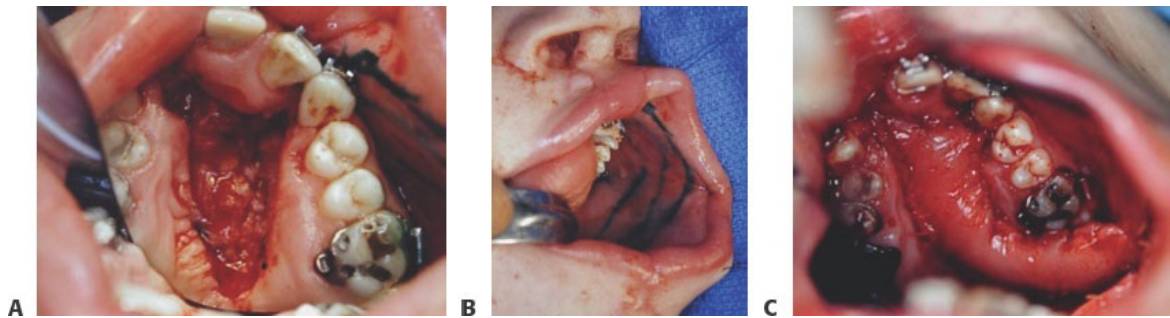
- Dissection commences at the distal end of the flap, with an incision through the mucosa, submucosa, and buccinator muscle. The facial artery is identified, ligated, and divided. It is important that the facial artery itself and not a branch has been identified before proceeding with the rest of the flap harvest.
- It is helpful to leave the tie on the cut facial artery in the flap long and use it to apply traction to facilitate the dissection.
- The rest of the flap is then scored, and the dissection proceeds just deep to the facial artery, taking only a small cuff of buccinator and orbicularis oris muscles near the commissure.
- The flap is about 1 cm in thickness and contains the facial artery along its entire length, which designs a long axial flap with length/width ratios as high as 5:1.
- The flap dissection continues until an adequate length has been achieved (often 8–9 cm), and is either based superiorly or inferiorly, leaving a mucosal pedicle base to ensure adequate venous drainage.
- The facial vein is not seen in the dissection and hence not harvested with the flap. However, there is adequate venous outflow via an extensive submucosal venous plexus, and the flap does not appear congested.
- The arc of rotation for superiorly based flaps is at the gingivobuccal sulcus

and, for inferiorly based flaps, the retromolar trigone.

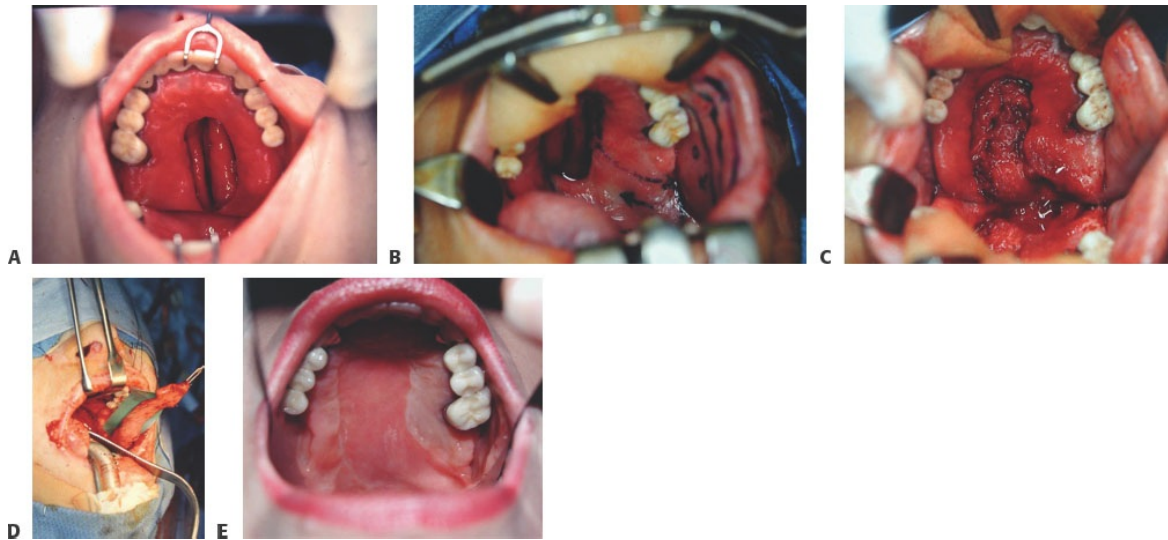
- **Superiorly based flaps** usually rotate 90 degrees when used for upper lip sulcus and vermilion reconstruction or to traverse an alveolar edentulous space to the palatal defect. It is preferable not to tunnel the flap but simply incise the mucosa from the base of the flap to the lip or palatal defect. The inset should be under no tension (**TECH FIG 1**).
- For nasal reconstruction, superiorly based flaps rotate 180 degrees and are tunneled through the gingivobuccal sulcus to the floor of the nose. To adequately inset these flaps into the nose, lateral rhinotomy incisions are required. Because of the bulk of the flap at its base, there will be temporary nasal airway obstruction, until the flap is divided and inset at 2 to 3 weeks.
- **Inferiorly based flaps** rotate at the retromolar trigone and may be used to repair tonsillar, floor of mouth, and tongue defects. They are also used to repair lower lip sulcus and vermilion. Again, it is best not to tunnel the flap, and it is safer to incise the mucosa between flap base and defect and inset the flap with no tension.
- When inferiorly based flaps are used to reconstruct posterior hard palate or soft palate defects, the bulkiness of the flap base may necessitate the use of a temporary bite block to prevent bite injury to the pedicle.
- A modification of the FAMM flap has been developed for use in palatal reconstruction where there is an intact dentition (precluding use of a superiorly based flap) and to avoid using a bite block with inferiorly based flaps. This involves the elevation of a mucoperiosteal palatal flap, which is the width of the FAMM flap and which is raised from the base of the FAMM flap as a turnover flap, which is dissected to approximately 8 mm of the palatal defect and used as a large nasal turn-in lining flap. Raising such a flap achieves two goals: providing nasal lining and creating a big enough trough to allow the FAMM flap to be inlayed, thus masking its bulky base and allowing a single-stage reconstruction without the need for a bite block.⁶
- The repair of the cheek donor defect is performed in layers, using absorbable sutures for the buccinator and mucosa (**TECH FIGS 2 and 3**).



TECH FIG 1 • Superiorly based FAMM flap for repair of a palatal fistula. **A.** A 15-year-old female with palatal fistula and alveolar gap. **B.** Design of superiorly based right FAMM flap. **C.** Elevated superiorly based FAMM flap. **D.** Repaired palate at 3 weeks.



TECH FIG 2 • **A.** Inferiorly based FAMM flap for repair of a large palatal defect. **B.** A 17-year-old male with large palatal defect and intact left dentition with no alveolar gap. **C.** Appearance of postinferiorly based FAMM flap—note the bulk at flap base requiring a bite block.



TECH FIG 3 • Inferiorly based FAMM flap used for the repair of palatal fistula. **A.** A 61-year-old female with palatal fistula post tumor excision. Note the intact dentition. **B.** Design of inferiorly based FAMM flap and anteriorly based mucoperiosteal palatal flap from base of FAMM flap to edge of defect. **C.** Mucoperiosteal palatal flap raised and used to repair nasal side of defect. **D.** Inferiorly based FAMM flap raised. **E.** FAMM flap inset.

PEARLS AND PITFALLS

Techniques

- It is essential to have the facial artery traverse the entire length of this long, thin flap to avoid ischemia at the distal tip and consequent failure of the reconstruction.
- Do not skeletonize the flap on the facial artery, as the venous drainage is by tiny venous plexus vasculature throughout the flap. It is important to leave some soft tissue around the base of the flap to ensure adequate venous drainage.
- Maintaining the proper plane of dissection should avoid injury to the branches of the facial nerve, whose terminal branches lie directly beneath the facial artery during the dissection, and they can be gently

dissected away from the artery.

Limitations

- A limitation to the FAMM flap is its size. Although larger intraoral cheek flaps can be designed on the facial artery, secondary donor-site problems such as cheek contractures may arise, so the use of flaps that are too wide should be avoided.

POSTOPERATIVE CARE

- It is essential to maintain good oral hygiene with regular mouth washes.
- The patient is commenced on a soft diet, which is advanced over the first week.
- The patient is counseled that there will be swelling in the cheek with some limitation of normal smile function. This is temporary and full and normal smile function returns once all swelling has subsided at 2 weeks.
- Any sutures that have not dissolved in the first 10 days can be removed.
- No special rehabilitation is required.

OUTCOMES

- The FAMM flap provides a versatile solution for a wide range of intraoral reconstructive needs.
- When based superiorly, the FAMM flap can be used to repair mucosal defects in the anterior hard palate, alveolus, maxillary antrum, nasal floor and septum, and upper lip sulcus, and vermillion.
- When based inferiorly, the FAMM flap can be used to close defects in the posterior hard palate, soft palate, tonsillar fossa, tongue, floor of mouth, lower lip sulcus, and vermillion.
- When used for palatal cleft defects, it eliminates the need for a palatal prosthesis.
- The base of the flap is thick, and when used for palatal, nasal, and alveolar defects, the flap base will need to be thinned or divided (which can be safely done at 2 weeks) and inset, to restore the nasal airway in cases of nasal lining reconstruction or contour restoration of the alveolus to allow dental rehabilitation.

COMPLICATIONS

- It is essential that the entire flap, especially its distal end, remains well perfused. This is the part which is most needed to complete the repair. This is achieved by ensuring maximum axi-ality with the facial artery running along the

entire length of the flap.

- With the use of larger flaps, the patients may experience some tightness and contracture at the donor site, requiring scar release with one or two Z-plasties of the contracted scar.

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41 Free Flap for Hemi-Tongue Reconstruction

CHAPTER

Carrie K. Chu and Periong Yu

DEFINITION

- The tongue is a highly functional organ responsible for speech, deglutition, taste, and airway protection.
- Glossectomy defects following oncologic resection represent the most common indication for oral cavity reconstruction.
- Glossectomy defects can be partial, subtotal, or total. In general, defects that exceed one-third of the tongue or include significant floor of mouth resection usually require free flap reconstruction. Small defects may be closed primarily or skin grafted.
- Goals of partial glossectomy reconstruction include provision of soft tissue coverage, restoration of intelligible speech, restoration of oral intake, maintenance of patent airway, and separation of the oral cavity from the structures of the neck when required. Re-establishment of sensation is a secondary but important goal.

ANATOMY

- The tongue is composed of two anatomic components. The anterior two-thirds within the oral cavity is the oral (or mobile) tongue, whereas the posterior third within the oropharynx is the base of the tongue. The boundaries of the base of the tongue include the circumvallate papillae anteriorly, the glossoepiglottic folds laterally, and the vallecula and the lingual aspect of the epiglottis posteriorly (**FIG 1A**).
- General sensation to the anterior two-thirds of the tongue is supplied via the lingual nerve (CN V3). The chorda tympani (CN VII), which accompany the lingual nerve, are responsible for taste.

- Taste and sensation for the posterior one-third tongue derive from the glossopharyngeal nerve (CN IX).
- Motor innervation of the intrinsic and extrinsic tongue musculature is via the hypoglossal nerve (CN XII), with the exception of the vagus nerve (CN X) for the palatoglossus muscle. The floor of the mouth, the ventral sulcus, and the lateral gutter facilitate the excursion of tongue muscle for its intelligent functions. The tip of the tongue easily touches the palate for precise pronunciation (**FIG 1B**).
- The lingual arteries, branches of the external carotid artery, provide vascular supply to the tongue. A secondary blood supply arises from the tonsillar branch of the facial artery and the ascending pharyngeal artery. Venous drainage is via the lingual veins into the internal jugular vein.

PATHOGENESIS

- Oral cavity and oropharyngeal cancers, including squamous cell carcinoma and minor salivary gland carcinomas, are the main indications for hemiglossectomy.
- Risk factors for oral cavity and oropharyngeal cancers include tobacco and/or alcohol use, human papillomavirus infection, elderly age, male sex, inhaled environmental or occupational exposures, and poor oral/dental hygiene.

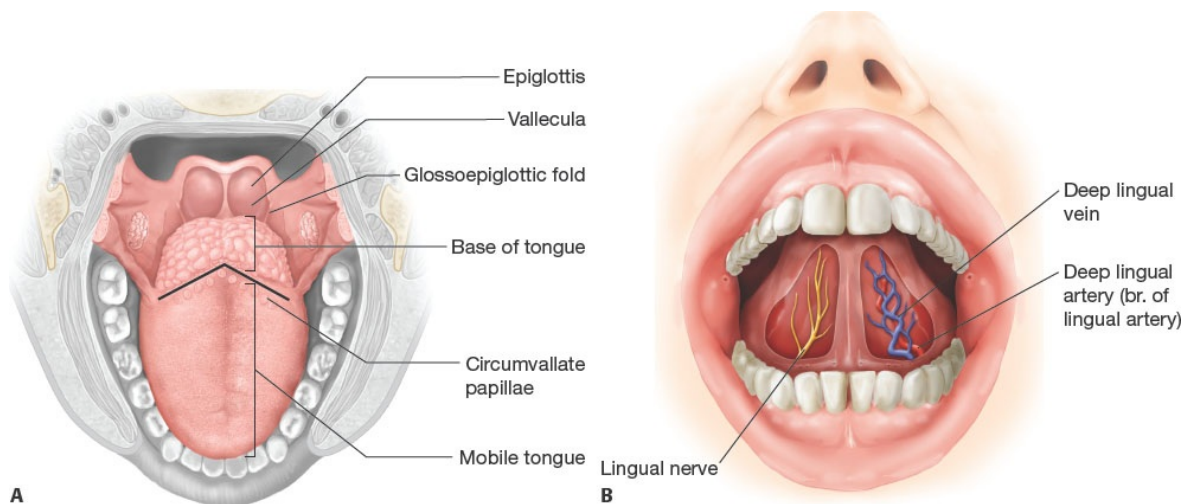


FIG 1 • A. Anatomy of the tongue. The tongue is composed of the anterior (mobile) tongue and the posterior base of tongue separated by the circumvallate papillae. **B.** The ventral sulcus allows the tip of the

tongue to touch the palate. The frenulum marks the midline of the ventral tongue. The lingual vessels travel on the ventral surface of the tongue and are close to the midline near the tip.

- Oral tongue cancers are typically treated with up-front surgical resection, whereas base of tongue cancers are frequently managed with neoadjuvant radiation followed by surgery as indicated.
- Glossectomy potentially compromises tongue function including speech, deglutition, and taste. The base of the tongue is more important for swallowing function, whereas the oral tongue is more important for speech and food manipulation. Restoration of these functions while preserving airway patency represents the main objective of hemiglossectomy reconstruction.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Symptomatology review should be performed including pain, swallow dysfunction, oral intake status, speech alteration, otalgia, paraesthesias, altered tongue mobility, and airway obstruction.
- History of neoadjuvant therapies should be noted. In cases of recurrence, records concerning prior surgical history, including neck dissection, should be reviewed in detail.
- The surgeon should be aware of factors that may compromise recipient vessel availability including radiation and prior cervical lymphadenectomy.
- Medical comorbidities and substance abuse history are both highly prevalent in this patient population.
- Occupation, hobbies, physical activity level, and hand dominance should be queried to select an optimal donor site.
- Head and neck examination should include the following elements:
 - Neck range of motion
 - Palpation of the facial artery
 - Quality of neck skin
 - Interincisal opening distance
 - Dental hygiene and presence of caries
 - Cranial nerve function (V, VII, XII)

IMAGING

- Computed tomography studies with contrast are reviewed for primary tumor dimensions including extension past midline, adjacent structures, and neck vessel patency.

SURGICAL MANAGEMENT

- Partial glossectomy defects smaller than one-third of the native tongue without a floor of mouth defect can typically be reconstructed with primary closure or skin grafting.
 - The latter may exhibit partial graft loss but ultimately will serve as a biologic dressing that allows for eventual mucosalization.
- Hemiglossectomy defects benefit from free flap reconstruction using a thin, pliable flap to avoid restricting functional tongue mobility.
 - These goals are distinguished from those associated with subtotal or total glossectomy, where the objective is to render a bulky flap reconstruction that provides adequate palatal contact to avoid aspiration and enhance speech intelligibility.
- Consideration should also be given to sensory reinnervation.
- Resection of the floor of the mouth combined with neck dissection creates a communication between the oral cavity and the neck along the lingual cortex of the mandible.
 - These defects, even if they involve less than one-third of the tongue, are best reconstructed with a flap to minimize the risk of infection and fistula formation, which can potentially delay crucial adjuvant therapy.
- The pectoralis major muscle or myocutaneous flap is a pedicled option for hemiglossectomy reconstruction. Its bulk, potential tethering and downward retraction are disadvantages for hemiglossectomy reconstruction. The functional outcomes are usually compromised.
 - Therefore, it is usually reserved for salvage after a failed free flap reconstruction or for use in high-risk cases deemed unsuitable for free flap reconstruction.

Preoperative Planning

- The potential functional impairment should be thoroughly discussed with the patient and family because these deficits will not only significantly affect their quality of life but their profession as well.
- Referral for dental extractions in preparation for flap inset and adjuvant radiation may be appropriate if significant caries or nonviable teeth are

identified.

- The availability of blood products based on preoperative type and cross should be confirmed.
- Potential donor-site assessment should be carried out including soft tissue thickness and quality of the upper extremity and thighs.
 - Hand dominance should be documented.
 - The radial and ulnar aspects of the forearm should be assessed for hair growth. A less hairy skin flap is preferred.
- Flap choices
 - In patients with very thin thighs, the anterolateral thigh flap is the first choice due to its minimal donor-site morbidity with the exception of young female patients.
 - Otherwise, the ulnar artery perforator flap is the first choice followed by the radial forearm flap as the ulnar artery flap creates a less conspicuous donor-site scar.
 - The most common flaps for hemiglossectomy reconstruction are described in this chapter, but consideration may be given to numerous alternative donor-site options that would provide thin, pliable tissue to meet the goals of reconstruction.
 - These include, but are not limited to, lateral arm, profunda artery perforator, anteromedial thigh, and medial sural artery perforator flaps.
- Preoperative nutritional status should be evaluated.
 - Some patients may have lost significant weight due to pain and inability to consume oral diet.
 - A percutaneous gastrostomy feeding tube may be necessary to provide adequate nutritional support before surgery.
- Antibiotic prophylaxis is administered before incision. For defects involving the aerodigestive track, 3 g of ampicillin/sulbactam is our antibiotic of choice, which is redosed every 6 hours.

Positioning

- The patient is placed in supine position, typically with the operating table reversed by 180 degrees.
- Placement of an underbody warmer avoids physical interference with multiple surgical sites.
- The dominant arm is tucked, while the contralateral potential donor arm is

prepped circumferentially toward the axilla.

- The arm is secured to the chest drapes to provide room for the extirpative team.
- It is then placed on an arm board for flap harvesting.
- The thighs are also prepared for potential thigh flap or as a skin graft donor site.
- The lower abdomen/groin may be prepared as a full-thickness skin graft donor site to cover forearm flap donor-site defect.
- A two-team approach is possible when harvesting a thigh-based flap.
 - With a forearm flap, flap elevation may require delay until the extirpative team completes the resection and neck dissection.

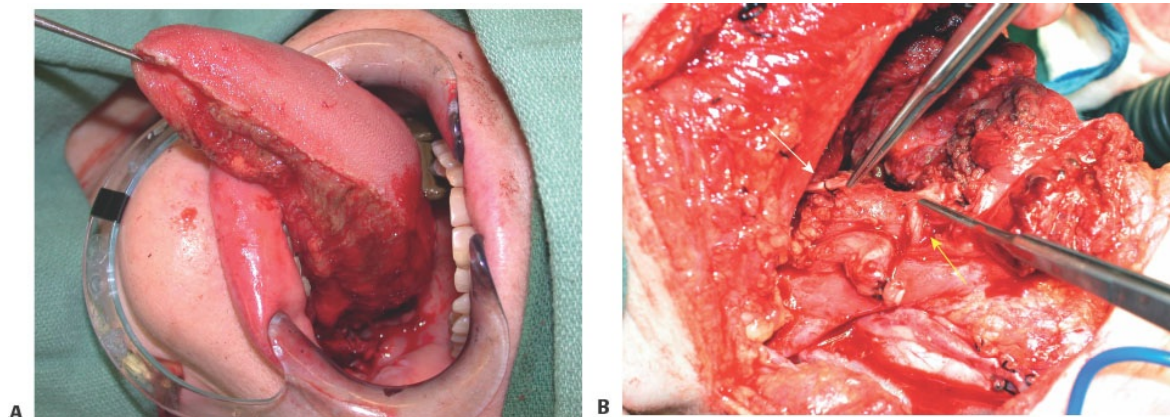
TECHNIQUES

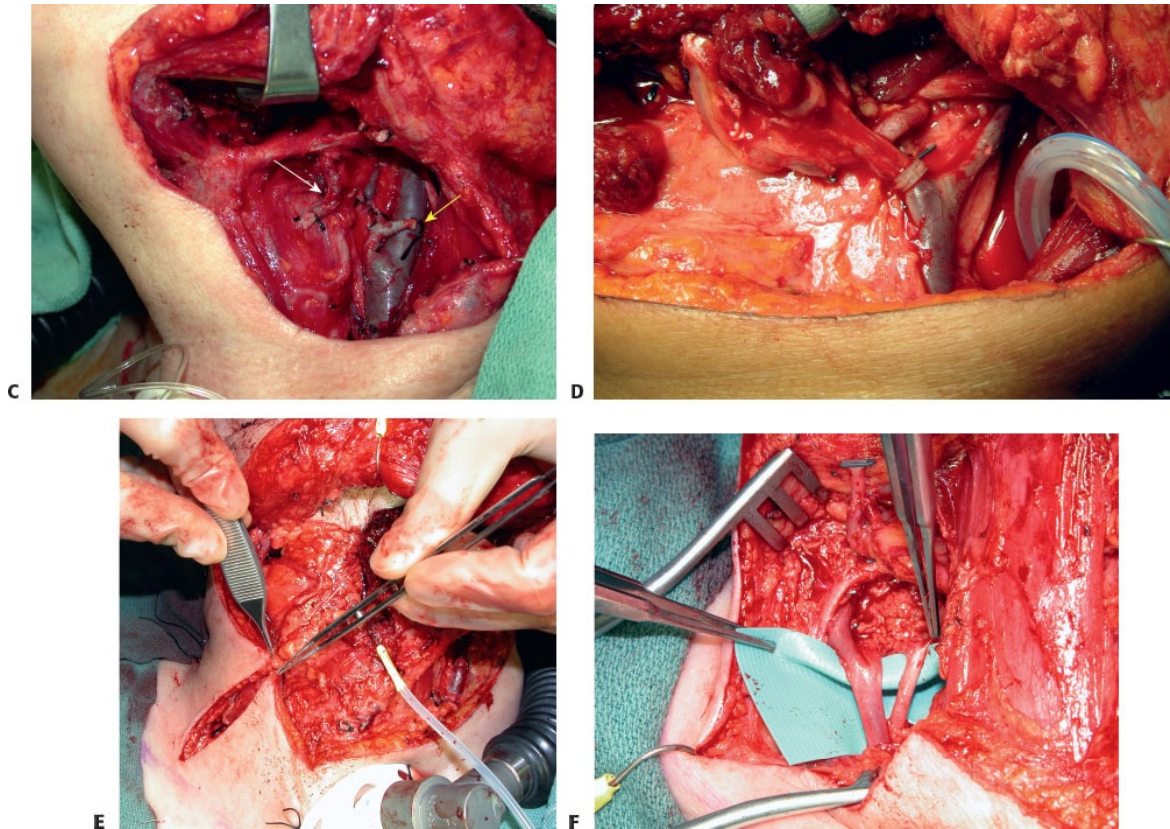
■ Recipient Site Preparation

- While waiting for margins, the defect is assessed, and recipient vessels are dissected out.
 - A Dobhoff feeding tube is inserted into the stomach intraoperatively if percutaneous gastrostomy is not indicated.
- The length of the surgical defect is measured from the tip of the remaining tongue to the posterior limit, which can be in the base of the tongue or immediately above the epiglottis (**TECH FIG 1A**). In the latter case, there will also be a defect in the lateral pharyngeal wall.
- The viability of the remnant tongue should be assessed as well. However, any debridement should be conservative and limited to tissue that is definitively nonviable. Marginal areas may benefit from time for recovery and demarcation postoperatively.
- The width of the defect includes the tongue as well as the floor of the mouth. A flap width of 6 to 8 cm is usually required to adequately recreate the lateral sulcus and provide enough surface area coverage.
- A neck dissection is commonly performed along with a glossectomy.
 - Extra soft tissue is included in the flap design to obliterate any submandibular or upper neck dead space.
- The transected end of the lingual nerve should be explored for potential

sensory reinnervation (**TECH FIG 1B**).

- The lingual nerve is the optimal recipient for sensory reinnervation of the neotongue compared to other options such as the inferior alveolar nerve and the greater auricular nerve.
- It is usually 2 mm in diameter and can be found along the lingual cortex and anterior to the angle of the mandible.
- The lingual artery is often exposed and divided during glossectomy. With a diameter between 2 and 2.5 mm in most cases, the lingual artery represents an ideal recipient target.
- The facial artery is often divided as well during a neck dissection and can be used as a recipient artery. Its diameter is similar to that of lingual artery.
- The artery is dissected back to its origin from the external carotid artery and brought under the posterior belly of the digastric muscle (**TECH FIG 1C**), which can be divided if it facilitates improved vessel access.
- The curved portion of the artery is removed to allow for unimpeded inflow, leaving only a 1-cm stump on the external carotid artery.
- Sometimes, the lingual and facial arteries share a common trunk, which may be more suitable as a recipient vessel as the vessels may become small after the bifurcation. The superior thyroid artery is usually much smaller in Western populations and is usually undisturbed during ablative surgery, thus less desirable as a recipient vessel.
- The author's preferred recipient vein is a branch of or the common facial vein stump on the internal jugular vein depending on the flap vein size. A vein coupler or flow coupler is used for end-to-end anastomosis (**TECH FIG 1D**).





TECH FIG 1 • A. A hemiglossectomy defect can extend from the tip of the tongue to the base of the tongue, sometimes all the way to the epiglottis. The length of the defect usually varies from 6 to 12 cm. **B.** The transected lingual nerve (*white arrow*) can be found on the lingual surface of the mandible near the angle. The hypoglossal nerve (*yellow arrow*) can be found immediately below the digastric muscle. **C.** Common recipient vessels include the lingual artery, facial artery (*white arrow*), the common facial vein (*yellow arrow*), and its branches. **D.** A vein coupler is used for end-to-end venous anastomosis to a facial vein branch. **E.** An incision is made from the apron neck incision toward the midclavicle to explore the transverse cervical vessels. **F.** These vessels are immediately above the clavicle and have good size

match with the flap vascular pedicle.

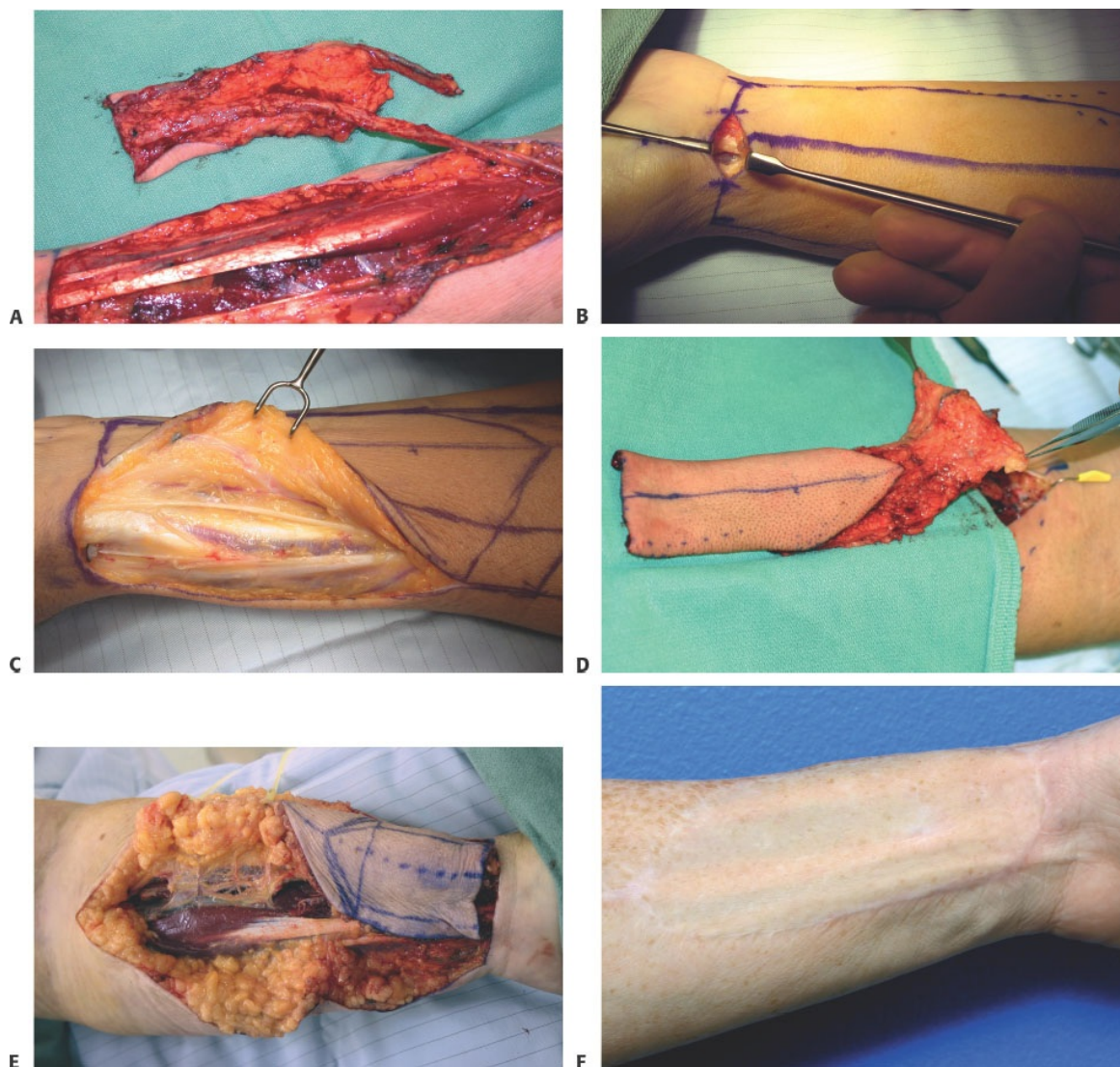
- If no facial vein branches are available, an end-to-side anastomosis on the internal jugular vein itself is a viable option.
- If the internal jugular vein is also unavailable, the external jugular vein, if it remains in good condition, is the next choice.
- The transverse cervical vessels are usually available even in the vessel-depleted neck¹ and can be easily reached with a radial forearm flap or anterolateral thigh flap without the need for vein grafting (**TECH FIG 1E,F**).
- Finally, the internal mammary vessels and the use of a cephalic vein turn-up can serve as the last resort.

■ Flap Harvest

Radial Forearm Free Flap

- A flap with a width of 6 to 8 cm and length of 10 to 12 cm is usually required for a true hemiglossectomy defect.
 - The flap width is centered on the radial vessels with the distal margin at the wrist crease.
 - Flap elevation is performed under tourniquet control.
- The use of the venae comitantes as outflow is preferable to the cephalic vein,² because the distance of the cephalic vein from the radial artery may unnecessarily increase the flap width or the cephalic vein is positioned at the edge of the flap, not ideal as venous outflow (**TECH FIG 2A**).
 - In rare occasions, the venae comitantes of the radial forearm flap are inadequate. A small transverse incision at the wrist crease is made first to explore the venae comitantes (**TECH FIG 2B**). If one of these veins is at least 1 mm in diameter, the cephalic vein may safely be excluded.
 - Otherwise, the flap design is shifted laterally to capture the cephalic vein.
- Suprafascial dissection is preferable. The thenar branch of the superficial radial sensory nerve can be preserved with suprafascial dissection (**TECH FIG 2C**).
- At the midforearm level, the lateral antebrachial cutaneous nerve can be found near the midline. This nerve can be included in the flap for sensory reinnervation.

- In most hemiglossectomy cases, a small dead space is created under the mandible. Inclusion of some adipofascial tissue from the proximal forearm is useful to fill the dead space.
 - The proximal forearm skin flaps can be elevated below the subdermal plexus, leaving the subcutaneous tissue attached to the flap and the vascular pedicle (**TECH FIG 2D**).
 - Alternatively, this adipofascial flap can be based on a proximal perforator (**TECH FIG 2E**). This addition represents an important measure to decrease risk of infection and fistula formation.
- As the venae comitantes are usually no larger than 1.5 mm in diameter before they converge, the vein is usually taken above the convergence, where the diameter is usually greater than 2.5 mm.
- Once the flap and the vascular pedicle are completely dissected, the tourniquet is released to perfuse the flap and the hand for several minutes before dividing the pedicle.
- For donor-site coverage, a full-thickness skin graft from the groin area is preferred to split-thickness skin graft.
 - Suprafascial dissection and full-thickness skin grafting can achieve superior donor-site healing (**TECH FIG 2F**).
 - The hand and forearm are immobilized with a splint for 6 days.



TECH FIG 2 • A. The venae comitantes are preferred for venous outflow of the radial forearm flap. Using the cephalic vein may unnecessarily take a wider flap or render the cephalic vein along the edge of the flap. **B.** A small exploratory incision is made first at the wrist crease to ensure one of the venae comitantes is at least 1 mm in diameter for adequate venous outflow. **C.** Suprafascial dissection can avoid tendon exposure and preserve the thenar branch of the radial sensory nerve. **D.** For submandibular dead space filling, some adipofascial tissue is recruited from the proximal

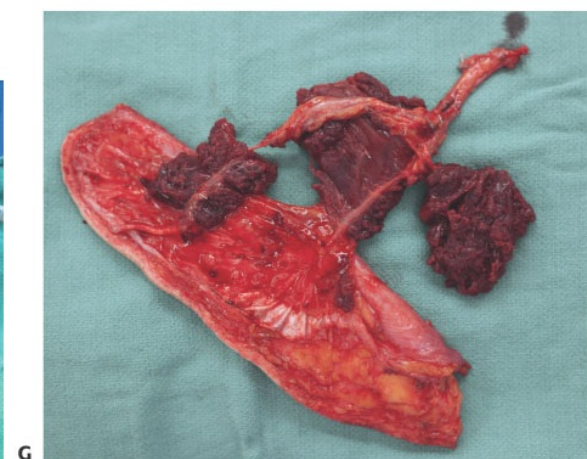
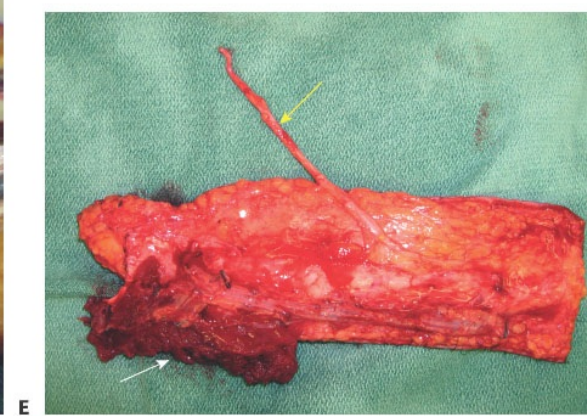
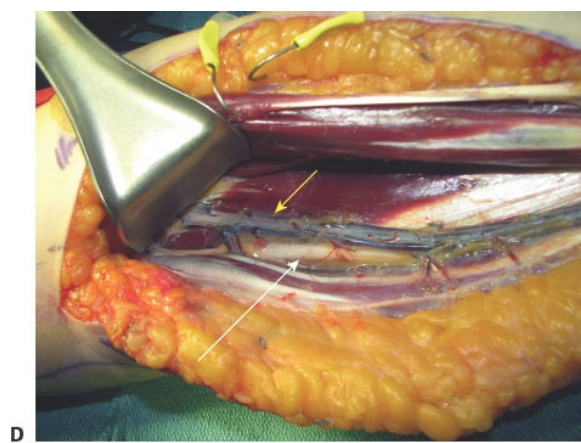
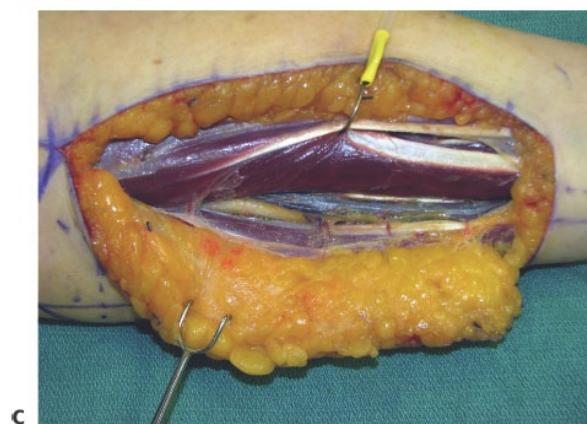
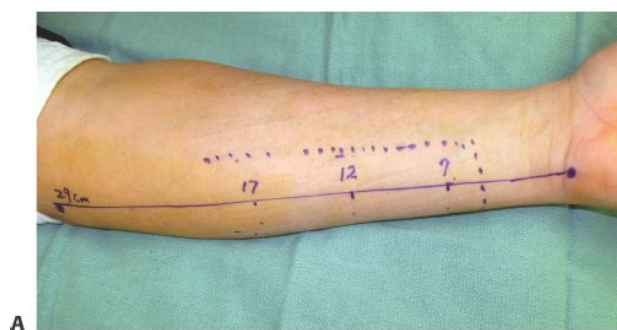
forearm. **E.** This adipofascial tissue can also be based on a proximal perforator. **F.** With suprafascial dissection and full-thickness skin grafting following a radial forearm flap harvest, an excellent donor site can be achieved.

Ulnar Artery Perforator Flap

- The use of the ulnar artery perforator flaps creates a more favorable donor site compared with harvest of the radial forearm. It is also less hairy and slightly thicker but as pliable as the radial forearm flap.³ It has become the author's preferred flap for partial glossectomy reconstruction unless a very thin thigh flap is available.
- The pedicle length of the ulnar artery perforator flap is much shorter. The length of the radial forearm flap pedicle is not typically necessary for hemiglossectomy reconstruction unless the recipient vessels are the transverse cervical vessels, and the shorter pedicle length of the ulnar artery perforator flap may be desirable to avoid kinking.
- A line is drawn between the pisiform and the medial epicondyle, which corresponds to the septum between the flexor digitorum superficialis (FDS) and flexor carpi ulnaris (FCU) muscles in which the ulnar neurovascular bundle travels.
- The distal border of the flap is designed 5 cm above the wrist crease to avoid tendon exposure (**TECH FIG 3A**).
- Dissection is performed under tourniquet control.
 - The radial and distal borders of the flap are incised first.
 - Suprafascial dissection is performed toward the ulnar side until the perforators are seen emerging between the FDS and FCU muscles (**TECH FIG 3B**).
- The fascia over the FDS is then incised, and subfascial dissection is carried out (**TECH FIG 3C**). The perforators are small; thus meticulous dissection is required.
 - The locations of the perforators are marked on the skin surface with a 5-0 Prolene suture.
- The ulnar nerve travels with the vascular pedicle closely together for the majority of its length. The vascular pedicle is carefully separated from the

ulnar nerve, and retraction of the nerve should be avoided.

- One should never be rough to the ulnar nerve during dissection. Any traction should be applied to the vascular pedicle, not to the nerve.
- Small vascular branches to the neighboring muscles are clipped and divided.
- The use of electric cautery should be avoided as these vessels are very close to the ulnar nerve.
- Proximally, the vascular pedicle takes a turn radially away from the ulnar nerve (**TECH FIG 3D**).
- Several muscular branches are divided to reveal the bifurcation with the common interosseous artery.
- The median nerve and its branches can also be seen (**TECH FIG 3E**). Any traction to these nerves should be avoided.
- The venae comitantes usually do not converge, but each vein should have a diameter 2 to 3.5 mm, more than adequate for venous outflow.
- The authors use the venae comitantes exclusively instead of superficial veins and have not encountered any venous outflow issues.
- The medial antebrachial cutaneous nerve is included in the flap for sensory reinnervation (**TECH FIG 3F**).
- A small segment of the FCU muscle can be included for dead space filling if an adipofascial flap cannot be obtained in very thin patients (**TECH FIG 3G**).
- Once the vascular pedicle is isolated, the tourniquet is released to perfuse the flap and hand before dividing the vascular pedicle. Donor site care is the same as radial forearm flap.



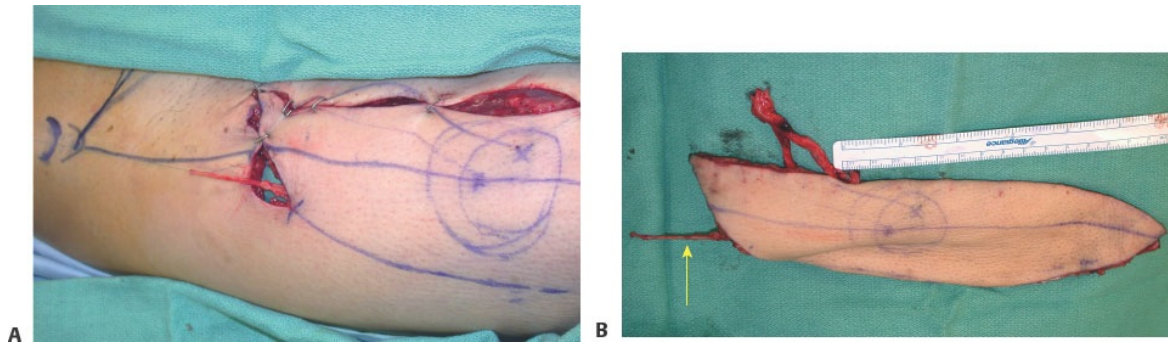
TECH FIG 3 • A. The ulnar artery perforator flap is designed with the distal border 5 cm proximal to the wrist crease to avoid tendon exposure. **B.** Suprafascial dissection is performed ulnarly until the ulnar artery perforators emerging between the FDS and the FCU muscles are identified. **C.** The fascia is then incised; the subfascial dissection proceeds ulnarly to expose the ulnar neurovascular bundle. **D.** In the proximal forearm, the ulnar vessels (*yellow arrow*) take a radial turn away from the ulnar nerve (*white arrow*). The bifurcation of the ulnar artery with the common interosseous artery is then reached, which is the limit of the pedicle dissection. The median nerve and its branches can be seen at this level. Traction on the nerve should be avoided. **E.** The medial antebrachial cutaneous nerve (*yellow arrow*) can be included for sensory reinnervation. A small segment of the FCU muscle (*white arrow*) can be included for submandibular dead space filling if needed. **F.** A thin anterolateral thigh flap is another good option for hemiglossectomy reconstruction. **G.** Various amounts of vastus lateralis muscle can be included for dead space filling.

Anterolateral Thigh Flap

- In thin patients, the anterolateral thigh flap can also be used for hemiglossectomy reconstruction. Flap dissection is performed as previously described by the author.^{4–6}
- To fill the submandibular dead space, various amounts of the vastus lateralis muscle are included in the flap (**TECH FIG 4A**).
- Primary thinning of the flap periphery can reduce bulk for hemiglossectomy reconstruction.
- The lateral femoral cutaneous nerve of the anterolateral thigh flap can be

included for sensory reinnervation (**TECH FIG 4B**).⁷

- Additional thigh-based options including anteromedial thigh^{8,9} and profunda artery perforator flaps are feasible but generally too thick for hemiglossectomy reconstruction.

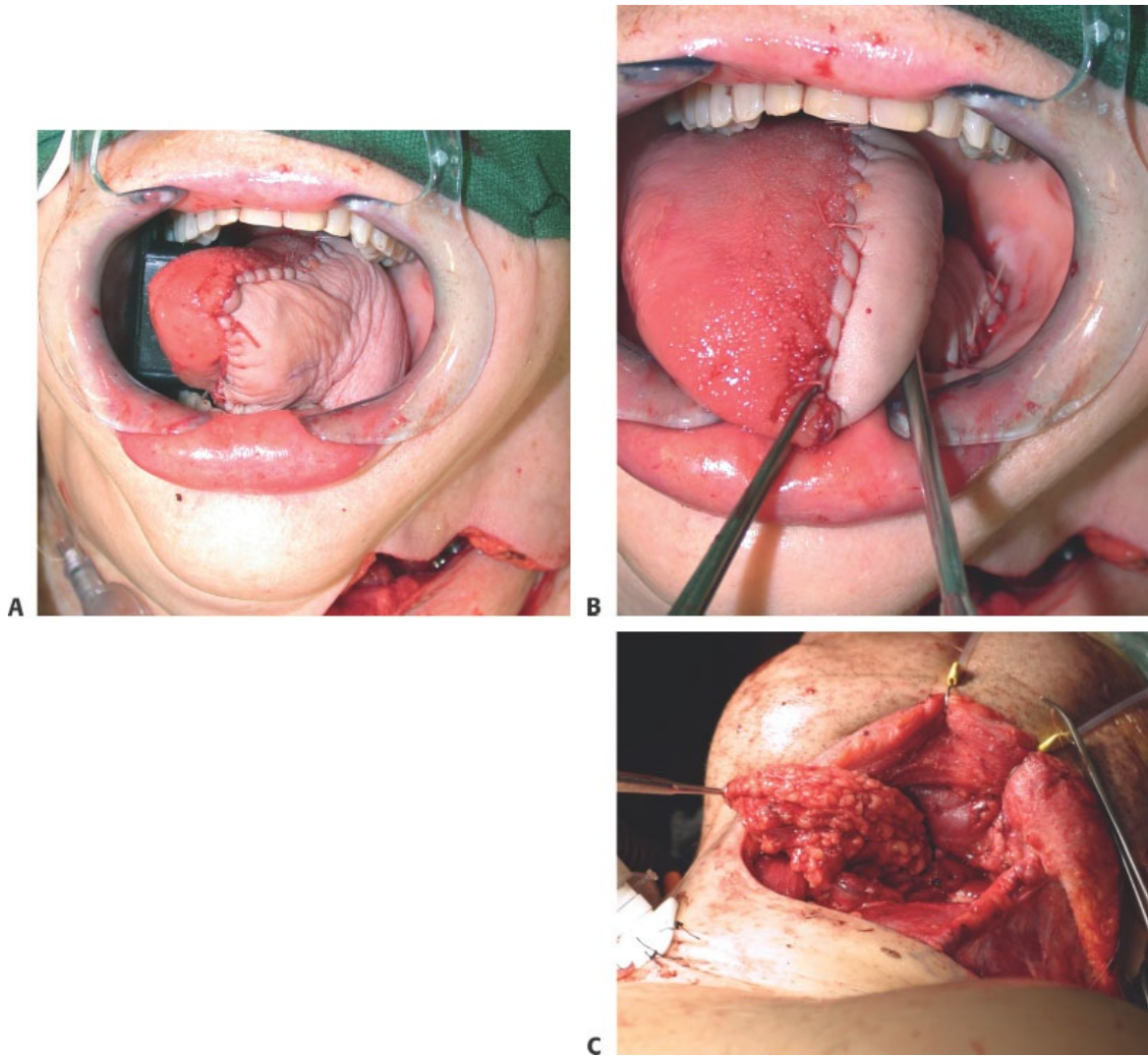


TECH FIG 4 • A. The lateral femoral cutaneous nerve (*arrow*) of the anterolateral thigh flap is used for sensory reinnervation. **B.** The harvested flap, showing with the vascular pedicle and lateral femoral cutaneous nerve (*yellow arrow*).

■ Flap Inset

- The distal end of the flap is oriented toward the tip of the remaining tongue.
 - The width of the distal flap lines up with the ventral surface of the remaining tongue from the tip to the frenulum attachment of the mandibular gingiva.
 - The two distal corners of the flap are anchored to these two structures, and the rest of the flap is draped over the glossectomy and floor of mouth defects toward the posterior limit of the defect.
 - Extra flap is trimmed to fit the defect.
- Flap inseting starts from the posterior end of the defect, either at the base of the tongue or above the epiglottis.
 - This part of flap inseting is completed through the neck exposure, before vascular anastomoses are performed.
 - Once flap inseting reaches the mandible, one can either proceed with vascular anastomosis or continue the inseting intraorally depending on the surgeon's preference and the ischemia time.

- Intraorally, one lateral edge of the flap is sutured to the gingiva and the other to the cutting edge of the remaining tongue.
- The key step in flap inseting is to recreate the ventral sulcus of the neotongue to avoid tethering.
 - The distal medial corner of the flap is sutured to the tip of the remaining tongue.
 - The distal cutting end (the width) of the flap is sutured to the ventral surface of the remaining tongue (**TECH FIG 5A**), thus creating a nice ventral sulcus and lateral gutter (**TECH FIG 5B**).
 - Great care should be taken not to catch the lingual vessels as they travel superficial and near the midline of ventral tongue (**TECH FIG 5C**).
- A single layer of interrupted 3-0 Vicryl sutures is preferred by the authors, although horizontal mattress sutures may be preferred by others in order to create a watertight seal.
 - It is important, however, not to tie the horizontal mattress sutures too tightly so as to avoid flap/mucosal edge necrosis leading to fistula formation.
 - When there is no gingiva left to attach the flap to, the flap can be sewn to the teeth by tying the suture knots around the teeth.
- Once the flap is partially or completely inset, the flap pedicle is brought under the mandible to the neck.
 - Meticulous care should be taken to avoid twisting of the pedicle.



TECH FIG 5 • A. The distal width of the flap is lined up with the ventral surface of the tongue to recreate the ventral sulcus. **B.** The rest of the flap is draped over the glossectomy and floor of mouth defect to recreate the lateral gutter. Both are important to prevent tethering. **C.** The adipofascial flap from the proximal forearm is just large enough to obliterate the submandibular dead space.

- When the lingual artery and common facial vein are used, the vascular pedicle is longer than needed.
- The pedicle should be carefully positioned with a gentle curve to avoid

kinking.

Sensory Reinnervation

- The cutting end of the lingual nerve is freshened, and the sensory nerve from the flap is coapted to the lingual nerve with several 8-0 nylon sutures.
 - This is usually done with loupe magnification, as the lingual nerve is inaccessible to the operating microscope.
 - Sensory recovery of the flap with this technique has been well documented, and therefore, sensory reinnervation is strongly recommended.
- After the vascular and nerve repairs are completed, the extra adipofascial tissue or muscle from the flap is carefully positioned to fill the submandibular space while avoiding pedicle compression (**TECH FIG 6**).



TECH FIG 6 • The reconstructed tongue should be able to lift and touch the palate without tethering. This is important to achieve intelligent speech.

■ Closure

- The oral cavity is irrigated with normal saline until clean.
- The neck wound is then irrigated with an ample amount of warm normal

saline, taking care not to squirt the saline directly on the vascular pedicle to avoid vessel spasm.

- Meticulous hemostasis is essential to avoiding a postoperative hematoma, which can compress the vascular pedicle. All areas should be carefully examined for hemostasis, especially in the neck dissection field, even if they have already been examined by the ablative surgeons.
- A 15 Fr Blake drain is placed in the neck, lateral to the internal jugular vein.
- At this point, the neck is slightly flexed (take out the shoulder roll and flex the neck to a neutral position), and the vascular pedicle is examined again.
 - Because the neck is usually hyperextended and turned to the opposite side during surgery, returning the neck to a neutral position can significantly change the position of the vascular pedicle, causing kinking or compression.
 - The pedicle is repositioned if necessary to avoid such problems.
- The neck incision is then closed.
- Finally, the reinforced tracheostomy tube is replaced with a no. 6 Shiley tube, if this has not been done already by the ablative surgeons.

PEARLS AND PITFALLS

Flap selection	■ Determine the goals of reconstruction based on extent of remaining native tongue. A hemiglossectomy defect should be reconstructed with a thin, pliable flap that will preserve mobility of the tongue remnant.
Avoid tethering	■ Adequate width of the distal flap (6 cm) is used to recreate the ventral sulcus, and the remaining flap width (6–8 cm) is used to recreate the lateral gutter. These steps are essential to avoid flap tethering that can significantly impair function. The patient should be able to lift the tip of the tongue to touch the palate after hemiglossectomy reconstruction (FIG 22).
Flap inset	■ Inset is mostly performed before microsurgical anastomoses to limit soft tissue swelling and bleeding. ■ Circumdental sutures can be used if remnant gingiva is inadequate.
Closure	■ Discontinue neck hyperextension, and restore neutral positioning prior to neck closure to ensure the absence of pedicle kinking.

POSTOPERATIVE CARE

- In most cases, patients may be awakened from general anesthesia and transferred to the surgical floor for flap monitoring.
- The traditional convention of intensive care monitoring with prolonged sedation and/or mechanical ventilation for head and neck reconstruction is unnecessary unless medical indications arise. This approach significantly expedites recovery and reduces cardiopulmonary morbidity.
- Pulmonary toilet is improved with spontaneous respiration, and the hemodynamic lability associated with continuous sedation is avoided.
- Flap monitoring regimens are surgeon dependent, but the authors practice hourly clinical examination of the intraoral flap for the first 48 hours as the standard.
- Pencil and/or implanted Doppler are used to supplement the monitoring regimens as available or required.
- Flap assessment is reduced to every 2 hours subsequently for the next 48 hours and to every 4 hours thereafter.
- Delirium tremens prophylaxis should be given to patients with history of alcohol abuse, which is prevalent among head and neck cancer patients.
- History of substance abuse and narcotic dependence may predispose patients to postoperative confusion and agitation and may lead to hypertension, hematoma, anastomotic breakdowns, and avulsion of the vascular pedicle. Prompt management of these issues with neuropsychiatric staff is important.
- Enteral tube feeding is initiated on postoperative day 1.
- Patients are allowed to mobilize starting on postoperative day 1 and ambulating by postoperative day 2.
- Broad-spectrum antibiotics such as ampicillin/sulbactam are usually continued for 3 days or longer, as indicated.
- A modified barium swallow study is performed by speech pathology typically on postoperative day 7 to evaluate for swallow function, leak, and aspiration.
- In patients with no leaks or aspiration, a liquid diet is started and then quickly advanced to a soft or regular diet as tolerated. If the patient received previous radiation, the swallow study may be deferred to 2 weeks after surgery.
- Patients are typically discharged between postoperative days 5 and 7.
- Oral hygiene is critical. Patients should rinse frequently with saline or Peridex until the flap is well healed.
- In patients with leaks or aspiration upon swallowing, oral intake is withheld,

and a modified barium swallow study is repeated in 2 weeks or longer, as clinically indicated.

- Tracheostomy downsizing, capping, and decannulation can be performed if clinically tolerated once acute postoperative surgical site swelling is diminished prior to discharge.
- In high-risk patients, delayed decannulation or long-term tracheostomy dependence may be indicated.
- Outpatient follow-up with speech therapy to improve swallow and speech function is beneficial.

OUTCOMES

- The most important predictor of functional outcome is the extent of remaining tongue. Good clinical and functional outcomes following hemiglossectomy reconstruction have been reported.^{10–12}
- Speech intelligibility after hemiglossectomy reconstruction has been studied using a standardized numeric speech therapy scale (4, greater than 80% intelligible; 3, 50%–80% intelligible; 2, less than or equal to 50% intelligible; 1, unintelligible; and 0, inability to speak). Patients who underwent partial glossectomy or hemiglossectomy had significantly superior speech function (mean scores 3.59, 3.74, respectively) compared with patients with subtotal glossectomy (3.14) or total glossectomy (2.42).
- Successful sensory reinnervation of the radial forearm flap has been well documented.^{13,14} Innervation was associated with better speech scores following hemiglossectomy reconstruction (3.89 vs. 3.42).
- Risk factors for poor swallowing function after glossectomy include age of 60 years or older and preoperative radiation.
- Swallow function after hemiglossectomy reconstruction has been evaluated based on type of diet tolerated (4, regular unrestricted diet; 3, soft diet; 2, pureed or liquid diet; 1, oral diet requiring tube-feed supplementation; and 0, tube-feed dependency).
- Patients who underwent more extensive resections (total glossectomy, 0.83; subtotal glossectomy, 1.49) had significantly worse swallow function than did those who received only a partial glossectomy or hemiglossectomy (2.47).
- Patients who received innervated flaps had superior swallowing outcomes compared with patients who received noninnervated flaps in our experience, but controversy exists surrounding this topic in the surgical community.

COMPLICATIONS

- In the authors' published experience, the overall 30-day complication rate following microsurgical reconstruction for glossectomy was 23.6%. Total flap loss rate was less than 1%.
- Potential complications include the following:
 - Flap arterial or venous thrombosis
 - Partial or complete flap loss
 - Bleeding or hematoma
 - Infection or abscess
 - Flap dehiscence
 - Orocutaneous fistula
 - Respiratory complications including pneumonia
 - Aspiration
 - Altered or poorly intelligible speech
 - Inability to swallow or tolerate oral intake, feeding tube dependence
 - Tracheostomy dependence
 - Flap donor-site complications (skin graft failure, seroma, paraesthesia, etc.)

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42 Floor of Mouth Reconstruction

CHAPTER

George N. Kamel, J. Alejandro Conejero, and Evan Garfein

ANATOMY

- The floor of mouth is a U-shaped mucosal structure covered by squamous mucosa that is bordered by the alveolar ridge of the mandible and extends posteriorly to the anterior tonsillar pillar (**FIG 1A**).
- Medially, the floor of the mouth (FOM) merges with mucosal, ventral surface of the tongue to the level of the frenulum, which divides the floor into two oval spaces.
- The FOM contents include the sublingual salivary glands, submandibular ducts, oral component of the submandibular salivary gland, the geniohyoid and genioglossus muscles, and the lingual and hypoglossal nerves.
 - The lingual nerve provides sensation to the FOM.
- The arterial supply to the FOM is from the lingual arteries, branches of the external carotid artery, as well as the mylohyoid and submental branches of the facial arteries.
- The mylohyoid and hypoglossus muscles provide both structural support to the contents of the FOM and serve as barriers to the submental and submandibular triangles of the neck (**FIG 1B**).
- The sublingual salivary glands, located beneath the mucosa of the anterior FOM, drain via the excretory ducts of Rivinus, which drains into the submandibular duct or directly into the FOM through the plica fimbriata (mucous membranes located on either side of the frenulum).
- The anterior FOM lymphatic drainage is to the submental and submandibular nodes, whereas the posterior FOM drains to the upper cervical lymph nodes.

PATHOGENESIS

- Floor of mouth squamous cell carcinoma (SCC)
 - Approximately 18% to 45% of all oral SCCs occur in the FOM, and most originate at the anterior midline.¹ As with other locations of oral SCCs, there is a strong association with alcohol consumption and tobacco smoking. There is an increasing incidence of HPV-associated head and neck SCCs in patients without traditional risk factors.
 - SCC tumors typically spread in a superior or horizontal fashion as the muscular floor of the FOM serves as a barrier to tumor spread. However, these tumors can also invade the submucosa, the intrinsic tongue muscles, and the contralateral space in the FOM.
 - The location of FOM structures and their association with the tumor affects the presentation of tumor invasion. In certain cases, SCCs may obstruct the ostia of the submandibular duct, which is located along either side of the frenulum resulting in inflammatory changes and ductal dilatation. In contrast, the sublingual glands are more prone to direct invasion due to proximity of the tumor. Invasion of the mandible upstages the tumor.
 - Cervical lymph node invasion is common at time of diagnosis, and hematogenous spread to distant sites including the liver, bones, and lungs must be ruled out.
- Floor of mouth salivary gland tumors and sarcomas
 - These tumors account for 3% to 5% of all head and neck cancers, most commonly appearing in the sixth and seventh decade of life.

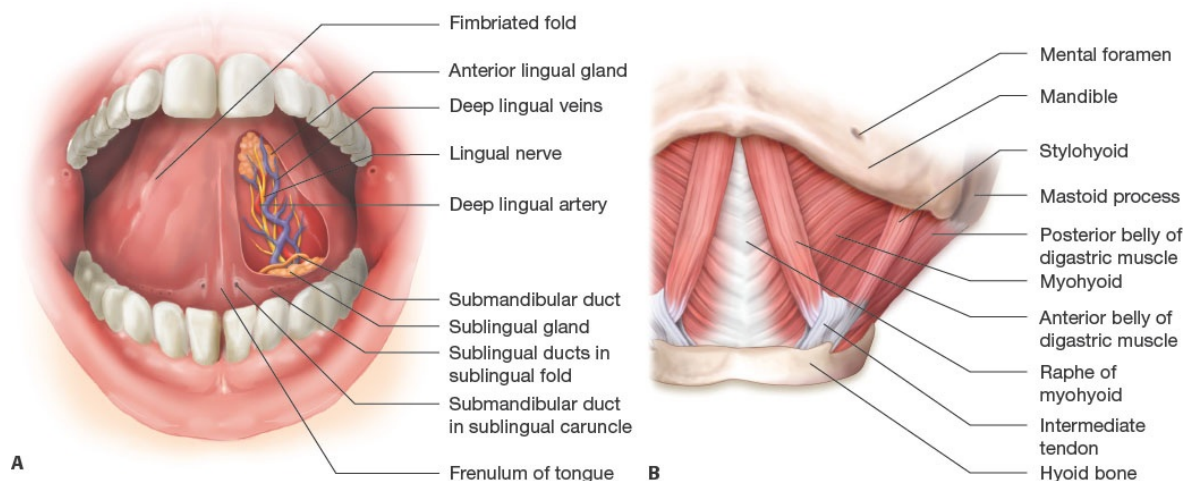


FIG 1 • Anatomy (A) and musculature (B) of the FOM.

- The etiology is multifactorial; however, occupations with an associated increased risk include mining, asbestos exposure, and rubber manufacturing.
- The most common of these tumors are adenoid cystic carcinoma and mucoepidermoid carcinoma.
- Most patients present with a painless slow-growing mass. Others may manifest with perineural invasion resulting in pain or numbness.
- Sarcomas of the oral cavity most often arise from the maxilla or mandible as an osteosarcoma, chondrosarcoma, rhabdomyosarcoma, or liposarcoma. Liposarcomas occur with equal frequency in the mandible and maxilla. Similar to other neoplasms of the oral cavity, surgical resection is the primary modality for treatment.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history begins with a thorough assessment of the onset of symptoms, duration, course, and associated risk factors, the most common of which are alcohol consumption and tobacco use.
- Symptoms of floor of mouth tumors may include an enlarging or recurrent mass, difficulty with speech, chewing or deglutition, odynophagia, halitosis, and red or white intraoral discoloration.
- The physical exam begins with inspection and palpation of both the extraoral and intraoral soft tissues. This includes assessment of the lips, intraoral labial mucosa, buccal mucosa, the dorsal and ventral surface of the tongue, the hard palate, and the FOM.
- The sublingual, submandibular, and parotid glands are palpated and examined for any abnormalities.
- The neck is inspected for signs of cervical lymphadenopathy as floor of mouth cancers typically metastasize to the cervical chain of lymph nodes. Evaluation of the anterior deep cervical lymph nodes, the preauricular and postauricular lymph nodes, is included in the examination.

IMAGING

- Numerous imaging modalities are available for both diagnostic as well as treatment planning and include plain radiographs, magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET).
- Plain radiographs or panoramic images are routinely used by dentists and may initially suggest a malignant lesion during an initial evaluation. CT scans, however, are currently the standard for primary tumor detection with a

specificity ranging from 81% to 100% and sensitivity of 41% to 82%.

- PET scan or PET/CT evaluates tissue metabolic activity and is used to assess for metastatic spread to lymph nodes as well as distant tissues.

SURGICAL MANAGEMENT

- Successful reconstruction after oncological extirpation is based on the following principles:
 - Tumor-free resection margins
 - Maximizing mobility of the remaining tongue
 - Watertight closure and seal that protects the neck structures from FOM secretions
 - Maintaining mandibular continuity
- Reconstructive options
- FOM defects arise most frequently from composite resections of the mandible and FOM or tongue and FOM. Less frequently, resection of soft tissue tumors or salivary gland cancers leads to isolated FOM defects.
- Many options exist for reconstruction of the soft tissue FOM defects. In general, the reconstructive options are dictated by the volume and type of tissue that is resected. Thus, soft tissue low volume defects require replacement with low volume soft tissue flaps. Large-volume composite defects that include soft tissues and bone may require reconstruction with osteocutaneous flaps. Rarely, complex cases may require more than one flap for reconstruction; however, in general, most defects of the FOM can be reconstructed with a single flap.
- Microvascular free flaps are the preferred reconstructive options for patients with floor of mouth defects because they have excellent blood supply; can be constructed of thin, pliable tissue; and can be customized to fit any defect.
- Soft tissue flaps such as the radial forearm, anterolateral thigh (ALT), medial sural artery perforator flap (MSAP) and pectoralis major musculocutaneous flaps are most commonly used for FOM reconstruction. The selection of reconstructive technique depends on patient factors, the extent and complexity of the surgical resection, and surgeon preference.
 - Patient factors include thickness of the subcutaneous fat layer in the flap donor sites and blood supply/circulation (eg, intact palmar arch).
 - Surgical factors include primarily the type and extent of resection. For example, complex defects that include wide resection of the FOM musculature and supporting structures may require a large volume composite

flaps that include skin and muscle to obliterate dead space, whereas low-volume defects restricted to the FOM mucosa may be better reconstructed with thin pliable flaps.

- Ultimately, the flap that is selected for reconstruction should maximize reconstructive goals of obtaining a watertight closure of the defect and maximize the potential to swallow and speak.

Soft Tissue Flap Options

- Radial forearm fasciocutaneous free flap
 - The radial forearm flap was first described by Yang in 1981 and later popularized by Soutar and McGregor in 1986 for intraoral reconstruction and is a skin and fascial flap based on the radial artery, its venae comitantes, and, often, the cephalic vein.²
 - It is considered the workhorse for many soft tissue head and neck defects and is adequate for moderate to large FOM defects.
 - It is pliable, thin, and has a long vascular pedicle measuring (10–15 cm). One may incorporate a portion of the radius bone or palmaris tendon if needed for reconstruction.
 - The superficial branch of the radial nerve lies adjacent to the radial artery, and this branch supplies sensation to the dorsal aspect of the thumb and index finger. This branch should be preserved during dissection of this flap.
 - The skin paddle of the radial forearm flap is supplied by fasciocutaneous branches of the radial artery, with venous drainage through the superficial cephalic vein and the deep venae comitantes.
 - Sensory innervation to the FOM can be restored in some cases by anastomosing the lateral antebrachial cutaneous nerve in the flap to the lingual or inferior alveolar nerves in the recipient site.³
 - The anatomical location of the radial forearm flap allows for simultaneous harvest by the reconstructive team at the time of tumor extirpation.
 - Disadvantages of the radial forearm flap include decreased circulation to the hand, risk of tendon exposure, radial nerve injury, painful neuroma, cold intolerance, and possible poor cosmetic result.
- Anterolateral thigh flap
 - The ALT flap, first described by Song in 1984 and further advanced by Wei, is a soft tissue perforator flap based on the descending branch of the lateral circumflex femoral artery (DLCFA), the largest branch of the profunda femoris.^{4,5}

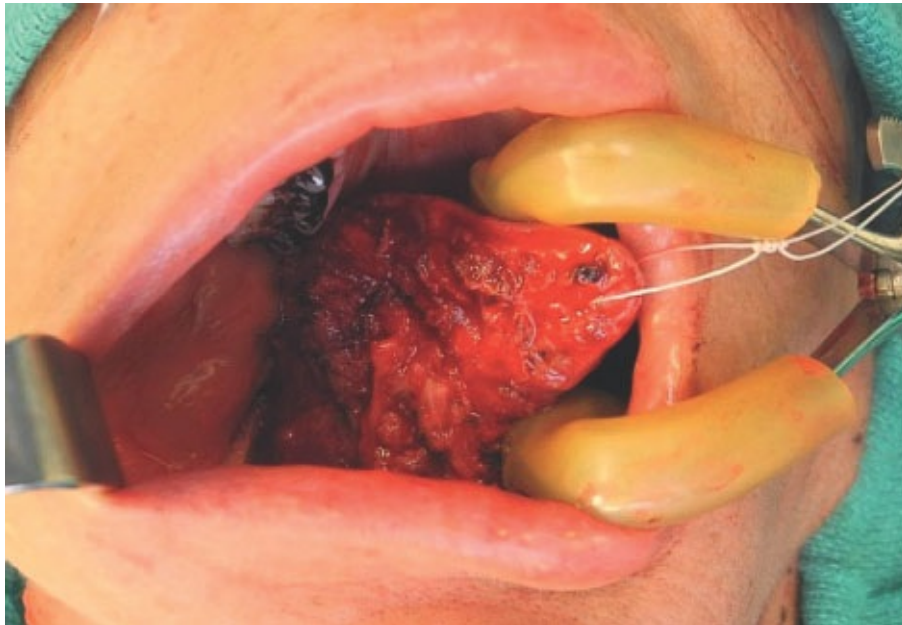
- The ALT flap has a long pedicle, ranging from 7 to 16 cm with reliable septocutaneous or musculocutaneous perforators arising from the descending branch of the LCFA.
- The location of the flap allows for simultaneous harvest at the time of tumor extirpation.
- The ALT flap has minimal donor site morbidity as one of its principal advantages and is an optimal choice for large volume complex defects of the FOM because it can be harvested with vascularized fascia and muscle if necessary.
- Disadvantages to the ALT flap include variable anatomy and location of the perforators. It should be avoided in small intraoral defects due to the potential increased bulk of this flap.
- Medial sural artery perforator flap
 - The MSAP flap was first described by Cavadas in 2001 for reconstruction of distal limb defects. In 2008, Chen introduced the MSAP free flap for intraoral reconstruction following cancer ablation.⁶
 - The MSAP flap is, in most patients, thin and pliable, suitable for intraoral defects.
 - The MSAP flap is associated with minimal donor site morbidity, and its locations allow for simultaneous harvest at the time of tumor extirpation.
 - The disadvantage of the MSAP flap is in the difficulty of identifying a reliable cutaneous perforator that may at times be mistaken for a muscular branch of the medial sural vessels.
- Pectoralis major musculocutaneous flap
 - The pedicled pectoralis major musculocutaneous flap first described by Ariyan in 1979 was considered the workhorse for oropharyngeal defects prior to the advancements made in free vascularized tissue transfer.⁷
 - The pectoralis major musculocutaneous flap is now most often used as a salvage flap in FOM reconstruction. The pectoralis major musculocutaneous flap is also useful in patients who are poor candidates for vascularized free tissue transfer or those with large defects who require two flaps for reconstruction.
 - The disadvantages include a contour defect, slight loss of arm adduction and rotation provided by the pectoralis major muscle, and added bulk in the neck caused by the pedicled muscle.

TECHNIQUES

■ Floor of the Mouth Reconstruction With a Radial Forearm Free Flap

Preparation of the Recipient Site

- The defect is carefully analyzed to understand the extent of the resection and the tissues necessary for reconstruction.
 - Specifically, attention is paid to the extent and pattern of mucosal defect as well as the volume of the defect created by resection of the FOM musculature/soft tissues (**TECH FIG 1**).
- If a microvascular free flap is planned, recipient vessels in the neck are identified, dissected, and made ready for microvascular anastomosis.
 - In patients who have had a previous neck dissection or radiation therapy, assessment of arterial inflow should be done. In most cases, however, the quality and patency of the vessels are easily assessed during the dissection.



TECH FIG 1 • Floor of mouth defect after partial tongue, FOM, and marginal mandibulectomy.

- If the resection is limited to the FOM mucosa, a tunnel is created in the FOM musculature to enable passage of the flap pedicle to the recipient vessels.
 - The tunnel should be large enough to account for postoperative swelling, thus avoiding vascular compression.
 - Hemostasis should be meticulously maintained because bleeding after pedicle transfer is difficult to control.

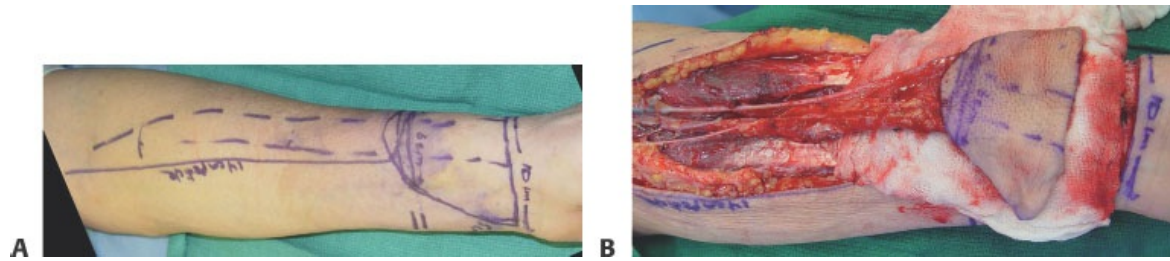
Flap Dissection

- Prior to the radial forearm free flap harvest, an Allen test using a pulse oximeter placed on the thumb with concomitant occlusion of the radial artery is performed to assess for blood flow between the superficial and the deep palmar arch systems.
- An appropriately sized skin paddle is designed based on the radial artery approximately 1 cm proximal to the wrist crease and, in most cases, including the cephalic vein (**TECH FIG 2A**).
- The forearm is exsanguinated, and a sterile tourniquet is insufflated to 200 to 250 mm Hg.
- An incision is then made through the subcutaneous tissue outlining the skin paddle and extending proximally toward the antecubital fossa.
- The dissection continues on the radial aspect of the flap, first identifying the cephalic vein and dissecting it out proximally and ligating the distal end.
- Next, the brachioradialis fascia is identified, and a subfascial dissection is performed taking care to preserve the paratenon of the brachioradialis tendon and preserving communicating venous branches of the cephalic vein. The superficial radial nerve is identified at the distal aspect of the dissection and is preserved.
- The dissection continues in an ulnar direction toward the palmaris longus and flexor carpi radialis (FCR) tendon in a subfascial plane, with care not to injure the paratenon of the FCR tendon. The pedicle is identified between the muscle bellies of the FCR and brachioradialis muscles.
- The distal ends of the radial artery, venae comitantes, and cephalic vein are identified, ligated with surgical clips, and divided.
- The radial forearm flap is then elevated off the flexor digitorum superficialis and flexor pollicis longus muscles toward the antebrachial fossa.
- The tourniquet is released, and hemostasis is ensured.
- Perfusion to the hand/thumb is verified, and the flap is allowed to reperfuse prior to division of the vascular pedicle (**TECH FIG 2B**).

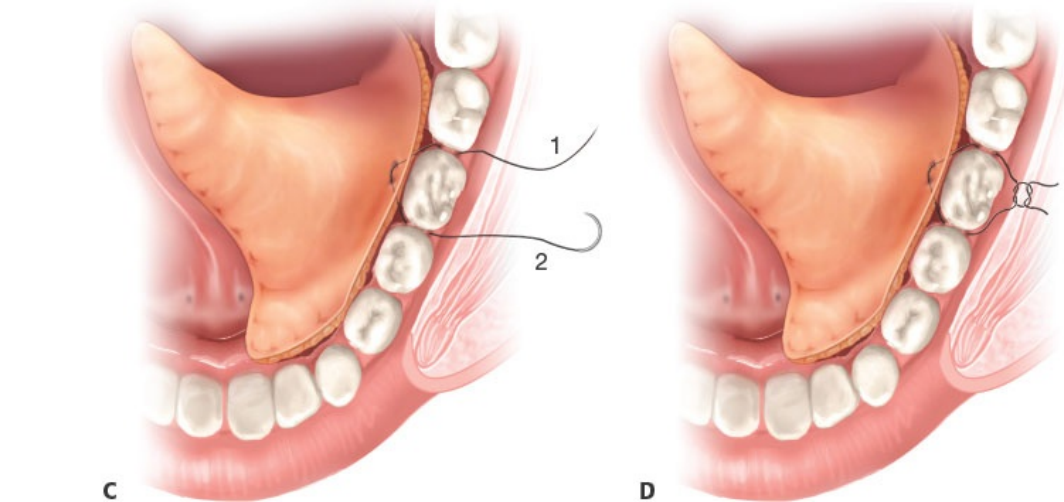
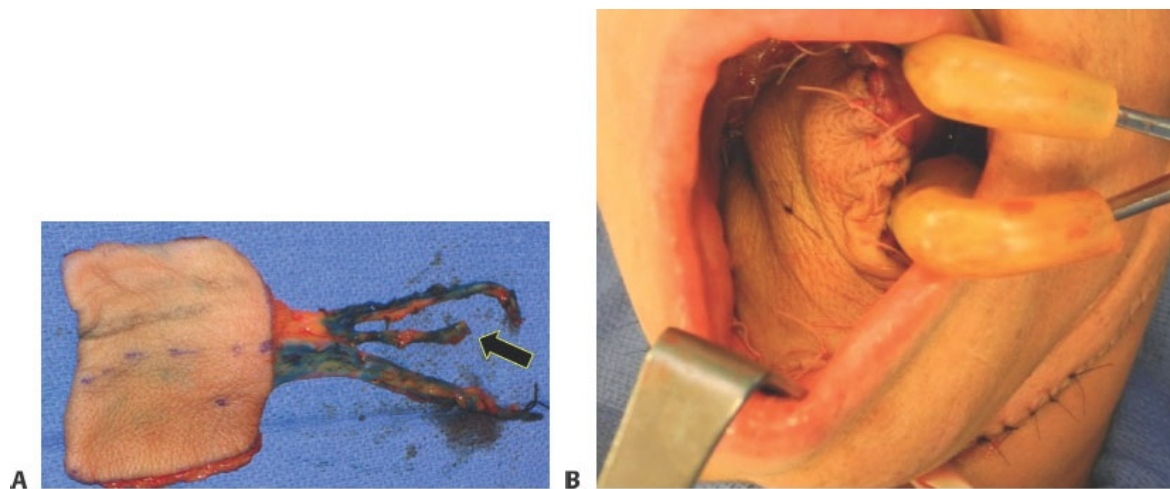
- The donor site is then closed in a layered fashion, and a split-thickness skin graft is applied.

Flap Inset

- The flap vessels are marked with methylene blue or a marking pen to maintain correct orientation and ligated (**TECH FIG 3A**).
- The flap is transferred to the head and neck area, and the pedicle vessels are passed through the FOM defect (or tunnel) to the recipient vessels taking care to avoid twisting or kinking of the pedicle.
 - This may be facilitated by using a Penrose drain passed through the tunnel to transfer the pedicle to the recipient site.
- The flap skin is inset into the defect using 2.0 Vicryl sutures in an interrupted fashion sutured to the remaining FOM mucosa. The inset begins at the deepest/least accessible portion of the FOM and proceeds toward the most accessible area (**TECH FIG 3B**).
- In some cases, there is insufficient mucosa available to suture to the flap.
 - In these cases, it is important to make sure that the flap is securely inset; otherwise, postoperative dehiscence and leak may occur. This is best accomplished by suturing the flap using a U-shaped stitch around the teeth.
 - The needle is passed through the gingiva distal (ie, behind) a tooth toward the intraoral defect. The suture is then passed through the skin entering the subcutaneous layer (ie, from deep to superficial). The needle is then passed through the flap skin through the skin in a U-shaped manner and then passed through the gingiva mesial to the tooth. The suture is tied around the tooth securely holding the flap in place (**TECH FIG 3C,D**).
- In most cases, most/all of the inset is performed prior to microsurgical anastomosis to ensure that the position of the pedicle does not change after inset.
 - In some cases, the flap is partially inset, microsurgery is performed, and the flap is then cut to final size and inset. However, usually with careful planning, minimal alteration of the flap is necessary.



TECH FIG 2 • **A.** Preoperative markings of a radial forearm flap. **B.** Radial forearm flap elevated on radial artery/vein and cephalic vein.



TECH FIG 3 • **A.** Radial forearm flap ligated and pedicle marked with *blue ink* to prevent kinking/twisting. Lateral antebrachial cutaneous nerve is shown (*arrow*). **B.** Final inset of the flap achieving a

watertight closure. **C,D.** Sequence of tying U-shaped suture around teeth to secure flaps in cases with inadequate remaining mucosa for flap suturing so that the knot is on the mandible side.

PEARLS AND PITFALLS

Indications	■ When reconstructing FOM defects, the goals of reconstruction are to maximize tongue mobility and maintain a watertight closure to prevent leaks.
Advantage	■ Microvascular free flaps are the preferred reconstructive options for patients with floor of mouth defects after tumor extirpation due to a more robust blood supply, flexibility in donor site harvest, and positional customization.
Approach	■ The defect should be carefully analyzed such that the right flap is selected. This decision is influenced by the volume of the defect, concomitant structures that may be involved, recipient vessels, and patient factors. ■ Care should be taken in flap design so that minimal alteration of the flap is necessary during inset if possible. ■ The flap should be securely inset to avoid dehiscence. If there is insufficient mucosa available to suture the flap, then sutures should be placed around the teeth.

POSTOPERATIVE CARE

- Patients are typically kept on bed rest for 12 to 24 hours postoperatively with the head of bed elevated to 30 degrees to minimize postoperative edema.
- Patients who undergo free flap reconstruction are monitored closely in the postoperative period using physical exam, use of transcutaneous Doppler probe, implantable Doppler probe, or combination thereof.
- Patients are treated with aspirin and/or Lovenox or subcutaneous heparin for deep venous thrombosis prophylaxis (unless otherwise contraindicated). Sequential compression devices are also utilized while the patients are on bed rest.

- Perioperative antibiotics targeted against intraoral microbial flora are maintained for 72 hours.
- Antibiotics may be necessary for longer periods of time in patients with contaminated wounds or those with severe tissue damage (eg, extensive surgery with or without radiation) or those with comorbid conditions (eg, poor dentition, obesity, uncontrolled diabetes, history of alcohol use).
- Enteral nutrition via feeding tube is started 24 hours postoperatively, and a speech and swallow evaluation is typically obtained by 7 to 14 days postoperatively.
- Patients are evaluated by physical therapy while in the hospital and are transitioned to either home or a rehabilitation facility upon discharge.

COMPLICATIONS

- Short-term postoperative complications may include bleeding, dehiscence, or flap failure from arterial/venous thrombosis.
- Long-term complications may include flap failure, salivary fistulas, wound dehiscence, or radiation-induced fibrosis yielding insufficient soft tissue to accomplish reconstructive goals.

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43 Reconstruction of Total Glossectomy Defects

CHAPTER

Mark Sisco and Mihir Bhayani

DEFINITION

- Total glossectomy defects occur most commonly in patients with malignancies of the tongue or floor of mouth.
- These complex defects require reconstruction with moderate to large volume flaps to restore the bulk of the tongue.
- Because the muscular action of the tongue is not restored by this procedure, the bulk of the reconstructed tissue is necessary for swallowing (by pushing the food to the back of the mouth). However, restoration of swallowing is not always feasible and depends on the amount of residual normal tongue base and floor of mouth that is preserved.

ANATOMY

- The oral cavity comprises the floor of mouth, oral tongue, alveolar ridge, buccal mucosa, and hard palate.
- The tongue itself is composed of intrinsic striated muscles that affect its shape. Extrinsic muscles, including genioglossus, hyoglossus, palatoglossus, and styloglossus, insert into the tongue and affect its position in the oral cavity.
- The blood supply to the tongue is almost entirely derived from the lingual arteries, which arise from the external carotid arteries.
- The base of tongue, which represents the posterior third of the tongue, is attached to the hyoid bone and represents the anterior-most portion of the oropharynx.
- The floor of mouth is the U-shaped mucosal reflection that spans the region between the mandibular alveolus and ventral tongue.
- The tongue has distinct functions to support mastication, deglutition,

sensation, and speech.

- For mastication, it moves food into position for chewing.
- During deglutition, the tongue propels the food bolus posteriorly into the oropharynx by progressively pressing against the hard palate in a retrograde fashion. This is followed by contraction of the palatoglossus muscles and elevation of the base of tongue. From this point onward, coordinated contraction of muscles in the pharynx and hypopharynx moves the bolus into the esophagus.
- The tongue is the most important articulator of speech and is critical to the production of all vowels and several consonants.

PATHOGENESIS

- Over 95% of tongue cancers are squamous cell carcinomas.
 - It is more common in males and often presents in the fifth and sixth decades of life.
- The most common etiology is smoking and chewing tobacco.
- Human papillomavirus has emerged as a new cause of base of tongue malignancies that arise from the lingual tonsils.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most patients with tongue cancer who present to the plastic surgeon have been determined to need resection of at least 25% of the tongue.
- Total glossectomy generally refers to removal of at least 75% of the tongue.
- Patients should be queried about a history of carotid disease, smoking, prior surgery, or radiation therapy.

IMAGING

- Patients who have a history of prior neck lymph node dissection or known carotid disease may benefit from angiography to determine optimal management.

SURGICAL MANAGEMENT

- The goals for reconstruction are as follows:
 - To enable complete resection of the tumor with wide margins
 - To achieve wound closure
 - To minimize donor morbidity
 - To restore function
- In the case of the total or subtotal glossectomy, these goals are best

accomplished by providing a reconstruction that minimizes dead space and provides bulk.

- This will reduce the likelihood of aspiration and provide a platform for food boluses during swallowing.
- If patients present with aspiration, the surgeon should plan for total laryngectomy at the time of total glossectomy.
- In general, the above goals are best met with microvascular transfer of a vertical rectus abdominis myocutaneous (VRAM) or anterolateral thigh (ALT) perforator flap. Pedicle flaps, such as the pectoralis myocutaneous flap, may be used but do not provide as much bulk or freedom in inset.

Preoperative Planning

- Potential donor sites should be examined, including the ALT and abdomen.
 - A determination of the donor site should be based on surgeon preference as well as the body habitus of the patient.
 - Patients who have had previous abdominal surgery or who have a large abdominal pannus may not be good candidates for a rectus-based flap.
- Patients should generally have gastrostomy tubes placed preoperatively or at the time of surgery.
 - If laryngectomy is not planned, patients should also have tracheostomy tube placed to secure the airway.

Positioning

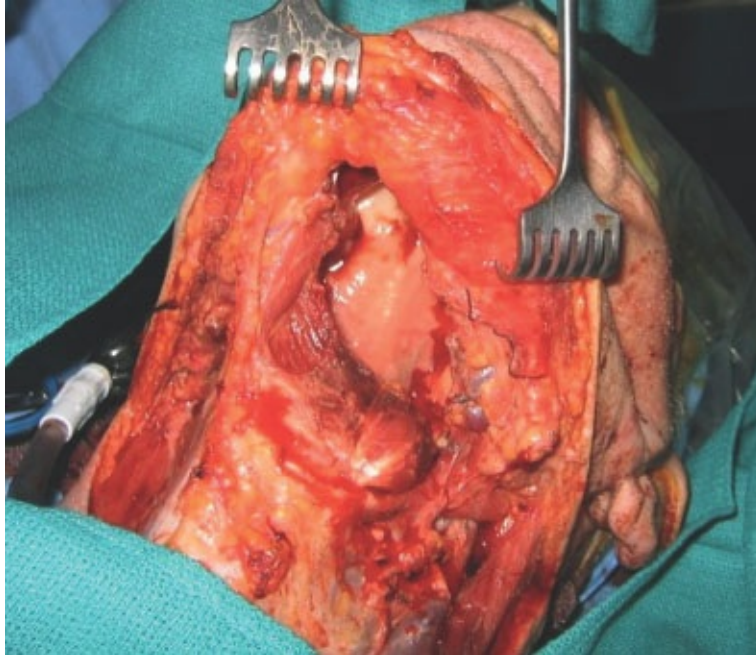
- A shoulder roll should be used to extend the neck.

TECHNIQUES

■ Anesthesia and Assessment of the Defect

- After anesthesia is initiated, the oral cavity and oropharynx are examined to assess the anticipated defect (**TECH FIG 1**).
- Tracheostomy is usually performed first, followed by glossectomy and then neck dissection as indicated.
- In cases in which a total glossectomy is known to be required, a two-team approach can be used to reduce surgery time.

- For total glossectomy defects, the primary goal is to create enough bulk anteriorly to allow contact between the flap and the hard palate when the mandible is closed.



TECH FIG 1 • Total glossectomy defect with preservation of a small portion of the right floor of mouth using a visor incision.

- If necessary, the flap may be folded upon itself to increase its bulk.

■ Flap Selection and Harvest

- A soft tissue flap with sufficient bulk and volume is selected. Most commonly, the VRAM flap or the ALT flaps are used since these flaps provide both skin and healthy muscle with sufficient bulk to reconstruct the missing tongue. In general, thinner fasciocutaneous flaps such as the radial forearm are less useful due to insufficient volume.
 - In this example, a musculocutaneous ALT flap was selected (**TECH FIG 2A,B**).
- Other myocutaneous flaps or fasciocutaneous flaps such as the gracilis or parascapular flap (with or without latissimus muscle), latissimus flap, etc. are

used less frequently.

- Recipient vessels are dissected in the head and neck area and made ready for microanastomosis.
- The flap is transferred to the head and neck area and inset into the defect using interrupted 2-0 braided absorbable sutures. This ensures tension-free inset and minimizes the risk of inadvertent flap avulsion of the anastomosis (**TECH FIG 2C**; Videos 1 and 2).

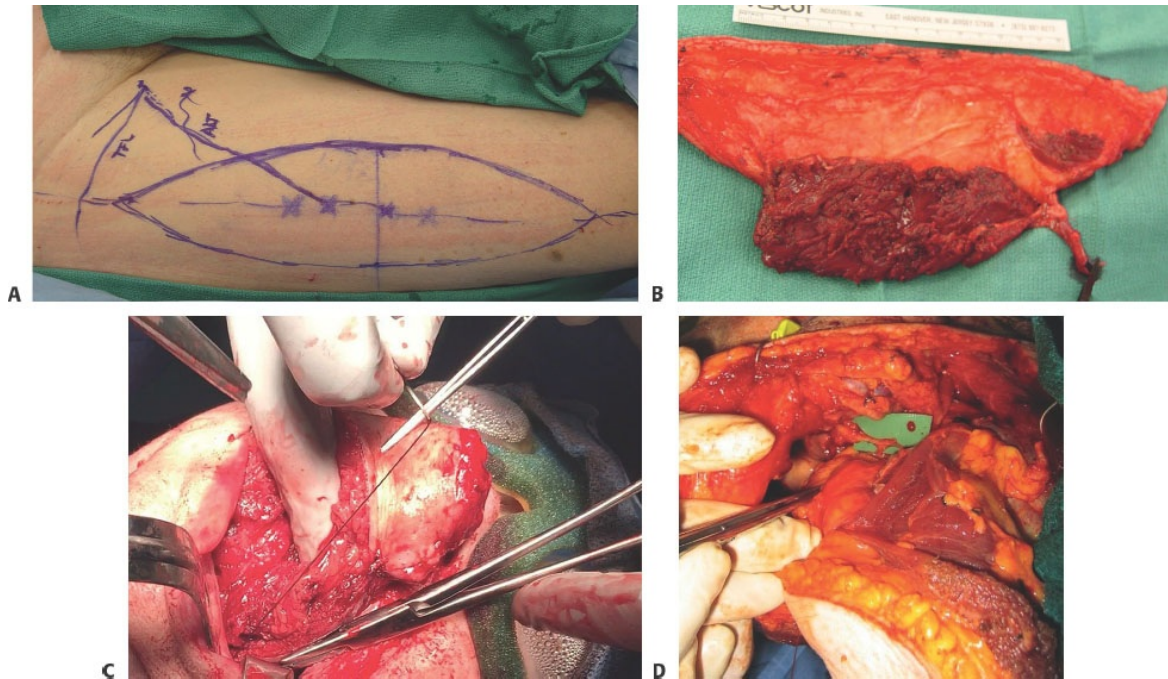


Video p3-c043_01



Video p3-c043_02

- The flap may also be neurotized by connecting the remnant of the lingual nerve (if preserved) to a cutaneous branch of the ALT flap (**TECH FIG 2D**). This is usually easiest to do before inseting the skin paddle for the flap.



TECH FIG 2 • A. Skin markings for anterolateral thigh myocutaneous flap. **B.** Harvested flap showing the skin and muscle portion. In these cases, it is best to keep the muscle and skin connected. **C.** Flap inset begins in the deepest portion of the defect with interrupted Vicryl sutures. **D.** Anastomosis of the lingual nerve to the cutaneous nerve of the flap can be performed if this nerve is preserved during the resection. This is most easily accomplished prior to inset of the skin paddle.

■ Flap Inset

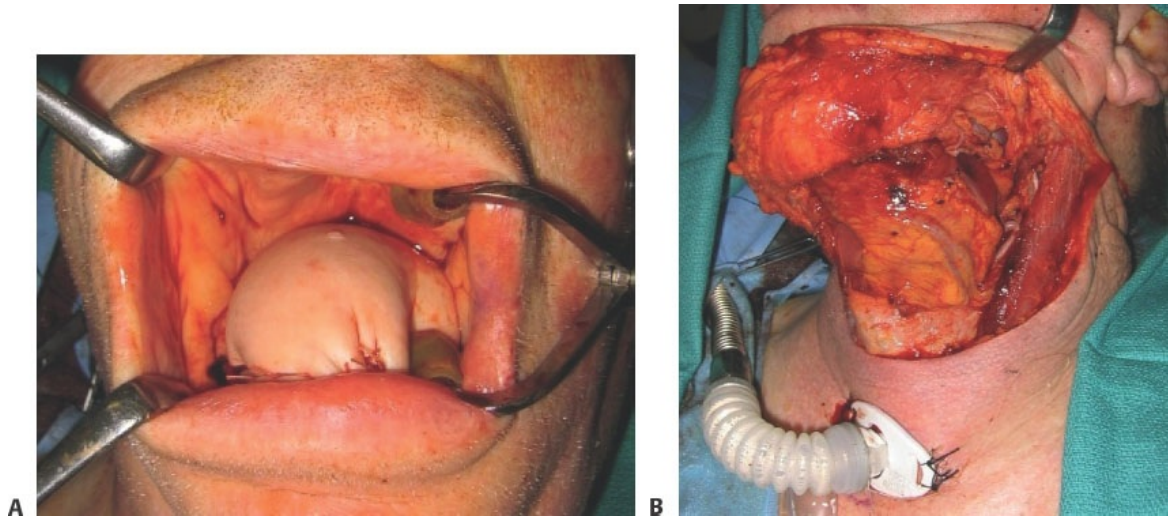
- Flap inset begins by passing the flap vessels into the neck and inset of the deepest/most dependent portion of the flap. The inset then progresses proximally, rolling the tissue inward to increase the bulk of the flap in the oral cavity.
- The vascular anastomoses are performed to high-flow vessels. These are most commonly the facial artery and common facial vein; however, the lingual or other arteries may be used.

- The venous anastomosis should be under sufficient tension to prevent kinking with neck motion. I prefer to use a microvascular coupler to a short branch from the internal jugular vein.
- Alternatively, an end-to-side anastomosis may be performed to the internal jugular vein. This requires the use of a small Satinsky clamp.
- Completion of the inset is performed, again using interrupted 2-0 braided absorbable sutures (**TECH FIG 3A**; Video 3).



Video p3-c043_03

- The muscle from the flap can be used to reconstruct the floor of mouth and sutured loosely to the mandible on each side (**TECH FIG 3B**). This is helpful to prevent leaks (or to contain them if they occur).
- A 10 Fr Blake drain is placed in the neck.
- The neck is closed in layers.
- The flap donor site is closed.



TECH FIG 3 • A. Inset flap demonstrating bulk of the flap (rounded appearance) intraorally. This bulk is necessary to propel food to the back of the mouth. **B.** Muscle inset in the floor of mouth to contain leaks. Microanastomosis is also shown.

PEARLS AND PITFALLS

Patient education and planning

- Patients requiring total glossectomy are at high risk for complications given that they are nutritionally compromised, they have advanced malignancies, they often smoke, and many have had prior surgery or radiation.

Surgical planning

- A successful reconstruction is most often achieved during the primary operation. It is significantly more difficult to achieve a successful reconstruction after a flap has necrosed, a fistula has formed, or a dehiscence has occurred.

Flap design

- A variety of flap designs have been proposed to allow various three-dimensional configurations. More complex shaping and folding of flaps may result in a greater risk of ischemia and partial flap loss, especially among smokers.
- Generally, the flap dimensions should be at least 30% larger than the floor of mouth defect for sufficient bulk. If an ALT flap is used and the patient is thin, a portion of the vastus lateralis can be used or the flap

can be partially de-epithelialized and folded upon itself.

POSTOPERATIVE CARE

- The patient is kept sedated and ventilated by tracheostomy overnight.
- Flap monitoring can be performed with clinical exam, handheld Doppler, or implantable Doppler.
- Oral hygiene is started 2 to 3 days postop with Peridex.
- Swallowing function is assessed before attempts at feeding.
- Drains are removed from the neck at 15 mL/d.
- Drains are removed from donor sites at 30 mL/d.

OUTCOMES

- Although most patients are able to verbally communicate with laryngeal preservation, 85% of patients are found to have intelligible speech.^{1,2}
 - In patients who have simultaneous total laryngectomy, about 50% of patients regain the ability to phonate.
 - Only 30% of those patients have intelligible speech. Reconstruction using free tissue transfer has been independently associated with improved speech outcomes when compared to pedicled reconstruction flaps.
- Most patients recover the ability to swallow after reconstruction of a total glossectomy defect.
 - Feeding tube dependence at 1 year postsurgery has been found to be anywhere from 50% to 75%.^{1,2}
 - At least 75% of patients are able to maintain some type of oral intake with one-third of patients able to be feeding tube independent. Flap choice has not been shown to have any effect on swallowing function.
- Maintenance of the flap bulk and volume is important for speech and swallowing (**FIG 1**).

COMPLICATIONS

- Patients are subject to the usual complications that may afflict any patients with locally advanced head and neck cancer.
 - These include pneumonia, deep vein thrombosis (DVT) or pulmonary embolus, and myocardial infarction.
- Wound healing complications are common, especially in smokers or patients with a history of prior radiation therapy.



FIG 1 • Long-term follow-up view demonstrating good height and bulk of the flap. Also note that the flap has re-epithelialized.

- Small fistulas may be managed conservatively with local care.
- Larger fistulas or those near the vascular pedicle may require operative intervention and closure with a secondary pedicle flap (eg, pectoralis or supraclavicular) as appropriate.
- Total flap loss generally requires a second free flap or possibly a pectoralis myocutaneous flap, depending on the etiology of the flap loss.³⁻⁶

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44 Reconstruction of Buccal Mucosal Defects

CHAPTER

Imran Ratanshi and Colleen M. McCarthy

DEFINITION

- Carcinoma can involve the buccal mucosa of the oral cavity.
- The treatment of buccal mucosa cancer is typically surgical resection.

ANATOMY

- The buccal mucosa lines the inner aspect of the cheek and the lip.
- Blood supply to the buccal mucosa is derived from buccal branches of the facial artery, superficial temporal artery, and internal maxillary artery.
- Sensory innervation to the buccal mucosa is provided by the trigeminal nerve.
- Anatomic borders (**FIG 1A**)
 - Superiorly border—attachments to the maxillary alveoli
 - Inferior border—attachments to the mandibular alveoli
 - Anterior border—lateral lip commissure
 - Posterior border—pterygomandibular raphe
- Relevant layers of the cheek from external to internal (**FIG 1B**)
 - Skin
 - Subcutaneous fat
 - Superficial musculoaponeurotic system (SMAS)/platysma
 - Parotid fascia/capsule
 - Parotid gland
 - Parotidomasseteric fascia
 - Masseter muscle
 - Buccal fat pad (within buccal space)
 - Buccinator
 - Buccal mucosa

■ There are three important spaces in the buccal region. These are potential sites for fluid collection, infection, or tumor spread.

■ Buccal space

- Anterior border—oral commissure
- Posterior border—anterior border of masseter
- Superior border—zygomatic process of maxilla, zygomaticus muscles
- Inferior border—depressor anguli oris and attachment of deep fascia to mandible
- Medial border—buccinator muscle (space is superficial to the muscle)
- Lateral border—platysma, subcutaneous tissue, skin

■ Pterygomandibular space

- Anterior border—posterior border of buccal space (anterior border of masseter)
- Posterior border—parotid gland
- Superior border—lateral pterygoid muscle
- Inferior border—inferior border of mandible (lingual surface)

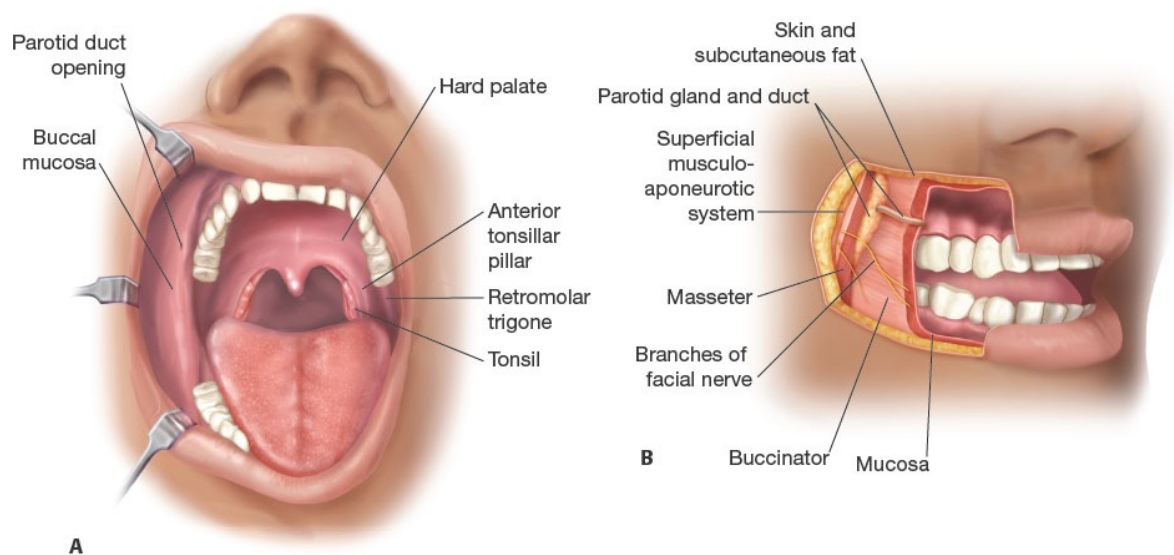


FIG 1 • A. Surface anatomy of the intraoral cheek surface. **B.** Anatomic layers of the cheek illustrated from external to internal. SMAS, superficial musculoaponeurotic system.

- Lateral border—ascending ramus of mandible (space is deep to mandible)
- Medial border—medial pterygoid muscle (space is superficial to this muscle)
- Masseteric (or submasseteric) space
 - Anterior border—anterior margin of masseter
 - Posterior border—parotid gland
 - Superior border—zygomatic arch
 - Inferior border—mandible
 - Lateral border—masseter
 - Medial border—lateral surface of mandibular ramus
- The buccal fat pad (of Bichat) occupies the buccal space. Contents of the buccal fat pad include
 - Motor buccal nerve
 - Sensory buccal nerve (V3)
 - Facial artery and vein
 - Buccal branch of maxillary artery
 - Terminal buccal branches of facial nerve
 - Parotid (Stensen) duct

PATHOGENESIS

- Buccal cancer originates in the mucosal lining of the cheeks inside the mouth.
- Squamous cell carcinoma is the most common type of pathology.
- No single risk factor causes buccal cancer.
- Risk factors for buccal cancer include a history of:
 - Premalignant conditions¹
 - Oral lichen planus and leukoplakia are common premalignant lesions.
 - Malignant conditions
 - Previous aerodigestive cancer
 - Modifiable risk factors^{1,2}
 - Tobacco (particularly chewing tobacco)
 - Alcohol abuse
 - Betel nut [or areca nut] (common in a South Asian chewed delicacy called “paan”)
 - Poor nutrition
 - Poor dentition

- Oral denture wear
- Viruses: HPV-16, HPV-18, HPV-31, HPV-33, and HPV-35; HHV-4 and HHV-8; HIV; EBV¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- Risk factors for buccal cancer should be identified, particularly smoking status. In a patient who is an active smoker, the risk of partial or complete flap loss is greater.
- A history of any prior surgeries or vascular line placement may limit the use of specific reconstructive options.
 - For example, a prior neck dissection may preclude the use of the facial artery musculomucosal (FAMM) flap if the facial artery has been previously ligated.
 - If level 1 (submental) nodes have been previously resected, use of the submental island flap or platysmal island flap is contraindicated.
 - Placement of a radial artery line for invasive blood pressure monitoring is a relative contraindication for use of a radial forearm free flap.
- History and clinical findings of prior irradiation may also be a relative contraindication to a locoregional flap reconstruction, depending on the condition of the tissues.
- A handheld pencil Doppler or duplex ultrasound can be used in the preoperative setting and/or in the operating room to determine the location of arterial perforating vessels.

SURGICAL MANAGEMENT

Preoperative Planning

- Potential donor sites must be considered preoperatively.
- Discussion with the resecting surgeon is helpful to estimate the defect size and potential for close or positive margins. If positive margins are anticipated, other nonsurgical treatment strategies should be explored.
- Need for adjuvant radiation therapy should influence the reconstructive modality.
- It is imperative that patency of the ulnar artery is confirmed with an Allen test in the preoperative period. Use of a bedside pulse oximeter can be a useful adjunct to objectively identify collateral flow in this setting.
- Intravenous and intra-arterial lines must also be avoided in the ipsilateral upper forearm if a radial forearm free flap is to be harvested.

Positioning

- The patient is placed in a supine position with neck in slight extension.
- General anesthesia with nasotracheal intubation will typically be employed.
- Tumor ablation will proceed by the ablative surgeon.
- The reconstructive surgeon may undertake simultaneous harvest of a microvascular flap if the surgical teams are certain that a free tissue transfer is indicated. Partial elevation of a flap may be employed, including pedicle dissection, and may be performed to optimize efficiency.

Approach

- The pliable nature of buccal mucosa allows for full mandible excursion. Therefore, primary closure of small to moderate-sized defects can lead to soft tissue restriction, ultimately resulting in trismus.
- Superficial mucosa-only defects can be reconstructed with a split-thickness skin graft or palatal graft.
- Alternatively, acellular dermis may be used in this setting and can serve as a scaffolding in which vascular ingrowth can occur with minimal scar contraction.
- Flap reconstruction may be indicated in circumstances where more bulk is desired than can be achieved with skin or dermal grafting alone.
- Many local and locoregional flap options have been described. Workhorse flaps utilized in restoring buccal mucosal lining include
 - Pedicled flap options:
 - Buccal fat transposition flap—for small buccal defects
 - Facial artery myomucosal flap—small to moderate-sized buccal defects that involve the alveoli and/or lips
 - Submental artery island flap—moderate-sized buccal defects
 - Platysmal island flap—moderate-sized buccal defects
 - Pectoralis major flap—moderate- to large-sized buccal defects in patients who are poor candidates for free flap reconstruction or in salvage cases
 - Microvascular free flap options—offer additional tissue bulk and the ability to contour donor tissue to fit a defect without restriction
 - Radial forearm fasciocutaneous flap
 - Thin, pliable soft tissue
 - Consistent blood supply with long vascular pedicle
 - Donor-site morbidity includes tendon exposure, injury to the dorsal radial

sensory nerve branch, and inferior appearance.

- Anterolateral thigh fasciocutaneous flap
 - Can often close donor site primarily
 - Best used in very thin patients or those in whom a radial forearm flap is not an option
 - Can be performed as adipofascial flap if more bulky donor site

TECHNIQUES

■ Autogenous Grafts

- For mucosa-only defects, very small defects may be repaired with primary closure. Small defects may be repaired with palatal mucosal grafts. For moderate-sized defects, a split-thickness skin graft can be employed to resurface the intraoral buccal lining.
- Skin grafts should be fenestrated to prevent accumulation of serous fluid and fixed with resorbable suture (eg, cat gut).³
- A tie-over bolster dressing using petroleum-impregnated gauze and nonresorbable suture (eg, silk) should be used to minimize shear and prevent saliva from entering below the skin graft surface.⁴ The bolster can also be tied extraorally.³
- A bite block may be considered if there is concern about dislodging the bolster dressing.
- Grafts should not be considered in the setting of anticipated radiation.

■ Acellular Dermal Matrix

- Human acellular dermal matrix (ADM) is a biomaterial derived from cadaveric skin that has been processed to remove cells and immunogenic antigens.
- ADM may be used in a similar manner to a skin graft.
- The ADM is sutured into place and a bolster applied similar to a skin graft.
- The bolster should be kept in place for 3 to 7 days.⁵
- Failure presents as a pale graft that easily sloughs from its wound base.

- Mild contraction can occur that is maximal at 3 to 5 weeks.⁵

■ Buccal Fat Pad Flap

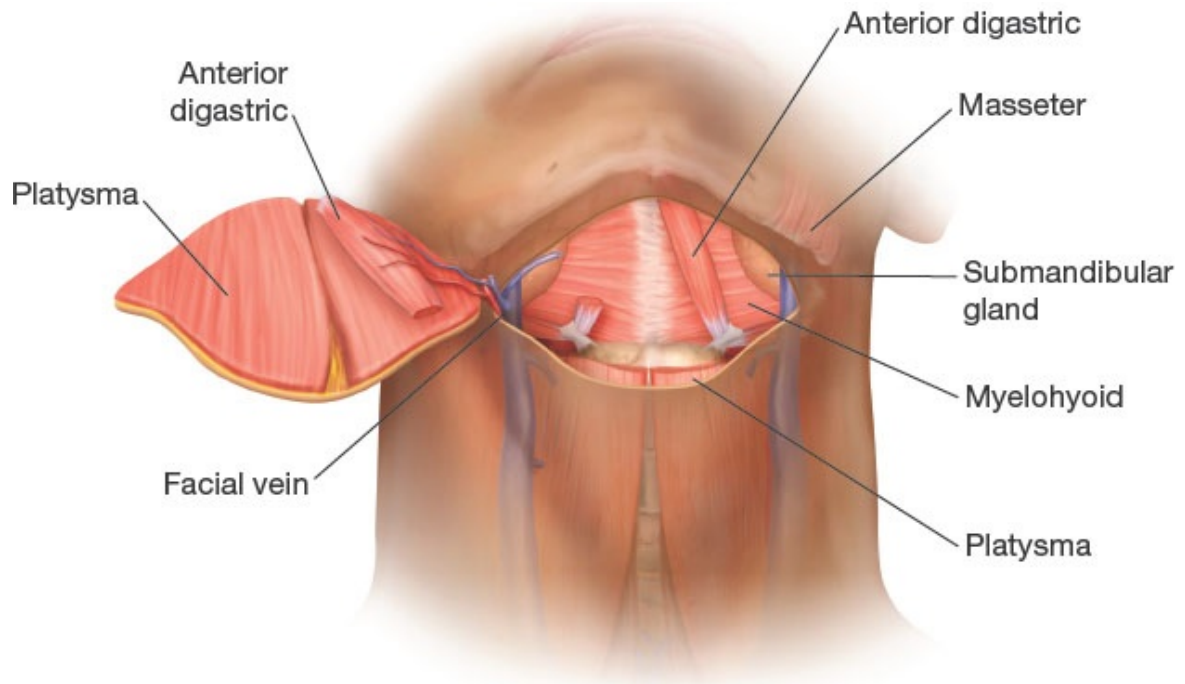
- The body of the buccal fat pad is centrally located over the parotid duct.
- The blood supply includes branches of the facial artery, internal maxillary artery, superficial temporal artery, and maxillary artery.
- The buccal fat pad can be mobilized to resurface a defect.
- Suitable for moderate-sized defects up to 5 cm. Cheek depression can occur in larger defects.⁶
- The flap can be mobilized through a 1-cm horizontal incision in the molar region, 5 mm above the second molar, and halfway between the Stensen duct and the upper gingivobuccal sulcus.
- An incision is then made in the buccinator muscle, and the capsule surrounding the fat pad is entered bluntly so as not to disrupt the buccal branches of the facial artery.
- Gentle extraoral pressure will help deliver the fat pad.
- The fat pad is mobilized and fixated into the adjacent defect with resorbable suture.
- The flap will be resurfaced by via re-epithelialization over 4 to 6 weeks.
- A bite block or splint should be considered for 12 to 14 days to avoid chewing through the pedicle or causing trauma to the flap.^{7,8}

■ Submental Island Flap

- The submental artery island flap is an axial fasciocutaneous flap.
- The vascular pedicle is based off the submental artery and vein and has a length of up to 5 cm. The submental artery takes origin from the facial artery 5 cm anterior the mandibular angle. It runs a tortuous course and supplies the submandibular gland and level 1 (submandibular) lymph nodes. The submental artery runs deep to the digastric muscle in 70% of cases. Therefore, the digastric muscle may be included in the flap.⁹
- The skin paddle of the submental artery extends from one angle of the mandible to the other. A pinch test determines the flap width. The flap comprises the skin, subcutaneous fat, platysma muscle, submental fat, and

lymph nodes.

- A handheld Doppler is used to identify cutaneous perforators just posterior to the mandibular arch and adjacent to the anterior belly of digastric.
- The upper border of the flap is drawn approximately one to two fingerbreadths below the lower border of the mandible to protect the marginal mandibular nerve and to reduce the risk of visible scar.^{8,10}
- The skin markings are incised down to and through the platysma muscle, taking care to preserve the common or anterior facial veins and the marginal mandibular nerve deep to platysma.
- Starting on the contralateral side to the pedicle, a subplatysmal dissection is then performed from lateral to medial.
- Next, the ipsilateral side is elevated. The skin is incised down to and through the platysma muscle similar to the contralateral side. The submental arteries are identified deep to the submandibular gland superiorly and are skeletonized with the subplatysmal skin island. Use of a handheld Doppler at this stage can be useful to identify and protect the pedicle.
- The anterior digastric muscle overlying the pedicle is harvested and included with the flap to protect the blood supply (**TECH FIG 1**).
- A tunnel is then made through the ipsilateral mylohyoid muscle to facilitate transfer into the oral cavity. A strip of mylohyoid muscle may be included with the pedicle to improve ease of transfer.
- The neck is then primarily closed. This can be aided by slight neck flexion.
- Tension on the pedicle may be minimized in the early postoperative period by turning the head toward the pedicle.



TECH FIG 1 • Elevation of the submental island flap.

■ Platysmal Myocutaneous Island Flap

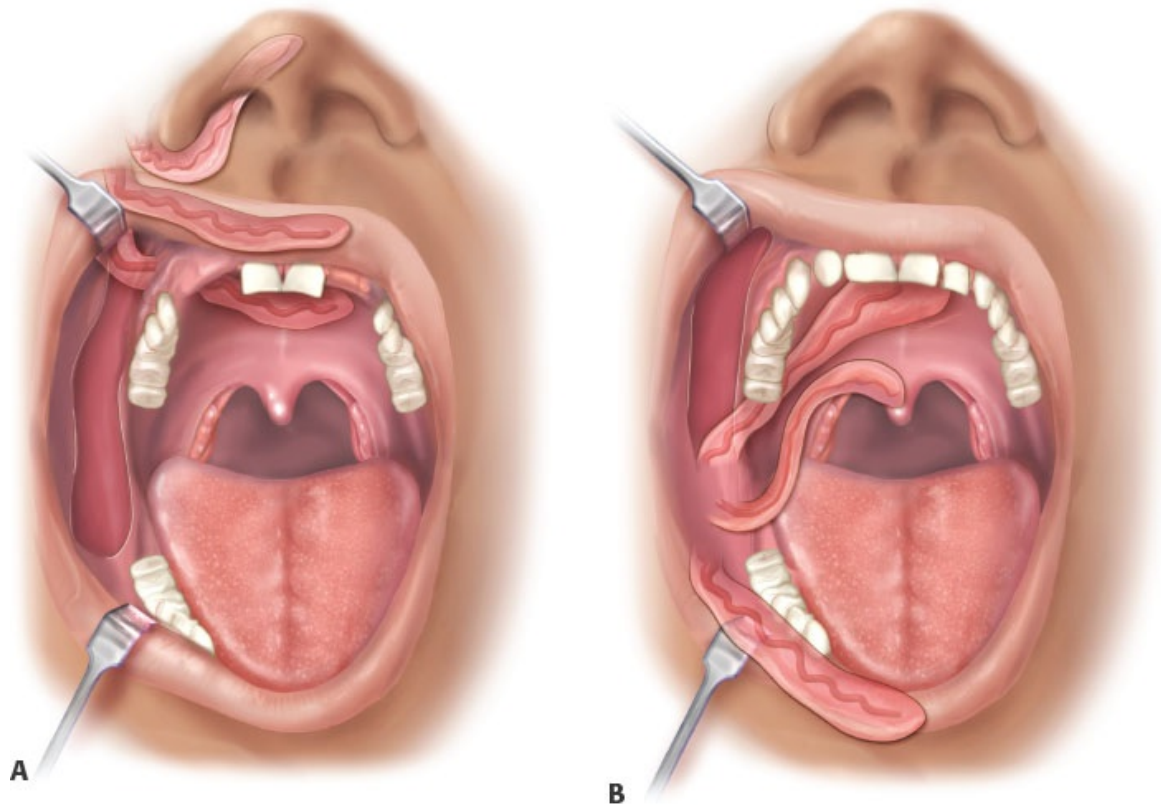
- The platysma is a paired Mathes and Nahai type II muscle that originates from the superficial fascia of pectoralis major and inserts over the angle of the mouth and caudal cheek.
- The dominant pedicle is the submental artery and venae comitantes. The minor blood supply is a branch of the suprasternal artery, which in turn is a branch of the suprascapular artery and vein.
- The skin island in a platysmal flap should be designed in the hairless region of the neck overlying the insertion of the sternocleidomastoid. A pinch test can be performed to estimate the flap width, but it should not exceed more than 5×7 cm.
- Flap dissection should be undertaken prior to tumor extirpation and neck dissection to avoid injury to the pedicle.
- The distal border of the flap is incised to and through the platysma muscle.
- The proximal border of the flap is incised through the skin only, preserving platysma muscle.
- The flap is then elevated from distal to proximal in a subplatysmal plane. Care should be taken to identify the marginal mandibular nerve.

Consideration should also be given to include the anterior belly of digastric muscle.^{8,11}

- The pivot point is about the lower border of the ipsilateral mandible.
- This flap may be at risk for venous congestion from compression over the mandible and can result in flap tip necrosis.

■ FAMM Flap

- The FAMM flap is an axial flap based on the facial artery.
- The course of the artery should be mapped extraorally and intraorally. The facial artery takes origin from the external carotid artery. The location of the facial artery can be identified along the lower border of the mandible, three fingerbreaths from the mandibular angle at the anterior border of the masseter muscle. The artery follows a tortuous course between the buccinator muscles and the muscles of facial expression toward the alar base. It is approximately one-half of an inch lateral to the oral commissure and one-quarter of an inch from the alar base. It continues as the angular artery and travels toward the medial canthus. This can be confirmed using a handheld Doppler.
- The FAMM flap is designed along the course of the facial artery just anterior to the parotid (Stensen) duct and consists of the buccal mucosa, a small amount of buccinator muscle, the facial artery, and a venous plexus (**TECH FIG 2A**). It can be approximately 1.5- to 2-cm wide.
- Both superiorly and inferiorly based flaps can be used depending on the defect location and arc of rotation required.
- To aid in the dissection, stay sutures can be placed above and below the commissure to create a taut buccal mucosa.
- Sharp dissection is used to dissect through the buccinator muscle to identify the artery.
- The artery is ligated distally, and dissection is then carried from distal to proximal to identify the artery near the oral commissure. Attachments of the facial artery to the overlying buccinators can be tenuous and must be kept intact.
- Once the flap is harvested, it is transposed and inset (**TECH FIG 2B**). The donor site may be closed primarily or grafting may be undertaken.¹²



TECH FIG 2 • Elevation (**A**) and transposition (**B**) options for the facial artery myomucosal (FAMM) flap.

■ Pectoralis Major Myocutaneous Flap

- The pectoralis major flap is a useful flap in patients with large buccal defects who have medical comorbidities that preclude free flap reconstruction or in salvage circumstances.¹³
- The pectoralis major is a Mathes and Nahai type V muscle whose dominant pedicle is the thoracoacromial artery and venae comitantes. Minor pedicles arise from the lateral thoracic artery and anterior perforators from the internal mammary artery between the second and fifth ribs. The sternocostal portion originates from the anterior chest wall from the second to sixth ribs.
- The pivot point is just below the clavicle. The surface landmark of the thoracoacromial pedicle the intersection of a line from the acromion process to the xiphoid notch, and a plumb line from the midclavicle. The pedicle can be found within a 2-cm radius of this point.
- Using reverse planning, a vertical or horizontal skin paddle can be designed

centered on the pectoralis major.

- The lateral flap is incised to anterior pectoralis muscle fascia. Skin and soft tissue lateral to the flap are then widely undermined.
- Next, the medial flap is incised to pectoralis muscle fascia, providing complete exposure of the muscle.
- The muscle is then elevated from distal to proximal, ligating the intercostal and lateral thoracic perforators.
- If an ipsilateral deltopectoral flap may be required, preservation of the second and third internal mammary perforators should be considered.
- During the lateral dissection, the pectoralis major is disinserted to facilitate mobilization. Ligation of the lateral pectoral nerve can also be considered for further reach.
- A subcutaneous tunnel overlying the clavicle is then developed to facilitate flap transfer toward the neck.
 - The medial half of the clavicle can also be divided to provide additional length and minimize compression on the venae comitantes.
- This flap is limited by additional bulk and may not be suitable for obese patients.
- A bulge will be observable on the ipsilateral neck where the flap has been turned over.

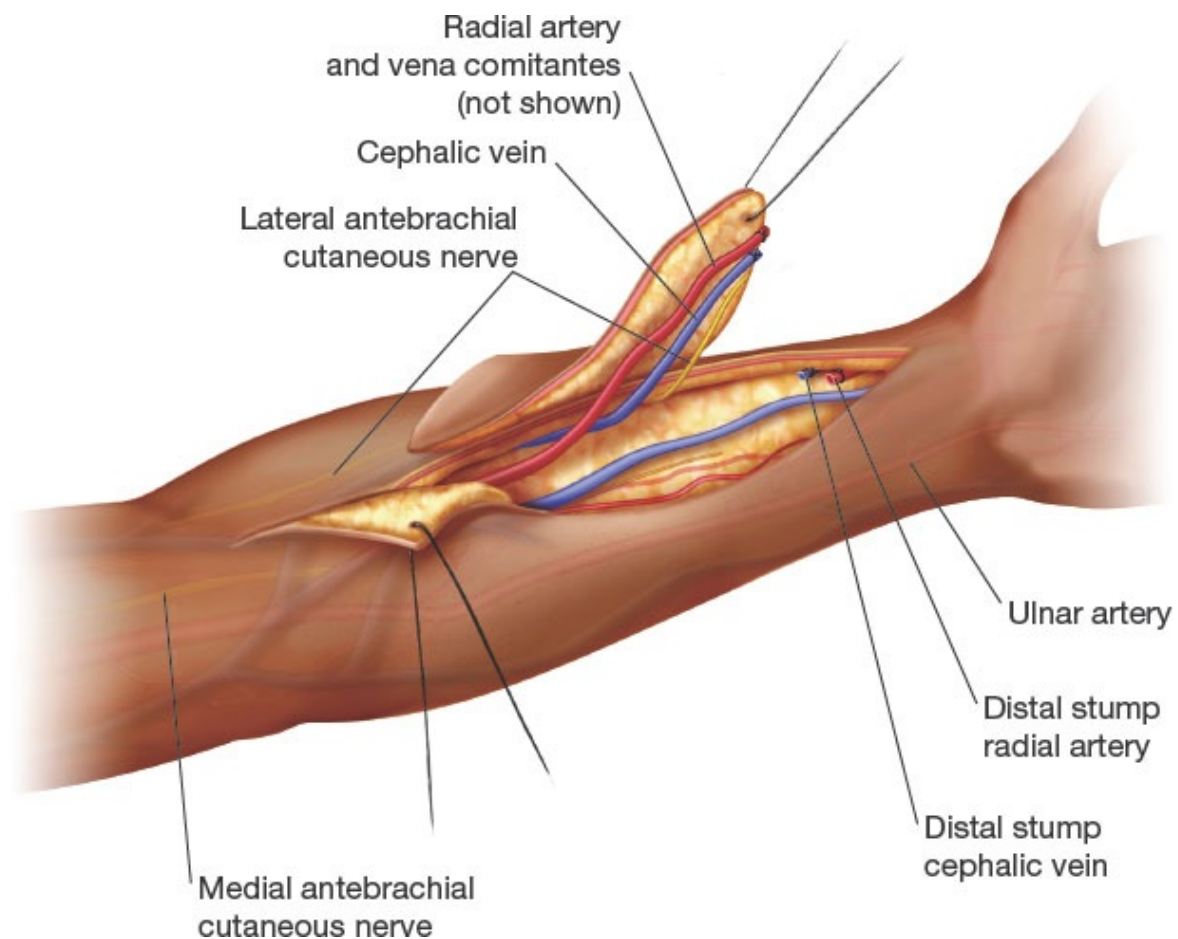
■ Radial Forearm Fasciocutaneous Free Flap

- The flap is harvested from the nondominant forearm (**TECH FIG 3**).
 - The course of the radial artery and superficial veins, including the cephalic vein, is marked.
 - Proximal venous compression can aid in identifying the superficial venous system.
 - The approximate course of the medial and lateral antebrachial cutaneous nerves can also be marked.
- The radial forearm flap is usually centered so that the midpoint of the flap follows a line halfway between the radial artery and the cephalic vein.
- The limb is exsanguinated and tourniquet is inflated.
- The distal flap margin is incised.
- Blunt dissection is used to identify three main structures:
 - Distal branches of the superficial radial nerve

- The radial artery and venae comitantes between the flexor carpi radialis and brachioradialis tendons
- The cephalic vein on the distal radial edge of the flap
- The radial artery, venae comitantes, and cephalic vein are ligated distally.
 - When results of an Allen test are in doubt, an Acland clamp can be placed on the radial artery to definitively assess hand perfusion prior to ligating the radial artery.
- An incision is made on the ulnar flap margin through the skin and fascia.
- Flap elevation proceeds from an ulnar to a radial direction deep to the volar antebrachial fascia, carefully protecting the paratenon overlying the wrist flexor tendons.
- The flexor carpi radialis muscle is identified, as is the lateral intermuscular septum on the lateral aspect of the muscle. Traction of the muscle in an ulnar direction will reveal the radial artery and its venae comitantes.
- An incision is made along the radial margin of the flap through the skin and underlying volar antebrachial fascia, and the flap is elevated from radial to ulnar, again preserving paratenon overlying the wrist flexor tendons, until the brachioradialis tendon is identified. Care must be taken to preserve the superficial sensory branches of the radial nerve.
- As dissection proceeds from the radial margin of the flap, the fascia is lifted off of the brachioradialis. The further proximal the dissection, the more the brachioradialis muscle conceals the artery beneath its volar medial border.
- The proximal flap margin is then incised, avoiding injury to the cephalic and basilic veins, as well as to the medial and lateral antebrachial cutaneous nerves.
- The lateral intermuscular septum and associated radial artery and venae comitantes and perforators are then elevated in a distal to a proximal direction. Deep branches to the volar surface of the distal radius and to adjacent muscle bellies are ligated.
- At the approximate junction of the middle and distal thirds of the arm, the superficial branch of the radial nerve penetrates the deep fascia to course superficial to this fascia. From this point of penetration distally, the deep fascia is incised longitudinally, freeing the nerve.
- A longitudinal incision proximally toward the antecubital fossa allows elevation of the proximal radial artery and any subcutaneous veins all the way to the bifurcation of the brachial artery as is necessary. A Weitlaner or

other retractor is useful to expose the pedicle deep to the brachioradialis and flexor carpi radialis muscle bellies. The proximal length of the cephalic vein can be dissected to be as long as required.

- The tourniquet is deflated, and immediate reperfusion of the flap and of the hand is revealed.
- A split-thickness skin graft is needed to close the donor site. The wrist should be immobilized for 2 weeks to avoid graft shear from the underlying wrist flexors.



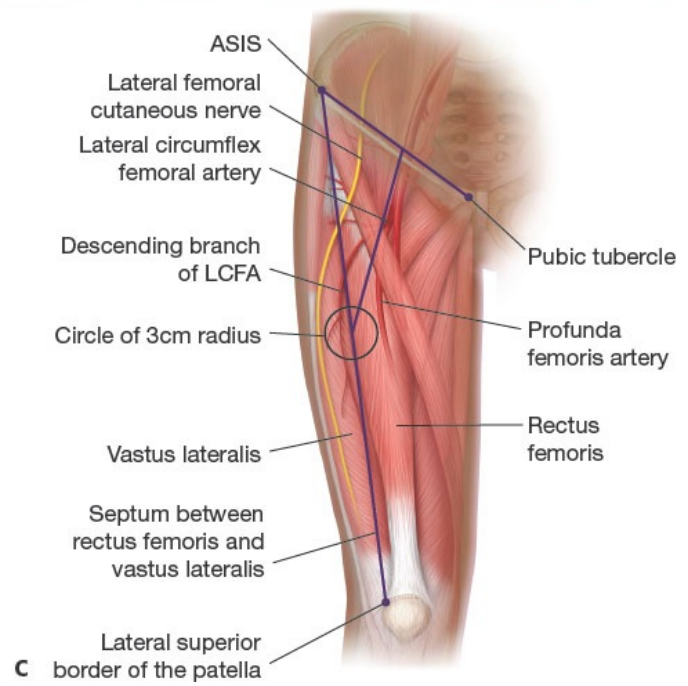
TECH FIG 3 • Anatomic structures encountered during elevation of the radial forearm flap.

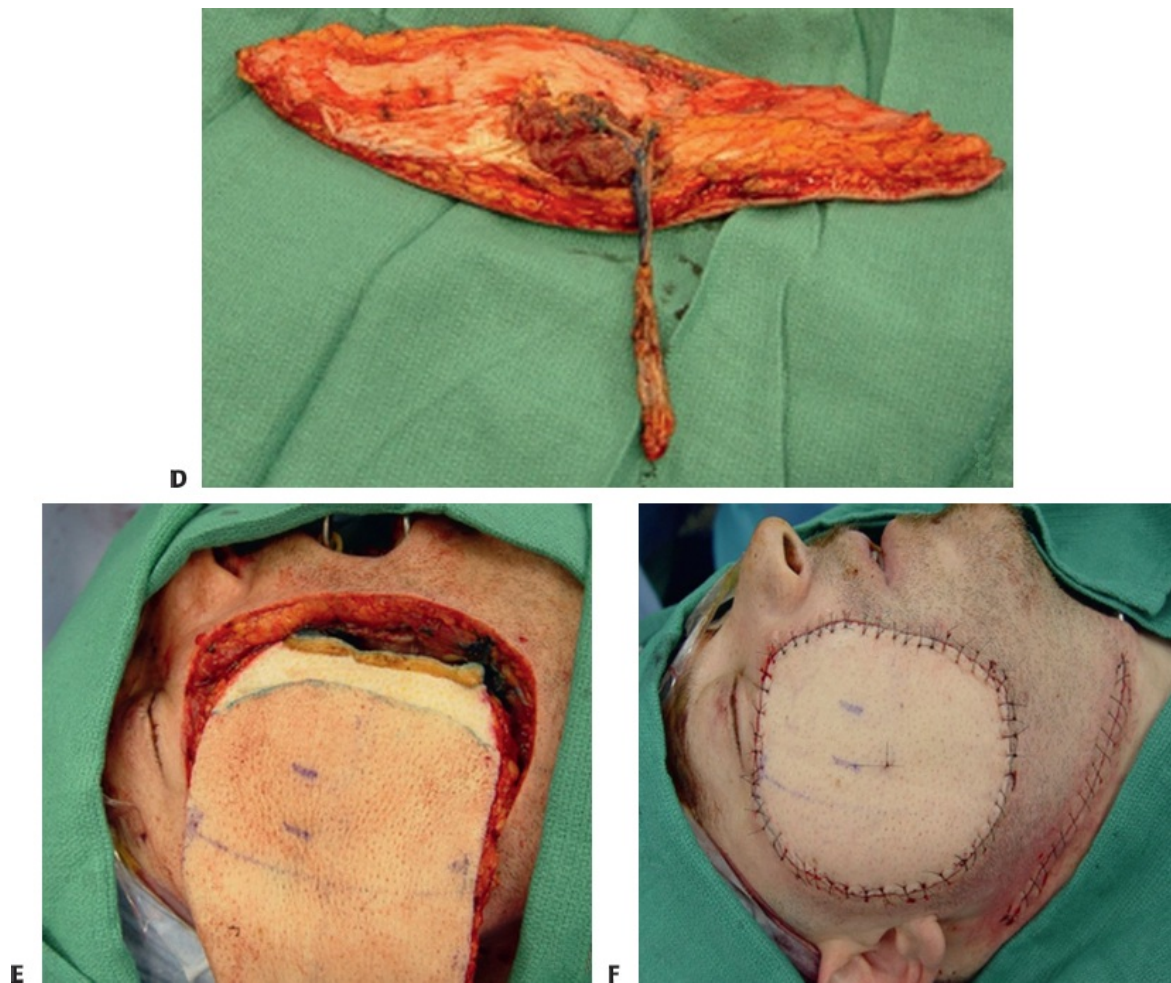
■ Anterolateral Thigh Fasciocutaneous Flap

- The anterolateral thigh flap is useful for moderate- to large-sized buccal defects in circumstances where the radial forearm is not an available donor

site (**TECH FIG 4A,B**).¹⁴

- A line is drawn between the anterior superior iliac spine to the superolateral border of the patella. This line represents the muscular septum between the rectus femoris and the vastus lateralis muscles (**TECH FIG 4C**).
- The cutaneous vessels are mapped by a Doppler probe centered over the midpoint of this line. Most skin perforators are located within a circle of 3-cm radius centered at this midpoint. The flap is centered over the location of these vessels, and its long axis is designed parallel to that of the thigh.
- Additional perforators can often be found 5 cm distal and 5 cm proximal to this point. If perforators cannot be readily identified, a Duplex ultrasound is useful in definitively identifying perforators. If none can be found, the opposite thigh should be considered.
- An incision is made along the distal 10 to 15 cm of the medial aspect of the flap down to and through the deep fascia on to the rectus femoris muscle belly.
- The rectus femoris muscle is identified based on its bipennate muscle fibers and a flat, stout tendon spanning its entire undersurface. A fat plane exists superficial to the lateral intermuscular septum between the rectus femoris and vastus lateralis.
- Once the septum is identified, the remaining medial skin and fascia incision is completed from distal to proximal.
- The rectus femoris muscle is retracted medially to expose the entire septum.
- The septocutaneous vessel can be clearly observed. An appropriate perforator can be selected. A pure septocutaneous course is less common. In most cases, the perforator follows a varied intramuscular course and typically gives off many small branches to the vastus lateralis muscle from the lateral and posterior sides of the vessel.





TECH FIG 4 • Use of an ALT free flap to reconstruct a full-thickness buccal defect from resection of an invasive squamous cell carcinoma. **A.** Planned resection with margin. **B.** Final defect. **C.** Surface landmarks for perforators and perforator anatomy for anterolateral thigh flap based on the lateral circumflex femoral system. **D.** Elevated ALT flap with vascular pedicle marked in ink on one side to identify twisting. **E.** The flap was folded to provide both intraoral lining and external skin. The interposing segment connecting the two surfaces was de-epithelialized. **F.** Final inset showing external skin paddle (internal paddle not shown).

- The superficial (anterior) course of the perforator is then exposed by dividing the overlying muscle, and the perforator is traced back to the main descending branch of the lateral circumflex femoral artery. The perforator can then be freed on its lateral, medial, and deep surfaces to free it completely to its origin.
- Once the perforator is freed, the lateral skin marking is incised down to and through the deep fascia.
 - The flap is elevated from a distal to proximal and lateral to medial direction, with care being taken to preserve the perforator (**TECH FIG 4D**).
- Once the flap is harvested, it is transposed and inset (**TECH FIG 4E,F**).
- Primary closure of the donor site can often be achieved. For larger skin paddles, a split-thickness skin graft may be required.
- In circumstances in which there is extensive subcutaneous tissue in the thigh, an adipofascial flap may be considered. This allows better tailoring to fit the defect thickness. The fascial surface that does not stretch is allowed to remucosalize.¹⁵ Therefore, it must be fitted to size or trismus will result.

■ Cutaneous Paddles of Chimeric Flaps

- Loss of buccal and additional oral cavity mucosa may be part of a composite defect involving bone, floor of mouth, and tongue.
- Chimeric flap designs can offer a skin cover for mucosal lining defects in conjunction with bone for segmental defects or muscle for dead space obliteration if required.
- Buccal resurfacing can be achieved using skin paddles of chimeric flaps.
 - Common examples include fibula osteocutaneous flap, scapula osteocutaneous flap, anterolateral thigh myocutaneous flap, and iliac crest osteocutaneous flap.

PEARLS AND PITFALLS

Complication

Iatrogenic injury to the

Pearls for Management

- When harvesting a submental island flap, the patient should not be paralyzed until after the mandibular branch of the facial nerve

marginal mandibular nerve during submental flap harvest	is identified.
Poor skin graft take	■ A bolster dressing of Xeroform and silk sutures may be applied to protect the skin graft from sheer and saliva. This should be maintained for 7 days.
Wound dehiscence	■ When inseting the flap, care should be taken to ensure a watertight closure. Horizontal mattress sutures can be helpful. However, sutures should not be overtight so as not to cause flap tip necrosis and poor healing. Where watertight closure is not possible, consideration of placing additional muscle to obliterate the dead space between the cheek and neck.
Fistula tract formation	■ Acute fistulas are best managed with regular irrigation and through-and-through intraoral and extraoral packing. Intraoral packing with Vaseline-impregnated gauze or Xeroform helps to form a plug to minimize saliva entry into the neck. Extraoral packing with saline-soaked or dry gauze helps to remove necrotic or infected debris.
Vascular compromise	■ Care should be taken to avoid excess pressure on the neck at the site of a vascular pedicle and/or anastomosis.

POSTOPERATIVE CARE

- A nasogastric tube or similar device should be employed until graft or flap take is established and intraoral wounds are sealed, usually around postoperative day 7.
- Pressure avoidance at the microvascular site is essential to reduce the risk of venous thrombosis, particularly if the external jugular system is used for venous anastomosis. If utilized, tracheostomy ties should not cause any neck compression whatsoever (while equally preventing the tracheostomy from dislodging).
- Securing the tracheostomy with sutures should be considered in circumstances in which this is not possible.
- Position restrictions that prevent a patient from turning toward the side of venous anastomosis can reduce the risk of twisting the venous pedicle and subsequent thrombosis.

- Routine monitoring of microvascular free tissue transfer should include an evaluation of both arterial and venous systems.
- For flaps whose skin paddles are difficult to visualize, a Cook-Swartz Doppler probe or equivalent device should be considered.

OUTCOMES

- The buccal region is important in speech, oral preparatory phase of swallowing, oral competence, and generating suction.¹⁶
- Loss of function results more from tumor extirpation, reconstruction, and radiation than the inciting tumor.
- If the donor tissue chosen appropriately meets the defect requirements, excellent functional outcomes can be achieved.
- Wound dehiscence can lead to fistula and abscess formation. This can delay adjuvant treatments such as radiation or chemotherapy. Therefore, efforts should be undertaken to avoid this complication where possible.

COMPLICATIONS

- Partial or complete graft loss
- Partial or complete flap loss
- Delayed wound healing
- Motor or sensory nerve injury
- Fistula formation
- Abscess formation
- Scar contracture
- Trismus
- Altered speech
- Loss of oral competence

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45 Jejunum Flap for Pharyngeal Reconstruction

CHAPTER

Farooq Shahzad and Babak J. Mehrara

DEFINITION

- The free jejunal flap is a workhorse for reconstruction of the hypopharynx and cervical esophagus.
- A flap of up to 20 cm can be harvested on a single jejunal vessel and its vascular arcade. This length limits the use of this flap for reconstruction of subtotal or total esophageal defects.
- For subtotal or total esophageal reconstruction, pedicled colon or gastric pull-up procedures are more appropriate in most cases.
 - However, both of these options have limited reach cephalad and may not extend all the way to the pharynx. In this situation, they can be combined with a free jejunal flap for the pharyngeal and cervical esophageal part of the reconstruction.
- Alternatively, total esophageal reconstruction can also be performed with a pedicled jejunal flap (pedicled in the abdominal donor site) with supercharging the distal flap arcade in the neck or chest.¹

ANATOMY

- The jejunum is the second part of the small intestine. It starts from the ligament of Treitz and extends to the ileum.
 - The lumen of the jejunum contains circular mucosal folds called plicae circulares.
 - These folds slow down the passage of food and increase the surface area for absorption.
 - They decrease in size and number distally along the small bowel.
- The blood supply of the small bowel is via the superior mesenteric artery. It

gives rise to multiple jejunal and ileal branches (**FIG 1**).

- These branches divide and form vascular loops called arcades.
- These arcades further divide to form secondary and tertiary arcades.
- The terminal vessels that supply the small bowel area are called the vasa recta.
- The veins accompany the arteries.
- A jejunal flap can be based on any jejunal artery and its accompanying vascular arcade. Free jejunal flaps are typically based on the ileal vascular arcade as defined by the recipient site needs (see below).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history and physical exam should identify those patients who are not eligible for the operation.
- Contraindications include chronic intestinal disease (eg, Crohn disease), ascites, and grave medical condition precluding a long operation.

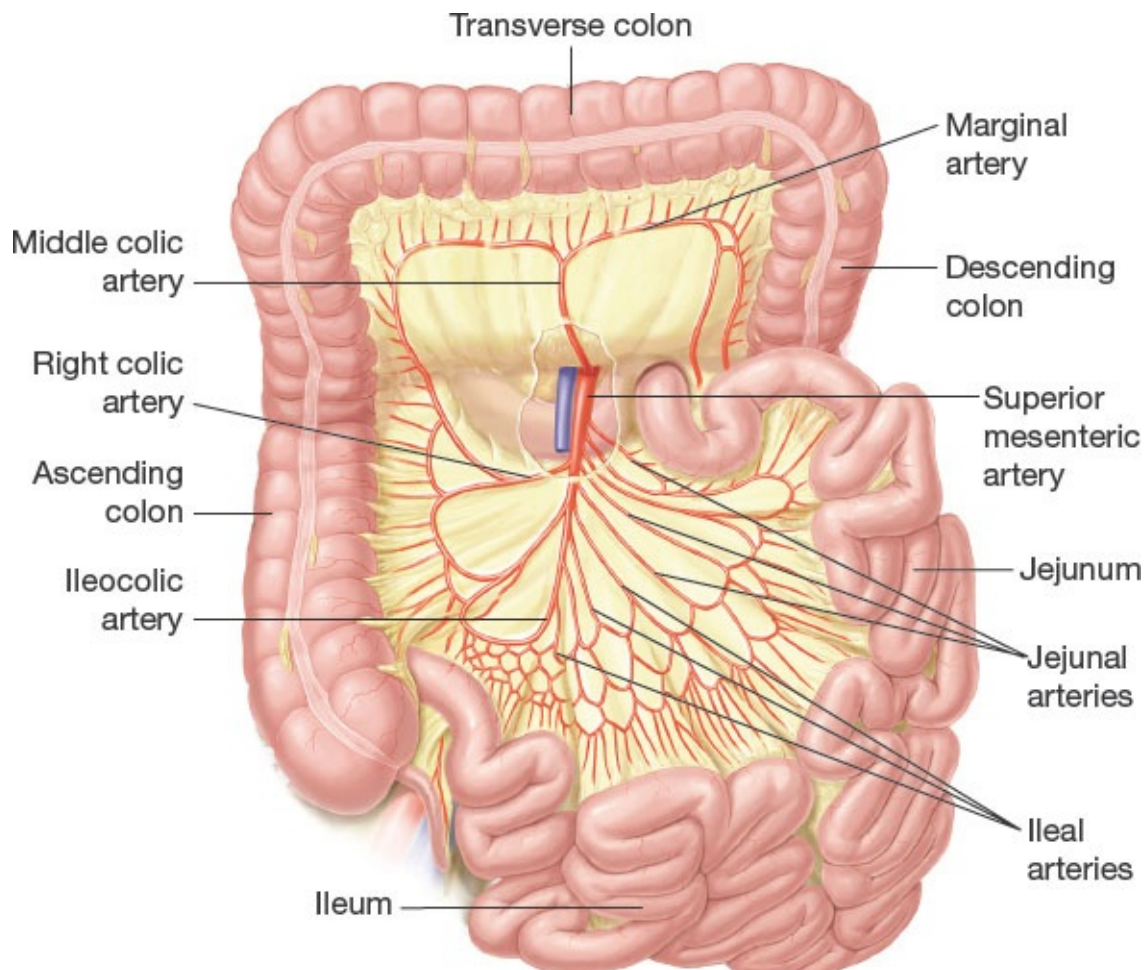


FIG 1 • Anatomy of the jejunum and intestines.

- Relative contraindications include multiple previous abdominal surgeries and limited pulmonary reserve.
- Other donor sites are assessed for potential backup options, including the pectoralis flap, internal mammary artery perforator (IMAP) flap, deltopectoral flap, supraclavicular flap, radial or ulnar forearm flaps, and anterolateral thigh (ALT) flap.
- Patients with thrombotic tendencies should be identified. This includes a history of deep vein thrombosis (DVT) or miscarriages or family history of thromboembolism.
- A hypercoagulability workup and hematology consult can be obtained if necessary.

IMAGING

- In general, no specific imaging is needed.
- A mesenteric angiogram can be performed to evaluate the patency of the vascular pedicle in patients suspected of having atherosclerotic occlusive disease. However, this is rarely done as the superior mesenteric artery is typically spared from atherosclerosis.

SURGICAL MANAGEMENT

- Jejunal free flap is most commonly used for circumferential defects of the cervical esophagus.
- It can also be used to patch smaller defects or repair incomplete defects, but in these situations, we prefer the radial forearm or ALT flaps.
- The ALT free flap is also a good option for circumferential pharyngoesophageal defects.
- The donor site for this flap usually requires a split-thickness skin graft, however, and is, in our opinion, more morbid than a jejunum flap. In addition, tubing an ALT flap results in an extra suture line (in addition to the proximal and distal pharyngeal anastomosis) requiring more surgical time and potentially increasing the risk of leak.
- As a result, we use this flap as a second-line option when the jejunum cannot be used. However, this idea is heavily debated.
- In patients who are not free flap candidates (medical condition necessitating a short operation or no available recipient neck vessels), regional pedicled flaps

like the pectoralis major myocutaneous flap or supraclavicular flap are more commonly used.

Preoperative Planning

- The plan for resection and neck dissection should be discussed with the ablative head and neck surgeon. This allows for a better understanding of the anticipated surgical defect so that a reconstructive plan can be developed. Furthermore, an informed discussion can be held with the patient, and appropriate consent can be obtained.
- It is also important to discuss the need for preservation of recipient vessels with the ablative surgeon.
- Preoperative bowel preparation can be performed. Often, a simplified bowel prep with clear liquid diet for 24 hours and a bottle of magnesium citrate the day before surgery is all that is necessary.

Positioning

- The patient is placed in the supine position for the duration of the case.
- Perioperative antibiotic prophylaxis is performed. We use cefazolin and metronidazole for head and neck cases.
- Sequential compression devices are used for DVT prophylaxis. Underbody warming device is used to prevent hypothermia during the case.
- The face and neck are prepped with an iodine-based solution.
 - The chest and abdomen are prepped with a chlorhexidine-based or iodine-based solution.
 - The entire field is draped as one for convenience.
 - The chest can be covered with a drape or towel to prevent heat loss.

Approach

- The jejunal flap can be harvested via an open or a laparoscopic approach.
- Open harvest of the jejunal flap is our preferred method. It is performed via a midline epigastric incision. Generally, we make an 8-cm incision above the umbilicus.
 - This technique is technically easier and expeditious and allows direct visualization of the flap and pedicle.
 - Moreover, the pedicle can be separated in situ prior to flap harvest, which is easier to perform than after pedicle division and cuts down on ischemia time.
- Laparoscopic-assisted harvest of the jejunal flap is performed via multiple

small laparoscopic incisions.² It requires expertise in minimally invasive techniques.

- This usually means that the assistance of a general surgeon is required for flap harvest.
- The advantage is decreased abdominal wall morbidity.
- The jejunum tolerates ischemia for approximately 2 to 2.5 hours. Thus, meticulous planning and expeditious execution are critical for a successful outcome.
- Hypothermia increases the ischemic tolerance of jejunal flaps, and some experts have described improved ischemic tolerance with cooling the flaps to 5°C,³ 6°C to 12°C,⁴ and 10°C.⁵ This is generally not necessary, as ischemia times are kept less than 2 hours if the recipient vessels are prepared and the team is ready to perform microsurgical anastomosis when the flap is harvested. In fact, some suggest that 2 hours of eutermic ischemia time is beneficial for postoperative outcomes as this approach may decrease mucous production.⁶

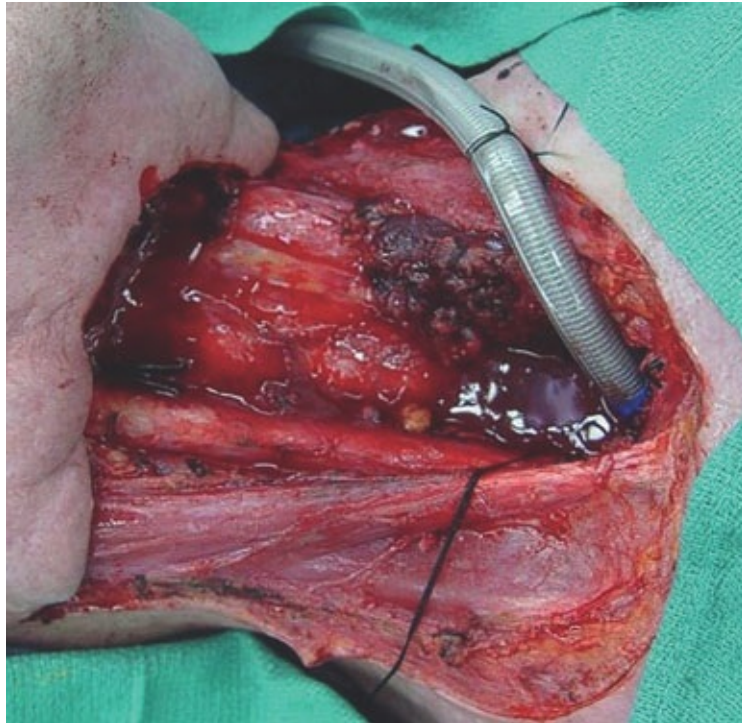
TECHNIQUES

■ Free Jejunum Reconstruction After Laryngopharyngectomy

Preparation of Recipient Area

- The extirpative defect is analyzed.
 - The length of the hypopharyngeal/esophageal defect is measured, and a determination is made whether it is amenable to reconstruction with free jejunal flap (**TECH FIG 1**).
 - If not, an alternate method of reconstruction is chosen.
- Recipient vessels in the neck are dissected and prepared.
 - The recipient artery and vein should be located close to each other because the donor vessels in a jejunal flap cannot be very widely separated.
 - The recipient artery is usually the superior thyroid, facial, or lingual artery.
 - The recipient vein is usually a branch of the internal jugular vein, the main trunk of the internal jugular vein (end to side), or the external jugular vein.

- However, any suitable artery or vein situated close together may be used.
- It is important to dissect the recipient vessels first (ie, prior to flap dissection) because the location of the vessels in relation to the defect determines flap design (see below).
- If there is pedicle bleeding or other problems during flap harvest, the flap can be immediately harvested, inset, and revascularized without additional increases in ischemia time.



TECH FIG 1 • Defect after laryngopharyngectomy.
Note wide skin excision and resection of the pharynx.

■ Jejunal Flap Harvest

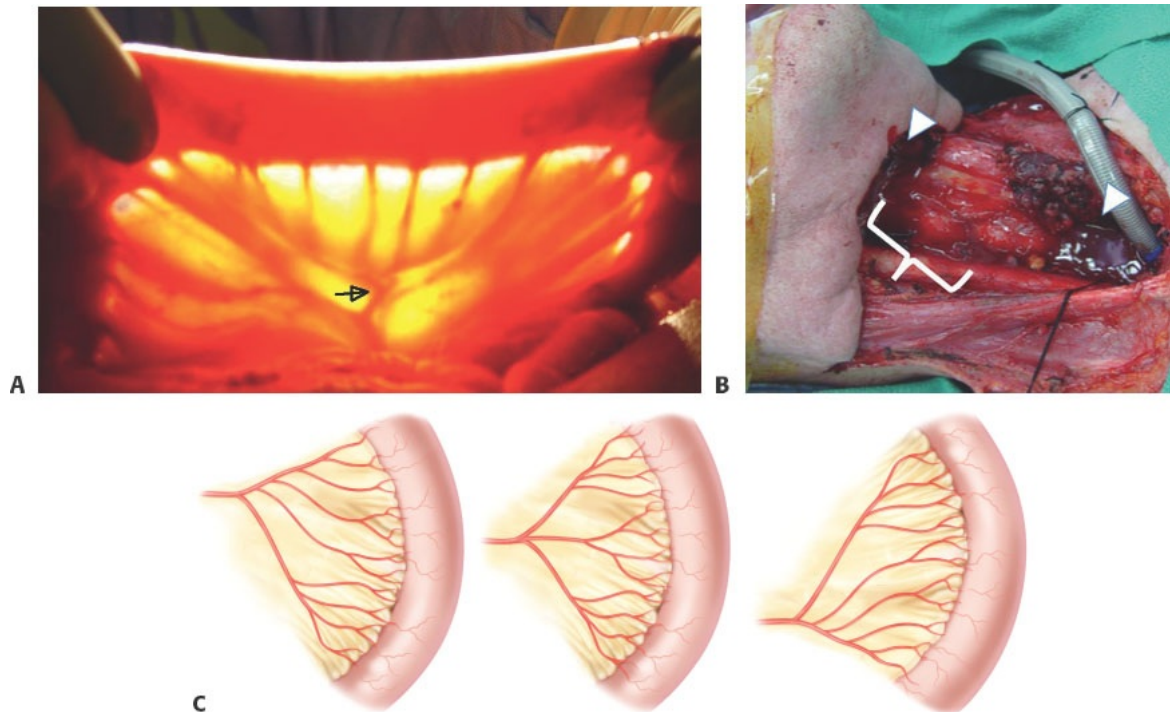
- A midline abdominal incision is made, from the xiphoid to above the umbilicus. The deep fascia and peritoneum are opened up to get access to the celiac cavity.
- The greater omentum and transverse colon are retracted cephalad.
 - The small bowel is run back till the ligament of Treitz is identified. From here, the small bowel is run for approximately 30 to 40 cm distally.
 - In this location, a suitable segment of jejunum is chosen for the flap. This

is because the vascular arcades are longest in this area, thus allowing longer pedicle length. Bowel reanastomosis is also easy here. Moreover, in the unfortunate event of flap pedicle thrombosis, another segment of bowel can be harvested more distally.

- The bowel is transilluminated to identify a suitable vascular arcade to base the flap on (**TECH FIG 2A**).
- Dimming the operating room lights and then shining the overhead lights or the headlight along an angle is used to illuminate the flap pedicle against a dark background.
- In choosing an optimal segment of bowel, important considerations are the length of bowel needed and the position of the recipient vessels in the neck in relation to the proximal jejunal anastomosis with the pharynx (**TECH FIG 2B,C**).
- The distance along a diagonal line from the proximal cervical defect to the position of the recipient vessels in the neck is measured and is used to design the flap with a vascular pattern that will minimize kinking, stretching, or compression of the anastomosis.
- The bowel and the accompanying fan-shaped piece of mesentery to be harvested are marked with a marker or methylene blue.
- The proximal bowel end is marked with a stitch to maintain orientation.
- The mesentery is ligated as a fan shape with the apex toward the pedicle.
- Dissection is begun by opening the mesentery adjacent to the bowel ends.
- A Penrose drain is placed through this opening on each side around the bowel for retraction.
- The mesentery is then ligated sequentially between two hemostats, tying off the small mesenteric vessels with 4-0 silk ties (alternatively, a LigaSure may be used to rapidly dissect and isolate the flap).
- Small mesenteric bites should be taken, as large bites result in bunching of the mesentery and thus effective shortening of the pedicle.
- Pedicle dissection is left to the end; this is done so that if there is troublesome pedicle bleeding, the vessels can be ligated and the flap can be transferred to the neck expeditiously.
- The proximal and distal ends of the jejunal flap are divided with an intestinal stapling device. We use a GIA 90 or 100 Ethicon Proximate Linear Cutter.
- The pedicle dissection is completed by incising the peritoneum over the vessels and carefully dissecting the vessels for a distance of approximately 1

to 2 cm.

- The vessels are then separated over a distance of approximately 1 cm to facilitate microsurgical anastomosis.
- Great care is taken during handling of the pedicle vein as it is very delicate and an injury can result in a mesenteric hematoma.
- The pedicle is then ligated with silk ties and the flap is transferred to the neck.



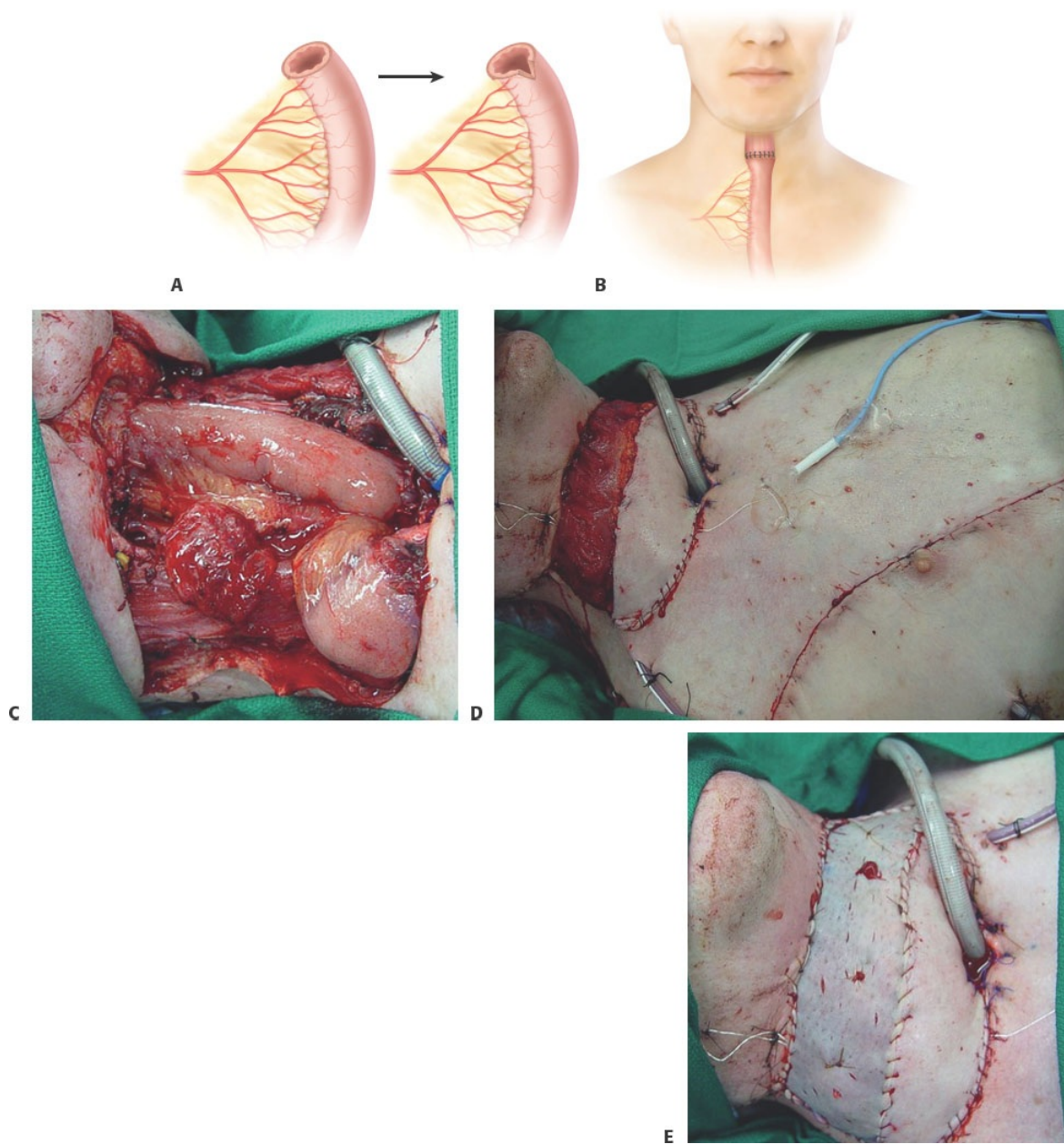
TECH FIG 2 • A. Transillumination of the jejunum flap is used to evaluate the vascular anatomy. Note length and position of the flap artery (*arrow*). **B.** The length of the bowel segment and the relationship of the pedicle length are determined. The length of the bowel segment is shown between the *arrowheads*. The position of the pedicle (and its length) is measured from the cervical margin of resection to the area where the vessels are located (bracketed area). **C.** Flap length and pedicle position are marked in the abdomen, and the pedicle vessels that most closely

match the location of the vessels are selected. For example, if the recipient vessels are located roughly midway along the length of the jejunum, the same position (ie, middle marking) is selected for flap design.

■ Flap Inset

- The flap is inset in an isoperistaltic manner.
- The proximal bowel anastomosis is performed to the pharynx or proximal esophageal remnant.
- There is usually a size mismatch between the larger pharyngeal segment and smaller jejunal lumen.
 - The jejunum can be widened by opening it at the proximal end longitudinally along the antimesenteric border as needed (**TECH FIG 3A,B**).
 - Another method is to fold the end of the jejunum and suture to itself, thus doubling the size of the lumen.
 - Alternatively, the proximal end of the flap can be stapled closed, and the anastomosis to the pharynx can be performed in an end-to-side manner.
 - Anastomosis is performed with interrupted 2-0 Vicryl sutures in an airtight manner.
- The anterior anastomosis is then reinforced with interrupted 4-0 PDS sutures from the pharyngeal muscles to the serosa of the jejunum.
- We usually perform the microvascular anastomosis after completion of the proximal bowel anastomosis to the pharynx. This is done under the microscope or loupe magnification.
 - Upon completion of revascularization, flap perfusion is assessed by color and bowel peristalsis, and the distal anastomosis is completed.
 - This operative sequence decreases the ischemic time and, more importantly, enables the surgeon to judge the precise length of jejunum necessary to span the defect as the bowel elongates following restoration of perfusion.
- The distal pharyngeal anastomosis is performed by placing the patient's neck in neutral or slightly flexed position to avoid redundancy.

- Full-thickness bites of the jejunum are sewn to the distal pharynx using interrupted 2-0 Vicryl sutures.
- A second layer can be done by oversewing the serosa on both sides with 4.0 PDS, thus reinforcing the repair and more precisely adjusting the tension on the jejunal segment.
- There is evidence to suggest that use of stapling devices is associated with a higher incidence of stricture formation.⁷
- In patients who are high risk for leak (eg, radiation and very proximal resection), a salivary bypass tube (we use Hood Salivary tubes) can be passed intraorally to span the proximal and distal anastomosis.
 - These tubes come in a variety of sizes and are usually sutured to the distal tongue (although the flange at the proximal portion usually maintains the tube in normal position).
 - This is tolerated only in patients who have undergone laryngectomy because the irritation from the tube in a patient with an intact larynx would be troublesome.
- A nasoenteric feeding tube is placed under direct vision to prevent disruption of the anastomosis. The feeding tube is guided through the flap and into the stomach.
 - If the abdomen is still open, the placement of the tube in the stomach can be verified by palpation.
- Flap monitoring is performed with an implantable Doppler device. A segment of bowel can also be exteriorized and used for direct flap monitoring. However, we have not found this technique useful. It has been argued that these flaps tolerate ischemia so poorly that salvage is unlikely in the event of flap vessel thrombosis.
- Drains are placed in the neck. They should not be close to blood vessels.
- Closure is performed, taking great care to prevent tight closure that could potentially compress the pedicle (**TECH FIG 3D,E**).



TECH FIG 3 • Jejunal flap inset. **A.** The proximal width of the jejunum can be increased by cutting the flap along the antimesenteric border for 2 to 3 cm. This widens the proximal lumen and can be used to match the size mismatch between the luminal diameter of the jejunum and the proximal pharynx. **B.** An alternative method to increase the width of the jejunum is to double the flap upon itself and anastomose the

jejunum in an end-to-side fashion. **C.** Jejunum flap inset into the defect with anastomosis to the right neck vessels. **D.** Pectoralis major myocutaneous flap is used to cover the flap and neck. **E.** Split-thickness skin graft is used for the skin defect in the upper neck.

■ Donor-Site Closure

- If two teams are available, the second team can perform this part of the procedure, while the other team is performing flap inset. This cuts down on patient time under anesthesia, in an already lengthy operation.
 - Otherwise, a moist lap is placed in the abdomen and this part is done in the end.
- The small bowel is reanastomosed. This can be performed in a handsewn manner with sutures or with an intestinal stapling device.
 - The mesentery is reapproximated with a running suture to prevent internal bowel herniation.
- The fascia and skin are closed.

PEARLS AND PITFALLS

Planning

- This operation requires meticulous planning and expeditious execution, as the ischemia time is only 2–2.5 hours.
- A backup plan for a free or pedicled flap should be in place.

Recipient site preparation

- It is critical to communicate with the ablative surgeon to preserve recipient vessels in the neck.
- The recipient vessels should be prepared prior to flap harvest.

Flap inset

- The flap should be inset in isoperistaltic orientation, and flap redundancy should be minimized. Otherwise, the patient will have long-term dysphagia.
- The proximal pharyngoesophageal anastomosis should be performed meticulously to avoid fistulas.
- The distal esophageal anastomosis is performed with interrupted sutures with the neck in a neutral or slightly flexed position to avoid redundancy.

	■ Stapling devices can be used for the distal anastomosis but may increase the risk of strictures.
Donor-site closure	■ A two-team approach allows flap inset and donor-site closure simultaneously, thus cutting down time under anesthesia.
Postoperative care	■ The head should be kept neutral to minimize stress on the esophageal anastomosis and kinking/stretching of the vascular anastomosis. ■ Circumferential tracheostomy ties are strictly avoided as they can compress the pedicle.

POSTOPERATIVE CARE

- Postoperative monitoring is performed in specialized units with nursing staff experienced in managing free flap patients.
 - We perform flap monitoring with implantable Doppler usually placed on the artery. Although this approach does not identify venous thrombosis, it is our belief that even if a venous thrombosis was identified early, the potential for salvage is very low.
- Patients are kept hydrated with monitoring of urine output and vital signs. Vasopressors are avoided if possible.
- The neck is positioned neutral, and pressure on the flap or area of anastomosis is avoided.
 - We generally avoid using pillows for neck positioning because this may result in vascular compression. Instead, a donut or small pillow may be used for patient comfort.
 - Circumferential tape or ties (eg, tracheostomy ties) are avoided.
- DVT prophylaxis is performed with subcutaneous enoxaparin. Aspirin may also be administered for 5 days in patients with atherosclerotic disease.
- Tube feeds are started on postoperative day 1 and then advanced as tolerated.
- A radiographic swallow study is performed on postoperative day 6 to 8 in nonirradiated patients and postoperative day 8 to 12 in patients with a history of radiation therapy (**FIG 2**).
 - If the study shows no leak, the feeding tube is removed and a clear liquid diet is started. This is then advanced as tolerated.
 - If the swallow study shows a leak, patients are made NPO for 6 to 8 weeks. A gastric feeding tube is placed by interventional radiology, and enteric feeds are initiated. The swallow study is repeated after 6 to 8 weeks.

- Leaks that cause neck infection (redness, drainage from the incision, etc.) require wide incision and drainage of the wound and may require additional intervention. However, in most cases, small leaks seal spontaneously with local wound care.



FIG 2 • Postoperative esophagogram after free jejunum reconstruction (denoted by bracketed section). Note the flow of contrast proximally and distally without evidence of leak.

OUTCOMES

- Swallowing is the primary end point to judge the success of pharyngoesophageal reconstruction. Most patients have some degree of dysphagia after reconstruction, but this improves over time with decreased mucus production.
- The most important determinant of dysphagia, however, may be the amount of tongue that is resected or defunctionalized.

- A recent review of our patients over the past 20 years showed that 86.5% of patients were discharged from the hospital on an oral diet.⁸
- Speech rehabilitation after a total laryngectomy is usually obtained with a tracheoesophageal puncture (TEP). This consists of the creation of a fistula between the neopharynx and tracheostoma and placement of a one-way valve. To speak, the patient occludes the tracheostoma and forces air through the valve from the trachea to the neopharynx. Vibration of the tubular pharyngeal walls produces sound, which is then articulated in the mouth to produce speech.
- Another method of speech rehabilitation is with the creation of a voice tube at the time of pharyngoesophageal reconstruction. The description of this technique is beyond the scope of this chapter, but essentially, it consists of creating two loops of the jejunum, one for reconstruction of the pharyngoesophagus and the other for creation of a tube that passes air from the trachea to the pharyngoesophagus.

COMPLICATIONS

- The overall flap success rate is 91% to 100%.^{9,10}
- Pedicle thrombosis occurs most commonly in the first few days postoperatively.
 - However, late thrombosis also occurs in patients who have a leak or infection. Unfortunately, flap salvage in these circumstances is rarely possible because this flap has poor ischemic tolerance. Most patients require a second flap.
- Fistulas occur more commonly at the proximal pharyngoesophageal anastomosis. The reported fistula rate is 5% to 18%.^{7,9-12} They are more common in patients who have previously been treated with radiation therapy.
 - Most fistulas close spontaneously with local wound care.
 - The rest require surgical closure and sometimes secondary flaps to bring in well-vascularized tissue for coverage.
- Strictures occur more commonly at the distal esophageal anastomosis. The reported stricture rate is 7.5% to 14%.^{7,9,11}
 - Strictures occur because of fibrosis of the distal anastomosis, flap redundancy resulting in kinking, or circumferential scarring in the distal pharynx. They are diagnosed with endoscopy or radiography.
 - Endoscopic dilation is the first-line treatment. Refractory cases are managed

surgically, with reanastomosis or excision of redundant segment.

- Abdominal donor-site complications include ileus, bowel obstruction, cellulitis, and wound dehiscence.
- A recent review of our patients over the past 20 years revealed an overall abdominal complication rate of 4.5%.⁸

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Anterolateral Thigh Flap for Pharyngoesophageal Reconstruction

46

CHAPTER

Edward I. Chang and Matthew M. Hanasono

DEFINITION

- Pharyngeal defects can commonly result after resection of laryngeal malignancy or, less commonly, a pharyngeal or esophageal primary tumor.^{1,2}
- Pharyngeal defects, either partial or circumferential, can be reconstructed with anterolateral thigh (ALT) free flaps to restore swallowing and potential for voice rehabilitation (**FIG 1**).^{1–5}
- Given the high incidence of preoperative radiation in this patient population, reconstruction of the pharyngeal defect using a free flap should also facilitate simultaneous neck wound reconstruction if necessary.
- Complications following pharyngeal reconstruction must be considered and include flap loss, infection, fistula, stricture, and neck wound dehiscence.

ANATOMY

- The arterial supply to the ALT flap is derived from branches of the lateral descending circumflex femoral artery arising from the profunda femoris artery.
 - The lateral descending circumflex vessels are located between the rectus femoris and vastus lateralis muscles and have a variable intramuscular course.
 - Venous drainage of the flap occurs via paired venae comitantes that terminate in the profunda femoris vein.^{6–8}
- The ALT flap can be harvested as a perforator-based fasciocutaneous flap, a myocutaneous flap including some or all of the vastus lateralis muscle, or as a chimeric flap by including portions of the vastus lateralis muscle supplied by a separate branch of the main pedicle.
- One or more perforators are usually found along an imaginary line connecting

the anterior superior iliac spine (ASIS) to the lateral patella.

- The perforators are typically located at the midpoint of this line and 5 cm proximally and distally, the so-called A, B, and C perforators named in a proximal to distal orientation.⁹
- The perforators typically arise from the main pedicle and can pass through the vastus lateralis muscle (musculocutaneous) or pass through the septum between the vastus lateralis and rectus femoris (septocutaneous).
- Occasionally, the perforators may originate from either the transverse branch or an oblique branch of the lateral circumflex artery.
- If multiple perforators are present, the flap can be divided into separate skin paddles to reconstruct the primary pharyngeal defect and to resurface the neck.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The quality of the neck skin and soft tissues should be carefully examined to determine the need for external coverage following tumor resection and reconstruction.
- This is particularly important in patients with a prior history of surgery and/or radiation.
- Neck dissection and severe radiation fibrosis may limit the availability of recipient blood vessels.
- In addition, many patients with head and neck cancer and those with a history of prior neck radiation have carotid vascular disease further challenging reconstruction in this setting. In these cases, preoperative imaging may be useful in select cases, and reconstructive surgeons should be prepared to use alternate recipient vessels with or without vein grafting. Patients should be counseled of this possibility as well as the potential for additional surgical incisions for recipient vessel exposure.
- The donor site should be examined also for prior surgical scars as well as the thickness of the soft tissue.
- Patients with excessive adipose tissue thickness in the thighs may not be good candidates for an ALT flap. In obese patients with thick thigh tissue, reconstruction of a circumferential defect is best performed with a jejunum flap or a thinner flap that can be tubed more easily.
- Harvesting the flap and sacrificing the lateral descending circumflex femoral artery have not been found to exacerbate peripheral vascular disease or precipitate limb ischemia; however, signs of vascular insufficiency should alert

the surgeon to potentially calcified vessels that may make the microvascular anastomosis more challenging.

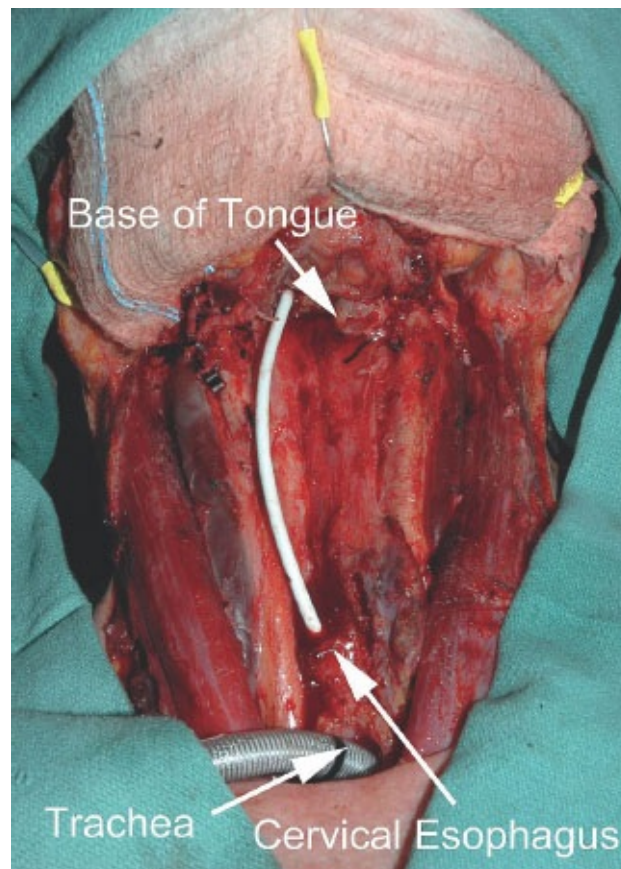


FIG 1 • Circumferential defect after laryngopharyngectomy, extending from the base of tongue to the cervical esophagus.

IMAGING

- Head and neck computed tomography (CT) with intravascular contrast is critical for evaluating the extent of the disease and planning the resection.
- The preoperative imaging can often decipher whether partial pharyngectomy will be performed or whether a segment involving the entire circumference of the pharynx will be resected.
- CT angiography can also guide recipient vessel selection. In the previously operated and/or irradiated neck, identification of alternate recipient vessels such as the transverse cervical vessels may be necessary.^{3,10}

- In certain circumstances, even more distant recipient vessels, such as the internal mammary vessels, are needed.
- No specific imaging studies are needed for the donor site. Although a CT angiogram can be performed in anticipation that a second skin paddle is needed, we do not routinely obtain them.

SURGICAL MANAGEMENT

Preoperative Planning

- Optimizing the patient to undergo a lengthy operation is critical and includes adequate nutrition via tube feeding, if necessary because many patients may have had difficulty swallowing and subsequent weight loss.
- Smoking cessation should be encouraged although, realistically, this is challenging to achieve in a short period of time.
- Preoperative consultation and medical clearance are also important in at-risk patients.
- Many patients with head and neck malignancies have a history of smoking and alcohol use and are therefore at risk for cardiovascular or hepatic complications.
- Preoperative imaging and optimization of cardiac function are important to prevent postoperative medical complications.

Positioning

- The patient is prepped in the supine position with the neck extended to facilitate neck dissection and recipient vessel exposure.
- The bed is typically turned 180 degrees with the foot of the bed facing the anesthetist, allowing the surgical teams complete access to the head and neck region.
- Both thighs should be prepped into the field to access harvesting the flap from either thigh.
- This is because in a small percentage of cases, there is a paucity of skin perforators in one thigh, in which case the other thigh can be used instead.
- The entire head and neck as well as the chest to the level of the xiphoid should also be prepped into the field, in case a pectoralis major myocutaneous flap is needed for neck wound coverage.

Approach

- The approach to reconstructing a pharyngeal defect should also take into account alternate flaps to reconstruct the defect.
- In general, free tissue transfer results in the most optimal outcomes, and other flaps such as the radial or ulnar forearm flap are also useful for partial pharyngectomy defects when the thigh flap is not available or in obese patients with thick thigh tissues.
- The lateral arm flap as well as other thigh-based flaps such as the profunda artery perforator (PAP) flap may also be good options.
- Our preference is to reconstruct circumferential defects with a thigh-based flap whenever possible; however, a free jejunal flap can also be considered.¹¹
- In patients who are not candidates for a free tissue transfer (ie, major comorbidities that preclude a long operation or lack of recipient vessels), pedicled flaps such as the pectoralis major myocutaneous flap, supraclavicular flap, or an internal mammary artery perforator flap can be considered.¹

TECHNIQUES

ALT Flap Harvest

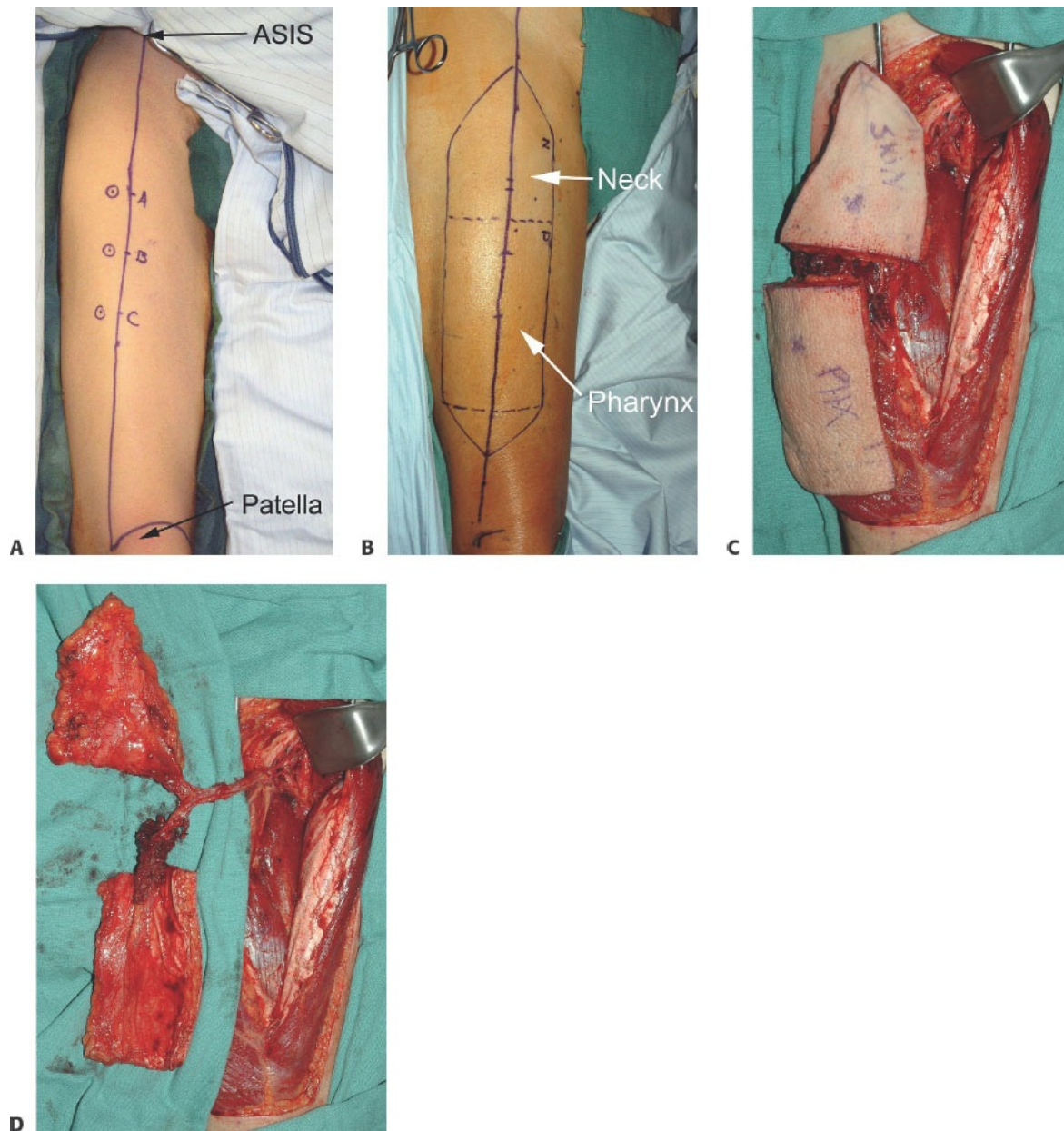


Video p3-c046

- The ASIS and lateral patella are marked, and a line is drawn connecting these two points.
- The line is divided in half and a point 5 cm proximal and distal are marked, which identifies the approximate location of the A, B, and C perforators

(TECH FIG 1A).⁹

- The exact dimensions of the skin flap depend on the size of the defect (see Reconstruction of Partial vs Circumferential Defects, later).
- The medial incision is made first and the dissection proceeds through the skin, subcutaneous tissues, and fascia.
 - A subfascial dissection is performed from medial to lateral to identify the cutaneous perforators.
- The flap outline can be adjusted after the perforator location has been confirmed so that the perforator is near the center or slightly superior to the center of the flap, if maximal pedicle length is critical.
- The cutaneous perforators can take an intramuscular path through the vastus lateralis muscle, or they may traverse through the septum between the vastus lateralis and rectus femoris muscles.
- Selection of the perforator depends on the length of pedicle that is needed (the more distal perforators will provide a longer pedicle) as well as the size of the perforators.
 - The larger the perforator (0.5-mm artery and 1-mm vein are commonly seen), the easier and safer the dissection.



TECH FIG 1 • A. To anticipate the location of the cutaneous perforating blood vessels, a line is drawn between the ASIS and the upper lateral corner of the patella, as shown in this right thigh image. Most commonly, perforators are located at the midpoint of this line (labeled B) and 5 cm above and below the midpoint (labeled A and C, respectively). **B.** Markings for a two-skin paddle anterolateral thigh (ALT) free

flap. One skin paddle will be used to create a pharyngeal conduit, and one skin paddle will be used to close the cutaneous defect that occurs in many patients due to contracture of a radiated neck skin. **C.** Completed dissection of the two–skin paddle ALT free flap. The skin paddle that will be used to reconstruct the pharyngeal conduit is 9.5-cm wide so that the diameter of the lumen will be 3 cm once the flap is tubed. **D.** Completed dissection of the two–skin paddle ALT free flap showing the dual perforator anatomy of the flap. The main lateral descending circumflex femoral pedicle can be visualized clearly with the dissection completed to maximize the length of the pedicle.

- Typically, one or two perforators are selected for dissection.
 - If separate skin paddles are necessary, these skin paddles can be based on their own perforator (**TECH FIG 1B,C**).
 - If separate perforators are not available for each skin paddle, the skin between these areas can simply be de-epithelialized; however, this does increase the bulk of the tissues in the region where the flap is folded on itself.
- The perforators are dissected and exposed until the main pedicle vessels (descending branches of the lateral circumflex femoral blood vessels) are visualized between the vastus lateralis and rectus femoris muscles.
 - The main pedicle is then dissected proximally toward the takeoff of the vessels from the profunda femoris muscle.
- Occasionally, the perforators may arise from the transverse branch or oblique branches of the lateral femoral circumflex vessels.^{3,6,7,10} This is typically not problematic (though it may limit the length of the pedicle), and the main pedicle vessels are dissected to their source to maximize vessel caliber and pedicle length.
- Once the medial (anterior) dissection is completed, the lateral (posterior) incision can be made based on the size of the flap that is needed, and dissection again proceeds down to the fascia.

- The fascia is incised, and the subfascial dissection is performed until the perforators are visualized.
- The perforators are then freed from the posterior approach, and the entire flap should now be perfused on the main pedicle (**TECH FIG 1D**).
- Once the resection has been completed, and adequate recipient vessels identified, the flap is harvested.
 - Ideally, branches of the external carotid artery are preferred along with branches of the internal jugular vein. However, the external jugular vein can also serve as a recipient vein if needed.
 - If no suitable branches of the external carotid are available, the transverse cervical vessels can serve as possible recipients. Vein grafting to more distant vessels such as the internal mammary vessels is also a potential option.³
- The flap is partially inset into the defect using absorbable sutures in a simple interrupted manner by paying careful attention to evert the skin and mucosa.
 - Insetting the flap in this manner sets the length and position of the pedicle and simplifies microsurgical anastomosis.
 - In some cases, it is simpler to perform the anastomosis prior to inset; however, this approach risks twisting or stretching the pedicle and should be done carefully.
- Once the flap inset is completed, the microvascular anastomosis is performed. The perfusion to the flap is assessed, and the flap is monitored either via the second skin paddle (if one is used for neck reconstruction) or an implantable Doppler ultrasound.
- The neck should be irrigated copiously, and the mouth should be flushed to assess for any leak in the flap inset that can result in a fistula.
 - The pedicle should be inspected prior to closure of the neck to make certain there are no twists or kinks in the pedicle.
 - Closed suction drains are placed prior to closure taking care to avoid direct suction or pressure on the pedicle.

Reconstruction of Partial vs Circumferential Defects

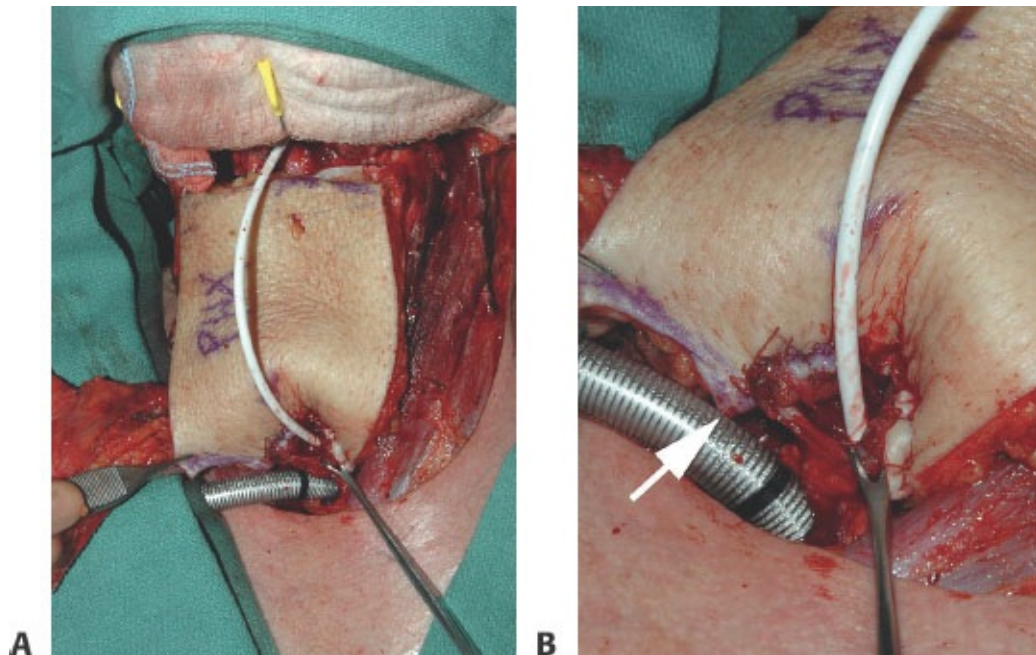
- Circumferential defects require a 9-cm-wide flap in order to tube the flap to create a 3-cm-diameter tube, according to the formula: $\text{circumference} = \pi \times \text{diameter}$.
- An additional 2- to 3-cm cuff of the thigh fascia can be harvested with the flap that will allow for a second layer closure of the defect. This second layer

may help to contain any small leaks and prevent the formation of a fistula.

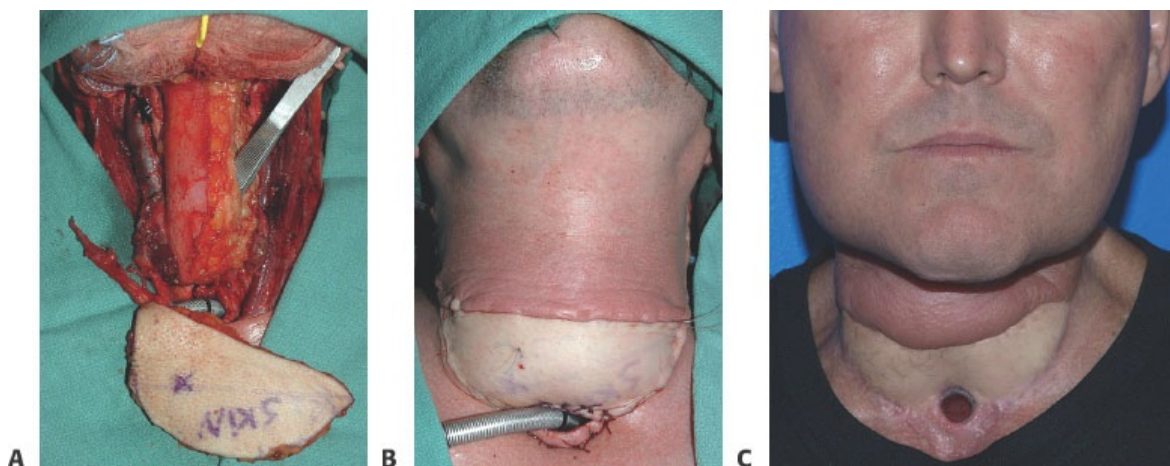
- We recommend completing the proximal (base of tongue) and distal (cervical esophagus) suture closure first, then the vertical suture closure last.
 - This gives the best visualization of the proximal and distal closures, which are the most technically challenging and where leaks most commonly occur.
 - The flap is inset such that the vertical suture line comes to lie 180 degrees away from the side of the microvascular anastomosis (**TECH FIG 2A**).
- The distal portion of the flap that will be inset into the cervical esophagus is designed with a dart that is then inset into a longitudinal cut made in the cervical esophagus.
 - This dart inset will break up the circumferential scar distally, thereby widening the distal anastomosis and will minimize or prevent cicatricial stricture (**TECH FIG 2B**).
- For partial defects, in which the posterior wall of the pharynx is preserved, the width of the remaining pharynx is measured and subtracted from 9 cm. This is the width of the ALT flap needed to create a 3-cm lumen for the pharyngeal reconstruction.
- One of the vertical suture closures is performed first, along the remaining posterior pharyngeal wall, and then the proximal and distal suture closures are performed.
 - The other vertical suture line is performed last.

Neck Skin Reconstruction

- In some cases, a second skin paddle can be used to reconstruct the neck skin in patients with poor skin viability or skin fibrosis from radiation therapy. This is performed most easily with a flap that has two cutaneous perforators by creating a second skin paddle to reconstruct the neck defect.
 - Either the proximal or distal perforator can be used for the neck reconstruction.
 - Poorly vascularized neck skin is debrided, and the skin paddle is interposed between the superior neck skin flap and the tracheal stoma, inferior neck, and chest skin (**TECH FIG 3**).



TECH FIG 2 • A. Partial inset of the ALT free flap pharyngeal conduit. The cervical esophagus and base of tongue suture lines are closed first, and the flap is then closed to itself to form a tube on the side that is contralateral to the microvascular anastomoses. **B.** Close-up of the inset of the ALT free flap to the spatulated cervical esophagus. The *arrow* points to a dart created in the flap to help minimize cicatricial stricture.



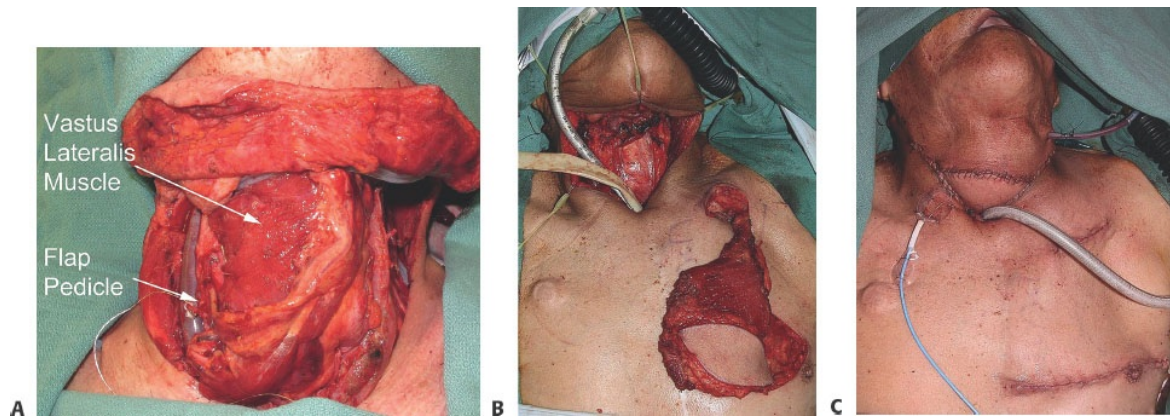
TECH FIG 3 • A. Nearly completed inset of the tubed

ALT free flap pharyngeal conduit showing the still open lateral suture line (forceps placed into the lumen) and the second skin paddle that will be used to close the neck defect. **B.** Completed neck closure. The second skin paddle of the ALT free flap allows for resection and replacement of poorly vascularized, fibrotic, and contracted neck skin, which minimizes the risk for wound dehiscence. **C.** Postoperative appearance, approximately 1 year after surgery.

- When there is only one cutaneous perforator, a portion of the vastus lateralis muscle can be harvested with the skin paddle (**TECH FIG 4A**).
 - This muscle is skin grafted, and in our experience, dehiscence is rare, even along the tracheal stomal suture line.
 - Alternatively, in partial-thickness defects, the skin flap can be folded upon itself with a de-epithelialized area in between to facilitate neck skin closure.
- A pectoralis muscle or myocutaneous pedicled flap can also be used to reconstruct the neck skin (**TECH FIG 4B**).
 - The muscle can also be placed over the ALT flap suture lines, to help decrease the chance for leakage.

Donor-Site Closure

- The donor site should be inspected for hemostasis and the incision closed in layers over closed suction drains.
- Most donor sites 9 cm or less in width can be closed primarily depending on the degree of laxity in the patient's soft tissue.
- If the donor site cannot be closed primarily, a skin graft can be placed over the exposed vastus lateralis and rectus femoris muscles.
 - A VAC dressing is often the simplest way to bolster the skin graft and precludes the need for closed suction drains.



TECH FIG 4 • A. In cases in which there is only one cutaneous perforator available and the neck skin requires reconstruction as well, a portion of the vastus lateralis muscle can be harvested with the flap and skin grafted. **B.** A second option is use of a pectoralis major myocutaneous pedicled flap. In this case, the flap has been “islanded” to minimize bulk proximally. The muscle portion of the flap provides a loose second layer of closure over the pharyngeal reconstruction. **C.** Completed neck closure.

PEARLS AND PITFALLS

Flap design

- Wait for clear margins by frozen section pathology before committing to the width of the flap.
- If two cutaneous perforators are available, one can be used to create a second skin paddle for neck skin reconstruction, if needed.
- In the setting of a single perforator, a portion of the vastus lateralis muscle covered with a skin graft can be used for neck resurfacing.

Microvascular anastomosis

- Meticulous technique and careful handling of the vessels are critical particularly in the previously radiated neck.
- Make certain there are no kinks or twists in the vessels.

Flap inset

- The inset should be a watertight closure.
- Irrigate in the mouth prior to and after completing the flap inset to

	assess for any leak. ■ Consider using the fascia for a second layered closure of the flap inset.
Flap monitoring	■ Clinical examination of an external skin paddle or portion of the vastus lateralis muscle is ideally used for monitoring. ■ In a completely buried flap, an implantable Doppler ultrasound can be used for monitoring.
Postoperative care	■ Patients should be maintained on prophylactic antibiotics for several days following reconstruction. Oftentimes, removal of the neck drains is a useful guide when antibiotics can be discontinued. The length of antibiotic treatment is also dependent on the quality of the neck skin, history of radiation therapy, and comorbid conditions that increase the risk of infections (eg, obesity, hypertension, diabetes mellitus). ■ A modified barium swallow (MBS) is performed to rule out leaks and confirm flap conduit patency prior to resumption of an oral diet. The MBS is performed approximately 2 weeks postoperatively in nonradiated patients and 6 weeks postoperatively in radiated patients.

POSTOPERATIVE CARE

- Patients ideally should be off the ventilator and should not need to be monitored in the intensive care unit unless that is the policy for flap monitoring.
- Flap monitoring includes physical examination of the flap by a trained professional (nurse, physician assistant, or surgeon) to assess for color, warmth, turgor, capillary refill, and a percutaneous Doppler signal.
- If the flap is entirely buried, an implantable Doppler is often placed and can be monitored according to protocol.
- The flap should be monitored at a minimum on an hourly basis for the first 2 days and then changed to every 2 hours for the next 2 days and then every 4 hours until discharge.
- The patient should be encouraged to keep the head midline and elevation to minimize any risk of traction or kinking of the pedicle when the patient turns his/her head.
- Patients may start increasing movement of their neck 2 weeks following the operation and potentially may need physical therapy for range-of-motion exercises.

- Elevation will help minimize postoperative swelling.
- Most patients will also have a new, permanent tracheostomy, which should be cleaned and suctioned frequently to prevent a mucous plug that can block the airway.
- Care should be taken to avoid external pressure on the neck to avoid venous obstruction and thrombosis. This includes tracheostomy ties, large pillows that may wrap around the neck, or other potential sources of pressure.
- Patients are encouraged to mobilize on postoperative day 1 and to begin ambulation on day 2.
 - A physical therapy consult may be necessary to facilitate mobilization.
 - Low molecular weight heparin should be started on postoperative day 1 for venous thromboembolism (VTE) prophylaxis.
- Patients should be maintained and continued on antibiotics for a minimum of 1 week, and drains should be monitored for any signs of bleeding, infection, or fistula. Removal of the neck drains is often a useful guide for when antibiotics can be discontinued.
 - The length of antibiotic treatment also depends on the quality of the neck skin, history of radiation therapy, and comorbid conditions that increase the risk of infections (eg, obesity, hypertension, diabetes mellitus).

OUTCOMES

- Free flap success rates at high volume institutions are generally well over 95%, approaching 99% success rates.
- Compared with jejunal flap reconstructions, ALT free flap reconstructions have been found to result in superior voice quality when a tracheoesophageal puncture (TEP) is performed with placement of a one-way valve voice prosthesis.^{4,5,8,12}
- Stricture and fistula rates are not significantly greater with the ALT free flap.
- The ALT free flap is also preferable because it avoids the need for a laparotomy.

COMPLICATIONS

- As with any surgery, there are risks of bleeding and infection following this operation that may require operative exploration to correct the complication.
- A leak or fistula may heal spontaneously if the fistula is small; however, larger fistulae often require surgery and potentially a pedicle pectoralis major muscle flap to close the fistula.

- Donor-site complications are rare, but some numbness in the distribution of lateral femoral cutaneous nerve is not uncommon.²
- Almost all patients return to their preoperative level of ambulatory activity in 3 months or less.

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47 Pectoralis Major Flap for Pharyngeal Reconstruction

CHAPTER

Michael A. Howard and Babak J. Mehrara

DEFINITION

- The pectoralis major muscle flap was first reported by Pickrell in 1947¹ and popularized for head and neck reconstruction by Ariyanas a myocutaneous flap in 1979.^{2,3}
- While free tissue transfer remains the standard for many head and neck defects, this pedicled flap is useful for reconstruction of partial pharyngeal defects due to the proximity of the donor site to the recipient area as well as the fact that this flap is usually not in the radiation field in patients with recurrent tumors.
- The pectoralis flap is also useful in cases in which microsurgery is not feasible or if coverage of the neck is required in complex reconstructions.
- The flap has the advantages of a healthy robust muscle with reliable vascular anatomy, simple harvest technique, and a wide arc of rotation.
- Goals of pharyngeal reconstruction:
 - Achieve primary wound healing
 - Maintain oral continence and facilitate swallowing while avoiding redundant pouches along food path
 - Prevent aspiration
 - Protect vital neck structures

ANATOMY

- The pectoralis major is a fan-shaped muscle of the anterior chest which functions to adduct and medially rotate the arm (**FIG 1**).

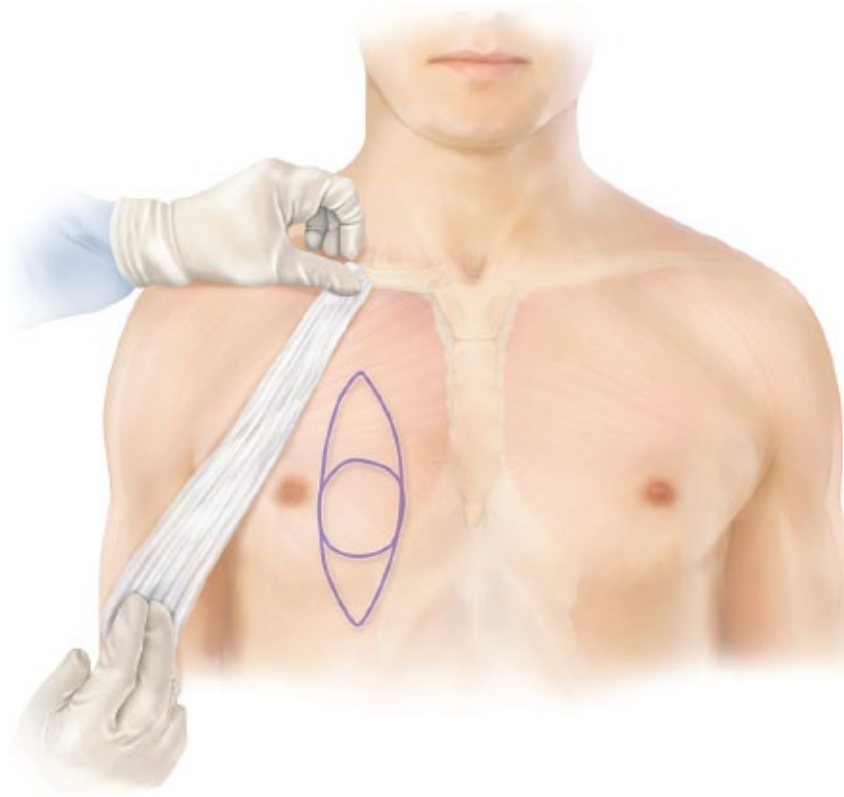


FIG 1 • Anatomy of the pectoralis major myocutaneous flap.

- The pectoralis muscle inserts into the medial one-third of the clavicle as well as the sternum and cartilaginous portions of ribs 1 to 6.
- The muscle originates as a tendinous insertion into greater tubercle of the humerus. The muscle in this area runs deep to the deltoid muscle, and the cleft that is formed between these two structures is referred to as the deltopectoral groove.
- The pectoralis muscle has a Mathes and Nahai type 5 blood supply, composed of a dominant pedicle (the thoracoacromial artery and vein) as well as secondary minor pedicles arising from parasternal perforators arising from the internal mammary artery and vein.
- The motor nerve supply of the pectoralis muscle is derived from the medial and lateral pectoral nerves.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A number of factors should be considered during flap selection and design.
- Defect location. The arc of rotation of the pectoralis flap can be estimated by

locating the pedicle of the flap and using a lap pad or suture that is held to the tip of the designed flap. The location of the pedicle can be marked by drawing a line from the acromioclavicular joint to the xiphoid. In most patients, a vertically drawn pectoralis myocutaneous flap can easily cover the upper portion of the hypopharynx.

- Size of defect. The pectoralis flap is not easily tubularized due to the thickness of the skin flap and muscle, as well as donor site complications arising from harvesting very wide skin flaps, and as a result, is not in most cases useful for circumferential defects.
- Prior chest surgery is also an important consideration since this may have resulted in scars that may decrease the utility of the flap or, less commonly, have injured the blood supply.
- The use of this flap in women for pharyngeal reconstruction is also complicated by the presence of breast tissue, and a history of breast cancer (and screening) should be elicited in these patients.
 - This is not a good option in patients with large breasts as the thickness of the flap complicates wound closure and may result in an unsightly donor defect.
- Smoking history does increase the risk of complications, and if possible, smoking should be stopped as long as possible prior to surgery (however, this may not always be feasible in patients with active tumors).

IMAGING

- Imaging is rarely necessary for the planning or design of a pectoralis major flap.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients who are referred for pharyngeal reconstruction have primary tumors of the hypopharynx/pharynx or suffer from aggressive or recurrent tumors of the surrounding structures (eg thyroid or larynx).
 - In many cases, the planned procedure involves laryngectomy and end tracheostomy and repair of the pharyngeal defect.
- Because the posterior wall of the larynx is closely adhered to the anterior wall of the pharynx, a strip of the pharyngeal wall is commonly resected with the laryngeal specimen.
 - These patients are good candidates for pectoralis myocutaneous flap

reconstruction.

- Similarly, the pectoralis flap is a good option in patients with small tumors of the pharynx in which a partial pharyngeal resection is performed.
- Patients with more extensive defects of the pharynx that require tubularization of a flap or reconstruction of nearly the entire circumference of the pharynx are better served with a free flap (tubularized anterolateral thigh or jejunum).
- Defects of the pharynx extending below the clavicle are most commonly reconstructed with a gastric pull-up or colon interposition flap.
- Once a suitable surgical candidate for a pectoralis flap is identified (usually after preoperative consultation with the head and neck oncologist), the patient is examined to assess the quality of the neck skin and subcutaneous tissues.
- Many patients who present for reconstruction of pharyngeal defects have previously undergone chemoradiation for laryngeal organ preservation and, as a result, have radiation damage to the skin. In these cases, plans should be discussed not just for reconstruction of the pharyngeal defect but also the overlying skin.

Positioning

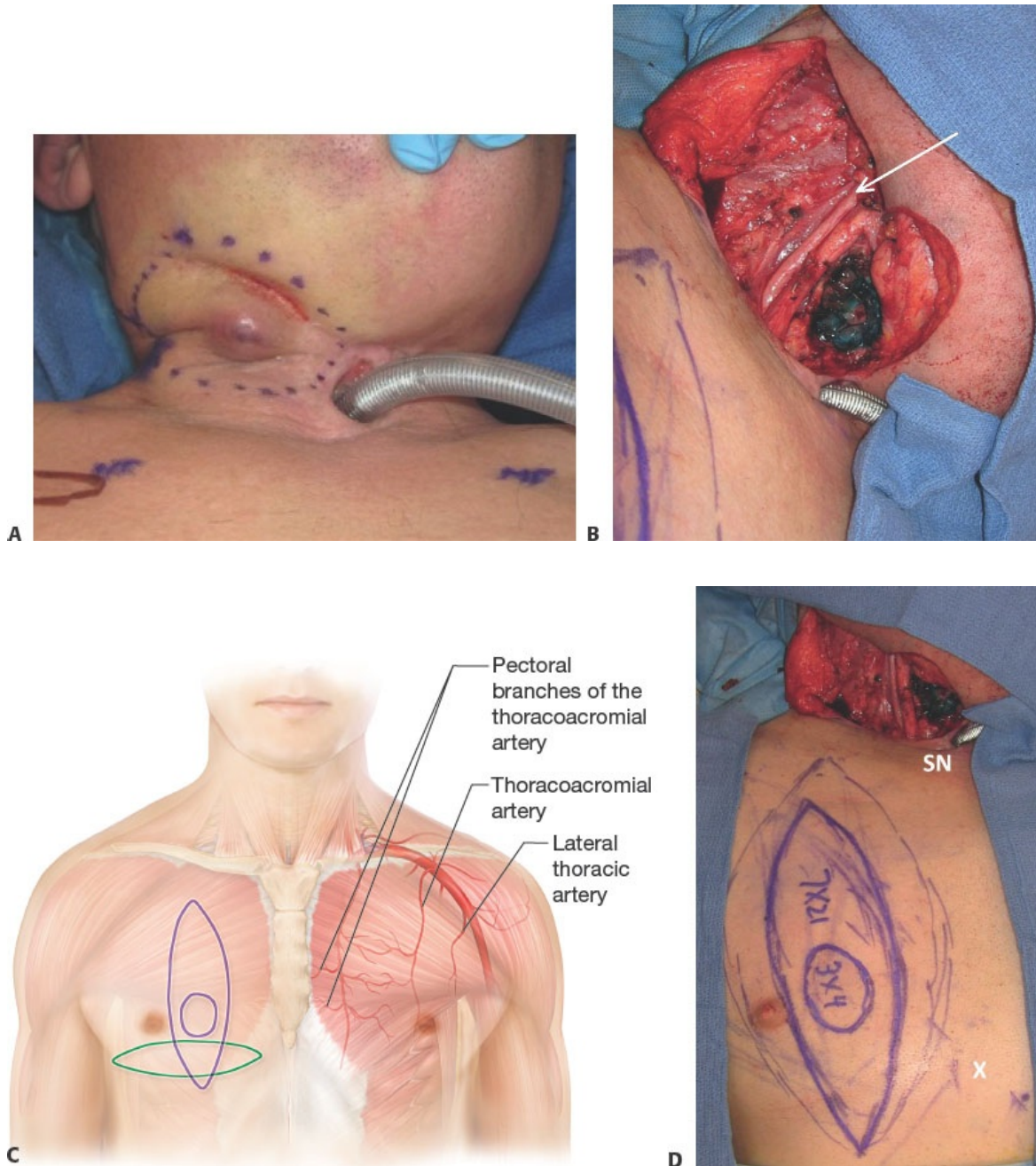
- The patient is positioned supine, and the bed may be rotated 90 degrees to allow easy access to the head and neck area.
- Surgery is performed under general anesthesia often after end tracheostomy has been placed.

TECHNIQUES

■ Flap Design

- The defect is assessed for viability of the mucosal edges (**TECH FIG 1A**).
 - The size of the defect is carefully measured, and the arch of rotation of the flap is assessed as discussed above to ensure tension-free closure.
- The flap pedicle is marked by drawing a line connecting the acromioclavicular joint to the xiphoid.⁴
 - **TECH FIG 1B** shows the defect in the right pharyngeal wall (marked with blue ink) and overlying skin after tumor resection.
- The flap skin paddle can be designed vertically or horizontally on the chest.

- Vertical skin paddles have excellent skin perfusion, close easily due to alignment with the relaxed skin tension lines, and have a suitable arch or rotation to repair defects of the anterior wall of the pharynx.



TECH FIG 1 • A. Markings for anticipated resection of recurrent squamous cell cancer of the right pharynx involving the skin. **B.** Defect in the lateral pharyngeal

wall (marked with blue ink) and overlying neck skin after resection. *Arrow* indicates the carotid artery and jugular vein. Design of (C) and markings for (D) a vertical pectoralis major myocutaneous flap. Note position of the flap medial to the nipple where the best perforators are usually found. SN, sternal notch; X, xiphoid.

- The most reliable skin perforators are located medial to the nipple; therefore, a vertical flap is usually drawn just medial to the areola (**TECH FIG 1C,D**).
- The flap width is based on the size of the defect, and a “pinch test” to ensure that the donor site can be closed primarily.
 - In rare cases, when a wide flap is needed, the nipple may be included in the flap design.
- A horizontal skin paddle is also possible and, if placed more distally on the flap, has greater arch of rotation. In addition, the horizontal skin paddle can provide greater flap width and cover nearly circumferential defects of the pharynx.
 - Care should be taken with flap design to capture skin perforators, and design of the flap below the inframammary crease should be avoided.
 - In some cases, a crescent-shaped flap can be drawn to capture parasternal perforators; however, this flap design is rarely useful in practice.
- A handheld Doppler may be used to define skin perforators, but this can be tricky since the perforators may be in the muscle rather than entering the overlying skin.
- In the example provided, the right pectoralis flap is marked in a vertical manner with the skin paddle located just medial to the areola.

■ Flap Elevation

- The skin paddle is incised, and the muscle is identified.
 - The skin medial to the flap is elevated to expose the sternal insertion of the muscle, and the pectoralis muscle is incised while perforating branches from the internal mammary vessels are ligated.

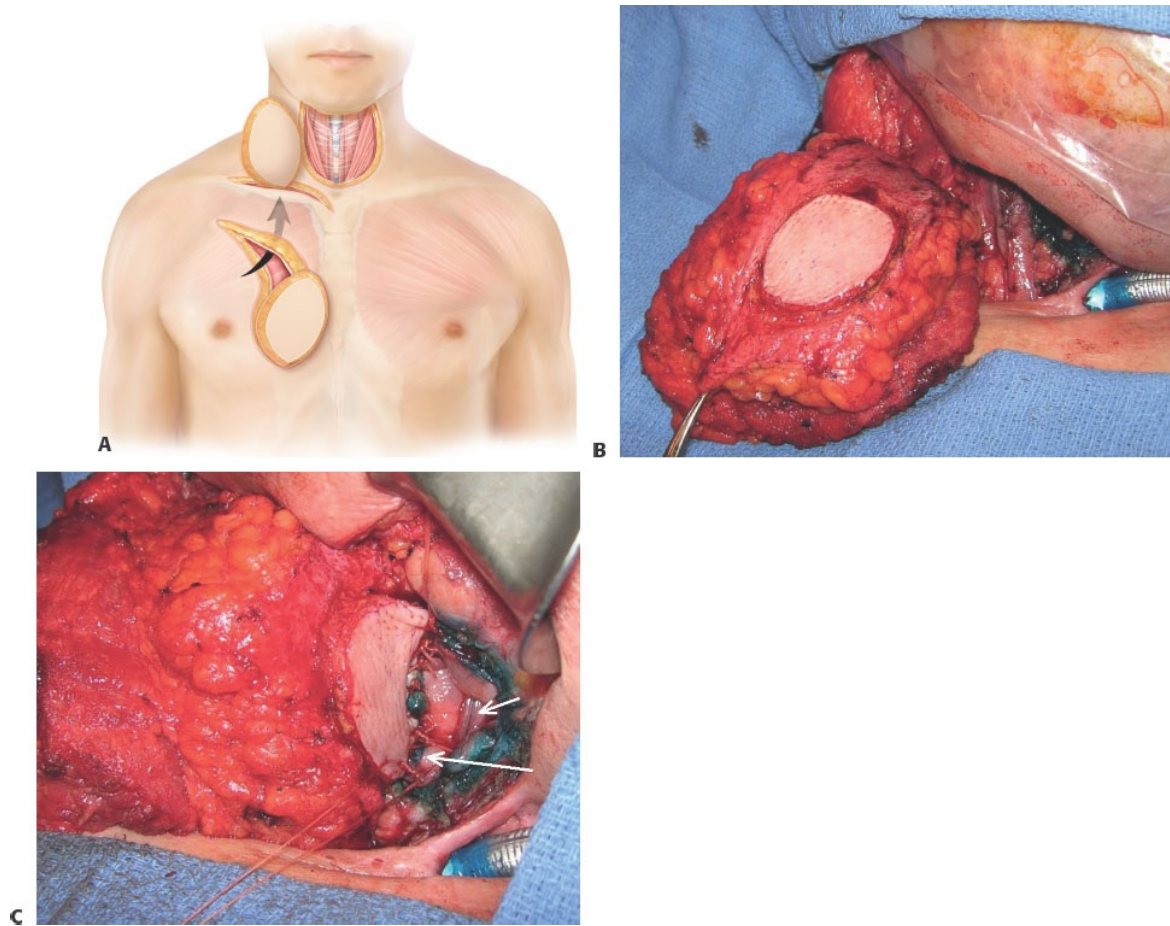
- The dissection continues from distal to proximal elevating the muscle above its chest wall insertion at the inframammary fold.
 - The dissection is continued proximally in the loose areolar plane, and the pedicle is visualized by reflecting the muscle.
 - At this point, one must decide how much muscle he or she will include with the flap.
 - Generally, most of the width of the pectoralis muscle is included in the flap to enable coverage of the exposed vascular structures after closure of the pharyngeal defect. In this case, the required width is marked on the muscle, and the muscle is incised from distal to proximal to excise the humeral insertion (this portion is not necessary in most cases and results simply in creating extra bulk).
 - The medial and lateral pectoral nerves entering this portion of the muscle are transected. This will allow the muscle to atrophy postop, thereby improving aesthetic outcome.
 - If possible, it is best to preserve the clavicular head of the pectoralis muscle since transection of this portion can cause additional morbidity and postop pain due to changes in the mechanical forces exerted on the humeral head.
 - In these cases, the thoracoacromial vessels are dissected as they enter into the flap just below the clavicular head of the muscle.
 - The muscle harvested in this area is narrowed to approximately 1 to 2 cm on each side of the pedicle to avoid bulkiness and postoperative neck contracture.
-

■ Flap Inset

- A subcutaneous tunnel is created over the clavicle with sufficient width to accommodate passage of the flap (**TECH FIG 2A**). Care should be taken to avoid injuring the external jugular vein.
- The edges of the defect can be marked with methylene blue to facilitate creation of a template for the skin paddle.
 - This is marked on the skin with some room for error, and the excess skin paddle is de-epithelialized since this step is easier to perform prior to passing the flap into the subcutaneous tunnel.
- The flap can be passed above the clavicular portion of the pectoralis muscle. If additional pedicle length is required, the flap can be tunneled below the

clavicular head of the pectoralis muscle or the clavicular portion of the muscle can simply be transected.

- Some surgeons describe passing the flap below the clavicle bone by resecting the medial portion of the bone to achieve greater length. This is rarely necessary in practice, however, and may result in injury to the brachial plexus, brachial artery, or brachial vein.
- The flap is folded backward on itself (ie, the skin paddle is facing posteriorly and toward the pharyngeal wall while the muscle is facing anteriorly).
 - Inset flap ensuring minimal tension and no constriction on the vascular pedicle (**TECH FIG 2B**).
- A feeding tube is passed into the stomach under direct vision.
- The flap is sutured to the pharyngeal defect using interrupted 2.0 Vicryl sutures (**TECH FIG 2C**). Care should be taken to achieve a watertight closure. The knots may be placed on the inside and a second layer closure to ensure a tight seal is performed with a running 4.0 PDS suture. All sutures should be with tapered needles.
- The muscle is draped over the defect and used to cover the carotid artery and internal jugular vein on both sides.
- The wound is copiously irrigated, and drains are placed lateral to the sternocleidomastoid muscles (ie, not crossing the flap or its pedicle).



TECH FIG 2 • A. Pectoralis flap rotation and inset. **B.** Flap has been de-epithelialized and is ready for inset after having been passed under the neck skin. **C.** Inset of the flap with interrupted 2.0 Vicryl sutures. The pharynx with nasogastric tube is indicated by the *short arrow* and the posterolateral inset by the *long arrow*.

■ Closure

- The neck skin is closed in layers to reapproximate the platysma with 2.0 Vicryl and the skin with 4.0 nylon sutures.
 - Neck skin closure can be facilitated by bringing the patients head out of extension as it is usually done to facilitate tumor extirpation.
- If the skin cannot be closed, a split-thickness skin graft can be applied to the

muscle and sutured into place.

- A Xeroform gauze is used to protect the skin graft and stapled into place.
- No bolster is necessary, and the skin graft should not be meshed if possible.
- The chest is closed after the placement of a drain.

PEARLS AND PITFALLS

Indications and assessment

- The pectoralis major myocutaneous flap is ideal for partial defects of the pharynx following laryngectomy.
- This flap is less useful for near circumferential or circumferential defects.
- The use of the flap may be limited in women due to intervening breast tissues.

Technique

- Vertical flaps have the best perfusion. The flap is drawn medial to the areola and designed to capture as many perforators as possible.
- Horizontal flaps are also possible but should not be designed below the IMF.
- Transection of the medial and lateral pectoral nerves results in muscle atrophy and decreased bulk.
- Preservation of the clavicular head of the pectoralis muscle is feasible in most cases and decreases postoperative morbidity.
- Partial de-epithelialization of the flap prior to tunneling in the neck is helpful.
- Avoid tension and achieve a watertight closure with absorbable sutures on taper needles. A two-layer closure is helpful for reducing leaks.

POSTOPERATIVE CARE

- The chest drain is removed when the output is less than 30 cc/24 hours. In patients with prolonged drain output, compression may be helpful but should be done with care to avoid compression of the pedicle.
- Ipsilateral arm activity:
 - Passive range of motion allowed 1 to 2 days after surgery
 - Progressive increase in active motion at 7 to 10 days
 - Unrestricted arm activity beginning 4 to 6 weeks after surgery

- The patient is maintained nothing-by-mouth (NPO) for 7 to 10 days and is maintained on feeding tubes for nutrition during this time period.
- Oral hygiene is maintained with dilute saline or chlorhexidine mouth rinses to reduce oral bacterial load.
- Although there is a paucity of literature or data on antibiotic use, we routinely keep patients treated in this manner on broad-spectrum antibiotic coverage (Gram negative, Gram positive, anaerobic) for 7 to 10 days.
- This is based on the fact that the procedure is contaminated and most patients are nutritionally compromised, and have a history of radiation, smoking, or alcohol use.
- A hypaque swallow (or dilute barium) is performed to ensure that there is no leak or aspiration. If clear, feeds are started with liquids and progressed to a soft diet.
- Swallow therapy is usually helpful for these patients.
- Neck drains are removed when output is less than 30 cc/24 hours.
- Neck sutures are removed in 2 to 4 weeks (longer period for patients with a history of radiation).

OUTCOMES

- The pectoralis flap is highly reliable with a low reported total flap loss rate (2%).⁵
- However, a high overall complication rate ranging between 20% and 50% has been reported and is related, in most cases to patient comorbidities.
- Fortunately, most of these complications are minor and heal without major intervention.

COMPLICATIONS

- Salivary leak and fistula formation is relatively common occurring in 5% to 35% of cases.
- These leaks are particularly common in patients with a history of radiation therapy and smokers.
- The most common area where leaks occur is the proximal anastomosis likely due to traction on this area due to the weight of the flap. Suturing the soft tissues of the flap to a solid area (ie, the inferior edge of the mandible periosteum) may be helpful but not always possible.
- Sixty to seventy percent of these fistulas heal spontaneously with wound care

over a 6- to 8-week period of time. During this time period, patients are maintained NPO and evaluated frequently. The wound should be opened widely to facilitate packing and wound care.

- Fistulas that do not heal spontaneously may require operative intervention for debridement and, rarely, a second flap.
- Strictures are also possible and occur most frequently in patients with a history of radiation. These are usually managed conservatively with dilatation.
- The most dreaded complication of pharyngeal reconstruction is exposure and infection of large vessels with blow out. Fortunately, this occurs rarely and often present with a “herald” bleed.
- The surgeon should not hesitate to evaluate a patient with angiography or in the operating room in these cases. Blowouts can be avoided by meticulous wound care and, if necessary, a second flap to cover the exposed vessels.

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Supraclavicular Island Flap for Oropharyngeal Reconstruction

48

CHAPTER

Michael W. Chu and Ernest S. Chiu

DEFINITION

- The oropharynx is the middle part of the pharynx from the level of the soft palate to the epiglottis and is bordered superiorly by the nasopharynx and the hypopharynx inferiorly.
- The supraclavicular artery island flap (SCAIF) is a fasciocutaneous, axial pattern, local rotational flap based on the supraclavicular artery.

ANATOMY

- The oropharynx is a musculomucosal tube that connects the nasal cavity and mouth to the upper aerodigestive tract and serves as a conduit for air and food.
- The arterial supply of the SCAIF flap is derived from the supraclavicular artery, a branch of the transverse cervical artery. The transverse cervical artery originates from the thyrocervical trunk which arises from the first portion of the subclavian artery.
 - Rarely, the supraclavicular artery arises from the suprascapular artery.¹
- The average length of the supraclavicular artery is 4 cm long (range 1–7 cm),² and its diameter is 1 to 1.5 mm² (**FIG 1**).
- The supraclavicular artery can be reliably found in the supraclavicular triangle, between the sternocleidomastoid, clavicle, and trapezius.
- The venous supply of the SCAIF flap is derived from vena comitantes accompanying the supraclavicular artery draining to the internal jugular vein. In addition, the SCAIF drains laterally to branches of the external jugular vein. These lateral branches are typically ligated during flap elevation.
- Sensory innervation of the SCAIF flap is derived from the supraclavicular

nerve arising from cervical roots C3 to C4. These nerves emerge from the deep fascia 1 to 2 cm anterior to the vascular pedicle, underneath the sternocleidomastoid muscle near the midpoint of the muscle belly.

- The nerve branches proximal to the pedicle with one branch exiting anterior to the flap and the other coursing axially along the length of the flap. This provides potential for the SCAIF to be a sensate flap (Sands, 2012).
- The average dimension of the skin paddle for the SCAIF flap is a length of 24.2 cm and width of 8.7 cm.³
- Contrary to initial reports,⁴ the SCAIF flap can be harvested beyond the deltoid muscle.³
- Flap delay or tissue expansion can increase the size of the flap to as large as 12 × 35 cm.⁵
- The arc of rotation for the supraclavicular flap has been reported up to be up to 180 degrees.¹ However, caution should be used when rotating flaps greater than 90 degrees to avoid venous obstruction.⁶
- The SCIAF flap has many advantages.
 - Thin, pliable, hairless flap with good color match for head and neck reconstruction
 - Harvest and reconstruction are in the same surgical field.
 - Consistent vascular anatomy with a large arc of rotation

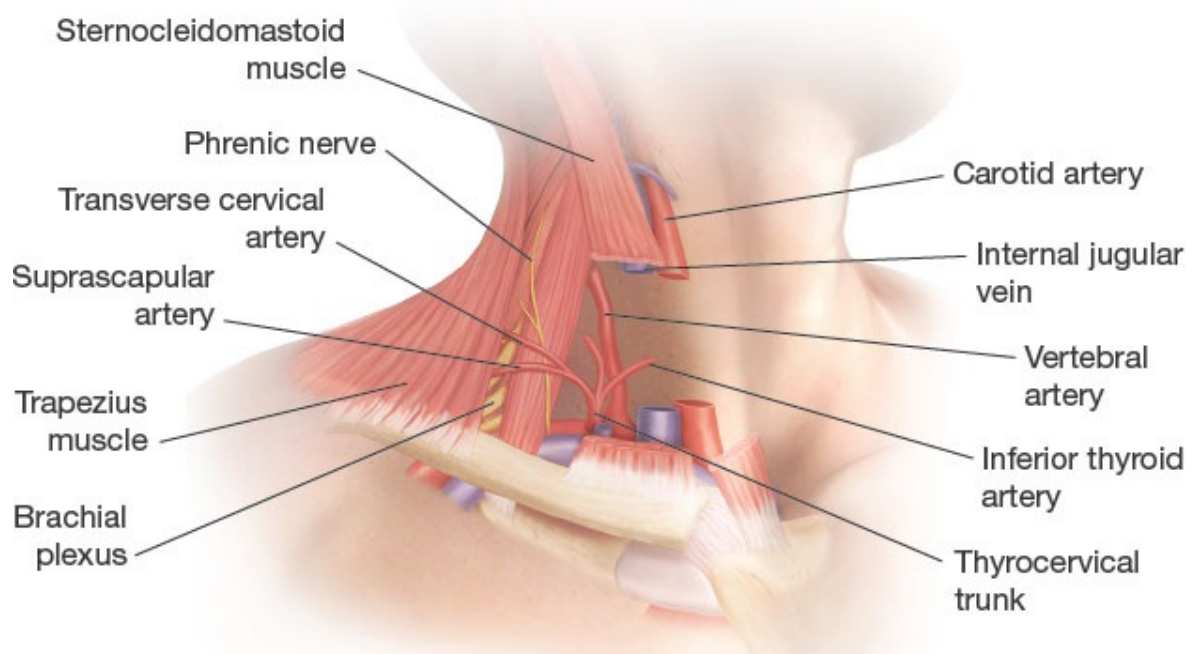


FIG 1 • Anatomy of the supraclavicular artery.

- Reliable flap blood supply that is preserved in most cases, even after neck dissection and previous radiation therapy⁷
- Does not require microsurgical expertise and decreased operative duration compared to microsurgical reconstruction⁸
- Primary closure of donor site if width is less than 8 cm
- Disadvantages
 - Risk of vascular pedicle compromise secondary to torsion or kinking particularly with increased arc of rotation⁶
 - Shoulder scar is visible with certain clothing choices.
 - Obese patients with thick supraclavicular tissues may not be good candidates.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most common cause of oropharyngeal defects is head and neck cancer. As a result, history of prior treatments (surgery, radiation) and risk factors for wound healing complications (ie, history of tobacco use, ethanol abuse, malnutrition) common in this patient population should be elicited.
- If reconstruction is performed at the time of tumor extirpation, then discussions with the ablative surgeon are important to delineate flap dissection and preservation of the flap pedicle.
- Physical exam should evaluate the pliability of the neck and shoulder skin, extent of prior surgery (if any), carotid pulse, lymphadenopathy, and, if possible, size and nature of the primary tumor.

IMAGING

- Routine preoperative radiographic imaging is not necessary in patients with no history of prior neck dissection.
- In patients who have previously undergone neck dissection (ipsilateral to the proposed flap site), angiography (CTA or MRA) can be done to confirm patency and characterize anatomy, vessel length, patency, and diameter of the supraclavicular artery.
- Handheld Doppler can also be used to confirm location and patency of the supraclavicular artery preoperatively and intraoperatively.
- Indocyanine green laser angiography is occasionally useful to evaluate

perfusion of the SCAIF after the flap has been elevated.

SURGICAL MANAGEMENT

- Reconstructive goals of oropharyngeal reconstruction are to promote rapid healing, re-establish the aerodigestive tract, and prevent wound complications and infection.



FIG 2 • Design of a supraclavicular arterial island flap measuring 10 × 7 cm. The *asterisk* represents the supraclavicular artery vascular pedicle found in the triangle delineated by the clavicle, sternocleidomastoid, and trapezius muscle.

- The main steps of the procedure are as follows:
 - Measure defect dimensions.
 - Design skin paddle centered over the axial course of the vascular pedicle.
 - Raise fasciocutaneous flap from lateral to medial.
 - Mobilize flap into defect.
 - Inset the flap by tunneling or interpolating the flap, or transpose the flap by islandizing the flap (propeller flap).

- Close the donor site (primarily or with skin grafts).

Patient Positioning

- The patient is positioned supine, and a shoulder roll is placed for neck extension.
- The head is supported by a small donut to prevent neck hyperextension.

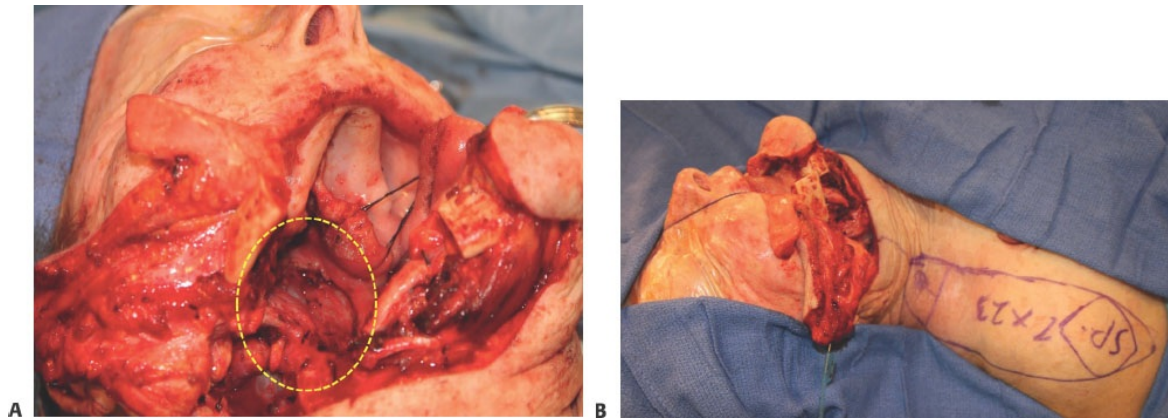
Preoperative Planning

- The position of the pedicle is estimated by marking the triangle formed by the clavicle inferiorly, sternocleidomastoid muscle anteriorly, and the trapezius muscle posteriorly (**FIG 2**).
- The position and patency of the supraclavicular artery can be confirmed using a handheld Doppler, and the axial direction of the pedicle can be traced onto the flap.
- Manual pinch test can confirm ability to primarily close the donor site.
- Arc of rotation is used to mark the distal aspect of the flap. Using a lap pad held at the level of the pedicle and marking the length of the flap is useful in this step.

TECHNIQUES

■ Markings

- The oropharyngeal defect is measured (**TECH FIG 1A**), and the supraclavicular skin is marked based on the arc of rotation and defect needs.
 - Generally speaking, the flap should be at least 1 to 2 cm wider than the defect to avoid closure of the defect in the pharynx under tension (**TECH FIG 1B**).
 - Flaps designed distal to the anterior deltoid muscle may become ischemic without a delay procedure. Distal flap necrosis will result in pharyngocutaneous fistulas and wound healing complications.
- A manual pinch test is used to confirm ability to close the donor site primarily.
- If primary closure of the defect is not feasible, a split-thickness skin graft can be harvested and applied with a VAC sponge bolster.

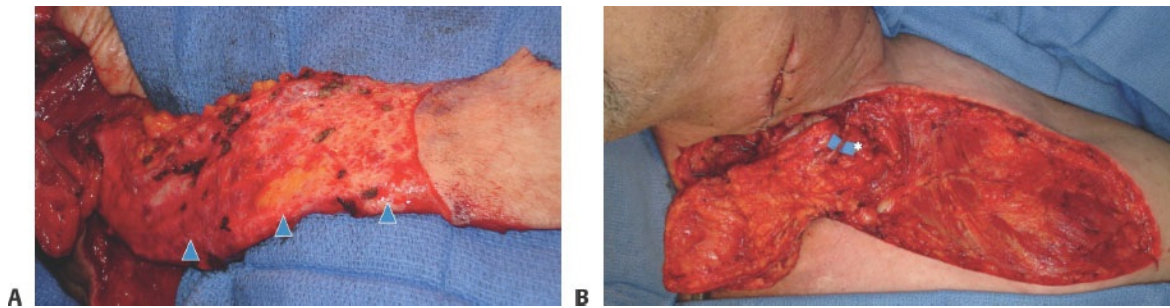


TECH FIG 1 • A. A 74-year-old woman with history of squamous cell carcinoma of right tonsil underwent composite resection including tonsillectomy, lateral pharyngeal wall, and soft palate (*circle*) through a lip-split incision. **B.** The oropharyngeal defect has been measured, and the flap has been marked out, measuring 7 × 23 cm. Manual pinch test confirmed laxity of the skin to allow primary closure.

■ Flap Harvest

- The skin over the deltoid muscle is incised, and the incision is carried down through the fascia of the anterior deltoid muscle.
- Flap dissection then proceeds rapidly in a subfascial plane from distal to proximal until the sternocleidomastoid muscle is exposed.
- At this point, the dissection proceeds proximally more carefully with blunt dissection and bipolar electrocautery to a point within 2 cm of the vascular pedicle.
- The vascular pedicle is not routinely skeletonized to avoid unnecessary trauma.
- A Doppler can be used to confirm vascular flow and the position of the pedicle on the undersurface of the flap as the dissection proceeds proximally.
- The SCAIF flap can be transferred as an island flap (ie, circumferential skin incisions around the marked flap; **TECH FIG 2A**) or as a transposed/interpolated flap maintaining the skin incisions around the proximal portion of the flap (**TECH FIG 2B**).

- The primary determinant of the type of flap is the arc of rotation that is required to reach the defect.
- Defects that can be easily reached by the transposed or interpolated flaps (ie, arc of rotation is less than 90 degrees, and there is no tension on flap inset) can be repaired with flaps that do not need incising the proximal skin markings.



TECH FIG 2 • A. The supraclavicular flap has been completely dissected and made into an island. The proximal portion is de-epithelialized (*arrowheads*) and ready to inset. **B.** The supraclavicular artery flap has been dissected from lateral to medial, and the neurovascular pedicle (*) has been skeletonized.

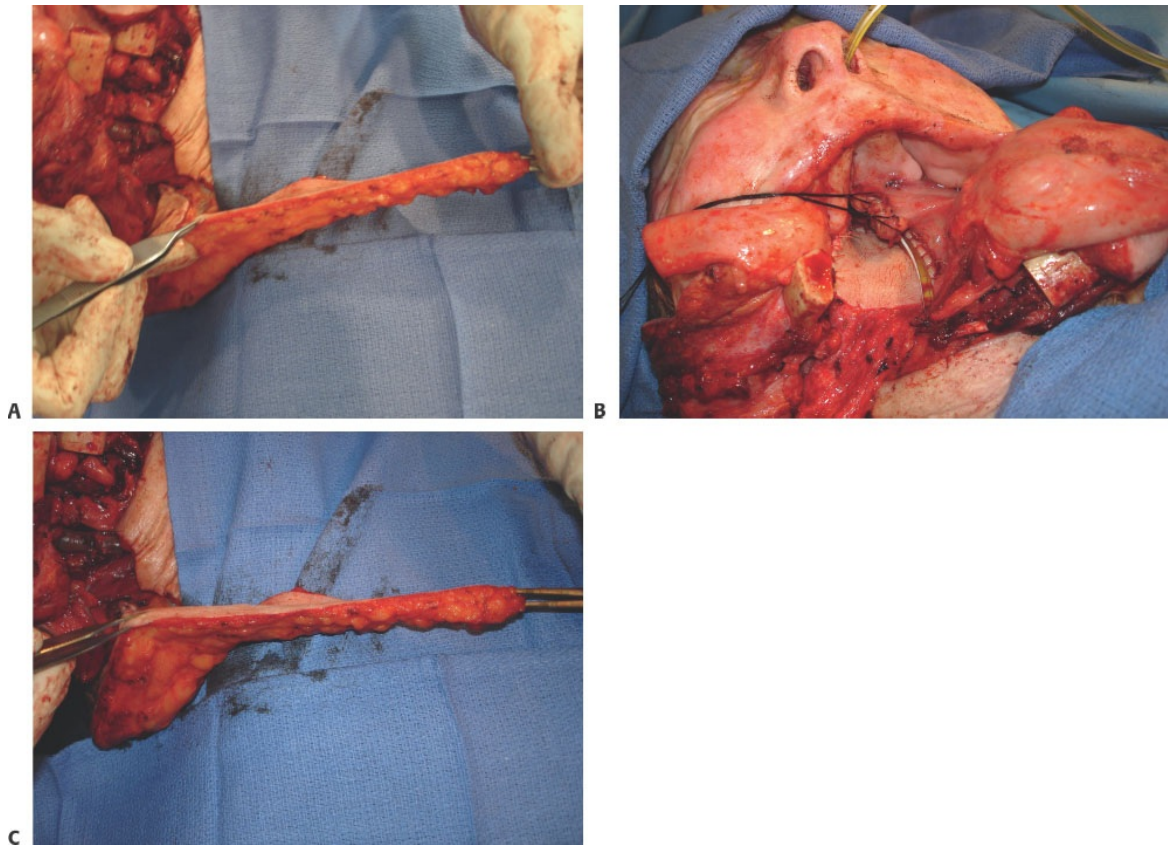
- The skin in these areas can be de-epithelialized and buried.
- This flap design maintains the best blood supply for the skin flap since the flap is supplied by both its axial blood supply as well as random branches through the proximal skin.
- If the flap is tunneled, however, care should be taken to prevent kinking or compression of the pedicle.
- In addition, if the flap is rotated at least 180 degrees, dissection of the vascular pedicle proximally should be considered to avoid compromise (see **TECH FIG 2B**).
- This type of flap is useful for defects that involve the middle or lower portions of the pharynx in which the SCAIF is turned over, tubed, or tunneled easily into the defect and the skin is inset into the defect in the correct orientation (ie, into the lumen of the pharynx).
- Defects of the oropharynx that are located above the tongue base or extend to the soft palate, as shown in this case example, are usually treated with

island flaps because this approach has increased flap reach and increased flap arc of rotation.

- In these cases, the flap dissection can be continued bluntly proximally to identify the flap pedicle, and the vessels can be dissected to avoid kinking the pedicle.
- The pedicle usually does not need to be skeletonized, however, and care should be taken to avoid injury to the venous drainage of the flap, thus avoiding venous congestion.

■ Flap Inset and Completion

- Once the flap is made into an island (**TECH FIG 3A**), it is inset into the pharyngeal defect by turning the patient's head away from the flap donor site (to set the maximum tension) and suturing the flap under no tension to the defect with interrupted 2.0 Vicryl sutures.
 - Care must be taken to achieve a watertight closure.
 - The proximal portion of the flap is de-epithelialized and used to fill dead space created by the resection (**TECH FIG 3B**).
- In rare cases, the flap can be thinned if it is excessively bulky; however, thinning within a 2-cm radius of the pedicle should be avoided (**TECH FIG 3C**).



TECH FIG 3 • A. The supraclavicular artery flap is made into an island, and the harvest is complete. **B.** It is rotated into the oropharynx. The proximal flap has been de-epithelialized (*arrowheads*), and the distal flap (*) is inset to cover the defect. **C.** The flap can be thinned primarily, with care to avoid thinning the flap within a 2-cm radius of the perforator.

- The neck skin is closed in layers by reapproximating the platysma with 2-0 Vicryl sutures and the skin with 4-0 nylon sutures.
- The donor site is closed by undermining the surrounding skin and closing in a layered fashion.
 - If the donor site cannot be closed primarily, a split-thickness skin graft is harvested, sutured into place with chromic sutures or staples, and bolstered with a VAC dressing.
- A single large Jackson-Pratt type drain is placed in the neck. Drains are not usually necessary in the donor site but may be used at the surgeon's

discretion.

- Tracheostomy ties and pressure around the donor site and vascular pedicle should be avoided.
 - The position of the pedicle is usually marked on the neck to avoid postoperative pressure.
- Dry dressings may be used if desired. Alternatively, bacitracin ointment can be applied to the donor site and neck wound for 24 hours until the skin is sealed.

PEARLS AND PITFALLS

Indications and assessment

- The SCAIF flap is an excellent choice for reconstruction of oropharyngeal defects.
- The flap is simple to harvest, has reliable anatomy, and is versatile.
- The donor site is relatively inconspicuous and well tolerated.

Flap design

- A lap pad may be used to estimate the length of flap and arc of rotation.
- Making an island of the flap with dissection of the pedicle increases the arc of rotation and flap reach without tension. However, pedicle dissection should be performed carefully to avoid venous congestion
- Avoid marking flaps distal to the anterior deltoid (high risk for distal tip necrosis). Flap delay may be helpful in these cases.

Technique

- Handheld Doppler or flap transillumination can be performed to localize the pedicle from the undersurface of the flap and avoid injury.
- Leaving a cuff of fascia and subcutaneous fat around the pedicle, even in cases where the flap is made into an island, is useful for avoiding injury to the vessels during flap dissection.

Postoperative care

- Avoid compression of the pedicle with trach ties.

POSTOPERATIVE CARE

- The patient is maintained nil per os (NPO) for 5 to 7 days with standard mouth care.

- Antibiotics with Gram-positive, Gram-negative, and anaerobic coverage are maintained for 24 to 48 hours in uncomplicated cases.
- In patients with contaminated wounds (ie, fistulas), history of radiation therapy, or factors that increase wound healing complications (eg, long smoking history, diabetes, obesity), antibiotic coverage may be maintained for a longer period of time at the surgeon's discretion.
- A swallow study is performed on POD 5 to 10, either a clinical bedside or a formal study with contrast dye, to confirm that the wound is water tight.
- In patients with a history of radiation, contaminated wounds, or history of salivary fistulas, longer periods of time may be required for healing (often 10–14 days prior to swallow).
- Physical therapy and rehabilitation for upper extremity range of motion and strengthening can begin 2 to 3 weeks postoperatively.
- Long-term outcomes are excellent with rapid healing, return to function, and acceptable donor site scarring in most patients (**FIG 3**).

OUTCOMES

- The success rate of SCAIF is very high, and total flap loss is rare.
- Functional deficits from the donor site are rare. But patients who have had previous neck dissections and radiation therapy may have decreased range of motion and strength that can be exacerbated by the SCAIF harvest. These patients should be referred for physical therapy as early as possible.

COMPLICATIONS

- Distal flap ischemia and necrosis may occur if the flap is marked beyond the vascular territory of the supraclavicular artery (distal to the anterior deltoid).
 - This may be avoided in some cases with a preoperative delay of the flap performed 2 to 3 weeks prior to the anticipated extirpative procedure.

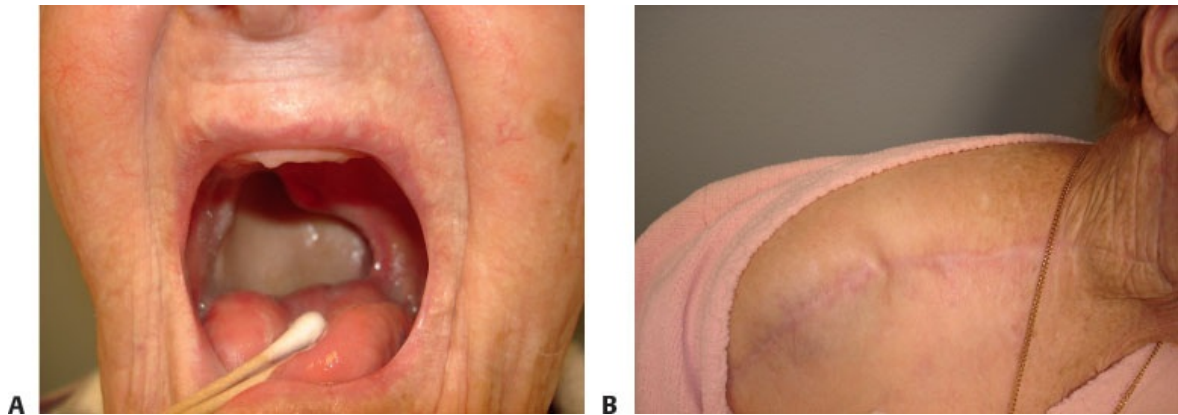


FIG 3 • One-year postoperative follow-up shows a healed, well-mucosalized supraclavicular flap in the oropharynx **(A)** and a well-healed, primarily closed, donor site scar **(B)**.

- Venous insufficiency can occur due to excessive rotation, tension on inset, compression from flap tunneling (especially in radiated skin), and tracheostomy ties.
- If the flap shows vascular compromise, inset stitches can be removed, leech therapy, nitroglycerin paste, or supercharging the flap with an additional venous anastomosis or derotating the flap and delaying definitive reconstruction. However, these techniques are often not feasible in oral cavity reconstruction.
- Donor site wound dehiscence may occur in excessively wide flaps. Therefore, if closure is too tight, then consider tissue expansion or skin grafting.
- Hematoma can cause airway compromise, wound healing complications, and flap loss.
 - Ensure adequate hemostasis at end of case and intervene as quickly as possible to avoid flap compression and airway compromise.
- Orocutaneous fistula formation is a relatively common complication of oropharyngeal reconstruction occurring in 5% to 35% of patients.
 - The risk of this complication increases significantly with preoperative radiation therapy. This risk can be mitigated with the use of meticulous technique for flap inset. Using the de-epithelialized component of the flap to bolster the repair and obliterate dead space is also useful.
 - Most orocutaneous fistulas heal spontaneously with good local wound care

and bypass of the oropharynx with a gastric tube for feeding.

- Fistulas that do not heal or close spontaneously within 3 months of surgery may require additional surgery.
- Strictures are also a frequent complication following oropharyngeal reconstruction particularly in patients treated with preoperative or postoperative radiation.
- Most of these cases can be treated with endoscopic dilatation; however, in rare cases, additional surgical intervention is necessary.
- Referred shoulder sensation and dysesthesia with swallowing can occur particularly if the flap is neurotized for oropharyngeal or oral cavity reconstruction.²

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Section XII: Facial Nerves

Facial Reanimation in the Oncologic Patient Using Nerve Grafts and Nerve Transfers

49
CHAPTER

Joseph H. Dayan

DEFINITION

- Facial reanimation in the setting of parotid tumors can be challenging, sometimes with unpredictable functional and aesthetic outcomes.
- Additionally, patients with locally advanced disease may not be ideal for multiple stage procedures over the course of several years.
 - A rapid and reliable functional result with the least number of procedures becomes a priority.
- This chapter focuses on reanimation strategies mainly using nerve grafts and nerve transfers depending on the clinical scenario.
 - Dynamic panfacial reanimation is the goal.
 - The reanimation procedures presented in this chapter are ideally performed at the time of tumor ablation if possible.

ANATOMY

- The masseter muscle is one of the muscles of mastication.
 - It arises from the lower border and medial surface of the zygomatic arch and inserts into the lateral surface of the mandible (**FIG 1**).
 - The muscle consists of three layers—superficial, middle, and deep.

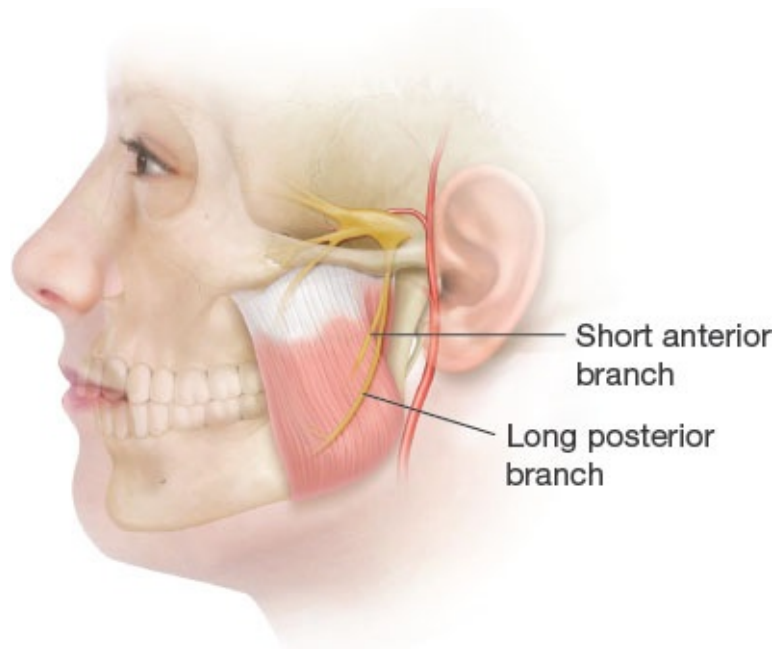


FIG 1 • Topography of the motor nerve to masseter. The main trunk typically divides into a long posterior branch and a shorter anterior superior branch.

- The superficial muscle fibers pass backward and downward; the deeper fibers are more vertical. The motor nerve to the masseter is derived from the mandibular division of the trigeminal nerve. It leaves the infratemporal fossa by passing over the lateral pterygoid muscle and mandibular notch. It enters the masseter muscle from its deep surface and courses down between its deep and middle layers by having a diameter of 1 to 2 mm. It becomes more superficial distally toward the anterior inferior part of the muscle and runs alongside the (friable) vascular pedicle that arises from the inferior alveolar artery.
- The facial nerve exits the stylomastoid foramen, turns superficially, and immediately enters the substance of the parotid gland where it is classically described as dividing into five branches—temporal (frontal), zygomatic, buccal, mandibular, and cervical.
- The nerve usually divides into upper (temporal) and lower (cervical) trunks at first, from which these branches arise. In practice, they constitute five variably interconnected groups of branches hereafter referred to as divisions.
- Despite the various studies of facial nerve anatomy, it may be more useful to envision the facial nerve as consisting of physiological and functional

divisions that do not necessarily correlate to the anatomic distribution of branches but instead relate to muscular groups and actions.

- The temporal branch of the facial nerve exits from the upper pole of the parotid gland at the level of the zygomatic arch and becomes superficial being plastered onto the underside of the temporoparietal fascia.
- The course of the nerve follows a line drawn from 0.5 cm below the tragus to 1.5 cm above the eyebrow, but 3D modeling demonstrates the branches cover a triangular area bordered between a line through the palpable zygomaticofrontal and zygomaticotemporal sutures and a vertical line 1 cm in front of the auditory meatus.
- At the lateral margin of the frontalis, these branches run deep to frontalis and orbicularis oculi (which it innervates), eventually reaching the glabella region to supply the depressors of the brow.
- The zygomatic division leaves the parotid gland to run just inferior the zygomatic arch immediately deep to the superficial musculoaponeurotic system (SMAS) to innervate the elevators of the upper lip and lower portion of orbicularis oculi.
- Distally, it runs on the undersurface of the zygomaticus muscle complex before ramifying more medially in the face. The buccal branches exit the anterior border of the parotid gland and run inferior to the parotid duct and on the surface of the buccal fat pad deep to the SMAS layer to supply the muscles of the mouth and cheek.
- Both zygomatic and buccal divisions have a highly overlapping distribution of innervation that allows transection of one or more branches without weakness; this is the basis of cross-facial nerve grafting.
- The mandibular branch leaves the lower portion of the parotid gland and swings down below the ramus of the mandible to supply the muscles of the lip and chin.
- Cadaveric dissections demonstrate that the nerve always comprises at least three major branches that run on the undersurface of the platysma and superficial to the facial vessels.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Unlike the nononcologic patient population, many of these patients receive adjuvant radiotherapy, with resulting volume loss and tissue contracture, and potentially negative effects on neurotization.
- While smile is often the most visually impressive feature to reanimate, the

patient's blink is the most time-sensitive and important function in terms of daily living.

- Once the patient has been denervated for over 2 years and the orbicularis oculi has atrophied beyond salvage, it becomes very challenging to recreate a blink.
- In contrast, a smile can be reliably restored years after irreversible denervation with a free gracilis or temporalis transfer.
- This is also the reason the author generally reserves temporalis transfer for cases in which native facial musculature is unsalvageable, as the temporalis generally does not restore eye closure.
- Lower lip motion and depression complete a symmetric outcome.
- If the patient presents within 2.5 years after the initial denervation, a needle electromyography (EMG) is performed specifically to assess viability of the orbicularis oculi, zygomaticus major, and depressor anguli oris.¹
- If there is muscle viability, nerve-to-masseter and minihypoglossal transfers are typically performed; if there is no viable muscle, functioning muscle transfer is required.

SURGICAL MANAGEMENT

- The first choice in nerve reconstruction of a discreet segmental defect is always primary nerve grafting. Only the facial nerve can provide spontaneous facial motion.
- The ideal patient is one that has a relatively short segmental defect, no tumor in the proximal facial nerve trunk, and no prior radiation (**FIG 2**).
- An anterolateral thigh free flap provides not only soft tissue replacement to fill the defect but also donor nerve graft in the form of a motor branch to the vastus lateralis muscle. The nerve can be left attached to the pedicle as a vascularized nerve graft or, more commonly, harvested separately to allow for greater freedom of inset.

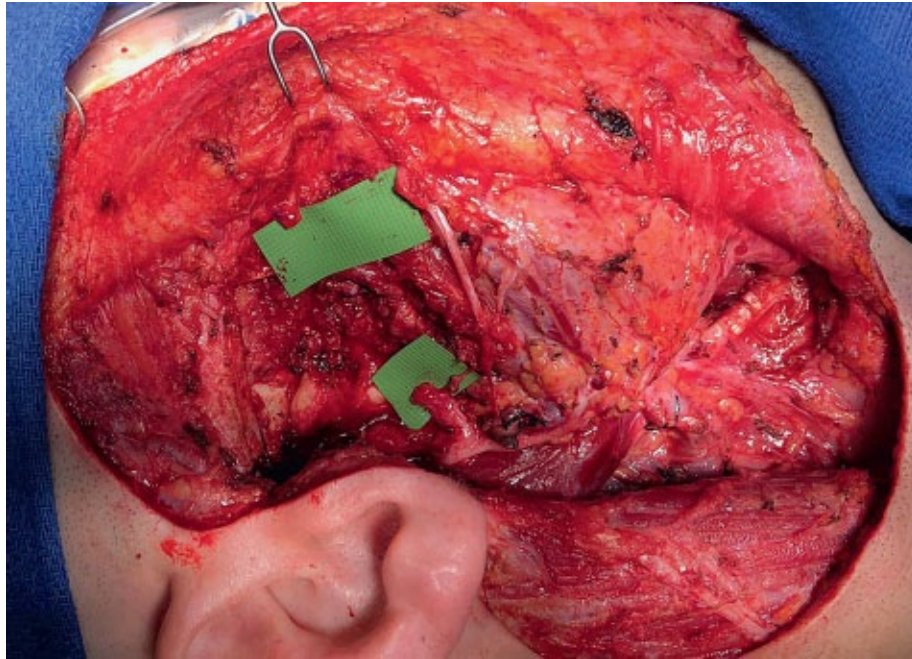


FIG 2 • This patient has undergone parotidectomy for adenoid cystic carcinoma with transection of the upper division of the facial nerve. He will lack brow elevation, blink, and smile. Additionally, he will be receiving adjuvant radiotherapy and has a significant volume deficit that can be disfiguring. This discreet defect with no microscopic disease proximally is ideal for primary nerve grafting.

- Patients who do not have a reliable proximal facial nerve stump available can have smile and at least lower eyelid motion restored with a nerve-to-masseter transfer. This will provide volitional but not spontaneous and emotional motion of the zygomaticus major and orbicularis oculi complex in 3 or 4 months.
- While not ideal, nerve-to-masseter transfer is highly reliable, and some patients may not require an upper eyelid weight and frequent eye drops once reinnervation is complete.
- In cases in which there is no proximal facial nerve trunk available, the author's practice has evolved to using dual nerve transfers so as to avoid a grotesque mass facial motion from a single nerve transfer to all distal branches.
- The patient is evaluated preoperatively to confirm normally functioning masseteric and hypoglossal nerves. If there is a deficiency, these nerve donors

are avoided, and other donors such as the spinal accessory nerve can be considered.

- Cross-face nerve grafting provides the potential for spontaneous motion when the ipsilateral facial nerve is unavailable.
- One significant drawback of this technique is the variability in strength of the outcome compared with nerve transfers that deliver reliable power but cannot compete with cross-face nerve grafting in terms of spontaneity.
- It is also most commonly performed in two stages, which may not be feasible in cases of more advanced disease.
- For patients in whom the ipsilateral nerve is unusable, however, this is the only procedure that provides spontaneous motion.

TECHNIQUES

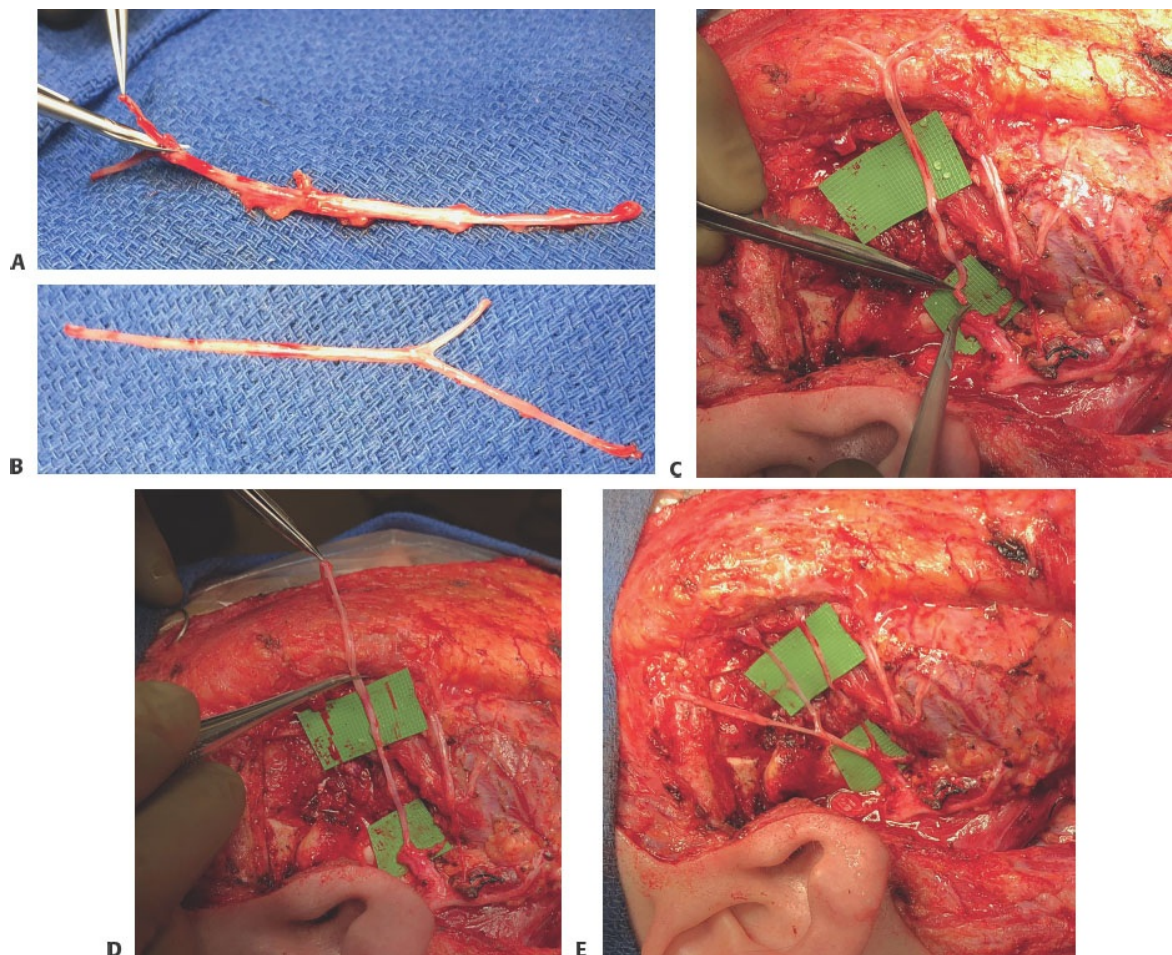
■ Nerve Grafting and Direct Repair

Nerve Reconstruction

- Following nerve harvest, the nerve is carefully prepared by removing the adventitia (**TECH FIG 1A**).
 - In theory, this maximizes the likelihood for nerve graft take and survival in the way a thinner skin graft has higher survivability than a thicker composite graft (**TECH FIG 1B**).
- The nerve is then brought to the field, and a neurorrhaphy is performed from the inferior fascicles of the upper division of the facial nerve to the distal zygomatic facial nerve branch for smile (**TECH FIG 1C**).
- An epineurial repair is performed with 10-0 nylon suture.
 - Ideally, during the time of tumor ablation, the specific fascicular bundles from the proximal facial nerve are stimulated and mapped to match the distal remnant facial nerve branches targeting smile and blink.
- Following proximal neurorrhaphy, the nerve graft is divided to allow adequate length for tension-free nerve repair (**TECH FIG 1D**).
- The distal end of the nerve graft is now repaired to the distal zygomatic branch for smile, typically running alongside the transverse facial artery.
 - Either 10-0 or 11-0 nylon is used, depending on the caliber of the nerve at this level. In this case, there is a single cable graft repaired in antegrade

fashion.

- If sural nerve graft is used, the proximal sural nerve is repaired in antegrade fashion, where there is not much branching from the sides.
- Once the sural nerve is harvested distal to where the medial and lateral sural nerves join, there is often significant branching, and a reverse orientation of the nerve may be preferable to minimize loss of axons through side branches in the nerve.
- The remaining nerve graft has a Y orientation, and this is repaired proximally to the more superior nerve fascicular bundles destined for blink.
- The two ends of the Y are then repaired to distal facial nerve branches targeted for blink (**TECH FIG 1E**).

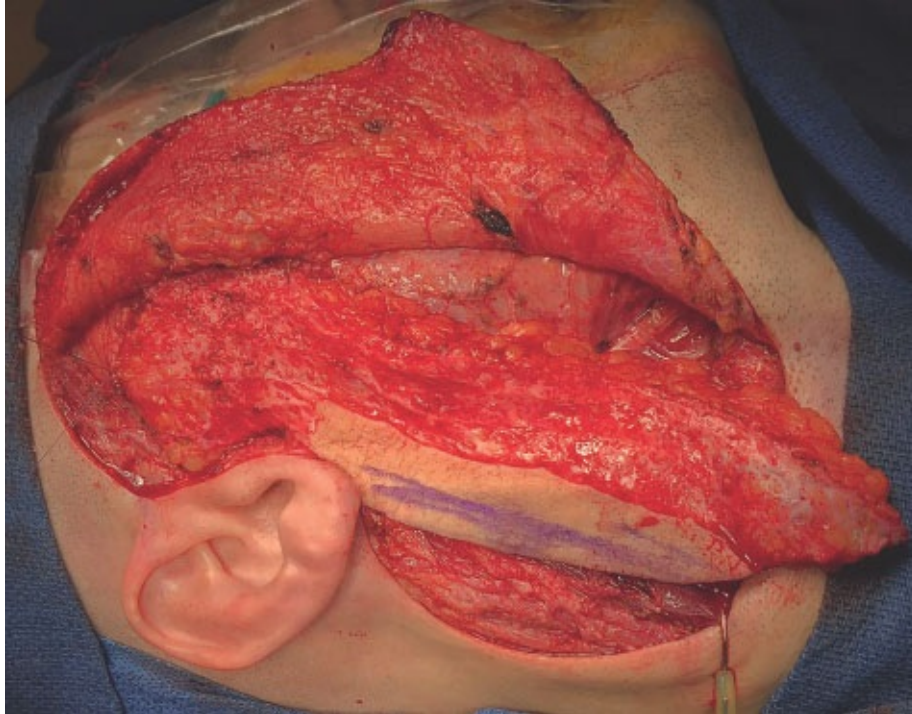


TECH FIG 1 • **A.** Adventitia is removed from the nerve graft that was harvested with the anterolateral thigh flap using a branch of the motor nerve to the vastus

lateralis. **B.** Nerve graft completely cleaned of adventitia. **C.** Epineurial nerve repair to the stump of the upper division of the facial nerve. **D.** Measuring the nerve graft required and precisely trimming to length as needed. **E.** Primary nerve grafting completed and repaired to distal facial nerve stumps for blink and smile.

Free Flap Defect Repair

- The facial nerve reconstruction is now complete, but a significant volume defect remains. Without volume replacement, the skin will contract and adhere to the masseter muscle, the ear may become sunken and tethered, and secondary nerve surgery in this region could be potentially hazardous.
- At this point, an adipofascial anterolateral thigh free flap is precisely shaped and inset, typically using the facial artery or superior thyroid artery and branch of the internal jugular vein as recipient vessels (**TECH FIG 2**).
- In cases in which direct nerve repair is challenging, as in a significant caliber mismatch or fascicular bundles that easily spread apart due to a flimsy epineurium, a nerve conduit is very useful and may provide a better outcome.^{2,3}
- There are a variety of choices available, including autologous vein as well as manufactured options, such as the porcine submucosal nerve tube.



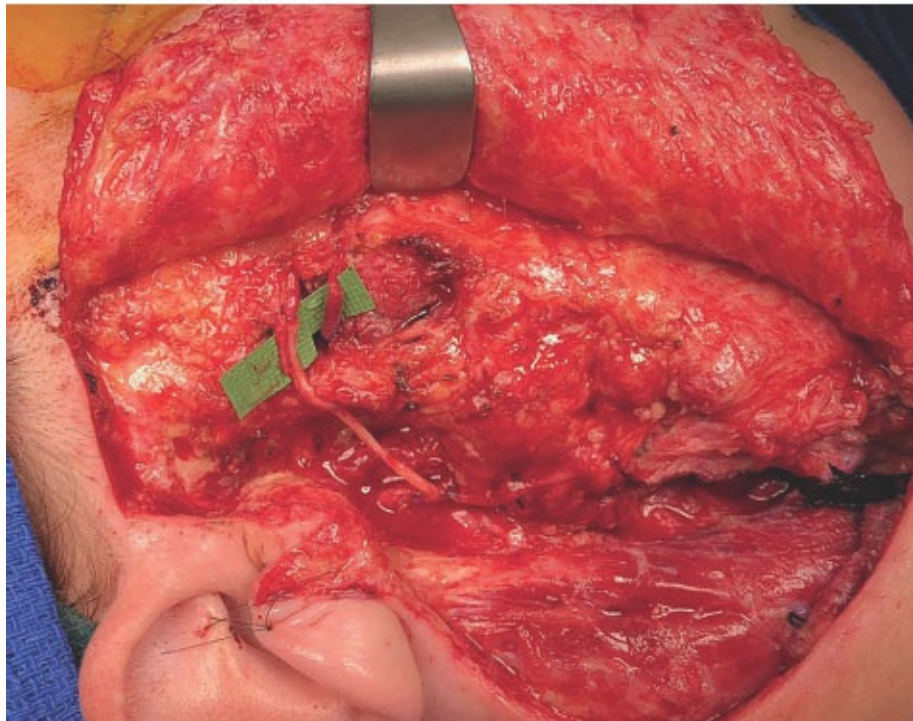
TECH FIG 2 • Adipofascial anterolateral the free flap to cover the nerve repairs and to maintain normal facial contour following radiotherapy.

■ Nerve-to-Masseter Transfer

- The nerve transfer procedure begins with palpating the corner where the inferior border of the zygomatic arch reaches the anterior border of the neck of the mandible.
- A horizontal incision at the inferior border of the zygoma is then made, and the posterior third of the superficial head of the masseter muscle is divided.
 - A whitish musculotendinous layer is then encountered, marking the start of the deep head of the masseter muscle.
 - The nerve lies within the deeper layers of this portion of the muscle.
- Using a nerve stimulator and bipolar cautery, sequential division of the deep head is performed layer by layer until the nerve to the masseter is identified.
 - It always runs with a vascular pedicle so if one encounters bleeding, cautery should not be used in order to avoid occult injury to the nerve.
- Gentle pressure is applied until bleeding is arrested, and the nerve is then unroofed and mobilized distally (inferiorly) until it begins to arborize where

it is divided and transposed anteriorly for nerve repair.

- This descending main trunk of the nerve to the masseter is generally used, and the smaller transverse branch of the nerve coursing anteriorly can be left intact to maintain some masseter function.
- Complete sacrifice of all masseteric branches will result in atrophy of the masseter muscle that may be particularly visible if no autologous tissue transfer was used to cover the parotidectomy defect.
- The nerve to the masseter can be repaired either directly with an epineurial repair to the distal facial nerve target or using a porcine nerve tube (**TECH FIG 3**).
- The donor and recipient nerves are telescoped into the tube until they just make contact.



TECH FIG 3 • Patient with sacrifice of the upper division of the facial nerve following parotidectomy with residual microscopic disease present in the proximal stump. Both nerve graft and a supplemental nerve-to-masseter transfer were used in the event the microscopic disease renders the nerve graft

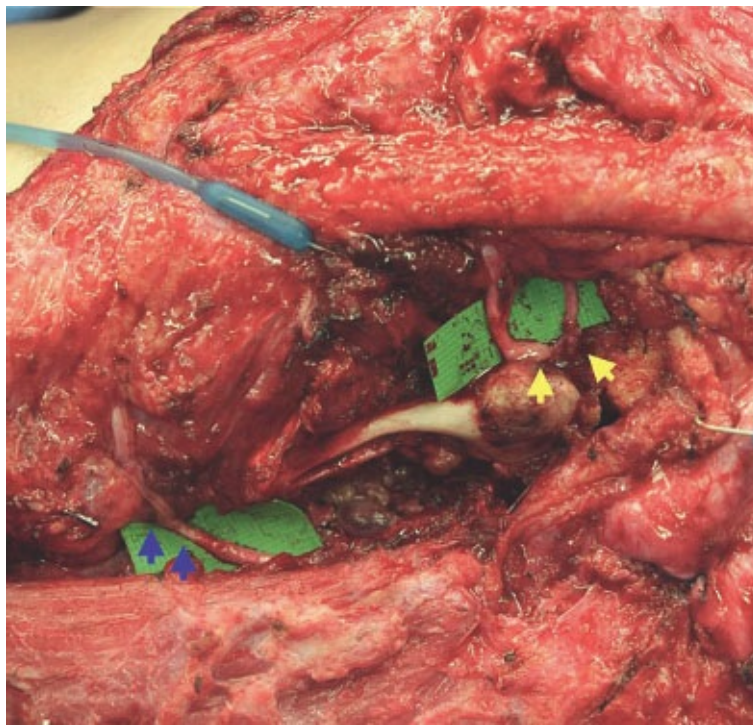
inadequate. A porcine nerve tube was used for neurorrhaphy from the nerve to the masseter to the zygomatic facial nerve branch for smile and lower eyelid motion.

- Two 9-0 nylon sutures are then placed at either end of the tube, 180 degrees apart, and sutured to the adventitia of the nerves to secure the tube.
- A nerve conduit may be preferable in cases where a flawless primary repair is not possible.
- Nerve caliber mismatch and the lack of a cohesive group of fascicles are situations where primary repair can be challenging.
- The specific target for nerve transfer is at the surgeon's discretion based on intraoperative stimulation of the distal facial nerve branches if performed at the time of ablation.
 - In the delayed setting, in which nerve branches cannot be stimulated, the zygomatic branch running with the transverse facial artery is commonly a target for nerve transfer.
 - Adjacent nerve branches can also be recruited and repaired in an end-to-side fashion to small side branches off of the main masseteric nerve trunk for more widespread reinnervation.
 - These reconstructions are typically covered with an anterolateral thigh adipofascial free flap for contour restoration.
- The patient is placed on a soft diet for 10 days to avoid aggressive masseteric contraction, which could disrupt the nerve repairs.

■ Dual Minihypoglossal and Masseteric Nerve Transfers (Dual Babysitter)

- The nerve-to-masseter transfer is performed as described above to the upper division of the facial nerve.
 - Additionally, a minihypoglossal nerve transfer is performed to the lower division of the facial nerve to restore lower facial motion.
- Once the hypoglossal nerve is identified beneath the digastric muscle just superficial to the carotid artery, an epineurial window is created on its cranial surface as previously described by Terzis.^{4,5}

- Up to 40% of the cross-sectional area of the cranial portion of the hypoglossal nerve can be transected without significant harm to hypoglossal function.
- In the author's practice, 30% of the nerve is incised, longitudinal to the fibers using a diamond knife until the fascicles are bulging out of the window.
- The surgeon must be confident that axotomies have been incurred to ensure axonal sprouting into the distal facial nerve target.
- The distal facial nerve branches, typically the marginal mandibular branch (**TECH FIG 4**) and oftentimes an additional buccal or cervical branch, are then sewn end to side to the hypoglossal nerve using 10-0 nylon suture.
- A short nerve graft may be necessary if the patient has a particularly long neck or if the parotidectomy defect extends very anteriorly.



TECH FIG 4 • A patient with adenoid cystic carcinoma of the parotid gland required radical parotidectomy with partial temporal bone resection and no usable proximal facial nerve stump. He underwent a nerve-to-masseter transfer to two distal zygomatic facial nerve branches (*yellow arrows*) and minihypoglossal nerve

transfer using end-to-side neurorrhaphy to the marginal mandibular nerve (*blue arrows*). An adipofascial anterolateral thigh free flap was placed over the nerve transfers to mitigate cosmetic distortion following radiation and provide cushion over the delicate nerve repairs in case of future surgical revision.

■ Cross-Face Nerve Grafts

Facial Nerve Exposure

- The approach begins with the unaffected side, where a modified preauricular facelift incision is made with an extension anteriorly below the mandibular border to expose the entire facial nerve.
 - Lidocaine and paralytics are avoided to ensure nerves can be reliably stimulated.
- The SMAS is elevated off of the capsule of the parotid gland where facial nerve branches can be seen at the anterior border of the parotid.
- Using a micromosquito dissector, a major zygomatic or buccal branch is identified by carefully spreading parallel to the direction of the fibers.
- The nerve is then unroofed proximally until the upper division and then the main trunk are encountered.
 - The entire nerve can then be exposed and mapped using a nerve stimulator.

Donor Nerve Selection

- Two dominant variables in decision-making on the input side of the reanimation are axonal load and nerve donor selection.
 - Axonal load has previously been shown to directly affect the power of muscle excursion.^{6,7}
 - The more the axons entering the graft, the more the power driving the targeted muscle.
- Nerve donor selection is equally critical because selecting the wrong nerve will lead to a failed reinnervation and synkinesis.
- Panfacial reanimation is the goal, with typically three cross-face nerve grafts placed for blink, smile, and lower lip depression.

- Crippling the normal side is avoided by ensuring that at least one nerve branch providing blink, smile, and lower lip depression is left intact.
- The facial nerve branch providing a pure blink with both superior and inferior portions of the orbicularis oculi muscle firing on stimulation is the nerve donor target.
- The more proximal the donor nerve is transected, the greater the axonal load. The nerve is taken as proximally as is feasible as long as an additional nerve providing blink is left completely intact.
- The same decisions are made for smile and lower lip depression using careful intraoperative stimulation.
- 0.5 milliamps is all that is required for stimulation, and the nerve should be completely dry.
- Inhalation agent is also turned off prior to facial nerve mapping as it may interfere with nerve stimulation.

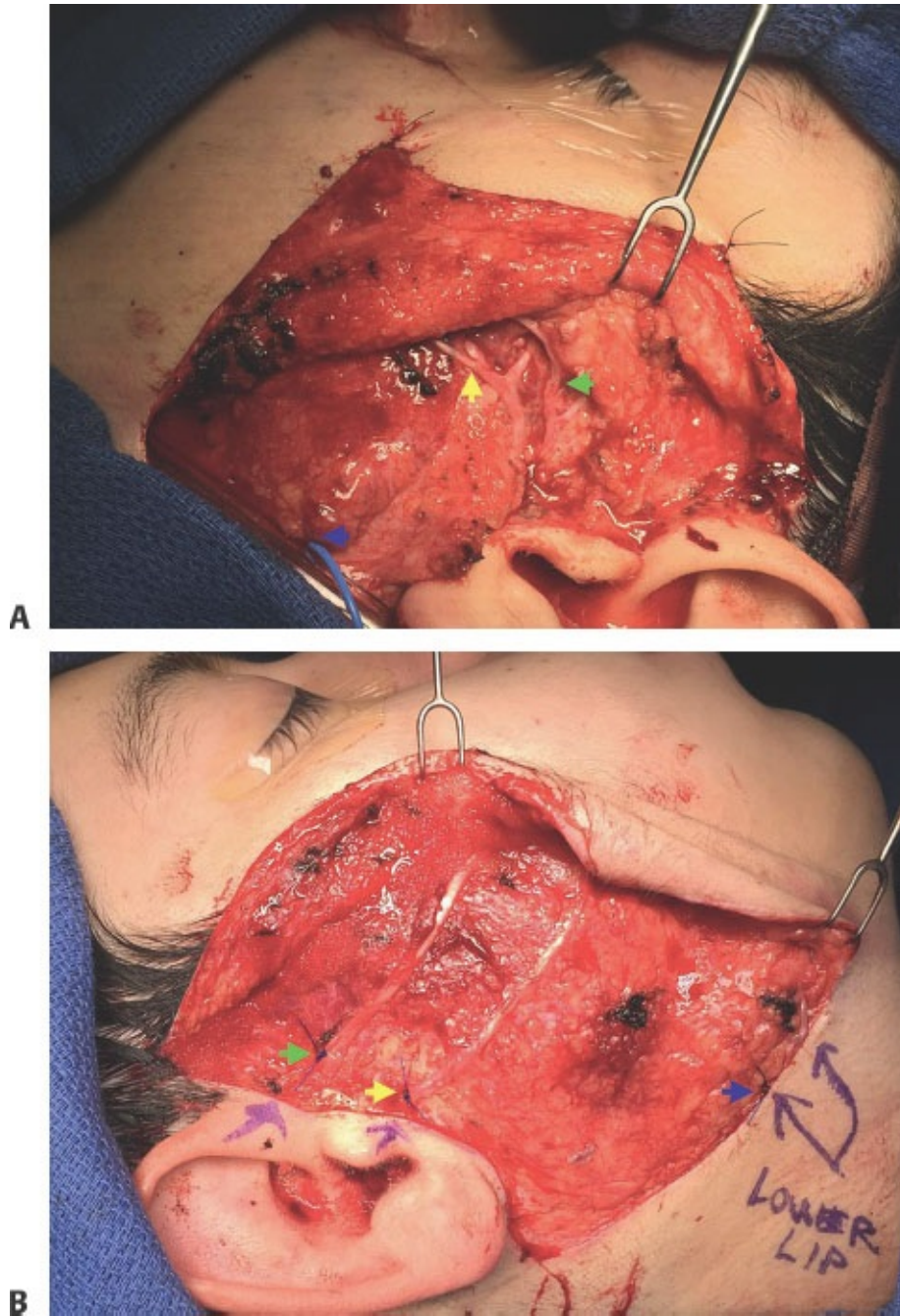
Tunnel Creation and Nerve Reconstruction

- Once nerves are selected and transected, subcutaneous tunnels are created and open up into the paralyzed side of the face, where a similar modified facelift incision is made.
- Two tunnels are made separately for smile and blink, one traveling just under the nose and one traveling just above the upper lip.
- One tunnel for two nerves can lead to unwanted synkinesis through cross-innervation between adjacent nerve grafts.
- The tunnel for lower lip motion is made below the mandible around the top of the neck.
- Bilateral sural nerves are harvested using a stair-step technique, with the proximal two-thirds of each sural nerve used for blink and smile and the distal thirds of the sural nerves sewn together for use in lip depression.
- Alternatively, saphenous nerve can be used. Twenty-five centimeters of nerve graft can reliably cross the entire face.
- The nerve grafts are then carefully repaired to their respective nerve donors on the normal side (**TECH FIG 5A**) and tunneled to the paralyzed side.
- The nerves are then secured to the preauricular region with 4-0 Prolene suture, and a photo is taken to mark the specific location of these nerves for reference in the second stage (**TECH FIG 5B**).
- The patient is followed with tapping the face along the length of the nerves, hopefully eliciting a Tinel's, which should progressively migrate across the

face.

Stage 2

- The second stage is performed 9 to 12 months later, when the distal ends of the nerves are identified and trimmed back at least 1 cm or more to healthy tissue.
- Frozen section biopsy of the nerve can confirm if there are viable-appearing axons and fascicles.
- If the patient had a babysitter or dual babysitter procedure and the muscle excursion is powerful, at least 50% of the fascicles receiving innervation from the babysitter are transected and plugged into the respective cross face nerve graft.



TECH FIG 5 • A. Three cross-face nerve grafts placed in the donor side for blink (*green arrow*), smile (*yellow arrow*), and lower lip depression (*blue arrow*). **B.** The same cross-face nerve grafts inset on the paralyzed side for future use. Blink (*green arrow*), smile (*yellow arrow*), and lower lip depression (*blue arrow*).

- If, however, the babysitter procedure resulted in a moderate or weak excursion, free functioning muscle in the form of a gracilis for smile is typically used on top of the partly functioning native musculature.
- If there is no muscle function, depending on the surgeon's confidence in the cross-face nerve graft, a dual-innervation approach can be performed using the nerve to masseter and the cross-face nerve graft plugged into the obturator nerve to the gracilis.
 - Functioning gracilis transfer is covered in another chapter of this text.
 - Regarding restoration of blink and lower lip depression, the platysma and digastric muscles can be used, respectively, as previously described by Terzis.^{8–10}

PEARLS AND PITFALLS

Timing	■ Perform facial reanimation at the time of tumor ablation when possible.
Graft choice	■ Ipsilateral nerve graft is the first choice when reliable.
Blink	■ Prioritize restoration of blink by neurotizing native orbicularis oculi if viable.
Nerve transfer	■ Use nerve transfers if proximal facial nerve stump is unreliable, if there is disease in the proximal stump, or if there was prior radiation.
Flaps	■ Liberally use adipofascial free flaps for parotidectomy bed reconstruction to mitigate the effects of radiation.



FIG 3 • A. Early postoperative result prior to nerve reinnervation following radical parotidectomy, temporal bone resection, dual babysitters, and adipofascial anterolateral thigh free flap. **B.** One year postoperative result following external beam radiotherapy with satisfactory recovery of pan-facial motion. No eyelid weight or eye drops were required.

OUTCOMES

- The early postoperative results of the patient in **TECH FIG 4** are shown in **FIG 3**.

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Temporalis Flap and Lengthening Temporalis Myoplasty for Facial Paralysis

50

CHAPTER

Andre Panossian

DEFINITION

- Facial paralysis is the result of facial nerve dysfunction (cranial nerve VII). It can be congenital or acquired, bilateral or unilateral. Patients with facial paralysis exhibit drooping of the lower face and loss of lip closure/elevation.
- Muscle transfers are indicated in cases of long-term, or permanent, facial paralysis (greater than 18 months).
- Regional or free muscle transfer can restore unidirectional movement of the lips and lower face by using branches of the contralateral facial nerve or unaffected ipsilateral cranial nerves (eg, trigeminal nerve branches for mastication [V3]).
- The temporalis flap is a procedure for transferring the function of the ipsilateral temporalis muscle in a retrograde, or “turnover,” fashion to the lips and oral commissure for the purpose of reanimating the lower face. The methods outlined herein include further refinements to the techniques originally developed by Gillies.
- The lengthening temporalis myoplasty is a procedure for reorganizing and transferring the function of the ipsilateral temporalis muscle in an orthodromic fashion to the lips and oral commissure for the purpose of reanimating the lower face. The methods outlined herein include further refinements to the techniques originally developed by McLaughlin¹ and refined by Labbé.^{2,3}

ANATOMY

- The temporalis is one of four muscles of mastication (innervated by cranial nerve V). It is a broad muscle that originates in the temporal fossa and inserts onto the coronoid process of the mandible.
- The temporalis consists primarily of two layers, deep and superficial, that converge onto a single tendon (**FIG 1A**). The tendon is broad and wraps around the coronoid process in a conical fashion, extending down onto the ramus for several millimeters.
- The muscle is dually innervated at the infratemporal crest by the deep temporal nerves (from the mandibular division of the trigeminal nerve V3). It also has dual circulation from the deep temporal arteries (branching from the maxillary artery) (**FIG 1B**).
- Muscle fibers from the masseter and the pterygoids attach to portions of the temporalis tendon as it passes through the zygomatic, or infratemporal, fossa.

PATHOGENESIS

- There are numerous causes of facial paralysis that are broadly classified as congenital or acquired.
- The most common form is acquired complete unilateral facial nerve palsy of an inflammatory etiology (ie, Bell palsy). Although most cases will resolve spontaneously, a small number of patients will continue to experience persistent facial paralysis or weakness causing noticeable asymmetry of function and appearance.
- The cause of a patient's paralysis must be investigated in order to direct treatment and estimate prognosis for recovery.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Preoperative evaluation of patients with facial paralysis includes a detailed history and assessment of the patient's current facial nerve function and secondary deformities.
- History
 - Etiology (trauma, viral, tumor, syndromic, etc.). It is important to determine whether the cause is congenital or acquired.
 - Associated symptoms (vertigo, tinnitus, vision changes, ataxia, apraxia, symptoms related to other cranial nerve palsies, stroke, etc.)
 - Treatments administered to date (radiation, slings, canthoplasty, muscle flaps, etc.)
 - Unilateral vs bilateral and complete vs partial facial paralysis

- Time course
 - Early: less than 12 months
 - Intermediate: 12 to 18 months
 - Late: greater than 18 months
- Physical examination is used to determine the location and extent of facial paralysis and resulting deformities. In addition, physical examination should document function of other cranial nerves and assess potential causes of facial paralysis (if possible).
- For assessment of facial paralysis and its sequela, the face is divided into thirds.
 - Upper third: Paralysis of the upper face results in brow ptosis, lack of forehead rhytides, and compensatory contralateral forehead elevation.
 - Middle third: Middle third paralysis results in incomplete eyelid closure with lower lid malposition (lagophthalmos and ectropion). The physical examination should document Bell phenomenon (a defensive movement of the eye that is present in most patients resulting in upward movement of the eye with eye closure) and reliance on eye lubricants. In addition, symptoms of epiphora and dry eyes should be elicited.

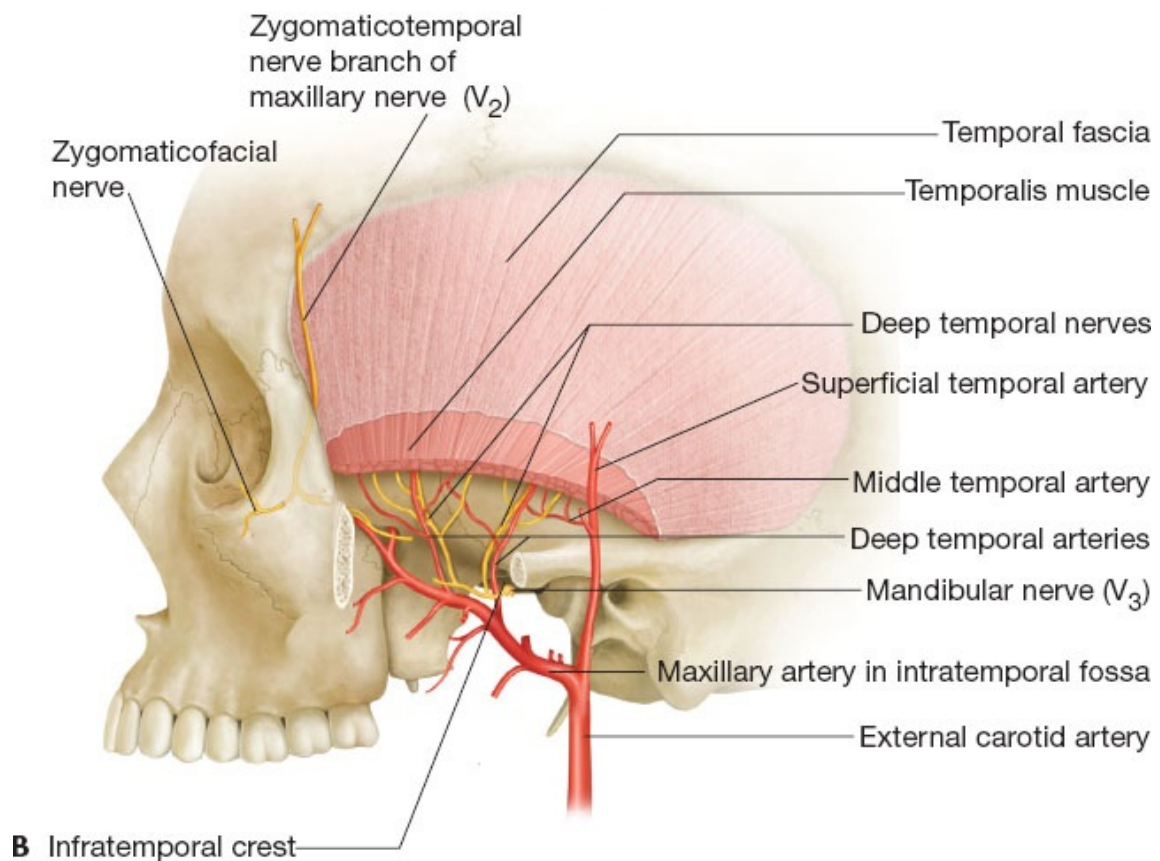
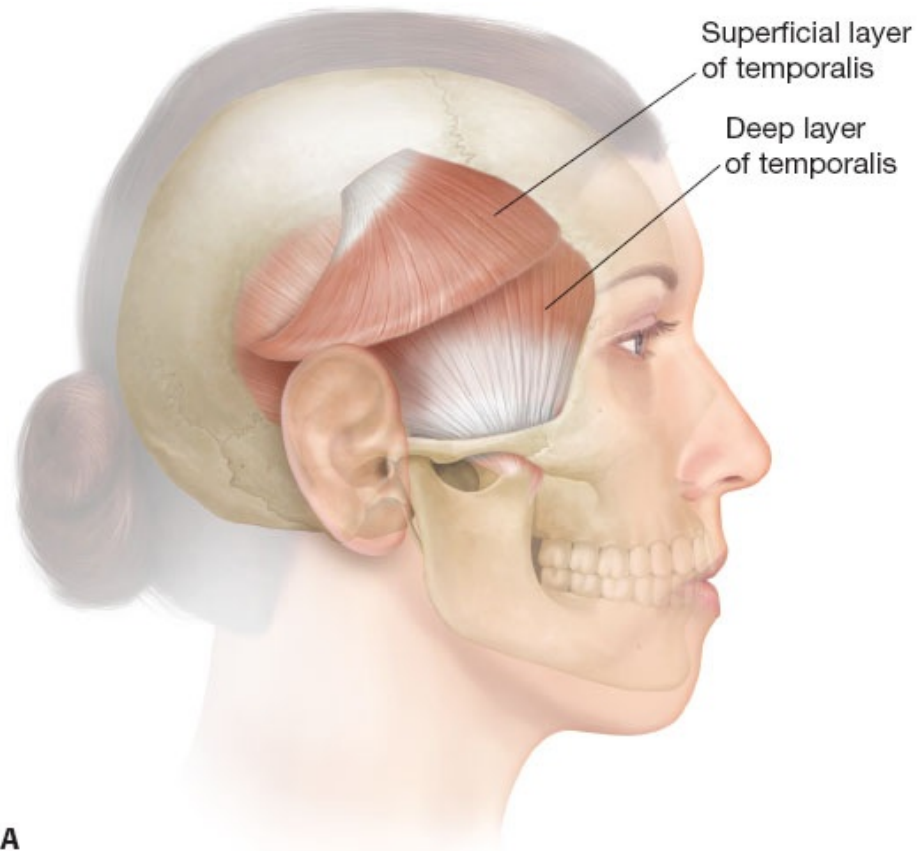


FIG 1 • A. The temporalis muscle consists primarily of superficial and deep layers. **B.** Dual neurovascular supply of the temporalis muscle. Deep temporal nerves derive from the mandibular division of the cranial nerve (V3), and deep temporal arteries branch from the maxillary artery.

- Lower third: Lower third paralysis results in mouth droop, drooling, loss of or asymmetric smile, pucker, articulation, and lower lip depression
- Smile assessment
 - Loss of nasolabial fold: Patients with partial facial paralysis will have partial loss or asymmetric nasolabial folds.
 - Contralateral deflection of the lips, accentuated with smiling (negative vector of excursion)
 - Incomplete bilabial closure
 - Record vector direction and length of oral commissure excursion of paralyzed and nonparalyzed sides (may be a negative number).
- Examination and documentation of remaining cranial nerve function particularly function of the fifth cranial nerve. This can be done simply by assessing temporalis and masseter muscle function when biting down.
- Diagnostic studies
 - Brain MRI is sometimes indicated to rule out tumor etiology or secondary compression.
 - Although nerve conduction studies may be helpful in treatment planning for facial paralysis patients in the intermediate term, they are of limited use in patients experiencing permanent or long-standing facial nerve palsy.

IMAGING

- Brain MRI or CT scans are occasionally needed when an intracranial mass or vascular malformation is suspected.
- In patients with long-standing (or, late) facial paralysis with proper early workup, diagnostic studies are rarely indicated in order to proceed to surgery.

SURGICAL MANAGEMENT

- Retrograde temporalis flap

- Temporalis flap is a retrograde, or “turnover,” muscle transfer that passes over the zygomatic arch, using the contraction produced by the temporalis.
- There are several versions of the retrograde temporalis flap for facial paralysis. We describe the traditional version with modifications herein.
- Candidates for a traditional temporalis flap exhibit permanent facial paralysis (greater than 18 months) with either no anticipated recovery or inadequate recovery.
- Unilateral or bilateral temporalis flaps may be performed simultaneously.
- Risks include temporal hollowing, adhesions, loss of mobility, excessive cheek bulk, unfavorable scarring, persistent asymmetry, and unusual facial dimpling.
- Lengthening temporalis myoplasty
 - Lengthening temporalis myoplasty is an orthograde, or orthodromic, muscle transfer deep to the zygoma, using the natural direction of pull produced by the temporalis (**FIG 2**).
 - Candidates for lengthening temporalis myoplasty exhibit permanent facial paralysis (greater than 18 months) with either no anticipated recovery or inadequate recovery.
 - Minimum age for procedure is approximately 5 years.
 - Unilateral or bilateral temporalis myoplasties may be performed simultaneously.
 - Risks include neurovascular injury to the temporalis muscle being transferred, avulsion of the tendon from the implantation site, temporal hollowing, adhesions, loss of mobility, unfavorable scarring, persistent asymmetry, and unusual facial dimpling.
 - Revision of the insertion site at the nasolabial fold may be required if there is loss of motion postoperatively.

Preoperative Planning

- Mark the location of the desired nasolabial fold (use unaffected side for symmetry, if unilateral). Patient must be able to participate in order to identify accurately the position of the nasolabial fold. In bilateral cases, the location is determined by digital manipulation of the upper lip skin to simulate a smile, thereby identifying the junction between cheek and lip (**FIG 3A**).
- Mark the direction or vector of excursion of the smile at the oral commissure and mid upper lip on the unaffected side and replicate for paralyzed side (**FIG 3B**).

Positioning

- Place the patient in supine position with shoulder roll to gently extend the neck.
- A standard endotracheal or armored tube is sutured orally in the midline, making sure there is no tension on the lips.
- Prep the entire head and neck, including oral and nasal passages, with diluted iodine or other prep solution.
- Inject 1:500 000 to 1 000 000 dilution of epinephrine solution in tumescent fashion over the temporalis muscle and midface. *Avoid use of local anesthetic solution* to prevent paretic effect on the temporalis muscle.

Approach

- Coronal and nasolabial fold incisions are outlined and confirmed. The dissection of the temporalis muscle is the first step.



FIG 2 • Concept of lengthening temporalis myoplasty as an orthodromic muscle transfer.



FIG 3 • **A.** Demonstration of the nasolabial fold simulated with posteriorly directed pressure of the upper lip skin. **B.** Preoperative facial markings of the intended nasolabial fold and vector of excursion as mirrored from the contralateral side.

TECHNIQUES

■ Temporalis Flap

Dissection

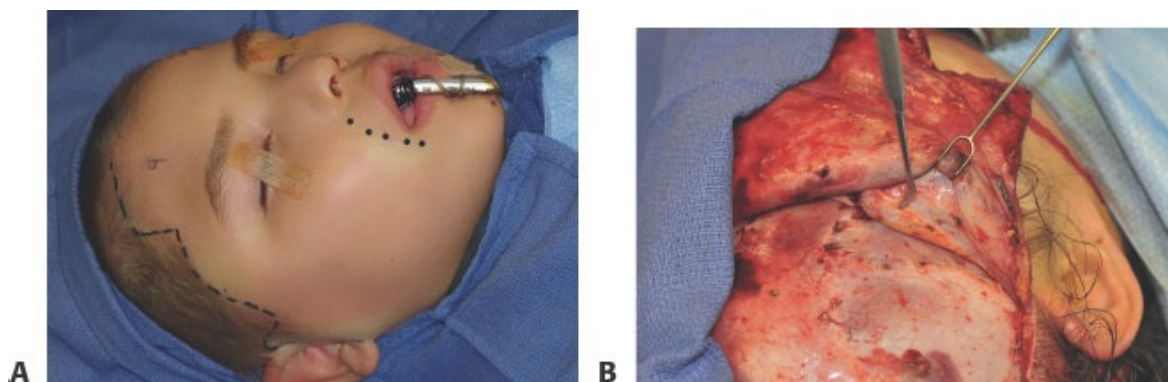
- Place a coronal anterior hairline incision from the ipsilateral parietal area, converging to a preauricular (facelift-type) incision.
 - Alternatively, a coronal incision (without preauricular incision) may be used in conjunction with a nasolabial fold counterincision. The nasolabial fold is verified, and key points are tattooed with gentian violet and a 25-gauge needle (**TECH FIG 1A**).
- Make the marked incisions, and elevate the anterior and posterior skin flaps in a deep subcutaneous plane. The plane must proceed along the superficial layer of the deep temporal fascia, preserving an unnamed fat pad over the anterior and inferior portion of the dissection.
- The fat pad must be elevated with the skin flap to avoid devascularization

and subsequent temporal hollowing (**TECH FIG 1B**).

- The dissection proceeds anteriorly onto the lateral orbital rim in a subperiosteal plane. This continues onto the zygoma and zygomatic arch, extending posteriorly to the location of the external acoustic meatus.
- At this point, the entire superficial surface of the temporalis is visualized.

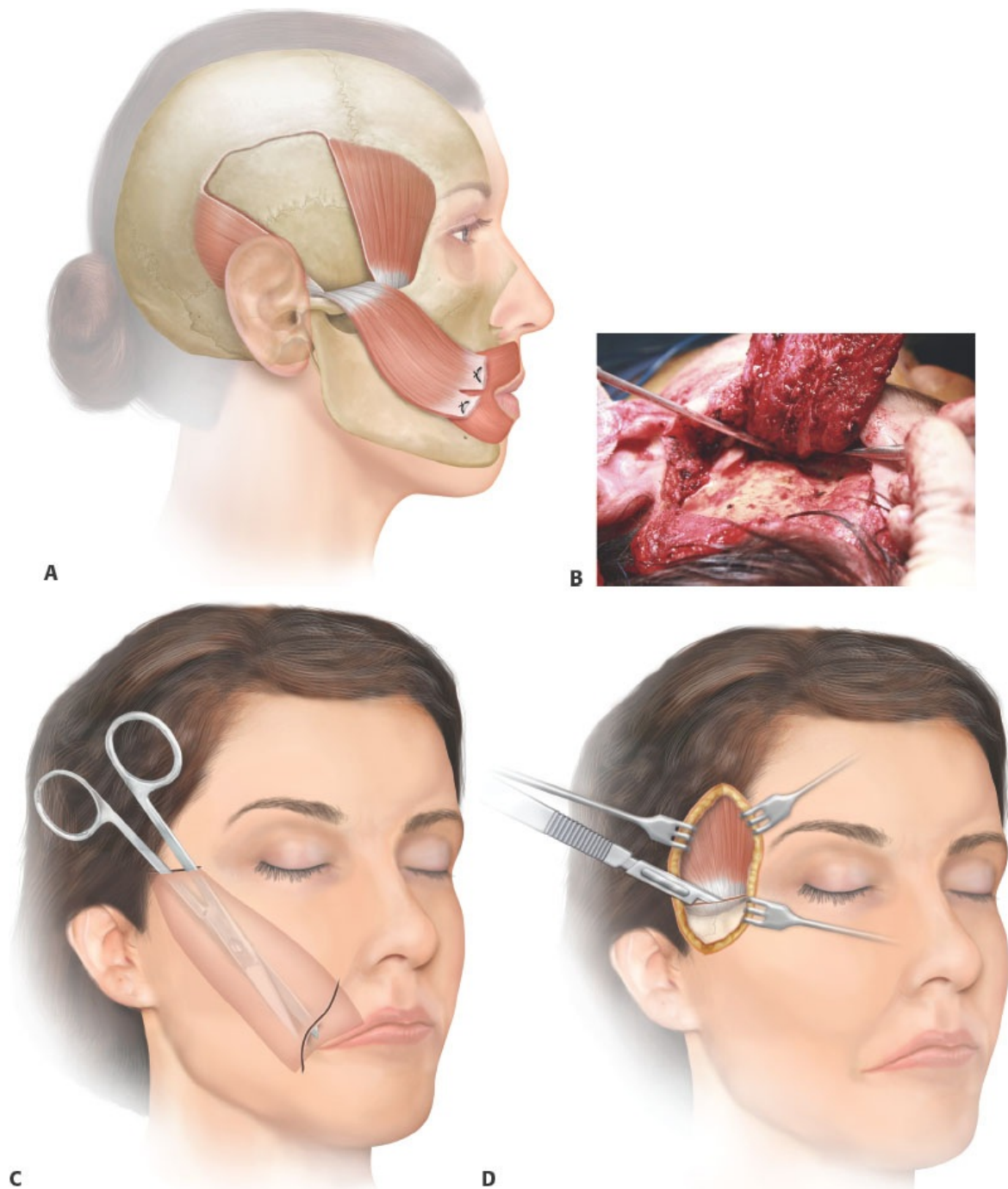
Flap Elevation

- Different options exist for elevation of the temporalis origin. Typically, only a strip of temporalis muscle of the middle third (approximately 4–5 cm wide) is designated for elevation and transfer to minimize temporal hollowing (**TECH FIG 2A**). This often involves a periosteal extension extending 1 to 3 cm into the parietal area.
- Elevation of the flap occurs in a superior to inferior direction in the subperiosteal plane.
- As the dissection reaches the infratemporal crest, careful release of the periosteum will increase the mobility of the muscle (**TECH FIG 2B**).
- Care must be taken to avoid injury to vessels emanating from the cranial base, which are difficult to visualize and control if ruptured.
- The preauricular skin flap is dissected in the subcutaneous plane to several millimeters anterior of the planned nasolabial fold (**TECH FIG 2C**).
- Dye marks on the skin assist in placement of anchoring sutures. These marks are made by tattooing the skin with gentian violet or equivalent dye.
- Place three or four anchoring sutures (0 or 2-0 PDS or equivalent) along the oral commissure and upper lip in a figure-of-8 fashion to simulate the desired smile vector.



TECH FIG 1 • A. Redraw the anterior hairline incision as necessary and extend into a preauricular incision.

Alternatively, only the coronal incision may be used with a counterincision in the nasolabial fold. **B.** The temporal fat pad located on the deep temporal fascia (indicated by instrument) must be elevated with the skin flap to avoid devascularization and temporal hollowing.



TECH FIG 2 • A. A 4 to 5 cm strip of temporalis muscle from the central section is elevated. The anterior portion of the muscle should not be elevated so as to avoid temporal hollowing. **B.** Dissection of the temporalis muscle at the infratemporal crest. Periosteal scoring may increase mobility, but care

must be taken not to injure the dual neurovascular pedicle. **C.** Creation of a subcutaneous tunnel for transmission of the temporalis muscle after it is turned over the zygomatic arch. **D.** Transverse releasing incision is placed in deep temporal fascia to increase the lengthening of the temporalis muscle flap.

- Sutures must be accurately placed to avoid eversion or inversion of the lip. This corresponds to the level of the orbicularis oris muscle.
- The temporalis muscle may now transfer over the zygomatic arch. An incision in the deep temporal fascia is helpful in achieving additional lengthening of the muscle when transferred (**TECH FIG 2D**).
- If muscle length is not an issue, the muscle may be anchored with little to no tension on the oral commissure and upper lip. Run a 5-0 nylon or Prolene suture over the repair for strengthening purposes.

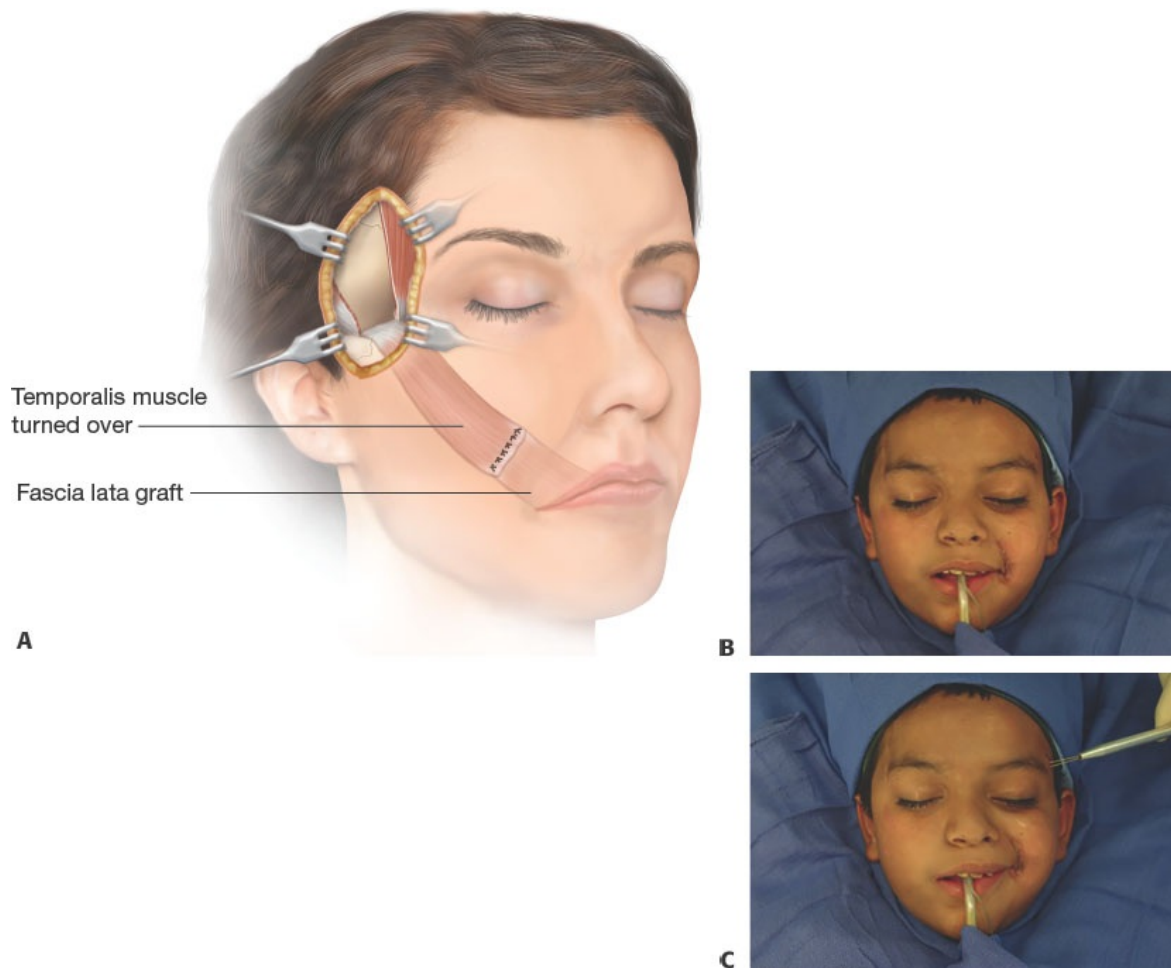
Interposition Graft

- Frequently, muscle length is insufficient, even with a periosteal extension. In this case, a tendon or fascia interposition graft is necessary. There are several options.
- Most commonly, a segment of fascia lata may be harvested from the lateral thigh. There are several techniques to harvest this structure.
- The author's preferred technique involves two incisions over the lateral thigh. A proximal transverse skin incision is placed over the lateral mid-thigh area. The fascia lata is dissected over its superficial surface. A transverse fascial incision is then placed, followed by parallel cuts directed distally. A counterincision is placed at the distal extent of the harvest, approximately 10 cm proximal to the lateral femoral condyle. A distal transverse fascial incision is made followed by delivering the fascia lata. A long clamp will facilitate transferring the fascia distally. A large 3- to 4-cm-wide length of fascia lata may be harvested for use in the face.
- Alternatively, a palmaris longus tendon graft may be harvested when present. The disadvantage is that the palmaris longus tendon is narrow and may not widely attach to the muscle and the perioral insertion site. A 1-cm proximal wrist crease incision is placed over the PL tendon. The tendon is identified and dissected bluntly as far proximally and distally as possible.

The distal insertion is then cut. A 1-cm mid forearm incision is then placed over the musculotendinous portion. The tendon is once again maximally dissected and transected proximally. The tendon is withdrawn and the incisions closed in standard fashion.

Flap Inset and Completion

- The distal portion of the temporalis flap is then prepared for implantation of the intervening tendon or fascia graft.
 - Several 4-0 Vicryl U-stitches are placed to prevent a “cheesewire” effect when anchored.
 - The graft is then secured to the distal portion of the temporalis flap with 2-0 PDS sutures in figure-of-8 fashion (**TECH FIG 3A**).
 - A small amount of overcorrection at the oral commissure is expected.
- The distal portion of the graft is then inset using the 2-0 PDS anchoring sutures along the oral commissure and upper lip in figure-of-8 fashion. A running 5-0 nylon suture is used to fortify the repair.
- The reconstruction may now be tested using a muscle stimulator. Observe movement at the oral commissure and upper lip with stimulation and adjust sutures as necessary (**TECH FIG 3B,C**).
- The resulting defect at the donor site may be filled by a local temporoparietal fascial flap or by an implant.
- A closed channel drain is placed in the temporalis fossa. If desired, an indwelling local anesthetic delivery catheter may be inserted into the vicinity of the neurovascular bundle to prevent spasm of the muscle postoperatively.
- Close incisions in standard layered fashion.
- Optional: injection of botulinum toxin into contralateral zygomaticus major and minor muscles and risorius to prevent excessive countertension on the repair



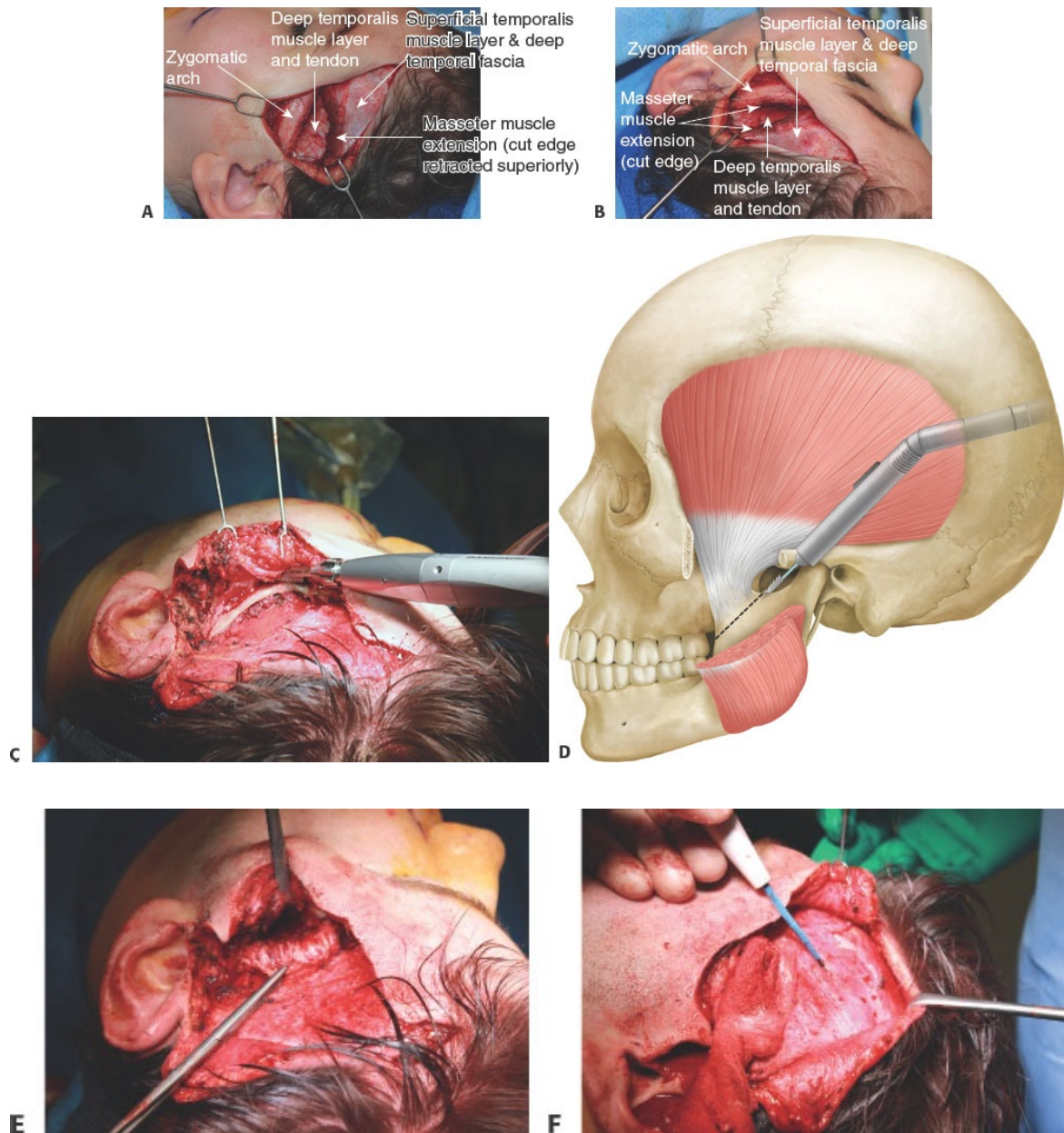
TECH FIG 3 • A. The temporalis muscle anchored at the oral commissure and the upper lip just distal to the nasolabial fold. An intervening fascia lata graft may be required to make up for insufficient muscle length. **B.** Percutaneous muscle stimulation prior to final closure allows for adjustment of the origin or the insertion of the temporalis as necessary.

■ Lengthening Temporalis Myoplasty

Flap Harvest

- Place a coronal anterior hairline incision from the ipsilateral parietal area to the root of the helix.
- Alternatively, a traditional bicoronal zigzag incision may be used.

- The nasolabial fold incision is verified, and key points are tattooed with gentian violet and a 25-gauge needle (see **TECH FIG 1A**).
- Begin with the coronal incision, and elevate the anterior and posterior skin flaps in a deep subcutaneous plane.
 - The plane must proceed along the superficial layer of the deep temporal fascia, preserving the fat pad over the anterior and inferior portion of the dissection.
 - The fat pad must be elevated with the skin flap to avoid devascularization and subsequent temporal hollowing (see **TECH FIG 1B**).
- The dissection proceeds anteriorly onto the lateral orbital rim in a subperiosteal plane.
 - This continues onto the zygoma and zygomatic arch, extending posteriorly to the location of the external acoustic meatus.
 - The masseter insertions onto the zygoma are dissected only from the superior and anterior surfaces of the arch to avoid complete disinsertion.
 - At this point, the entire superficial surface of the temporalis is visualized.
- Identify the true temporalis tendon, which is located deep to muscle fiber contributions from the masseter near the zygomatic arch (**TECH FIG 4A,B**).
- Osteotomy of the zygomatic arch is performed to facilitate visualization and dissection of the temporalis tendon in the infratemporal space.
 - Oblique osteotomies at the anterior and posterior borders are performed, leaving the masseter attached to the osteotomized segment inferiorly (**TECH FIG 4C**).
 - The loose segment will need to be repaired at the conclusion of the surgery with either plate or wire fixation.
- A broad Freer elevator is used to bluntly dissect away the masseter fibers over the anterior surface of the temporalis tendon until its insertion on the coronoid.
 - This is a blind dissection, unless a zygomatic arch osteotomy has been performed.
- Coronoidectomy can be performed at this stage via exposure through the infratemporal space or later through the nasolabial fold incision (**TECH FIG 4D**).



TECH FIG 4 • Lateral (A) and bird's eye (B) view showing identification of the temporalis tendon deep to masseter contributions near the zygomatic arch. C. Zygomatic arch osteotomy can be performed with a reciprocating saw or osteotome in an oblique fashion to facilitate plate fixation at the conclusion of surgery. D. Coronoidectomy is performed in an oblique fashion posterosuperiorly to anteroinferiorly through the

sigmoid notch to maximize temporalis tendon extension onto the mandibular ramus. The periosteum is stripped only in the path of the osteotomy. **E.** Coronoid process is grasped and gently retracted superiorly. A Freer elevator is used to carefully release muscle contributions from the masseter and pterygoids. **F.** Incision of the deep temporal fascia, maintaining a 1-cm cuff anteriorly and superiorly for muscle anchoring.

- The periosteum is stripped from the sigmoid notch and directed inferiorly toward the anterior border of the mandibular ramus.
- *Do not* strip off the temporalis tendon. Only expose the intended osteotomy site.
- A reciprocating saw is then used to perform the osteotomy.
- The coronoid process is grasped with a clamp and gently retracted superiorly as muscle fibers from the masseter and pterygoids are stripped away with a broad Freer (**TECH FIG 4E**).
- The temporalis fascia is incised circumferentially to begin the deep dissection. A 1-cm cuff of fascia is preserved anteriorly for reanchoring the muscle in its new position (**TECH FIG 4F**).

Elevating and Advancing the Temporalis Muscle

- Elevate the temporalis muscle in its entirety from the temporalis fossa using a periosteal elevator (see **TECH FIG 2B**).
- As the dissection reaches the infratemporal crest, identify the dual neurovascular supply with a nerve stimulator.
- Careful release of the periosteum will allow for increased mobilization of the muscle. Care must be taken to avoid injury to vessels emanating from the cranial base, which are difficult to visualize and control if ruptured.
- Additional muscle fiber contributions from the lateral pterygoid are now bluntly separated from the temporalis tendon anteriorly.
- Gentle superior and posterior traction on the temporalis may facilitate this process.
- Incise the nasolabial fold along the tattooed markings and dissect posteriorly

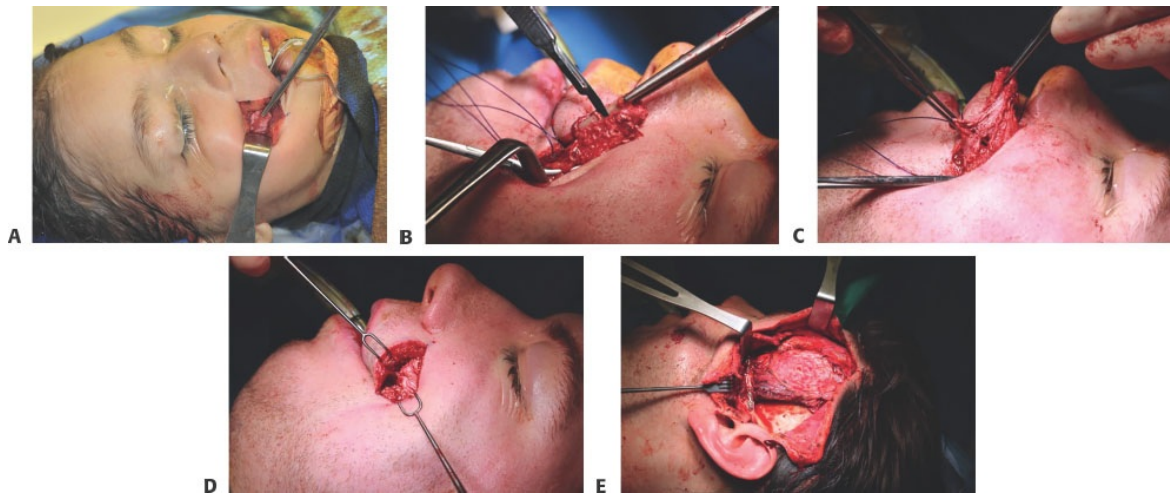
for 1.5 to 2 cm in a subcutaneous plane. Then bluntly enter the buccal space and tunnel toward the infratemporal space and the coronoid process.

- Create a wide tunnel to allow sufficient space for passage of the musculotendinous segment of the temporalis.
- Retract the subcutaneous tissues to sufficiently expose the coronoid process and the superior portion of the anterior mandibular ramus.
- If coronoidectomy was not performed at the prior step, it can be performed at this stage through the nasolabial fold incision. Refer to the description above.
- Grasp the coronoid process with a clamp, and gently advance through the buccal space tunnel while bluntly separating additional attachments from the masseter and pterygoid muscles to the tendon circumferentially using a broad Freer.
 - If there is insufficient advancement of the tendon, additional dissection in the infratemporal fossa may be necessary (**TECH FIG 5A**).
- Place three or four anchoring sutures (0 or 2-0 PDS or equivalent) along the oral commissure and upper lip in a figure-of-8 fashion to simulate the desired smile vector.
 - These sutures are more easily placed prior to transferring the temporalis muscle to the nasolabial fold.
 - Sutures must be accurately placed to avoid eversion or inversion of the lip. Ideally, this corresponds to the level of the orbicularis oris muscle.
- Place an atraumatic vascular clamp along the tendon, proximal to the coronoid process to prevent retraction into the tunnel. Strip the tendon meticulously from the coronoid process using a scalpel and/or Freer elevator (**TECH FIG 5B**).
- The temporalis tendon may now be opened broadly from its original conical configuration. Gently trim loose strands from the end (**TECH FIG 5C**).
- Secure the tendon in its new location with the anchors placed previously. Run a 5-0 nylon or Prolene suture over the repair for fortification of the repair (**TECH FIG 5D**).
- Tension and overcorrection at the oral commissure must be avoided. No intervening tendon or fascia interposition graft is necessary.
- The temporalis tendon advances distally by rotating the muscle anteriorly and inferiorly in the temporalis fossa. This results in repositioning of the posterior portion anteriorly, leaving an “empty space” posteriorly.

- Reanchor the muscle origin to the cuff of the temporalis fascia using 0 or 2-0 PDS or Prolene sutures (**TECH FIG 5E**).

Completion

- The reconstruction can now be tested using a muscle stimulator. Observe movement at the oral commissure and upper lip with stimulation, and adjust sutures as necessary (see **TECH FIG 3B,C**).
- If the zygomatic arch was osteotomized, it must be fixed with plates or wires.
- A closed channel drain is placed in the temporalis fossa. An indwelling local anesthetic delivery catheter is inserted into the vicinity of the neurovascular bundle to prevent spasm of the muscle postoperatively.
- Close incisions in standard layered fashion.
- If wished, botulinum toxin can be injected into contralateral zygomaticus major and minor muscles and risorius to prevent excessive countertension on the repair.



TECH FIG 5 • **A.** Delivery of coronoid process with attached temporalis tendon through the tunnel created in the buccal space. It is then anchored with sutures along the oral commissure and upper lip. **B.** The temporalis tendon is stripped away from the coronoid process. An atraumatic vascular clamp placed proximal to this point prevents retraction of the tendon

into the buccal tunnel. **C.** The temporalis tendon is gently stripped of loose attachments and spread to create a broad surface for anchoring. **D.** The temporalis tendon is secured in place with the anchoring sutures. **E.** The origin of the temporalis is rotated to advance the posterior half of the muscle into the infratemporal fossa for lengthening at the distal end. The muscle is reanchored with no tension applied at the nasolabial fold. The zygomatic arch is reduced and secured with plate fixation.

PEARLS AND PITFALLS

Anatomy

- Proper release of the temporalis muscle is dependent on full release of attachments from the masseter and pterygoid muscles.
- A frequent mistake is the incorrect identification of the true temporalis tendon. Failure to identify and excise the superior extension of masseter fibers will result in their incorporation into the advancing tendon and inability to easily pass through the infratemporal tunnel.

Temporalis flap

- The most common problem encountered is insufficient length of temporalis muscle, requiring an intervening graft. In order to maximize lengthening, additional release of periosteum at the level of the infratemporal crest is sometimes helpful.
- Minimize the amount of intervening tendon or fascia graft by maximizing mobility of the muscle.
- In elevating the skin flap over the temporalis muscle, be sure to identify the temporal fat pad as the dissection reaches the zygomatic arch. The fat pad must be elevated with the skin flap to maintain viability and to avoid postoperative temporal hollowing.
- The risk of temporal hollowing is also minimized by leaving the anterior third of the muscle intact.

Lengthening temporalis myoplasty

- The most common problem encountered is insufficient release of the temporalis muscle resulting in limited advancement. It is important to carefully proceed with dissection of the masseter and

pterygoid contributions that can bind the muscle.

- Also, if the infratemporal fossa is narrow despite adequate release of extraneous muscle attachments, then it may be necessary to excise a small amount of masseter muscle located posterior to the zygomatic arch.
- Osteotomy of the coronoid process should be oblique through the sigmoid notch with sufficient inferior angulation to capture as much temporalis tendon as possible without destabilizing the mandible.
- In elevating the skin flap over the temporalis muscle, be sure to identify the temporal fat pad as the dissection reaches the zygomatic arch. The fat pad must be elevated with the skin flap to maintain viability and to avoid postoperative temporal hollowing.

Therapy

- Therapy must begin between 3 to 4 weeks following surgery to allow for proper excursion of the muscle and to avoid adhesions.

POSTOPERATIVE CARE

- Drains and anesthetic pump catheter are removed at 2 days postoperatively.
- Avoid contact sports and hard foods for 6 weeks.
- Begin therapy for facial muscle rehabilitation with a focus on muscle retraining at 3 to 4 weeks. Work closely with the therapist to avoid excessive massage at the insertion site and to encourage biofeedback techniques. Mirror exercises (mime therapy) are the cornerstone of successful muscle retraining.

OUTCOMES

- Movement of the lips may be seen soon after surgery.
- Postoperatively, spasm of the temporalis muscle may occur, leading to tension on the reconstruction and an overcorrected appearance that may last several days to weeks. This is temporary and resolves spontaneously over 2 to 3 months. Continued improvements in muscle excursion occur over 1 to 3 years.
- After flap creation, it is common to have noticeable bulk over the zygomatic arch. Patients must be made aware of this during the preoperative consultation.
- After a lengthening procedure, the full range of muscle excursion may not be seen for several weeks to months. As muscle spasm improves, and the muscle accommodates to its new position and resting length and increased control, and excursion of the lips is seen.

COMPLICATIONS

- Avulsion of the temporalis tendon insertion site may occur. This may be

related to the constant spasm and stimulation of the temporalis muscle due to persistent innervation.

- In addition, the contralateral functioning facial musculature may add to tension on the reconstruction. Tendon avulsion may occur in the first 4 weeks following surgery. Loss of nasolabial fold definition and mouth drooping, coupled with lack of visible movement, may result.
- Adhesions of the temporalis tendon in the subzygomatic space may occur, limiting muscle excursion and visible movement.
- If the complications listed above occur, revision surgery for adhesiolysis and tendon reimplantation may proceed no sooner than 6 months postoperatively.

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51 Labbé Procedure: Lengthening Temporalis Myoplasty

CHAPTER

Daniel Labbé and Pierre Guerreschi

DEFINITION

- Facial paralysis sequelae might lead to major physical and social consequences that can drive patients to isolation, unemployment, and depression.
- The facial asymmetry observed at rest is aggravated by facial motion.

ANATOMY

- All facial muscles can be affected.
- Muscles on the paralyzed side do not contract effectively and can even be the object of erratic cocontractions.
 - After a few years, they can even spasm in an intermittent or permanent manner, leading to facial twitch or hemifacial spasm.
- Muscles on the opposite side tend to be overactive and thus aggravate the facial asymmetry.

PATIENT HISTORY AND PHYSICAL FINDINGS

- We differentiate three different clinical pictures: complete facial paralysis, facial paresis, and spasms with secondary muscle overactivity. These different clinical pictures can occur simultaneously successively over time.
- Complete facial paralysis leads to both static and dynamic asymmetries.
 - At rest, the median line is offset to the healthy side. The forehead is relaxed, smooth, and inexpressive.
 - The eyebrow is droopy especially toward the outside; we often note a ptosis of the eyebrow's outer corner aggravating an eventual dermatochalasis.
 - The lower eyelid is also impacted by the absence of muscle tone. It droops,

leading to an eversion of the eyelid with an ectropion that varies according to the patient's age.

- The cheek is flaccid and distended.
- The commissure droops.
- Spontaneous facial animation unveils and aggravates the facial asymmetry.
- Facial paresis mimics this clinical picture. When static, the facial symmetry might be almost normal, yet facial animation will unveil the asymmetry.
- During the course of the pathology, some muscles can spasm, sometimes progressing to real contractures leading to hemifacial spasm.
 - This spasm can remain clonic and discreet or worsen and become a contracture, with varying degree of pain severity. It is associated with progressive motor impairment. It becomes more severe when the patient becomes emotional or stressed.
 - Several muscle groups can therefore be affected by spasms: the depressor labii inferior (DLI) muscles can be spastic, with at the forefront the depressor anguli oris (DAO)/platysma complex. The spasm of this muscle group prevents the elevation of the labial commissure.
- On the healthy side, muscles often progress to overactivity.
 - The frontalis muscles mark forehead wrinkles and elevates the eyebrow on the healthy side, even at rest.
 - The levator anguli oris muscles are also frequently affected by offsetting the mouth toward the healthy side in an exaggerated manner.
 - The overactive DLI impairs elocution by everting the median labial line toward the healthy side.
 - Finally, the platysma neck cords are a sign of platysma muscle overactivity.

IMAGING

- Imaging studies are rarely needed in patients with chronic facial paralysis or facial paresis.
- In rare instances, brain MRI or CT scans may be necessary to rule out an intracranial cause of facial paralysis.

NONOPERATIVE MANAGEMENT

- Botulinum toxin is largely used for all stages of facial paralysis and concerns all facial muscles.
 - It is particularly relevant because its action is very selective on the different muscle groups, yet its effectiveness is temporary.¹ It allows for a fine action

on the overactive muscles, especially the zygomaticus major and minor and the DLI, where myectomy procedures are more complicated to perform.²

- In facial paresis, botulinum toxin can treat spasms and cocontractures.
- Interestingly, when regularly treated, muscles become atrophied, and the therapeutic action of the botulinum toxin seems to last longer over time.

SURGICAL MANAGEMENT

- Myoplasty techniques use the adjacent muscles with different innervations (V) to reanimate the functions normally provided by the paralyzed facial muscles.³ The first myoplasty was performed by Lexer with the masseter muscle at the beginning of the 20th century.
- Some anatomic-pathologic data reinforce the choice of myoplasty surgery: simultaneous action with the muscles responsible for facial mimics, proximity, and presence of a trigeminofacial reflex.
- The muscle mobilized during myoplasty must retain its own innervation and vascularization. It is essential to harvest enough quantity of muscle taking into account the location of its vascular and nerve pedicles.
- Lengthening temporalis myoplasty first published in 1997⁴ was inspired by the use of the temporalis muscle previously described.
- This technique is a synthesis and an achievement, even if its author considers that the technique could still be improved (June 10, 2013). It consists of mobilizing the entire temporalis muscle freed from its distal and proximal insertions. Lowering the temporalis muscle through the buccal fat pad is associated with a lengthening of the muscle to the detriment of its posterior fibers.⁵
- The insertion of the muscle transfer onto the lip is done according to the type of smile. Studying the patient's smile during the preoperative period is essential to match as closely as possible the smile symmetry at rest and when contracting.

Preoperative Planning

- The refined preoperative study of the patient's smile on the healthy side helps determine the respective insertions of the zygomatic muscles and superficial and deep elevator muscles of the upper lip and also help refine the type of smile that needs to be achieved.
- These anatomic landmarks identified on the healthy side will be transposed onto the paralyzed side as a mirror image to locate precisely the anchor points

of the muscle flap.

- The nasolabial fold and its exact shape, concave or straight, are also refined. The impaired nasolabial fold on the paralyzed side is restored by passively lifting up the lower lip and moving it backward.
- This is performed when the patient is sitting down and then controlled again with the patient lying down.

Positioning

- The patient is positioned in the supine position, and orotracheal intubation is performed.
- The tube is fixed to the lower incisors via a wire thread.
- The sterile draping completely frees the cephalic extremity up to the upper clavicular notches.

Approach

- Two surgical approaches are necessary to perform the procedure: a zigzag Cairns approach and a nasogenial approach for smile reanimation.

TECHNIQUES

■ Lengthening Temporalis Myoplasty

Exposure and Osteotomies

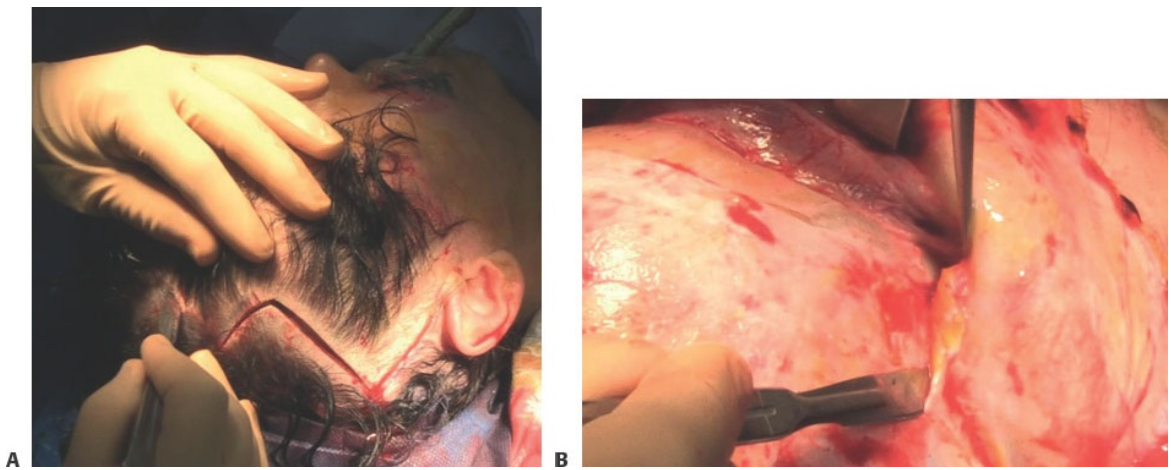
- With the zigzag Cairns approach, a flap of scalp is detached in the subgaleal plane to expose the entire temporalis muscle (**TECH FIG 1A**).
- About 2 cm above the orbital rim, the periosteum is incised, and the dissection continues in a subperiosteal plane along the external orbital margin.
- Passing through the two sheets of the superficial aponeurosis of the temporalis muscle, the temporalis aponeurosis is resected at the level of the superexternal angle of the orbit. The dissection goes through the two sheets of the superficial aponeurosis that contains the fat pad and the median temporal vascular pedicle (**TECH FIG 1B**).
 - We make sure to leave the fat contained in the two sheets of this aponeurosis attached to the scalp flap to avoid an unsightly temporal notch

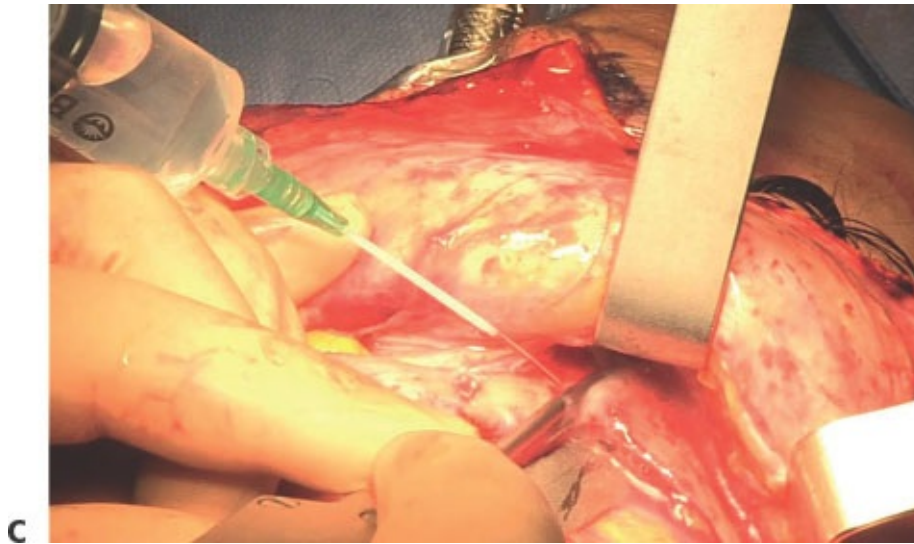
(Video 1).



Video p3-c051_01

- The retrozygomatic dissection frees the superficial side of the muscle from its insertions on the zygomatic arch.
- The subperiosteal dissection on the deep side of the zygomatic arch is performed with a “periosteal elevator.”





TECH FIG 1 • A. A zigzag Cairns approach allows to expose the entire temporalis muscle. **B.** The dissection goes through the two sheets of the superficial aponeurosis of the temporal muscle. **C.** Osteotomy of the zygomatic arch.

- Osteotomy of the zygomatic arch (**TECH FIG 1C**):
 - The temporalis muscle is protected with the malleable retractor to perform the osteotomy of the zygomatic arch in order to put it in valgus with the subjacent scalp flap.
 - This gesture is completed by freeing the residual fibers of the masseter muscle, inserted into the deeper of the two layers of the superficial aponeurosis of the temporal muscle.
- Osteotomy of the coronoid process: after the subperiosteal dissection of the sigmoid notch, we place a malleable retractor on the internal side of the upper branch of the mandible to perform the osteotomy of the coronoid process.

Myeloplasty

- Incision of the aponeurosis of the temporalis muscle and deep dissection of the muscle.
 - The incision of the aponeurosis of the temporalis muscle leaves a thin flap of this aponeurosis inserted into the temporal crest to allow the reinsertion of the muscle at the end of the procedure (**TECH FIG 2A**).
 - The temporalis muscle is freed from the temporal fossa using the

Obwegeser-type periosteal elevator (**TECH FIG 2B**).

- The surgeon needs to perform the dissection with caution around the deep temporal pedicles.
- Via the nasolabial approach, the anchor points of the tendon of the upper lip are positioned according to the preoperative drawing.
- Commonly, three Prolene 4.0 thread sutures are tested during the procedure to ensure the correct shape of the smile (Video 2).



Video p3-c051_02

- The tendon is passed via the buccal fat pad of Bichat.
- Via the nasolabial approach, a tunnel is created via the buccal fat pad. Then, via the transjugal approach, the coronoid process is securely seized with Kocher forceps (**TECH FIG 2C**).
- The tendon of the temporalis muscle inserted in the coronoid process is lowered through the jaw toward the labial commissure that needs to be reanimated.
- To facilitate this lowering, one needs to pull back the masseter muscle fibers with the Obwegeser-type periosteal elevator (Video 3).



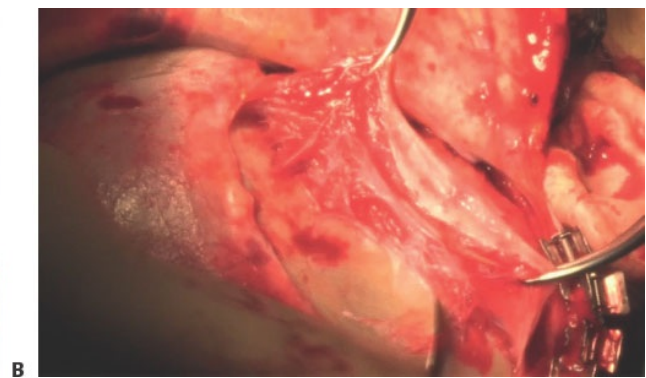
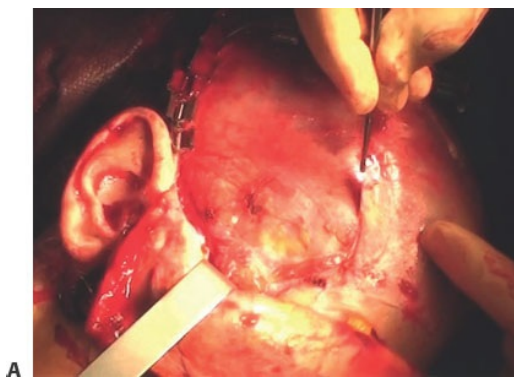
Video p3-c051_03

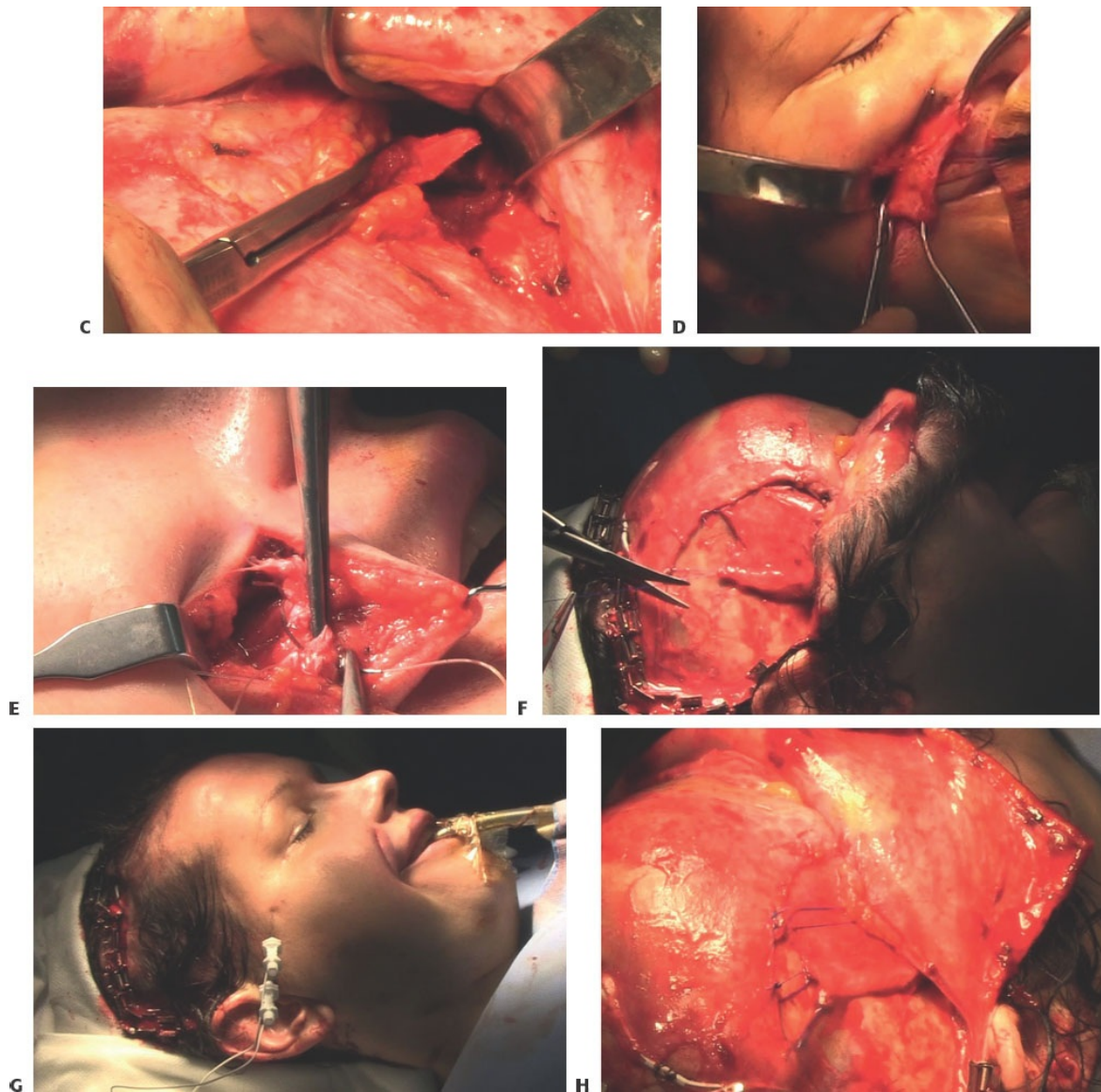
- The tendon is then resected from the coronoid process with a cold blade while preserving a maximum of tendon fibers.
- The tendon is then spread out using two Halsted forceps in a vascular clamp (**TECH FIG 2D**).
- We fix the prepared tendon to the anchor points, making sure not to wrinkle the skin (**TECH FIG 2E**); then, we close with 3.0 barbed suture thread to complete the insertion of the muscle on the entire lip.
- The muscle is reinserted in the temporal area on the aponeurotic flap left in place in the anterior part of the temporal crest to obtain a symmetric result using separate Flexocrin 3.0 sutures (**TECH FIG 2F**).
- The surgeon's assistant monitors the absence of elevation of the labial commissure during the fixation of the muscle on the temporal crest.
- We perform a percutaneous electrostimulation during the surgery to validate the shape of the reanimated smile by contracting the transferred temporalis muscle (3–8) as well as validating the amplitude gained for the labial commissure course (**TECH FIG 2G**) (Video 4).



Video p3-c051_04

- Osteosynthesis of the zygomatic arch is performed with nonresorbable thread.
- It is essential to reinsert the fat pad from the split aponeurosis at the top of the temporal crest with a U-shaped suture (**TECH FIG 2H**).
- Surgical closure is performed over two silicon surgical drains, one in the transjugal opening and the other in the temporal area.
- Surgical closing of the scalp is done using staples or resorbable sutures, especially in children.





TECH FIG 2 • **A.** The incision of the aponeurosis of the temporalis muscle leaves a thin flap of this aponeurosis inserted into the temporal crest to allow the reinsertion of the muscle at the end of the procedure. **B.** The temporalis muscle is freed from the temporal fossa using the Obwegeser-type periosteal elevator. **C.** The coronoid process is securely seized with Kocher forceps. **D.** The tendon is then spread out using two Halsted forceps. **E.** The tendon is fixed to the anchor points making sure not to wrinkle the skin.

F. The muscle is reinserted in the temporal area on the aponeurotic flap. **G.** A percutaneous electrostimulation is performed during the surgery to validate the shape of the reanimated smile by contracting the transferred temporalis muscle. **H.** Reinsertion of the fat pad from the split aponeurosis at the top of the temporal crest.

PEARLS AND PITFALLS

Under- or overcorrection

- At the end of the surgery, the shape of the smile must be tested via electrical stimulation of the muscle before waking up the patient. One must ensure not to have major overcorrection that would lead to a permanent retraction of the labial commissure.

Temporal notch

- The fat pad located between the two sheets of the superficial aponeurosis of the temporalis muscle must remain fixated to the scalp flap and reinserted at the end of the procedure.

Retraction of the labial commissure

- Each step of the dissection allows the complete freeing of the temporalis muscle that remains attached to its deep pedicles. It is important to free the numerous insertions with the masseter muscle.

Perioperative blood loss

- The bitemporal approach is a hemorrhagic one. It is essential to use Michel suture clips or fix the surgical drape on the two margins of the scalp used for the surgical approach.

Horizontal direction of the labial commissure traction vector

- The external fibers of the tendon correspond to the muscle fibers of the posterior part of the temporalis muscle. Reinserted preferably on the commissure, they help give a proper horizontal direction to the labial commissure traction vector.

POSTOPERATIVE CARE

- Rehabilitation can start 3 weeks after surgery. The speech therapist is in charge of this rehabilitation.
- The patient follows a three-step protocol to go from a mandibular smile to a

temporal smile to finally achieve a spontaneous smile.

- During the first step, to obtain a symmetric smile, the patient must clench the jaw in order to contract the transferred temporalis muscle. This is what we call the mandibular smile.
- During the second step, the patient can obtain an almost symmetrical smile without clenching the jaw. This is called the voluntary temporal smile.
- Finally, the last rehabilitation phase helps the patient obtain a spontaneous smile attributed to brain plasticity.
- It is essential to accompany the patient for at least 6 months of rehabilitation and propose Botulinum toxin treatment for overactivity and cocontractures.

OUTCOMES

- Lengthening temporalis myoplasty can and must offer the patient better symmetry at rest and offer movement capacity of the labial commissure when smiling, thus underlining the nasolabial fold.
 - This procedure can be proposed when the labial commissure contracture is 50% less important than the one on the healthy side, in spite of a well-conducted rehabilitation program.
- In case of partial paresis, lengthening temporalis myoplasty can, most times, help the patient retrieve facial movements present before the procedure, as there is no risk for the facial nerve.
 - The new movements allowed by the transferred temporalis muscle are then complementary of the preoperative facial mimic.

COMPLICATIONS

- Postoperative hematoma: managing hemostasis during the procedure requires caution.
 - Achieving hemostasis as the end of the procedure is essential especially for the bitemporal approach.
 - Two Redon drains are left in place for 3 days after surgery for vacuum wound drainage: one in the subgaleal plane and the other one in the intrajugal tunnel.
- Local infection: The distal insertion into the labial commissure can become infected because it is partially devascularized during the procedure, and the nasolabial approach is close to the oral cavity.
 - It is important to use a vascular clamp to seize the temporalis muscle tendon in a nontraumatic manner.

- Prophylactic antibiotic therapy is prescribed for 1 week postoperatively.

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52 Babysitter Nerves for Facial Reanimation

CHAPTER

Adel Y. Fattah

DEFINITION

- The aim of facial reanimation is to provide facial symmetry at rest and synchronized coordinated facial expression.
- When the facial nerve is unusable but facial musculature is intact, reinnervation is preferred.
- Cross face nerve grafting (XFNG) allows for the contralateral facial nerve to direct its activity to the paralyzed side.
- The main issue for this technique is the long period of time for nerve regeneration to occur along the graft. This results in irreversible muscle atrophy unless the grafts are performed soon after initial denervation, as it typically takes 6 to 12 months for axons to reach their target muscle.
- In addition to the axon growth, there is a degree of axonal “dropout,” as regenerating axons fail to complete their journey along the full length of the graft affecting clinical outcomes.^{1,2}
- To overcome this, the babysitter procedure was introduced to provide a rapid reinnervation to the muscle while awaiting nerve growth across these long grafts.³
- The term *babysitting* in its original context is used to describe the maintenance of viable musculature while waiting for the cross face nerve grafts to grow and reinnervate the musculature to achieve spontaneous animation.
- Since its inception using the hypoglossal nerve, the principle has developed, and other cranial nerves have been used to babysit the facial musculature such as the motor nerve to masseter.⁴

- The author has exclusively used the masseter nerve because there is less morbidity.
- There is little or no functional deficit produced by using the motor nerve to masseter as a donor. By contrast, hypoglossal nerve sacrifice can result in issues with speech and swallowing, even in the minihypoglossal transfer.
- There is no synkinesis with tongue movement; there is some with chewing, but this abates with training.
- There is no need for interposition grafts of sural or greater auricular nerves with their own donor sensory deficits. Additionally, axons will only have to cross one neurorrhaphy, which reduces time to reinnervation.
- To combat the axonal dropout in XFNG, another form of babysitting may be used.
 - This involves the coaptation of an end-to-side sensory nerve to the cross face nerve graft at a point along its length to provide a source of neurotrophic factors to encourage axonal growth toward the target.⁵
- Therefore, reanimation of the paralyzed face can be optimized by using a motor nerve to babysit the musculature and sensory nerves to babysit the cross face nerve graft.
- In this chapter, the author will describe the preparation of the motor nerve to masseter and its transfer to the ipsilateral facial nerve to babysit the facial musculature. The sensory babysitting of the cross face nerve graft will also be described.

ANATOMY

- The masseter muscle is one of the muscles of mastication.
 - It arises from the lower border and medial surface of the zygomatic arch and inserts into the lateral surface of the mandible.
 - The muscle consists of three layers—superficial, middle, and deep (**FIG 1**).
 - The superficial muscle fibers pass backward and downward, and the deeper fibers are more vertical. The motor nerve to masseter is derived from the mandibular division of the trigeminal nerve. It leaves the infratemporal fossa by passing over the lateral pterygoid muscle and mandibular notch. It enters the masseter muscle from its deep surface and courses down between its deep and middle layers having a diameter of 1 to 2 mm. It becomes more superficial distally toward the anterior inferior part of the muscle and runs alongside the (friable) vascular pedicle that arises from the inferior alveolar artery. Proximally, within the muscle, it gives a number of small short

branches, but it typically has one or two significant branches, one longer than the other, that can yield 2 to 3 cm of useful nerve before terminal branching.⁶⁻⁸

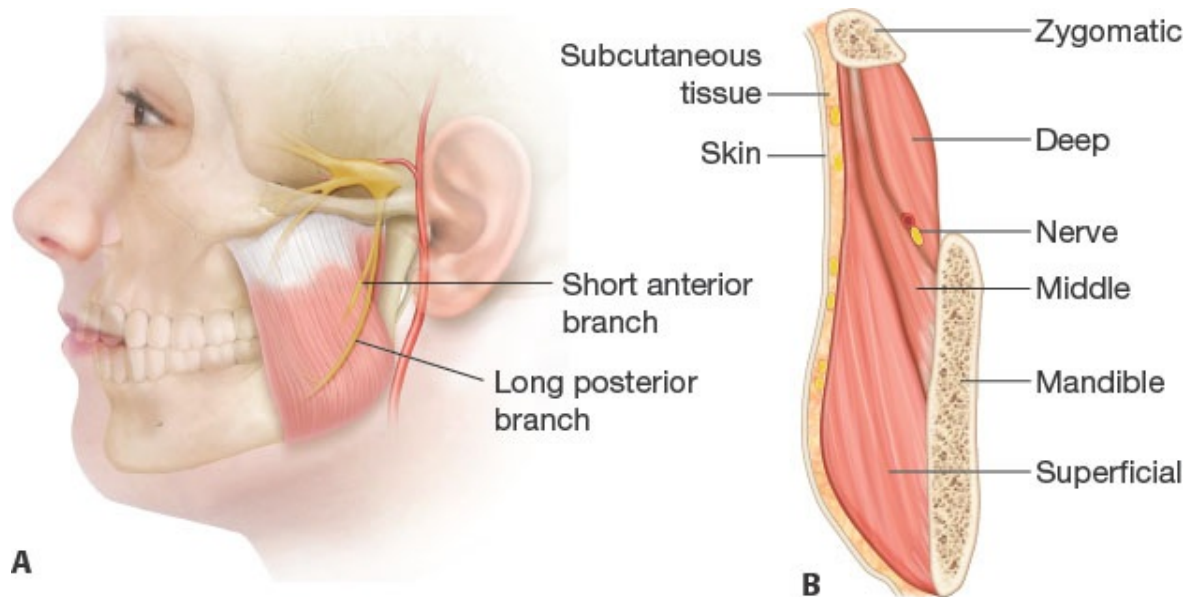


FIG 1 • A. Topography of the motor nerve to masseter. The main trunk typically divides into a long posterior branch and a shorter anterior superior branch. **B.** The nerve (N) lies deep in the muscle, which comprises superficial (s), middle (m), and deep (d) portions.

- The facial nerve exits the stylomastoid foramen, turns superficially, and immediately enters the substance of the parotid gland where it is classically described as dividing into five branches—temporal (frontal), zygomatic, buccal, mandibular, and cervical.
- The nerve usually divides into upper (temporal) and lower (cervical) trunks at first, from which these branches arise. In practice, they comprise five variably interconnected groups of branches hereafter referred to as divisions.
- Despite the various studies of facial nerve anatomy, it may be more useful to envision the facial nerve as consisting of physiological and functional divisions that do not necessarily correlate to the anatomic distribution of branches but instead relate to muscular groups and actions.
- The temporal branch of the facial nerve exits from the upper pole of the

parotid gland at the level of the zygomatic arch and becomes superficial being plastered onto the underside of the temporoparietal fascia.

- The course of the nerve follows a line drawn from 0.5 cm below the tragus to 1.5 cm above the eyebrow, but 3D modeling demonstrates that the branches cover a triangular area bordered between a line through the palpable zygomaticofrontal and zygomaticotemporal sutures and a vertical line 1 cm in front of the auditory meatus.⁹ At the lateral margin of frontalis, these branches run deep to frontalis and orbicularis oculi (which it innervates), eventually reaching the glabella region to supply the depressors of the brow.
- The zygomatic division leaves the parotid gland to run just inferior the zygomatic arch immediately deep to the superficial musculoaponeurotic system (SMAS) to innervate the elevators of the upper lip and lower portion of orbicularis oculi.
- Distally, it runs on the undersurface of the zygomaticus muscle complex before ramifying more medially in the face. The buccal branches exit the anterior border of the parotid gland and run inferior to the parotid duct and on the surface of the buccal fat pad deep to the SMAS layer to supply the muscles of the mouth and cheek.
- Both zygomatic and buccal divisions have a highly overlapping distribution of innervation that allows transection of one or more branches without weakness; this is the basis of XFNG.
- The mandibular branch leaves the lower portion of the parotid gland and swings down below the ramus of the mandible to supply the muscles of the lip and chin.
- Cadaveric dissections demonstrate that the nerve always comprises at least three major branches that run on the undersurface of the platysma and superficial to the facial vessels.¹⁰

PATHOGENESIS

- A nerve injury that is significant enough to damage the axon leads to Wallerian degeneration. It takes around 72 hours for the process to become established to the point that nerve conduction fails.
- One method of determining such axonotmesis vs neurapraxia is to demonstrate conduction in the peripheral nerve segment. When there is no regrowth of axons distally, the end organs eventually undergo irreversible changes, which hinder muscle recovery from prolonged denervation.¹¹
- The quality of the recovery following repair depends chiefly on the number

of axons that successfully reach their correct targets and the subsequent myelination of these axons.

- Therefore, treatment is best achieved by reinnervating the end organ as effectively as possible, specifically delivering as many axons as soon as possible to the end organ.
- As well as changes in the muscles, nerves that are chronically denervated (ie, have suffered axonotmesis) undergo changes proximally; the myelin sheaths collapse with reductions in conduction velocity and changes in the cell bodies.
- Long nerve grafts such as XFNGs also suffer chronic denervation changes reducing the capacity for nerve regeneration. Donor axons from sensory nerves can protect nerve grafts from chronic denervation and thereby improve axonal growth through the graft.⁵ Such protection of chronically denervated nerves improves regeneration due to endogenous trophic support.¹²

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most important factor in the history is determining the premorbid status of facial animation and time since the injury as this will determine the presence of viable facial musculature that may act as a target for reinnervation.
- In general, the sooner innervation is re-established, the greater the likelihood of a better functional outcome.
- Most clinicians would suggest that reinnervation of musculature is attempted within 12 to 24 months of injury. Thereafter, results may be unpredictable.
- The examination is directed toward muscle-specific objectives and determines the presence of intact donor nerves. Therefore, examination of the facial nerve of the affected side should delineate that the deficit one is attempting to reconstruct.
- Muscle-specific treatment goals include brow elevation, eyelid closure, smile, and lower lip function.
- Cranial nerve examination is performed specifically looking for donor nerve activity, such as contralateral facial nerve function (examining each division) and activity of the muscles of mastication.
- Palpate the cheek and feel for the presence and power of masseter and temporalis contraction to determine innervation.
- Examination of the tongue is performed for deviation that will indicate hypoglossal nerve activity.

SURGICAL MANAGEMENT

- General management of facial palsy has been published in detail elsewhere,¹³ but the principles of reanimation remain: the re-establishment of movement, *for which the muscle is required with a nerve to control that motor function*.
- Soon after facial nerve injury, the muscle remains intact for a short time, and reinnervation of this can yield good results.
- Once the native muscle has atrophied, new muscle will need to be imported to re-establish the muscle-specific functions outlined above.
- The key points to evaluate are the presence of a functioning proximal nerve stump (mainly based on the history) and the time elapsed after the injury (that will indicate the likelihood of functioning facial musculature).
- By definition, the requirement for a cranial nerve transfer (babysitter) intimates that a proximal nerve stump is unavailable (**FIG 2**).

Preoperative Planning

- Preoperative planning is informed by clinical examination as outlined above.
- Electrical conduction studies are useful if there is debate over the presence of viable facial musculature, but it is generally not used after 1 year because after 18 to 24 months after injury, the likelihood of adequate active muscle sufficient for reconstruction is low.

Positioning

- The patient is positioned supine on the operating table with a shoulder roll to extend the neck and a head ring to support the head that is rotated to the opposite side (**FIG 3**).

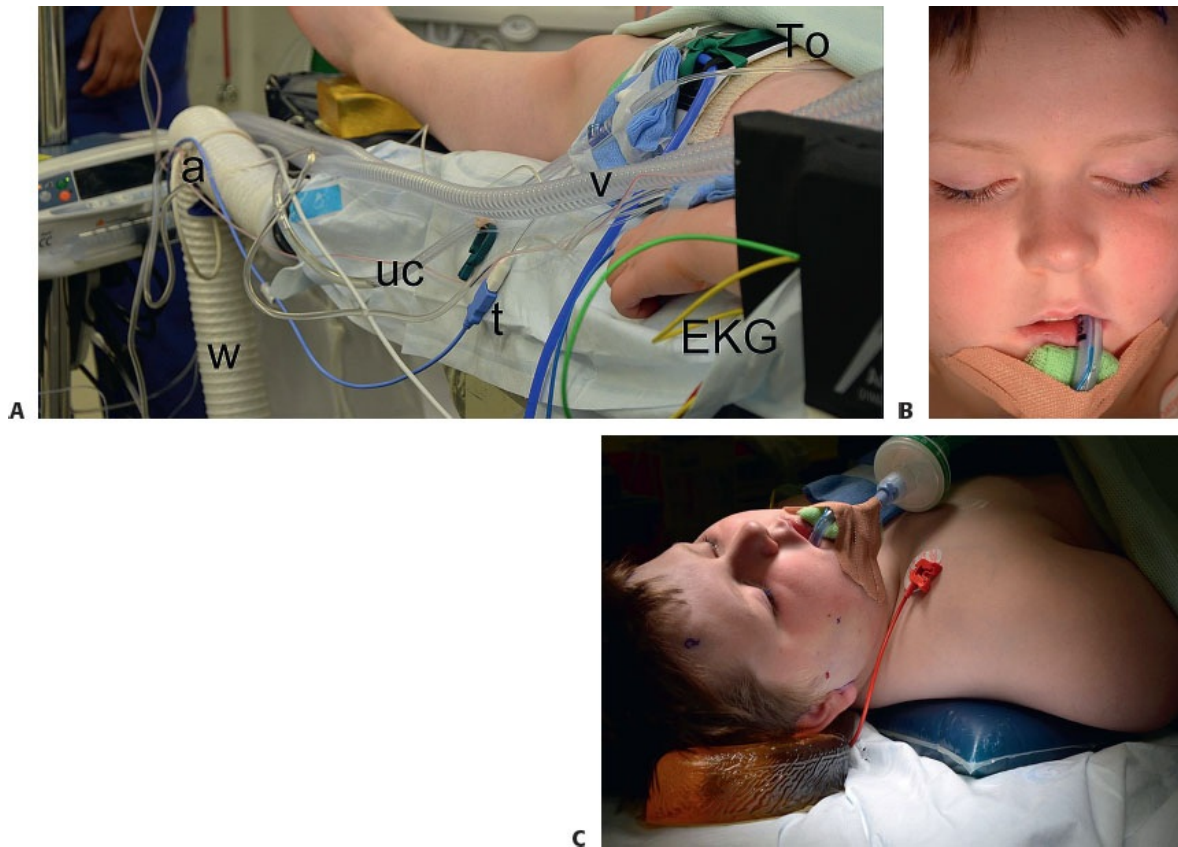


FIG 3 • A. Lines are restricted to one side of the patient to allow access to the anesthesiologist without the surgical team obstructing. a, arterial line; w, warming blanket; uc, urinary catheter; t, temperature probe; v, ventilation circuit; To, tourniquet; EKG, EKG leads. **B.** Tarsorrhaphy using polypropylene suture through the gray line of the eyelid is used to avoid corneal exposure. The tube is positioned to the side away from the proposed intraoral incision. **C.** The head is positioned on a head ring with a shoulder roll providing neck extension. Not shown: the legs are prepared to allow a full range of movement below the knee; a sterile tourniquet is also applied.

- An orotracheal intubation is performed with a “south-facing” tube that is neatly taped in the midline to maintain as much symmetry as possible. This is

to allow the movements of the face to be observed during neurostimulation of the donor facial nerve and easy access to the upper buccal sulcus for access to the graft if required.

- The face is infiltrated with a 1:400 000 solution of adrenaline prior to preparation and draping to allow adrenaline time to work.
- Local anesthesia is not used to permit nerve stimulation; likewise, the anesthesiologist should be aware to avoid intraoperative paralysis.
- Typically, 20 to 50 mL of infiltration is used; the volume should be sufficient to facilitate hydrodissection of the skin flap.

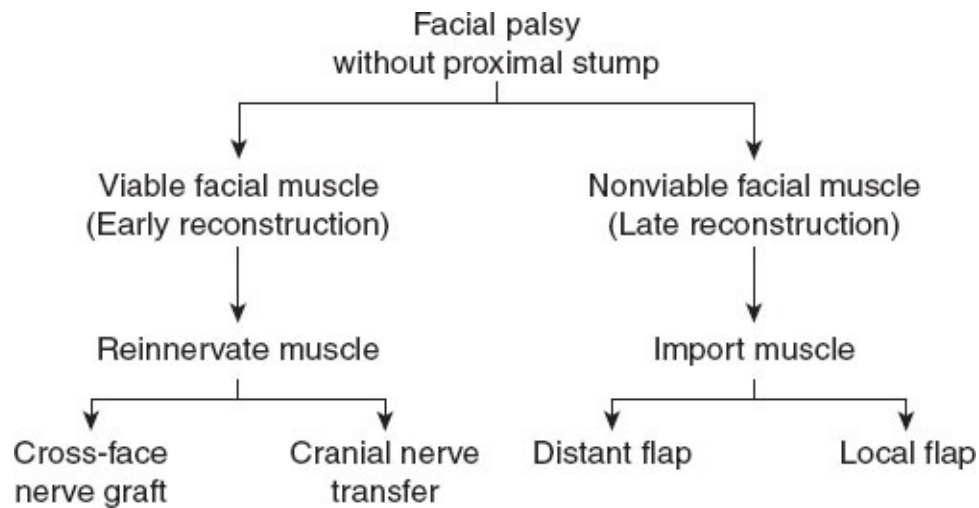


FIG 2 • Flowchart summarizing options for facial nerve reconstruction without an ipsilateral proximal stump. Native muscle reinnervation is preferred for early reconstruction, whereas the muscle will need to be imported in later cases. Such muscle may then be innervated by contralateral facial nerve (XFNG) or cranial nerve transfer.

- The face is prepared with aqueous povidone-iodine solution, and the mouth is also prepared.
- A throat pack is inserted, and the head is draped in a turban fashion with the ears exposed.
- If a sural nerve harvest is to be performed, access to one or both legs must be unhindered: a U or W drape is used, and the whole leg is prepared to allow the

legs to be maneuvered to afford access for sural nerve harvest.

- A sterile tourniquet is applied to the thigh.
- In a unilateral case (eg, V–VII transfer only), lines and blood pressure monitoring equipment are connected to the contralateral side, and the table is positioned so that the surgical team is on one side and the anesthetic team has unfettered access to the other.
- A urinary catheter is inserted and removed at the end of the case.
- In long cases, such as cranial nerve transfer with free gracilis flap harvest or use of multiple XFNGs, tarsorrhaphies are performed to protect the cornea.
- A pressure-reducing mattress is advised with repositioning of the patient partway through the procedure to ensure that pressure areas are not at risk. This involves the team shifting the body weight from one hip/shoulder to the other with minimal disturbance to the position of the surgical field.

Approach

- For XFNG and masseter nerve transfer, the approach to the face is via a modified facelift incision.
- The full length of the incision runs from 1 to 2 cm above the zygomatic arch, along the anterior border of the root of the helix, down the edge of the tragus, and at the lobule of the ear, curves behind the angle of the mandible.
- Traditionally, this incision extends downward toward the neck in the manner of a parotidectomy incision.

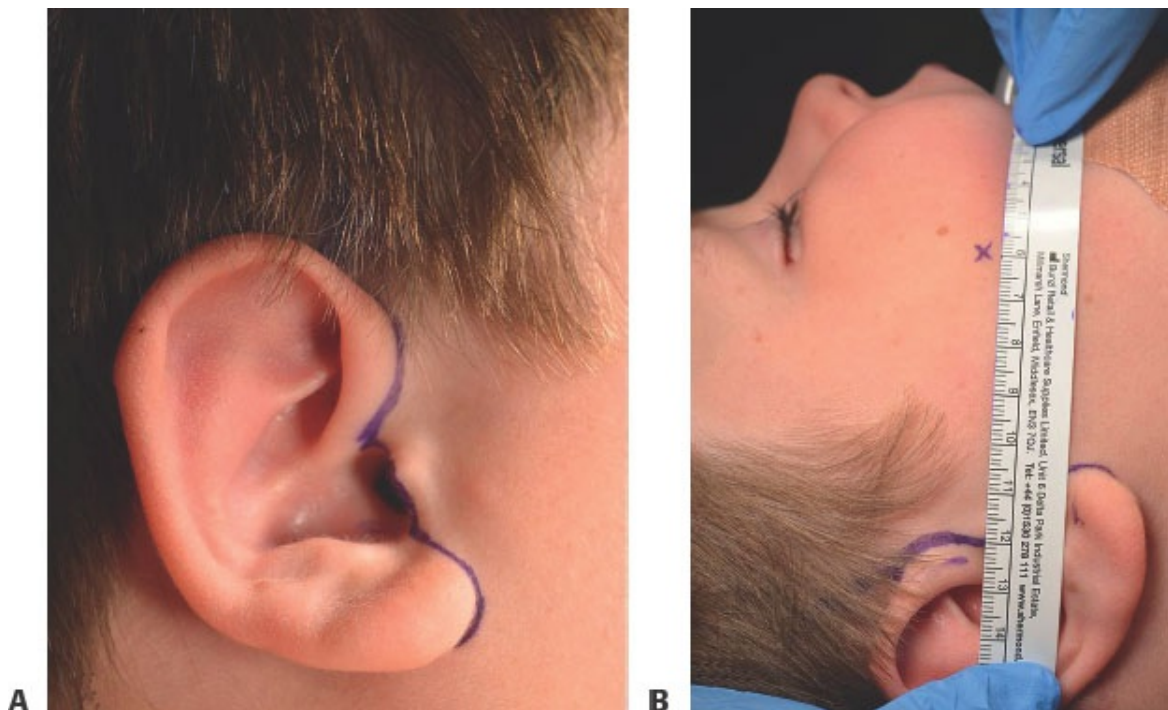
TECHNIQUES

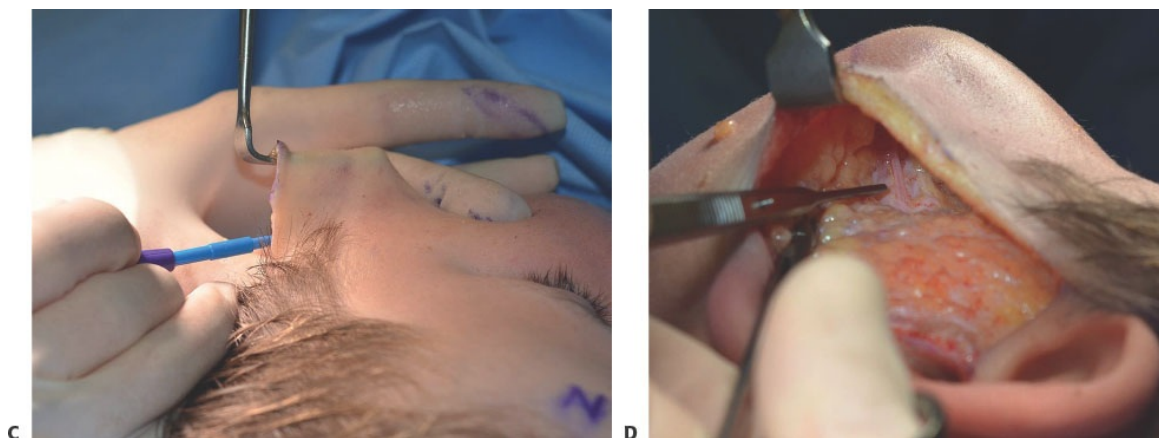
■ Exposure of the Facial Nerve

- In most XFNG procedures, sufficient access is gained to identify the donor facial nerve and motor nerve to masseter by using the preauricular portion of the incision alone (**TECH FIG 1A**).
- If further access is required, the incision is taken behind the ear lobe and then down along the anterior border of sternomastoid.
- Prior to infiltration, a point midway between the root of the helix and the commissure of the mouth is marked.
- This corresponds to “Zuker point,” a landmark for the position for the

zygomatic/buccal branches that animate the smile (**TECH FIG 1B**).

- The upper portion of the incision is marked as a soft curve parallel to the curve of the helical margin, and as the tragus is approached, the incision is carried into the fossa immediately above the tragus; here, a right-angle change in the direction of the incision is made to help align the skin for closure.
- Thereafter, the incision is carried along the “edge” of the tragus, and at the incisura (between tragus and antitragus), another perpendicular change of direction is made anteriorly and then inferiorly to run along the crease between the anterior lobule and cheek.
- The right-angle changes of direction will counteract the tendency of scar contraction to create an indistinct tragal contour.
- The lower part of the incision is then carried inferior and behind the lobule just outside of the natural crease. Placing the incision in the crease effaces this natural landmark.
- The skin incision is made with the blade just through the dermis; then, the blade is turned forward, and the skin is lifted anteriorly for a few millimeters.





TECH FIG 1 • **A.** Incision required for access to the facial nerve. Note that the right-angle turns above and below the tragus. **B.** Markings for the facial nerve dissection midway between the root of the helix and the oral commissure. X indicates the Zuker point. **C.** Raising of the skin flap. While the assistant holds retractors, the operating surgeon places traction on the skin with the middle finger and on the SMAS with the thumb. **D.** Forceps point to the exposed facial nerve.

- Immediately superior to the tragus, the subcutaneous plane over the SMAS is easiest to enter, dissection proceeds here, and once anterior to the tragus, the facelift flap can be lifted off the tragus safely in a retrograde direction.
- Thereafter, most of the dissection is continued with Bovie monopolar cautery.
- Careful skin traction with the left hand allows rapid dissection anteriorly until the anterior border of the parotid gland is reached; this is usually just proximal to the Zuker point (**TECH FIG 1C**).
- Here, the SMAS becomes noticeably thinner and monopolar that is switched for scissor dissection.
- Using a careful spreading motion with the scissors, the sub-SMAS plane is entered, and the speed of dissection is slowed for identification of facial nerve branches (**TECH FIG 1D**).
- The facial nerve branches sit on the surface of the buccal fat pad, and neurostimulation with a bipolar stimulator (Neurosign 100, Spring

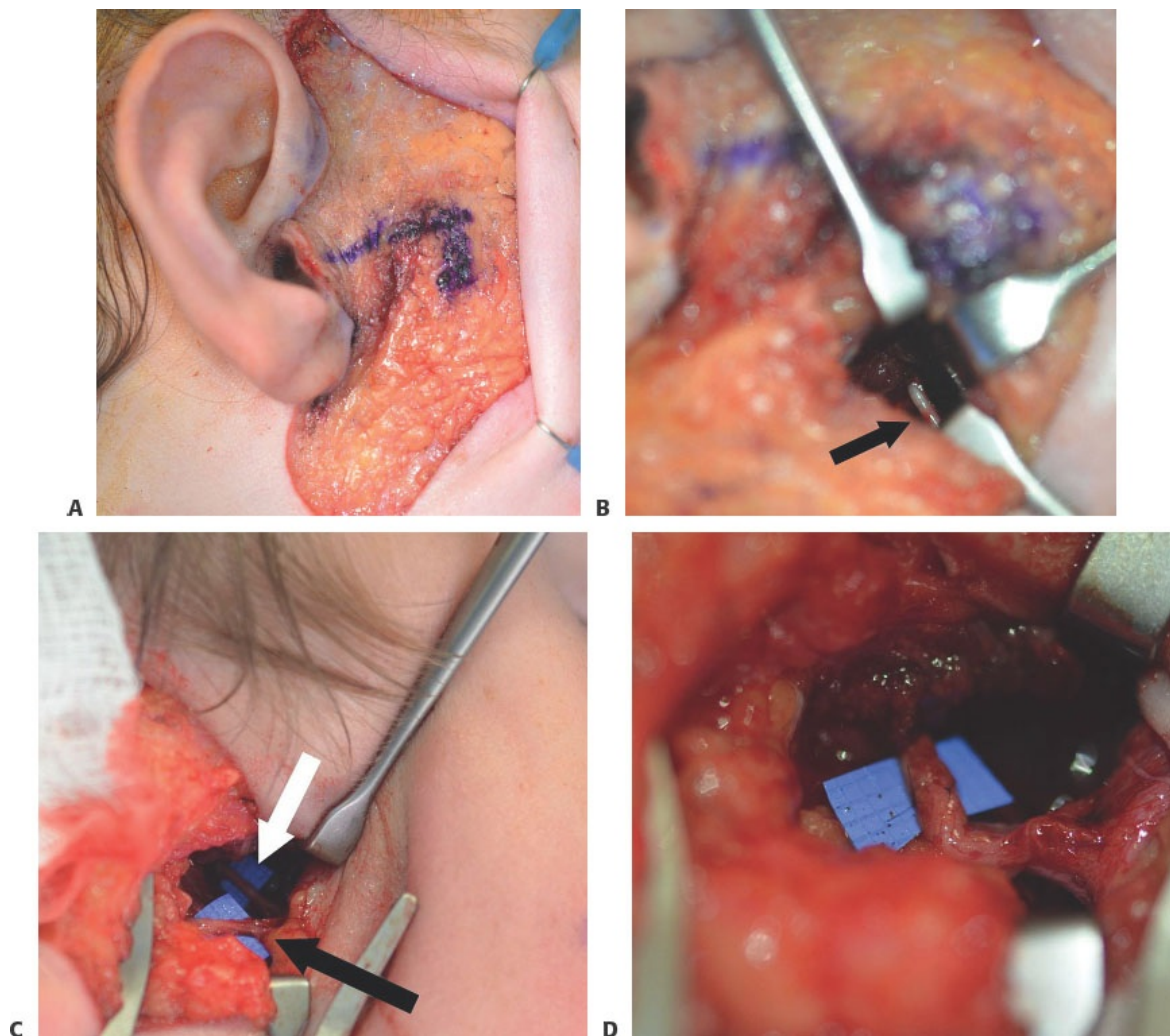
Gardens, UK) may be used to discern between ligamentous structures and functioning facial nerve branches.

- Once facial nerve branches are identified, they are then dissected retrogradely into the parotid gland to find branches that will match the size of the donor nerve.
 - Nerves to be used as recipients for transfer are prepared and tagged with microsuture material but are not divided to ensure ease of location at the time of neurorrhaphy.
-

■ Exposure of the Motor Nerve to Masseter

- Once the facelift flap has been raised and facial nerve dissection completed, attention is turned to the donor nerve.
 - The point at which the nerve can be found is 1 cm below the lower border of the zygomatic arch 3 cm anterior to the tragus (**TECH FIG 2A**).
 - At this point, an incision is made in the parotid fascia that is parallel to the facial nerve branches and is approximately 2 cm long.
 - Dissection is performed slowly with meticulous hemostasis, as bleeding from the multiple tiny vessels in the parotid can make deeper dissection and visualization of the nerve challenging.
 - As the dissection proceeds through the parotid, spreading scissors parallel to the direction of the facial nerve minimizes risk of damage with care taken to identify and protect facial nerve branches.
- Once the fascia over the masseter muscle is reached, a small amount of blunt undermining is performed to free the parotid from the underlying muscle and facilitate retraction.
 - Thereafter, a muscle-splitting dissection is performed through the masseter muscle.
 - Cautiously and with meticulous hemostasis, the muscle is parted, and small amounts of muscle fibers are removed as required to create a path to the deeper muscle.
 - The assistant is vital, retracting with Ragnell or cat's paw retractors (**TECH FIG 2B**).
 - Once a "plane" of tendinous tissue is found, the transition between the deep and middle layers of the muscle is indicated.
 - At this point, the neurostimulator is used to help guide the dissection.

- Once the nerve is found, careful dissection is used to dissect it proximally and distally (**TECH FIG 2C**).
- The vessels running alongside are friable and bleed easily. The use of diathermy near the donor nerve is cautious, and pressure is used to achieve hemostasis.
- The nerve is dissected as far as possible proximally, extending the muscle dissection to facilitate this.
- Then, distal dissection proceeds.
 - The nerve typically splits into two or three branches, and these are followed as far as is practicable to create a length of nerve that can be brought up to the recipient facial nerve.
 - The time taken to free the nerve effectively is repaid later with the ease of neurorrhaphy.



TECH FIG 2 • A. Markings on the SMAS 3 cm in front of the tragus and 1 cm below the zygomatic arch indicate the position of the motor nerve to masseter. **B.** The assistant is critical in retracting the muscle during the fiber-splitting approach to the nerve. The nerve is seen in focus in the depth of the incision. **C.** The proximity of the motor nerve to masseter (*white arrow*) to the buccal branch of the facial nerve (*black arrow*) is demonstrated. **D.** Completed neurorrhaphy. The minimal number of sutures is used, and fibrin glue is then used to complete coaptation (not shown).

- Standard neurorrhaphy is performed with the operating microscope.
 - 9/0 nylon microsuture material is used, and either end-to-end or end-to-side coaptation is utilized.
 - Two or three sutures are used to align the epineurium, and then Tisseel glue (Baxter Int., USA) is used to complete the neurorrhaphy (**TECH FIG 2D**).
- Immediately, before the Tisseel glue is applied, a large-gauge permanent-colored monofilament suture is placed near the neurorrhaphy to loosely encircle the nerve.
 - This marks the nerve branch for identification at the second procedure should a contralateral XFNG needs to be coapted to the ipsilateral facial nerve for restoration of spontaneous smile.

■ Sensory Babysitter for Cross Face Nerve Graft

- The technique of XFNG is detailed in Chapter 49. The design and harvest of the gracilis muscle is described in this chapter.
- The XFNG is broadly used in two different situations:
 - To be banked near the piriform aperture for connecting to a free muscle flap at a second procedure (**TECH FIG 3A**).
 - To be tunneled through to the paralyzed side of the face and banked near the nonfunctioning facial nerve to be coapted to the distal facial nerves after a period of babysitting the musculature by the motor nerve to masseter. This adds contralateral facial nerve input for spontaneity of

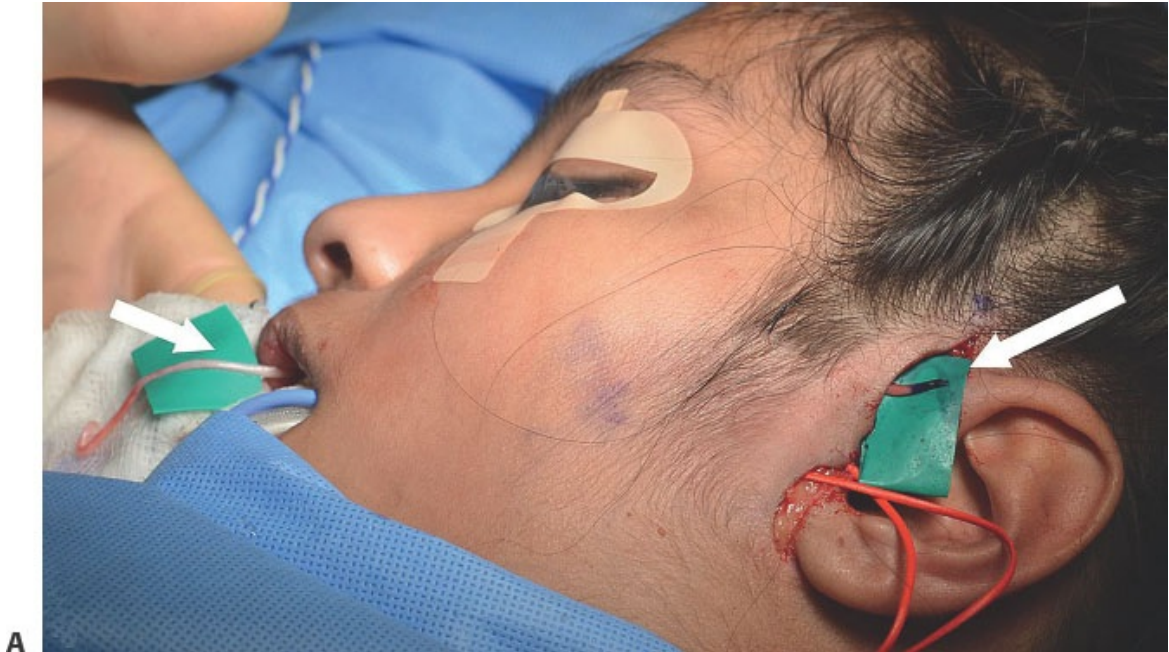
movement as well as conscious control by the motor nerve to masseter in response to bite.

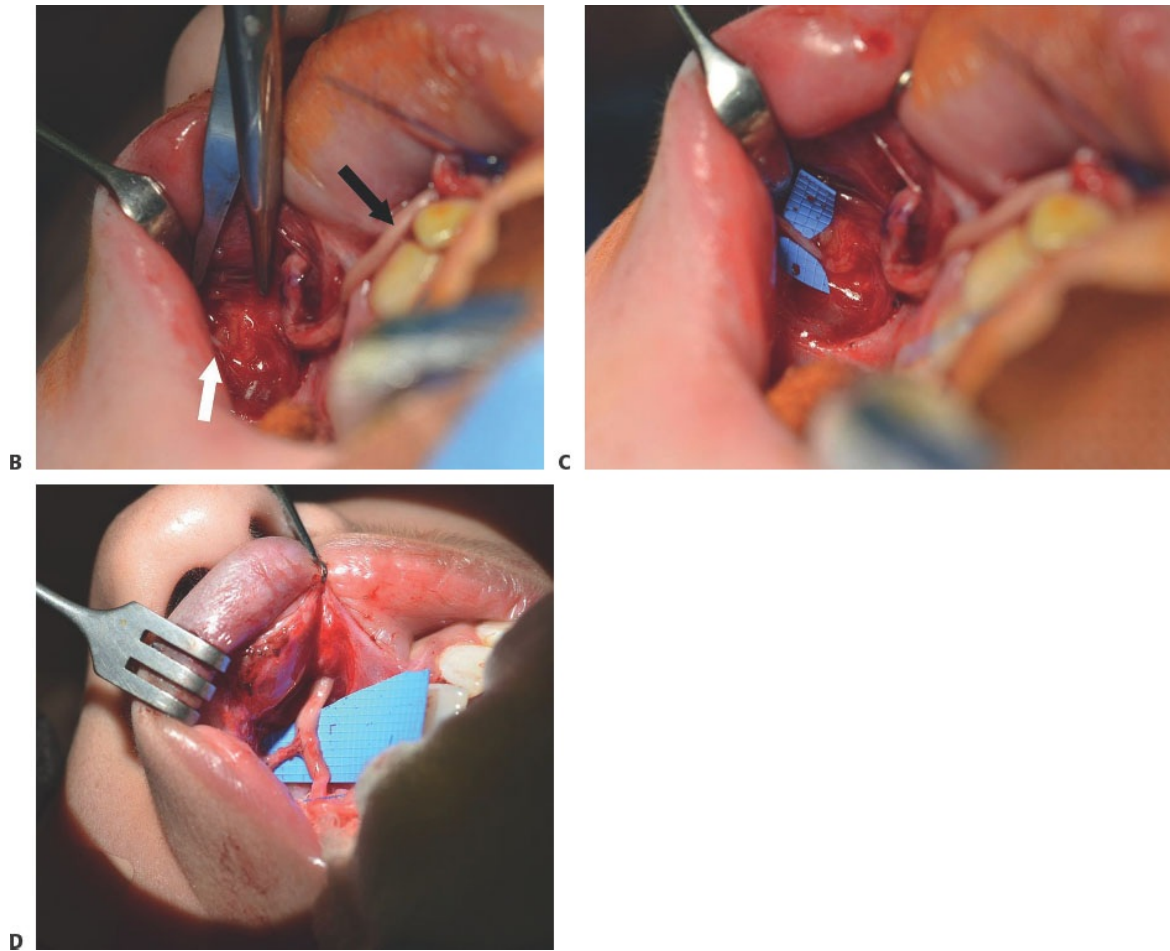
- A buccal sulcus incision is used as a site of access to allow the nerve to be tunneled across the face into the contralateral side, or if combined with a gracilis flap, the neurorrhaphy can be performed via this incision.
 - Additionally, this incision is used to identify a branch of the infraorbital nerve that can be used as the babysitter for the XFNG.
- Once the donor branches have been selected, a large hemostat, such as Tudor Edwards artery forceps (Scala Surgical, London, UK), is used to create a preperiosteal tunnel to the buccal sulcus.
- Prior to creating the tunnel, local anesthetic is injected into the mucosa of the buccal sulcus where the intended incision is to be made to perform the babysitter neurorrhaphy.
- Once the tip of the hemostat is seen, it is positioned to reach the contralateral lip beyond the frenulum.
- Here, an incision is made with a blade or monopolar diathermy down onto the hemostat.
 - A silicone loop is attached to the end of the hemostat to ensure the tunnel is not lost, and attention is turned to developing the buccal sulcus incision.
 - The incision is extended and sited just below the apex of the buccal sulcus (as one would for a Le Fort I osteotomy) with efforts to avoid crossing the frenulum.
- If the nerve is needed as a XFNG to the contralateral facial nerve, a tunnel is made through to the contralateral face where the damaged facial nerve has already been exposed and identified. It is banked in a location that is easily identifiable at a subsequent procedure.
 - It is tacked to the surrounding soft tissue with a large-gauge (4/0 or 3/0) permanent-colored monofilament suture to allow rapid identification for the second procedure, which would comprise re-elevation of the facelift flap identification of the distal facial nerve branches and coaptation in an end-to-side or end-to-end manner depending on the requirements.
- Hemostasis in the buccal sulcus is achieved, and a spreading motion with the tenotomy scissors perpendicular to the direction of the orbicularis fibers is performed. This will tease out sensory nerves that ramify throughout the upper lip (**TECH FIG 3B**).
 - Under ×3.5 loupe magnification, a large branch is selected and carefully

dissected back far enough to reach the XFNG in the buccal sulcus in a tension-free manner (**TECH FIG 3C**).

- The operating microscope is brought in and the field prepared.
 - A wet sponge is placed into the oral cavity to push the tongue back and create a platform upon which neurorrhaphy can be performed.
 - Microscope background is placed on the swab to facilitate manipulation of the nerves, and retracting “fishhooks” are used to hold the lip in position.
- An epineural window is made in the XFNG, and the infraorbital nerve branch is carefully aligned.
 - The window is adjusted for size match. Once an alignment is achieved, two or three 9/0 nylon sutures are used to maintain the alignment, and the nerve is returned into the buccal sulcus incision in the desired position (**TECH FIG 3D**).
 - The alignment of the nerves is checked and the neurorrhaphy completed with Tisseel glue.
- Once the Tisseel has set, the incision is closed with 5/0 Vicryl Rapide (Ethicon) in a two-layer watertight fashion: using a running mattress suture in one direction, locking the knot, and then suturing back on yourself in an over-and-over fashion to complete the two-layer closure.
- Once the Tisseel has coagulated (set), the operative field is washed with copious amounts of warmed saline.
- The second careful round of hemostasis is performed, and the underside of the skin flap is also checked.
- A small suction drain is placed exiting behind the ear.
 - The drain itself is held away from the sites of neurorrhaphy by using a loop of fast-absorbing suture such as catgut or Vicryl Rapide (Ethicon).
 - Care is taken to position this suture such that it will not hinder removal of the drain.
- Key subcuticular sutures using 4/0 undyed Vicryl are placed: upper border of the tragus, lower border of the tragus, and inferior-most lobule. These serve to align the skin edges accurately.
 - Thereafter, two or three additional sutures are placed to give strength to the closure.
- Intracuticular closure is performed with 4/0 polypropylene in a looped fashion. This allows for four or five sutures to close the whole incision and be easily removed in the office at the 10th to 14th postoperative day.

- Nylon does not “run” as easily as polypropylene and is avoided.
- Chloramphenicol ointment is applied to the wound margin, and no further dressings are required.





TECH FIG 3 • **A.** Cross face nerve graft (*arrows*) demonstrated after being tunneled through to the buccal sulcus. **B.** The use of the tenotomy scissors to spread perpendicular to the fibers of orbicularis oris allows the sensory branches of the infraorbital nerve to be teased out (*white arrow*; *black arrow* indicates nerve graft). **C.** The branch is seen more clearly after further dissection. **D.** End-to-side coaptation of the infraorbital nerve branch to the cross face nerve graft.

PEARLS AND PITFALLS

Meticulous hemostasis	■ Bleeding makes visualization of structures difficult; careful “bloodless” dissection facilitates ease of dissection. ■ Hematoma of the masseter muscle causes trismus or may compromise the facelift flap if not treated rapidly.
Hemifacial microsomia	■ In these instances, the motor nerve to masseter can be small caliber yet still provide powerful neuronal input.
Incision placement along the tragus	■ Placing the incision along the “edge” of the tragus avoids the bulky appearance and awkward suturing when closing a retrotragal incision positioned on the inner surface of the tragus. Additionally, the assistant should not place skin hooks into the tragus during initial skin elevation. The delicate skin tears through easily, and adequate retraction can be achieved by placing a hook in the more robust skin immediately superior and inferior to the tragus.
Synkinesis	■ Regular surveillance is required to look for and address synkinesis early.

POSTOPERATIVE CARE

- Postoperative care revolves around a warm, well-hydrated, and pain-free patient.
 - The patient has “slow wake-up” to minimize the risk of coughing and hematoma postoperatively.
- Postoperative discomfort is largely related to facial swelling; therefore, the patient is nursed head up to mitigate this cause of the pain.
- Adequate analgesia and antiemetics are tailored to the patient.
 - Typically, regular acetaminophen (IV until oral intake is achieved) is used with aliquots of oral morphine to ensure the patient is pain-free. Tylenol or Percocet can be used upon discharge for adults but are often discontinued by patients quickly following discharge as the swelling subsides.
 - In children, the absorption of codeine may be unpredictable, and therefore, oral morphine is recommended to take home.
 - A laxative is initiated following surgery and stopped once the opiate analgesia is discontinued and normal bowel activity resumed.
- Longer procedures that involve exposure or tunneling via the oral cavity will indicate the use of antibiotics for 24 to 48 hours postoperatively.
- The patient is reviewed the next day and swelling is usually worse; patients are counseled regarding this preoperatively.
 - The drain is removed the following morning, as drainage is typically

minimal.

- Significant volumes of drainage for more than a day or so should prompt consideration of a salivary fistula and request for analysis of drain fluid for salivary amylase.
- Soft diet is started on the next day and maintained for 2 weeks; thereafter, a graded return to full diet is undertaken.
- In general, the patients may be discharged the following postoperative day if comfortable and are accompanied.
- Once movement is detected in the face, facial therapy and rehabilitation are initiated by an experienced facial physiotherapist.
- Graded biting exercises are started to teach the patient to learn to control the degree of facial movement by biting.
- Mirror therapy is used and the patient given a program of exercises to perform at home.
- Regular review and guidance are required to look for synkinesis and to develop strategies to address this.

OUTCOMES

- In the few studies to date, masseter to facial nerve transfer has good outcomes with improvements in oral continence, resting tone, and smile with occasional spontaneous smile.^{4,14}
- There is, as yet, no published clinical data on end-to-side sensory nerve babysitting, and current studies are ongoing.

COMPLICATIONS

- Poor or unaesthetic scarring may occur, and usual counseling and information are provided. Infection risk is very low as is incidence of hematoma; patients are informed about likely that treatments should either occur including return to theater, washouts, and IV antimicrobial therapy.
- Salivary fistula and Frey syndrome (gustatory sweating) are rare complications. Failure of reinnervation is also mentioned to the patients.
- Synkinesis is common and is minimized by careful evaluation of the nerve branches and consideration of synergistic movements.
- It is treated with intensive facial physiotherapy and judicious use of botulinum toxin in selected cases¹⁵; the details are beyond the scope of this chapter.
- Persistent trismus may occur and is treated in the standard fashion with warm

packs, stretching exercises using wooden spatulas, and reassurance.

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53 Gold Weight Insertion for Upper Eyelid Reanimation

CHAPTER

Larissa A. Habib and Brian Marr

DEFINITION

- Upper eyelid loading with a gold weight is the treatment for paralytic lagophthalmos causing exposure keratopathy. This is due most commonly to facial nerve damage following trauma, infection, ischemic event, or tumor.
- Pure gold is used for its density and to minimize allergic reaction.
 - The weights range from 0.8 to 1.6 g.

ANATOMY

- The upper and lower eyelid meet at the medial and lateral canthus with the lateral canthus sitting 2 to 4 mm higher than the medial (**FIG 1**).
- The palpebral fissure is approximately 28 to 30 mm in length and 9 to 10 mm in height.
- The eyelid anatomy can be divided into anterior and posterior lamellae.
- The anterior lamella consists of the skin and the orbicularis oculi muscle.
 - The eyelid skin is the thinnest in the body (less than 1 mm). The epidermis receives its nourishment from a deeper connective tissue layer as it lacks blood vessels and lymphatics. There is a sparse amount of fat in the preseptal and preorbital skin and is absent in the pretarsal skin.
 - The orbicularis oculi is loosely adherent to the skin and divided into orbital and palpebral portions. The palpebral portion is further divided into pretarsal and preseptal and functions in blinking and voluntary winking. The orbital portion is for forced closure.
- The posterior lamella consists of the tarsus and the conjunctiva.
 - The tarsus is composed of dense fibrous tissue. It is approximately 1 mm thick and provides the structural support of the eyelid. The upper eyelid tarsus

extends from the punctum to the lateral canthus and is 30 mm long and 7 to 10 mm high, with the highest portion being centrally. The lower tarsus ranges from 3.5 to 5 mm in height. The ciliary border contains meibomian gland orifices that provide the lipid layer of the tear film. The medial and lateral ends are attached to the orbital rim by the medial and lateral palpebral ligaments.

- The conjunctiva is a nonkeratinized, stratified squamous epithelium that lines the inside of the eyelids and provides coverage to the sclera.
- Upper eyelid retractors
 - The levator palpebrae superioris arises at the orbital apex and courses anteriorly for 40 mm ending in the aponeurosis 10 mm behind the septum. At this junction, it changes direction to vertical and then inserts inferiorly onto the lower third of the tarsal plate. In addition, some fibers pass anteriorly to the eyelid crease.

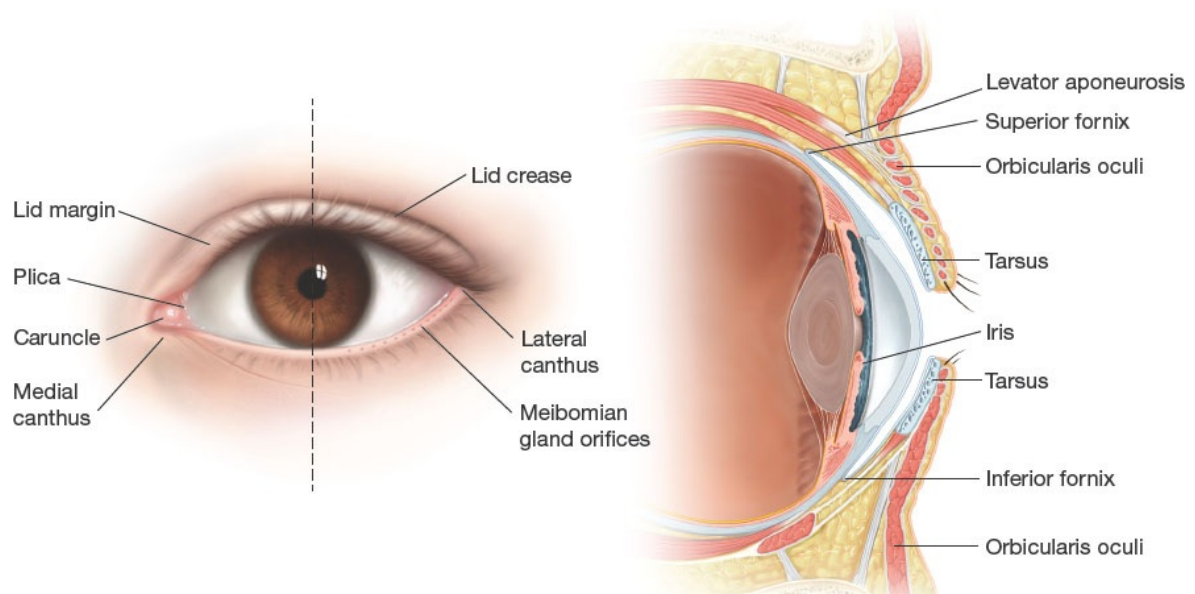


FIG 1 • External and sagittal section depicting the eyelid anatomy and the surrounding structures.

- Mueller muscle originates from the undersurface of the levator at the muscular aponeurotic junction and then travels between the levator and the conjunctiva to insert on the superior border of the tarsus. It is innervated by the sympathetic nervous system.
- The lower eyelid retractors are fascial extensions of the inferior rectus muscle

originating as the capsulopalpebral fascia. The lower lid retractors insert at the inferior border of the tarsal plate. A small portion of the lower eyelid retractors joins with Tenon capsule at the inferior fornix and courses anteriorly to form the lower lid crease.

- Blood supply to the eyelids is derived from branches of both the internal and external carotid arteries.
- Medially, two palpebral branches (superior and inferior marginal arteries) arise from the ophthalmic to supply the upper and lower lid. These arteries then travel horizontally as the marginal arcades, which lie on the tarsal plate (4 mm from the upper margin and 2 mm from the lower margin).
- Laterally, the lacrimal artery provides branches to both the upper and lower lid, which then travel horizontally to anastomose with the marginal arcades.
- The external carotid contributes through branches of the facial, superficial temporal, and infraorbital arteries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Facial paralysis can occur from many causes including tumor, postsurgical, infection, trauma, idiopathic Bell palsy, and cerebral vascular accidents.
- Ocular complications can range from superficial punctate keratopathy to corneal ulcer or even perforation secondary to lagophthalmos.
- A slit-lamp examination should be performed to assess the cornea.
- The preoperative evaluation includes a detailed examination of the function of the levator muscle and the compromised orbicularis.
- This is crucial in choosing the proper weight to allow patient to open eye once weight is placed.

IMAGING

- If the cause of the cranial nerve VII palsy is unknown, then imaging as well as a complete neurologic examination should be done for diagnosis before surgical correction is done.

SURGICAL MANAGEMENT

Preoperative Planning

- The appropriate weight is determined preoperatively by taping the weight onto the upper eyelid at the medial third of the lid with the patient sitting upright.
- The appropriate weight should allow for complete closure but prevent ptosis greater than 2 mm.

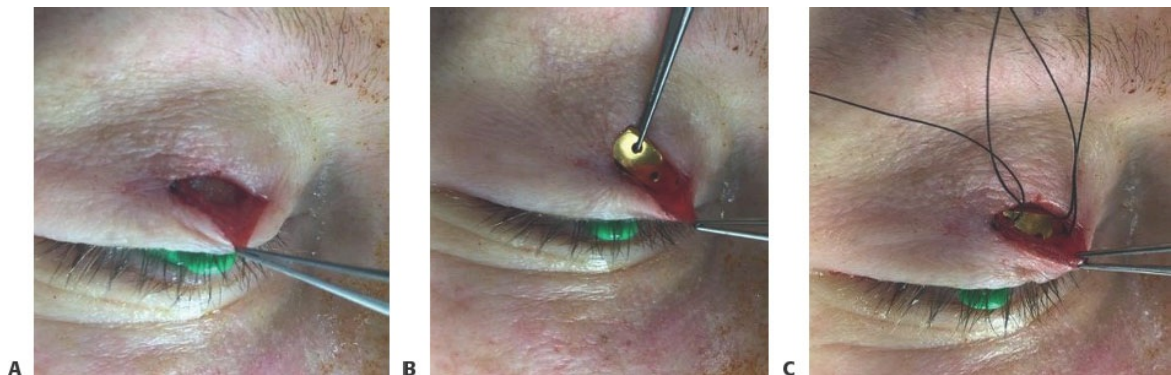
Positioning

- The patient should be erect during testing and supine during surgery.

TECHNIQUES

■ Pretarsal Approach

- A lid crease incision should be marked preoperatively.
 - In elderly patients with levator dehiscence, the incision can be marked where the crease should be.
- Local anesthetic with 1% lidocaine and 1:100 000 epinephrine is injected into the subcutaneous tissue of the upper eyelid.
- Skin incision is made in the premarked area using a no. 15 blade.
- Dissection is carried through the orbicularis to identify the septum.
- Careful hemostasis is obtained using bipolar cautery.
- Dissection is carried through the orbicularis down to the superior border of the tarsus. The pretarsal portion of the orbicularis is then dissected downward from the tarsus to the eyelash line to create a pocket, taking care to remain at least 2 mm above eyelid margin (**TECH FIG 1A**).
- The appropriate weight is placed over the tarsus just medial to the midpupillary line and secured with 6-0 silk to the tarsal plate taking care to avoid going through the conjunctiva (**TECH FIG 1B-D**).
- Skin is closed with a running subcuticular stitch secured on either end with a single interrupted 6-0 chromic (**TECH FIG 1E**).



TECH FIG 1 • **A.** After an incision is made in the eyelid

crease, dissection is carried to the tarsal plate and levator muscle. **B.** A gold weight is placed on the tarsus with inferior border 2 mm from lid margin. **C,D.** Silk sutures are used to hold the gold weight in place on the tarsus. **E.** Subcuticular closure.



■ Postseptal Approach

- The lid crease incision and local anesthesia are done as above.
- The septum is incised at the superior border of the tarsus, and the postseptal fat is retracted superiorly to visualize the underlying levator aponeurosis. Dissection is carried out superiorly to the muscle fibers of the levator to form a pocket 2 to 3 mm medial to the medial limbus.
- The weight is placed, and a temporary suture is made to close the skin and muscle.
- Sedation is lightened to allow the patient to sit up and open and close the eyes to assess for closure.
- The weight is then secured with one superior stitch to the aponeurosis or to muscle and two inferior stitches to the aponeurosis just superior to the tarsus using 6-0 silk.
- Postseptal fat is then draped over the weight, and the septum is closed with two or three interrupted 6-0 Vicryl sutures.
- Skin is then closed with a running subcuticular stitch secured on either end

with a single interrupted 6-0 chromic.

PEARLS AND PITFALLS

- Technique**
- The orbicularis oculi does not need a separate closure, and in fact, this may lead to accentuation of the lid crease.
 - When making the pretarsal pocket, refrain from burrowing too close to the eyelid margin to avoid disrupting the eyelash follicles and causing inadvertent eyelash loss.
 - After securing the gold weight, evert the lid to ensure that no sutures are exposed on the tarsal conjunctival side.
 - Older patients with exceptionally thin eyelid skin may benefit from a postseptal placement to avoid extrusion at the eyelid margin.

POSTOPERATIVE CARE

- Antibiotic steroid ointment combination with patch for 48 hours.
- The ointment should be continued twice a day for a week.

OUTCOMES

- A retrospective review of 107 patients found that 14% required revision surgery at a mean time of 11.7 months after primary placement. Indications included prominent implants in 71%, poor eyelid contour in 67%, and persistent erythema in 29%.¹
- Rofagha et al.² found a 10.6% extrusion rate and with Kaplan-Meier analysis found extrusion rate to be 3% at 12 months, 5% at 24 months, 10% at 5 years, and 35% at 153 months.

COMPLICATIONS

- Extrusion of weight
- Astigmatism (more common with pretarsal placement)³
- Allergic contact dermatitis

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Operative Techniques in Plastic Surgery

VOLUME II

Kevin C. Chung, MD, MS

EDITOR-IN-CHIEF

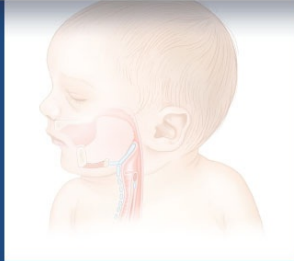
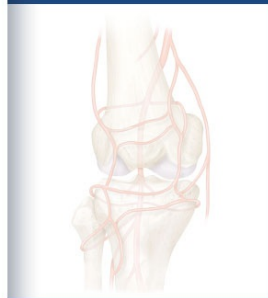
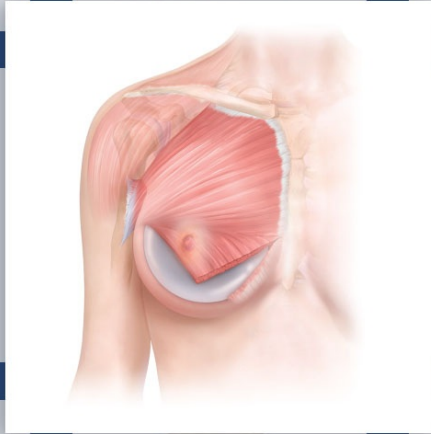
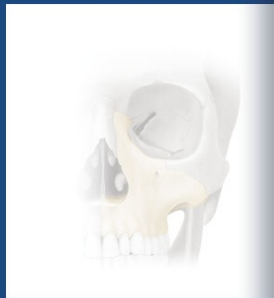
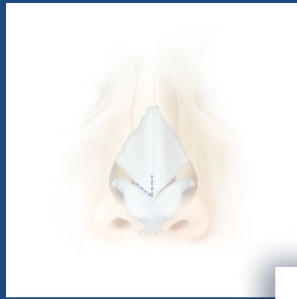
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PART 4

Plastic Surgery of the Breast



Section I: Augmentation Mammoplasty

1 Transaxillary Breast Augmentation

CHAPTER

Louis L. Strock

DEFINITION

- Hypomastia. This patient requested that she have a procedure to enlarge her breasts in a conservative way. She also stated that she preferred to have her breast implants placed in a way that would allow her to avoid incisions on her breasts (**FIG 1A,B**).

ANATOMY

- To manage the request of this patient, the level and shape of the inframammary fold (IMF) will be lowered with the aid of endoscopic assistance. The pectoralis major muscle and overlying fascia will be divided according to external markings and correlated with internal muscle anatomy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- This patient is a 34-year-old woman who presented for breast augmentation after having had three children. She requested that her breasts be enlarged to a small C cup, with as soft a feel as possible. Her examination was remarkable for mild asymmetry, thin tissue, and large nipple size. Her breast base width measurement was 11 cm, and pinch thickness measurements were 1.5 cm laterally, superiorly, and medially. She was also noted to have extremely large nipples that she requested to have reduced at the time her breast implants were placed (**FIG 2**).

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative planning centered on the choice of breast implant type in the context of her aesthetic goals and tissue type. She preferred the feel and intermediate projection of a Mentor MemoryGel smooth wall, round, moderate plus profile silicone gel device. Other options considered included the same device type in moderate and high profile versions, and a moderate height, moderate projection shaped highly cohesive gel device. She stated preference of a partial subpectoral plane of placement over a subfascial approach. Incision choices offered to this patient included inframammary and transaxillary, with the latter preferred by the patient to attempt to avoid incisions visible on her breasts. Nipple reduction was requested by the patient, to be performed following completion of the breast augmentation procedure and access incision closure.

Equipment

- A standard HD endoscopic tower and camera are used in this procedure. This equipment is identical to that used for any subspecialty that utilizes an endoscopic tower and camera. The endoscope that is preferred is a 10-mm 30-degree angled scope, that is intended to fit correctly into the Emory Endoscopic retractor (**FIG 3**). A cautery handle with a suction end is used, and holds a cautery tube with a spatulated end. This is the basis for the dissection at the heart of this procedure. Additionally, 4-prong Freeman skin hooks, 2 mirror image Agris-Dingman dissectors, a 1-in fiberoptic retractor with suction port, facelift scissors, and two 1-in short Deaver retractors make up the instrument set for the procedure.¹

Positioning

- The patient is positioned with the arms out ninety degrees and straightened on armboards. All equipment, cords, and tubing are directed toward the feet of the patient in the midline. This allows for ease of transition during the procedure for device placement on either side. There is adequate separation of the anesthesia equipment from the head and shoulders of the patient to allow the surgeon to stand above the shoulder on each side during the endoscopic tissue release portion of the procedure on each side (**FIG 4**).

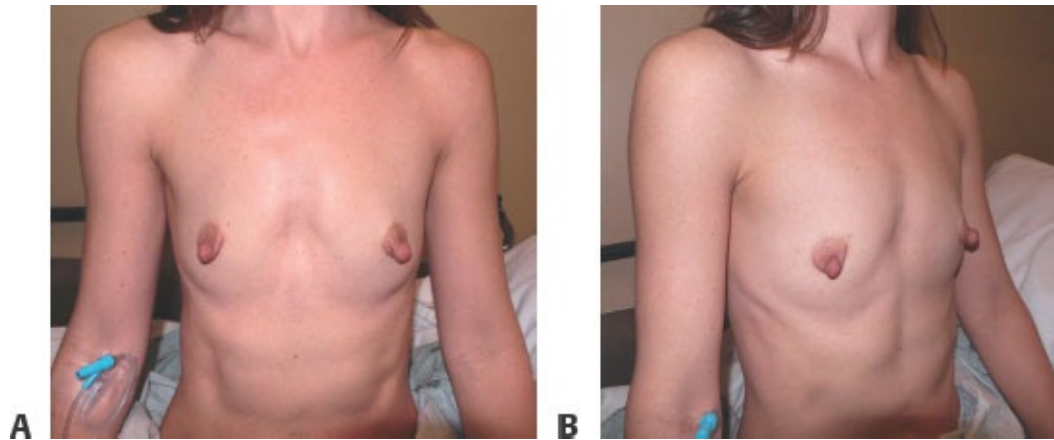


FIG 1 • A,B. Preoperative photos showing thin tissue patient. She has minimal breast volume, poor inframammary fold definition, and distinctly large nipples.



FIG 2 • Frontal markings show plan to lower the inframammary fold to accommodate dimensions of device to be used.



FIG 3 • Instrument tray used for the procedure. The Emory Endoscopic retractor is with paired 10-mm 30-degree-angled endoscope. The cautery handle has a suction port in back, and a hub for hollow cautery rods with spatulated ends. The author prefers mirror image J-shaped rods, but other variants are available. Four-prong skin hooks, two mirror image Agris-Dingman dissectors, two 1-in. Deaver retractors, facelift scissors, and Adson-Brown forceps complete the set.



FIG 4 • All equipment is positioned at the foot of the bed, including the endoscopic tower. All cords are kept in a central position to prevent having to move them during the procedure, regardless of which side is being augmented. The patient is positioned with the arms out

at 90 degrees. The endoscopic portion of the procedure is performed with the surgeon above the shoulder.

Approach

- The procedure can be performed adequately in this patient with use of inframammary or transaxillary approaches for incision access. The periareolar approach is more difficult given the relatively small size of the areola in this patient. Her thin tissue makes a partial subpectoral, or dual plane, approach preferred to maximize soft tissue cover over the implants.

TECHNIQUES

■ Incision and Initial Dissection

- An S-shaped incision was planned, centered in the axillary apex (**TECH FIG 1**). This incision pattern was selected because it allows for a long functional length in a patient with a narrow area of hair-bearing skin in the axilla. The long portion of the incision was marked within the longest existing skin crease. The anterior extension is placed to stay behind the posterior aspect of the pectoralis major muscle. This is critical to keep the incision hidden during recovery. A cross-hatch is made centrally to facilitate skin closure. The incision is made through the hair-bearing skin to the subcutaneous tissue. The anterior skin flap is raised in an anterior direction toward the lateral edge of the pectoralis major muscle. The skin flap is kept thin to avoid entry into the axillary contents. This helps to avoid damage to the intercostobrachial nerve. Once the lateral border of the pectoralis major muscle is identified, its fascia is incised, and the subpectoral space is entered under direct vision. A finger sweep technique is used to further develop the separation between the pectoralis major and pectoralis minor muscles.

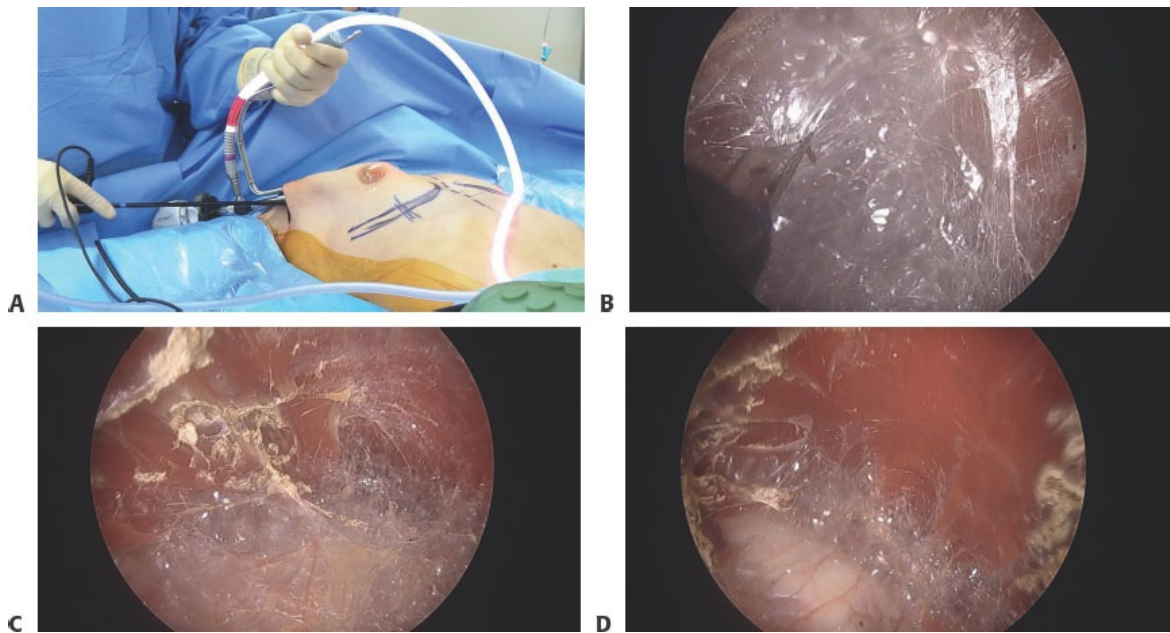


TECH FIG 1 • In this patient, an S-shaped incision was planned. This incision design was used due to the narrow width of the segment of hair-bearing skin. This design permits a longer functional length to attempt to minimize potential damage to the device during placement, and minimize ultimate incision visibility during recovery.

■ Optical Cavity

- Once the entry between the incision and the space between the pectoralis major and minor muscles has been defined, the endoscopic retractor is introduced. Once correctly positioned, the 10-mm 30-degree-angled endoscope is brought into the operative field and placed into the retractor sheath. The camera head on the endoscope is checked for proper orientation, a critical step to ensure safety with the technique. The suction cautery is then used to create an optical cavity from the undersurface of the pectoralis major muscle (**TECH FIG 2A**). Staying on the undersurface of the muscle allows for variations in rib cage anatomy to not be a problem. This is performed in a uniform fashion to create optimal visualization of the pectoralis major muscle in preparation for the muscle release. The author feels that using the cautery to create the optical cavity is critical to avoid significant blood staining of tissues that can otherwise make endoscopic tissue dissection difficult. *The key to this procedure is to avoid bleeding in the tissue pocket!* (**TECH FIG 2B–D**). Though the initial descriptions of this procedure advocated use of the Agris-Dingman dissectors, the author has found that the occasional bloody

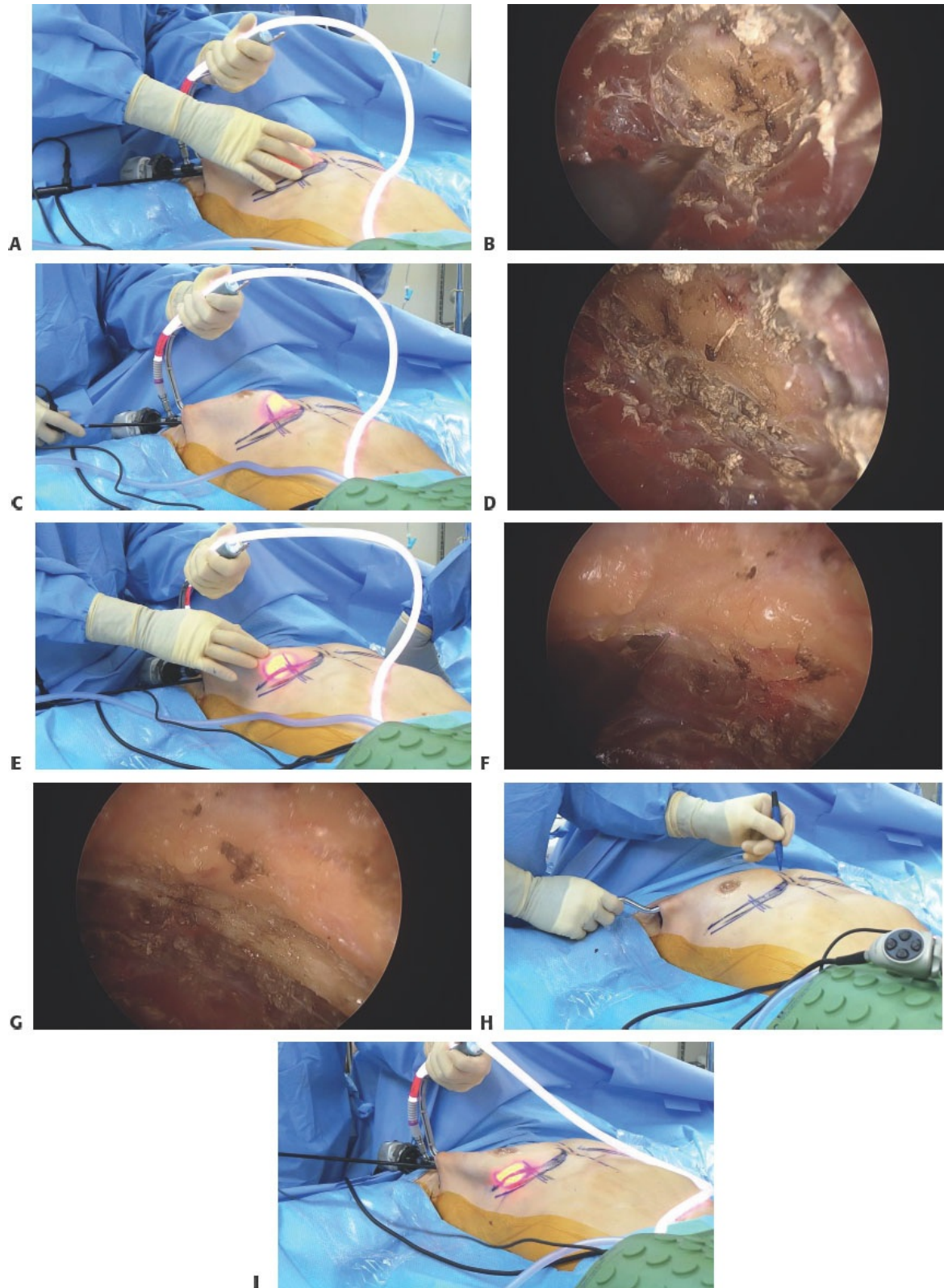
outcome from that approach can be avoided with use of the cautery to create the optical cavity.²



TECH FIG 2 • A. The endoscopic equipment is used in a way that ensures proper orientation of the endoscopic tower. The camera head is checked to confirm correct alignment and orientation for the endoscopic dissection. The suction cautery allows for successful smoke evacuation, vital to correct endoscopic visualization. **B–D.** Endoscopic view of the entry into the subpectoral space. Note areolar plane and lack of anatomic markings. Orientation on this right sided dissection is as follows: left is medial, right is lateral, the rib cage is inferior, and the pectoralis major muscle is superior. The optical cavity is created using the cautery off the undersurface of the pectoralis major muscle. The entire base of the pectoralis major muscle is dissected to complete creation of the optical cavity.

■ Pectoralis Major Muscle Release

- Successful creation of an optical cavity facilitates release of the pectoralis major muscle. The first step to release of the pectoral muscle is to correlate internal anatomy with external landmarks. This is the key step to the technical control needed to control the level and shape of the IMF (**TECH FIG 3A–D**). An advantage of the axillary approach is that, when performed as described, the surgeon has a direct and clear view of the pectoralis major muscle and fascial layers that cannot be matched with an inframammary approach. Additionally, the incision itself has no bearing on the IMF or the level it is placed.
- In the patient shown, the plan was to lower the IMF. The initial muscle release is performed to divide the muscle at a level several millimeters above the existing IMF, medial to lateral, again carefully correlating external landmarks to internal anatomy. Transillumination can be very helpful in confirming that the muscle has been divided at the desired level. Once this has been confirmed, the cautery is used to dissect in a very controlled and limited fashion in a plane superficial to the lower muscle cuff. Because of the magnification of the endoscope, limited tissue cuts make powerful and significant changes in the area of the IMF. Transillumination can again be used to confirm that the release is to the desired level of the new IMF. The muscle edges of the upper and lower cuffs are inspected and contacted with the cautery if any bleeding points are noted. *It is of critical importance that overdissection be avoided!* (**TECH FIG 3E–G**) Additionally, it is critical to understand that when planning to lower the IMF, the actual *release of the pectoralis major muscle should never be below the existing IMF*, as such a release will consistently result in a double bubble deformity. If the goal is to maintain the IMF at the same level without change, then the pectoralis major should be divided at a level 1.5 to 2 cm above the existing IMF. When properly performed, visual clarity afforded by the endoscope allows for the prepectoral fascia to be divided or maintained as needed.



TECH FIG 3 • A. The start of the release of the pectoralis major muscle is based on correlating

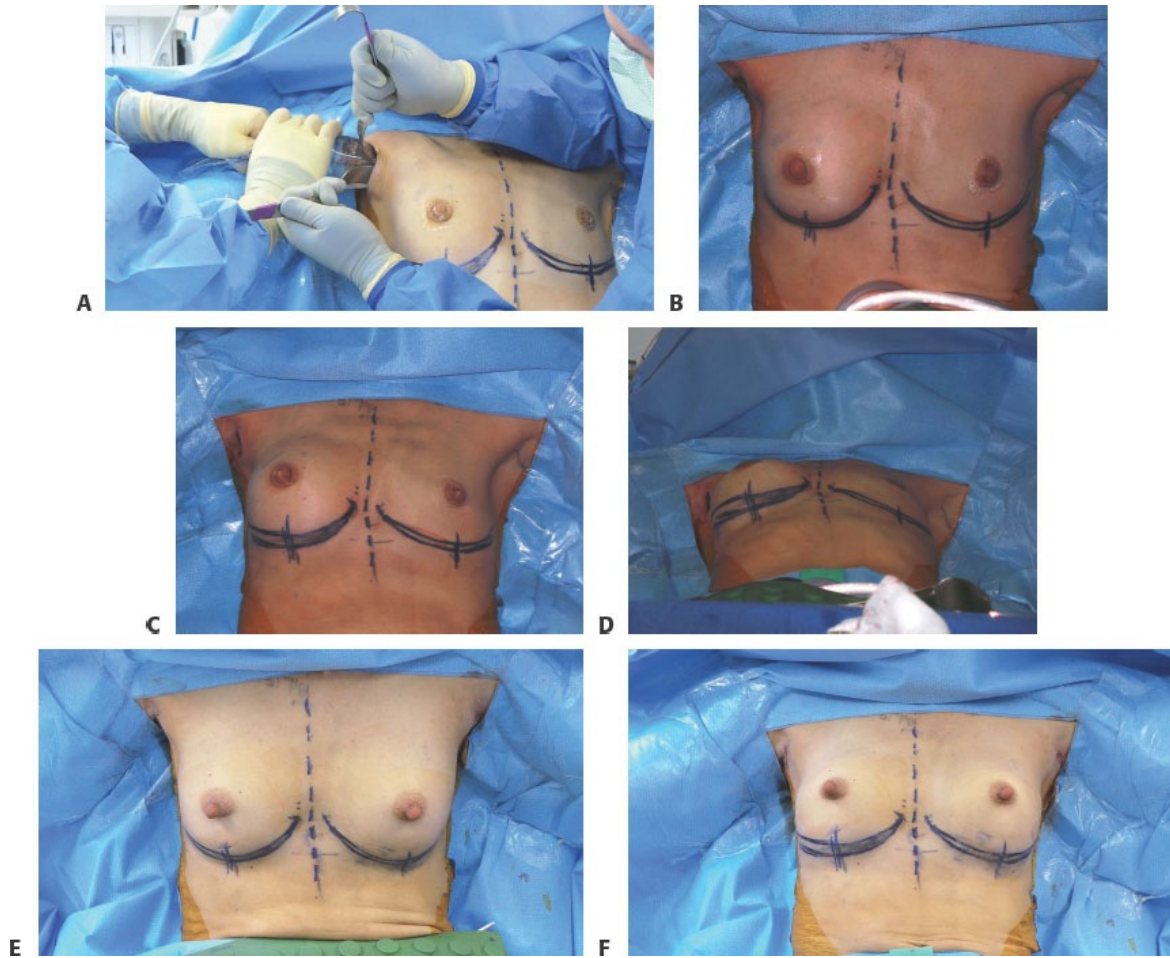
external markings with internal anatomy. **B,C.** The release level is just above the existing level of the IMF. The correct level can also be confirmed by transillumination, as shown. **D.** The completion of the initial release is shown. **E.** Transillumination confirms the IMF level from the initial dissection, and then after the fold is lowered in a precise manner. The lateral portion of the tissue pocket is underdissected intentionally at this stage. **F,G.** The IMF is lowered by dissection just superficial to the prepectoral fascia of the lower muscle cuff. This is shown before (**F**) and after (**G**) the controlled release, performed to match external markings. Note that small cuts performed in this way are needed to lower the IMF, and that any overrelease is difficult to correct with this approach and should be aggressively avoided! (**H**). The adequacy of the periphery of the dissection is checked with the aid of Agris-Dingman dissectors, placed in a way to avoid excessive contact with the underlying ribs. **I.** The endoscopic equipment is used to make any final refinements and to check hemostasis prior to device placement. The device selection is made at this time so that the dimensions of the pocket are refined to match the dimensions of the device to be placed.

- The Agris-Dingman dissectors are then used to confirm the adequacy of the peripheral extent of the dissection (**TECH FIG 3H**). They are used in a way to minimize contact with rib periosteum. They are not used to manipulate the muscle at this point in the procedure.
- The endoscopic retractor and endoscope are reintroduced to recheck for optimal hemostasis and complete any refinements of the soft tissue release in preparation for device placement (**TECH FIG 3I**). On completion of this, the endoscope is removed and retractor is used as a conduit for placement of

preferred irrigation solutions.

■ Device Placement

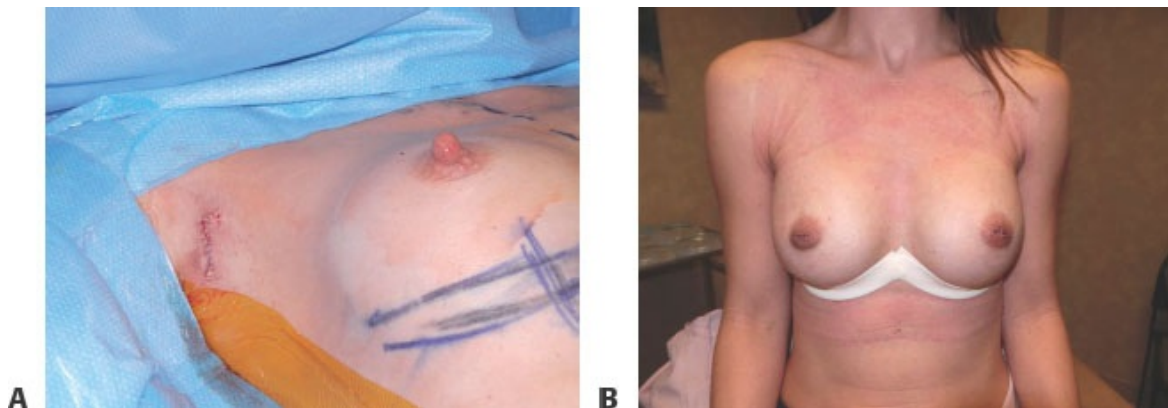
- Selection of the specific device to be used can now proceed according to surgeon preference. It is the author's preference to make this decision at the time of pocket refinement so that the dimensions of the tissue pocket can fit the width of the device as closely as possible. It is also the author's preference that once the device is selected, the packaging is opened on the back table and handled by the surgeon only with new gloves. Antibiotic solution is placed into the implant container, after which the device is placed into an insertion sleeve (**TECH FIG 4A**). Although the procedure can be performed without this, it seems appropriate that this simple measure can help decrease contact between the device and the skin and subcutaneous tissues, including hair-bearing skin, to attempt to lessen exposure of the device to bacteria during placement.
- After placement, the correct position of the device vertically in the tissue pocket is confirmed with the patient placed in a sitting position. Additionally, the fit of the implant to the width of the pocket is checked, so that the posterior aspect of the device lies flat against the rib cage and the anterior surface is flat against the muscle and breast tissue in the dual plane. Any adjustments are made as needed (**TECH FIG 4B–F**). If a shaped implant has been used, the vertical position must be confirmed carefully, because these devices are not able to be manipulated postoperatively in the same way that smooth devices can be. Additionally, correct orientation of the device must be checked by inspection of the upper device landmarks available, which varies between manufacturers. A fiberoptic retractor is used for this purpose.^{3,4}



TECH FIG 4 • A. In preparation for device placement, two 1-in. Deaver retractors are used to open access to the tissue tunnel. One is placed parallel to the clavicle and one parallel to the lateral rib cage to maximize the opening. An insertion sleeve is used to assist in placement and to minimize device contact with skin and subcutaneous tissues. **B–D.** Photos are shown following placement of the first device in the three positions used to confirm that the device is placed to the level of the modified IMF and to confirm the overall adequacy of appearance. Note that the pocket fits the implant precisely. **E,F.** Following placement of the second device, the appearance of the second side is confirmed and overall symmetry is checked.

■ Closure and Dressings

- After completion of the second side, a fiberoptic retractor is used for inspection of the upper tissue pocket. After meticulous hemostasis has been obtained, the upper pocket is irrigated with saline solution. The deep dermis is closed using 3-0 PDS, followed by 5-0 plain gut (**TECH FIG 5A**). The axillary skin closure must be secure given its exposure to repetitive movement and perspiration.
- One inch Microfoam (3M Corporation) tape is used to reinforce the level and shape of the IMF. This tape reinforcement also pushes tissue swelling away from the IMF area.
- Gauze is placed over the incision followed by 4-inch Microfoam tape. This is important to generate pressure over the axilla to discourage fluid collections and keep the devices as low as placed in the operating room (**TECH FIG 5B**).



TECH FIG 5 • A. Incision is closed in a multilayer fashion. **B.** Initial postoperative visit 1 day following procedure. Tape along the IMF, placed at the conclusion of the procedure is in place to help stabilize the shape and level of the IMF.

Incision design	■ Anterior extension of incision must be planned to <i>not extend beyond the posterior border of the pectoralis major muscle</i>.
Incision to pectoralis major muscle	■ A thin skin flap is raised anteriorly from the incision until the lateral border of the pectoralis major muscle is identified.
Entry into the subpectoral space	■ The lateral pectoralis major muscle fascia is incised allowing entry into the space deep to the pectoralis major and above the pectoralis minor muscle. A finger sweep is used to aid in identifying the space clearly.
Optical cavity creation	■ Cautery dissection is used to create a uniform space, or optical cavity, first developing the areolar plane <i>just deep to the pectoralis major</i>. This is continued until the entire undersurface of the pectoralis major can be clearly delineated, in preparation for the muscle release.
Pectoralis major muscle release	■ The initial cut into the pectoralis major muscle is made just above the existing IMF, confirmed and controlled by <i>correlating external landmarks to internal anatomy</i>. ■ This correlation must be rechecked repeatedly. ■ The IMF is then lowered by dissection just superficial to the prepectoral fascia of the lower muscle cuff.
Postoperative dressing	■ Pressure is placed to address the soft tissue tunnel used for device placement, to prevent the device from moving upward in the early postop period.

POSTOPERATIVE CARE

- Postoperative pressure dressing is removed 1 to 3 days after the procedure. The tape reinforcement of the IMF is kept in place for 1 week (**FIG 5**).
- Patients are encouraged to begin controlled arm movement the day after the procedure.
- Patients are free to begin nonimpact aerobic exercise after 1 week. That includes unlimited cycling. All aerobic exercise can resume after 2 weeks.



FIG 5 • Second postoperative visit at 1 week confirms excellent shape. The tape along the IMF is removed but additional support from a tight underwire bra is used to help stabilize the IMF.

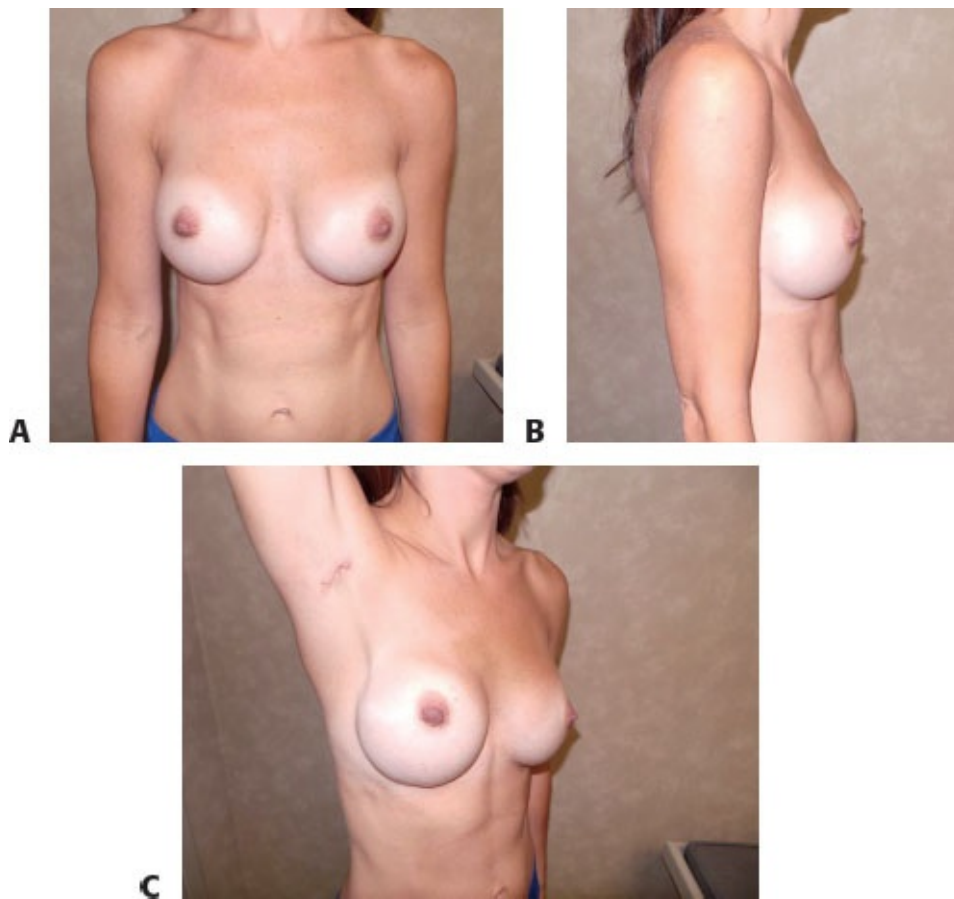


FIG 6 • A–C. Postoperative photos at 6 months.

OUTCOMES

- Postoperative photos are shown on postoperative intervals. Photos are shown of frontal, oblique, lateral, and axillary incision at 6 months (**FIG 6**) and 18 months (**FIG 7**).⁵

COMPLICATIONS

- Complications associated with the procedure are those of breast augmentation.
- Unique to this version of breast augmentation is the potential for the device to shift back up into the soft tissue tunnel used for placement. Only after this aspect of care has been mastered, in addition to technique for creation of the tissue pocket, can shaped devices be used with this approach. If textured/shaped implants shift upward during the recovery period, it is not likely that they can be returned to the correct position.

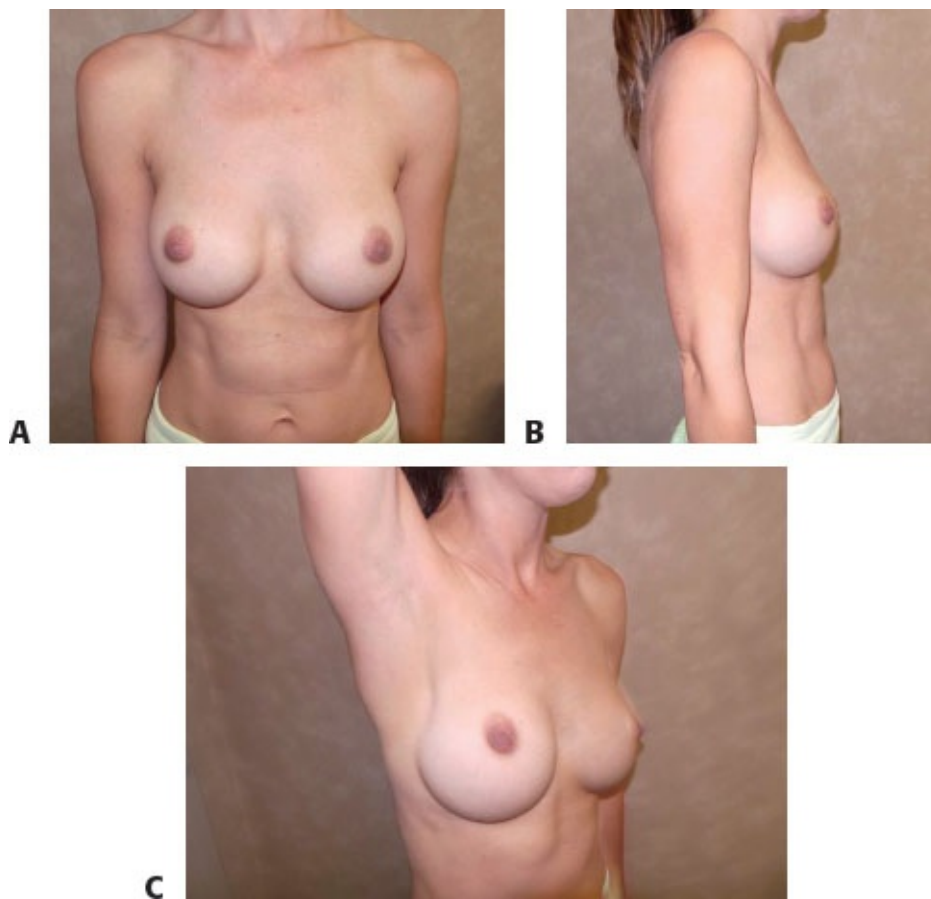


FIG 7 • A–C. Postoperative photos at 18 months.

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Breast Augmentation: Subglandular, Subfascial, and Submuscular Implant Placement

2

CHAPTER

Chet Mays and Bradley Calobrace

DEFINITION

- A critical choice in breast augmentation is where to place the implant pocket.
 - Subglandular
 - Subfascial
 - Submuscular (for purposes of this paper, submuscular refers to below the pectoralis major)
- Implant choice, size, and location are based on a variety of patient qualities.
- A biodimensional analysis is essential in determining the optimal implant type, size, and pocket location. There are many methods of evaluation. The High Five system described by Tebbetts is a systematic approach that illustrates the most important aspects of evaluation, including the following:²⁴
 - Base width of breast
 - Base width of implant
 - Nipple to fold distance
 - Estimate of final implant volume
 - Pocket determination based on skin pinch thickness

Subglandular Implant

- The subglandular implant is deep to the breast tissue and superficial fascia, but superficial to the deep pectoralis fascia, coming to rest on the inframammary fold (**FIG 1**).
- The subglandular pocket has long been regarded as the most natural pocket.²

- The advantages of subglandular implant placement include the following:
 - It avoids implant deformation or distortion that can be seen in the subpectoral position
 - Enhances the improvement in the constricted or ptotic breast
 - Allows an easier dissection plane
 - Decreased postoperative discomfort
 - Allows access to the inframammary fold (IMF) as the superficial and deep fascial components merge
- There are some disadvantages of the subglandular pocket, which include the following:
 - Pocket with the least soft tissue coverage to disguise the implant
 - Increased visibility or palpability of implant with wrinkling or rippling
 - Higher capsular contracture rate
 - Less support and stabilization of the implants, especially shaped devices, compared to subfascial or submuscular pockets

Subfascial Implant

- Advantages to placing the implant in a subfascial pocket (**FIG 2**) include the following^{1,3,23}
 - It avoids implant deformation or distortion (animation deformity) that can be seen in the subpectoral position.
 - This position provides additional soft tissue coverage between the implant and the skin as compared to the subglandular pocket.
 - Fascia provides additional support to minimize implant edge visibility and palpability seen most commonly with subglandular placement.
 - Fascia provides support of implant especially in the upper pole minimizing excess implant movement and potential rotation with shaped implants.
 - Less postoperative pain as compared to submuscular placement
 - Fascia provides a distinct layer separating the implant from the overlying breast parenchyma.
- The disadvantages of a subfascial pocket include the following:
 - Less soft tissue coverage compared to submuscular coverage

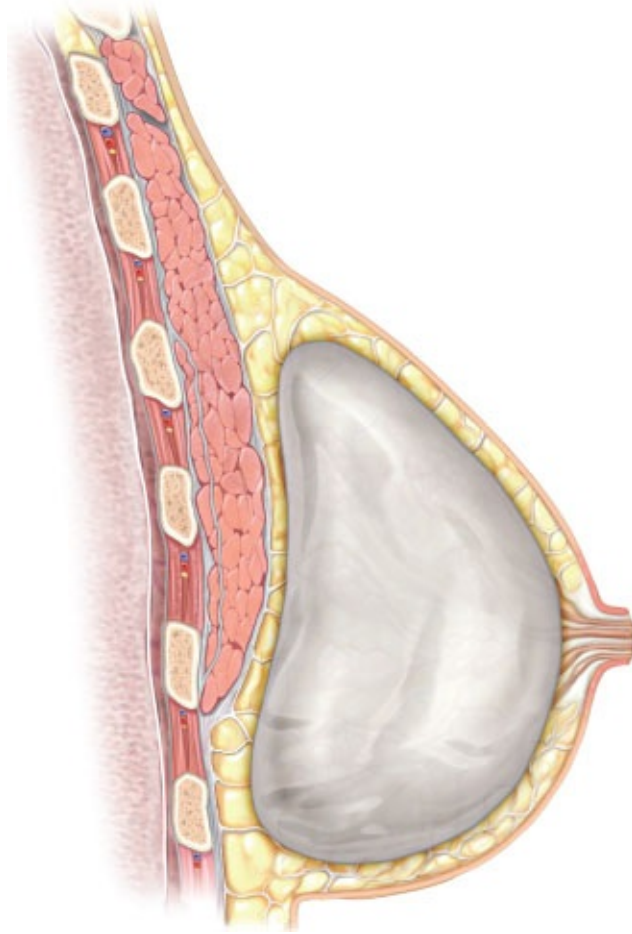


FIG 1 • Subglandular implant placement is deep to the breast tissue but superficial to the pectoralis fascia.

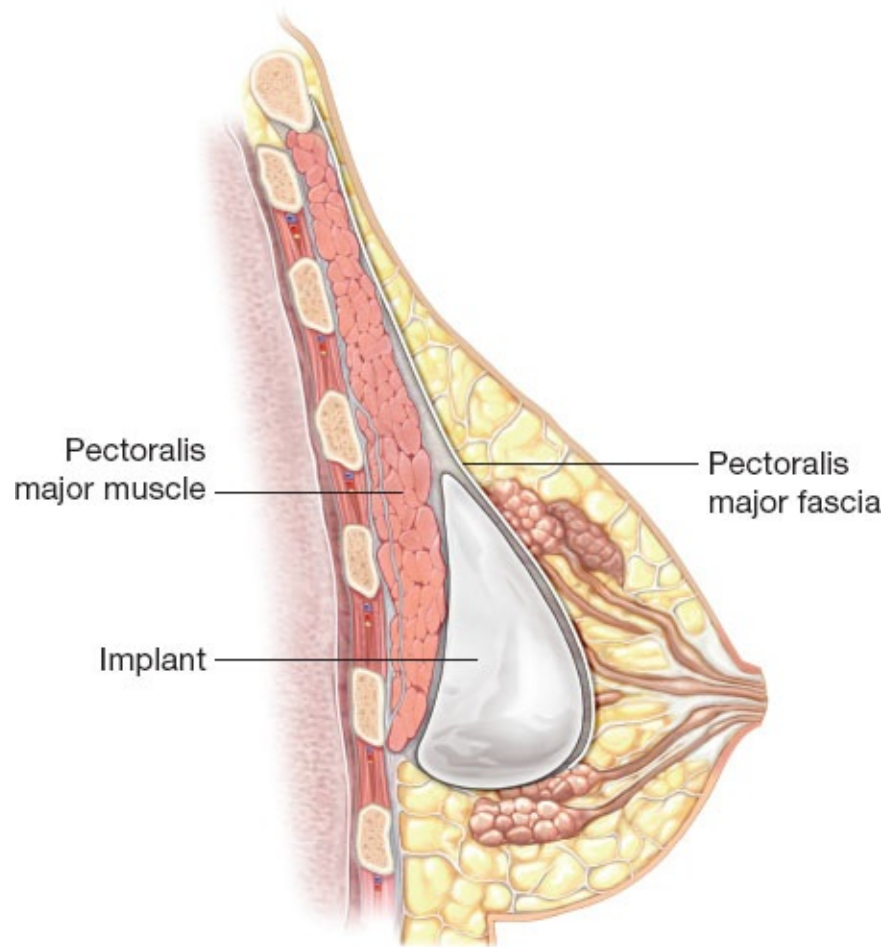


FIG 2 • Subfascial implant placement is deep to the breast tissue and the pectoralis major fascia but superficial to the muscle.

- More challenging dissection to separate deep pectoral fascia from underlying muscle while keeping fascia intact.
- Higher rate of capsular contracture compared to submuscular

Submuscular Implant

- Advantages to placing the implant in a submuscular pocket (**FIG 3**) as compared to placement in the subglandular or subfascial pocket include the following:
 - Lower capsular contracture rates^{1,4}
 - Enhanced coverage of the implant
 - Reduced issues with wrinkling

- Sloping natural upper pole
- Enhanced support for the breast implant
- Enhanced radiographic imaging with mammogram^{5,22}
- The disadvantages of a submuscular pocket include the following:
 - Animation deformity
 - Increased risk of implant superior malposition with waterfall deformity
 - Increased postoperative pain
 - Limited expansion of the lower pole of breast (required to expand constricted and ptotic breasts)
- The most significant attribute of the submuscular pocket is in providing maximum soft tissue coverage for the implant. The widespread use of saline implants and wrinkling issues led to surgeons looking for improved implant coverage. After the moratorium on silicone was lifted, surgeons in the United States continued to use the submuscular pocket with mostly smooth and to a limited extent textured silicone implants.⁶

ANATOMY

- An understanding of the breast blood and nerve supply is critical when performing breast surgery (**FIG 4AB**).
- Muscular attachments are shown in **FIG 4C**.
- The breast is a skin appendage contained within layers of the superficial fascia.
 - The superficial layer of this fascia is near the dermis and is not distinct from it.
 - The deep layer of the superficial fascia is more distinct and is identifiable on the deep surface of the breast when the breast is elevated in a subglandular augmentation mammoplasty.

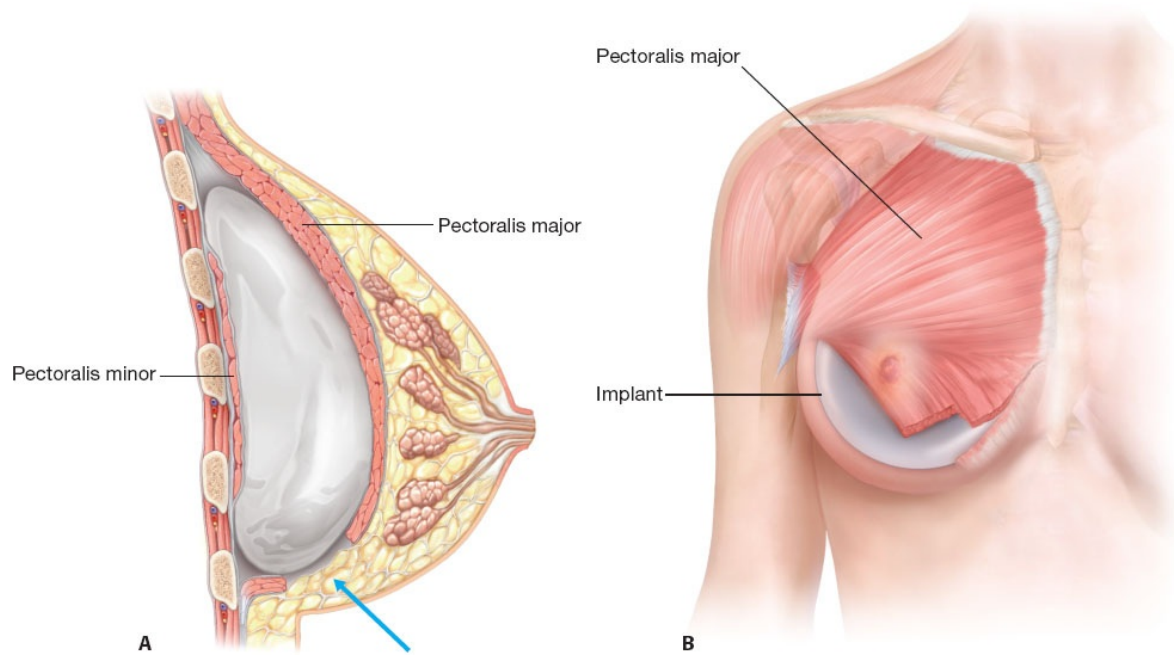
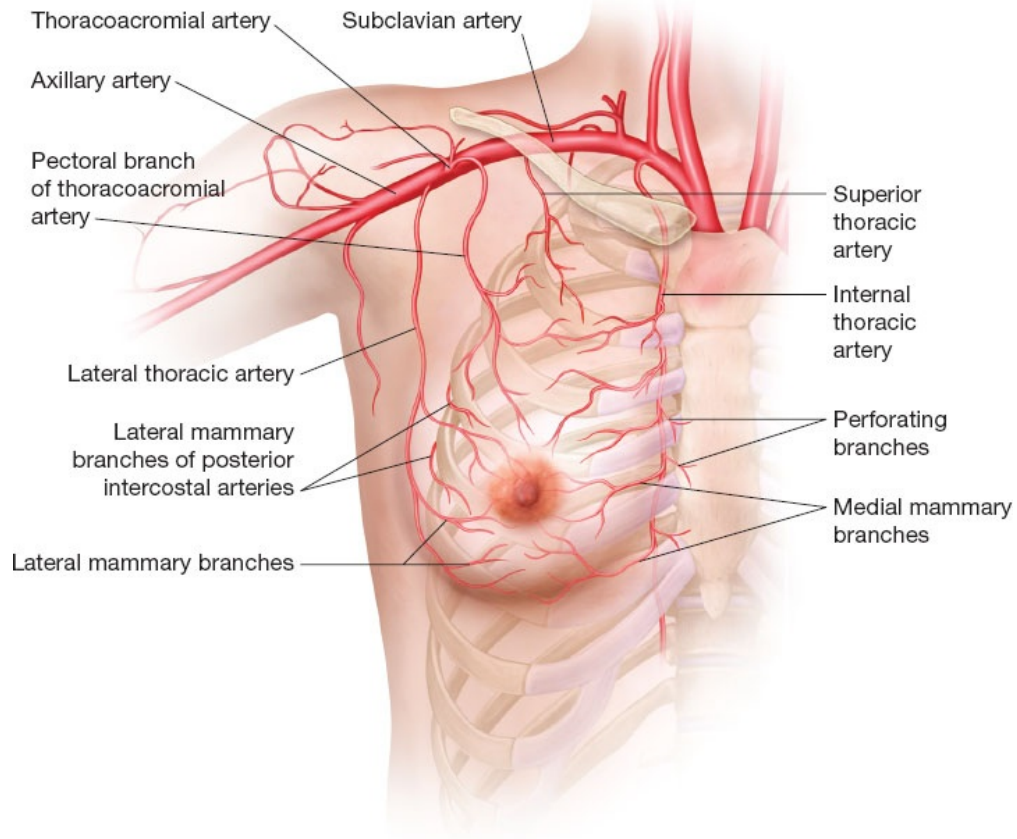
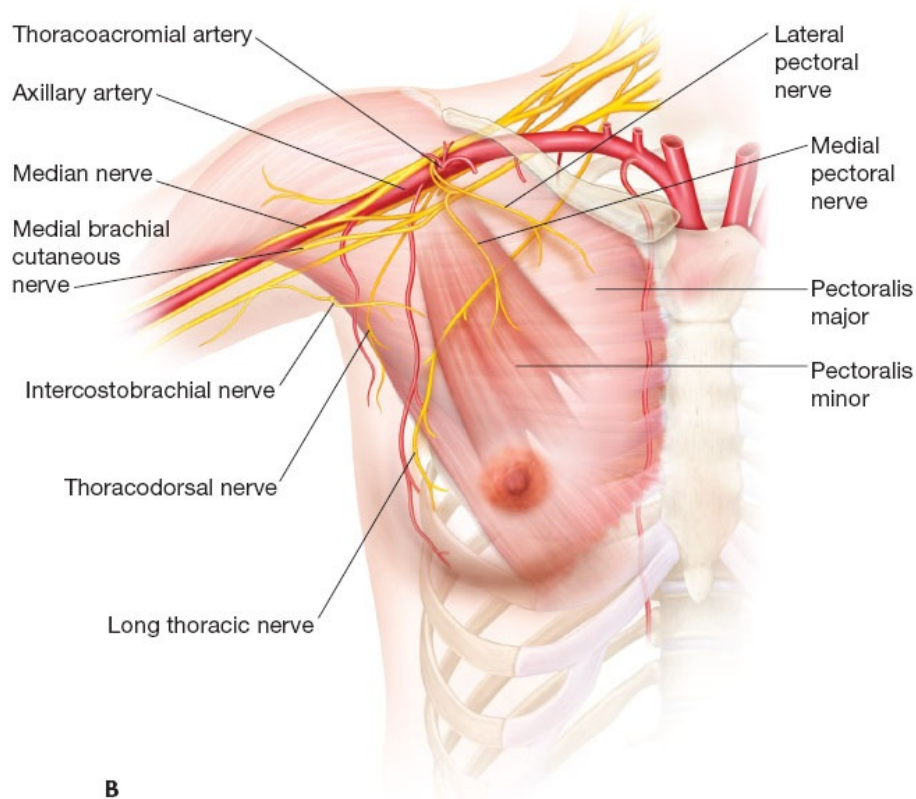


FIG 3 • A. Submuscular position of the implant with overlying pectoralis muscle and breast parenchyma. Note that the released inferior edge of the pectoralis major allows lower pole expansion (*arrow*). **B.** Anterior view of the implant placement below the pectoralis major.



A



B

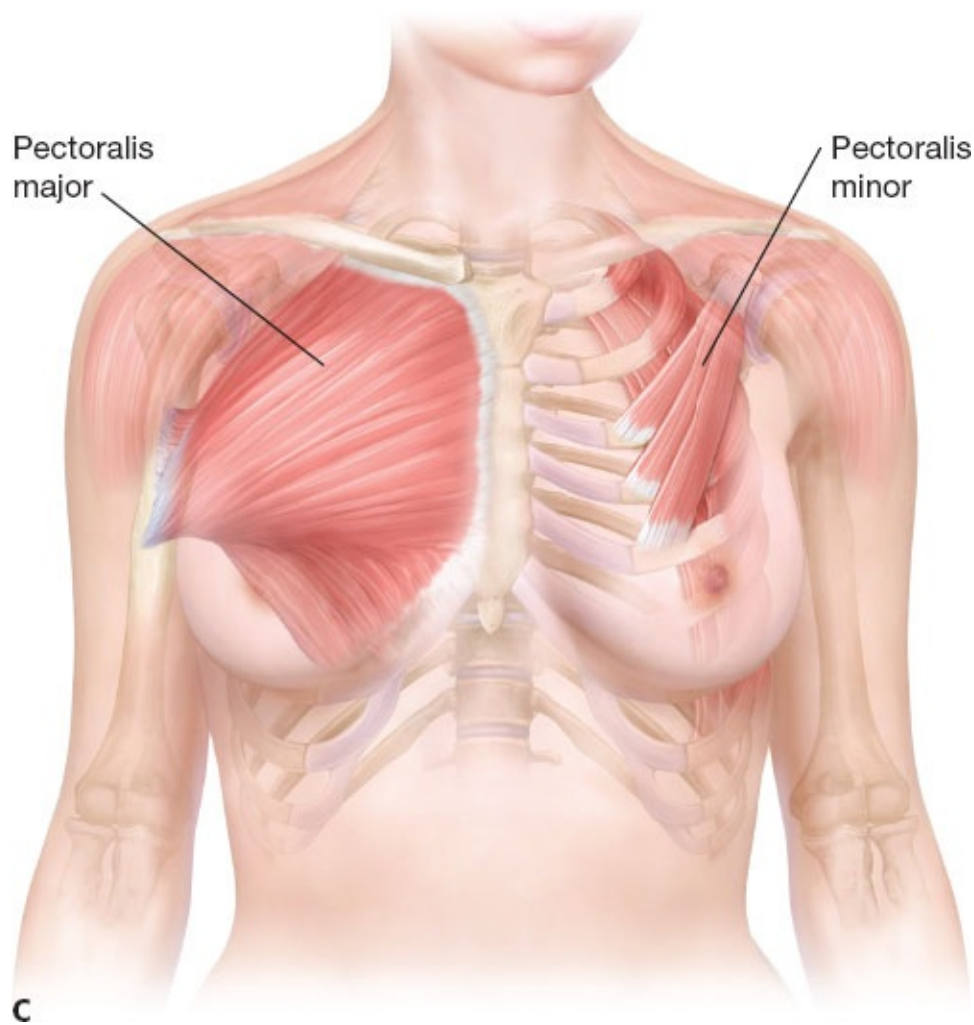


FIG 4 • A. Arterial blood supply of the breast. **B.** Nerve branches supplying the breast. **C.** Muscular attachments to the chest. The pectoralis major is removed on the right side of the picture revealing the underlying pectoralis minor.

- There is loose areolar tissue between the deep layer of the superficial fascia and the fascia to cover the pectoralis major that and to cover the adjacent rectus abdominis, serratus anterior, and external oblique muscles.
- The deep pectoralis fascia has its origin on the clavicle and sternum, extending toward the lateral border of the muscle to form the axillary fascia (**FIG 5**).
- It continues down to cover the latissimus dorsi muscle, rectus abdominis,

serratus anterior, and external oblique.

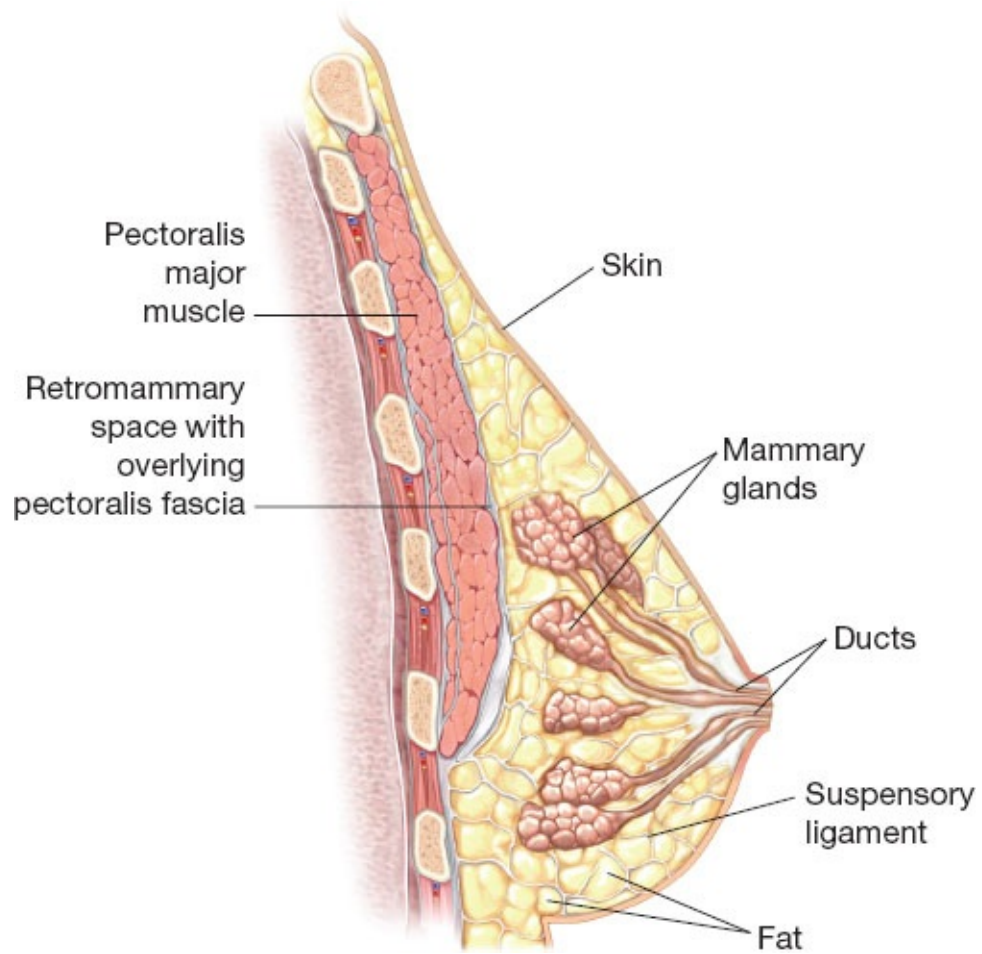


FIG 5 • Breast anatomy showing pectoralis fascia posterior to the breast tissue.



FIG 6 • Histologic slide of the inframammary fold (IMF) showing the superficial and deep fascia fusing together.⁷

- The subfascial pocket is deep to this deep pectoral fascia but superficial to the underlying muscle.
- This fascia is thin and more fragile in the lower two-thirds of the pectoralis muscle and becomes denser and substantial in the upper third of the muscle.
- The thin fascia in the lower aspects of the breast can make the initial subfascial dissection more challenging, which becomes easier as the dissection proceeds toward the upper pectoralis muscle.
- The deep fascia overlying the pectoralis and the deep layer of the superficial fascia underlying the breast unite with the dermis to form the IMF (**FIG 6**).⁷

PATIENT HISTORY AND PHYSICAL FINDINGS

- Initial consultation should evaluate the patient's goals and anticipated results with the breast augmentation.
- A thorough history and physical should be done to identify any risk factors for the procedure, including bleeding or clotting disorders.
- Any history of breast lumps, masses, or breast disease should be elicited.

- A family history is required.
- In planning for optimal implant pocket selection, it is important to determine the desired appearance or “look” the patient is seeking.
- The submuscular pocket is more likely to create a smooth, sloping upper pole with minimal roundedness in the upper pole.
- A patient desiring a more rounded upper pole with a more obvious “implant appearance” with implant shape visibility may prefer a subglandular implant, provided there is adequate soft tissue coverage.
- The subfascial approach can provide a compromise between the two; the implant will be in a plane similar to the subglandular, but the additional fascia layer will minimize implant edge visibility and palpability that can be seen with the subglandular pocket.
- The preoperative exam of the breast augmentation patient will guide the surgeon’s implant selection and pocket placement. The physical exam measurements should include the following (**FIG 7**):

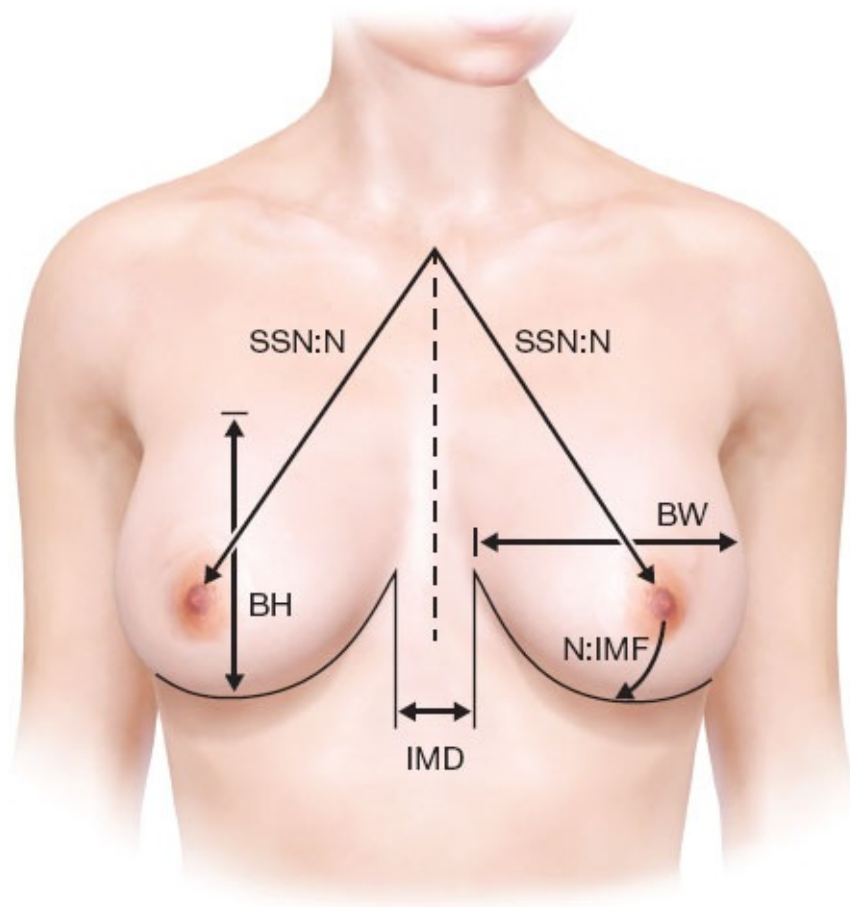


FIG 7 • Necessary physical exam breast measurements.

- Breast width (BW)
- Sternal notch to nipple (SSN:N)
- Breast height (BH)
- Nipple to IMF (N:IMF) at rest and under maximal stretch.
- Upper pole pinch (UPP), medial pinch (MP), and lateral pinch (LP)
- Intermammary distance (IMD)

Pinch Test

- A key point of the exam is the upper pole pinch test.
 - A pinch test of less than 2 cm indicates the need for a submuscular placement of the implant to avoid noticeable rippling (**FIG 8A**).
 - If the pinch test is more than 2 cm (1 cm of soft tissue thickness), the patient is a candidate for a subglandular or subfascial pocket (**FIG 8B**). (The deep fascial layer will provide additional coverage over the implant to allow for subfascial placement.)
- Implant selection impacts adequacy of soft tissue coverage. Keep in mind the thinner the soft tissue, the greater the risk of implant palpation and rippling.
 - Some implants are prone to more wrinkling, including underfilled saline implants and textured devices.
 - We require a pinch test of more than 2 cm if placing the implant subfascially or subglandularly, where the soft tissue coverage is firm and good quality.
 - If the soft tissue coverage is lax and poor quality or if the implant selected is deemed at risk for wrinkling, a pinch test greater than 3 cm is more reliable in providing adequate coverage and minimizing the risk of rippling.
- Adequate soft tissue coverage in the upper pole in a subglandular augmentation will camouflage the transition between the breast and implant, aiding to a smooth natural upper pole.
- The deep fascia overlying the implant in the subfascial pocket will provide additional support and coverage in the upper pole and minimize the implant edge visibility, which can be seen if implants are placed in the subglandular pocket with limited upper pole coverage.
- If the patient prefers a full, rounded upper pole with an obvious transition between her implant and soft tissue, a subglandular implant would be

preferred even if the pinch test is less than 2 cm.

- One must have a discussion regarding visible and palpable rippling of the implant if placing the implant subglandular and the pinch test is less than 2 cm.
- Capsular contracture can be reduced by using a textured implant in the subglandular position, but one must consider the risks of rippling with textured implant in a patient with inadequate upper pole coverage with a pinch test of less than 2 cm.¹

Physical Assessment

- Assess for all asymmetries, including breast volume, IMF, nipple-areolar complex (NAC), and chest wall.
- Chest wall (skeletal and muscle) abnormalities or asymmetries are often underappreciated and can significantly alter the final result (**FIG 9**).⁸
- Pectus excavatum occurs occasionally, whereas pectus carinatum and Poland syndrome are rare.⁹
- Central deformities are typically ameliorated sufficiently by breast augmentation alone.
- Deep pectus excavatum deformities can be treated simultaneously with a custom solid silicone implant made from a plaster mold, although most patients decline this option.
- Poland syndrome (absence of sternal head of pectoralis muscle) is best addressed with subglandular augmentation as the sternal head of the pectoralis major muscle is absent. When more severe, more extensive adjunctive procedures, such as tissue expansion, fat grafting, and latissimus muscle transfer, may be required.¹⁰
- Hemithorax asymmetry due to differences in shape, protrusion, or regression can create an uneven breast foundation, suggesting different size implants despite equivalent breast volumes.

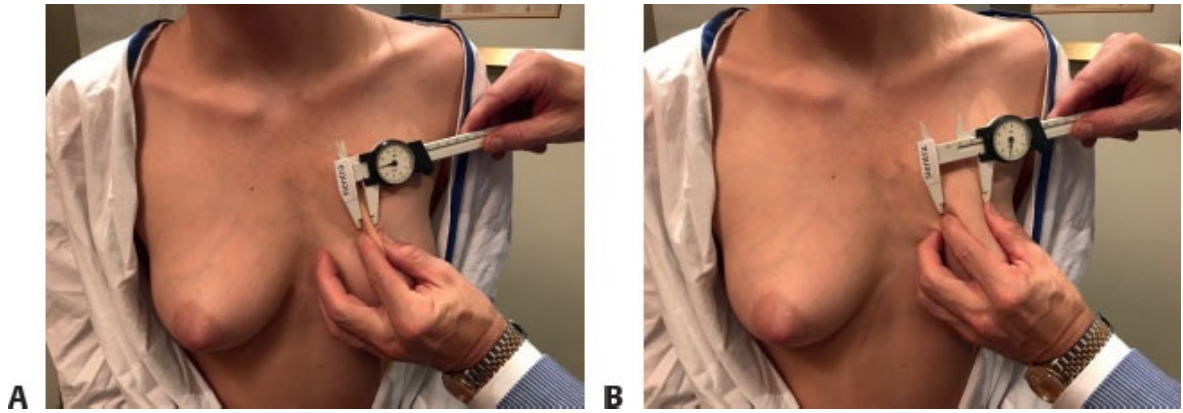


FIG 8 • A. Upper pole pinch test less than 2 cm and **(B)** more than 2 cm.

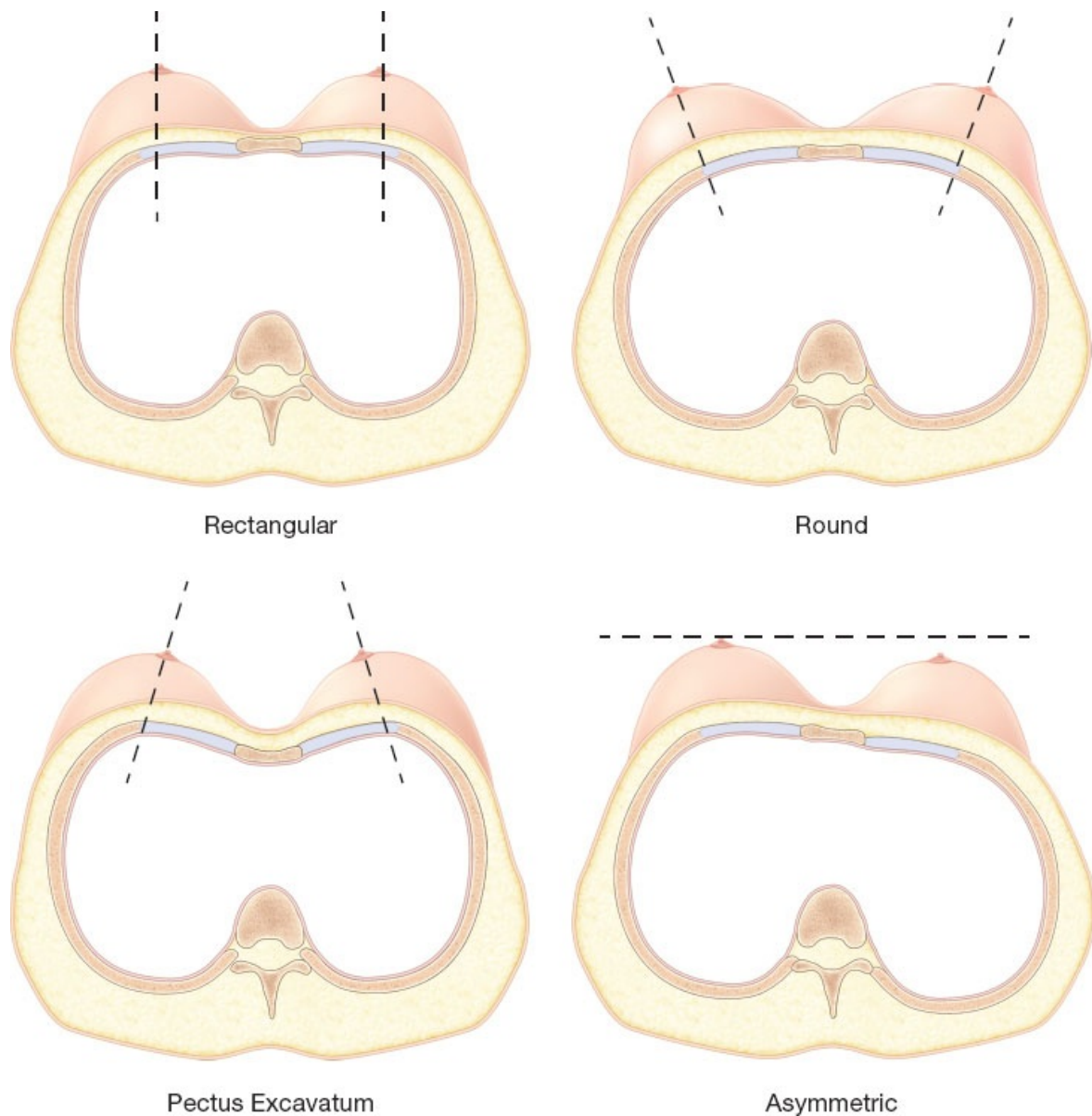


FIG 9 • Examples of chest wall abnormalities.

- Unilateral prominence of the chest wall is often associated with scoliosis (**FIG 10**).
- Subtle unilateral pectoralis hypertrophy should not affect subglandular or subfascial implant placement, but it could affect subpectoral placement and overall implant projection.

IMAGING

- Screening mammography per the American College of Surgeons is recommended for patients over 40 years of age.

- Many plastic surgeons recommend a baseline mammogram at 35 or older prior to a breast augmentation, especially if a family history is present.
- Any additional diagnostic studies are guided by the preoperative exam.



FIG 10 • Left chest wall prominence compared to the right chest wall.

- Any palpable mass requires evaluation, usually with a diagnostic ultrasound and/or mammogram.

SURGICAL MANAGEMENT

- The preoperative evaluation and decision-making are a critical step in achieving optimal outcomes in breast augmentation.
- Capsular contracture is the leading indication for revision breast surgery after a breast augmentation and every effort should be made during planning and execution to minimize the risk of capsular contracture postoperatively. Placement of breast implants in the submuscular pocket has consistently demonstrated reduction in capsular contracture rates compared with the other pocket choices.^{1,4}
- Validated steps to reduce this risk include the following:
 - Nipple shields¹¹
 - No-touch technique¹²
 - Use of an insertion sleeve¹³
 - Pocket irrigation with triple antibiotics¹⁴
 - Inframammary incisions⁴
 - Use of textured implants^{1,4}

Preoperative Planning

Incision

- The decision on incision placement is based on a variety of variables:
 - Patient and surgeon preferences
 - Anatomic considerations
 - Implant type and size
 - Issues of capsular contracture, breast-feeding, and NAC sensation
- There are many potential advantages of the inframammary approach, including the following:
 - Well-hidden scar in the fold of the breast
 - Incisional length is unlimited, thus can accommodate any and all implant choices
 - Excellent visualization for dissection of the implant pocket
 - The ability to control the IMF position during incision closure
 - Can be used for any complication revision
 - Lower capsular contracture
 - Minimal issue of a scar contracture creating deformity
 - Potentially less nipple sensation changes
- Potential disadvantages of the inframammary incision include the following:
 - The scar is located on the breast
 - Scar may be more visible if breast fold is absent or if the scar becomes pigmented
 - Must determine final IMF position preaugmentation and place scar precisely in planned new fold.
 - Scar position more vulnerable to irritation from the bra
- There are many potential advantages of the periareolar approach, including the following:
 - Scar can be camouflaged in the areolar border
 - Direct visualization and access into the breast pocket
 - Can lower the IMF to any location without predetermining location
 - Central access allows use in most revision cases with optimal visualization and access to the upper pole of the breast
 - Access for parenchymal breast scoring in constricted breast deformities
- Potential disadvantages of the periareolar incision include the following:
 - The scar is located on the breast

- Access is through a tunnel and may limit visualization in dense, heavy breasts
- Cannot use if areolae are too small
- Poor scarring possible and can create significant deformities
- IMF control sutures not possible when IMF is lowered
- Transection of breast ducts may increase bacterial contamination
- Potentially higher capsular contracture rates¹⁵
- Good candidates for the inframammary approach may include the following:
 - Small areola
 - When controlling IMF is desired
 - Indistinct areolar border
 - Desire for no scar on the breast
 - Potentially when placing larger implants
 - Desire future breast feeding as interference with lactation has been implicated with periareolar incision.⁵
 - Concerns with nipple sensation, although no strong data to support this concern.^{3,16}
- Good candidates for the periareolar approach may include the following:
 - Very distinct areolar borders present
 - When areola large enough to accommodate implant and avoid implant trauma
 - When performing a concurrent mastopexy
 - Indistinct or absence of IMF to hide scar
 - When lowering IMF (IMF position does not need to be predetermined)
 - Treatment of tuberous breasts (parenchymal scoring, IMF lowering)
- The incision should be as small as possible but large enough to dissect the pocket and place the implant without distorting or injuring the device.
 - Incision length ranges include 3 to 4.5 cm for saline implants, 4 to 6 cm for silicone round implants, and 4.5 to 7 cm for shaped cohesive silicone implants.¹⁷
 - The length of the incision would be smaller with saline than with silicone implants. Factors requiring increased incision length include the following:
 - Implant volume
 - Implant texture
 - Silicone compared to saline
 - Increased gel cohesiveness (silicone gel firmness)
 - Increase implant projection

- Shaped implants (cohesiveness and gel distribution)
- When using the periareolar approach, the incision is made around the areola and the dissection is carried inferiorly the appropriate distance to accommodate the selected breast implant.
- However, when the approach is through an IMF incision, the final position of the fold postaugmentation must be predetermined so the incision can be placed accurately in that location.
- Before surgery, the IMF is identified and marked in the sitting position (**FIG 11A**). To determine the true IMF position, the breast is autorotated inferiorly to identify the inferior extent of the attachments of the IMF (**FIG 11B**).
- The distance measured from the nipple to the true fold under maximal stretch assesses the amount of lower pole skin available to accommodate the selected implant.
- The amount of lower pole skin required and the ultimate position of the fold is a function of many factors, including the type of implant (saline vs silicone, round vs shaped), size of implant, pocket location, and the strength and stability of the soft tissue of the lower pole.
- An acceptable standard that can be used is to follow the guidelines that an implant with a base diameter of 11 cm requires 7 cm, a base diameter of 12 cm requires 8 cm, and a base diameter of 13 cm requires 9 cm from nipple to fold.¹⁸
- Another useful method of estimating fold position is based on implant height and projection and can be used for round or shaped implants¹⁷:
 - Optimal nipple to IMF distance = (1/2 implant projection) + (1/2 implant height)
 - IMF lowering = (optimal nipple to IMF distance) – (measured nipple to IMF distance)
- If the measured nipple to fold distance is less than the desired or optimal distance, the fold will need to be lowered.
- Keep in mind that textured and smooth implants have different effect on the lower pole skin and fold over time. A larger smooth implant will lead to more stretch on the lower pole compared to a smaller or textured implant.



FIG 11 • A. The inframammary fold is a natural boundary where the chest and the breast meet. **B.** Autorotation of the breast. N:IMF is 6 cm at rest. N:IMF is 8 cm on stretch/autorotation.

Pocket Control

- Pocket control is key and begins during preoperative markings to design the pocket size necessary to accommodate the selected implant.
- Controlling the pocket involves placement of the IMF, defining the medial and lateral pocket margins.
 - This creates the desired cleavage and prevents lateral migration or malposition of the implant.
- Whereas smooth implants often are designed with a larger pocket to allow for implant mobility and perceived softness, pocket design should be more limited when using a textured implant.
 - Excess movement can lead to irritation and seroma formation.
- When using a shaped textured implant, a controlled pocket is even more essential to minimize the risk of implant rotation postoperatively.
 - This requires defining the lateral, medial, and inferior as well as the superior border and limiting the pocket to only what is required to accommodate the

shaped device.

- The implant and pocket should ultimately have a “hand-in-glove” fit.¹⁹

Positioning

- Patients are placed on the operating room table in the supine position.
- The arms are secured to the arm board at approximately 45 degrees to stabilize the patient in the upright position. Actual arm placement is between 45 and 60 degrees (**FIG 12**).
- Some surgeons place the arms directly by the patient’s side.
- Having the arms abducted to 90 degrees should be avoided because this does not allow the breasts to be in a relaxed position when sitting the patient up to check adequacy of implant placement and soft tissue redraping.

Approach

- Before surgical preparation, 50 mL of a local field block of 1/4% lidocaine, 1/8% bupivacaine, and 1:400 000 epinephrine is injected into breast (Table 1).
- A 20-mL syringe with a 22-gauge spinal needle is used to inject the anesthetic into the dermis along the planned incision line, deep to the dermis along the IMF, the medial pectoral border, the anterior axillary line, and deep to the breast parenchyma, in a fanning fashion throughout the area of planned pocket creation (**FIG 13**).
- These injections provide assistance not only in operative hemostasis but also in the management of postoperative pain.
- This is less important in the subglandular augmentation as postoperative pain is significantly less than with a submuscular augmentation.



FIG 12 • Arms abducted at approximately 45 to 60 degrees in supine position.

Table 1 Breast Local Anesthetic Formula	
Drug	Amount
½% lidocaine plain	25 mL
½% lidocaine/1:200 000 epinephrine	25 mL
½% bupivacaine/1:200 000 epinephrine	25 mL
Injectable saline	25 mL
<i>Total concentration: ¼% lidocaine, 1/8% bupivacaine, 1:400 000 epinephrine</i>	100 mL

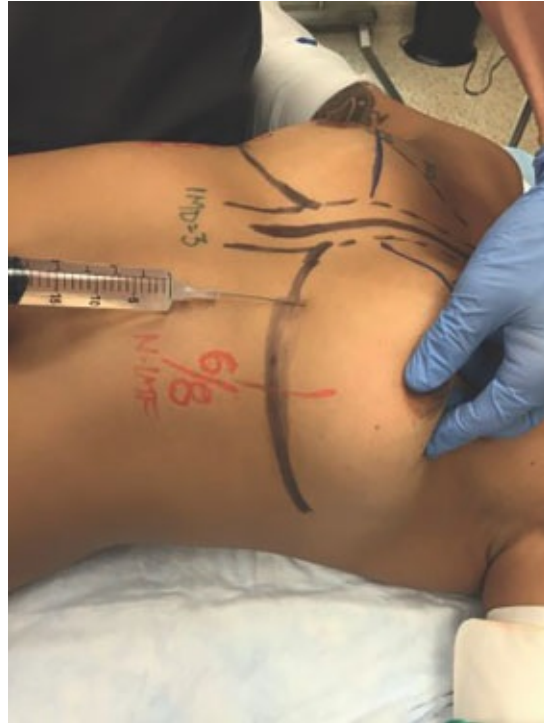


FIG 13 • Breast infusion with 20-cc syringe and a 22-gauge spinal needle.

TECHNIQUES

■ Subglandular and Subfascial Placement

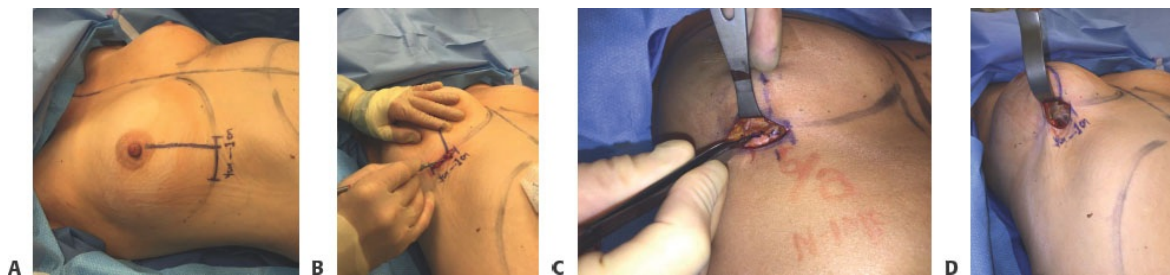
- The distinction between the subglandular and the subfascial plane is subtle and opinions differ on whether it is of clinical importance.
- The common aspect is both involve dissection superficial to the muscle and avoid both, the animation deformity associated with the muscle and the limitation the muscle plays on the ability of the implant to expand the breast envelope.

Inframammary Fold Incision

- A variety of incisional approaches to the subglandular, subfascial, or submuscular pocket are possible, the inframammary fold (IMF) being the most common.
- This incision is performed the same for both subglandular or subfascial

pockets.

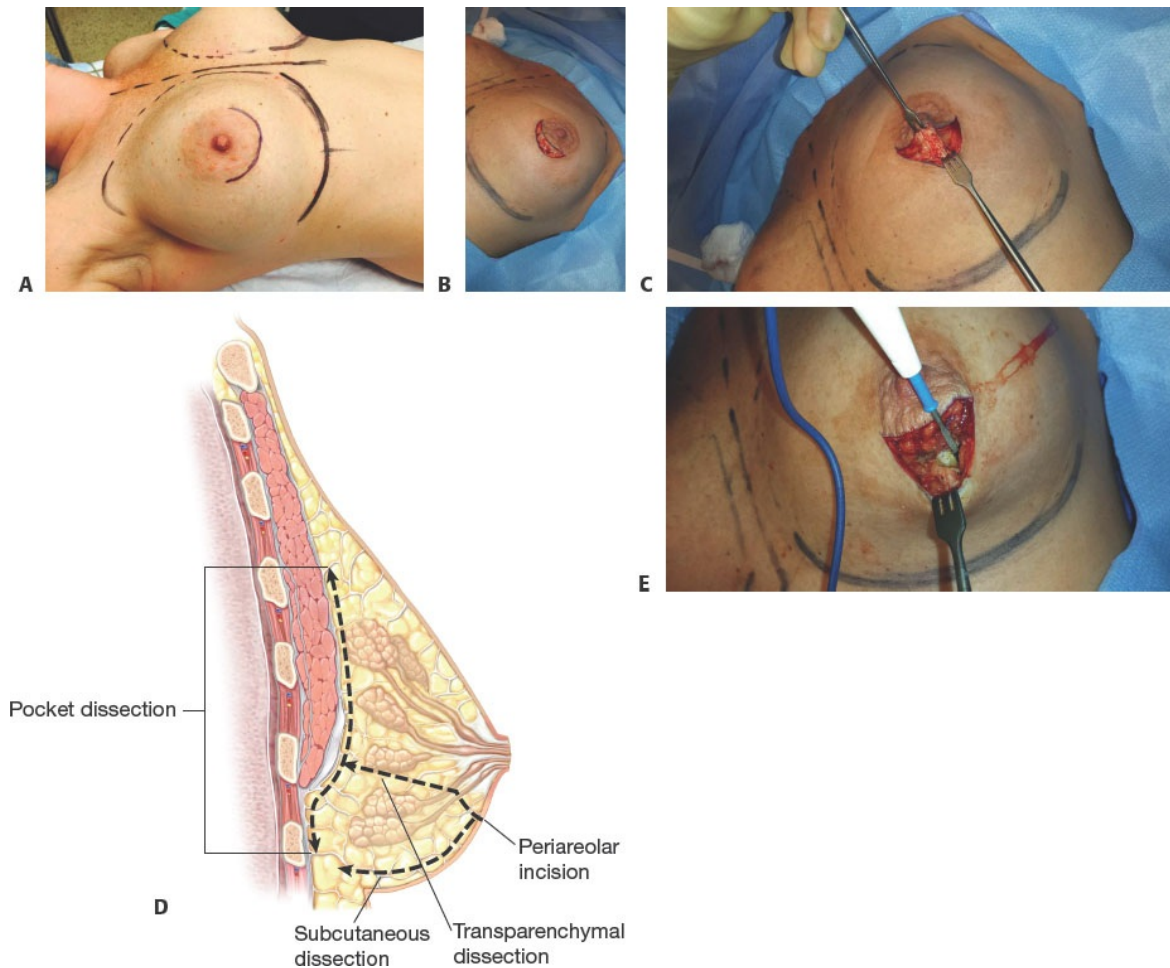
- After determining the IMF position (either the native true fold position or the planned lowered position), a paramedian line is drawn through the center of the breast and bisects the newly drawn IMF.
- The incision's medial extent begins 1 cm medial to the paramedian line and extends laterally for the appropriate distance, as previously described based on the implant type (**TECH FIG 1A**).
 - The incision is made with a no. 15 blade through the skin to the mid-dermis (**TECH FIG 1B**).
- Dissection is then carried out with electrocautery through the skin and subcutaneous tissue, beveling superiorly while rotating the breast off of the chest wall.
- Once dissection has been carried superiorly for 1 cm, the dissection is carried through the superficial fascia and toward the chest wall.
- The beveling preserves a small cuff of superficial fascia at the incision, which ensures the fold is not inadvertently lowered and also provides a cuff of Scarpa fascia that will prove useful during closure (**TECH FIG 1C**).
- As dissection proceeds toward the chest wall, a constant upward retraction of the breast tissue is maintained, exposing the pectoralis major with its overlying fascia (**TECH FIG 1D**).
 - The upward retraction of the breast tissue is key, as the suspensory ligaments of the breast concomitantly elevate the muscle to expose the muscle edge.
 - The only distinguishing characteristic is at the level of the IMF incision, dissection begins over the pectoralis fascia for the subglandular pocket or deep to the fascia for a subfascial pocket.
 - The elevation of the subglandular pocket is superficial to the pectoralis fascia, and the elevation of the subfascial is deep to the breast and fascia, but superficial to the muscle.



TECH FIG 1 • A. Paramedian line drawn from the nipple to the IMF. Note the 5 cm incision length. **B.** 5-cm inframammary incision. **C.** Cuff of Scarpa fascia. **D.** Upward rotation of the breast with retractor exposes the underlying pectoralis muscle.

Periareolar Incision

- Development of the periareolar incision differs slightly based on either subglandular or subfascial implant placement is intended. The differences are distinguished below.
- The planned incision location is marked directly on the border of the inferior areolar and breast skin with a series of dots.
- The dots are used instead of a line for more accurate visualization of the exact areolar border.
- It is most important to follow the exact outline of the areolar border even if irregular because any deviation off the border to smooth the incision outline leads to a more visible scar (**TECH FIG 2A**).
- The planned incision should extend equidistance medial and lateral from the midline but not to exceed half of the circumference of the areola.
- With the skin placed under tension by the assistant, the incision is made precisely on the areolar border with a no. 15 blade through the skin to the mid-dermis (**TECH FIG 2B**).
- Dissection then proceeds through the deep dermis and breast parenchyma with electrocautery.
- The skin edges are retracted inferiorly and superiorly, and dissection is carried down through the parenchyma toward the pectoralis fascia (**TECH FIG 2C**).



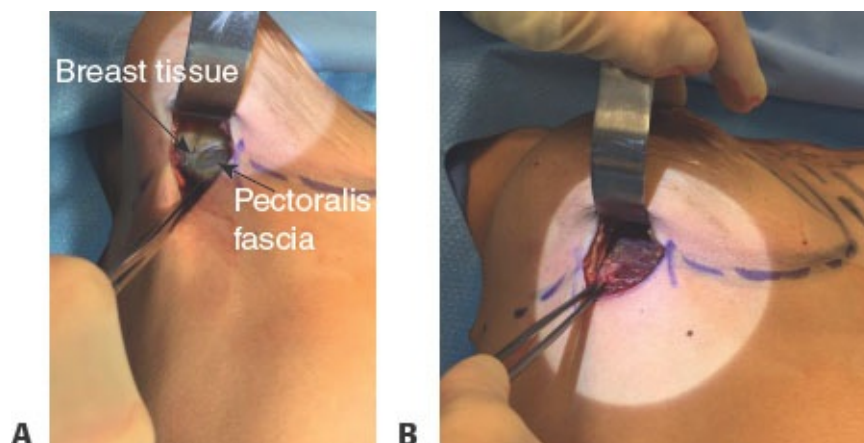
TECH FIG 2 • A. Periareolar incision noted with *dark purple line*. **B.** Periareolar incision along inferior border of NAC. *Solid black line* is the IMF. **C.** Periareolar incision along inferior border of NAC with counter tension. Be careful not to aggressively undermine the NAC. *Solid black line* is the IMF. **D.** Schematic of the transparenchymal and subcutaneous approach. **E.** Periareolar transparenchymal approach with electrocautery. *Solid black line* is the IMF.

- The dissection should be directed in an inferior direction to ensure that the nipple-areolar complex (NAC) is not inadvertently undermined during dissection and the blood supply compromised.
- Dissection proceeds either directly through the breast tissue

(transparenchymal) to the pectoralis fascia or inferiorly under the skin (subcutaneous) until the fascia is reached at the fold. The authors prefer the transparenchymal approach (**TECH FIG 2D,E**).

Subglandular Pocket

- With the subcutaneous periareolar approach (like the IMF approach), the breast elevation and pocket creation begins at the fold and proceeds superiorly in the subglandular plane.
- The IMF is a fusion of the deep fascia attached to the pectoralis and the superficial fascia of the breast.
 - Care is taken to prevent disruption of the IMF as the breast is elevated off the pectoralis fascia.
- If the transparenchymal periareolar approach is used, the dissection is directed through the breast down to the pectoralis fascia.
- The subglandular pocket is then developed as an inferior flap and superior flap with its overlying breast tissue, creating a continuous pocket superficial to the pectoralis muscle fascia.



TECH FIG 3 • A. Elevation of the overlying breast tissue with underlying pectoralis muscle and fascia. **B.** Subglandular pocket with pectoralis muscle/fascia visible posterior to the pocket.

- If the fold is inadvertently disrupted and the IMF lowering is not planned, the fold must be controlled with deep fascial sutures at the time of incision closure.

- Continued upward retraction of the breast will elevate the breast and its underlying superficial fascia as a single unit, leaving the deep pectoralis fascia attached to the muscle.
- The dissection is carried superiorly, medial and lateral to create the desired pocket (**TECH FIG 3**).

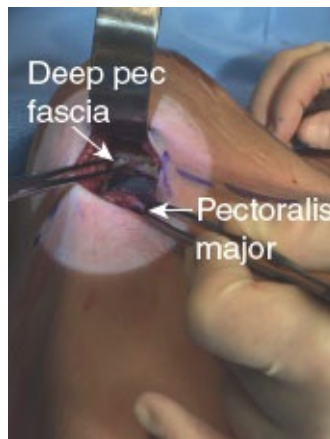
Subfascial Pocket

- With the subcutaneous periareolar approach (like the IMF approach), the breast elevation and pocket creation begins at the fold and proceeds superiorly in the subfascial plane.
- The IMF is a fusion of the deep fascia attached to the pectoralis and the superficial fascia of the breast.
 - Care is taken to prevent disruption of the IMF as the breast and underlying pectoralis fascia are elevated off the underlying pectoralis muscle.
- If the transparenchymal periareolar approach is used, then dissection is directed through the breast down to the pectoralis fascia.
 - The subfascial pocket is then developed as an inferior flap and superior flap of fascia with its overlying breast tissue, creating a continuous pocket superficial to the pectoralis muscle but beneath the fascia.
- If the fold is inadvertently disrupted and the IMF lowering is not planned, the fold must be controlled with deep fascial sutures at the time of incision closure.
- The inferior extent of the pectoralis fascia is thin and elevation is best carried out with the cut current of the electrocautery. The superior fascia is thicker and more developed providing more easily dissected plane.
- Continued upward retraction of the breast will elevate the fascial plane.
- The fascia is left attached to the overlying breast tissue and elevated as a single unit.
- The dissection is carried superiorly, medial and lateral to create the desired pocket (**TECH FIG 4**).

Pocket Control

- As with any breast augmentation, pocket control is key.
- Avoid overdissection of the pocket laterally to optimize medial projection of the implant and minimize lateralization of the implant.
 - Subglandular implants have less lateral drift compared with submuscular

implants because they lack the lateral action of the forceful pectoralis muscle contraction.



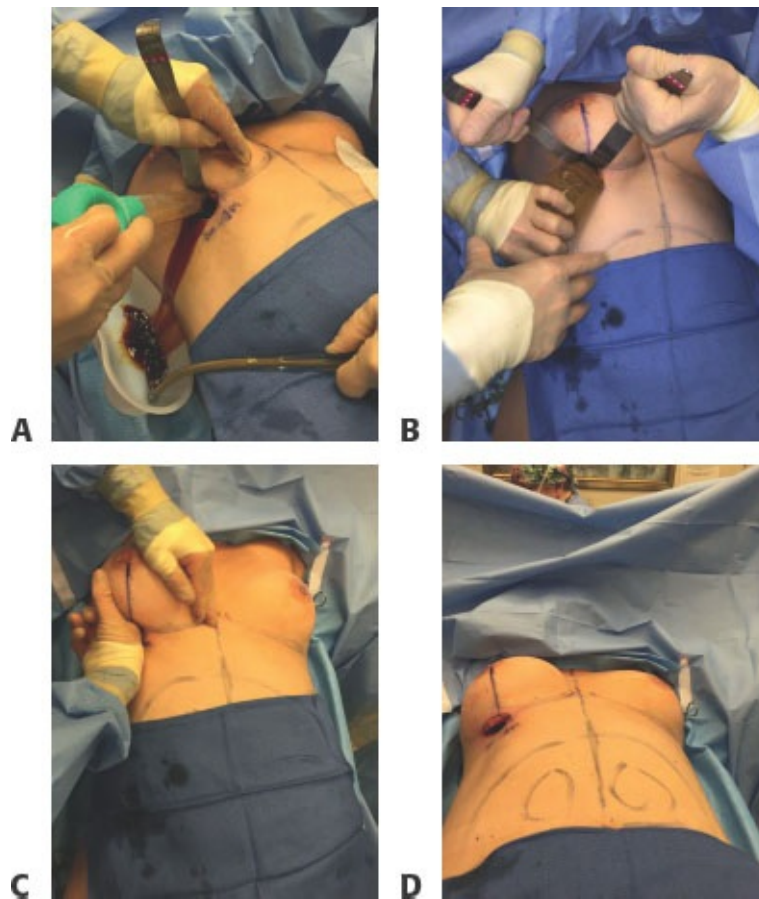
TECH FIG 4 • Creation of the subfascial plane. The deep pectoralis fascia is elevated with the breast tissue exposing the underlying pectoralis major muscle.

- As one carries the subglandular dissection medially, the midline can quickly be violated due to the lack of sternal muscle attachments that usually limit the dissection in the submuscular plane.
- The fascia is adherent to the underlying pectoralis muscle as the sternum is approached in the subfascial dissection and will provide some limitation to medial overdissection compared to the subglandular pocket.
- Overdissection can lead to implant medialization and the potential for postoperative symmastia. This is especially true when the chest wall is concave or slanting medially. Special caution with limited medial dissection is warranted in these cases.
- Remember if IMF lowering is needed, the dissection is in the subglandular pocket, as the attachments creating the fold are superficial to the deep pectoral fascia.²⁰

Implant Placement

- Once dissection is complete, the pocket is irrigated with triple antibiotic solution (1 g cefazolin sodium, 80 mg gentamicin, 50 000 units bacitracin mixed in 500 mL of normal saline) and hemostasis is assessed (**TECH FIG 5A**).

- The authors as a personal preference generally remove bacitracin and add betadine solution (50 cc) to the irrigation mixture if no allergy exists.¹⁴
- The implants are soaked in the irrigation solution before insertion. Gloves are changed and rinsed with the irrigation solution to remove any residue.
- In the authors' practice, the implant is placed into the pocket with the assistance of an insertion sleeve such as the Keller funnel (**TECH FIG 5B**).
- The opening of the funnel should be cut large enough to allow easy egress of the implant through the funnel. This is confirmed by passing the implant with irrigation solution through the funnel before insertion.
- The implant orientation is confirmed in the funnel, and a maneuver of squeezing the implant through the funnel with pressure exerted on the back of the funnel slips the implant into the breast pocket.
- These maneuvers provide a “no-touch” technique, which has been associated with lower capsular contracture rates.¹³



TECH FIG 5 • A. Irrigation of breast pocket prior to

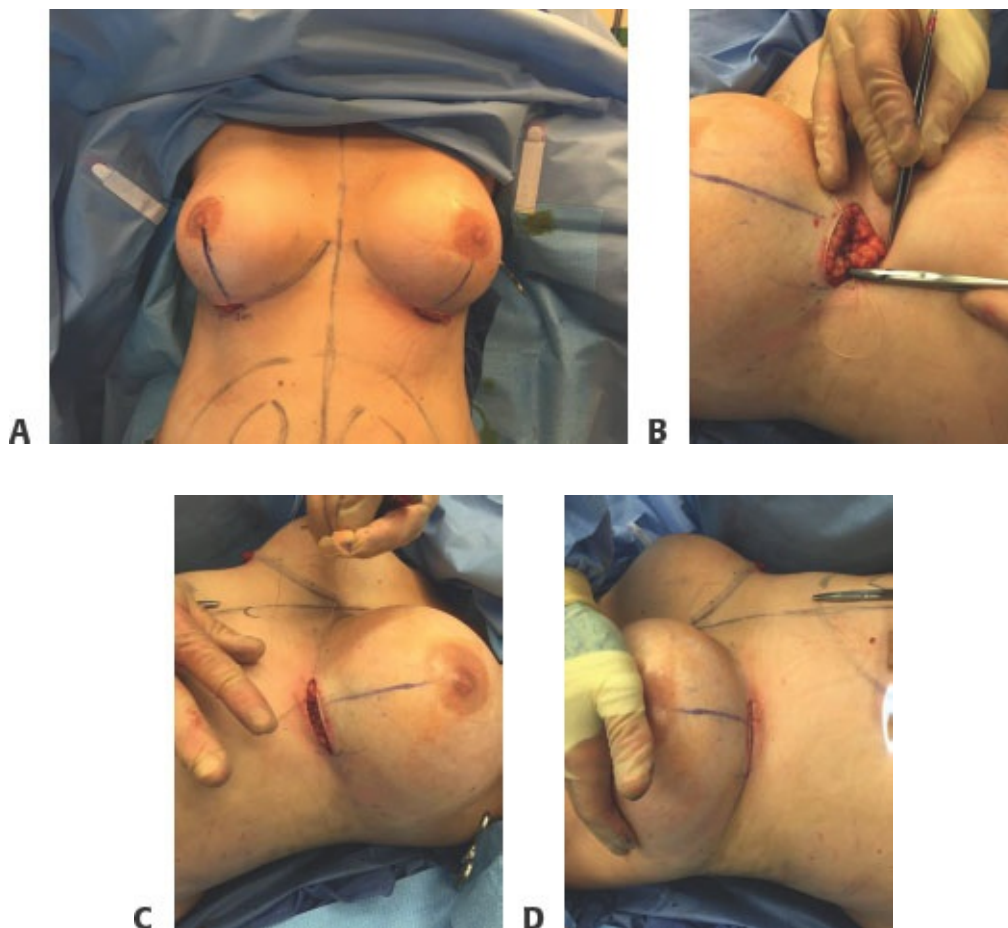
implant placement. **B.** Insertion of breast implant into subglandular pocket with Keller funnel. **C.** Hand-assisted implant pocket assessment and breast tissue redraping. **D.** Note the pocket control and the medial projection of the implant in the supine position.

- Once the implant is in the pocket, a finger-assisted assessment and manipulation of the implant within the pocket is necessary to confirm its proper placement and assure appropriate redraping of the breast parenchyma over the implant (**TECH FIG 5C**).
- This maneuver is especially important with textured devices, as these implants are less mobile and less likely to stretch the pocket and, thus, a distortion or wrinkling of the implant in a tight pocket may be permanent if not resolved before closure.
- Repeated removal and insertions of the implant should be avoided to minimize implant or incision damage, potential contamination, and pocket overdissection. This is especially important with shaped implants, as a stretched pocket from over manipulation could lead to implant rotation postoperatively (**TECH FIG 5D**).

Pocket Closure

- Before incision closure, the patient should be placed in the upright position to assess implant position, fold position, and symmetry (**TECH FIG 6A**).
- The inframammary approach is useful to control the fold position during the final closure.
 - The cuff of superficial Scarpa fascia that was preserved during the initial incision is used to secure the fold during closure.
- If the IMF structure is stable, and was not violated or lowered during the pocket formation, reapproximation of the superficial fascia during closure is usually adequate.
- If the fold is mobile from inherent weakness or was disrupted with fold lowering, the pocket closure should include stabilization of the fold.
 - Fold stabilization is accomplished by incorporating the deep fascia in the closure.
 - The Scarpa fascia cuff is sutured to the deep fascia in the lower incisional edge during the closure of the IMF (**TECH FIG 6B**).

- Both the periareolar and inframammary incision are closed in three layers: deep fascia/parenchyma (2-0 Vicryl running), deep dermis (4-0 PDS interrupted), and subcuticular (4-0 PDS running) (**TECH FIG 6C**).
- Periareolar incisional closures do not stabilize the fold structure as it does with an IMF incision closure.
- If using a textured device, the implant must be seated at the desired position at the base of the breast pocket because it is less likely to settle in the pocket postoperatively as can be seen with smooth breast implants (**TECH FIG 6D**).



TECH FIG 6 • **A.** Patient sitting upright prior to final closure to assess for symmetry and final aesthetic result. **B.** Fold stabilization with a 2-0 Vicryl incorporating the deep fascia in the Scarpa fascial closure. **C.** Image of the final closure incorporating superficial Scarpa fascia and deep fascia as one

consistent layer without the presence of an incisional step off. **D.** Downward pressure on the implant/breast demonstrates a locked and stable IMF.

■ Submuscular (Subpectoral) Implants

Inframammary Fold Incision

- Although the submuscular pocket can be accessed by any incision (periareolar, inframammary, transaxillary, transumbilical), the most common approach is through the inframammary incision.
- After determining the IMF position (either the native true fold position or the planned lowered position), a paramedian line is drawn through the center of the breast and bisects the newly drawn IMF.
- The incision's medial extent begins 1 cm medial to the paramedian line and extends laterally for the appropriate distance, as previously described based on the implant type (see **TECH FIG 1A**).
 - The incision is made with a no. 15 blade through the skin to the mid-dermis (see **TECH FIG 1B**).
- Dissection is then carried out with electrocautery through the skin and subcutaneous tissue, beveling superiorly while rotating the breast off of the chest wall.
- Once dissection has been carried superiorly for 1 cm, the dissection is carried through the superficial fascia and toward the lateral pectoral border deep on the chest wall.
- The beveling preserves a small cuff of superficial fascia at the incision, which ensures that the fold is not inadvertently lowered and also provides a cuff of fascia that will prove useful during closure (see **TECH FIG 1C**).
- Dissection is carried down toward the chest wall while maintaining a constant upward retraction of the breast tissue, ultimately exposing the lateral edge of the pectoralis muscle.
 - The upward retraction of the breast tissue is key as the suspensory ligaments of the breast will concomitantly elevate the muscle (see **TECH FIG 1D**).
- It is imperative to not cut the muscle unless you can elevate the muscle off the chest wall.

- Inability to elevate the muscle most likely indicates that the identified muscle is actually not the pectoralis, but rather the serratus, rectus, or an intercostal muscle.
- Dissection through an intercostal could lead to penetration of the pleural space and pneumothorax.
- Once the lateral border of the pectoralis is identified, the fascia is incised to expose the underlying muscle. Continued upward retraction of the breast will elevate the lateral border, allowing further dissection and placement of the retractor beneath the overlying pectoralis muscle.

Periareolar Incision

- The planned incision location is marked directly on the border of the inferior areolar and breast skin with a series of dots. The dots are used instead of a line to allow more accurate visualization of the exact areolar border.
- It is most important to follow the exact outline of the areolar border even if irregular as any deviation off the border in order to smooth the incision outline leads to a more visible scar.
- The planned incision should extend equidistance medial and lateral from the midline but not to exceed half of the circumference of the areola (see **TECH FIG 2A**).
- With the skin placed under tension by the assistant, the incision is made precisely on the areolar border with a 15 blade through the skin to the mid-dermis.
 - Dissection then proceeds through the deep dermis and breast parenchyma with electrocautery (see **TECH FIG 2B,C**).
- The skin edges are retracted inferiorly and superiorly, and dissection is carried down through the parenchyma toward the pectoralis fascia.
- The dissection should be directed in an inferior direction to insure that the NAC is not inadvertently undermined during dissection and blood supply compromised.
- Dissection proceeds either directly through the breast tissue (transparenchymal) to the pectoralis fascia or inferiorly under the skin (subcutaneous) until the fascia is reached at the fold. The authors prefer the transparenchymal approach (see **TECH FIG 2D**).
- With the subcutaneous periareolar approach (like the IMF approach), the breast elevation and pocket creation begins at the fold and proceeds superiorly in the subpectoral pocket.

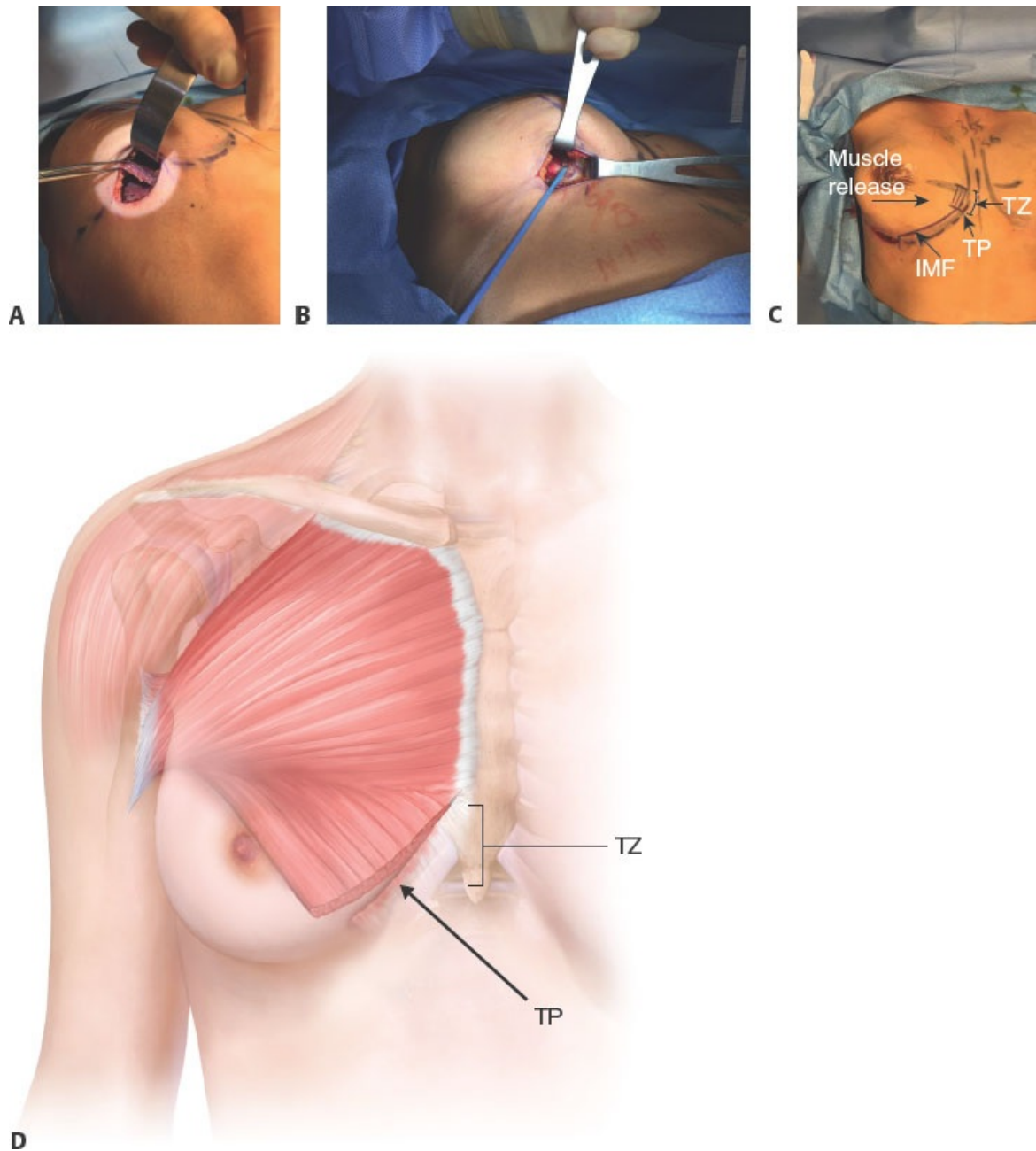
- The IMF is a fusion of the deep fascia attached to the pectoralis and the superficial fascia of the breast (see **FIG 6**). Take care to prevent disruption of the IMF as the breast and pectoral fascia are elevated.
- If creating a subpectoral dual plane pocket, dissection proceeds subcutaneously or transparenchymal down to the lateral border of the pectoralis muscle.
- If accessing the submuscular pocket, the lateral border of the pectoralis is identified and the fascia is incised to expose the underlying muscle. Continued upward retraction of the breast will elevate the lateral border, allowing further dissection and placement of the retractor beneath the overlying pectoralis muscle
 - When creating the submuscular pocket, it is imperative to not cut the muscle unless it can be elevated off the chest wall.
 - Inability to elevate the muscle most likely indicates that the identified muscle is actually not the pectoralis, but rather the serratus, rectus, or an intercostal muscle.
 - Dissection through an intercostal could lead to penetration of the pleural space and pneumothorax.

Pocket Dissection

- After the subpectoral space is entered, dissection is carried upward centrally to the superior extent of the pocket.
- Dissection is then carried laterally just superficial to the pectoralis minor until the lateral border of the pocket is reached.
 - Keep lateral dissection of the pocket to a minimum with the cautery because the breast/nipple neural supply from the lateral cutaneous nerves can be inadvertently cut.
 - Blunt dissection of the lateral edge of the pocket decreases the chance of nerve transection.
- Carry the dissection inferiorly along the lateral border of the pocket, identifying and staying superficial to the serratus muscle until the inferior extent of the pocket at the IMF is reached.
 - Avoid overdissection of your pocket laterally to facilitate optimal medial projection of the implant.
- The pectoralis is then released along the planned IMF, staying 1 cm superior to the fold to account for caudal muscle descent.
- Dissection directly at the fold will often lead to a fold that is lower than

planned as the muscle retracts inferiorly (**TECH FIG 7A**).

- As the dissection is carried medially along the IMF, it is critically important to stop it at the most medial extent along the sternum (**TECH FIG 7B**).
- Preservation of the most caudal attachment of the pectoralis muscle at the *transition point* (TP) along the sternum is critical to minimize the chance of window shading of the pectoralis with subsequent medial implant exposure and animation deformities (**TECH FIG 7C,D**).
- A *transition zone* (TZ) of tapered muscle release connects the transition point to the main body of medial pectoral muscle along the sternum.
- The extent of the pocket is completed by defining the medial pectoral border and dividing all of the accessory slips of pectoralis muscle that insert along the ribs, preserving only the main body of the muscle as it inserts along the sternum.



TECH FIG 7 • A. Inferior/lateral border of the pectoralis major after it was released along the IMF. **B.** Inferior release of the pectoralis major heading medially toward the sternum. **C.** Transition zone (TZ) and transition point (TP). Dashed line reveals pectoralis muscle release medially up to the TP. Solid line represents the inframammary fold (IMF). **D.**

Schematic demonstrating the release of the pectoralis off of the chest wall to the transition point (*TP*). Notice the transition zone (*TZ*) which is a zone of thinning of the muscle at the caudal end of the sternum just medial to the *TP*.

- Dividing these muscle slips with electrocautery instead of blunt dissection improves postoperative cleavage and maintains hemostasis. Although completely dividing all accessory slips is required to achieve maximal cleavage, division of the main body of medial pectoralis muscle should be preserved, other than conservative thinning at the transition zone, to minimize the risk of postoperative wrinkling or implant show.
- This division of the inferior pectoralis muscle just above the IMF during initial pocket dissection creates a level 1 dual plane. Thus, all subpectoral pockets where the muscle is released inferiorly are actually dual-plane pockets, as the segment between the caudal edge of the divided muscle and the IMF is subglandular.²¹
- The level of dual plane required varies, and each surgery can be tailored to provide the optimal level based on soft tissue requirements and implant selection.
- The greater the amount of breast parenchyma or breast laxity, the greater the level of dual plane.
- It is this creation of a lower pole subglandular pocket that allows for an optimal breast-implant interface and soft tissue redraping.
- Failure to optimize the breast-implant interface can lead to a waterfall deformity, with the breast sliding off of the implant.
- When submuscular, IMF lowering can be more challenging as it is tempting to carry the dissection under the muscle inferiorly to lower the fold.
- The dissection along the chest wall at the level of the fold is deep to the suspensory ligament structures that create the IMF.
- IMF lowering in the subpectoral pocket requires transitioning into a more superficial plane above the pectoralis fascia to lower the IMF.²⁰
- Dissection deep to the pectoral fascia will likely result in a lowered fold with persistence of the fold structure, resulting in a double-bubble deformity.
 - This is more likely when dissection begins from above, such as a periareolar or transaxillary approach.

- When using an IMF incision, the dissection below the native fold begins in the subcutaneous plane until the pectoralis muscle is reached, resulting in appropriate obliteration of the native fold at the correct level.

Implant Placement

- The implants are bathed in the irrigation solution before insertion. Gloves are changed and rinsed with the irrigation solution to remove any residue (see **TECH FIG 5A**).
- In the authors' practice, the implant is placed into the pocket with the assistance of an insertion sleeve such as the Keller funnel (see **TECH FIG 5B**).
 - The opening of the funnel should be cut large enough to allow easy egress of the implant through the funnel. This is easily confirmed by passing the implant with irrigation solution through the funnel prior to pocket insertion.
 - The implant orientation is then confirmed in the funnel, and a maneuver of squeezing the implant through the funnel with gentle pressure exerted on the back of the funnel allows the implant to slip effortlessly into the breast pocket.
 - These maneuvers provide a “no-touch” technique, which has been associated with lower capsular contracture rates.^{12,13}
- Once the implant is in the pocket (see **FIG 3A**), a finger-assisted assessment and manipulation of the implant within the pocket is necessary to confirm its proper placement and ensure appropriate redraping of the breast parenchyma over the implant (see **TECH FIG 5C**).
 - This maneuver is especially important with textured devices, as these implants are less mobile and less likely to stretch the pocket and, thus, a distortion or wrinkling of the implant in a tight pocket may be permanent if not resolved before closure.
- Repeated removal and insertions of the implant should be avoided to minimize implant or incision damage, potential contamination, and pocket overdissection.
 - This approach is especially important with shaped implants, as a stretched pocket from overmanipulation could lead to implant rotation postoperatively.

Pocket Closure

- Before incision closure, the patient should be placed in the upright position

to assess implant position, fold position, and symmetry, and the adequacy of the dual plane (see **TECH FIG 6A**).

- The IMF approach for submuscular implant placement is useful to control the fold position during the final closure. The cuff of superficial Scarpa fascia that was preserved during the initial incision is used to secure the fold during closure.
 - If the IMF structure is stable and has not been violated or lowered during the procedure, reapproximation of the superficial fascia during closure is usually adequate.
 - If the fold is mobile and unstable from either inherent weakness or from disruption during fold lowering, the pocket closure should include stabilization of the fold.
 - Fold stabilization is accomplished by incorporating the deep fascia in the closure.
 - The Scarpa fascia cuff is sutured to the deep fascia in the lower incisional edge during the closure of the IMF (see **TECH FIG 6B,C**).
- Both the periareolar and inframammary incision are closed in three layers: deep fascia/parenchyma (2-0 Vicryl running), deep dermis (4-0 PDS interrupted), and subcuticular (4-0 PDS running).
- If using a textured device, the implant must be seated at the desired position at the base of the breast pocket because it is less likely to settle in the pocket postoperatively as can be seen with smooth breast implants (see **TECH FIG 6D**).

PEARLS AND PITFALLS

Live by the pinch

- A pinch test of less than 2 cm should guide the surgeon away from subglandular and subfascial pocket creation.
- Implants that are more prone to rippling (eg, textured implants, saline implants) or poor quality soft tissue might require an even thicker soft tissue coverage and a pinch test of more than 3 cm may be warranted.

Avoid midline overdissection

- No muscle sternal attachments encountered in subglandular or subfascial plane. Symmastia prevention is important.
-

Control the fold	■ If IMF is mobile, disrupted or lowered, the closure must incorporate the deep fascia to secure the fold.
Reduce capsular contracture risk	■ Textured implants in the subglandular/subfascial pocket, no-touch technique, nipple shields, pocket irrigation with triple antibiotics, insertion sleeve, submuscular implant pocket, inframammary incision, and cohesive-shaped implants.
Pocket control	■ Precise pocket dissection to minimize malposition, rotation, lateral drift.
Periareolar incision	■ Avoid undermining the NAC to minimize disruption of the blood supply to the nipple.
Subfascial pocket entry	■ Use the cut current to facilitate elevation of the thin fascia. Fascia thickens as you move superiorly.
Submuscular pocket entry	■ If you cannot lift the muscle (pectoralis major) off the chest wall, <i>do not</i> cut it.
Respect the transition point and zone	■ Divide pectoralis muscle 1 cm above the fold to the transition point, thin along the transition zone, and release only accessory muscle slips along sternum to prevent wrinkling and window shading of muscle.
Optimize submuscular dual plane	■ Place implants submuscular and create a subglandular pocket in the lower pole with a dual plane to optimize breast tissue-implant relationship.

POSTOPERATIVE CARE

- Incisions are covered with Steri-strips.
- Contour tape is placed along the fold and lateral breast.
- Breasts are wrapped with a Kerlix and Ace wrap for 24 hours.
- For textured implants, a breast band is worn for 1 week.
- Early range of motion, beginning in the recovery room, is initiated for all patients, which includes shoulder rolls in both directions in addition to elevation of the arms outward to the sides and over the head.
- With smooth devices, implant massage begins postoperatively on day 4 and includes displacing the implant upward and downward in the pocket, crossing the arms and pulling the implants inward to create cleavage, and downward pressure on the implants to stretch the lower pole.

- With textured implants, both round and shaped, limited arm movement other than range of motion is recommended for the first week.
- Implant massage with textured implants is contraindicated, because the textured surface can irritate the pocket and potentially create serous fluid around the implant. Likewise, the implants are placed in a controlled pocket with the implant positioned appropriately at the base of the pocket; displacement could lead to implant malposition or, in the case of shaped devices, rotation of the implant.
- Patients are allowed to resume wearing regular bras after 4 weeks but should continue with sports bras during bedtime for an additional 2 to 4 weeks to limit lateral implant movement during pocket formation.
- Normal activity resumes within a few days after surgery, but exercise and high-impact activity should be delayed for 3 to 4 weeks for subfascial and subglandular implants and 4 to 6 weeks for submuscular implants.
- If a variety of smooth and textured (round or shaped) breast implants are being used within a practice, it is extremely important to communicate to ancillary staff the type of device placed with each patient to initiate the appropriate postoperative protocol, as inappropriate instructions can lead to postoperative problems such as seromas, malposition, and rotational deformities.
- Whereas smooth implants often seem high initially and often require downward massage and the use of breast bands or bandeaus, textured devices that are appropriately seated in the base of the breast pocket should only occasionally require such maneuvers.
- Whereas smooth implants will seem more mobile and softer in the first few weeks after surgery in comparison with textured devices, the textured implants will soften with modest movement often present after 4 to 6 weeks.

OUTCOMES

- Preoperative and postoperative photos of bilateral subglandular breast augmentation are shown in **FIG 14**.

COMPLICATIONS

- Capsular contracture
- Infection
- Malposition (symmastia, double-bubble, lateral drift, superior malposition with waterfall) (**FIG 15**)



FIG 14 • Preoperative and postoperative photos of a 31-year-old woman who underwent bilateral subglandular breast augmentation through an IMF incision, with 355 cc moderate profile textured implants.

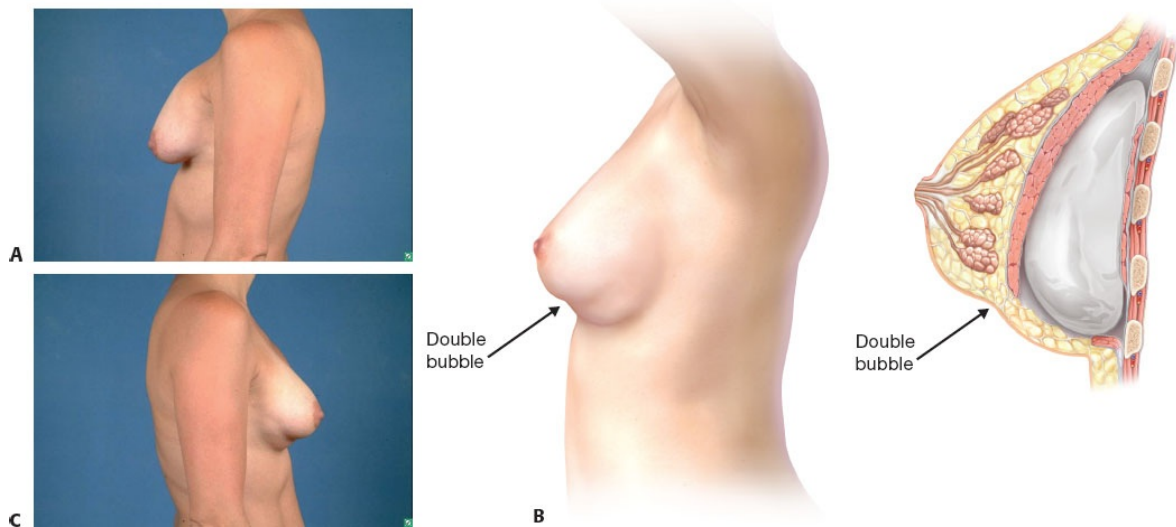


FIG 15 • **A.** Waterfall deformity with the breast tissue falling off of the implant. Black curvilinear line represents the breast-implant interface. **B, C.** Double-bubble deformity resulting from overdissection deep to

the pectoralis major muscle attachments on the chest.

- Double capsule/seroma
- Nipple and breast sensation changes
- Implant failure (leak rupture, fracture)
- Implant extrusion
- Neuropraxia
- Poor scarring

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3 Breast Augmentation Plane: Dual Plane

CHAPTER

Bill Kortesis and Charalambos “Babis” Rammos

DEFINITION

- According to the American Society for Aesthetic Plastic Surgery (ASAPS) 2016 statistics, breast augmentation was the second most common aesthetic surgical procedure performed in the USA, with approximately 311 000 procedures performed.¹
- A thorough physical examination of the prospective breast augmentation candidate is imperative.
- Any asymmetry of breast size, nipple position, and inframammary fold is documented.
- The most commonly used implant locations are partial subpectoral and subfascial.
- A combination of two pocket locations in the same breast (dual plane) can address the implant-soft tissue dynamics that may occur.

ANATOMY

- In dual plane augmentation, the implant lies partially behind the pectoralis major muscle, and partially behind the breast parenchyma (in dual planes simultaneously).²
- The parenchyma-muscle interface is specifically altered, and a specific group of pectoralis major muscle origins are totally divided.
 - The inferior origins of the muscle are only divided without any division of the sternal attachments.
 - A plane between the parenchyma and the anterior surface of the muscle is formed to a varying degree, resulting in three different types of dual plane: type I, type II, and type III.

PATHOGENESIS

- Micromastia occurs as a developmental phenomenon either as primary mammary hypoplasia or due to chest wall pathology such as Poland syndrome.
- It may also present as an involutional process, due to weight loss or after pregnancy and lactation.
- Micromastia may lead to a negative body image and have a negative effect on quality of life.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Goals and expectations of the patient are discussed in detail during consultation.
- A thorough personal and family history is performed focusing on:
 - History of any breast disease and breast cancer
 - History of pregnancy
 - Desire for future pregnancy
 - Mammogram: Screening mammogram is obtained for any patient over 35 years old.
- Physical examination focuses on:
 - Current height and weight
 - Current breast size and desired breast size
 - Palpation for any breast masses, lymph nodes, or nipple discharge
 - Observation of breast ptosis and degree of ptosis, and the need for synchronous mastopexy
 - Observation of chest wall and breast asymmetries, such as differences in inframammary fold height, nipple-areola complex (NAC) height, breast volume, and breast shape

IMAGING

- The authors use the VECTRA 3D imaging and simulation system for all patients interested in breast augmentation. The device takes a three-dimensional photograph that can then be visualized in the monitor, with the addition of breast measurements.
- Differences between the two breasts, such as breast volume and sternal notch to nipple distance, can be depicted (**FIG 1**).

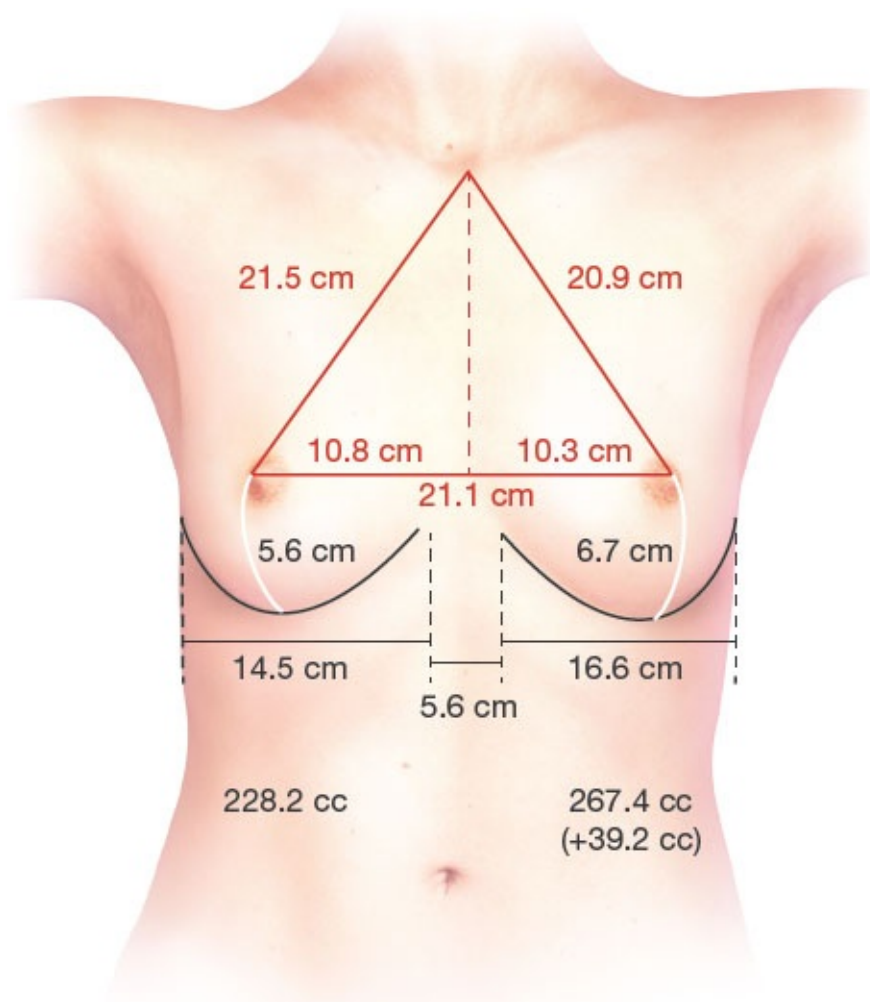


FIG 1 • Three-dimensional photograph of a 27-year-old female using the VECTRA 3D imaging device. Breast measurements are shown. Differences between right and left breast in terms of volume and sternal notch to nipple distance are recorded.

- Using different implant shapes and sizes, the surgeon produced a simulated postsurgical result, allowing the patients to have a visual image of the outcome. It has been shown that the use of the VECTRA 3D imaging system may provide a high degree of accuracy for breast volume (90%) and contour (98.4%).³

SURGICAL MANAGEMENT

- The main objectives of breast augmentation are as follows:
 - Enhancement of breast shape and volume
 - Improving self-esteem and quality of life.⁴ A prospective analysis using the BREAST-Q showed that breast augmentation is associated with high patient satisfaction and significant improvements in quality of life.⁵

Preoperative Planning

- Breast measurements
 - Breast width at its widest point
 - Nipple to inframammary fold (N-IMF) distance
 - Sternal notch to nipple distance
 - Breast height
- Assessment of breast parenchyma and skin
 - Elasticity: This is performed with deflection of the skin, and observation for resistance.
 - Pinch test: This is performed at the superior and medial portion of the breast, between the examiner's thumb and index finger. A result of less than 2 cm is most of the times an indication for placement of the implant in the subpectoral plane.
- Choice of implant volume. Sizers are placed in a bra and compared to the images obtained by the three-dimensional imaging.
- The patient is marked preoperatively in the upright standing position (**FIG 2**).
 - Midline, from sternal notch to xiphoid
 - Inframammary fold
 - Superior, medial, and lateral borders of the breast. The medial borders are marked 1.5 cm lateral to the midline, so as to prevent synmastia.
 - Breast meridian
 - Incision. For an inframammary approach, the marking is placed below the inframammary fold, centered at the breast meridian, most often 4 cm in length, 2 cm medial and 2 cm lateral to the meridian.



FIG 2 • The markings are made in the preoperative area and reviewed with the patient.

Positioning

- The patient is brought to the operating room and placed in the supine position on the operating table with the arms extended up to 90 degrees and well secured to the arm boards. Both shoulders should be at the same height.

Approach

- Inframammary incision placement
 - Wide exposure, better visualization
 - Easier manipulation of the inframammary fold position
 - Easier placement of the implant
- Submuscular pocket and retromammary plane creation
- Dual plane augmentation⁶ (**FIG 3**).
 - Type I dual plane: Complete division of pectoralis major muscle origin across the inframammary fold, stopping at the medial aspect, with no separation of the parenchyma-muscle interface
 - Most routine breasts
 - All of the parenchyma should be above the inframammary fold
 - Minimally stretched lower pole envelope. Areola to inframammary fold distance under stretch between 4 and 6 cm
 - Maximal muscle cover over the implant, compared to all types

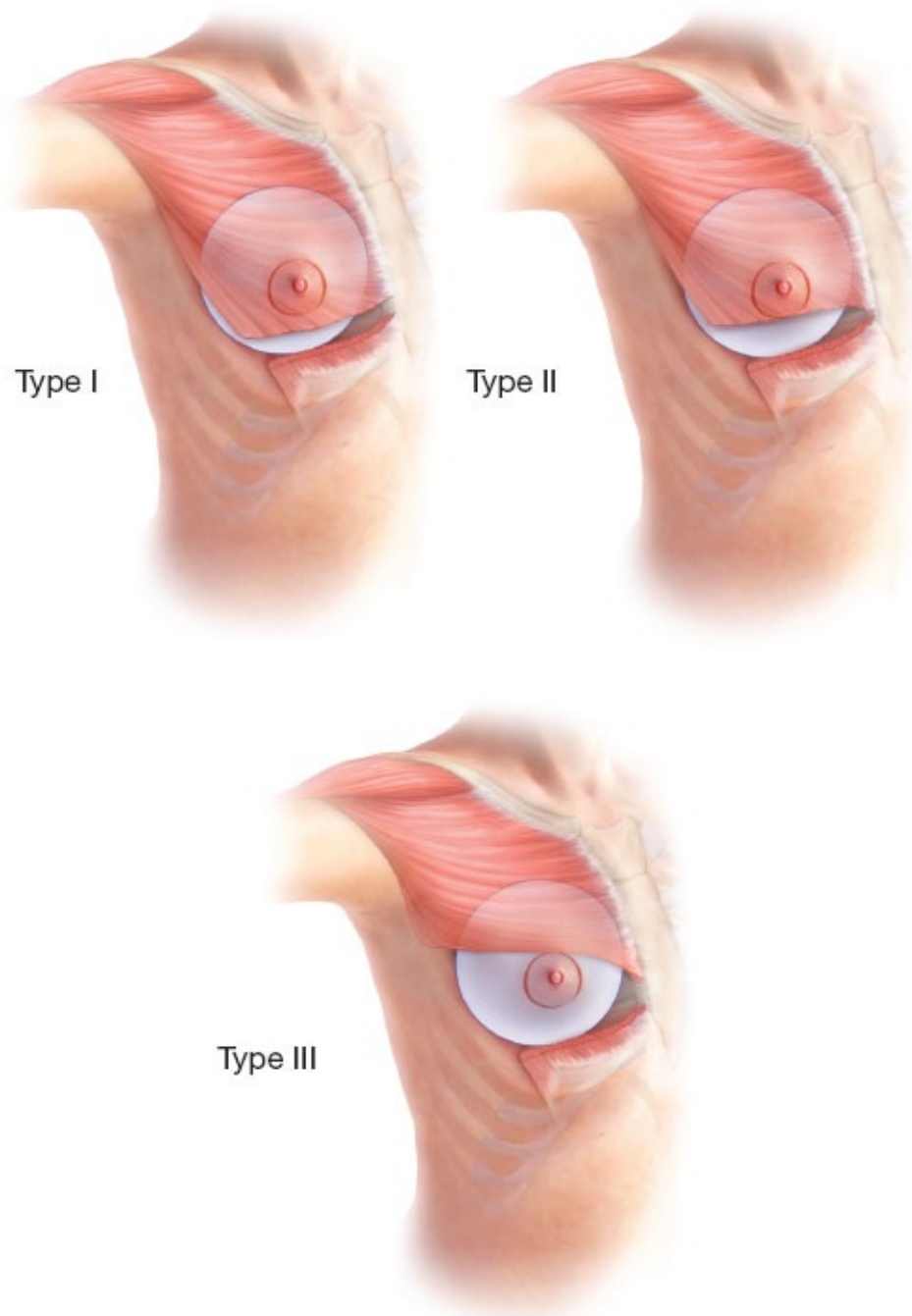


FIG 3 • Dual-plane augmentation techniques. The inferior origins of the pectoralis major muscle are disinserted, with preservation of the sternal origins. The more cephalad the dissection between the muscle and the parenchyma, the more cephalad the retraction of the pectoralis muscle.

- Type II dual plane: Complete division of pectoralis major muscle origin across the inframammary fold, stopping at the medial aspect, with synchronous retromammary pocket plane formation to the level of the inferior border of the areola
 - Lower pole envelope more stretched, areola to inframammary fold distance under stretch between 5.5 and 6.5 cm
 - Most of the parenchyma should be above the inframammary fold.
 - Mobile breast tissue over the pectoralis muscles
- Type III dual plane: Complete division of pectoralis major muscle origin across the inframammary fold, stopping at the medial aspect, with synchronous retromammary pocket plane formation to the level of the superior border of the areola
 - Markedly stretched lower pole envelope, areola to inframammary fold distance under stretch between 7 and 8 cm
 - Most of the parenchyma lies below the inframammary fold.

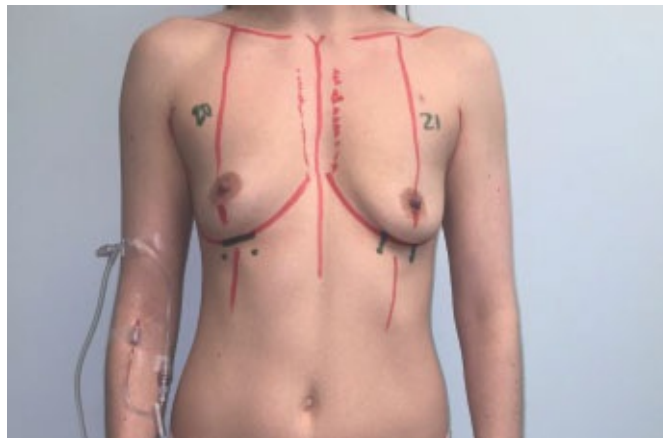


FIG 4 • Preoperative markings of a 25-year-old female undergoing breast augmentation. Dual plane technique type I was used on the right breast, and dual plane technique type II on the left. The lower pole envelope of the right breast is minimally stretched, compared to the more stretched lower envelope on the left breast.

- Breast parenchyma slides off the surface of the pectoralis.
- Constricted lower poles

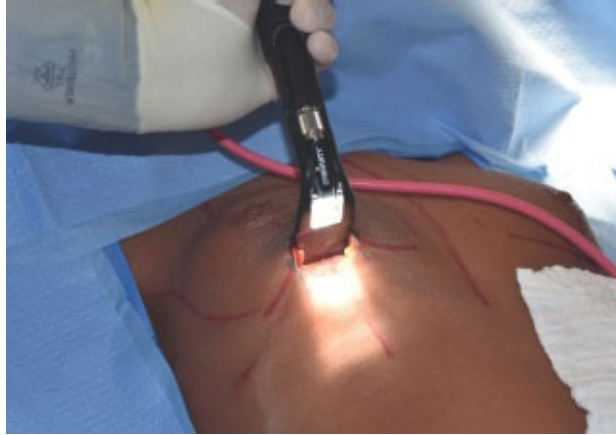
- The same patient may benefit from different types of dual plane augmentation on the two breasts (**FIG 4**).

TECHNIQUES

■ **Inframammary Approach With a Smooth Round Silicone Implant, Partial Subpectoral Placement, and Dual Plane Type II Placement**

Incision and Dissection

- Tegaderm is placed on top of the nipple-areola complex (NAC).
- Local anesthesia containing a mix of lidocaine and Marcaine with epinephrine is injected into the marked incision and as a breast block.
- The inframammary incision is made sharply through the dermis and the superficial layer of the fat until the Scarpa fascia is encountered.
- A double skin hook is placed followed by an Army-Navy retractor and dissection is continued with Bovie electrocautery cephalad with care not to violate the Scarpa fascia.
- The breast tissue is divided, and the pectoralis muscle fascia is identified.
- Suprafascial dissection is carried accordingly to create a type II dual plane dissection.
- After dual plane dissection, the pectoralis muscle is grasped and divided till the areolar space under the muscle is identified.
 - A lighted retractor is then placed below the pectoralis major muscle and strong upward traction is placed so as to separate the pectoralis major from the pectoralis minor muscle (**TECH FIG 1**).
 - The initial fiber incision is made medially, where pectoralis major is absent.
- Pocket dissection is performed with the monopolar electrocautery and there is no use of blunt dissection.
- Submuscular dissection proceeds from medial to lateral in a clockwise fashion for the left breast and in an anticlockwise fashion for the right breast, until the pocket is of appropriate size.



TECH FIG 1 • Dual plane dissection type II is performed before proceeding with pocket creation. Use of a lighted retractor to separate the pectoralis major from the pectoralis minor muscle.

- Care is taken to avoid any contact with the ribs so as to decrease postoperative pain.
- Care is taken to disinsert the medial origin of the pectoralis major muscle so as to achieve adequate expansion of the lower pole.
 - Care is taken to not disinsert the sternal fibers of the muscle.
- Meticulous hemostasis is achieved.

Implant Insertion and Closure

- Tester gel implants are inserted, and the patient is placed in the upright seated position. If there are areas for additional dissection, these are marked.
- The pockets are irrigated with triple antibiotic solution.
- The formal implants are then placed in a sterile manner using the no-touch technique.
 - The implant is transferred to the Keller funnel avoiding any contact with the operating table or the surgeon's gloves (**TECH FIG 2A**).
 - A Deaver retractor is used by the assistant to facilitate placement of the implant (**TECH FIG 2B**).
- Closure is performed in three layers:
 - 2-0 Vicryl is used for the breast parenchyma (**TECH FIG 2C,D**).
 - 4-0 Monocryl is used for interrupted deep dermal sutures, followed by a running subcuticular 4-0 Monocryl suture.

- The patient is placed again in an upright seated position for final assessment (**TECH FIG 2E**).



TECH FIG 2 • A,B. The Keller funnel is used for placement of the implants. The no-touch technique is used. There is direct transfer of the implant to the funnel without touching the implant. **C.** Deeper layer that will be closed is grasped with forceps. **D.** Closure of the deeper breast tissue is performed before skin closure. **E.** Patient at the seated upright position with the implants in place.

PEARLS AND PITFALLS

Hemostasis	■ Meticulous hemostasis should be achieved to avoid postoperative hematoma and an inflammatory response that may lead to capsular contracture.
Pectoralis muscle	■ The most medial fibers of the pectoralis major muscle should be released to avoid a constricted lower pole. Carefully not to disinsert the sternal fibers as that can lead to window-shading and decreased implant coverage.
Dual plane	■ Advantage of increasing implant and breast parenchyma interface, expanding the lower pole, and allowing for changes of the nipple-areolar complex.
Implant placement	■ The no-touch technique is used at all times, to avoid implant contamination.
Dissection	■ Dissection should be accurate to accommodate the implant and overdissection should be avoided at all times.
Ribs	■ Contact with the ribs should be avoided, so as to decrease postoperative pain.

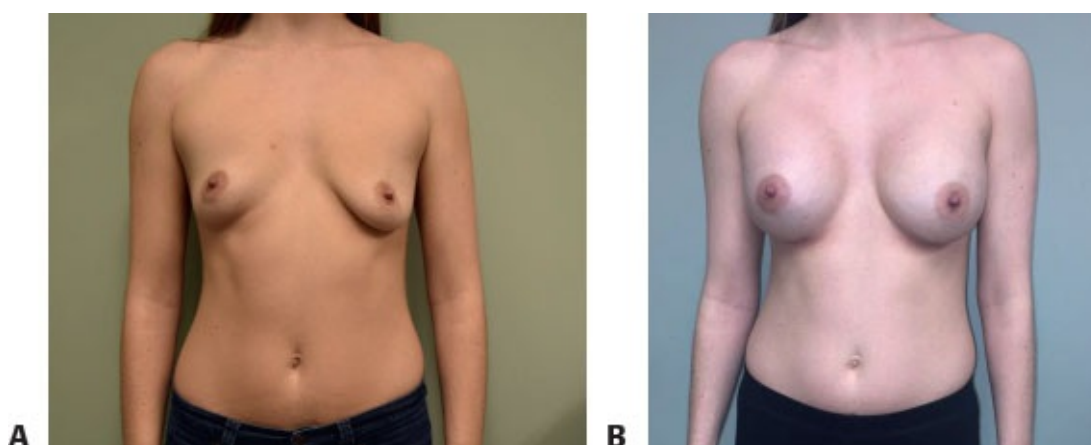


FIG 5 • A. Preoperative frontal view of a 25-year-old woman with micromastia. **B.** Patient 1 month after submuscular breast augmentation with a 345-mL smooth round implant with moderate projection. Dual

plane augmentation type I was performed on the right, and dual plane augmentation type II was performed on the left.

POSTOPERATIVE CARE

- Patients are discharged at the same day of surgery after they recover in the postoperative anesthesia care unit.
- Postoperative medications
 - Oral analgesics
 - Seven-day course of oral antibiotics
- Paper tape is used to cover the incisions.
- A soft bra is used.
- Activity
 - Patients are instructed to avoid heavy lifting, no more than 10 lb, for 10 days.
 - Light exercise is permitted starting postoperative day 1. Additional exercises such as arm abduction and arm elevation are encouraged, to achieve stretching of the pectoralis major muscle and accelerate recovery by decreasing pain.
- Patients may shower on postoperative day 1.
- Manual massage for round implant starts as soon as tolerated by the patient with the aim to prevent capsular contracture.
- Follow-up appointments are scheduled for day 1, 1 week, 3 weeks, 3 months, 6 months, and 1 year.

OUTCOMES

- A clinical example of a patient with inframammary breast augmentation with smooth round silicone implants and dual plane augmentation is shown in **FIG 5**.

COMPLICATIONS

- Hematoma formation is rare and ranges from 0.5% to 1%.
- Infection is rare and occurs in less than 1% of the patients.
- Double-bubble deformity may occur due to violation of Scarpa fascia at the level of the inframammary fold, with subsequent caudal migration of the implant in relationship to the breast mound.
- The cause of capsular contracture is inflammation, which in turn may be due

to tissue trauma, bacteria, and blood.

- The use of the Keller funnel has been shown to lead to a statistically significant reduction in the incidence of reoperations performed due to capsular contracture within 12 months of primary breast augmentation.⁷

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Breast Augmentation with Round and Anatomic Implants

4

CHAPTER

Bill Kortes and Charalambos “Babis” Rammos

DEFINITION

- Round implants are most commonly used in the United States.
 - They are symmetrical in height and width and have varying projections for a given volume, typically designated as low, moderate, high profile, and extra high.
 - The more the projection increases for a fixed volume, the more the width of the device decreases (**FIG 1A**).
 - Round implants may be smooth or textured and may be filled with either saline or silicone gel.
 - Fourth and fifth generation round silicone devices, currently used in the market, are designed with thinner shells and a more cohesive gel.
- Anatomic (shaped) implants have become an important alternative for breast augmentation.
 - Shaped implants are textured to reduce movement and can have differences in height, projection, and width.
 - They have greater projection in the caudal portion and less projection in the cephalic portion (**FIG 1B**), mimicking the natural shape of the breast.
 - The more cohesive and dense silicone gel (fifth generation) allows the implant to maintain its shape, and resist the natural forces exerted by the soft tissue envelope.
 - Orientation markings on the device position it properly in the breast pocket.

ANATOMY

- The breast extends from the 2nd or 3rd rib down to the 6th or 7th rib (cephalad

to caudad) and from the lateral sternum to the anterior axillary line (medial to lateral).

- The major blood supply to the breast is from the internal mammary artery.
- Lateral and anterior branches of the second through sixth intercostal nerves provide innervation to the skin overlying the breast.

PATHOGENESIS

- Micromastia occurs as a developmental phenomenon either as primary mammary hypoplasia or due to chest wall pathology such as Poland syndrome.
- It may also present as an involutional process, due to weight loss or after pregnancy and lactation.
- Micromastia may lead to a negative body image and have a deleterious effect on quality of life.
- According to the American Society for Aesthetic Plastic Surgery (ASAPS) 2015 statistics, breast augmentation was the second most common aesthetic surgical procedure performed, with approximately 306 000 cases.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- Goals and expectations of the patient are discussed in detail during consultation.
- A thorough personal and family history is performed.
 - History of any breast disease and breast cancer
 - History of pregnancy
 - Desire for future pregnancy
 - Mammogram: Screening mammogram is obtained for any patient over 35 years of age.
- Physical examination
 - Current height and weight
 - Current breast size and desired breast size
 - Palpation for any breast masses, lymph nodes, or nipple discharge
 - Observation of breast ptosis and degree of ptosis, and the need for synchronous mastopexy

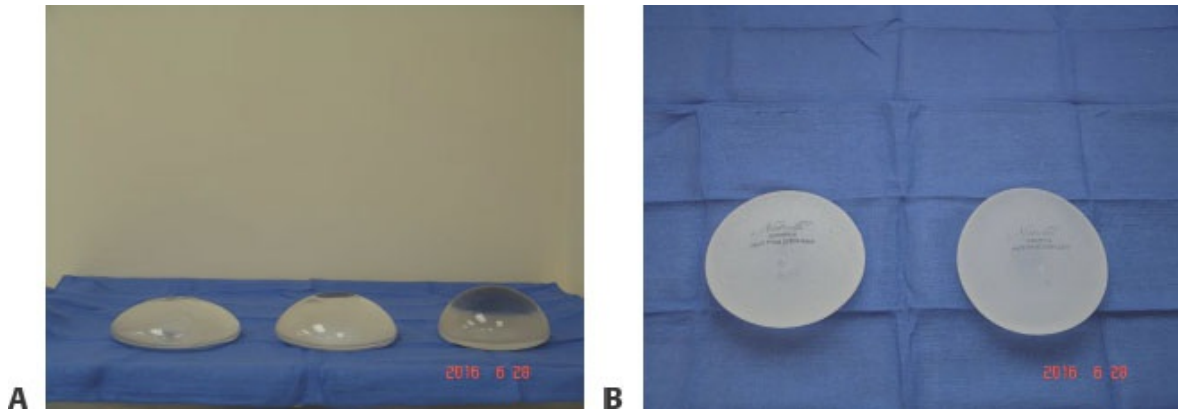


FIG 1 • A. Lateral view of a moderate projection (*left*), full projection (*center*), and extra full projection (*right*) 400 mL smooth round silicone gel implant. As the projection increases, the height and the width of the device decrease. **B.** Moderate height, full projection (*left*) and full height, full projection (*right*) anatomic 420-mL gel implants as seen from above.

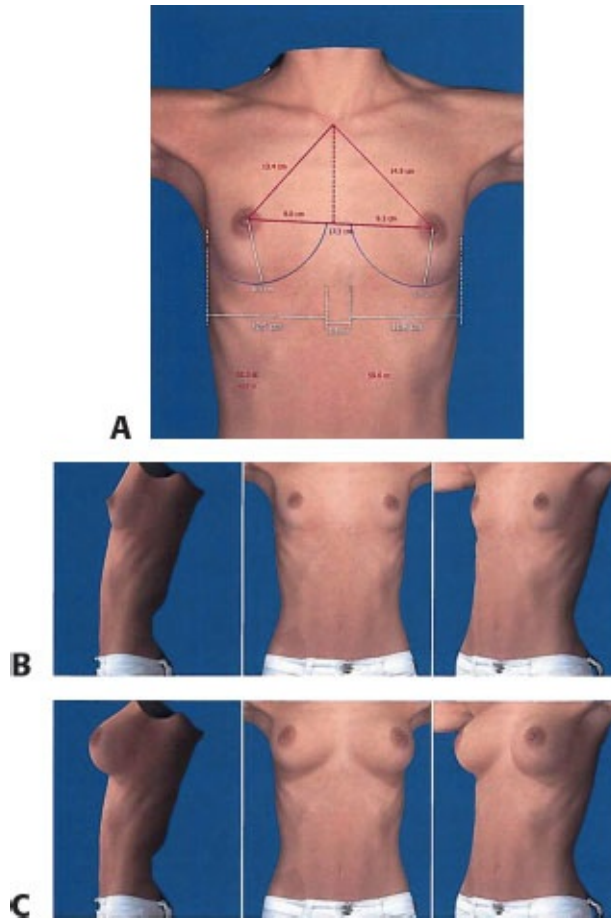


FIG 2 • Three-dimensional photograph of a 24-year-old female using the VECTRA 3D imaging device. **A.** Breast measurements. **B.** Preoperative frontal, lateral, and oblique views. **C.** Simulated images obtained using a 320-mL shaped implant.

- Observation of chest wall and breast asymmetries, such as differences in inframammary fold height, nipple-areolar complex height, breast volume, and breast shape

IMAGING

- The authors use the VECTRA 3D imaging and simulation system for all patients interested in breast augmentation. The device takes a 3D photograph that can then be visualized in the monitor, with the addition of breast measurements (**FIG 2A,B**).
- Using different implant shapes and sizes, a simulated postsurgical result is

produced, allowing the patients to have a visual image of the outcome (**FIG 2C**).

- The use of the VECTRA 3D imaging system provides a high degree of accuracy for breast volume (90%) and contour (98.4%).²

SURGICAL MANAGEMENT

- Main objectives of breast augmentation:
 - Enhancement of breast shape and volume
 - Improve self-esteem and quality of life.³ A prospective analysis using the BREAST-Q showed that breast augmentation is associated with high patient satisfaction and significant improvements in quality of life.⁴
- Main indications for use of a round implant:
 - Desire for a fuller look
 - Good skin quality and overall breast anatomy
 - Concerns about device rotation
- Main indications for use of an anatomic implant:
 - Thin patients with little breast volume. In this patient population, the final shape of the breast will be determined by the device itself.
 - Patients with deficiency at the inferior pole
 - Patients with chest height-width disproportions, such as patients who have a very long, but not very wide chest, or have a very wide, but not very long chest.
 - Patients with breast asymmetries. By using a variety of heights, widths, and projections, these asymmetries may be overcome.
 - Patients who do not want a full round upper pole appearance.
- Main factors to consider when using shaped implants rather than round implants:
 - Incision length needs to be slightly longer because of the filling material traits.
 - Orientation: Precise placement of the implant is critical as disorientation will lead to distortion of the breast shape.
 - Implant height needs to be chosen wisely to avoid overfilling or underfilling of the upper pole of the breast.
 - Lowering the inframammary fold is important.
 - Different methods have been described for the projected postoperative inframammary fold, including those by Caplin.⁵

- The authors prefer to use the nipple to inframammary fold at stretch and the implant width (Table 1).
- For either type of implant, the main steps of the procedure are the same:
 - Make the incision and aim cephalad with attention not to violate Scarpa fascia.
 - Create a dual plane.
 - Identify the pectoralis major muscle edge and incise.
 - Create a subpectoral pocket with care not to elevate the pectoralis minor muscle.
 - Place tester implants (sizers).
 - Exchange tester implants for the formal implants.
 - Close the wound in layers.

Preoperative Planning

- At the time of consultation
 - Breast measurements
 - Breast width at its widest point.
 - Nipple to inframammary fold (N-IMF) distance.
 - Sternal notch to nipple distance.
 - Breast height.
 - Assessment of breast parenchyma and skin
 - Elasticity: This is performed with deflection of the skin, and observation for resistance.
 - Pinch test: This is performed at the superior and medial portion of the breast, between the examiner's thumb and index finger. A result of less than 2 cm is usually an indication for placement of the implant in the subpectoral plane.
 - Choice of implant volume. Sizers are placed in a bra and compared to the images obtained by the 3D imaging.

Table 1 Calculations for Lowering the Inframammary Fold for Anatomic Implants

Breast Implant Width	Nipple to Fold Distance ^a
11.0 cm	7.0 ± 0.5 cm
11.5 cm	7.5 ± 0.5 cm

12.0 cm	8.0 ± 0.5 cm
12.5 cm	8.5 ± 0.5 cm
10.0 cm	9.0 ± 0.5 cm
13.5 cm	9.5 ± 0.5 cm
14.0 cm	10.0 cm^b

^aUnder maximal stretch.

^bNo more than 10 cm.

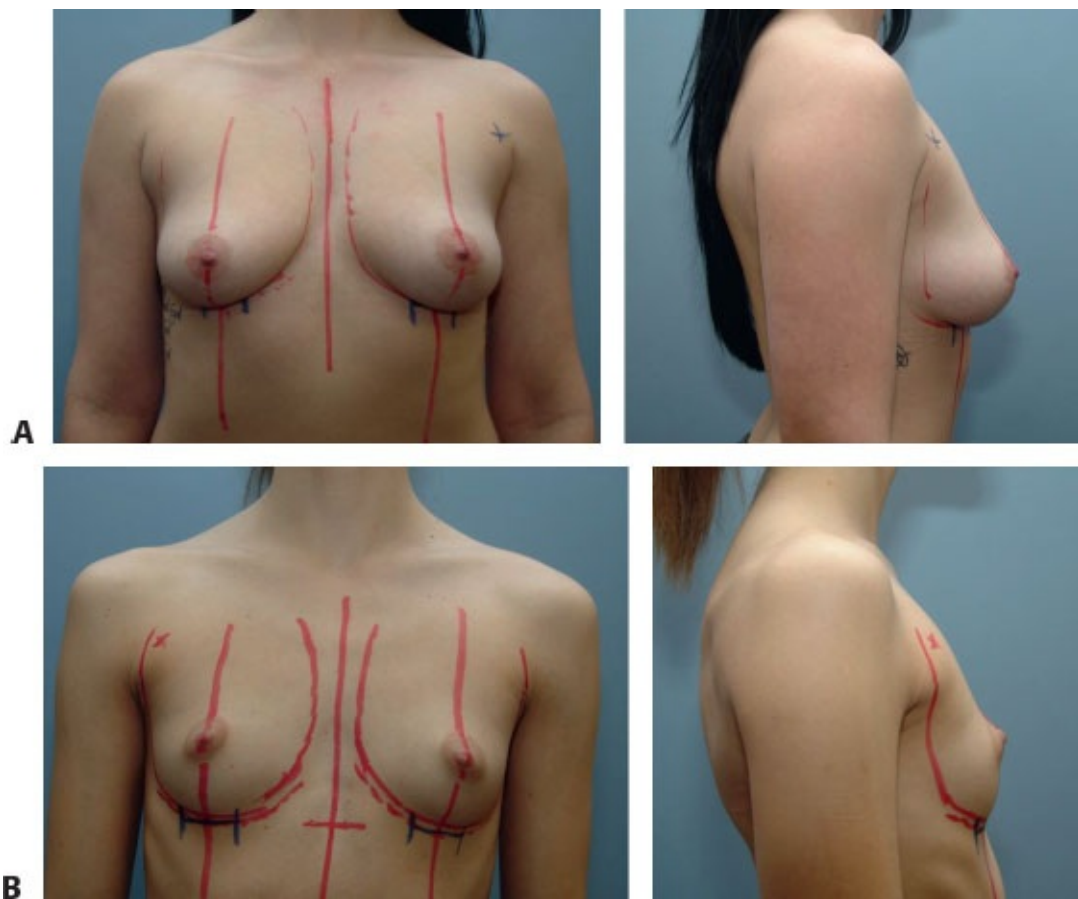


FIG 3 • The markings are made in the preoperative area and reviewed with the patient. **A.** Markings for round implants. **B.** Markings for shaped implants.

■ Preoperatively, the following markings are made with the patient in the upright standing position (**FIG 3**):

- Midline, from sternal notch to xiphoid

- Inframammary fold
 - For anatomic implants, the projected postoperative fold position is based on the aforementioned measurements.
- Superior, medial, and lateral borders of the breast. The medial borders are marked 1.5 cm lateral to the midline, so as to prevent synmastia
- Breast meridian
- Marking of the incision
 - For round implants using an inframammary approach, the marking is placed below the inframammary fold, centered at the breast meridian, most often 4 cm in length, 2 cm medial, and 2 cm lateral to the meridian.
 - For shaped implants using an inframammary approach, the marking is placed at the expected postoperative inframammary fold, centered at the breast meridian, most often 5 cm in length, 2.5 cm medial, and 2.5 cm lateral to the meridian.

Positioning

- The patient is brought to the operating room and placed in the supine position on the operating table with the arms extended up to 90 degrees and well secured to the arm boards.
- The shoulders should be at the same height.

Approach

- Incision placement
 - Inframammary
 - Placement of the incision at the inframammary fold for round implants and at the expected postoperative inframammary fold for anatomic implants.
 - Wide exposure, better visualization
 - Easier manipulation of the inframammary fold position
 - Easier placement of the implant
 - Periareolar
 - Incision is made at the inferior border of the areola
 - Scar generally heals well
 - Wide exposure
 - Approach involves either dissecting straight down through the breast or creating a lower breast flap to the level of the inframammary fold.
 - Transaxillary

- Incision is placed at the axilla, lateral to the edge of the pectoralis major muscle
- Hidden scar, not close to the breast
- More challenging pocket dissection
- Natural-appearing results have been reported with this approach and the use of shaped implants.⁶
- Pocket
 - Partial subpectoral
 - Submuscular pocket is created with release of the lateral border of the pectoralis major attachments and its inferomedial attachments.
 - Lower part of the implant is covered by the underside of the breast, and superior part of the implant is covered by the pectoralis major muscle.
 - Subglandular
 - Pocket is created between the underside of the breast and the anterior fascia of the pectoralis muscle.
 - Less technically challenging
 - Subfascial
 - Pocket is created between the anterior fascia of the pectoralis major muscle and the muscle itself.
 - Additional coverage of the implant provided by the fascial layer.
- With either type of implant, the authors most often use the inframammary approach, with placement of the implant in a partial subpectoral plane, and creation of a dual plane.
- Alternatively, implants can be placed in the subfascial plane.

TECHNIQUES

■ Inframammary Approach With Partial Subpectoral Placement and Dual Plane Creation

Incision and Dissection

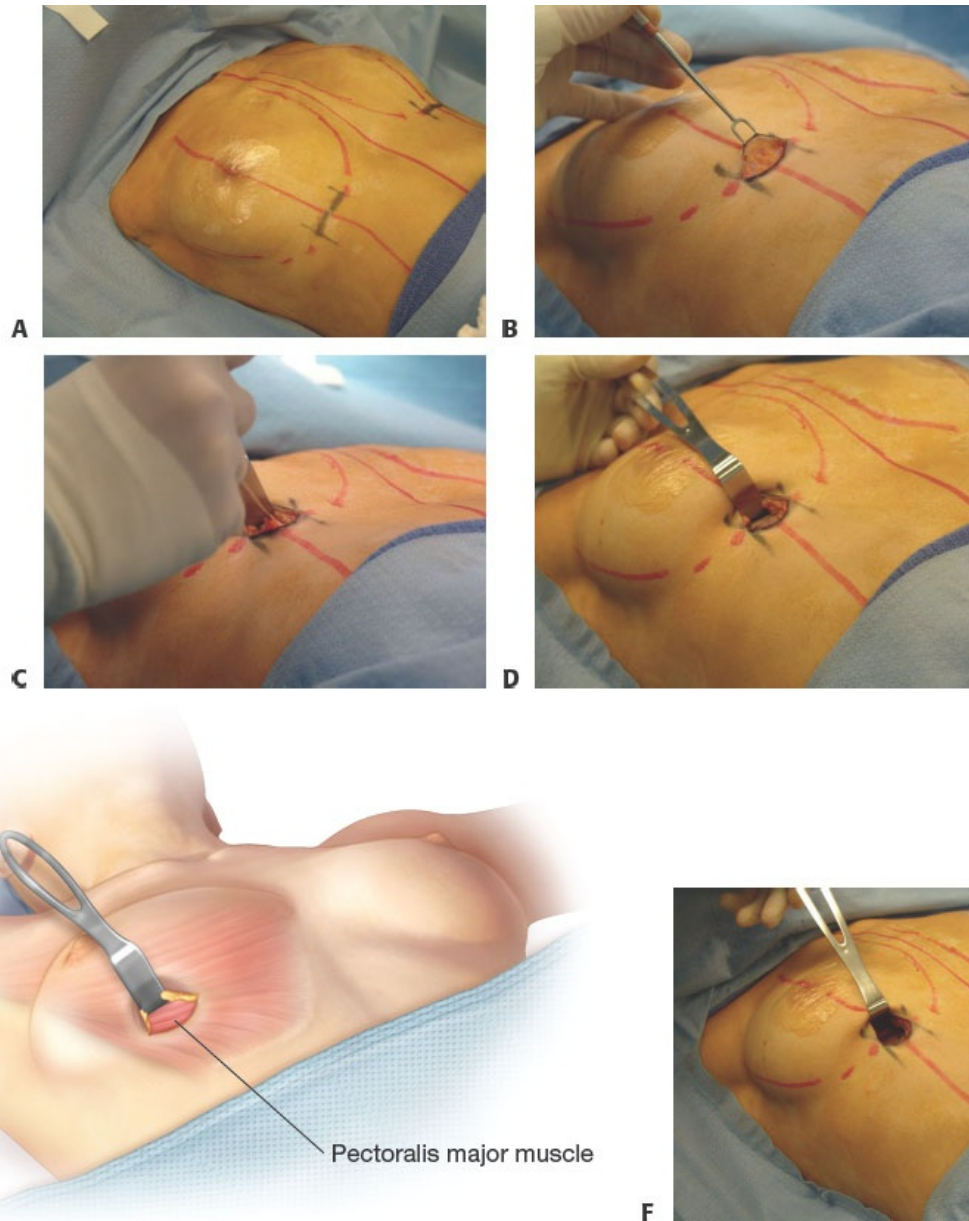
- Tegaderm is placed on top of the nipple-areolar complex (**TECH FIG 1A**).
- Local anesthesia containing a mix of lidocaine and Marcaine with

epinephrine is injected into the marked incision and as a breast block.

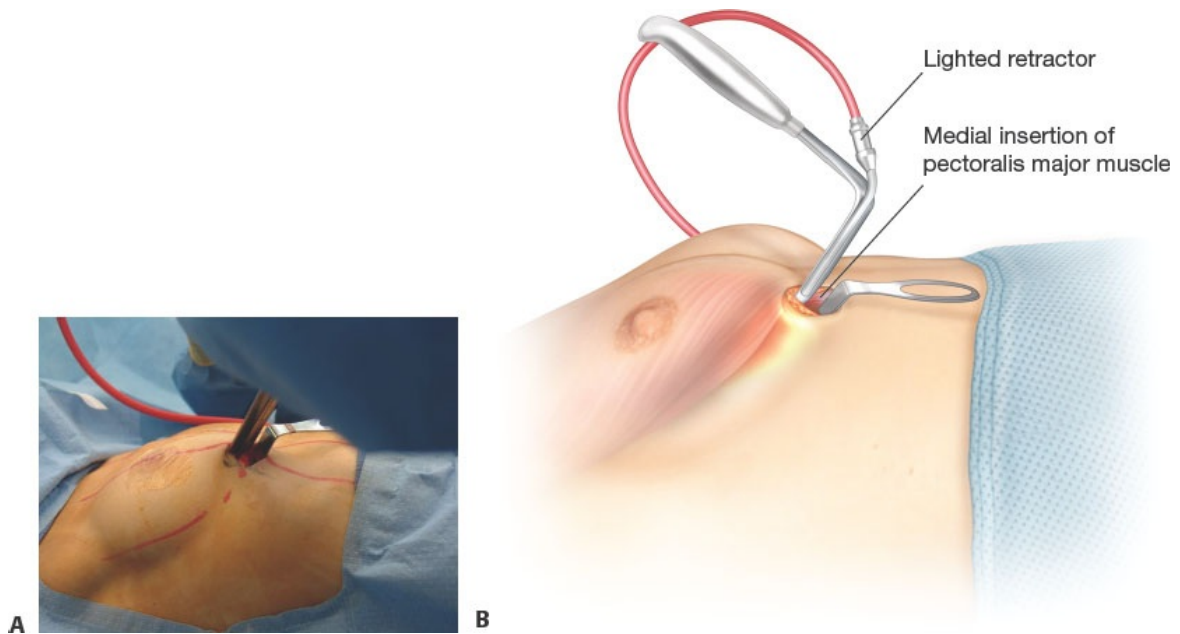
- The inframammary incision is made sharply through the dermis and the superficial layer of the fat until Scarpa fascia is encountered (**TECH FIG 1B**).
- A double skin hook is placed followed by an Army Navy retractor, and dissection is continued with bovie electrocautery cephalad with care taken not to violate Scarpa fascia (**TECH FIG 1C**).
- The breast tissue is divided, and the pectoralis muscle fascia is identified (**TECH FIG 1D,E**).
- Suprafascial dissection is carried accordingly to create a dual plane dissection (**TECH FIG 1F**).
- After dual plane dissection, the pectoralis muscle is grasped and divided till the areolar space under the muscle is identified.
 - A lighted retractor is then placed below the pectoralis major muscle, and strong upward traction is placed so as to separate the pectoralis major from the pectoralis minor muscle.

Pocket Creation

- Pocket dissection is performed with the monopolar electrocautery and without use of blunt dissection.
- Submuscular dissection proceeds from medial to lateral in a clockwise fashion for the left breast and in an anticlockwise fashion for the right breast, until the pocket is of appropriate size.
 - Care is taken to avoid any contact with the ribs so as to minimize postoperative pain.



TECH FIG 1 • A. Tegaderm is applied over the nipple-areolar complex. **B.** Inframammary incision made to the level of Scarpa fascia. **C.** Dissection continues in a cephalad direction. **D,E.** After breast tissue division, the pectoralis major muscle is encountered. **F.** Dual plane dissection is performed before proceeding with pocket creation.



TECH FIG 2 • A,B. The medial origin of the pectoralis major muscle is identified and will be incised to achieve lower pole expansion.

- The medial origin of the pectoralis major muscle is disinserted so as to achieve adequate expansion of the lower pole (**TECH FIG 2**).
- Meticulous hemostasis is achieved.

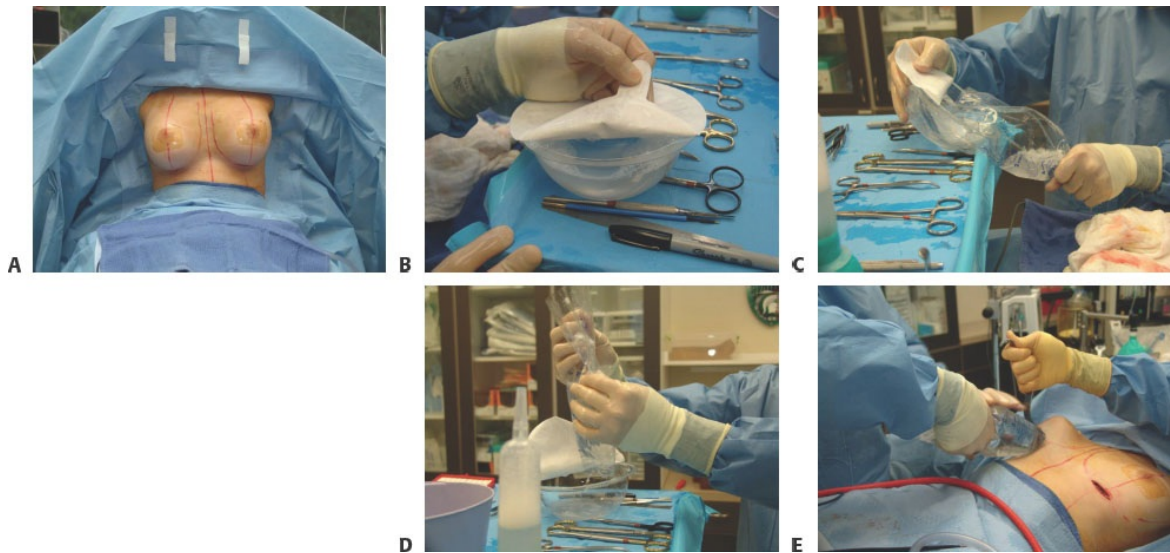
Implant Placement

- Tester implants are placed and the patient is placed in the upright seated position (**TECH FIG 3A**).
 - If there are areas for additional dissection, these are marked.
- The pockets are irrigated with triple antibiotic solution.
- The formal implants are then placed in a sterile manner using the no-touch technique.
 - The packaging is opened, and the implant is transferred to the Keller funnel, avoiding any contact with the operating table or the surgeon's gloves (**TECH FIG 3B–D**).
 - A Deaver retractor is used by the assistant to facilitate placement of the implant (**TECH FIG 3E**).

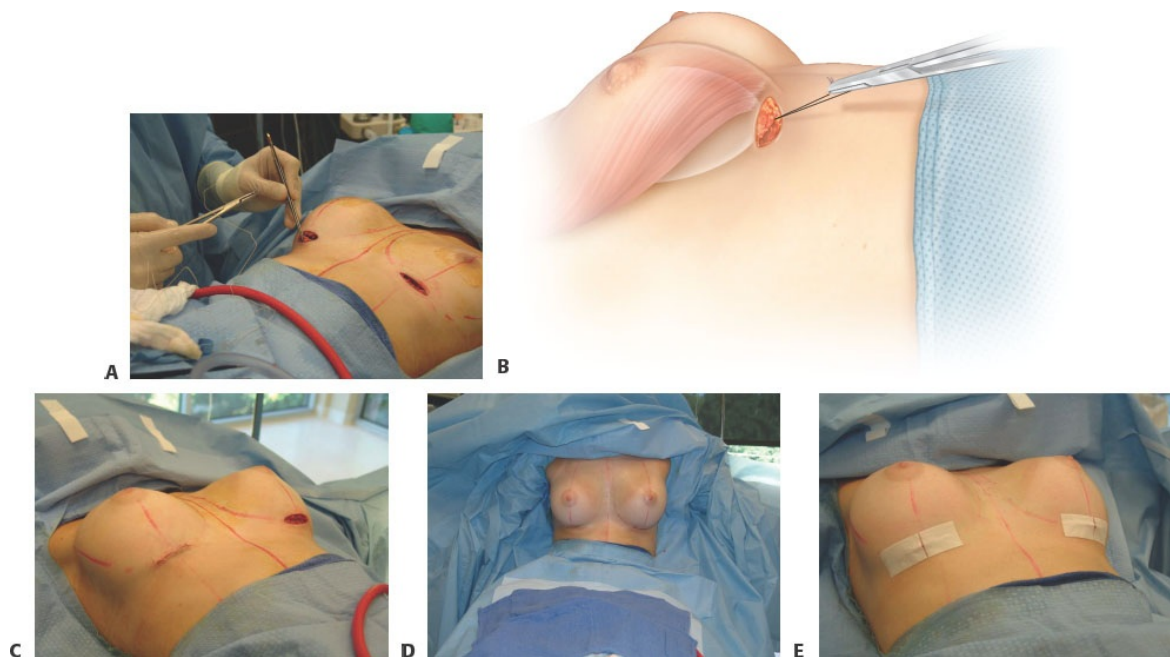
Completion

- Closure is performed in three layers:

- 2-0 Vicryl is used for the breast parenchyma (**TECH FIG 4A,B**)
- 4-0 Monocryl for interrupted deep dermal sutures, followed by a running subcuticular 4-0 Monocryl suture (**TECH FIG 4C**)
- The patient is placed again in an upright seated position for final assessment (**TECH FIG 4D**).
- Paper tape is placed over the incisions (**TECH FIG 4E**).



TECH FIG 3 • A. Patient in the upright seated position with tester gel implants placed. **B–E.** The no-touch technique incorporating the Keller funnel is used for placement of the implants.



TECH FIG 4 • **A.** Deeper layer that will be closed is grasped with forceps. **B.** Closure of the deeper breast tissue is performed before skin closure. **C.** Skin closure is performed. **D.** Patient at the seated upright position with the formal implants in place. **E.** Paper tape placed over the incisions.

■ Inframammary Approach with Subfascial Placement

- The technique is similar to the partial subpectoral technique in terms of marking, incision placement, implant insertion, and closure.
- The difference pertains to the pocket dissection.
 - The pocket is created between the anterior fascia of the pectoralis major muscle and the muscle itself, providing an additional layer of coverage for the implant.
 - The pocket is dissected laterally to the lateral edge of the pectoralis major muscle.

Hemostasis	■ Meticulous hemostasis should be achieved to avoid postoperative hematoma and an inflammatory response that may lead to capsular contracture.
Pectoralis muscle	■ The most inferior medial fibers of the pectoralis major muscle should be released to avoid a constricted lower pole.
Dual plane	■ Advantage of increasing implant and breast parenchyma interface, expanding the lower pole, and allowing for changes of the nipple-areolar complex.
Implant orientation	■ Proper orientation of shaped implants is verified to avoid distortion of the shape of the breast.
Implant placement	■ The no-touch technique is used at all times, to avoid implant contamination, and excessive force is avoided to prevent damage of the device.
Incision placement	■ For round implants, the inframammary incision should be placed slightly lower in regard to the inframammary fold, to avoid a high rising scar onto the breast.
Projected inframammary fold	■ Lowering of the inframammary fold for anatomic-shaped implants is performed as needed based on preoperative measurements.
Dissection	■ Dissection should be accurate to accommodate the implant, and overdissection should be avoided at all times.
Ribs	■ Contact with the ribs should be avoided, so as to decrease postoperative pain.

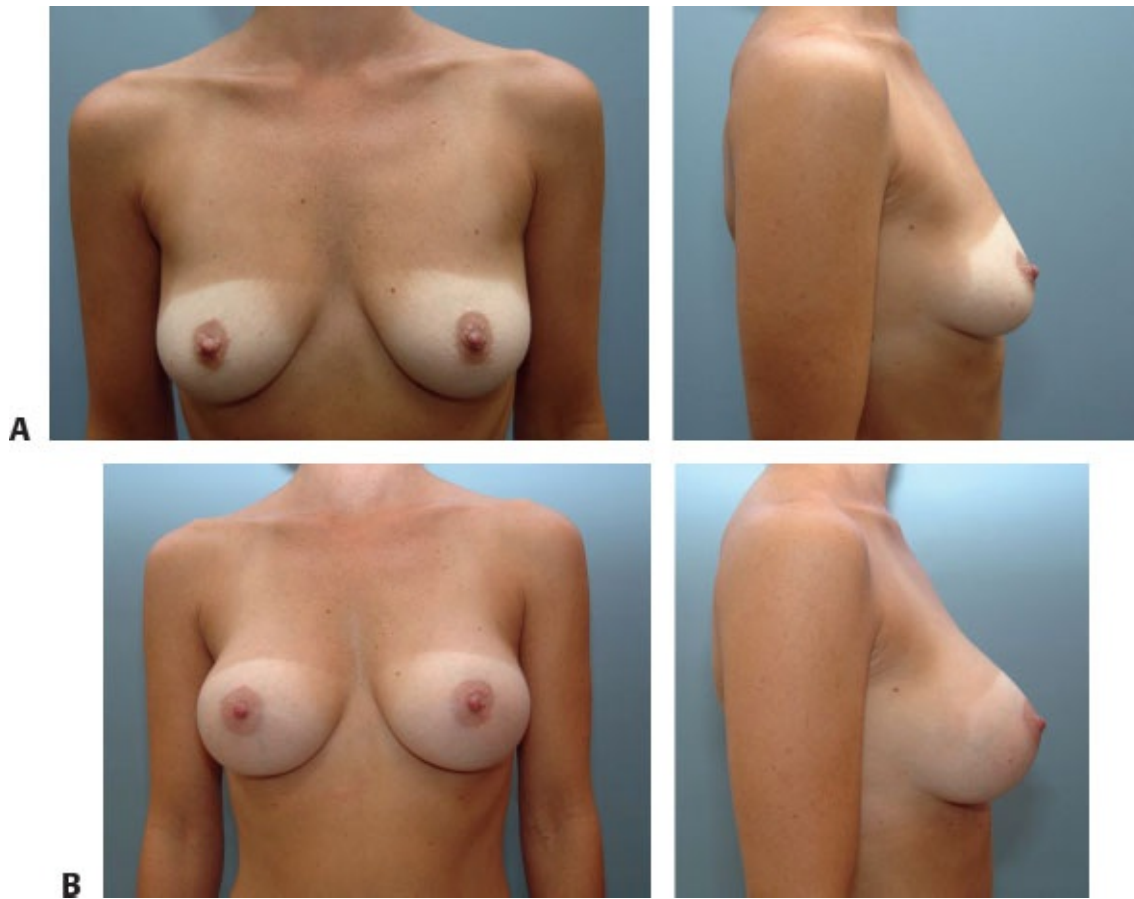


FIG 4 • A. Preoperative frontal and lateral views of a 38-year-old woman with micromastia (above). **B.** Images obtained at 3-month follow-up after subfascial breast augmentation with a 300-mL smooth round implant with moderate projection.

POSTOPERATIVE CARE

- Patients are discharged at the same day of surgery after they recover in the postoperative anesthesia care unit.
- Postoperative medications include oral analgesics and a 7-day course of oral antibiotics.
- A soft bra is used.
- Patients are instructed to avoid heavy lifting, no more than 10 lb, for 10 days.
 - Light exercise is permitted starting postoperative day 1. Additional exercises, such as arm abduction and arm elevation, are encouraged to achieve stretching of the pectoralis major muscle and to accelerate recovery by

decreasing pain.

- Patients may shower in postoperative day 1.
- Manual massage
 - For round implants, manual massage of the implant starts as soon as tolerated by the patient with the aim to prevent capsular contracture.
 - For anatomic implants, no manual massage is performed.
- Follow-up appointment is scheduled for day 1, 1 week, 3 weeks, 3 months, 6 months, and 1 year.

OUTCOMES

- Clinical examples of patients with breast augmentation with round and anatomic implants are shown in **FIGS 4** and **5**, respectively.

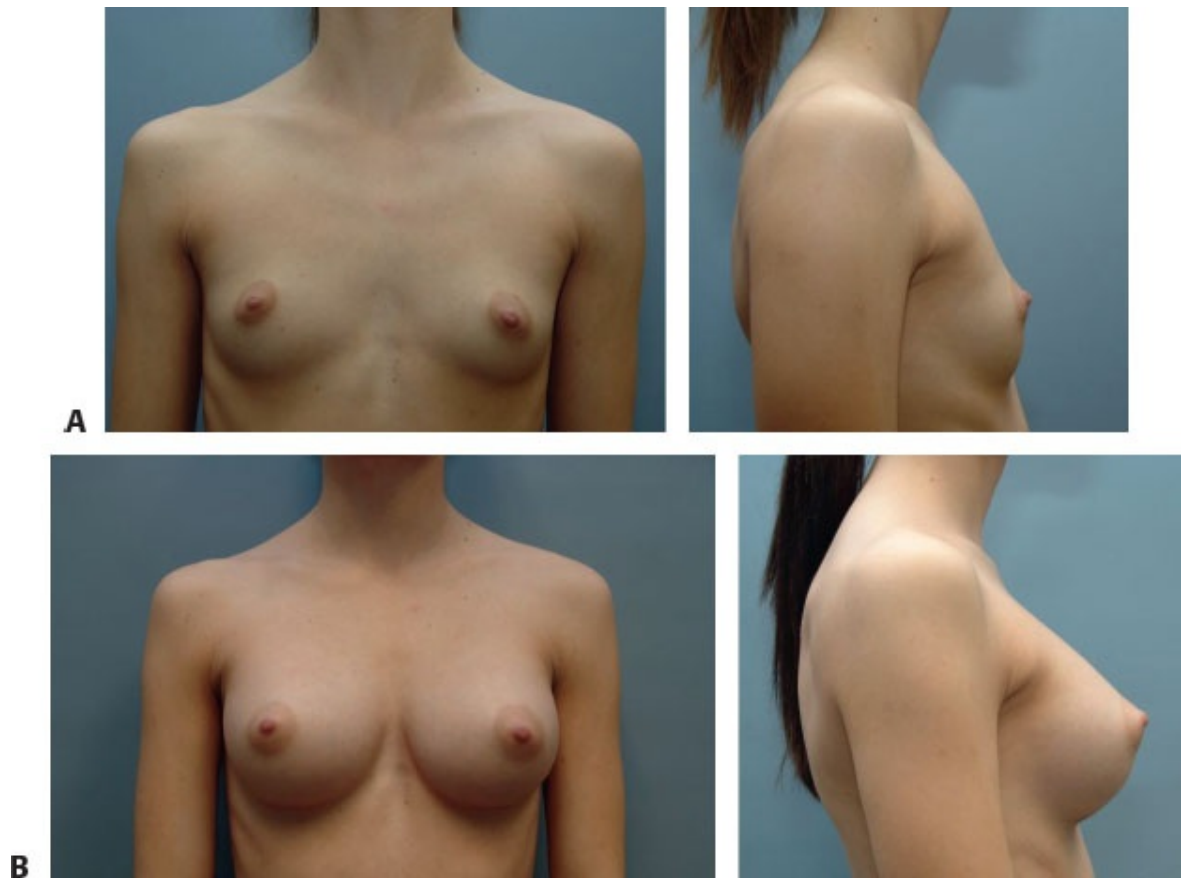


FIG 5 • A. Preoperative frontal and lateral views of a 24-year-old woman with micromastia. **B.** Images obtained at 3-month follow-up after submuscular breast augmentation with a 255-mL moderate height, full

projection–shaped implant.

COMPLICATIONS

- Hematoma formation is rare and ranges from 0.5% to 1%.
- Infection is rare and occurs in less than 1% of the patients.
- Double-bubble deformity may occur due to violation of Scarpa fascia at the level of the inframammary fold, with subsequent caudal migration of the implant in relationship to the breast mound.
 - Rotation rate with the use of anatomic implants has been reported to be less than 2.5% at 6 years.⁷
- The cause of capsular contracture is inflammation, which in turn may be due to tissue trauma, bacteria, and blood.
 - The use of the Keller funnel has been shown to lead to a statistically significant reduction in the incidence of reoperations performed due to capsular contracture within 12 months of primary breast augmentation.⁸
 - Shaped, highly cohesive implants have lower rates of capsular contracture.⁹
- Anatomic implants have low rates of rupture.¹⁰

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5 Female to Male Transgender Breast Surgery

CHAPTER

Ann R. Schwentker

DEFINITION

- Transgender person: individuals who identify with a gender that is distinct from their assigned sex at birth.
- Gender dysphoria: emotional stress caused by differences between a person's assigned sex and his/her gender identity.
- Transition: a period of formal transformation of one's gender identity that may include changing name, clothing, preferred pronouns, gender-affirming hormones, and/or surgery.
- Female to male, trans man: a person assigned female gender at birth who identifies as male.
- Male to female, trans woman: a person assigned male gender at birth who identifies as female.

ANATOMY

- The anatomy may vary widely, depending on the patient's body habitus.
- All patients have excess glandular breast tissue. Other factors that influence surgical planning include the following:
 - Whether or not there is areolar enlargement
 - Nipple position
 - The amount of skin excess

PATIENT HISTORY AND PHYSICAL FINDINGS

- The World Professional Association for Transgender Health (www.wpath.org) has published a Standards of Care manual that should be consulted in determining an individual's suitability for surgery. In particular, it is desirable

that patients be supported by a mental health professional to manage their dysphoria.

- Thorough breast exam including any masses, asymmetry, nipple/areolar size and position, ptosis, and skin excess.
- The importance of nipple sensation to the patient should be assessed. All available techniques may reduce or eliminate nipple sensation and erectile function¹ and make breast-feeding impossible, which may dissuade some patients.

IMAGING

- Any masses should be imaged and worked up as for a female with a breast mass.
- Patients who above age 45 should have a preoperative mammogram. It is not possible to remove 100% of breast tissue with this procedure, and patients should discuss with their medical doctors whether postoperative mammograms are necessary.

NONOPERATIVE MANAGEMENT

- Many patients begin transitioning by wearing binders. These can cause chafing and intertrigo, which should be treated prior to surgery.
- Patients may experience significant breast gland involution after starting testosterone therapy. Although this is not sufficient to avoid surgery, it may alter the surgical plan in small-breasted patients.

SURGICAL MANAGEMENT

- Insurance coverage for transgender surgery is variable. Comorbidities that may increase the chance of insurance coverage for surgery include the following:
 - Breast cancer, breast mass, or BRCA positivity
 - Fibrocystic disease with documented intractable pain
 - Intertrigo
 - Symptoms of macromastia

Preoperative Planning

- Patients with small areolae and very small (A cup) breasts may be candidates for periareolar mastectomy.
- If there is significant skin excess, a breast amputation will almost always be preferable.

Positioning

- The patient is positioned supine with the arms at 90 degrees and securely wrapped to arm boards (**FIG 1**). The table is placed so that the patient can be moved to a seated position during surgery.



FIG 1 • Intraoperative positioning.

TECHNIQUES

■ Periareolar Mastectomy

- This results in fewer scars but makes it more difficult to control nipple size and position.
- If the areola is small, a semicircular infra-areolar incision is made. This may also be made within the areola to further camouflage the scar.²
- If the areola is enlarged or there is slight skin excess, a periareolar donut is designed and de-epithelialized, with a full-thickness semicircular incision inferiorly.
- 3 to 4 mm of breast tissue is preserved on the deep surface of the areola for blood supply. This dissection is performed sharply.
- The remainder of the breast gland is separated from the subcutaneous tissue using primarily blunt dissection at the level of the breast capsule. The gland may also be detached from the pectoralis fascia on its deep surface using blunt dissection.
- Hemostasis is obtained, and a closed suction drain is placed.

- The incision is closed by gathering the skin around the areola to position the nipple inferiorly and laterally, using absorbable sutures.

■ Breast Amputation With Free Nipple Grafts



Video p4-c005

- The large inframammary scar may be positioned at the inferior border of the pectoralis, and the free nipple grafts allow control of nipple size and position.
- The nipple is removed as a 28 × 22 mm (or desired shape/size) oval full-thickness skin graft, thinned, and placed on moist gauze.
- The inferior incision is marked just below the inframammary fold to be sure that the retaining ligaments are removed because the fold is a distinctly female structure. It is horizontal medially and can curve superiorly in its lateral portion to follow the curve of the pectoralis major muscle.
- The superior incision is marked by pulling the breast down over the inframammary fold and transposing the fold anteriorly, taking care to remove all areolar tissue.
- The incision should not be extended too far medially or laterally, as extra dog ears can be addressed with tailoring or an in-office local procedure at a later date. Ideally, the incision is the width of the pectoralis muscle.
- The breast gland is removed as in a mastectomy, dissecting at the level of the breast capsule, preserving all subcutaneous fat and the pectoralis fascia. Dissection proceeds up to the clavicle.
- The inferior skin flap is undermined if necessary and advanced to align with

the inferior border of the pectoralis major muscle. This both hides the scar and decreases tension on the final closure.

- The incisions are closed over drains, advancing the dog ears toward the middle of the breasts to shorten the scars.
- The nipple position is marked using paper patterns with the patient in the seated position.
- The nipple location is de-epithelialized, and the nipples sutured into position with long Vicryl sutures and fast-absorbing gut.
- The nipples are dressed with tie-over xeroform bolsters.

PEARLS AND PITFALLS

Nipple position

- Male nipples vary widely in size and position but are typically oval (wider transversely), lower, and more lateral than female.³
- It can be helpful to have patients bring a photo of their ideal nipple size/shape/position for planning purposes.

Hematoma/seroma

- Closed suction drains are used until drainage decreases.
- Compression (ACE or binder) is used for 6 weeks.
- Lifting is limited for 6 weeks.

IMF incision placement

- It is critical to remove the skin and ligaments of the IMF to avoid the depression that will result if this is simply released from the fascia and advanced.
- The inferior incision can then be advanced as in a reverse abdominoplasty to allow the incision to align precisely with the inferior border of the pectoralis muscle, which camouflages the scar.

Biopsy

- The removed tissue is biologically female breast tissue and as such should always be sent for pathologic examination.

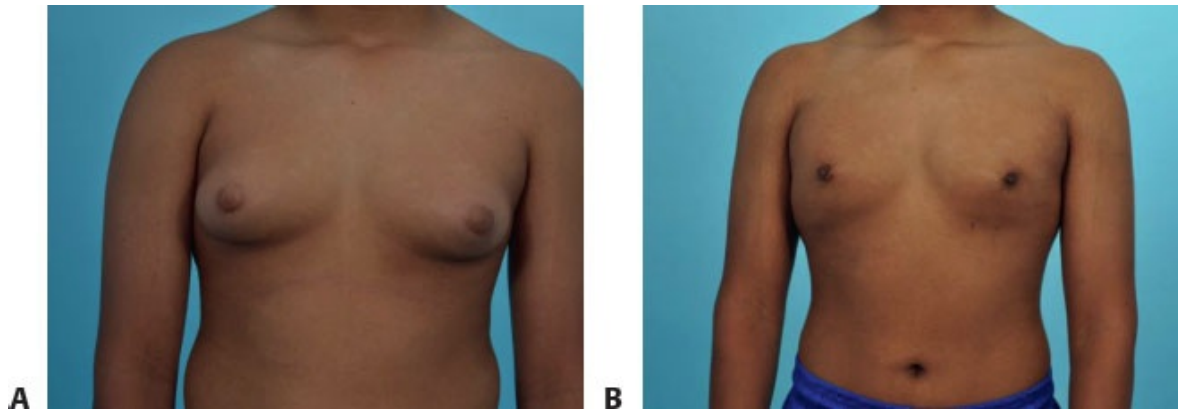


FIG 2 • A. Preoperative photograph. Note small areolae and breasts with limited skin excess. **B.** Postoperative photograph of same patient 1 year after periareolar mastectomy. No areolar reduction was performed. Note the mild hypertrophic scar on the right, which later underwent revision.

POSTOPERATIVE CARE

- Drains remain until drainage decreases below 30 cc in two consecutive 24-hour periods.
- Nipple bolsters are left for 10 to 14 days. The nipples are then treated with Bacitracin and large Band-Aids for another week or until scabbing resolves. Scar massage begins at 4 weeks.
- A circumferential ACE bandage is used for 1 week, and then, patients may transition to binder or spandex undershirt.
- Lifting and upper body exercise are strictly limited for the first 6 weeks. Thereafter, bulking up the pectoralis muscles is strongly encouraged, as it assists with camouflaging the scars.

OUTCOMES

- Satisfaction in this patient population is generally high^{1,4} (**FIGS 2 to 4**).
- Minor revisions (scar revision, nipple revision, dog ears) are commonly required.^{3,4}

COMPLICATIONS

- Hematoma requires urgent return to the operating room and evacuation.³
- Seroma may often be treated with aspiration and compression. The skin flaps

are anesthetic for several weeks, and this is well tolerated.

- Nipple loss is extremely rare and generally results from premature loss of bolsters. Either tattooing or nipple reconstruction may be performed.
- Hypertrophic scarring is managed with scar massage, Kenalog injection, and/or revision as indicated.

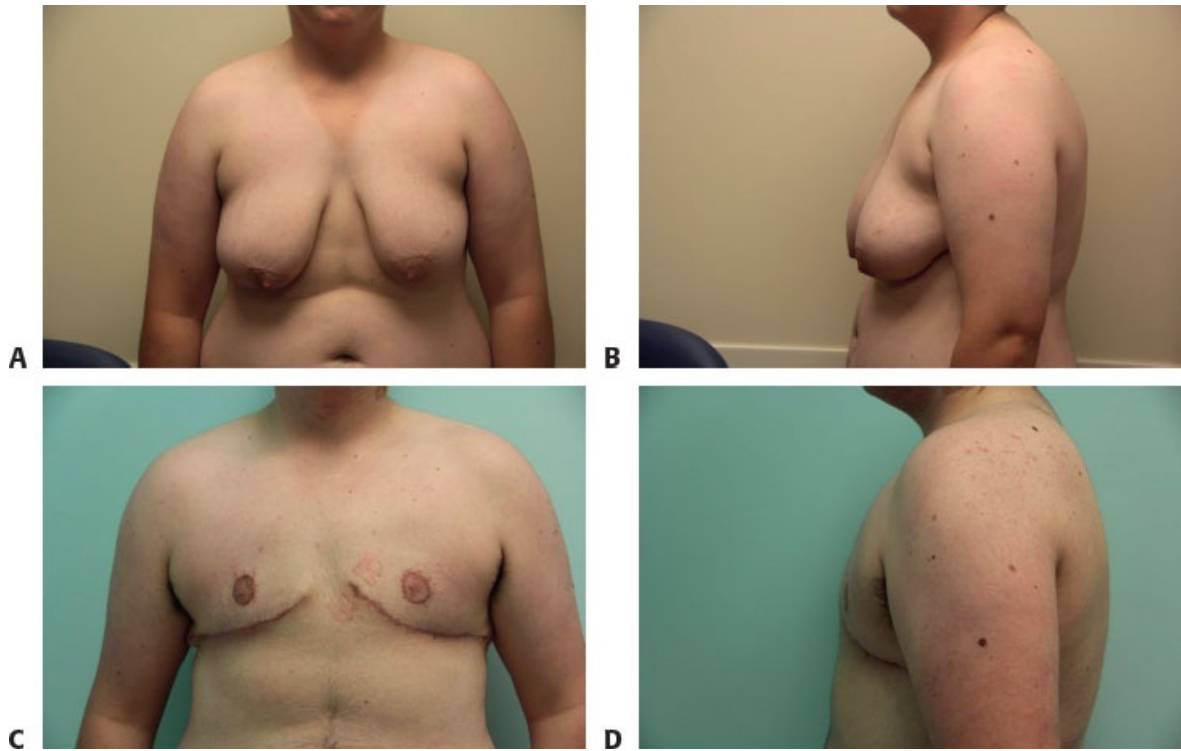


FIG 3 • **A,B.** Preoperative photograph. Note large, heavy, pendulous breasts with enlarged areolae. **C,D.** Postoperative photograph of same patient 4 months after breast amputation with free nipple grafts.

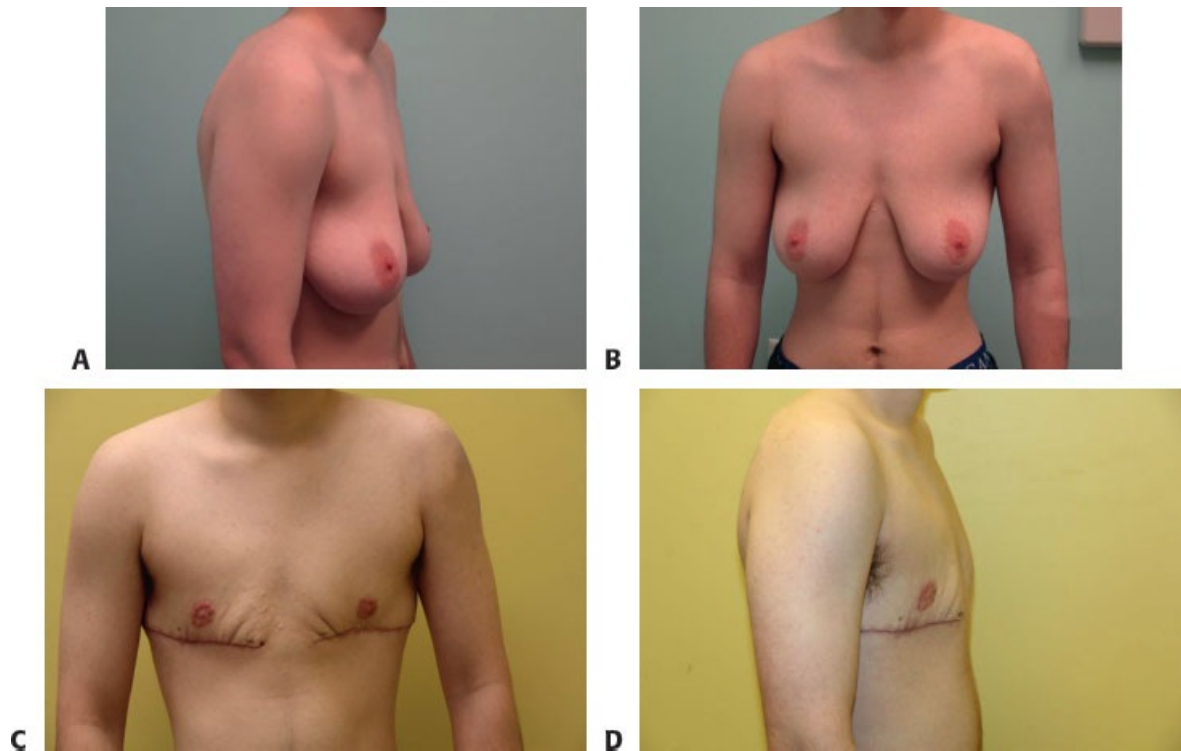


FIG 4 • A,B. Preoperative photograph. Note pendulous breasts with significant skin excess. **C,D.** Postoperative photograph of same patient 1 month after breast amputation with free nipple grafts. Note that wrinkling of the medial dog ears has not yet resolved in this early photograph.

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Section II: Mastopexy

6 Mastopexy: Periareolar, Vertical, and Wise Pattern

CHAPTER

R. Ter Louw and Scott Spear[†]

DEFINITIONS

- Ptosis of the breast is described by the Regnault classification (**FIG 1**).
 - Grade 1: minor ptosis; the nipple is at the level of the inframammary fold, above the lower contour of the gland.
 - Grade 2: moderate ptosis; the nipple is below the level of the inframammary fold, above the lower contour of the gland.
 - Grade 3: major ptosis; the nipple is below the level of the inframammary fold, at the lower contour of the gland.
- Mastopexy—*masto* meaning breast, *pexy* meaning to lift or fixate.
- Periareolar mastopexy results in a scar camouflaged in the junction of the pigmented areolar and unpigmented breast skin.
 - Concentric mastopexy, eccentric, “donut” mastopexy
- Vertical or circumvertical mastopexy results in a scar camouflaged in the junction of the pigmented areolar and unpigmented breast skin with a vertical extension along the breast meridian down toward the inframammary fold.
 - There may be a transverse scar as well if there is too much skin to be tailored in the circumareolar and vertical components.
- Wise pattern mastopexy is planned from the outset to result in a scar around the areola, a vertical extension along the breast meridian down to the inframammary fold, with a horizontal scar hidden in the inframammary fold.

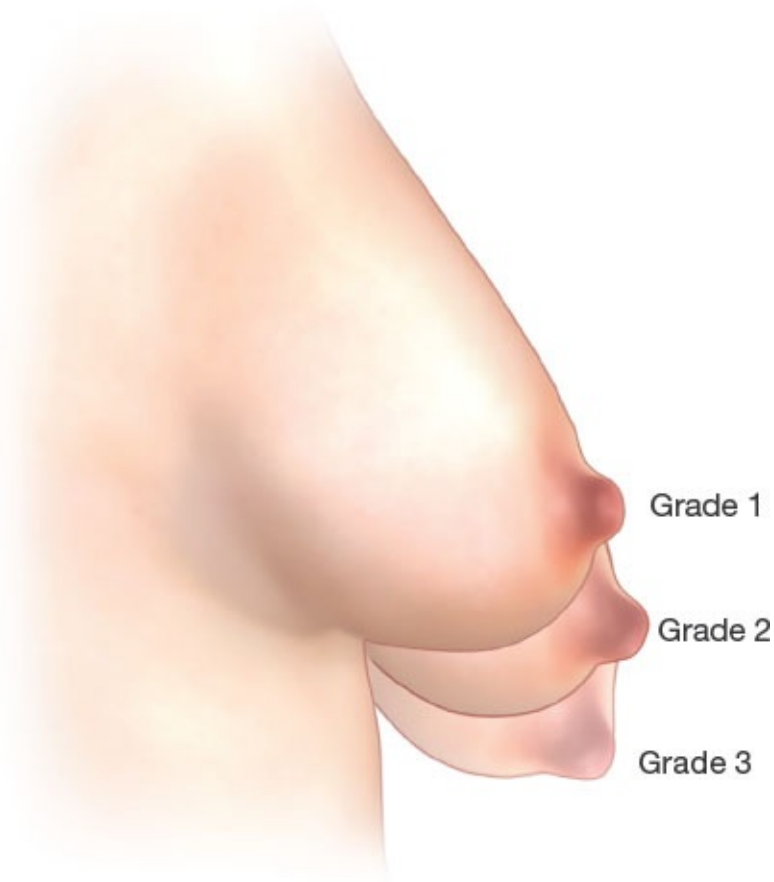


FIG 1 • Regnault classification of breast ptosis. Grade 1: nipple-areolar complex at the level of the inframammary fold. Grade 2: nipple-areolar complex below the level of the inframammary fold. Grade 3: nipple-areolar complex at the lowest portion of the breast.

ANATOMY

- The arterial supply of the breast is predominantly based off internal mammary perforators and the lateral thoracic artery.
- Sensation to the nipple is derived from the 4th posterior intercostal nerve.
- Cooper ligaments suspend the breast, originating on the pectoralis fascia and inserting into the dermis of the breast.
- The borders of the breast:
 - Superior—clavicle
 - Inferior—inframammary fold
 - Lateral—latissimus muscle

- Medial—sternum

PATHOGENESIS

- Decreased elasticity of breast tissue with aging
- Hormone-induced inflation and deflation of breast tissue
- Stretch of Cooper ligaments
- Deflation of breast envelope following breast feeding

PATIENT HISTORY AND PHYSICAL FINDINGS

- History
 - Current cup size, height, and weight
 - Childbearing, breast-feeding, and future family planning
 - Personal and familial cancer history
 - Prior breast surgery, biopsies, radiation
 - Date of last mammogram
- Examination¹
 - Regnault classification of ptosis
 - Soft tissue evaluation: skin laxity, density of glandular tissue
 - Soft tissue masses, axillary lymphadenopathy, nipple discharge
 - Critical measurements
 - Nipple to sternal notch
 - Nipple to inframammary fold
 - Breast width
 - Nipple to midline
 - Areolar diameter
 - Patient weight, height, and bra size
 - Symmetry of nipple position and breast size should be noted and mentioned to the patient in the initial consultation. If present before surgery, asymmetry will persist postoperatively to some degree.
 - Chest wall deformities as well as the presence or absence of pectoralis major and latissimus muscles should be noted.

IMAGING

- A yearly screening mammogram is recommended beginning at age 40, or 10 years earlier than a primary relative's diagnosis of breast cancer.

DIFFERENTIAL DIAGNOSIS

- Tuberous breast deformity
- Pseudoptosis

SURGICAL MANAGEMENT

Preoperative Planning²⁻⁴

- Preoperative planning in the mastopexy patient is critical for obtaining an aesthetic result.
 - Mastopexies have been the source of a disproportionate amount of litigation, so the surgeon should not take these operations lightly. Understanding the indications and limitations for each type of mastopexy will aid in avoiding trouble.
- Periareolar mastopexy is most useful in patients who need limited movement of the nipple-areolar complex.
 - It allows for movement of the nipple-areola complex approximately 2 cm. Attempting to move the nipple more than 2 cm will result in flattening of the breast mound.
 - Periareolar mastopexy is ideal for grade 0 or 1 ptosis, glandular ptosis, or in the setting of combined augmentation mastopexy (**FIG 2A,B**).
- Vertical mastopexy is a versatile operation that allows the surgeon to resite the nipple, regardless of the degree of ptosis, while reshaping the breast mound and tailoring the skin envelope (**FIG 2C-F**).

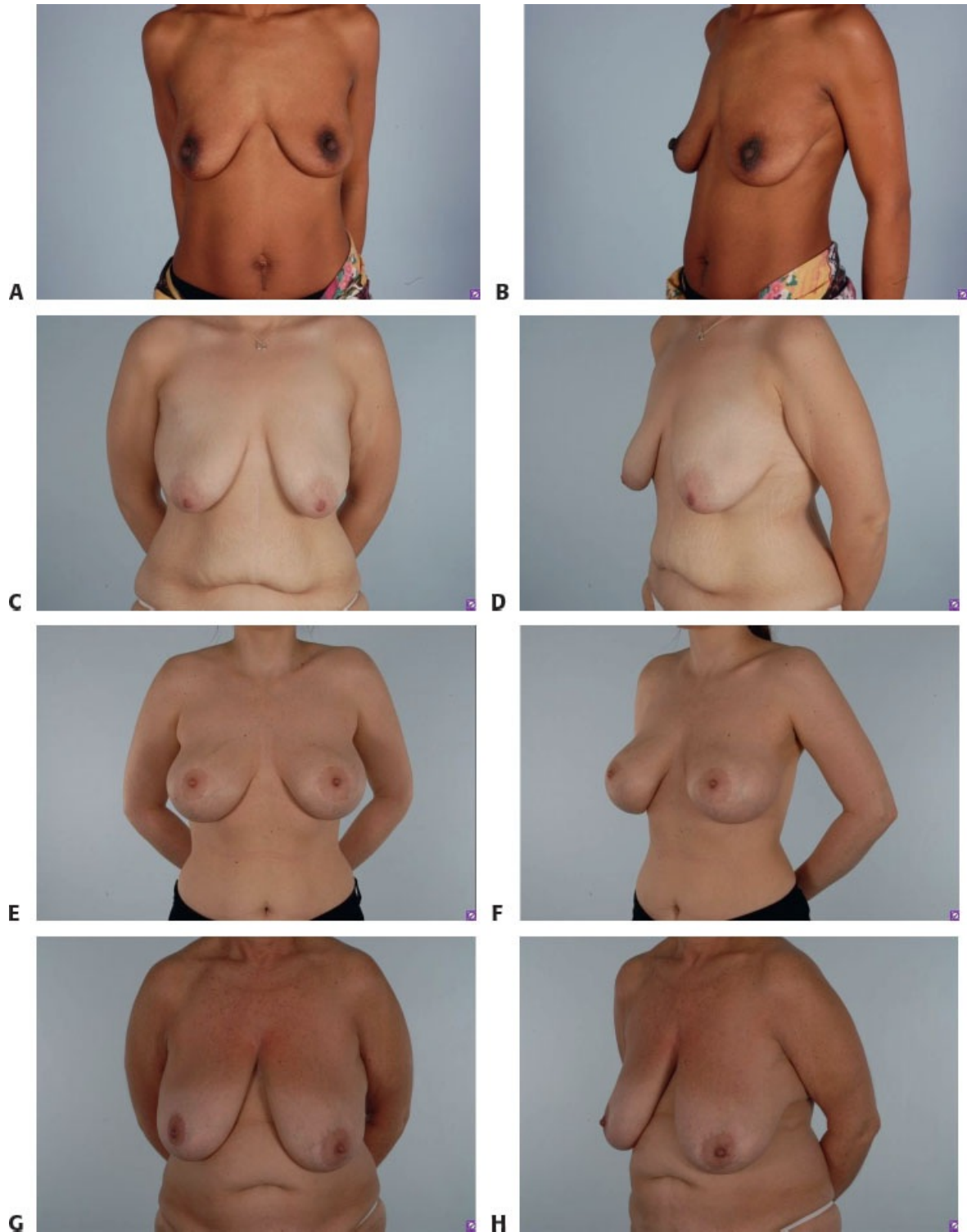


FIG 2 • A,B. Preoperative photographs of an ideal patient for periareolar mastopexy with grade 1 ptosis and deflated breast parenchyma. **C,D.** Preoperative

photographs of a patient with grade 2 breast ptosis with planned vertical mastopexy and augmentation mammoplasty. **E,F.** Preoperative photos of a patient before undergoing revision mastopexy for treatment of pseudoptosis. **G,H.** Preoperative photos of patient with grade 2 ptosis and asymmetry after mild weight loss. She requested mastopexy while maintaining breast volume.

- Wise pattern mastopexy is typically reserved for patients with significant skin redundancy that do not want a decrease in breast volume (**FIG 2G,H**).
- Patients with nipple to inframammary fold distance of 12 cm or greater may be good candidates for this procedure, with the trade-off of an additional horizontal scar under the breast.
- In vertical mastopexies, the decision to incorporate a horizontal incision is a function of removing dog ears at the IMF. The true Wise pattern mastopexy requires marking and committing to the surgical incisions with the patient in the standing position.
- The entire Wise pattern incision pattern can be de-epithelialized to maintain breast volume.

Positioning

- The patient should be positioned supine on the operating room table with the hips at the flexion point of the bed to facilitate the sitting position intraoperatively.
- The arms may be tucked at the patient's side or out on arm boards but should be secured and padded adequately.

TECHNIQUES

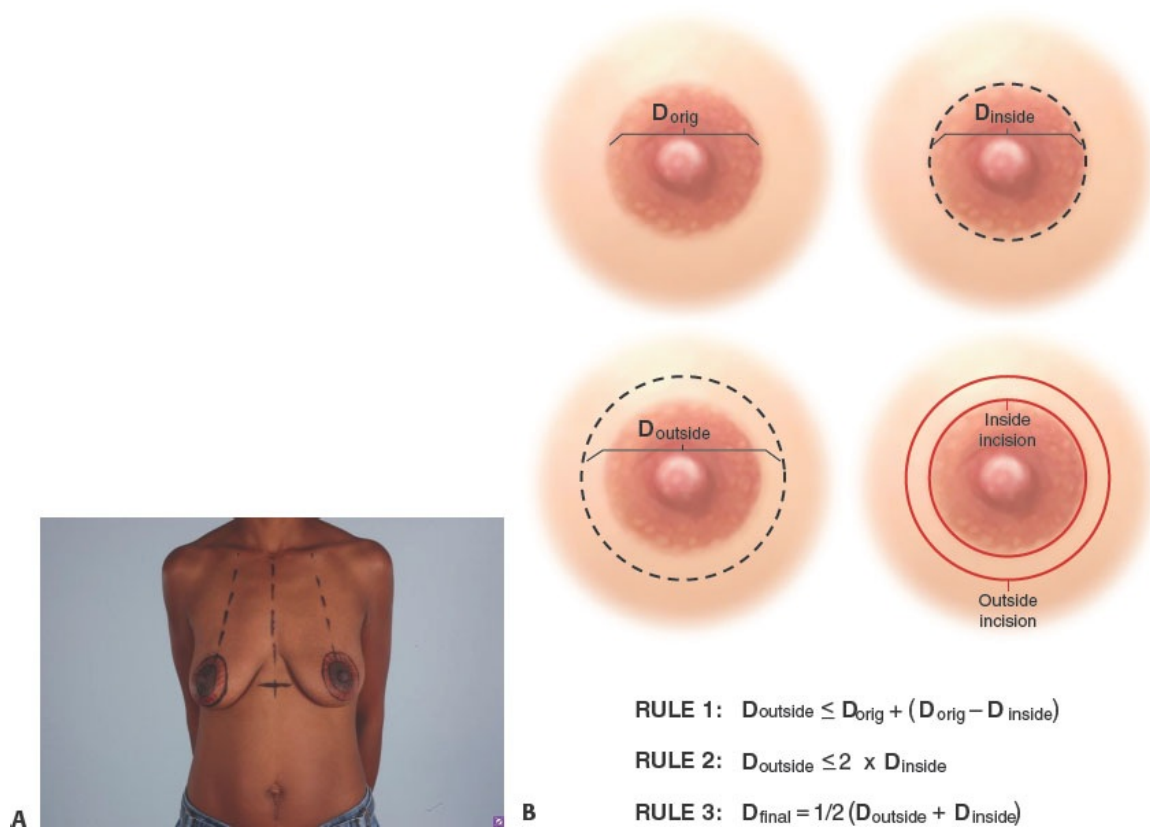
■ Periareolar Mastopexy

Planning and Markings

- The concentric or donut mastopexy is indicated for patients with minimal or

grade 1 breast ptosis.

- The surgeon should not attempt to achieve an aggressive movement of the nipple-areolar complex with this technique as it may excessively flatten the contour of the breast, produce a dilated widened areola, or result in poor circumareolar scarring.
 - The concentric mastopexy should be applied only to patients with reasonably aesthetic nipple position within the minimally ptotic breast.
 - If the nipple is not within the breast meridian, eccentric or crescentic mastopexy should be considered.
- The patient is marked in the anatomic standing position, with arms at the sides.
- The midline, inframammary fold, and breast meridian are marked.
- The overall breast symmetry and NAC are assessed.
- The proposed nipple position is transposed from the IMF to the anterior breast skin.
- The outer mastopexy circumference is typically marked freehand (**TECH FIG 1A**).
 - The outer markings skirt the edges of the areola medially and laterally.
 - The critical upper and lower limits of the typically oval outer periareolar pattern are determined superiorly by the desired new upper border location for the superior edge of the areola and inferiorly by the length of skin desirable to leave between the lower edge of the areola and the IMF (typically 5–8 cm depending on the size of the breast)



TECH FIG 1 • A. Markings begin by identifying the midline, inframammary fold, and breast meridian for each breast. The estimated degree of nipple elevation is marked at the 12 o'clock position, addressing any asymmetry in nipple height that may be present. Finally, the outer diameter of the new nipple areolar border is drawn, with the skin to be de-epithelialized shaded in *red*. **B.** Three rules to aid preoperative planning of periareolar mastopexies. (Adapted from Spear SL, Kassan M, Little JW. Guidelines in concentric mastopexy. *Plast Reconstr Surg*. 1990;85(6):961–966.)

- The inner pattern is usually drawn as a round circle using a “cookie cutter” pattern of 38 to 42 mm.
- Basic guidelines for concentric mastopexy described by Spear et al.⁵ provide guidelines for nipple-areolar marking (**TECH FIG 1B**).

- First and most importantly: Diameter outside – diameter original should be equal to or less than (diameter original – diameter inner), meaning it is preferable to remove more pigmented skin than unpigmented skin.
- Second: Diameter outside should ideally be no more than two times the diameter inside.
- Third: Diameter final = $\frac{1}{2}$ (diameter outside + diameter inside).

Incisions and Closure

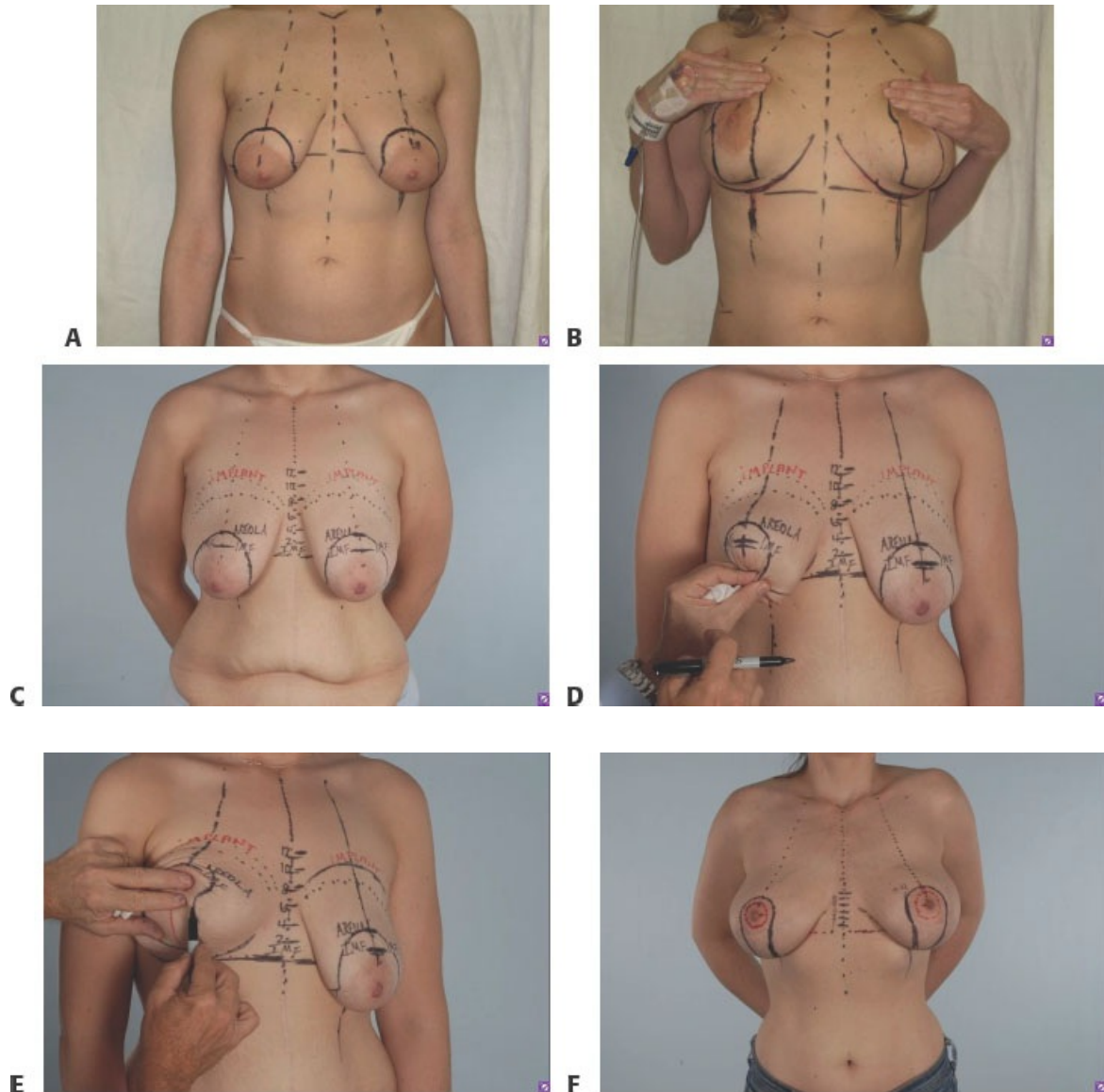
- A 38- or 42-mm cookie cutter is used to mark the proposed nipple-areola diameter with the assistant applying mild tension.
- The inner circle is incised first, followed by the outer circle for efficiency in using the applied counter-tension.
- The remaining donut (often eccentric) is de-epithelialized with a no. 10 or 15 blade. The nipple blood supply is adequate from underlying parenchymal perforators in the native breast unless there is an implant behind the breast. Thus, a full-thickness skin incision may be made circumferentially.
 - Limited superficial circumferential subcutaneous undermining with electrocautery can be performed to decrease tension with closure.
- Closure needs to be carefully done and meticulous and is performed with each suture bite directly opposite to the previous other side to equally distribute areolar tissue along the larger outer diameter.
- If areolar widening is a concern, a carefully placed permanent purse string or wagon wheel (eg, Gore-Tex) suture may be used.
- Mild periareolar wrinkling is common in the immediate postoperative period, but routinely settles in 1 to 2 months.
 - Severe wrinkling or puckering implies poor closure technique or overly aggressive skin excision.

■ Vertical Mastopexy

Planning and Markings^{6,7}

- The addition of a vertical incision to the mastopexy significantly increases its utility.
 - Vertical mastopexy can adequately correct all grades of ptosis.
- The patient should be marked in the standing position and should begin with midline, IMF, and breast meridian (**TECH FIG 2A,C,F**).

- The breast meridian marking should be carried inferiorly onto the patient's abdomen, as it will aid in placement of the vertical mastopexy markings (**TECH FIG 2B**).



TECH FIG 2 • Preoperative marking photographs of a vertical mastopexy in a patient with grade 2 ptosis. **A.** The markings begin with midline, breast meridian, and inframammary folds. Next, the vertical mastopexy incision is marked by placing the superior most part of the keyhole incision approximately 2 cm above

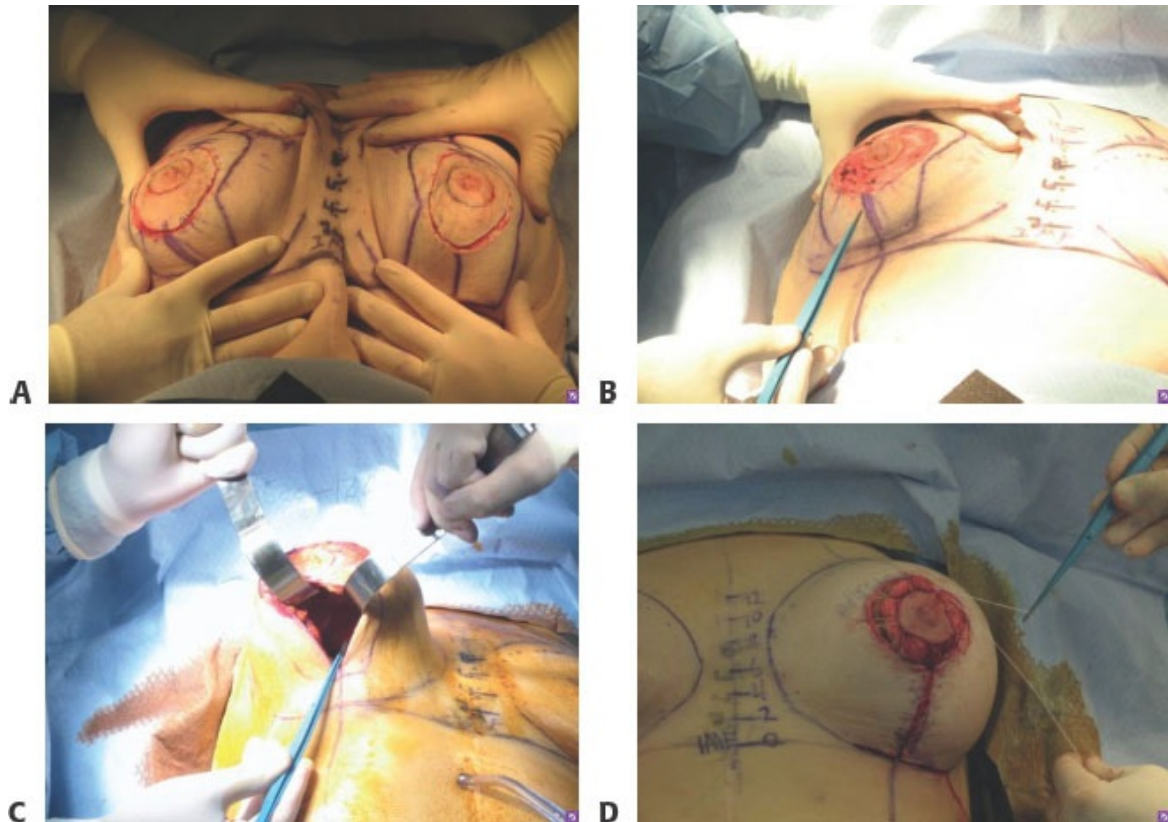
proposed nipple position or the IMF. **B.** The inferior part of the vertical incision stops 2 cm above the IMF. **C–E.** Preoperative markings for a third patient, who was undergoing vertical mastopexy with augmentation. **C.** Preoperative markings begin with marking the midline, breast meridian, the inframammary fold, and the proposed nipple position. The upper border of the breast tissue marked with the *dotted black line*. The proposed location of the upper border of the implant is estimated 8 to 10 cm below the clavicle. **D.** Moderate tension is placed on the breast skin to cone the breast and estimate the width of skin to be excised from the vertical extent of the vertical mastopexy. **E.** After the pinch test, the vertical incision is then drawn and stops 2 cm above the inframammary fold. **F.** Preoperative markings for in a different patient undergoing vertical revision mastopexy for treatment of pseudoptosis begin with midline, breast meridian, and inframammary folds in *black marker*. Midline 1-cm increments are marked from IMF in the superior direction to aid with improving symmetry of nipple position. Finally, the vertical mastopexy is incision marked with the inferior most point stopping 2 cm above the IMF.

- The proposed nipple position is transposed from the IMF to a comparable point on the front of the breast bilaterally.
- The new nipple position should then be measured for symmetry.
- Periareolar markings can be drawn with the aid of a keyhole or freehand.
- The vertical component is marked by medial and lateral displacement of the breast (**TECH FIG 2D,E**). By gently displacing the breast laterally, the medial vertical incision can be marked at the breast meridian. Likewise, the breast is displaced medially, and the lateral vertical incision can be marked at the breast meridian.

- If the patient is also undergoing augmentation, the proposed upper border of the implant is marked as well, as shown in **TECH FIG 2C–E**.

Incisions and Closure

- A vertical mastopexy incision popularized by Lejour is described here.^{3,8}
- First, a 38- or 42-mm cookie cutter is used to mark the nipple.
 - It is incised with a no. 10 or 15 blade followed by incision of the outer periareolar marking (**TECH FIG 3A**).
 - The incision is carried to the level of the dermis.
 - The intervening skin segment is de-epithelialized with preservation of the subdermal plexus (**TECH FIG 3B**).
- The vertical incisions can then be carried out through the dermis.
 - When glandular rearrangement is planned, electrocautery is used to vertically incise the glandular tissue to the level of the chest wall.
 - The gland is then elevated off of the chest wall from medial to lateral.
- Attention is then paid to creating skin flaps in the plane between breast parenchyma and subcutaneous fat along the vertical mastopexy incision.
- Medial and lateral glandular pillars have been created and may be used for autoaugmentation of the breast (**TECH FIG 3C**).
 - Rotation of the medial or lateral glandular pillar in the subglandular plane moves the ptotic breast tissue to a more aesthetically pleasing position.



TECH FIG 3 • **A.** Intraoperative photograph following nipple incision guided by 42-mm cookie cutter. Incision around nipple with 42-mm cookie cutter and incision around the planned periareolar de-epithelialized portion. **B.** Intraoperative photograph after de-epithelialization. The remainder of the skin within vertical mastopexy incision may be excised just below level of the dermis. **C.** Medial and lateral parenchymal pillars are created to allow for autoaugmentation of the breast. **D.** Demonstration of a periareolar wagon wheel Gore-Tex suture technique to prevent widening of the nipple-areolar complex.

- The pillars are then approximated with 2-0 PDS to shape the breast mound. The skin is approximated with staples, and the patient is brought to sitting position on the operating room table for visual inspection.
- The periareolar incision may be closed with a regular or interlocking

pursestring Gore-Tex suture if areolar widening is a concern (**TECH FIG 3D**).

Other Techniques

- The standard vertical mastopexy relies upon glandular pillars and skin for support. The Graf technique uses a chest wall–based, inferior glandular flap to augment the upper pole.
 - The glandular flap is passed through a sling of superficial two-thirds of pectoralis muscle to provide further support.
 - Its utility and longevity are well described by Graf et al.⁹
- Acellular dermal matrix (ADM) is well established in the setting of breast reconstruction. ADM is yet another option for providing support to the glandular pillars, or it can be used in lieu of the pectoralis loop for support in the Graf procedure.
 - The parenchymal pillars are sewn together with absorbable suture.
 - Then ADM is fashioned to the lower pole under mild tension to help support the breast mound (**TECH FIG 4**).



TECH FIG 4 • **A.** Intraoperative view of medial and lateral pillars being sutured together with absorbable monofilament suture. **B.** Intraoperative view demonstrating medial and lateral pillars sutured together. **C.** The pillars are supported with an inferior sling of acellular dermal matrix to prevent the recurrence of pseudoptosis or “bottoming out.”

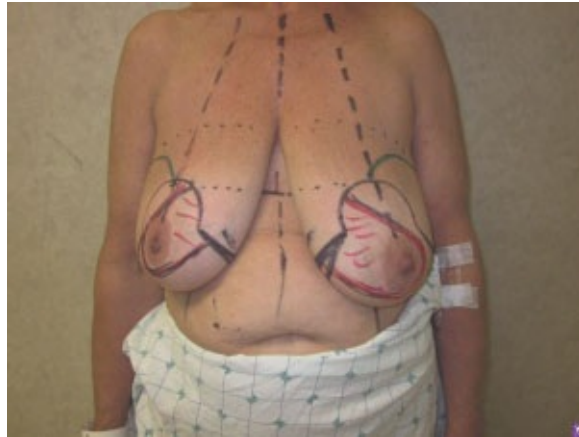
■ Wise Pattern Mastopexy

Planning and Markings

- The planned inverted T incision pattern allows for resection of redundant

skin and glandular tissue in patients with more significant ptosis.

- This technique is similar to the Wise pattern used in reduction mammoplasty, with the goal to primarily reshape the breast mound, rather than reducing the volume.
- The patient is marked in the anatomic standing position, with arms at the sides (**TECH FIG 5**).



TECH FIG 5 • Preoperative markings for Wise pattern mastopexy begin by marking the midline, breast meridian, upper border of the breast, and inframammary folds in *black marker*. The inframammary fold is then transposed anteriorly onto the breast skin to estimate nipple placement. This is represented by the *lower horizontal dotted black line*. The keyhole breast template is used to mark new nipple diameter and vertical incision, also in *black marker*. The *red marker* represents the dermoglandular pedicle, which will be de-epithelialized to maintain nipple blood supply.

- The midline, inframammary fold, and breast meridian are marked, and overall breast symmetry and NAC is assessed.
- The proposed nipple position is transposed from the IMF bilaterally. The top of the proposed areola is marked 2 cm above the new nipple position. The keyhole marker is used to trace the periareolar incision.

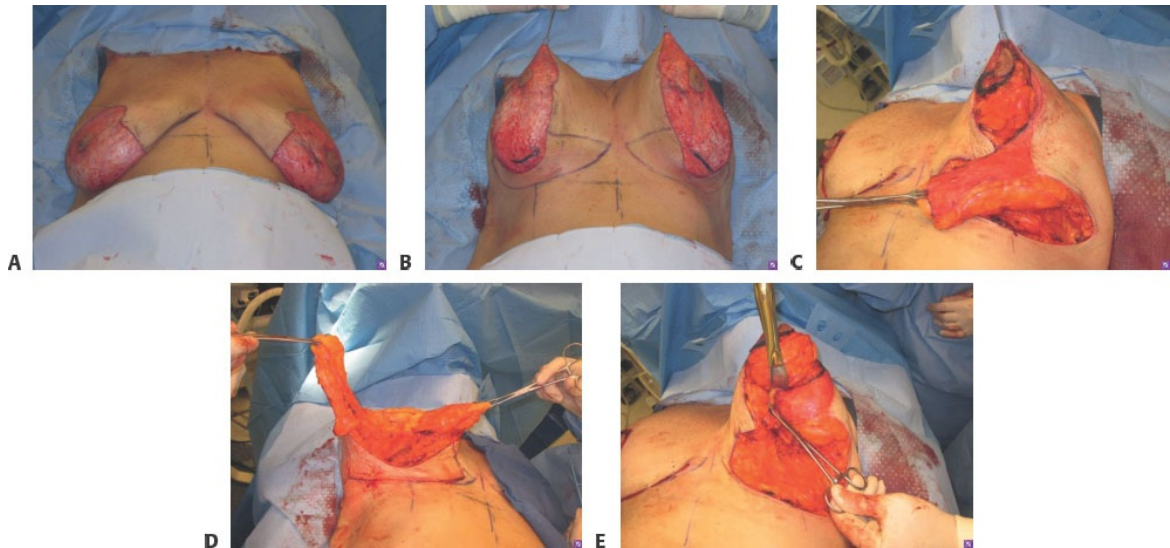
- The breast is displaced medially and laterally to help determine the width of the inverted T incision.
- The choice of glandular pedicle supporting the NAC varies by the size and shape of each breast.
 - The senior author prefers a broad superior dermoglandular or superomedial dermoglandular pedicle supported by the internal mammary artery perforators.
- The vertical incision length, planned areola-to-fold distance, varies with breast size.
 - Areola-to-fold distances typically range from 6 to 9 cm in length.
 - The wider the breast, the longer the vertical component must be to create adequate lower pole breast volume.
 - Making the areola-to-fold distance too small tethers the lower portion of the breast, creating a wide and boxy contour.
- The nipple is generally marked with a 42-mm cookie cutter.
- With the assistant placing the breast on tension, the nipple incision is made with a no. 15 blade.
- The remainder of the breast incisions are made.
 - When planning a Wise pattern mastopexy, the horizontal excisions are marked in the standard reduction mammoplasty fashion.

Incisions and Closure

- If committed to a Wise pattern mastopexy, all incisions may be carried out with a scalpel.
- To preserve breast volume, the entire Wise pattern incision can be de-epithelialized (**TECH FIG 6A,B**).
- In similar fashion, medial and lateral pillars are created with electrocautery (**TECH FIG 6C,D**).
 - Once the pillars are created, they are used to autoaugment the breast in a retroglandular plane (**TECH FIG 6E**).
 - The excess central inferior wedge of tissue may be mobilized and transposed superiorly based upon a medial, lateral, or inferior pedicle if volume autoaugmentation is desired.
 - The two medial and lateral pillars are stabilized with internal absorbable sutures.
- The skin is tailored closed with a skin stapler to assess symmetry, and the patient is moved to the sitting position on the operating room table for final

assessment and adjustments.

- Incision closure is performed in the standard fashion with buried monofilament absorbable sutures.
- A closed suction drain may be left in place and removed at or after the first postoperative visit.



TECH FIG 6 • A. The nipple incision is carried out after measurement with a 38- to 45-mm cookie cutter. In contrast to a breast reduction, all the skin within the Wise pattern is de-epithelialized. **B.** The breast are retracted superiorly with skin hooks to allow de-epithelialization of the inferior Wise pattern skin. **C.** After the lower pole skin has been removed, incisions are carried through the breast tissue to chest wall. This develops lateral and medial pillars. (The later pillar is shown here in the retractor.) **D.** The medial and lateral pillars are displayed here. **E.** The medial and lateral pillars are tucked under the dermoglandular pedicle supporting the nipple to provide autoaugmentation.

PEARLS AND PITFALLS

Periareolar mastopexy¹⁰

- Do not attempt to move the nipple-areolar complex more than 2 cm as it will flatten the breast.
- Use the three concentric mastopexy rules described by Spear et al. to avoid complications.
- Superficially undermine surrounding breast skin flaps for tension-free closure.
- Mastopexy should be performed after augmentation in a combined procedure, as augmentation will decrease the amount of skin resection necessary.

Vertical mastopexy^{8,11,12}

- This technique may be combined with augmentation. If augmentation mastopexy is planned, augmentation should be performed first. The subpectoral or subglandular plane may be initially accessed through the vertical incision or the inframammary incision.
- The vertical incision should stop 2 cm above the IMF to avoid disrupting the fold. The excess gathered skin will settle in 2–3 months or the excess can be trimmed with a dog ear correction in the IMF.
- Tailor tacking the vertical incision closed and sitting the patient supine are useful in assessing the initial result and symmetry.
- If the outer marked areolar diameter is significantly larger than the inner areolar diameter, a blocking suture is useful to prevent areolar enlargement or scar widening.
- More aggressive mastopexy with a planned excision in the fold can be performed in patients with excessive skin laxity or cases without simultaneous augmentation.

Wise pattern mastopexy

- Reserved for grade 3 ptosis or breast requiring significant skin redundancy.
- Medial and lateral de-epithelialized skin flaps may be used to provide upper pole autoaugmentation.
- Use the inframammary fold or most projected point of the breast for ideal nipple placement to avoid malposition, particularly a high-riding nipple.
- Maintain an adequate dermoglandular pedicle in high-grade ptosis to prevent nipple-areolar necrosis.

POSTOPERATIVE CARE

- Compressive surgical bra
- No strenuous upper body exercise activity for 4 to 6 weeks
- Surgical drains typically not needed
- 24 hours or less of perioperative antibiotics
- Occlusive dressing for 48 hours

OUTCOMES

- Mastopexy is an operation with a steep learning curve, and special attention should be paid to preoperative planning and patient selection (**FIG 3**).
- Patient and surgeon expectations should be discussed to ensure agreement on a realistic result.
- When properly planned and executed, mastopexy has high satisfaction rates.
 - However, patients with significant ptosis, diabetes, obesity, tobacco use, or prior radiation should be approached with caution.

COMPLICATIONS

- Bleeding, infection, dehiscence, delayed wound healing
- Nipple-areolar necrosis in the previously irradiated or augmented breast
- Areolar widening, hypertrophic or widened scar
- Asymmetry
- Nipple malposition

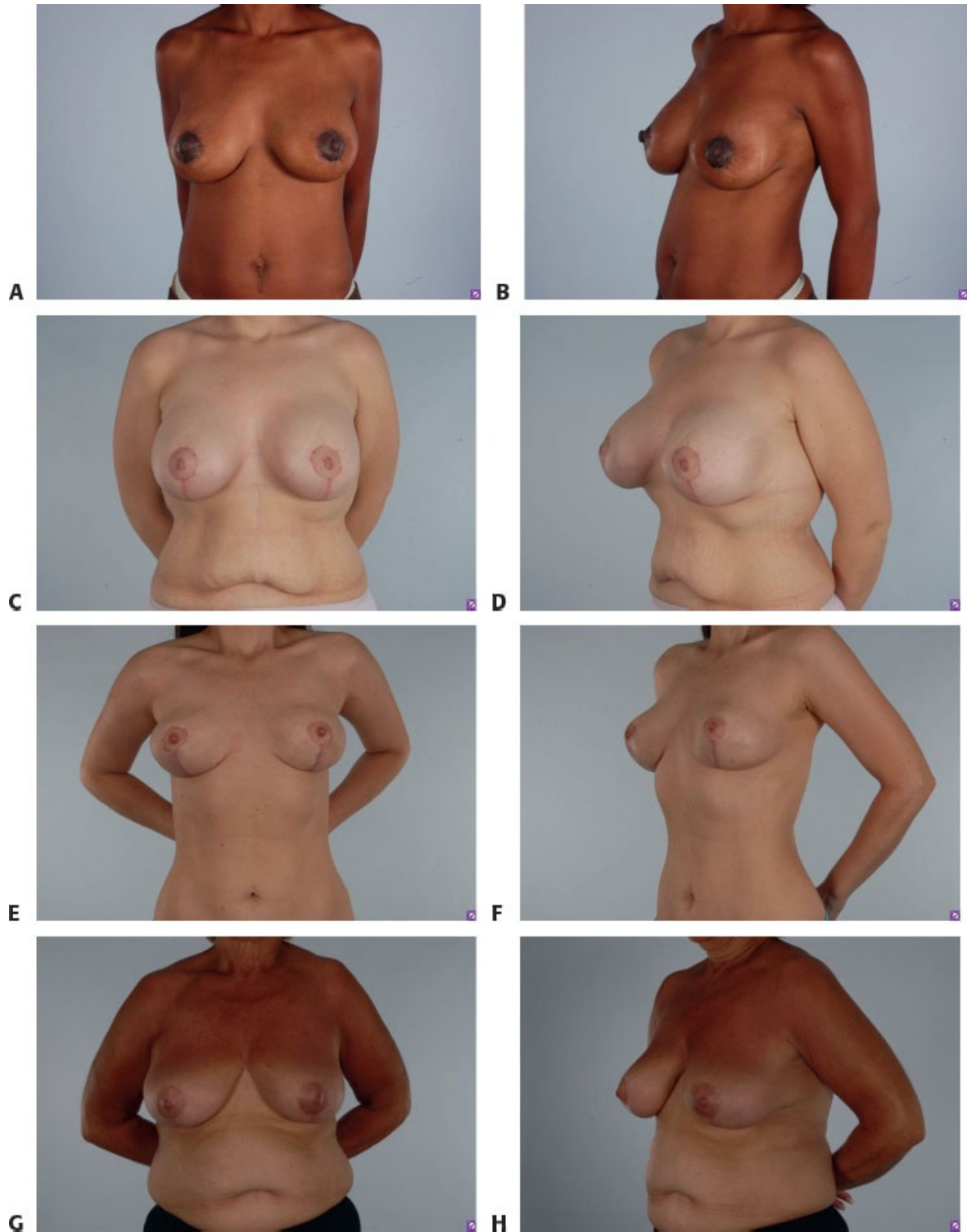


FIG 3 • A,B. Postoperative photos of the patient in **FIG 2A,B** after periareolar mastopexy show an improved upper pole breast slope and skin envelope with

resolution of ptosis. **C,D.** Postoperative photos of the patient in **FIG 2C,D** after vertical mastopexy and augmentation. **E,F.** Postoperative photos of the patient in **FIG 2E,F** after revision vertical mastopexy using acellular dermal matrix for treatment of pseudoptosis. **G,H.** Postoperative photos of the patient in **FIG 2G,H** about 6 months after Wise pattern mastopexy.

ACKNOWLEDGMENT

Dr Ter Louw dedicates this chapter to the memory of Scott L. Spear, MD, FACS, who passed away during its preparation. Founding Chair of the Georgetown University Hospital Department of Plastic Surgery, Washington, DC, Dr Spear was an innovator, a skilled and thoughtful surgeon, a mentor to many, and a dedicated husband, father, and friend.

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Section III: Reduction Mammoplasty

7

CHAPTER Reduction Mammoplasty

Peter Henderson and Joseph J. Disa

DEFINITION

- Breast hypertrophy can be a physically and socially debilitating condition that frequently leads women to seek surgical intervention. Macromastia is defined as symptomatic breast tissue less than 1500 g, and gigantomastia is defined as symptomatic breast tissue greater than 1500 g.
- Reduction mammoplasty has two elements: skin excision pattern and parenchymal excision/pedicle design. With few exceptions, these two elements are independent variables that can be combined in any manner. The vertical-only skin excision pattern and the superomedial pedicle design are increasingly commonly used, and are often combined, especially in patients in whom the maintenance of upper pole projection is important, and the degree of ptosis/excess skin is not excessive.

ANATOMY

- The boundaries of the breast are commonly considered to be the clavicle cranially, the inframammary fold caudally, the sternum medially, and the lateral/anterior aspect of the latissimus muscle laterally. The tail of Spence extends from the upper outer quadrant into the axilla (**FIG 1**).
- The blood supply to the breast is from perforators from the internal mammary (thoracic) artery and vein, as well as the thoracoacromial and lateral thoracic vessels.
- The breast is innervated by the 4th through 6th intercostal nerves.
- In females, the areola is usually round and 38 to 40 mm.

- Breast ptosis is most commonly graded on the Regnault scale (**FIG 2**). Grade 0 (no ptosis) indicates that the nipple sits cranially to the IMF. Grade 1 indicates that the nipple sits at the level of the IMF. Grade 2 indicates that the nipple sits caudal to the IMF but not at the caudal-most point of the breast. Grade 3 indicates that the nipple sits at the caudal-most point of the breast. Pseudoptosis is when the nipple sits at or above the IMF, but there is excessive breast tissue below the IMF (this has a characteristic “bottomed out” appearance).
- Common, clinically relevant breast measurements include nipple-sternal notch and nipple-IMF distances.
- Bra sizes are an imperfect way to gauge breast size (not in the least because most women do not wear the correct size bra). The convention is that the “number” in the breast size is the circumference of the chest wall (measured just caudal to the breast). The “cup” size is indicated by a letter, with each letter’s position in the alphabet indicating the increased number of inches that are measured when the circumference around the breasts is measured (eg, “32B” means that the chest wall circumference is 32 in., and the circumference around the breasts is 34 in.).

PATHOGENESIS

- Breast hypertrophy is a congenital disorder that frequently is exacerbated by weight gain. Especially in young patients, it can be due to increased end-organ responsiveness to estrogen.

NATURAL HISTORY

- In addition to being socially debilitating in young patients, breast hypertrophy can progress to physical ailments, including “notching” of the shoulders due to the bra straps, neck and upper back pain, and intertriginous infections.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Detailed patient and family history of breast disease is crucial (including benign tumors, malignancy, screening, etc.), and information regarding any prior radiation treatment and the operative reports from any prior breast procedures (most notably partial mastectomy/“lumpectomy” or prior breast reduction) should be obtained.

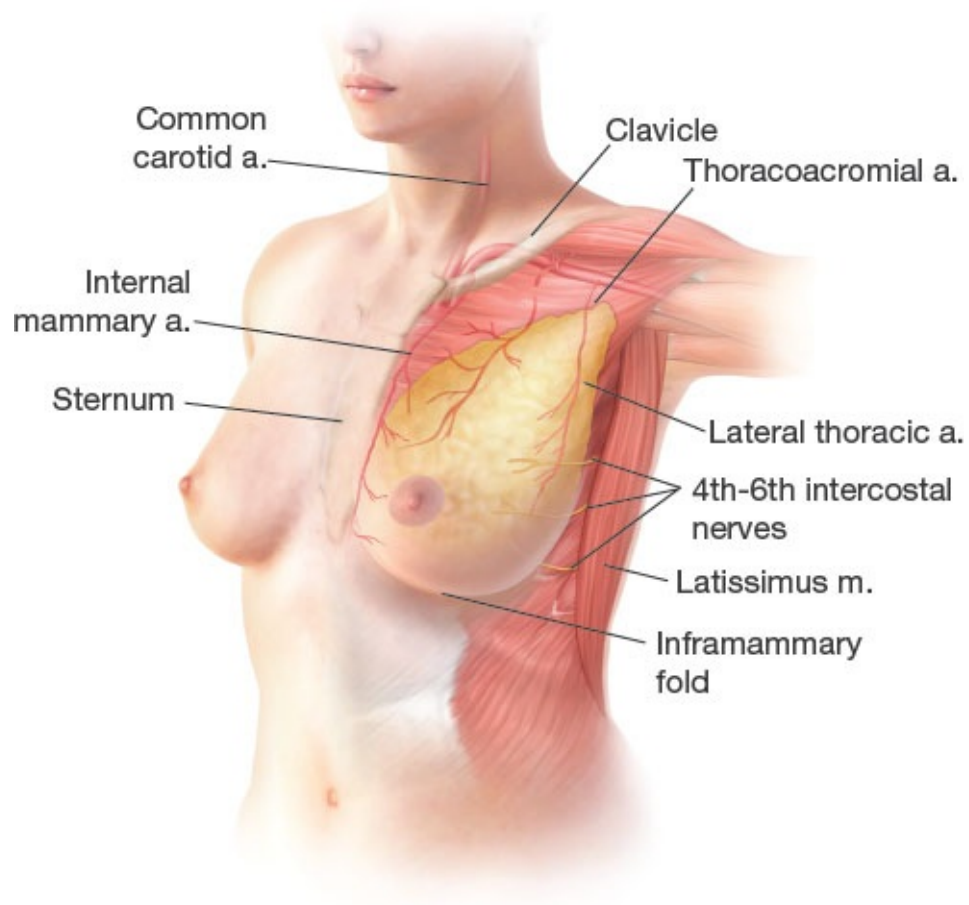


FIG 1 • Breast anatomy.

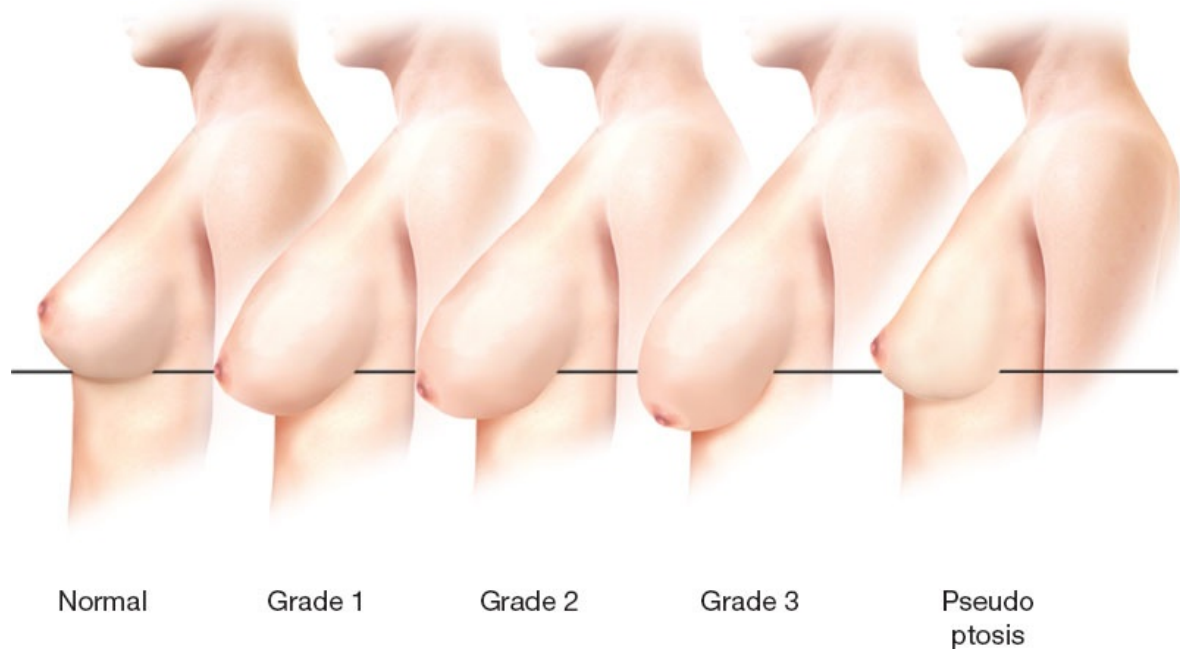


FIG 2 • Regnault scale for breast ptosis.

- Factors relevant to lifetime estrogen exposure, such as age at menarche, menopause (if applicable), number of pregnancies, and use of birth control medications, are also important.
- Breast-feeding history (including plans for future childrearing) is mandatory.
- Nicotine use should be carefully investigated; most surgeons will not perform this elective procedure on anyone who has smoked in the past 2 to 4 weeks.
- Personal importance of erogenous breast sensitivity should be discussed, as decreased or complete absence of nipple sensation is a possible consequence.
- Symptoms related to breast hypertrophy (shoulder notching, back pain, intertriginous infections, and difficulties with personal hygiene) should be noted.
- Physical exam should note any asymmetry between breasts, complete bimanual examination for masses in both breasts and bilateral axillae, and appropriate breast measurements (nipple-sternal notch, nipple-IMF).

IMAGING

- In patients who are of an age when standard, surveillance breast imaging is recommended (40–50 years, depending on the recommending agency), and mammography should always be performed prior to any breast reduction procedure. Many surgeons will obtain surveillance imaging prior to reduction regardless of age, though this practice is not formally endorsed.

DIFFERENTIAL DIAGNOSIS

- Though unlikely, the possibility of a large breast mass must be considered when a patient is evaluated for presumed breast hypertrophy.

NONOPERATIVE MANAGEMENT

- Weight loss may lead to a small incremental improvement in symptoms but rarely is significant enough to sufficiently alleviate symptoms.
- Liposuction is a reasonable approach in a very small subset of patients (namely those with excessive breast volume without ptosis).

SURGICAL MANAGEMENT

Preoperative Planning

- It is important that a frank discussion occur between surgeon and patient regarding each patient's wishes for postoperative breast size. This will rarely have a significant impact on the type of procedure performed but will impact the amount of breast tissue excised.

Positioning

- Patient should be positioned supine on the operating room table.
- Because the patient will be flexed at the waist in order to “sit upright” during the procedure, secure the arms (usually out, on arm boards) and head, and ensure that the patient's waist is appropriately positioned relative to the break in the table.

Approach

- Options for skin excision patterns include the “Wise pattern” (“anchor” or “inverted T”) and vertical-only (“mosque”). Options for parenchymal excision/pedicle design include superior, superomedial, medial, inferior, central mound, lateral, and bipedicle (among others).¹

TECHNIQUES

■ Vertical, Superomedial Pedicle Reduction Mammoplasty

- Inject wetting solution into the inferomedial and inferolateral portions of the resection specimen (what would be the medial and lateral parts of the “anchor” in the traditional Wise pattern excision).
- Mark the neo-areola with a nipple sizer (“cookie cutter”); most surgeons use 42 mm.
- Incise partial-thickness dermis of the pedicle and the circumareolar incision.
- Place the breast tourniquet.
- De-epithelialize the pedicle (taking care not to inadvertently undermine the nipple-areola complex).
- Incise full-thickness dermis around the pedicle.
- Remove the breast tourniquet.
- Incise the breast parenchyma straight down to the chest wall, taking care not

to undermine the pedicle.

- Incise full-thickness dermis to the rest of the skin incisions.
- Undermine the inferomedial and inferolateral corners just below the dermis (many surgeons will use curved Mayo scissors, especially if wetting solution has been injected).
- Remove the skin/fat/breast parenchyma specimen as one single piece.
- Irrigate and ensure hemostasis.
- Weigh specimens.
- Rotate the pedicles (clockwise on the right breast and counterclockwise on the left breast) to ensure that they rest comfortably in a tension-free manner.
- Place “pillar stitches” between the resulting medial and lateral pillars through the breast parenchyma (with or without the overlying dermis).
- Assess for symmetry, with potential interventions for insufficient symmetry being the excision of additional tissue and altering the pillar stitches.
- Use of closed-suction drains is typically unnecessary.
- Close the skin in the deep dermal and subcuticular positions.²⁻⁴

■ Central Mound Reduction Mammoplasty

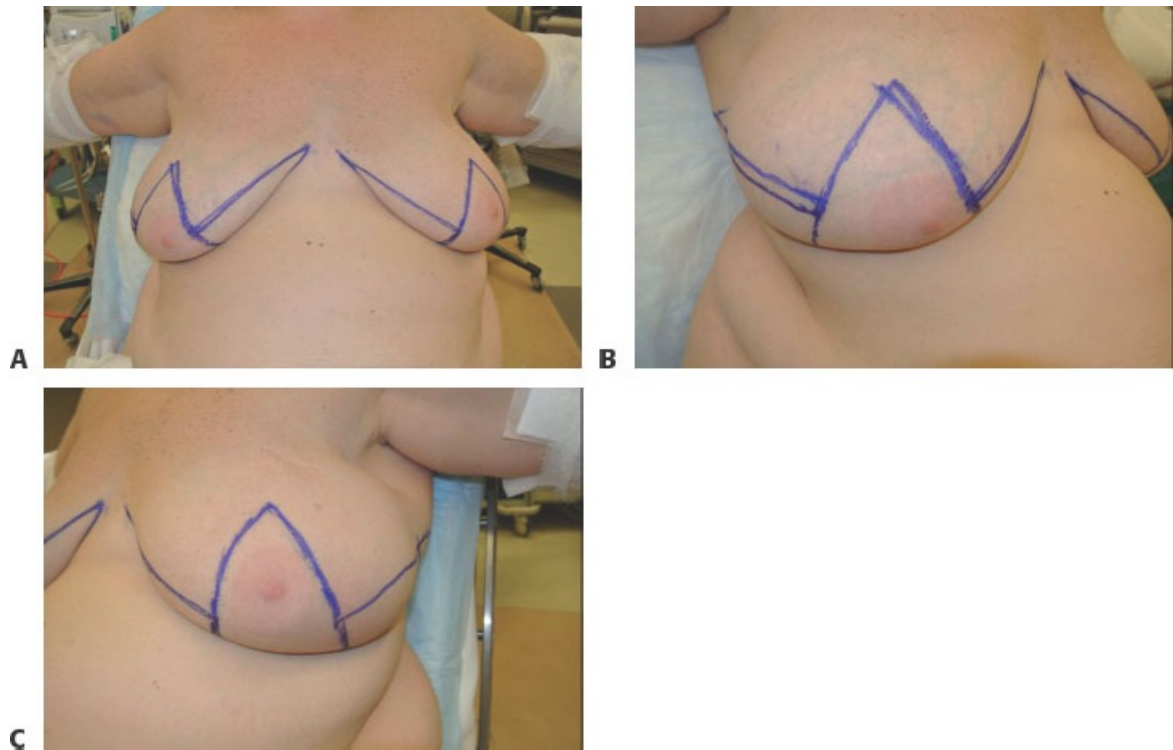
Markings

- Preoperative markings should be done in the upright or sitting position (**TECH FIG 1A-C**).
 - The most reliable location for the nipple-areola complex is with the superior border at the level of the inframammary fold (this provides better results than a predetermined nipple-sternal notch distance, or the midhumeral point).
- It is advisable to initially mark a vertical-only skin excision pattern (later a horizontal component can be excised if needed).
- Nipple sizers (usually 42 mm) are used to define the new borders of the areola (if at all possible, remove all additional areolar tissue to prevent unsightly pigmented skin at closure lines).

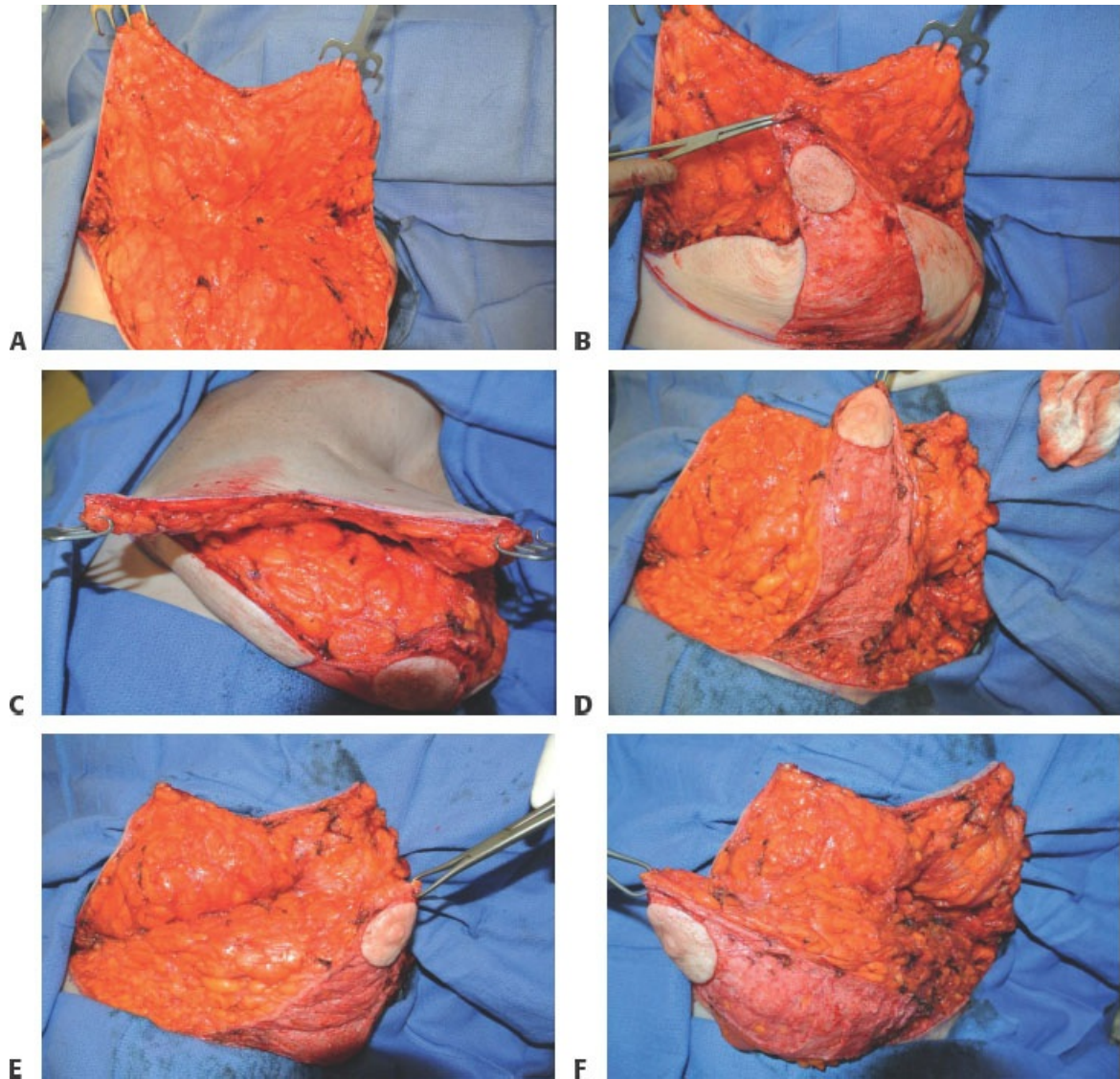
Excision of Parenchyma

- Incise the circumareolar and vertical-only skin excision markings, and de-epithelialize all tissue besides the newly defined nipple-areola complex.

- Excise as much breast parenchyma inferior to the nipple-areola complex as necessary in order to achieve the desired breast size (**TECH FIG 2A-C**).
- The central tenet of the central mound technique is to maintain a pedicle directly from the nipple-areola complex to the underlying pectoralis major muscle; therefore, do not undermine the nipple-areola complex in the course of removing excess breast parenchyma (**TECH FIG 2D-F**).



TECH FIG 1 • Markings for central mound breast reduction using the Wise pattern.



TECH FIG 2 • A–C. Skin flaps of appropriate thickness to maintain adequate vascularity are elevated off the gland laterally, medially, and superiorly. **D–F.** The footprint of the breast is left attached to the muscle and is not undermined.

- If necessary, skin flaps medial, superior, and lateral to the nipple-areola complex can be created in order to allow for the necessary mobility to transpose the nipple-areola complex into its final position near the level of the inframammary fold. This is done in a manner angling away from the nipple-areola complex (thereby creating a “cone” with the nipple-areola

complex at the apex). The parenchyma of the skin flaps should be at least 2 cm thick to maximize vascularity.

- Excision of the breast parenchyma leads to the creation of medial and lateral “pillars,” which are sutured together with deeply placed, heavy, slowly absorbable sutures.

Completion

- The patient is flexed at the waist to “sit up.”
- At this point, the breast is examined to determine whether there is sufficient excess skin and/or breast parenchyma to warrant the excision of a horizontal wedge of tissue. If so, the markings should be made such that the closure will fall at the level of the inframammary fold. If no further breast parenchymal excision is warranted, the skin can be removed by de-epithelialization alone. If the patient would benefit from the excision of additional breast parenchyma, then the horizontal wedge can be taken as a full-thickness segment.
- The tissue is irrigated and hemostasis is ensured.
- Closed-suction drains can be placed, depending on surgeon preference.
- The areola is inset to its new location, and the skin is closed (**TECH FIG 3**).



TECH FIG 3 • Intraoperative appearance after gland and nipple-areola repositioning.

Skin excision pattern

- When the vertical-only skin excision pattern is attempted, the amount of excess skin at the inferior portion of the vertical wound should be examined. A mild amount of “bunching” can be tolerated, as it usually “settles out” over the first 6 months. A moderate or significant amount of excess skin should be excised in a transverse direction, essentially converting the “vertical-only” skin excision pattern into a Wise pattern.

Nicotine use

- Nicotine use (either in cigarettes or in nicotine patches) significantly increases the risk of NAC ischemia, fat necrosis, and other wound healing complications. The nicotine metabolite cotinine can be detected in the urine, and a point-of-care test can be performed in the preoperative area immediately prior to the scheduled operation if concern exists.

Parenchymal excision

- Efforts should be made to minimize the amount of parenchymal tissue removed underlying the final location of the NAC (superior and lateral to the pedicle); overresection can lead to poor NAC projection.

POSTOPERATIVE CARE

- Bras that provide maximal support (and do not contain any rigid components like underwire) should be worn for the first 2 to 4 weeks.
- If closed-suction drains were used, they will likely be able to be removed in 1 to 7 days.
- Nipple-areola complex ischemia/necrosis is a rare but dreaded complication that should be checked for regularly in the immediate to early postoperative period (creation of a pedicle that is sufficiently wide and thick can significantly reduce the risk of this happening). If NAC ischemia is thought to present in the early postoperative period, periareolar sutures can be removed, undoing the inset and potentially releasing any ischemia-inducing configuration.

OUTCOMES

- Most patients are satisfied following breast reduction procedures (**FIG 3**).
- Use of superomedial pedicle is thought to maximize upper pole fullness and reduce the likelihood of pseudoptosis (“bottoming out”) that is thought to occur more frequently with an inferior pedicle design.
- Nipple sensation is rarely absent, but usually decreased relative to the preoperative baseline. Occasionally, nipple sensation is increased

postoperatively due to decrease stretch/tension once the excess weight/volume has been removed.

- Ability to breast-feed is impaired in approximately 40% of patients.

COMPLICATIONS

- Hematoma can occur, but risk can be minimized if hemostasis is diligently attempted.
- Seroma can occur and can usually be addressed with percutaneous drainage.
- Fat necrosis can be a consequence of parenchymal ischemia. It usually softens (if not completely resolves) in a matter of months, but sometimes requires surgical excision.

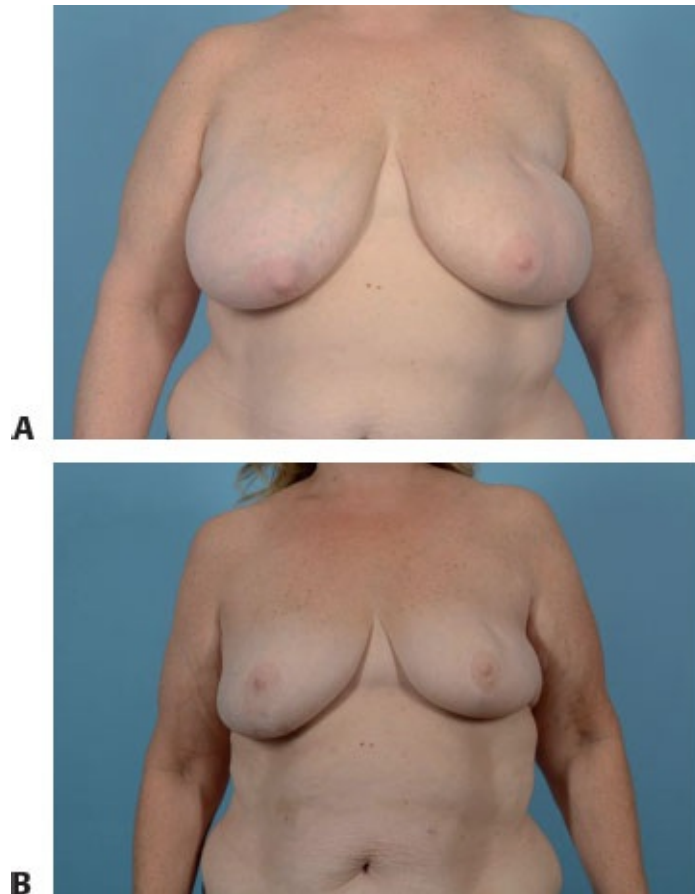


FIG 3 • A. Patient preoperatively. **B.** Three years after breast reduction.

- NAC ischemia is rare but can potentially lead to necrosis and complete loss of the NAC.

- Alterations in nipple sensation or breast-feeding ability are not uncommon, and the patient should be counseled in the preoperative period as to the possibility of this occurring.

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CHAPTER Inferior Pedicle

Paul A. Ghareeb and Albert Losken

DEFINITION

- Reduction mammoplasty remains one of the most commonly performed operations by plastic surgeons.
- Inferior pedicle reduction mammoplasty is one of the most widely used reduction techniques because it is easy to learn, is safe, and has reproducible outcomes.¹
- This technique was described and refined in the 1970s by Ribiero, Robbins, Georgiade, and Courtiss and Goldwyn.^{2,3}
- Is most commonly utilized with a Wise pattern (inverted T) skin excision.
- The inferior pedicle reduction technique is extremely versatile and can be used in almost any reduction procedure. We have found it to be useful in patients with long nipple to notch distances and those with large anticipated reduction specimens.
- The complication rates for inferior pedicle reductions have been shown to be equivalent for small and large (greater than 1000 g) reductions, making this technique particularly useful when treating gigantomastia.⁴

ANATOMY

- Borders of the breast
 - Superiorly: clavicle
 - Medially: sternum
 - Inferiorly: superior border of rectus fascia
 - Laterally: anterior border of latissimus
- Blood supply
 - Intercostal perforators

- Primary blood supply to the inferior pedicle
- Internal mammary perforators
- Lateral thoracic artery
- Thoracoacromial artery
- Innervation
 - Intercostal sensory branches
 - The fourth intercostal sensory nerve provides the majority of sensation to the nipple-areolar complex (NAC).
 - The sensory branches course just above pectoralis fascia before piercing the breast parenchyma to supply the overlying skin and nipple. It is important to maintain a layer of breast tissue over the pectoralis when performing reduction mammoplasty to prevent damage to these nerves.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Focused history
 - Current brassiere size and desired size after mammoplasty is important to determine with the patient preoperatively in order to guide goals and expectations.
 - Symptoms of macromastia and any interventions attempted must be elucidated and recorded preoperatively.
 - History of childbirth, breast-feeding, and desire to have further children are important to discuss. With the inferior pedicle technique, most women maintain the ability to breast-feed postoperatively but should be counseled on this during the consultation.
 - Mammographic history if applicable, as well as family history of breast disease or cancer.
 - A history of smoking should be discussed prior to any reduction, and patients should be counseled to stop smoking at least 1 month prior to reduction mammoplasty due to the significantly increased risk of wound healing complications.
- Physical exam
 - Examine the overall breast shape, asymmetries, previous scars, and estimate breast size in grams. Always examine for breast masses and nipple sensation. Record breast measurements including sternal-notch-to-nipple and nipple-to-inframammary fold distances.
 - Patients considered to be good candidates for an inferior pedicle reduction

often times have long nipple to notch and nipple to IMF distances, which can both be easily addressed with this technique. Furthermore, patients with boxy-appearing breasts can be shaped effectively with the skin excision.

- Evaluate existing ptosis utilizing the Regnault classification.
- Note any additional axillary tissue laterally that would not be resected with standard reduction mammoplasty. This is often an area that the patient assumes will be treated with standard reduction procedures but must be counseled that this is an additional area that must be treated.

IMAGING

- Mammography is recommended for women who meet screening criteria.
- No other routine imaging is required preoperatively.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative markings are critical to the success of any breast reduction.
- The patient is examined in the standing position, with her arms resting to either side.
- The midline is marked first from sternal notch to the umbilicus.
- The true breast meridian is then marked on each side from the midclavicular line down onto the abdominal wall. Note that this may not always align with the position of the NAC.
- Pitanguy point is then identified and marked by placing one's fingers underneath the breast at the inframammary fold and curling them forward to be palpated by the opposite hand. This allows the surgeon to determine the final resting position of the NAC. This is approximately 21 cm from the sternal notch but can vary depending on the body and breast shape.
 - It is important to mark this point correctly at the IMF. By marking too high, one may produce a “sunny side up” nipple, which points upward, or a “snoopy deformity” by placing the nipple too far inferiorly.
- The vertical limbs of the Wise pattern are then created approximately 7 cm in length on each side, starting at Pitanguy point and coursing inferiorly. A McKissock keyhole tool may be used for the purpose of creating the vertical limbs, but we prefer to use the medial and lateral distraction technique. In this fashion, the breast is distracted medially and laterally, and the vertical limb is drawn in continuity with the superior and inferior breast meridian markings.

- The distance between the base of the vertical limbs correlates with the final change in breast base diameter.
- The horizontal markings are then drawn to connect the vertical limbs to the inframammary fold marking at the medial and lateral most aspects of the breast.
- The horizontal takeout can be tailored as short or long as necessary to achieve the desired outcome. The markings are typically carried out further for larger resections or boxy-appearing breasts, whereas in smaller reductions, can be achieved with a shorter horizontal scar.
- The IMF marking is made just above the level of the existing IMF. It can be preserved at the inverted T-junction if viability of the upper flaps is a concern.
- After the markings have been completed, they should be compared to the contralateral side to ensure symmetry. In asymmetric reductions, this may be difficult to assess.
- **FIG 1** demonstrates the standard preoperative markings for an inferior pedicle reduction.



FIG 1 • A,B. Preoperative markings for the inferior pedicle Wise pattern reduction in a patient undergoing bilateral oncoplastic reduction for a left breast cancer.

Positioning

- The patient is placed supine on the operating room table and is positioned to be able to sit up if necessary.

- The arms are extended on arm boards, taking care not to over extend and distort the breast. They are secured with standard straps and soft padded wraps to facilitate placing the patient in the upright position.
- The breasts are prepped and draped to include the sternal notch, clavicles, and lateral most aspects of the breast and axilla. For unilateral procedures, the contralateral breast is exposed to be examined during the procedure.

Approach

- At the start of the procedure, the planned inferior pedicle is designed from the inframammary fold incision along the breast meridian to include a 1-cm cuff of tissue surrounding the NAC. The base of the pedicle should be 8 to 10 cm in width to ensure proper vascularity of the NAC. This is kept wider in bigger reductions with longer pedicles.
- The NAC is then marked by sight or with a cookie cutter at 40 to 44 mm, and the final nipple position is planned and marked at the apex of the vertical limbs. No tension is applied to the NAC while marking to reduce the likelihood of creating an unnatural final appearance.
- A line approximately 1 cm above the inframammary fold is marked for the inferior aspect of the Wise pattern. This is performed to avoid disrupting the dense attachments of the fold.

TECHNIQUES

■ Incision

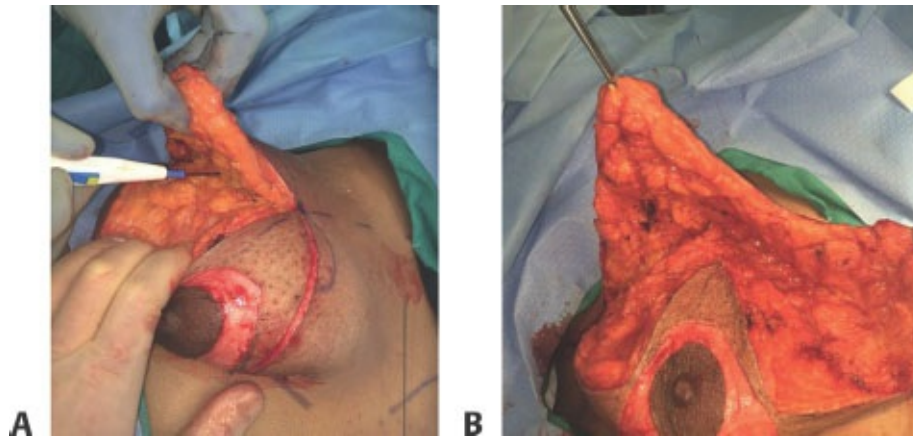
- The nipple is incised sharply with a knife through the epidermis only.
- The remainder of the Wise pattern markings and the planned inferior pedicle are then incised sharply, and the pedicle is de-epithelialized with a large curved Mayo scissors or a no. 10 blade (**TECH FIG 1**).
 - It is helpful to place a towel around the base of the breast and secure tightly with a clamp to maintain appropriate tension for de-epithelialization.
 - Linear partial-thickness incisions through the epidermis with a scalpel can further assist with de-epithelialization with scissors.



TECH FIG 1 • The Wise pattern has been incised and the inferior pedicle de-epithelialized.

■ Dissection

- The superior flaps are then developed up toward the breast base. The extent of dissection depends on the size of the breasts and the pedicle and is limited if possible. These are generally created approximately 1 in. thick to maintain upper pole fullness and to ensure vascularity to the overlying skin (**TECH FIG 2B**).
- The nondominant hand is typically placed under the breast, and the parenchyma is grasped and rolled inferiorly over the hand to provide tension for dissection when an assistant is unavailable to retract.
- Once the superior flaps have been created, the dermoglandular pedicle is developed straight down to the chest wall. The pedicle should not be undermined in order to prevent nipple necrosis.
- The “two finger” dissection technique is useful when developing the pedicle to provide tension. The nondominant index and long fingers are used to spread the parenchyma, and the tissue is divided with cautery. This allows the surgeon to retract for him or herself, which is the best way to ensure that the pedicle is not being undermined.



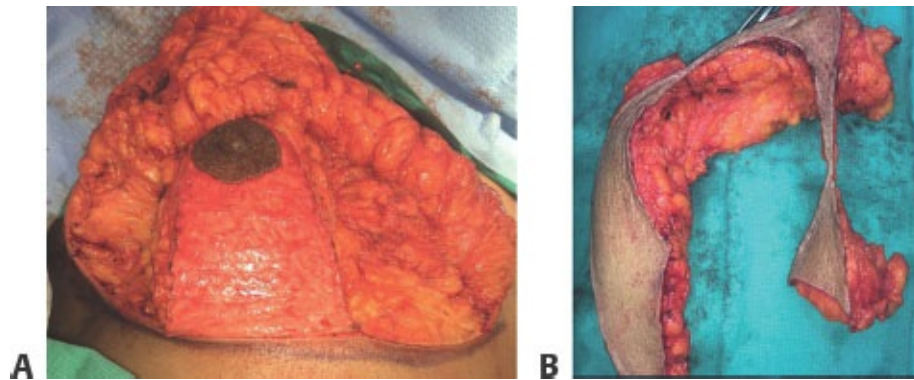
TECH FIG 2 • A,B. The superior flaps are elevated first. These are kept relatively thick to ensure enough superior pole fullness and to help prevent bottoming-out.

- The pedicle is kept wider at the base to ensure optimal vascularity.

■ Resection

- The medial resection is then carried out. Care is taken initially to leave some breast tissue at the medial aspect of the excision to maintain medial fullness. This is examined after tailor tacking, and further resection can be carried out if required.
- The superior and lateral areas are then resected, and the entire specimen is handed off en bloc to be weighed (**TECH FIG 3**). The breast parenchyma is kept superiorly if possible to maintain upper pole fullness. However, we will typically over-resect the lateral aspect of the reduction due to the common presence of additional axillary tissue. This can be further treated with liposuction if necessary.
- The inferior corners of the vertical limbs are then brought down and secured at the breast meridian marking to form the inverted T, and the rest of the breast is tailor-tacked with staples to evaluate shape and symmetry. Additional resection can be performed at this time to achieve a satisfactory result.
- Often times, there remains excess skin that can be removed. This is often found at the vertical component but can also occur at the medial or lateral

horizontal incision. Appropriate tailor tacking at this point in the procedure is important to identify these areas for further resection.



TECH FIG 3 • A. The inferior pedicle is demonstrated after medial and lateral resection has been carried out. **B.** The resected specimen is demonstrated. Note that the majority of resected tissue is from the lateral aspect of the breast.

■ Suturing

- Internal shaping sutures are not generally used in our practice but can be considered based upon surgeon preference.
- If the final NAC position was not previously marked and incised, this may now be done so. It is often helpful to sit the patient up to ensure that the NAC is symmetrically placed at the point of maximal projection on the breast mound. This is often measured at 4 to 5 cm from the inframammary fold to the inferior aspect of the NAC.
 - A suture can be used in a pendulum fashion to ensure symmetric positioning of the nipple.
- Drains are not typically used in our reduction procedures but may be considered based on surgeon preference.
- The inverted T junction is closed first with an external 3-0 monofilament suture in half-buried horizontal mattress fashion. The T junction at the NAC base is next closed in similar fashion, followed by the rest of the incisions. The incisions are closed with 3-0 monofilament suture in interrupted deep dermal fashion, followed by a running subcuticular stitch with 3-0 or 4-0

monofilament suture (**TECH FIG 4**). Mastisol and Steri-Strips are then placed over the incisions, and padding is placed over the breasts. A supportive surgical brassiere is placed in the operating room at the completion of the case.



TECH FIG 4 • The final on-table result after closure and inset of the NAC. The inferior T junction is closed with an external half-buried horizontal mattress suture. In this case, the left side (oncologic side) was kept bigger in anticipation for radiation therapy.

PEARLS AND PITFALLS

Markings and incision

- The preoperative markings are key to achieving a successful outcome in reduction mammoplasty.
- Mark and incise the inframammary fold incision approximately 1 cm above the true IMF to avoid disrupting the fold.
- The horizontal incision can be made as long or short as necessary to properly shape the breast.

Flaps and pedicle

- One can choose whether to develop the superior flaps or pedicle first, but in our experience, it is easier to develop the flaps first and then to use the “two finger” technique to develop the pedicle. This technique for pedicle development can be utilized for other pedicle types as well.
- The surgeon must be aware of the pedicle at all times when performing the resection. Avoiding undermining of the pedicle is critical to a safe

procedure.

- Developing thicker superior flaps will prevent flattening of the upper pole and further protect against bottoming out.

NAC

- Leave a layer of breast parenchyma over the pectoralis fascia to avoid damaging the sensory nerves to the nipple.
- The NAC should never be placed too high or too medial, because this creates an unnatural look and may be difficult to conceal in a bathing suit or brassiere.
- The NAC should be observed for signs of ischemia or congestion prior to completion of the procedure. In rare circumstances, conversion to a free nipple graft can be performed for salvage if the NAC is felt to be nonviable.

POSTOPERATIVE CARE

- The vast majority of reduction mammoplasties in our practice are performed on an outpatient basis and are seen back in the office within 2 weeks for a routine postoperative appointment.
- The patient is kept in a supportive surgical bra or wireless sports bra at all times except when showering for the first 4 to 6 weeks. Once all of their incisions have healed, they are cleared to begin wearing a bra with underwiring.

OUTCOMES

- Satisfaction rates with reduction mammoplasty are among the highest in any area of plastic surgery, with approximately 95% of patients stating they would do it again if given the choice.^{5,6} Several reports using validated questionnaires have determined reproducible improvement in both physical and psychosocial symptoms postoperatively.^{5,7} Furthermore, reduction surgery has been found to be a stimulus for further weight loss and blood glucose control in motivated patients.⁸
- The reoperation rates for reduction mammoplasty are approximately 8% to 9%.⁹ Most of these cases are for scar revision, although some patients require revision for fat necrosis or other causes.
- Postoperative results are demonstrated in **FIGS 2** and **3**.

COMPLICATIONS

- The overall complication rate for reduction mammoplasty ranges widely from 5.1% to 45% in the literature.^{6,9–11} Most complications are mild in nature and

can be treated conservatively.

- Wound healing problems are the most common complication of Wise pattern reduction mammoplasty. This most commonly occurs at the inferior T junction, and in almost all cases may be treated conservatively with Silvadene or moist wet to dry dressings with resolution.

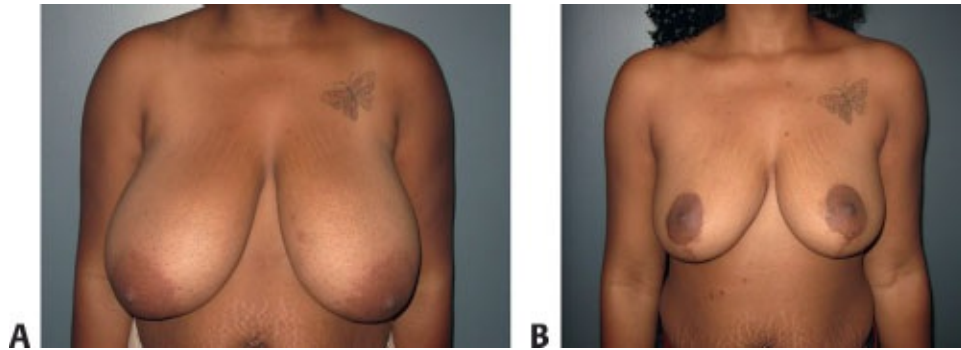


FIG 2 • (A) Preoperative and **(B)** postoperative result of a 27-year-old female who underwent inferior pedicle reduction mammoplasty. An inferior pedicle was chosen for easier inset. A superior or superomedial pedicle would have been fairly long and harder to appropriately reduce. Her nipple to notch measurements were 34.5 cm on the right and 34 cm on the left, while her nipple to IMF measurements were 16 on the right and 17 on the left. Final resection volumes were 1088 g on the right and 959 g on the left.

- To avoid necrosis at the T junction, one must take care to avoid shearing the skin edges from the underlying breast tissue and excessive tension on the closure at this area.
- Bottoming out, which refers to the development of excess lower pole tissue and stretching over time, is a phenomena that can occur with inferior pedicle reductions. There have been several techniques presented to prevent this, but at the current time, we do not routinely perform any additional maneuvers to avoid this.
- Hematomas, fat necrosis, and infectious complications are relatively common following reduction mammoplasty. Most can be treated conservatively, but

some patients will require surgical intervention.

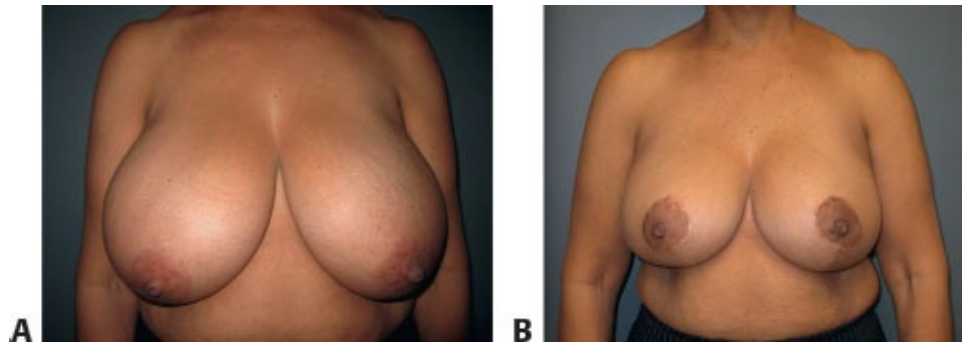


FIG 3 • (A) Preoperative and **(B)** postoperative result of a 54-year-old female who underwent inferior pedicle reduction mammoplasty. In this case, most of the breast volume was carried superiorly, and therefore, an inferior pedicle was chosen. Her nipple-to-notch measurements were 33 cm on the right and 32 cm on the left, while her nipple-to-IMF measurements were 16 cm bilaterally. Her final resection volumes were 801 g on the right and 706 g on the left.

- Nipple-areola complex sensation is often affected following reduction mammoplasty. The greatest degree of sensitivity change persists in the early preoperative period, but most patients have improved or normal sensation at 6 months postoperatively.¹² Theoretically, the inferior pedicle technique leaves more branches of the fourth intercostal nerve to the NAC intact, possibly providing some benefit when compared to other pedicle types.
- Nipple ischemia and necrosis is a rare but unfortunate complication of any reduction mammoplasty procedure. The overall risk of either partial or full necrosis is approximately 3.6%.¹¹ Partial-thickness loss can be treated conservatively with Silvadene and dressing changes, whereas full-thickness defects must often be debrided and primarily closed for optimal results. Depigmentation can occur after partial-thickness loss, especially in darker colored areolas.

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9 Breast Reduction with Free Nipple Graft

CHAPTER

Paul A. Ghareeb and Albert Losken

DEFINITION

- Reduction mammoplasty is one of the most commonly performed operations in plastic surgery.
- Free nipple graft reduction was first reported by Thorek in 1922.¹
- This technique is typically reserved for patients at high risk for nipple loss, in patients who wish to be smaller than what can be achieved by preserving the nipple on a pedicle, and in those who are at increased anesthetic risk.
- The nipple may be preserved with the areola as a composite graft or may be harvested by itself with subsequent tattooing of the areola.

ANATOMY

- Borders of the breast:
 - Superiorly: Clavicle
 - Medially: Sternum
 - Inferiorly: Superior border of rectus fascia
 - Laterally: Anterior border of latissimus
- Blood supply:
 - Intercostal perforators
 - Internal mammary perforators
 - Lateral thoracic artery
 - Thoracoacromial artery

PATIENT HISTORY AND PHYSICAL FINDINGS

- Focused history:
 - Current brassiere size and desired size after mammoplasty is important to

determine with the patient preoperatively.

- Free nipple graft reduction is a good option in patients who wish to be smaller than what can be achieved with a pedicled reduction.
- Symptoms of macromastia and any interventions should be documented.
- History of breast-feeding and the desire to have further children are important to discuss.
 - Patients undergoing free nipple graft reduction should be counseled about the inability to breast-feed postoperatively, as this may affect their decision to undergo this procedure until childbearing is complete.
- Mammographic history if applicable, as well as family history of breast disease or cancer.
- A history of smoking should be discussed prior to any reduction, and patients should be counseled to stop smoking at least 1 month prior to reduction mammoplasty due to the significantly increased risk of wound healing complications.
- Physical exam:
 - Examine the overall breast shape, asymmetries, previous scars, and estimate breast size in grams. Examine for breast masses and nipple sensation. Record breast measurements including sternal notch to nipple and nipple to inframammary fold distances.
 - Evaluate existing ptosis utilizing the Regnault classification.
 - Note any additional axillary tissue laterally that would not be resected with standard reduction mammoplasty. This area must be pointed out preoperatively so that patients understand where the limit of resection will be.

IMAGING

- Mammography is recommended for women who meet screening criteria.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients who are good candidates for free nipple graft reduction include the following:
 - Patients who are at increased risk for nipple necrosis, including patients with gigantomastia (where greater than 2000 g of tissue per breast is expected to be resected)
 - Patients who would like to be smaller than what a pedicled reduction can

provide

- Patients with medical comorbidities who would not tolerate a longer operation, as the free graft technique is significantly shorter
- Patients who are smokers or who have other comorbidities whereby breast amputation is safer than having undermined Wise pattern flaps
- Furthermore, any breast reduction where the NAC is felt to be nonviable may be converted to a free nipple graft.
- The surgical markings are performed in the preoperative holding area, with the patient standing and arms resting on each side.
- We typically utilize a Wise pattern skin excision pattern when performing a free nipple graft procedure for optimal shaping of the skin envelope (**FIG 1**). Our technique for marking is described in detail in the Inferior Pedicle chapter.

Positioning

- The patient is placed supine on the operating room table, with arms extended on arm boards and secured with soft roll. It is important not to extend the arms too far, as this may distort the breast shape.
- The patient is positioned at the break of the bed, so that she may be placed in the upright position if necessary.

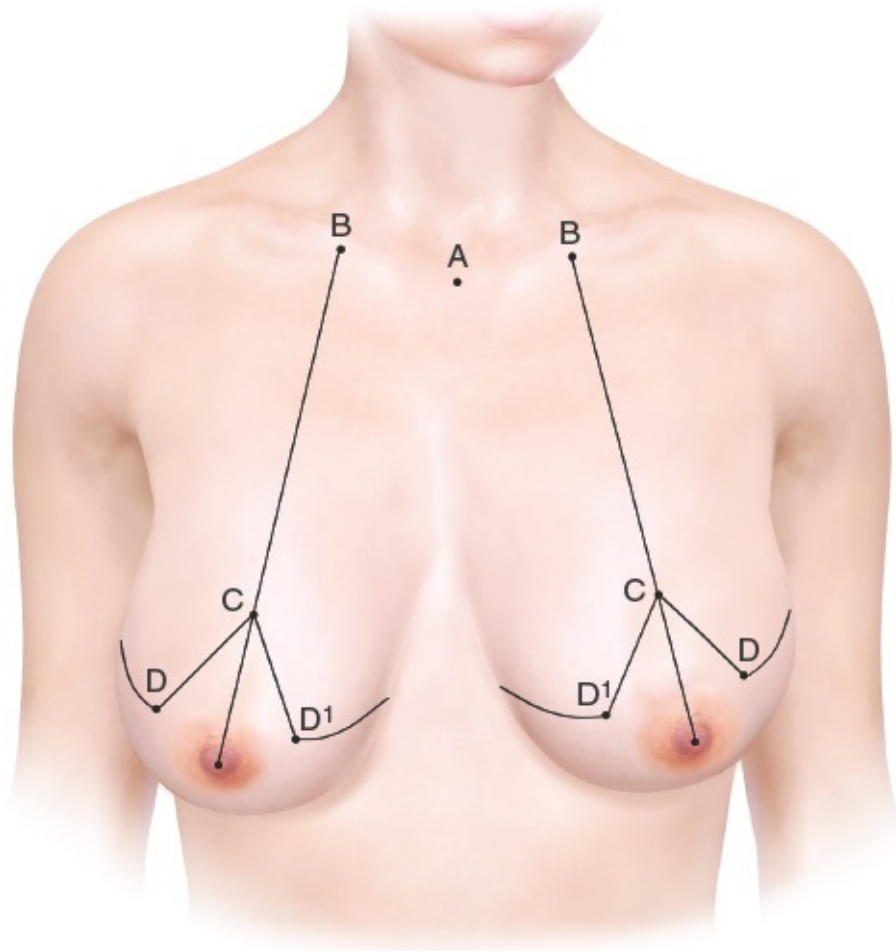


FIG 1 • Wise pattern skin excision markings.

Approach

- The method of nipple graft to be performed is determined by the patient's skin color and quality, scarring, and desires.
- We feel that tattooing of the areola oftentimes produces superior results as compared with the free nipple-areolar graft, especially in patients with darker skin who are at risk for depigmentation. However, in patients who do not wish to undergo future tattooing, the areola should be grafted.
- If the entire nipple-areolar complex is to be grafted, the nipple is marked with a cookie cutter at approximately 40 to 44 mm.
- If the nipple is to be harvested with subsequent tattooing of the areola, then the nipple base is marked.
- The standard Wise pattern markings are re-marked, with the inframammary fold incision marked at 1 cm above the actual fold. This is to preserve the

dense attachments present in this area.

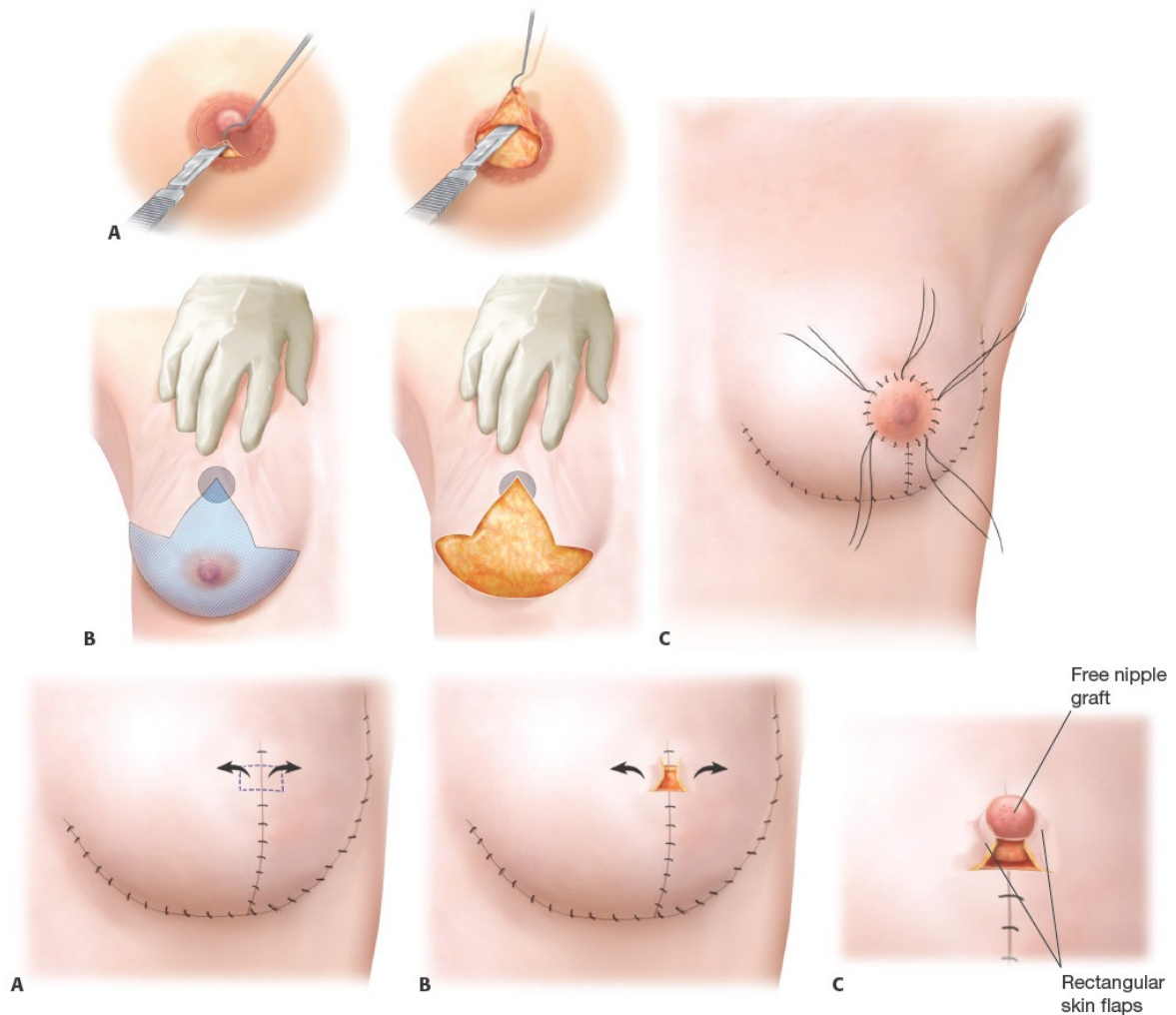
- The resection pattern is based on breast amputation techniques, with the majority of the reduction specimen taken out as a wedge at the inferior pole of the breast.
- Many other techniques have been described for resection of breast tissue, including the creation of dermoglandular flaps to provide improved projection. However, we feel that with a conservative resection and preservation of superior and central breast tissue with minimal undermining, adequate shape can be created.

TECHNIQUES

- If the initial surgical plan is to perform a free nipple graft, then the nipple is harvested first (**TECH FIG 1A**).
- After the nipple is harvested, the inferior breast tissue is resected in a wedge-shaped pattern, making sure to preserve enough tissue superiorly to maintain adequate breast projection.
 - The Wise pattern markings are incised sharply.
 - The resection is typically started at the superior aspect of the breast.
 - At first, minimal tissue is resected from the vertical component of the Wise pattern. This is maintained to ensure adequate projection and can always be resected later if necessary.
 - Once the horizontal component of the Wise pattern is reached, the dissection is aimed inferiorly toward the fold and carried down to the chest wall (**TECH FIG 1B**).
 - It is easy to over-resect with this technique. It is important to aim caudally when performing the initial resection and not to undermine the superior breast flaps. More tissue can always be resected if necessary after the initial specimen is removed.
- After the resection has been carried out, the remaining inferior breast tissue is tucked superiorly and the breast is tailor-tacked and examined for shape and symmetry.
- If required, additional tissue may be resected prior to closure. Oftentimes, excess fullness remains laterally and should be excised.
- If the skin envelope is felt to be too loose, additional skin can be resected from the vertical components. By excising more lateral vertical skin, the

lateral aspect of the breast can be advanced medially to provide a more defined lateral breast border.

- Once adequate shape has been obtained, the incisions are closed with a 3-0 monofilament absorbable suture in deep dermal fashion, followed by a running subcuticular stitch.
- Drains are not typically used in our practice.
- Another option is to attempt an inferior or central mound and if it seems as though the pedicle is too long or the nipple appears congested or poorly perfused, it can be converted to a shorter glandular mound and free nipple or nipple areolar graft.
- It is important not to commit to a keyhole reduction pattern if a graft is anticipated.
- Free nipple and areolar grafting
 - The NAC is incised sharply with a knife and harvested as a full-thickness graft.
 - Once the breast has been reduced and all incisions have been closed, the point of maximal projection is marked with the cookie cutter at 40 to 44 mm. This area is then de-epithelialized.
 - After adequate thinning with a scissor on the back table, the graft is then secured to the recipient bed with a 4-0 or 5-0 absorbable suture (**TECH FIG 1C**).
 - A xeroform and cotton-ball tie-over bolster is then used to secure the graft.
- Free nipple grafting
 - The nipple is transected at the base sharply with a knife.
 - After the reduction is complete, the point of maximal projection is marked.
 - Two small rectangular flaps are lifted in a horizontal fashion to provide for increased contact between the nipple and recipient bed (**TECH FIG D–F**).
 - The nipple graft is then placed between the flaps and is secured at the base.
 - The edges of the nipple are trimmed, and the flaps are sutured to the nipple edges with a 5-0 absorbable suture to allow for maximal graft survival.
 - A Telfa nonstick dressing is applied to the nipple and secured with Steri-Strips to act as a bolster.



TECH FIG 1 • A. The nipple-areola complex is sharply removed with a no. 10 blade. It is then thinned on the back table to an appropriate depth for grafting. **B.** (Left) The proposed area of breast tissue to be excised is marked. (Right) The tissue is removed, making sure to leave enough tissue superiorly and centrally with minimal undermining. **C.** The nipple is inset with a 5-0 absorbable suture after final closure is achieved. A Xeroform tie-over bolster is utilized to maintain graft position for 1 to 2 weeks. **D.** After closure of the reduction incisions, two small rectangular flaps are designed to allow placement of the nipple graft. **E.** Elevation of the rectangular flaps.

F. Insetting of the nipple graft within the rectangular flaps to allow for maximal nipple graft revascularization and take.

PEARLS AND PITFALLS

Skin excision	■ Wise pattern skin excision pattern is well suited for free nipple graft reduction.
Nipple graft technique	■ The nipple can be grafted alone, or the nipple-areolar complex can be grafted as a unit. ■ Often grafting the nipple alone with subsequent tattooing is optimal but involves an additional step and cost.
Do not over-resect	■ It is easy to over-resect tissue. Be sure to leave enough tissue behind to adequately shape the breast.
Bolstering	■ The bolster should be left in place for 1 to 2 weeks to maximize graft take.
Improving projection	■ An inferior dermoglandular flap can be created if needed to augment projection.

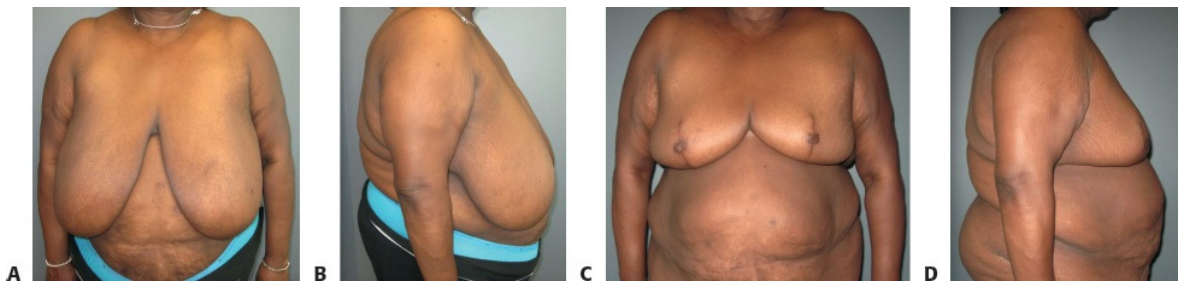


FIG 2 • **A,B.** Preoperative photos of a 54-year-old female presenting with gigantomastia. Her nipple-to-notch measurements were 51 cm on the right and 50 cm on the left. Her nipple-to-fold measurement was 20 cm bilaterally. **C,D.** Postoperative results after free nipple-only reduction with a Wise pattern skin excision, before ultimate tattooing of the areola. The resection

specimens weighed 2102 g on the left and 2126 g on the right.

POSTOPERATIVE CARE

- The vast majority of reduction mammoplasties in our practice are performed on an outpatient basis. Patients undergoing free nipple graft reduction are instructed to maintain the bolster dressing until their follow-up appointment. This is removed in the office approximately 10 to 14 days postoperatively, and the graft is assessed. A protective dressing is then kept on for an additional 2 weeks.
- The patient is kept in a supportive surgical brassiere or wireless sports brassiere at all times except when showering for the first 4 to 6 weeks. Once the incisions have healed, she is cleared to begin wearing a brassiere with underwiring.

OUTCOMES

- Pre- and postoperative photos of free nipple graft reductions are shown in **FIGS 2 and 3**.
- Reduction mammoplasty is one of the most satisfying procedures performed by plastic surgeons, with approximately 95% of patients willing to undergo the procedure again when surveyed.^{2,3}
- Reoperation rates for reduction mammoplasty are around 8% to 9%. Most of these are for scar revisions, although rarely they may include other causes.⁴
- Nipple sensitivity and erectile function may be preserved to some degree, but in certain situations may be lost completely.⁵
- With the free nipple graft technique, the ability to breast-feed is lost. Patients must be counseled on this prior to the operation.

COMPLICATIONS

- Overall complication rates following breast reduction vary widely in the literature, from 5.1% to 45%.⁶⁻⁸ Most of these complications are minor and may be treated conservatively.
- Complications following free nipple breast reduction are likely less common than other techniques, because the length of the procedure is often shorter and there is minimal undermining and repositioning of breast tissue.
- Wound healing complications are often lower in free nipple reductions, owing

to decreased undermining.⁹ This is most often treated with local wound care, but in some cases debridement and closure or skin grafting may be necessary.

- Partial or full graft loss is extremely uncommon in our practice but can occur. Severe cases may be treated with debridement and delayed nipple reconstruction.
- Hypopigmentation may occur and is more troublesome in patients with darker skin (**FIG 4**). Patients should be counseled on this prior to surgery, and free nipple-only grafts with subsequent tattooing should be considered in these patients.
- When free nipple-areolar grafts undergo hypopigmentation, it is difficult to correct this with tattooing.

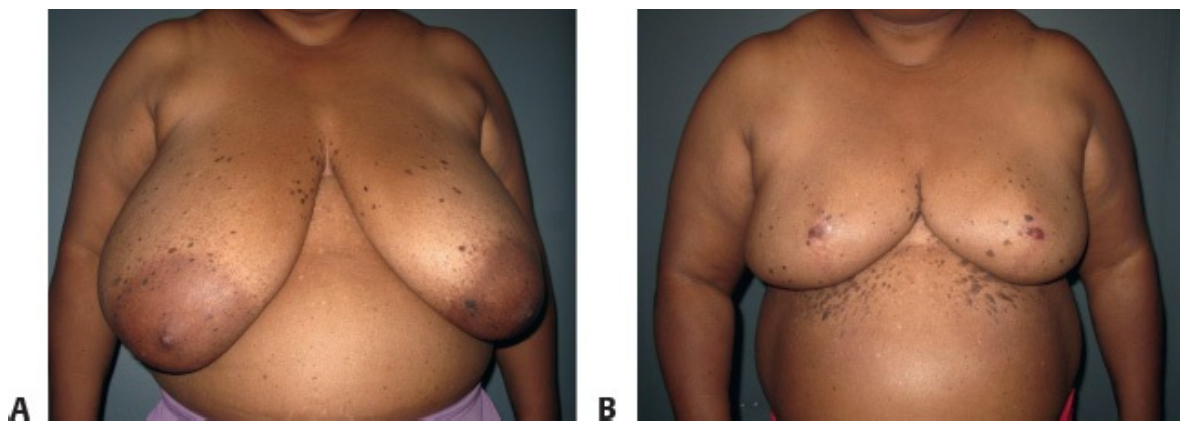


FIG 3 • A,B. Pre- and postoperative photos of a 61-year-old female with gigantomastia. She wished to be much smaller and did not have a preference for nipple sensibility or function. Her nipple-to-notch measurements were 42 cm on the right and 41 cm on the left. Her nipple-to-fold measurements were 23 cm on the right and 20 cm on the left. She underwent a free nipple-only reduction with a Wise pattern skin excision. The total amount of tissue excised was 2300 g on the right and 1900 g on the left.

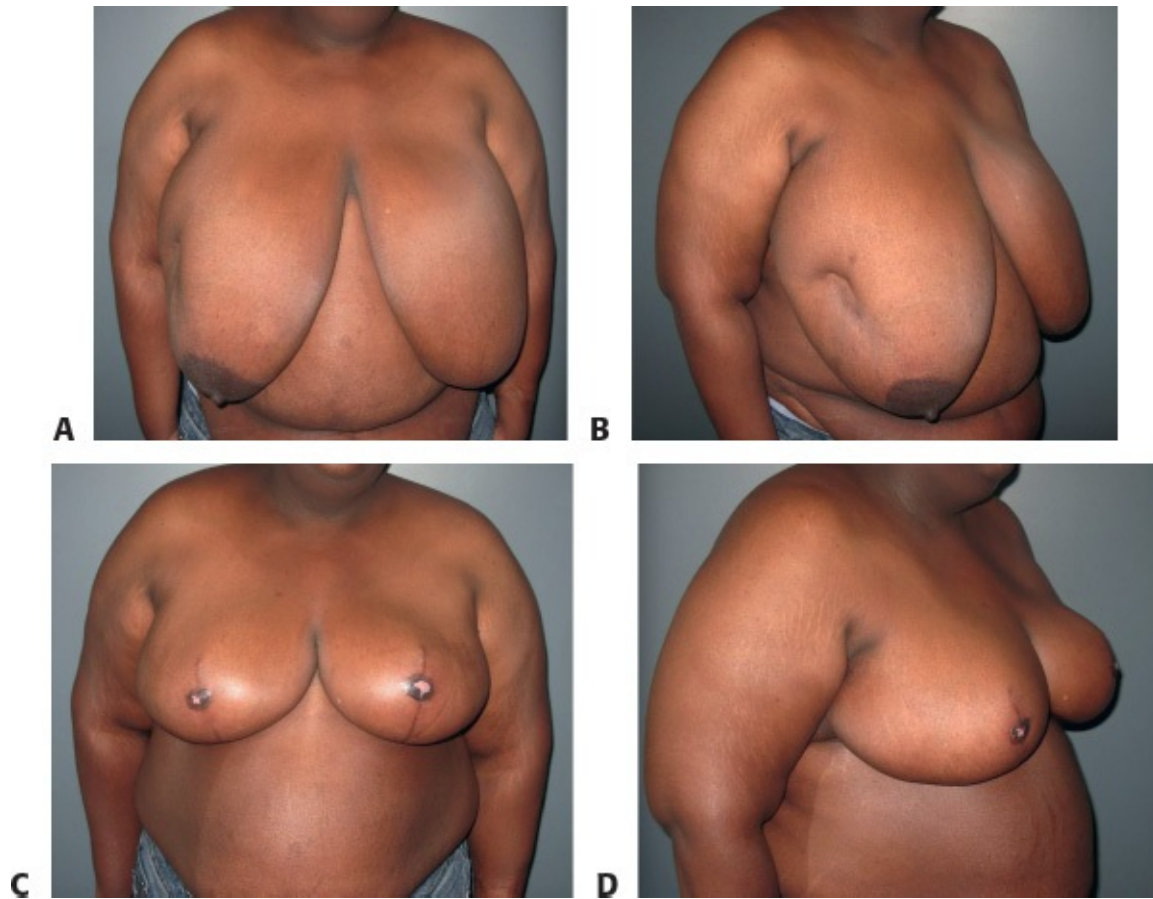


FIG 4 • A,B. Preoperative photos of a 29-year-old female with a right breast scar. Her nipple-to-notch measurements were 47 cm on the right and 50 cm on the left. Her nipple-to-IMF distances were 26 cm on the right and 20 cm on the left. **C,D.** Postoperative photos after bilateral free nipple reduction using a Wise pattern skin excision, before areolar tattooing. The amount of tissue resected was 2350 g on the right and 2250 g on the left. She developed some hypopigmentation of the grafts bilaterally.

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10

CHAPTER Gynecomastia

John T. Stranix and Alexes Hazen

DEFINITION

- Gynecomastia refers to benign, excessive enlargement of parenchymal tissue in the male breast. The etiology of gynecomastia is multifactorial, often idiopathic, and affects up to 40% to 50% of men.¹

ANATOMY

- In gynecomastia, the excess glandular tissue is typically centered under the nipple-areola complex (NAC), with a predominantly fibrous component (**FIG 1**).
- Pseudogynecomastia refers to diffuse fatty enlargement of the male breast related to obesity and demonstrates a predominance of adipose vs fibrous tissue.
- Normal male breasts are flat in appearance with mild fullness around the NAC.
- The male NAC diameter is normally 2 to 4 cm (mean 2.8 cm) and centered on the midclavicular line over the fourth intercostal space. Mean sternal notch to nipple distance is 20 cm.
- The pectoralis muscle provides superior fullness to the anterior male chest that transitions inferiorly to flat tissue over the lower chest at the level of the inframammary fold (IMF).
- A well-defined IMF results in a more feminine breast appearance.

PATHOGENESIS

- Benign proliferation of male breast parenchyma occurs due to a relative increase in the ratio of free estrogen to androgen locally in the breast.²

- Physiologic gynecomastia occurs in newborns (circulating maternal estrogens), adolescents (excess plasma estradiol during early stages of puberty), and men after age 65 (decreased testosterone production).
- Neonatal and pubertal gynecomastia are typically self-limiting and usually resolve over several months to years.
- Pathologic gynecomastia can result from various metabolic (cirrhosis, renal failure), endocrine (hypogonadal state, hyperthyroidism), oncologic (adrenal or testicular tumors), or congenital (Klinefelter syndrome) disorders.
- Pharmacologic gynecomastia has been linked to a number of medications and occurs by several known mechanisms; however, direct mechanisms have not been identified for all associated medications.³
- Gynecomastia does not increase the risk of male breast cancer development compared to the normal male population.
- Patients with Klinefelter syndrome, however, have up to a 50 times increased risk of developing breast cancer.⁴ Due to the elevated oncologic risk in this population, an excisional technique should be used to provide a specimen for pathology analysis.

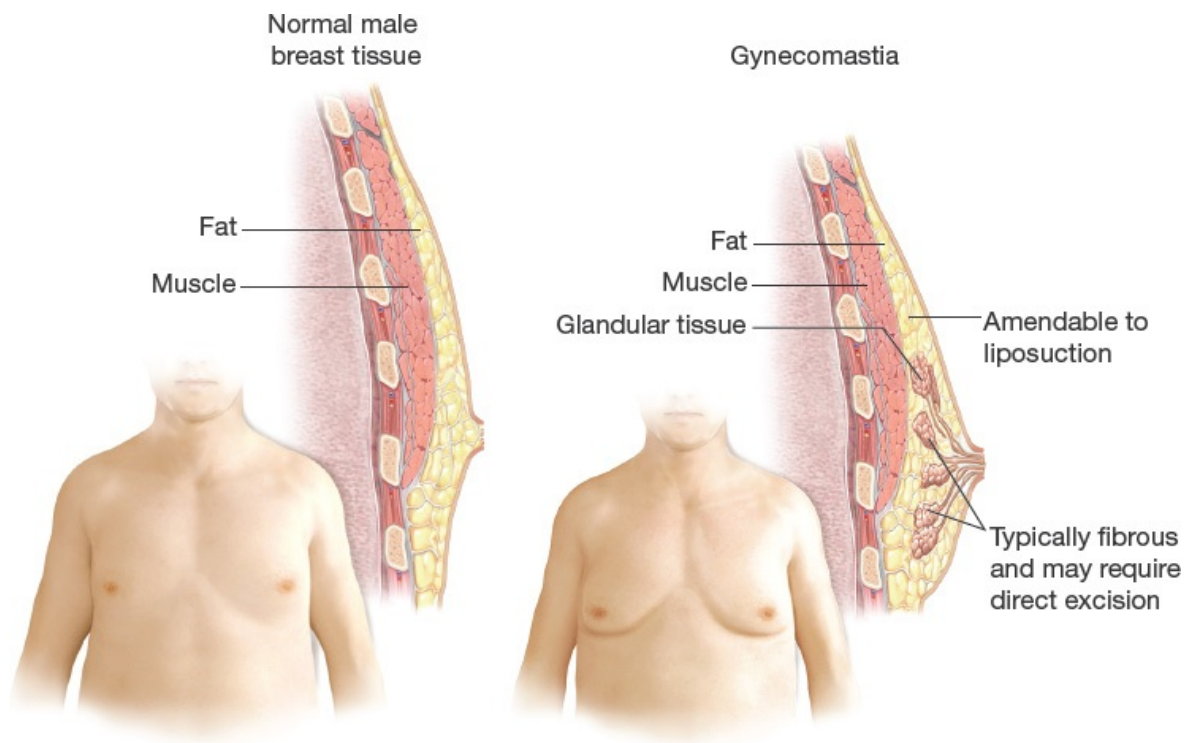


FIG 1 • Cross-sectional depiction of normal male chest

anatomy compared to gynecomastia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Clinical evaluation of enlarged male breasts begins with a detailed history and review of symptoms, focusing on elucidating known causes of gynecomastia and differentiation from pseudogynecomastia and tumor.
- History should include age, onset and duration of enlargement, breast symptoms (pain, tenderness, discharge), medications, alcohol or recreational drug use, and social/psychological effects of breast enlargement. Past medical, surgical, family, and reproductive history should also be obtained.
- Signs/symptoms of liver disease, malnutrition, kidney failure, hyper- or hypothyroidism, weight changes, adrenal disease, and malignancy.
- Physical examination
 - Breasts should be assessed for symmetry, nipple abnormalities, glandular or fat predominance, skin excess, degree of ptosis, and nodules or masses. Approximately 50% of gynecomastia is bilateral.¹ Axillary and supraclavicular lymph node basins should be examined in the setting of a suspicious mass.
 - Glandular tissue in gynecomastia is characterized by mobile, rubbery subareolar breast tissue.
 - Masses or nodules with abnormal firmness, overlying skin changes, eccentric location, or associated nipple discharge should raise concern for breast carcinoma.
 - Secondary sexual characteristics should be examined: body hair distribution, muscle mass, penile development, and testicular size, consistency, and symmetry.
 - Signs of systemic disease should also be evaluated: thyromegaly, exophthalmos, hepato- or splenomegaly, abdominal masses, ascites or cirrhotic stigmata, visual fields, cranial nerves, and fundoscopy.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Laboratory or radiographic studies are not necessary in most cases of gynecomastia.
- Mammography, and possibly biopsy, is indicated if findings on physical examination are consistent with a breast neoplasm.
- Testicular ultrasound should be obtained in the setting of prepubertal bilateral

gynecomastia, evidence of undervirilization, and/or a testicular mass.⁵ Endocrine labs are also appropriate in this situation; consider karyotype if Klinefelter syndrome is possible.

- Laboratory testing should be directed by abnormalities identified on history and physical exam.

DIFFERENTIAL DIAGNOSIS

- Physiologic
- Drug-induced
- Hypogonadism
- Tumors
- Systemic
- Congenital
- Familial
- Miscellaneous
- Idiopathic

NONOPERATIVE MANAGEMENT

- The majority of patients with new-onset gynecomastia are best managed with reassurance and observation for 12 to 18 months.^{1,6}
 - No detectable abnormality is found in up to 60% of patients on initial evaluation.⁵
- Correction of underlying causes should be performed: discontinue offending medications, correct hormonal imbalances, address metabolic or endocrine disorders.
- Medical therapy with testosterone and aromatase inhibitors has had limited success. Treatment with tamoxifen, however, has been shown to result in gynecomastia regression in recent randomized trials.¹

SURGICAL MANAGEMENT

- Surgical intervention should be considered for patients with a diagnosis of symptomatic gynecomastia of duration greater than 12 months.
 - Due to irreversible fibrosis of hypertrophic breast tissue that develops 6 to 12 months after the onset of gynecomastia, medical treatments beyond that stage are unlikely to result in significant regression.^{1,7}
- Surgical treatment of gynecomastia has evolved to become increasingly less invasive through the use of liposuction and endoscopy; however, more severe

cases often require open techniques with a higher scar burden.

- Multiple classification systems have been developed to guide surgical management. The system devised by Rohrich et al.⁷ classified gynecomastia based on breast size and degree of ptosis.

Preoperative Planning

- In addition to standard components of informed consent, the preoperative consultation must include a discussion of scar burden/location, possible need for direct excision of residual subareolar fibrous tissue, as well as the potential for undercorrection requiring a second-stage procedure.
 - Even patients with only mild gynecomastia may have a residual fibrous component that is not amenable to liposuction and requires excision.
- Preoperative markings are performed with the patients in the upright sitting or standing position.
- Prophylactic antibiotics covering skin flora are administered prior to skin incision.

Positioning

- Surgery is performed under general anesthesia as an outpatient procedure.
- Patients are positioned supine with arms abducted and secured to padded, adjustable arm boards. The hips are centered over the bed break, and the patient is secured with a safety strap.
 - Intraoperative assessment of adequate/symmetric resection requires sitting the patients fully upright in the operating room and they should be secured in a manner that enables this to be safely accomplished.
- Sequential compression devices are applied to the lower extremities.
- The entire anterior chest is prepped into the field to allow intraoperative symmetry assessment. Chest hair is removed with electric clippers as needed.

Approach

- Patients with mild to moderate glandular hypertrophy (grades I and II) rarely have significant skin excess. Definitive treatment with suction-assisted lipectomy, power-assisted liposuction (PAL), and/or ultrasound-assisted liposuction (UAL) is frequently possible; direct excision of residual subareolar fibrous tissue may be required.^{7,8}
 - UAL is often associated with improved skin retraction, making it a more

effective treatment modality for gynecomastia than conventional liposuction alone.⁹

- PAL has been shown to reduce operative fatigue and improve control in chest wall contouring.¹⁰
- Patients with more severe gynecomastia and/or ptosis (grades III and IV) typically require resection of excess skin and possibly NAC repositioning.
- Our preference is to perform redundant skin excision along the IMF.
- In extreme cases, breast amputation with free nipple grafting may be necessary.

TECHNIQUES

■ Ultrasound-Assisted Liposuction

Markings

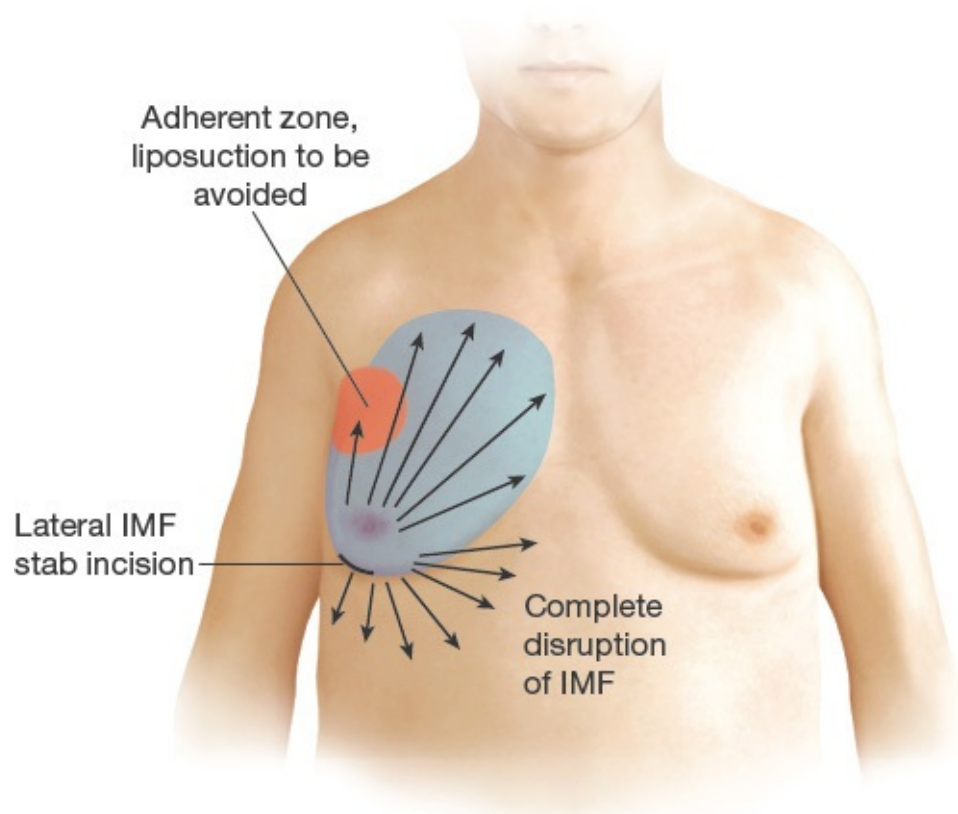
- With the patient standing, the IMF, breast boundaries, and planned incision sites along the lateral IMF are marked.
- Concentric topographic marks centered over the most prominent area of the breast may also be drawn to assist with liposuction.
- An inferior semicircular periareolar incision may be included if direct excision is anticipated.

Liposuction

- Use a no. 11 blade to make bilateral breast stab incisions along the lateral IMF.
 - Additional stab incisions (periareolar, upper anterior axilla) may improve cross-hatching and undermining/disruption of the IMF.
- Systematically infiltrate all treatment areas in multiple layers with wetting solution using a 3.0-mm cannula with a 1:1 ratio of infiltrate to estimated aspirate (superwet technique).
 - Wetting solution consists of 1 L of lactated Ringer solution containing 1 cc of 1:1000 epinephrine and 30 cc of 1% lidocaine.
- Perform UAL on a high energy level using a 3.0- to 5.0-mm cannula connected to a standard surgical aspirator. Unlike traditional liposuction, the intermediate and immediate subdermal adipose layers are targeted to achieve

maximal skin retraction using a careful bimanual technique with constant and deliberate passes in a radial fashion (**TECH FIG 1**). Routine skin protection measures should be used to prevent thermal injury.

- Concentrate additional passes through the dense fibrous tissue in the subareolar region; consider increasing the energy level if needed for greater effect in this area.
- Completely undermine and disrupt the IMF to achieve a smooth transition from the breast to the upper abdomen.
- Use extreme caution when suctioning the adherent zone over the superolateral pectoralis muscle (only minimally for contouring if necessary).
- Primary treatment end points are loss of tissue resistance or blood in the aspirate.
- Convert to standard liposuction or PAL using a 3.0- to 5.0-mm cannula to evacuate residual emulsified fat in the deep and intermediate layers in performing final contouring.

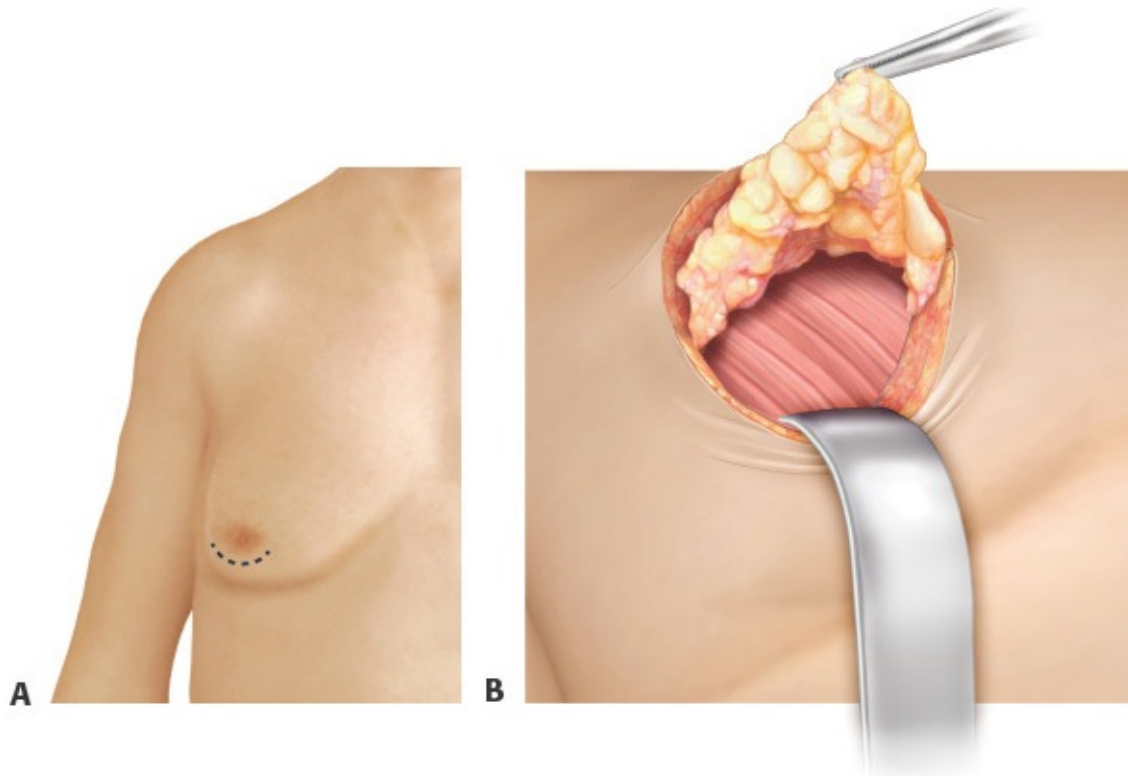


TECH FIG 1 • Depiction of liposuction technique.

Lateral IMF access incision and *black arrows* depict passes of the cannula. The area to be liposuctioned is shown in *blue*. The superolateral adherent zone over the pectoralis major is shown as a *red circle* that should be avoided by the cannula. Inferiorly, the cannula is used to disrupt the IMF and allow for a smooth contour onto the upper abdomen.

Removal of Persistent Tissue

- Often dense subareolar tissue persists despite target liposuction (not uncommon even in mild gynecomastia), requiring morcellation or direct excision.
- Arthroscopic shaver morcellation, using a standard orthopedic arthroscopic system connected to an endoscopic shaver cannula with a rotating dentated cutting tip.¹¹
 - The arthroscopic shaver cannula is inserted through the lateral IMF stab incision with the dentated opening on the tip directed away from the skin.
 - With the cannula oscillation speed set between 4000 and 6000 rpm, the shaver is repeatedly passed through the residual subareolar fibrous tissue until the desired result is achieved.
- Direct excision through an inferior semicircular periareolar incision (**TECH FIG 2**).
 - An inferior periareolar incision is made with a no. 15 blade that can be extended to encompass the entire inferior half of the areola if necessary.
 - Cautery is used to circumferentially dissect out the readily palpable firm glandular tissue. Roughly 1 cm of immediately subareolar glandular tissue should be left to avoid a depression or saucer deformity.



TECH FIG 2 • A. Location of periareolar incision for direct excision of glandular tissue. **B.** Dense fibrous tissue not amenable to liposuction is excised directly.

■ Redundant Skin Excision

Markings

- With the patient standing, the IMF, midclavicular line, and breast boundaries are marked.
- A horizontal ellipse is drawn with its inferior aspect, following the IMF.
- The superior line of the ellipse is drawn to mark the area of planned skin excision based on the amount of skin laxity.
- Following completion of parenchymal liposuction, the patient should be positioned sitting upright on the operating table to assess the breast skin envelope and degree of excess/ptosis.
- Mark the IMFs bilaterally again. This will serve as the inferior border of the ellipse for skin excision.
- Along the length of the IMF, use the pinch test to determine the width of the

ellipse needed to remove the excess skin and close under minimal tension. Mark the superior border of the ellipse to be excised accordingly.

Excision and Completion

- Incise the marked ellipse through the dermis and remove the excess skin using cautery in a subcutaneous plane.
 - This exposure provides an excellent opportunity to confirm complete disruption of the IMF as well. Any residual bands or attachments should be divided with cautery.
- After hemostasis is obtained, place a closed suction drain with a remote egress laterally.
- Reapproximate skin with resorbable buried deep dermal sutures and a running subcuticular stitch.

■ Breast Amputation With Free Nipple Grafting

Markings

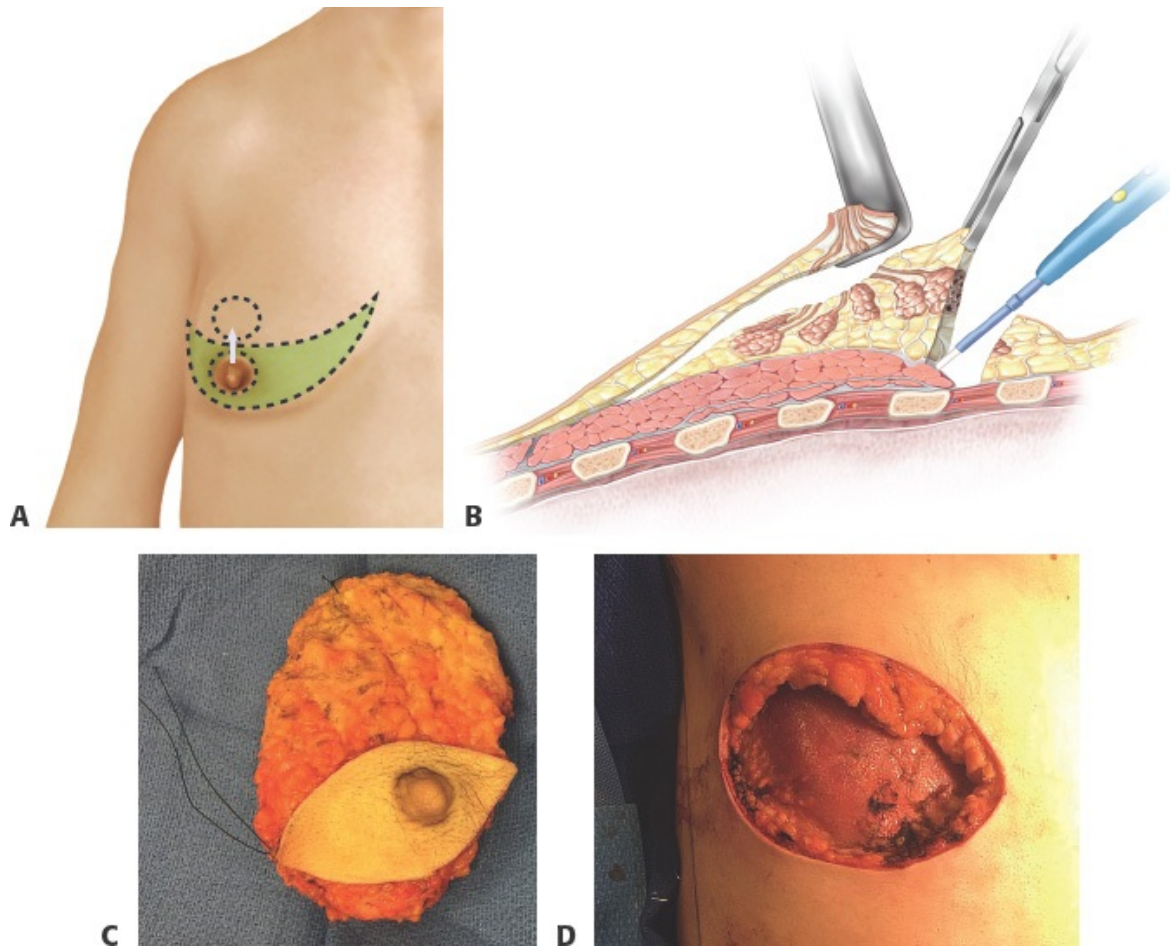
- With the patient standing, the IMF, midclavicular line, and sternal notch are marked.
- Similar to the excess skin excision pattern described, a horizontal ellipse is drawn with its inferior aspect following the length of the IMF.
- Because of the severe ptosis requiring mastectomy, the superior line of the ellipse is drawn to mark the area of planned skin excision based on the amount of skin laxity and includes the NAC (**TECH FIG 3**).

Tissue Excision

- Infiltrate the breast parenchyma and planned incisions (**TECH FIG 4A**) with a dilute solution of 0.5% lidocaine with 1:200 000 epinephrine.
- Outline the NAC and excise it as a full-thickness graft. Debride any fat from the underside of the graft and store it in saline-soaked gauze.
- Incise the superior aspect of the ellipse through dermis using a no. 15 blade.
- Elevate the superior breast skin and subcutaneous tissue in the superficial fascial plane similar to a mastectomy flap, using cautery, knife, or scissors as preferred (**TECH FIG 4B**).



TECH FIG 3 • Grade III gynecomastia with preoperative markings for mastectomy with free nipple grafting. Inner ellipse excised to make defatting the free nipple graft easier, and the planned skin excision (*outer ellipses*) is resected parallel to IMF and estimated by pinch test.



TECH FIG 4 • A. Planned incisions for subcutaneous mastectomy with free nipple grafting. The subcutaneous tissue shown in *green* is excised. The scar is placed along the level of the IMF. **B.** The breast tissue is elevated off the pectoralis fascia. **C.** Mastectomy specimen with short stitch marking superior and long stitch lateral. Notice how far superiorly the glandular resection extends. **D.** Resulting defect after mastectomy, which is closed in layers.

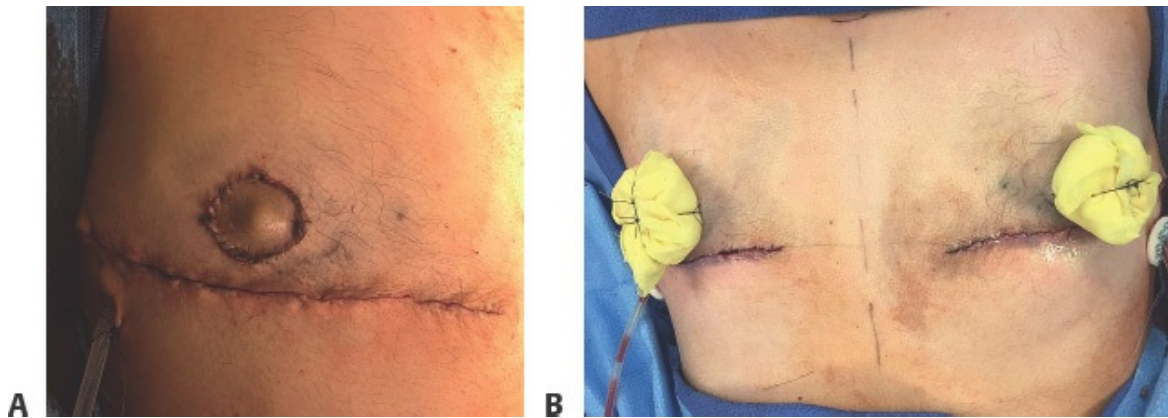
- Once the superior aspect of the breast tissue is reached, it is elevated off the pectoralis fascia from superior to inferior until reaching the level of the IMF and the inferior aspect of the ellipse.
- Ensure that the superior and inferior skin flaps of the ellipse will close

without tension, and then incise the inferior aspect of the ellipse and remove the breast tissue (**TECH FIG 4C,D**).

- Confirm hemostasis and close the new IMF incision primarily in layers.
- Repeat the same procedure on the contralateral side.

Nipple Grafting

- Draw the new NAC position as a 3-cm-wide oval centered in the midclavicular line over the fourth intercostal space.
- Once satisfied with nipple position and symmetry, de-epithelialize the 3-cm ovals.
- Trim the free nipple grafts to fit with the nipples centered on the oval and secure using 4-0 chromic suture on a taper needle (**TECH FIG 5A**).
- Apply bolster dressings of cotton soaked with mineral oil and wrapped in Xeroform gauze. Secure these with silk sutures over bilateral NACs (**TECH FIG 5B**).
- These bolsters remain in place for 5 to 7 days postoperatively.



TECH FIG 5 • **A.** Free nipple grafts are inset over de-epithelialized area above the IMF incision. **B.** Bolsters applied to free nipple grafts for 5 to 7 days.

PEARLS AND PITFALLS

Subglandular

- Consider excising residual subareolar fibrous tissue at the time of

excision	UAL using either the arthroscopic shaver or direct excision technique. ■ Maintain 1 cm of subcutaneous tissue under NAC to avoid a saucer deformity.
Liposuction technique	■ Focus UAL on the subdermal adipose tissue to achieve maximal skin retraction. ■ Avoid suctioning the adherent area over the superolateral pectoralis muscle. ■ Completely undermine/disrupt the IMF to create a smooth inferior chest transition.
Intraoperative assessment	■ In order to adequately evaluate the surgical result, sit the patient upright on the operating table following resection to ensure satisfactory contour and symmetry.
Revisions	■ Wait more than 6 months for maximal skin retraction prior to performing resection of residual excess skin/tissue.
Duration of gynecomastia	■ Gynecomastia present for more than 12 months is unlikely to resolve spontaneously due to parenchymal fibrosis and typically requires surgical intervention.
Postoperative care	■ Chest compression dressings should be worn continuously for 2 weeks postoperatively.

POSTOPERATIVE CARE

- Except in rare instances of extremely large resections, these cases are performed as ambulatory procedures with patients going home the same day.
- Patients are instructed to wear a chest compression garment or Ace wrap for 2 weeks postoperatively. This maintains pressure on the chest to minimize hematoma and seroma formation.
- Closed suction drains are placed only for procedures that include more than liposuction. These are typically removed at the first postoperative visit.
- Postoperative follow-up visits are scheduled at 1 week, 4 weeks, and 4 to 6 months.
- Patients who underwent UAL-only resection should be re-evaluated around 6 months to allow time for skin retraction before determining the need for revision with excision of excess skin and residual parenchymal tissue.^{7,8}

OUTCOMES

- Gynecomastia reduction surgery outcomes show high overall patient

satisfaction rates. Overall complication rates range from 14.5% to 53% with hematoma being the most common.^{12–14} Hematoma rates appear higher in open subcutaneous mastectomies (11%–16%), compared to cases treated with liposuction alone (1%).^{9,12–14} Inadequate resection with the need for revision is the most common long-term complication.^{7,8}

COMPLICATIONS

- Hematoma
- Seroma
- Infection
- Inadequate resection
- Poor scarring
- Contour deformity/asymmetry
- Sensory changes

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Section IV: Breast Reconstruction for Partial Mastectomy Defects

Partial Breast Reconstruction With Local Tissue Rearrangement

11
CHAPTER

Moustapha Hamdi

DEFINITION

- The treatment of breast cancer is an evolving field. Different modalities are continuously being developed to maximize patient survival while minimizing the treatment's morbidity.¹⁻⁵
- Currently, the two main options for the management of primary breast cancer are total mastectomy and lumpectomy/quadrantectomy with radiation.¹⁻⁵
- Studies have shown that women diagnosed at early stages of invasive breast cancer have equivalent outcomes when they are treated with lumpectomy and radiation therapy or modified radical mastectomy.²⁻⁵
- Oncoplastic surgery is a combination of breast conservative surgery and an immediate partial breast reconstruction.⁶
- This chapter reviews partial breast reconstruction after partial mastectomy.

ANATOMY⁷

The Blood Supply

- The blood supply of the breast is a rich anastomotic network derived from the axillary, internal thoracic (internal mammary), and two intercostal arteries.

- Multiple factors can influence how robust each of these sources of inflow may be (age, endocrine activity, overall health, systemic diseases, eg, diabetes/atherosclerosis, smoking, radiotherapy).
- The major inflow sources, from medial to lateral, are the internal mammary segmental perforators, the intercostal perforators, the thoracoacromial perforators, and the external mammary artery.
- The anteromedial and anterolateral intercostal perforators are major contributors to the vascularization of the nipple-areola complex (NAC).
- The venous drainage is a dual system: a superficial subdermal plexus, which eventually meets up in the deep system, and a deep system, which accompanies the mentioned arterial system.

The Nerve Supply

- The medial and central breast sensations come from the second through the sixth anteromedial intercostal nerves.
- The nipple-areola sensation is contributed by the third, fourth, and fifth anteromedial and anterolateral intercostal nerves.
- Careful consideration of the nerve supply helps to maximize nipple sensation. When pedicled flaps (see Chapter 22) are passed into partial mastectomy defects, the tunnel should be created high enough to avoid lateral denervation to the breast.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Breast and plastic surgeons must have a thorough understanding of breast anatomy, physiology, and the qualities of an aesthetically pleasing breast shape.
- Surgeons performing the oncoplastic approach should consider the aesthetic subunits when planning cosmetic quadrectomies, resections, and reconstructions.
- Also, knowledge of the anatomical landmarks, breast proportions, and shape is essential to achieve a pleasing outcome.
- Preoperative evaluation of the patient and her breasts must be standard and detailed.
- The examination must include the following:
 - Evaluation of breast skin, elasticity, thickness, scars, and any defining marks such as tattoos, stretch marks, contour irregularities, and previous breast surgery should be taken into account when planning breast-conserving therapy (BCT).

- Palpation for masses or abnormalities in the breast parenchyma, nipple inspection, and detailed documentation of breast sensation are integral.
- Breast shape, grade of ptosis, and size are determinants of success in surgical treatment.
- The base and width of the breast, the width of the NAC, the height of the nipple, and the distance from the sternal notch, midline and inframammary crease, must be recorded in detail.
- Any natural breast asymmetry should be pointed out to the patient before surgery.
- Different body types, skin laxity, and fat distribution are important factors in the decision-making process.

SURGICAL MANAGEMENT

Oncological Approach

- Indications: Most early-stage cancers (T1 and T2 cancers with or without nodal involvement) are indicated for BCT.^{6,8}
- Contraindications: Patients with a high probability for recurrence, especially those with multicentric disease, those who are pregnant or have collagen vascular disease, or those who have a history of prior radiation therapy.^{6,8}
- Relative contraindications include the following:
 - Patients with a high probability of subsequent cancers (BRCA mutations)
 - Patients who are likely to have a poor cosmetic result, which includes patients with a high tumor/breast ratio
 - Medially and inferiorly based tumors
 - Tumors that require removal of the NAC

Clinical Approach

- The success of this procedure depends on the size of the cancer, the anatomical position, and the volume of resection needed to achieve clear margins in relation to the volume of the breast.
- The choice of the technique used depends on many factors, including the extent of resection, the time of surgery, the breast size and tumor location, and patient preferences.
- Preoperatively, incision lines and preservation of the NAC should be discussed with the oncologic surgeon and patient.
- The estimation of the defect size after tumor resection and breast size/tumor

ratio is a guideline to the choice of the reconstructive method (**FIG 1**).

- Immediate correction of asymmetry by a contralateral mastopexy or reduction should also be discussed (Table 1).
- There are two basic types of surgery techniques in partial breast reconstruction: volume displacement and volume replacement.
 - Volume displacement techniques refer to advancement, rotation, or transposition of large local breast flaps into the smaller created defect, redistributing the volume loss. The dissection involves the advancement of a full-thickness segment of breast fibroglandular tissue to fill the dead space. Volume displacement procedures and surgical scars are optimal when combined with mastopexy-reduction techniques. The tumor is excised within the planned markings of the reduction specimen in medium, large, or ptotic breasts, and the remaining parenchyma is sufficient enough to reshape the breast mound.
 - Volume replacement techniques are technically more difficult and are used in small to moderate-size breasts or when the tumor/breast ratio is large and the remaining breast tissue is insufficient for the rearrangement and the replacement of the defect. Volume replacement with the use of nonbreast local or distant flaps provides both tissue for the filling of the glandular defect and the skin deficiency of the reconstructed breast (see Chapter 22).

Table 1 Important Considerations in Partial Breast Reconstruction

1.	Incision lines
2.	Nipple-areola preservation
3.	Estimation of defect size after tumor resection
4.	Reconstructive method depending on breast size/tumor size ratio
5.	Consider delayed immediate reconstruction if doubt about margins
6.	Status of contralateral breast: no surgery vs mastopexy/reduction or prophylactic mastectomy

Preoperative Planning

- The patient is preferably marked before surgery. The breast size, tumor size, and location as well as the final defect size are estimated.
- Good communication between teams, oncological and reconstructive, if this is being performed by a two-team approach

- It is important to understand the importance of blood supply to the nipple, placement of skin incisions, and have an understanding of breast aesthetics.
- It is equally important that the reconstructive surgeon realize the size and location of the tumor, importance of margin status, and locoregional control.
- Both surgeons should review the radiographic imaging and discuss the anticipated defect location and defect size, as well as whether or not the resection would include skin.
- This will assist with determination of the most appropriate glandular pedicle required to maintain nipple viability and reshape the mound.
- Anticipate a backup plan, as occasionally the defect is different to that anticipated, and an alternative approach is required. The incisions for the tumor resection are chosen from an oncological aspect but in the most aesthetically pleasing fashion.
- Planning of skin incisions and parenchymal excisions follow templates using reduction mammoplasty and mastopexy techniques.
- The pattern can be rotated laterally or medially to fit the location of the tumor. The choice of the pedicle is related to the tumor location (Table 2).
- Tumors involving the lower pole are the most easily treated because this region is removed during most reduction techniques.

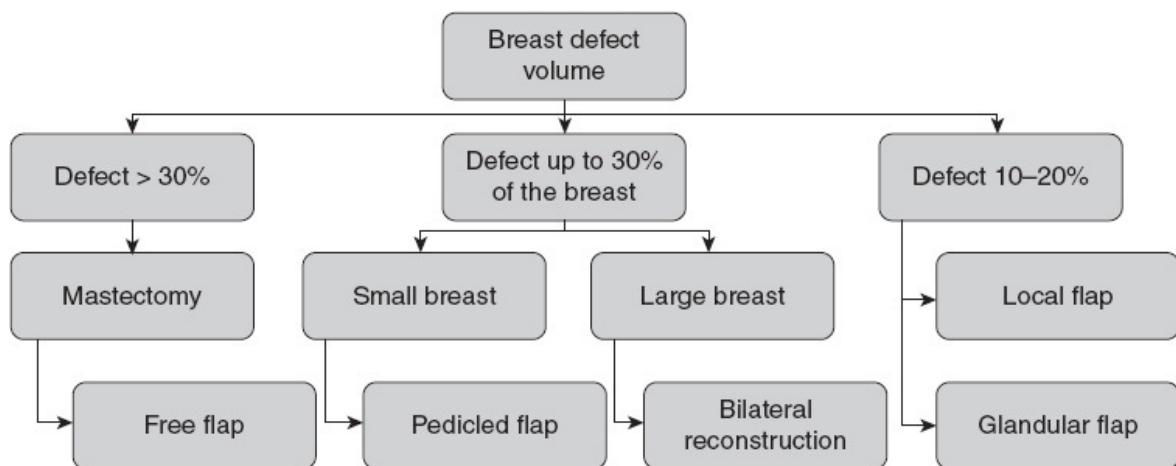


FIG 1 • An algorithm to partial breast reconstruction.

Table 2 Choice of Pedicle Based upon Location of the Defect

Location of the Defect	Choice of Pedicle
Inferior, inferomedial, or	Superior, superomedial or superolateral

inferolateral	pedicle
Superior	Inferior or centroinferior pedicle
Superomedial	Superolateral pedicle with an inferocentral component to fill the defect
Superolateral	Superomedial pedicle with an inferocentral component to fill the defect
Central	Inferior pedicle

- A similar mammoplasty technique is performed on the contralateral breast to match the size and shape of the tumor-affected breast.
- If radiation is planned, consider keeping the tumor-affected breast about 10% larger in size compared to the contralateral remodeled breast because some shrinking and volume changes of the radiated breast are likely to occur.
- However, immediate partial reconstruction should be delayed if the surgeon is uncertain about the margins or tumor extension (eg, tumors with large in situ component) despite the preoperative radiological assessment. A *delayed immediate reconstruction* can still be performed within a few days after the definitive margins become known.

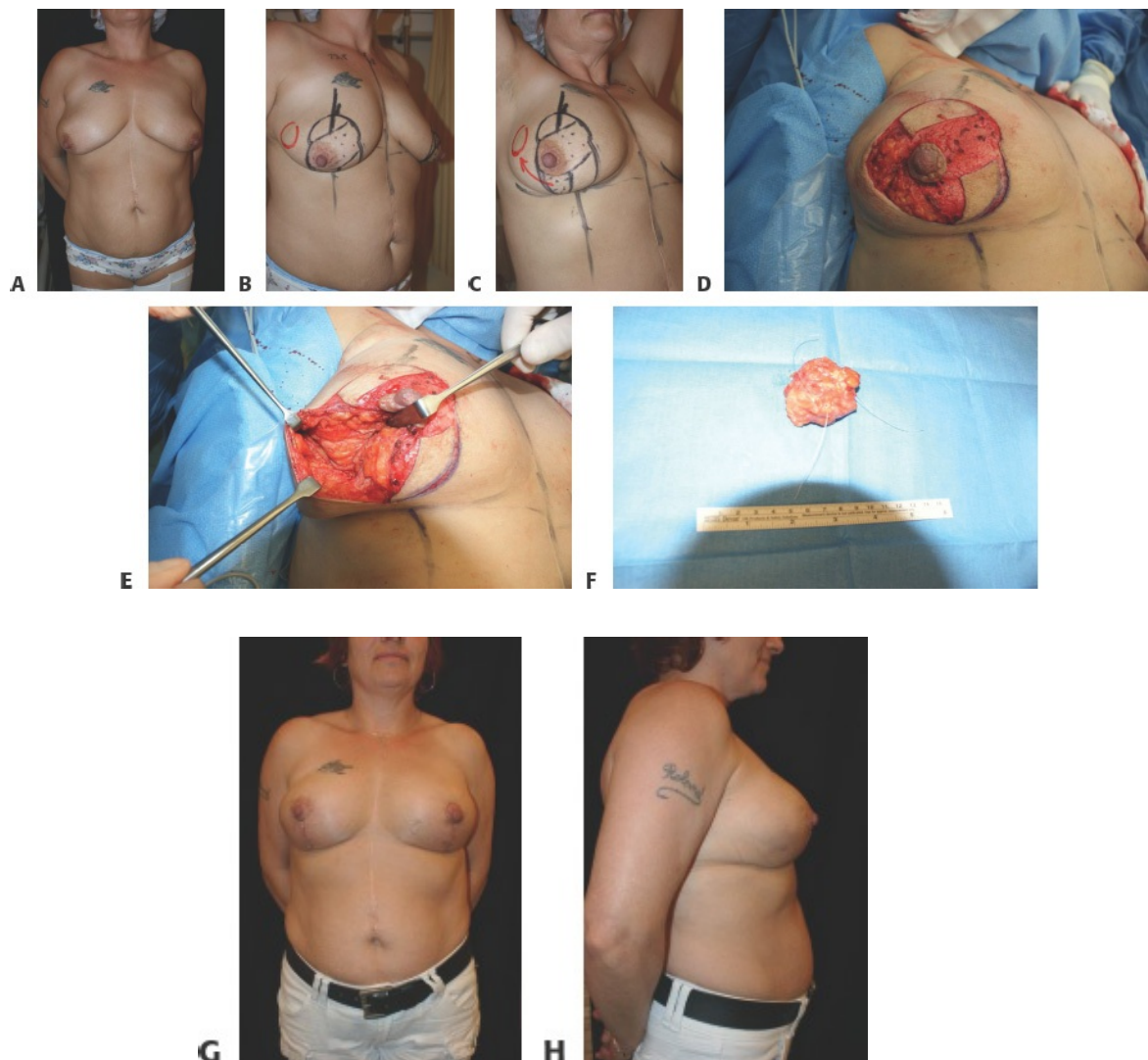
TECHNIQUES

■ Tumor Resection

- Tumor removal is performed in the usual fashion using safe and effective oncological principles.^{9,10}
- Intraoperative margin assessment could include radiographical imaging, macroscopic assessment, frozen section, or touch cytology.
- We have found that patient selection, cavity sampling, and generous resection further reduce the incidence of positive margins.
- The cavity is then clipped for postoperative surveillance and guidance for radiation boosts to the tumor bed if required.

■ Principles of Rearrangement Techniques⁶

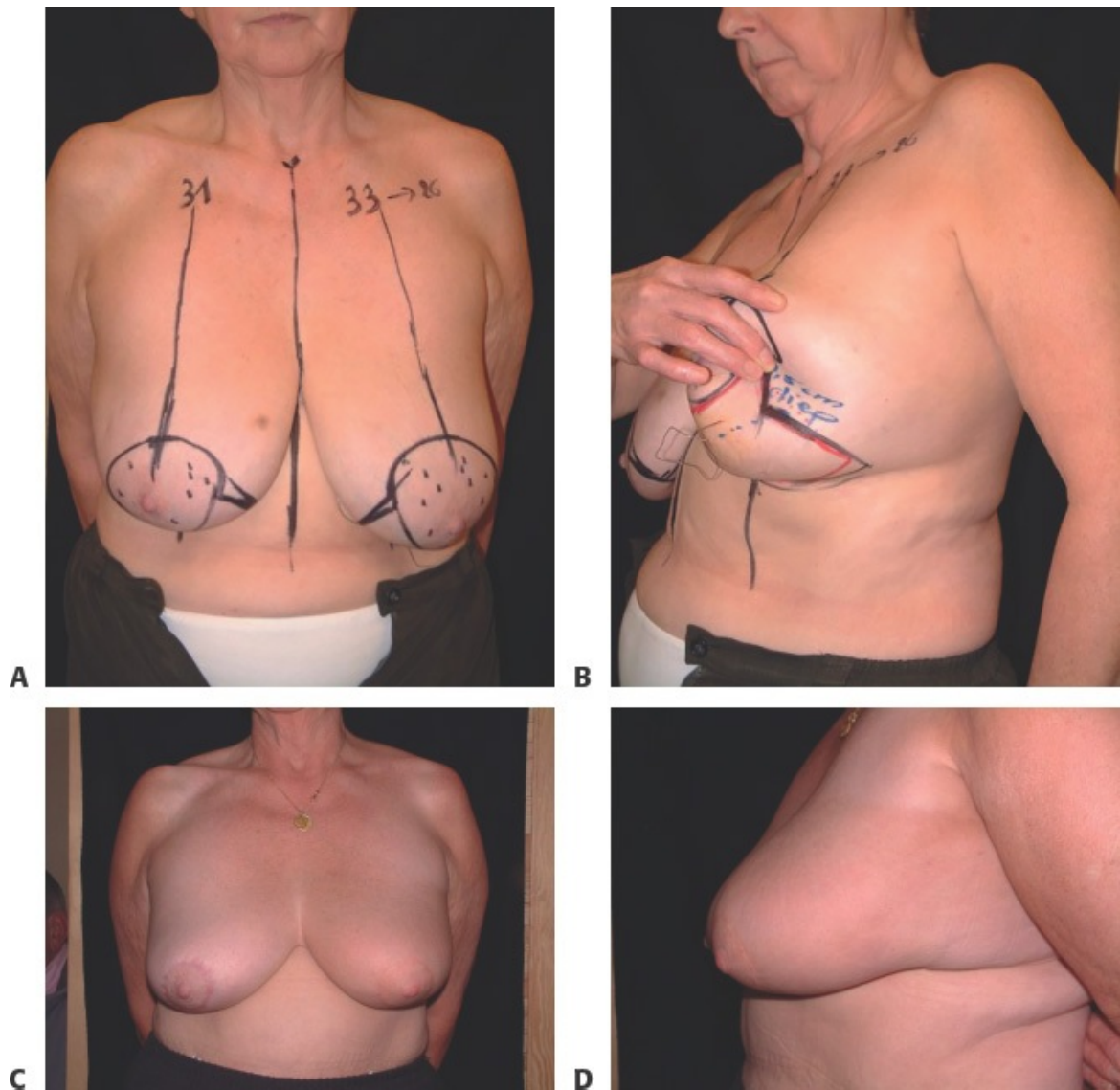
- For nipple pedicle choice, the shortest pedicle will maximize nipple viability and allow additional glandular manipulation without worrying about nipple compromise.
- As a general rule, if the pedicle points to or can be rotated into the defect, it can be used (Table 2).
- When it is not possible to preserve the nipple, either because of the size of the breasts or because of the location of the tumor, options include amputation and free nipple graft, or nipple reconstruction at a later date.
- The pedicle is de-epithelialized and dissected enough to allow rotation into the proposed nipple position (**TECH FIG 1**).



TECH FIG 1 • A 48-year-old patient who was a

candidate for BCT for a T2 tumor over the superolateral quadrant. **A.** Preoperative view shows ptotic breasts. **B.** The surgical plan consisted of a vertical scar mammoplasty with a superomedial pedicle technique. **C.** A glandular flap extension was planned to fill the defect in the lateral quadrant after tumor removal. **D.** The pedicle was deepithelialized. **E.** The lumpectomy was done through the lateral mammoplasty incision. **F.** The tumor was oriented and sent to the pathology analysis. **G.** The result: front view showed a good breast symmetry. **H.** The result: a lateral view showed a good breast contour without any deformity.

- If the defect is removed within the reduction specimen, it is then adequately filled through glandular displacement with the pedicle or remaining glandular tissue (**TECH FIG 2**).
- If it is thought that additional glandular flaps are required to fill the dead space, a decision is made based on what tissue is available:
 - *Single pedicle technique:* If the defect can be filled by rotating an extended portion of the original nipple pedicle, this is often the technique of choice. This works well for smaller defects in women with smaller or moderate-sized breasts, or when tissue can be taken with the pedicle from a less cosmetically sensitive area and rotated to fill a defect.
 - *Secondary pedicle technique:* This is used in larger defects with large breasts if the primary pedicle or residual parenchyma is not sufficient. A second pedicle is designed to fill the dead space separate from the nipple pedicle.
- Glandular shaping is performed using absorbable sutures where necessary, and the skin is then redraped over the mound.
- Drains are used if the defect is in communication with the axillary dissection.



TECH FIG 2 • A 64-year-old patient who was diagnosed with T2 ductal carcinoma of the left breast. A 3-cm tumor was located in the inferolateral quadrant. An inverted-T mammoplasty with superior pedicle was planned in order to perform a quadrantectomy with immediate partial reconstruction and contralateral remodeling for symmetrization. **A.** Preoperative view shows the mammoplasty markings. **B.** The quadrantectomy was planned within the inverted-T mammoplasty pattern. **C,D.** The result after

radiotherapy at 1 year postoperatively.

PEARLS AND PITFALLS

Timing	■ Delayed partial breast reconstruction should be considered in every situation where tumor margins could not be adequately determined preoperatively.
Marking	■ The contralateral nondiseased side should be designed to be a bit higher to anticipate the long-term breast sagging. ■ The affected breast (cancer side) should be marked to end up with larger volume comparing to the contralateral breast to anticipate postoperative irradiation effect).
Tumorectomy	■ Tumor specimen should be clearly oriented for pathology. ■ Posttumorectomy defect should be marked by surgical clips.
Pedicles	■ Avoid large tissue detachment in high-risk patients. ■ Avoid dead space, especially in the lower breast.
Follow-up	■ Close collaboration and communication between plastic surgery, radiologist, and oncologist is mandatory to discuss breast changes after breast rearrangement surgery.

POSTOPERATIVE CARE

- Patients receive VTE prophylaxis during the time of relative immobilization.
- Patients leave the hospital when the drains are removed, which is in average 1 to 2 days.
- A sports bra is applied for 4 weeks postoperatively.
- Adjuvant irradiation of the breast, if indicated, can be started at 6 weeks postreconstruction. Adjuvant chemotherapy can start 3 weeks postoperatively.

OUTCOMES AND COMPLICATIONS

- The 5-year survival of partial mastectomy with radiation is not statistically different when compared to mastectomy alone in patients with stage I or II breast cancer.²⁻⁵
- The 5-year incidence of in-breast tumor recurrence was higher in the lumpectomy and radiation patients compared to the quadrantectomy and

radiation patients (8.1% vs 3.1%).^{2,3}

- In lumpectomy, the goal is tumor excision with clear surgical margins.
- In quadrantectomy, a wide excision is performed with an additional 1 to 2 cm or even more of healthy parenchyma around the tumor, including skin and underlying muscle fascia.
- The majority of local recurrences occur at the site of initial tumor excision (57% to 88%) or in the same breast quadrant (22% to 28%).¹¹
- The presence of DCIS at the surgical margin is associated with the identification of residual DSIC in 40% to 82% of re-excised specimens and is correlated with margin widths of 41% at 1 mm, 31% at 1 to 2 mm, and 0% with 2 mm of clearance.³
- A recent meta-analysis showed lower positive margins after oncoplastic surgery (12%) compared to breast conservative surgery without oncoplastic reconstruction (21%).¹²
- Local recurrences were also lower after oncoplastic surgery (4.2% compared to 7% with BCT alone).¹²⁻¹⁴
- Approximately 10% to 30% of patients are dissatisfied with the aesthetic result after partial mastectomy with radiation.^{15,16}
- Oncoplastic surgery or partial breast reconstruction allows for wider tumor resection with aesthetic favorable outcomes and lower positive margins.¹⁵⁻²¹
- Incorporating a reduction mammoplasty with partial mastectomy can potentially be a complex procedure.^{22,23}
 - The aesthetic outcome was considered good or very good in 81% of patients.^{12,18-21}
- Recent literature, however, suggests that early complications are similar to mere reduction mammoplasty. In a review by Spear et al., none of the complications significantly interfered with healing, radiation, chemotherapy, or the quality of the result.^{22,23}

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12 Local Flaps in Partial Breast Reconstruction

CHAPTER

Moustapha Hamdi and Fadi Bakal

DEFINITION

- Partial breast reconstruction is an area of evolving interest with improving surgical techniques; it is indicated in breast conservation therapy (BCT), which is on its own a popular treatment option for women with breast cancer.^{1,2} The rate of its use has increased from 40% in 1991 to 60% in 2002 when compared with mastectomy, and that trend continues to rise.¹
- Oncoplastic surgery within multidisciplinary approach is standard in BCT.
- The oncoplastic surgical approach allowed surgeons to tailor the techniques to prevent deformities, minimize involved margins, and reduce the potential for local recurrence.
- Partial breast reconstruction with pedicled flap is alternative to mastectomy in selected patients as such in patients with a high tumor/breast size ratio.
- Every case requiring partial breast reconstruction should be addressed within a multidisciplinary approach.
- Pedicled perforator flaps provide adequate partial breast reconstruction with minimal donor-site morbidity.

ANATOMY

- The latissimus dorsi (LD) flap has a constant anatomy.^{3–5} The blood supply of the latissimus dorsi comes from a terminal branch of the subscapular artery. The subscapular artery runs about 5 cm before dividing into the scapular circumflex and thoracodorsal arteries.
- The thoracodorsal artery gives off one or two branches to the serratus anterior muscle and one branch to the skin (**FIG 1**).
- Perforating vessels from the intercostal and lumbar arteries supply the muscle

and overlying skin.^{11,12}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Breast and plastic surgeons must have a thorough understanding of breast anatomy and physiology and the qualities of an aesthetically pleasing breast shape.
- Surgeons performing the oncoplastic approach should consider the aesthetic subunits when planning cosmetic quadrantectomies, resections, and reconstructions.³
- Also, knowledge of the anatomical landmarks, breast proportions, and shape is essential to achieve a pleasing outcome.
- Preoperative evaluation of the patient and her breasts must be standardized and detailed.
- The examination must include the following:
 - Evaluation of breast skin, elasticity, thickness, scars, and any defining marks such as tattoos, stretch marks, contour irregularities, and previous breast surgery should be taken into account when planning BCT.

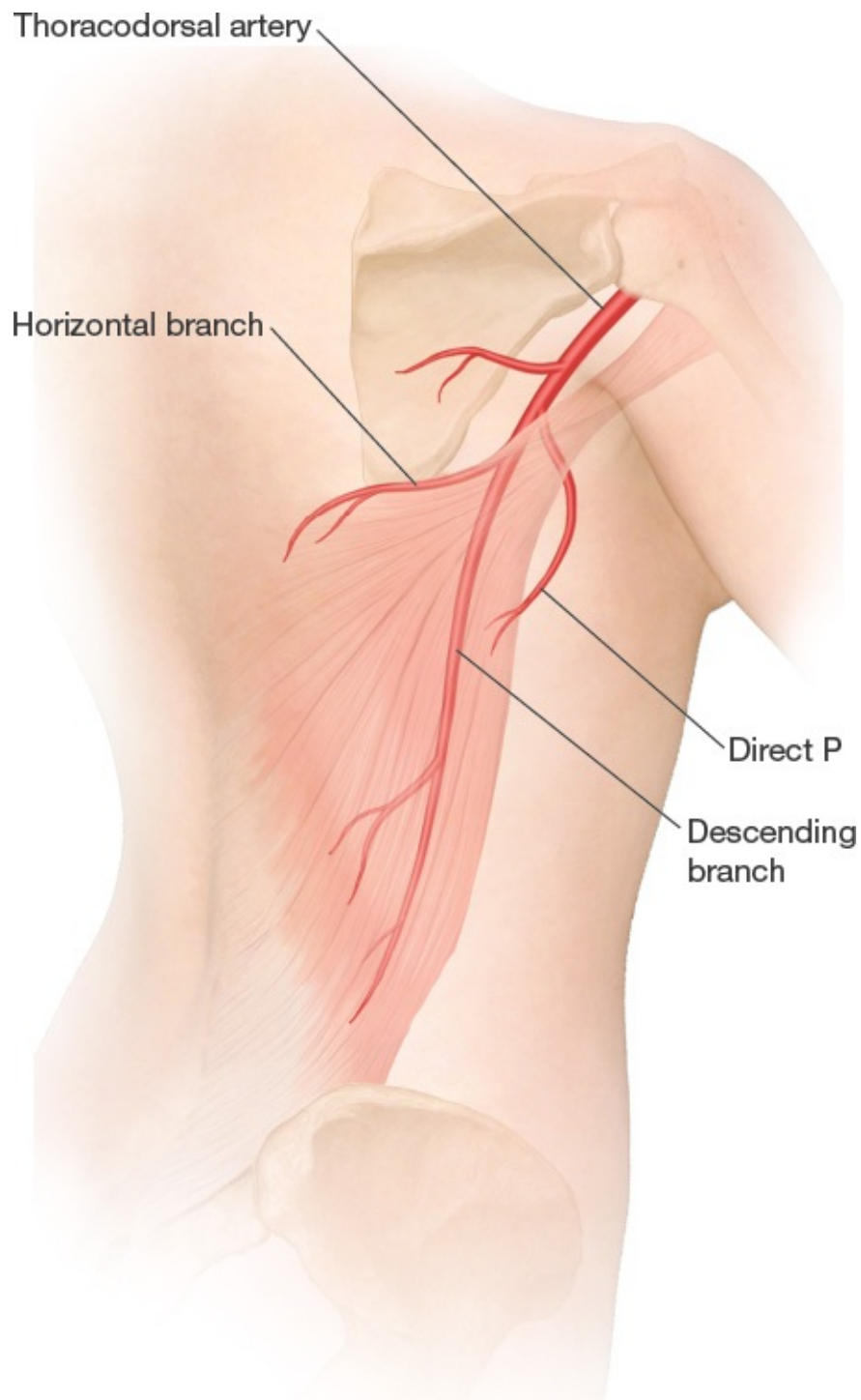


FIG 1 • The TD vessels most commonly divide into five branches, but two are dominant muscular branches: the transverse branch, and the lateral or vertical branch. Both branches give musculocutaneous perforator to the skin. A direct branch can also be found, which courses

anteriorly around the LD muscle toward the skin.

- Palpation for masses or abnormalities in the breast parenchyma, nipple inspection, and detailed documentation of breast sensation are integral.
- Breast shape, grade of ptosis, and size are determinants of success in surgical treatment.
- The base and width of the breast, the width of the NAC, the height of the nipple, and the distance from the sternal notch, midline, and inframammary crease must be recorded in detail.⁴
- Any natural breast asymmetry should be pointed out to the patient before surgery.
- Different body types, skin laxity, and fat distribution are important factors in the decision-making process.

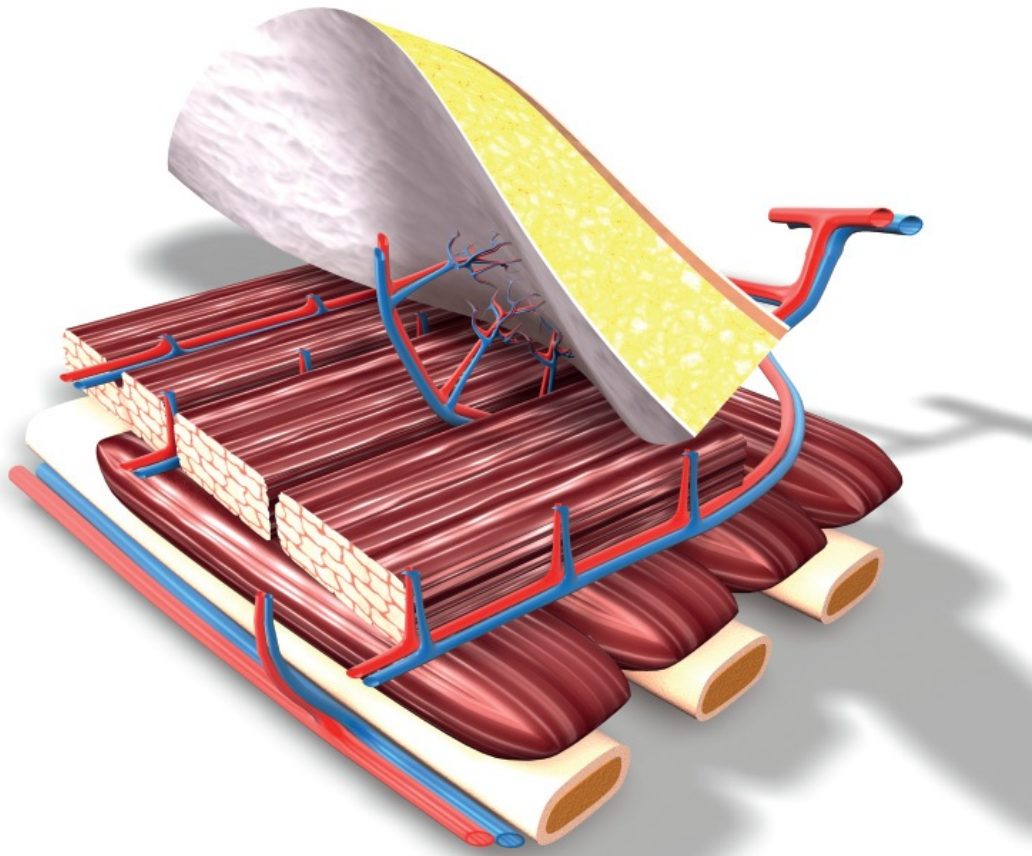
SURGICAL MANAGEMENT

- Depending on the location and the size of the breast defect, different flaps can be used for partial mastectomy reconstruction based on the thoracodorsal-serratus, intercostal, or superior epigastric vessels.^{2–18}
- A small lateral defect can easily be closed with a skin rotation flap or lateral thoracic axial skin flap. However, most of these flaps become unavailable when axillary lymph node dissection is performed.
- Lateral breast defects are usually reconstructed using a flap based on the thoracodorsal system. The LD musculocutaneous flap is the most commonly used.
- Currently, perforator flaps are more often used to spare muscle function.
 - The pedicled perforator flaps mostly used by us for partial breast reconstruction, classified according to the basic nutrient arteries and recommended by the “Gent” Consensus update in 2002,⁶ are
 - Thoracodorsal artery perforator (TDAP) flap
 - Serratus anterior artery perforator (SAAP) flap
 - Intercostal artery perforator (ICAP) flap
 - Superior epigastric artery perforator (SEAP)
- A similar skin paddle to the classical LD musculocutaneous flap can be raised on perforators either from the thoracodorsal or intercostal vessels.

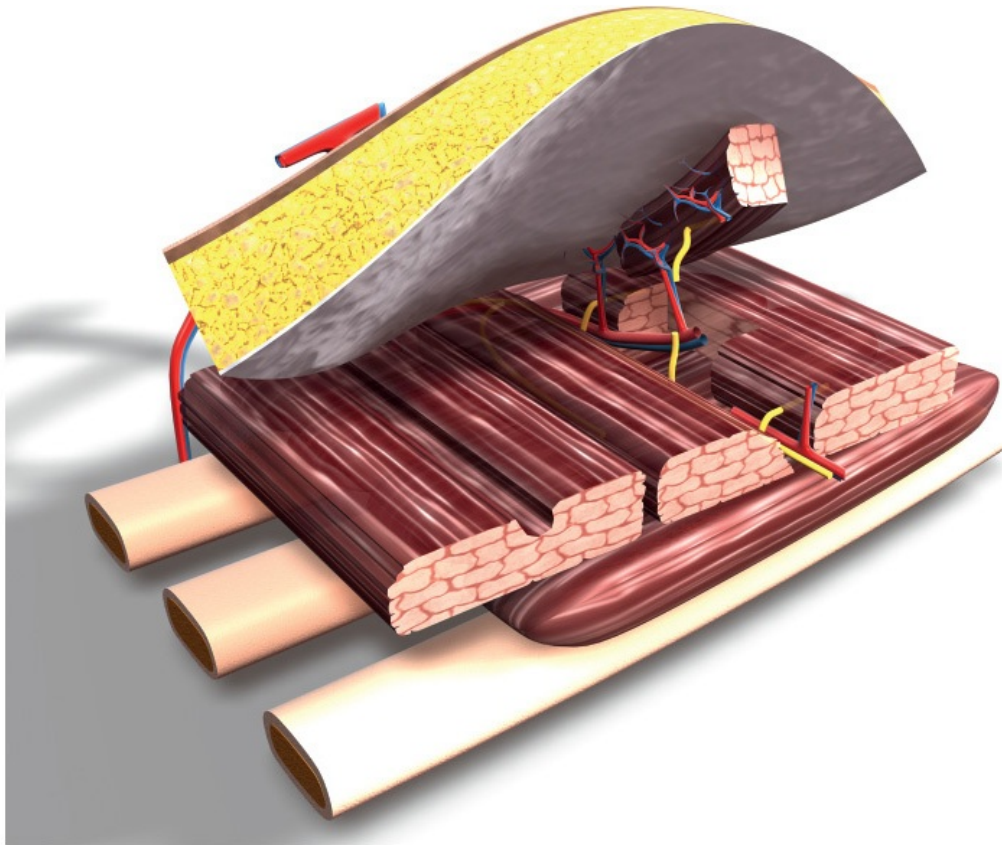
Types of Flaps

TDAP Flap

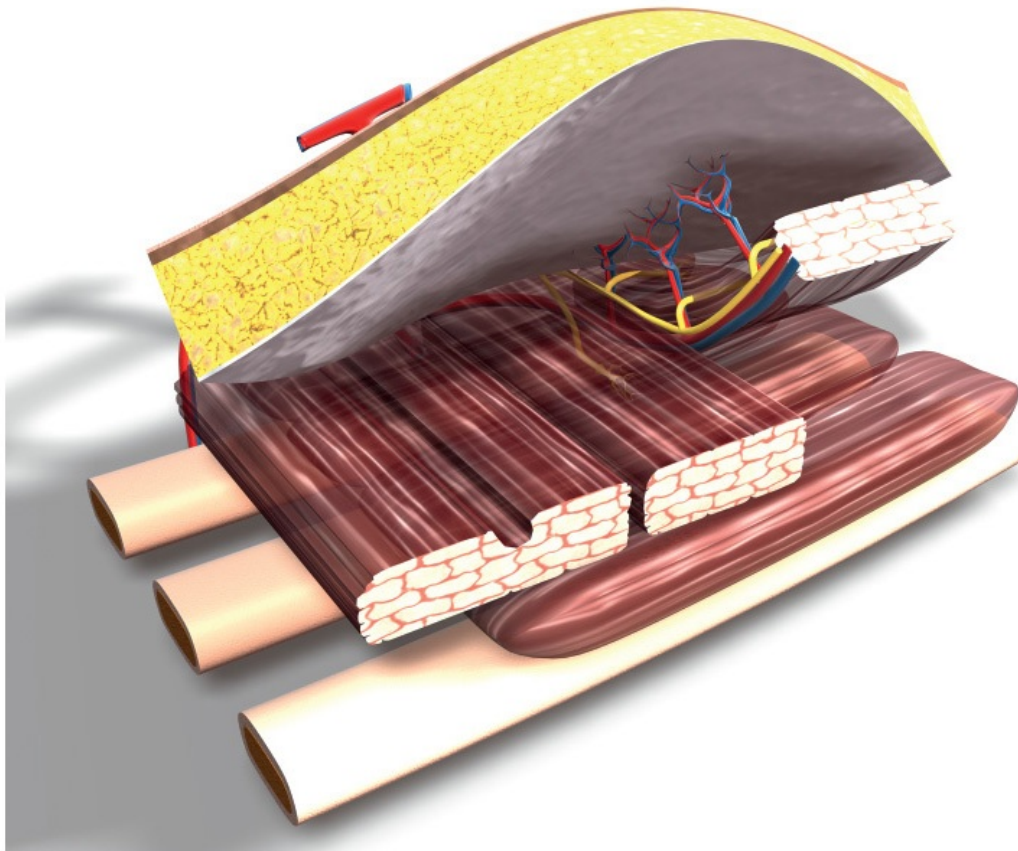
- The TDAP flap is based on perforators originating from the descending (vertical) or horizontal branches of the thoracodorsal vessels (see **FIG 1**) (**FIG 2**). Anatomic studies on cadavers have reported the presence of 2 to 3 musculocutaneous perforators from the vertical branch.⁷⁻⁹
- The proximal perforator enters the subcutaneous plane obliquely 8 to 10 cm distal to the posterior axillary fold and 2 to 3 cm posterior to the anterior border of the muscle. The second perforator is found 2 to 4 cm distally to the first one.
- Occasionally, a direct cutaneous perforator arising from the thoracodorsal vessel passes around the anterior border of the muscle, making flap harvesting easier (see **FIG 1**).
- There may not be always a single reliable perforator for the TDAP flap, due to anatomical variations. In this case, the surgeon must be aware and prepared to modify the flap dissection intraoperatively, as a muscle-sparing TDAP flap.



A



B



C

FIG 2 • Illustrations show: TDAP flap with musculocutaneous perforators (**A**). **B**. TDAP flap with perforator still attached to 4 × 2 cm muscle segment (muscle-sparing TDAP type I). **C**. TDAP flap raised on the descending branches and its perforators (muscle-sparing TDAP flap type II). Reprinted from Hamdi H, et. al. Pedicled perforator flaps in breast reconstruction: a new concept. *Br J Plast Surg*. 2004;57(6):531-539, with permission from Elsevier.

- The TDAP flaps are classified as follows⁹:
 - TDAP flap, when no muscle component is included in the flap.
 - TDAP-MS-I, where a small segment of muscle (4 × 2 cm) is kept attached to the back of the perforator vessels. The muscle segment protects the perforator from excessive tension and provides more freedom in flap positioning (**FIG 2B**).
 - TDAP-MS-II is indicated when multiple but small perforators are encountered. A larger segment, up to 5 cm wide along the anterior border of the LD muscle together with the descending branch of the thoracodorsal vessels, is then included within the flap in order to ensure maximal blood supply to the skin paddle (**FIG 2C**).

ICAP Flap

- The ICAP flap is based on perforators, arising from the intercostal vessels.
- The intercostal vessels form an arcade between the aorta and the internal mammary vessels and divide in 4 segments: vertebral, intercostal, intermuscular, and rectus segments (**FIG 3A**).^{11,12}
- The ICAP flaps are classified as follows (**FIG 3B**):
 - The dorsal intercostal artery perforator (DICAP) flap. The flap is based on perforators originating from the vertebral segment of the intercostal vessels.
 - The lateral intercostal artery perforator (LICAP) flap, based on perforators arising from the intercostal segment.
 - The anterior intercostal artery perforator (AICAP) flap. The nutrient perforators of this flap arise from the muscular or rectal segment.
- The intercostal segment, which is the longest (12 cm), is very important

because it gives 5 to 7 musculocutaneous perforators.¹¹

- The LICAP, commonly used in breast surgery, originates from the costal segment of the intercostal vessels. The largest perforator is most frequently found in the 6th intercostal space, 0.8 to 3.5 cm from the anterior border of the LD muscle.¹² The pedicle has adequate length, allowing the rotation of the flap up to 180 degrees without tension and with no need to extend the dissection into the costal groove. An intercostal nerve may be included in the harvesting as an ICAP-sensate flap.
- For small defects, the LICAP is designed on the lateral aspect of the thorax. For moderate-large defects, the distal limit of the skin pad can reach the posterior thoracic region, planned in a fashion similar to the skin pad of an LD flap.¹²
- The AICAP flap is outlined over the upper abdomen, so that the final scar will be hidden under the brassiere strap. The donor site can be closed primarily if it is up to 6 cm wide (preoperative pinch test to be assured) or else in a reversed abdominoplasty fashion. The advantage of AICAP and SEAP flaps (see below) is that the patient is prepped in a supine position throughout the whole procedure. These flaps are mostly known for defects in the inferomedial quadrant of the breast.

SAAP Flap

- The SAAP flap is based on a connection between the thoracodorsal artery branch to the serratus anterior muscle and the intercostal perforators. It is not a constant perforator; 21% of cases there is a connection between the serratus anterior branch & the intercostal perforators.¹²
- When an appropriately sized perforator is identified in front of the anterior border of the LD, it can be followed back to the nutrient artery, which in this case is the serratus anterior branch, by dissecting the pedicle within the fascia and the fibers of the aforementioned muscle.

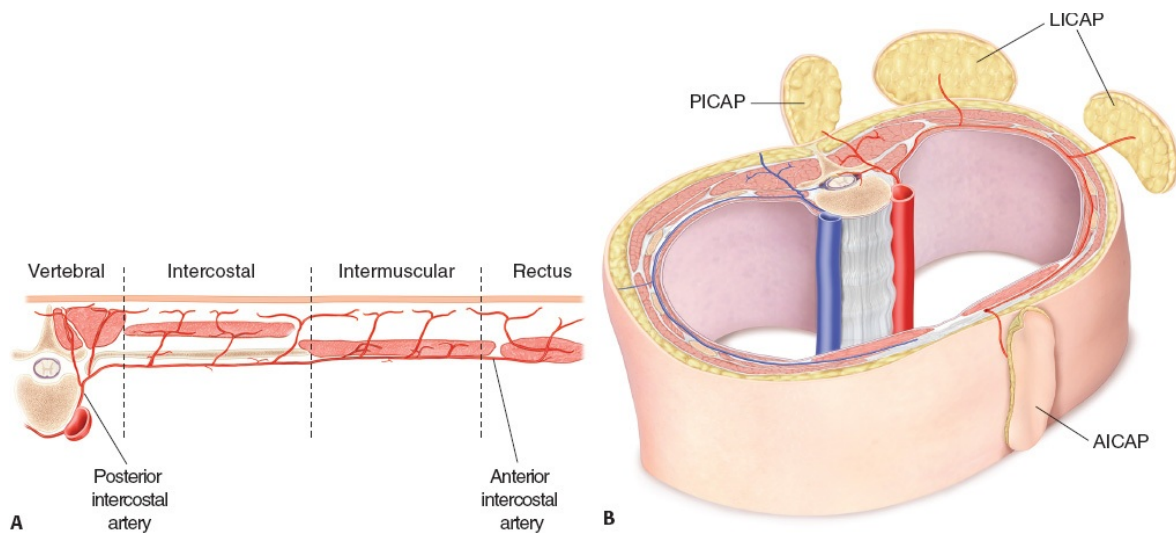


FIG 3 • The anatomy of the intercostal perforators. **A.** Four segments to the intercostal vessels: the vertebral, intercostal, intermuscular, and rectus segment. **B.** Intercostal perforator flap classification: PICAP, posterior intercostal artery perforator; LICAP, lateral intercostal artery perforator; AICAP, anterior intercostal artery perforator.

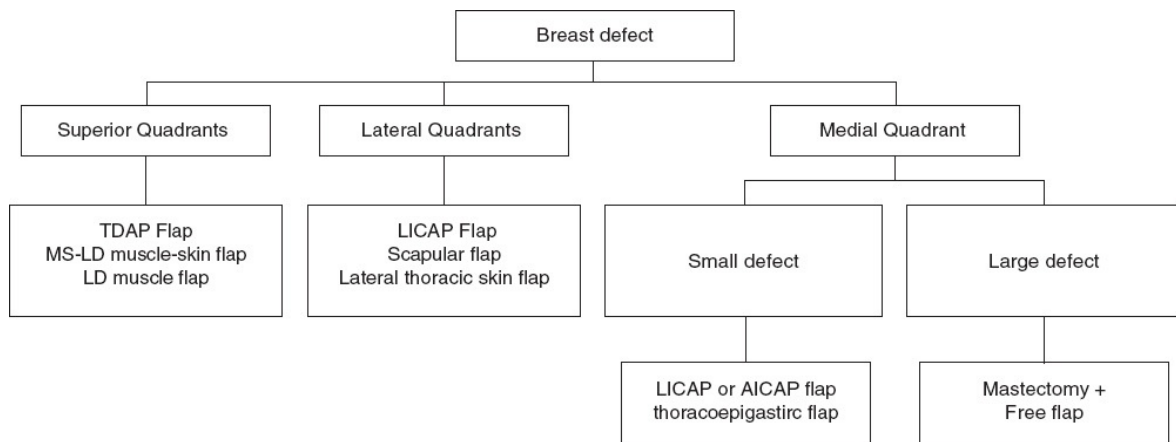


FIG 4 • Algorithm for using flaps for partial breast reconstruction. TDAP, thoracodorsal artery perforator; MS-LD, muscle-sparing latissimus dorsi; LICAP, lateral intercostal artery perforator; AICAP, anterior intercostal artery perforator.

SEAP Flap

- The SEAP flaps are based on perforators arising from either the superficial or the deep branch of the superior epigastric artery, and the perforator flaps are named SSEAP and DSEAP, respectively.¹⁵
- The SEAP flap has similar indications as the AICAP flap¹⁵; however, it has a longer pedicle that allows it to reach the defect with less tension.
- Pedicled SEAP flaps should be used only in selected cases, because it excludes the secondary use of abdominal tissue for autologous breast reconstruction (DIEAP, SIEAP, TRAM flaps) if completion mastectomy is later on indicated (**FIG 4**).

Preoperative Planning

- Perforator mapping with correct flap design is the keystone in these oncoplastic techniques.³
 - To localize the thoracodorsal perforators, a unidirectional Doppler (8 Hz) ultrasonography examination is performed for perforator mapping in the planned skin flap area. This device, although quite handy and less costly, has the disadvantage of generating false-negative and false-positive signals and provides less detailed anatomic vessel information.
 - This is due to the misleading background signal from the thoracodorsal vessels, which can be confusing and difficult to distinguish from the perforator signal. To avoid this, the patient is positioned, as in surgery, at a lateral position with 90 degrees of shoulder abduction and 90 degrees of elbow flexion.
 - Also, multidetector (MD) row CT scan can be used with accuracy to localize the perforator.³
- The patient is marked before surgery. The breast size, tumor size, and location as well as the final defect size are estimated.
- The incisions for the tumor resection are chosen from an oncological aspect but in the most aesthetically pleasing fashion.
- The TDAP (thoracodorsal artery perforator) flap planned for the partial breast reconstruction is designed to include the located perforators (one or more) at the proximal part if feasible, in the directions of relaxed skin lines, the brassiere line, or even horizontally according to the patient's preference.
- Skin laxity and fat excess in the lateral thorax and back area are estimated by the pinch test. The size of the flap is determined by the need for defect

coverage and is an average of 20×8 cm.

- The skin drawings are applied at first with the patient in an upright position, and the anterior border of the LD muscle is palpated and marked also.
- Then the patient is placed in a lying position on her side, with the reconstruction side facing upward, as in surgery, for the perforator mapping and the flap design in the lateral thorax. The skin island is always extended over the anterior border of the LD to include the premuscular perforators if present.
- If the defect is more medially, the flap is designed more distally, further in the back. The same design is applied for the LICAP; however, the flap is placed more anteriorly, toward the breast. The AICAP or SEAP flaps are usually designed under the inframammary fold along the rib.

Positioning

- The patient is prepped and positioned in the supine position for the tumor excision. After the lumpectomy/quadrantectomy at clear margins, clips are placed in the wound bed and left there, in order to indicate the area for future radiation therapy.
- If the plan is to proceed with TDAP, LICAP, or SAAP flap, the patient is positioned and prepped again in the lateral position as in the typical LD musculocutaneous flap dissection.
- For AICAP/SEAP flap, the patient remains in the original position.

TECHNIQUES

■ Basics of Flap Harvesting

- The flap harvesting starts with skin incisions.
- A posterior approach is usually used in TDAP flap. The surgeon continues dissection down to the LD suprafascial plane while beveling in favor of the flap in order to gain as much of extra tissue as possible. Harvesting proceeds from the back to the axillary region. Further harvesting under loop magnification continues meticulously, until the perforator vessel is visualized. If the perforator is visibly pulsatile and adequate in caliber (greater than 0.5 mm for the whole bundle), the dissection continues along

the perforator course up to the nutrient thoracodorsal pedicle. If a large pedicle length is required, the TD vessels can be dissected up to their subscapular vessel origin and included in the flap.

- If the perforators have an intramuscular course, dissection is performed in the direction of the muscle fibers, and any nerves that come across are carefully preserved. Within the muscle, all the perforator side branches are either ligated or coagulated. If two perforators are found along the same course, they can both be included within the flap, without sacrificing any muscle fibers.
- In case the perforators are inadequate in size, the flap harvesting is continued as muscle-sparing LD, preserving a small piece of muscle attached to the posterior wall of the perforators, sacrificing only minimum fibers and, most important, salvaging the muscle innervation. This modification is also useful when the flap is intended for the medial breast area, because it protects the perforators from presumed tension.
- The flap harvesting carries on, with the skin incisions continued proximal to the axilla and lateral to the LD, and the dissection proceeds anteriorly, until the flap is freed from the donor-site tissues and left connected only to the vascular pedicle. The pedicle is carefully passed under a subcutaneous tunnel in the axilla–lateral thoracic area that has been previously prepared to the recipient breast area, avoiding any avulsion of the pedicle.
- The donor site is sutured in three anatomical layers with a drain in place, and the patient is returned again to the supine position.
- Before final closure of the defect, the flap can be partially or totally de-epithelialized (depending on the native skin reservations of the recipient site) and folded accordingly, to give extra projection to the reconstructed breast mound but always in a tension-free manner.
- In LICAP flap dissection, an anterior approach is performed from the breast side toward the anterior-free border of LD muscle. Perforator dissection is done within the serratus muscle until its origin from the costal groove. Further dissection is usually not needed.

■ TDAP Flap

Flap Design

- The patient is positioned in lateral decubitus with the shoulder in 90 degrees

of abduction and the elbow in 90 degrees of flexion.

- In this position, the anterior border of the LD muscle is palpated through the skin and marked.
- A 5- to 8-MHz Doppler probe allows accurate location of the perforators in the posterior axillary line, 8 cm below the axillary crease and within 5 cm from the anterior border of the LD muscle.
 - More recently, CT scanning has been successfully used to preoperatively detect the best perforator and will certainly become a great tool for thoracodorsal perforator mapping in the future.
- Subsequently, the skin island is designed to include the audible perforators and can be oriented in different directions depending on the reconstructive needs and anticipated orientation of the scar (**TECH FIG 1**).
- The flap paddle is better oriented to fit into the skin lines and parallel to the rib direction, which provides the best inclusion of the angiosome territory.

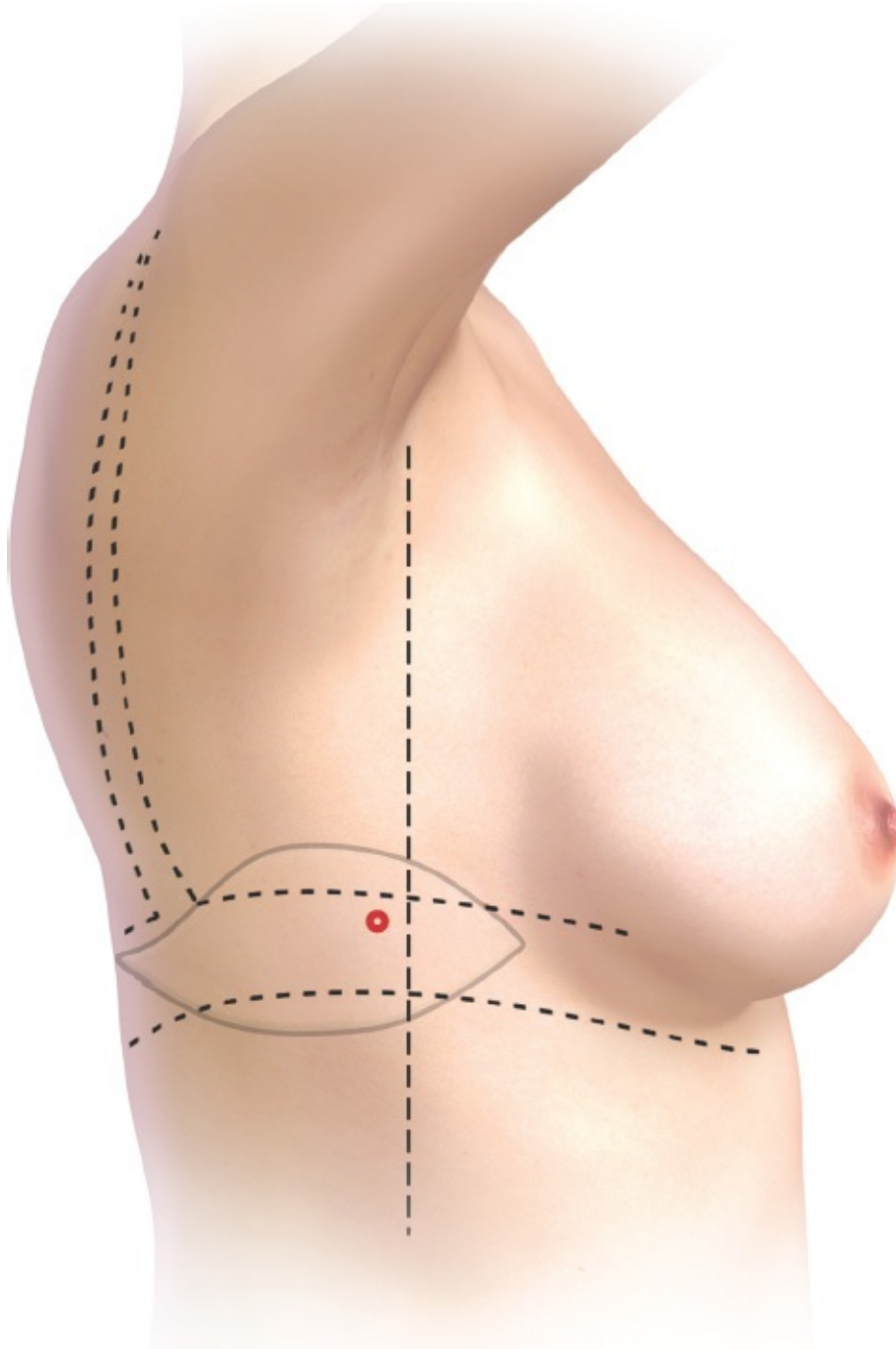
Flap Harvesting

- The incision starts at the inferior anterior border of the flap, which allows for identification of the anterior border of the LD muscle and eventual repositioning of the anterior border of the flap.
- The dissection proceeds from distal to proximal and from medial to lateral at the level just above the LD muscle fascia until a suitable perforator is identified (**TECH FIG 2**).
 - A perforator originating from the vertical branch is preferred because dissection is easier due to fewer connections with other vessels and a shorter intramuscular course.
 - If two perforators lie along the same line, both can be incorporated within the flap without cutting additional muscle.
 - A perforator should be visibly pulsatile and have a diameter suitable for microvascular anastomosis.
- Once a suitable perforator is identified, intramuscular dissection is rather straightforward.
 - The muscle is split longitudinally and the perforator dissected cranially.

Flap Placement and Completion

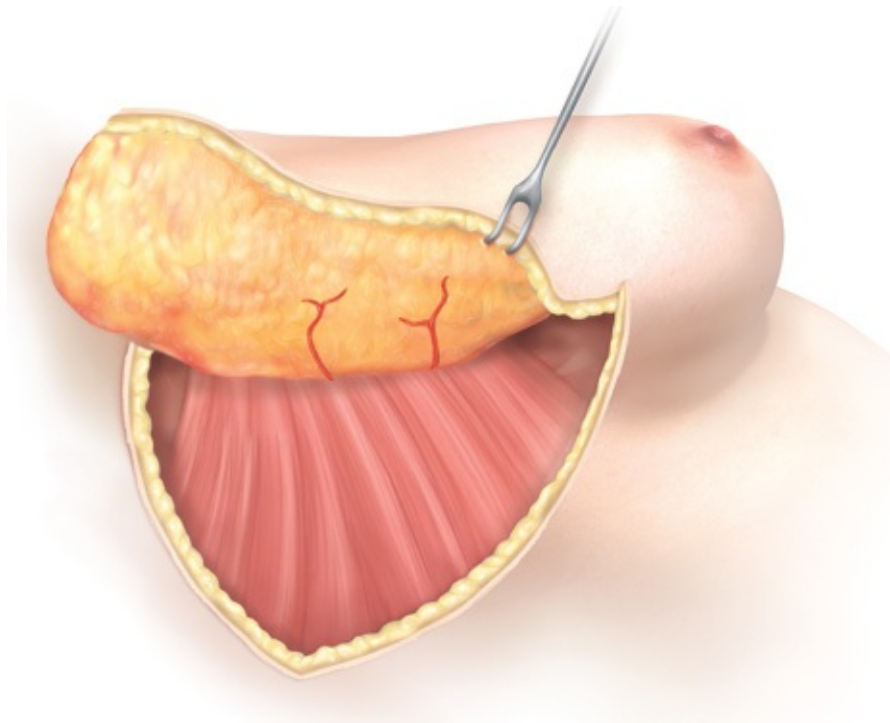
- The next step is to free the anterior border of the LD muscle and look underneath.
- Total pedicle length depends on the location of the perforator on the muscle,

as the length of the intramuscular course adds up with the length of the oblique course on top of the muscle and the length of the thoracodorsal pedicle itself (**TECH FIG 3A**).



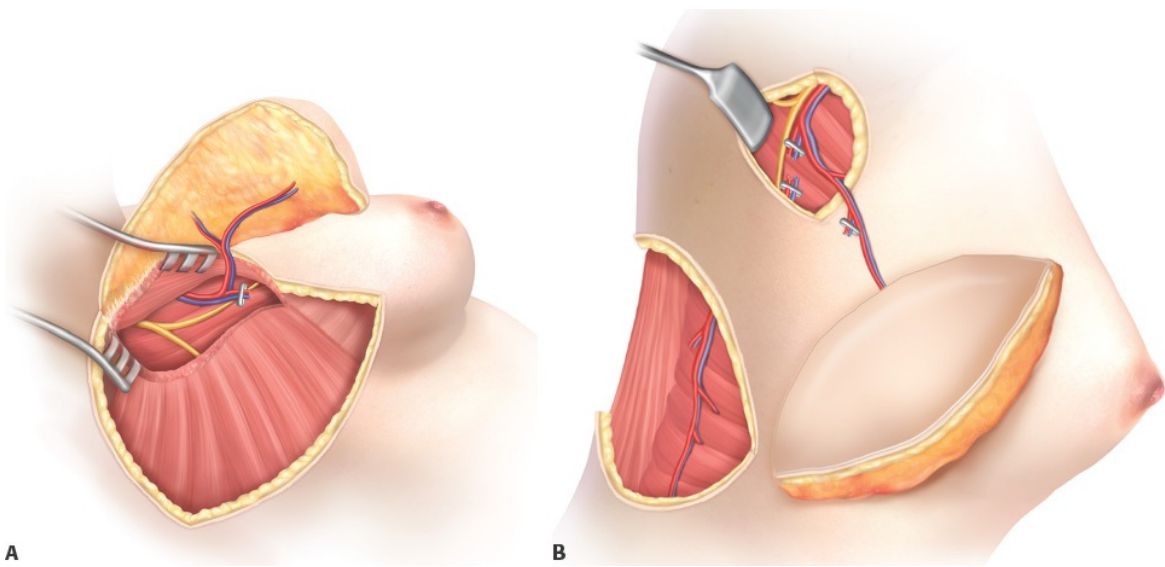
TECH FIG 1 • Surgical technique of TDAP flap harvesting. Flap design. The perforator is located

using unidirectional Doppler and is usually found 6 to 8 cm from the posterior axillary fold. The flap is designed within the brassiere region (*dotted line*) and crosses the anterior border of the LD muscle (*dashed line*).

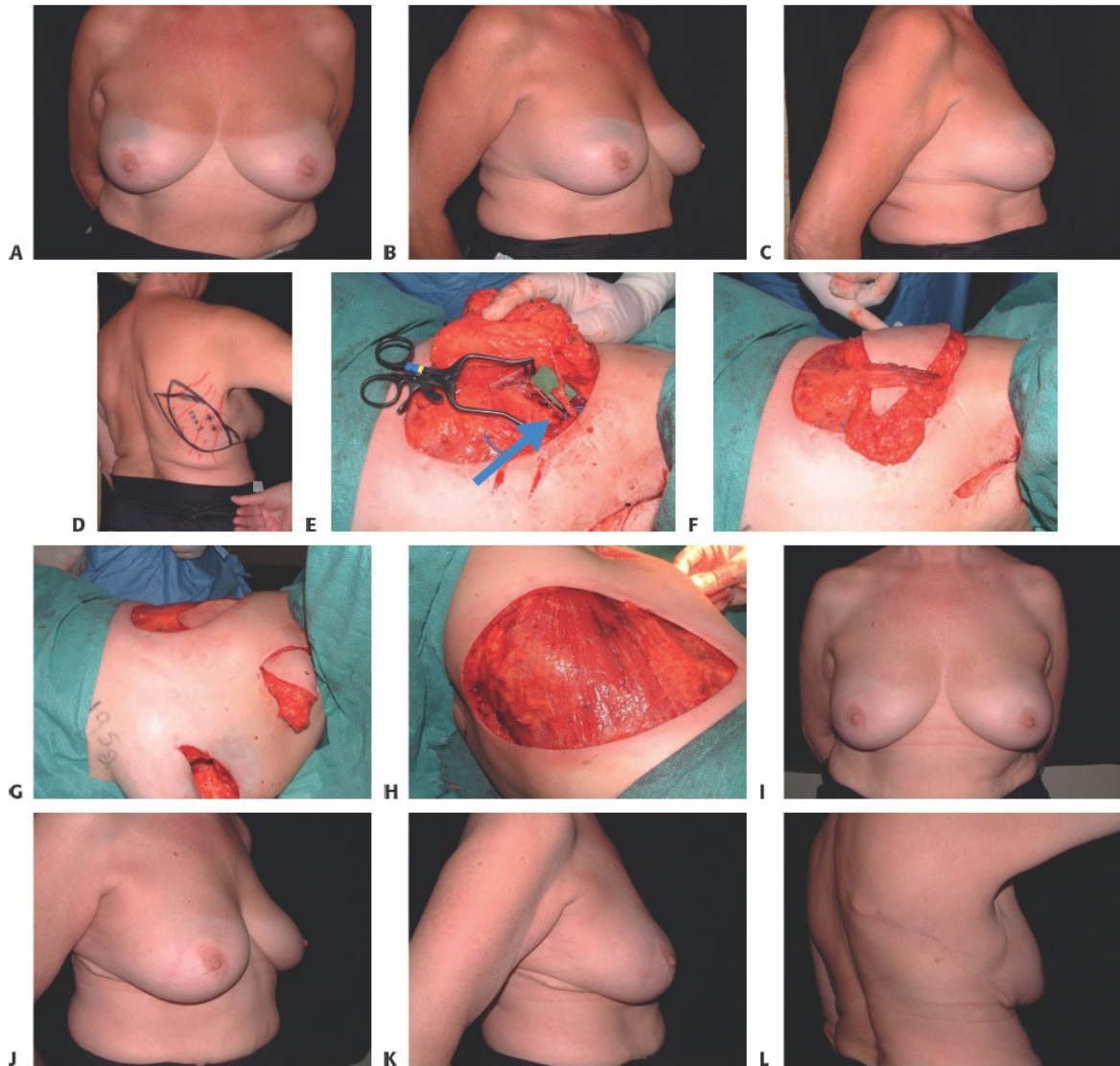


TECH FIG 2 • The flap is dissected from the LD muscle until the perforators are encountered.

- This usually yields a pedicle length of 7 to 12 cm.
- The motor nerves to the LD run on a deeper plane, which allows for complete freeing of the pedicle without injuring the nerves.
- Once the complete intramuscular trajectory has been dissected, harvesting the thoracodorsal pedicle proceeds.
- The skin paddle is carefully passed through the split muscle and subcutaneously into the defect through the axilla (**TECH FIG 3B**).
- At the end, closed suction drains are placed and donor site is closed primarily in three layers.
- The technique is illustrated in a clinical case (**TECH FIG 4**).



TECH FIG 3 • A. The LD muscle is split and the perforator dissected back to the main pedicle. The TD nerve is preserved. **B.** The flap is pulled through the axillary incision and into the breast defect.



TECH FIG 4 • A patient undergoing a quadrantectomy for a tumor of the superolateral quadrant of the right breast. The quadrantectomy specimen weighed 195 g. Reconstruction is with a completely de-epithelialized TDAP flap based on one perforator. **A–C.** Preoperative views. **D.** The flap design with the marked perforators, located by Doppler. **E.** The dissection of the perforator through the split LD muscle. The TD nerve is preserved (*arrow*). **F,G.** The TDAP flap is passed through the split LD muscle and then through the axilla. **H.** The LD muscle is left intact.

I–K. Postoperative views. L. Donor site.

PEARLS AND PITFALLS

Indications	■ Any immediate partial reconstruction should be delayed if the surgeon is uncertain about the margins or tumor extension. ■ A delayed reconstruction can still be performed within a few days after the definitive margin status is known.
Flap markings	■ Using Doppler or CT scan imaging is essential to locate the perforators. ■ Skin paddle should be extended anteriorly toward the inframammary fold.
Perforator flap harvesting	■ Perforators must be pulsating and have a good diameter (more than 0.5 mm) if a flap is to be harvested.
Outcome	■ Seroma incidence at the donor site after harvesting perforator flap is reduced to 0%. ■ Long-term aesthetic result after pedicled flaps is very satisfactory despite the irradiation.

POSTOPERATIVE CARE

- Postoperatively, protocol perforator flap monitoring is implemented.
- Patients are administered VTE prophylaxis during the time of relative immobilization.
- Patients leave the hospital when the drains are removed, which is in average 3 to 5 days.
- The arm is hold in 45-degree abduction. Arm stretching is restricted for a week. Physiotherapy can be started afterward. Most of patients required between 9 and 14 sessions of shoulder physiotherapy.
- Patients treated for BCT with pedicled perforator flaps have a short rehabilitation course.¹⁸
- Adjuvant irradiation of the breast, if indicated, can be started at 6-week postreconstruction. Adjuvant chemotherapy can start 3 weeks postoperatively.

OUTCOME AND COMPLICATIONS

- Donor-site morbidity after harvesting locoregional pedicle perforator flaps for partial breast reconstruction is reduced to a minimum. Only a very limited rate of seroma formation has been observed and treated mainly conservatively. Wound dehiscence of the donor site usually when closed under tension is another infrequent event managed with local treatment.
- Data from a recent study show a seroma rate of 5.5% in MS-TDAP II flaps, compared to no seroma formation in perforator flaps. Other postoperative complications observed were wound dehiscence (4%), infection (2%), and hematoma (2%).⁹
- Partial or total flap losses are rare incidents and one must exclude coagulopathies or other medical diseases and conditions.
- Palpable (partial) fat necrosis of the flap has been observed and can be treated, if necessary, by excision and primary closure or reconstruction by a local flap. Or if necrosis is too extensive, a mastectomy with total breast reconstruction can be indicated.⁹
- Unpleasing scars, flap contractures, and volume loss are less rare sequelae and may need secondary surgical treatment.
- Flap reconstruction of breast defect may give a “plugged-in” appearance, which seems to slightly improve after radiation therapy. It is hard to predict the long-term outcomes of partial breast reconstruction with pedicled perforator flaps due to the indefinite impact of irradiation to the final result.
- Some patients who undergo partial breast reconstruction with a TDAP flap document an initial decrease in forward arm elevation and passive abduction, which recovers over time.¹⁸

Prognosis

- Many concerns have been raised about oncologic safety of oncoplastic surgery.
- A recent meta-analysis showed that oncoplastic surgery is an oncological safe procedure, with even lesser recurrence rates (4%) compared to breast conservative surgery (7%) alone.¹⁹
- After oncoplastic reduction mammoplasty, resection margins are more often negative, and if recurrences occur, they most often occur in the preoperative quadrant of the tumor and not the location after displacement techniques.²⁰
- As stated earlier, if DCIS is present, oncoplastic techniques should be used

cautiously.

- Local recurrence rates reported in the literature for oncoplastic surgery vary from 0% to 7% of the patients.^{19–21}

Oncological Follow-Up

- Oncological follow-up after oncoplastic procedures remains important.
- Given the rearrangement of parenchymal tissues, scar tissue or fat necrosis is not uncommon and might be suspicious on several radiological imaging modalities.
- Biopsy with fine needle aspiration, core biopsy, or excisional biopsy can be necessary to rule out tumor recurrence (up to 25%).²¹
- The addition of breast remodeling procedures does not seem to affect mammographic sensitivity, and qualitative changes are similar to those found following BCT alone.²¹

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Section V: Prosthetic Breast Reconstruction

13 CHAPTER Delayed Tissue Expansion

Hana Farhang Khoei, Edward C. Ray, and Joseph J. Disa

DEFINITION

- Delayed breast tissue expansion occurs after mastectomy skin has healed and after all adjuvant therapy has been completed.

ANATOMY

- Diagram of the chest wall (sagittal) showing tissue planes of the breast (**FIG 1**). From superficial to deep, layers include the skin, subcutaneous tissue, breast parenchyma, and *pectoralis major* muscle.
- The dissection involves creating a pocket deep to the *pectoralis major* muscle but above the *pectoralis minor* muscle.

PATIENT HISTORY AND PHYSICAL FINDINGS

History Taking

- Cancer history
- Previous adjuvant therapy, including radiation and chemotherapy
- Define the goals and expectations of the patient
- Psychosocial
- Overall fitness for surgery

Physical Exam

- Breast dimension: base width, height, projection, position, and symmetry of inframammary fold (IMF)
- Skin integrity

- Changes in skin due to prior irradiation
- Scars
- Contralateral breast
- Presence of a functioning ipsilateral *latissimus dorsi* muscle

IMAGING

- Imaging usually not necessary
- May consider ultrasound to assess thickness of skin flap

SURGICAL MANAGEMENT

- Delayed tissue expansion

Preoperative Planning

- Tissue expander (TE) selection
 - Size is determined by breast width of patient.
 - Most TE are anatomical and textured with integrated valves.
- Assessment of skin integrity and suitability for expansion
 - Irradiated skin or poor skin quality may suggest the need for *latissimus dorsi* myocutaneous flap.
- Markings
 - Should be done with patient in standing position prior to the operation
 - The most important is to identify the IMF.
 - Achieve symmetry with contralateral breast or, if bilateral, create a natural-appearing fold that is not too high.
 - Mark breast footprint.
 - Superior, medial (2 cm from midline), IMF, and anterior axillary fold (AAF)

Positioning

- Supine with arms either extended on arm boards (preferred) or tucked
- Ensure body and shoulders are centered on the table.

Approach

- One standard approach for delayed tissue expanders

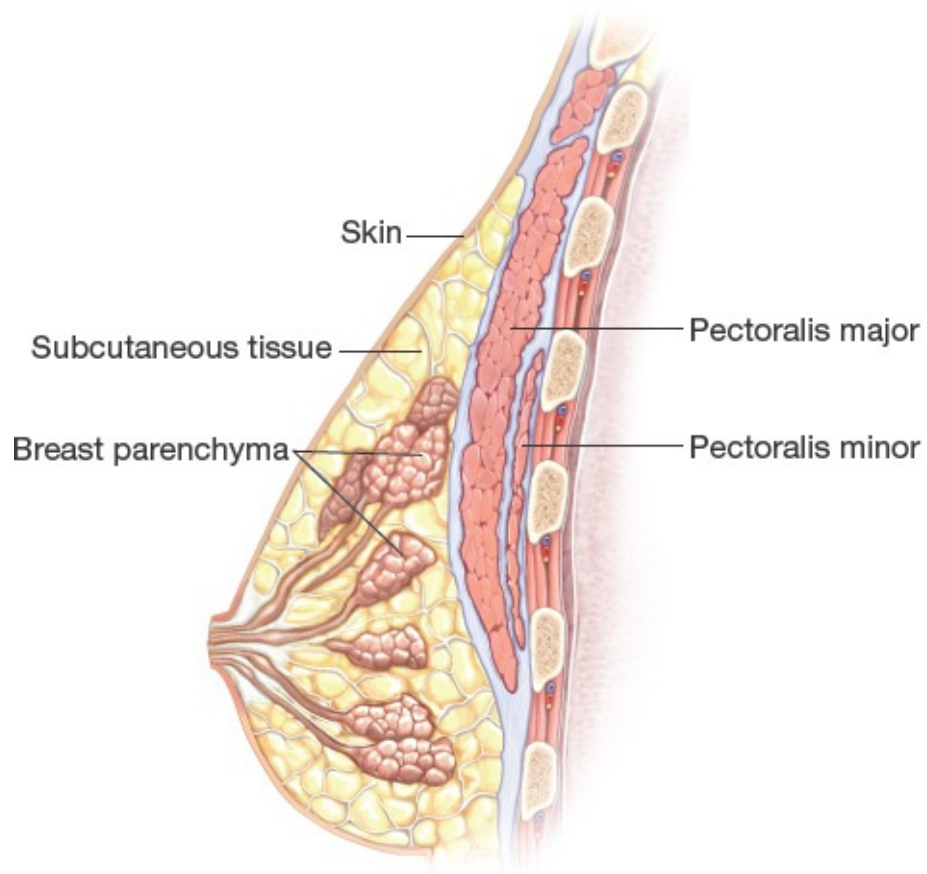


FIG 1 • Relevant anatomy of the chest wall: Sagittal cross section: *Note skin, subcutaneous tissue, breast parenchyma, pectoralis major, and minor muscle on diagram.*

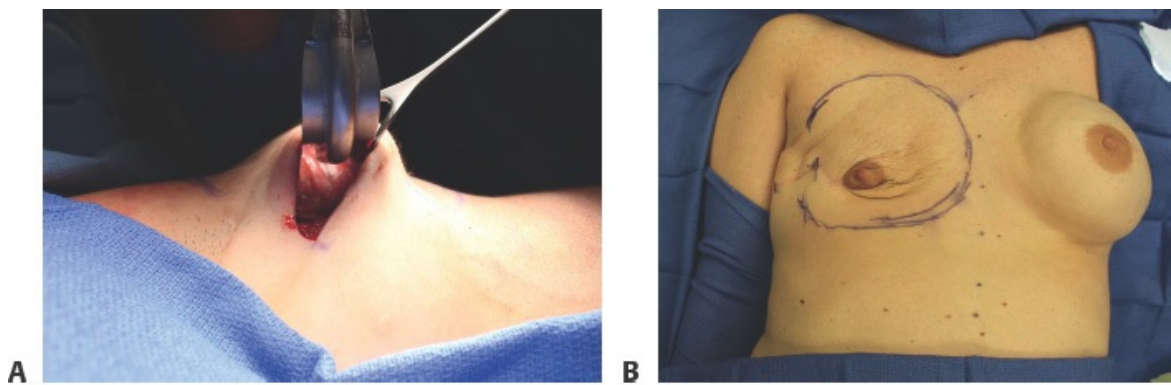
TECHNIQUES



Video p4-c013

■ Creation of Submuscular Tissue Expander Pocket (TECH FIG 1)

- Excise mastectomy scar.
- Elevate mastectomy skin flaps.
- Expose *pectoralis major* muscle enough to allow entry of TE.
- Enter the submuscular layer either at the inferior or lateral border of the *pectoralis major* muscle or split the muscle in the direction of its fibers.
- Avoid elevation of *pectoralis minor* muscle.
- If needed, dissection of the *pectoralis major* muscle can be extended either to the subcutaneous plane inferiorly and laterally or into the submuscular/subfascial plane (ie, elevating *serratus anterior* muscle).
- The decision is based on the quality of the mastectomy skin flaps.



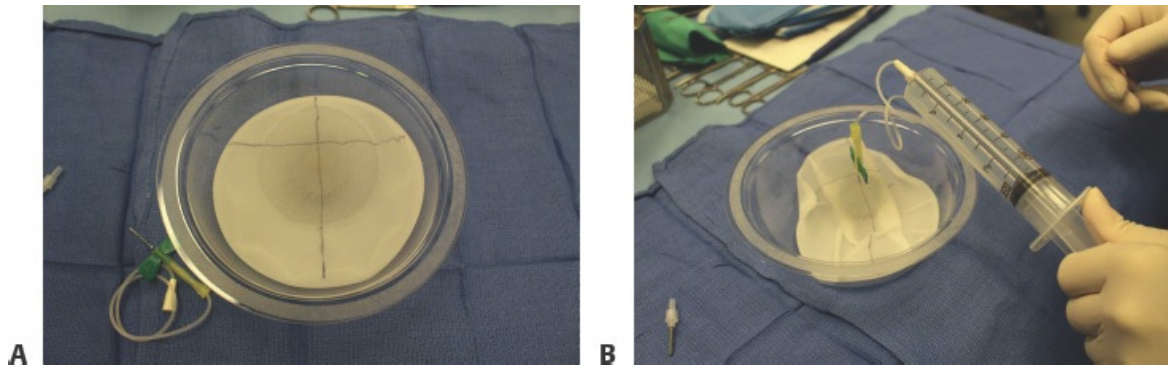
TECH FIG 1 • A. Creating the submuscular pocket using a lighted retractor. **B.** Showing the extent of submuscular pocket dissection. Solid line indicates the extent of dissection.

■ Release of Capsule Scar

- Must release any scar tissue that will restrict expansion of the mastectomy flaps
- Capsulotomy performed as needed (if there was a prior implant)
 - Typically, limited to a superior and medial capsulotomy
 - Care taken to avoid allowing the TE to migrate too far laterally
 - When lowering of IMF or greater lower pole expansion is desired, an inferior capsulotomy is performed.
- Capsulectomy as needed
 - Can facilitate better expansion

■ Insertion of Tissue Expander

- Expander is placed such that the zone of maximum expansion is located in the lower pole of the reconstructed breast.
- May insert some fluid in TE, depending on the amount of skin laxity.
- Ensure proper orientation of the TE (markings on TE can be helpful) (**TECH FIG 2**).
- When coverage of the expander by the muscle is insufficient, an engineered tissue substitute may be used.
 - The most common is acellular dermal matrix (ADM) such as AlloDerm. (LifeCell, Bridgewater, NJ).
 - These may be fenestrated to minimize the risk of undrained submuscular seromas and to optimize incorporation into the overlying subcutaneous tissue.



TECH FIG 2 • A,B. Show marking and filling of TE.

■ Closure of Wound

- Layered closure of the muscle and skin
- Use of drains is optional, depending on surgeon preference, expected fluid accumulation, or use of ADM.

PEARLS AND PITFALLS

Tissue expander selection

- Based on breast width and volume

Tissue expander placement

- Ideally, should establish IMF in the preoperative setting, with patient in a standing position

Skin quality

- Thin or radiation-damaged skin may require *latissimus dorsi* myocutaneous flap to facilitate expansion.

POSTOPERATIVE CARE

- If used, drains are kept in place until output drops below a given threshold.
 - Drains may be subcutaneous, submuscular, or both.
- Postoperative antibiotics are used according to surgeon preference and patient risk factors.
- The patient is placed in a loosely fit surgical brassiere.
 - The use of an underwire brassiere is avoided for several weeks after surgery.

OUTCOMES

- Cochrane review identifies only one randomized control trial (RCT) assessing outcomes for immediate vs delayed breast reconstruction.¹
 - This RCT was subject to high bias, and no conclusion could be made.
- In general, immediate reconstruction provides better aesthetic outcomes due to preservation of the native skin envelope.³
 - This allows for a more rapid expansion to desired volume and better control of breast shape and ptosis.
- Immediate reconstruction may also reduce the psychological burden of patients living with the disease, thus decreasing anxiety and depression while improving self-esteem.²
- Delayed reconstruction allows for mastectomy skin flaps to heal before implant placement, thus decreasing the risk of infection and seroma formation.³
- A recent retrospective study suggested that delayed reconstruction was associated with decreasing operative and nonoperative complications relative to immediate reconstruction.³

COMPLICATIONS

Bleeding or Hematoma

- Hematomas around the tissue expander increase the risk of infection and predispose to the development of capsular contracture.
- If a hematoma of significant size is recognized, it should be promptly evacuated.
- Drains do not prevent hematomas but may be useful indicators of excessive bleeding after surgery.

Infection

- May present early or late and in the form of cellulitis or periprosthetic infection.
- Uncomplicated mastectomy skin cellulitis can be treated with a trial of intravenous antibiotics or, occasionally, oral antibiotics.
- If cellulitis fails to resolve with antibiotic therapy, or the infection worsens (eg, patient develops sepsis or skin breakdown), then the TE is removed, drains are placed, and the patient is given an appropriate course of antibiotics.

- Signs of systemic illness related to a periprosthetic infection indicate the need for prompt implant removal.

Mastectomy Skin Necrosis

- Superficial or partial-thickness flap necrosis is managed conservatively with local wound care.
- Small areas of full-thickness necrosis may also be managed with local wound care if there is muscle or other vascularized tissue deep to the skin that will allow secondary healing.
 - When ADM becomes exposed, salvage becomes much more challenging.
- Larger areas of mastectomy skin flap necrosis require resection of the necrotic skin with immediate wound closure.
 - Should consider removing fluid from the TE to allow for tension-free closure of the mastectomy skin.
 - If skin defect is too large, the device may require removal and possibly skin grafting over the *pectoralis major* muscle.
 - Secondary attempts at reconstruction may require autologous tissue flaps if the chest skin cannot be expanded.

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14 Tissue Expander With Acellular Dermal Matrix

CHAPTER

Gabriel M. Kind

DEFINITION

- Two-stage tissue expander-to-implant reconstruction with prosthetic implants is the most common type of breast reconstruction in the United States.^{1,2}
- The use of acellular dermal matrix (ADM), originally described for direct-to-implant reconstruction,^{3,4} has become increasingly common in two-stage procedures as well.⁵⁻⁷
- The potential benefits of this technique include more precise recreation of the inframammary fold (IMF), control of the pectoralis major muscle, reduced risk of implant palpability, reduction in capsular contracture rates, and a larger initial expander volume (and consequently fewer office visits for tissue expansion), with less dissection of the chest wall musculature when compared to total muscle coverage of the tissue expander (TE).
- All of these potential benefits would presumably improve aesthetic results and, at least for the latter benefit, result in less morbidity.
- Recently, there have been reports describing the placement of implants wrapped with dermal allograft in the prepectoral position.
- This technique has the potential to decrease the incidence of some of the muscle-related complications associated with subpectoral placement, namely, pain associated with manipulation of the muscle at the initial surgery, discomfort associated with pectoralis major flexion postoperatively, and the animation deformity seen in some patients with flexion of the pectoralis major muscle.⁸

ANATOMY

- The pectoralis major muscle has sternocostal, costal, and abdominal origins

and inserts on to the proximal humerus. It is a type V muscle, with a dominant arterial pedicle from the thoracoacromial trunk and multiple secondary arterial sources from parasternal perforators.

PATHOGENESIS

- Breast cancer occurs in approximately 12% of women in the United States. It is estimated that nearly 250 000 new cases of invasive breast cancer will be diagnosed in 2016, along with 61 000 cases of in situ disease.
- Although there are significant regional differences, mastectomy is performed in approximately 35% of those newly diagnosed, and approximately 35% of those women undergo breast reconstruction.
- The rate of breast reconstruction has risen steadily, from 11.6% in 1998 to 36.4% in 2011.⁹
- In 2014, of the 102 215 breast reconstructions performed in the United States, 74 694 (73%) used a TE and implant.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- The use of dermal allograft for soft tissue support at the time of mastectomy is an intraoperative decision based on several factors, including the thickness of the mastectomy skin flaps, the anatomy of the pectoralis major muscle, and the desired initial volume of the TE.
- If ADM is not used, either a total submuscular pocket is created or partial muscle coverage of the expander is accepted.

IMAGING

- Not indicated or necessary

SURGICAL MANAGEMENT

Preoperative Planning

- The footprint of the breast is measured. The height and width of the breast are used to determine which TE to order. Usually two or three differently sized expanders are ordered for each case.
- If mastectomy has already been performed, the pectoralis major muscle function is assessed. Rarely, a paralytic or atretic muscle is identified preoperatively. In such cases, a larger piece of ADM may be necessary.

Positioning

- The patient is placed supine with both arms abducted and secured on well-padded arm boards or tucked depending upon surgeon preference.

Approach

- There are a number of different incisions used for mastectomy. TE insertion can be performed via any of the incisions used.
- In nipple-sparing procedures, care should be taken to avoid handling of the nipple to decrease the chance of contamination. Adhesive plastic drapes can be placed for this purpose.

TECHNIQUES

■ Subpectoral Tissue Expander Placement With Dermal Allograft

Markings

- The footprint of the breast, including the IMF, is marked with the patient standing and again under anesthesia.
- Once the mastectomy is completed, hemostasis is confirmed.

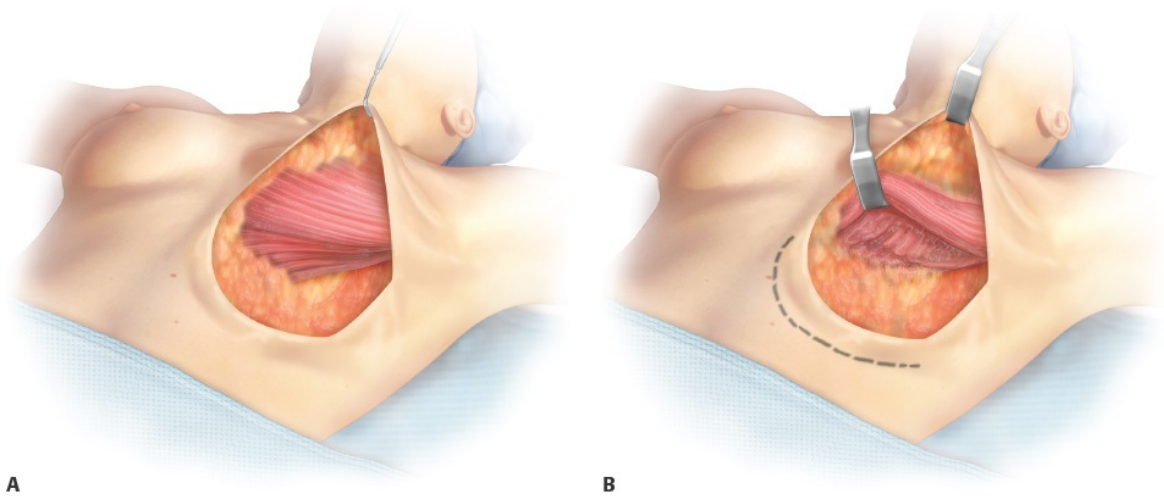
Creation of Subpectoral Pocket

- The pectoralis major muscle is elevated to create a subpectoral pocket across the footprint of the breast (**TECH FIG 1**). The sternocostal origin is released as necessary.
 - There is significant variability in the location of the origin of the pectoralis major muscle.
 - Muscle attachments are preserved wherever possible. This will reduce the size of the ADM required.

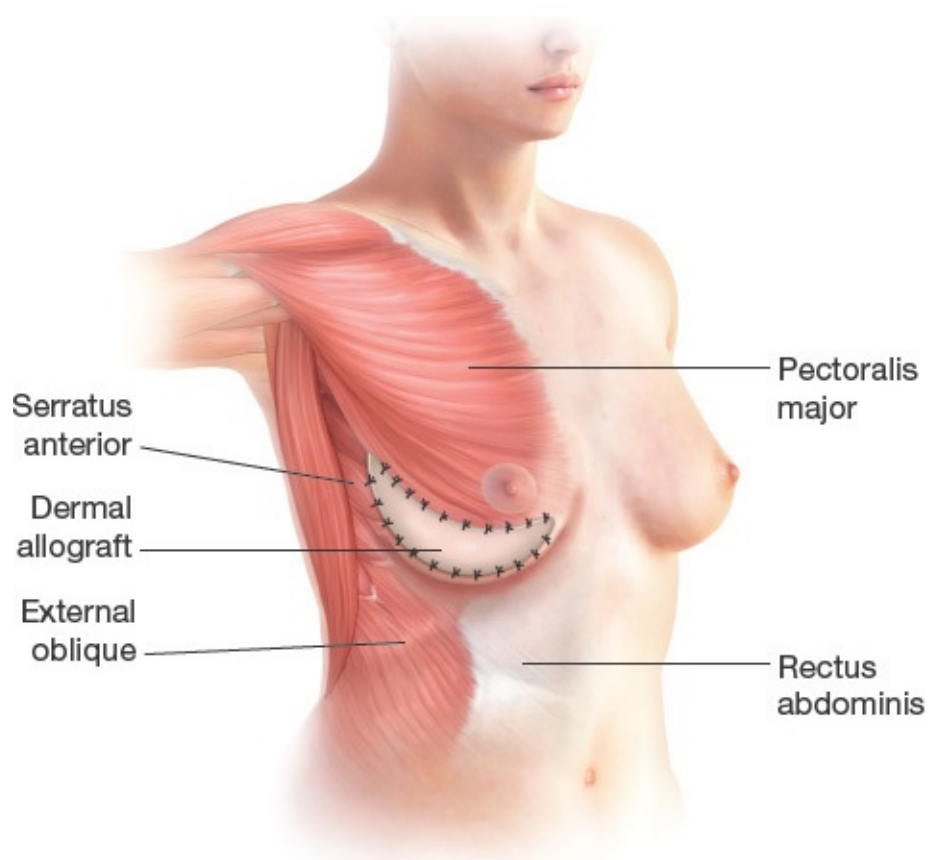
Preparation and Suturing of Dermal Allograft

- A sheet of dermal allograft is prepared by irrigating it with normal saline followed by antibiotic solution. ADM is provided in various sizes.
 - Generally 4 to 8 cm × 14 to 18 cm sheets are used; more recently shaped pieces have become available.
 - Prefenestrated ADM is used, or fenestrations are cut into the ADM, to encourage revascularization.

- The use of thick or thin ADM also depends upon the preference of the surgeon.
- Care is taken to place the dermal (shiny) side of the ADM facing the undersurface of the mastectomy flaps.
- The dermal allograft is sutured to the chest wall along the desired position of the IMF.
- I prefer running absorbable barbed suture (2-0 PDO Quill) for this, although other suture types have been described, perhaps most commonly some type of an absorbable suture is used.



TECH FIG 1 • A,B. The pectoralis major muscle is elevated across the footprint of the breast.



TECH FIG 2 • The dermal allograft is secured to the IMF. The ADM is secured along the IMF to a point equal or superior to the vertical midpoint of the breast.

- The lateral extent of the ADM-IMF suture line should be at least to a point equal to the vertical midpoint of the breast.
- Patients with thin mastectomy flaps may benefit from continuing the ADM further superolaterally, but this may tether the pectoralis major and is generally not required (**TECH FIG 2**).

Preparation and Placement of Tissue Expander

- A TE is selected based on the width of the breast footprint, the weight of the mastectomy specimen, and the patient's desired size.
- The TE is prepared by removing the air and inserting 50 to 100 mL of saline.
 - Some prefer methylene blue–tinted saline, whereas others prefer to fill the expander with air.
- The TE is placed in the wound and secured in place using 2-0 PDS suture if

suture tabs are utilized. For expanders without tabs, precise pocket formation will limit movement of the expander.

- The ADM is trimmed to fit the defect in the inferolateral aspect of the subpectoral pocket.
- The upper border of the ADM is sutured to the lower border of the pectoralis major muscle (**TECH FIG 3**).
- Additional saline is injected into the TE.
 - In a total skin and nipple-sparing mastectomy, the expander is filled to approximately 50% of its capacity.
 - In non-nipple-sparing mastectomies, the final volume is determined by the limitation of the skin flaps.

Closure

- Closed suction drains are placed through stab incisions in the lateral chest wall.
 - For larger breasts and cases where axillary dissection is performed, two drains are used. For smaller breasts, one drain is used.



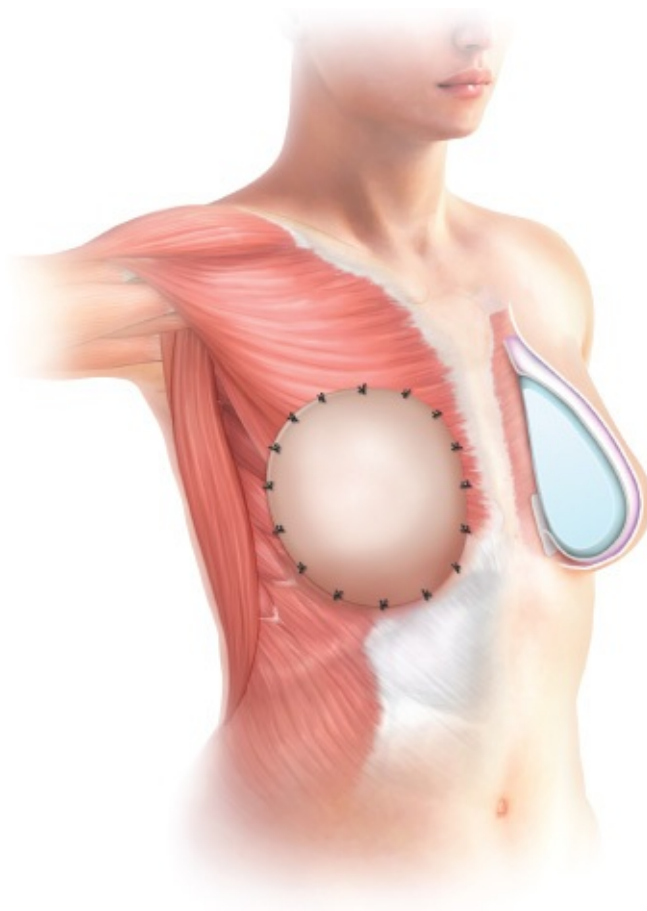
TECH FIG 3 • Typical appearance of ADM secured to the chest wall inferiorly and the pectoralis major muscle superiorly.

- The mastectomy flaps are debrided of nonviable skin and closed in layers.
 - Usually, 2-0 Vicryl is used in the deep tissues followed by 3-0 and 4-0 Monocryl in the skin.
 - The incision is dressed with dermal glue and a sterile dressing.

- The chest is wrapped with an Ace wrap.

■ Prepectoral Tissue Expander Placement With Dermal Allograft

- As in the subpectoral technique, markings are made of the breast footprint and IMF, and following mastectomy, hemostasis is confirmed.
- The prepectoral technique is not recommended in patients with excessively thin or poorly vascularized flaps.
- A large sheet of dermal allograft (16×20 cm) is secured across the chest wall, several centimeters superior to the desired position of the IMF.
- The ADM is draped inferiorly and sutured to the chest wall slightly inferior to the desired position of the IMF.
- The TE is placed, and the ADM is folded over the tissue expander and then secured superiorly to the chest wall.
- The ADM is trimmed to the shape of the expander and then secured medially and laterally to the chest wall (**TECH FIG 4**).



TECH FIG 4 • Dermal allograft secured to the chest wall with the implant in the prepectoral position.

PEARLS AND PITFALLS

Symmetry of the IMF

- Begins with symmetrical skin markings. In a bilateral case, leaving the first side open after placing the TE and ADM allows for visual confirmation of symmetrical placement of the TE and ADM along the IMF on the second side.

Symmetry of tissue expander placement

- The patient can be brought to a sitting position after inserting the TE(s) to confirm adequate symmetry.

Proper

- Care must be taken to place the TE in the appropriate location and

placement of the tissue expander	orientation. It is common to leave it too far superior and/or lateral on the chest wall.
Inset of the ADM	■ The ADM should be trimmed so that there are no folds or corners. If there is a palpable fold, it should be excised and closed (similar to a “dog-ear” excision). Redundancy of the ADM should be minimized. This can sometimes be accomplished by filling the expander. If the muscle or skin does not permit enough filling to eliminate significant redundancy, the ADM needs to be trimmed further.
Seroma management	■ Seromas can be safely aspirated superficial to the expander port. Tissue expansion can proceed as scheduled during seroma aspiration. Oral antibiotics should be considered if a seroma requires multiple aspirations.

POSTOPERATIVE CARE

- Oral antibiotics are continued until drains are removed.
- Drains are removed when the output is less than 30 mL/24 hours for 2 consecutive days.
- Tissue expansion is usually started 2 to 3 weeks postoperatively.
- Expansion volume can vary but typically ranges from 30 to 120 cc per fill.
- Overexpansion is avoided, as that can lead to a more redundant pocket and more visible rippling.

OUTCOMES

- Many of the benefits of ADM use in breast reconstruction are subjective and surgeon dependent. Several authors have reported favorable aesthetic outcomes.^{3–6}
- With regard to more objective measures of outcomes, there are multiple retrospective series that report increased TE fill at the time of mastectomy plus TE/ADM and fewer postoperative visits for expansion.^{4,10–14}
- There are several retrospective series that report diminished pain with ADM use.^{4,5,15}
- There are several reports of an absence of capsular contracture in breasts reconstructed with ADM, with follow-up times ranging from 6.5 to 52 months.^{3–5,16} This compares favorably with reported rates of capsular contracture as high as 14% in patients undergoing reconstruction without

ADM.¹⁷

- There are also published data showing lower rates of capsular contracture in radiated breasts reconstructed with TE/ADM compared to historical controls.^{13,18,19}
- Published reports describing prepectoral reconstruction with ADM are encouraging, but preliminary, as there is only short-term follow-up available at this time. A large series reports low complication rates at 6 to 26 months but gives no data regarding aesthetic results or pain compared to the subpectoral approach.⁸
- Questions remain regarding the role of fat grafting to mask rippling and the visibility of the upper pole of the implant, as well as the long-term complication rates using the prepectoral technique.

COMPLICATIONS

- Complications associated with ADM use in breast reconstruction are similar to those reconstructed without ADM. Published series comparing ADM use with TE reconstruction generally do not show statistically relevant differences in overall complication rates.
- The overall complication rates for reconstructions using ADM range from 3% to 49%.^{20–23} Two studies show statistically significantly higher incidences of seroma,^{12,21} but several other studies do not show an increased rate of seroma with ADM use.^{13,14,22,24} A recent review showed that the use of dermal allograft has a pooled relative risk of seroma of 1.85.²⁵
- Mastectomy flap necrosis was shown in two reports to be higher in patients undergoing TE/ADM reconstruction.^{14,21} However, in both series, there was a higher TE volume, which is known to cause a higher rate of mastectomy skin necrosis.
 - Caution should be taken when filling TEs at the time of mastectomy, as increased TE volume has been shown to correlate with mastectomy skin necrosis, with or without the use of ADM.
- There are multiple conflicting reports regarding the use of ADM and infection, with authors concluding both an increased risk and no increased risk of infection. Meta-analyses have shown increased relative risk of infection with ADM use in breast reconstruction of 2.47 and 2.7.^{26,27}

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CHAPTER Immediate Tissue Expander

Eric G. Halvorson and Joseph J. Disa

DEFINITION

- Immediate tissue expander placement is performed following skin-sparing or nipple-sparing mastectomy as a prelude to either two-stage implant reconstruction or “delayed-immediate” autologous reconstruction.
- The advantages of expander placement (compared to immediate autologous reconstruction) include shorter operation, lack of donor site, shorter hospital stay, shorter recovery, ability to adjust final volume, and a “perkier” result.
- The disadvantages of expander placement include multiple postoperative office visits for expansions, discomfort associated with the expansion process, a second (albeit outpatient) surgery if proceeding with two-stage implant reconstruction, and the permanent risks of implants (capsular contracture, rupture, rotation, rippling, infection, malposition, and exposure).

PATIENT HISTORY AND PHYSICAL FINDINGS

- It is beneficial for the initial consultation to occur separate from multidisciplinary clinic visits focused on cancer care. Patients presenting to the plastic surgeon after such visits are often overloaded with information and overwhelmed by all the options and information related to reconstruction.
- It is critical to determine the patient’s goals for reconstruction and to ascertain their preferences with respect to breast size, breast shape, willingness to accept surgical risk, willingness to accept donor-site morbidity, operative length, hospital stay, recovery process, postoperative follow-up protocol, secondary surgeries, and long-term complications.
- Having a physician extender well versed in reconstructive options to meet with patients and show them patient photographs is an incredibly helpful prelude to

the physician-patient consultation.

- Physical examination of the breasts is performed to evaluate any masses and whether or not skin involvement or peau d'orange is present. The overall size and degree of ptosis are noted.
- Patients with skin involvement or significant ptosis will typically require skin excision. If performed as an inverted "T" or Wise pattern, the risk of mastectomy flap necrosis is increased.
- Alternatively, one can perform a generous horizontal, oblique, or vertical ellipse or two-stage Wise pattern excision with the vertical closure first and a horizontal excision at the inframammary fold (IMF) 3 to 6 months later.
- The breast width, height, and projection are measured in centimeters. These measurements are used for selecting a tissue expander (as described in the following text).

SURGICAL MANAGEMENT

- Ideal candidates for expander placement are thin nonsmokers undergoing bilateral mastectomy who have not, and will not, receive radiotherapy.
- Smokers are prone to mastectomy flap necrosis and infection.
- Radiotherapy increases the risk of infection, implant exposure, and capsular contracture.
- Previously radiated skin will not expand well.
- Although obesity increases the risk of complication for any type of reconstruction, heavier patients tend to have better cosmetic results with autologous reconstruction than with implants, as it can be difficult to match the opposite breast after a unilateral mastectomy or give adequate volume/ptosis after a bilateral mastectomy.
- Patients with very large breasts who require skin removal during mastectomy are at risk for mastectomy flap necrosis and tend to require secondary procedures to address residual excess skin. These patients often have ample donor sites for autologous reconstruction, which may be a better option.
- Patients with small breasts who want them to be larger can achieve that goal through expansion.
- Patients who have minimal ptosis and want their breasts to be slightly smaller are candidates for single-stage implant reconstruction.
- Using a tissue expander as a bridge to autologous reconstruction, so-called delayed-immediate reconstruction, is considered when the patient is likely to receive postoperative radiation therapy, as radiating autologous flaps can result

in fat necrosis, firmness, and shrinkage.

- A minority of surgeons prefer to accept the risks of radiating an autologous flap when compared to the risks of performing delayed reconstruction in a radiated field.
- Other reasons to consider delayed-immediate reconstruction are to gain control of the skin envelope, to expedite surgery and adjuvant therapy, and to modify risk factors (smoking, obesity) and when patients are undecided.

Preoperative Planning and Implant Selection

- Good communication with the breast surgeon is important to ensure oncologic goals are maintained and that reconstruction is appropriately staged.
- Patients with advanced disease, requirement for immediate postoperative adjuvant therapy, unstable social environment, and/or uncertainty regarding goals for reconstruction may be better served by delayed reconstruction.
- Prior to mastectomy, the patient must be marked in the standing position. The IMF is marked on each side, and the midline is drawn between the sternal notch and xiphoid process. The overall outline of the breasts is marked.
- Although a transverse ellipse around the nipple-areolar complex (NAC) is commonly used for the mastectomy incision, the authors' preference is an oblique ellipse parallel to the pectoralis major fibers (**FIG 1**). This renders the medial scar less visible in clothing, allows for better subincisional muscular coverage, and facilitates a stair-step approach during the exchange procedure (as described in the following chapter).
- Tissue expanders are selected preoperatively based on the width of the patient's breast. There are many different tissue expanders to choose from, but most are textured and anatomic, providing lower pole projection.
 - Some are taller than they are wide, some are wider than they are tall, and some are semicircular or crescentic and focus on lower pole expansion.
 - Some have tabs to secure the expander.
 - Most have integrated metal ports that are located with magnets, although a remote port is useful when placing the expander under a thick flap (such as a latissimus dorsi flap in an obese patient). In such patients, finding the port with a magnet can be difficult and a longer needle is required, placing the expander at risk for rupture.



FIG 1 • An oblique mastectomy incision is used. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.)

Positioning

- Patients are placed in the supine position under a general anesthetic with arms padded circumferentially and abducted at 80 to 90 degrees.
- Following mastectomy, the patient is positioned such that the sternum is parallel to the floor (via head elevation or reverse Trendelenburg).

TECHNIQUES

■ Tissue Expander Placement

First Step—Wound Assessment

- Following mastectomy, the wounds are irrigated and hemostasis is obtained.
- The mastectomy flaps are evaluated by examining their thickness and assessing color and capillary refill.
- Areas where dermis is exposed internally should be carefully evaluated externally.
- Areas where the external skin is pale without capillary refill should be excised.

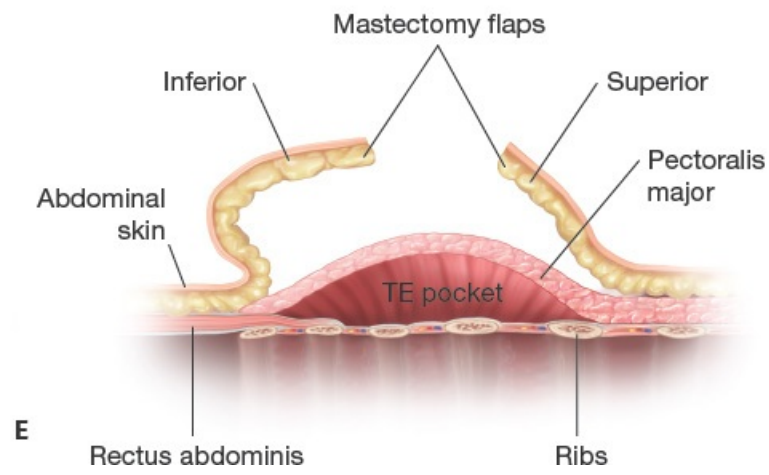
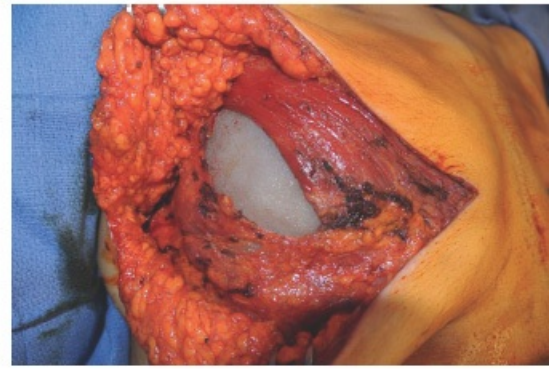
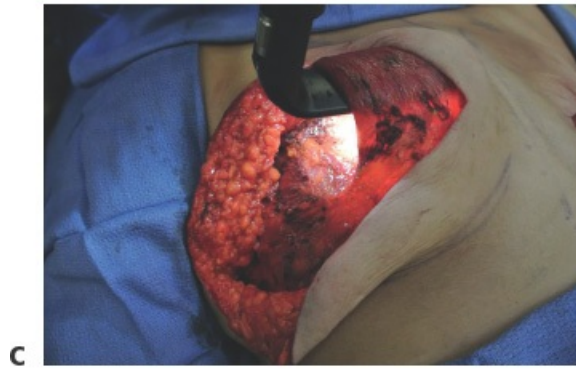
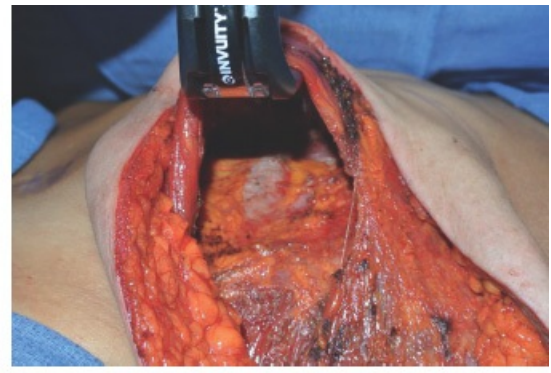
- Laser-assisted indocyanine green fluoroscopy has been promoted to assess mastectomy flap perfusion; however, guidelines for its use and interpretation have not been firmly established.¹
- Use of tumescent solution by the extirpative surgeon makes assessment of mastectomy flaps difficult and has been shown in some studies to be associated with a higher rate of mastectomy flap necrosis.^{2–4}
- When there is significant concern for mastectomy flap necrosis, or if debridement of questionable tissue will lead to closure under tension or an open wound, then aborting reconstruction is strongly advised.
- If necessary, the IMF can be recreated with interrupted suture; however, the position of the inferior edge of the expander will ultimately determine the IMF, which can be adjusted further during an exchange procedure if desired.
 - Some surgeons try to establish the native IMF during this initial procedure (which may make the exchange procedure simpler), whereas others intentionally place the expander lower than the IMF to increase lower pole expansion and projection (which requires recreation of the IMF with suture during the exchange procedure).
 - The author's preference is to preserve the native IMF when performing single-stage implant reconstruction, when placing a significant initial fill volume in the expander, or when the IMF is already low.
 - When performing delayed two-stage implant reconstruction or when placing minimal initial fill volume in the expander, placing the implant below the IMF will preferentially expand the lower pole and permit the surgeon to create minimal ptosis at the exchange procedure (as described in the following chapter).
 - Another reason to consider placing the expander lower than the native IMF is when adjuvant radiotherapy is expected. Radiotherapy almost always causes fibrosis and contracture of the pectoralis major and soft tissue surrounding the implant, with superior migration of the expander.

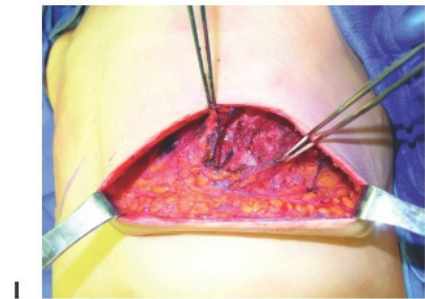
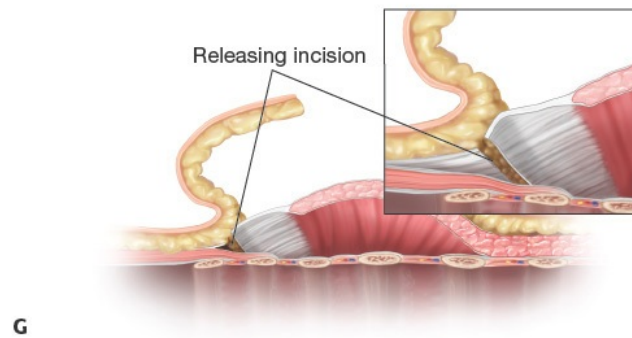
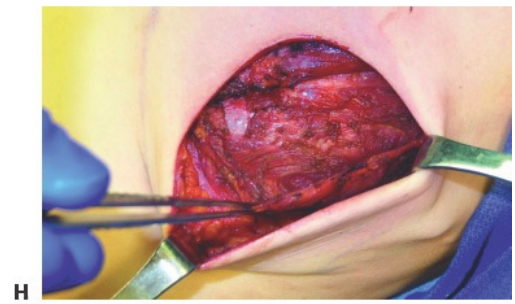
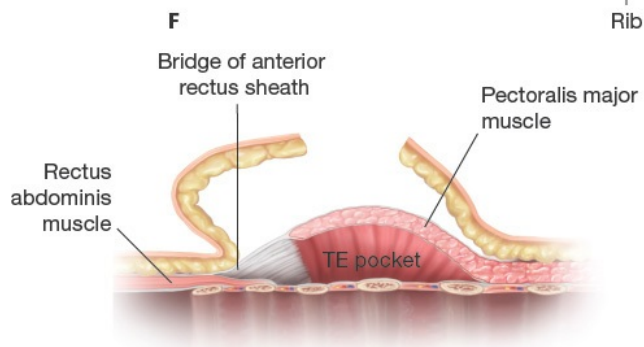
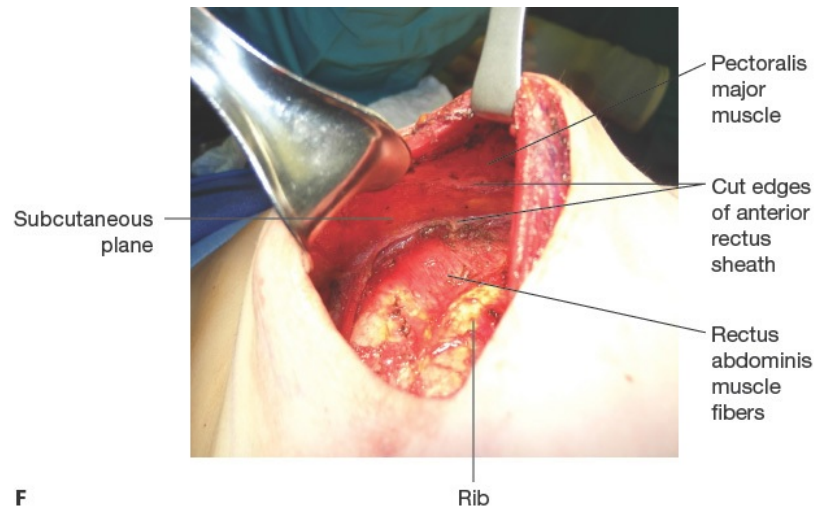
Second Step—Creation of Implant Pocket

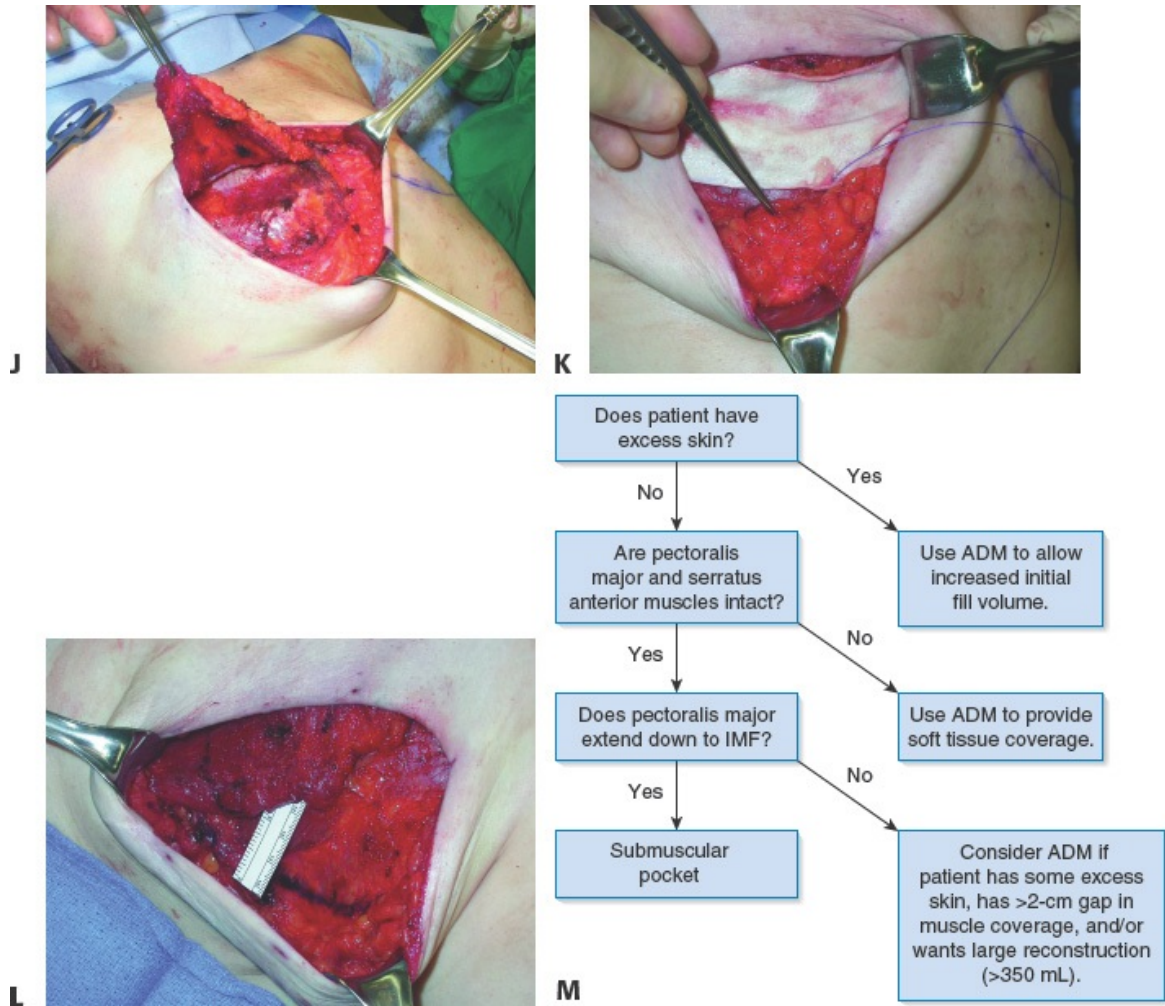
- The tissue expander cannot be covered by the mastectomy flaps alone, which are thin and offer poor soft tissue coverage. Ideally, the surgeon should provide complete musculofascial coverage with the pectoralis major and serratus anterior muscles (**TECH FIG 1A**) or use an acellular dermal allograft (ADM) or other product in addition to the pectoralis major muscle.
 - An emerging technique is to use complete acellular dermal matrix (ADM)

coverage with adjuvant fat grafting at the time of implant exchange, which is beyond the scope of this chapter.

- The lateral edge of the pectoralis major muscle is pinched between the surgeon's index finger and thumb and pulled away from the chest, revealing a loose areolar plane between the pectoralis major and minor muscles. Dissection in this plane commences with Bovie cautery, but once the subpectoral space is entered, much of the superior and medial implant pocket can be created via blunt digital dissection before using lighted retractors for direct visualization.
- A lighted retractor is quite helpful to finish medial dissection, as great care must be taken to ligate or cauterize the intercostal perforators (**TECH FIG 1B,C**).
- The medial boundary is defined externally by the preoperative markings that define the patient's native breast form. Internally, it is quite common to release the medial and inferomedial origins of the pectoralis major muscle. It is important not to release this area excessively, as symmastia can result and is difficult to correct.
- After the subpectoral plane is developed, the inferior insertion of the pectoralis major muscle is examined (**TECH FIG 1D**).
 - If the patient's muscle reaches the IMF, then a submuscular pocket can be created down to the IMF with supple and adequate soft tissue coverage that will respond well to expansion (**TECH FIG 1E**).
 - More commonly, however, the pectoralis major inserts above the IMF. In this scenario, to provide autologous implant coverage inferiorly, one must continue dissection past the pectoralis major insertion and under the anterior rectus sheath until just below the IMF.
- Transitioning from the subpectoral plane to underneath the anterior rectus sheath is sometimes technically difficult and may result in a few gaps in coverage that can be closed after the pocket is fully created. A lighted retractor is necessary for this portion of the procedure.







TECH FIG 1 • A. Following mastectomy, the pectoralis major and serratus anterior muscles are visualized as these are the muscles used for expander coverage. If these muscles have been affected by mastectomy, using an ADM in their place is considered. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **B, C.** A lighted retractor is very helpful for both expander placement and the implant exchange procedure. Here, the lighted retractor is shown during creation of the subpectoral pocket superomedially, where dissection proceeds carefully

so intercostal perforators can be visualized and carefully ligated if necessary. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **D.** The relationship between the most caudal extent of the pectoralis major muscle and the IMF determines whether or not the anterior rectus sheath will be necessary to provide complete submusculofascial coverage of the expander. If the muscle originates at or below the IMF, as shown in this figure, then there is no need to elevate the anterior rectus sheath. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **E.** Schematic diagram patient anatomy when the pectoralis major originates at or below the IMF. In this case, a submuscular pocket can be created down to the IMF that will be supple and respond well to expansion. TE, tissue expander. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **F.** At or just below the IMF, the anterior rectus sheath is divided horizontally to enter the subcutaneous plane. If this is not performed, lower pole expansion will be limited by the stiff anterior rectus sheath. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **G.** Schematic diagram patient anatomy when the pectoralis major muscle originates above the IMF. In this case, the gap

between the caudal border of the pectoralis and IMF must be bridged by elevating the anterior rectus sheath. At or just below the IMF, the sheath must be incised horizontally to enter the subcutaneous space; otherwise, the inferior pocket will not expand well. Alternatively, an ADM can be used to bridge this gap. TE, tissue expander. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **H.** For lateral and inferolateral coverage, a partial-thickness serratus anterior muscle flap is elevated and shown in this photograph. If the fascia is robust and intact, that can be used alone; however, this is seldom the case. An incision in the muscle parallel to the inferolateral edge of the pectoralis major muscle is made and the flap is elevated laterally until the anterior axillary line or sufficiently to create the desired pocket width for the chosen expander. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **I.** Following elevation of the serratus anterior muscle, the inferolateral aspect of the implant pocket will still be adherent to the chest wall. If retractors are placed under the pectoralis major and serratus anterior muscles, this area of adhesion will be exposed and inferolateral dissection will elevate the serratus anterior and external oblique muscles off the chest wall to complete implant pocket dissection. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **J.** If an ADM is used, the

pectoralis major muscle is elevated from the chest wall by dividing its inferior and inferomedial origin. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **K.** A piece of ADM is prepared appropriately, according to the manufacturer's recommendations, and is sewn in with the epidermis side facing the implant. A 6- × 16-cm piece is usually sufficient. The inferomedial and inferolateral corners of the ADM are trimmed to create a curved inferior border, and it is secured to the IMF and lateral pocket using a running 2-0 monofilament slowly absorbing suture. The transition from the IMF to the lateral pocket must be a gentle arc that mimics the opposite side. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **L.** A ruler is used to measure the width of the surgically created pocket. The proper pocket width can be determined by either patient anatomy (eg, the anterior axillary line) or the dimensions of the expander desired. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **M.** Algorithm to determine when to use ADM. IMF, inframammary fold. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.)

- The anterior rectus sheath is quite stiff and will not expand well unless an

incision is made transversely across the sheath just below the IMF, entering the subcutaneous plane (**TECH FIG 1F,G**).

- If the anterior rectus sheath is released above the IMF, one would obviously enter the implant pocket. The goal is to provide complete and supple submusculofascial coverage without gap between the pectoralis major and the IMF.
- Alternatively, the pectoralis major can be released from the chest wall and a piece of ADM (or other product) can be sewn to the IMF inferiorly using a running 2-0 absorbable braided suture.
- Following creation of a subpectoral pocket with or without elevation of the anterior rectus sheath, inferolateral coverage must be provided.
 - Autologous coverage is provided by elevating the serratus anterior fascia if robust, or more commonly a partial-thickness muscle flap if the fascia is thin or traumatized from the mastectomy.
 - An incision in the serratus anterior is made at the level of, and parallel to, the inferolateral edge of the pectoralis major muscle, and a fascial or musculofascial flap is elevated to the anterior axillary line (**TECH FIG 1H**).
 - Alternatively, one can determine the width of the implant pocket based on the width of the desired tissue expander and stop lateral dissection when a sufficient pocket width is achieved (usually 1 cm wider than tissue expander).
 - At this point, the inferior and lateral dissections will be complete, but the inferior serratus and superolateral external oblique muscles will still be attached to the chest wall. By retracting inferiorly and laterally, this plane is exposed and the muscles can be elevated off the chest wall to open the inferolateral pocket (**TECH FIG 1I**).
- If an ADM is used, the origin of the pectoralis major is taken down starting inferolaterally and extending medially and then superiorly along the sternal origin to approximately the 4th rib (**TECH FIG 1J**).
 - The ADM will provide inferolateral implant coverage, and there is no need to elevate the serratus anterior. In this case, the IMF and anterior axillary line are marked internally and the ADM is sutured along a line that transitions in an arc from the IMF to the anterior axillary line using a running 2-0 absorbable braided suture (**TECH FIG 1K**).
 - Alternatively, one can mark the lateral mammary fold based on the width of the desired tissue expander and suture the ADM to this line (**TECH FIG**

1L).

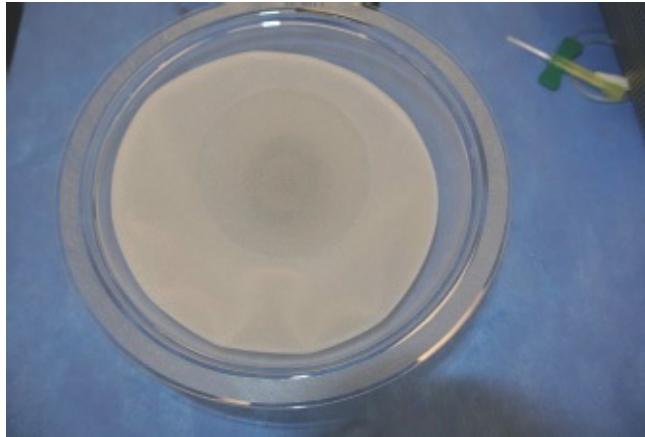
- One can tailor the surgically created IMF to match the contralateral native IMF during unilateral reconstruction. If performing bilateral reconstruction, then it is imperative to create symmetric IMFs.
- The advantages of using an ADM are that it avoids any morbidity associated with elevation of the rectus sheath and serratus anterior, it allows for a greater initial fill volume (and thus fewer postoperative expansions), it allows precise control of the IMF, it may reduce operative time, and it may preserve lower pole fullness.
- Disadvantages include cost and an increased incidence of seroma, infection, and reconstructive failure in patients with risk factors such as obesity, smoking, and/or radiation.⁵
- Although some surgeons use an ADM routinely and others do not, the author's preference is to use ADM selectively (**TECH FIG 1M**).
- If the pectoralis major muscle extends to the IMF and the patient does not desire a large breast reconstruction, then complete submusculofascial coverage is performed. In most other cases, ADM is utilized unless the patient has significant risk factors (obesity, radiation, tobacco use).

Third Step—Preparation of Tissue Expander

- Intraoperatively, a ruler is used to measure the width of the surgically created implant pocket, which ultimately determines the expander to be used. Alternatively, one can create a pocket wide enough to accommodate the desired expander.
- The authors' preference is to measure the surgically created pocket based on native patient anatomy and choose an expander that is 1 cm narrower in width (the expander is always wider than its base when expanded).
- Tissue expanders come with air in them to prevent the inner shell from sticking to itself. There are usually markings for orientation, but it is helpful to draw a vertical line on the expander with a marking pen to assist with positioning the expander in the pocket.
- A needle (usually 23 gauge) is inserted into the port, and all air is removed.
 - The most commonly used tissue expanders are anatomic (creating lower pole expansion), and thus, they are textured (to prevent rotation). There is typically more shell inferiorly, and while deflating the expander, it is important to fold excess shell inward as opposed to folding it upward and

on to itself, where it might cover the port and get punctured (**TECH FIG 2**).

- The authors' preference is to place 60 to 180 mL of sterile saline in the tissue expander prior to placement, which allows the anterior shell to move away from the rigid backing. It is important to control positioning of this backing as it is what determines final expander position.



TECH FIG 2 • The tissue expander is marked with a vertical line for orientation. All air is removed with the excess inferior implant folded inward as shown to avoid puncturing the inferior implant while placing needles for expansion in clinic postoperatively. A minimum of 60 mL of saline is instilled. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.)

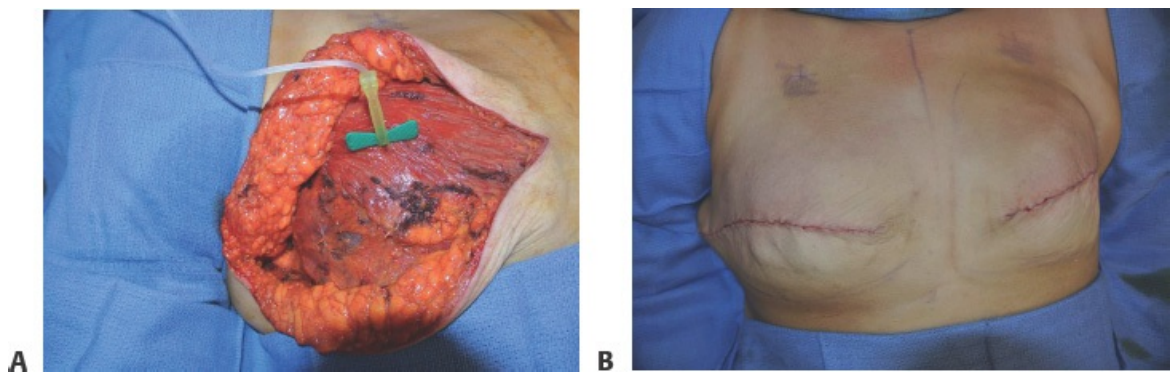
- It can be helpful to put 1 mL of methylene blue in 1 L of injectable saline and use this for the initial expander fluid. If the expander is punctured during closure, it will be evident due to the dye. Additionally, during expansions in clinic, the blue dye will confirm when the port is accessed.

Fourth Step—Placement of Tissue Expander and Closure

- The pectoralis is retracted away from the chest wall and the expander is

placed into the pocket taking great care to orient it correctly.

- It is important to note the rigid backing of the expander and place the caudal edge at the IMF or below if desired. Be sure to unfold all edges of the expander and ensure it is as medial as desired.
- If performing bilateral reconstruction, symmetry in expander placement should be confirmed by palpating the expander ports on each side and ensuring symmetric horizontal and vertical positioning.
- If an expander requires adjustment in positioning, it is critical to grasp the rigid backing of the implant and then adjust the position. If only the ports or anterior shell are adjusted, this usually has no effect on the position of the backing, which determines implant position once fully inflated.
- The inferolateral edge of the pectoralis major muscle is sutured to the anteromedial edge of the serratus anterior muscle with running absorbable 2-0 braided suture, closing the pocket. A small opening is left superolaterally to allow egress of fluid.
- Alternatively, if an ADM is used, the pectoralis major muscle is sewn to the ADM with interrupted figure-of-8 braided absorbable 2-0 suture (**TECH FIG 3A**).
- The author's preference is to inflate the tissue expander with sterile saline as much as the soft tissue (muscle/skin) will allow without creating tension. This is typically 120 to 240 mL.
- It is important to do this prior to skin closure, as placing the needle through the muscle will occasionally cause bleeding, which can be controlled directly. Otherwise, a hematoma could expand in the subcutaneous space without notice until the patient is out of surgery.



TECH FIG 3 • **A.** The inferolateral edge of the pectoralis major is sewn to the superomedial edge of

the serratus anterior with a running 2-0 absorbable polyfilament suture to cover the implant. The expander can then be subsequently filled further depending upon the tolerance of the submuscular pocket and the mastectomy skin flaps. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.) **B.** The patient is shown following placement of tissue expanders and closure over closed suction drains. Internal absorbable sutures are used, with skin glue as the only dressing. No bra is applied, which might apply pressure to tenuous mastectomy flaps. (From: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol. 2. Philadelphia, PA: Wolters Kluwer, 2000.)

- In cases where there is significant concern regarding the cutaneous circulation, then only 0 to 60 mL of inflation is advisable.
- Two closed suction drains are placed in the subcutaneous space. One is oriented superiorly and the other inferiorly.
 - In low-risk patients with smaller breasts, a single drain may be placed via the axilla and extending inferiorly along the lateral border and then across the IMF toward the midline.
- The skin is closed with interrupted 3-0 absorbable monofilament suture for the dermis and a running 4-0 absorbable monofilament suture for subcuticular closure (**TECH FIG 3B**).
 - The authors' preference is to use skin glue alone as a dressing, without placement of a surgical bra, which applies pressure to the tenuous mastectomy flaps and is an impediment to physical examination.
- Antibiotics are continued parenterally for at least 24 hours postoperatively.
 - Although some studies support the use of postoperative prophylactic antibiotics until the drains are removed⁶, others have shown no difference

between this regimen and 24 hours alone.⁷

- Drains are removed when output is less than 30 mL per 24 hours and expansion is begun typically 2 weeks postoperatively. Expansion can continue on a weekly basis, adding as much fluid as the patient will tolerate without discomfort (usually 60 to 120 mL).
- Once expansion is complete according to patient preference and surgeon's satisfaction, the author's preference is to perform one additional overexpansion, which can provide some additional tissue to create minimal ptosis at the exchange procedure at least 1 month later (as described in the following chapter).

PEARLS AND PITFALLS

Indications

- Patients with a history of radiation are poor candidates for implant reconstruction.
- Risk factors for infection and wound healing complications include smoking, radiation, and obesity.

Incision placement

- An oblique incision parallel to the pectoralis muscle fibers provides the best appearance and easiest approach for the exchange procedure.
- Excess skin can be excised through a linear incision only, as additional incisions will compromise circulation and risk mastectomy flap necrosis. Secondary procedures are frequently necessary in patients with excess skin.

Expander selection

- Expanders are selected based on breast width, not volume.

Expander placement

- Marking the expander assists in correct orientation.
- Remove all air and place saline dyed with methylene blue to allow detection of implant rupture as well as confirmation of port access for staff performing expansions.
- Provide 24 hours of postoperative antibiotics.

POSTOPERATIVE CARE

- Following the mastectomy and tissue expander placement, the patient is maintained on antibiotics for at least 24 hours.

- Drains remain in place at least 3 days and then are removed when output is less than 30 mL/d.
 - Only one drain from each side should be removed at a time, as sometimes the output of the second drain will increase after the first drain is removed.
 - The author's preference is to allow patients to shower with drains in place.
- The patient should be seen within 1 week to evaluate for postoperative infection and/or mastectomy flap necrosis and to remove drains if appropriate.
- Range of motion is limited to 90 degrees of shoulder abduction for 2 weeks, and then full range of motion is permitted. Heavy lifting (greater than 10 lb) is avoided for 1 month.
- Expansion is begun 2 weeks after surgery and continued on a weekly basis thereafter until the patient and surgeon are happy with the final volume.
- One additional "overexpansion" is performed, and the exchange procedure is scheduled at least 1 month later to allow the tissues to soften.

OUTCOMES

- Please see the chapter on implant exchange for a discussion of the outcomes of implant reconstruction in general.
- Although patients are typically happy to have "something there" following mastectomy, expanders are often uncomfortable, and the process of tissue expansion can cause discomfort, especially after each expansion.
- Many patients will describe the expander as a "rock under my arm," and it is important to reassure them that this improves dramatically following the exchange procedure.
- The overall success rate of expander reconstruction is roughly 95% to 98%, with a 2% to 5% risk of implant loss due to necrosis and infection.

COMPLICATIONS

- Bleeding
- Infection
- Injury to surrounding structures (eg, cutaneous nerves)
- Mastectomy flap necrosis
- Seroma
- Asymmetry, imperfect cosmetic result

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16 Replacement of Expander With Permanent Implant

CHAPTER

Eric G. Halvorson and Joseph J. Disa

DEFINITION

- Exchange of an expander for a permanent implant is performed as the second stage in two-stage implant breast reconstruction, following mastectomy and tissue expander placement (covered in previous chapter).
- The advantages of two-stage implant reconstruction (compared to autologous reconstruction) include shorter operation, lack of donor site, shorter hospital stay, shorter recovery, patient control over final volume, and a “perkier” result.
- The disadvantages of two-stage implant reconstruction include multiple postoperative office visits for expansions, discomfort associated with the expansion process, a second (albeit outpatient) surgery, and the permanent risks of implants (capsular contracture, rupture, rippling, infection, malposition, and exposure).

PATIENT HISTORY AND PHYSICAL FINDINGS

- The initial consultation will have taken place prior to mastectomy and tissue expander placement; however, it is important to review the patient’s interim medical history prior to the exchange procedure, as interim changes are not uncommon as a patient progresses through breast cancer treatment, and their medical problems to assess risk factors for wound healing complications, for example, diabetes, radiation therapy, obesity, and smoking.
- If patients have had radiotherapy, then waiting 3 to 6 months before performing the exchange procedure is advised.
- Physical examination of the breasts is performed to evaluate expander size and position as well as the soft tissue envelope.
- Implants often require position adjustment using capsulotomy and/or

capsulorrhaphy.

- Radiation changes are noted (if applicable), and if the skin and soft tissue surrounding the mastectomy scar are very thin, then an IMF approach to the exchange procedure should strongly be considered. Cutaneous recurrence should always be excluded.
- Areas of soft tissue deficiency are evaluated for possible autologous fat grafting. This is fairly common in the upper pole.
- Donor sites are also assessed. The medial thighs and hips are good donor sites. The abdomen should be spared as a possible future donor site for autologous reconstruction, if appropriate.
- Expander size and volume is reviewed and determines implant selection (covered in the following text).

SURGICAL MANAGEMENT

- Ideal candidates for two-stage implant reconstruction are thin, nonsmokers undergoing bilateral mastectomy who have not, and will not, receive radiotherapy.
 - Smokers are prone to wound healing complications and infection.
 - Radiotherapy increases the risk of infection, implant exposure, and capsular contracture.
- Although obesity increases the risk of complications for most procedures, unless other risk factors are present, the exchange procedure on obese patients is very safe. Most of their risk will have occurred during the mastectomy and expander placement.
- The exchange procedure can be an opportunity to modify implant position and also address some excess skin via lenticular excision.

Preoperative Planning and Implant Selection

- Good communication with the breast surgeon and medical oncologist ensures oncologic goals are maintained and that reconstruction is appropriately staged.
- The exchange procedure is typically delayed until one month following chemotherapy.
 - If radiotherapy is planned, the exchange procedure can be performed between chemotherapy and radiation, or 3 to 6 months following radiation. This is often determined by the preferences of the medical oncologist and radiation oncologist.
 - Patients on extended adjuvant therapy can safely undergo the exchange

procedure; however, the specific agent must be assessed for risk of wound healing complications and/or thromboembolic events, and a discussion with the medical oncologist is advised.

- Prior to the exchange procedure, the patient must be marked in the standing position.
- The IMF is marked on each side and the midline is drawn between the sternal notch and xiphoid process.
- A horizontal line is drawn from the lowest point of the IMF on each side to the midline, which helps identify vertical asymmetries in expander position.
- The medial silhouette of each expander is marked, which helps identify horizontal asymmetries in expander position.
- The ideal contour for the final implants is marked, revealing areas where capsulotomy will need to be performed to adjust the implant pocket.
- If applicable, areas of soft tissue deficiency are outlined for autologous fat grafting, and the donor sites are marked.
- Final implants are selected primarily based on volume, although width should be taken into consideration. A full discussion of implant types is beyond the scope of this chapter.
- The majority of surgeons use smooth, round, high-profile silicone implants for reconstructive purposes, although textured anatomic silicone implants are also available.
- Patients with very wide chests may require a moderate-profile implant that will have a larger base diameter for a given volume (although less projection).
- A comparison of saline vs silicone implants is also beyond the scope of this chapter, but suffice it to say that the issue is controversial. The authors' preference is to offer both types to patients noting the following advantages and disadvantages for each implant type:
 - Saline
 - Advantages: Implant rupture is immediately detected; removal/replacement of a ruptured implant is simple and quick.
 - Disadvantages: Re-expansion may be required if implant ruptures and is not replaced expeditiously; firmer than silicone, although this difference is negligible when good soft tissue coverage is present; higher potential for rippling if underfilled.
 - Silicone

- Advantages: Softer, more “natural” feel
- Disadvantages: Rupture is often clinically silent until capsular contracture and/or extracapsular rupture occurs, removal of a ruptured implant is a difficult operation that can involve removal of native tissue thus compromising subsequent reconstruction, and monitoring for silent implant rupture using magnetic resonance imaging (MRI) is not proven and has a definite risk of false positives and unnecessary surgeries.

Positioning

- Patients are placed in the supine position under a general anesthetic with arms padded circumferentially and abducted at 80 to 90 degrees. The patient is positioned such that the sternum is parallel to the floor via head elevation or reverse Trendelenburg.

TECHNIQUES

■ Implant Exchange

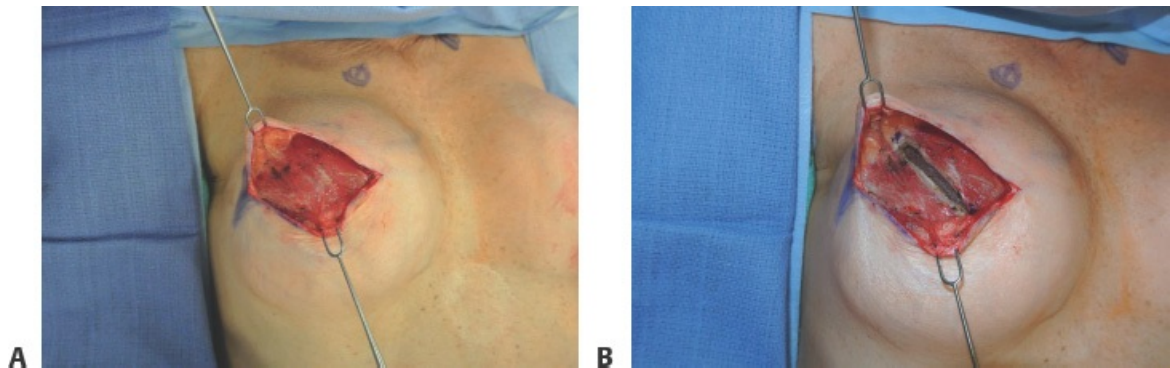
First Step—Removal of Tissue Expander

- As noted earlier, the patient is marked in the standing position. Asymmetries are noted, and the ideal contour for the final implants is marked.
- If performing fat grafting, the donor sites should be injected with tumescent solution at the beginning of the case to allow the epinephrine to take effect.
- The mastectomy scars have often widened during expansion and these can be excised.
- A stair-step approach to the implant pocket is usually performed, so any wound breakdown in one layer does not expose the suture line of the other layer.
 - If the scar is oriented obliquely (**TECH FIG 1A**), 2 to 4 cm of superomedial skin elevation will expose the pectoralis major, which can be incised parallel to the muscle fibers.
 - If a transverse approach was used, then superolateral and inferomedial skin elevation is required to expose the pectoralis major and allow for an incision parallel to the muscle fibers.
- The implant pocket is entered and the capsule is bluntly separated from the

expander, which is removed. If the expander is too large, it can be ruptured with a needle or scalpel to assist in removal. If there was any doubt about the final expander volume, it can be measured at this point (**TECH FIG 1B**).

Second Step—Creation of Implant Pocket

- Ideally, the expanders can be removed and the permanent implants placed without further intervention; however, this is rarely the case. Superior and superomedial capsulotomy is often required to soften the transition from the chest wall to the implant (**TECH FIG 2A,B**).



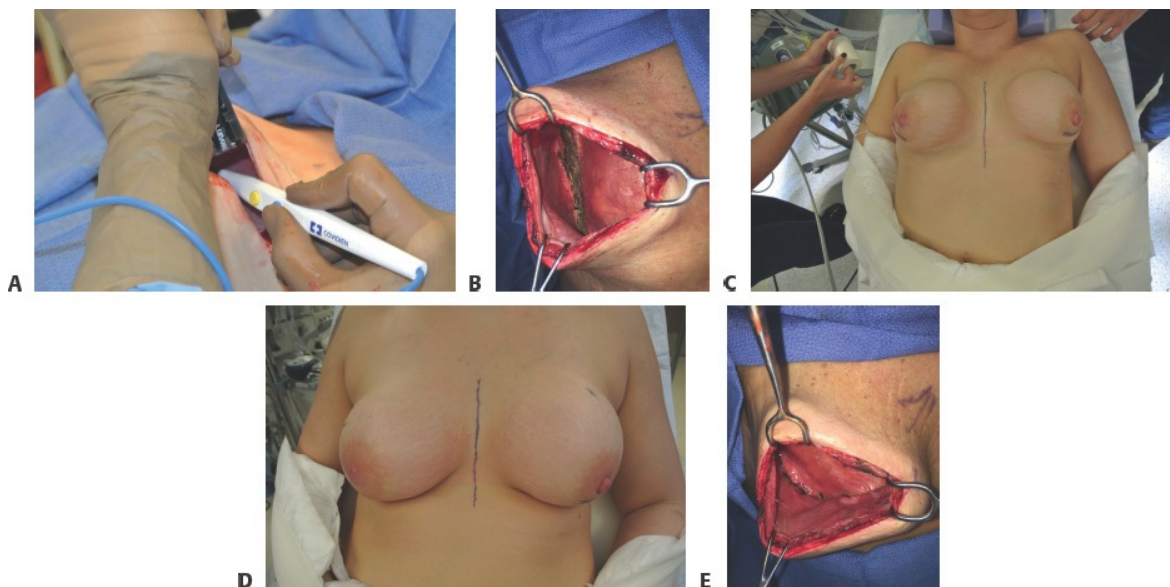
TECH FIG 1 • A. If the oblique incision is used for mastectomy, it is easy at the exchange procedure to elevate a superomedial flap exposing the pectoralis major muscle where it tends to be thicker. This will allow a “stair-step” approach to the implant pocket. Any wound healing issue at one level will not expose the suture line at the other level. (From Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer; 2014.) **B.** A muscular incision is made parallel to the pectoralis major muscle fibers to access the implant pocket. The capsule is also incised with cautery, and the expander is bluntly separated from the capsule. (From Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative*

Techniques in Surgery. Vol 2. Philadelphia, PA: Wolters Kluwer; 2014.)

- The pocket may need to be medialized, lateralized, elevated, or displaced inferiorly. These can all be accomplished through capsulotomy.
- If the final implant is roughly the same width as the expander, then a corresponding capsulorrhaphy at the opposite side of the pocket is necessary using figure-of-eight interrupted 0 suture.
- If the implant is wider than the expander, this may not be necessary as the capsulotomy will increase pocket diameter.
- If the expander was placed below the IMF, or if the IMF needs to be elevated, this is accomplished with figure-of-eight interrupted 0 suture.
 - The patient is sat upright (**TECH FIG 2C,D**) and the inferior mastectomy flap is lifted away from the chest wall.
 - Usually, the old IMF can be visualized and marked; otherwise, the desired IMF can be marked.
 - The needle is passed through the capsule and the IMF marking externally is visualized. The needle tip should just catch the deep dermis, resulting in a small indentation when tied. These indentations will resolve in several weeks.
 - After passing the needle through the capsule/dermis, tension can be adjusted by examining the fold externally and elevating it as desired.
 - Internal inspection with the suture still under tension will indicate where the corresponding suture throw in the chest wall must be made. Suturing into the rib should be avoided, as this results in pain.
 - The first suture is placed at the center of the IMF and then one to two sutures are placed medially and laterally until an adequate fold is created (**TECH FIG 2E**).
- Some surgeons prefer to establish the IMF at the initial operation, potentially with an acellular dermal matrix (ADM), which has the added benefit of permitting a higher initial fill volume. A greater initial fill volume has the potential to better preserve lower pole fullness.
- No time is spent reconstructing the IMF at the exchange procedure. Although this may be a simpler approach, it may result in a blunted IMF.
 - The authors' preference is to treat each case individually and surgically create a crisp IMF at the exchange procedure if necessary. For example,

patients undergoing delayed reconstruction will benefit from significant lower pole expansion and thus the expander is placed inferior to the desired IMF and the IMF is reconstructed at the exchange procedure.

- A patient with minimal excess skin and ptosis undergoing immediate reconstruction may benefit from an ADM to maximize the initial fill volume (preserve lower pole fullness), establish the IMF, and avoid inferior capsulorrhaphy at the exchange procedure.
- To further expand the lower pole and create minimal ptosis, capsulotomy of the inferior pocket is then performed. A horizontal capsulotomy half way up the inferior mastectomy flap, at least 4 cm off the chest wall, will expand the lower pole of the pocket. Additional radial capsulotomies can be added for further lower pole expansion or elsewhere to create symmetric pockets.
- During pocket creation, it is helpful to have a temporary sizer inflated (with air or saline) to roughly the desired implant volume, which can be placed into the implant pocket to assess position, shape, and volume. This is particularly important in bilateral reconstructions, where two sizers are required to confirm pocket symmetry.



TECH FIG 2 • A,B. A superomedial and superior capsulotomy is made just above the chest wall using a lighted retractor. This will soften the transition from chest wall to implant and allow for more implant mobility within the pocket. (From Halvorson EG. Two-

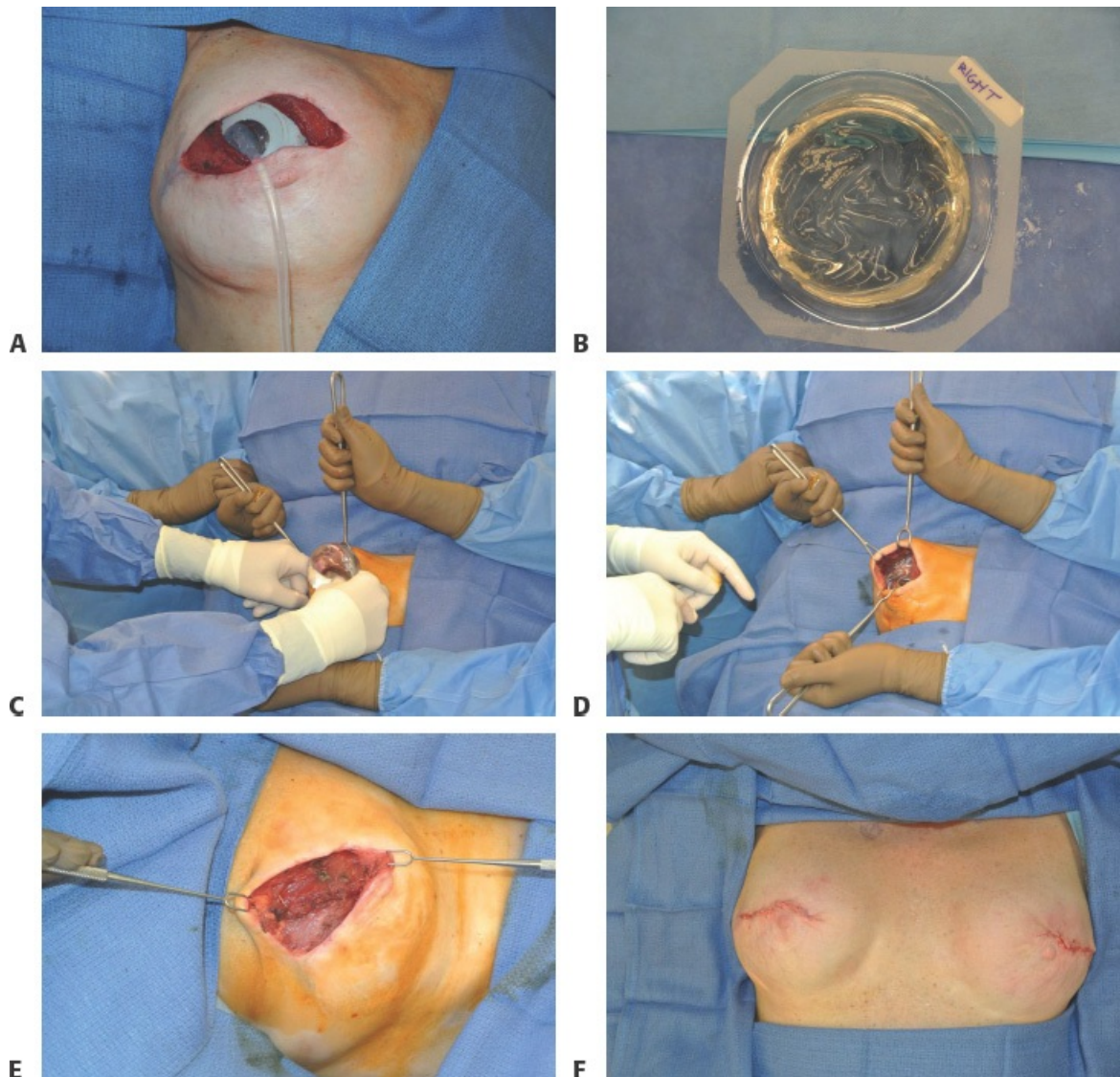
stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer; 2014.) **C,D.** The patient is positioned upright with both upper extremities well padded and secured to the operating room table or arm boards. **E.** Inframammary fold and/or lateral mammary fold sutures are placed to define the fold and adjust pocket dimensions as needed. (From Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer; 2014.)

- If the sizer is loose and slips laterally, lateral capsulorrhaphy sutures should be placed.
- If autologous fat grafting is to be performed, the authors' preference is to do it while the temporary sizers are in place to avoid inadvertent rupture of the permanent implants.
 - Fat grafts are harvested, processed, and injected into the subcutaneous, intramuscular, and submuscular planes via the incision or small stab incisions as determined by preoperative examination and markings.
 - The sizers are removed, and the implant pocket is once again irrigated to remove any possible fat grafts that have been placed into the implant pocket. A full description of fat grafting techniques is beyond the scope of this chapter.

Third Step—Implant Selection and Closure

- When ordering implants for the exchange procedure, it is wise to order implants that are one size smaller and one size larger than the implant size determined by the patient's final expansion volume (prior to final overexpansion). As mentioned earlier, temporary sizers are usually used and can be adjusted to determine an acceptable final implant volume.
 - Inflating the sizer beyond the final expander volume usually results in excessive upper pole fullness, a noticeable step-off between the chest and implant, and tight closure. The chest should transition to the implant smoothly, and the breast mound should have slight ptosis.

- When placing saline implants, choose an implant that has the desired volume as the upper end of its volume range. For example, if 380 mL is the desired implant volume, use an implant with a volume range of 360 to 390 mL.
- This avoids rippling at the expense of making the implant slightly firmer. Some surgeons will in fact overfill the implant by 10% to avoid rippling.
- Disposable sizers can be used prior to final implant placement (**TECH FIG 3A**).



TECH FIG 3 • A. Disposable sizers are used to determine the optimal implant. The patient is viewed in the upright position. (From Halvorson EG. Two-stage

implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer; 2014.) **B –D**. Next, the permanent implant is selected. The field is surrounded by clean sterile drapes and clean gloves are used to place the implant. Care is taken to avoid implant contact with the skin. (Credit: Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer, 2014.) **E,F**. The pectoralis is reapproximated with an absorbable suture, and the wound is closed in layers. (From Halvorson EG. Two-stage implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer; 2014.)

- The pockets are irrigated, hemostasis is obtained, and the final implants are opened.
 - Although many surgeons will prep the patient, place new drapes, dip retractors in prep solution, and handle the implants with fresh gloves, there is no data to support these practices. The authors do not take any special precautions, as the procedure is a clean, sterile procedure (**TECH FIG 3B–D**).
- The implants are placed and the muscular closure is performed with a running 2-0 braided absorbable suture. The capsule is not included in this closure if possible, thus creating an anterior capsulotomy (made upon initial approach to the implant pocket).
- No drains are placed. The skin is closed with interrupted deep dermal 3-0 monofilament absorbable suture and a running 4-0 subcuticular absorbable suture (**TECH FIG 3E,F**). A skin glue is applied, and a brassiere is only used if supporting the implant in a particular position is desired.

Implant selection

- Implants are selected based on volume primarily, taking breast width into consideration. High-profile implants are typically used, except in patients with wide chests who benefit from moderate-profile, wider implants.

Adjunct procedures

- Consider fat grafting to address contour deformities, improve the soft tissue, and soften the contours of the implant.

Patient expectation

- Two-stage implant breast reconstruction is typically a year-long process.
- Symmetry in the nude is always the goal but is seldom achieved. Symmetry in clothing is the most reasonable expectation.

POSTOPERATIVE CARE

- Following the exchange procedure, patients may shower after 48 hours. The exchange procedure is sterile, and the mastectomy flaps have been delayed and have robust perfusion. No postoperative antibiotics are given. Range of motion is limited to 90 degrees of shoulder abduction for 2 weeks, and then full range of motion is permitted. Heavy lifting (greater than 10 lb) is avoided for 1 month.

OUTCOMES

- Patient satisfaction with implant breast reconstruction is high, provided the preoperative consultation appropriately identified the patient's priorities, goals, and preferences with respect to reconstructive options, and realistic expectations were discussed.
- Although some studies have indicated that patients undergoing prosthetic reconstruction are less satisfied than are those undergoing autologous tissue reconstruction,^{1,2} other studies have shown significant improvements in psychosocial outcomes regardless of the type of reconstruction.³
- It is common to tell patients undergoing implant reconstruction that, on average, they will require some form of surgery every 10 years. These could be procedures for symmetry, infection, rupture, or capsular contracture. Although some surgeons exchange silicone implants every 10 years to avoid extracapsular ruptures, most only offer surgery if a problem is identified.
- One study evaluated long-term outcomes of autologous vs implant reconstruction and noted stable survival of 90% of autologous reconstructions

vs a gradual decline to 70% survival of implant reconstructions.⁴ In general, autologous reconstructions improve or remain stable with time, whereas implant reconstructions tend to worsen slightly over time.

- There is no increased risk of breast cancer recurrence in patients undergoing therapeutic mastectomy and implant reconstruction. Detection of recurrence and outcome when recurrence is detected are not affected by the presence of an implant reconstruction.⁵

COMPLICATIONS

- Bleeding
- Infection
- Long-term risks of implants: capsular contracture, rupture, rippling, infection, malposition, and exposure
- Asymmetry, imperfect cosmetic result

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17 Direct-to-Implant Breast Reconstruction

CHAPTER

Amy S. Colwell and Eric J. Wright

DEFINITION

- Following mastectomy, the reconstructive goal is to recreate a natural-appearing breast, which may improve quality of life and body image.
- Direct-to-implant (DTI) reconstruction involves placement of the permanent implant at the time of mastectomy in one stage.
- DTI reconstruction is a cost-effective, low complication rate procedure with outcomes similar to two-stage tissue expander/implant reconstruction in experienced centers.¹
- Alternatives to DTI include no reconstruction, two-stage tissue expander/implant reconstruction and autologous reconstruction with flaps or fat.
- In comparison with tissue expander reconstruction, there are fewer office visits and one less surgical procedure. Compared to autologous reconstruction, there is no donor site morbidity.

ANATOMY

- The breast skin is preserved or reduced to accommodate an appropriate-size implant.
- Skin-sparing or nipple-sparing mastectomy keeps the native breast skin envelope intact by crafting a natural shape with immediate round or shaped implant insertion. In nipple-sparing procedures, the nipple ducts are removed with the mastectomy and the outer epidermis and dermis are retained with the rest of the breast skin.
- Ideal candidates for nipple-sparing mastectomy have grade 1 to grade 2 nipple ptosis.

- Patients with grade 3 ptosis may be better candidates for skin-sparing mastectomy or mastopexy prior to mastectomy.
- The implant has total, partial, or no muscle coverage under the breast skin.
- The pectoralis major muscle most commonly covers the implant superiorly. Inferiorly, acellular dermal matrix (ADM) or mesh serves as an extension of the pectoralis major muscle to cover the implant inferiorly.

PATIENT HISTORY AND PHYSICAL FINDINGS

- DTI reconstruction can be performed in unilateral or bilateral mastectomies and in reconstruction for cancer or prophylaxis.
- Ideal candidates for DTI reconstruction are otherwise healthy patients, with moderate size breasts, who desire to retain approximately the same breast size.
- Patients who desire a significantly larger size are more safely treated with tissue expander/implant reconstruction.
- Relative contraindications to DTI include active smoking, uncontrolled diabetes, and immunosuppressive medications.
- Planned postoperative radiation, obesity, prior breast scars, and previous lumpectomy/radiation may increase the risk of complications, but they are not absolute contraindications to performing DTI reconstruction.
- The breasts are assessed for volume, symmetry, nipple position, inframammary fold (IMF) position, and breast base width.
- Patients with very small (less than 100 g) or very large (greater than 900 g) breasts are typically better candidates for tissue expander/implant reconstruction.
- If a patient has asymmetry, a better cosmetic outcome may be achieved in two stages for bilateral reconstructions.

IMAGING

- Preoperative mammogram or MRI can determine the oncologic safety of proceeding with a nipple-sparing vs skin-sparing mastectomy based upon the proximity of the cancer to the nipple.

SURGICAL MANAGEMENT

- Surgical management requires either a team approach with the surgical oncologist and plastic surgeon or an oncoplastic surgeon experienced in both mastectomy and reconstruction.
- During the preoperative visit, patients are to be counseled on the possibility of

a two-stage tissue expander/implant reconstruction or delayed reconstruction depending on the intraoperative mastectomy skin viability.

- Though saline implants can be used, silicone implants are used more commonly to create a more nature look and feel.
- Smooth round implants are softer than are anatomic implants and typically provide more superior pole fullness.
- Textured anatomic implants are firmer than round implants and typically have reduced risk of rippling. These implants may better match a contralateral breast in unilateral reconstructions and may have less contracture after postmastectomy radiation.
- Partial pectoralis muscle coverage of the implant is the most common technique with an inferior sling of ADM or synthetic mesh.
- Compared to total muscle coverage, partial muscle coverage gives more natural breast shape and can accommodate a larger size implant.
- Compared to no muscle coverage, partial muscle coverage has better soft tissue coverage in the upper pole, and it is less expensive.
- Human ADM is the most common material used to provide an inferior sling.² Alternative materials include porcine skin, bovine skin, and synthetic meshes made from silk, Vicryl, and titanium. These products provide precise control of the lateral and inframammary pocket borders along with the lower pole projection. They also support the implant and help keep the pectoralis muscle on stretch.
- The authors describe their preferred technique using partial muscle coverage with an inferior pole sling of human ADM.

Preoperative Planning

- A paravertebral block can be performed for perioperative and postoperative analgesia.
- Reference markings are placed including the IMF bilaterally and planned lateral border of the breasts.
- For skin-sparing procedures, the incision is placed around the areola, with or without small medial and lateral extensions.
- For nipple-sparing procedures, an inferolateral IMF incision optimizes mastectomy, lymph node sampling, and reconstruction.
- Alternative incisions in NSM include lateral radial, vertical, or extension of a nonradiated scar (**FIG 1**).

- A full-thickness periareolar incision is typically avoided to decrease risk of nipple and skin loss.
- Circumvertical mastopexy or Wise pattern mastopexy procedures at the time of mastectomy are associated with a higher risk of complications and are typically avoided.
- The goal is for placement of an appropriate-sized implant within the pocket for uneventful wound healing and centralization of the nipple if preserved.

Positioning

- The patient is placed in the supine position with arms extended, secured on arm boards, and angled to the side.

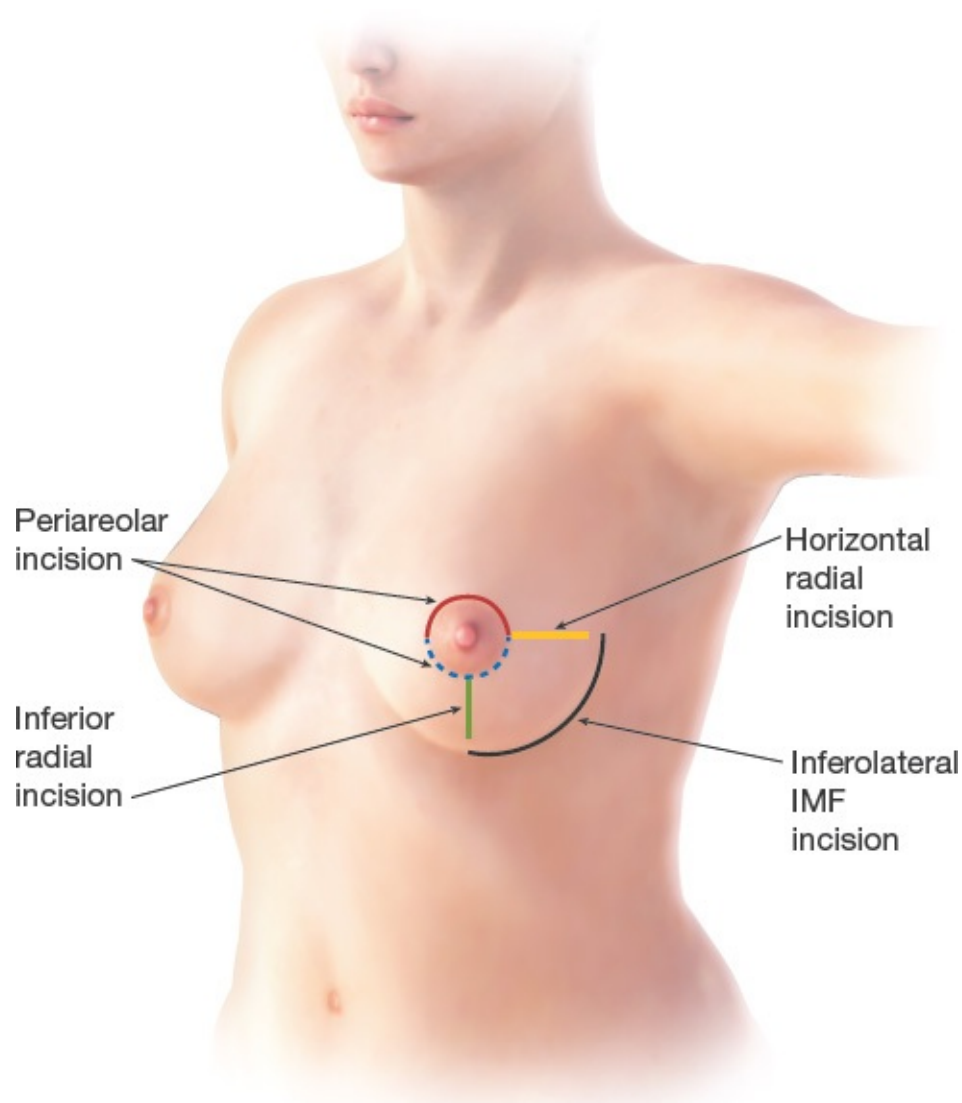


FIG 1 • Depending on tumor location and surgeon preference, these are the possible incision locations for nipple-sparing mastectomy.

- Intraoperatively, the patient will be placed in the sitting position to assess size and symmetry before permanent implant placement.

Approach

- Implant placement can be performed through any access incision used for the mastectomy.
- For NSM, an inferolateral IMF incision is most commonly used and has excellent appearance.³

TECHNIQUES

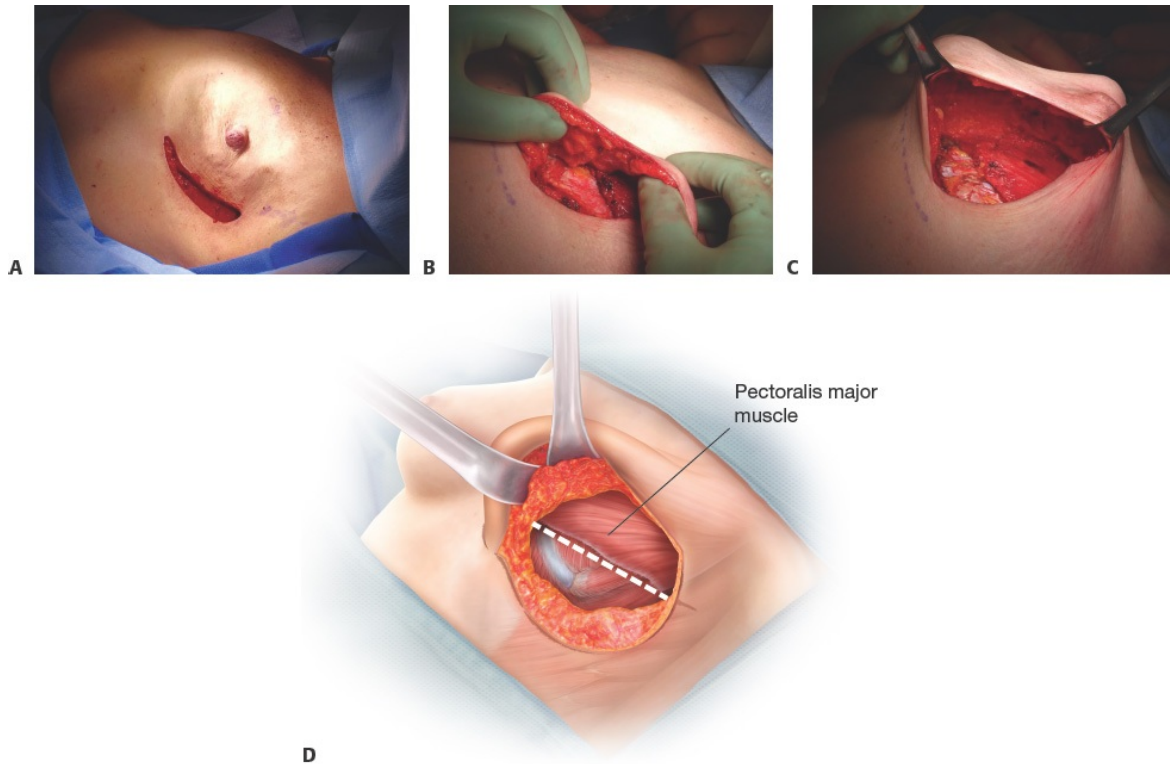
- **Direct-to-Implant Reconstruction with Partial Muscle Coverage and Acellular Dermal Matrix (Video)**



Video p4-c017

Pocket Creation

- Intravenous antibiotics are administered prior to the surgical incision (**TECH FIG 1A**).
- The patient is reprepped with chlorhexidine, and new drapes are placed over existing drapes after completion of the mastectomy.
- The mastectomy skin flaps are assessed for perfusion based upon appearance/color, thickness of skin flaps/visibility of the dermis, and capillary refill (**TECH FIG 1B**).
 - Concern for ischemia necessitates two-stage or delayed reconstruction. If available, perfusion devices can be used to help assess relative skin ischemia and perfusion.
 - Ideal mastectomy skin flaps have a relatively even layer of subcutaneous fat with no exposed dermis and no red or blue discoloration.
- Mastectomy specimens are weighed to assess the volume removed.
- The patient is paralyzed for easier subpectoral dissection and pocket closure once the implant is placed.
- The pectoralis major muscle is elevated from the lateral border to create a subpectoral pocket. The inferior insertion of the pectoralis major muscle is released to approximately the 4 or 8 o'clock position (**TECH FIG 1C,D**).
 - Care is taken to not violate the IMF with muscle release if intact. Hemostasis is confirmed throughout the pocket.



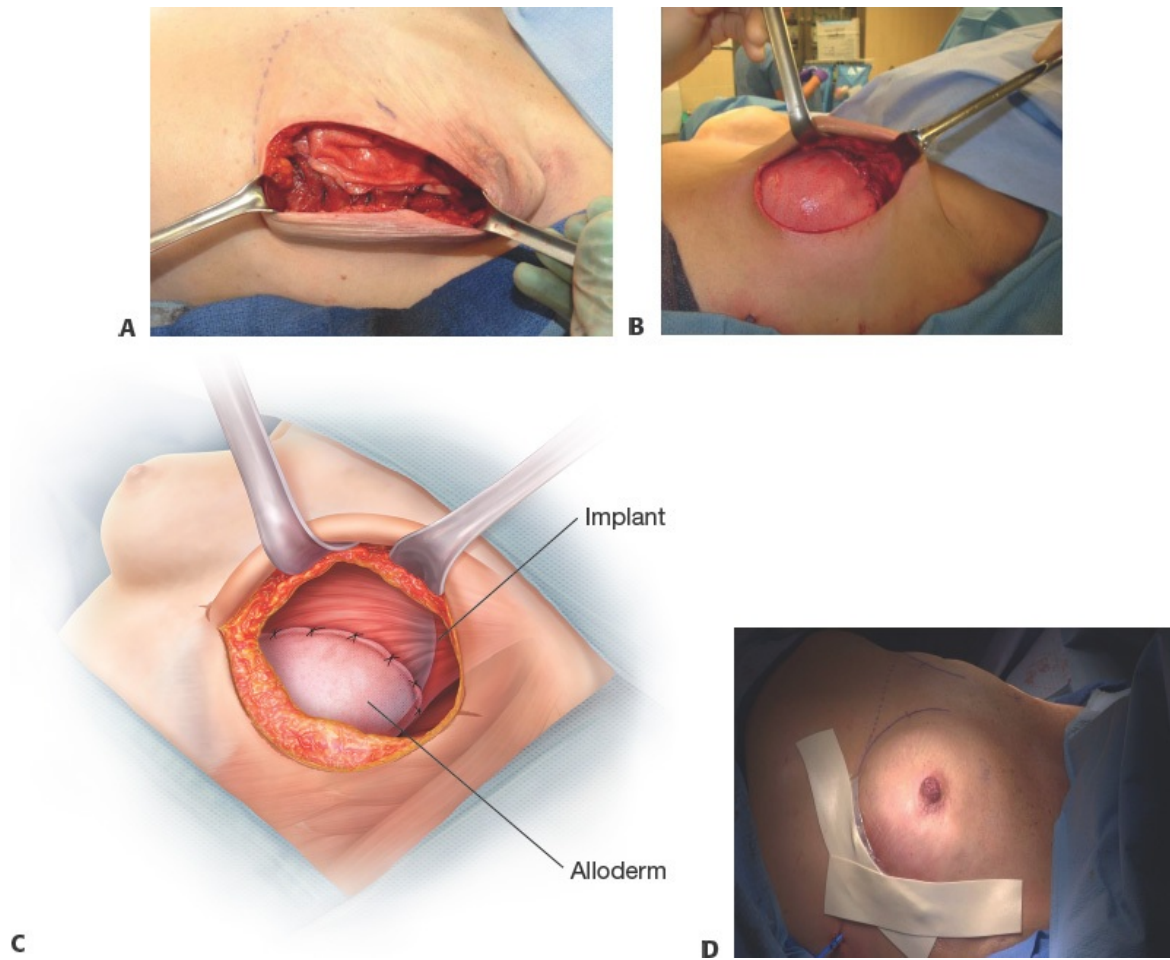
TECH FIG 1 • A. The inferolateral inframammary fold incision is commonly used to perform the nipple-sparing mastectomy and reconstruction. This incision gives access to perform the sentinel lymph node biopsy. **B.** Mastectomy flaps are inspected at the start of the case. Ideal flaps will have an even layer of subcutaneous fat with no skin discoloration. **C,D.** The pectoralis muscle is released along the sternum from 4 o'clock to 8 o'clock along the inferior border. (**D** from Colwell AS. Direct-to-implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer Health; 2015:1471-1475.)

- Based upon the natural breast diameter and volume/diameter of the expected implant, the lateral border of the pocket is marked by extending over the serratus muscle.
- This marking is placed 1 cm less than the expected diameter of the implant

to compensate for the stretch of human ADM. If a stiffer material is used, this marking can be adjusted.

ADM and Implant Placement and Closure

- Rectangular or contoured ADM is sutured to the released border of the pectoralis muscle and IMF loosely medially to accommodate medial implant placement (**TECH FIG 2A**).
 - The ADM is sewn to the chest wall in the inferior and lateral position to help prevent bottoming out and lateral malposition. The authors prefer braided permanent sutures for the chest wall stitches, although absorbable sutures are also commonly used.
- Silicone or saline sizers are used to confirm implant size and pocket dimensions.
- Temporary tacking sutures secure the pectoralis muscle to the ADM, and the patient is placed in the upright position.
 - After symmetry and appropriate pocket appearance are confirmed, the permanent implant is chosen based primarily on the volume and breast base width.
- New gloves are used when handling the implant.
 - Triple antibiotic solution with cefazolin, gentamicin, and bacitracin is used for pocket irrigation.
- Two no. 15 Bard drains are placed lateral to the incision and secured.
 - One drain is placed internally along the IMF, and the other is placed laterally toward the axilla and extending over the pectoralis muscle.
- After implant insertion, the pectoralis muscle is secured to the ADM using a braided absorbable suture (**TECH FIG 2B,C**).
 - The tension is adjusted and ADM trimmed as necessary to create a tight pocket around the implant that helps to avoid lateral and inferior malposition.
- The incision is de-epithelialized 2 to 3 mm, and a three-layered closure is performed with absorbable sutures followed by skin glue.
 - An occlusive dressing is applied over the incision and Biopatches are placed around the drains.
- Elastic foam tape and Tegaderm are often used to help stabilize the implant and nipple position (**TECH FIG 2D**).



TECH FIG 2 • **A.** The acellular dermal matrix is sutured with permanent suture to the chest wall and pectoralis muscle. **B,C.** After implant placement, the acellular dermal matrix is sutured to the released inferior border of pectoralis muscle. **D.** After closure, final dressing with elastic foam is placed to help with position. (**C** from Colwell AS. Direct-to-implant breast reconstruction. In: Mulholland MW, ed. *Operative Techniques in Surgery*. Vol 2. Philadelphia, PA: Wolters Kluwer Health; 2015:1471-1475.)

Preoperative assessment	■ Appropriate patient selection improves outcomes.
Intraoperative assessment	■ Before committing to a direct-to-implant reconstruction, the mastectomy skin flaps must be viable without injury. The patient should always be consented for possible tissue expander placement.
Technique	■ Suture the ADM loose medially and tight laterally to avoid lateral displacement. Use of a sizer will help determine appropriate pocket dimensions for proper implant selection. ■ For skin-sparing mastectomy, choose higher profile implants if possible to help overcome the flattening effect of losing the nipple. ■ For NSM, choose the width of implant to centralize the nipple. A lower profile implant may be necessary to avoid shifting the nipple laterally, which can be seen when the implant is too narrow.

POSTOPERATIVE CARE

- Patients are typically hospitalized overnight but may stay 2 days postoperatively.
- On postoperative day 1, a supportive surgical brassiere is placed avoiding excess constriction that can decrease perfusion.
- Patients are allowed to shower following the surgery.
- Patients are discharged home on oral antibiotics until the drains are removed.
- Drains are removed in follow-up clinic once the output has decreased to less than 30 cc per 24 hours. Typically, one drain per side is removed 1 week after surgery and the other is removed the second week after surgery. Drains are not kept longer than 4 weeks.
- Strenuous activity is limited for 8 to 12 weeks following the procedure.
- For smooth round implants, massage begins 1 month after the procedure.

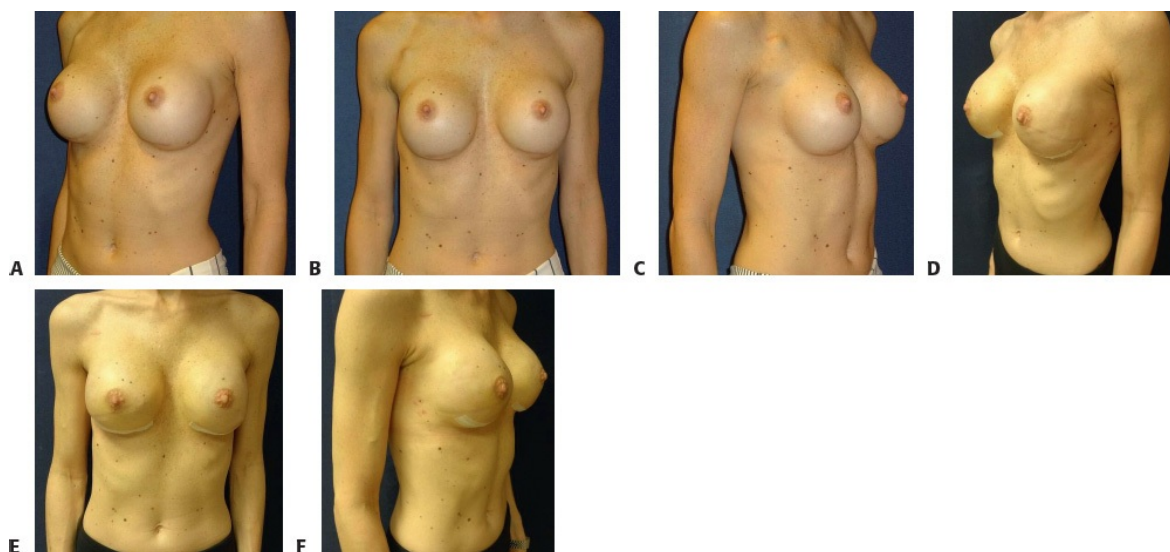


FIG 2 • A–C. A 36-year-old woman before and **(D–F)** after nipple-sparing mastectomy with direct-to-implant reconstruction.

- Pathology of the nipple specimen is reviewed. If positive, the nipple is excised with a 2- to 3-mm margin of areolar skin.
- The immediate postoperative appearance may have contour irregularities due to the unevenness of the mastectomy skin flaps and ADM-muscle interface. This resolves over the course of a few weeks once the suction drains are removed and the skin begins its recovery.

OUTCOMES

- A single-institution, three-surgeon study found DTI reconstruction with ADM had similar low rates of complications and explantations compared to traditional tissue expander/implant reconstruction¹ (**FIGS 2** and **3**). This cohort was followed for an average of 5 years and was found to have similar revision rates for malposition, size, fat grafting, and capsular contracture between DTI and tissue expander reconstruction.⁴
- In a review of 500 nipple-sparing mastectomies with immediate reconstruction performed at one center, DTI reconstruction was performed in 59% vs 41% for two-stage expander/implant reconstruction. The rate of implant loss was 1.9% with no significant difference between DTI and two-stage tissue expander reconstructions.⁴
- An 8-year experience with DTI reconstructions using ADM in 466

reconstructed breast had an overall complication rate of 3.9% and overall revision rate of 9.4%, similar to two-stage reconstructions.⁵



FIG 3 • A–C. A 40-year-old woman before and **(D–F)** after nipple-sparing mastectomy with direct-to-implant reconstruction.

- A 5-year experience with 682 reconstructions found no difference in the revision rate between DTI and two-stage expander reconstructions.⁶

COMPLICATIONS

- Skin/nipple necrosis: Skin necrosis requires aggressive management to prevent infection or exposure of the implant. Small areas can be debrided and closed in the clinic setting. Larger areas require return to the OR for excision and possible downsize of the implant or placement of a tissue expander.
- Infection: Erythema, fever, drainage, pain, and swelling are signs of a cellulitis or periprosthetic infection. If symptoms are mild, oral antibiotics can be administered. If severe, the patient is admitted to the hospital for intravenous antibiotics. If the symptoms do not improve, the patient is returned to the operating room for washout and removal or replacement of the implant.
- Hematoma, seroma, and asymmetry are other potential complications.
- Long-term complications include implant rippling, capsular contracture,

implant rupture, malposition, and contour irregularities.

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Section VI: Latissimus Flap Breast Reconstruction

18

CHAPTER **Latissimus Flap**

Peter Henderson and Joseph Disa

DEFINITION

- The principal reason to undergo a latissimus dorsi (LD) myocutaneous flap for breast reconstruction is to recruit healthy skin to replace lost breast skin. The volume of subcutaneous tissue is often insufficient to adequately replace the breast mound. In this case, the most common approach is to place tissue expanders (TEs) at the time of the LD flap, followed by expansion and ultimately exchange for permanent implants at a later date (but in the appropriately selected patient, breast reconstruction can be performed in a single stage, with the permanent implants placed at the time of the LD flap).¹
- LD flap breast reconstruction without placement of any sort of prosthetic device (TEs or permanent implants) would be done in one of three scenarios:
 - First, if the patient's build is so thin that minimal breast mound is needed in order to provide the desired breast projection
 - Second, if the patient is obese and has a large amount of fat in the four fat compartments of the back, as described for the low transverse extended LD flap concept by Bailey et al. (parascapular fold, lumbothoracic fold, lumbar fold, or suprailiac fold).
 - Third, if the decision has been made that there will be no attempt to recreate any appreciable breast mound at the current time (if the patient's preferences change in the future change, a prosthetic device could be placed at a subsequent operation). In the case of this reason, the LD flap would be best thought of as a means of providing soft tissue coverage for chest wounds and not of actual "breast reconstruction," per se.

ANATOMY

- The LD is a Mathes-Nahai type V muscle. The dominant pedicle is the thoracodorsal artery and vein (off the subscapular artery and vein), and multiple secondary pedicles arise from the lumbar vessels (**FIG 1**).
- The origins of the muscle are the spinous processes of T7-T12, the thoracolumbar fascia, the iliac crest, the inferior angle of the scapula, and ribs 9 to 12.
- The insertion is the floor of the intertubercular or bicipital groove of the humerus.
- The innervation is the thoracodorsal nerve (off the posterior cord of the brachial plexus).
- The function of the LD is to adduct, extend, and internally rotate the ipsilateral arm.

PATHOGENESIS

- The indication for the LD myocutaneous flap is most commonly breast skin loss due to ischemia (particularly following skin-sparing or nipple-sparing mastectomy) and/or radiation-induced injury.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient's breast history (prior procedures as well as adjuvant or neoadjuvant therapy) should be elicited to understand the timing and expected progression of the sequelae.
- If TEs are in place, it is important to understand if tissue expansion is complete or if it is still under way.
- Physical examination should focus on assessing the surface area of skin needed, and the volume of breast mound needed.
- The back should be examined for thickness/volume of the skin and subcutaneous tissue, as well as any prior incisions.

IMAGING

- No imaging is necessary for preoperative planning.
- If necessary, appropriate surveillance for breast disease (mammography, MRI, etc.) should be performed.



FIG 1 • Latissimus dorsi anatomy.

NONOPERATIVE MANAGEMENT

- If TE is in place and skin necrosis has occurred in the absence of infection or exposure of the TE, one approach is to continue expansion—in fact overexpansion—in order to excise and perform primary closure at the time of exchange, which obviates the need for recruitment of additional skin.

SURGICAL MANAGEMENT

Preoperative Planning

- If breast TE will be used, it is chosen based on base diameter and then desired projection.
- If permanent implants are to be used, they must be chosen prior to the procedure. Important variables are fill substance, size, shape, and texture. This should be a joint decision-making process between the patient and the

reconstructive surgeon.

- The fill substance can be either saline or silicone (the outer shell is made of silicone in both cases). Saline has a less “natural” feel, but no surveillance is recommended; if rupture were to occur, it would be readily apparent, and saline is assuredly medically inert. Silicone has a more “natural” feel, though it is recommended to have a regular MRI surveillance imaging to evaluate for the possibility of rupture.
- The most important variable in choosing the size of the implant is the base diameter (there is a decreasing emphasis on the volume, as it is a variable that can change based on the shape of the device).
- The shape can be either round or anatomic (“form stable” or “gummy bear”). Anatomic implants were designed, in theory, to give more of a natural appearance. Round implants have greater upper pole projection and may not look as “natural” and instead have an “augmented” look, which may be desirable to some patients.
- All anatomic implants have a textured surface, whereas round implants can be either textured or smooth.^{2,3}

Positioning

- Positioning is one of the greatest challenges of performing the LD flap.
- If bilateral LD flaps will be performed, then prone positioning is mandated for harvest of the flaps.
- If a unilateral LD flap will be performed, then flap harvest can be performed either prone or in the lateral decubitus position.
- If the patient had been prone for harvest, then inset is best performed after the patient is flipped supine. If the patient had been in the lateral decubitus position for harvest, then options include repositioning supine or else releasing the devices used to hold in the lateral decubitus position in order to place the patient in a “near-supine” position.

Approach

- The optimal orientation of the skin paddle has been debated. Some advocate for a skin paddle that will be closed in a roughly horizontal orientation, thereby making it easily hidden in the “bra line.” Others advocate for orienting the skin paddle obliquely, with the medial aspect being more cranial and the lateral aspect being more caudal. An orientation of 90 degrees from that orientation has been done but commonly leads to a widened scar and is therefore usually

avoided.

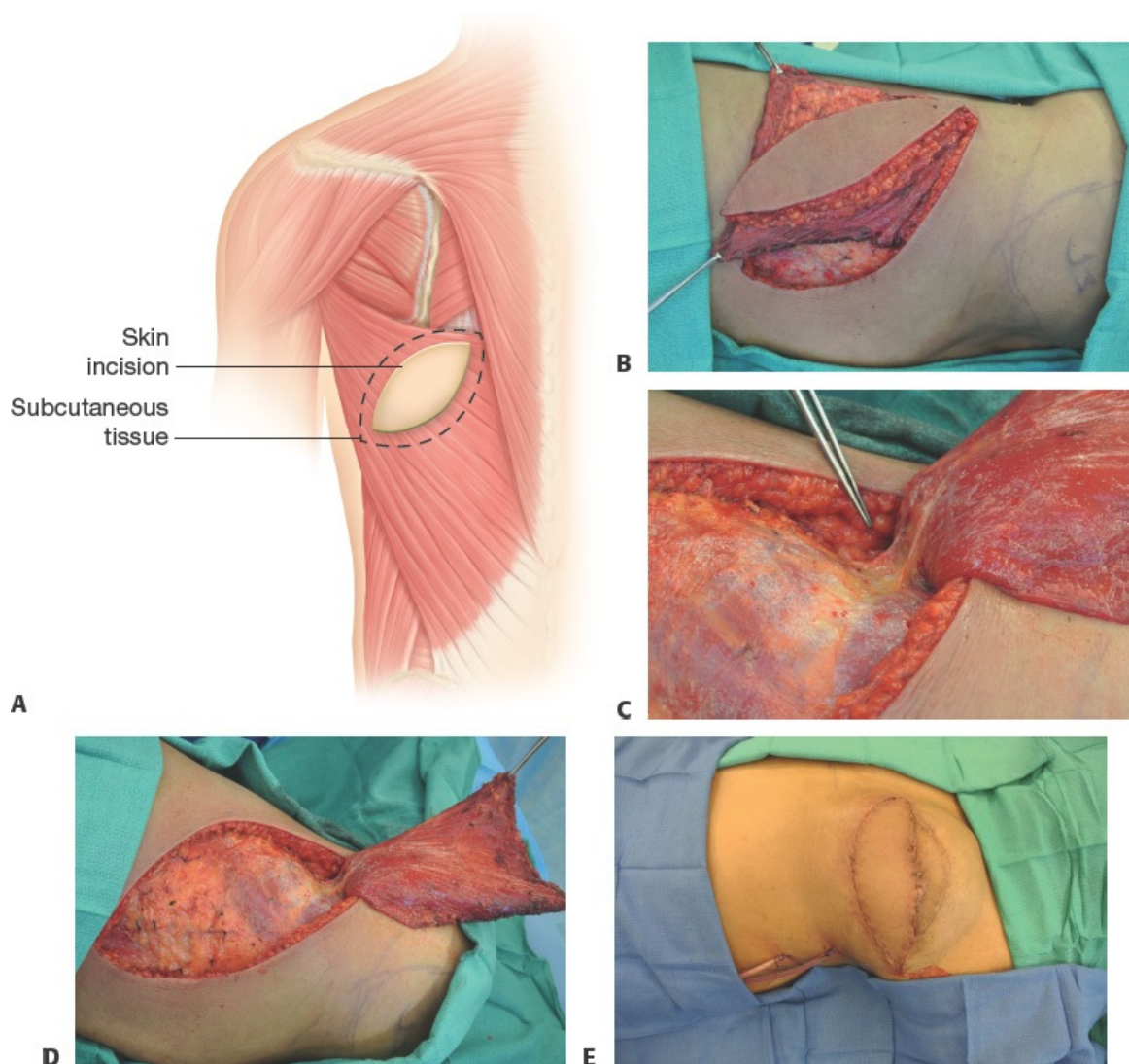
TECHNIQUES

■ Latissimus Dorsi Myocutaneous Flap

- If the mastectomy was not performed on the same day, the mastectomy defect must be recreated, and decisions need to be made about the excision of any amount of skin.
- Position the patient in the prone or lateral decubitus position; ensure that appropriate padding of all sensitive areas (axilla, face, genitals, limbs, etc.) is performed with a deflatable beanbag, pillows, and foam.
- Incise the epidermis and dermis of the skin paddle (full thickness).
- Divide the subcutaneous tissue down to the LD fascia. Some surgeons prefer to divide straight down to the fascia, whereas others bevel away from the skin paddle to increase volume and/or capture additional perforators (**TECH FIG 1A**). Commonly, this beveling is performed particularly in the fat deep to the Scarpa fascia.
- Some advocate for suturing the skin paddle to the fascia to reduce the chance of injury (or even avulsion) of the skin paddle.
- Raise the skin flaps in the plane either just superficial to the LD fascia or deep to the LD fascia directly on the muscle. Borders of the dissection plane include the superior (free) margin of the LD, nearly to the midline, the thoracolumbar fascia near the iliac crest, and the lateral (free) margin of the LD. Of note, the inferior aspect of the trapezius muscle will be encountered at the superomedial aspect of the LD, and the plane of dissection must remain deep to the trapezius. Additionally, the serratus muscle can be difficult to distinguish from the LD at the lateral margin.
- Elevate the LD off the underlying fascia (**TECH FIG 1B**). Two approaches are possible: create the plane deep to the muscle first and then divide the nonfree margins (medial and inferior) or else divide the nonfree margins first, and then peel the LD muscle off the underlying fascia. Either way, be careful not to raise the serratus muscle with the LD; this can be best protected against by mobilizing in a medial-to-lateral direction at the superior aspect.
- As dissection continues superolaterally toward the thoracodorsal pedicle,

care must be taken to avoid injury to the artery and vein that run in the plane immediately deep to the muscle (**TECH FIG 1C**).

- If arc of rotation is not sufficient to reach the recipient site on the anterior chest wall, a number of maneuvers can be used to increase the arc of rotation. First, one can mobilize the latissimus all the way up to the tendinous insertion on the humerus; this will require skeletonization of the thoracodorsal vessels. Second, one can divide the serratus branch of the thoracodorsal pedicle. Third, one can divide the proximal tendinous insertion of the LD, partially, 90%, or completely; doing so enhances the arc of rotation, but increases the likelihood of stretch injury to and/or avulsion of the pedicle (**TECH FIG 1D**).⁴



TECH FIG 1 • A. Diagram of beveling. B. Raising

latissimus dorsi muscle flap. **C.** Thoracodorsal pedicle.
D. Elevated flap. **E.** Inset of flap.

- Create the subcutaneous tunnel from the back to the anterior mastectomy wound. The tunnel should be 3 to 4 fingerbreadths wide, and the tunnel should be made as far superior as possible in order to preserve the inframammary fold and to prevent an unsightly bulge that is not obscured in the axilla.
- Pass the flap through the tunnel into the anterior mastectomy pocket. While doing so, ensure that there is no unnecessary torque or twisting of the pedicle.
- Place closed-suction drains in the donor site.
- Irrigate and ensure hemostasis and close the back wound in layers.
- Dress the back wound.
- Turn the patient to the supine position for inset. If the patient was prone, this will require repositioning. If the patient was in the lateral decubitus position, it is possible to release the beanbag and ease the patient into a nearly supine position (otherwise, the patient should be positioned and repositioned as if she had been prone).
- Complete delivery of the flap through the subcutaneous tunnel.
- Inset the LD muscle to the chest wall, taking care to recreate the inframammary fold and affixing medial enough to generate medial fullness and avoid excess lateral/axillary fullness.
- If TEs will be placed, do so in the pocket created by the LD muscle, prior to completion of inset.
- If permanent implants will be placed, most surgeons recommend using a removable sizer intraoperatively in order to choose the most appropriate size and shape of implant and then place the appropriately sized permanent implant into the pocket.
- Though unequivocal evidence is lacking, many surgeons choose to employ a combination of Betadine, topical antibiotics, and the “no touch” technique in order to reduce the risk of infection and capsular contracture. Most surgeons will place 100 to 150 mL of saline in each expander at the time of placement and then begin serial expansions as an outpatient in about 2 weeks.
- Place at least one closed-suction drain in the mastectomy pocket.
- The native breast skin is closed to the LD skin paddle with sutures in the deep dermal and the subcuticular positions (**TECH FIG 1E**).⁵⁻⁷

PEARLS AND PITFALLS

- Technique**
- Some surgeons advocate for transection of the thoracodorsal nerve. This has the advantage of reducing animation, but increases the likelihood of vascular pedicle injury and may lead to increased muscle atrophy.
 - Keeping the tunnel as superior as possible (near the axilla) will preserve the inframammary fold and prevent an unsightly bulge on the inferior, lateral chest wall.
 - Hematoma and seroma are common complications at the back donor site. Ensure meticulous hemostasis, place drains, and consider “quilting sutures” to reduce the amount of dead space.

POSTOPERATIVE CARE

- The anterior (breast) drains may be removed relatively early, though the posterior (back) drains should be left longer (at least 7 days) to minimize the incidence of seroma.
- If breast TEs were placed, then serial percutaneous expansions usually begin approximately 2 weeks postoperatively and continue with weekly or biweekly expansions of approximately 50 mL/session until the desired size is achieved.
- Patients can expect to resume full activities by 6 weeks.

OUTCOMES

- Functional deficiency as a result of loss of one (or even both) LD muscles is minimal, except in individuals who would otherwise participate in strenuous physical activity that emphasizes the upper body (swimming, rock climbing, etc).⁸

COMPLICATIONS

- Seroma at the donor (back) site is not uncommon and can be protected against by leaving drains for at least 7 days and performing intraoperative measures that reduce the dead space.
- Transient venous congestion of the skin paddle can be observed, though tissue loss is uncommon.

- Fat necrosis is uncommon, because of the limited amount of subcutaneous tissue in the LD flap (compared to the abdomen-based flaps).
- Exposure of the breast device can occur. If it is a TE and if there are no signs of infection, it is possible to complete expansion and then exchange for permanent implant. If the exposed device is a permanent implant, or if signs of infection are present, the device almost always must be removed (and can be replaced immediately in only limited circumstances).

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Section VII: Abdominal Flap Breast Reconstruction

19 CHAPTER TRAM

Peter Henderson, Jeffrey A. Ascherman, and Joseph J. Disa

DEFINITION

- The pedicle transverse rectus abdominis myocutaneous (TRAM) flap for breast reconstruction was first described by Hartrampf et al. in 1982, and it heralded the onset of a new era of abdomen-based autologous breast reconstruction. This procedure has been modified and improved upon, such that today free perforator flaps from the abdomen (as well as other sites such as the buttocks and thighs) have become the most modern, cutting-edge procedures available. But it is indisputable that the pedicle TRAM is a procedure that every reconstructive surgeon must have available in his or her armamentarium, to use as both a form of primary breast reconstruction as well as a salvage procedure in the case of failure of device-based reconstruction or other non–abdomen-based autologous reconstruction.^{1,2}

ANATOMY

- The rectus abdominis (RA) is a Mathes-Nahai type III muscle. The two dominant pedicles are the superior epigastric vessels (off the internal mammary artery and vein) and the deep inferior epigastric vessels (off of the external iliac artery and vein). The superior epigastric vessels approach the RA from the cranial direction on the central portion of the deep surface of the RA. The deep inferior epigastric vessels approach the RA from the lateral aspect of the caudal portion of the RA, on the deep surface (**FIG 1**).³
- The origins of the RA are the sternum and the 5th-7th ribs.
- The insertion is the pubic symphysis.

- Innervation is from multiple branches of the intercostal nerves, which penetrate the lateral aspect of the posterior rectus sheath and enter the RA muscle on its deep surface.
- The function of the paired RA is to flex the trunk at the waist.
- The rectus sheath is composed of the aponeuroses of the external oblique, internal oblique, and transversus abdominis muscles (**FIG 2**). Cranial to the arcuate line (aka “arcuate line of Douglas” and “linea semicircularis”), the anterior rectus sheath is composed of the aponeuroses of the external oblique and the anterior leaflet of the internal oblique, and the posterior rectus sheath is composed of the aponeuroses of the posterior leaflet of the internal oblique and the transversus abdominis (as well as the transversalis fascia). Caudal to the arcuate line, the anterior rectus sheath is composed of the aponeuroses of the external oblique, internal oblique, and transversus abdominis muscles, and the posterior rectus sheath is composed of only the transversalis fascia.

PATHOGENESIS

- The pedicle TRAM procedure is indicated for breast reconstruction when skin and/or subcutaneous tissue is needed, and the patient has sufficient excess abdominal skin and fat to serve as donor tissue.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient’s breast history (prior procedures as well as adjuvant or neoadjuvant therapy) should be elicited to understand the timing and expected progression of the sequelae.
- Nicotine use is highly deleterious to the outcomes of this operation and should be avoided at all costs. Tumor resection must occur in a timely fashion, but reconstruction can be delayed until the patient has stopped smoking.

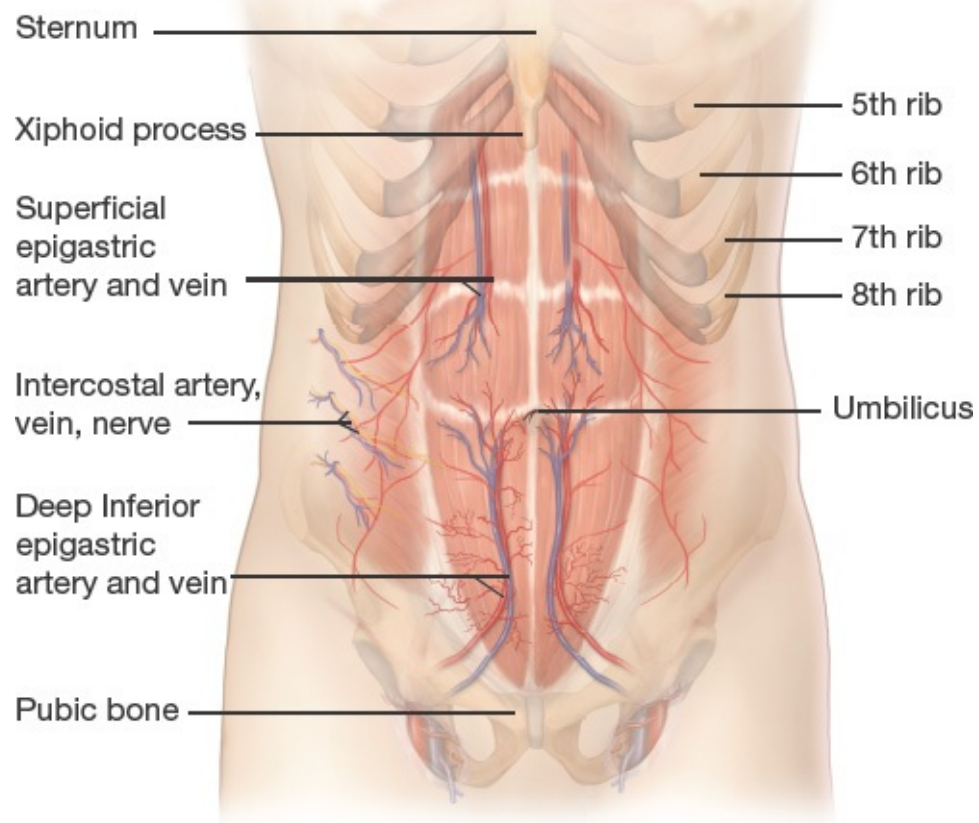


FIG 1 • Rectus abdominis anatomy.

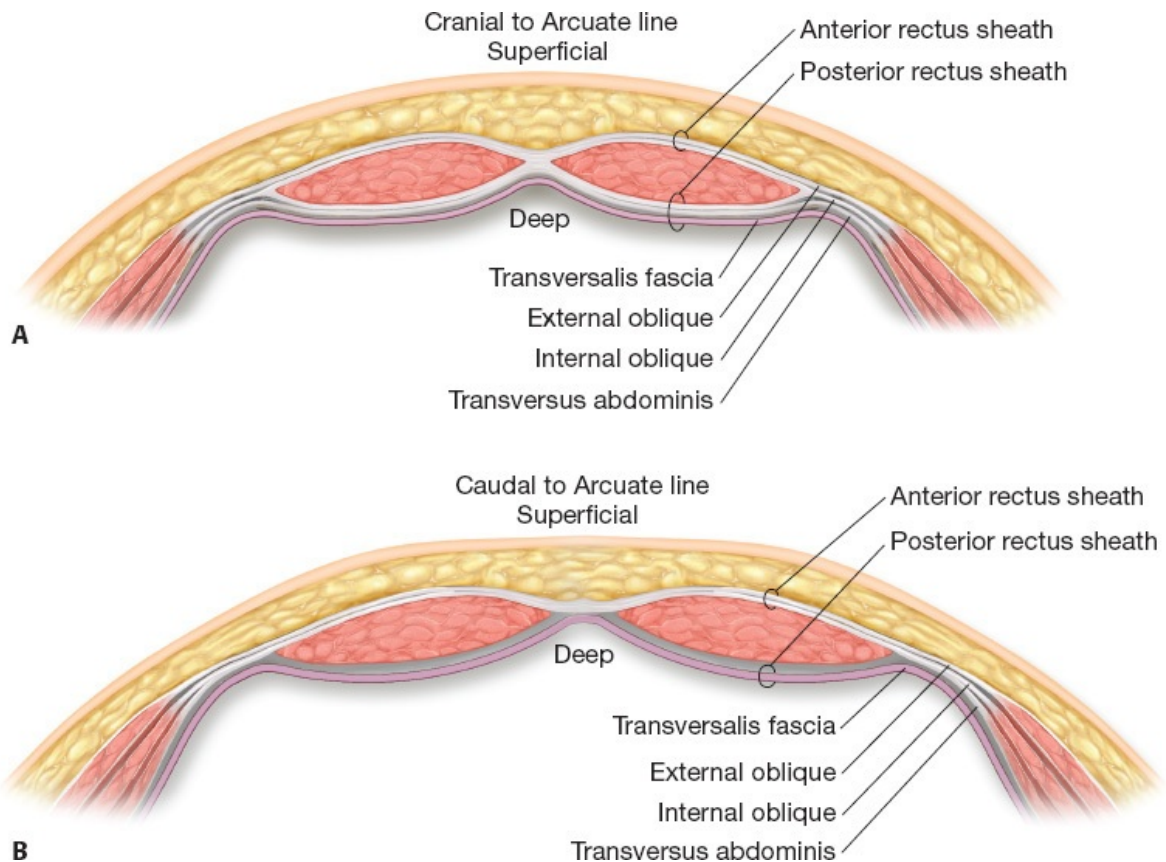


FIG 2 • Contributions to rectus sheath cranial and caudal to arcuate line.

- In patients who will undergo radiation therapy, the surgeon and patient may choose to delay the reconstruction until the radiation is completed.
- Surgical history should focus on prior abdominal operations, breast operations, and cardiac procedures (to determine if the internal mammary artery has been used as a cardiac bypass or has potentially been damaged during rewiring of a sternotomy; this is the source vessel for the superior epigastric artery).
- Physical exam of the chest should focus on assessing the surface area of skin needed, and the volume of breast mound needed.
- The abdomen should be examined for amount of subcutaneous tissue and excess skin and estimated laxity (in terms of defect that can be closed without undue tension). Prior abdominal scars should be noted (midline scars usually render the tissue contralateral to the pedicle unable to be included in the flap). Any hernias (umbilical, incisional, etc.) should be noted.
- An acoustic (handheld) Doppler can be used to identify perforators (especially

if a fascia-sparing approach is to be used)

IMAGING

- CT angiography can be performed if there is any question about the patency of the superior epigastric vessels, as well as for identification of abdominal wall perforators.

NONOPERATIVE MANAGEMENT

- Breast reconstruction is never mandatory and can be deferred if the patient's wishes or comorbidities preclude it from happening.

SURGICAL MANAGEMENT

Preoperative Planning

- Decision must be made as to whether the amount of skin and subcutaneous tissue that is needed at the recipient (breast) site can be reliably met with a unipedicle TRAM. Smoking, prior abdominal incisions, and large breasts can decrease the likelihood that a unipedicle TRAM is suitable. Near-infrared fluorescent angiography can provide valuable semiquantitative data to assist in clinical decision-making.
- If concern that a single pedicle will not suffice, available measures to increase the surface area and volume that can be safely carried with the flap include performing a bipedicle TRAM (using both superior epigastric pedicles) and performing surgical delay (2 weeks prior to the reconstruction).^{4,5}

Positioning

- Supine
- Ideally, arms are tucked (but sometimes that is not possible if breast surgeons are performing axillary sentinel lymph node biopsy or full axillary dissection; in that case, the arms can be tucked after the breast surgeons complete their portion of the operation).
- The patient's waist should be positioned at the appropriate break in the bed so that a flexed (semi-Fowler) position can be utilized to assist with closure of the abdomen.

TECHNIQUES

■ TRAM Flap for Breast Reconstruction

Preparation

- Preoperatively, the patient is marked in the standing position (**TECH FIG 1**).
- Prep the patient, including the entire bilateral breasts and abdomen to the groin. Make sure to clean the umbilicus.
- If necessary, perform surgical delay of the TRAM flap prior to definitive reconstruction.
 - This can take the form of either dividing the skin and subcutaneous tissue but not otherwise raising the flap, or dividing the deep inferior epigastric pedicle alone.
- At the time of definitive reconstruction, inspect the mastectomy defect, or else recreate the mastectomy defect (in the plane immediately superficial to the pectoralis major muscle) if the reconstruction is delayed relative to the mastectomy.
- If the procedure will be performed as a unipedicle TRAM, the surgeon must decide which superior epigastric pedicle will be used (left or right); some surgeons advocate for using the pedicle ipsilateral to the breast defect, whereas others advocate for using the contralateral pedicle.
 - The ipsilateral pedicle will often allow the surgeon to create more ptosis in the reconstructed breast, whereas the contralateral pedicle may initially allow the pedicle to appear flatter as it crosses the upper abdomen.
 - It is also possible to use a bipedicle TRAM to maximize the amount of tissue that can be harvested. The surgeon can either split the flap in the midline or leave it intact, depending on the needs of the defect.

Dissection and Flap Elevation

- Incise the skin and subcutaneous tissue down to the external oblique fascia (laterally) and the anterior rectus sheath (medially).
 - If direction of dissection bevels outward, the volume of recruited tissue is greater, and the likelihood of capturing important perforators increases.
 - Also incise the skin and subcutaneous tissue surrounding the umbilicus down to the anterior rectus sheath.
- Elevate the “abdominoplasty” flap off of the anterior rectus sheath, using the costal margin and the xiphoid as the limits of dissection (**TECH FIG 2B**).



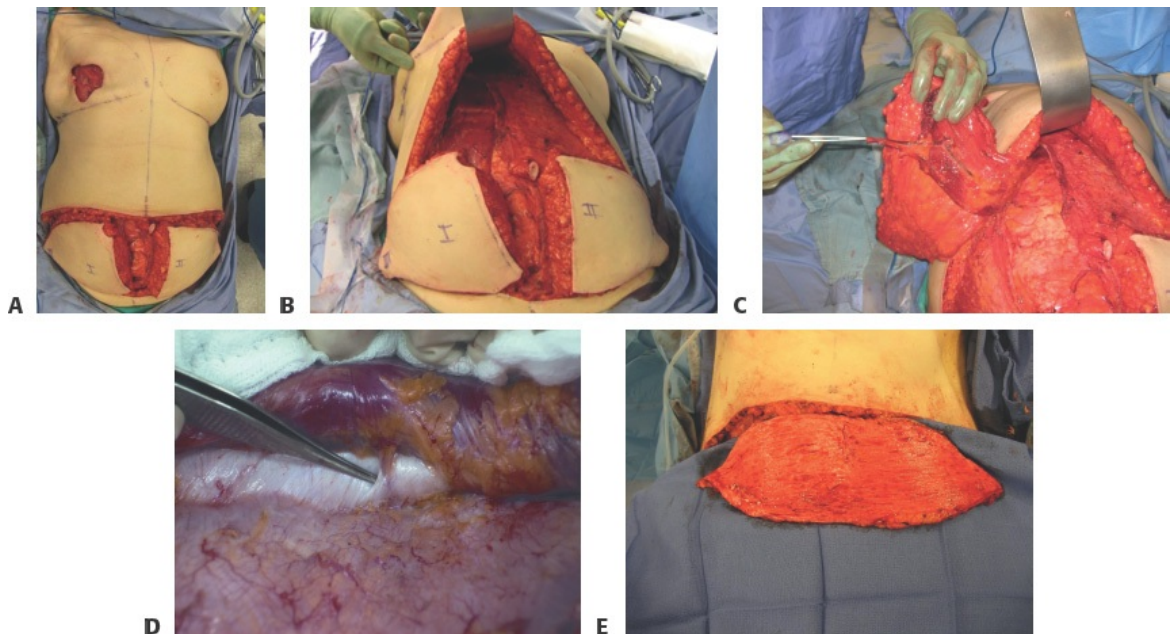
TECH FIG 1 • Markings for ipsilateral unipedicle TRAM breast reconstruction.

- At the level of the external oblique fascia, separate the skin and fat flap from the underlying fascia in a lateral-to-medial direction; one can move quickly until the lateral edge of the rectus sheath (linea semicircularis) (**TECH FIG 2C**).
- Depending on the amount of fascia intended to be taken as part of the flap, one can either incise anterior rectus sheath at the lateral edge or carefully continue dissecting the flap off of the anterior rectus sheath until the lateral row perforators are found (**TECH FIG 2D**).
 - In this case, a maximal amount of anterior rectus sheath can be spared, and the likelihood of postoperative incisional hernia decreases.
- If unilateral breast reconstruction and unipedicle TRAM will be used, the flap on the side contralateral to the pedicle is completely raised.
 - If bipedicle TRAM will be used, or if bilateral TRAM flaps are being raised, the tissue connection between the flap and the underlying fascia will be maintained overlying both the left and the right pedicles.
- Moving in a direction away from the flap, elevate the anterior rectus sheath off of the rectus abdominis (RA) muscles (this dissection must continue cranial to the costal margin).
 - Separating the fascia and the muscle will be difficult at the tendinous insertions; at these points, err on the side of fascia to avoid injury to the superior epigastric pedicle, which can be very superficial at the level of the inscriptions.
- Determine how much RA muscle will be included in the flap.

- Most surgeons will use the entire width of the muscle, but it is possible to preserve a lateral strip (the intercostal neurovascular pedicle enters the muscle from the deep surface of the lateral aspect).
- Isolate and divide the deep inferior epigastric vessels; do so as far caudally as possible to preserve length in case the flap would benefit from “supercharging” (anastomosing the deep inferior epigastric vein to augment venous outflow) because of venous congestion.
- Moving in a caudal-to-cranial direction, raise the flap (skin, subcutaneous tissue, fascia, and muscle) off of the posterior rectus sheath (**TECH FIG 2E**).
 - Ensure that the vascular pedicle is included in the flap (and minimize the risk of injury to the pedicle) by dissecting precisely at the superficial surface of the posterior rectus sheath (ie, all areolar tissue is included in the flap).

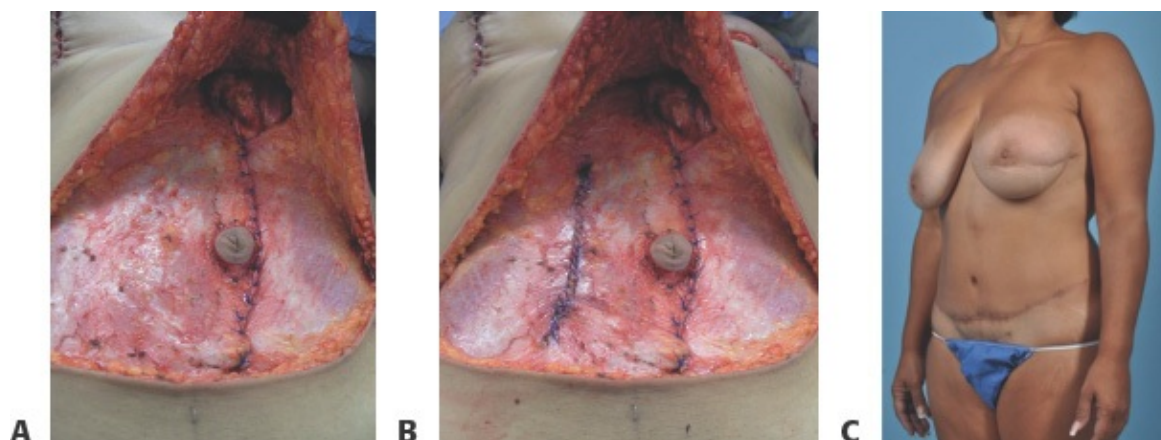
Passing and Insetting the Flap

- Create a subcutaneous tunnel between the mastectomy space and the abdomen that is at least four fingerbreadths wide.
 - Most surgeons advocate for the tunnel being as far medial as possible, but that may increase the likelihood of an unsightly bulge near the midline.
- Pass the flap through the tunnel, ensuring that no problematic twisting, or kinking, of the pedicle has occurred.
- Inset the flap to the chest wall and the overlying skin.



TECH FIG 2 • A. Right mastectomy defect and skin incisions done bilaterally for unipedicle TRAM. (Only a hemiflap was needed in this case.) **B.** Abdominal skin flap elevated and anterior rectus sheath elevated off the muscle. **C.** Deep inferior epigastric pedicle has been divided, and the flap is raised off the posterior rectus sheath in preparation for delivery in to the mastectomy space. **D.** Lateral row perforator exiting the muscle and entering the skin paddle. **E.** Pedicled TRAM in situ completely de-epithelialized in a different patient.

- If nipple-sparing mastectomy was performed, it is possible to have a flap with no cutaneous portion, but even in that case some surgeons would advocate for including a skin paddle to use as an indicator (this can easily be excised under local anesthesia after the viability of the flap has been ensured).
- Place closed suction drains.
- Some surgeons close the anterior rectus sheath with nonabsorbable sutures, whereas others may use long-lasting absorbable sutures (**TECH FIG 3A**).
- Ensure that all layers of anterior rectus sheath are included (caudally, the external oblique and internal oblique aponeuroses tend to separate) (**TECH FIG 3B**).
- If the wound cannot be primarily closed, mesh should be used (**TECH FIG 3C**). Even if it can be primarily closed, some surgeons choose to reinforce the fascial closure with mesh.
- Place closed suction drains.
- Flex the patient at the waist to reduce tension, and then close the abdominal defect by suturing the Scarpa fascia, the deep dermis, and the skin.
- Mature the umbilicus by incising the skin at the point overlying the umbilical stalk. There is no consensus on the best shape for the skin excision, but most would advocate for some noncircular shape (as an uninterrupted circle is prone to contracture/stenosis in the long term).



TECH FIG 3 • **A.** Primary closure of the rectus sheath with permanent sutures. **B.** Contralateral plication of the abdominal wall to centralize the umbilicus. **C.** Mesh reinforcement of the primary rectus sheath repair.

PEARLS AND PITFALLS

Dissection of rectus abdominis

- It is advisable to dissect the rectus abdominis muscle to a point cranial to the costal margin; doing so maximizes the arc of rotation. Remember that the superior epigastric pedicle pierces the posterior rectus sheath at a point caudal to the costal margin; thus, the superior aspect of the muscle can be disinserted from the cranial attachments to the ribs and xiphoid to further increase arc of rotation as long as it is done very carefully *cranial* to the costal margin.

Dissection of umbilicus

- A previously unidentified umbilical hernia is not uncommon and must be watched for during the umbilical dissection. If identified, it should be reduced and repaired.

Dissection of anterior rectus sheath

- The locations at which the pedicle is most at risk during the dissection of the anterior rectus sheath off of the rectus abdominis muscle are at the tendinous inscriptions (the muscle is very thin and fused with the overlying aponeurosis; the underlying pedicle is in close proximity). Risk can be minimized by erring on the side of the rectus sheath, instead of dissecting into the muscle.

Equipment

- Have hospital bed available at end of operation (instead of stretcher); this will reduce the number of transfers between beds and thereby reduce the likelihood of undue tension being placed on the patient's abdominal closure

POSTOPERATIVE CARE

- Ensure that patient remains in semi-Fowler ("beach chair") position for the early postoperative period (staying flexed at the waist reduces tension at the abdominal closure).
 - This should be maintained both while in bed and when walking.
 - Restrictions can usually be relaxed in 1 to 2 weeks.
- Avoid strenuous activity for 6 weeks to reduce likelihood of developing hernia at fascial closure site(s).

OUTCOMES

- In case of unipedicle TRAM, functional deficit is minimal (**FIG 3**).
- If bipedicle TRAM has been performed, or bilateral TRAMs have been raised (and therefore both RA muscles have been rendered nonfunctional), some weakness in flexing the waist (ie, sit-ups) may occur.

COMPLICATIONS

- Complete flap loss is extremely rare. Partial flap loss can occur and is more commonly due to venous congestion than to arterial insufficiency. Use of near-infrared laser angiography to assess for flap perfusion can help in operative decision-making.
- Wound healing complications at the breast site can occur due to flap ischemia or native breast skin damage (such as due to radiation or ischemia due to excessive thinning of the mastectomy flaps). Wound healing complications at the abdominal closure site can occur due to excess tension or systemic vasoconstriction (such as caused by nicotine use).
- Infection is relatively uncommon, though of greater significance when prosthetic mesh was used in the abdominal closure.
- Hernia development at the fascial closure site can occur due to poor technique (most notably excess suture tension leading to fascial ischemia) and can be decreased by avoiding strenuous activity for 6 weeks after the operation. Including mesh in the abdominal closure may further minimize the chance of hernia and bulge development.

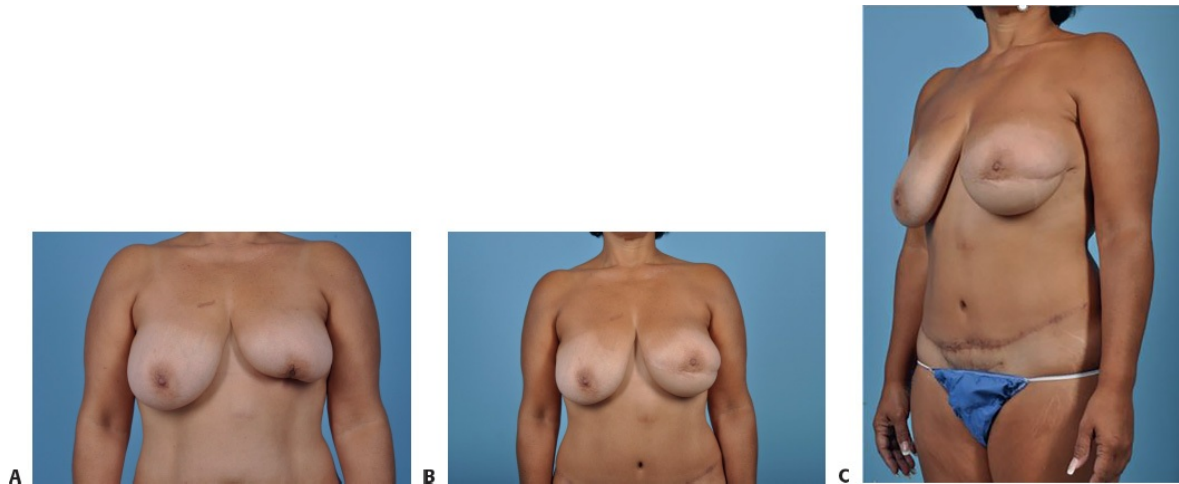


FIG 3 • Preoperative (**A**) and postoperative (**B,C**) appearance of a patient who underwent partial breast reconstruction with a ipsilateral pedicle TRAM flap.

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CHAPTER Free TRAM

Jennifer A. Klok and Toni Zhong

DEFINITION

- The free transverse rectus abdominis myocutaneous (TRAM) flap is composed of lower abdominal skin, subcutaneous fat, anterior rectus fascia, and a segment of the rectus abdominis muscle. The pedicle for this flap is the deep inferior epigastric artery (DIEA).
- The variations in free abdominal flaps based off the DIEA have been classified according to the inclusion and width of the rectus abdominis muscle used. The muscle-sparing (MS) free TRAM flaps spare either the lateral muscle (MS-1) or the medial and lateral muscle segments (MS-2). At either extreme are the free TRAM flap (MS-0), which includes the entire width and partial length of the muscle, and the MS-3 or deep inferior epigastric perforator (DIEP) flap, which preserves the entire muscle.¹
- For the purposes of this chapter, the free TRAM (MS-0) flap will be discussed. This flap was first described by Holstrom in 1979.²
- The free TRAM flap has typically been used for the purpose of breast reconstruction. However, other uses include chest wall, upper extremity, lower extremity, and head and neck reconstruction.

ANATOMY

- The rectus muscle has a dual blood supply that coalesces in choke vessels at the umbilicus where the deep superior epigastric and deep inferior epigastric systems meet.³
- The free TRAM flap is based off the deep inferior epigastric vessels. The pedicle originates from the external iliac artery and then travels cephalad to enter the lateral and deep surface of the rectus abdominis muscle a few

centimeters below the arcuate line. Just above the level of the arcuate line, the vessels typically divide into a medial and lateral row and continue superiorly, sending perforating branches through the muscle to supply the overlying skin and fat (**FIG 1A,B**).^{3,4}

- Three variations in DIEA branching patterns have been described, the type II variation with medial and lateral row branching being the most common at 57% to 84%. Type I vessels continue cephalad with the muscle as a single artery (27% to 29%), whereas type III vessels divide into three branches and are least common (14% to 16%).³⁻⁵
- On average, five to six perforators originate from the DIEA.⁴ In a free TRAM flap, all or most of these perforators are preserved.
- The nerve supply to the rectus abdominis muscle originates from the lower six thoracic intercostal nerves. The nerves travel in the fascia of the transversus abdominis muscle and enter posteriorly at the junction between the lateral and middle third of the muscle.³
- Functionally, the rectus abdominis muscle acts to flex the torso, originating at the pubic symphysis and inserting onto the fifth to seventh rib cartilages.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Discussing patient goals and expectations for breast reconstruction is one of the most important aspects of the initial consultation for surgery.
- It is essential to conduct a thorough review of past medical history, surgical history, medications, allergies, smoking history, personal or family history of clotting disorders, and detailed breast cancer history.
- Of particular importance on surgical history are number and type of abdominal surgeries to assess adequacy of the donor site.
- It is important to understand the details of the patient's breast cancer history. All neoadjuvant and expected adjuvant therapies need to be discussed and documented.

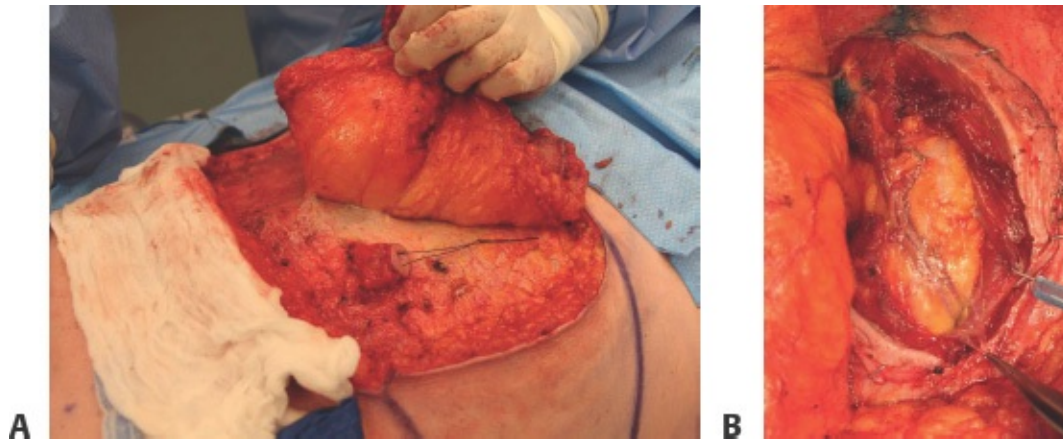


FIG 1 • A. Photo showing the most superior perforators from the medial and lateral rows near the level of the umbilicus. **B.** The course of the DIEA with its two venae comitantes is seen here through a long window in the rectus abdominis muscle (top of photo is cephalad). The forceps at the bottom of the image is lifting the transversalis fascia. This layer is elevated to expose the pedicle in proximity to the vessel origin.

- If the patient is expected to have postoperative radiation, it is still our typical practice to delay autologous reconstruction until 12 months after completion of radiation.
- Tamoxifen is stopped for 2 weeks prior to and after surgery.
- Any questionable clotting disorder history warrants consultation with a hematologist.
- We will not operate on patients who are smokers. They are required to quit smoking a minimum of 6 weeks prior to surgery. This includes being off nicotine patches. Nicotine urine tests are performed on recent ex-smokers.
- On physical exam, assess the patient's overall body habitus, BMI, and brassiere cup size.
- Examine breasts for scars, skin quality (including radiation changes), palpable masses, symmetry, ptosis, and perform standard breast measurements.
- Examine abdomen for scars, skin quality, and amount of excess skin and subcutaneous tissue (pinch test), and palpate for hernias.

IMAGING

- At our center, all patients have computed tomography angiography (CTA) of the abdomen prior to their surgery.
- The CTA assists with surgical planning in identification of dominant perforators as well as their intramuscular course from the pedicle.^{5,6}
- Having this preoperative understanding of the vessel anatomy for each individual patient can help to guide the decision between doing an MS-3 perforator flap (**FIG 2A**), which is our preference, and flap that includes muscle to incorporate additional perforators (**FIG 2B**).
- Alternative imaging techniques include color Doppler (duplex) ultrasound, handheld Doppler, and magnetic resonance angiography.⁶

SURGICAL MANAGEMENT

- Broad indications for choosing autologous reconstruction over implant-based reconstruction include the following: patient goals and expectations, adequate donor site tissue, longevity of reconstruction, resistance to undergo multiple future surgeries, amount of ptosis of the contralateral native breast, importance that the patient places on natural look and feel of the reconstruction, and history of chest or breast radiation.⁷
- Although we perform free TRAM flaps, we aim for DIEP and MS-TRAM flaps in the majority of our breast reconstructions. Sometimes, a full free TRAM is needed; however, this is rarely the case. Maximum preservation of rectus fascia and muscle whenever possible to limit abdominal morbidity should be the goal in reconstruction.
- Indications for choosing a full free TRAM over a MS-TRAM or DIEP flap are few but relate to a need for increased flap perfusion and can be divided into patient and intraoperative factors.¹
- Patient factors include recent history of smoking, prior abdominal liposuction, abdominoplasty or multiple abdominal surgeries with extensive scarring in the rectus abdominis muscle, and large flap volume (greater than 1000 g) required in patients with aforementioned risk factors.^{1,8–10}
- Intraoperative factors include the number and size of perforators located during flap elevation. The presence of a dominant perforator at least 1.5 mm in diameter would indicate suitability for a perforator flap. If no single dominant perforator is located or the reliability of selected perforator(s) for supply of the flap becomes questionable after temporary occlusion of other identified perforators, then an MS-TRAM or free TRAM is indicated.¹

- If the medial and lateral row perforators are found to be so widely separated that they come off the extreme edges of the muscle and are so small in caliber to the extent that at MS-TRAM off one row would be inadequate, then the whole width of the muscle would need to be harvested in a full TRAM.
- An additional intraoperative scenario that might steer the surgeon to convert to a free TRAM includes encountering a severely scarred or attenuated rectus abdominis muscle where the musculocutaneous perforators are encased in scar and unidentifiable.

Preoperative Planning

- Optimize the patient for surgery with appropriate consultations to anesthesia, medicine, and/or hematology as needed.
- Carefully review the CTA to understand the size, location, and intramuscular course of the perforators.

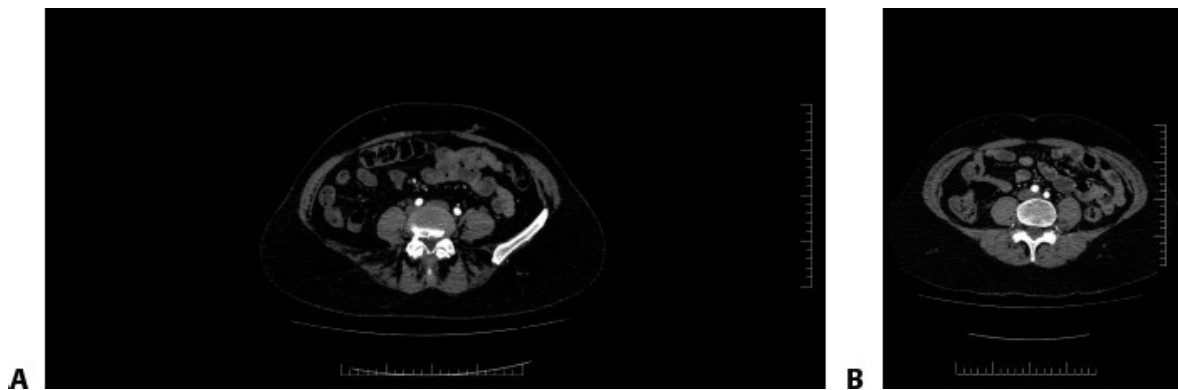


FIG 2 • A. CTA of a patient's abdomen demonstrating an obvious dominant perforator (greater than 1.5 mm in size) coming from the medial branch of the left DIEA. This patient will likely be a good candidate for a DIEP flap. **B.** The largest perforator seen on the right hemiabdomen is shown here and is quite small in size (less than 1.5 mm). Intraoperatively, it may be determined not to be reliable enough to support the flap. More perforators may be required, and in this case, a free TRAM or MS-TRAM would be considered.



FIG 3 • Demonstrates positioning of the patient. The bed is turned 180 degrees so that the anesthetic machine is at the foot of the bed. The patient's arms are tucked, the face is protected, and all bony prominences are well padded.

- Prior to surgery administer heparin 5000 U subcutaneously and apply thromboembolism deterrent stockings (TEDs) and sequential compression devices (SCDs).
- Give intravenous antibiotics (usually cefazolin) prior to incision.

Positioning

- Position the patient supine with the arms tucked and the surgical table turned 180 degrees (**FIG 3**). This creates more space for surgeons and assistants as well as room for the microscope in the field.

Approach

- **Retrograde approach:** Start distally by lifting the lateral edge of muscle to identify the pedicle and elevate flap from caudal to cephalad.
- **Anterograde approach:** Transect superior edge of muscle just above the most

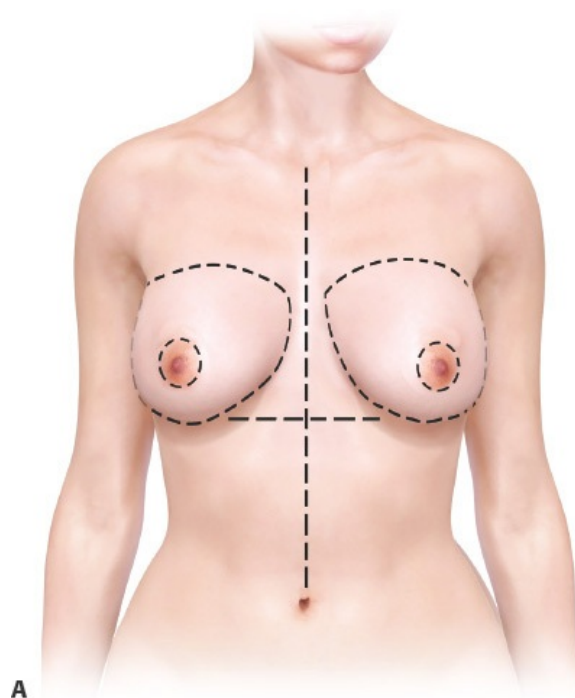
superior perforators and elevate flap from cephalad to caudad.

- **Fascial sparing approach:** Always try to spare as much muscle fascia as possible by closely hugging the medial and lateral perforator rows during dissection.

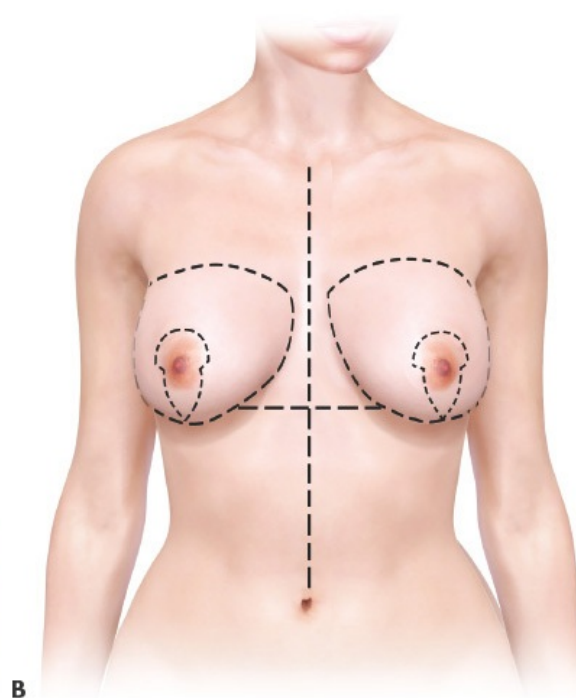
TECHNIQUES

■ Markings

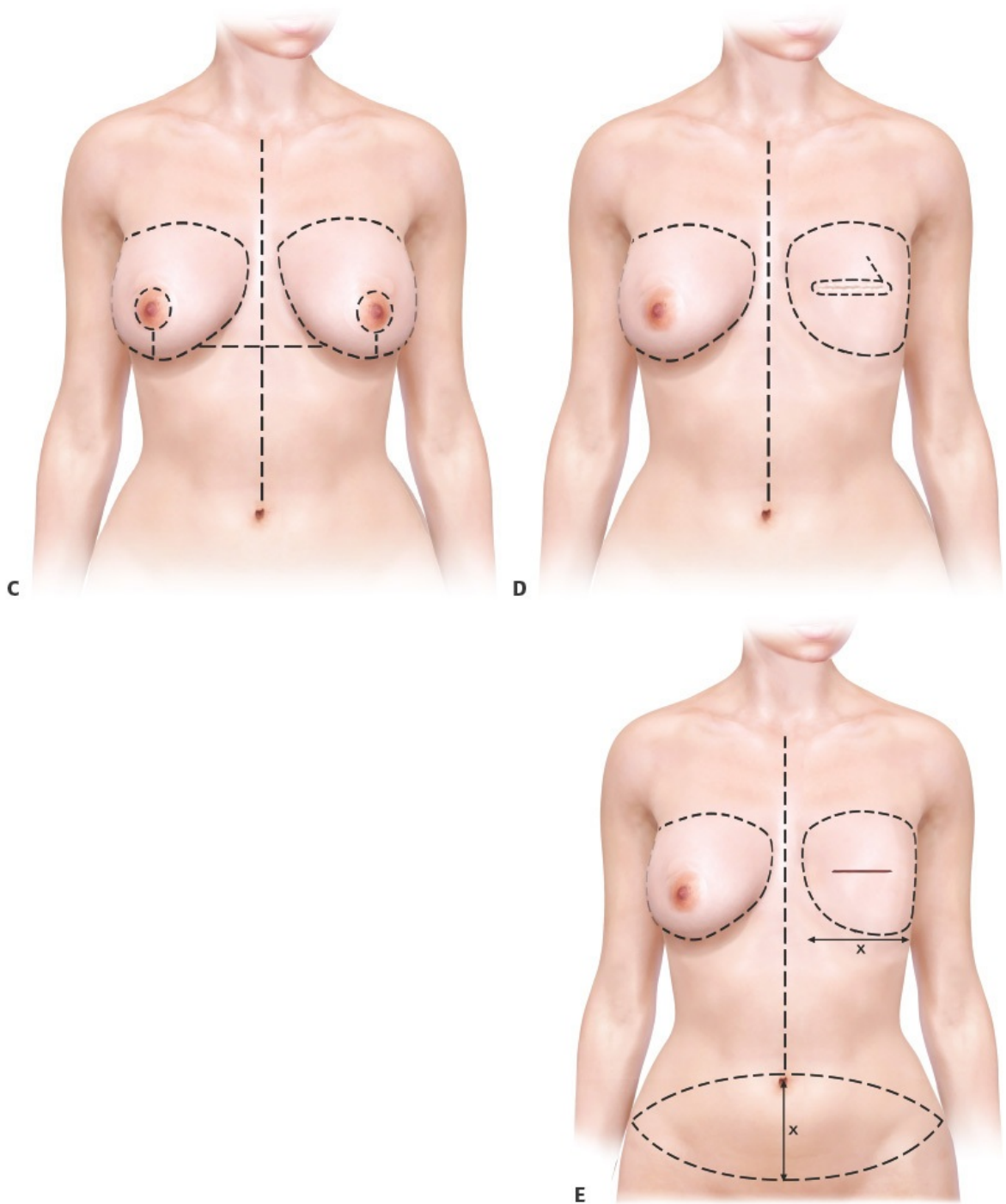
- Markings are done preoperatively with the patient standing.
- Start with the breast markings and mark the sternal notch, sternal midline, inframammary folds (IMF), and breast borders.
 - We use one of three mastectomy incisions in immediate reconstruction cases. These include circumareolar, circumvertical pattern with skin reduction, or circumareolar with straight vertical incision (**TECH FIG 1A–C**).
 - In delayed reconstruction, the mastectomy incision is marked for excision. A superolateral back-cut or pleat is drawn on the superior mastectomy skin to avoid the pinched appearance of the flap just below the mastectomy scar. The lower mastectomy skin borders are marked for eventual excision (**TECH FIG 1D**).
- The abdominal incision is marked superiorly above the umbilicus and inferiorly along the suprapubic crease. The incision lines are checked using a pinch test. The height of the abdominal flap should match the width of the breast (**TECH FIG 1E**).



A



B



TECH FIG 1 • A. Circumareolar mastectomy incision for immediate reconstruction. **B.** Circumvertical mastectomy incisions resulting in mosque pattern with vertical scar used in immediate reconstruction for patients with skin laxity and ptosis. **C.** Circumareolar

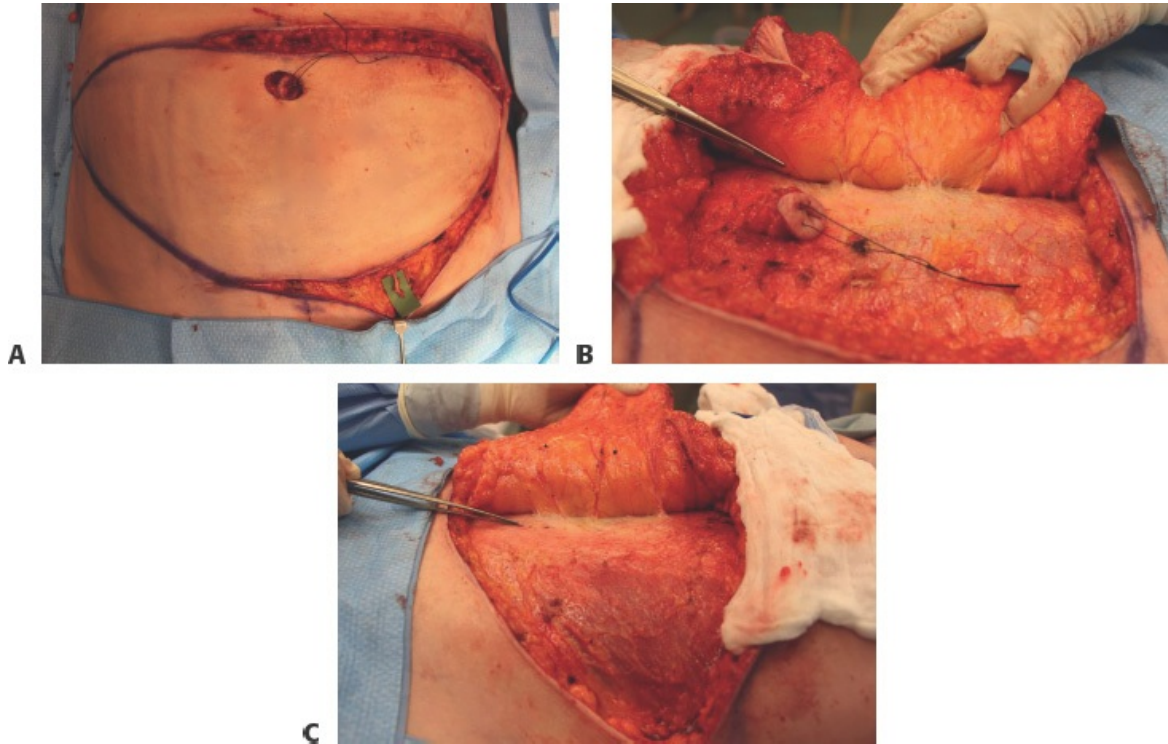
mastectomy incision with vertical extension for immediate reconstruction in patients with a tight skin envelope to aid in exposure of the recipient vessels without over-retraction on the mastectomy flaps. **D.** Markings for delayed breast reconstruction illustrating excision of the mastectomy scar and back-cut incision on the upper lateral mastectomy flap to improve final flap contour. The shaded lower mastectomy skin will eventually be removed and the flap inset on top. **E.** Abdominal flap markings demonstrating the height of the flap midline equaling the width of the breast.

■ Perforator Identification

- Confirm preoperative markings with patient on the operative table.
- Use a handheld Doppler to identify perforators based on CTA mapping and mark with suture.
- Isolate the umbilicus, leaving a cuff of fat around the stalk but taking care not to dissect too widely and inadvertently injure the periumbilical perforators.
- Make superior abdominal incision and dissect down to rectus fascia, beveling superiorly.
- Create inferior incision, taking care to first identify and dissect approximately 5 cm of the superficial inferior epigastric vein (SIEV) before completing the incision down to the fascia (**TECH FIG 2A**).
- Ensure that patient is fully paralyzed before proceeding.
- Start elevating skin flap from lateral to medial in suprafascial plane using electrocautery. Proceed carefully upon reaching the lateral border of the rectus abdominis muscle and begin to identify the lateral row perforators. At this point, lower the cautery settings.
- In a bilateral case, split the flap along the midline and elevate flap from medial to lateral to reveal the medial row perforators. In a unilateral case, the flap often crosses midline to incorporate a portion of the contralateral side depending on size requirements for the reconstruction. Once the size of the flap is determined, divide the flap and elevate from medial to lateral to

identify the medial row perforators.

- In the free TRAM flap, all identified perforators in both the medial and lateral rows are preserved (**TECH FIG 2B,C**).



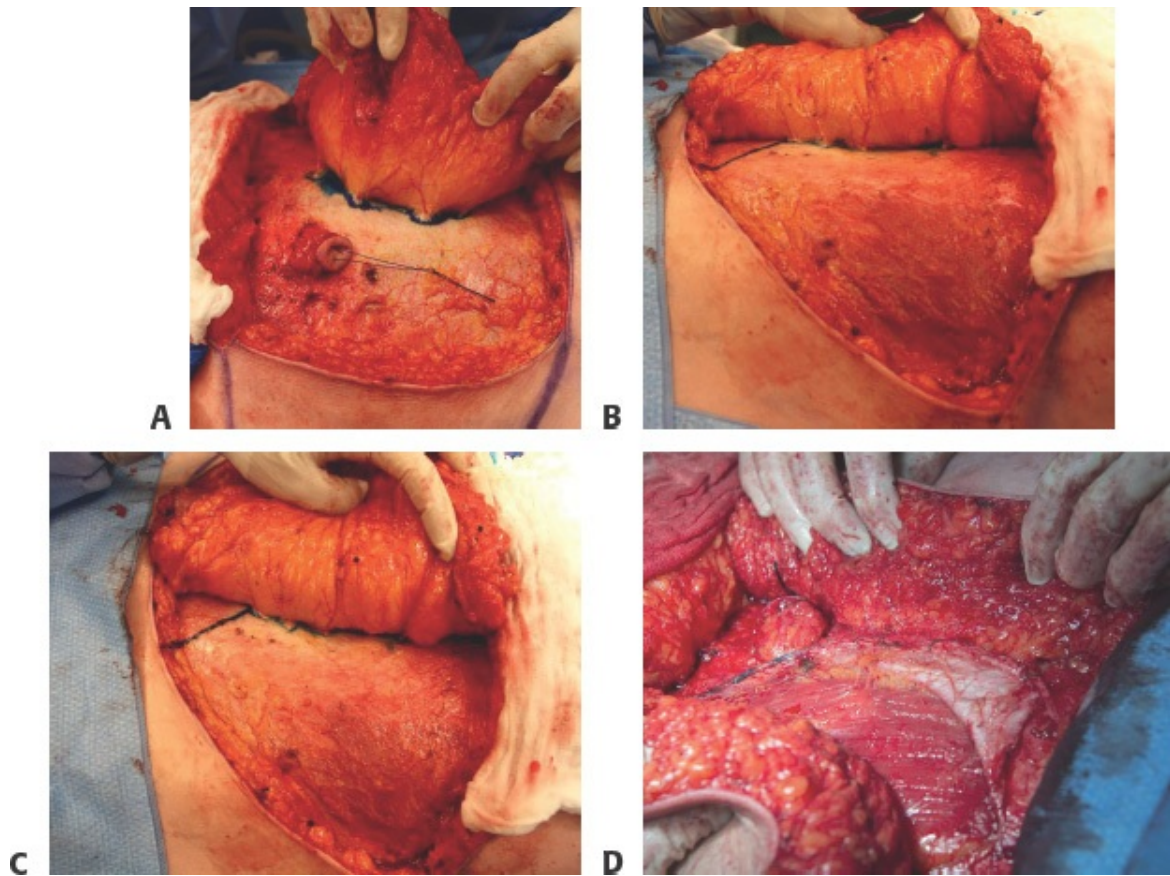
TECH FIG 2 • A. The superficial inferior epigastric vein (SIEV) is shown at the bottom right of the photo. Its location is superficial to the Scarpa fascia at this level and approximately one-third of the distance between midline and the anterior superior iliac spine (ASIS). This vein is spared whenever possible in our dissection to provide a backup for venous outflow.
B,C. Exposure of the medial and lateral row of perforators originating from the deep inferior epigastric system. All of these perforators will be preserved and included in the free TRAM flap.

■ Fascial Dissection



Video p4-c020

- Mark fascia closely around selected perforators with methylene blue to spare as much fascia as possible (**TECH FIG 3A–C**).
- Use forceps and a scalpel to make the first incisions through fascia immediately around the perforators. The forceps are used to lift the fascia upward prior to incision to avoid injury to vessels directly beneath fascia.
- Once dissection around the perforators is done, complete the fascial incision with cautery on the cutting setting along a line to the lateral and inferior end of the muscle where the pedicle is expected.
- Once the incisions are complete, use forceps and electrocautery to elevate the fascia off the rectus abdominis muscle medially and laterally.
- Reflect fascia back on itself and staple for retraction (**TECH FIG 3D**).



TECH FIG 3 • A,B. Fascial sparing technique is used during flap dissection. The methylene blue is used to mark out the fascial incision, ensuring that it is tight to exposed perforators. **C.** View of the lateral row in **(B)** shows the oblique inferolateral extension made to complete the fascial incision down to the level of the pedicle. **D.** After the fascia has been incised and elevated off the rectus abdominis muscle, it is stapled back to provide optimal exposure for the intramuscular dissection.

■ Intramuscular Dissection

- We typically perform the intramuscular dissection in a retrograde approach. Perform this part systematically and carefully. Dissect layer by layer to avoid diving into the muscle and injuring the pedicle or perforators.

- First, elevate the inferolateral edge of the rectus abdominis muscle to find the pedicle as it begins to travel beneath the muscle (**TECH FIG 4A**). Dissect through transversalis fascia to visualize its location and note its course as it travels superiorly under the muscle.
- Then dissect a long window through the muscle directly over the pedicle in a retrograde direction. Use tenotomy dissecting scissors and bipolar cautery to make this opening in the muscle down to the pedicle (**TECH FIG 4B**). Ligate larger branches with clips to prevent thermal damage to the main vessels.
- As the inferior perforators from the medial and lateral row are approached, transect the muscle transversely to its medial and lateral edge. Perform this one layer at a time keeping in mind that some perforators have a tortuous course through the muscle.
- Once the inferior edge of the muscle is divided, transect the superior edge of muscle just above the upper periumbilical perforators. Take care to identify the superior epigastric vessels at this level and ligate with clips.
- Once the muscle has been released inferiorly and superiorly, gently lift the flap and use bipolar cautery to divide any further attachments to the pedicle or muscle on its posterior surface.
- Caudally, use deep retractors to find the origin of the main vessels in the pelvis. The free TRAM flap requires a longer pedicle than does the perforator flap. We prefer to dissect a pedicle of at least 7 cm in length in situ on mild stretch (**TECH FIG 4C**).
- Temporarily staple the flap in place on the abdomen until the recipient vessels have been prepared (see below).
- When ready to do microsurgery, mark the anterior surface of the vessels for orientation, ligate the deep inferior epigastric artery and vein(s) with two vascular clips on each vessel, and start ischemia time.



TECH FIG 4 • A. Photo showing the inferolateral edge

of the rectus abdominis muscle being elevated to identify the deep inferior epigastric vessels entering the undersurface of the muscle. **B.** Demonstrating layer-by-layer dissection through the muscle using tenotomy scissors and bipolar cautery. This approach reduces risk of injury to perforators and pedicle. It also allows for precise hemostasis, keeping the operative field unstained. **C.** Photo demonstrating the fully dissected TRAM flap prior to ligation of the pedicle. Note that the length of the pedicle is at least 7 cm in the free TRAM flap.

■ Recipient Vessel Dissection—Internal Mammary Vessels

- This step is performed after completion of the mastectomy in an immediate reconstruction or after creation of a subcutaneous breast pocket under the superior mastectomy flap in a delayed reconstruction. It is done simultaneously during the abdominal flap harvest.
- The third rib is identified via palpation and using sternal notch and angle landmarks.
- Electrocautery is used to split the pectoralis major muscle directly over the rib cartilage. Use clips for ligating perforators seen along the medial pectoralis border. This reduces the risk of any thermal damage transmitted to the recipient vessels below.
- Split the rib perichondrium longitudinally over the rib from the sternum to about 3 cm lateral using cautery or a scalpel. Make vertical incisions at each end of the cut to create an H-type incision.
- Use a periosteal elevator to strip the perichondrium off the rib cartilage, taking care to hug the surface of the rib as the posterior perichondrium is released.
- Remove the rib cartilage with a rongeur (**TECH FIG 5A**).
- Use bipolar cautery and tenotomy scissors to remove the perichondrium overlying the internal mammary vessels, which are typically about 1 cm lateral to the sternum. Start about 1 to 2 cm lateral to where the vessels are

expected and elevate perichondrium from lateral to medial.

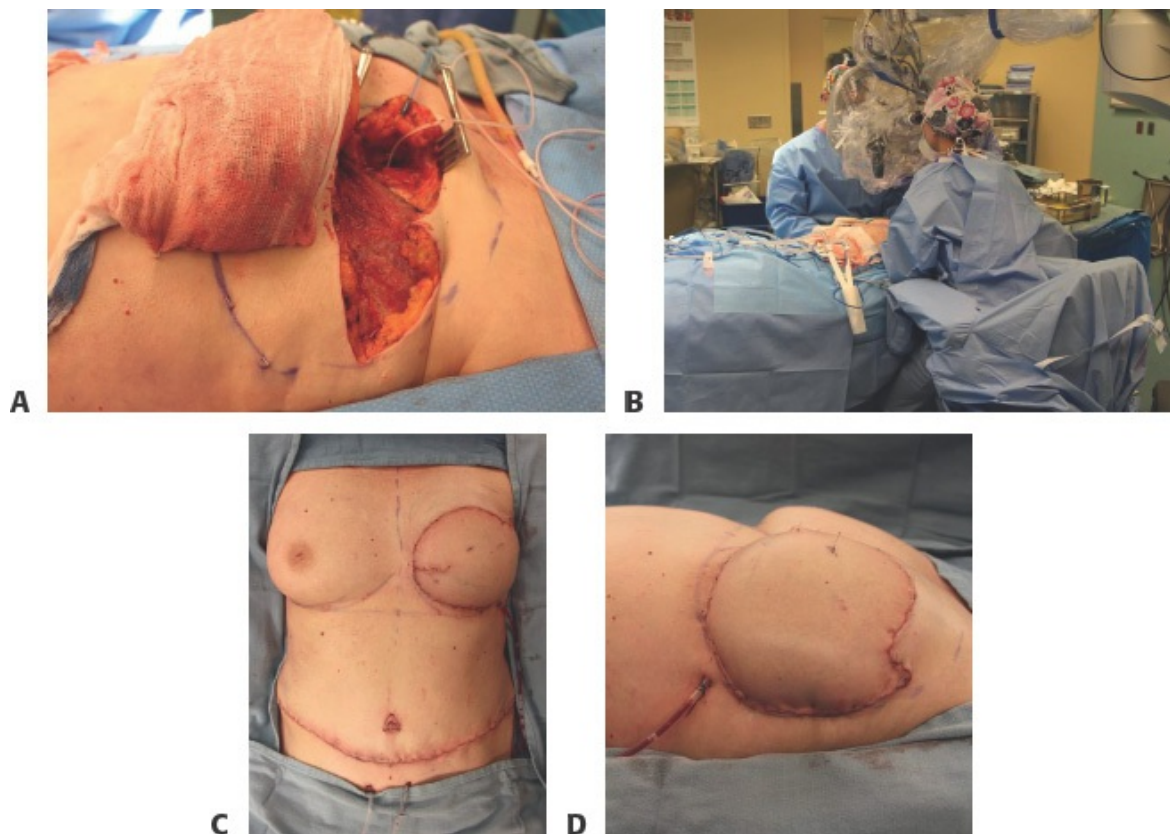
- Proceed cautiously when removing the perichondrium from directly above the recipient vessels. Take care to first visualize any branches and ligate with clips as these tear and bleed quite easy.
- If further length on the vessels is desired, remove intercostal muscle above the vessels.
- A medial and lateral vein may be seen on either side of the artery. Often, there is only a medial vein present (**TECH FIG 5B,C**).
- Clear the vessels of surrounding tissue beneath the perichondrial layer under the microscope in preparation for the microsurgical anastomosis.
- The thoracodorsal artery and vein are an alternative option for recipient vessels. For some surgeons, these are preferential in the immediate reconstruction setting as they are often exposed following mastectomy and axillary dissection.



TECH FIG 5 • **A.** View of the perichondrium after removal of the third rib cartilage. The posterior perichondrium overlies the recipient vessels and will subsequently be removed. **B.** The perichondrium has been removed and the medial and lateral internal mammary veins as well as the internal mammary artery in between are seen in this photo. **C.** The vessels have been completely cleared under the microscope and are ready for microsurgical anastomosis.

■ Microsurgery and Flap Inset

- Typically, the contralateral abdominal flap is used for reconstruction of the breast when the internal mammary vessels are used as recipients. In this way the flap is positioned vertically to better match the contour of a natural breast shape.⁷
- Rotate the flap 90 degrees such that the pedicle lies medially on the chest and the umbilical incision is positioned laterally toward the axilla. In a right breast reconstruction, the flap is rotated 90 degrees counterclockwise, and in a left breast reconstruction, the flap rotates 90 degrees clockwise.
- Note that if the ipsilateral abdominal flap is used, then the umbilical incision will rotate to lie at the inferomedial aspect of the reconstructed breast.
- Wrap the flap in a saline-soaked sponge and staple to the chest to prevent shifting of flap and eliminate tension on the pedicle during microsurgery.
- Use self-retaining retractor and fishhook retractors for optimal exposure. We also use a pediatric size drain applied to suction and stapled into place at our anastomosis site to minimize pooling of fluid during the microsurgery (**TECH FIG 6A**).



TECH FIG 6 • A. Demonstrates a standard setup in

preparation for microsurgery. A single self-retaining retractor and fishhook retractor provide excellent exposure of the recipient vessels as well as adequate space for the anastomosis. A pediatric size drain attached to suction (upper left side of the photo) is stapled into place just above the recipient vessels. This keeps the field dry for better visualization during the microsurgery. A moist saline gauze is wrapped around the flap and secured into place with staples. The pedicle is draped into the chest to meet the recipient vessels without being under any tension. **B.** Both surgeons are comfortably seated for microsurgery. The microscope easily fits into the space at the head of the bed, the hassle of maneuvering around the anesthetic machine having been eliminated by turning the bed at the beginning of the case. **C,D.** Flap inset in delayed breast reconstruction. An oblique back-cut dart was made in the superolateral mastectomy skin to improve upper pole contour and prevent a pin cushioned appearance. In this patient, the ipsilateral abdominal flap was harvested, and the repaired umbilical opening is seen on the medial aspect of the breast. If the contralateral flap had been used, the umbilical incision would be positioned laterally on the reconstructed breast.

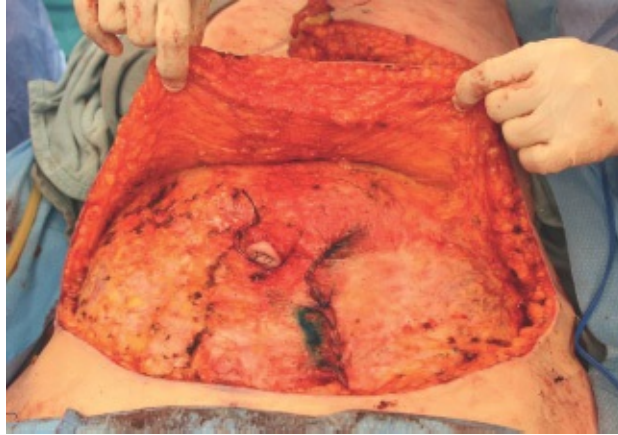
- Clear the flap vessels and separate the artery from the vein(s) to provide enough length for comfortable anastomosis to the recipient vessels. Flush the artery with heparinized saline until clear fluid is seen coming out of the vein.
- The surgeons are seated comfortably throughout the microsurgery procedure (**TECH FIG 6B**).
- The microanastomosis is performed, first of the vein and then of the artery. A

coupler device is used for the vein. The artery is sutured with 8-0 or 9-0 nylon suture.

- Once the microsurgery is complete, the flap is inset. Often, the medial aspect of the flap is sutured to the medial pectoralis in two to three places to reduce traction on the pedicle.
- The flap is de-epithelialized in all areas that will lie under the mastectomy flaps, and the flap is trimmed conservatively as needed for the desired breast size. Observe the color and amount of bleeding during de-epithelialization as indication of the patency of the anastomoses.
 - In immediate reconstruction, the skin paddle on the flap becomes a circle in place of the nipple-areola complex.
 - In delayed reconstruction, the mastectomy scar is completely excised and sent to pathology. The mastectomy skin below the scar is removed after the microsurgery is complete and the flap is inset in its place. The TRAM flap is only de-epithelialized superiorly where it will lie under the upper mastectomy flap (**TECH FIG 6C,D**).

■ Abdominal Closure

- Close the abdomen with the bed partly flexed during the microsurgery for better efficiency.
- We do minimal undermining of the superior abdominal flap as we have found this to lower overall seroma rates (**TECH FIG 7**).
- Repair the anterior rectus sheath fascia with no. 1 Prolene suture. Use a Prolene inlay mesh if the fascial closure is too tight.
- Insert two Jackson-Pratt drains under the abdominal flaps.
- Mark the umbilical position.
- Close the abdominal incision in three layers, starting with the Scarpa fascia and then the deep dermal and skin layers.
- Create an incision (we use a chevron style) for the umbilicus and inset.



TECH FIG 7 • Demonstrates minimal undermining of the upper abdominal flap. This reduces seroma formation and maintains vascularity to the skin.

PEARLS AND PITFALLS

Muscle relaxation

- Ensure full muscle relaxation during flap elevation.
- Communicate with anesthetist before and during surgery.

Fascia

- Always try to spare as much rectus fascia as possible to avoid tension with closure.

Pedicle dissection

- Dissect pedicle in retrograde fashion.
- Create long muscle window to have better visualization of vessels.

Pedicle length

- Longer pedicle length is required in free TRAM compared to perforator flap.

Recipient vessel

- Ensure ample length on IMA exposure so as avoid working in a deep hole during microsurgery.

Abdominal flap

- Minimize undermining of upper flap to decrease seroma formation.

POSTOPERATIVE CARE

- Each patient receives a standardized care routine postoperatively with

experienced nursing care on the ward.

- Hourly flap monitoring (color, capillary refill, temperature, turgor, and Doppler) for first 24 hours in step-down unit or ICU
- Bed rest for the first night, up to chair the next day, and walking on postoperative day (POD) 2
- NPO the first night with progression of diet the next day if no flap concerns
- Enoxaparin 40 mg SC daily while in hospital, started POD 0
- Aspirin 81 mg daily for the first 6 weeks, started POD 1
- Abdominal binder applied for 6 weeks
- The typical discharge date is POD 3 for unilateral reconstructions and POD 4 for bilateral or immediate reconstructions.

OUTCOMES

- Several studies have reported abdominal donor site morbidity, including bulge or hernia and functional weakness, to be higher in free TRAM vs DIEP patients.^{11,12}
- However, a recent multicenter, patient-reported outcomes study found no significant difference in BREAST-Q scores for physical well-being of the abdomen between free TRAM and DIEP flap reconstruction.¹¹
- With regard to other outcomes, the literature has shown that the risk of fat necrosis is lower in free TRAM flaps when compared to DIEP flaps.¹²

COMPLICATIONS

- Early complications
 - Hematoma or seroma (donor site or flap site)
 - Venous congestion
 - Flap loss (partial or total)
 - DVT/PE
 - Infection
 - Mastectomy flap necrosis
 - Abdominal skin or umbilical necrosis
- Late complications
 - Fat necrosis (flap)
 - Delayed wound healing
 - Abdominal bulge or hernia
 - Aesthetic (asymmetry, malposition)

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Muscle-Sparing Free Transverse Rectus Abdominis Myocutaneous (TRAM) Flap

21

CHAPTER

Arash Momeni and Liza C. Wu

DEFINITION

- Acquired amastia following mastectomy is associated with significant psychological distress.¹
- Breast reconstruction following prophylactic mastectomy or mastectomy for breast cancer has been demonstrated to improve health-related quality of life and patient-reported outcomes.²
- Favorable long-term patient satisfaction is particularly associated with autologous breast reconstruction using abdominal tissue.^{3–5}
- In contrast to the traditional free TRAM flap in which the entire width of the rectus abdominis muscle is harvested, the muscle-sparing free TRAM flap only incorporates a small amount of rectus abdominis muscle along with overlying anterior rectus sheath, thus, reducing donor-site morbidity.

ANATOMY

- The rectus abdominis muscles are flat muscles located on either side of the midline that originate from the 6th to 8th costal cartilages and the xiphoid process and insert on the pubic symphysis.
- Each rectus abdominis muscle rests within a fascial sheath (ie, rectus sheath) that is formed by the confluence of the aponeuroses of the oblique (external and internal) and transversus abdominis muscles.
- Above the arcuate line, the aponeurosis of the internal oblique splits, thus contributing to the anterior and posterior rectus sheath by joining with the

external oblique aponeurosis and transversus abdominis aponeurosis, respectively.

- Below the arcuate line, all three aponeuroses form the anterior rectus sheath.
- The rectus abdominis muscle has a dual blood supply via the superior and deep inferior epigastric vascular arcade.
 - These vessels originate from the external iliac vessels.
 - Perforating vessels from these arcades pierce the rectus abdominis muscle to perfuse the overlying skin and soft tissues.
 - The blood supply to the lower anterior abdominal skin via the superior epigastric artery is indirect and relies on “choke” vessels located in the midabdomen.
 - In contrast, perforators emanating from the deep inferior epigastric artery represent a more direct source of blood supply to the lower anterior abdominal skin.
 - This represents the anatomic basis for the more robust blood supply of the free muscle-sparing (MS) TRAM flap compared to the pedicled TRAM flap.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for patients presenting for autologous breast reconstruction using an MS-TRAM flap includes a detailed history and focused physical examination.
- History
 - Preoperative smoking cessation is strongly encouraged in order to decrease the risk of wound infection, mastectomy skin necrosis, and abdominal flap necrosis.⁶
 - Pre-existing medical conditions, such as diabetes mellitus, hypertension, etc., need to be optimized preoperatively.
 - Obesity is a specific consideration that may lend itself to increased intraoperative and postoperative complications such as increased blood loss, wound healing issues, and hernia formation.⁷
- Physical examination
 - The abdomen is inspected for pre-existing scars that may preclude MS-TRAM flap harvest.
 - Although appendectomy and Pfannenstiel scars do not pose clinical problems (unless the deep inferior epigastric vessels were previously

ligated), subcostal incisions can be associated with a higher rate of delayed wound healing due to compromised perfusion to the watershed area of the abdominal flap.

- Midline scars are not necessarily problematic, particularly in bilateral reconstructions.
 - Merely unilateral reconstructions in patients with large breasts in whom more than two perfusion zones are required may occasionally necessitate raising the MS-TRAM flap as a bipedicle flap.
 - Previous liposuction is not a contraindication; however, a true abdominoplasty is.⁸
- Palpation of the abdomen is performed to document the presence of ventral and/or umbilical hernias.
 - Repair of an umbilical hernia at the time of autologous breast reconstruction risks the development of umbilical necrosis.
- The height of the MS-TRAM flap is determined preoperatively and should correspond to breast width.
 - It may be helpful to determine the degree of abdominal tissue laxity by having the patient flex at the waist, as this gives a reasonable estimate of how much tissue can be harvested without subjecting the closure line to undue tension.
- Breast examination/palpation is important to assess preoperative breast volume as this can necessitate modification of flap design to optimize a volume match.

IMAGING

- Preoperative imaging is not routinely required prior to MS-TRAM flap harvest.
- Only in select patients, ie, patients with previous abdominal procedures in which the deep inferior epigastric vessels or its perforators were at risk for injury, is a CT angiography obtained to confirm the presence of suitable vessels.

SURGICAL MANAGEMENT

- Parameters to consider include the following:
 - Timing of reconstruction
 - Immediate vs delayed reconstruction
- Immediate reconstruction has several advantages. These include the ability to

reconstruct a breast mound in a single procedure as well as ease of obtaining an aesthetically appealing result due to the presence of the breast skin envelope.

- Delayed reconstruction can be offered at anytime after mastectomy and adjuvant chemotherapy. In cases of postmastectomy radiotherapy, we recommend waiting 6 months after the end of radiation to allow for the recovery of the soft tissues from radiation injury. Furthermore, scarred or irradiated skin that prevents adequate ptosis should be excised and replaced with abdominal skin.
- Need for adjuvant radiotherapy
 - Radiotherapy after MS-TRAM flap-based reconstruction can result in volume loss, skin contracture, fat necrosis, and poor appearance.⁹
 - Options to remedy the detrimental radiation-induced effects include a “delayed-immediate” approach, in which a tissue expander is placed immediately and eventually replaced with autologous tissue following completion of radiotherapy, or immediate reconstruction with an MS-TRAM flap that is designed approximately 10% to 15% larger than the contralateral breast to account for the anticipated volume loss.
- Recipient vessels
 - The decision as to whether the ipsilateral or contralateral MS-TRAM flap is used is predominantly determined by the choice of the recipient vessels (see Techniques).

Preoperative Planning

- Preoperative patient assessment should reveal the presence of adequate amount of lower abdominal soft tissue for the purpose of breast reconstruction.
- Clinical examination should rule out pre-existing abdominal scars that would preclude the harvest of an MS-TRAM flap.
- Preoperative landmarks include the umbilicus, anterior superior iliac spines (ASIS), and the suprapubic crease.
- The elliptical skin island of the MS-TRAM flap includes the areas between the upper border of the umbilicus and the suprapubic crease and the ASIS bilaterally.

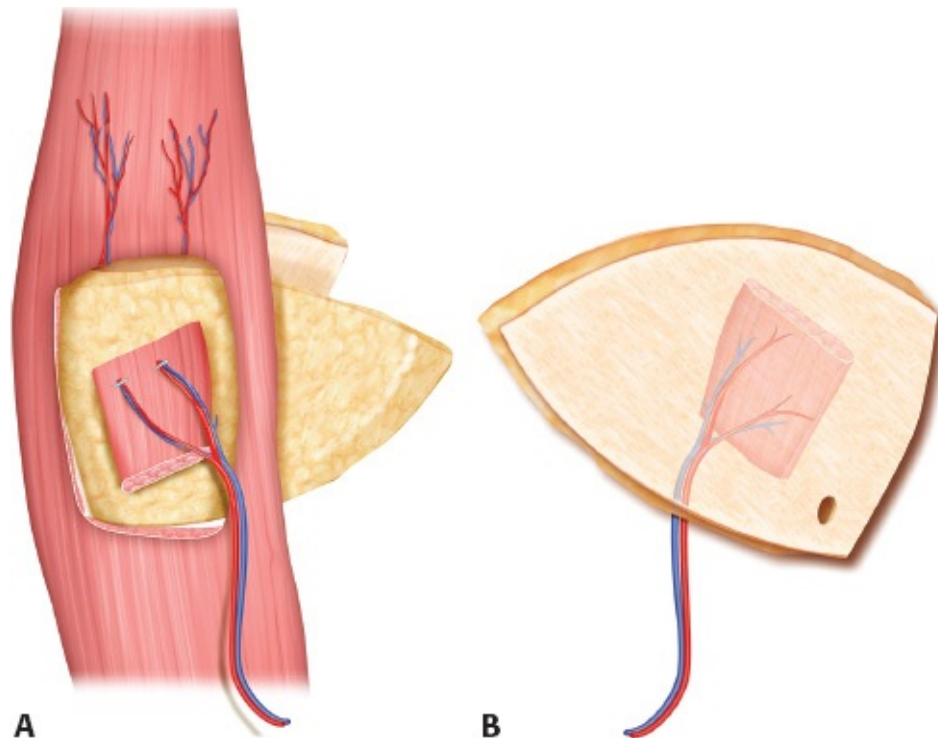


FIG 1 • A,B. Illustration of a free MS-TRAM flap based on the deep inferior epigastric vessels with limited rectus abdominis muscle attached to the skin island (Courtesy of D.W. Low, MD).

Positioning

- The patient is positioned supine on the operating table with bilateral upper extremities abducted.
- The operating table should allow hip flexion to decrease tension during donor-site closure.

Approach

- The lower abdominal skin can be harvested in a variety of different ways based on the amount of rectus muscle included as well as its vascular pedicle.
 - Options include
 - Pedicled TRAM flap (see Chapter 32)
 - Free TRAM flap—Full width of rectus abdominis muscle is harvested (see Chapter 34)
 - Free MS-TRAM flap—Part of the rectus abdominis muscle is harvested

(**FIGS 1** and **2**)

- Free deep inferior epigastric perforator (DIEP) flap—No rectus abdominis muscle is harvested (see Chapter 36)
- Free superficial inferior epigastric artery (SIEA) flap—The anterior rectus sheath is not violated and the abdominal flap is raised based on the superficial epigastric vessels (see Chapter 37)



FIG 2 • Clinical image of a free MS-TRAM flap. Note the small segment of rectus abdominis muscle harvested with the flap.

TECHNIQUES

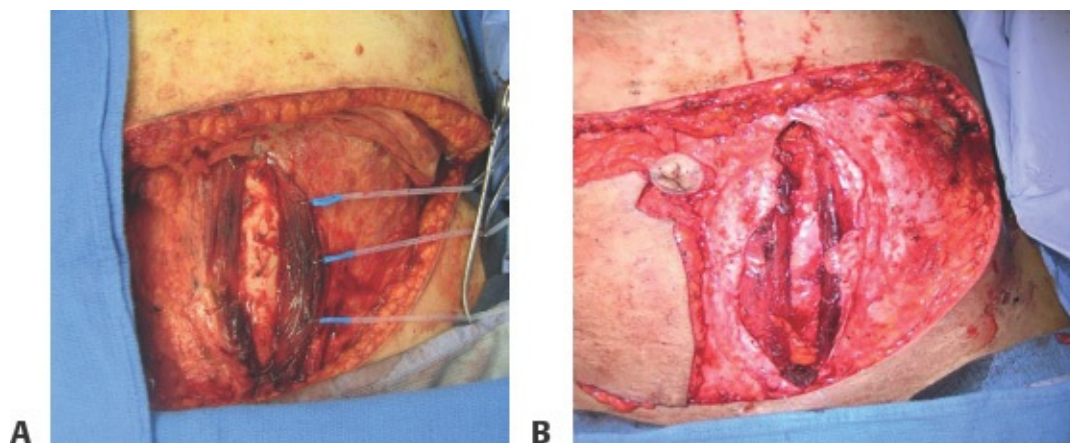
■ Free MS-TRAM Flap Harvest

- Landmarks: Umbilicus, anterior superior iliac spines (ASIS), suprapubic crease
- Skin incision is made along the upper border of the flap.
- Dissection is carried down to the abdominal wall fascia followed by undermining of the upper abdominal skin and soft tissues to the level of the xiphoid and costal margin.
 - It is critical to spare perforating vessel in the subcostal region to maximize perfusion to the abdominal skin flap.
- The patient is temporarily sat up and the superior abdominal skin is draped

over the MS-TRAM flap island to confirm the ability to obtain donor-site closure at the completion of the procedure.

- The lower border of the MS-TRAM flap is incised followed by identification of the superficial inferior epigastric (SIE) vessels.
 - The SIE vein (SIEV) is found approximately 4 to 5 cm lateral to the midline. The SIEA is approximately 2 to 3 cm lateral to the SIEV.
 - At this point, the surgeon should determine if the SIE vessels are suitable to apply a SIEA flap.
 - If the SIEA is of inappropriate caliber (less than 1.5 mm) or not present, the SIEV is dissected over the course of 4 to 5 cm and ligated. This provides for an additional outflow vein or a source of vein graft.
- Next, flap dissection proceeds from lateral to medial until the lateral row of perforators emanating from the anterior rectus sheath is visualized.
 - In unilateral breast reconstruction, the skin island opposite the vascular pedicle is dissected off of the abdominal wall, across the midline, and up to the medial row of perforators.
 - In bilateral breast reconstruction, the skin island is transected in the midline followed by medial-to-lateral dissection until the medial row of perforators is identified.
- Once the decision is made on which perforators to include, the anterior rectus sheath is incised below to the inferior-most perforator. The anterior rectus sheath is divided inferolaterally toward the vascular pedicle of the flap.
- The deep inferior epigastric vessels are identified along the lateral edge of the rectus abdominis muscle and followed all the way to their origin, ie, the external iliac vessels.
- Superiorly, the anterior rectus sheath incision is extended to incorporate the chosen perforators. It is critical to keep the amount of fascial harvest to a minimum.
- The amount of muscle divided in a MS-TRAM flap is dependent on the topography of perforators.
 - The lateral- and medial-most perforators determine the width of rectus abdominis muscle that is divided.
 - The rectus abdominis muscle is split along its fibers at the level of the lateral-most perforator and the medial-most perforator, respectively.
 - It is important to confirm that the main vascular pedicle is located within the harvested segment of rectus abdominis muscle.

- Small vascular branches traveling away from the perforator-carrying central muscle segment are carefully ligated and divided.
 - In order to reduce the width of rectus abdominis muscle that is sacrificed, it is critical to stay close to the perforators and to follow their intramuscular course (**TECH FIG 1**).
- After recipient vessel dissection and confirmation of adequate recipient vessels, the deep inferior epigastric vessels are ligated close to their origin, followed by transection of the central rectus abdominis muscle segment inferiorly and superiorly.

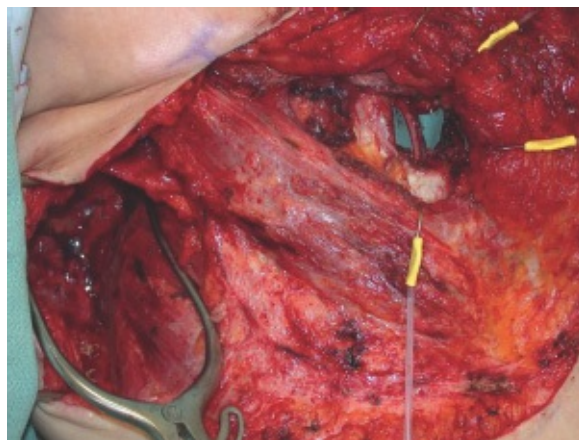


TECH FIG 1 • **A.** Donor-site defect following MS-TRAM flap harvest. **B.** Donor-site defect following MS-TRAM flap harvest. Note, preservation of rectus abdominis muscle medially and laterally.

■ Recipient Vessel Dissection

- The most common recipient vessels are the internal mammary artery (IMA) and vein (IMV) (**TECH FIG 2**).
- The pectoralis major muscle is divided along its fibers at the level of the 3rd rib.
- After identification of the 3rd rib, the intercostal space between the 3rd and 4th rib is assessed for the possibility of a rib-sparing approach to the IM vessels.
- If the intercostal space is adequately wide (greater than 2 cm), a rib-sparing approach is chosen.

- The pectoralis major muscle is divided along its fibers between the 3rd and 4th rib.
 - The intercostal muscles are divided lateral to the level of the IM vessels vertically beginning inferolaterally at the level of the cartilaginous and bony junction. Next, in a lateral to medial direction, the intercostal muscle cuff is excised at the level of the pleura until the IM vessels are visualized encased in adipose tissue.
 - Completion IM vessel dissection follows after removal of the adipose tissue and lymphatics surrounding the IMA and V in the space between the 3rd and 4th rib.
- If a rib-sparing approach is not possible, the cartilage of the 3rd rib is most commonly removed for the purpose of IM vessel dissection.
 - The perichondrium of the 3rd rib is incised transversely on its anterior surface from its junction with the sternum to approximately 1 cm medial to the costochondral junction.
 - Subperichondrial dissection follows anteriorly, superiorly, and inferiorly. Complete posterior dissection is not mandatory.
 - The costal cartilage is then removed with a rongeur.
 - The posterior perichondrium is incised vertically lateral to the IM vessels followed by lateral-to-medial dissection.
 - Meticulous dissection with ligation of small intercostal branches is critical to maintain a bloodless field.



TECH FIG 2 • Recipient vessel dissection: The pectoralis major muscle is split and the right internal mammary vessels are dissected.

- After identification of the IM vessels, the soft tissues between the superior border of the 4th rib and the inferior border of the 2nd rib are excised, thus, providing for a long vascular segment that facilitates microsurgical anastomosis.
 - Other possible recipient vessels include the thoracodorsal vessels, the circumflex scapular vessels, the thoracoacromial vessels, and the axillary artery and vein.
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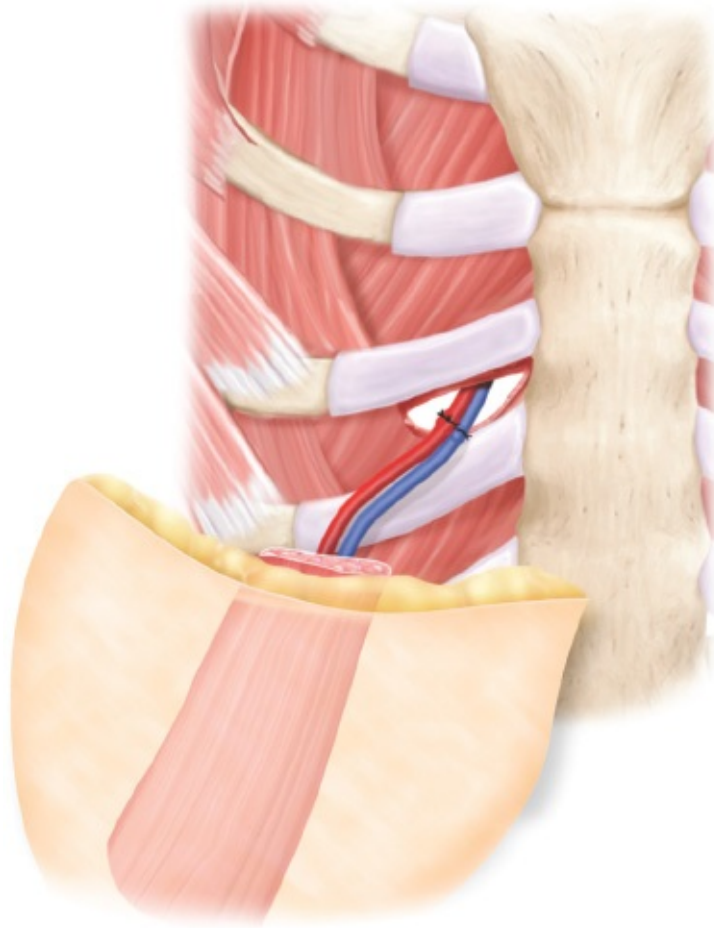
■ Abdominal Donor-Site Closure

- Meticulous donor-site closure is critical if abdominal hernias and bulges are to be avoided.
- Inferiorly primarily fascial closure is performed with figure-of-eight polypropylene sutures with buried knots.
- Fascial closure is routinely reinforced with polypropylene mesh.
- The polypropylene mesh is placed between the rectus abdominis muscle and the anterior rectus sheath.
 - It is critical to ensure that the mesh is positioned inferiorly within the rectus sheath so as to buttress the fascial repair site.
 - Size 0 polypropylene sutures are used to secure the mesh.
 - The mesh is secured with buried mattress sutures: first, inferiorly; then superiorly and medially; and, finally, laterally.
- In cases on minimal fascial excision with MS-TRAM flap harvest, primary fascial closure is performed. However, in cases of moderate (greater than 2–3 cm) fascial excision, a bridging mesh technique of anterior rectus sheath closure is preferred to minimize postoperative abdominal discomfort secondary to an overly tight fascial closure.
- Next, the patient is raised to facilitate skin closure.
- The superior abdominal skin flap is temporarily stapled into place and the site of the umbilical transposition is marked.
 - An opening in the abdominal skin flap is created, followed by removal of a core of subcutaneous tissue.
 - The umbilicus is sutured into place with interrupted deep dermal 4-0 absorbable monofilament sutures followed by a subcuticular closure with a 5-0 absorbable monofilament suture.
- Two suction drains are placed exiting the abdominal wound laterally.

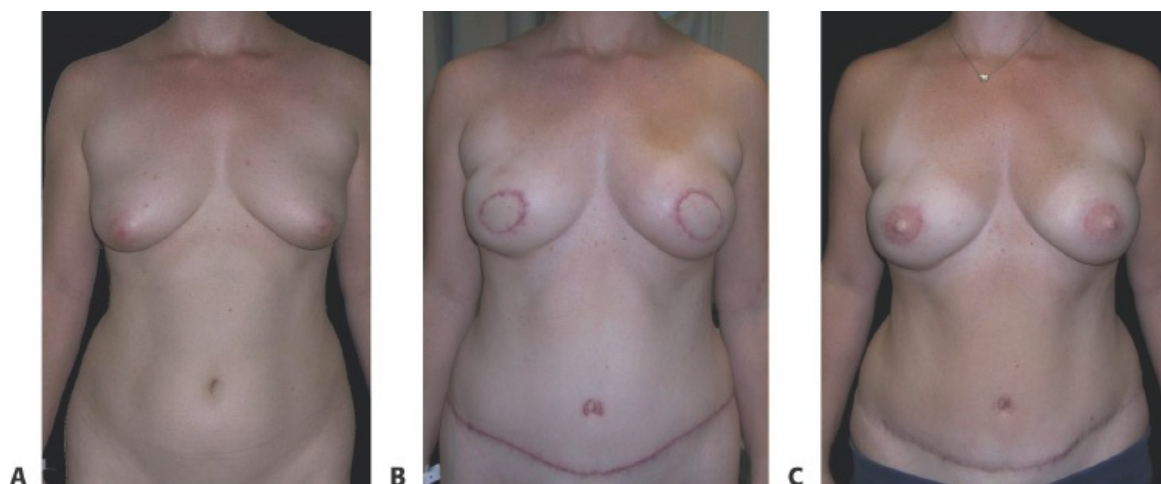
- Layered closure is performed with approximation of Scarpa fascia followed by deep dermal and subcuticular closure.
 - Sterile dressings are applied.
-

■ MS-TRAM Flap Inset

- Whenever the internal mammary vessels are chosen as recipient vessels, the contralateral MS-TRAM flap is used for reconstruction.
 - The MS-TRAM flap is rotated 90 degrees with the umbilicus positioned inferolaterally (**TECH FIG 3**).
- The ipsilateral MS-TRAM flap is used whenever the thoracodorsal vessels are chosen as recipient vessels.
 - Here, the umbilicus is positioned inferomedially after rotating the flap 90 degrees.
- After performing microsurgical anastomoses, the flap is secured in place with 2-0 absorbable sutures.
 - The flap is secured medially at the level of the 3rd rib as well as along the superomedial, superior, and superolateral borders of the breast footprint.
 - A suction drain is placed and wound closure performed with interrupted absorbable sutures for deep dermal closure following by subcuticular closure.
- Finally, Doppler examination is performed and the site with an audible Doppler signal is marked with a 5-0 polypropylene suture.
- **TECH FIG 4** displays a case example of bilateral immediate breast reconstruction with free MS-TRAM flaps.



TECH FIG 3 • Illustration demonstrating anastomosis of the deep inferior epigastric vessels to the internal mammary vessels. Note that the left MS-TRAM flap has been transferred to the right chest with the flap being rotated 90 degrees so that the umbilicus is positioned inferolaterally (Courtesy of D.W. Low, MD).



TECH FIG 4 • Preoperative (**A**), early postoperative (prior to nipple-areola reconstruction) (**B**) and late postoperative (after nipple-areola reconstruction) (**C**) images of a patient who underwent bilateral immediate breast reconstruction with free MS-TRAM flaps.

PEARLS AND PITFALLS

Indications	■ Patients with adequate amount of lower abdominal soft tissue for the purpose of breast reconstruction. ■ Absence of abdominal scars precluding MS-TRAM flap harvest.
Imaging	■ Routine use of preoperative imaging is not indicated. ■ Merely in cases in which prior abdominal surgery places the deep inferior epigastric vessels or its perforators at risk is preoperative CT angiography warranted.
Flap dissection	■ Minimize abdominal wall morbidity by having the lateral- and medial-most perforators determine the width of rectus abdominis muscle that is divided. ■ Minimize fascial excision. ■ Preserve the SIEV as an additional drainage source or potential vein graft.
Donor-site	■ Meticulous fascial closure is paramount to minimize the risk of

closure	abdominal hernia or bulge formation. ■ Routinely use polypropylene mesh in donor-site closure, even if primary fascial closure is performed. ■ Avoid an overly tight fascial closure; use bridging mesh in cases of moderate fascial excision (>2–3 cm).
Flap inset	■ The contralateral MS-TRAM flap is used whenever the IM vessels are chosen as recipient vessels. ■ The ipsilateral MS-TRAM flap is used in cases in which the thoracodorsal vessels are used as recipients.

POSTOPERATIVE CARE

- Following extubation and transfer to the PACU, the patient is admitted to a step-down unit.
- Flap checks are performed via a combination of clinical and Doppler examination hourly for the first 48 hours, followed by every 4 hours until discharge.
- The patient is kept NPO until the morning of postoperative day (POD) 1 and is then started on a clear liquid diet. Diet is advanced to a regular diet on POD 2.
- Activity restrictions include out of bed to chair on POD 1 followed by ambulation on POD 2.
- No specific anticoagulation is indicated. Patients merely receive heparin 5000 U subcutaneously every 8 hours for the duration of the hospitalization.
- The patient is typically discharged home on POD 3 to 4. Instructions are provided regarding incision and drain care.

OUTCOMES

- The issue of donor-site morbidity associated with MS-TRAM flap harvest was investigated in a matched-pair analysis of a total of 104 patients.¹⁰
 - Fifty-two MS-TRAM flap patients were matched with 52 abdominoplasty patients.
 - Postoperative complication rate, including the rate hernia and abdominal bulge formation were similar in both groups.
 - A higher degree of patient satisfaction with the appearance of the abdominal scar was noted among TRAM flap patients.¹⁰
- Using the BREAST-Q, Macadam et al. performed a multicenter study including 1790 patients and did not detect any significant difference in patient-reported outcomes between patients undergoing reconstruction with DIEP flaps

vs MS-TRAM flaps.¹¹

COMPLICATIONS

- Wound-related complications can be as high as 30% to 50%⁹ and include
 - Simple infections
 - Seromas
 - Hematomas
 - Skin flap necrosis
 - Delayed wound healing
- Additional complications include
 - Fat necrosis
 - Flap loss (approximately 1%)¹²
 - Abdominal bulge/hernia formation

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22 DIEP Flap Breast Reconstruction

CHAPTER

Pierre M. Chevray

DEFINITION

- Breast reconstruction following mastectomy can be accomplished with prosthetic breast implants, autologous tissue flaps, or a combination of the two.
- Autologous tissue flaps from the lower abdomen are capable of creating the most natural, lasting, and maintenance-free reconstructed breasts with the highest long-term patient satisfaction when compared to other methods of breast reconstruction.¹
- Autologous tissue flaps have donor-site morbidity and require longer and more complex surgery, with a longer recovery period, compared to implant-based breast reconstruction.
- Techniques to harvest lower abdominal flaps of skin and subcutaneous tissue for breast reconstruction have evolved from the pedicled TRAM flap, to the free TRAM flap, to the muscle-sparing free TRAM flap, to the DIEP flap, to the SIEA flap, in order to minimize donor-site morbidity.²
- The DIEP (Deep Inferior Epigastric Perforator) flap has become the most popular lower abdominal free flap used for breast reconstruction because of its balance of sparing rectus abdominis muscle function while still providing a well-vascularized and reliable flap of skin and subcutaneous tissue.^{3–5}

ANATOMY

- The vascular pedicle of the DIEP flap is the deep inferior epigastric (DIE) artery and veins, and their branches which perforate through the rectus abdominis muscle (perforators), into the subcutaneous fat of the anterior abdominal wall.
- The DIE vessels originate from the external iliac vessels in the pelvis, course

anteriorly and superiorly, in the retroperitoneal plane, to the inferolateral border of the rectus abdominis muscle. The DIE vessels continue superiorly, within the rectus sheath, on the deep surface of the rectus abdominis muscle, from which branches to the muscle and perforators into the overlying flap tissue originate. Terminal branches of the DIE vessels coalesce with the terminal branches of the deep superior epigastric vessels (**FIG 1**).

- The single most common branching pattern of the DIE artery is that it bifurcates into two parallel branches that course superiorly on the underside of the rectus abdominis muscle. One branch runs along the medial side of the muscle, giving rise to the “medial row” of perforators, and the other runs along the lateral side of the muscle, giving rise to the “lateral row” of perforators. However, this branching pattern is variable.
- Generally, lateral row perforators pierce the muscle perpendicular to the plane of the flat, straplike, rectus abdominis muscle and are easier to dissect compared to medial row perforators, which tend to travel obliquely, from medial to lateral, and superior to inferior, through the muscle and require dissection along greater distances within the muscle when compared to lateral row perforators.

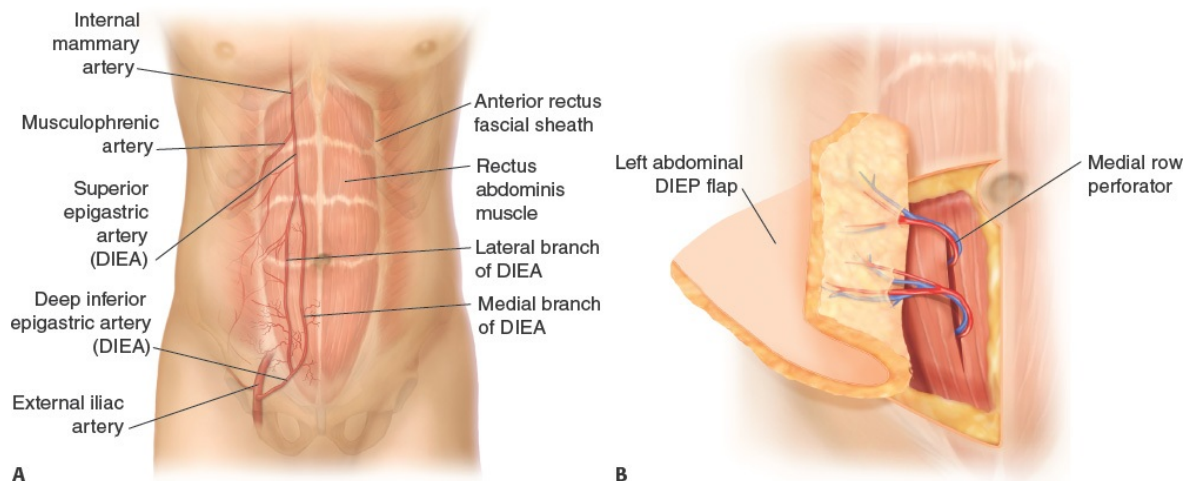


FIG 1 • A. Deep inferior epigastric artery (DIEP) flap anatomy showing a right hemiabdominal DIEP flap skin paddle overlying the right rectus abdominis muscle containing the medial and lateral branches of the deep inferior epigastric (DIE) artery, which gives off the medial and lateral row of perforators. **B.** The left

hemiabdominal DIEP flap is reflected laterally, as it would be during exposure of the medial row of perforators.

- The limits of the DIEP flap skin paddle are several centimeters superior to the superior edge of the umbilicus, inferiorly to the level of the pubic bone, and laterally to the anterior axillary line. It is possible, usually in younger and thinner patients, to transfer this entire lower abdominal flap based on the perforators from one DIE vascular pedicle.
- The skin paddle of lower abdominal flaps has been divided into zones.⁶ Zone 1 is the paramedian region of the flap skin paddle overlying the rectus abdominis muscle and is the best perfused area of the flap. Zone 2 is lateral to Zone 1. Zone 3 is the mirror image of Zone 1, on the opposite side of the vertical midline. Zone 4, lateral to Zone 3, is the furthest from the perforators and thus the least well-perfused zone and most likely to suffer fat necrosis.
- Selecting which perforators to keep, and which are not necessary and can be sacrificed, is one of the critical decisions during this operation and requires the most experience and judgment.
- Generally, the single largest perforator will perfuse Zone 1 of a DIEP flap. However, in most breast reconstructions, Zones 1 and 2 are necessary to reconstruct a large enough breast.
- Zones 1, 2, and 3, and sometimes Zone 4, can be perfused by including more perforators.
- The rectus abdominis muscle is segmentally innervated, and the skin paddle of the DIEP flap receives sensory innervation from the thoracoabdominal branches of the intercostal nerves T7-T11, which run between the internal oblique and transversus abdominis muscles and then enter the lateral border of the anterior rectus sheath.
- These thoracoabdominal nerves run roughly transversely, just deep, and within the rectus abdominis muscle along with the accompanying vascular branches of the intercostal arteries and veins to anastomose with the DIE vessels, which run roughly vertically.
- The sensory nerve fibers run with the perforators through the rectus abdominis muscle and anterior rectus sheath, into the overlying subcutaneous tissue of the DIEP flap, to innervate the skin. The motor fibers branch into the substance of the rectus abdominis muscle to innervate it.

- These motor and sensory nerves run superficial to the DIE vessels, and for all practical purposes, must be divided to harvest and transfer the DIEP flap. Some surgeons repair the nerves that are divided.

PATHOGENESIS

- The DIEP flap is most commonly used for breast reconstruction following mastectomy for treatment of breast cancer, or risk reduction in patients with a genetic increased risk of breast cancer such as BRCA 1 or 2 gene mutations.

NATURAL HISTORY

- Rates of breast reconstruction have been slowly rising over the past 40 years. However, in the United States, less than half of patients who are treated with mastectomy have breast reconstruction,^{7,8} and rates of breast reconstruction are substantially lower elsewhere in the world.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The DIEP flap can be used for total, or partial, breast reconstruction in patients who have had a mastectomy or partial mastectomy (lumpectomy, segmental mastectomy), respectively.

IMAGING

- CT and MR angiography is used by some surgeons to visualize the DIE vascular pedicle and perforators preoperatively. Some believe this can decrease operative times; however, the author does not use preoperative imaging of any kind.

NONOPERATIVE MANAGEMENT

- Breast reconstruction has been shown to improve the quality of life of patients who have had a mastectomy.
- The Women's Health and Cancer Rights Act of 1998, a federal law in the United States, mandates commercial health insurance companies to cover breast reconstruction after a mastectomy, surgery on the opposite breast to improve breast symmetry, and breast prostheses. Despite this law, less than half of patients who have a mastectomy in the United States have breast reconstruction.
- Nonsurgical treatment would include using an external breast prosthesis, which fits into a brassiere cup or is part of a custom-made brassiere.

SURGICAL MANAGEMENT

Preoperative Planning

- The objective of the operation is to improve the quality of life of the mastectomy patient by reconstructing a breast mound that is as similar to a natural breast as possible.
- Absolute contraindications for this operation are prior full abdominoplasty or uncorrectable hypercoagulable state.
- Relative contraindications are a body mass index greater than 40 kg/m^2 , hypercoagulable state, previous abdominal liposuction, and prior abdominal surgery that may compromise the flap or abdominal wall.
- The risks of the surgery to be discussed with the patient include the risks of surgery in general (infection, bleeding, pain, scarring, hematoma, seroma, and delayed healing) and the specific risks of this surgery, which are abdominal hernia, bulge, weakness, and partial or total flap loss.
- For immediate breast reconstruction, the incisions for the mastectomy are discussed with the breast surgeon. A common issue is, should a patient with ptotic breasts who would like smaller or more lifted reconstructed breasts have a nipple-sparing mastectomy (NSM), even if it is oncologically acceptable? If yes, how long after the NSM and DIEP flap reconstruction will you perform a mastopexy that involves a periareolar incision?
 - Anecdotally, the author likes to wait at least 6 months.
 - Alternatively, the patient may be treated with a lumpectomy and oncoplastic mastopexy and complete any adjuvant treatments and then undergo NSM and DIEP flap breast reconstruction.
 - A third option, in patients without breast cancer such as patients with BRCA mutations, is to have a mastopexy or breast reduction first and then, 6 or more months later, undergo NSM and DIEP flap reconstruction.

Preoperative Markings

- Preoperatively, with the patient standing upright, mark the anterior midline from the sternal notch down to the pubis. Mark both inframammary folds (IMFs). Then draw a horizontal line from the most inferior point of each IMF across the midline to the opposite IMF to determine if one side is lower or higher than the other side (**FIG 2**).
- Also with the patient standing, mark the superior flap incision line. This is typically about 2 cm superior to the superior border of the umbilicus but can vary from the level of the superior border of the umbilicus, up to about 5 cm

above this.

- This transverse line curves inferiorly as it is extended laterally in both directions, and generally ends several centimeters lateral and superior to the anterior superior iliac spine (ASIS).
- The lower this incision is made, the lower and more easily concealed, the longer the transverse abdominal donor-site scar will be, but the less flap skin surface area and less flap subcutaneous fat volume that is harvested (see **FIG 2**; **FIG 3**).
- The lower transverse abdominal incision is also marked preoperatively with the patient standing. This is typically drawn in the natural suprapubic crease and extends laterally, curving gently upward to meet the superior incision line several centimeters superior and lateral to the ASIS (see **FIG 2** and **3**).



FIG 2 • Patient prepared and draped with arms abducted at 90 degrees on arm boards. The vertical midline, bilateral inframammary folds (IMF), horizontal extension of the nadir of both IMF, and the proposed DIEP flap skin paddles have been marked preoperatively with the patient standing. Bilateral nipple-sparing mastectomies via IMF incisions have been completed.

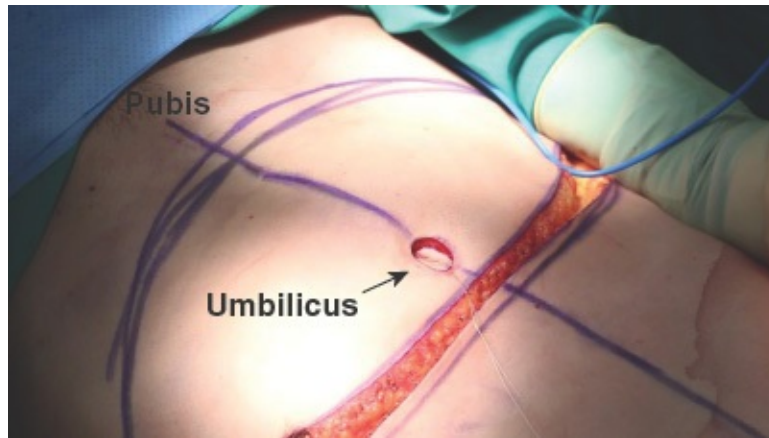


FIG 3 • Initial DIEP flap harvest with patient supine. (Note that in all intraoperative photos, the patient's head is to the right.) The umbilicus has been cored out from the DIEP flaps, and the upper abdominal incision has been made. The umbilicus has been tagged at its 12 o'clock position with a suture, which will be used later to find the umbilicus and bring it out for inseting once the abdominal donor site has been closed. Note that the initial, more superior, upper and lower abdominal incision markings, which were made preoperatively, have both been lowered by about 2 cm based on an intraoperative pinch/grab evaluation of the abdominal donor site with the patient's head and back raised to 45 degrees.

Positioning

- The patient is positioned supine with the arms abducted 90 degrees on arm boards. Alternatively, if no axillary lymph node surgery is planned, the arms may be tucked. This allows for easier positioning of a dual head operating microscope for two surgeons, but care must be taken not to injure the patient's hands and arms when raising the patient's head and back to close the abdominal donor site.
- The operating table may be reversed (turned 180 degrees) underneath the patient, in what is sometimes called a "C-arm position." This allows the head and back to be raised nearly to 90 degrees upright, which some surgeons desire

for evaluating inseting and shaping of the DIEP flap.

TECHNIQUES

- In immediate breast reconstruction, DIEP flap harvest can begin at the abdomen at the same time the breast surgeon is performing the mastectomy at the chest. Alternatively, the DIEP flap surgery can begin after the breast surgeon is finished.
- Typically, the patient cannot be paralyzed until the breast surgeon has completed any axillary lymph node surgery, and this may make dissection of perforators at the abdomen difficult due to the contraction of the rectus abdominis muscle when stimulating the motor nerves with the electrocautery.
- In a unilateral breast reconstruction, assess if a hemi-DIEP flap will provide sufficient volume and skin surface for the reconstruction or if tissue across the midline needs to be harvested.
- Once the patient is under general anesthesia, raise the head and back of the patient to about 45 degrees, or more, and perform a pinch/grab test to assess if the abdominal donor site can be closed after flap harvest along the marked incision lines. Raise or lower the upper abdominal incision line to adjust.
- The upper abdominal incision is commonly at the level of the superior border of the umbilicus or up to several centimeters superior to this. Return the patient to the supine position. **FIG 3** shows an example where the initially marked upper and lower abdominal incision lines were both lowered intraoperatively by about 2 cm after the pinch/grab test of the donor site.

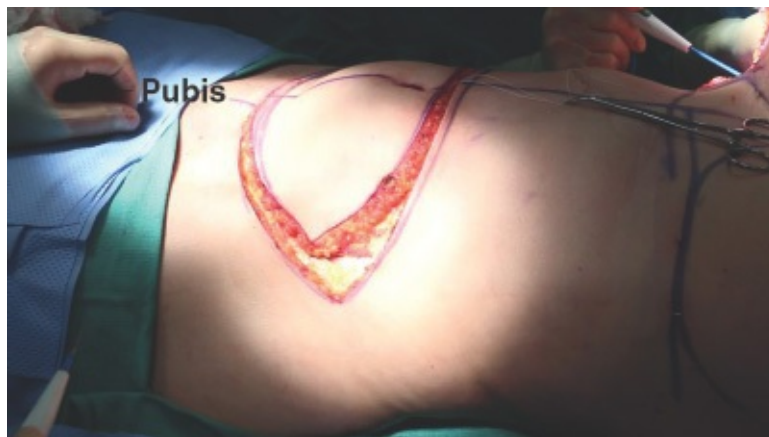
■ DIEP Flap Harvest

Incision and Flap Elevation

- The abdominal incisions are made. The superior incision is beveled superiorly to capture more subcutaneous tissue volume with the flap and to decrease the thickness of the cut edge of the upper abdominal donor-site flap. This creates a better thickness match between the upper and lower cut edges of the abdominal donor-site incision at closure.
- The upper abdominal donor-site flap of skin and subcutaneous tissue is elevated off the anterior rectus fascia for 5 to 10 cm to allow closure of the

donor site. Raising this abdominal skin flap superiorly to the xiphoid process usually does not substantially increase mobility of the skin flap and will decrease vascularity of the midline upper abdominal tissue.

- The lower abdominal incision is made just barely through the dermis and into the subcutaneous fat, in order to identify, and not injure, the superficial inferior epigastric and/or the superficial circumflex iliac vessels. If there is a large enough superficial artery, harvest of a superficial inferior epigastric artery (SIEA) flap may be considered (see SIEA flap chapter). If there is a large vein, it is dissected free inferiorly for 4 to 8 cm, ligated, and divided. This is done to provide additional venous drainage or to be used as a vein graft, if needed, in the case of venous congestion of the DIEP flap.
- The umbilicus is cored out from the surrounding DIEP flap tissue and tagged with a suture. Leave some fat around the stalk of the umbilicus to minimize the risk of devascularization. Minimize the diameter of the umbilicus because a smaller diameter umbilicus will draw surrounding upper abdominal skin inward and deeply, resulting in a less visible circumferential scar (see **FIG 3**).
- For bilateral DIEP flap reconstructions, or unilateral cases where a hemiflap is sufficient, the vertical midline incision separating the right and left DIEP flaps is made.



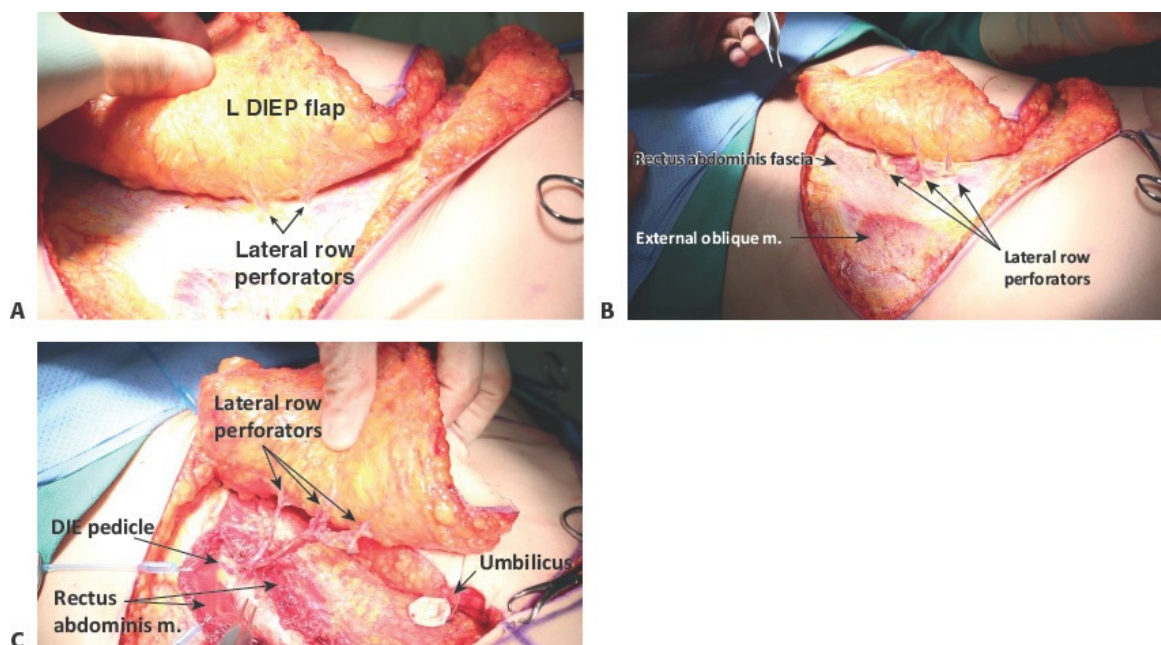
TECH FIG 1 • Left lateral view of patient just before beginning elevation of the left abdominal DIEP flap to expose and dissect vascular perforators. Note that the surgical oncologist is performing the right mastectomy. Note also that in this patient, the right IMF is about 2 cm lower than the left IMF. This is indicated by the

markings extending medially from the nadir of each IMF, which were drawn preoperatively while the patient was standing. This IMF asymmetry will be corrected with sutures.

- The DIEP flaps are elevated off the abdominal muscle fascia using electrocautery at a low setting of 20 in the coagulation mode. The edge of the flap tissue is grasped and is retracted and reflected at a greater than 90-degree angle away from the abdominal wall in order to spread the plane between the subcutaneous fat of the flap and the anterior rectus fascia so that vascular perforators can be visualized (**TECH FIG 2A**).

Perforator Location and Selection

- The DIEP flaps are raised from lateral to medial (**TECH FIGS 1** and **2A,B**) to expose the lateral row of perforators, from medial to lateral to expose the medial row of perforators, and from superior to inferior, and inferior to superior.
- Rarely are perforators located superior to the umbilicus used because they are located at one corner of the flap and thus are less likely to perfuse a large area of the flap, and they require incision and dissection through more rectus abdominis muscle.



TECH FIG 2 • A. Left abdominal DIEP flap elevation showing identification of two lateral row perforators. **B.** Left abdominal DIEP flap elevation showing three lateral row perforators. The anterior rectus abdominis muscle fascia between the perforators has been divided, and perforator dissection through the muscle is about to begin. **C.** The left abdominal DIEP flap has been raised on three lateral row perforators. The DIE pedicle is visible and about to be dissected.

- Perforators located more than 10 cm inferior to the umbilicus are rarely used because they tether the pedicle to the underside of the flap and shorten the effective length of the pedicle.
- The largest perforator is most commonly in the medial row, located within several cm of the umbilicus. However, sometimes the largest perforator is in the lateral row. When harvesting a hemiabdominal DIEP flap, the one largest perforator is often sufficient to perfuse the flap. This can be tested by occluding the other perforators with Acland clamps for 5 to 10 minutes and evaluating the color of the flap and arterial bleeding at the edges of the flap.
- Two or three perforators may be necessary to adequately perfuse the flap.
- It is advantageous to select perforators within the same medial or lateral row as this minimizes the amount of rectus abdominis muscle fibers that are divided during flap harvest (**TECH FIG 2C**).

Perforator Dissection

- The selected perforators are dissected free from the anterior rectus fascia. There is an opening in the fascia that each perforator passes through. The edge of this hole in the fascia is exposed with the cautery, grasped with toothed forceps, elevated to allow the underlying perforator to fall away, and divided with the cutting cautery to enlarge the opening. These enlarged openings around the selected perforators in the fascia are connected by incising the fascia between them (see **TECH FIG 2B**).
- The perforators are carefully dissected free from the rectus abdominis muscle using bipolar cautery on a low setting, such as 20. It is important to retract the muscle fibers away from the perforator vessels using “fish-hook”

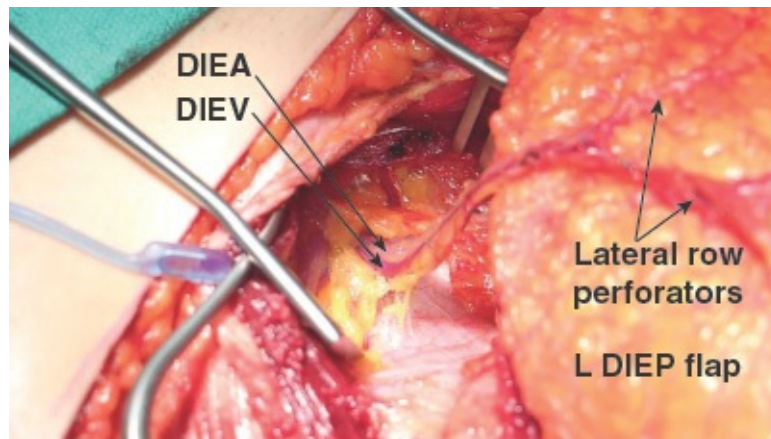
or Weitlaner retractors and directly grasp the muscle fibers immediately adjacent to the perforator vessels, pulling them away and dividing them with bipolar cautery (see **TECH FIG 2C**).

- Much of the muscle can be bluntly dissected (pushed) away from the perforator vessels until a small vascular branch of the perforator into the muscle is encountered. The smallest of these branches are divided using the bipolar cautery. Others are clipped with small vascular clips and divided with scissors.
- Dissection of the selected perforators continues until they are freed from the rectus abdominis muscle, and the junction with the DIE vascular pedicle is reached (see **TECH FIG 2C**).
- The DIE vessels are sometimes within the rectus abdominis muscle and have to be dissected free from the muscle fibers like the perforators. Further inferiorly, the DIE vessels will always be in a fatty or loose areolar plane deep to the rectus abdominis muscle, between the muscle and the posterior rectus sheath.

DIE Vessel Dissection

- There are segmental intercostal neurovascular bundles entering the lateral border of the rectus sheath. These run in a superolateral to inferomedial direction and anastomose with the DIE vessels. The intercostal vessels must be divided.
- These intercostal nerves within these intercostal neurovascular bundles continue over (superficial to) the DIE vessels and branch into the rectus abdominis muscle to innervate the muscle and follow the perforator branches of the DIE vessels through the muscle and into the flap to provide sensory innervation to the abdominal flap skin. These intercostal nerves are divided where they cross over the DIE vessels. If desired, these nerves can be repaired, after transposing the ends deep to the DIE vessels.
- Continue to dissect the DIE vessels inferiorly toward their origin from the external iliac vessels. Deep to the inferior quarter of the rectus abdominis muscle, the DIE vessels diverge from the underside of the muscle and run in a deep and lateral direction through the preperitoneal fat to meet the external iliac vessels (**TECH FIG 3**).
- The pedicle vessels are dissected to within a few cm of their origin from the external iliac vessels to ensure adequate pedicle length to reach the internal mammary or thoracodorsal recipient vessels at the chest.

- De-epithelialize as much of the flap skin as possible while the flap is still in situ at the abdomen (see section below on Insetting the DIEP Flap).



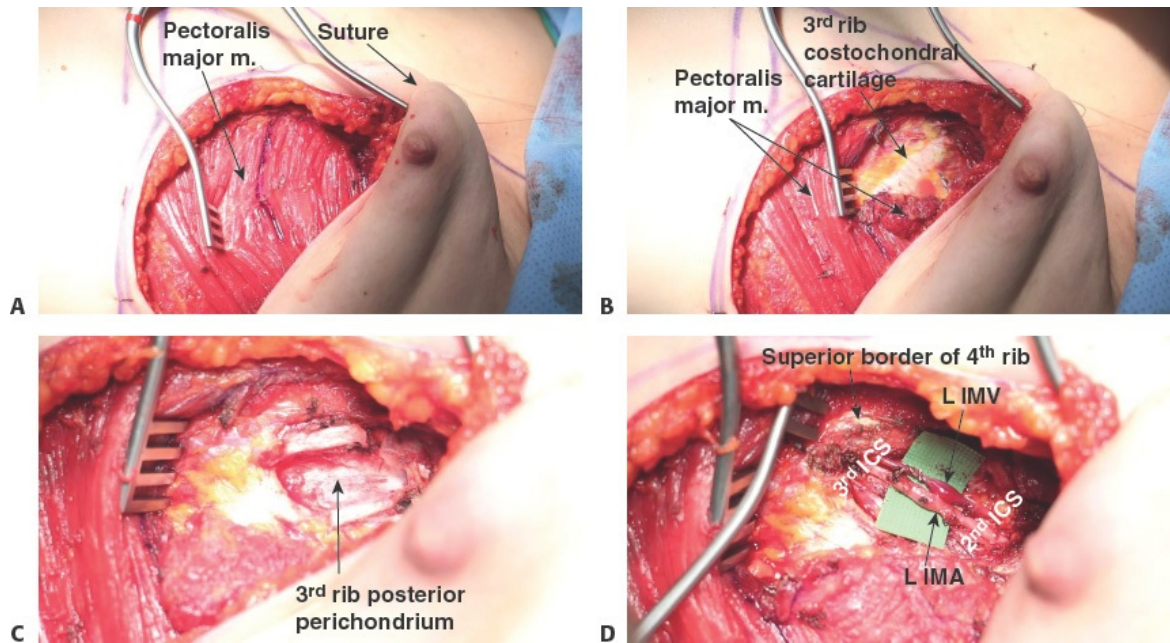
TECH FIG 3 • Dissection of the left abdominal DIEP flap pedicle continues to within 1 to 2 cm of its origin from the external iliac vessels. Two Weitlaner retractors are used for exposure. DIEA, deep inferior epigastric artery. DIEV, deep inferior epigastric vein.

■ Exposure and Preparation of Internal Mammary Recipient Vessels

- The breast surgeon will typically have completed the unilateral or bilateral mastectomy surgery by the time the DIEP flap dissection is completed, and dissection of the recipient vessels can begin.
- The internal mammary recipient vessels are preferred over the thoracodorsal vessels as the arteries are larger in caliber and a better size match to the DIE pedicle vessels and are more superficially and centrally located making microsurgical vascular anastomosis technically easier and allowing improved flap positioning.
- The mastectomy skin flaps must be retracted sufficiently to expose the third intercostal space adjacent to the sternum and to allow the operating microscope a line of sight to this area perpendicular to the chest wall. The mastectomy incision may have to be lengthened to achieve this exposure. A combination of Weitlaner retractors and fishhook elastic retractors or retaining sutures are used for this exposure (**TECH FIG 4A**). The tension,

pressure, and time of retraction of the mastectomy skin flaps should be minimized to minimize the risk of mastectomy skin flap necrosis.

- A small 3 × 5 cm trapezoidal flap of pectoralis major muscle is elevated off the underlying third intercostal space and reflected laterally (**TECH FIG 4B**). It is important to divide the origins of the pectoralis major muscle of this small flap far enough medially to expose the lateral border of the sternum at the third intercostal space.
- The perichondrium of the medial-most 2.5 cm of the third rib costochondral cartilage is incised in the shape of an “H” and opened like window shutters off of the cartilage using a freer elevator.
- A rongeur is used to remove the medial-most 2.5 cm of the third costochondral cartilage, being careful not to enter, tear, or avulse any of the underlying posterior perichondrium.
- Once the rib cartilage has been removed (**TECH FIG 4C**), the posterior perichondrium is incised at the lateral end of the exposure and divided from lateral to medial carefully avoiding injuring the internal mammary vessels, which are immediately deep to the posterior perichondrium.
- The internal mammary vein is medial to the internal mammary artery when there is only one vein (**TECH FIG 4D**).
- The posterior perichondrium and the third intercostal space soft tissue are excised and discarded.
- The internal mammary artery and vein are dissected free from each other, and the surrounding soft tissue from the second intercostal space (just superior to the excised third rib cartilage and perichondrium) inferiorly to the superior border of the 4th rib (see **TECH FIG 4D**).

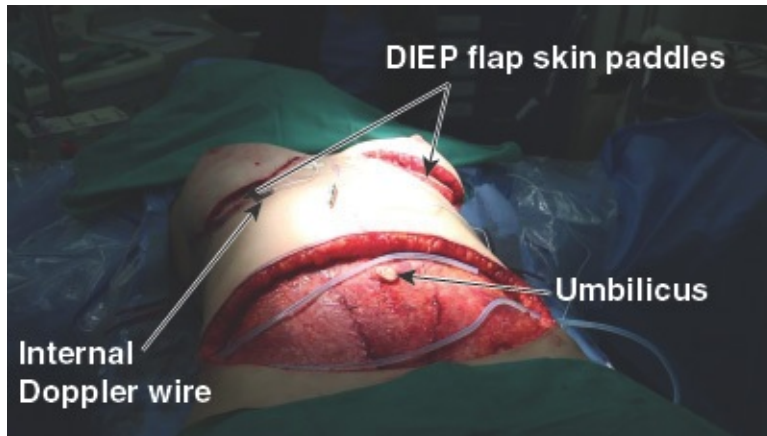


TECH FIG 4 • A. Exposure for left internal mammary recipient vessel preparation following nipple-sparing mastectomy via an inframammary incision. A Weitlaner retractor and suture are used for this exposure. The incisions along the lines of the muscle fibers to raise a laterally based flap of pectoralis major muscle are marked. **B.** Left internal mammary recipient vessel preparation. The trapezoidal flap of pectoralis major muscle overlying the third costochondral cartilage has been reflected laterally. **C.** Left internal mammary recipient vessel preparation. The left third costochondral cartilage has been removed with a rongeur, leaving the perichondrium. **D.** Left internal mammary recipient vessel preparation. The third rib perichondrium and portions of the second and third intercostal muscles have been removed. The left internal mammary artery and vein are exposed and dissected free circumferentially from the second intercostal space (ICS) down to the superior border of the fourth rib. IMA, internal mammary artery. IMV,

internal mammary vein. ICS, intercostal space.

■ Control of the Footprint of the Reconstructed Breast

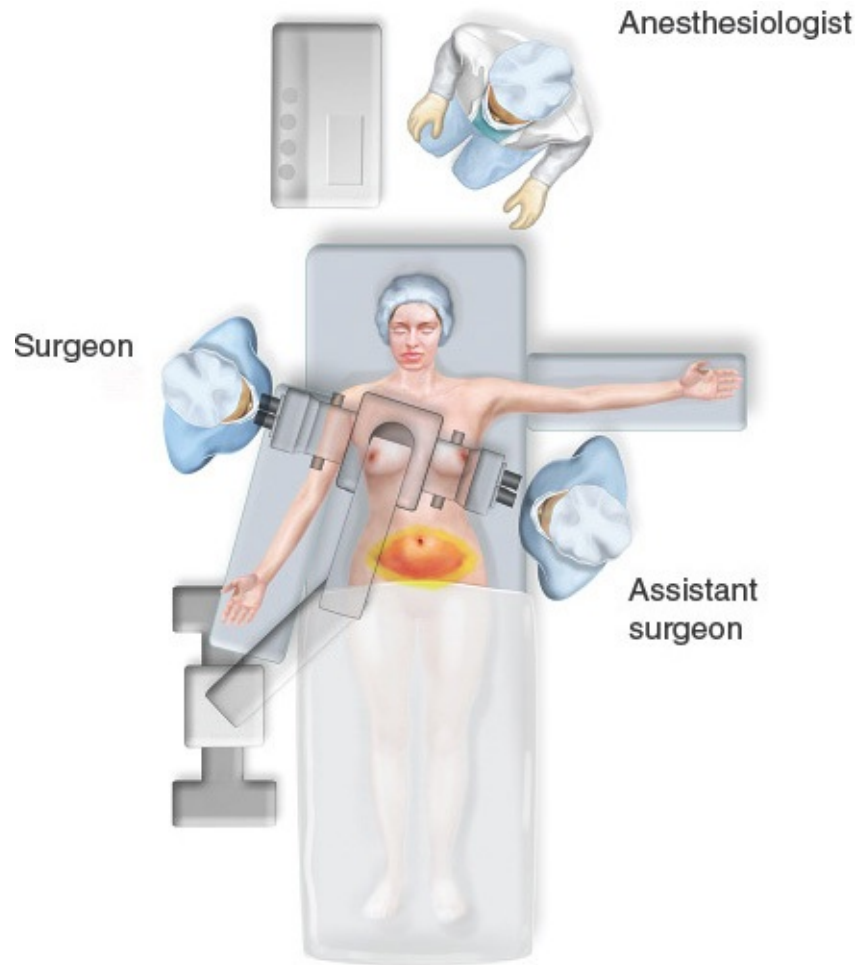
- Two 15 French fluted closed suction drains are exited from the chest wall lateral to the lower lateral border of the breast. One drain is placed along the inframammary fold (IMF) of the reconstructed breast, and the second drain is placed superficial to the pectoralis major muscle in the upper breast.
- The IMF is fixed in the desired position using three to four simple interrupted 2-0 PDS sutures placed through the pectoralis major muscle fascia and into rib periosteum.
- In delayed breast reconstructions, the skin and subcutaneous tissue lateral to the breast is dissected free from the underlying chest wall and axillary contents. In immediate reconstructions, this dissection will have been done by the breast surgeon performing the mastectomy.
- This lateral breast and subaxillary lateral chest wall skin and subcutaneous tissue is advanced anteriorly (in the anatomic position) and sutured into position using several simple interrupted 2-0 PDS sutures. If this is not done, this tissue tends to fall posteriorly and inferiorly, creating a roll of excess tissue, and/or the DIEP flap can migrate laterally into this space.
- The skin of the DIEP flap that is not needed is de-epithelialized while the flap is still in situ at the abdomen. This way, the flap does not need to be removed from within the mastectomy skin envelope once it is placed there.
- For immediate reconstructions with a nipple-sparing mastectomy, a small elliptical segment of skin paddle measuring 1.5×6 cm is kept to be brought out along the IMF (**TECH FIG 5**). For immediate reconstructions with a skin-sparing mastectomy, a 9-cm-diameter circular skin paddle in the middle of the DIEP flap is kept initially. Later, once the flap is transferred, a 5-cm-diameter skin paddle is made for future nipple reconstruction. For delayed breast reconstructions, only the lateral-most few cm of the DIEP flap is de-epithelialized while the flap is still in situ at the abdomen.



TECH FIG 5 • Abdominal donor site and flap inseting. The anterior rectus fascia is closed primarily, and two drains are placed at the abdominal donor site.

■ Harvest, Transfer, and Revascularization of the DIEP Flap

- The operating microscope is prepared, brought into position over the internal mammary recipient vessels, and adjusted (**TECH FIG 6**). Note that some surgeons use loupes only and do not use an operating microscope.
- The DIEP flap is harvested by ligating the DIE artery and vein(s) with metal clips and dividing them with scissors.
- The DIE artery and vein(s) are flushed with 2 cc each of 100 mg/mL heparinized saline.
- The flap is transferred to the chest wall and secured with two or three simple interrupted 3-0 Vicryl sutures to the chest wall skin if needed.
- The internal mammary vein (IMV) is ligated with a metal clip and divided with scissors. The microvenous anastomosis is created using a flow-coupler device. Most commonly, 2.5 or 3.0 mm diameter couplers are used for the larger right IMV, and 2.0 or 2.5 mm couplers are used for the smaller left IMV.
- The arterial anastomosis is completed after the venous microanastomosis. The IMA is ligated with a metal clip and divided with scissors. The IMA and DIEP flap artery are placed in a double approximating Acland clamp and the anastomosis completed with typically eight simple interrupted 9-0 nylon sutures.



TECH FIG 6 • Setup of the surgeon, assistant surgeon, and microscope for DIEP flap revascularization to the internal mammary recipient vessels at the chest. The ipsilateral patient arm is lowered so the surgeon can stand by the ipsilateral patient shoulder. The assistant surgeon stands below the contralateral abducted patient arm. This allows both surgeons to stand close enough to the microsurgical field and be 180 degrees apart to be able to simultaneously use a dual head operating microscope.

■ Insetting the DIEP Flap and Shaping a Breast

- It is important that the flap volume matches the footprint of the reconstructed breast and mastectomy skin flap volume. If the DIEP flap is not wide enough, or not large enough in volume to fill out the mastectomy skin envelope, it will leave a depression or hollow at the superomedial reconstructed breast. Suspending the flap to the superomedial mastectomy pocket with sutures will result in flattening of the flap and loss of projection of the reconstructed breast. Therefore, if the flap volume is inadequate to fill out the mastectomy pocket, it is best to reduce the perimeter of the reconstructed breast by elevating the IMF and closing down the lateral mastectomy pocket with 2-0 PDS sutures. See Section “Control of the footprint of the reconstructed breast” above.
- The thickest part of the flap, which is usually the vertical midline cut edge, is placed along the IMF. In other words, a right abdominal DIEP flap is turned 90 degrees clockwise to inset, whereas a left abdominal DIEP flap is turned 90 degrees counterclockwise to inset, for either the left or right breast. The DIEP flap is placed within the mastectomy skin envelope.
- The vascular pedicle, anastomoses, internal mammary vessels, and flow-coupler wire are examined by retracting the DIEP flap and carefully arranged to avoid kinks or twists.
- In immediate reconstruction with a nipple-sparing mastectomy, I leave a small skin paddle within the mastectomy incision. For an inframammary incision, I leave a 1.5×6 cm fusiform-shaped ellipse of skin within this incision (see **TECH FIG 5**). For a vertical infra-areolar incision, I leave a smaller, 1.5×3 cm fusiform-shaped ellipse of DIEP flap skin. Both of these small narrow skin paddles are usually excised at the revision/touch-up surgery done 3 or more months after the DIEP flap breast reconstruction.
- In immediate reconstruction with a skin-sparing mastectomy, I usually leave a 4.5 to 5 cm circular DIEP flap skin paddle to replace the excised nipple-areolar complex. This diameter allows future nipple reconstruction with a C-V flap entirely within the flap skin paddle, which will eventually be tattooed.
- The dermal edges of the DIEP flap are sutured to the mastectomy skin envelope with a single layer of inverted dermal 3-0 Monocryl and dressed with antibacterial ointment and Xeroform gauze. No brassiere or other dressings, or support, are used.

■ Closure of the Abdominal Donor Site

- The anterior rectus fascia is closed with buried interrupted figure-of-eight 0 PDS sutures. The rectus abdominis muscle is not sutured (see **TECH FIG 5**).
- The upper abdominal skin and subcutaneous tissue flap is elevated off the fascia for several cm superiorly. It is not necessary to elevate this all the way to the xiphoid process.
- Fluted 15-Fench round drains are brought out from each end of the abdominal donor-site incision and secured with 2-0 nylon sutures. The left drain is placed transversely along the lower donor site, and the right sided drain is placed transversely across the upper donor site, superior to the umbilicus (see **TECH FIG 5**).
- The head and back of the patient are raised sufficiently to be able to close the donor site without excessive tension. With the patient flexed at the hips, the bed is placed in Trendelenburg to bring the back of the patient parallel to the floor.
- The upper and lower abdominal skin flaps are closed with multiple simple interrupted 2-0 clear PDS sutures to reapproximate the superficial fascia and subcutaneous fat. The skin is closed with a running subcuticular 2-0 Monoderm Quill suture.
- A 20 × 8 mm ellipse of skin and underlying cylindrical core of fat are excised from the upper abdominal skin flap overlying the umbilicus. The umbilicus is brought out through this hole, and inset using multiple inverted dermal 4-0 Monocryl sutures.
- The umbilicus and abdominal donor-site incision are dressed with antibiotic ointment, Xeroform gauze, dry sterile gauze, and tape.

PEARLS AND PITFALLS

Perforator selection

- Lateral row perforators, in general, have a more direct course through the rectus abdominis muscle to the DIE pedicle and are easier to dissect, compared to medial row perforators, which often run diagonally through greater amounts of the rectus abdominis muscle. The largest perforators are more commonly in the medial row, but medial row perforators are not required, unless a DIEP flap including tissue across the midline is being harvested.

Congested

- Occasionally, a DIEP flap will become venous congested during

flap during harvest	flap harvest, while still in situ at the abdomen. If this is mild, it will often resolve over 1–2 hours as venous interconnections within the flap “open up” and venous outflow redistributes.
Venous insufficiency	■ Venous insufficiency, manifest by venous congestion of the DIEP flap, is more common and more difficult to detect than arterial insufficiency. I recommend using an internal venous Doppler probe, especially one where the Doppler probe is integrated into a venous anastomotic coupling device. You cannot leave the operating room if the flap skin paddle is at all blue in hue and has less than 1-second capillary refill. This is venous congestion and must be addressed. On the other hand, a free flap can appear very pale, and without detectable capillary refill, as long as there is an arterial Doppler flow signal present.
Insetting	■ Set the perimeter/footprint of the reconstructed breast, and de-epithelialize the DIEP flap before transfer, so that the flap is placed within the mastectomy skin envelope only once, and does not have to be removed for de-epithelializing the periphery or adjusting the perimeter of the mastectomy pocket. This will avoid the risks of taking the flap in and out of the mastectomy skin envelope, and it will save time.
Flap orientation	■ A typical DIEP flap pedicle is long enough to allow the ipsilateral or contralateral flap to be used to reconstruct a breast. All else being equal, it is advantageous to use an ipsilateral flap, especially in delayed breast reconstruction, because this places the least well-perfused tissue, and most likely portion to suffer partial flap loss or fat necrosis, at the lateral and inferior region of the reconstructed breast.
Postoperative	■ No postoperative anticoagulation regimen has been proven more effective than others. I give patients 325 mg of aspirin daily while they are inpatients starting as soon as the patient is awake enough to swallow. I also give patients 40 mg of low molecular weight heparin subcutaneously daily while they are inpatients, starting at 5 PM on the 1st postoperative day.

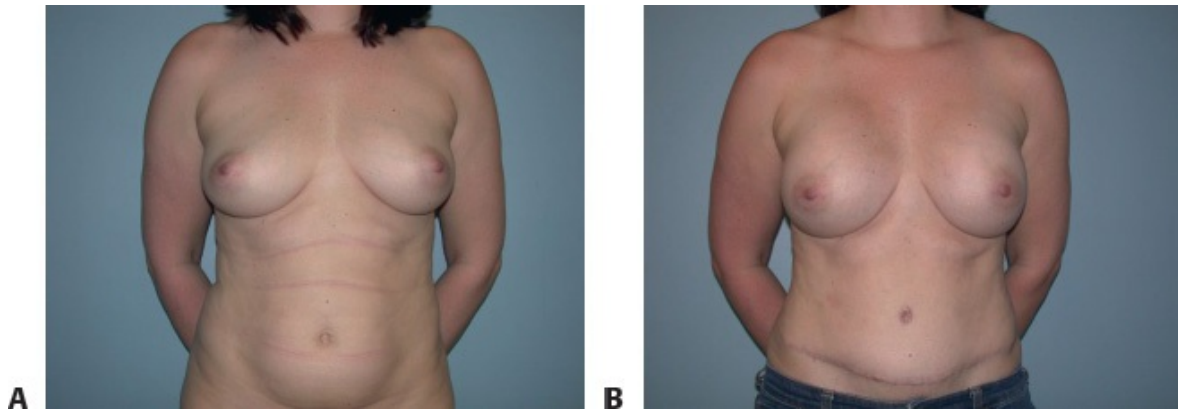


FIG 4 • A. Preoperative frontal view of patient shown in **FIG 2** and **TECH FIG 6**. **B.** Postoperative frontal view of patient shown in **FIG 2** and **TECH FIG 6**, 8 months after bilateral nipple-sparing mastectomies, and bilateral immediate breast reconstruction with DIEP flaps. Bilateral 190-cc smooth silicone implants were added to augment the reconstructed breast volume.

POSTOPERATIVE CARE

- Patients have perfusion of the DIEP flap monitored hourly for the first 24 hours and then every 2 hours for the next 48 hours by the nurses.
- Patients are not allowed to eat or drink, except for ice chips to moisten their mouths, until viability of the DIEP flap is confirmed on the morning of the 1st postoperative day, at which time a regular diet is allowed.
- Patients are given aspirin 325 mg orally daily starting immediately postoperatively and as long as they are inpatients.
- Patients are given 40 mg of low molecular weight heparin subcutaneously daily starting at 24 hours after completion of the surgery.
- On the morning of the 1st postoperative day, patients transfer with assistance from their bed into a chair for 15 minutes to 3 hours.
- On the 2nd postoperative day, patients ambulate with assistance outside of their hospital room at least once.
- On the 3rd postoperative day, intravenous fluids and the Foley catheter are discontinued in the morning, and patients are asked to ambulate with assistance outside of their hospital room at least three times.
- Starting of the 3rd postoperative day, patients are asked to shower and wash all

surgical sites with soap and water daily.

- Some patients are discharged home in the afternoon of the 3rd postoperative day. Most patients are discharged home on the 4th postoperative day.
- Patients are asked not to wear a brassiere, not to sleep prone or on their sides, and not to raise their elbows higher than their shoulders for the first 2 weeks after surgery.
- Patients are asked not to submerge any surgical wound underwater (so no bathtub, hot tub, or swimming) and not to perform any activity which causes impact, or jarring of their body, for 4 to 5 weeks postoperatively.
- Patients are given prophylactic intravenous antibiotics as long as they have an I.V. in the hospital, and then Bactrim DS twice daily until removal of the last drain.
- Drains are removed once the output has fallen to less than, or equal to, 30 mL/d, for 2 consecutive days. Occasionally, one or two drains are removed before discharge from the hospital. Typically, some of the drains are removed at the first office visit 5 to 10 days after discharge from the hospital, and the remaining drains are removed at the second postoperative office visit 1 week later.
- An outpatient surgery to improve reconstructed breast shape and symmetry, repair abdominal donor-site dog-ears, and for nipple reconstruction is typically done, at the earliest, 3 months after the initial DIEP flap reconstruction surgery.

OUTCOMES

- Autologous tissue flaps from the lower abdomen are capable of producing the best, long-lasting, and most maintenance-free reconstructed breasts of any method of breast reconstruction.¹
- A reconstructed breast, which looks and feels like a natural breast, can be achieved with a DIEP flap and nipple-sparing mastectomy done via an inframammary incision (**FIG 4**).

COMPLICATIONS

- With experience, the DIEP free flap loss rate, and emergent take-back rate, should be at or below 1% and 5%, respectively.
- Partial flap loss and fat necrosis are more common in obese patients and patients who smoke. Both of these are usually managed nonoperatively.
- A true hernia at the abdominal donor site is exceedingly rare, with a frequency of a fraction of a percent of patients.

- A lower abdominal bulge, to some degree, occurs in about 5% of patients. Abdominal bulges are not a health risk and are repaired if the patient desires by plication and polypropylene mesh overlay.
- The most common reasons for emergent take back are venous insufficiency/congestion of the DIEP flap and hematoma at the reconstructed breast. Venous congestion can cause a hematoma secondarily and can be mistaken for a hematoma by the inexperienced surgeon. A breast hematoma does not cause venous occlusion of the DIEP flap pedicle or anastomosis, but can result from venous congestion.

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Abdominal Breast Reconstruction Using a SIEA Flap Approach

CHAPTER

Adrian S. H. Ooi, Deana Shenaq, Julie E. Park, and David H. Song

DEFINITION

- Abdominal-based flaps for breast reconstruction can be divided into pedicled and free flaps based on their arterial supply.
 - Pedicled
 - Transverse rectus abdominis myocutaneous (TRAM) flap
 - Free
 - TRAM flap
 - Muscle-sparing TRAM (MS-TRAM) flap
 - Deep inferior epigastric perforator (DIEP) flap
 - Superficial inferior epigastric artery (SIEA) flap
- The free TRAM, MS-TRAM, and the DIEP flaps are based on a deep inferior epigastric vascular pedicle arising directly from the external iliac vessels.
 - In the free TRAM flap, the entire width of rectus muscle is taken to capture all the perforators within that segment.
 - In the MS-TRAM flap, a cuff of rectus muscle is harvested to capture multiple perforators from the deep inferior epigastric pedicle.
 - In the DIEP flap, only the perforating vessels to the subcutaneous fat and skin are harvested and the rectus muscle is not sacrificed.
- The SIEA flap is based on the subcutaneous superficial inferior epigastric vascular pedicle arising from the femoral vessels in the femoral triangle. Harvest of the flap does not involve any rectus muscle or fascia.

ANATOMY

- The SIEA flap is a Mathes and Nahai fasciocutaneous type A flap, harvested from the lower abdomen.
- The skin island for the SIEA flap extends laterally to the anterior superior iliac spine (ASIS), medially to the midline or just past it, and from the level of the umbilicus superiorly to the pubic tubercle inferiorly.
- Vascular anatomy
 - Arterial
 - The SIEA is a branch of the femoral artery and arises from the femoral artery 2 to 3 cm below the inguinal ligament (**FIG 1**).
 - It is present in 49% to 91% of patients.^{1,2}
 - The average size of the SIEA is 1.2 to 1.6 mm and average length 4 to 6 cm.³
 - It is present in both groins in 58% of patients.⁴

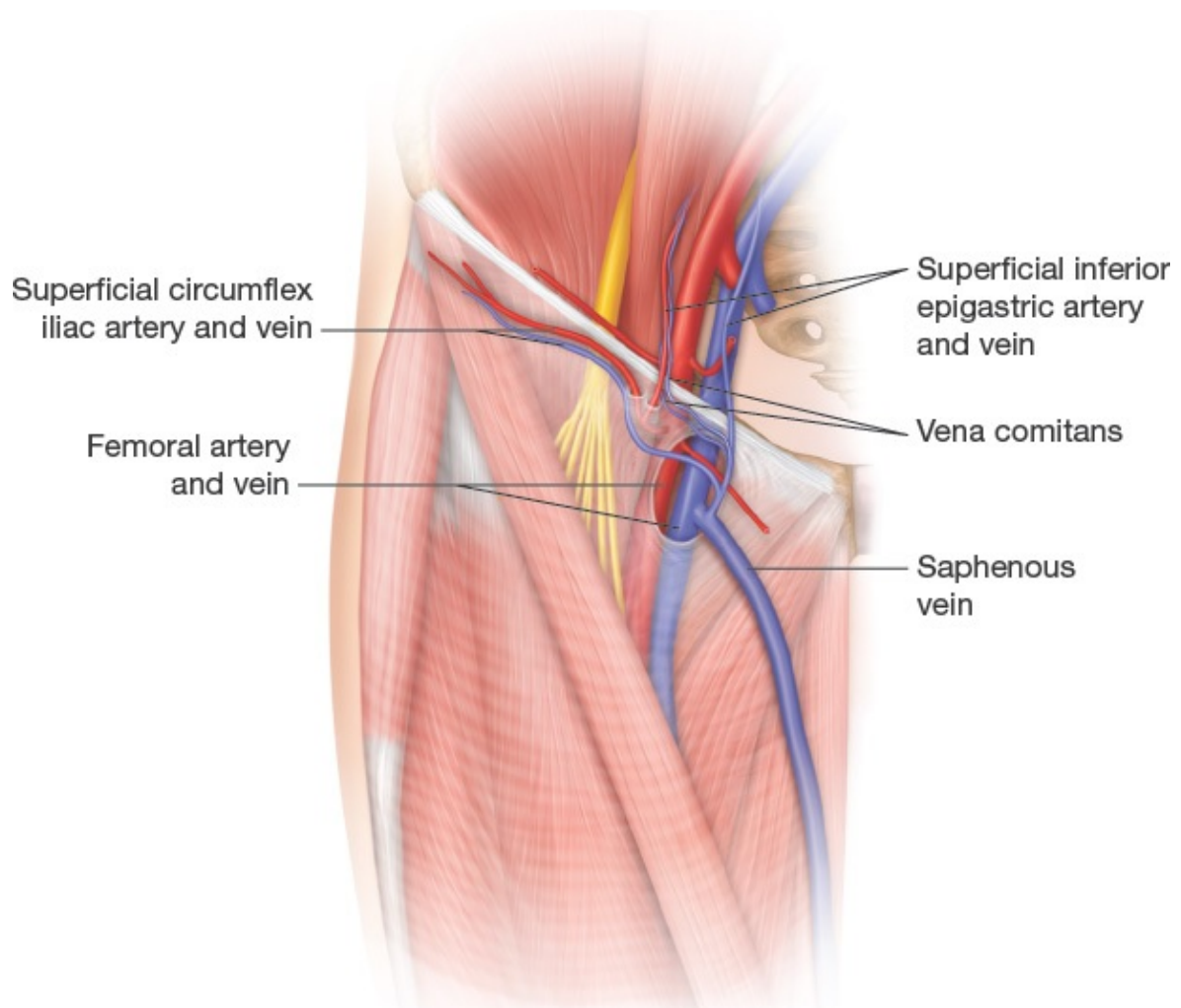


FIG 1 • Vascular anatomy of the superficial inferior epigastric system.

- In about 75% of cases, it arises from a common origin with the superior circumflex iliac artery (SCIA).⁵
 - The course of the artery is variable in relation to the superficial inferior epigastric vein (SIEV), usually arising up to 3 cm lateral to the SIEV and deep to the Scarpa fascia.
 - After piercing the cribriform fascia, the SIEA courses inferolaterally for a short distance immediately above the deep fascia.
 - It runs in a superolateral direction before crossing the inguinal ligament at roughly the midpoint between the pubic tubercle and the ASIS.
 - The SIEA then pierces the Scarpa fascia to run in the superficial fatty layer of the abdomen before arborizing with the periumbilical perforators of the deep inferior epigastric artery.
- Venous drainage
- The venous drainage of the flap is through up to two venae comitantes of the epigastric artery and/or the SIEV (see **FIG 1**).
 - Diameter: 1.3 to 4 mm¹
 - The surface marking of the SIEV is one-third of the way between the pubic symphysis and the ASIS.
 - The SIEV directly drains the subcutaneous plexus and is usually located superficial and medial to the SIEA in the superficial fatty layer of the abdomen.
 - The venae comitantes of the SIEA typically drain into SIEV.⁶
 - Occasionally, the superficial circumflex iliac vein (SCIV) and SIEV join into a common branch before draining into the femoral vein and if taken together can be used to enhance venous drainage of the flap (**FIG 2**).
- Flap vascular territory
- The literature consists of varying reports using different measurement parameters stating flap perfusion can range from the hemiabdomen to 100% of the entire abdominal flap.^{1,2,6}
 - We have found harvesting of the tissue across the midline to be unreliable, and would not advocate going past the hemiabdomen without testing perfusion either clinically with clamping off all other vascular input on the

contralateral side or utilizing intraoperative fluorescence imaging.

- The flap receives sensory innervation via the segmental intercostal nerves T10-T12.

PATHOGENESIS

- Breast defects requiring SIEA flap reconstruction can be partial or total mastectomy defects and can arise from a variety of pathologies including:
 - Postcancer resection

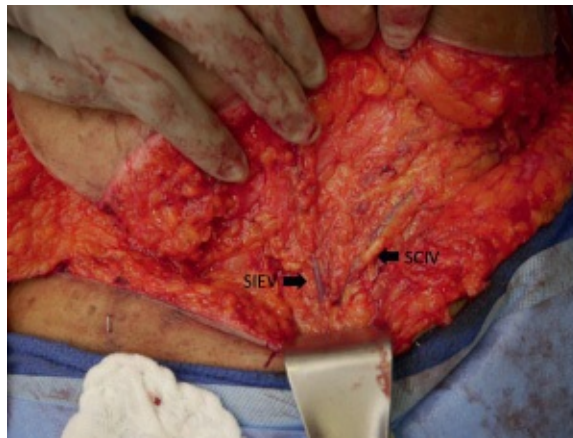


FIG 2 • The left superficial inferior epigastric (SIEV) and superficial circumflex iliac veins (SCIV) draining into a common branch.

- Prophylactic resection
- Failed implants
- A single large mastectomy defect may require a complete abdominal flap for coverage. An SIEA flap can be used together with the contralateral SIEA, DIEP, or MS-TRAM flap.
- The SIEA flap has been used for coverage of other defects including:
 - Head and neck
 - Upper extremity and hand
 - Lower extremity

NATURAL HISTORY

- Holmström reported the first use of a free abdominoplasty flap based on the deep inferior epigastric vessels in 1979.⁷

- Hartrampf pioneered the use of the pedicled TRAM flap for breast reconstruction in 1982.⁸
- While sacrificing rectus muscle, the free TRAM gained increasing popularity for breast reconstruction due to the use of the dominant blood supply to the rectus muscle, the deep inferior epigastric pedicle, to perfuse the abdominal tissue. It also allowed for more freedom in inseting and shaping the breast.⁹
- To minimize donor-site morbidity from harvest of the rectus muscle, the free MS-TRAM and DIEP flaps were developed following improvements in microsurgical knowledge and technique. Varying amounts of rectus muscle are left behind after harvest to maintain abdominal wall integrity and strength.
- Further evolution of the abdominal tissue flaps led to the development of the SIEA flap. The flap, first used by Antia and Buch for facial reconstruction in 1971 and further elucidated by Taylor and Daniel in their cadaveric studies of 1975, is based on a subcutaneous pedicle and completely spares the rectus fascia and muscle. Grotting first reported on its use in breast reconstruction in 1991, and owing to its obvious donor-site benefits has rapidly gained popularity ever since.^{10–12}

PATIENT HISTORY AND PHYSICAL FINDINGS

- A focused history and examination relevant to any form of free flap reconstruction should be performed. In particular, the following should be elucidated and corrected if possible:
 - History of tobacco use
 - Obesity
 - Previous irradiation
 - Prothrombotic conditions
 - Anticoagulant use
- Similar criteria are applied to the SIEA flap as when determining the suitability of a patient for a free DIEP, MS-TRAM, or TRAM.
 - Sufficient redundant lower abdominal skin and fat
 - Approximates final desired breast volume
 - Allows for primary donor-site closure analogous to an abdominoplasty
 - Abdominal scars
 - Transverse lower abdominal scars such as in a Pfannenstiel incision may preclude the use of the SIEA or even deep inferior epigastric pedicles.
 - Midline laparotomy scars limit the abdominal tissue use to a single

hemiabdomen as the perfusion across the midline is no longer reliable.

IMAGING

- Though not essential, several preoperative investigative techniques can be used to elucidate the vascular anatomy of the abdominal flap.
 - Doppler ultrasound
 - Can be used pre- and intraoperatively to locate perforators and pedicle position.
 - Used postoperatively for flap monitoring
 - CT-angiogram and MR-angiogram
 - Used preoperatively to elucidate location of abdominal perforators and the route of the source vessels
 - Can be used to select cases where the SIEA is suitable for use
 - Fluorescence imaging
 - Intraoperative administration of ICG via a peripheral vein after the hemiabdominal flap has been isolated on its pedicle and imaging with an infrared camera can help to assess the flap vascular territory.

DIFFERENTIAL DIAGNOSIS

- Reconstructive options for breast defects include but are not limited to:
 - Implant-based reconstruction +/- acellular dermal matrix
 - Immediate implant
 - Primary expander with implant exchange
 - Expander-implant
 - Pedicled flaps
 - Latissimus dorsi (LD)
 - TRAM
 - Free flaps
 - LD
 - TRAM
 - MS-TRAM
 - DIEP
 - SIEA
 - Superior gluteal artery perforator (SGAP) flap
 - Inferior gluteal artery perforator (IGAP) flap

- Gracilis muscle–based flaps
- Anterolateral thigh
- Pudendal artery perforator (PAP) flap
- Lateral thigh perforator (LTP) flap

SURGICAL MANAGEMENT

- Options of breast reconstruction should be tailored to each individual patient based on her disease process, adjuvant treatment, body habitus, and personal preference.
- Although implant-based breast reconstruction provides an expeditious reconstructive option, it is associated with implant-related complications as well as aesthetic outcomes which can be below expectations, especially in the setting of postoperative radiotherapy.
- We consider implant-based reconstruction in these scenarios:
 - The patient refuses autologous tissue use or has no autologous options.
 - Bilateral mastectomies
 - No postreconstructive radiation planned
 - Patient is unable to tolerate prolonged surgery.
- Abdominal tissue-based breast reconstruction has been the standard for the past few decades. Whether used in an immediate or delayed setting, it is associated with better aesthetic outcomes and higher rates of patient satisfaction.¹³
- The TRAM, MS-TRAM, and DIEP have been described in detail in other chapters, and owing to the variability of the SIEA remains the workhorse of abdominal tissue transfer options.
- However, in the instances when an SIEA flap can be used, there is decreased donor-site morbidity, an expedited harvesting, and similar aesthetic outcomes.

Preoperative Planning

- Indications
 - Patients desiring breast reconstruction with autologous tissue and having sufficient abdominal skin and fat without limiting abdominal scars.
- Flap selection
 - If the internal mammary (IM) vessels are used as recipients, a contralateral SIEA flap is used. This allows the short pedicle to be positioned at the internal IM vessels once the flap is placed in the breast pocket. If anastomosis to the

thoracodorsal (TD) system is planned, an ipsilateral SIEA flap is used (**FIG 3**).

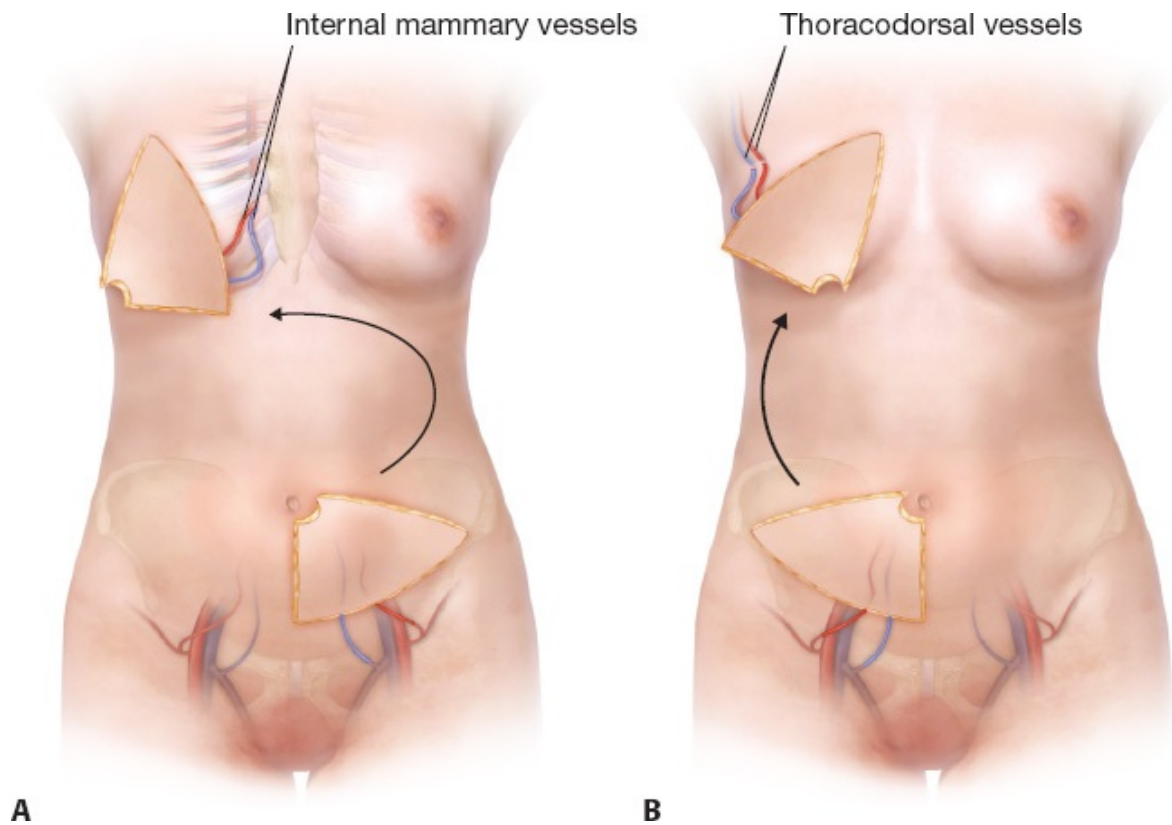


FIG 3 • A. If anastomosis to the internal mammary vessels is planned, a contralateral SIEA flap is used. **B.** If anastomosis to the thoracodorsal system is planned, an ipsilateral SIEA flap is used.

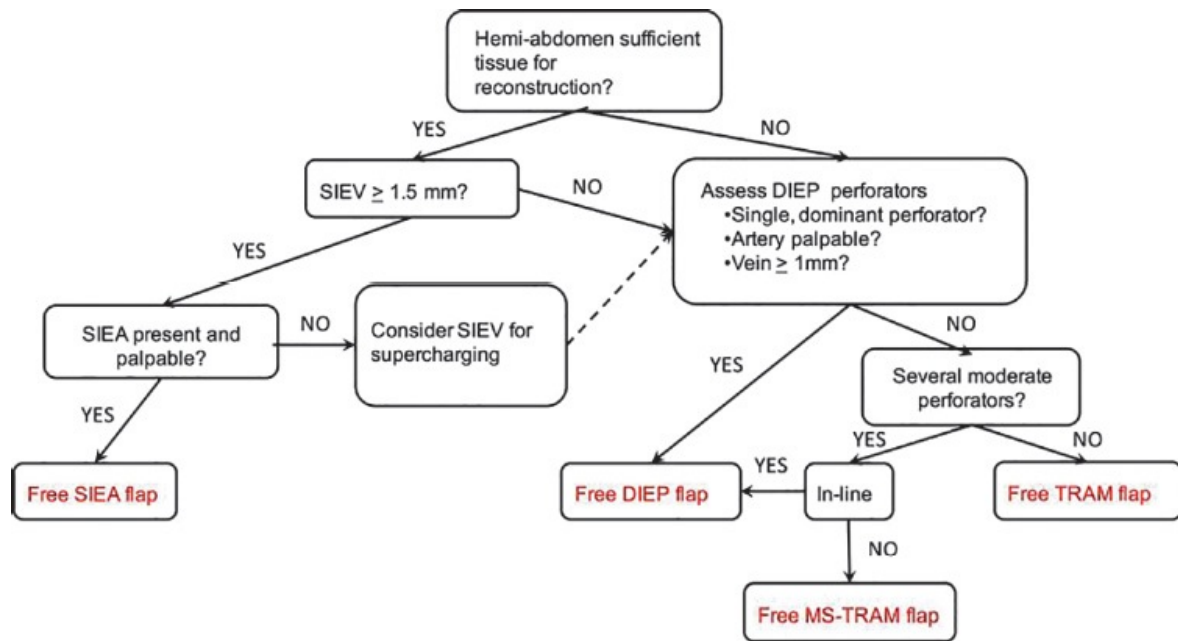


FIG 4 • Our decision-making algorithm for free abdominal flap breast reconstruction.

- We base our selection of SIEA flap reconstruction based on a simple intraoperative algorithm (**FIG 4**).
 - Assess the SIEV
 - If the SIEV is present and ≥ 1.5 cm, then the SIEA is assessed.
 - Assess the SIEA
 - If the SIEA pulsation is palpable and a hemiabdomen is sufficient for reconstruction, then a SIEA flap is used.
 - If the SIEA is not present or palpable, then a DIEP or MS-TRAM is performed.
- Many authors have used the caliber of the SIEA to as a criterion of suitability for the SIEA flap. In our experience, if the SIEA is palpable at the incision and the SIEV is ≥ 1.5 cm, the SIEA flap can be used even if the SIEA artery is less than 1 mm. In our consecutive series of 500 abdominal-based flaps, we have found the SIEA to be of use in 123 cases (29%).¹⁴
- We do not advocate the routine use of preoperative imaging for SIEA flap reconstruction.
- Marking
 - Patient marking is similar to that of the DIEP and free TRAM, with the lateral borders of the abdominal ellipse ending at the right and left ASIS (**FIG**

5).

- The superior transverse incision of the abdominal ellipse is designed to include the periumbilical perforators.
- The major difference is the location of the inferior incision of the transverse ellipse. To encounter the SIEA at a larger caliber and optimize it as an option, it is recommended to lower the inferior incision, and we frequently mark this 5 cm above the mons pubis.

Positioning

- Positioning is similar to the free DIEP and TRAM.
- The patient is placed supine with hips positioned at the flex point of the operating table to enable a “jack-knife” position which aids in the closure of the abdominal incision.
- Calf compression pumps are placed for mechanical DVT prophylaxis.

Approach

- Intravenous antibiotics are given 30 minutes before skin incision.
- Whenever possible, the procedure is done by two teams, with one team harvesting the flap and the other preparing the recipient pocket and vessels.
- The IM vessels are the first choice for SIEA flap reconstruction. Use of the TD system leads to difficult microsurgical anastomosis and in cases where the SIEA pedicle is of insufficient length may necessitate vein grafts which increase the complexity of the procedure.

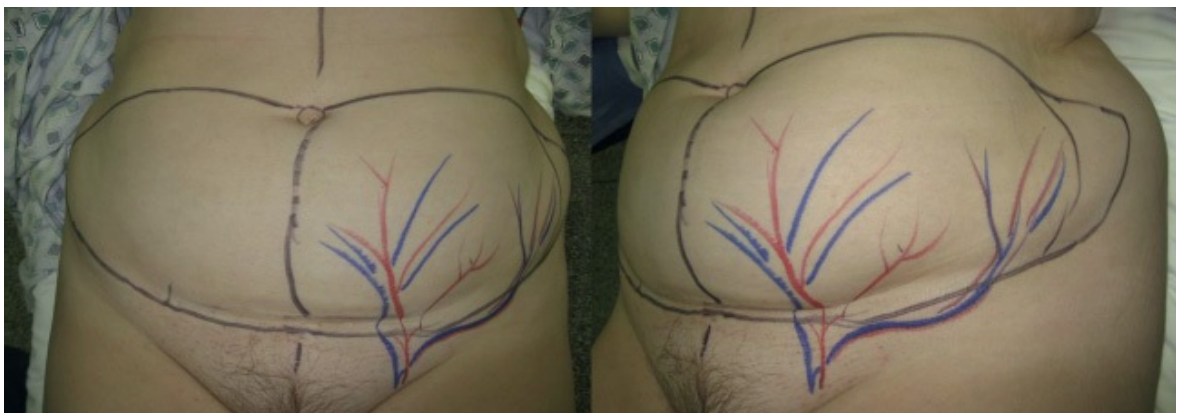


FIG 5 • Superficial inferior epigastric artery flap marking.

TECHNIQUES

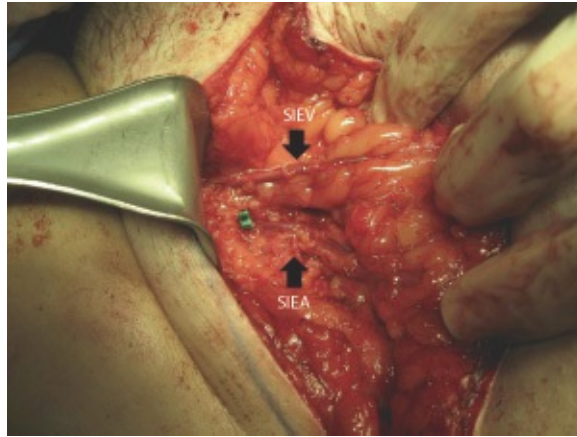
■ SIEA Flap

Incision and Exposure

- The lower incision is sharply incised, and careful dissection proceeds as the SIEA and SIEV are in the superficial fat layer of the flap. The SIEV in particular can be very superficial and lie just beneath the dermis (**TECH FIG 1**).
- The SIEV is located at approximately a point one-third between the pubic tubercle and the ASIS.
- The SIEA lies in an area up to 3 cm lateral to the SIEV and can be found deeper in the superficial fat compartment.
- The SIEV and SIEA are exposed and suitability determined as previously described. If suitable, the procedure proceeds with pedicle dissection.

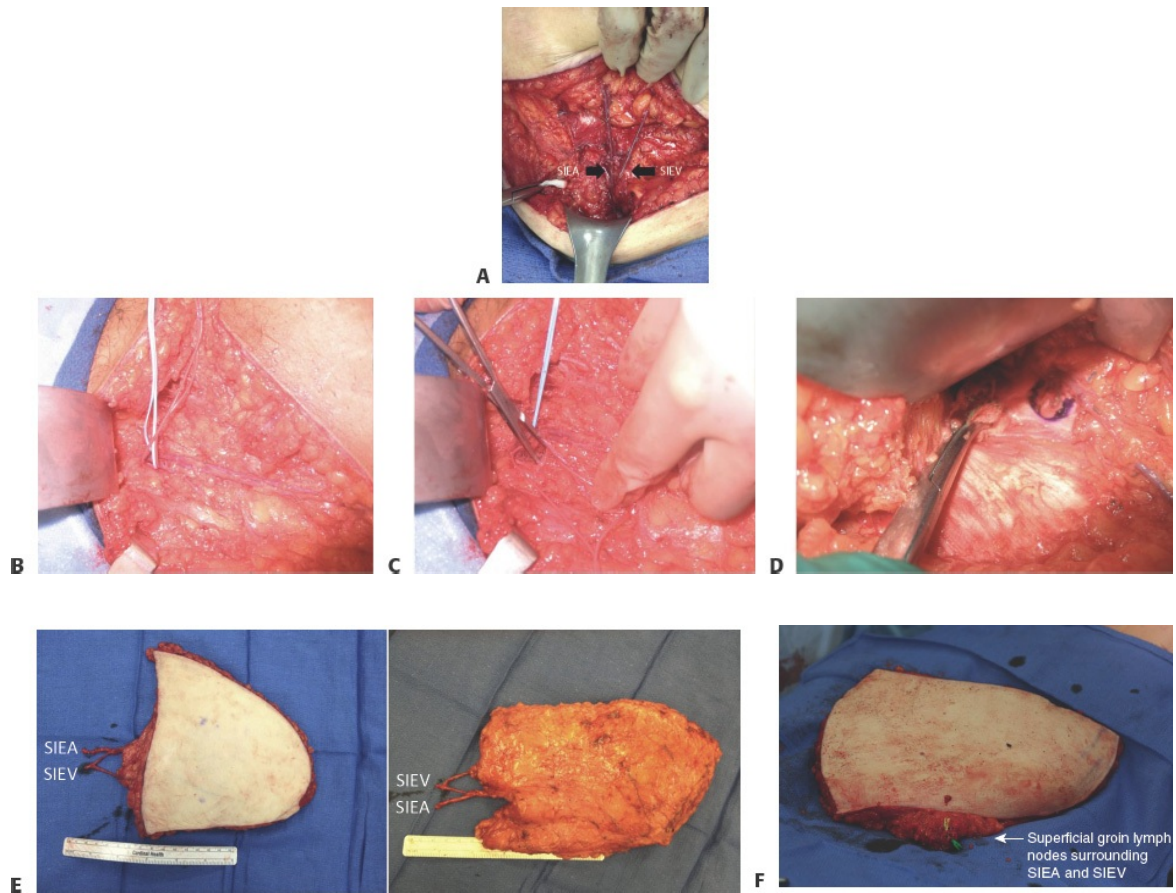
Dissection

- Anterior dissection of the pedicle proceeds initially without circumferential isolation. This protects the artery from traction injury and prevents spasm.
- Gentle cephalad retraction of the flap coupled with vertical retraction of the lower groin skin will give clear access to anterior dissection of the pedicle (**TECH FIG 2A**).
- The route of the SIEV is straightforward and it can be easily dissected caudally toward the femoral vein.
 - When the SCIV is identified at the lower lateral edge of the flap and can be traced to a common origin with the SIEV at the femoral vein, the common branch is taken. This helps to improve venous drainage of the flap (see **FIG 2**).
 - If more than one superficial vein is found draining the flap and entering into separate source veins, these should be dissected out and clamped prior to pedicle ligation to determine dominance.



TECH FIG 1 • Exposure of the SIEV and SIEA.

- The path of the SIEA from the flap to its origin at the femoral artery is more complex.⁶
 - The SIEA initially travels caudally from the flap.
 - Prior to entering the femoral sheath, the SIEA sharply turns superomedially.
 - To increase the length and caliber of the artery, the cribriform fascia should be fully opened and the vessel traced all the way to its origin at the common femoral artery. This increases SIEA length by 1 to 2 cm and yields a larger diameter vessel (**TECH FIG 2B-D**, Video 1).
 - Any branches close to the origin from the femoral artery are clipped long for potential use as a point at which to spatulate the artery to address size mismatch.
 - Caution should be taken in cases where the SCIA merges with the SIEA to form a common pedicle at the take-off from the femoral artery. In these cases, both the SCIA and SIEA can be taken together with the flap.



TECH FIG 2 • **A.** Dissection of the right SIEV and SIEA with cephalad retraction of the flap and vertical retraction of the lower groin skin. **B.** Dissection of the right superficial inferior epigastric artery (SIEA) to the cribriform fascia. **C.** Opening of the cribriform fascia to maximize exposure of the origin of the SIEA. **D.** Close up of the cribriform fascia outlined in *blue ink*. **E.** Completion of harvest a right sided SIEA flap. **F.** Harvest of the superficial groin lymph nodes lateral to the SIEV (*yellow microvascular clamp*) together with a left-sided SIEA (*green microvascular clamp*) flap.

- Once the anterior dissection is complete along the full length of the vessel, posterior dissection of the pedicle can proceed. This is done carefully to avoid traction on the vessels (**TECH FIG 2E**).
- Concomitant vascularized lymph node transfer (VLNT).

- The superficial groin lymph nodes lie lateral to the SIEV and can be harvested together with the pedicle (**TECH FIG 2F**). To avoid harvesting the deeper lymph nodes, which can lead to lower limb lymphedema, we recommend the use of reverse lymphatic mapping with radioisotope to identify the sentinel lymph node.¹⁵

Completion of Flap Harvest

- Once pedicle dissection is completed, harvest of the abdominal tissue proceeds.
- The superior incision is completed sparing the umbilicus, and the flap is dissected off the abdominal muscular fascia in the avascular plane.
 - Any intercostal perforators encountered along the way are carefully ligated.
- When dissection reaches the borders of the rectus muscle at the semilunaris, care must be taken to identify the DIEP perforators.
- If there is any question of SIEA perfusion of the flap, microvascular clamps can be applied to the DIEP perforators to assess the perfusion based upon the superficial system.
- Once it is determined that the flap can survive on the SIEA alone, the DIEP perforators are securely ligated.
- Because the SIEA has a short pedicle, we recommend de-epithelializing the majority of the flap in situ on the abdomen to avoid injuring the microanastomosis once the flap has been delivered to the mastectomy defect. This is especially important for larger flaps with the small aperture of a skin-sparing mastectomy.

Recipient Vessels and Microanastomosis

- Our order of choice of recipient vessels are:
 - Pulsatile IM artery (IMA) perforator with adequate IM vein (IMV) perforator
 - IMA and IMV—the rib can usually be spared with an intercostal space of 3 cm. We typically target the 2nd or 3rd intercostal space.
 - If lymph nodes are required in the axilla, or on the rare occasion where the internal mammary vessels are not available, the thoracodorsal system is used.
- If the flap pedicle is too short, vein grafts have to be used to prevent tension on the anastomosis.

- When there is significant vessel size mismatch between the IMA and the SIEA, manipulation via back cuts or spatulation can be performed. The back-cut on the antimesenteric side of the vessel allows for a technically easier anastomosis. Alternatively, if there are any distal branches, the pedicle could be spatulated at a branch point to increase vessel diameter.¹⁴ Finally, end-to-side anastomosis between the SIEA and the IMA has been described.
- The SIEV is usually of sufficient size and there is rarely any mismatch with the IMV. Use of a venous coupler usually facilitates any venous anastomosis size mismatch and short pedicle. We hand sew the vein if the SIEV is greater than 4 mm in diameter as use of a coupler can cause redundancy of the thick SIEV within the lumen and cause occlusion.
- Overall, the SIEA is particularly prone to spasm and careful dissection, as well as minimizing the amount of anastomotic revisions, is paramount to successful execution of this flap.

Flap Inset

- The main issue when insetting the SIEA flap is the short pedicle length. Care must be taken not to cause traction on the vessels, especially in the setting of an immediate reconstruction with a skin-sparing mastectomy and small aperture.
- As mentioned previously, we perform the majority of flap de-epithelialization with the flap in situ in the abdomen before ligation of the pedicle and transfer. Any de-epithelialization performed with the flap in the chest must be undertaken with the utmost care. Remember the superficial nature of the SIEV when de-epithelializing, insetting, and securing the flap.
- Insetting the flap in the superomedial direction first takes the tension off the pedicle. The remainder of the mastectomy skin can then be carefully draped around the flap.
- The mastectomy skin envelope to flap relationship must be evaluated. If the flap is relatively small within a large skin envelope:
 - Reduce the skin envelope
 - Consider a contralateral breast reduction
 - Place anchoring sutures from the flap to the chest wall
 - Use external support such as a surgical brassiere that is fitted carefully to prevent compression while giving inferior and lateral support.
- A closed suction drain is placed exiting at the lateral IMF and draining the superior portion of the flap, ending just away from the microanastomoses

site.

Donor Site Closure

- Donor-site closure is similar to that of the free DIEP and TRAM, except that the abdominal muscular fascia remains untouched and no closure of this is required.
- The upper abdominal flap is undermined to the border of the ribs laterally and the xiphoid process superiorly, being careful to ligate any significant perforators along the way.
- Once the microanastomosis is complete and de-epithelialization is complete and the flap has been secured in position in the breast defect, the operating table can be adjusted into a “jack-knife” position with the patient’s hips flexed to allow tension-free abdominal closure.
- Skin staples are used to temporarily approximate the skin edges, usually requiring some adjustment from lateral to medial.
- Key to donor-site closure is approximating the Scarpa fascia from the upper and lower abdominal flaps with absorbable 2-0 polyfilament sutures. Once this is done, skin closure can be done with technique of choice. Abdominal closed suction drains should be used.

PEARLS AND PITFALLS

Preoperative preparation	■ Caution in patients who are heavy, active smokers for increased risk of vasospasm
Exposure	■ Lower the abdominal incision to encounter the SIEA at a larger caliber.
Pedicle dissection	■ Perform anterior rather than circumferential dissection of the artery first to minimize vasospasm. ■ Dissect the artery completely to the femoral artery. ■ Avoiding unnecessary periarterial lymph node harvest increases pedicle length.
Raising the flap	■ De-epithelialize the flap in situ on the abdomen.
Microanastomosis	■ Maximize recipient vessel length. ■ Back-cut or spatulate the SIEA for cases where there is

	vessel mismatch.
	■ Intraoperative papavarine is useful to address any arterial spasm.
Inset	■ Careful support of the flap to prevent ptosis
Postoperative care	■ Keep the patient warm and reduce pain and anxiety to prevent vasospasm.

POSTOPERATIVE CARE

- General care for the SIEA flap is similar to the postoperative care for other free tissue reconstruction of the breast. At our institution:
 - A near infrared (NIRS) tissue spectroscopy monitor is placed on the flap and the patient is sent to the postoperative care unit for a period of monitoring.
 - Once the patient is stable, she is sent to the floor. The flap is monitored clinically for color, temperature, capillary refill, turgor, and handheld Doppler signal as well as continuous tissue oximetry.
 - Incentive spirometry as well as chemical and mechanical DVT prophylaxis is started.
 - Patients are kept NPO for the approximately the first 24 hours. If the patient and flap are doing well by the first postoperative day (POD) morning, the diet is advanced after evaluation on morning rounds. The urinary catheter is removed and the patient is advised to sit out of bed in a chair and encouraged to ambulate later in the day. Intravenous antibiotics are converted to oral antibiotics after the first 24 hours.
 - POD 2 and 3 are spent with continuation of ambulation and converting all pain control to oral medications. Patients are usually discharged on POD 3.
- Specific considerations regarding the postoperative care of the SIEA flap center around arterial spasm, which can happen up to more than 48 hours postoperatively.
 - This can manifest in a variety of ways:
 - A clinically cool, pale flap
 - Absent Doppler signal
 - Steady drop in NIRS tissue spectroscopy of 15 to 20 points and leveling off
 - Arterial spasm can result from any combination of factors including:
 - Ptosis of the flap placing stretch on the vascular anastomosis
 - Patient pain and anxiety

- Dehydration
- Reduced patient core temperature
- Maneuvers to alleviate arterial spasm include the following:
 - A surgical brassiere can be placed to give support.
 - Adequate treatment of pain, warming, and antianxiolytics can be administered as necessary.
- If the spasm does not resolve after these measures, operative exploration is warranted.

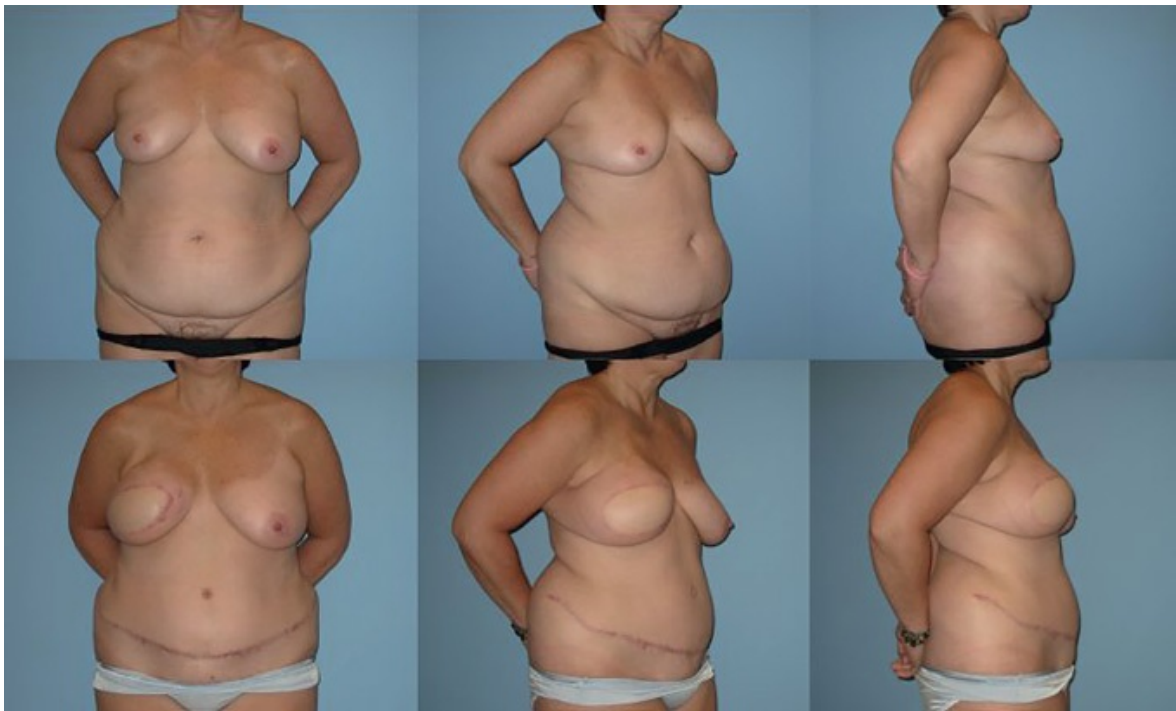


FIG 6 • Preoperative (*above*) and postoperative (*below*) photos of a right breast reconstructed with a left abdominal SIEA flap.

OUTCOMES

- The SIEA flap has similar aesthetic outcomes to the other abdominal-based flaps (**FIG 6**).
- There is a steep learning curve associated with the flap and high conversion rate to another free flap.¹⁶
- There are no risks of hernia or bulge because the rectus fascia and motor

nerves to the rectus muscles are not disturbed.

- In our series of 145 free abdominal flaps based on the superficial system, overall success rates were 95%.¹⁴

COMPLICATIONS

■ Vascular thrombosis and flap loss

- An analysis of 99 SIEA flaps performed in 82 patients showed an overall arterial thrombosis rate of 6.1%, venous congestion rate of 2%, partial flap loss of 5.1%, and total flap loss of 5.1%.¹⁷
- In an analysis of 69 SIEA flaps, the rate of venous or arterial thrombosis was 17.4%, with 2.9% total flap loss, significantly greater numbers than in a comparative DIEP flap group.¹⁸
- Another study of outcomes of 44 SIEA flaps against 125 DIEP flaps showed significantly higher re-exploration rates in the SIEA group (20%) vs the DIEP group (7%). A subset analysis showed arterial problems to be significantly higher among SIEA flaps (14%) vs DIEP flaps (1%). None of the arterial thromboses were salvageable.¹⁹
- In our series, there were nine cases of re-exploration for vascular problems (6.2%), three with purely venous thrombosis and six with arterial thromboses. Two of the flaps with venous thromboses were salvaged, whereas none of the flaps with arterial thromboses were salvaged. Eighty percent of the flaps with arterial thromboses lost had arterial revisions at the initial operation. SIEA spatulation did not correlate with increased thromboses rate.¹⁴

■ Fat necrosis

- In a large series of 99 free SIEA flaps, fat necrosis rates were found to be 1%. These authors routinely used tissue across the midline, discarding zone IV of the flap and any tissue assessed to have poor perfusion intraoperatively.¹⁷
- In a case series of 228 patients, it was found that the fat necrosis rates for free SIEA, DIEP, and MS-TRAM flaps were 14%, 25%, and 5%, respectively.²⁰
- A further systemic review of fat necrosis rates in abdominal free flaps reinforced this and showed the SIEA to have a mean fat necrosis rate of 8.1% (range 5.7% to 13.5%). This was lower than the free DIEP flap and slightly higher than the free MS-TRAM. Risk factors for necrosis included obesity, pre-existing abdominal scars, pre- and postoperative irradiation, and smoking.²¹
- In a more recent study of a single center's experience of SIEA flaps vs DIEP

flaps, the flap necrosis requiring debridement in the SIEA group was 14% (6/44 patients) vs 3% (4/125 patients) in the DIEP group.¹⁹

- An analysis of our series of 145 free flaps based on the superficial system, the fat necrosis rate was 10.3%.¹⁴

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24 Recipient Vessel Exposure —Internal Mammary and Thoracodorsal

CHAPTER

Theodore A. Kung and Adeyiza O. Momoh

DEFINITION

- Recipient vessels for microsurgical breast reconstruction are required to re-establish perfusion in transferred free flaps.
- Perfusion through these vessels is most critical early on after free tissue transfers, when flaps are entirely dependent on the recipient vessels for inflow and outflow. Over time, collateral perfusion is typically established from the surrounding soft tissue bed.
- The primary recipient vessels for breast reconstruction are the internal mammary and thoracodorsal vessels.

ANATOMY

Internal Mammary Vessels

- The internal mammary artery (IMA) is a paired artery on both sides of the sternum that arises from the subclavian artery. It transitions into the superior epigastric vessels at about the sixth intercostal space.
- The internal mammary vein (IMV) is also paired, runs parallel to the IMA, arising from the superior epigastric vein and ending in the brachiocephalic vein.
- The vessels are 1 to 2 cm lateral to the sternum and run deep to the intercostal muscles and ribs.
- Both vessels give off intercostal branches laterally that run inferior to the first six ribs. Perforators to the overlying breast and skin are also given off by the IMA and IMV in the first 5 to 6 intercostal spaces.

- The right and left IMAs are of similar diameter (1.9–2.1 mm) at 3rd and 4th intercostal spaces where they are typically used.^{1,2} At the level of the 3rd intercostal space, the IMA lies lateral to the IMV or between two IMVs.
- The left IMV bifurcates at a higher level than does the right IMV (3rd rib on the left vs 4th rib on the right). At the level of the 3rd ICS, the left IMV is on average smaller than the right (2.5 mm vs 3 mm).³

Thoracodorsal Vessels

- The thoracodorsal artery (TDA) and the circumflex scapular artery are the two main branches of the subscapular artery, which arises from the third division of the axillary artery (**FIG 1**).
- The TDA travels along the lateral thoracic wall before diving into the latissimus dorsi muscle about 9 cm from its origin. Prior to its entry into the muscle, the TDA consistently (99%) gives off a branch to the serratus anterior muscle.⁴
- The TD vessels are commonly divided for microvascular anastomosis just proximal to the serratus branch where the diameter of the artery is approximately 3 mm.⁵ Preservation of the serratus branch also allows for the use of a pedicled latissimus dorsi flap and an implant for breast reconstruction in case free tissue transfer is unsuccessful.

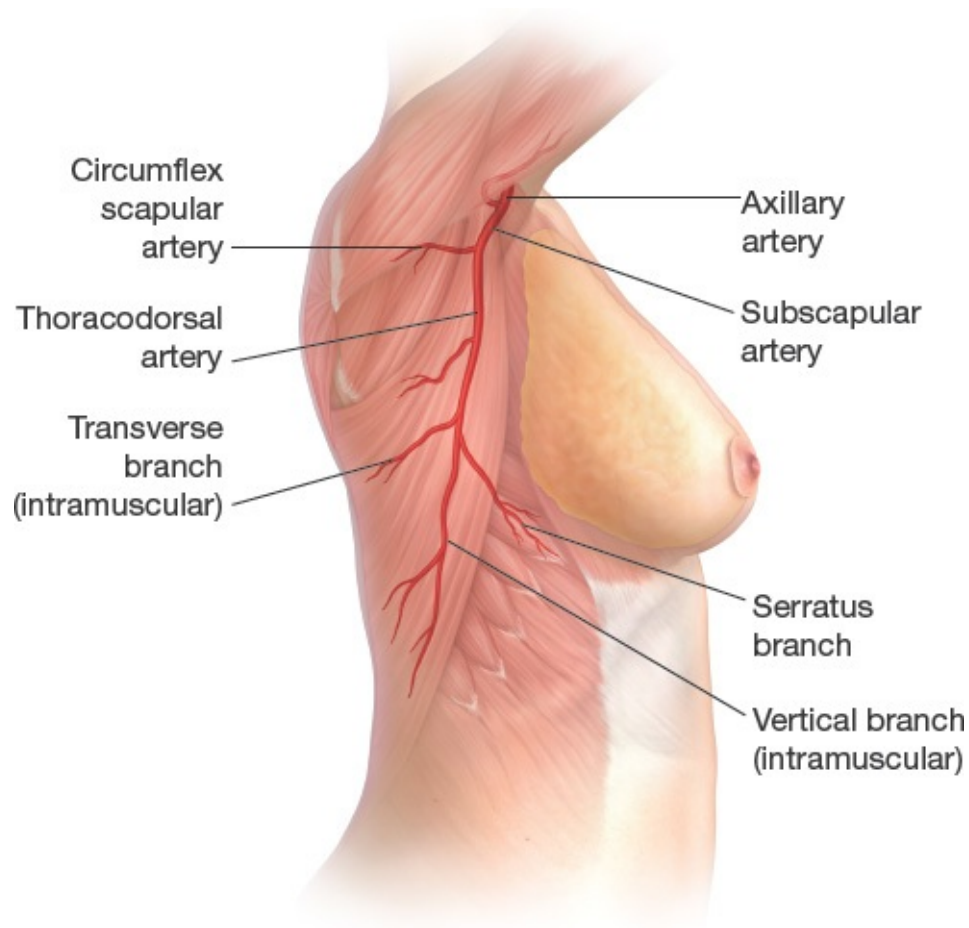


FIG 1 • Illustration of the thoracodorsal vessels arising from the subscapular system.

- Proximally, there are often two veins that unify into a single TD vein. The TD vein travels with the TD artery and has an average diameter of 3.4 mm at its origin and 1.6 mm where it enters the latissimus dorsi muscle.⁶
- The TD nerve enters the axilla deep to the axillary vein at a point several centimeters medial to the origin of the subscapular vessels. The nerve then continues toward the subscapular system and eventually travels parallel with the TD vessels along the lateral thoracic wall (**FIG 2**).

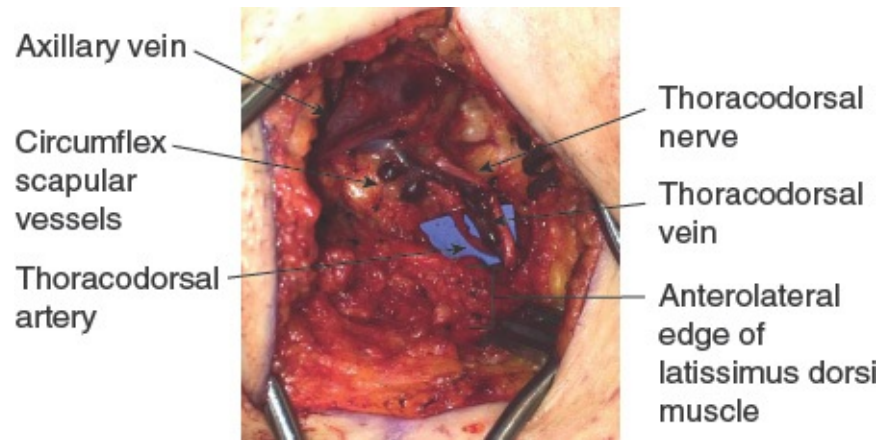


FIG 2 • Exposure of the thoracodorsal artery, vein, and nerve prior to their entry into the latissimus dorsi muscle. The nerve should be dissected free to prevent any kinking of the vessels after anastomosis.

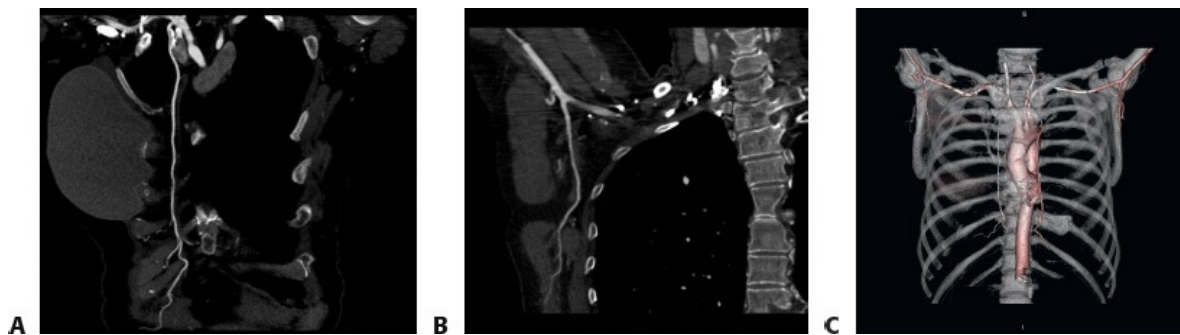


FIG 3 • **A.** A CT angiogram of the chest with sagittal slices showing continuity of the IM. **B.** TD arteries. **C.** Additional 3D reconstruction provides an overall view of the thoracic vessel anatomy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history of prior thoracic and breast procedures including axillary lymph node dissections and prior chest wall radiation are important to determine possible compromise to the IM or TD vessels.
- The continuity of IM vessels is seldom affected by oncologic breast procedures; however, a history of radical chest wall tumor resections or coronary bypass procedures may prevent use of the IM vessels as recipients.
- Thoracodorsal vessels are at greater risk of injury during axillary lymph node

dissections and should be approached with caution in the setting of delayed reconstruction in such patients.

- A history of radiation should prompt an anticipation of friable recipient vessels. IM vessel friability introduces technical challenges with exposure and anastomosis but can be consistently overcome with careful vessel handling.

IMAGING

- There is limited value to routine preoperative imaging of IM or TD vessels in the absence of a history that suggests potential compromise.
- If a patient has had a preoperative breast MRI, that status of the mammary vessels may be evident.
- When needed, CT angiography provides detailed information on the vascular anatomy for surgical planning (**FIG 3**).

SURGICAL MANAGEMENT

- The decision on which recipient vessel is to be used is made preoperatively. The internal mammary vessels are the authors' preferred option for immediate and delayed microsurgical breast reconstruction with the TD vessels serving as a backup option.
- If immediate reconstruction following mastectomy and axillary lymph node dissection is performed, the TD vessels are often already partially exposed and may be considered for anastomosis. However, the vessels must be carefully inspected for any injury or spasm resulting from the extirpation surgery. Additionally, the flap pedicle must be of sufficient length to reach the TD vessels for anastomosis.
- In contrast, with delayed breast reconstruction and especially following radiation therapy, significant scarring can be expected within the axilla. Dissection of the thoracodorsal vessels in this setting is usually more time-consuming and has a higher risk of vessel injury.

Preoperative Planning

- The risks and benefits of costal cartilage resection with IM vessel exposure should be discussed in addition to the rare potential for a pneumothorax during vessel exposure.

Positioning

- When the IM vessels are selected for anastomosis, the patient is positioned

supine with arms either tucked at the sides or abducted at 90 degrees.

- When the TD vessels are used, the ipsilateral arm should be prepped to allow for adjustments in position during the operation. The arm boards should be kept under sterile drapes in order to adjust arm abduction during the operation. It is most ergonomic for the surgeon to be positioned above the arm board on the side of the anastomosis while the assistant is positioned below the contralateral arm board (**FIG 4**).

Approach

- IM vessels are either exposed with costal cartilage resection or in the intercostal space through a rib-sparing approach. The former is the authors' preferred approach.

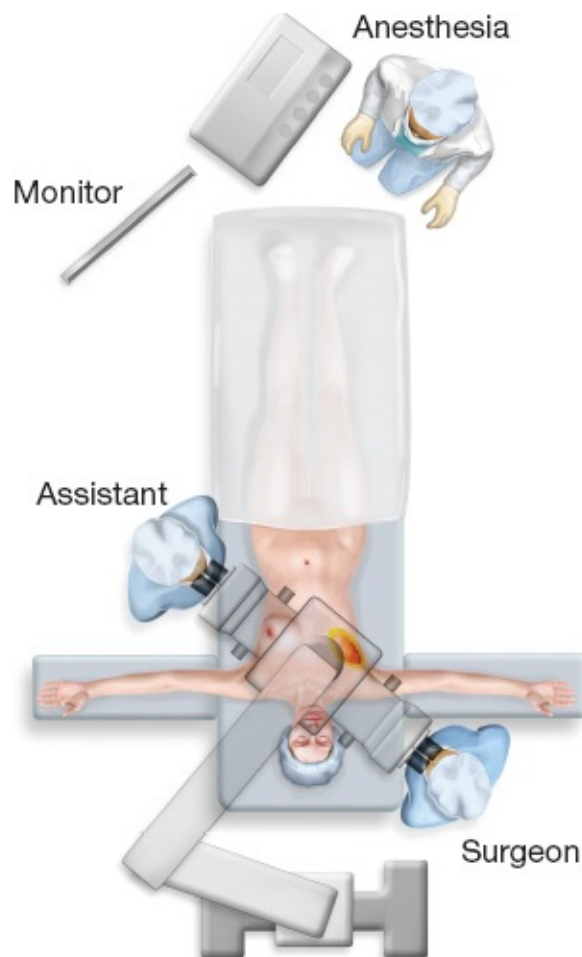


FIG 4 • Ergonomic surgeon and assistant positioning with use of the TD vessels as recipients.

- TD vessels may be accessed through the mastectomy incision. From this approach, adequate exposure is often difficult and requires retraction of the lateral border of the pectoralis major muscle or the use of additional instruments.⁷ Alternatively, the authors favor a separate incision in the axilla. In many breast cancer patients, a previous scar from sentinel lymph node biopsy may already be present. Slight abduction of the arm and the use of self-retaining retractors facilitate microsurgical anastomosis even in overweight patients.⁸

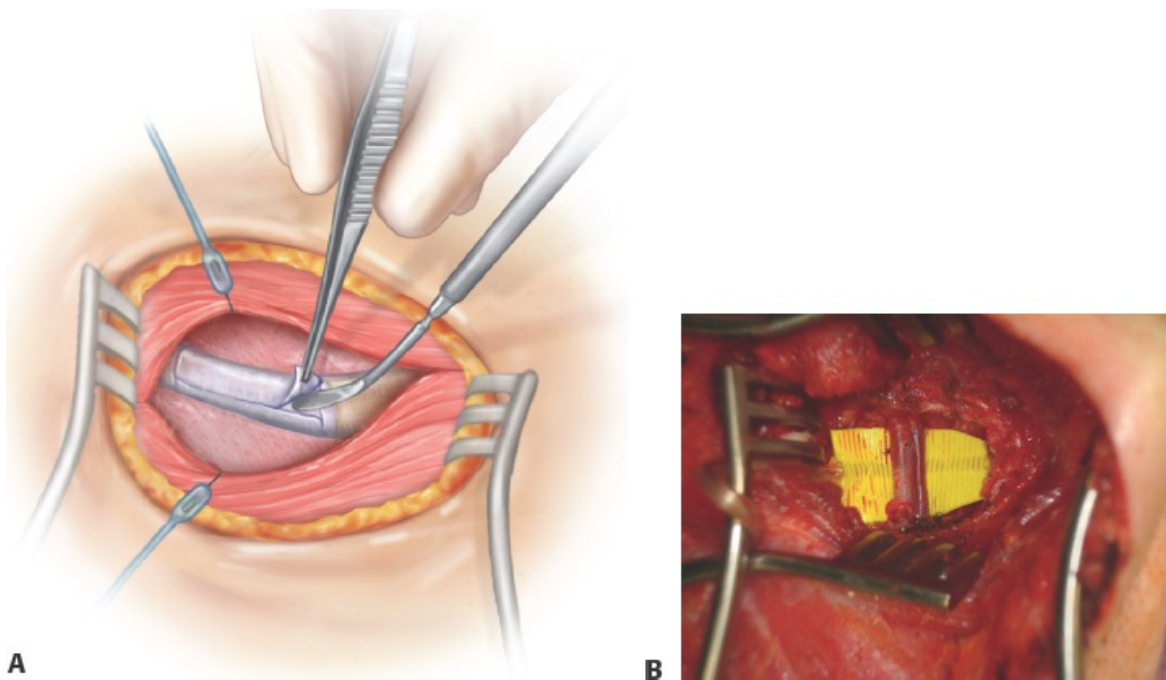
TECHNIQUES

■ Internal Mammary Vessel Exposure

- In the setting of an immediate reconstruction following a skin-sparing mastectomy, the breast pocket is first irrigated and hemostasis achieved with electrocautery as needed.
- An Army-Navy retractor is temporarily introduced to retract medial mastectomy skin for visualization of the medial anterior chest wall.
- The cartilaginous portion of the 3rd rib is palpated through the pectoralis major muscle. The muscle fibers over this medial aspect of the rib are split along the fibers with electrocautery and a Weitlaner retractor is introduced between the muscle fibers (handles lateral) to provide exposure of the underlying rib. The muscle split is performed from the lateral edge of the sternum to a point approximately 6 cm lateral to the sternum.
- The anterior costal perichondrium is scored along its length with the electrocautery and also perpendicular to the lengthwise incision at the medial and lateral extents of the exposed cartilage.
- A Freer elevator is then used to elevate the perichondrium off the underlying cartilage on its superficial surface, around the superior and inferior borders of the rib (**TECH FIG 1A**).
- The lateral cartilage is then excised with a rongeur down to the posterior perichondrium, taking care not to violate this posterior plane at this time.
- A second Weitlaner retractor is introduced perpendicular to the first (handles cephalad), anchored laterally at the cut edge of the rib, and used to retract the medial mastectomy skin out of the field. At this point, the Army-Navy

retractor is no longer needed. In patients with large skin flaps, a few skin hooks might be necessary to adequately retract redundant mastectomy skin.

- Excision of the remainder of the cartilage proceeds from lateral to medial to expose the posterior perichondrium. The IMA and vein are sometimes visible through the posterior perichondrium at this point.
- An incision parallel to the cut edge of the rib is made laterally through the posterior perichondrium with a scalpel. A Freer is then introduced underneath the perichondrium and used to push all soft tissue and vessel downward, proceeding toward the sternum.
- The posterior perichondrium is then split with a tenotomy scissor from lateral to medial exposing the underlying IMA and IMV.
- The posterior perichondrium is bluntly dissected off the underlying vessels with a Freer.
- Small vessel branches from the IMA and IMV are identified, ligated with microsurgical clips, and cut.
- The posterior perichondrium is then excised completely with a cautery at low settings to provide optimal exposure of the recipient vessels.
- If additional length is desired, the intercostal muscles cephalad and caudal to the vessels can be excised. To gain size in the exposed vessels, the intercostal muscles cephalad to the vessels can be excised.
- The IMA and IMV are dissected circumferentially with a Freer elevator. All side branches are ligated with microsurgical clips and cut with tenotomy scissors.
- A background mat with attached suction (authors' preference) is then placed beneath both vessels (**TECH FIG 1B**).
- Papaverine is applied, and a warm moist gauze is placed over the vessels until they are ready to be used.



TECH FIG 1 • A. The 3rd rib exposed deep to the pectoralis major muscle (fibers retracted with a Weitlaner retractor). Elevation of perichondrium over medial segment of the rib with a Freer. **B.** Exposure of the internal mammary vessels with a background in place.

■ Thoracodorsal Vessel Exposure

- A 6-cm curvilinear incision is made within the axillary fossa just inferior to the axillary crease. The incision should not extend anteriorly beyond the anterior axillary fold. If present, a previous scar from sentinel lymph node biopsy should be incorporated into the incision.
- Dissection is performed through the subcutaneous fat using the electrocautery until the axillary fat is reached. The axillary fat pad is more yellow in color than the subcutaneous fat.
- Two Weitlaner retractors are positioned within the incision to spread the axillary fat pad apart.
- Branches of the intercostobrachial nerve are encountered within the axillary fat pad and should be preserved if possible.
- At this point, nontoothed forceps and bipolar cautery should be used.

- The TD vessels can be found by two approaches:
 - Locating the anterolateral edge of the latissimus dorsi first and then performing dissection along its deep surface to identify the TD neurovascular bundle
 - Locating the axillary vein first and then exposing the takeoff of the subscapular vessels. Dissection is then carried distally to identify the TD vessels.
 - With the first method, the lateral edge of the latissimus dorsi muscle can be found by gentle tapping of the electrocautery tip to bring about muscle contractions. The point at which the neurovascular hilum enters the undersurface of the muscle is approximately 2 to 3 cm away from its anterolateral edge. The TD vessels are identified, separated from the TD nerve, and followed proximally.
 - With the second method, blunt dissection with a finger through the axillary fat pad is performed in the direction of the axillary vessels. The pulsations of the axillary artery can easily be appreciated by palpation, and this can guide the direction of dissection. The axillary vein is anterior to the axillary artery; when it is encountered, meticulous dissection should proceed along its length to identify branches traveling inferiorly. Once the subscapular artery and vein are identified, they are dissected distally to locate the branch point of the circumflex scapular vessels and their continuation as the TD vessels.
 - Often, the circumflex scapular branch needs to be ligated to achieve adequate pedicle length and to prevent kinking of the pedicle.
 - The branch to the serratus anterior muscle should be identified and preserved. The TD vessels are usually divided just proximal to the serratus anterior branch point.
 - When sufficient pedicle length has been obtained, a McCabe dissector is used to separate the TD artery, vein, and nerve. Once divided, the TD vessels should be positioned superficial to the nerve to prevent a “clotheslining effect” of the nerve on the pedicle.
 - Particularly in larger patients, performing the anastomosis deep within the axilla can be quite difficult. To ameliorate this problem, a moist gauze is packed into the axilla and the divided TD vessels may subsequently be positioned more superficially.
-

PEARLS AND PITFALLS

Technique

- IMA and IMV size at the level of the 3rd rib are consistently well matched with the commonly utilized deep inferior epigastric vessels; as often as possible, this is the ideal site for recipient vessel.
- The 4th rib in some cases is in a central location within mastectomy defects and might be easier to access than the 3rd rib. The IMVs on the left are appreciably smaller at the level of the 4th rib; plan to dissect proximal through the intercostal muscles to improve on IMV size.
- Plan for additional length of the IM vessels with possible proximal and distal dissection extending to the ribs above and below in cases with a traditionally short flap pedicle or in morbidly obese patients with very large flaps.
- To avoid injury to the IM vessels, it is critical to begin rib resection and elevation of the posterior perichondrium lateral to the vessel location. Dissect from lateral to medial.
- Keep vessel handling and cleaning of the adventitia to a minimum in radiated fields to avoid vessel injury.
- In some patients, exposed to radiation or with a low BMI, there may be very little adipose tissue between the posterior perichondrium and the pleura. Careful blunt dissection is needed to avoid an injury to the pleura.

Pleural injury

- During exposure of the IM vessels, small tears in the parietal pleura may occur. These rents may either be left unrepaired or carefully closed with fine absorbable suture.
- To evaluate for a pneumothorax, a positive pressure test may be performed. The rent is completely submerged in normal saline and the anesthesiologist delivers a breath of positive pressure ventilation. When the injury is limited to the parietal pleura, a positive pressure test will not result in air escape.

Pneumothorax

- A pneumothorax results when the injury extends through the parietal pleura, through the visceral pleura, and into the lung parenchyma.
- A positive pressure test will result in bubbles appearing from the injury.
- When this is detected in the operating room, the air within the pleural space must be evacuated and an airtight closure of the parietal pleura should be performed. A small red rubber catheter

on suction is placed into the pleural space and a purse-string suture is thrown around the pleural rent but left untied. As the anesthesiologist delivers a breath of positive pressure ventilation, the catheter is removed and the purse string is tied securely. The positive pressure test is repeated to check for air escape. Postoperatively, a chest x-ray is performed. Any significant lung collapse warrants a chest tube.

POSTOPERATIVE CARE

- Based primarily on postoperative flap care or protocol

OUTCOMES

- Flap complication and survival rates with use of the internal mammary or thoracodorsal vessels are similar.^{9,10}
- Conversions from TD vessels to IM vessels tend to be more common in radiated patients with previous axillary lymph node dissections.¹¹
- Occasional contour deformities and temporary discomfort at the site of rib resection are experienced by patients with IM vessel exposure. When present, contour deformities are easily addressed with autologous fat grafting, and chest wall discomfort resolves with time.

COMPLICATIONS

- Hematomas in the early postoperative period can be experienced with potential rapid enlargement of the breast mound with an arterial bleed. Large hematomas place pressure on the vascular pedicle and increase the risk of vascular compromise. Clinically significant hematomas are taken back to the operating room for evacuation and hemostasis.
- The axillary artery and vein are in close approximation to the brachial plexus. Careful dissection using bipolar cautery will prevent iatrogenic nerve injury.
- Arms should be well padded to avoid pressure-related complications.
- Neuropraxia due to prolonged arm abduction may be treated expectantly, but prevention is the best strategy.

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Inferior Gluteal Artery Perforator Flap Breast Reconstruction

25

CHAPTER

Katie E. Weichman

DEFINITION

- Fujino et al. first popularized the gluteal donor site for breast reconstruction in 1975 as a free myocutaneous flap, and Shaw further refined it in 1983.^{1,2} Additional modification of this myocutaneous flap by Paletta and Le-Quang et al. to use the inferior gluteal vessels as donor vessels was also described. However, despite initial success, it was abandoned secondary to technical difficulty and postoperative morbidity to the sciatic nerve.
- After the popularization of perforator flaps by Koshima, both the inferior and superior gluteal artery perforator flaps were described and gained popularity in reconstructive surgery.
- The inferior gluteal artery perforator (IGAP) flap was first described as a pedicled flap for ischial pressure sores by Blondeel in 2002.
- Allen further expanded the IGAP flap for breast reconstruction in 2004.³ He further advanced this perforator flap, with a widely accepted in-crease technique. This technique uses skin and tissue in the buttock area based on the IGAPs and minimizes the scar in the gluteal crease.⁴
- Though abdominally based free flaps remain the most common choice for breast reconstruction secondary to sufficient skin and soft tissue, patients may require alternative donor sites for various reasons. These reasons include lack of abdominal donor sites secondary to prior abdominoplasty, inadequate volume in the abdomen, and patient preference. Approximately 20% of patients are not candidate for abdominally based free flaps.²
- Advantages of IGAP flaps include the ability to harvest as a sensate flap (posterior cutaneous nerve of the thigh), hidden donor site, lack of risk of

abdominal hernia/bulge, and increased breast projection based on the consistency of the buttock fat. Additionally, IGAP has a slightly longer pedicle when compared to SGAP, and the risks of aesthetic donor-site morbidity with increased beveling of adjacent fat are decreased.

- Disadvantages include difficult patient positioning in bilateral cases, tedious dissection with a long oblique intramuscular course, potential injury to sciatic or posterior femoral cutaneous nerves, and significant arterial and venous mismatch of the pedicle.

ANATOMY

- The inferior gluteal artery originates from the internal iliac artery and is the smaller of its terminal branches. It exits the pelvis through the greater sciatic foramen and accompanies the greater sciatic nerve, internal pudendal artery and vein, and the posterior femoral cutaneous nerve.
- Anatomically, after perforating the sacral fascia, the inferior gluteal vessels exit below (caudal) to the piriformis muscle and above (cranial) to the coccyx (**FIG 1**).
- Once it exists below the piriformis, it divides into several perforators, usually more than the SGAP flap, and then travels in an intramuscular fashion to supply the inferior portion of the buttock.
- The length of the perforator depends on the area of the buttock supplied. Inferomedial perforators tend to be shorter with less intramuscular course (3–5 cm), whereas superolateral perforators tend to have a longer intramuscular course (4–6 cm). Therefore, lateral perforators are preferentially chosen for longer pedicle length.
- In 91% of patients, the inferior gluteal vessels travel with the posterior femoral cutaneous nerve (S1-S2) to the posterior thigh.⁵ Therefore, if desired, a neurosensory flap is possible if nerves are preserved.
- The inferior gluteal vein is associated with the inferior gluteal artery; however, it receives multiple tributaries in the subsacral fascia fibroconnective tissue. These vessels are prone to bleeding at the level of the pelvis and are quite large and friable. These vessels are routinely larger than superior gluteal veins.
- The perforating vessels, which are all musculocutaneous, are located inferior to the exit point below the piriformis muscle.
- Several studies have looked at these perforating vessels and found IGAP flaps have a mean number of 7 perforators (range 4–10), with an average intramuscular length of 8.7 cm (range 6–14 cm) and a mean total pedicle

length of 13.4 cm (range 10–17 cm). Additionally, the mean main vessel diameter was found to be 5 mm (range 4–7 mm) for the inferior gluteal artery and 7.7 mm (range 6–10 mm) for the inferior gluteal vein.⁶

- Understanding the course of the sciatic nerve and the posterior femoral cutaneous nerve is paramount to this flap dissection. These nerves often run together with the inferior gluteal artery as it emerges from the sciatic foramen below the piriformis muscle. The posterior cutaneous nerve is generally more medial in relation to both the inferior gluteal artery and sciatic nerve. Both nerves run posterior to the gluteus maximus muscle.

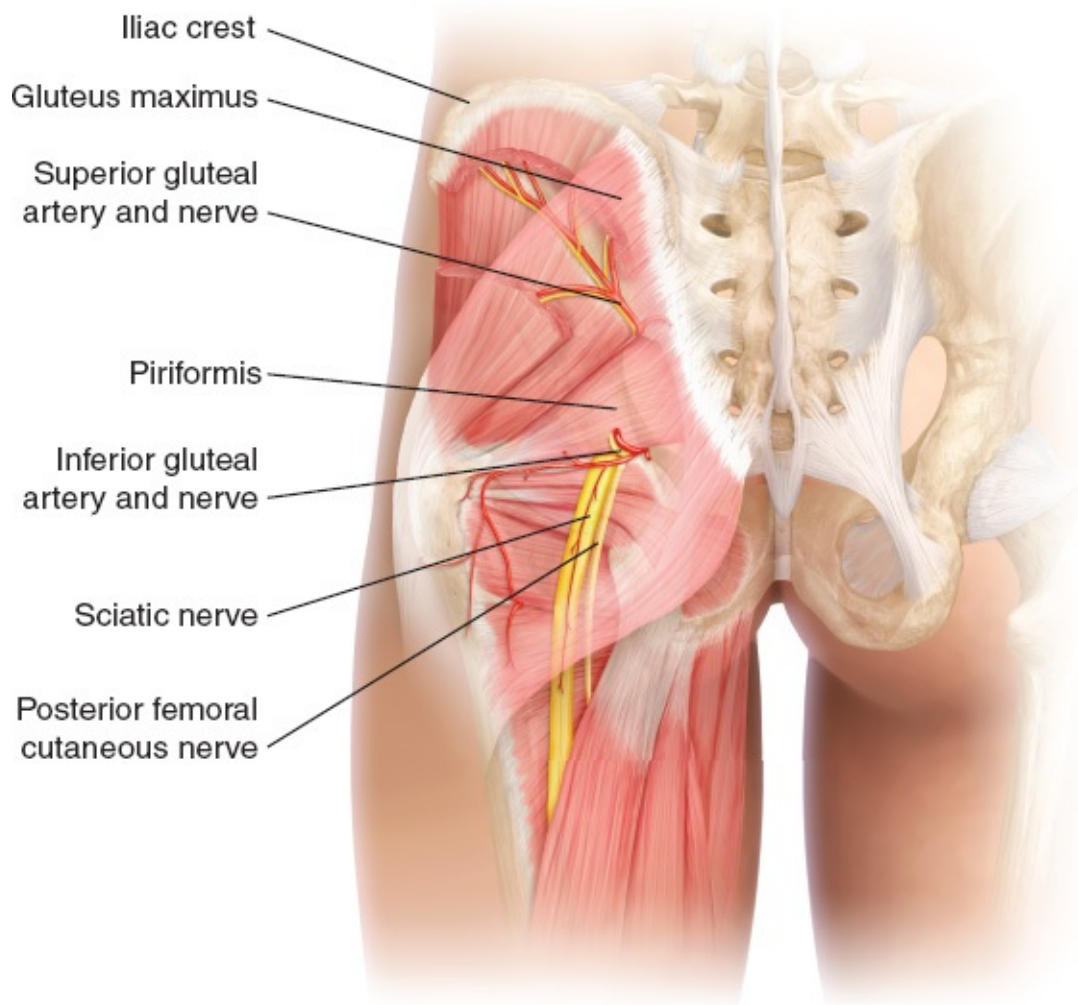


FIG 1 • Location of the inferior gluteal artery in relation to the piriformis muscle, posterior femoral cutaneous nerve, and sciatic nerve as it penetrates the sacral fascia, the space behind the gluteus maximus muscle.

■ Sciatic nerve

- The nerve is generally visualized during the submuscular dissection below the sacral fascia, as it exits the sciatic foramen below the piriformis muscle and travels posterior to the gluteus maximus muscle and anterior to the inferior gemellus muscle.
- Provides motor and sensory control to almost the entire posterior leg and foot
- Derived from spinal nerves L4-S3 and is the largest, widest, single nerve in the body

■ Posterior femoral cutaneous nerve (S1-S2)

- Can be observed at two points during the dissection
 - First, along the inferior incision of the skin paddle, in the gluteal crease, in the subfascial plane, where the investing muscular fascia of the gluteus maximus muscle and fascia lata coalesce
 - Second, during submuscular/subfascial dissection proximally with the inferior gluteal artery pedicle and sciatic nerve
 - Provides sensation to the posterior thigh, leg, and perineum
 - Derived from the sacral plexus and has three main branches:
 - Inferior cluneal nerves (most likely encountered on inferior skin paddle incision)
 - Three of four in number
 - Turn upward around the lower border of the gluteus maximus
 - Provide sensibility to the skin covering the lower lateral portion of the gluteus maximus
 - Perineal branches
 - Supply the skin covering the perineum
 - Main continuation in the posterior thigh
 - Travels posterior to fascia lata anterior to long head of biceps femoris
 - In mid leg, pierces fascia and travels with the lesser saphenous vein in the subcutaneous plane
 - Provides sensation to posterior and medial thigh, popliteal fossa, and superior leg

■ There are several muscles that are highlighted for IGAP dissection in the posterior gluteal area.

■ Gluteus maximus

- Origin: Gluteal surface of the ilium, lumbar fascia, sacrum, and

sacrotuberous ligament

- Insertion: Gluteal tuberosity of the femur and iliotibial tract
- Action: External rotation and extension of the hip joint
- Arterial supply: Superior and inferior gluteal arteries
- Innervation: Inferior gluteal nerve (L5, S1, and S2)
- Gluteus medius (deep to the gluteus maximus)
 - Origin: Gluteal surface of the ilium
 - Insertion: Greater trochanter of the femur forming the iliotibial tract
 - Action: Abduction of the hip, preventing adduction of the hip, and medial rotation of the thigh
- Piriformis (deep to the gluteus maximus)
 - Origin: Anterior portion of the sacrum
 - Insertion: Greater trochanter of the femur forming the iliotibial tract
 - Action: External rotator of the thigh
 - Arterial supply: Inferior gluteal artery, superior gluteal artery, and lateral sacral artery
 - Innervation: Nerve to the piriformis (L5, S1, and S2)
- Gluteus minimus (deep to gluteus maximus and gluteus medius)
 - Origin: ilium under the gluteus minimus
 - Insertion: greater trochanter of the femur forming the iliotibial tract
 - Action—works in concert with gluteus medius: abduction of the hip, preventing adduction of the hip, and medial rotation of the thigh
 - Arterial supply: superior gluteal artery
 - Innervation: superior gluteal nerve (L4, L5, S1)

PATIENT HISTORY AND PHYSICAL FINDINGS

- This includes patients with a history of breast cancer, patients undergoing prophylactic mastectomy, patients with congenital abnormalities, and transgender patients.
- Physical examination includes examination of the abdomen, medial thighs, and buttock to assess availability of excess tissue.
- Patients who are candidates for IGAP flap are generally nulliparous, with inadequate abdominal soft tissue, prior abdominoplasty, prior abdominal flap harvest, or prior abdominal liposuction.
- Patients should have estimated mastectomy specimen weights of no more than

350 to 400 g and cup size no greater than C cup.

- Timing of reconstruction should be planned in patients with prior history of breast irradiation. The authors prefer to wait 6 months after the completion of radiation therapy prior to completing delayed reconstruction.
- Smoking status is assessed also.
- Additionally, tamoxifen should be withheld 3 weeks prior to surgery.

IMAGING

- Patients considering IGAP flap reconstruction should undergo preoperative imaging with either computed tomography angiogram (CTA) or magnetic resonance angiography (MRA) of the pelvis and lower extremity.
- Imaging is performed in the prone position and coordinating with the radiologist for appropriate evaluation of images.
- Perforators should be described as they exit the deep muscular fascia and described based on location in an x-y axis. The gluteal fold will be set as zero on the y-axis, and the midline will be set as zero on the x-axis. Important bony landmarks that should be noted including the coccyx, the summit of the posterosuperior iliac crest, and the most lateral point of the greater trochanter⁷ (**FIG 2**).
- The description of the perforator should include the size of perforator as it exits the fascia and length of course to the inferior gluteal artery as it travels through the gluteus maximus and inferior to the piriformis back to the origin on the internal iliac artery. This should be described in relation to the coccyx, posterior superior iliac crest, and the most lateral point of the greater trochanter.

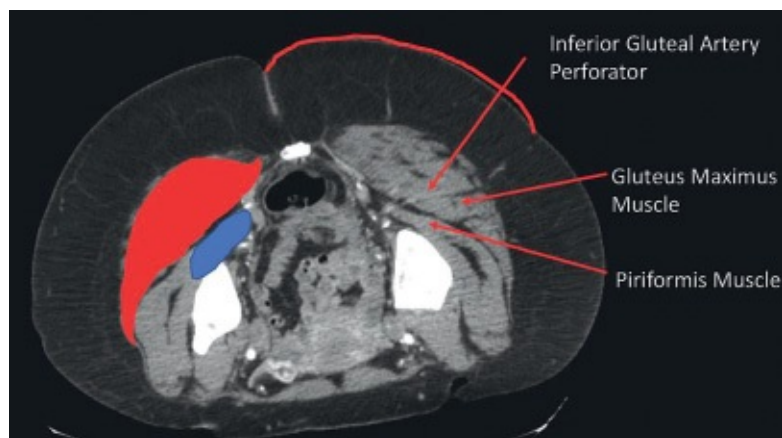


FIG 2 • Locations of IGAP perforator on axial CT scan

including the gluteus maximus muscle and piriformis muscle.

SURGICAL MANAGEMENT

- The authors perform IGAP flaps on patients either undergoing immediate or delayed breast reconstruction.
- Additionally, this procedure can be performed on patients who required multiple flaps secondary to volume and skin deficit and require reconstruction in a stacked fashion.⁸ This includes both patients having immediate stacked reconstruction and patients who have autologous reconstruction that requires secondary augmentation in a delayed fashion.
- Unilateral breast reconstruction with bilateral IGAP flaps has been described.⁹
- Flap weights have been seen between 148 and 833 g.⁴
- The operation requires loupe magnification for perforator dissection and microsurgical instruments.
- Although the microsurgical anastomosis can be performed under loupe magnification, the authors prefer the use of the operative microscope.

Positioning

- Patient is positioned in the lateral decubitus position for unilateral flaps and in the prone position for bilateral flaps.
- The perforator location should be double checked with the patient in the lateral decubitus position.

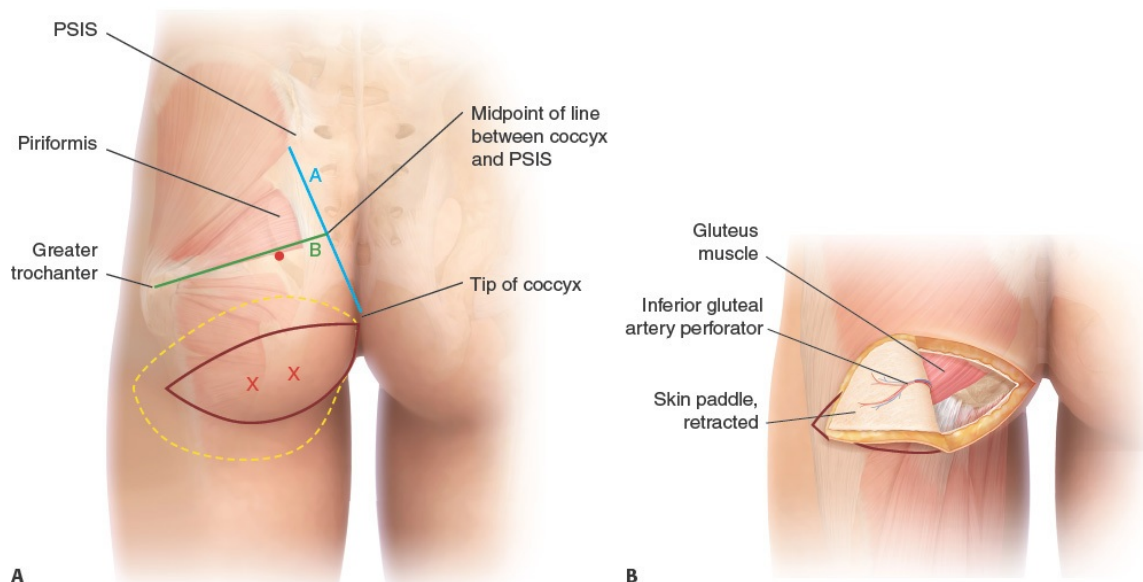
Approach

- A two-team approach can be used for IGAP flap harvest.
 - After intubation, the patient is placed in lateral decubitus position, and ipsilateral chest wall, buttock, arm, and leg are prepped into the field.
 - The second microsurgeon prepares the recipient site and vessels.
 - The primary microsurgeon will start with flap harvest.

TECHNIQUES

■ Flap Design and Markings

- Patients are marked in the standing position.¹⁰
- The flap is designed as a horizontal ellipse with the axis centered over the gluteal fold.
- The inferior border of the flap is marked in the gluteal fold (**TECH FIG 1A**).
- Based on preoperative images, using a handheld 5- to 8-MHz Doppler, the main perforators are marked clearly on the skin.
- Dissection can be performed in a clockwise or counterclockwise fashion to determine the best perforators.
 - No more than two perforators should be chosen.
- The superior aspect of the skin island ellipse is marked to capture these perforators, and the direction that parallels the gluteal crease is determined by the pinch test.
- Flap dimensions have been described as large as 8 × 18 cm but can be as long as 25 cm. The desired width of the flap is based on judgment to avoid excessive tension on the closure.
- Additional fat to be captured in the flap harvest should also be noted during marking (**TECH FIG 1B**).

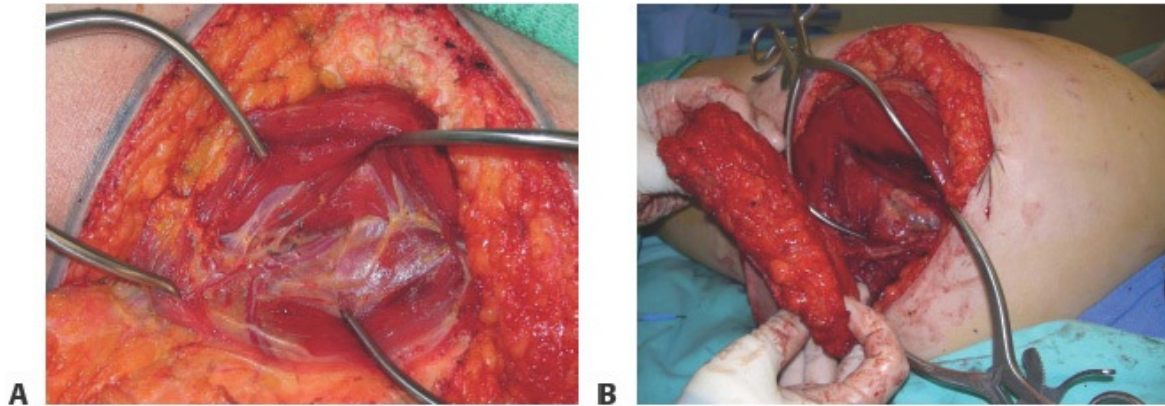


TECH FIG 1 • A. Inferior gluteal artery perforator flap markings in relation to the greater trochanter, *red line* represents the inferior border of the piriformis muscle

(midpoint of the line connecting posterosuperior iliac spine and coccyx to the apex of the greater trochanter). Inferior incision lies within the gluteal fold and superior incision incorporates perforators. **B.** Inferior gluteal artery perforator flap marked on patient noting incorporation of surrounding fat to increase bulk of flap.

■ Flap Harvest

- Harvest of the flap should be done under loupe magnification.
- Incision of the skin ellipse is made inferiorly and medially first.
- Posterior cutaneous nerve of the thigh is identified and preserved along the inferior border of the incision.
- Superior and lateral incisions are then made and superior and inferior beveling to include the maximum amount of fat and soft tissue.
- Lateral fat can also be captured additionally to include the saddlebags.
- Care should be taken to preserve medial fat over the ischium to prevent pain and pressure in the postoperative period. The fat in this area is notable with lighter color and larger globule ration overlying the iliotibial tract.
- Flap elevation begins in a lateral to medial fashion and gluteal fascia is incised early (**TECH FIG 2A**).
- Subfascial dissection proceeds until perforators are identified.
- Once the chosen perforator has been identified, dissection proceeds with the use of bipolar cautery through the gluteus maximus muscle using standard perforator dissection techniques.



TECH FIG 2 • A. Elevation of IGAP flap in a lateral to medial fashion in subfascial plane over the gluteus maximus muscle. Inferior gluteal artery perforator is present and seen coming through the muscle to the flap. **B.** Intraoperative photo of dissection of inferior gluteal artery perforator and vena comitans with splitting of gluteus maximus muscle in the direction of the fibers.

- It is important to split the gluteus maximus muscle in the direction of the fiber along the septum to avoid technical error (**TECH FIG 2B**).
- Unlike the SGAP flap, it is often unnecessary to open the sacral fascia to dissect in the submuscular or subgluteal flap plane for increased pedicle length.
 - This is secondary to the risk of intraoperative damage to the sciatic nerve and posterior cutaneous nerve of the thigh.
 - However, as compared to SGAP flaps, the submuscular/subsacral fascia dissection and venous confluence are easier with less variability.
- Significant mismatch of the inferior gluteal artery and vein is seen under the sacral fascia. There are multiple communications and branches that require ligation near the pedicle.
- Flaps are then harvested with either tie or double clip in the pelvis and placed on ice on the back table.
- Closure of the donor site proceeds in layers and over closed suction drains. Care is taken to avoid raising the gluteal fold by more than 1 cm.
- Patient is then repositioned into the supine position for microsurgical

anastomosis.

■ Recipient Vessel Exposure

- Exposure of the recipient vessels proceeds in the standard technique.
 - Both rib-sparing and rib-sacrificing techniques have been described.¹¹
-

PEARLS AND PITFALLS

Physical findings

- This flap is really a tertiary flap choice; therefore, abdomen and thigh donor sites should be used preferentially based on high incidence of flap failure and technical difficulty associated with IGAP flaps.
- Scar position in the gluteal crease should be marked preoperatively in the standing position.

Technique

- Two-surgeon approach is helpful when harvesting the flap and preparing the recipient site.
- Choice of number of perforators and perforators selected should be aided by imaging and difficulty of intramuscular dissection. More than 2 perforators should not be selected.
- Beveling superiorly, inferiorly, and laterally can help add additional tissue to the flap and is imperative for increasing flap volume. However, light-colored medial fat must be spared to prevent donor-site discomfort when sitting secondary to pressure over the ischium.
- As the inferior gluteal artery perforator dissection moves proximally, the sciatic nerve is palpated to avoid injury. When the perforator enters the main trunk of the descending inferior gluteal artery, the sciatic nerve is separated and not visualized.
- Dissection of the submuscular/subfascial pedicle is not always required and can prevent injury to posterior cutaneous nerve of the thigh and sciatic nerve.
- Venous thrombotic complications are most common and size mismatch is possible. Therefore, avoiding kinking during inset is imperative.

Postoperative

- Compression garment should be worn for 1 month postoperatively.
-

Complications

- Postoperative donor-site problems remain the most common complication.
- If venous thrombosis occurs, vein graft will likely be required for salvage, and possible vein donor sites include the dorsal foot, hand, and turn down from proximal cephalic vein.

POSTOPERATIVE CARE

- Patients routinely stay in the hospital for 3 to 4 days postoperatively.
- Pain control can be augmented with intraoperative subcutaneous bupivacaine (Exparel) administration in addition to scheduled ibuprofen/Toradol.
- Patients have routine transcutaneous Doppler checks, and monitoring can be further augmented by ViOptix technology. The authors prefer flap checks q 15 minutes $\times$ 2 hours, q 30 minutes $\times$ 1 hour, q 1 hour $\times$ 24 hours, and q 4 hours until discharge.
- Postoperatively, sitting can be initiated on POD no. 1 and ambulation on POD no. 2.
- Patients routinely stay in the hospital for 3 days and then are discharged home on postoperative aspirin $\times$ 30 days.
- Drains remain in place until less than 30 mL $\times$ 24 hours.

OUTCOMES

- IGAP flap for breast reconstruction provides an adequate reconstruction. The buttock fat is less pliable with a greater skin to fat ratio as compared to a natural breast due to a developed reticular system. This flap gives increased projection of the breast secondary to this quality.
- The IGAP flap offers a successful reconstruction in 90% to 96% of patients.
- Secondary revision with fat grafting to the breast and local tissue rearrangement to the donor site is common.
- Should be used as a tertiary flap in breast reconstruction, with abdominal and thigh donor site preferred (**FIG 3**)

COMPLICATIONS

- Donor-site complications remain the most common complications associated with IGAP flap dissection. These complications include:
 - Seroma is common and reported in as many as 25% of patients.
 - Hematoma
 - Wound healing problems (including dehiscence and wound infection)

- Avoid tension across the incision with minimal skin paddle height and focus on undermining superiorly, inferiorly, and laterally to gain additional fatty tissue.
- Total flap loss is a dreaded complication of breast reconstruction with IGAP flap. Based on available series, the failure rate is likely between 2.5% and 6.5%.¹²
- These complications can be associated with arterial or venous thrombosis or difficulty with perforator dissection but most commonly associated with venous thrombosis in a delayed fashion with that being observed in up to 13% of flaps.
- This can be attributed to kinking of the vein and significantly size mismatch. Prompt take back to the operating room is required for either revision of arterial anastomosis or venous anastomosis in the cases of arterial or venous insufficiency. Vein grafts are often necessary for salvage.
- These complications often present in the first 24 to 48 hours.
- Fat necrosis in fasciocutaneous flaps for breast reconstruction is commonplace. However, the fat necrosis rate in IGAP flaps has been seen to be between 3.5% and 10%. Treatment of fat necrosis is variable and can include revision with direct excision or liposuction.
- Sciatic nerve injury is possible; however, reapproximation to the gluteus maximus muscle helps to avoid significant sequelae.
- Persistent sensory disturbances greater than 3 months can be seen in 19% of patients in their posterior leg. This complication is associated with injury or sacrifice of the posterior cutaneous nerve of the thigh, due to intimate association with the pedicle.¹³ However, most of these complications diminish over time.

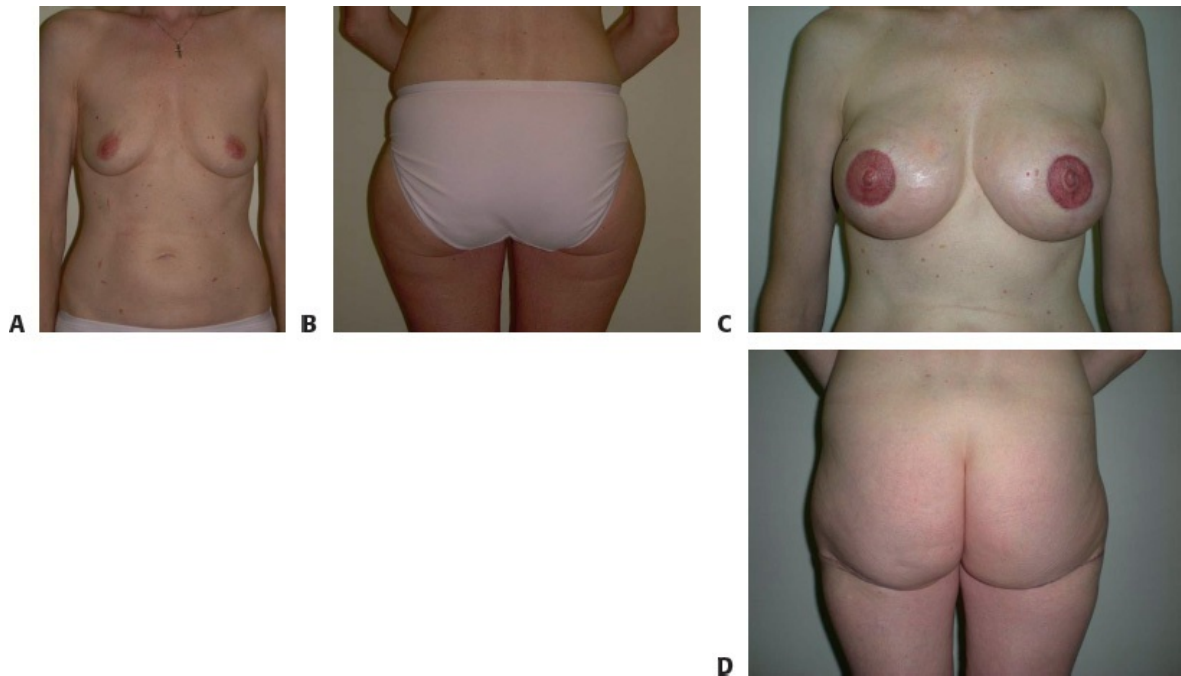


FIG 3 • Preoperative and postoperative results. **A.** Preoperative AP view of a 42-year-old female with history of right breast DCIS and size 34A breasts. **B.** Preoperative PA view of patient. **C.** Postoperative AP view of patient after bilateral mastectomy and immediate IGAP reconstruction. **D.** Postoperative PA view of patient after bilateral IGAP harvest.

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26 Superior Gluteal Artery Perforator Flap Breast Reconstruction

CHAPTER

Katie E. Weichman

DEFINITION

- The superior gluteal artery perforator (SGAP) flap is a variation of the gluteal artery myocutaneous flap initially described by Shaw and further modified by Codner and Nahai for use in breast reconstruction.^{1,2} This perforator flap was first described as a pedicled flap by Koshima and used for repair of sacral pressure sores³ and further expanded for use as a free flap in breast reconstruction when described by Allen and Tucker in 1995.⁴ This perforator flap uses skin and tissue in the buttock area based on the SGAPs. The flap has been further modified by Blondeel in 1999 for use in breast reconstruction as a sensate flap.⁵
- While abdominally based free flaps remain the most common choice for breast reconstruction secondary to sufficient skin and soft tissue, patients may require alternative donor sites for various reasons. These reasons include lack of abdominal donor sites secondary to prior abdominoplasty, inadequate volume in the abdomen, and patient preference.

ANATOMY

- The superior gluteal artery originates from the internal iliac artery and is its largest branch. It runs backward between the lumbosacral trunk and the first sacral nerve and exits the pelvis through the sciatic foramen just above the upper border of the piriformis muscle and inferior to the gluteus medius.
- Anatomically, this exit point between the piriformis and the gluteus medius has been shown to be about 6 cm from the PSIS and 4.5 cm lateral to the midline of the sacrum or at the junction of the proximal and middle thirds of a

line connecting the PSIS to the apex of the greater trochanter of the femur (**FIG 1**).

- Once it passes out of the pelvis, it immediately divides into a superficial and deep branch.
- The superficial branch enters the deep surface of the gluteus maximus muscle and divides into several branches that perforate through the gluteus maximus muscle onto the skin. These are the perforating vessels that will be followed in SGAP dissection.
- The superior gluteal vein is associated with the superior gluteal artery; however, it receives multiple tributaries as it enters the pelvis that requires ligation during harvest.
- The perforating vessels are located inferior to and lateral to the anatomical exit point of the superior gluteal artery. Several studies have looked at these perforating vessels and found SGAP flaps have a mean number of 7.2 perforators (range 5–10), with an average intramuscular length of 5.33 cm (range 3–11 cm) and a mean total pedicle length of 9.8 cm (range 6.0–15.5 cm).⁶
- There are several muscles that are highlighted for SGAP dissection in the posterior gluteal area (**FIG 2**).
 - Gluteus maximus
 - Origin: Gluteal surface of the ilium, lumbar fascia, sacrum, and sacrotuberous ligament

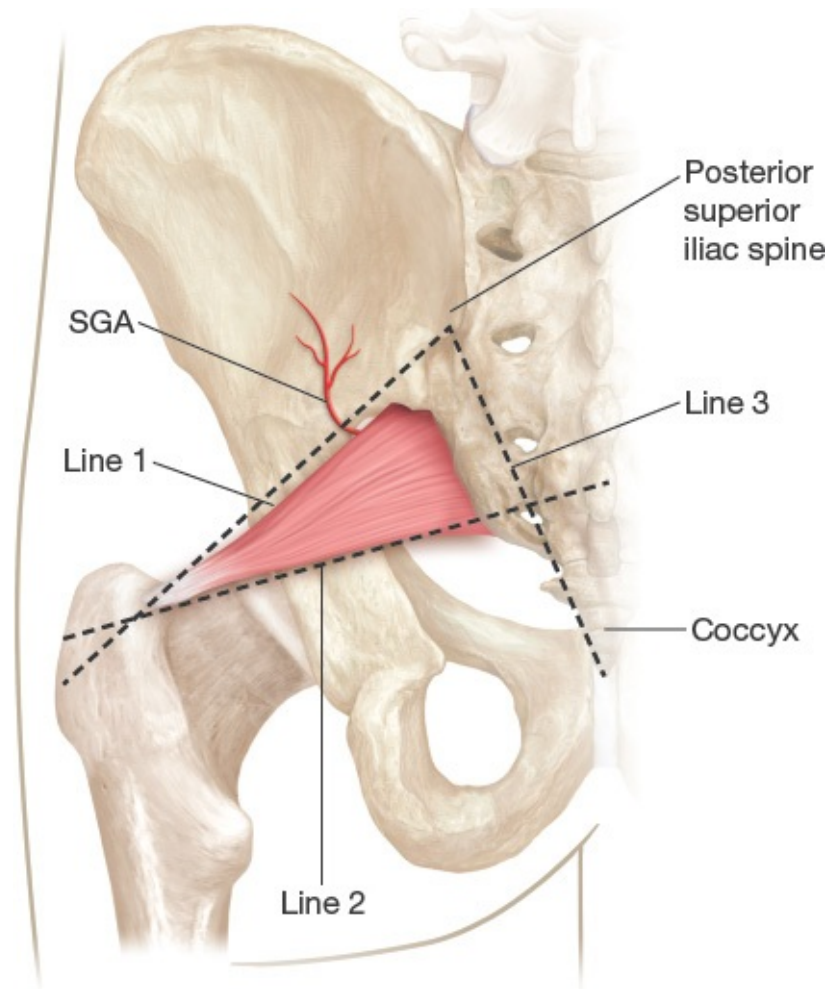


FIG 1 • Anatomical relationships of superior gluteal artery. *Line 1* connects posterior iliac spine to apex of greater trochanter. Superior gluteal artery is located at the junction between the proximal and middle third of this line. *Line 2* connects the midpoint of the gluteal crease to the superior greater trochanter. *Line 3* connects the posterior iliac spine to the coccyx. *Line 2* represents the inferior border of the piriformis muscle.

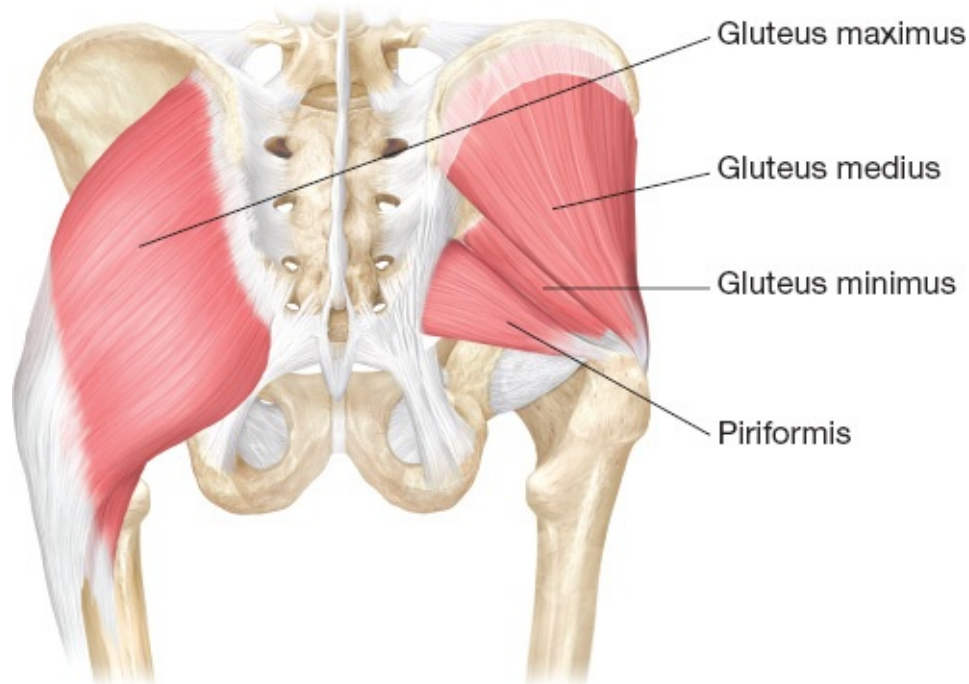


FIG 2 • Important musculature of the posterior trunk involved in SGAP dissection.

- Insertion: Gluteal tuberosity of the femur and iliotibial tract
- Action: External rotation and extension of the hip joint
- Arterial supply: Superior and inferior gluteal arteries
- Innervation: Inferior gluteal nerve (L5, S1, and S2)
- Gluteus medius (deep to the gluteus maximus)
 - Origin: Gluteal surface of the ilium
 - Insertion: Greater trochanter of the femur forming the iliotibial tract
 - Action: Abduction of the hip, preventing adduction of the hip, and medial rotation of the thigh
- Piriformis (deep to the gluteus maximus)
 - Origin: Anterior portion of the sacrum
 - Insertion: Greater trochanter of the femur forming the iliotibial tract
 - Action: External rotator of the thigh
 - Arterial supply: Interior gluteal artery, superior gluteal artery, and lateral sacral artery
 - Innervation: Nerve to the piriformis (L5, S1, and S2)
- Gluteus minimus (deep to gluteus maximus and gluteus medius)

- Origin: Ilium under the gluteus minimus
- Insertion: Greater trochanter of the femur forming the iliotibial tract
- Action: Works in concert with gluteus medius: abduction of the hip, preventing adduction of the hip, and medial rotation of the thigh
- Arterial supply: Superior gluteal artery
- Innervation: Superior gluteal nerve (L4, L5, S1)

PATIENT HISTORY AND PHYSICAL FINDINGS

- This includes patients with a history of breast cancer, patients undergoing prophylactic mastectomy, patients with congenital abnormalities, and transgender patients.
- Physical examination includes examination of the abdomen, medial thighs, and buttock to assess availability of excess tissue.
- Timing of reconstruction should be planned in patients with prior history of breast irradiation. The authors prefer to wait 6 months after the completion of radiation therapy prior to completing delayed reconstruction.
- Smoking status is also assessed.
- Additionally, tamoxifen should be held 3 weeks prior to surgery.

IMAGING

- Patients considering SGAP flap reconstruction should undergo preoperative imaging with either computed tomography angiogram (CTA) or magnetic resonance angiography (MRA) of the pelvis and lower extremity.
- Imaging is performed in the prone position and coordinating with the radiologist for appropriate evaluation of images.
- Perforators should be described as they exit the deep muscular fascia and described based on location in an x-y axis. The gluteal fold will be set as zero on the y-axis, and the midline will be set as zero on the x-axis. Important bony landmarks that should be noted include the coccyx, the summit of the posterosuperior iliac crest, and the most lateral point of the greater trochanter⁷ (**FIG 3**).

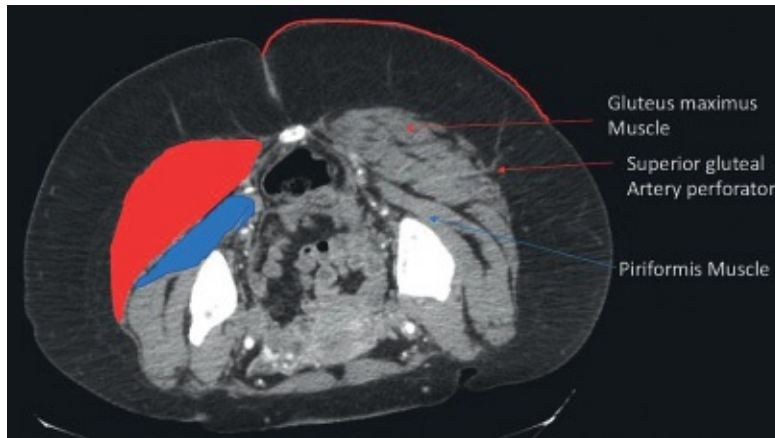


FIG 3 • Locations of SGAP perforator on axial CT scan including the gluteus maximus muscle and piriformis muscle.

- The description of the perforator should include the size of perforator as it exits the fascia and length of course to the superior gluteal artery as it travels through the gluteus maximus and superior to the piriformis back to the origin on the internal iliac artery. This should be described in relation to the coccyx, posterosuperior iliac crest, and the most lateral point of the greater trochanter.

SURGICAL MANAGEMENT

- The authors perform SGAP flap on patients either undergoing immediate or delayed breast reconstruction.
- Additionally, this procedure can be performed on patients who required multiple flaps secondary to volume and skin deficit and require reconstruction in a stacked fashion.⁸ This includes both patients having immediate stacked reconstruction and patients who have autologous reconstruction that requires secondary augmentation in a delayed fashion.
 - Unilateral stacked SGAP flaps have been described.⁸
 - PAP and augmenting prior SGAP flap have also been described.⁹
- Flap weights have been seen between 210 and 820 g.⁴
- The operation requires loupe magnification for perforator dissection and microsurgical instruments.
- While the microsurgical anastomosis can be performed under loupe magnification, the authors prefer the use of the operative microscope.

Preoperative Planning

- Patients are marked in the standing or sitting position.
- The superior gluteal artery is identified and marked as noted above at the junction of the proximal and middle thirds of a line connecting the posterior iliac crest to the lateral most portion of the greater trochanter of the femur. The perforators are most likely found in a 3-cm radius of the point.
- A second line is drawn from the PSIS to the coccyx.
- A third line is drawn to represent the piriformis muscle from the midpoint of the line between the PSIS and coccyx to the superior edge of the greater trochanter.
- Based on preoperative images, using a handheld 5- to 8-MHz Doppler, the main perforators are marked clearly on the skin.
- The flap is then designed and should be centered over the perforators. The skin island should be oriented parallel to the bikini line and medially should be marked in a fishtail to avoid a dog-ear at the gluteal crease. In general, the flap should be at a 45-degree slant cranially from medial to lateral.
- The apex of the flap is marked beginning two to three fingerbreaths below the gluteal crease in the midline extending laterally and superiorly.
- Flap dimensions have been described as large as 30 cm × 13 cm; however, generally, it can be between 6 and 13 m wide and 20 and 25 cm in length.⁵ The desired width of the flap is based on judgment to avoid excessive tension on the closure.
- Additional fat that you would like to capture in the flap harvest should also be noted during marking (**FIG 4**).

Positioning

- The patient is positioned in the lateral decubitus position for unilateral flaps and in the prone position for bilateral flaps. If bilateral reconstruction, this will have to start in the supine position for either mastectomy in immediate reconstruction or preparation of site in delayed reconstruction and vessel harvest. This supine position will be followed by prone positioning and finally supine positioning again.

Approach

- A two-team approach can be used for SGAP flap harvest. The first team is utilized for site preparation and vessel exposure and the second team for flap

harvest. Alternatively, for bilateral cases, flap harvest can be performed synchronously.

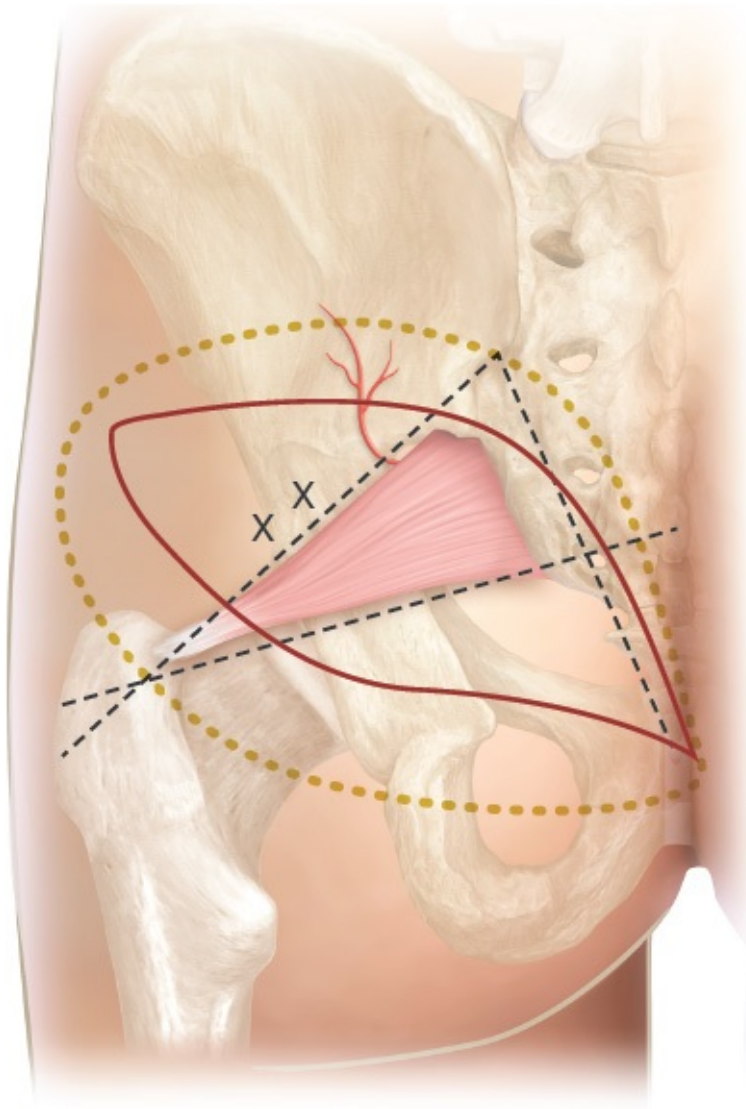


FIG 4 • Flap markings in relation to *Line 1* (from posterior iliac spine to apex of greater trochanter), *Line 2* (from the midpoint of the gluteal crease [*Line 3*] to the superior greater trochanter), and *Line 3* (posterosuperior iliac spine to coccyx).

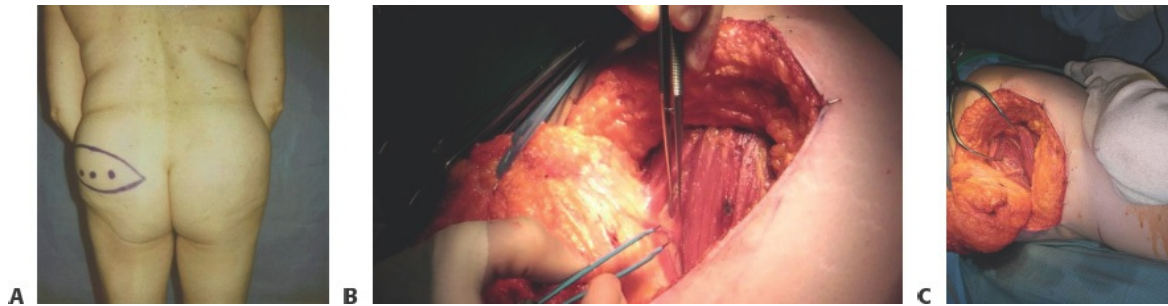
TECHNIQUES

■ Superior Gluteal Artery Perforator Flap

- Markings: See above
- Harvest of the flap should be done under loupe magnification.
- Incision of the skin ellipse is made laterally with both superior and inferior incisions being opened (**TECH FIG 1A**).
- If additional fat is desired, beveling is necessary to capture the fat.
- Above the muscular fascia, the superior cluneal nerves can be identified at the superior border of the flap. These can be included if large enough to allow a sensate flap. The superior cluneal nerves are the terminal ends of the lateral rami of the posterior rami of lumbar spinal nerves L1, L2, and L3.
- Suprafascial dissection proceeds above the gluteus maximus muscle in the direction of the fibers until the area around SGAP perforator is encountered.
- The gluteal fascia is then incised and elevated in a lateral to medial fashion above the muscle.
- Once the chosen perforator has been identified, dissection proceeds with the use of bipolar cautery through the gluteus maximus muscle using standard perforator dissection techniques.
- It is important to split the gluteus maximus muscle in the direction of the fiber along the septum to avoid technical error (**TECH FIG 1B**).
- At the deepest point of dissection through the gluteus maximus, the posterior fascia is encountered, and it must be opened.
- Once opened, the subgluteal fat pad is exposed, there is a dangerous intricate vascular network, and the veins in this area tend to be fragile.
- At this point, Gelpi retractors in the piriformis and gluteus medius are required to get adequate exposure of the vessel at its origin (**TECH FIG 1C**).
- If pedicle length is adequate prior to dissection in the subgluteal fat pad, then dissection can stop prior to entry.
- Additional 2 to 3 cm of length can be gained in the subgluteal flat plane.
- Once the dissection of the perforator back toward the superior gluteal artery as it emerges between the piriformis and the gluteus medius has been completed, the remainder of the skin incisions can be made (inferiorly and medially).
- The skin paddle is then lifted from the muscle and the flap is isolated on the perforators.
- Flaps are then harvested with either tie or double clip in the pelvis and

placed on ice on the back table.

- Closure of the donor site proceeds in layers and over closed suction drains. Care is taken to avoid undermining over the iliac crest and greater trochanter to avoid disruption of periosteal skin ligaments.
- The patient is then repositioned into the supine position for microsurgical anastomosis.



TECH FIG 1 • Intraoperative dissection. **A.** Intraoperative markings. **B.** Split of gluteus maximus muscle during perforator dissection. **C.** Dissection in the subgluteal fat plane.

■ Recipient Vessel Exposure

- Exposure of the recipient vessels proceeds in the standard technique.
 - Rib-sparing and rib-sacrificing techniques have been described and can be utilized with this flap.¹⁰
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PEARLS AND PITFALLS

Physical findings

- Preoperative imaging and marking remain the most important part of the preoperative workup. When marking the skin paddle, make sure the paddle is centered over the perforators and is oriented in a 45-degree angle with the dog-ear run out into the gluteal crease.

Technique

- Mark skin paddle without tension to avoid donor-site deformity and step-offs.
- Make only superior and lateral incisions first.
- Dissect in the suprafascial plane until the periperforator area, and

then make fascial incision in the direction of the gluteus maximus muscle to avoid increased incidence of seroma.

- Must split the muscle, after fascial incision is made, in the direction of the fibers to allow careful dissection.
- When ligating large venous branches in the subgluteal fat plane, leave minimal length on the branch from the pedicle for risk of predisposition to venous thrombosis.
- When closing donor site, close in layers and avoid undermining superiorly and laterally resulting in contour abnormalities and functional abnormalities.

Postoperative

- Patient should be maintained in compression garment 1 month postoperatively.

Complications

- High flap loss rates are possible, and donor-site complications remain the most difficult to handle and can require revision surgery with scar revision and fat grafting occasionally.

POSTOPERATIVE CARE

- Patients routinely stay in the hospital for 3 to 4 days postoperatively.
- Pain control can be augmented with intraoperative subcutaneous bupivacaine (Exparel) administration in addition to scheduled ibuprofen/Toradol.
- Patients have routine transcutaneous Doppler checks, and monitoring can be further augmented by ViOptix technology. The authors prefer flap checks q 15 minutes $\times$ 2 hours, q 30 minutes $\times$ 1 hour, q 1 hour $\times$ 48 -hours, and q 2 hours until discharge.
- Postoperatively, sitting can be initiated in patients on POD no. 1 and ambulation on POD no. 1 or POD no. 2 depending on the patient.
- Foley is removed on POD no. 2.
- Patients routinely stay in the hospital for 3 days and then are discharged home on postoperative aspirin $\times$ 30 days.
- Drains remain in place until less than 30 mL $\times$ 24 hours.

OUTCOMES

- SGAP flap for breast reconstruction provides an adequate reconstruction; however, the buttock fat is less pliable as compared to a natural breast due to a developed reticular system. The flap allows for increased projection of the breast secondary to this quality (**FIG 5**).
- The SGAP flap offers a successful reconstruction in 93% to 97% of patients.^{11,12}

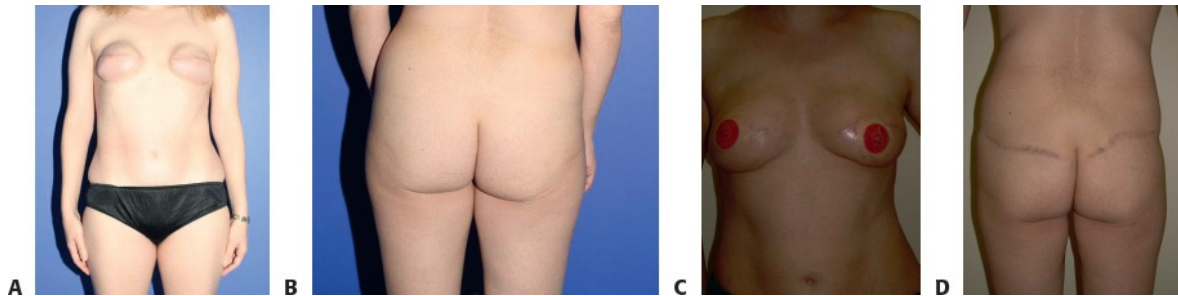


FIG 5 • A–D. Clinical case example.

COMPLICATIONS

- Donor-site complications remain the most common complications associated with SGAP flap dissection. These complications include the following:
 - Seroma of which the incidence can be decreased if suprafascial dissection is undertaken. The incidence of seroma has been seen in as many as 13.5% of patients.
 - Hematoma can be seen in as many as 1% to 3% of patients.
 - Wound healing problems (including dehiscence and wound infection) can be seen in as many as 4% to 6% of patients.
- Total flap loss is a dreaded complication of breast reconstruction with SGAP flap. There are no large series of SGAP for breast reconstruction in the literature; however, failure rates are likely between 5% and 8% secondary to the short pedicle and tedious perforator dissection. These complications can be associated with arterial or venous thrombosis or difficulty with perforator dissection. In the largest series describing SGAP, arterial thrombosis occurred in 3.7% of patients, venous thrombosis occurred in 3.7% of patients, and both arterial and venous thrombosis occurred in 3.7% of patients.¹¹ Prompt take back to the operating room is required for either revision of arterial anastomosis or venous anastomosis in the cases of arterial or venous insufficiency. These complications routinely present in the first 24 to 48 hours.
- Fat necrosis in fasciocutaneous flaps for breast reconstruction is commonplace. However, the fat necrosis rate in SGAP flaps is unknown secondary to the lack of large series. However, it has been seen in as many as 3% to 6% of patients, which is similar to other fasciocutaneous flaps.¹¹ Treatment of fat necrosis is variable and can include revision with direct excision or liposuction with fat grafting as an augmentation.

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Section VIII: Other Free Flaps

27 Profunda Artery Perforator Flap for Breast Reconstruction

CHAPTER

Katie E. Weichman and Nicholas Haddock

DEFINITION

- The profunda artery perforator (PAP) flap is a variation of the posterior thigh myocutaneous flap, which was initially described by Hurwitz¹ and further popularized for reconstruction of burn contractures, pressure sores, and extremity wounds.^{2,3} Since its description by Allen et al. in 2010, it has been recently popularized for use in breast reconstruction.⁴
- Although abdominally based free flaps remain the most common choice for breast reconstruction secondary to sufficient skin and soft tissue, patients may require alternative donor sites for various reasons. These reasons include lack of abdominal donor site secondary to prior abdominal surgery or abdominoplasty, inadequate volume in the abdomen, and patient preference.

ANATOMY

- The profunda femoris artery originates from the common femoral artery. It runs deep in the thigh and between the pectineus and the adductor longus and on the posterior side of the adductor longus.
- The profunda femoris artery gives off several branches including lateral circumflex femoral artery, medial circumflex femoral artery, and several perforating branches that perforate the adductor magnus muscles to the posterior and medial compartments of the thigh.

- There are typically three to four perforating arteries originating from the profunda femoris.
 - First perforating artery passes posteriorly between the pectineus and adductor brevis and then pierces the adductor magnus close to the linea aspera.
 - Second perforating artery larger than the first pierces the tendons of the adductor brevis and adductor magnus and divides into anterior and posterior branches.
 - Third perforating artery is given off below the adductor brevis, and it pierces the adductor magnus and divides into branches that supply posterior femoral muscles.
- The perforating vessels used in the PAP flap have been evaluated in imaging studies based on both size and location and perfusion.
 - The perforator is consistently found in the upper medial thigh posterior to the gracilis. The most common location of the perforator in the medial thigh is exiting the fascia in the vicinity of the adductor magnus about 3.8 cm from the midline and 5.0 cm below the gluteal fold. The second most common perforator location is in the vicinity of the biceps femoris and vastus lateralis at 12 cm from the midline and 5.0 cm below the gluteal fold⁵ (**FIG 1**).
- The thigh has three compartments: anterior compartment, medial compartment, and posterior compartment. The medial and posterior compartments are highlighted for profunda artery flap dissection (**FIG 2**).
- The medial compartment includes the obturator externus muscle, gracilis muscle, adductor longus muscle, adductor brevis, and adductor magnus.
 - Gracilis muscle
 - Origin: The line on the external surfaces of the body of the pubis, inferior pubis ramus, and the ramus of the ischium
 - Insertion: Medial surface of proximal shaft of the tibia
 - Action: Adducts the thigh at the hip and flexes the knee
 - Arterial supply: Medial femoral circumflex
 - Innervation: Obturator nerve
 - Adductor longus
 - Origin: External surface of the body of the pubis (triangular depression inferior to pubic crest and lateral to pubic symphysis)
 - Insertion: Linea aspera to middle one-third of the shaft of the femur
 - Action: Adducts and medial rotates the thigh at the hip

- Arterial supply: Profunda femoris
- Innervation: Obturator nerve
- Adductor magnus
 - Origin: Ischiopubic ramus
 - Insertion: Posterior surface of the proximal femur, linea aspera, and medial supracondylar line



FIG 1 • Posterior thigh perforator location based on CT scanning. Described as location from the gluteal fold and from the midline.

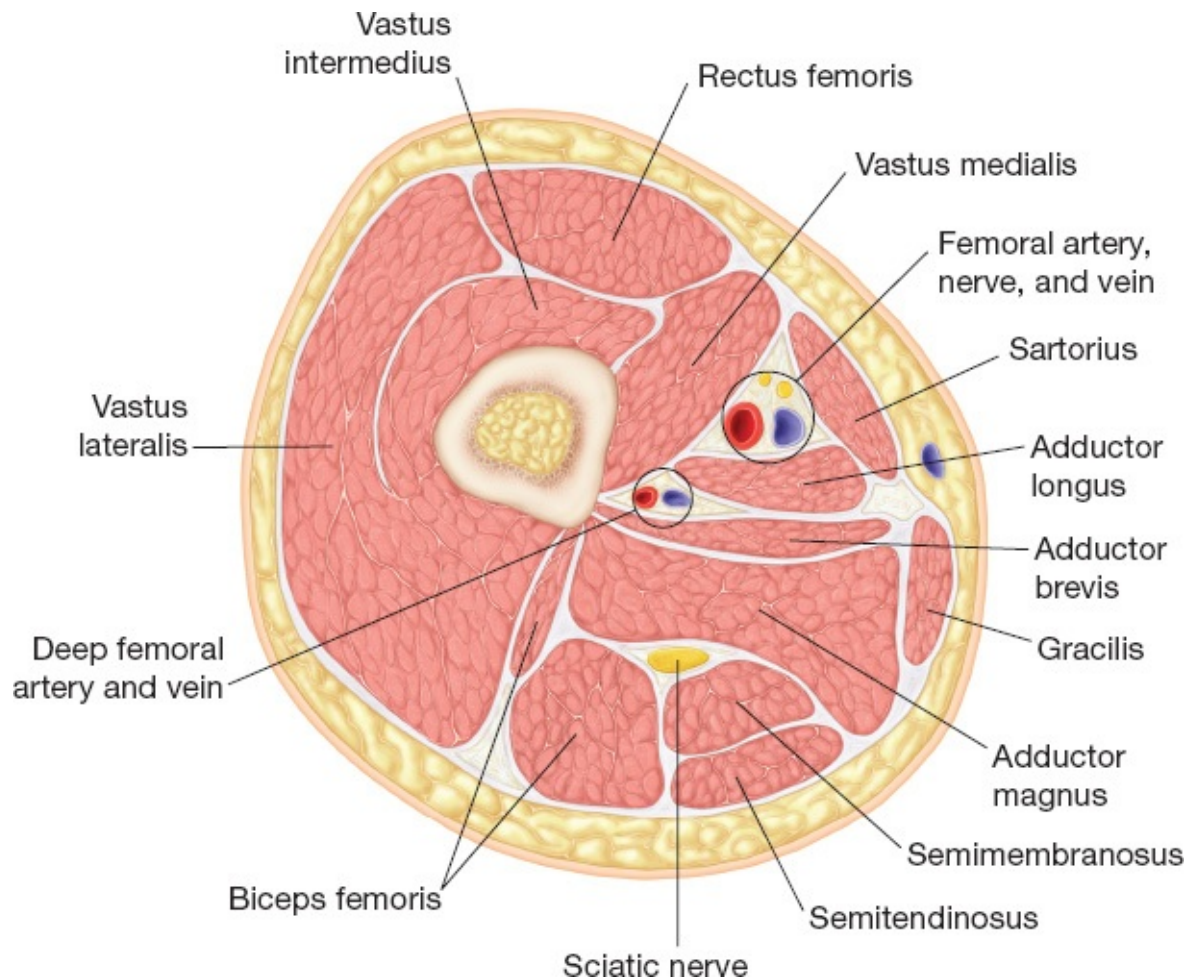


FIG 2 • Cross section of the thigh at the level of the profunda artery perforators.

- Action: Adducts and medially rotates the thigh at hip joint
- Arterial supply: Profunda femoris
- Innervation: Obturator nerve
- The posterior compartment has three muscles: biceps femoris, semitendinosus, and semimembranosus.
 - Biceps femoris
 - Origin—long head: Ischial tuberosity
 - Origin—short head: Linea aspera on posterior surface of the femur
 - Insertion: Both insert onto the head of the fibula as a single tendon.
 - Action: Flexion at the knee and extends the hip
 - Arterial supply: Profunda femoris artery and perforators of profunda

femoris artery

- Innervation: Sciatic nerve

■ Semitendinosus

- Origin: Ischial tuberosity of the pelvis
- Insertion: Medial surface of the tibia (pes anserinus)
- Action: Flexes the leg at the knee joint and extension of the hip
- Arterial supply: Inferior gluteal artery and perforating arteries from the profunda femoris
- Innervation: Sciatic nerve (tibial portion)

■ Semimembranosus

- Origin: Ischial tuberosity
- Insertion: Medial tibial condyle
- Action: Flexion of the leg at the knee joint and extension of the hip
- Arterial supply: Profunda femoris and gluteal arteries
- Innervation: Sciatic nerve (tibial portion)

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients present for evaluation for either delayed or immediate breast reconstruction.
 - This includes patients with a history of breast cancer, patients undergoing prophylactic mastectomy, patients with congenital abnormalities, and transgender patients.
- Physical examination includes examination of the abdomen and posteromedial thighs to assess availability of excess tissue.
- Timing of reconstruction should be planned in patients with prior history of breast irradiation. The authors prefer to wait 6 months after the completion of radiation therapy prior to completing delayed reconstruction.
- Smoking status is also assessed.
- Additionally, tamoxifen should be held 2 weeks prior to surgery and 2 weeks after surgery.

IMAGING

- Patients considering PAP flap reconstruction should undergo preoperative imaging with either computed tomography angiogram (CTA) or magnetic resonance angiography (MRA) of the pelvis and lower extremity.
- Imaging is performed in the supine position and coordinated with the

radiologist for appropriate evaluation of images.

- Perforators should be described as they exit the deep muscular fascia and described based on location in an x-y axis. The gluteal fold will be set as zero on the y-axis, and the posterior border of the gracilis will be set as zero on the x-axis (**FIG 3**).

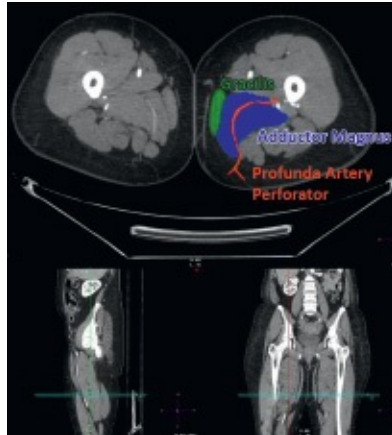


FIG 3 • CTA of the lower extremity identifying the location of the profunda artery perforator behind the gracilis traversing the adductor magnus toward the profunda femoris artery.

- The description of the perforator should include the size of perforator as it exits the fascia, length of course to the profunda femoris, distance from midline, and distance from gluteal crease. Additional information includes location of the perforator in relation to gracilis, adductor longus, adductor magnus, and semimembranosus.

SURGICAL MANAGEMENT

- The authors perform PAP flap on patients either undergoing immediate or delayed breast reconstruction.
- Additionally, this procedure can be performed on patients who required multiple flaps secondary to volume and skin deficit and require reconstruction in a stacked fashion.^{6,7} This includes both patients having immediate stacked reconstruction and patients who have autologous reconstruction that require secondary augmentation in a delayed fashion.
- Unilateral stacked PAP flaps have been described.⁸

- Bilateral stacked deep inferior epigastric artery perforator (DIEP) and PAP flaps have been described.⁶
- PAP and augmenting prior superior gluteal artery perforator flap has also been described.⁷
- The technique has been shown effective on patients with body mass index between 18.2 kg/m² and 38.7 kg/m², and flap weights have been shown between 172 and 695 g.^{4,7,9}
- The operation requires loupe magnification for perforator dissection and microsurgical instruments.
- Though the microsurgical anastomosis can be performed under loupe magnification, the authors prefer the use of the operative microscope.

Preoperative Planning

- Some surgeons prefer to mark the patients in the office on the day prior to surgery as the marking process is time-consuming.
- Patients are marked in the standing position (**FIG 4**).
- Based on preoperative images, a handheld Doppler can identify the main perforators. If marked in the standing position, these perforator markings may shift once positioned in the operating room. Therefore, similar to other perforator flap elevations, this step may be unnecessary.

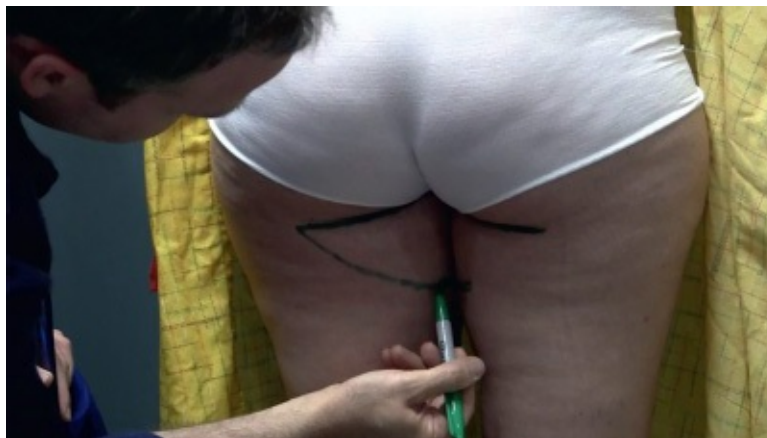


FIG 4 • Preoperative markings of profunda artery perforator flap. An elliptical incision starting medially at the adductor longus and laterally to the lateral edge of the gluteal crease. The flap measures 6 to 7 cm in width, and the perforators are identified with a handheld

Doppler and based on the distance from the gluteal crease and the distance from midline.

- The superior margin is marked at or approximately 1 cm below the gluteal crease.
- The inferior margin is marked 6 to 7 cm below the superior margin depending on perforator location and skin pinch.
- The horizontal markings are started laterally and carried medially in an ellipse to capture the perforators and traditionally extend 25 to 35 cm.
 - The medial border is the medial border of the adductor longus.
 - The lateral border is the lateral border of the gluteal crease.
- Additional fat that you would like to capture in the flap harvest should also be noted during marking.

Positioning

- Patient is positioned in the frog-leg position.
 - When initially described, patients underwent PAP harvest in the prone position and then flipped to the supine position, but authors have moved toward harvest in the supine position based on experience.
 - The entire leg is prepped and sterile sequential compression devices (SCDs) are routinely placed. This allows manipulation of the leg throughout the procedure.

Approach

- Routinely, a two-team approach is required.
 - One team performs recipient artery exposure, internal mammary artery and vein, thoracodorsal artery and vein, or serratus branches.
 - The second team performs flap harvest. This can be done either ipsilateral or contralateral depending on comfort.

TECHNIQUES

■ Profunda Artery Perforator Flap

Team 1

- Harvest of the flap proceeds in a medial to lateral fashion.
- The incision at the medial tip of the flap is made first. This is overlying the adductor longus muscle. The flap is raised going laterally in subcutaneous plane until the gracilis muscle is encountered. Gracilis perforators are often encountered and if so they should be transected. If large, they can be maintained until the PAP perforator is identified.
- The muscular fascia overlying the gracilis is incised vertically (in the direction of the muscle's fibers) at the lateral/posterior border of the gracilis and subfascial dissection continues (**TECH FIG 1**).
- The gracilis is then retracted anteriorly, and the fascia overlying the adductor magnus is identified and also incised.
- Dissection proceeds in a subfascial plane going laterally/posteriorly until the perforator is identified.
- Once the perforator is identified, intramuscular (adductor magnus) perforator dissection continues in a standard fashion.
- Dissection stops at the origin on the profunda femoral artery. Occasionally, dissection may be stopped earlier when the loose areolar plane at the end of the adductor magnus muscle is encountered. Here, the length and caliber of the vessels are usually adequate; however, you may dissect the perforator back to the origin on the profunda femoral artery if inadequate.¹⁰



TECH FIG 1 • Profunda artery perforator intramuscular dissection with staggered approach to maintain adductor magnus viability and function. This dissection was performed to the vessel origin.

Team 2

- Exposure of the recipient vessels proceeds in the standard technique.
- Rib-sparing and rib-sacrificing techniques have been described.¹¹

PEARLS AND PITFALLS

Physical findings

- Preoperative imaging and marking remains the most important part of the preoperative workup. Be careful with the height of the markings as this could create tension on the closure. Additionally, avoid extending the incision outside of the gluteal fold to maintain a well-hidden scar.

Technique

- Be prepared for the dominant perforator to be caudal within the adductor magnus.
- Pedicle dissection is often performed within a tunnel, and therefore, great care must be taken to identify and control posterior branches.
- If the perforator is deep in the adductor magnus, then a stair-step dissection can be performed from posterior and then a second dissection point anterior to the adductor magnus.

Postoperative

- Patients are maintained in a compression garment for the first month following surgery.

Complications

- Postoperative donor-site problems remain the most common complication.

POSTOPERATIVE CARE

- Patients routinely stay in the hospital for 3 to 4 days postoperatively.
- Patients are monitored in a flap unit for the first 48 hours with q 1 hour vascular checks.
- Patients have routine transcutaneous Doppler checks, and monitoring can be further augmented by other technologies based on surgeon preference.
- Postoperatively, sitting is initiated on POD no. 1 in a beach-chaired position.
- Patients are discharged home on postoperative aspirin for 30 days.

OUTCOMES

- Outcomes of breast reconstruction with PAP flap are superior. The flap allows for great coning of the breast as well as a soft contour on the chest. Patients

who have an abundant posterior thigh tissue and small breasts are the best candidates for this type of reconstruction. The mean flap weights for this type of reconstruction are in the mid-400 g (**FIGS 5** and **6**).

- The new breast has the shape and feel of a natural breast.
- The PAP flap offers a successful reconstruction in 97.1% to 99.4% of patients.

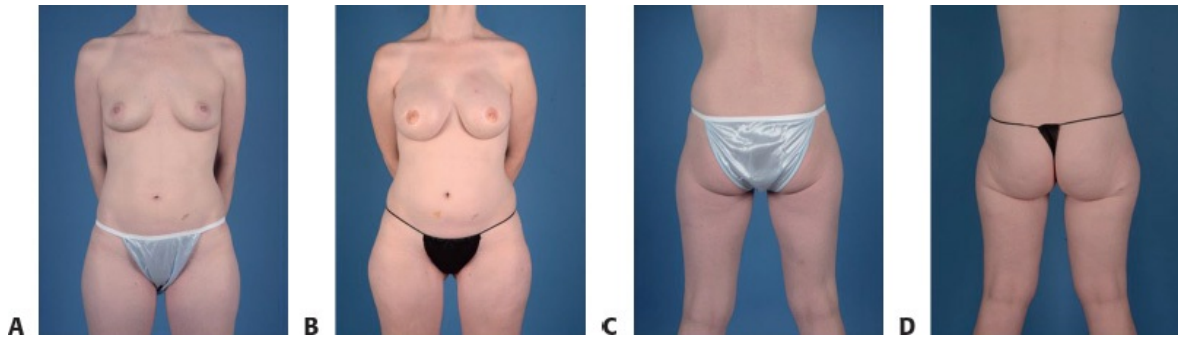


FIG 5 • A 39-year-old female with history of left breast cancer who underwent bilateral mastectomy and bilateral profunda artery perforator flap followed by nipple reconstruction and tattooing. **A.** Preoperative AP photo. **B.** Postoperative AP photo. **C.** Preoperative posterior view. **D.** Postoperative posterior view.

COMPLICATIONS

- Hematomas can occur in either the thigh donor site or the breast. They occur in 1% to 2% of patients.^{7,9} If a hematoma occurs in the breast, concern for venous congestion of the flap should be raised. Patients require reoperations for hematomas in both the breast and the thigh donor site due to concern for infection and direct pressure necrosis of the skin.
- Total flap loss is a dreaded complication of breast reconstruction with PAP flap. Fortunately, the reported incidences of total flap losses have been seen between 0.6% and 2.9% of flaps.^{7,9} These complications can be associated with arterial or venous thrombosis or difficulty with perforator dissection. Prompt take back to the operating room is required for either revision of arterial anastomosis or venous anastomosis in the cases of arterial or venous insufficiency. These complications usually present in the first 24 to 48 hours.
- Fat necrosis in fasciocutaneous flaps for breast reconstruction is commonplace. In PAP flap reconstruction, the incidence has been reported

between 1.3% and 7.0%.^{7,9} Treatment of fat necrosis is variable and can include revision with direct excision or liposuction.

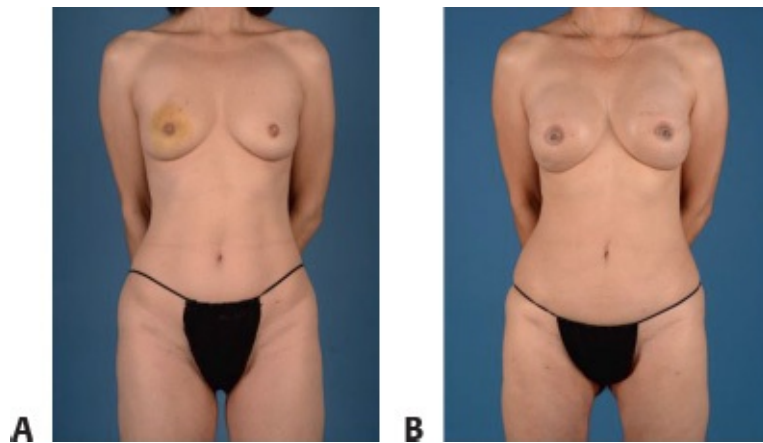


FIG 6 • A 44-year-old female with history of right breast cancer s/p bilateral nipple-sparing mastectomy and immediate reconstruction with profunda artery perforator flap. **A.** Preoperative AP view. **B.** Postoperative AP view.

- The most common complication associated with PAP flap breast reconstruction remains donor-site complications. Dehiscence of the closure as well as infection can occur at the donor site and occurs between 3.6% and 8.2% of donor sites. Treatment of these complications ranges from healing by secondary intention to revision of donor-site scar closure in a secondary procedure.

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28 Transverse Upper Gracilis Flap for Breast Reconstruction

CHAPTER

Adeyiza O. Momoh

DEFINITION

- The transverse upper gracilis (TUG) flap is a medial thigh–based musculocutaneous flap option for breast reconstruction.
- It serves as a second- or third-line autologous flap option in patients who lack abdominal donor tissue necessary for breast reconstruction (**FIG 1**).
- The TUG flap is typically used to reconstruct small to moderate-sized breasts based on limitations of medial thigh soft tissue volume.

ANATOMY

- The flap is based on the medial circumflex femoral vessels, which branch off the profunda femoris vessels.
- The ascending branch of medial circumflex femoral reliably perfuses the gracilis muscle and skin/adipose tissue of the upper medial thigh, extending from just medial to the femoral neurovascular bundle to the midline of the posterior infragluteal region.
- The flap pedicle is located at the anterior border of the gracilis and can be found approximately 8.5 cm inferior to the pubis.¹
- The pedicle length is relatively short averaging 6.7 cm, with an average arterial diameter of 2.2 mm and average venous diameter of 2.3 mm.
- Anterior to the gracilis muscle, the pedicle runs deep to the adductor longus muscle and comes off the profunda femoris just anterior to the adductor longus.
- A transverse skin paddle measuring 30 × 10 cm is possible²; a vertical skin paddle extension positioned directly over the central aspect of the gracilis can be included to gain additional volume¹ (**FIG 2**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed medical history is necessary given that there is a potential for a lengthy operation under general anesthesia.
- The surgeon should be aware of all medications that might have an impact on the operation and recovery such as anticoagulants, tamoxifen, and chemotherapeutic medications; also important to assess is the patient's smoking history and the presence of hypercoagulable conditions.
- The history should then focus on details of the patient's breast pathology and reasons for mastectomy. This should also include information on neoadjuvant or planned adjuvant treatment following mastectomy in the setting of immediate reconstruction.
- Prior treatments to the breast and chest wall including radiation therapy and the time from the last treatment should be discussed in cases of delayed breast reconstruction.

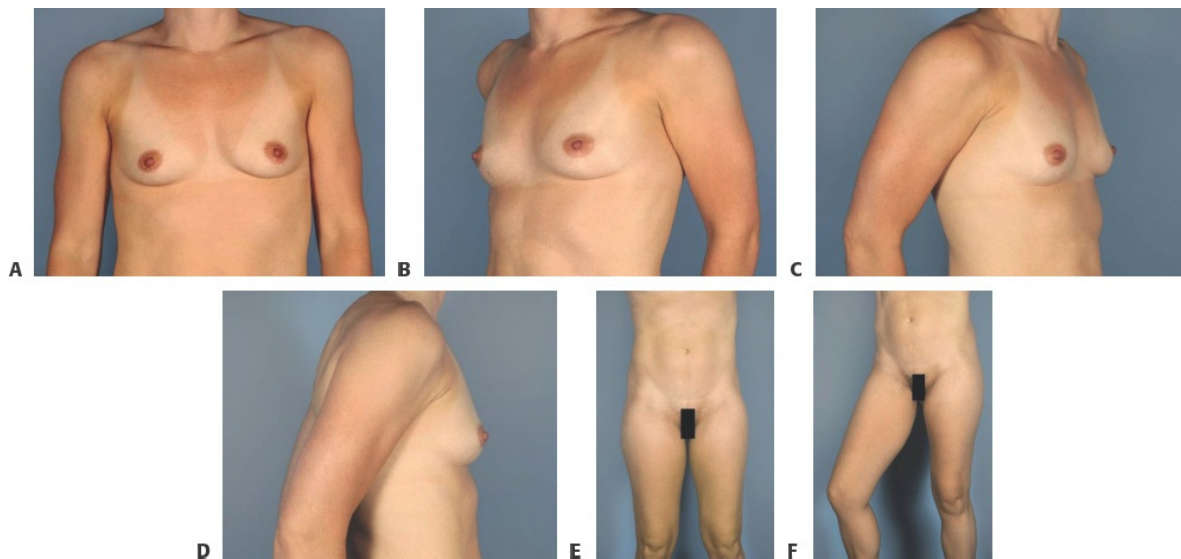


FIG 1 • A–F. Patient with left breast cancer who is to undergo bilateral mastectomies with immediate autologous breast reconstruction. She has limited tissue for an abdominal-based flap reconstruction. Her thigh soft tissue is a good option for small-sized breast reconstructions.

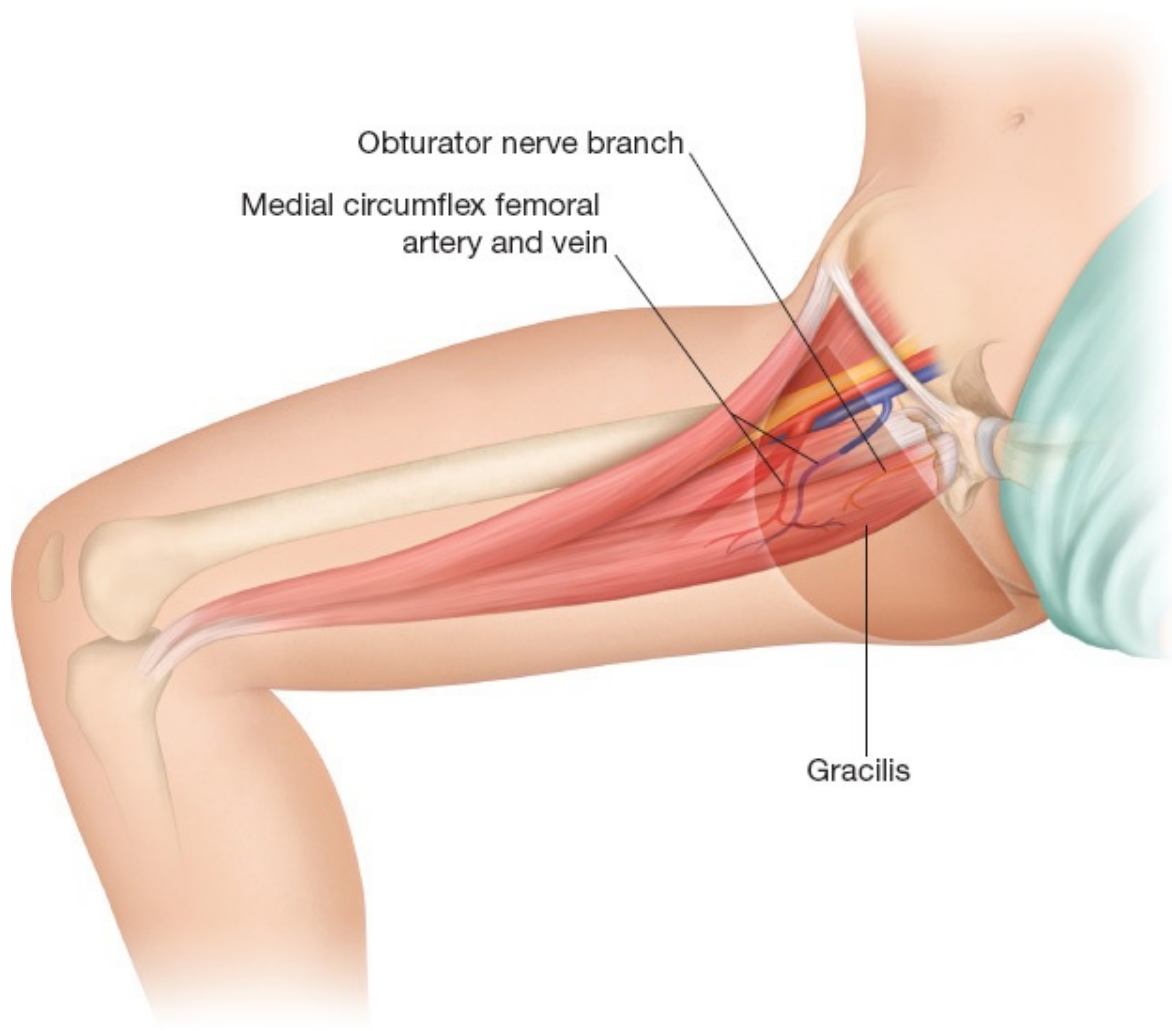


FIG 2 • Illustration demonstrating the flap skin paddle design and vascular anatomy.

- Information on prior operations to the chest or breast and the potential donor sites (in this case the thighs) should be elicited.
- In addition to the breast examination assessing breast size, degree of ptosis, and base width, the patient should be asked about her desired breast size postreconstruction.
- With an appreciation of the patient's desired size, the medial thighs/posterior thigh can be assessed, palpating and gently pinching to determine the possibility of achieving the desired volume.

IMAGING

- There is limited value to routine preoperative imaging of recipient vessels or

the flap vasculature in the absence of a history that suggests potential compromise. CT angiography is currently the imaging modality of choice for recipient or donor-site vascular studies.

SURGICAL MANAGEMENT

- The author performs immediate breast reconstruction with two teams, the oncologic and reconstructive team, working simultaneously. Flap harvest is performed while the mastectomies are performed.
- The goal of the first operation is the free tissue transfer to establish the breast mound. In cases of unilateral breast reconstruction, contralateral procedures for symmetry are performed in a subsequent procedure.

Preoperative Planning

- Appropriate referrals and consultations should be made for clearance and patient optimization prior to surgery based on the history and physical.
- The risks and benefits of breast reconstruction using tissue from the medial thighs should be discussed, including the risk for flap loss, medial thigh scars that drift low onto the thighs and that could widen.
- Preoperative markings of the breasts and thighs are performed prior to returning to the operating room.
- Markings of breast landmarks including the midline and inframammary folds and the planned incisions for mastectomy are performed with the patient sitting.
- The thighs are marked with the patient standing to visualize the inguinal and gluteal crease. The patient also externally rotates the thigh to aid with the markings. The upper marking is approximately 1 cm inferior to the inguinal and gluteal crease. A pinch test is performed just posterior to the gracilis to determine how far inferior the lower marking can be made over the medial thigh. This marking extends anterior and posterior, tapering to end medial to the femoral neurovascular bundle (anteriorly) and the midline of the posterior thigh.

Positioning

- The entire procedure is performed with the patient in supine position. The arms are extended and secured to arm boards.
- To aid with space for the two-team approach, the operating table is turned 180 degrees such that the patient's head is furthest from the anesthesiologist.

Approach

- Flap harvest is performed from an anterior to posterior approach, and the hips are flexed and externally rotated (frog legged) for portions of the case as needed (**FIG 3**).



FIG 3 • Positioning of the hip in flexion and external rotation to provide exposure of the medial thigh for flap harvest.

TECHNIQUES

■ Flap Harvest

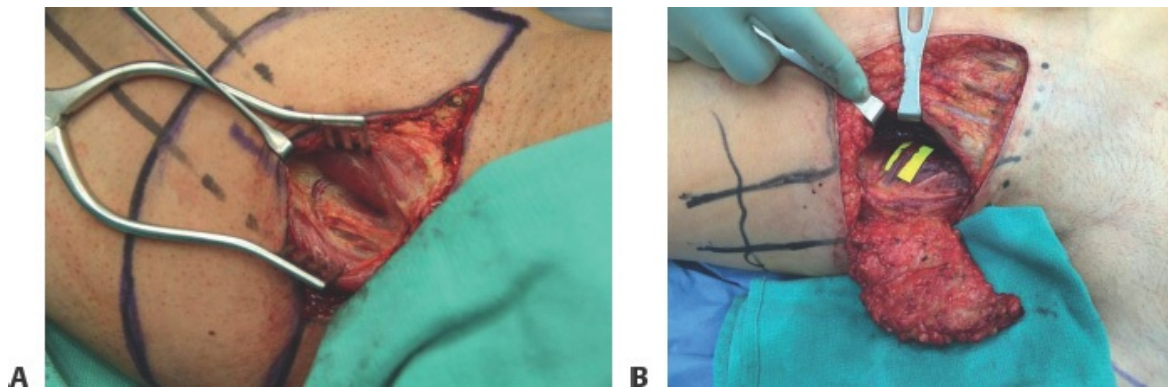
Dissection

- An incision is made along the anterior half of the superior skin paddle markings.
- Bovie electrocautery is then used to dissect through the dermis and subcutaneous tissue down to the muscles of the medial thigh. The gracilis muscle and the adductor longus (just anterior to the gracilis) are identified.
- Once the gracilis is identified, dissect inferiorly along its anterior border to identify the circumflex femoral vessels (**TECH FIG 1A**).
- With identification of the vascular pedicle, the inferior skin paddle incision for the anterior half of the flap is completed with a scalpel. A Bovie is then used to dissect down to the muscle fascia inferiorly.

- The flap is then elevated from anterior to posterior in the suprafascial plane until the saphenous vein is encountered. The saphenous vein is preserved and the dissection plane deepened posterior to the vein and over the adductor longus muscle.
- At the anterior border of the gracilis, the adductor longus muscle is retracted anteriorly with Army-Navy retractors, and dissection of the vascular pedicle identified earlier is performed.
- Vessel branches from the pedicle to the underside of the adductor longus are isolated, ligated with clips, and divided (**TECH FIG 1B**).
- Additional dissection of the flap pedicle is performed from the anterior border of the adductor longus, exposing the pedicle all the way to the profunda femoris.

Flap Elevation

- With the flap pedicle completely dissected out, elevation of the posterior half of the skin paddle can then be performed.
- The hip is flexed providing exposure of the posterior thigh, and incisions along the superior and inferior markings for the posterior half of the flap are made.
- A Bovie is then used to elevate the flap from the posterior toward the anterior aspect of the flap. All fat superficial to the semimembranosus and semitendinosus muscles is captured from the posterior thigh region, which is where most of the volume of the flap resides.
- Elevation over the adductor magnus to the posterior border of the gracilis ends the posterior flap elevation.
- Dissection underneath the gracilis muscle is then performed bluntly.
- Suprafascial dissection over the gracilis is performed distally toward the knee for the desired length of the gracilis to be harvested with the flap.
- On the more distal anterior border of the gracilis, the minor pedicle to the gracilis is identified, ligated with hemoclips, and divided.
- The gracilis is then divided distally underneath the medial thigh skin and proximally through the superior incision.
- At this point, the flap is fully elevated and only tethered to the thigh by its vascular pedicle (**TECH FIG 2**).
- The artery and veins (two venae comitantes) are ligated with clips just distal to the takeoff from the profunda femoris, and the vessels are divided with tenotomy scissors.



TECH FIG 1 • **A.** Early identification of the circumflex femoral vessels through a limited superior incision prior to proceeding with additional incisions and flap elevation. **B.** Isolation of the length of the circumflex femoral vessels as they run underneath the adductor longus muscle (retracted).



TECH FIG 2 • Fully elevated flap with division of the proximal and distal gracilis muscle.

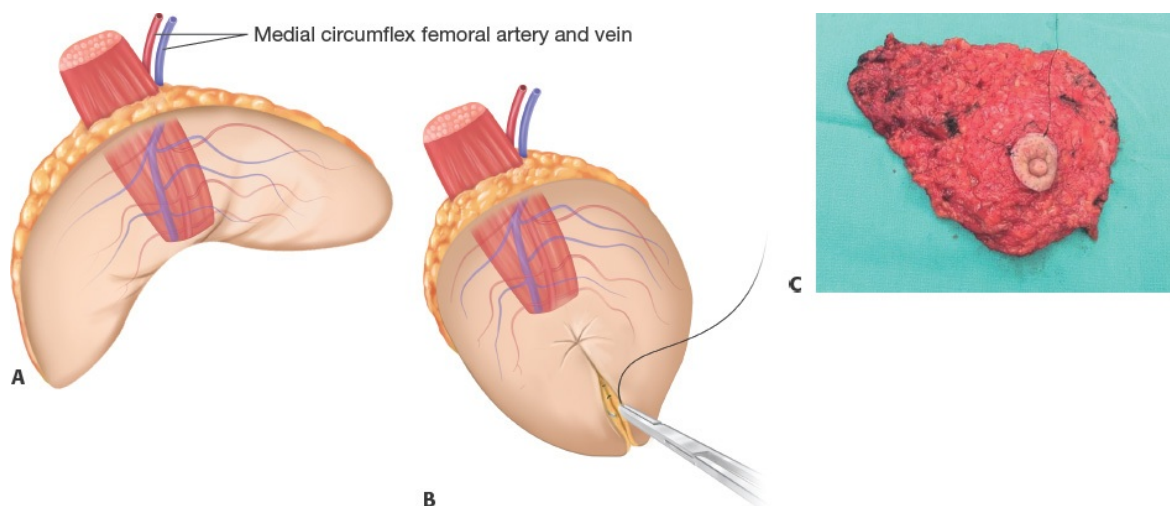
Flap Preparation and Placement

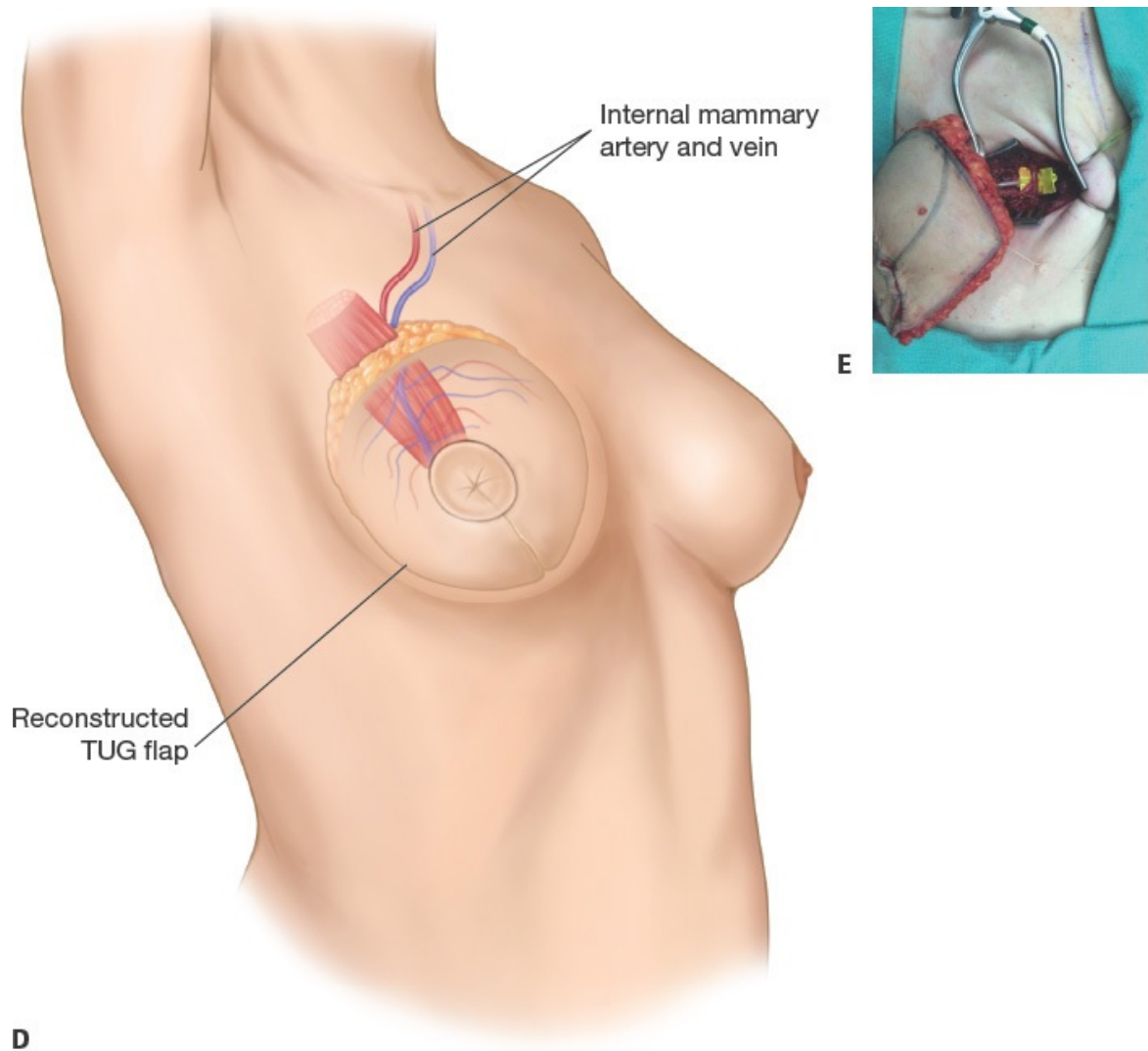
- The flap is taken to a back table, where it is flushed with copious amounts of heparinized saline from the arterial end.
- Shaping of the flap is then performed on the back table, folding the superior border of the skin flap on itself and creating a circular-appearing flap (**TECH FIG 3A–C**).

- Flap skin edges are approximated with interrupted deep dermal sutures.
- The internal mammary vessels (the author's preferred recipients) are exposed with excision of the medial cartilaginous segment of the 3rd or 4th rib (see chapter on recipient vessel exposure).
- The flap is positioned on the chest wall such that the gracilis muscle will be inset in the superior pole of the breast. The flap is temporarily secured to the chest wall skin with Vicryl sutures (**TECH FIG 3D,E**).
- With the aid of an operating microscope, the veins are coupled and the arteries hand-sewn in an end-to-end fashion.
- Once reperfused, the flap is advanced into the mastectomy defect and secured to the pectoralis fascia with interrupted Vicryl sutures to avoid traction on the short pedicle.

Completion

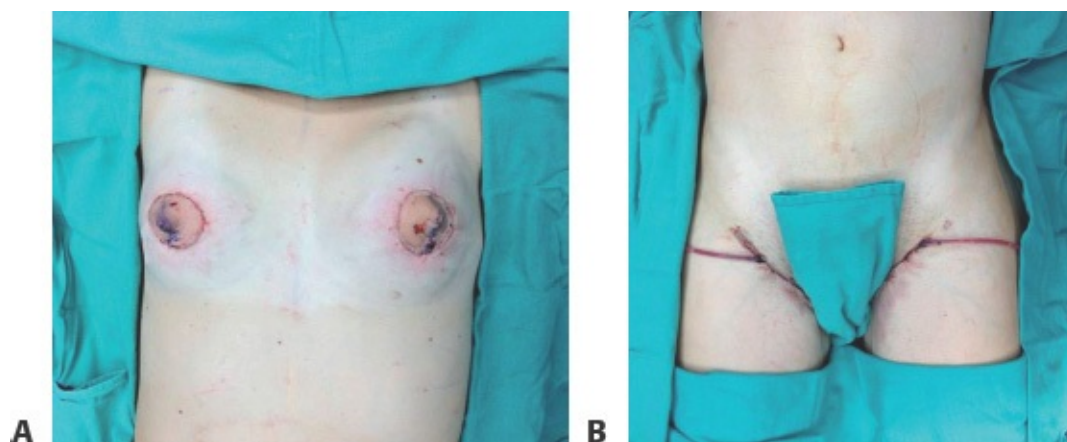
- De-epithelialization of the flap skin is performed as needed, a drain is placed within the mastectomy defect, and skin edges are approximated in layers.
- A Doppler signal is identified and marked with a 5-0 Prolene suture.
- The donor site is then irrigated and a drain is placed in the upper thigh defect.
- Closure of the thigh donor site is performed in layers. Colles fascia (superiorly) is approximated to the deep fascia of the skin flap at the inferior border of the defect. The deep dermis and subcuticular layers are then approximated (**TECH FIG 4**).
- Skin glue is then applied to the donor-site incision to minimize dressings that have to be placed in this region of the thighs.





D

TECH FIG 3 • A–C. Shaping of the harvested flap to create a circular and conical mound that mimics the excised breast tissue. **D,E.** An option for positioning of the shaped flap on the chest wall for the microvascular anastomosis. The flap is placed within the mastectomy defect in this orientation with the distal gracilis muscle placed in the upper pole of the breast.



TECH FIG 4 • A,B. On table result after inset of flaps and closure of thigh donor sites.

PEARLS AND PITFALLS

Harvest technique

- Early identification of the gracilis and the flap pedicle through the superior incision allows for rapid subsequent flap elevation.

Microsurgery

- As the flap pedicle is relatively short, plan on providing exposure of at least the entire length of the internal mammary vessels between two adjacent ribs.
- To address the expected arterial size mismatch (medial circumflex femoral artery smaller than the IMA), consider exposure of the IMA at the 4th rib instead of the 3rd.
- Plan on spatulating the flap artery to account for the size mismatch.

Donor site

- Efforts should be made to anchor the inferior thigh skin flaps to the Colles fascia to avoid inferior scar migration and widening.

Skin paddle

- The TUG flap skin paddle is at times darker than breast skin and may grow hair in some patients.
- The darker color may obviate the need for tattooing in cases of immediate reconstruction where the skin paddle is used for nipple reconstruction.
- Laser therapy might be needed to limit hair growth.

POSTOPERATIVE CARE

- The head of the bed and consequently the patient's breasts are placed in slight elevation of 30 degrees or greater.
- Patients are transferred from the OR to the postanesthesia care unit and subsequently to a surgical floor where monitoring can be performed.
- Prior to leaving the operating room, flap monitoring is initiated with continuous near-infrared spectroscopy (NIRS) tissue oximetry. This is continued for 72 hours postoperatively.
- Serial Doppler assessments are also performed in addition to standard flap physical examinations (color, temperature, capillary refill) every hour for the first 24 hours. Flap evaluations are then spaced out to every 2 hours and 4 hours on postoperative days 2 and 3, respectively.
- Daily aspirin and DVT prophylaxis (subcutaneous injections) are the only forms of anticoagulation used routinely.
- Diet is advanced from clear liquids to a regular diet on postoperative day (POD) 1 with restrictions to caffeine intake.
- Patients are assisted out of bed to a chair on POD 1 and ambulate on POD 2; Foley catheters, intravenous fluids, and medications are discontinued on POD 2.
- Patients are discharged home on POD 3 to POD 5 with outpatient follow-up scheduled a week after discharge.

OUTCOMES

- Success rates ranging from 96% to 100% have been reported in larger series in the literature.²⁻⁵
- Soft and aesthetically pleasing breast reconstructions are achieved with the TUG flap (**FIG 4**).
- A good number of flaps, however, require some fat grafting to address contour abnormalities and volume deficiencies (**FIG 5**).
- Satisfaction with TUG flap reconstructed breasts from the patient's perspective is high; patient satisfaction with the donor site is similarly high, even when scars are visible⁵ (**FIG 6**).

COMPLICATIONS

- Thigh donor-site wound dehiscence, delayed wound healing, and suture fistulae are common complications, particularly when the limits of skin paddle width are pushed.⁵
- Inferior displacement of donor-site scars results in scars that cannot be hidden

(**FIG 7**); revisions might be necessary to reposition scars, anchoring the soft tissue to Colles fascia or the periosteum of the pubis.

- Pain along the scar, posterior thigh hypesthesia, and traction on the labia majora are also noted donor-site complications that have an impact on quality of life and sexuality.⁵
- Donor-site seromas are possible with disturbance of the upper thigh lymphatics but can be avoided by staying medial to the neurovascular bundle with the anterior flap elevation.

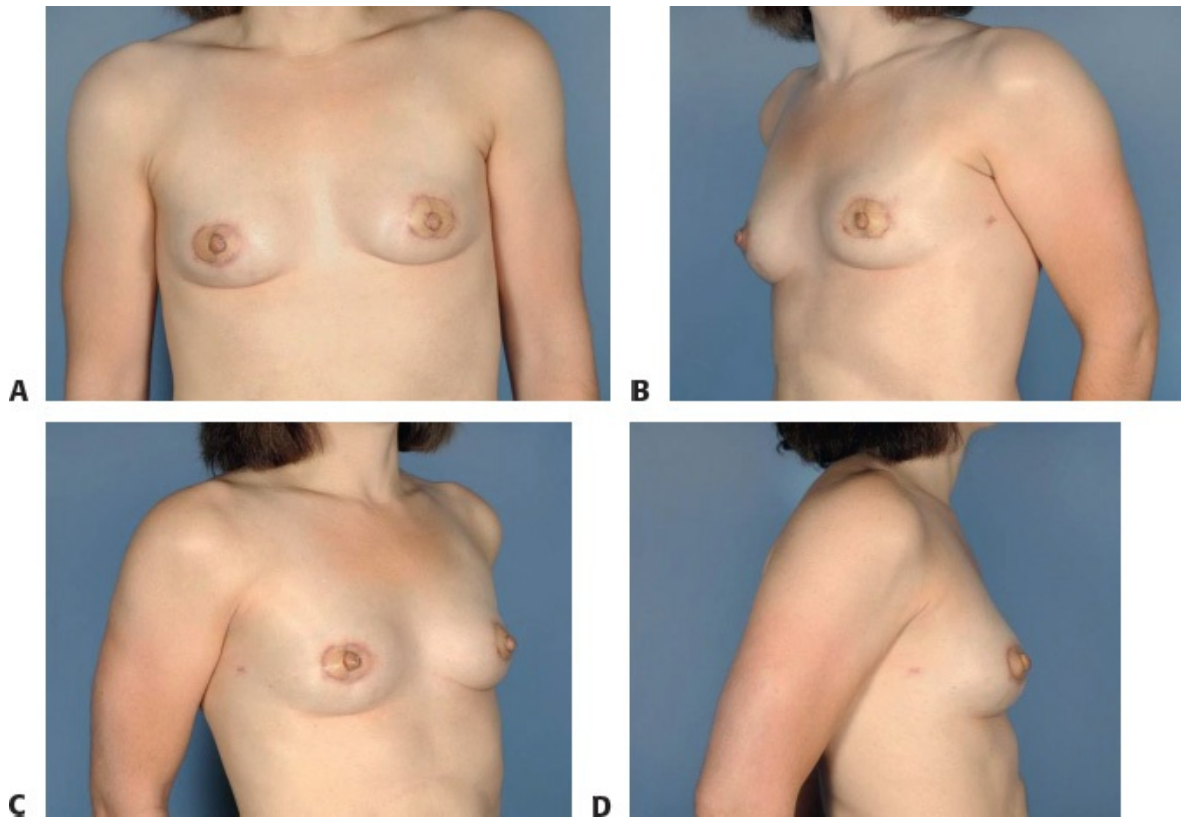


FIG 4 • A–D. Postoperative result after immediate TUG flap reconstruction with subsequent fat grafting and nipple reconstructions.

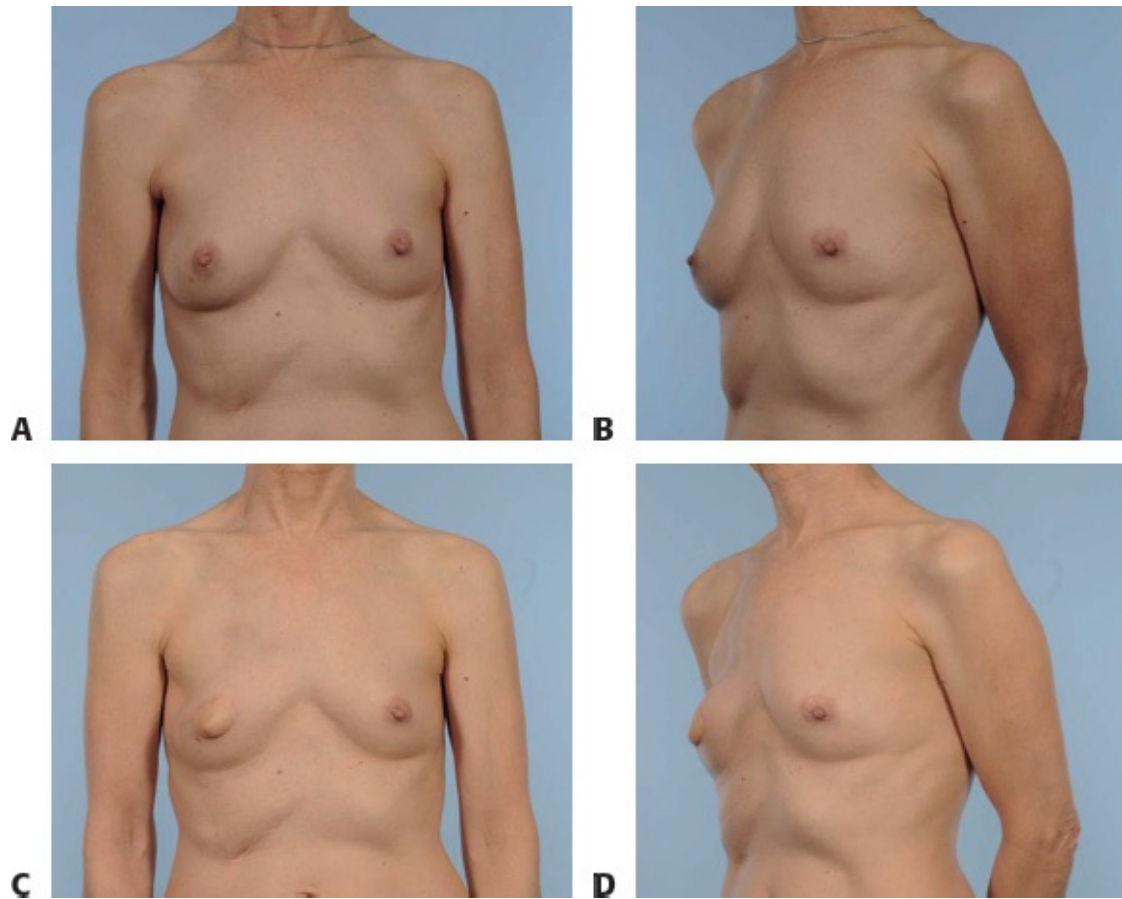


FIG 5 • A–D. Patient with right breast cancer who underwent a right mastectomy with immediate TUG flap reconstruction. Volume deficiencies at the superior and superolateral poles of the breast will require autologous fat grafting.

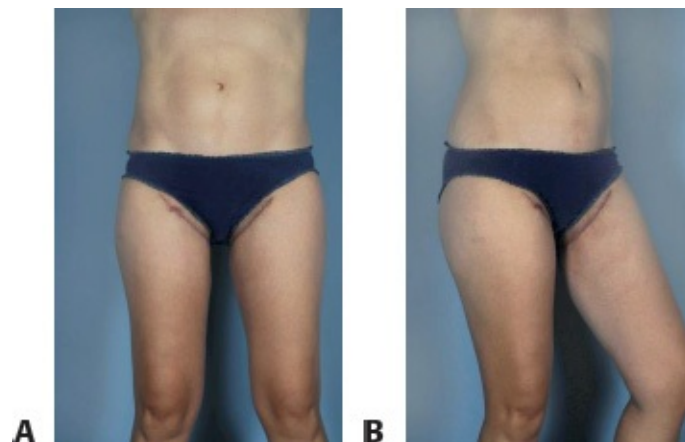


FIG 6 • A,B. Upper thigh donor-site scars that are visible in undergarments.

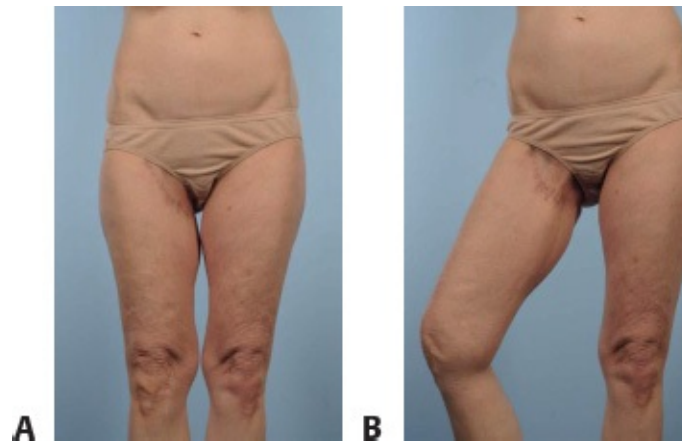


FIG 7 • A,B. Significant inferior displacement of an upper thigh donor-site scar.

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29 Skate Flap for Nipple Reconstruction

CHAPTER

Katie E. Weichman

DEFINITION

- Nipple-areolar reconstruction is the final stage of postmastectomy reconstruction. This procedure has been shown to positively influence overall satisfaction with breasts and outcomes in several series and transforms the mound to a breast.^{1,2}
- The skate flap is a commonly performed technique in both implant and autologous reconstruction.
 - This local flap was first described by J. W. Little in 1994 for nipple reconstruction after mastectomy and breast reconstruction.
 - Further modifications of this flap have been described by Cordeiro for primary use in implant reconstruction and Hammond for use in autologous reconstruction.^{3,4}
 - Although there are several additional iterations of the skate flap, the author prefers these two techniques.
- The Cordeiro modification to the skate flap has two main advantages.
 - It avoids elevating the body of the flap with a central wedge of subcutaneous fat as initially described by Little. The central wedge of subcutaneous fat creates a defect that requires primary closure, resultant fat undermining, and significant deformation of the remaining areola. The Cordeiro technique incises through only the epidermis, dermis, and subcutaneous fat without any undermining, resulting in a central subcutaneous stalk for volume without a secondary defect.
 - A tripoint stitch to the dermal platform is used when the two skate wings are sutured together at the 6 o'clock position.
- Hammond's modification to the skate flap provides the ideal nipple

reconstruction for autologous reconstruction. This technique provides a nipple with adequate bulk and long-term projection but uniquely allows for primary closure of the donor site with minimal distortion of the breast.

- This technique requires experience with the purse-string technique in breast reduction and mastopexy.

ANATOMY

- The skate flap is a local flap with a pedicle of epidermis, dermis, and subcutaneous fat centered at the site of the desired future nipple. The skate flap is named based on skin flaps that are shaped like wings of a skate fish (**FIG 1**).
- Blood supply
 - Subdermal plexus
 - Subcutaneous plexus

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients undergoing skate flap nipple reconstruction have reached the end of the reconstructive process.
- Indications: A history of breast cancer requiring mastectomy, prophylactic mastectomy, congenital abnormalities, and transgender patients who have had mastectomy with complications associated with silicone injection
- History of radiation therapy or need for further radiation therapy should be considered when deciding timing of nipple reconstruction.
- Patients should not be actively smoking for at least 3 months prior to surgery.
- Patients should have a final breast mound without need for further revision.
- Nipple reconstruction should be performed when the breast has taken its final form and has adequately settled to prevent malposition.
 - This timing is least 3 months to 6 months after either the direct to implant reconstruction, tissue expander exchange for implant, or the autologous reconstruction. All revisions of the breast mounds should be performed prior to nipple reconstruction.
 - Revision of autologous reconstruction can often be performed synchronously with nipple reconstruction; however, assuring correct nipple position can be more challenging with an increased incidence of nipple malposition requiring further revision.

SURGICAL MANAGEMENT

- The authors perform skate flaps for nipple-areolar reconstruction when the

nipple-areolar complex is absent.

- Patients who desire larger nipples and agree to harvest of full-thickness skin graft from a secondary donor site (abdomen, inner thigh, or lateral chest wall roll) should be considered for the Cordeiro modification. Patients with autologous reconstruction should be considered for the Hammond modification.

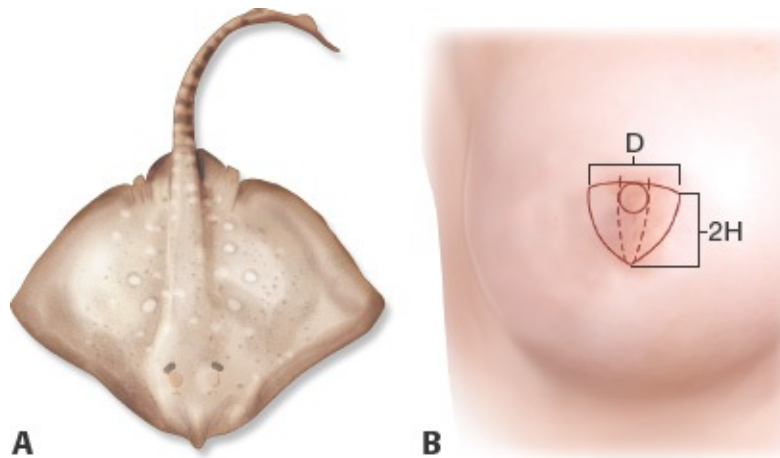


FIG 1 • A. Skate fish. **B.** Skate flap centered on breast mound. D represents the diameter of nipple and pedicle of nipple; H represents the desired height of the nipple. The length of the flap wings measures at least 3D, and the height of wings measures 2H.

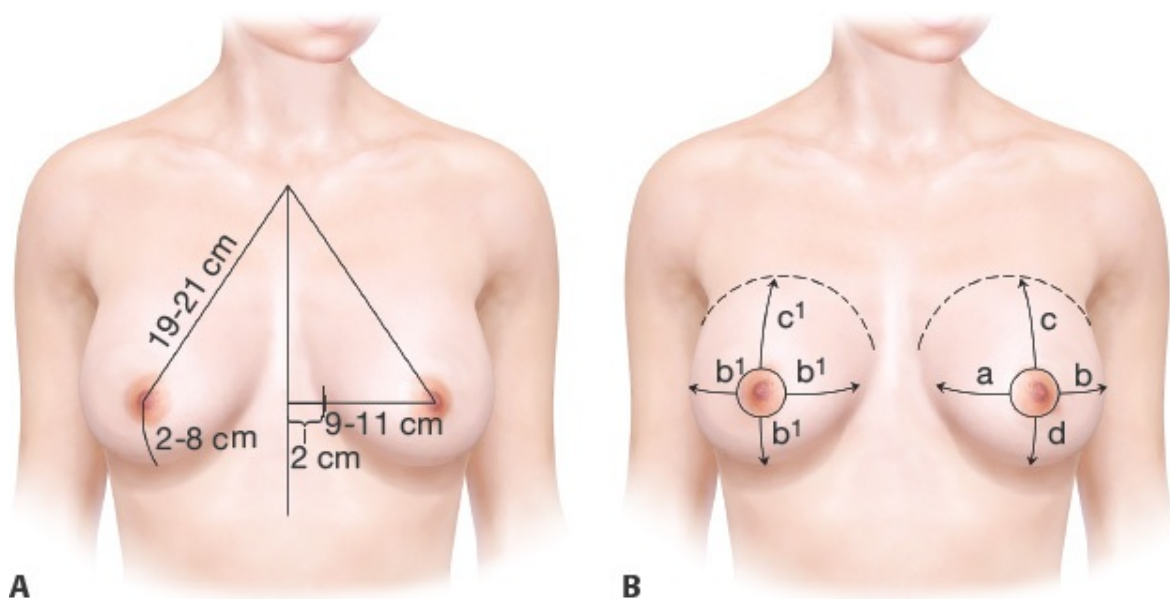


FIG 2 • A. Traditional landmarks for nipple position. Sternal notch to nipple distance of 19 to 21 cm. Distance from midline to nipple measuring 9 to 11 cm. Distance from nipple to inframammary fold measuring 7 to 8 cm. **B.** Ideal nipple position in asymmetric breasts. Maintain ratios of nipple in relation to the medial breast border, lateral breast border, inframammary fold, and superior breast extent.

- A 50% reduction of the nipple projection should be anticipated, and therefore, skate flap should be designed accordingly based on patient preference and contralateral nipple size in unilateral reconstructions.^{5,6}

Preoperative Planning

- Patients are marked in the standing position with shoulders relaxed in the preoperative holding area.
- Nipple position should be centered on the breast at the point of maximal convexity and projection. Additionally, it should be symmetric to the contralateral nipple in unilateral reconstructions. In bilateral reconstructions, nipple position is often easier to match, and the location is less critical as long as it is symmetric and located on the center of the breast.
- Specific landmarks are often helpful in determining the correct position of the nipple-areolar complex on the breast. These include the level of the contralateral nipple-areolar complex, the position at the Pitanguy point (reflection of the inframammary fold), and triangle from the sternal notch to nipple/midsternal line (**FIG 2A**).
- When breasts are asymmetric, the surgeon should try to maintain the ratios of the nipple to the breast footprint. This includes midline, lateral breast, superior breast, and inframammary fold (**FIG 2B**).

Positioning

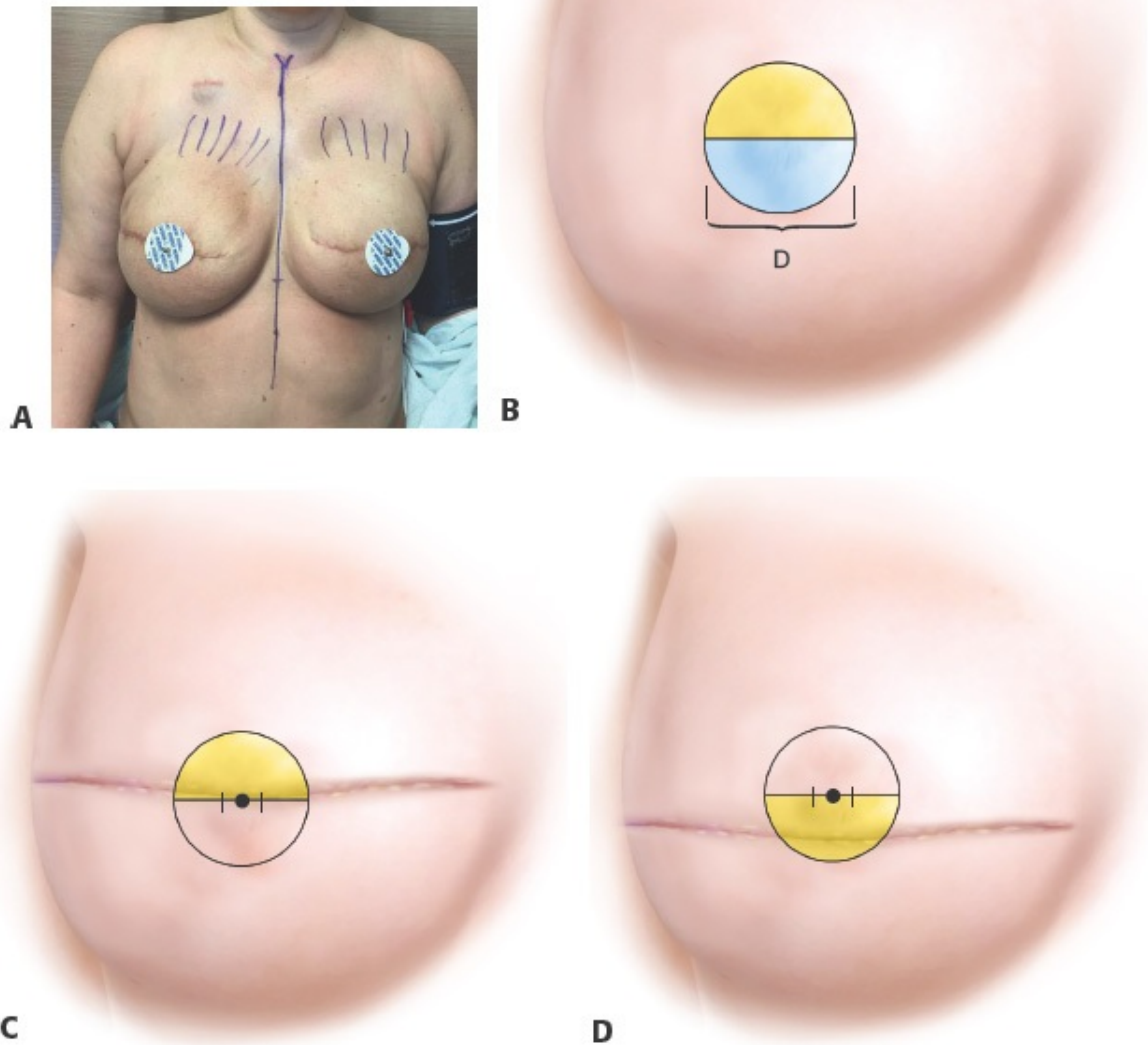
- The patient is positioned in supine position. Surgery should be performed in the operating room because a full-thickness skin graft is needed to cover the nipple site.

TECHNIQUES

■ Cordeiro Modification of the Skate Flap

Flap Design

- Generally, the desired diameter of the nipple is designed to be 1 cm. The nipple is marked based on the above guidelines and is confirmed by both the surgeon and the patient as being in an acceptable position.
 - The use of an EKG lead, as a surrogate for the nipple-areolar reconstruction, is routinely used in the preoperative area (**TECH FIG 1A**).
- In unilateral reconstruction, the diameter of the areolar is matched to the contralateral breasts and is generally 38, 42, or 48 mm. A cookie cutter template is used to create a perfect circle (**TECH FIG 1B**).
- In bilateral reconstruction, choice between 38 and 42 mm is made by the surgeon and patient, and the cookie cutter template is used to create a perfect circle.
- The axis of the skate flap is designed so that the mastectomy scar does *not* cross either the wings or body of the flap.
- A horizontal line is then drawn cephalad or cranial to the desired nipple location depending on the mastectomy scar to form a semicircle that will be de-epithelialized and the opposite semicircle that will be used to construct the skate flap.
 - Based on this, the nipple reconstruction will be superiorly or inferiorly oriented based on the mastectomy scar (**TECH FIG 1C,D**).
- The body of the skate flap is the 1- x 1-cm square outlining the nipple centrally.
- The wings of the skate flap are the two triangles just outside the body peripherally.
- Full-thickness skin graft is designed using the same 38-, 42-, or 48-mm cookie cutter template used in skate flap design.
 - Donor sites include groin, abdomen, and lateral chest wall dog-ear. The groin has been shown to have the best areolar color match; however, donor site can be unacceptable to some patients.⁴

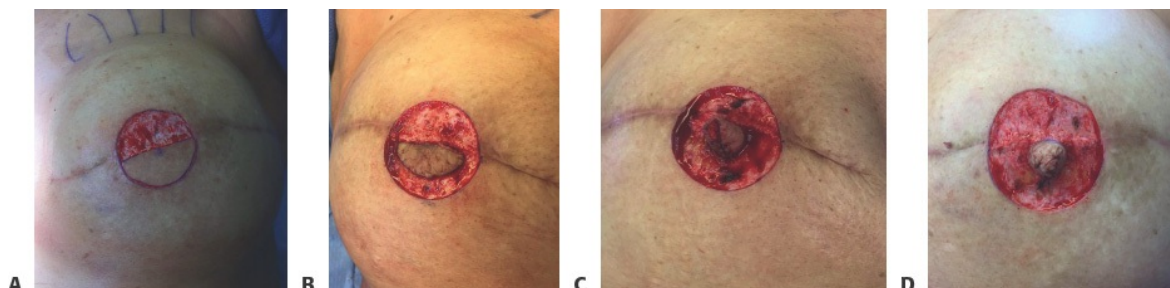


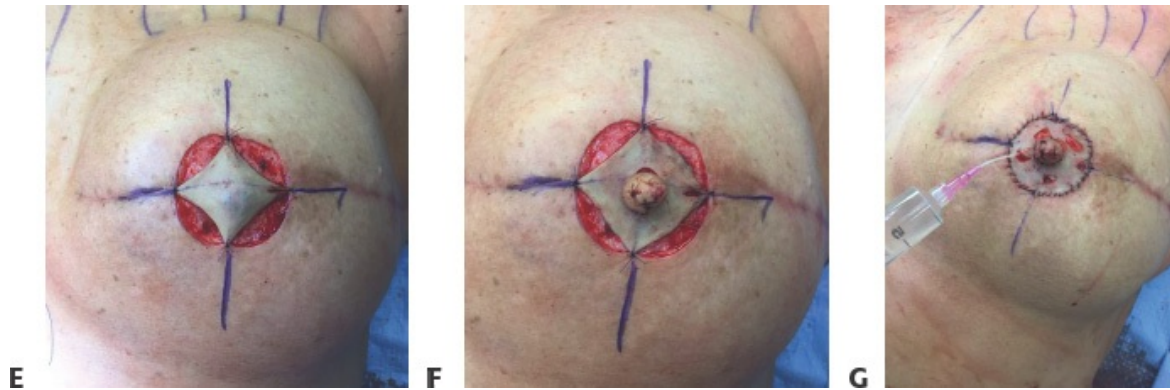
TECH FIG 1 • **A.** Preoperative use of ECG leads to confirm desired nipple-areolar position. **B.** Design of Cordeiro modification of the skate flap. Nipple position is marked with 1-cm diameter circle at the appropriate point. D represents the diameter of the areola, and the areolar is marked using a cookie cutter template of appropriate size (38, 42, or 48 mm) based on contralateral side. Base of the flap is the 1-cm

representation on the line cranial to the nipple measuring the diameter of the circle. The superior semicircle (yellow) is de-epithelialized, and the inferior semicircle (blue) is elevated in the subcutaneous plane to become the skate flap. **C,D.** Position of nipple-areolar complex in relation to mastectomy scar. (C) Cranial scar position resulting in superiorly based skate flap. (D) Caudal scar position resulting in inferiorly based skate flap.

Elevating and Insetting the Flap

- The semicircle that is opposite the base of the skate flap is incised and de-epithelialized (**TECH FIG 2A**).
- The wings of the skate flap are then incised and raised in the deep dermal plane until the peripheral margin of skate body is reached and then the plane is deepened into the subcutaneous plane (**TECH FIG 2B**).
- Subcutaneous fat is included to improve nipple projection.
- Once the skate body is fully elevated, the wings of the skate flap are wrapped around the skate body to form a cylinder 1 cm in height, with a diameter of 1 cm, using 4-0 chromic sutures (**TECH FIG 2C**).
- The cap of the nipple is then closed, and excess dog-ears are excised and closed using 4-0 chromic sutures (**TECH FIG 2D**).
- Full-thickness skin graft is marked in situ to proper positioning of 12, 3, 6, and 9 o'clock and the center of the graft.
- Adequate preparation and thinning of the full-thickness skin graft is necessary for complete skin graft take.
- The full-thickness skin graft is then sewn down onto the areolar bed using a running 5-0 Prolene suture (**TECH FIG 2E**).





TECH FIG 2 • Intraoperative steps of skate flap elevation. **A.** De-epithelialization of superior hemicircle. **B.** Raising skate flap wings in subcutaneous plane. **C.** Wrapping of skate flap wings to create the nipple. **D.** Folding cap over nipple and trimming of lateral dog-ears. **E.** Securing full-thickness skin graft into place over areolar bed. **F.** Delivery of nipple through areolar skin graft. **G.** Irrigation with angiocatheter under pie-crusted full-thickness skin graft.

- A circular hole is then made in the center of the skin graft to allow the delivery of the nipple through the areolar graft (**TECH FIG 2F**).
- The nipple is then sewn down to the graft with 4-0 chromic suture.
- Pie crusting of the graft is then performed with either small sharp scissors or a no. 11 blade scalpel.
- Irrigation with saline and a flexible 20-gauge angiocath is then performed to remove any debris (**TECH FIG 2G**).
- A bolster-type dressing is created and placed.

■ Hammond Modification of the Skate Flap

Flap Design

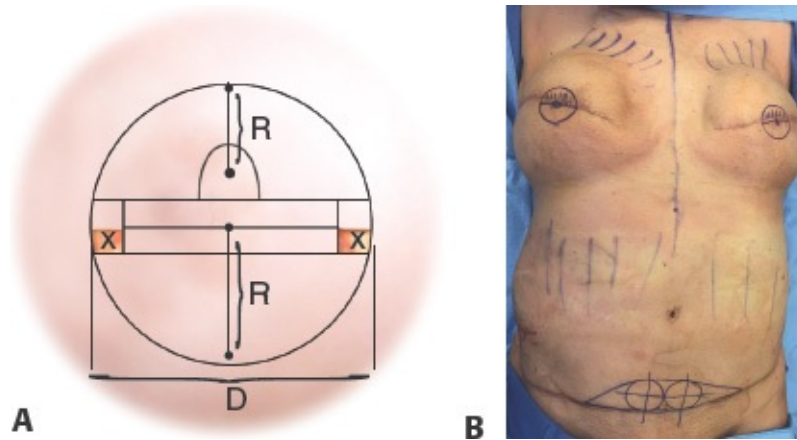
- The desired nipple diameter is generally 1 cm, and the flap is drawn with the measured vertical height designed to be 2 times the projection of the opposite nipple based on an approximate loss in projection in the long term of 50%⁷

(**TECH FIG 3A**).

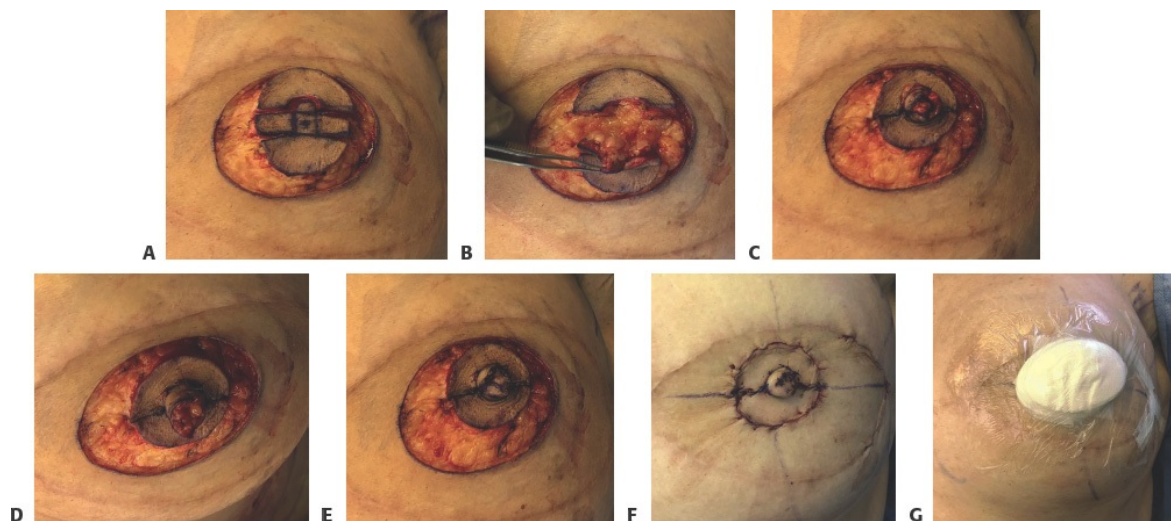
- The diameter of the skate flap (or horizontal width) is measured to provide the desired areolar diameter, usually between 40 and 50 mm.
- The vertical cap is drawn as a smooth oval and the height is generally equal to the vertical height of the skate flap wings (generally 1 cm) to allow this to come over the top of the flap without tension (**TECH FIG 3B**).
- The inferior areolar skin is marked from the midpoint of the skate flap wings at 90 degrees with the radius of the desired areolar diameter (eg, radius is 21 mm in a 42-mm desired areola)
 - A gentle arc connects the point to the medial and lateral limits of the width of the skate flap.
- The superior areolar skin is marked from the center of the cap extending superiorly with the same radius (eg, radius of 21mm in a 42-mm desired areola).
 - Again, the gentle arc connects the superior extent to the medial and lateral limits of the width of the skate flap.

Elevating and Insetting the Flap

- All incisions are made full thickness through the dermis (**TECH FIG 4A**).
- The skate flap wings are elevated with an even layer of fat; usually only 1 to 2 mm of fat are included (**TECH FIG 4B**).
- The central cap of the skate is elevated just at the level of the dermis.
- The superior and inferior areolar skin islands are then further released and closed using 3-0 Monocryl sutures (**TECH FIG 4C**).
- The wings of the skate flaps are de-epithelialized or trimmed, depending on the desired amount of projection, and are then wrapped around the base and sutured together using 4-0 chromic sutures (**TECH FIG 4D**).
- The cap is then closed over the top and closed using 4-0 chromic sutures (**TECH FIG 4E**).
- Using a CV-3 Gore-Tex suture on a Keith needle, a purse-string suture is placed within the deep dermis of the surrounding peripheral edges of the periareolar pattern.
 - The knot requires at least 10 throws and must be buried.



TECH FIG 3 • A. Design of Hammond flap modification. Routinely, the radius (R) is measured to be 21 mm and the diameter (D) is marked at 42 mm. The projection (P) is generally marked at 1 cm. In most instances, C (cap length) will equal the projection of the nipple to allow for a tension-free closure. Redundant flap is crossed out. The center of the nipple is indicated in red. **B.** Intraoperative markings of Cordeiro modifications of skate flap with abdominal harvest of full-thickness skin graft.



TECH FIG 4 • Intraoperative steps of Hammond purse-string skate flap elevation. **A.** Full-thickness incisions of construct, excluding base of skate flap. **B.**

Skate flap wing elevation in the subcutaneous plane. **C.** Primary closure of superior and inferior areolar skin islands after elevation of skate flap wings. **D.** Wrap of skate flap wings to the midline and closure. **E.** Cap closure. **F.** Closure of periareolar purse string. **G.** Dressing with eye patch and adhesive dressing.

- After the purse-string sutures have been drawn closed, the skin is closed with a running, subcuticular 4-0 absorbable monofilament suture with a taper needle (**TECH FIG 4F**).
- Usual dressings are placed over the skin incisions, and the nipple reconstruction is covered with an eye patch and an adhesive dressing (**TECH FIG 4G**).

PEARLS AND PITFALLS

Physical findings

- Nipple position on asymmetric breasts remains a great challenge.
- Obtain breast symmetry PRIOR to nipple-areolar reconstruction.
- Radiation proves challenging, and nipple reconstruction should be only undertaken if there was resolution of acute radiation changes, no evidence of late radiation changes, and appropriate thickness of mastectomy skin flaps.⁸

Technique

- Preoperative marking in the standing position with shoulders relaxed is pivotal and the most important part of a successful operation. If markings are made with shoulders abducted, the nipple-areolar complex may be displaced superiorly and laterally, and if made with the shoulders hunched, the nipple will be too high postoperatively.
- Preoperative markings must LOOK right. Proper appearance should supplant measurements.
- It is far better for nipple position to be low and lateral rather than high or medial.
- The axis of the skate flap must be designed so that the mastectomy scar does not cross the wings or the body of the flap.
- Full-thickness skin grafts must be appropriately thinned for best

take.

- In the Hammond technique, using the Gore-Tex for the purse sutures requires at least 10 knots and buried knots.
- Subcuticular running layer should be done with TAPER needle so as not to cut the Gore-Tex suture.
- Tension-free closure of donor site is imperative and prevents both nipple flattening and distortion of breast mound.

Postoperative

- The Cordeiro modification with full-thickness skin graft requires compressive bolster dressing to remain watertight and partial graft loss is possible.
- Projection loss is estimated to be about 50%; therefore, nipples are often designed to be overprojecting. Occasionally, a minor revision in the office setting is necessary if the reconstructed nipple maintains too much projection.

Complications

- Postoperative donor site problems remain the most common complication.
- Early dressing changes and showers after 48 h are recommended.

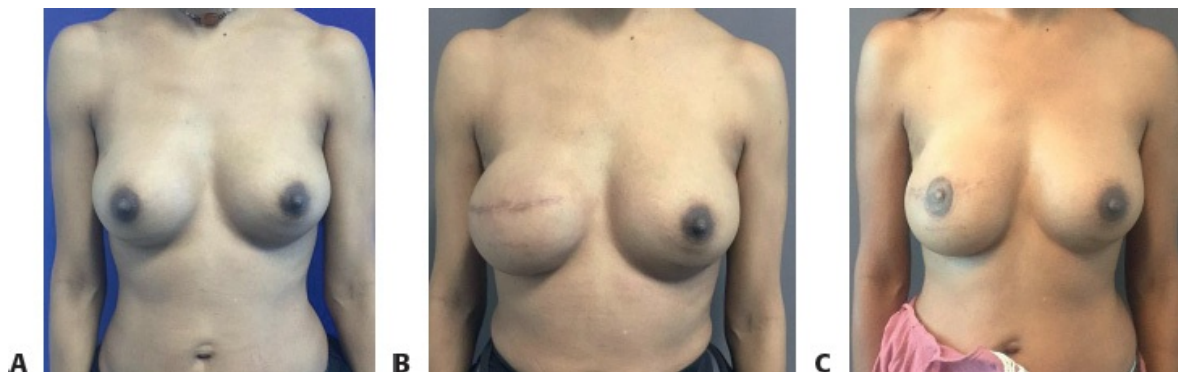


FIG 3 • This 47-year-old woman had cancer of the right breast and underwent right mastectomy with tissue expander reconstruction followed by breast reconstruction with the Cordeiro modification of the skate flap. **A.** Preoperatively. **B.** After mastectomy and implant exchange. **C.** Eight months after skate flap reconstruction of right breast.

POSTOPERATIVE CARE

- Patients routinely have occlusive dressings in place for 5 to 7 days.

- Avoid compression to the NAC, which can affect ultimate projection of the nipple.

OUTCOMES

- Skate flaps for nipple reconstruction provide good projection with minimal complications in patients undergoing nipple reconstruction after mastectomy.
 - Overall decrease in projection is noted to be between 50% to 75% over time.⁴
- Patients undergoing the Cordeiro modification have good long-term results and projection (**FIG 3**).
- Similarly, patients undergoing the Hammond purse-string modification have good long-term results and symmetry (**FIG 4**).
- Secondary revision in patients with too much projection is possible and requires a small in-office procedure to decrease the projection.

COMPLICATIONS

- Cordeiro modification complications
 - Major complications are possible but very rare and include
 - Complete necrosis of nipple or skin graft
 - Infection of the implant
 - Implant extrusion
 - In the Cordeiro modification, rates of minor complications are low and seen in around 7%.
 - These include donor site complications (dehiscence, infection, and cyst formation).
 - Recipient complications are very rare and include partial graft loss.
- Hammond modification complications
 - Donor site dehiscence and local wound problems can occur.
 - Additionally, the desired areola may become ovoid instead of round secondary to tension on the closure and tissue underneath. The tattoo can help with the problem.



FIG 4 • This 43-year-old woman had cancer of the left breast and underwent bilateral mastectomy and DIEP flap reconstruction followed by Hammond flap reconstruction. **A.** Preoperatively. **B.** After mastectomy and DIEP flap. **C.** Eight months after skate flap breast reconstruction.

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30 C-V Flap for Nipple Reconstruction

CHAPTER

Katie E. Weichman

DEFINITION

- Nipple-areolar reconstruction is the final stage in the process of postmastectomy reconstruction.
- This procedure has been shown to positively influence overall satisfaction with breasts and outcomes in several series and transforms the mound to a breast.^{1,2} The C-V flap is the most commonly performed technique in both implant and autologous reconstruction.
- This local flap was first introduced in 1994 by Bostwick for use in nipple reconstruction after mastectomy and breast reconstruction.³ Long-term results with this technique were further shown by Losken and Bostwick in 2001.⁴
- The C-V flap evolved from the skate flap but uniquely allows primary closure of the donor site.
- The main advantage of this technique is that the full-thickness skin graft is not required.
 - The main limitation is maintenance of projection of the C-V flap, as the thickness of the subcutaneous tissue and dermis is the main determinant of nipple projection. The loss of intraoperative volume has been shown to be up to 50%.⁵
- Further modifications of this flap to maintain and increase projection have been described and include using rolled triangular dermal fat flaps, a “Swiss roll” flap, V-V flap, CC-V flap, and C-V-M flap.^{6–10}

ANATOMY

- The C-V flap is a local flap with a pedicle of epidermis, dermis, and subcutaneous fat centered at the site of the desired future nipple. The basic

concept of the C-V flap is that the nipple consists of three flaps: 2 V flaps and 1 C flap.

■ Blood supply

- Subdermal plexus
- Subcutaneous plexus

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients undergoing C-V flap nipple reconstruction have reached the end of the reconstructive process.
- Patients having a history of breast cancer requiring mastectomy, prophylactic mastectomy, and congenital abnormalities and transgender patients who have had mastectomy with complications associated with silicone injection are indicated for the procedure.
- History of radiation therapy or need for further radiation therapy should be considered when deciding timing of nipple reconstruction.
- Patients should not be actively smoking at least 3 months prior to surgery.
- Patients should have a final breast mound without need for further revision.
- Nipple reconstruction should be performed when the breast has taken its final form and has adequately settled to prevent malposition.
 - This timing is least 3 to 6 months after either the direct to implant reconstruction, tissue expander exchange for implant, or the autologous reconstruction. All revisions of the breast mounds should be performed prior to nipple reconstruction.
 - Revision of autologous reconstruction can often be performed synchronously with nipple reconstruction; however, ensuring correct nipple position can be more challenging with an increased incidence of nipple malposition requiring further revision.

SURGICAL MANAGEMENT

- The authors perform C-V flaps for nipple-areolar reconstruction when the nipple-areolar complex is absent.
- A 50% reduction of the nipple projection should be anticipated, and therefore, C-V flap should be designed accordingly based on patient preference and contralateral nipple size in unilateral reconstructions.^{4,5}

Preoperative Planning

- Patients are marked in the standing position with shoulders relaxed.

- Nipple position should be centered on the breast at the point of maximal convexity and projection. Additionally, it should be symmetric to the contralateral nipple in unilateral reconstructions. In bilateral reconstructions, nipple position is often easier to match and the location is less critical as long as it is symmetric and located on the center of the breast.
- Specific landmarks are often helpful in determining the correct position of the nipple-areolar complex on the breast. These include the level of the contralateral nipple-areolar complex, the position at the Pitanguy point (reflection of the inframammary fold), and triangle from the sternal notch to nipple/midsternal line (**FIG 1A**).
- When breasts are asymmetric, the surgeon should try to maintain the ratios of the nipple to the breast footprint. This includes midline, lateral breast, superior breast, and inframammary fold (**FIG 1B**).

Positioning

- The patient is positioned in the supine position and the procedure can be performed in the office under local anesthesia or in the operating room.

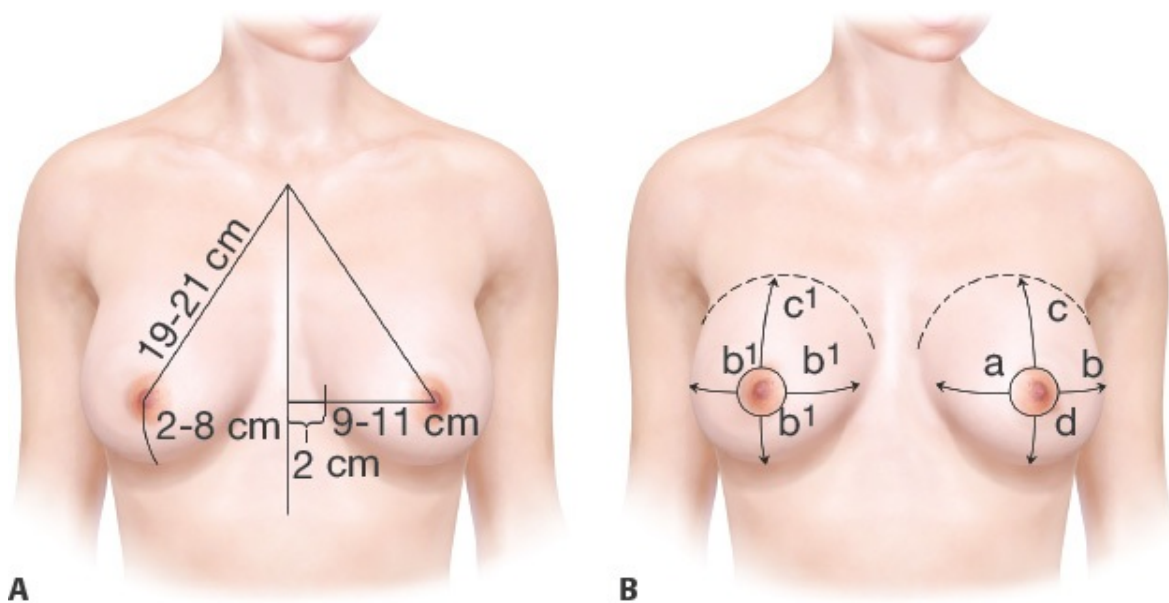


FIG 1 • A. Traditional landmarks for nipple position. Sternal notch to nipple distance of 19 to 21 cm. Distance from midline to nipple measuring 9 to 11 cm. Distance from nipple to inframammary fold measuring 7 to 8 cm. **B.** Ideal nipple position in asymmetric breasts.

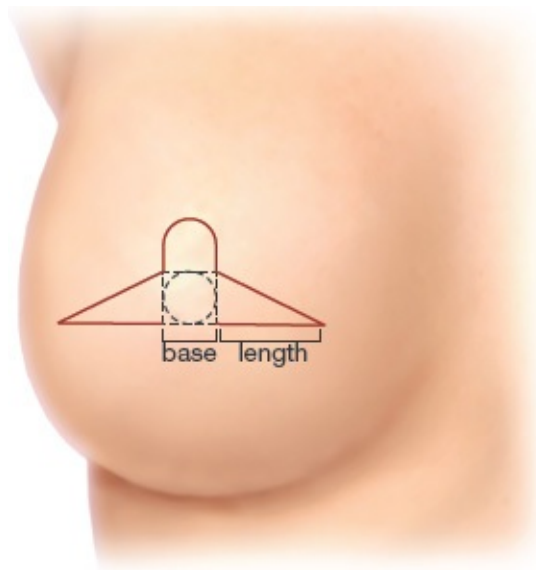
Maintain ratios of nipple in relation to the medial breast border, lateral breast border, inframammary fold, and superior breast extent.

TECHNIQUES

■ C-V Flap

Flap Design

- Generally, the desired diameter of the nipple is designed to be 1 cm.
 - The nipple is marked based on the above guidelines (see **FIG 1**) and is confirmed by both the surgeon and the patient as being in an acceptable position (**TECH FIG 1**).
- The axis of the C-V flap is designed so that the mastectomy scar does NOT cross either the C or V flaps.
- The base of the nipple is marked to 1 cm in width and height.
- The V flaps are then marked measuring 2.0 to 2.5 cm in length
- The C flap is then marked 1 cm in width and 0.5 to 1 cm in height depending on the skin laxity.

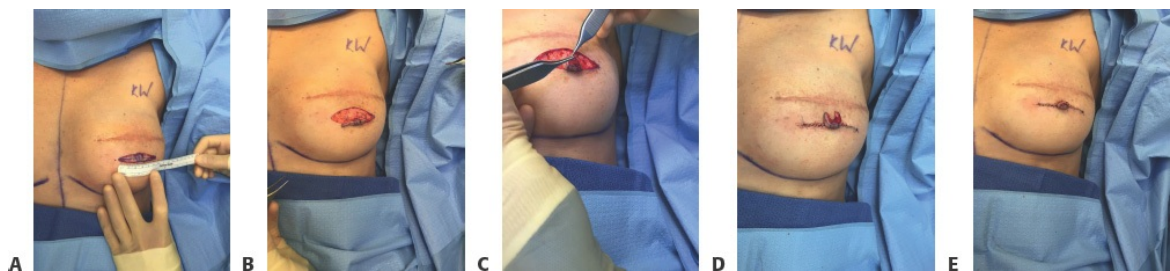


TECH FIG 1 • Design of C-V flap. A nipple with a base

of 1 cm and height of 1 cm is designed. The lateral V flaps are marked measuring 2 to 2.5 cm in length, and the C flap is designed with a height of 0.5 to 1 cm depending on skin laxity.

Elevating and Insetting the Flap

- The incisions are made to define the C and V flaps with care taken not to transect the base of the flap or the attachment of the C flap to the vertical wall (**TECH FIG 2A**).
- The two V flaps are then elevated in a lateral to medial fashion with some subcutaneous tissue (**TECH FIG 2B**).
- Subcutaneous fat is included to improve nipple projection.
- The C flap is then elevated to the base of the desired nipple with care to maintain some fat at the base (**TECH FIG 2C**).
- The donor site is then closed primarily in two layers with 3-0 Monocryl deep dermal and running 5-0 Prolene suture (**TECH FIG 2D**).
- The V flaps are then wrapped around the base overlapping and secured using 4-0 chromic sutures.
- The C flap is then closed as the cap of the nipple (**TECH FIG 2E**).
- A bolster-type dressing is created and placed, using two eye patches and an adhesive dressing to avoid pressure on the nipple reconstruction.



TECH FIG 2 • Intraoperative incisions of C and V flaps. **A.** Care made to not transect the base or the C flap attachment to the vertical wall. **B.** V flaps elevated in a lateral to medial fashion with subcutaneous tissue. **C.** C flap is elevated to the base with care to maintain fat along the base. **D.** Donor-site closure

primarily. **E.** V flaps are advanced and wrapped around the base, and the C flap is closed over the top of the V flaps as a cap.

PEARLS AND PITFALLS

Physical findings

- Nipple position on asymmetric breasts remains a great challenge.
- Obtain breast symmetry PRIOR to nipple-areolar reconstruction.
- Radiation proves challenging, and nipple reconstruction should be undertaken only if there was resolution of acute radiation changes, no evidence of late radiation changes, and appropriate thickness of mastectomy skin flaps.¹¹

Technique

- Preoperative marking in the standing position with shoulders relaxed is pivotal and the most important part of a successful operation. If markings are made with shoulders abducted, the nipple-areolar complex may be displaced superiorly and laterally, and if made with the shoulders hunched, the nipple will be too high postoperatively.
- Preoperative markings must LOOK right. Proper appearance should supplant measurements.
- It is far better for nipple position to be low and lateral rather than high or medial.
- The axis of the C-V flap must be designed so that the mastectomy scar does not cross the flaps.
- Tension-free closure of donor site is imperative and prevents both nipple flattening and distortion of breast mound.

Postoperative

- Projection loss is estimated to be about 50%.
- Dressing to avoid compression to the nipple reconstruction in the early postoperative period is imperative.

Complications

- Postoperative minor partial flap loss and delayed wound healing problems are the most common.
- Infection requiring implant removal is possible.



FIG 2 • A 55-year-old woman with a history of left breast cancer underwent left mastectomy and tissue expander reconstruction followed by implant exchange and right breast mastopexy. Three months after mastopexy and exchange, the patient had left nipple reconstruction with C-V flap. **A.** Preoperative appearance. **B.** Postoperative appearance after implant exchange and mastopexy. **C.** Appearance 12 months after C-V flap reconstruction.

POSTOPERATIVE CARE

- Patients routinely have occlusive dressings in place for 5 to 7 days
- Avoid compression to the NAC, which can affect ultimate projection of the nipple.

OUTCOMES

- C-V flaps for nipple reconstruction provide good projection with minimal complications in patients undergoing nipple reconstruction after mastectomy.
 - Overall decrease in projection is noted to be between 50% over time.^{4,5}
- Patients undergoing C-V flaps have good long-term results and patient satisfaction (**FIG 2**).

COMPLICATIONS

- C-V flap
 - Major complications are possible but very rare and include
 - Complete necrosis of nipple
 - Infection of the implant
 - Implant extrusion

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DEFINITION

- Nipple reconstruction is the final stage in breast reconstruction and allows the reconstructed breast to most closely resemble the natural breast.
- There are many different techniques used to reconstruct the projecting portion of the nipple-areolar complex; those reviewed in this chapter form the basis for many other techniques.

ANATOMY

- The nipple-areolar complex is an average of 4 cm in diameter, the nipple 1.3 cm in diameter, with the projecting portion 9 mm in length.¹
- The aesthetic ideal for the location of the NAC is at the apex, or most projecting aspect of the breast mound.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Nipple reconstruction should be offered to appropriate candidates, generally as the final step in the breast reconstruction process.
- Nipple reconstruction is typically performed at least 3 months after either autologous or final implant placement to allow incisions to completely heal and the shape of the reconstruction to stabilize.
- Presence and location of previous scars from breast reconstruction should be noted.
 - The presence of a scar across the breast mound and its location may influence the chosen reconstructive technique and decisions regarding placement.
- Thickness of the skin and subcutaneous tissue as well as a history of radiation should be noted.

- In the case of implant-based reconstruction, if the soft tissue overlying an implant is excessively thin or damaged from prior irradiation, nipple reconstruction may carry a greater risk for skin necrosis, infection, and implant exposure.
- Under these circumstances, surgical nipple reconstruction should not be offered or should be offered with caution. The patient may still be a candidate for tattooing alone.

NONOPERATIVE MANAGEMENT

- Tattooing without reconstruction of the projecting portion of the nipple is a nonsurgical option.

SURGICAL MANAGEMENT

- Once the decision has been made to pursue nipple reconstruction, the surgeon must decide whether this will be combined with other revisionary procedures. This may dictate the operative setting and anesthetic requirement, that is, office vs outpatient surgery.
- Nipple reconstruction alone can often be accomplished in the office with local anesthesia.

Preoperative Planning

- The location of the new nipple to be reconstructed is marked preoperatively with the patient standing, oftentimes in front of a mirror to allow for patient feedback.
- Silicone nipples or telemetry pads can help illustrate the reconstructed nipple location (**FIG 1A,B**).

Positioning

- For unilateral reconstruction, the nipple position will reflect the contralateral nipple position. If a contralateral symmetry procedure is needed, which will change the position of the native nipple, that is, reduction or mastopexy, the reconstructed nipple will reflect this new position.
- The operation is performed with the patient in a supine position with arms abducted 90 degrees or tucked at the patient's sides. The patient should be positioned with the option to elevate to a sitting position if desired.

Approach

- Chosen technique may be based on nature and location of existing scars, as

well as surgeon preference. All techniques are associated with the tendency for soft tissue contraction and decrease in nipple projection.

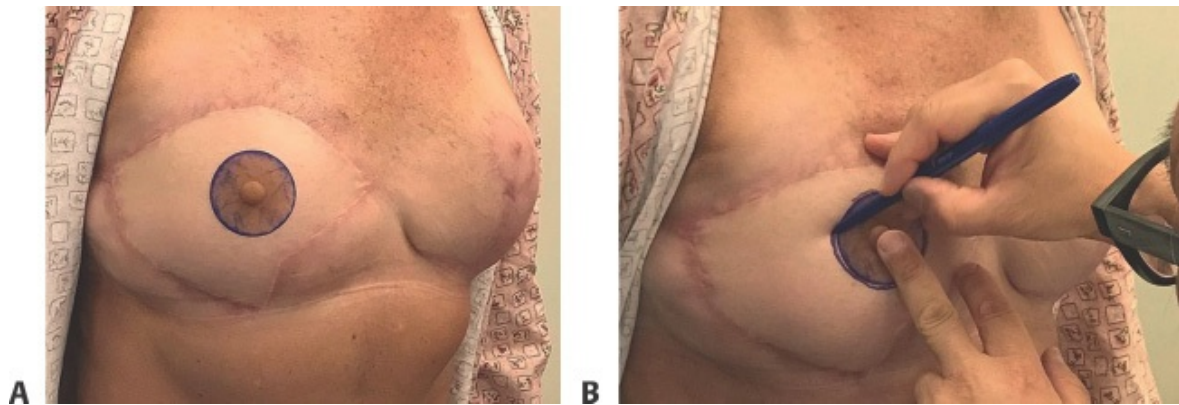


FIG 1 • A. Silicone nipples or telemetry pads can be used to mark the site of the new nipple. **B.** The silicone nipple can be traced to form the outside of the keyhole pattern.

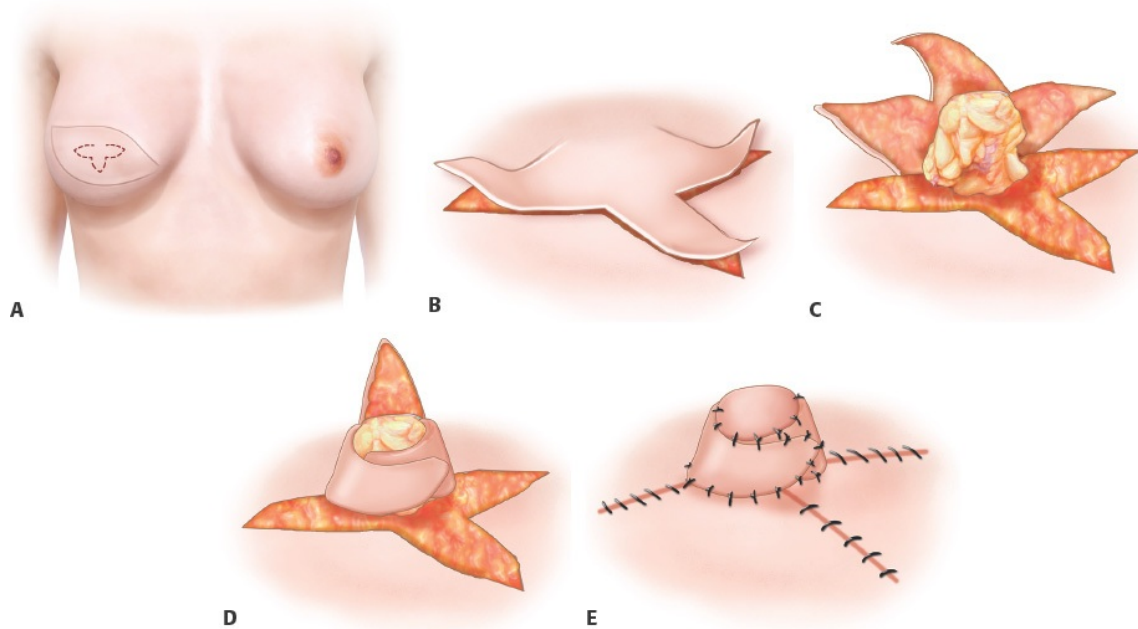
TECHNIQUES

■ Star Flap

- The star flap produces a moderately projecting nipple and minimal flattening of the breast mound but does not offer projection of an areola or circular border.
- Three limbs are designed around a central portion (**TECH FIG 1A**). The central portion base width determines the width of the nipple. The length of the limbs of the star is based on the size of the contralateral nipple or a width of 4 cm if there is no nipple present. The scars can be included in a tattoo at a later point in time that will help to camouflage them.
- The lateral wings of the flap are elevated sharply in a subdermal plane (**TECH FIG 1B**).
- The central wing of the flap is elevated distal to proximal including a gradient of subcutaneous fat with the most at the central base, serving as the bulk of the nipple (**TECH FIG 1C**).
- One lateral wing is wrapped centrally, followed by the other lateral

wing. Lastly, the central wing is closed over top. These are secured to each other with interrupted percutaneous, nonabsorbable monofilament suture (**TECH FIG 1D**).

- The donor sites of the three wings are closed primarily (**TECH FIG 1E**).



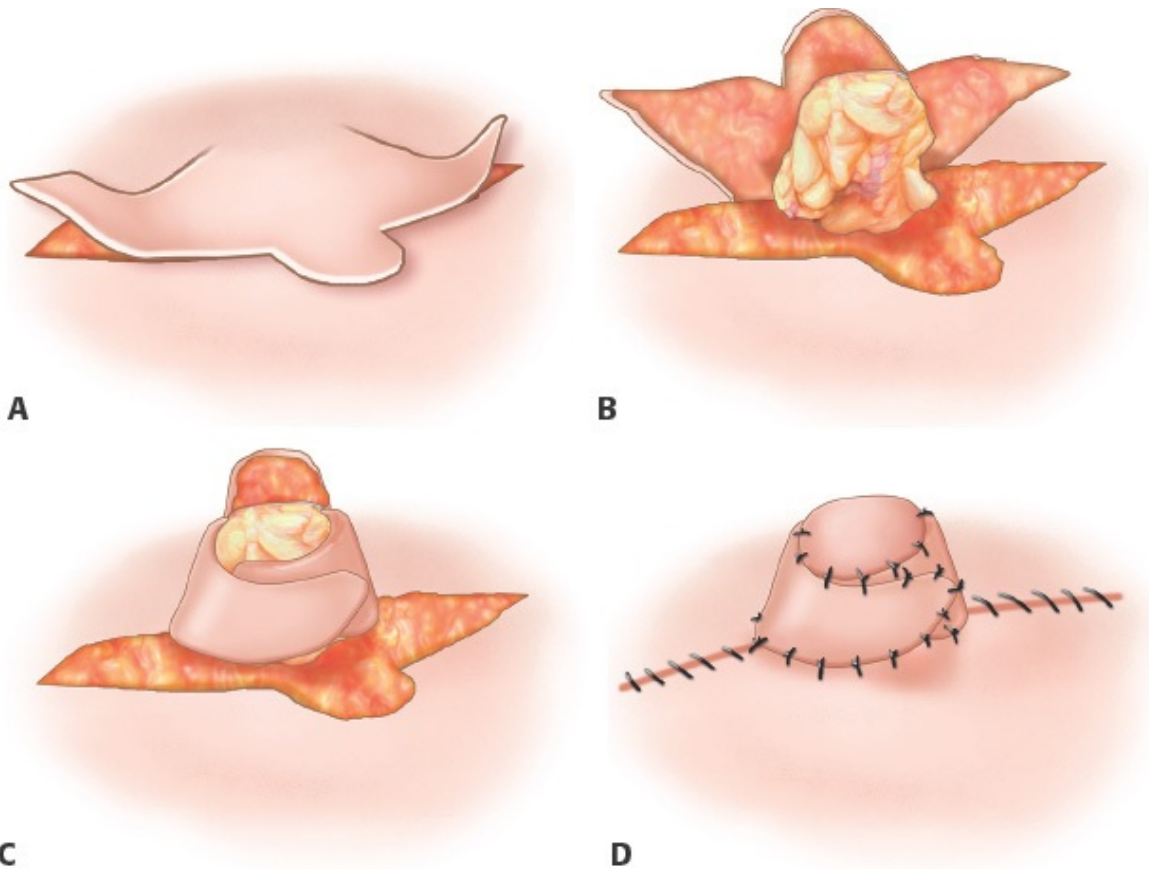
TECH FIG 1 • **A.** Basic design of the star flap. **B.** The lateral wings are elevated in a subdermal plane. **C.** The central wing is elevated subdermally, progressively recruiting subcutaneous tissue to add bulk. **D.** The lateral wings are wrapped around the central base. **E.** The central wing is closed over top. The donor sites are closed primarily.

■ C-V Flap

- Similar to the star flap, the C-V flap produces a moderately projecting nipple, no areolar projection, and no circular scar.
 - The C-V flap is composed of two lateral limbs (V shaped) and central component (C shaped). The lateral limbs are raised sharply in a subdermal plane (**TECH FIG 2A**).
 - The central C-shaped portion is raised with subcutaneous tissue included to

add bulk to the nipple (**TECH FIG 2B**).

- Each V-shaped lateral limb is then brought centrally and secured together, end to end or overlapping for greater nipple projection (**TECH FIG 2C**).
- The C-shaped central component is brought over the top of the reconstructed nipple and secured to form the nipple (**TECH FIG 2D**).
- The donor sites are closed primarily.



TECH FIG 2 • A. Lateral limbs are elevated subdermally. **B.** The central C-shaped portion is elevated, including a layer of subcutaneous tissue. **C.** Lateral limbs are wrapped centrally. **D.** The C limb is closed over top of the lateral limbs and donor sites closed primarily.

■ Keyhole Flap

- The keyhole flap produces a moderately projecting nipple and areola. It

lends well to reconstruction on circular skin paddles of autologous reconstructions.

- The nipple is based on a central wedge, which is shaped like a keyhole, surrounded by a semicircularly incised skin flap (**TECH FIG 3A**).
- The keyhole and the border of the nipple are incised sharply. The keyhole is raised with some subcutaneous fat along the dermis (**TECH FIG 3B,C**).
- The keyhole is folded upon itself to create the projecting portion of the nipple (**TECH FIG 3D**).
- The remaining circular portion of the flap is advanced to fill the donor site, which is then closed primarily (**TECH FIG 3E–G**).
- The keyhole flap (or any of the techniques described in this chapter) can be combined with a tattoo after healing. Tattoo combined with keyhole flap is shown in **TECH FIG 3H**.



TECH FIG 3 • A. Basic design of the keyhole flap. **B.** The incisions are made sharply. **C.** The central portion is elevated, progressively recruiting subcutaneous tissue. **D.** The central portion is folded on itself and secured with 5-0 nylon. **E.** The apex of the remaining inner circular edge is secured as a tristitch with the central portion. **F.** The apex of the outer circular edge is secured with a tristitch. **G.** The donor site is closed with interrupted deep dermal 5-0 Vicryl suture followed by running 5-0 nylon. **H.** Postoperative result of bilateral nipple reconstructions using the keyhole technique, followed by tattoo.

■ Nipple-Sharing Technique

- Patients with contralateral nipples greater than 5 to 6 mm may be candidates for this technique.
 - The location of the new nipple on the reconstructed breast is marked and de-epithelialized.
 - Then, a traction suture is placed through the distal end of the contralateral nipple, which is then placed on stretch. The distal 50% of it is removed sharply with a scalpel.
 - The transected nipple is secured to the de-epithelialized recipient site with chromic sutures and dressed with a bolster, or a nipple protector is used to secure it.
 - The donor site is closed with either a purse-string or interrupted sutures.
 - Reconstruction of the areola may be accomplished with tattoo or skin graft from distant donor sites including excess skin from the abdomen or superomedial thigh.

■ Autologous, Allograft, and Alloplastic Materials

- A variety of autologous, allograft, and alloplastic materials have been described to augment and sustain projection of the nipple, including cartilage, acellular dermal matrix, silicone, hyaluronic acid, and prosthetic devices.

- The chosen material must be manipulated into an acceptable size and shape to serve as a nipple.
- Materials can be combined with a C-V flap, placing them under the C-shaped central portion of the flap. The lateral V-shaped limbs of the flap are wrapped around the material and secured with permanent suture.
- Alternatively, a semicircular pocket can be dissected, the material placed within the pocket, and the skin closed over top. This can then be combined with a tattoo for pigment after healing has been completed (**TECH FIG 4**).



TECH FIG 4 • Postoperative results after left breast subdermal cartilage allograft placement, followed by tattoo.

PEARLS AND PITFALLS

Patient selection	■ Candidates with implants must have healthy skin of sufficient thickness to avoid major complications such as implant exposure.
Timing	■ Nipple reconstruction should be performed as the final procedure, ideally after results of other symmetry procedures and revisions have had time to stabilize, at least 3 months.
Technique selection	■ Star and C-V flaps work well for implant-based reconstructions. ■ The keyhole flap is ideal for autologous reconstruction with a round skin paddle and can also be used for implant-based reconstruction with a semicircular outer incision.

- Consider nipple share for patients with excessive contralateral nipple length.
- Use of foreign materials can be helpful with maintaining projection; however, patients should be counseled preoperatively that the projection is maintained continuously, unlike a native nipple with erectile function.

Outcomes

- Patients should always be cautioned preoperatively that some degree of loss of projection is expected.
- Always consider flap design relative to existing incisions, as this will impact blood supply.

POSTOPERATIVE CARE

- The reconstructed nipple is protected with a formal nipple shield or gauze with a central portion removed to accommodate the projecting nipple.
- In cases of nipple share and skin grafting to the areola, the bolster may be left for 5 to 7 days, similar to a full-thickness skin graft.

OUTCOMES

- The star flap is associated with a 43% loss in nipple projection at 12 months.²
- The C-V flap has been shown to have a 32% loss of projection at 12 months.³
- Nipple-sharing technique can be associated with some decrease in sensation of the donor site. This was a subjective finding in 47% of patients who underwent this technique.⁴

COMPLICATIONS

- Virtually all techniques are associated with loss of projection to some degree.
- Infection, asymmetry, malposition, graft loss, and wound separation are other potential complications.
- Nipple reconstruction performed over thin, compromised skin can lead to wound healing problems resulting in implant exposure.
- Using foreign devices for nipple augmentation may be complicated by exposure or extrusion, necessitating removal of the device.

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32 Low-Volume Fat Grafting for Contour Correction

CHAPTER

Nolan Karp and Jordan Frey

DEFINITION

- The popularity of fat grafting to the breast has grown immensely since it was first described in the late 19th century with greater than 60% of plastic surgeons now utilizing fat grafting in reconstructive breast surgery.^{1,2}
- Autologous fat grafting has proven to be extremely efficacious in correcting volume and contour deformities both after postmastectomy breast reconstruction and after breast-conserving therapy.^{1,3–5}
- However, autologous fat grafting is most commonly employed in postmastectomy breast reconstruction as an adjunctive procedure after implant- or flap-based reconstruction.^{1,4,5}

ANATOMY

- Contour deformities of the breast to be corrected with small-volume fat grafting may arise from a myriad of anatomical etiologies.
- In implant-based breast reconstruction, the gentle slope of the natural superior chest wall–breast junction is often difficult to reconstruct, resulting in a superior shelf contour deformity.
- Additional volume or contour abnormalities to be corrected may arise from size discrepancy between the implant and breast envelope or inadequate implant volume or due to complications of the initial reconstruction, such as mastectomy flap necrosis.⁶
- In autologous breast reconstruction, irregularities requiring fat grafting may develop due to inadequately sized flaps secondary to donor site paucity as well as from flap complications, such as fat necrosis.⁶
- Patients with small breasts or large tumors are particularly prone to contour

irregularities that require fat grafting after breast-conserving therapy.³

- Possible anatomical donor sites for small-volume fat grafting of the breast include the abdomen, flanks, lateral and medial thighs, back, and buttocks.⁵
- Adipocyte viability does not appear to differ based on the donor site from which it is harvested.^{1,7,8}

PATIENT HISTORY AND PHYSICAL FINDINGS

- The decision to proceed with fat grafting to the breast for contour correction after either breast reconstruction or breast-conserving therapy is based largely on physical examination and patient preference.
- Patients should be followed at regular intervals after their initial breast reconstruction to evaluate for evolving breast volume asymmetries or contour irregularities.
- In evaluating a subpectoral implant reconstruction, the breasts should be examined both statically and with pectoral contraction to observe for dynamic irregularities.
- Patient expectations should be assessed prior to proceeding with fat grafting; patients should be made aware of any prereconstruction breast asymmetries that will not be changed by fat grafting.
- Donor sites are chosen based on availability and patient preference to ensure that there is sufficient autologous fat to correct all breast deformities.⁸

IMAGING

- Patient photography should be obtained after breast reconstruction and compared with preoperative photographs to help plan for contour correction with fat grafting.
- Traditional radiographic imaging is typically not required prior to secondary breast reconstruction with small-volume fat grafting.
- MRI may at times be helpful in assessing the volume required for adequate contour correction; there is a substantial added cost with this technology, however.
- 3D imaging has recently been employed to assist with preoperative identification and quantification of breast volume deficiencies and asymmetries.^{9,10}

SURGICAL MANAGEMENT

- Patients should wait a minimum of 3 to 4 months after their final implant

placement, flap reconstruction, or breast-conserving procedure prior to proceeding with fat grafting for contour correction.

- This will allow adequate time for tissues to heal and soften, both defining the final contour of the breast and increasing recipient bed vascularity.
- In general, small-volume fat grafting of the breast is best accomplished under general anesthesia given the multiple areas of surgery and need for position changes.

Preoperative Planning

- Physical examination, patient photography, and 3D imaging should be utilized preoperatively to precisely plan the location and amount of fat grafting required for adequate contour correction.^{9,10}
- Given the fluctuating nature of adipose deposits, potential donor sites should be reassessed on the day of surgery to plan the volume of autologous fat to be harvested from each site.

Positioning

- Patient positioning in the operating room is dependent on the donor sites from which autologous fat will be obtained.
- Patients should be positioned on a bed permitting flexion at the hips so that the patient may be able to “sit up” during the procedure.
- A prone position with arms extended forward in a diver’s pose is necessary if the back or buttocks are to be harvested.
- If required, the patient should begin in the prone position for autologous fat harvest prior to being placed in the supine position for additional fat harvest and recipient site grafting as indicated.
- A supine position is planned if the abdominal, flank, or lateral and medial thigh donor sites are to be harvested.
 - These sites are advantageous as both donor site harvesting and recipient site fat injection can proceed without position change.
- In the supine position, the arms should be abducted at approximately 90 degrees and secured to the arm boards in preparation for sitting the patient up during the procedure.

Approach

- The donor site areas from which the autologous fat will be harvested should be

marked with concentric circles. Recipient site areas into which the fat will be grafted should be marked with cross-hatches on the patient.

- Markings for cannula access incisions should be placed in all donor and recipient sites within relaxed skin tension lines in areas typically hidden by clothing.

TECHNIQUES

■ Tumescence Infiltration of Donor and Recipient Sites

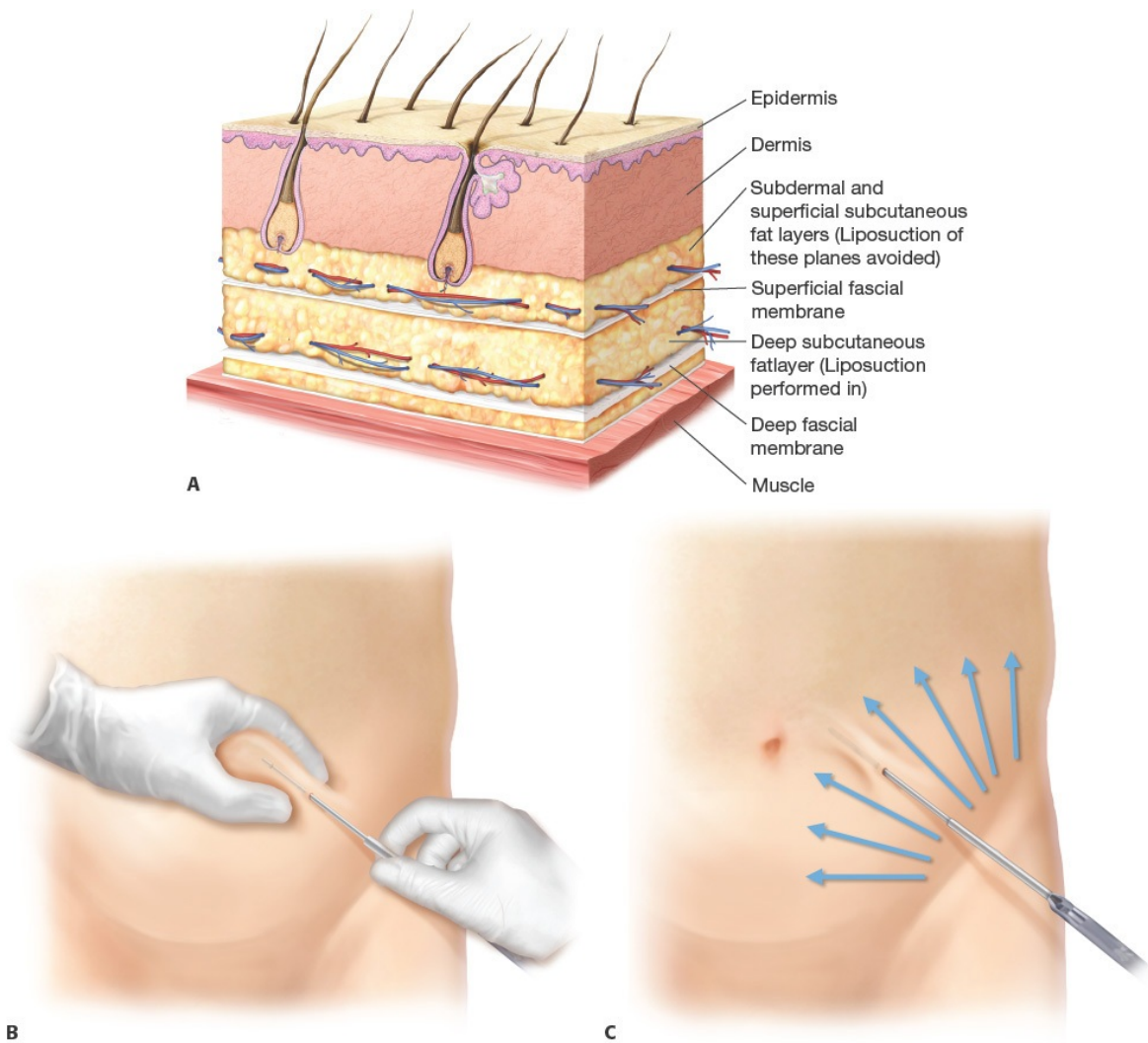
- Tumescence solution is prepared using 20 cc of 2% lidocaine, 1 mg of 1:1000 epinephrine within one liter of lactated Ringer solution.⁸
- Lidocaine concentrations of 35 mg/kg have been proven safe using the tumescence technique.¹¹
- Planned 2-mm stab incisions near donor and recipient sites are made with an 11-blade while pinching the skin to avoid damage to deeper structures.
- Tumescence solution is infiltrated using a tumescence cannula at rates ranging from 50 to 200 mL/min into all areas of autologous fat harvest as well as all planned recipient sites.¹¹
- The end point of tumescence infiltration is judged on the basis of tissue turgor and skin blanching and is generally in the ratio of 2:1 infiltrate to aspirate.¹¹
- Ideally, 15 to 20 minutes is allowed to elapse prior to liposuction fat harvesting to maximize the vasoconstrictive effect of the tumescence solution.¹²

■ Donor Site Autologous Fat Harvesting With Liposuction

- Given ease and efficacy of use, suction-assisted liposuction is the senior author's preferred method of donor site autologous fat harvesting.
 - Adipocyte viability with handheld and suction-assisted liposuction is equivalent when utilized with tumescence solution infiltration.⁸
- Generally, 3 to 4 mm cannulas are preferred as greater cannula size has been

associated with improved adipocyte viability.⁸

- Multiperforated or two-hole Coleman cannulas may be employed with similar outcomes.^{8,13}
- Cannula length is chosen based on the reach required for each given donor site.
- Fat is harvested from the deep layer of subcutaneous fat, taking care to avoid the subdermal and superficial fat layers (**TECH FIG 1A**).
 - Liposuction of the subdermal or superficial fat layers can result in visible and unattractive skin dimpling.
- Within each donor site area, tissue is rolled between the thumb and index finger of the nondominant hand, while the liposuction cannula makes broad passes between the digits (**TECH FIG 1B**).
- After each 2 to 3 passes of the cannula in one area, the cannula is reoriented to an adjacent region to avoid overliposuction in any discrete area, which will result in donor site depressions and asymmetries (**TECH FIG 1C**).
- In the abdomen, posterior direction of the liposuction cannula risks perforation of the peritoneal cavity with concomitant intra-abdominal injury.
 - Caution must also be exercised in the epigastric and subcostal abdominal regions where inattentive technique can risk violation of the thoracic cavity.
- Fat harvesting proceeds until sufficient fat to correct all breast irregularities (estimated preoperatively) is obtained or all planned donor sites are depleted of useable autologous fat without the creation of donor site deformity.



TECH FIG 1 • A. Cross-sectional anatomy of the skin and subcutaneous fat. Liposuction fat harvesting for small-volume fat grafting of the breast should be performed in the deep subcutaneous fat layer while the subdermal and superficial fat layers are avoided to prevent donor site contour abnormalities such as dimpling. **B.** Technique for donor site autologous fat harvesting. The donor site tissue (abdominal tissue in this figure) is rolled between the thumb and index finger of the nondominant hand while the liposuction cannula makes broad passes between the digits. This provides the surgeon with tactile manual feedback that

will assist with maintaining the cannula in the appropriate fat plane. **C.** “Fanning” technique for donor site liposuction. After each 2 to 3 passes of the liposuction cannula in one area, adjacent tissue is taken up in a fanning pattern to avoid overliposuction in any one area.

■ Fat Aspirate Processing

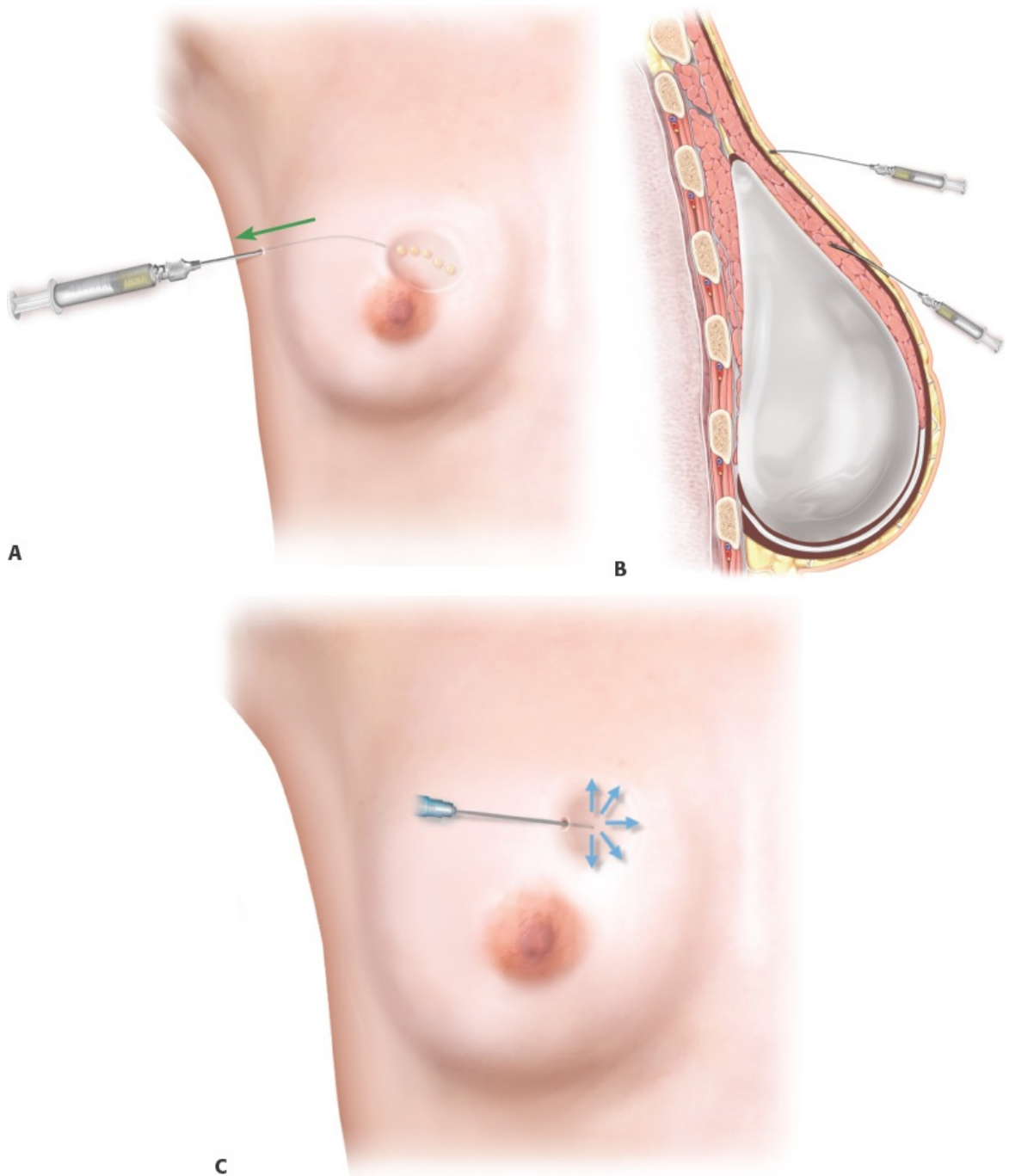
- Autologous fat aspirate, once harvested, must be processed to separate the fat, stromal vascular fraction cells, and adipose-derived stem cells from tumescent solution and blood.⁸
- Fat aspirate may be processed by centrifugation, gravity separation, washing, and/or filtration.⁸
- Although animal studies suggest that centrifugation with filtration provides smaller fat grafts with impaired integrity, in vivo patient studies show no difference in fat graft retention based on different processing techniques.⁸
- Centrifugation forces greater than 50 g after suction-assisted liposuction have been shown to result in significant adipocyte damage; this effect is not observed after handheld liposuction.⁸
- After centrifugation, the lowest layer of the fat aspirate contains the most viable adipocytes for injection while higher layers progressively contain less viable cells.⁸
- The senior author currently prefers a combined hand washing-filtration system for autologous fat processing prior to small-volume fat grafting of the breast.

■ Recipient Site Fat Grafting (Video)

- Filtered fat is separated into 3- or 6-mL syringes and attached to the chosen cannula.
- Injection cannulas are generally smaller in diameter than harvesting cannulas and only have a single distal or lateral port for fat egress.¹³
- The cannula size utilized will depend on the body area to be grafted with 16- or 17-gauge cannulas most often employed for small-volume fat grafting of

the breast.¹³

- The length, shape, and curve of the cannula chosen are based on the geometry of the recipient site and location of recipient site access incisions.¹³
- The cannula is inserted into the access incision and guided into the area to be grafted; fat is slowly injected as the cannula is withdrawn^{8,13} (**TECH FIG 2A**).
- Approximately 1-2 mL is injected with each pass of the cannula.¹³
- Scar contracture release may be performed through multiple punctures with the beveled tip of an 18-gauge needle to prevent dimpling and undue tension at the site of fat injection¹⁴ (**TECH FIG 2B**).
- After implant-based breast reconstruction, processed fat may be injected into both the subcutaneous fat and muscle planes as indicated to correct any contour deformities (**TECH FIG 2C**).



TECH FIG 2 • A. Harvested and processed fat is slowly injected into any recipient site contour deformities through the access incision as the cannula is withdrawn. In this figure, the recipient site access incision is hidden in the anterior axillary line. **B.** Scar contracture release is often performed prior to fat

injection through multiple punctures with the beveled tip of an 18-gauge needle to prevent dimpling and undue tension at the site of injection. This is especially useful after breast-conserving therapy in order to create sufficient space for the fat to be grafted. **C.** After implant-based breast reconstruction, fat may be injected into both the subcutaneous fat and muscle layers as indicated to correct any contour deformities present. The decreased fat retention typically observed with injection into contractile muscle is obviated after breast reconstruction due to pectoralis disinsertion. Care must be taken to avoid trauma to the implant itself from the cannula that can result in rupture.

- In autologous breast reconstruction, fat may be injected into the subcutaneous fat plane or into the flap itself; care must be taken to protect the vascular pedicle if deeper fat injection is planned.
- After breast-conserving therapy, fat is typically injected into the glandular breast tissue and less often into the subcutaneous fat plane.
- Scar contracture release is usually required to create space for the fat in this circumstance.
- Slower injection speeds result in larger fat deposits; however, faster injection speeds increase the risk of adipocyte cellular injury.⁸
- Each planned recipient site is sequentially injected to the desired final effect and contour correction.

■ Wound Closure

- Donor site harvest and recipient site access incisions are closed with simple interrupted fast-absorbing sutures and dressed with adhesive bandage strips and semioclusive dressings.
-

PEARLS AND PITFALLS

Preoperative planning	■ 3D imaging may be utilized preoperatively to analyze predicted volume requirements in the breast and aid in patient education.^{9,10}
Donor and recipient site access incision placement	■ Recipient site access incisions for the breast can be hidden in the anterior axillary line, the medial and lateral breast folds, and the inframammary fold. ■ Avoid access incisions in the upper medial breast, abdomen or flanks above the bikini line, and lateral or medial thighs below the bikini line. ■ Particular care must be taken when donor site stab incisions are made in the groin; the femoral artery should be palpated with incisions made laterally to avoid both the femoral artery and more medial femoral vein.
Tissue planes of fat injection	■ Care should be taken to avoid overly superficial or subdermal injections that will result in unaesthetic visible and palpable deformities.
Initial fat injection	■ Care is taken to achieve optimal placement during initial fat transfer. ■ Alteration of any undesired fat accumulations is difficult to achieve with massage or manual manipulation and may require liposuction of the abnormal area.¹³
Intraoperative assessment of contour correction	■ The patient should be periodically sat up by flexing the operative bed during fat injection to assess breast volume and symmetry in both the supine and upright position. ■ Fat may even be injected with the patient in the upright, seated position.
Complications	■ Although not reported, intravascular fat injection resulting in devastating fat embolism with small-volume fat grafting to the breast is a theoretical risk of the procedure. ■ Utilizing blunt tip injection cannulas and injecting only during cannula withdrawal will minimize the risk of intravascular injection.

POSTOPERATIVE CARE

- Generally well tolerated, patients usually are discharged on the same day as their small-volume breast fat grafting procedure.

- Oral antibiotics with skin flora coverage should be provided for up to seven days; this is especially important in cases of secondary fat grafting after implant-based breast reconstruction to avoid prosthesis-related infections.
- Surgical bras may be provided to patients with instructions to avoid underwire bras or pressure on the areas in which fat was injected for at least 6 weeks.
- Compressive garments may also be worn over the abdominal, flank, back, or thigh donor sites according to patient and/or physician preference.
- Patients should be advised to expect some leakage of fluid from access incisions for 1 to 2 days and bruising of the donor site for the first 2 to 3 weeks postoperatively.¹⁵

OUTCOMES

- Secondary small-volume fat grafting as an adjunct to breast reconstruction and breast-conserving therapy has been shown to significantly improve aesthetic breast contour and volume.^{3,15,16}
- Patient satisfaction after secondary small-volume fat grafting to the breast appears high.⁴
- The amount of fat retained long term after small-volume fat grafting to the breast ranges from near 40% to 50%.¹
- Larger volumes of fat grafting appears to have increased retention, whereas the donor site likely has no significant influence on fat retention.⁵
- Abnormalities found on surveillance radiographic breast imaging after fat grafting are acceptably low and less than those seen after reduction mammoplasty.¹⁷
- Despite concern, the risk of locoregional breast cancer recurrence does not appear to be increased after secondary small-volume fat grafting to the breast.¹⁸

COMPLICATIONS

- Donor site issues, most frequently irregularities and depressions, represent the most common complications after this procedure.^{15,19}
- Other donor site issues, such as hematoma and seroma formation, are less prevalent.^{15,19}
- Donor or recipient site infection after small-volume fat grafting to the breast is rare, generally less than 1%.^{4,15,19}
- Implant rupture, if fat grafting is performed after prosthetic breast

reconstruction, is likewise rare but may occur due to cannula trauma.

- Fat necrosis and oil cysts may develop after small-volume fat grafting of the breast, more commonly if fat is injected in larger aliquots within the same tissue plane.
- Significant blood loss with this procedure is very rare, especially with the use of tumescent solution during which blood loss approximates 1% of the total fluid aspirated.¹¹

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33 Large-Volume Fat Grafting for the Breast

CHAPTER

Wesley N. Sivak and J. Peter Rubin

DEFINITION

- Autologous fat grafting has become a common technique for addressing volume and contour deficiencies in plastic surgery.
- A survey conducted in 2013 showed that approximately 80% of plastic surgeons have incorporated fat grafting into their clinical breast surgery practice.¹
- Fat grafting has been utilized for facial rejuvenation, breast augmentation, mitigating radiation damage, capsular contracture, post-traumatic deformities, congenital anomalies, and burn injuries.
- Autologous fat grafts have numerous beneficial characteristics including simple surgical procedure, low cost, and nearly universal accessibility.
- Although early use was largely as an aesthetic treatment, recent advancements have made fat grafting an attractive alternative for many reconstructive challenges.
- Contour abnormalities and volume defects of the breast routinely require large-volume fat grafting, often necessitating several sessions to achieve the desired result.

ANATOMY

- Female breasts are composed of glandular tissue that produces milk and adipose tissue; the amount and distribution of fat largely determine the size and shape.
- Milk production within the breast occurs within lobules that are organized into 15 to 20 lobes. Milk travels through a network of ducts that coalesce and exit the skin via the nipple.

- Adipose tissue, connective tissue, and ligaments provide support and shape to the breast. Nerves passing through these tissues provide sensation. The breast contains abundant blood vessels, lymph vessels, and lymph nodes.
- The breast due to its architecture and rich blood supply responds well to fat transfer; the architecture permits expansion of the tissues while ensuring close proximity to blood supply.
- Fat grafts are typically harvested from a donor region of abundance (eg, abdomen, flank, or thigh) and serially injected into the deficient recipient site.
- Harvested adipose tissue is composed of particles of tissue encompassing adipocytes and stromal vascular fraction cells, which include adipose stem cells (ASCs) or preadipocytes, fibroblasts, vascular endothelial cells, and a variety of immune cells.
- Clinical studies have demonstrated safety and favorable fat graft retention rates with strict adherence to basic principles and proper, rigorous technique (ie, Coleman technique).
- Stromal vascular fraction cells (and the ASCs within) improve fat graft survival, largely through their angiogenic properties.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient selection must begin with a detailed history, noting pertinent medical comorbidities that may limit therapeutic potential.
- Candidates must be able to withstand the anesthetic requirements of the procedure; it may not be prudent to offer fat grafting to those with significant systemic ailments.
- Fat grafting to small areas can be performed under local anesthesia, but large-volume grafting will generally require sedation at a minimum.
- Physical examination entails a thorough assessment of the defect in question in addition to assessment of potential donor sites.
- This allows the physician to formulate a plan for correction of the defect in question.
- Patients must be informed that several rounds of fat grafting may be needed to achieve the desired results.
- For fat grafting to the breasts, significant fat volume is generally required; often, there is a limit as to the correction that can be made given the paucity of fat in some patients.
- Asking the patient to gain weight prior to the procedure is feasible only if the patient is willing and able to maintain that weight afterward. This strategy is

generally not recommended as weight loss following fat grafting can lead to loss of volume and failure to maintain adequate correction.

IMAGING

- For breast fat grafting, screening mammography should be performed preoperatively consistent with current guidelines.
- Typically, no radiologic or other diagnostic studies are required; physical examination alone will suffice to formulate an effective grafting strategy.

SURGICAL MANAGEMENT

- It is not sufficient to merely graft fat diffusely in the breast. The grafted fat must be placed appropriately to accomplish the desired objectives of shaping the breast.
- The surgeon must be familiar with the potential levels of placement (eg, subdermal, subglandular, intramuscular, and suprapariosteal) and the amounts necessary at each level to accomplish a desirable change.
 - These amounts will vary across regions of the body as well as from patient to patient.
 - Determining the amounts of fat to place and the levels in which to place the fat in order to create subtle, lasting contour changes requires a sophisticated surgical plan.
- The Coleman method of fat grafting remains essentially unchanged since the original inception three decades ago.²
 - The process relies upon harvesting the fat gently to preserve its architecture, refining the fat with centrifugation to remove nonviable components and provide a predictable volume, and placement of the fat in small aliquots to increase the surface area and ensure a robust blood supply to the grafted tissue.
 - When these principles are adhered to, fat grafting can be a reproducible and safe procedure.
 - Histologic studies have shown that this method of harvesting and refinement with centrifugation yields fat with a high percentage of survival and near-normal adipose cellular enzyme activity.³
- However, this method of fat processing lacks efficiency for large-volume fat grafting. Therefore, the Coleman technique is used to refine results of large-volume fat grafting (“touch-up” procedures), and a simple method of harvesting large volumes of fat with machine-powered suction and decanting

the aspirate is described below.

Preoperative Planning

- Patients should be marked in the standing position prior to surgery. When in the operating room, significant changes in breast shape can occur with changes in position.
- Areas of volume deficiency on the breast should be marked and the volume to be added estimated, keeping in mind that approximately 40% resorption of volume can be expected during healing. The plane of injection will depend on surgical goals. Superior pole fullness can be achieved predominantly with subcutaneous injection, whereas increasing central projection will require deep injection.
- A mastopexy can be performed concurrent with fat grafting, and we recommend a technique with minimal parenchymal dissection to preserve nipple/areolar blood supply after grafting.
- Concentric circles should be drawn around adipose depots that are going to be harvested to ensure areas are not overharvested.

Positioning

- With the patient in the supine position, both typical donor sites (eg, abdomen, flank, and thigh) and the breasts are easily accessible.
- Following fat harvest and processing, grafting can be done with the patient either supine or with the bed flexed into a sitting position with arms abducted.
 - Sitting position will allow for better assessment and correction of ptosis, clearly delineating the inframammary fold.
 - Supine position will make it more difficult to judge changes in shape during the fat injection.

Approach

- For large-volume fat injection, the principles of harvest and injection must be adapted to enable greater volumes of fat to be handled efficiently in the operating room.

TECHNIQUES

■ Fat Harvest

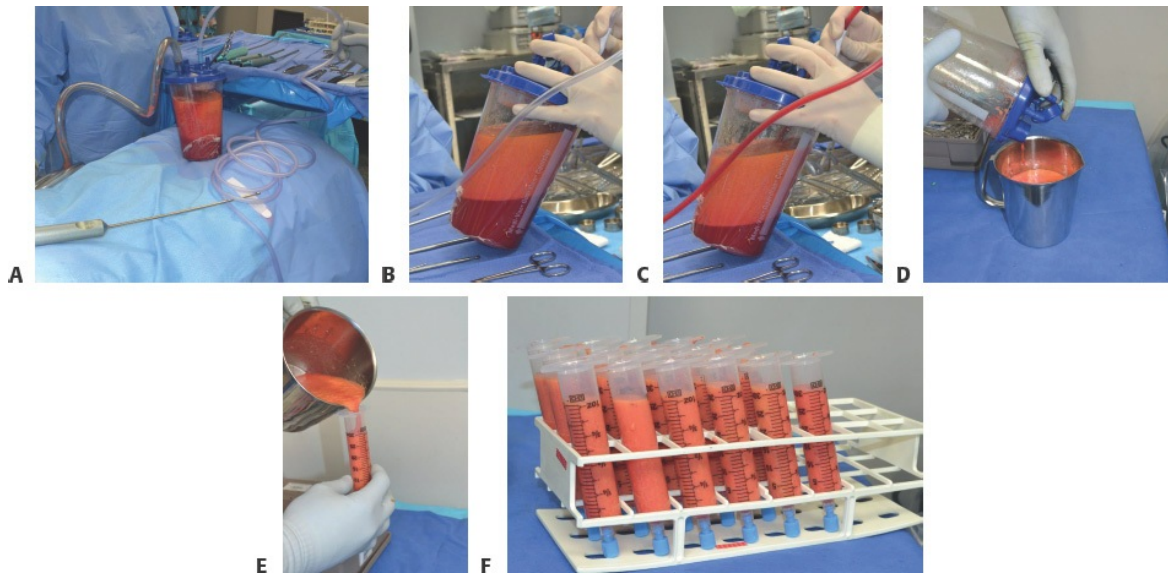
- Access incisions should be hidden in skin creases, scars, stretch marks, or hair-bearing areas, if at all possible.
 - For large-volume harvest, local anesthetic solution is then infiltrated using a blunt infiltration cannula.
 - Local anesthetic mixture consists of 0.025% lidocaine with 1:1 000 000 epinephrine and is a standard wetting solution used for liposuction.
 - The amount of solution infiltrated is equal to the amount of fat removed (1:1 ratio, superwet technique).
 - After waiting approximately 10 minutes for the local anesthetic solution to take effect, fat is then harvested using a 3-mm harvesting cannula.
 - The cannula may be utilized with any vacuum- or power-assisted liposuction equipment or simply attached to a syringe.
 - For small-volume harvest, local anesthetic solution is then infiltrated using a blunt infiltration cannula.
 - Local anesthetic mixture consists of 0.1% lidocaine with 1:200 000 epinephrine and is a higher concentration of epinephrine than a standard wetting solution used for liposuction.
 - The amount of solution infiltrated is equal to approximately 25% of the amount of fat removed (injected sparingly).
 - After waiting approximately 10 minutes for the local anesthetic solution to take effect, fat is harvested using a Coleman bucket handled harvesting cannula attached to a 10-cc syringe barrel.
 - Following harvest, incisions are closed with interrupted 5-0 fast-absorbing sutures.
-

■ Fat Processing

- For small-volume Coleman technique, a Luer-Lok plug is used to cap the syringe.
- The plunger is removed, and the syringe is placed into a sterile centrifuge.
- Centrifugation at 3000 rpm (1200 g) for 3 minutes concentrates the fat so that the aqueous components (ie, local anesthetic and blood) can be removed and discarded by releasing the Luer-Lok plug.
- Any oil layer can be decanted off the top and/or wicked away with gauze

pads.

- The processed fat is then ready for injection.
- For larger volumes, simple decantation from a large reservoir can be utilized in lieu of centrifugation (**TECH FIG 1**). Fat is collected into a sterile canister and allowed to decant for 5 to 10 minutes. Aqueous fluid is aspirated and the fat poured into 30-cc syringe barrels.

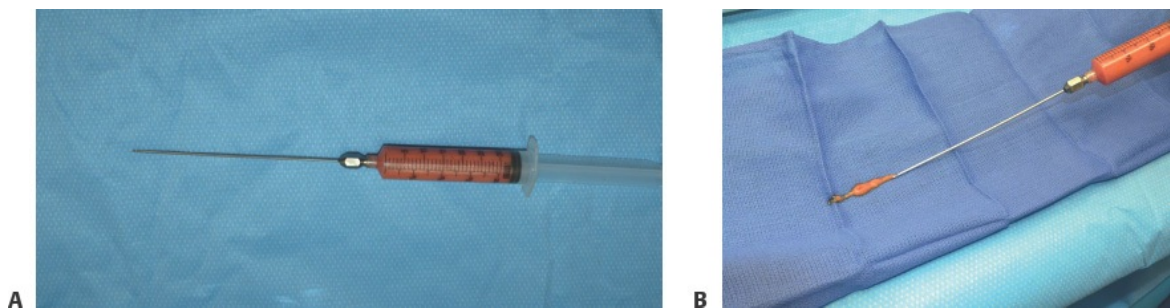


TECH FIG 1 • **A.** Large-volume fat harvest and processing represent a logistical challenge in the operating room. A simple apparatus consists of a sterile collection chamber set up in-line on the sterile field. Machine-generated suction from a standard liposuction aspirator is applied through the system, and a standard liposuction cannula of 3- or 4-mm diameter is used to harvest fat into the vessel. **B,C.** The aspirate is allowed to decant until the fat separates from the aqueous layer. The aqueous layer is then removed by aspiration with a suction cannula. Commercially available vessels for large-volume fat collection are also constructed with spigots at the base to drain the aqueous layer. (Reproduced from Sivak WN, Rubin JP. Repair and grafting fat and

adipose tissue. In: Neligan PC, ed. *Plastic Surgery*. 4th ed. London: Elsevier, 2017, with permission.) **D**. The sterile graft material can be handled by placing it in a vessel with a pour spout (**E,F**) and then filling capped 30-cc syringe barrels from the back. (Reproduced from Sivak WN, Rubin JP. Repair and grafting fat and adipose tissue. In: Neligan PC, ed. *Plastic Surgery*. 4th ed. London: Elsevier, 2017, with permission.)

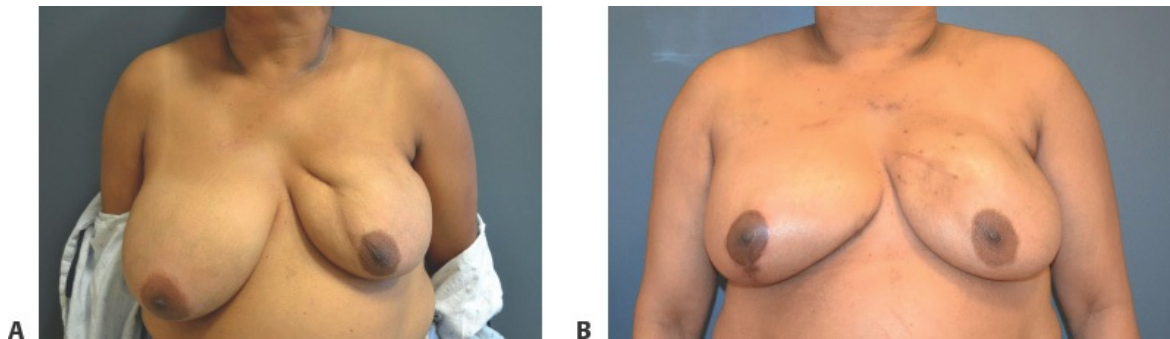
■ Fat Injection

- Planned incision sites are anesthetized with 0.5% lidocaine with 1:200 000 epinephrine, and small stab incisions are made for the placement of fat through 14- or 16-gauge injection cannulas.
- A blunt-tipped injection cannula is connected to the 30-cc syringe (**TECH FIG 2A,B**).
- Three to four injection sites are used, and these can be placed inferiorly and laterally so they are less visible.
- The success of the fat grafting procedure depends not only on the harvesting and refinement but also on the placement of the fat in a manner that increases its chance for optimal survival.



TECH FIG 2 • A. For large-volume fat grafting, a 16-gauge blunt-tipped cannula can be used with the 30-cc syringes, **(B)** and the fat should be easily flowable. (Reproduced from Sivak WN, Rubin JP. Repair and grafting fat and adipose tissue. In: Neligan PC, ed.

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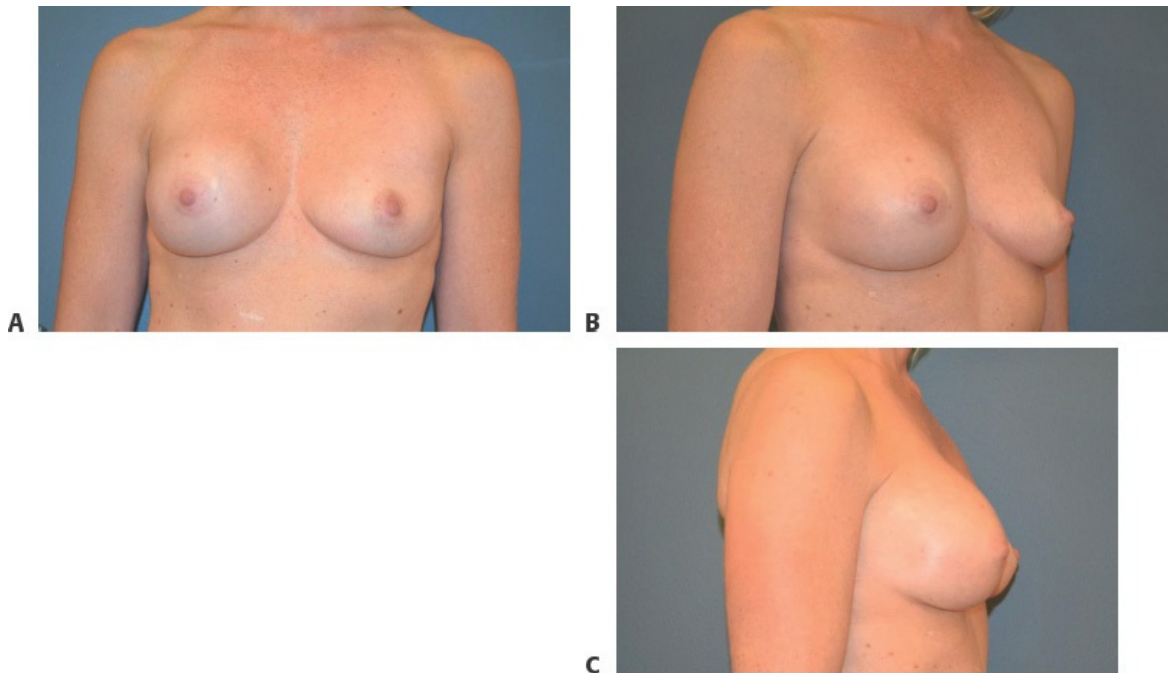


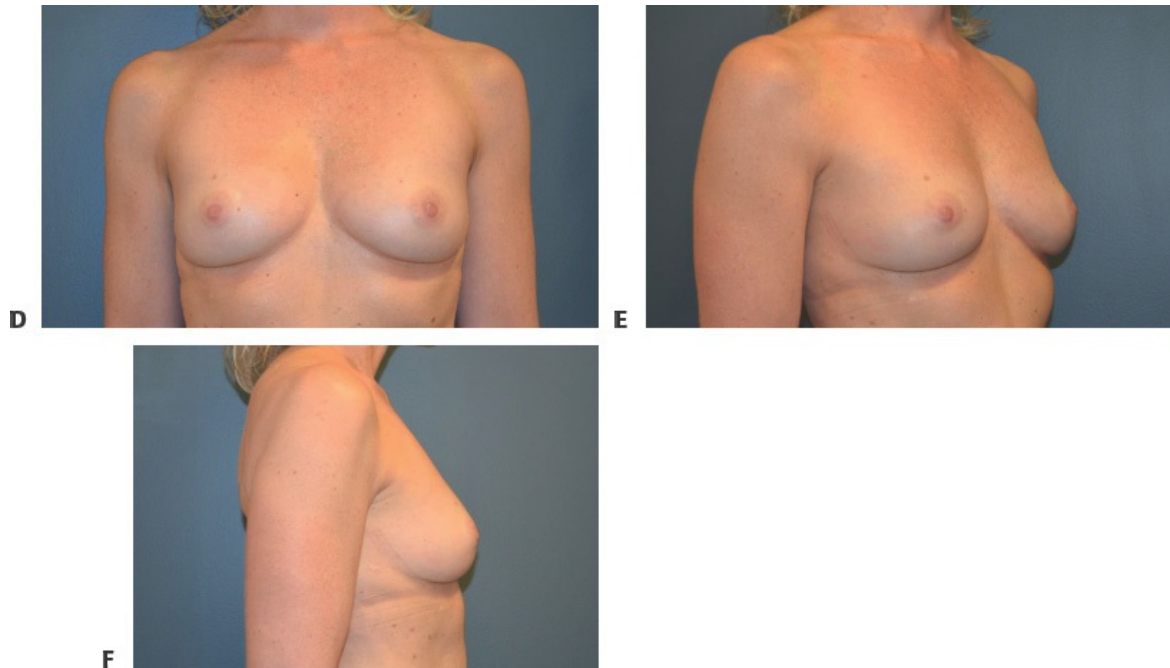
TECH FIG 3 • A. 54-year-old woman 3 years status post left breast quadrantectomy and radiation therapy for invasive breast carcinoma. **B.** Patient shown 5 months status post fat grafting with scar release of the left breast and concurrent reduction of left breast for symmetry. (Reproduced from Sivak WN, Rubin JP. Repair and grafting fat and adipose tissue. In: Neligan PC, ed. *Plastic Surgery*. 4th ed. London: Elsevier, 2017, with permission.)

- This means maximizing the contact surface area of the fatty parcel with the surrounding tissue, such that a blood supply can be conferred to the newly grafted fat.
- Transferring large globules of fat can result in central necrosis of the mass with subsequent resorption and loss of volume or possibly even cyst formation.
- The fat is gently placed during the withdrawal of a blunt infiltration cannula. Recall fat can be placed at different levels to accomplish different effects—determining where and at what level to place fat relies upon the skill and experience of the surgeon.
- Grafting fat immediately beneath the dermis can improve the quality of the skin, decrease wrinkling, and decrease pore size and may even reduce scarring.
- Deeper injection within the breast can be used to increase central

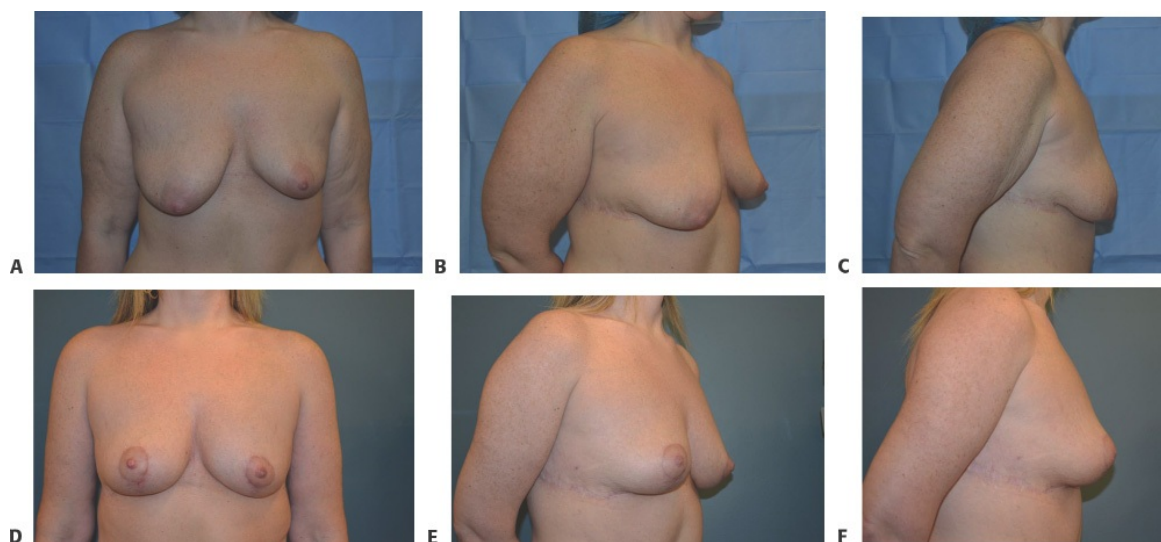
projection.

- Fat can be placed intramuscularly, as needed.
- Structure should be purposefully built up with tiny aliquots of fat rather than attempting to insert larger aliquots and then mold the tissue after it is placed.
- Manual molding of the shape should be considered if an irregularity is noted at the time of placement, as the surface must be smooth before leaving the operating room.
- The stab incisions used for placement of the fat can be closed with single interrupted 5-0 fast-absorbing sutures.
- Examples of large volume fat grafting are shown for lumpectomy defect (**TECH FIG 3**), replacement of implants (**TECH FIG 4**), and cosmetic mastopexy/augmentation (**TECH FIG 5**).





TECH FIG 4 • A–C. Removal of breast implants and replacement with fat graft in the same procedure. This 48-year-old woman had severe right breast capsular contracture with pain. This was a recurrent problem for this patient. She presented for explantation of the implants. (Reproduced from Sivak WN, Rubin JP. Repair and grafting fat and adipose tissue. In: Neligan PC, ed. *Plastic Surgery*. 4th ed. London: Elsevier, 2017, with permission.) **D–F.** Patient 18 months after removal of 350-cc smooth round saline implants and simultaneous grafting of 380cc of fat per breast. (Reproduced from Sivak WN, Rubin JP. Repair and grafting fat and adipose tissue. In: Neligan PC, ed. *Plastic Surgery*. 4th ed. London: Elsevier, 2017, with permission.)



TECH FIG 5 • A–C. A 34-year-old woman with ptosis and asymmetry. Pre-existing flank scar is from a prior upper body lift. **D–F.** She underwent bilateral mastopexy with minimal parenchymal dissection and 350cc of fat grafting to the left breast to balance the asymmetry in volume. Postoperative views are shown at 4 months.

PEARLS AND PITFALLS

Fat harvest	■ The fat harvest is, in itself, a procedure that must be done in a manner to avoid contour deformities and may also have aesthetic goals for that anatomic region.
Fat processing	■ A sterile liposuction canister can be kept on the field for easy and efficient decanting. ■ Large-volume canisters that include filters and outflow ports are commercially available. ■ Workflow efficiency is key for large-volume fat grafting.
Fat injection	■ Injection of local anesthetic solution with epinephrine at the injection site helps to reduce bruising. ■ Special care must be taken when placing fat superficially, as surface irregularities are more apt to be apparent.

- Breast injection port sites can be kept inferior and lateral so they are less visible.

POSTOPERATIVE CARE

- Care of the patient after fat grafting remains relatively simple.
- A loosely fitting surgical bra keeps the patient comfortable and avoids excessive pressure on the grafted sites.
- Direct pressure upon the grafted area should be avoided for 1 month (no sleeping on stomach).
- Donor sites may be dressed with compression garments or an abdominal binder if large volumes are harvested.
- Preoperative antibiotics are used, along with 5 days of antibiotics postoperatively.

OUTCOMES

- With fat grafting, secondary procedures, or touch-up procedures, are always possible because of unpredictable resorption.
 - Infiltration and swelling at the time of surgery, in addition to the unpredictable resorption of fat, make the precise estimation of final volume after healing difficult, especially when compared with silicone implants.
 - Patients should be instructed that multiple rounds of grafting might be required to achieve the desired end result.
- In reconstructive cases, the soft tissue envelope often limits the surgeon, and as tissue quality improves after initial fat grafting, the area may become more receptive to larger subsequent volumes.
 - It is far better to undercorrect a deficient area and return to the operating room for a second stage, if necessary, at a later date, than to overfill the tissues.

COMPLICATIONS

- Fat grafting procedures to the breast by and large are deemed to be low risk and are associated with low perioperative morbidity rates given proper patient selection. Soreness and swelling are common, but not every patient will experience them.
- The most significant risk remains the unpredictable nature of the graft, where the recipient site may simply reabsorb most of the transferred fat. The extent of resorption at this time cannot be predicted for a given individual, but some

degree of resorption will happen in every patient.

- Rare but possible fat transfer risks and complications include allergic reaction to the local anesthetic, permanent discoloration caused by a ruptured blood vessel, fat necrosis, oil cyst formation, calcification, overcorrection, perioperative bleeding, hematoma at the treatment or donor site, a blood-borne infection (more likely if combined with another cosmetic procedure), scarring, and a fat embolism from direct fat injection into a blood vessel.
- The most problematic is the high potential for contour irregularities visible through the skin, which can occur in both the recipient and donor sites.
 - In the recipient sites, excess grafted fat will appear as lumps beneath the skin and is generally the result of placement of a volume that is too large just beneath thin skin.
 - Irregularities in the donor sites can be pronounced, particularly if too much fat is removed from a single area.
 - Significant changes in weight can also result in related changes in the size of the area grafted; therefore, patients are encouraged to have fat grafting procedures performed when they are at their ideal body weight and to maintain that weight indefinitely.

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Section IX: Lymphedema

34 Lymphedema Microsurgery for Breast Cancer–Related Upper Limb Lymphedema

CHAPTER

Ming-Huei Cheng and Jung-Ju Huang

DEFINITION

- Lymphedema can be inherited or a complication after lymph node dissection. Breast cancer–related lymphedema (BCRL) is a potential complication after axillary lymph node dissection, particularly in patients who have or will receive adjuvant radiation.
- With the subcutaneous accumulation of lymphatic fluids, the typical early sign of lymphedema is swelling of the affected limb. Occasionally, patients may present with pain as the first symptom of lymphedema.
- Definitive diagnosis can be confirmed by lymphoscintigraphy.

ANATOMY

- There are approximately 600 to 700 lymph nodes located in a human body, and the axilla is one of the most concentrated areas.
- Axillary lymph node dissection (ALND), as a procedure for breast cancer staging and treatment, often results in lymphedema of the upper extremity of the affected site, which is exacerbated by radiation therapy.^{1,2}

PATHOGENESIS

- The lymphatic system maintains fluid homeostasis, absorbs dietary fat, and facilitates the host immune response. Once disturbed, fluid homeostasis is blocked and subsequent disease is initiated.

- Unbalanced fluid homeostasis can cause protein-rich fluid to leak into the interstitial tissue, resulting in swelling, local tissue inflammation, adipose deposition, and fibrosis.
- A compromised local immune defense makes a patient more susceptible to infection, and repeated cellulitis is one of the common features of lymphedema.
- Although breast surgeons have reduced the frequency of axillary dissection through the use of sentinel lymph node biopsy (SLNB), upper extremity lymphedema can still occur after SLNB or ALND.

NATURAL HISTORY

- BCRL is the major factor that compromises a breast cancer patient's quality of life after treatment.¹
- The presentation time and symptoms of lymphedema are highly variable among patients.
 - Risk factors that contribute to the severity of lymphedema other than radiotherapy include infection and obesity.
 - The incidence of BCRL ranges from 12% to 49%.^{1,2}
- As it differs from most traditional treatments that involve excision or other destructive procedures, microsurgical treatment for lymphedema aims to drain the accumulated fluid from the affected extremity.
- Lymphaticovenous anastomosis (LVA) is the first microsurgery procedure to treat lymphedema.
 - However, this approach has not been popular until recent years, as more accurate diagnostic tools to identify lymphatic vessels have become available, such as indocyanine green (ICG) lymphography.³
- Another microsurgical treatment is vascularized lymph node transfer, which was first developed in an animal study in the 1990s.
 - The idea of transferring healthy, unaffected lymph nodes from other donor sites to the affected extremities provides another approach for microsurgical lymphatic fluid drainage once the lymphatic vessels are destroyed and LVA is not possible.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with BCRL may experience discomfort, swelling, and recurrent cellulitis of the affected extremity.
 - The first sign of lymphedema is often swelling.

- Occasionally, they present with intractable pain for an unknown reason or with repeated cellulitis.
- The resultant problems may become both a physical and psychosocial problem.
- Physical examinations of a lymphedema-affected extremity often reveal nonpitting swelling and thickening of the skin (which can be peau d'orange skin or even woody in more advanced stage).
- It is not uncommon to find skin erosion or ulceration or signs of infection on the skin.
- Occasionally, brachial plexus dysfunction can occur.
- With long-term involvement, the skin of the affected extremity can present elephantiasis nostra verrucosa, which appears hyperkeratotic with cobblestonelike skin and some papillomatous plaques.
- Clear or light yellow fluid can ooze from the skin.
- The tissue may become malodorous in the setting of poor hygiene.

IMAGING

- Accurate diagnosis and grading of lymphedema help to identify suitable treatments.
- Measurement of the limb circumference and calculation of the difference between the normal and diseased extremity often appears to be the first, easy diagnostic tool.
- The level for measurement by the authors includes 10 cm above and below the elbow. The circumference difference can then be calculated accordingly (**FIG 1**).
- Lymphoscintigraphy remains the standard diagnosis for lymphedema.
- With the injection of a tracer molecule with technetium-99m into the dermis of a distal hand, the traveling of Tc-99 can be traced. Information regarding the clearance of the injection tracer, obstruction status (such as total or partial obstruction), and possible obstruction level/presentation of dermal backflow can be provided.
- With a similar injection technique, ICG (indocyanine) dye is intradermally injected into the distal hand (often the 2nd and 4th web spaces).
- With an infrared light source and diagnostic devices, such as PDE (Hamamatsu Photonics, Hamamatsu City, Japan), SPY (Novadaq Mississauga, Canada), and infrared detector–incorporated microscopy, the traveling course of the ICG dye (mainly inside the lymphatic vessels) can be

identified. ICG lymphography provides a dynamic and panoramic view of the lymphatic drainage with time. It is a powerful tool for both lymphedema diagnosis and intraoperative planning for lymphatic surgery.

- The main drawback is that the detection of the ICG is limited to approximately 1 cm underneath the skin.

DIFFERENTIAL DIAGNOSIS

- Diseases other than lymphedema can present with swelling of extremities, such as mechanical obstruction and venous thromboembolism.
- Ultrasonography to assess the status of venous drainage is recommended.

NONOPERATIVE MANAGEMENT

- Nonoperative management strategies include manual massage, complex decongestive physiotherapy (CDP), and compression garments.

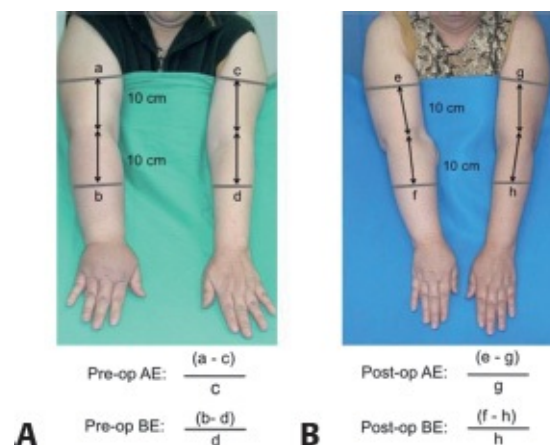


FIG 1 • Measurement of volume differentiation of circumference before **(A)** and after **(B)** lymphedema surgery. To do this, the circumferences of the upper arm and forearm are first measured at the level of 10 cm above and below the elbow.

SURGICAL MANAGEMENT

- Microsurgical treatment for BCRL includes LVA, vascularized lymph node transfer (VLNT), and the combination of microsurgical breast reconstruction and lymph node transfer using an abdominal flap with superficial groin lymph node transfer.

- A “Barcelona cocktail” is a combination of microsurgical breast reconstruction with superficial groin lymph node transfer to the axilla and LVA in the forearm, which aims to complete surgical treatment at one stage.
- Early interventions provide better recovery because the pathological progress of adipose deposition and fibrosis can be better prevented. This is especially true when LVA is considered.
- Microsurgical treatments may not achieve the same degree of volume reduction as liposuction; instead, they gradually stop the disease progression by effectively draining lymphatic fluid into the venous system.
 - Patients with fibrosis may still benefit from surgery with adjuvant procedures, such as liposuction and/or partial soft tissue resection.
- The selection of treatment is based on the severity of lymphatic obstruction and clinical symptoms (**FIG 2**).

Lymphaticovenous Anastomosis

- Technological advancements in diagnosis and mapping have allowed LVA to become a popular procedure for lymphedema treatment in early-grade cases with promising results.
- Different surgeons have different preferences for performing LVA, including the method (end-to-end, end-to-side, and side-to-end), locations, and numbers of LVAs that have to be done.
- Supramicrosurgery, including anastomosis of vessels as small as 0.8 mm or less to small subdermal veins, has been recommended.⁴ To prevent postoperative venous reflux, a suitable recipient vein should present with minimal backflow after it is cut. Strong backflow from the subdermal veins may result in venous blood backflowing into the lymphatics. This results in a limited chance for lymphedema recovery, ecchymosis, and discomfort.

Vascularized Lymph Node Transfer

- VLNT can be effective in patients with different stages of lymphedema, including advanced stage.^{5,6}
- There are two different theories supporting its mechanism for lymphatic drainage.
 - One is based on lymphangiogenesis and spontaneous lymphatic connection.⁷
 - The other is based on the inherent lymphaticovenous connection inside the flap.⁸

- Cheng and colleagues demonstrated in animal studies and intraoperative images evidence to support their theory of this mechanism.⁹ By injection of ICG dye into the subcutaneous tissue of lymph node containing flaps, ICG is eventually drained via the flap donor vein.
- Conversely, drainage is absent when the dye is injected into non-lymph node-containing flap.⁹ They have demonstrated that the inherent lymphaticovenous connection is the main mechanism for lymphatic drainage. Combined with “catchment effect” and “gravity” effect, VLNT placed in the distal recipient site would offer the most benefit for lymphatic drainage.

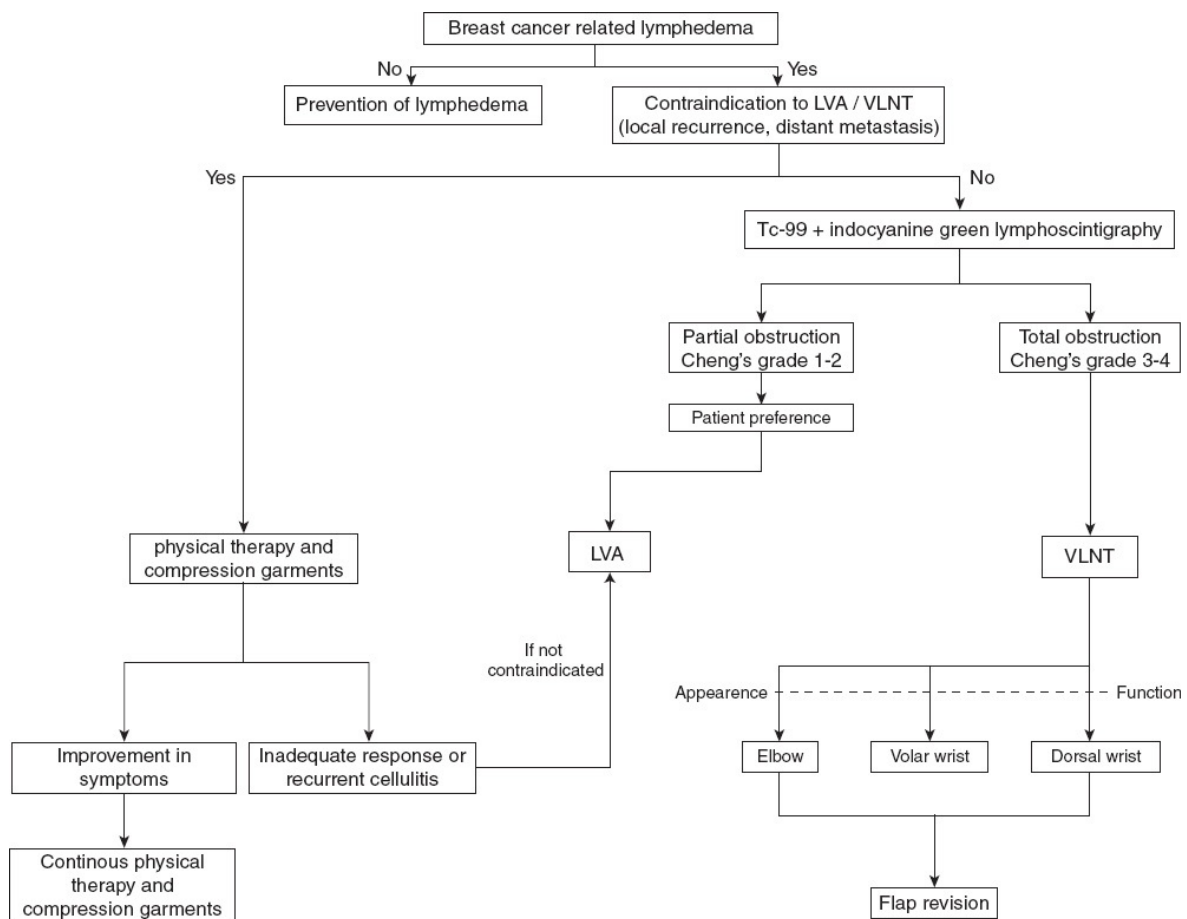


FIG 2 • Algorithm for surgical approaches of breast cancer–related lymphedema (BCRL).

Preoperative Planning

- Cheng and colleagues developed a disease grading system that includes both clinical symptoms and diagnostic results from lymphoscintigraphy⁶ (Table 1).

Based on the staging system, patients are graded from 0 to IV according to the lymphedema severity.

- By combining preoperative symptoms and diagnostic findings, mainly lymphoscintigraphy and ICG lymphography, an algorithm has been developed to more accurately assign the patients to appropriate treatment (see **FIG 2**).
- If the lymphatic obstruction is partial and functional lymphatic vessels can still be identified in ICG lymphography, LVA can be considered a good surgical option.
- However, if the lymphatic obstruction is complete and functional lymphatics are not identifiable, VLNT is the best surgical option.
- Patients who have stage III or IV lymphedema usually require additional procedures other than microsurgical treatment to optimize the results.
- Patients showing a linear pattern of lymphatic vessels with ICG lymphography can be selected for LVA with predictably good outcomes.
- The preoperative use of duplex ultrasonography aids in the selection of the optimal flap for VLNT.⁸ Additionally, duplex ultrasonography can be useful in determining recipient vessels for VLNT.⁸
- More detailed preoperative examinations, such as computer tomography (CT) scan or magnetic resonance imaging (MRI), can be helpful to further differentiate the disease pathology and identify the donor and recipient vessel quality.

Positioning

- Patients are in the supine position for both LVA and VLNT.
- Hyperextension of the neck is required if submental lymph node flaps or transverse cervical lymph nodes are selected as donor sites.

Approach

- For LVA, surgical approach includes one to several 3-cm incisions, depending on preoperative ICG lymphography.
- Surgical approach for VLNT includes flap harvest and recipient site preparation. There are many donor flaps for VLNT depending on preoperative evaluation and the surgeon's preference. Advance selection of appropriate recipient site is equally important (proximal vs distal on the extremity).
- Some surgeons place the VLNT into the axilla where a previous axillary scar exists. The scar will need to be fully released during VLNT. However, we

prefer to place the lymph node flap in a more distal recipient site.

- A distally transferred lymph node flap may function better than proximally transferred lymph node flaps. One possible explanation could be that with disease progression, gravity draws the fluid to a more dependent site.
 - In contrast to the need for a compression garment after surgery in patients receiving lymph node transfer to the axilla, the authors do not recommend a compression garment for patients with a distally transferred lymph node flap. We believe that omitting a compression garment is also an important part of enhancing the quality of life after lymphedema treatment.
 - To balance the appearance and postoperative effectiveness of the surgery, the flap may be placed more proximal to the elbow, depending on the severity of lymphedema and area with the most fluid accumulation.
 - Table 2 lists commonly used lymph node-carrying flaps and the pros and cons for each flap.
 - The submental lymph node flap has a constant donor-site vascular anatomy and greater number of lymph nodes. As it was first introduced as a skin flap, Cheng and colleagues modified the submental flap harvest to include lymph nodes at neck levels Ia and Ib and transferred it to a distal recipient site for treatment of lower extremity lymphedema.
 - Compared to the groin lymph node flap, the submental flap has a longer vascular pedicle with a larger vessel size for microsurgical anastomosis and lymphatic drainage. The flap thickness is less than that of the groin flap, making it a better choice in terms of postoperative appearance of the recipient site when distal transfer is selected.
 - The disadvantage of this flap is the potential injury to the marginal mandibular branch during flap dissection. To prevent this, meticulous dissection of the nerve off the facial vessels is required with the assistance of an operative microscope. Additionally, the platysma muscle may be completely or partially sacrificed, resulting in pseudoparalysis of the marginal mandibular nerve. For prevention, the authors recommend partial platysma preservation during flap harvesting.
 - Unlike most of the available lymph node flaps with a cutaneous flap, the omentum flap is within the abdomen, and its harvest requires abdominal surgery.
 - An endoscopic approach has been well developed for omentum lymph node flap harvesting, with reduced donor-site morbidity and improved appearance.
-

Table 1 Cheng's Grading and Related Management for Lymphedema

Grade	Symptoms	Circumferential difference (%)	Lymphoscintigraphy	Management
0	Reversible	<9	Partial occlusion	CDP
I	Mild	10–19	Partial occlusion	LVA, liposuction, CDP
II	Moderate	20–29	Total occlusion	VLNT, LVA
III	Severe	30–39	Total occlusion	VLNT + additional procedure
IV	Very severe	>40	Total occlusion	Charles procedures and VLNT

Circumferential difference: circumference of the affected limb subtracted from the circumference of the healthy limb and divided by the circumference of the healthy limb, which is measured at 10 cm above and below the elbow. CDP, complex decongestive physiotherapy; LVA, lymphaticovenous anastomosis; VLNT, vascularized lymph node transfer.

From Patel KM, Lin CY, Cheng MH. A prospective evaluation of lymphedema-specific quality-of-life outcomes following vascularized lymph node transfer. *Ann Surg Oncol*. 2015;22(7):2424-2430.

Table 2 Comparisons of Various Donor Sites of Lymph Node–Carrying Flaps

Cutaneous Lymph Node Flaps					
	Submental	Groin	Supraclavicular	Lateral thoracic	Omentum flap
Number of lymph node	+++	+++	+	++	+++
Artery/vein size	+++	++	+	+++	++
Pedicle length	+++	++	++	+++	+
Reliability of skin paddle	++++	+++	+	++	N/A
Ease of harvest	+++	++	++	+	+++
Donor-site scar	+++	+++	++	+++	+++

Advantages	Thin flap with concealed donor scar, reliable pedicle	Reliable pedicle Concealed donor scar	Thin flap	Lengthy pedicle	Rich lymph nodes
Disadvantages	Risk of marginal mandibular nerve injury	Thick flap Short pedicle	Damage thoracic duct when the left side is selected, chest wall numbness	Injury of sentinel lymph node of upper extremity, sacrificing the thoracodorsal nerve	Risk paresthesia and interdigital numbness of lower extremity

++++, great; +++, good; ++, fair; +, poor.

- The vascularized omentum flap contains numerous small lymph nodes and is currently our second-line lymph node flap. Its vascular pedicle is as small as 2 to 3 mm in diameter, but it is short and thin walled for microvascular anastomosis. Most of the lymph nodes can be found along the great curvature; therefore, the flap can be elevated with only the tissues around the pedicle, and most of them can be preserved in situ.
- Compared with the cutaneous lymph node flaps, the omentum flap lacks a skin paddle for replacing skin defects or flap monitoring after transfer.
- Care should be taken to avoid compressing the pedicle vein at wound closure.

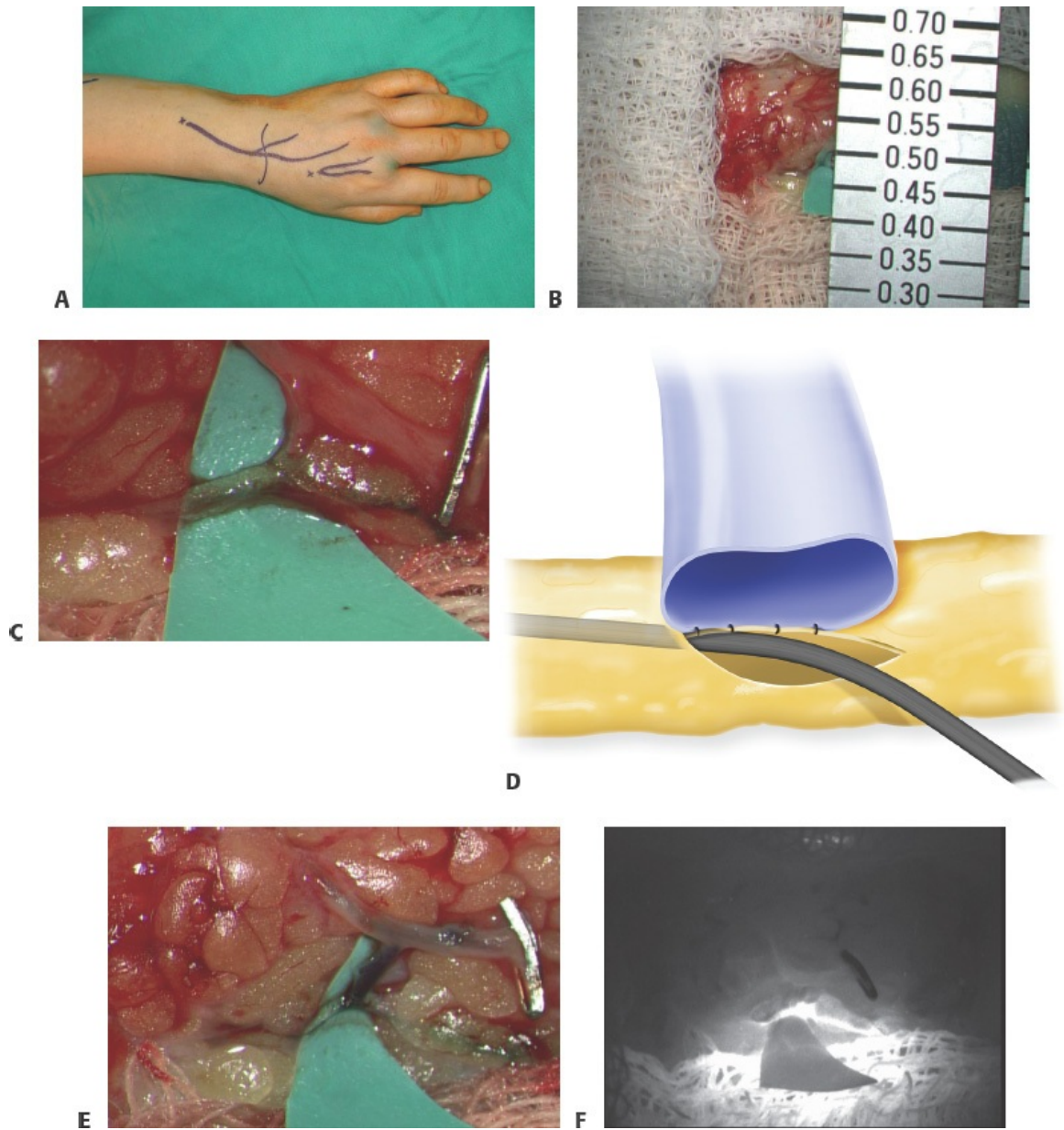
TECHNIQUES

■ Lymphaticovenous Anastomosis

- Before surgery, patients were treated with ICG lymphography to confirm the presence of functional lymphatic vessels.
- Functional lymphatic vessels presenting as a linear pattern in ICG lymphography are then selected and marked as the target for LVA. After ICG mapping, the linear lymphatic vessels are marked, and an incision can be

transversely planned for 3 to 4 cm in length (**TECH FIG 1A**).

- After incision, another distal subdermal injection with blue dye is then performed, and lymphatic vessels can be identified accordingly under a microscope.
- A submental vein is then selected from the surrounding area. A good subdermal recipient vein for LVA should present with less venous backflow to prevent retrograde venous flow into the lymphatic vessels.
- Anastomosis can be performed with end-to-end, end-to-side, or side-to-end anastomosis, depending on the preference of the surgeon. The lymphatic vessels are usually small in caliber (0.5–0.8-mm diameter) (**TECH FIG 1B**).



TECH FIG 1 • **A.** Before performing LVA, lymphatic vessels are detected by ICG lymphangiography, and the lymphatic vessels are marked. **B.** A lymphatic vessel sized 0.5 mm is identified. **C.** The lymphatic vessel is dissected. **D.** The technique of doing side-to-end LVA with a 6-0 nylon as stent inside the lymphatic vessel. **E.** Side-to-end LVA was performed. **F.** With the same view under ICG evaluation mode, ICG can be identified inside the lymphatic vessels, and the

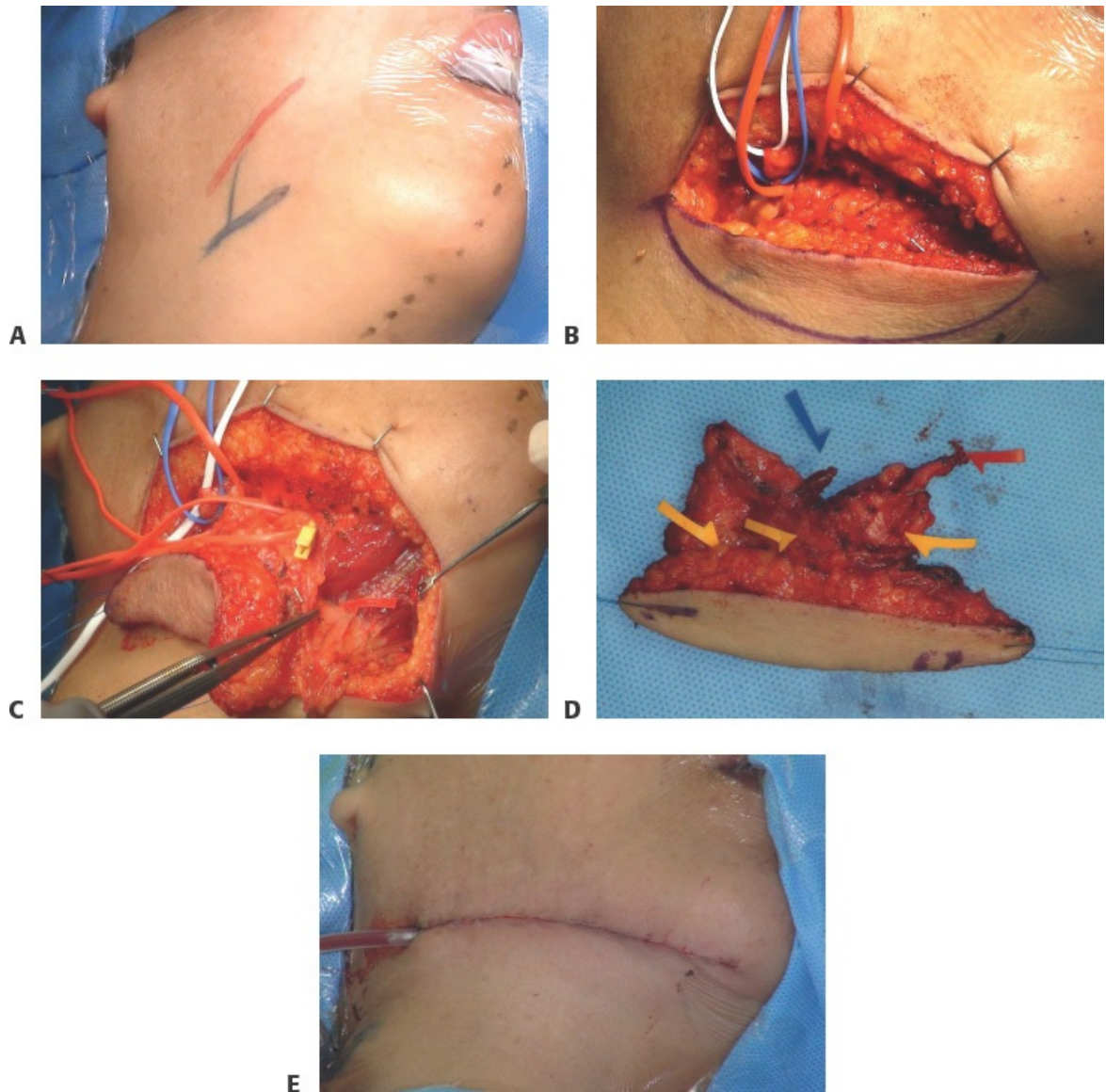
recipient vein confirmed the patency of the anastomosis.

- To see the lumen clearly and promote better visualization and anastomosis, an intravascular stent can be placed using 6-0 nylon suture under a microscope with 40× magnification (**TECH FIG 1C**).
- Multiple different techniques and methods of anastomosis have been used, such as T-shaped anastomosis, diamond-shaped anastomosis, octopus-shaped anastomosis, and ladder-shaped anastomosis. Many of these techniques were designed to simultaneously use a limited recipient vein for anastomosis with several lymphatic vessels.
- The authors recommended a side-to-end anastomosis to allow drainage of most of the lymphatic fluids from the same lymphatic vessel (**TECH FIG 1D–F**). Further large-scale series evaluating the outcomes of LVA are necessary.

■ Vascularized Lymph Node Transfer

Donor Site

- A lymph node flap can be selected among different donor sites. In general, the authors prefer subcutaneous lymph nodes over omentum lymph nodes.
- Subcutaneous lymph node flaps with a skin paddle are important for both flap monitoring and extra skin for tension-free wound closure. However, if the omentum lymph node flap is selected, a skin graft on the top of the flap should be considered instead of burying the flap inside the subcutaneous pocket to avoid compression of the pedicle vein.
- In the example case, at the donor site, the midline of the neck and facial artery and vein are identified and marked (**TECH FIG 2A**).
- An incision is first made along the upper border of the flap and facial artery, and the facial vein and marginal mandibular branch of facial nerve are identified and carefully dissected out (**TECH FIG 2B,C**).
- The pedicle of the flap is then divided (**TECH FIG 2D**) and the donor site closed (**TECH FIG 2E**).

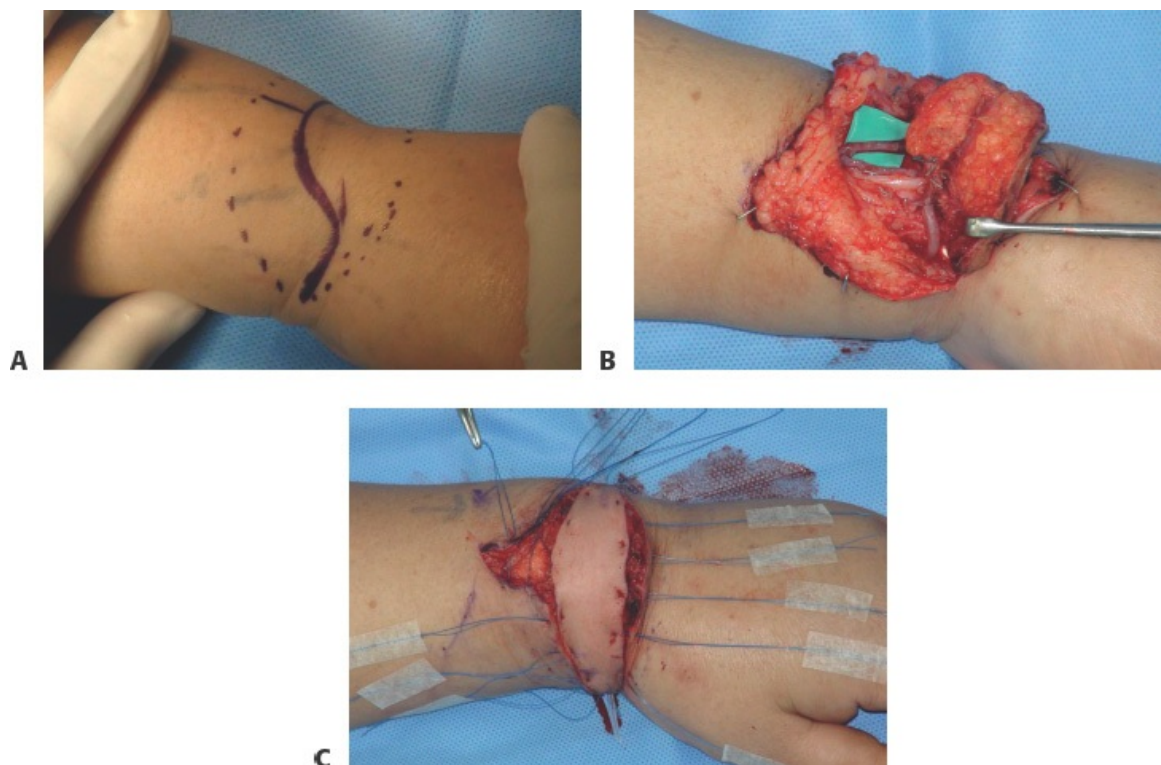


TECH FIG 2 • Example case of free submental lymph node flap transfer to treat upper limb lymphedema. **A.** Before surgery, the midline of the neck and facial artery and vein were identified and marked. **B.** Incision was first made along the upper border of the flap and facial artery; facial vein and marginal mandibular branch of facial nerve were identified and carefully dissected out. **C.** Flap dissection was completed. *Red arrow* showed the donor artery of the flap. **D.** The pedicle of the flap was divided. *Red arrow*, artery; *blue*

arrow, vein; *yellow arrow*, lymph nodes. **E.** The donor site was closed primarily.

Recipient Site

- Recipient site selection is based on the severity of lymphedema.
 - The authors recommended transfer of the lymph node flap to the wrist in advanced lymphedema. ICG lymphography with the lymphatic drainage pattern can be a good reference for recipient site selection. The flap should be placed distally if severe dermal backflow is present.
- To use the wrist as the recipient site, the dorsal branch of radial artery in the snuffbox is often selected as a recipient artery, and the cephalic vein is often selected as a recipient vein.
- A lazy S incision is transversely made along the dorsal crease of the wrist (**TECH FIG 3A**).
- Subcutaneous dissection is then carried out. The fibrotic tissue should be removed to create a pocket with adequate space for a lymph node flap inset and adequate space to compensate for swelling of the lymph node flap after absorbing the lymphatic fluid inside the flap.
- The recipient vessels should be well prepared with removal of all the fibrotic adventitia to prevent restriction of blood flow from the fibrotic tissues.
- Microvascular anastomosis is performed first, following with tension-free flap inset and wound closure (**TECH FIG 3B,C**).
- The flap often becomes engorged after it is transferred to lymphedema recipient site because of transit of fluid into the lymph node in the first 7 days following the operation.
- Adequate pocket size for inset of the flap skin paddle will allow for tension-free wound closure, and avoidance of pedicle vein compression is critical for achieving an optimal result.



TECH FIG 3 • **A.** A lazy S incision was made along the wrist to identify the recipient vessels. **B.** The flap was transferred to the recipient site and anastomosis was accomplished. **C.** Flap inset.

PEARLS AND PITFALLS

Imaging

- Definitive diagnosis of lymphedema can be achieved using lymphoscintigraphy.
- ICG lymphography can be a good diagnostic and surgical guided tool. The results of ICG lymphography are used to separate the patients into LVA or VLNT groups. For LVA, it can provide good intraoperative lymphatic mapping.

LYMPHATICOVENOUS ANASTOMOSIS

Technique

- Do surgery only on patients presenting linear pattern of ICG lymphography.
- Selection of a small subdermal vein without venous reflux as a

	recipient vein ■ Side-to-end anastomosis is recommended ■ Intravascular stent of lymphatic vessel using 6-0 nylon to prevent back wall suture ■ Tension-free wound closure to prevent compression
Postoperative care	■ Restriction of ambulation for 3 days ■ Compression garment is <i>not</i> recommended.
VASCULARIZED LYMPH NODE TRANSFER	
Technique	■ Recipient site selection should be based on the lymphatic obstruction; in general, distal transfer presents better results. ■ Subcutaneous lymph node flap is recommended to include its skin paddle for tension-free wound closure and flap monitoring. ■ Be sure to release all the fibrosis and create a subcutaneous pocket that is larger than enough for flap inset. ■ Release and adventitiectomy are important while preparing the recipient vessels. ■ Tension-free flap inset and wound closure are important. ■ Never hesitate to use therapeutic dose of anticoagulants.
Postoperative care	■ Intensive monitoring of the flap ■ Avoid ambulation for 7 days. ■ Prophylactic antibiotics for 7 days

POSTOPERATIVE CARE

Lymphaticovenous Anastomosis

- After surgery, it is recommended that patients rest with limited ambulation for the first 3 days.
- Parenteral prophylactic antibiotics are given for 3 days.
- Movement is gradually increased after the first postoperative day.
- Compression garments are not required after surgery.

Vascularized Lymph Node Transfer

- After surgery, patients are admitted to microsurgical intensive care unit for postoperative monitoring of the flap.
- Flaps are monitored using pencil Doppler detection of both artery and vein every 2 hours.

- Postoperative prophylactic antibiotics are given for 1 week.
- The use of anticoagulants depends on intraoperative findings. The authors found that there is a high tendency of thrombosis formation in lymphedema surgery. Therefore, the use of therapeutic dose of anticoagulation is not uncommon.
- Patients are allowed to walk freely and move the upper extremity 1 week after surgery.
- Compression garments are not required after surgery.

OUTCOMES

Lymphaticovenous Anastomosis (FIG 3)

- The largest series of LVA for upper extremity lymphedema was reported by Chang and colleagues with significant improvement after LVA in 96% of patients.
- Constant improvement of volume reduction was observed from 33% 3 months after surgery to 42% after 1 year.¹⁰
- A better volume reduction after LVA was reported for earlier lymphedema stage for upper extremity lymphedema.
- The most important consideration in performing LVA is that it is difficult to ensure a 100% patency rate after surgery.
- Patency has been reported as low as 0% patency 3 weeks after surgery by Puckett¹¹ to 93% after 7 years of follow-up by Campisi et al.¹²

Vascularized Lymph Node Transfer (FIGS 4 to 6)

- In patients with advanced stage lymphedema, it has been reported that VLNT has better results than does LVA.⁵
- A reduction rate of 39% was with 18 months of follow-up using distal vascularized lymph node transfer.
- With an average follow-up of 29 months, Brucker and colleague reported that 84% of the patients reported improvement of their lymphedema symptoms after vascularized lymph node transfer.¹³
- Although distal transfer of the flap often results in an unsightly skin paddle in the beginning, revision surgery after the development of symptoms can significantly improve the appearance.
- It is not uncommon for patients to require some other additional procedure to achieve better volume reduction and appearance after microsurgical

approaches. These procedures often include liposuction, wedge resection of part of the proximal soft tissue, or debulking of the transferred skin flap.

Quality of Life After Lymphedema Microsurgery

- VLNT helps to improve the patient-reported outcomes as soon as after the 1st week of surgery.
- By using health-related quality of life (HRQoL) merits, Patel and colleagues prospectively evaluated patients undergoing vascularized lymph node transfer for upper or lower extremity lymphedema and reported improvement regarding the domains of function, body appearance, symptom, and mood in proportion to the improvement of limb circumference.⁶

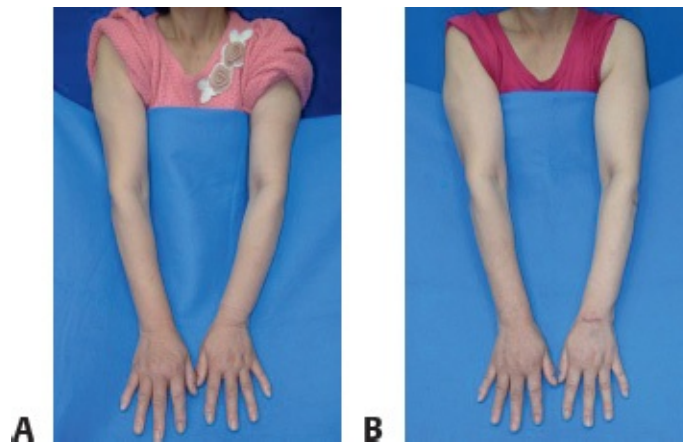


FIG 3 • A. This 60-year-old woman shown in **TECH FIG 1** underwent mastectomy and chemotherapy for left breast cancer and experienced BCRL. **B.** At 12-month follow-up after LVA, she had reduction rates of 5% and 20% at the above-elbow level and below-elbow level, respectively, in her left arm.

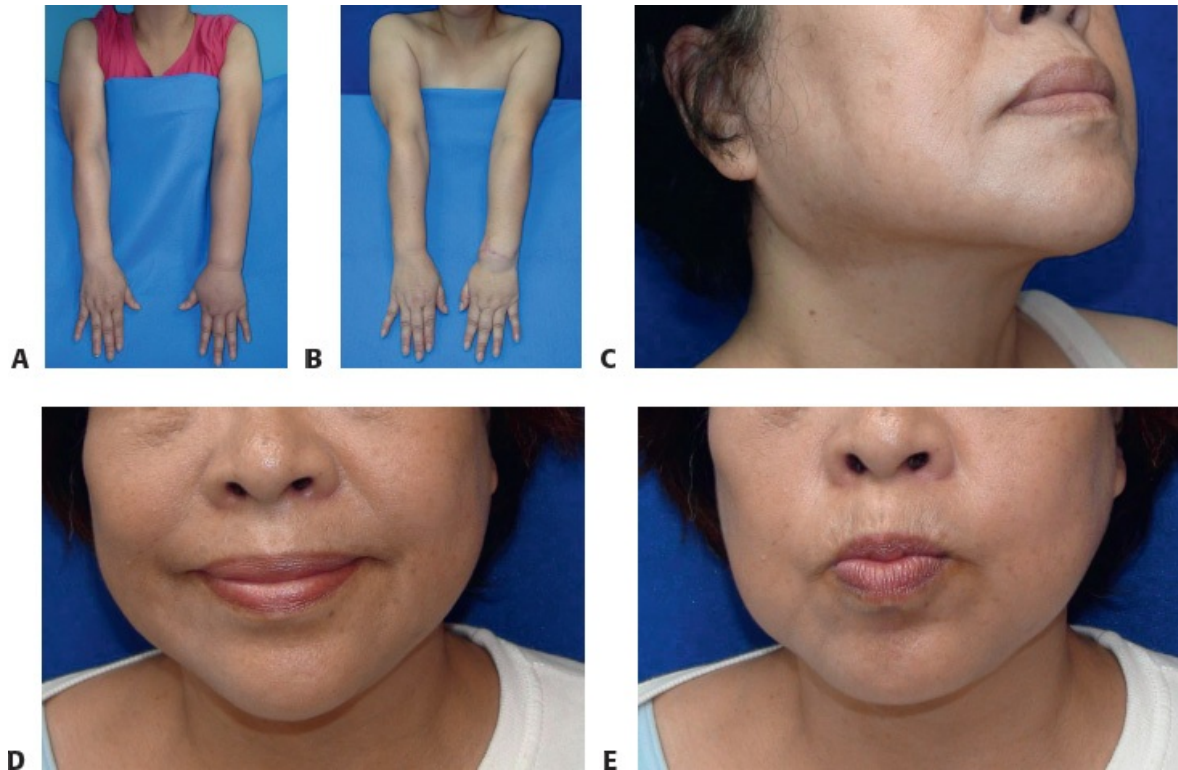


FIG 4 • This 56-year-old woman with left breast cancer is pictured in TECH FIGS 2 and 3. She received skin-sparing mastectomy and tissue expander reconstruction followed by chemotherapy for breast cancer. **A.** Left upper arm nonpitting edema presented 6 months after surgery. **B.** At 30 months of follow-up, she presented with reduction rates in her left arm lymphedema of 35% and 20% at the above-elbow level and the below-elbow level, respectively. **C–E.** Her donor-site scar was well concealed, and there were no donor-site morbidities.

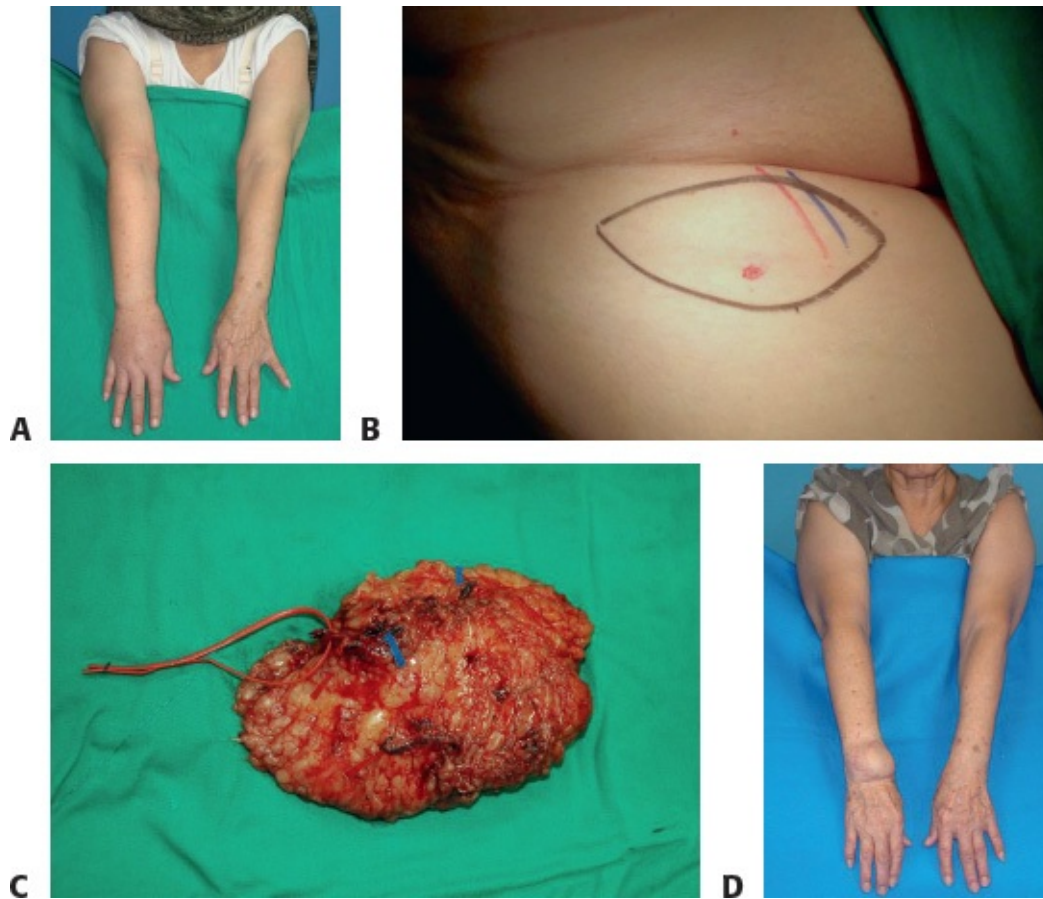


FIG 5 • This 79-year-old woman had a history of right breast cancer after modified radical mastectomy, radiotherapy, and chemotherapy. She started to experience right upper arm swelling 6 months after breast cancer treatment. She received vascularized groin lymph node flap transfer 14 months after the first presentation of lymphedema. **A.** Preoperative appearance of the upper extremities. **B.** Vascularized groin lymph node flap of 10 × 5 cm was designed on her left groin area. **C.** Vascularized groin lymph node flap was harvested based on the medial artery (*red arrow*) and vein (*blue arrow*). **D.** At 24-month follow-up, she had reduction rates of 30% and 35% in the upper arm and forearm, respectively.

- The improvement in the HRQoL appeared as soon as the first month, and the improvement was continued and sustained during the 1 year of follow-up.
- Gratzon evaluated the psychosocial outcome of vascularized lymph node transfer using the LYMQoL prospectively and revealed early steady improvements with respect to the function, appearance, mood, and symptoms.¹⁴
- Using Upper Limb Lymphedema Questionnaire 27, Brucker and colleagues evaluated the quality of life after simultaneous breast reconstruction and vascularized lymph node transfer with inspiring results.
- With an average follow-up of 29 months, 84% of the patients reported improvement of their lymphedema symptoms.¹³

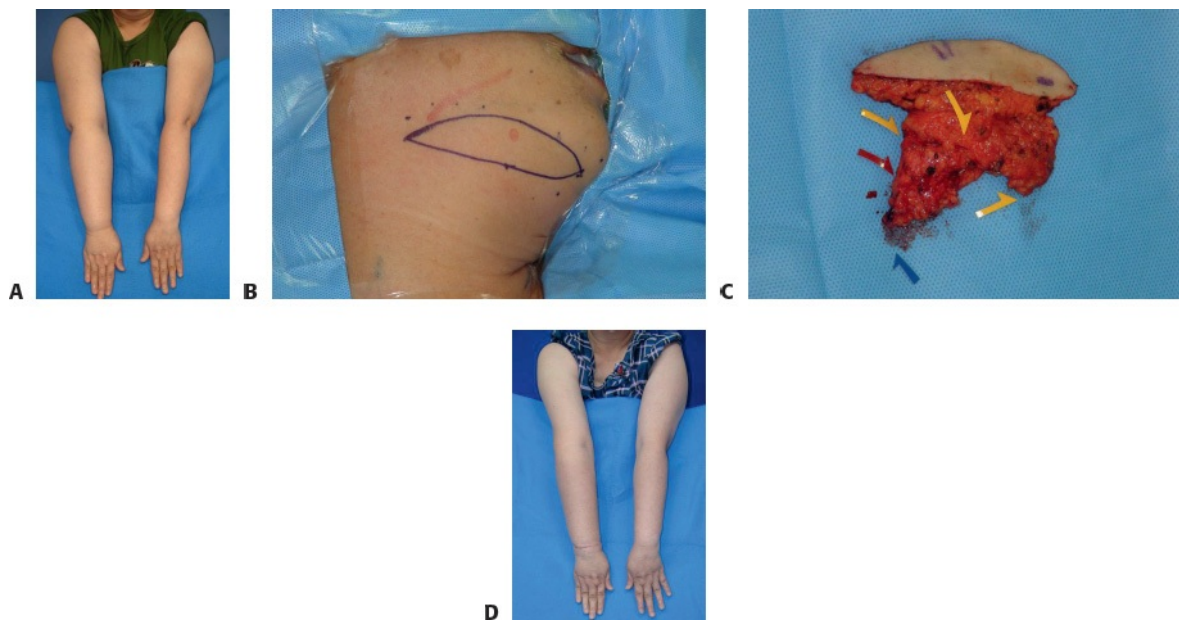


FIG 6 • This 52-year-old woman had a history of right breast cancer, stage II, after modified radical mastectomy, chemotherapy, and radiotherapy and lung metastasis after wedge resection of the tumor. She presented with right upper arm lymphedema 1 year after surgery and received vascularized submental lymph node flap transfer 4 years after her first presentation of lymphedema. **A.** Preoperative appearance of bilateral upper extremities. **B.** Vascularized submental lymph node flap of 8.5 × 2.5 cm

was designed. **C.** Vascularized submental lymph node flap was harvested based on submental artery (*red arrow*) and facial vein (*blue arrow*). Lymph nodes were visualized during surgery (*yellow arrow*). **D.** At 18-month follow-up, she had reduction rates of 35% and 42% at the above-elbow level and below-elbow level, respectively.

- Although the different groups continue to have different preferences for recipient and donor-site selection, vascularized lymph node transfer seems to work by different designs and combinations of breast reconstruction with an abdominal flap.

COMPLICATIONS

- Complications of LVA include obstruction of the anastomosis and venous reflux into the lymphatics. To prevent this, the recipient vein should be a small subdermal vein with limited backflow.
- Common complications of vascularized lymph node transfer include early thrombosis of the vein, partial or total loss of the skin paddle, and infection.
- To ensure a safe flap transfer, inclusion of skin paddle for intensive monitoring is recommended.
- It seems that there is a higher incidence of thrombus formation in vascularized lymph node transfer. To minimize this risk, therapeutic dose anticoagulation is occasionally required.

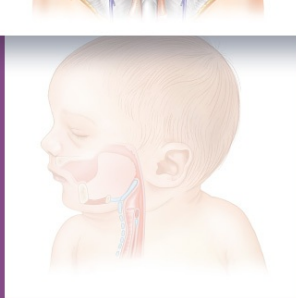
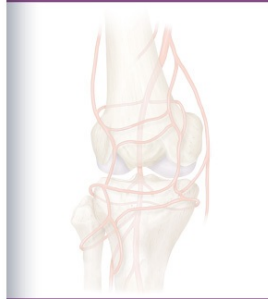
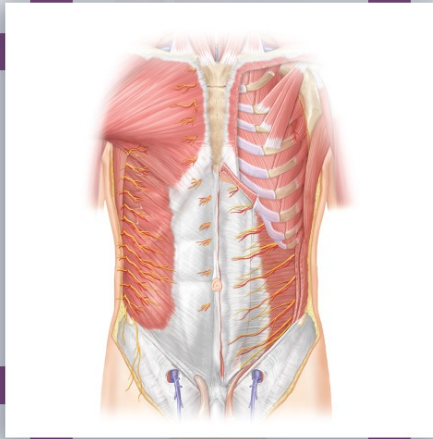
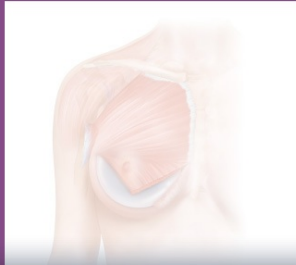
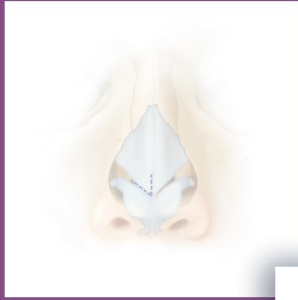
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PART 5

Trunk Reconstruction and Body Contouring



Section I: Reconstruction of the Chest Wall

1 Pectoralis Flap for Chest Wall Reconstruction

CHAPTER

Jeff J. Kim and David H. Song

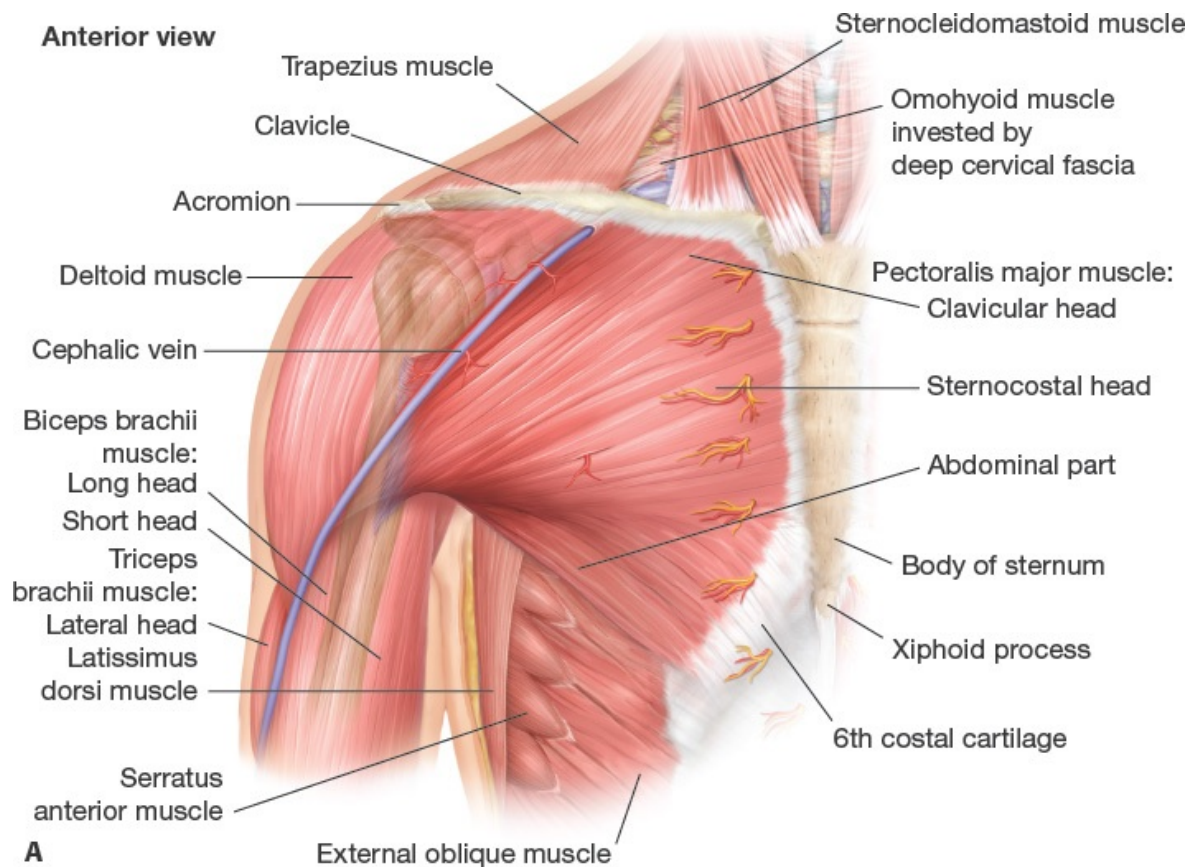
DEFINITION

- Chest wall defect: Most common etiologies include trauma, tumor resection, osteoradionecrosis, deep sternal wound infections, and chronic empyemas.
- Chest wall functions: Protection of visceral organs, support of respiratory mechanics, and base scaffold for shoulder/upper limb
- Basic defect management concepts: Adequate debridement of infection/nonviable tissue, reconstruct to re-establish form and function, replacing like with like whenever possible
- Reconstructive goals:
 - Stabilize thoracic skeletal defect to return proper respiratory mechanics.
 - Obliterate intrathoracic dead space that may predispose to infection.
 - Protect vital intrathoracic structures.
 - Provide soft tissue coverage for closure.
 - Recreate aesthetic contour.
- Defects requiring skeletal support to prevent paradoxical motion: 5 cm or more in diameter or two or more rib resection anteriorly, twice as much for lateral and posterior defect; radiated tissue can often tolerate larger defect due to rigidity from fibrosis.

ANATOMY

- Pectoralis major

- Origin: Sternum, 1st to 6th costal cartilage, clavicle (**FIG 1A,B**)
- Insertion: Lateral lip of bicipital groove of humerus
- Innervation: Medial and lateral pectoral nerve from medial, lateral cord of brachial plexus
- Function: Adduction, extension, and medial rotation of shoulder
- Borders: Superficial to pectoralis minor, superior and superficial to serratus anterior, inferior to the subclavius; two heads converge laterally inferior to deltoids; lateral border forms the anterior axillary fold/wall
- Vascular anatomy (**FIG 1C**)
- Mathes and Nahai classification: type V muscular flap—thoracoacromial artery (dominant) and internal mammary perforators (secondary segmental)



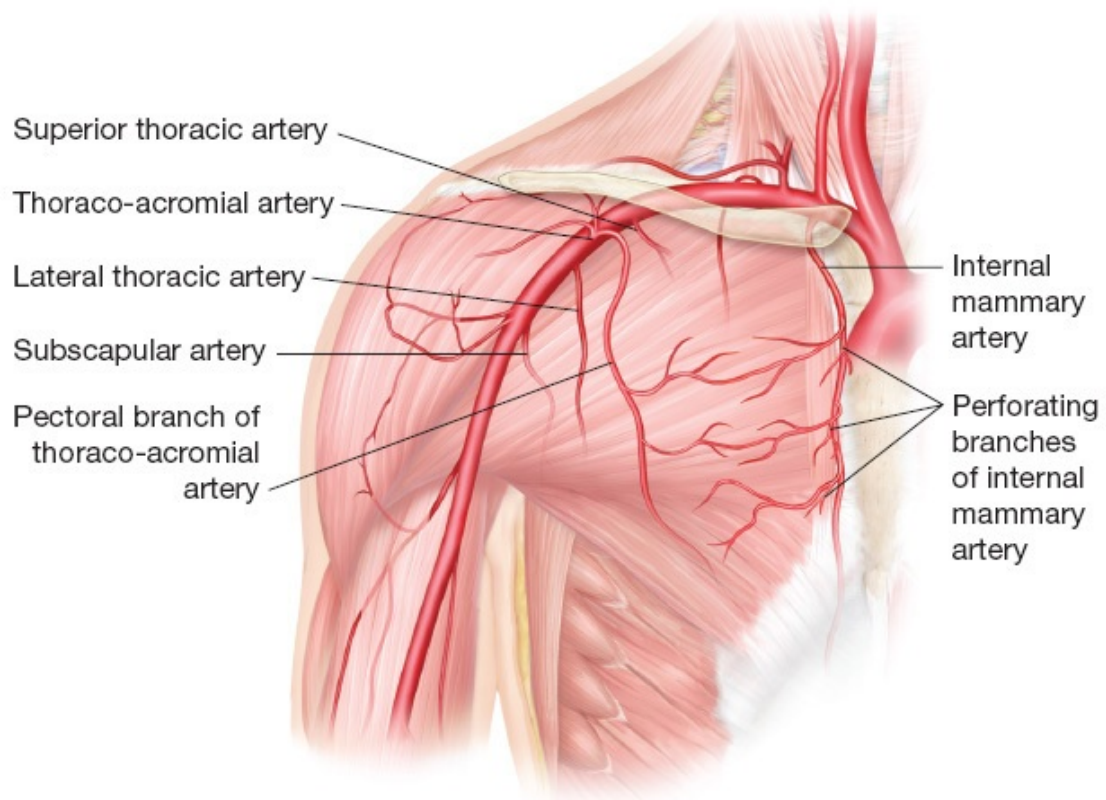
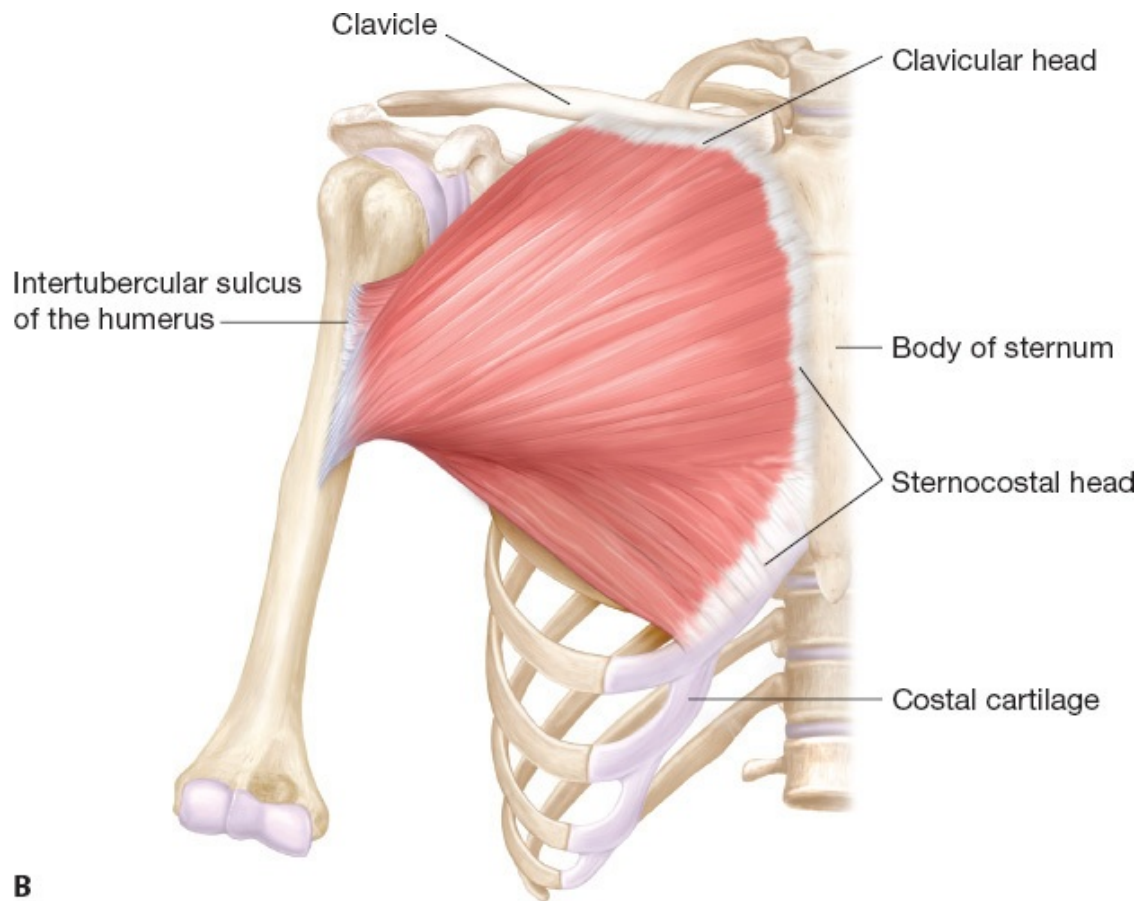


FIG 1 • A. Muscular anatomy of anterior chest and shoulder. **B.** Origin and insertions of the pectoralis major. **C.** Vascular anatomy of blood supply to pectoralis major.

- Thoracoacromial artery arises from second portion of axillary artery deep to pectoralis minor, travels laterally and merges superomedially to pectoralis minor, and divides into four branches as it pierces the clavipectoral fascia. The dominant branch to the sternocostal portion is the pectoral branch, which courses deep to pectoralis major after piercing through the clavicopectoral fascia medial to pectoralis minor before dividing into muscular and cutaneous branches; clavicular branch arising lateral to pectoralis minor has much shorter pedicle (1 cm) before exclusively supplying the clavicular head, subclavius muscle, and soft tissue around the clavicle.
- Internal mammary artery (IMA) provides reliable secondary segmental pedicles through its perforating branches that pass through the intercostal spaces 1 to 2 cm lateral to the sternal edge; usually three perforators provide the muscle through the first to third intercostal space with branches coming through first or second space being the most dominant.
- Venous drainage: Muscle drains mainly via venae comitantes of the pedicles, through pectoralis branch into the axillary vein, while overlying skin drains through venules accompanying arterial perforators.

PATHOGENESIS

- Most common etiology and mechanism of chest wall defects requiring reconstructive interventions include injury from trauma, iatrogenic (radiation, cardiothoracic surgery), infection, congenital deformity, and neoplasm.

NATURAL HISTORY

- Tansini is often credited with first use of muscle flap in chest wall reconstruction using latissimus dorsi.¹
- Jurkiewicz and others transposed the pectoralis major into the mediastinum either based on the thoracoacromial pedicle or as a turnover flap based on perforators of the IMA.²
- Nahai introduced a modification of the turnover pectoralis major flap by dividing the muscle medial to the thoracoacromial pedicle and using only the

medial two-thirds of the pectoralis major for definitive coverage of the mediastinal wound.³

- Tobin suggested the splitting of the pectoralis major muscle into sternocostal, external, and clavicular segments and the preserving of the thoracoacromial pedicle.⁴
- Morain suggested the splitting of the pectoralis major muscle into segments but leaving some of the segments intact to preserve muscle function for smaller defects requiring only a small portion of muscle.⁵

PATIENT HISTORY AND PHYSICAL FINDINGS

- Preoperative evaluation for patients requiring pectoralis flap for chest wall reconstruction is mostly based on history and physical examination.
- History
- Etiology, chronicity
 - Important to note history of radiation and history of surgery, including history of coronary artery bypass grafting (CABG)/IMA harvest and other chest incisions. Also important to note pulmonary function and history of chronic obstructive pulmonary disease
 - Social: Smoking history
- Physical examination
 - Important to note size, location, and tissue composition of defect
 - Soft tissue: Size and location
 - Skeletal: Number of ribs and size of skeletal defect
 - Intrathoracic: Size and volume of dead space
 - Respiratory mechanics: Skeletal stability, presence of paradoxical motion, soft tissue compliance
 - Previous scars, radiation changes

IMAGING

- Preoperative computed tomography (CT) is not absolutely necessarily from a reconstructive standpoint, especially in wounds requiring further debridement where final size and composition of defect will invariably change.
- If a CT scan is available, however, it can provide some preoperative insight for operative planning in some cases.

DIFFERENTIAL DIAGNOSIS

- Trauma

- Empyema
- Poststernotomy mediastinitis
- Osteoradionecrosis
- Tumor resection of anterior chest wall

NONOPERATIVE MANAGEMENT

- For small and superficial wounds or defects with no exposed vital structure or functional defect, it may be possible and appropriate to manage using simple wound care methods with either traditional wet to dry gauze dressings or negative pressure wound therapy.
- In cases of heavily contaminated or actively infected wounds (except deep sternal infections), local wound care may be more appropriate initial method of management to prepare the wound bed prior to proceeding with definitive operative reconstruction.

SURGICAL MANAGEMENT

- Pectoralis major offers large muscular flap with robust blood supply, with arc of rotation based on thoracoacromial pedicle by allowing coverage of central, supraclavicular, and axillary or lateral chest wall defects, as well as being able to be transposed to an intrathoracic position for obliteration of dead space.
- The pectoralis major is most commonly used as an advancement flap to cover anterior chest wall defects in the upper part of the chest, classically for wounds resulting from an infected median sternotomy after open heart surgery.⁶
 - This technique allows for repeat subsequent procedures through the midline incision, including further debridement and costochondral resection, without sacrificing viability of reconstruction.¹
- Turnover flap is based off its medial segmental blood supply from perforators of IMA allows coverage of wounds extending further inferiorly or to the contralateral side or to provide large bulk of healthy tissue to obliterate more significant area of dead space.
- Contraindications/disadvantages:
 - Low sternal and xiphoid defects may be out of reach for the pectoralis flap.
 - If IMA has been harvested for prior cardiac bypass procedure, secondary perfusion through segmental pedicles off IMA would not be available for a turnover flap.
- Other surgical options:
 - Local flaps: Latissimus dorsi, rectus abdominis, serratus anterior, omentum

- Free tissue transfer

Preoperative Planning

- A good history and physical examination will usually suffice for preoperative purposes, as final size and extent of defect will often not be established until called on intraoperatively after resection/debridement.
- Location, extent of defect, and availability of the pedicles (prior radiation, surgery) will primarily dictate whether reconstruction will be based off thoracoacromial vs internal mammaries, unilateral vs bilateral, or if at all.
- If size and extent of defect will not be fully established until intraoperatively, the surgeon should be prepared and comfortable to use alternative options, including other local flaps or even free tissue transfers.

Positioning

- The patient is positioned supine on the operating table.
- The arm should be adducted to the side and secured via tucking it on the side from which the flap is planned to be harvested (**FIG 2**).
- This allows for ease of surgeon positioning and access, especially in case humeral attachments need to be divided.
- It also allows for physiologic advancement where the pectoralis major muscle is not placed on passive stretch as in an abducted/arm out position.
- The opposite arm should be out.
- For ease of identifying landmarks, entire anterior chest surface should be prepped and draped into the field, with clavicle and acromial process of the scapula exposed superiorly and upper arm and midaxillary line laterally.

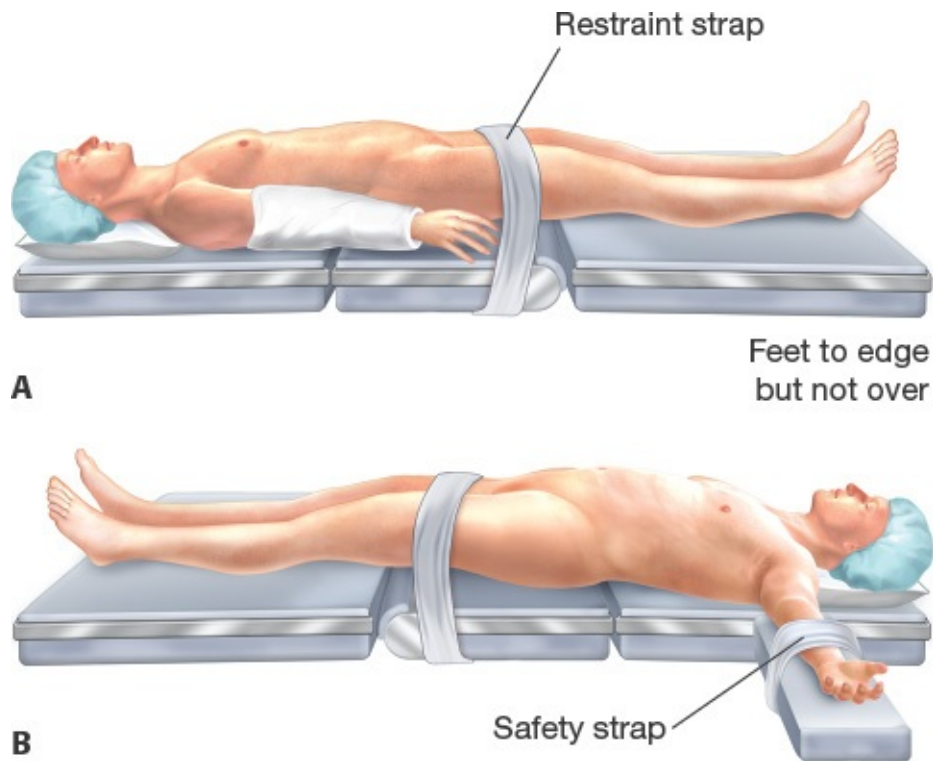


FIG 2 • Preoperative patient positioning: supine with arm on operative side adducted (**A**) and tucked and the other arm out (**B**).

Approach

■ Pedicle landmarks

- Thoracoacromial pedicle originates at the cross section of line drawn from the acromial process of the scapula to the xiphoid and perpendicular line originating at the junction between middle and lateral third portion of the clavicle (**FIG 3**).
- Internal mammary perforators can be found piercing through within intercostal spaces, about two fingerbreadths lateral from the costosternal junction.

■ Incisions

- Depending on location of defect/wound, a separate incision may not be required to access around the muscle for necessary releases. Muscle can often be completely released through the wound.
- For small median sternotomy wounds, lateral counterincision can often be helpful to more easily access insertion of the muscle at the anterior axillary

fold.

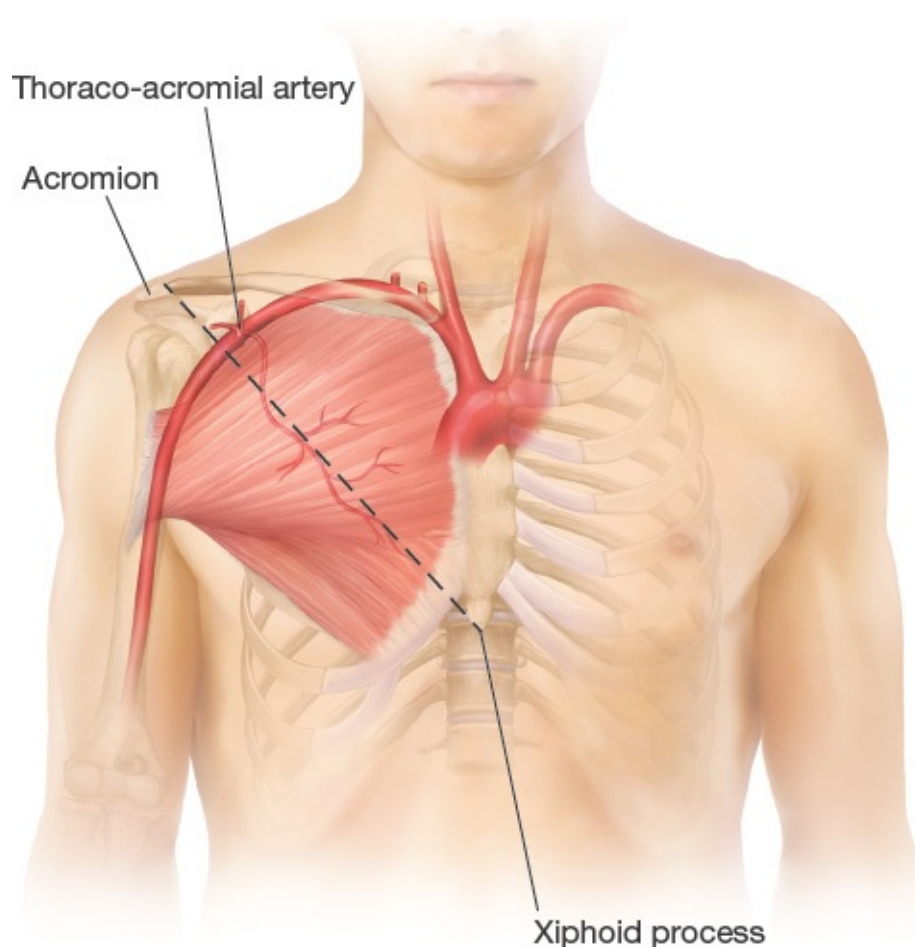


FIG 3 • Markings for thoracoacromial pedicle.

- If not accessed through pre-existing wound, depending on the choice of vascular pedicle, location of defect, and plan for inclusion of cutaneous skin paddle, incisions may be varied.
 - Most useful incision is often placed along the lateral border of the muscle, with option to extend the incision curved inferomedially under the breast in subpectoral groove or inframammary fold (IMF) on females (this incision can be used for either pedicle and entire surface of the muscle can be accessed).
- Skin paddle
 - Design should be centered on a line drawn from tip of acromion to xiphoid process (approximate course of pectoral branch of thoracoacromial pedicle) on males or centered along the IMF for females.

- Skin paddle width of up to 8 cm can be expected to be closed primarily.

TECHNIQUES

■ Harvest for Rotation-Advancement Flap

- This flap is based off the primary thoracoacromial artery.
 - If accessed via medial sternal wound, skin incision can be extended vertically as needed. If a myocutaneous flap is planned, the muscle can be accessed superolaterally and inferomedially through the incision around the skin paddle.
 - Identify the plane between the subcutaneous tissue of the chest wall and the anterior surface of the pectoralis fascia.
 - Dissection should continue superolaterally toward the axilla until the entire anterior surface of the muscle is exposed.

Raising the Muscle

- Dissection of muscle off the chest along the medial insertion is generally more difficult so it may be helpful to raise the muscle off starting at the lateral edge, where the subpectoral plane is easier to identify.
 - It usually can be identified through blunt dissection just using the fingers (placement of counter skin incision over this area laterally on the chest surface may allow for easier access).
- Submuscular dissection can then proceed medially freeing the inferior attachment of the muscle along the rectus abdominis and external oblique aponeurosis and then subsequently proceed superolaterally toward the axilla/pedicle.
- When dissecting the medial attachment of the muscle, care should be taken to ligate the intercostals and internal mammary perforators
 - It is important to leave some perforators from muscle to overlying skin to maximize healing potential of midline and to minimize postoperative seroma formation.
- As muscle is elevated toward superolaterally, care is to taken to find the right plane to avoid elevating the pectoralis minor and leaving it intact in situ.
 - Blunt finger dissection can be performed along the anterior surface of pectoralis minor, which will aid in identification of pectoralis minor branch

from the thoracoacromial artery, which should be divided closely to the pectoralis minor muscle to avoid damaging the main pedicle (**TECH FIG 1**).

- Usually dividing the medial attachment and lifting the muscle off the chest wall thoracic cage is sufficient to mobilize the muscle to cover the sternotomy defect medially, but further mobilization can be achieved by releasing the clavicular attachments superiorly or dividing the sternocostal head from clavicular head of the muscle.
- As the clavicular head of the muscle is dissected off the clavicle working in a medial to lateral direction, when approaching the lateral third of the clavicle, care is taken as subclavian vein can be found just deep to this landmark.
- Staying on the anterior surface of clavicle during release/dissection of muscle will minimize any risk of injuring critical structures.
- Humeral insertion can also be released laterally for further mobilization through separate incision near the humeral insertion at the lateral lip of bicipital groove; however, this usually accentuates aesthetic distortion of anterior axillary landmark.

Approaching the Pedicle

- An Allis or Babcock is used to grab the thick head of the muscle that has been freed of the clavicle, and careful dissection of the upper portion of the muscle can proceed.
- The thoracoacromial artery should be identified as it exits the subclavicular space and enters the underside of the pectoralis major muscle.
- All muscle lateral to the pedicle is expendable and should be divided to maximize excursion and advancement of the flap medially.
- Careful inspection of the pedicle reveals initial lateral course of the pedicle prior to turning medially toward along fibers of the muscle. Careful dissection of the pedicle proximal to this “elbow” level can allow for straightening out of the vessel and maximize its length.

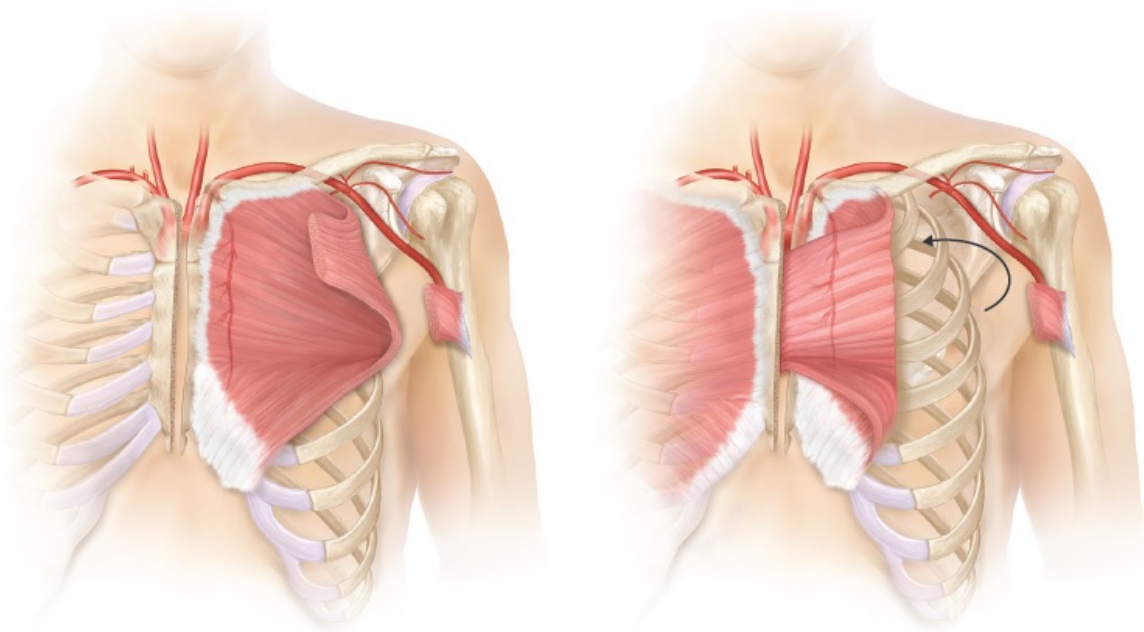


TECH FIG 1 • Rotation-advancement flap harvest. Release of medial, inferior, and lateral insertion of muscle while preserving thoracoacromial pedicle attachment.

■ Harvest for Turnover Flap

- This flap is based off perforating branches of internal mammary, often used when inferior pole of sternal wound requires coverage.
 - Disadvantages include relying on secondary blood supply.
- Entire anterior surface of the muscle should be dissected free off the overlying subcutaneous tissue.
- Raising of the muscle should begin laterally at the anterior axillary fold and proceed medially. A counter skin incision over this area can be very helpful for access.
- As the muscle is divided superolaterally, the humeral insertion of the pectoralis major muscle should be divided.
 - Modification can be made by dividing the muscle medial to the thoracoacromial pedicle and using only the medial two-thirds muscle.
 - Humeral insertion and anterior axillary fold can be preserved by dividing the muscle medial to it and anchoring the lateral portion of the muscle to the chest wall to preserve function and minimize donor-site morbidity.⁷

- Proceed to divide clavicular and inferior attachments, being mindful of the subclavian vessels deep to the clavicle.
- As medial attachment is approached, care should be taken to identify and protect the perforating vessels from IMA, which will arise about 2 cm medial to the costosternal junction.
- No medial attachment beyond these vessels should be divided since the vessels themselves limit medial transposition of the flap (**TECH FIG 2**).

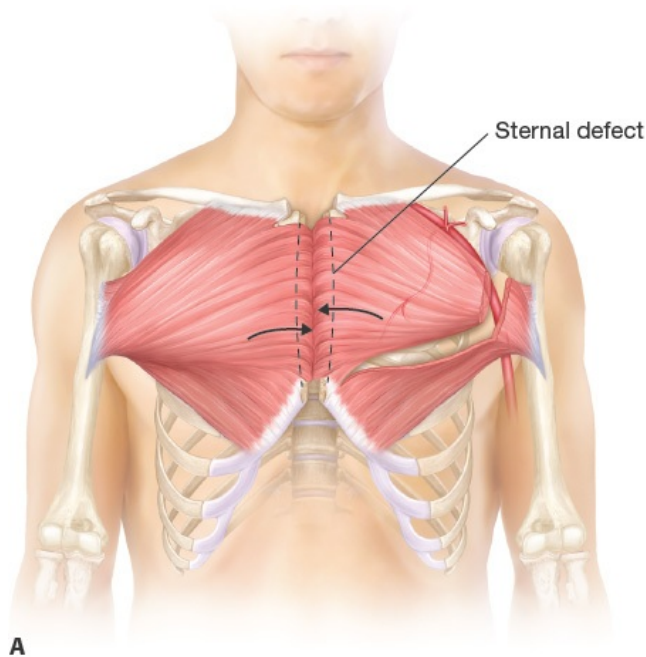


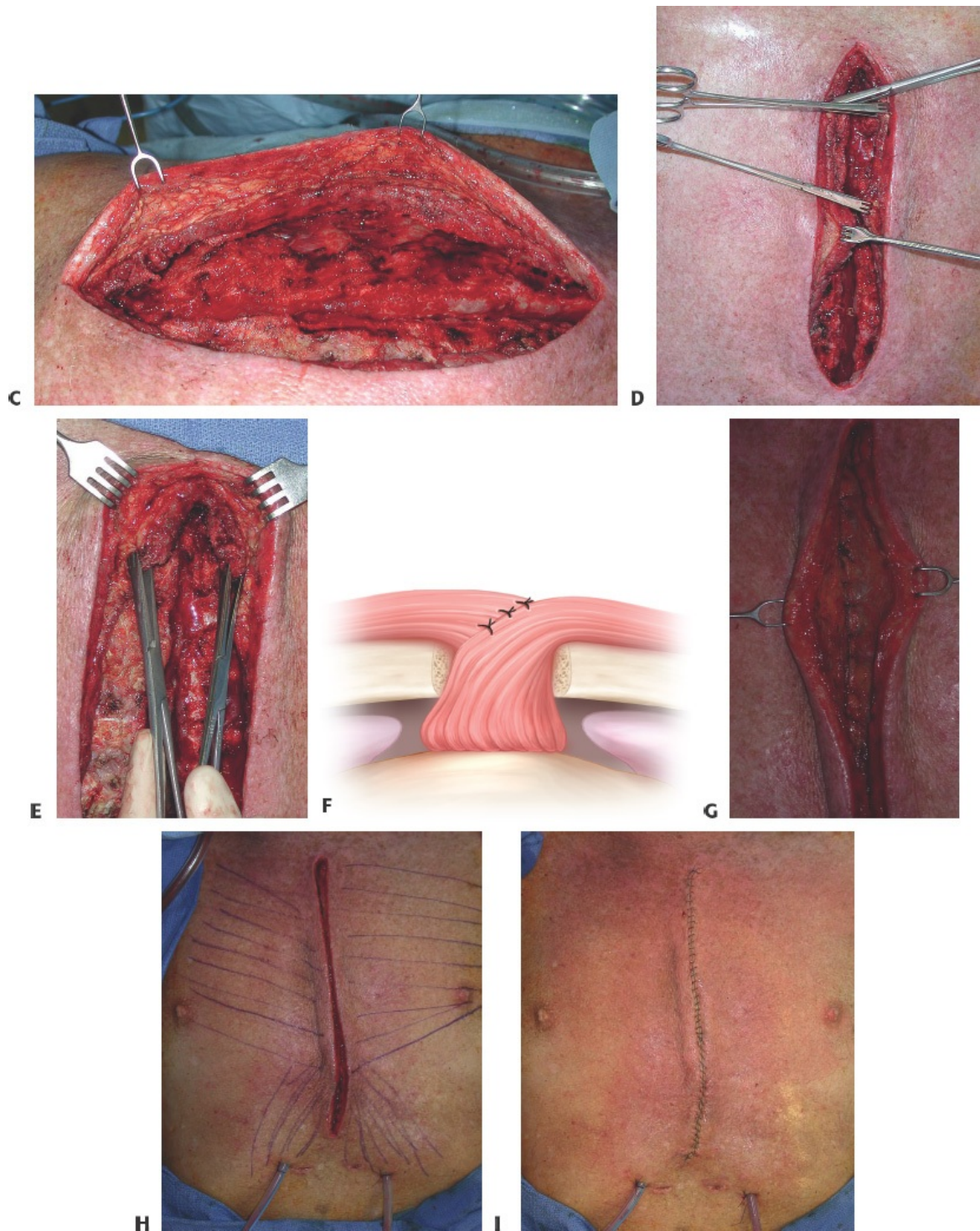
TECH FIG 2 • Turnover flap. Thoracoacromial pedicle is ligated to allow for turnover of the lateral portion of the muscle medially. Medial blood supply from internal mammary vessels is preserved.

■ Bilateral Advancement Flap

- This flap is often used for larger sternotomy wounds to obliterate deeper sternal dead space (**TECH FIG 3A,B**).
- Superiorly, dissection ends just below level of the clavicle.
- Laterally, elevation off the chest wall should be performed so just enough muscle can be mobilized from either side to approximate the two muscles together with minimum tension (usually between midclavicular to anterior axillary line; **TECH FIG 3C**).

- Humeral insertion, pedicle axis, innervation, and pectoralis minor should all be left intact.
- Inferiorly, dissection is continued deep to the muscle and deep to anterior rectus fascia, until level of xiphoid.
- The inferior insertion of the pectoralis major is elevated without detaching the muscle from the superior portion of anterior rectus sheath. The rectus muscle should be left intact (**TECH FIG 3D,E**).⁸
- The wound is closed (**TECH FIG 3F-H**).
- Three drains should be placed: one medial drain, two laterally (one under each flap; **TECH FIG 3I**).⁶





TECH FIG 3 • Bilateral advancement of pectoralis major. **A.** Design of flap. **B.** Large sternal wound before debridement. **C.** Pectoralis major muscle dissected off the chest wall after complete

debridement of sternum. **D.** Bilateral pectoralis major muscle advancement showing minimal tension. **E.** Raising the pectoralis major in conjunction with the superior portion of the rectus abdominis muscle as one single unit to close the xiphoid region. **F.** Pectoralis major advancement closure complete. **G.** Cross-sectional view of defect repair. **H.** Muscle layers closed. **I.** Closure completed with two drains in place.

PEARLS AND PITFALLS

Drains	■ Placement of closed suction drains in spaces above and below the pectoralis muscle is critical to avoid seromas. Drains will typically stay in for up to 3 weeks. Care must be taken to avoid placing closed suction drains directly over the right ventricle. Closed suction drains that are well placed can also be set to continuous wall suction at -70 mm Hg or less to assist in obliterating the dead space.
Flap harvest	■ Muscle harvest can be extended to the insertion of the pectoralis major into the humerus. For greater mobility, the humeral insertion can also be detached and the entire muscle can be transferred based on the thoracoacromial vessels with reliability.
Coverage	■ The inferior portion of the sternal wound is the most difficult to cover. Developing the pectoralis major muscle in continuity with the superior origin of the rectus abdominis muscle can create greater vascularized coverage for the inferior most extent of the wound. This allows for an entire unit of both pectoralis major muscle and the superior origin of the rectus muscle to be advanced into the inferior sternal wound. Often, the superior epigastric artery must be ligated to gain greater mobility. This then allows for the entire unit to be based upon the thoracoacromial system above and the deep inferior epigastric system below.
Turnover flaps	■ Turnover flaps are based on the secondary blood supply from the internal mammary system and thus are unreliable but can be used when the internal mammary vessels on the respective side have not been sacrificed. This maneuver mandates a close examination of the vasculature and blood supply with the use of either pencil Doppler probes or preoperative duplex.

POSTOPERATIVE CARE

- Keeping drains up to 3 weeks leads to decrease in seroma rate. Any drains in intrathoracic spaces should be put to low continuous wall suction to prevent possible pneumothorax.
- When wound dehiscence is encountered, wound irrigation and light gauze packing can be employed along with negative pressure dressings. Readvancement of the pectoralis myocutaneous unit can be considered once the wound is in bacteriologic control and all necrotic or infected tissues are removed.
- Other shoulder girdle muscles will compensate for weakened abduction, internal rotation, and flexion.
 - Starting 6 weeks, start consistent fair to moderate physical therapy for range of motion, flexibility, and strengthening only. Thereafter, full range of motion with resistance and weight training is allowed.

COMPLICATIONS

- Seroma/hematoma
- Skin/flap necrosis, wound dehiscence
- Infection
- Donor-site complications
 - Contour deformities
 - Impaired shoulder functions

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2 Sternal Debridement and Application of Muscle Flaps

CHAPTER

Sean M. Fisher, Jeff J. Kim, and David H. Song

DEFINITION

- Deep sternal wound infections (DSWIs) are a feared postoperative complication of open heart surgery, with a reported global incidence of 0.25% to 2.8%.¹
- Sternal infections may be classified based on the system popularized by Pairolero and Arnold^{1–3}:
 - Type I: Demonstrate serosanguineous drainage without evidence of deep soft tissue, bone, or cartilage involvement.
 - Type II: Demonstrate purulent drainage, cellulitis, and mediastinal suppuration.
 - Type III: Osteomyelitis, costochondritis, and/or foreign bodies are commonly present.
- Alternative classification systems are based on the extent of damage to underlying tissue or relative anatomic location of the wound.²
- Sternal necrosis can result in critical-size defects in the thoracic wall with exposure of underlying thoracic structures, necessitating the involvement of reconstructive surgeons.
- Sternal nonunion is defined as pain or clicking with objective measures of instability lasting greater than 3 months, albeit in the absence of signs of infection.⁴

ANATOMY

- The thoracic cage has mechanical and protective properties, serving as an attachment point for a number of chest wall muscles and acting as a key protective barrier for thoracic organs.

- The sternum acts as a cornerstone of the thoracic cage and is composed of the manubrium, the body, and the xiphoid process.
- Manubrium
 - Superior most aspect of the sternum, helping anchor the pectoral girdle via the sternoclavicular joints, and as the anterior aspect of the superior thoracic aperture (**FIG 1A**)
 - Sternal angle serves as a critical surface landmark, composed of the manubrium angled posteriorly to the body at the manubriosternal joint.
 - Contains articular surfaces at the superolateral aspect, allowing for articulation with the left and right clavicle
 - Facets inferior to the sternoclavicular joints represent the site of attachment for the first costal cartilage, whereas demifacets at the inferolateral aspect allow for articulation with the superior aspect of the second costal cartilage (**FIG 1B**).
 - Serves as the site of attachment for the sternocleidomastoid, pectoralis major, sternohyoid, and sternothyroid muscles
- Body
 - Narrow, flat bone that is oriented longitudinally with palpable transverse ridges
 - Contains facets along the lateral aspect, allowing for articulation with the 3rd to 6th costal cartilages
 - Demifacets at the superior and inferior aspect allow for shared articulation between the 2nd and 7th costal cartilages with the adjacent sternal components (see **FIG 1B**).
 - Serves as the major attachment for the pectoralis major
- Xiphoid process
 - Inferior aspect of the sternum and demonstrates variable morphology
 - Along with the body of the sternum, the xiphoid process articulates with the 7th costal cartilage via superolateral demifacets.
 - Serves as an attachment point for the diaphragm and rectus abdominis

PATHOGENESIS

- The primary insult in DSWIs may begin as a site of focal sternal osteomyelitis without external evidence of infection when sternal fixation is inadequate or may be due to skin breakdown with subsequent penetration of bacteria to deeper layers.

- Presentation often demonstrates a highly variable time course, ranging from days to years following cardiac surgery.²
- In cases requiring surgical debridement, Gram-positive organisms, namely *Staphylococcus*, have been found to be overwhelmingly responsible for infection.⁵
- In addition to male sex, conditions associated with patients' habitual state have been shown to be risk factors in the development of DSWIs and associated morbidity and mortality.
 - Diabetes mellitus (DM), COPD, BMI over 30, chronic steroid use, and smoking are known predictors of DSWI.
 - Bilateral internal mammary artery (IMA) grafting for CABG also increases the risk of postoperative DSWI, as it may reduce sternal vascularity, and should be avoided in those patients with DM and other high-risk comorbidities.^{1,2}
- Sternal nonunion represents a similar, yet separate, diagnosis that may necessitate sternal debridement as a treatment strategy.
- Both intrinsic and extrinsic factors may contribute to an increased propensity in developing sternal nonunion following median sternotomy or traumatic injury.
 - Factors that are dependent on patients' habitual state closely mimic those risk factors associated with DSWI.
 - These include DM, COPD, obesity, chronic steroid use, malnutrition, and osteoporosis.⁴
 - Intraoperative technical errors, as well as postsurgical factors, may also play a role in the development of sternal nonunion.⁴

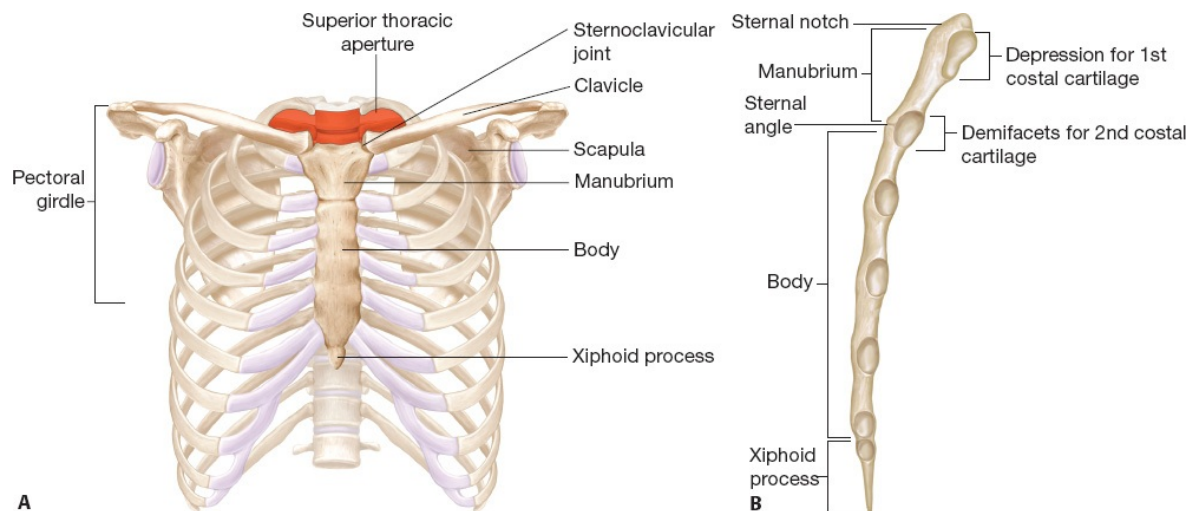


FIG 1 • A. The sternum represents an anterior anchor point for the pectoral girdle, attaching via the sternoclavicular joint bilaterally. The superior thoracic aperture, noted in *red*, houses the trachea, esophagus, and thoracic duct, as well as a variety of nerves and vessels. **B.** Lateral view of the sternum demonstrates the manubrium, the body, and the xiphoid process with corresponding facets and demifacets for articulation with corresponding costal cartilage.

NATURAL HISTORY

- Julian et al. first described the median sternotomy in 1957, which initially met resistance due to reported rates of infection exceeding 5%.¹
- As the technique gained traction in open cardiac surgery, and advances were made allowing for surgical intervention in patients with more extensive comorbidities, DSWIs began being described with incidence ranging from 3% to 5%^{1,6,7} and associated mortality as high as 50%.^{1,2}
- Classification of the wound often typifies the time course to presentation^{1,2}:
 - Type I: Often presents within the first few days following surgery
 - Type II: Typically occurs a few weeks following surgery
 - Type III: Can occur months to years following surgery
- A second classification system proposed by Jones et al. attempts to further qualify the severity of the wound by addressing the extent of involvement in underlying tissues⁸:

- Type 1a: Superficial wound with skin and subcutaneous tissue dehiscence
- Type 1b: Superficial wound with exposure of the sutured deep fascia
- Type 2a: Deep wound with exposed bone and stable wired sternotomy
- Type 2b: Deep wound with exposed bone and unstable wired sternotomy
- Type 3a: Deep wound with exposed necrotic or fractured bone, unstable sternotomy, and exposed heart
- Type 3b: Type 2a, 2b, or 3a wound with septicemia
- Marked improvement in outcomes has been demonstrated, due to the utilization of myocutaneous flaps for reconstruction, with more recent morbidity reported as low as 8% to 15%.^{1,2}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Surgical history, physical exam, and history of trauma are imperative in the initial assessment of patients suspected of having a DSWI or sternal malunion, as well as complaints of ongoing pain, sternal clicking, or subjective instability.
- Signs of infection may vary based on the time of presentation in relation to patients' history of cardiac surgery, as laid out by Pairolero and Arnold.³
- Physical examination
 - Inspect the skin for median sternotomy scar.
 - Assess whether evidence of DSWI is present such as erythema, purulent discharge, fever, wound dehiscence, or frank necrotic tissue.
 - If an open wound is present, the extent of necrotic tissue should be assessed by evaluating the viability of different flap options based on the expected extent of excision.
 - Stability of the sternum can be assessed with direct palpation.
 - If sternal nonunion is suspected, clicking may be elicited with movement.

IMAGING

- Computed tomography (CT) is the mainstay of imaging support when suspicion of DSWI is high, allowing for the evaluation of the depth of dehiscence as well as sternal nonunion⁵ (**FIG 2A**).
- ^{99m}Tc-leukocyte imaging also has value in the early detection of DSWIs (**FIG 2B**).

NONOPERATIVE MANAGEMENT

- Nonoperative management is based on the extent of the infection, evidence of instability, and clinic signs of systemic infection.

- Mainstay of nonoperative management includes long-term IV antibiotics and incision and drainage of limited/superficial abscess collection, followed by local wound care with frequent wet to dry gauzes, topical antibiotics, or negative pressure wound therapy (NPWT).⁵

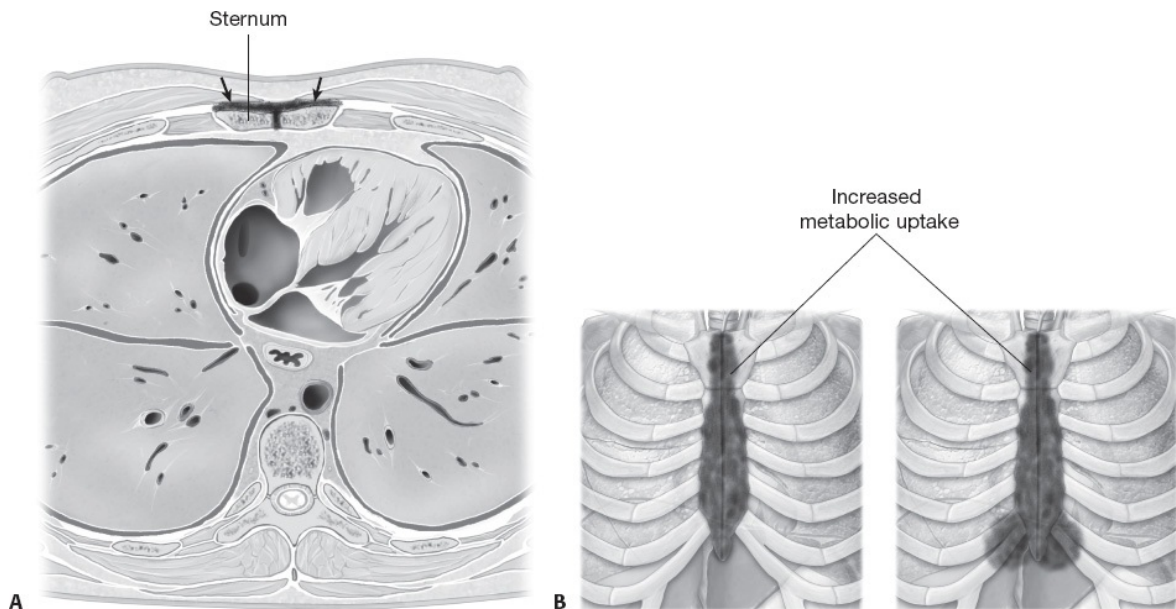


FIG 2 • A. Axial CT demonstrating fluid collection, as indicated by the *arrows*, resulting in the separation of the sternum into two distinct halves. **B.** ^{99m}Tc-leukocyte scan taken at 4 hours (*left*) and 20 hours (*right*) after leukocyte radiolabeling. Diffuse uptake of the distal sternum is noted at 4 hours, with lateral extension at 20 hours. Surgical intervention confirmed infection in areas noted to have enhanced signaling. 20 hours after leukocyte radiolabeling. Diffuse uptake of the distal sternum is noted at 4 hours, with lateral extension at 20 hours. Surgical intervention confirmed infection in areas noted to have enhanced signaling.

SURGICAL MANAGEMENT

- The need for surgical intervention is dependent on wound severity and may include complete debridement of devitalized tissue, removal of preexisting

hardware, fixation of sternal fragments, partial or total sternectomy, and eventual reconstruction utilizing myocutaneous flaps.^{2,8,9}

- Indications for sternal debridement include the presence of devitalized tissue, positive Gram stains of parasternal fluid, and notable sternal instability.^{8,9}
- Timely surgical debridement has been shown to result in shorter hospital stays and fewer postoperative hospitalizations.¹⁰
 - Depending on the extent of devitalized tissue and time course since median sternotomy, either limited or complete debridement may be indicated.^{8,11}
 - Single-stage intervention, with immediate flap coverage, has been shown to reduce the duration of hospital stays.^{1,8,11}
 - Serial stage approaches utilizing bridging NPWT may avoid the need for a vascularized flap or reduce the total number of flaps needed.
- Consideration for flap selection is based largely on:
 - Anatomic location/extent of the defect
 - Prior surgical history, including prior CABG requiring IMA grafting, as this may prevent the use of pedicled flaps based on IMA perforators or the utilization of the IMA as recipient vessels in free flap transfer

Preoperative Planning

- Usually, a thorough history and physical examination are sufficient for preoperative planning. Evaluation of imaging studies can sometimes help elucidate less obvious infection and sternal nonunion.
- Given the extent of defect, adequacy of debridement may not be known until the time of the procedure. Surgeons should be prepared for all possibilities, including the need for sternal fixation, definitive closure/reconstruction after debridement, and various appropriate flap options given patients' surgical history (ie, previous IMA harvest for CABG) and location/size of defect.

Positioning

- In general, the patient is placed supine on the operating table with arms abducted and secured to an arm board.
 - If not already onboard, preoperative evaluation by cardiothoracic surgery should be performed, and need for groin prep or possible cardiopulmonary bypass should be discussed.
- If latissimus dorsi flap is planned, the patient will need to be positioned in lateral decubitus position and repositioned intraoperatively to supine once flap

is raised.

Approach

- Sternal debridement should proceed from superficial to deep, carefully and continually reassessing the viability of tissues at the margins as further debridement is carried out.
- Depending on the location and extent of the final wound/defect following debridement, separate skin incisions/approaches frequently may be necessary for accessing local/regional muscles to be used for reconstruction.
- Approaches for access/harvest of specific flaps will be discussed in subsequent respective chapters.

TECHNIQUES

■ Sternal Debridement

- Generous debridement of all devitalized tissue is imperative to avoid complications and need for return to the OR for additional operations.
- Debridement should start superficially with soft tissue, continually assessing the viability of tissue at the margins and the need to continue further.
 - Marginal/questionable tissue should be as aggressively debrided as safely possible down to clearly healthy, bleeding tissue.
 - When in doubt, tissue/bone cultures should be sent to help tailor postoperative antibiotic regimen.
- In case of bony involvement or suspected osteomyelitis, any prior hardware should be removed before bone debridement is carried out using rongeurs and curettes.

■ Sternal Fixation

- Depending on the location/extent/etiology of sternal defect, a variety of techniques have been described for fixation of fragments and nonunions.
 - Obliquely oriented sternal wiring, figure-of-eight peristernal wiring, and parasternal wiring help by adding additional lateral support.
 - Steel banding, polymer tapes, and absorbable sutures can be used for repair

of nonunions.

- Plate-based systems, such as the SternaLock System (Biomet Microfixation, Warsaw, IN), can be used when adequate bone stock is available for secure purchase from adjacent sides.
 - Requires close approximation of sternal halves using bone-reducing forceps
 - A variety of plate configurations can be used in conjunction with monocortical, self-tapping screws to allow for adequate union of sternal halves.
 - Provides rigid fixation and minimizes recurrence of nonunion/sternal wounds

■ Workhorse Muscle Flap Options for Reconstruction

- Detailed techniques of harvesting each flap will be discussed in their respective chapters.

■ Pectoralis Major

- Common choice of repair for ease of harvest and reliability of flap, especially for defects involving the superior aspect of the sternum
- Minimal functional donor-site morbidity especially compared to other options such as the rectus abdominis flap
- Can be used either as an advancement rotational flap based on the thoracoacromial pedicle for superior defects or a turnover flap based on IMA perforators for more distal and inferior defects, as well as for obliteration of significant dead space in the midline
- Secondary segmental blood supply may not be available in patients with history of IMA harvest.

■ Latissimus Dorsi

- Large, well-vascularized/reliable muscular flap is useful in the case of lateral defects—may not reach anterior midline defects especially superiorly

- Subscapular system can be used to harvest composite flap when concomitant bony reconstruction is also desired.
- Require intraoperative repositioning for harvest and inset

■ Rectus Abdominis

- Good for inferior midline defects
- Not available for patients with history of CABG and IMA harvest as pedicled flap would likely require a rotational flap based off the superior epigastric artery
- More significant functional donor-site morbidity (eg, hernias) when compared to pectoralis or latissimus flap

■ Omentum

- Can be useful in extensive defects with significant dead space/volume requirement for reconstruction as the omentum is able to conform to the recesses of deep wounds.
- Highly vascularized and has a high concentration of vascular endothelial growth factor, promoting extensive angiogenesis
- However, requires more invasive entry into the peritoneal cavity with risk of spreading infection and postoperative ventral hernia formation
- Use of omental flap for sternal defect reconstruction is largely of historical importance prior to rise in use/availability of various myocutaneous options.

PEARLS AND PITFALLS

- | | |
|--------------------|--|
| Debridement | <ul style="list-style-type: none">■ Early and aggressive debridement is imperative in decreasing the morbidity and mortality especially in DSWIs.■ In most cases, cardiothoracic surgery will already be involved, but if not, preoperative evaluation and intraoperative assistance/standby should be arranged prior to performing any excisional debridement. |
| Antibiotics | <ul style="list-style-type: none">■ Empiric therapy should consist of broad coverage against Gram-positive cocci and Gram-negative bacilli with special consideration |

	for methicillin-resistant <i>Staphylococcus aureus</i> based on its prevalence at individual institutions. Fluid and tissue cultures should be obtained when possible, to help tailor appropriate regimen.
Flap selection	■ For most sternal wound/defects requiring reconstruction, pectoralis major is a reasonable first choice given its ease of accessibility and reliability as a muscular flap; latissimus dorsi and rectus abdominis should be considered next if pectoralis is not available/contraindicated.
Negative pressure	■ In the absence of active infection or exposure of vital intrathoracic structures, NPWT can often be used to temporize urgent need for operative intervention.
Wound therapy	■ Well-documented efficacy in reducing wound size and promoting wound healing—can often reduce the complexity or all together need for surgical intervention. ⁷

POSTOPERATIVE CARE

- After debridement without reconstruction
 - Frequent local wound care should be performed to keep wounds clean—wet to dry gauze or topical ointment dressings should be changed 2 or 3 times a day, whereas NPWT should be changed once every 2 to 3 days, especially if there is question of residual infection.
 - Wound cultures should be followed/repeated as necessary to tailor antibiotic regimen.
 - Depending on the presence of defect/exposure of critical structures that ultimately needs to be addressed with reconstruction, activity should be limited until repair is completed.
- General considerations after reconstruction with muscle flap (flap-specific postoperative care issues will be further discussed in respective chapters)
 - Drains: seroma is one of the most frequent complications following a large muscle flap harvest.
 - Conservative management regarding drain duration minimizes the chance of postoperative seroma.
 - Criterion of less than 25 mL per drain per day, for 2 successive days, is often used, though some reports note that 3-week duration regardless of output is associated with lower seroma rate.
 - Wound dehiscence:

- Requires wound irrigation and light gauze packing
- The presence of healthy, viable muscle tissue without evidence of vital structure exposure allows for secondary wound closure.
- Consider supportive brassiere in those patients with large cup size breasts, as this population has been shown to have a greater risk of wound dehiscence following mediastinal operations.¹²
- Activity:
 - Four to six weeks of rest following procedure
 - Consistent physical therapy for range of motion, flexibility, and strengthening should be started to rehabilitate and compensate for the loss of muscle function from donor site.

OUTCOMES

- Immediate consideration of sternal debridement with single-stage flap reconstruction has been shown to reduce morbidity and mortality when compared to those who underwent sternal preservation therapy with attempted rewiring.¹³
- Reported mortality following immediate debridement has been reported as 0% to 1%, whereas mortality in those who underwent delayed debridement ranges from 14% to 47%.¹²
- No consensus as to whether single-stage intervention with immediate flap coverage or delayed debridement with bridging NPWT results in improved morbidity or mortality.
- Jones et al. retrospectively reviewed 186 patients who had undergone sternal wound reconstruction over a 20-year period.⁸
 - Flap closure complications (35), recurrent infection/wound dehiscence (24), and reexploration/wound necrosis (11) were among the most common complications noted.
 - Regression analysis showed that hypertension, smoking, previous sternotomy, IMA harvest, and previous sternal reconstruction were statistically significant risk factors in predicting outcomes.
 - Mortality was 9.1%, and those patients presenting with septicemia at the time of diagnosis had a risk of death 11 times greater than those who were not septic.
- Both early surgical debridement and single-stage repair have been shown to reduce the average hospital stay in patients with DSWI.^{8,10}

COMPLICATIONS

- Hematoma/seroma
- Wound dehiscence
- Delayed union or nonunion following sternal fixation
- Partial or complete flap loss
- Donor-site complications (loss of muscle function, contour deformity, ventral hernia)
- Recurrent wound infection

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3 Rectus Abdominis Flap for Thoracic Reconstruction

CHAPTER

Maureen Beederman and David H. Song

DEFINITION

- Chest wall defects can involve the skin, subcutaneous tissue, muscle, rib, and underlying thoracic viscera.
- The rectus abdominis muscle flap (with or without overlying skin) can be used for chest wall defects and is especially useful for anterior, lower sternal, and parasternal defects.¹
- A vertical rectus abdominis myocutaneous (VRAM) flap contains both rectus abdominis muscle and overlying skin and subcutaneous tissue, supplied by a pedicle and its musculocutaneous perforators, with skin paddle oriented in a vertical direction.
- A transverse rectus abdominis myocutaneous (TRAM) flap contains both rectus abdominis muscle and overlying skin and subcutaneous tissue, supplied by a pedicle and its musculocutaneous perforators, with skin paddle oriented in a horizontal direction.
- Rectus abdominis flaps can be used to fill a large amount of dead space or to cover prosthetic materials used for chest wall stabilization, such as methyl methacrylate, mesh, or titanium plates.

ANATOMY

- The rectus abdominis muscle is a Mathes-Nahai type III muscle with two dominant vascular pedicles: the superior epigastric artery and inferior epigastric artery.
- The superior epigastric artery is a continuation of the distal portion of the internal mammary artery (IMA), which originally arises from the subclavian artery.

- The inferior epigastric artery arises from the external iliac artery.
- The rectus abdominis muscle has a predictable blood supply, making it a dependable option for reconstruction.
- Secondary blood supply also arises from intercostal arteries.
- Rectus abdominis muscle consists of two muscle bellies separated by the linea alba.
 - Each muscle is enclosed in fascia, which is formed from the aponeurosis of the external oblique, internal oblique, and transversus abdominis muscles.
 - Rectus abdominis muscle origin: xiphoid and 5th to 8th costal cartilages
 - Rectus abdominis muscle insertion: pubic symphysis
- The rectus abdominis muscle is thick, bulky, and durable and is good for filling dead space.
- One can raise the muscle in a vertical (VRAM) or transverse (TRAM) manner, depending on the size and orientation of the defect.

PATHOGENESIS

- Chest wall defects can occur as a result of trauma, tumor resection, infection, congenital disorders, or radiation-induced necrosis.
- Infectious sources include empyema, bronchopleural fistula, or mediastinitis after cardiothoracic surgery.
 - Sternal wound infection risk factors include obesity, diabetes, COPD, and bilateral harvest of IMAs during prior cardiothoracic surgery (compromising blood supply to the sternum and overlying tissues).²

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history is important to consider when planning for chest wall reconstruction, as it will affect the reconstructive decision-making and options.
 - Consider previous attempts at chest wall closure and reconstruction, specifically if other local flaps have been used, including latissimus dorsi, pectoralis major, or omental flap.
 - Significant prior abdominal surgery, including autologous breast reconstruction or abdominoplasty, which could affect blood supply to the rectus abdominis muscle
 - One or both IMAs may have been harvested for prior cardiac surgery, which may adversely affect the superior epigastric artery blood supply to rectus abdominis musculature and need to be closely examined. However, owing to extensive intercostal collaterals, mostly a superiorly based flap is viable.

- The presence of an ostomy or urostomy can potentially affect utility of rectus abdominis muscle.
- A history of diabetes or history of smoking can affect small vessels and compromise blood supply to the skin of VRAM/TRAM flaps.
- Other risk factors that can compromise reconstruction include obesity, malnutrition, older age, steroid use, and other comorbidities.
- Discussion of future treatment planning with thoracic surgeon
 - Determine whether the patient has had or will need to undergo future radiation therapy, as this will affect local tissue quality and flap options.
- Physical examination
 - Assess chest wall space requiring reconstruction, including the presence of mediastinitis or other localized infections, bronchopleural fistula, and exposure of vital organs.
 - Determine whether bony reconstruction is required.
 - Skeletal support is most often required for lateral and posterolateral wall defects.¹
 - Number of ribs removed and history of chest wall radiation can affect the need for structural support.

IMAGING

- Imaging may not be required for all patients.
- CT of the chest and abdomen may be done to assess extent of tumor, invasion of surrounding structures, amount of dead space, and possible fluid collections or infection.
- Assess abdominal wall integrity, including the presence of any hernias.

NONOPERATIVE MANAGEMENT

- If no exposure of underlying vital structures, consider using negative pressure wound therapy (NPWT) to manage wound initially.
 - Should be used only in clean wounds; if infection is present, will require appropriate debridement of all infected tissues prior to use of NPWT.

SURGICAL MANAGEMENT

- Coverage of chest wall defects can either be immediate, commonly following tumor resection, or delayed, commonly following mediastinitis or other chest wall infections.

PREOPERATIVE PLANNING

- Must consider whether skeletal stabilization is required, especially if ribs are resected.
 - Skeletal chest wall reconstruction is outside the scope of this chapter but an important consideration when planning reconstruction and deciding the best reconstructive option.
- If more than four or five ribs are resected or if total sternotomy is performed, skeletal reconstruction is most often needed to prevent flail chest and maximize pulmonary function and to protect underlying vital organs.
- For pedicled rectus abdominis reconstruction, consider whether IMA (one or both) has been sacrificed during previous cardiac surgery and check for viability when raising flap. Typically, due to a rich network of collaterals from the 8th intercostal network, the flap should be suitable.
 - If IMA has been harvested, determine if enough time has passed for intercostal collaterals to form; consider basing flap superiorly off intercostal collaterals.³
- If rectus abdominis flap is being used for filling of dead space after infection, ensure that all devitalized and infected components of the wound have been thoroughly debrided prior to flap inseting.

POSITIONING

- For harvesting the rectus abdominis flap, supine positioning is optimal, with arms abducted on arm boards.
- Depending on the location of the defect, the patient may also be in lateral decubitus positioning, which still allows harvest of the rectus muscle.

APPROACH

- Based on the size and shape of the defect, consider whether muscle only or musculocutaneous flap is required.

TECHNIQUES

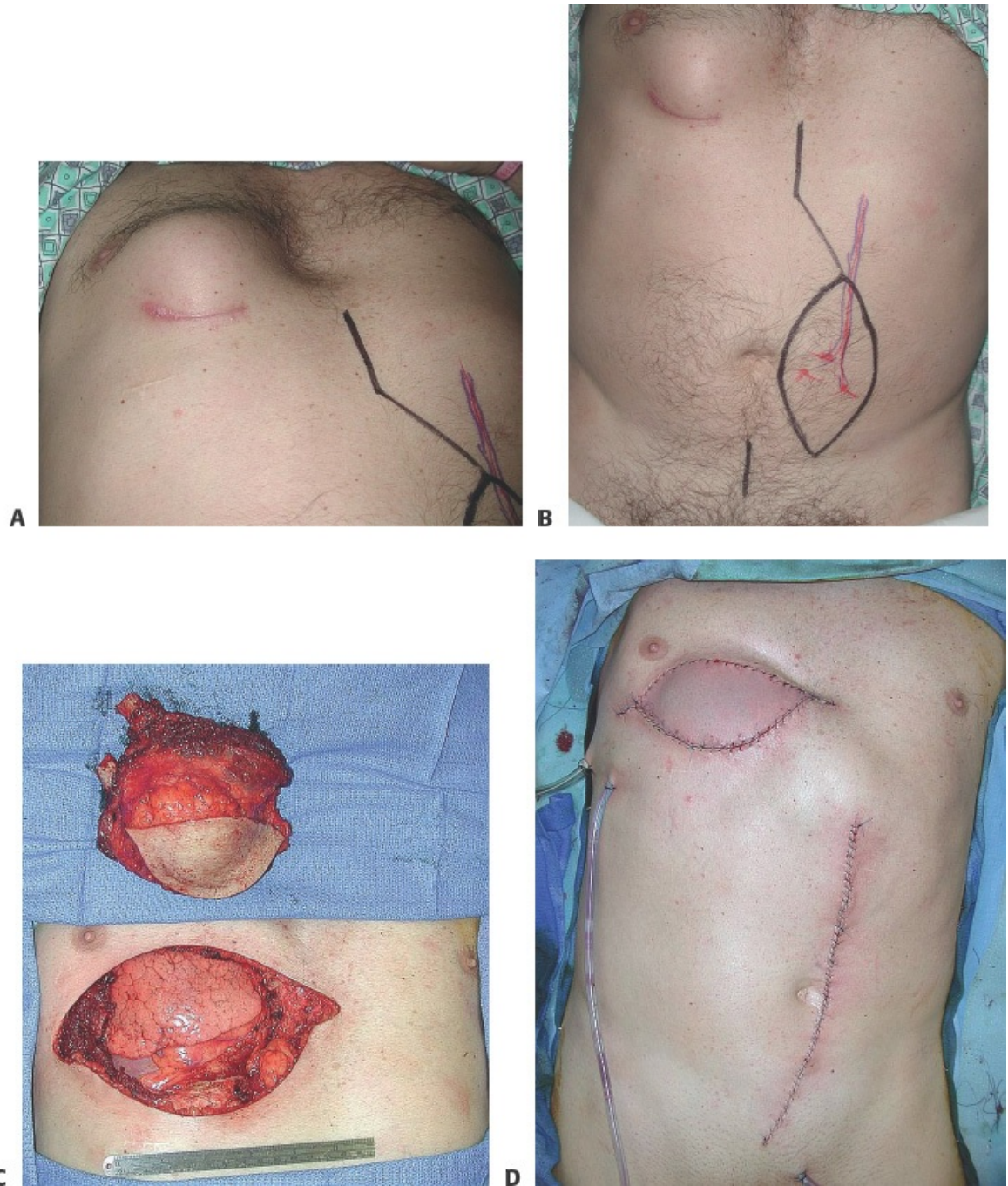
■ Rectus Abdominis Musculocutaneous Flap

- Create a template to design your flap based on the proposed defect size.

- Design the flap either vertically (VRAM) or transversely (TRAM), depending on the location and size of defect (**TECH FIG 1A**).
- The flap should be designed to capture periumbilical perforators (**TECH FIG 1B**).
- Handheld Doppler can be used preoperatively to locate possible perforators prior to starting flap elevation.
- Make an incision just lateral to the midline on the side of the muscle to be harvested.
 - If a sternotomy incision is already present, simply extend this incision inferiorly.
- Make incision through skin and subcutaneous tissue and dissect to the medial and lateral perforators in order to spare as much anterior sheath fascia as possible.
- Incise fascia longitudinally, just lateral and medial to the perforators.
- Dissect laterally, superiorly, and inferiorly, until desired size is reached. Ensure that all suitable musculocutaneous perforators are identified and protected during flap elevation.
- Identify both the superior epigastric artery and the deep inferior epigastric artery.
- Once the deep inferior epigastric artery has been identified, ligate it close to its origin at the pubic symphysis.
- Divide the rectus abdominis muscle from its insertion on the pubic symphysis or more superior to the pubic symphysis if not using the entire muscle.
- Interpolate rectus abdominis myocutaneous flap into defect space (**TECH FIG 1C,D**).
- Flap can either be tunneled below an existing skin bridge or interpolated into defect.
- Close anterior rectus sheath primarily in a figure-of-eight fashion.
 - If donor-site defect is too large, mesh may have to be used to prevent hernia formation.
- Inset the flap in a layered fashion, ensuring that there is no tension on the vascular supply.
- Place closed suction drains in both the donor and recipient sites.

Pedicled Rectus Abdominis Muscle-Only Flap

- Harvesting a muscle-only rectus abdominis flap is similar to the VRAM/TRAM harvest, with a few key distinctions.
- Consider using a rectus abdominis flap if there is enough local chest wall skin for coverage or if planning to harvest a split-thickness skin graft for coverage.
- Make a midline incision through the skin and subcutaneous tissue down to the anterior rectus fascia.
- Incise rectus fascia longitudinally, just lateral to the midline.
- Dissect laterally and inferiorly according to your template defect size until desired size is reached.
 - The entirety of the rectus abdominis muscle or just a portion may be used.



TECH FIG 1 • **A.** Large right chest wall chondrosarcoma to be resected, just inferior and medial to right nipple, measuring more than 5 cm. **B.** A contralateral vertical rectus abdominis musculocutaneous flap is designed based on the above defect. The flap is designed near the umbilicus

to capture the periumbilical perforators, which are marked in *red*. **C.** Final defect was 13 × 8 cm with exposed lung and diaphragm. The resected mass involved two ribs and the parietal pleura. In this specific case, Gore-Tex mesh was used to prevent lung herniation prior to inset of the rectus abdominis flap. **D.** Postoperative picture showing closure of the defect with the vertical rectus abdominis musculocutaneous flap and midline closure of the donor site. One Jackson-Pratt drain is seen in the recipient site, as well as a nearby chest tube.

- During dissection, identify the superior epigastric artery (which is the artery the flap will be based on) and the deep inferior epigastric artery.
- Ligate musculocutaneous perforators, if only harvesting muscle and not overlying skin and subcutaneous tissue.
- Once the deep inferior epigastric artery has been identified, ligate it close to its origin at the pubic symphysis.
- Interpolate rectus abdominis muscle into defect space, either tunneled below a skin and subcutaneous tissue bridge or directly into the defect.
- Close anterior rectus fascia primarily or using a piece of mesh if any significant tension is present or for added support.
- Inset rectus abdominis muscle flap into defect and close surrounding local skin in layers over the muscle.

PEARLS AND PITFALLS

Supercharging arterial supply or venous drainage

- Consider performing microsurgical anastomosis to aid with venous drainage or arterial supply if recipient vessels are available by hooking up the divided deep inferior epigastric artery and/or vein.

Placement of

- It is important to place drains in the recipient site, and sometimes

Jackson-Pratt drains	in the donor site, to prevent hematoma formation, which can lead to flap compromise.
Prior chest wall surgery or radiation therapy	■ Knowledge of prior reconstructive efforts and/or history of radiation is important prior to making a decision on flap design and elevation, as this could affect the blood supply and overall soft tissue coverage of the defect.
Intercostal artery–based rectus abdominis flap	■ If bilateral internal mammary arteries have previously been utilized or damaged (often the case with cardiothoracic surgery), consider harvesting rectus abdominis flap based on intercostal artery perforators.
Identify and protect key blood vessels	■ For superiorly based pedicled flaps, ensure that the superior epigastric artery is identified and protected. ■ It is also important to identify the deep inferior epigastric artery prior to dividing it.

POSTOPERATIVE CARE

- Jackson-Pratt drains are often placed in both the donor and recipient sites.
 - Abdominal drain (donor site) is typically placed to wall suction.
 - Chest drain (recipient site) is typically placed to bulb suction.
 - Discontinue drains once output is less than 30 cc for 2 consecutive 24-hour periods.
- Patient will often require a chest tube, if the pleural cavity is violated. This is managed by the thoracic surgery team.
- Flap monitoring, if possible
 - If skin paddle is present, monitor warmth, color, skin turgor, and capillary refill.
 - Tight inset may lead to arterial compromise or venous congestion, so clinical monitoring is important even though this is not a free flap.
- Avoid heavy lifting during immediate postoperative period to avoid hernias.

OUTCOMES

- Use of vascularized muscle flaps, including the rectus abdominis flap, has decreased morbidity and mortality associated with chest wall infections and tumor resection.
- Rectus abdominis flaps have been shown to be superior to other flap options (including pectoralis advancement flaps) for coverage of the inferior portion of

the central chest wall.⁴

COMPLICATIONS

- Hematoma and seroma formation
- Compromise of vascular pedicle
- Partial or total flap lost
 - If flap is superiorly based, the prior harvest of IMA for cardiac surgery can lead to distal tip necrosis, most commonly located at the superior portion of the chest wall.
- Hernia formation
- Wound dehiscence of either the donor or recipient site

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4 Omental Flap for Thoracic Reconstruction

CHAPTER

Amir Inbal and David H. Song

DEFINITION

- The omentum is rich in vasculature, lymphatics, and fat and serves an important immunologic function within the abdominal cavity.
 - The original anatomical term *epiploic* is derived from the Greek word *epipleein*, which means to float on. It was so named to reflect how the omentum “floated” anterior to the intestines.
- The omental flap can be harvested as a pedicled or free flap and is commonly used as a pedicled flap for thoracic reconstruction.
- These flaps are historically used to revascularize the myocardium and cover intra-aortic balloon pumps and ventricular assist devices.
- Thoracic and chest wall defects are attributable to congenital malformations or acquired deformities and can cause significant physical and psychological morbidity.

ANATOMY

- The region of the thorax amenable to pedicled omental flap reconstruction includes the central and lateral thorax and its contents, most commonly the sternum, pericardium, pleural cavity, and at times the overlying skin. When needed, the flap can extend to reach beyond the chest.
- Thorax: Composed of the skin, muscles, bones, and internal organs/structures located between the neck and the abdomen
 - Muscles include pectoralis major, pectoralis minor, serratus anterior, serratus posterior, rectus abdominis, external oblique, intercostal muscles, latissimus dorsi, and trapezius.
 - Thoracic skeleton

- Ribs—form the rib cage by attaching to vertebral bodies posteriorly and sternum anteriorly (variable)
- Sternum—long, flat bone in the center of the chest composed of the manubrium, body, and xiphoid process
- Thoracic vertebrae
- Internal organs/structures that should be addressed when reconstructing the thorax include the lungs, heart, pericardium, pleura and pleural space, esophagus, trachea and bronchus, superior vena cava, thymus gland, diaphragm, liver, gallbladder, pancreas, duodenum, and pancreas.
- Dominant blood supply provided by paired internal mammary arteries (branch of subclavian artery)
 - Run posterior to costal cartilage adjacent to sternum with one or two venae comitantes.
 - Interconnect with transverse cervical, thoracoacromial, lateral thoracic, and posterior intercostal arteries.
 - Cutaneous perforating vessels supply overlying tissues and skin
- Omentum
 - The omental flap is based on the greater omentum found in the abdominal cavity (**FIG 1A**).
 - It contains visceral peritoneum, fat, lymphatic tissue, a rich vascular arcade, and macrophage collections (milky spots).
 - It is a nonneurotized flap.
 - It originates from the peritoneum of the greater curvature of the stomach. From here, the two layers of the visceral peritoneum descend anterior to the small intestines, folding backward upon itself at a variable level within the abdominal or pelvic cavity to ascend and enclose the transverse colon before attaching to the posterior abdominal wall. With the two layers of visceral peritoneum folded upon itself, it effectively creates a four-layered structure.
 - The right border of the greater omentum may be attached to the second portion of the duodenum.
 - The left border of the greater omentum is continuous with the gastrosplenic ligament.
 - In a study of 200 cadavers and 100 patients who had abdominal surgery, the average omental length was 25 cm for men (range, 14–36 cm) and 24 cm for women (range, 14–34 cm). The average omental width was 35 cm for men (range, 23–46 cm) and 33 cm for women (range, 20–46 cm). Size of the

omental flap ranges from 300 to 1500 cm².¹

- The greater omentum is supplied by the right and left gastroepiploic arteries, which communicate with a rich vascular network within the two layers of the greater omentum along the greater curve of the stomach (**FIG 1B**).
- Vascular supply from the right: celiac trunk to common hepatic artery to gastroduodenal artery to right gastroepiploic artery
- Vascular supply from the left: celiac trunk to splenic artery to left gastroepiploic artery
- The short gastric arteries originating from the splenic artery, superior to the left gastroepiploic artery, also serve as an additional source of blood supply to the omentum by multiple collateral vessels.
- The right gastroepiploic artery is usually the dominant vessel supplying the omentum. It is usually 2 to 3 mm in size, and the vein is typically larger.
- From the anastomoses of the right and left gastroepiploic arteries, the accessory, right, middle, and left omental arteries descend within the greater omentum. There is a rich connective arcade between these vessels within the omentum.
- Five anatomic variations of the arcade have been described:^{2,3}

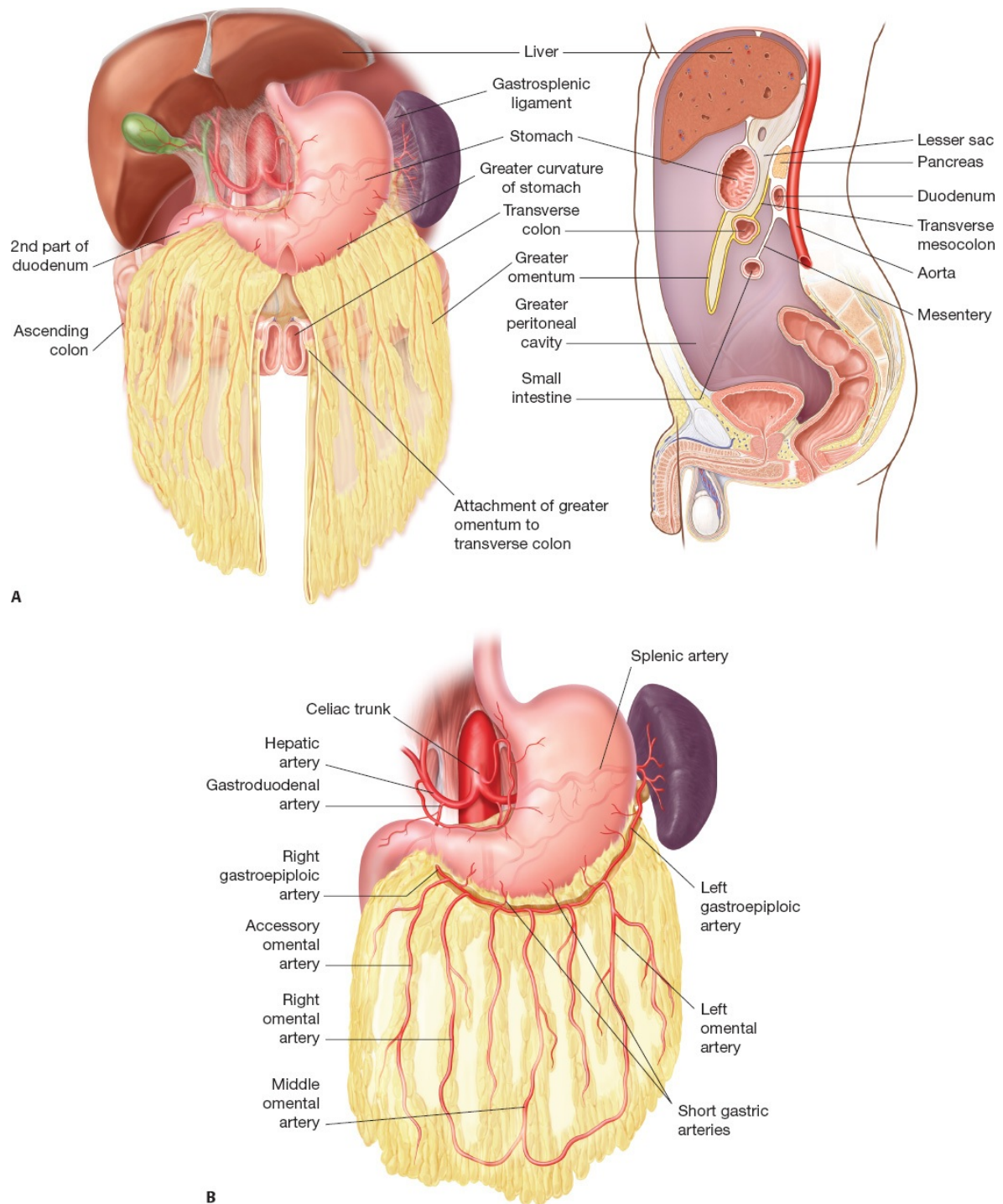


FIG 1 • A. Anatomy of the greater omentum within the abdominal cavity. **B.** Vascular anatomy of the omental flap.

- Type 1 (81.7%): middle omental artery bifurcation in the lower third, with

anastomoses to the right and left omental arteries

- Type 2 (11.0%): middle omental artery bifurcation in the middle third, before anastomoses to the terminal branches of the right and left omental arteries
 - Type 3 (4.5%): middle omental artery bifurcation in the upper third into two or three branches
 - Type 4 (1.2%): middle omental artery absent and replaced by several short omental arteries
 - Type 5 (1.6%): Left omental artery does not join the left gastroepiploic artery
- A robust venous system accompanies the arterial arcade and drains into the right and left gastroepiploic veins.

PATHOGENESIS

- Full-thickness defects of the anterior thoracic cavity can arise from a variety of causes:⁴
- Infections
 - Necrotizing soft tissue infections
 - Mediastinitis
 - Sternal osteomyelitis
 - Fistulae
 - Bronchopleural
 - Esophagopleural
 - Trauma
 - Iatrogenic
 - Radiation injury
 - Postsurgical wound breakdown
 - Exposed hardware (eg, aortic grafts, breast implants, vertebral, sternal plates, or ventricular assist devices)
 - Neoplastic
 - Contour congenital defects of the chest wall
 - Poland syndrome
 - Other breast defects
- Flail chest: paradoxical chest movement during respiration of a portion of the rib cage after it loses continuity with the surrounding chest wall resulting in

inefficient ventilation.

- Most often the result of trauma or oncologic resection of a significant portion of the chest wall
- May require reconstruction with soft and/or bony tissue
 - Defects 5 cm in diameter or larger generally require skeletal fixation.
- Risk factors for sternal dehiscence and infection include chronic obstructive pulmonary disease, obesity, diabetes, and bilateral harvest of the internal mammary vessels.
- Radiation-induced injury may cause significant scarring and nonfunctional tissue that will require debridement and reconstruction.

NATURAL HISTORY

- Without adequate treatment, defects of the anterior thorax can lead to devastating consequences including paradoxical breathing, osteomyelitis, mediastinitis, and death.
- The greater omentum can be harvested from the abdominal cavity without any major loss of function.
- Over time, the omental flap contracts slightly to “bed down” at the defect site.
- The omental flap provides soft tissue coverage only. In cases in which the chest wall is unstable due to loss of structural support, alternative methods such as wires, plates, mesh, or bony reconstruction are required.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for patients requiring thoracic reconstruction includes a detailed assessment of the etiology of the defect, the patient’s underlying medical and functional status, the state of the pleural cavity, the extent of the soft tissue defect, and whether skeletal support is required and reconstructive options available.
- It is important to note whether the internal mammary vessels have been previously injured or sacrificed.
- The etiologic factors of the defect should be elicited in history taking, as well as its suitability for reconstruction.
 - Dirty or actively infected wounds or those with residual tumor are not amenable to reconstruction.
 - Bacterial cultures should be obtained and targeted antibiotic therapy started as necessary.
- A detailed medical history should be noted including cardiovascular problems,

lung pathology, smoking, immunocompromise, and nutritional status.

- As much as possible, any underlying medical condition should be corrected or optimized prior to undergoing definitive reconstruction.
- Special attention should be addressed with regard to history of previous abdominal surgery, trauma, and any other abdominal morbidity, as these may cause to preclude the omentum flap as a reconstructive option.
- Available reconstructive options or prior attempts at reconstruction should be noted.
- Physical examination
 - The skin is inspected for previous scarring, prior incisions, active infection, or radiation changes.
 - Hernias are noted. Laparoscopic surgical port site scars should be carefully searched. Any prior surgery in the abdominal cavity can lead to intra-abdominal adhesions, increasing the difficulty of omental flap harvest.
 - Missing tissues are noted.
 - Soft and/or hard tissue defects may be present.
 - Breathing mechanics are evaluated.
 - Pulmonary function tests are useful for evaluation of baseline pulmonary status.
- Routine preoperative laboratory testing should be performed.
- Obtain a baseline chest radiograph.
 - Computed tomography (CT) should be considered in cases of complex or extensive defects.
- The defect should be thoroughly examined again, if possible, under general anesthesia. The location, size, depth, and extent of the defect must be noted. Exposed vital structures such as the pericardium, major vessels, or hardware require more emergent coverage. Active infection or tumor should be excluded.
- Patients may present with postoperative sternal wounds after cardiac or mediastinal surgery.
 - Pairolero and Arnold classified wounds based on timing of presentation of infection:⁴
 - Type I—Occur soon after surgery, may contain incisional breakdown with serosanguineous discharge and/or sternal instability
 - Type II—Occur weeks after surgery, and cellulitis, mediastinal purulence, and positive cultures may be present

- Type III—Occur months to years after surgery and contain draining sinus tracts and chronic osteomyelitis
- Type II and III wounds often require operative reconstruction.

IMAGING

- Thoracic imaging
 - Chest radiographs in the anteroposterior and lateral dimensions can aid in assessment of the defect. Although lacking in sensitivity and specificity, they can be helpful in raising suspicions for other cardiac or lung pathology.
 - CT scans of the thorax are useful in preoperative evaluation of the thoracic structures, in delineating the extent of the defect, as well as in locating any underlying tumor or abscess.
 - Compared with CT scans, magnetic resonance imaging (MRI) scans are more sensitive at detecting osteomyelitis and evaluating the soft tissues. However, they are seldom required.
 - Vascular studies such as CT angiography may be warranted if tumor resection or trauma is thought to compromise the vascular anatomy or when extent of vascular involvement is unknown. In addition, if a free flap is planned, the vasculature anatomy can be assessed for recipient vessels.
- Abdominal imaging
 - In general, no investigations are needed to assess the omentum. In cases of previous abdominal surgery or trauma, where there may be significant adhesions or damage to the omentum, use of the omental flap would be avoided. An exception is previous laparoscopic surgery where no complications and minimal manipulation of abdominal contents have been confirmed.
 - CT of the abdominal wall may assist in evaluating patients with a history of surgery or trauma to the area.
 - Vascular studies such as CT angiography may be warranted if compromised vascular anatomy is suspected secondary to previous surgery or trauma.
 - Laparoscopic surgery enables a direct intraoperative “peak” at the omentum and its vascularity facilitating decision-making regarding its use.

DIFFERENTIAL DIAGNOSIS

- Other flaps that can be used to reconstruct defects of the anterior thoracic cavity include:
 - Pedicled flaps

- Pectoralis major muscle flaps
 - Advancement based on the thoracoacromial blood supply
 - Turnover based on the internal mammary blood supply
- Rectus abdominis flaps based on the superior epigastric artery
 - Muscle only
 - Myocutaneous
- Latissimus dorsi flaps (usually for more lateral defects of the anterior thoracic cavity)
- Internal mammary artery perforator flap
- Free flaps

NONOPERATIVE MANAGEMENT

- When left long enough, any wound can heal without operative intervention. However, healing time, exposure of vital mediastinal structures or hardware, and the risk of intervening infection must be taken into consideration.
- There are a variety of wound dressings that can be used, ranging from simple wet-to-dry dressings to advanced silver-containing biomaterials, which are beyond the scope of this chapter.
- A useful bridge to reconstruction is the use of a negative pressure wound therapy (NPWT) system, which can aid in wound bed preparation and allow for patient and wound optimization prior to definitive wound coverage.

SURGICAL MANAGEMENT

Preoperative Planning

- The omental flap can be harvested as a pedicled or free flap. For defects of the thorax, it is commonly used as a pedicled flap.
- The size of the omental flap is variable and dependent on individual patient anatomy.¹ The reach of the pedicled omental flap depends on its size.
- Compared with muscle flaps, omental flaps allow better lining of the inferior third of the mediastinum, provide more bulk, and conform to the deep recesses of the mediastinum.⁵
- The general indications for the use of thoracic defects requiring omental flap reconstruction are⁶:
 - Full thickness in nature exposing the underlying bone, mesh (eg, ADM), hardware, or mediastinal contents

- Where dead space obliteration in the thorax is required
- Considered a good option for radionecrotic chest wounds, with its theoretical advantage of having immunogenic properties.
- Foul-smelling, contaminated, or infected wounds
- Provides a large surface area cover especially when extending the arc of rotation. If used for skin and subcutaneous tissue coverage, the omental flap can be skin grafted in the same sitting.
- When covering a prosthetic material, musculocutaneous flaps are preferred to omentum and skin graft owing to a better seal by the former.
- Good source of bulk providing volume for pleural defects or any dead space obliteration
- Can plug and wrap around bronchopleural fistula.
- Due to its donor-site morbidity risks by intra-abdominal incursion, the omentum is considered a second option when other fasciocutaneous or musculocutaneous options are unavailable and thus provides a secondary flap source when other flap options are exhausted.
- Risks of abdominal donor-site insult to the patient must be considered.
- Relative contraindications include previous abdominal trauma, surgery, or infection.

Preoperative Planning

- The thoracic defect requiring reconstruction needs to be assessed and optimized prior to definitive coverage. This may require multiple debridements and the use of NPWT and antibiotic therapy.
- We use the omental flap if there are no other pedicled flap options available to meet the reconstructive demands. Most commonly, no preoperative imaging is necessary for omental flap assessment.
- The omental flap can generally reach most of the central thorax up to the sternal notch and the lower parts of the pleural cavities (**FIG 2**). When detached only from the colon, it can reach the nipple in 75% of cases.⁷

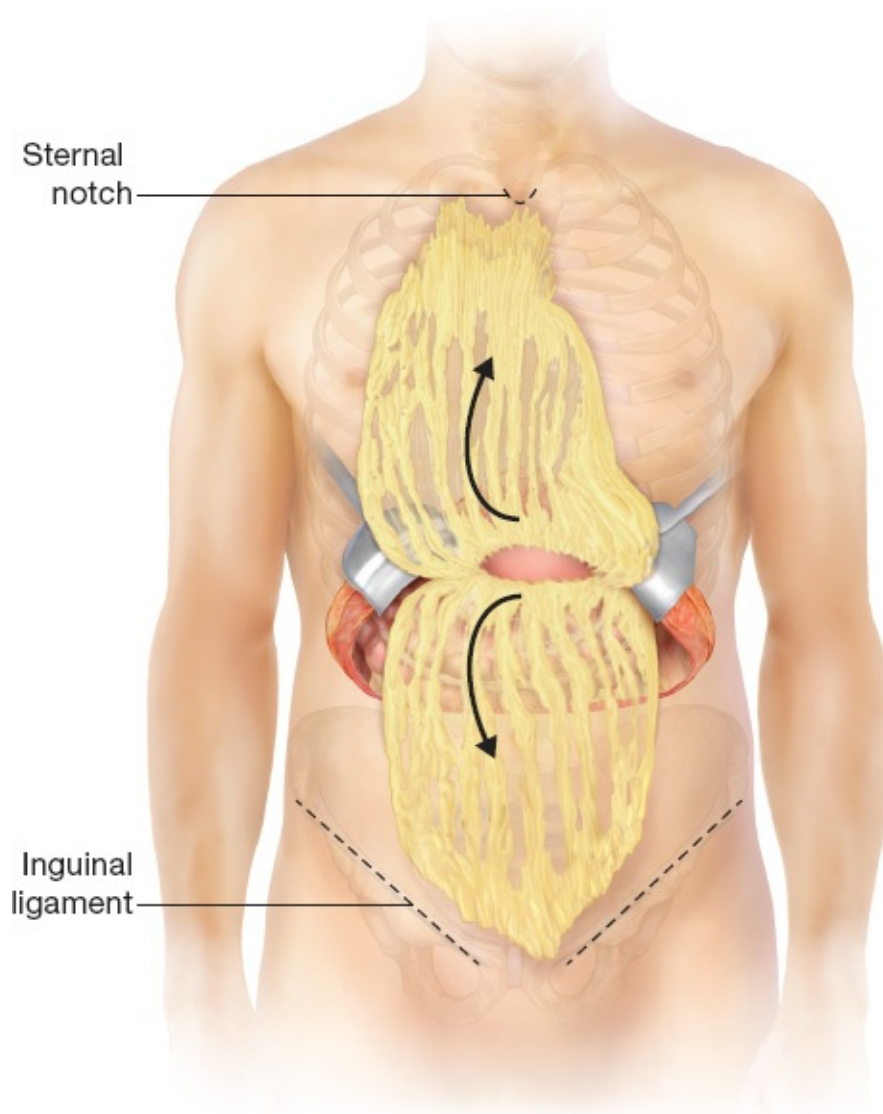


FIG 2 • Potential reach of the pedicled omental flap.

- If planned as a free flap, recipient vessel choice and preparation are required.
- Location and size of the defect are ideally identified prior to surgery to guide decisions regarding flap dimension, harvest technique, and required vascular pedicle length (ie, transposition or free flap).
- Ideally, microbiological and histological examinations should be established prior to flap harvest.
- Arc of rotation considerations when considering a pedicled omental flap:
 - Can extend to reach “knees to neck.”
 - Arch includes the mediastinum and anterior, lateral, and posterior chest wall.⁸

- A flap based on the left gastroepiploic pedicle has a greater arc of rotation compared to the right gastroepiploic vessel, which is the dominant of the two.
- Involved tissue types
 - Skin: identifying skin involvement is important for determining if a musculocutaneous flap or omentum with a skin graft is required. The decision to use omentum would be a very large surface area wound that requires skin graft use. Skin graft should be meshed to allow fluid transudation through.
 - Muscle:
 - Determine which muscles are involved and the level of functionality with remaining muscles.
 - If resection, radiation, or infection compromises a local musculocutaneous flap that would otherwise be available, this is critical to know prior to surgery as an omentum flap may be the best option for reconstruction.
 - Bony defects greater than 5 cm or involving more than 3 to 4 contiguous ribs are likely to benefit from structural support in addition to soft tissue coverage.
- Wound age
 - Acute vs chronic wounds often influences the quality of localized tissue vascularity, extent of fibrosis, and local wound healing capabilities as a result of inflammation-dependent changes.
 - This may indicate the use of the more distally located omentum with its known immunogenic properties.
 - Condition of the surrounding tissue. The presence of irradiated skin, previous scars/contractures, localized infection or inflammation, and acute trauma influences the regional tissue integrity and subsequently requires consideration while determining the reconstructive approach and complexity.
 - Patient lifestyle, general health, and functional status guide flap selection for those patients where preservation of muscular functionality is warranted.
- Prognosis
 - Life expectancy and patient-specific goals must be considered when determining complexity of reconstruction.
 - Abdominal morbidity must be considered in patients with poorer overall prognoses especially if their diseases or conditions involve abdominal morbidities.
- Preoperative patient preparation
 - Two days prior to surgery, mechanical bowel preparation is performed.

- Patient is placed on clear liquid diet.
- Preoperative prophylactic antibiotic regimen is given as indicated for laparotomy.
- Intraoperative considerations
 - Nasogastric tube is inserted and kept in place for 2 postoperative days.
 - Chest tube is considered for chest wall defects involving the pleura.
 - Deep venous thrombosis (DVT) prophylaxis is considered in accordance with major surgeries of the abdominal wall and thoracic surgery.
 - Two-team approach is possible and should be considered.

Positioning

- The patient is positioned supine for best exposure. This is done for both the open and laparoscopic harvest technique.
- Sterile preparation of the operative field should include the entire abdomen extending to the thorax where the defect is located.
 - Intraoperatively, the defect and donor site should be partitioned as much as possible to prevent cross-contamination.
- If skin grafting of the omental flap is required, the planned donor site should be prepared.
- The patient may be placed in partial or complete lateral decubitus position for posterior defects. For this approach, the laparoscopic approach can be considered.

Approach

- Laparotomy (open approach)
 - Partial upper midline (epigastric) incision is the most commonly used. It can be performed in a longitudinal or transverse fashion.
 - A complete midline incision is considered when a previous surgical scar can be used or in those cases demanding better exposure.
 - We use the open technique when the thoracic defect is already communicating with the upper part of the abdominal cavity.
- Laparoscopic^{9,10}
 - Considered in selected patients, especially if there is no communication between the thoracic wound and the abdominal cavity
 - Can assist in pedicle or free flap harvest with minimal size incisions

- This technique has the advantages of reduced postoperative pain, shorter postoperative bed rest, lower rate of respiratory and wound complications, and earlier resumption of oral nutrition.¹¹
- After laparoscopic harvest, the pedicled omental flap can be delivered into the thoracic cavity in two ways:
 - Via a limited incision in the diaphragm
 - If harvested as a free flap, the omentum can be delivered via an extension of the infraumbilical laparoscopic access port.
- There is a learning curve, and the surgeon must be competent at handling laparoscopic equipment within the abdominal cavity, as well as being equipped to handle any complications related to harvest, such as:
 - Intra-abdominal bleeding
 - Bowel perforation
 - Other visceral injuries
- The laparoscopic approach requires carbon dioxide insufflation within the abdominal cavity. This can lead to increased cardiac afterload and decreased cardiac output, and can be detrimental to and precipitate arrhythmias in patients with significant cardiac disease, and should proceed with caution in this patient population.¹² Additional precautions can include:
 - Preoperative echocardiogram assessment and optimization
 - Intraoperative invasive hemodynamic monitoring
 - Slower carbon dioxide insufflation of the abdominal cavity
- Partial or total harvest of the omentum can be done based on reconstructive requirement. Careful trimming of the omental flap can be done based on knowledge of its vascular anatomy.

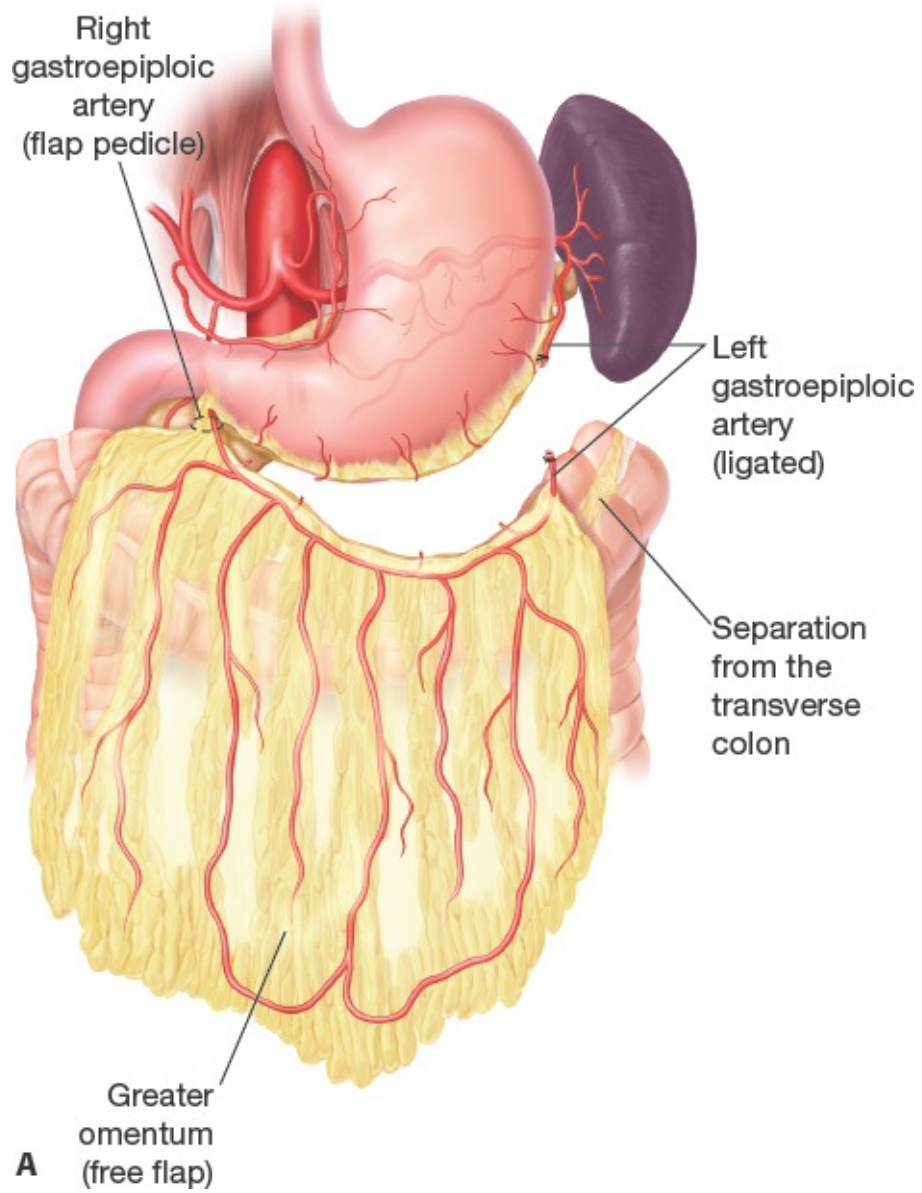
TECHNIQUES

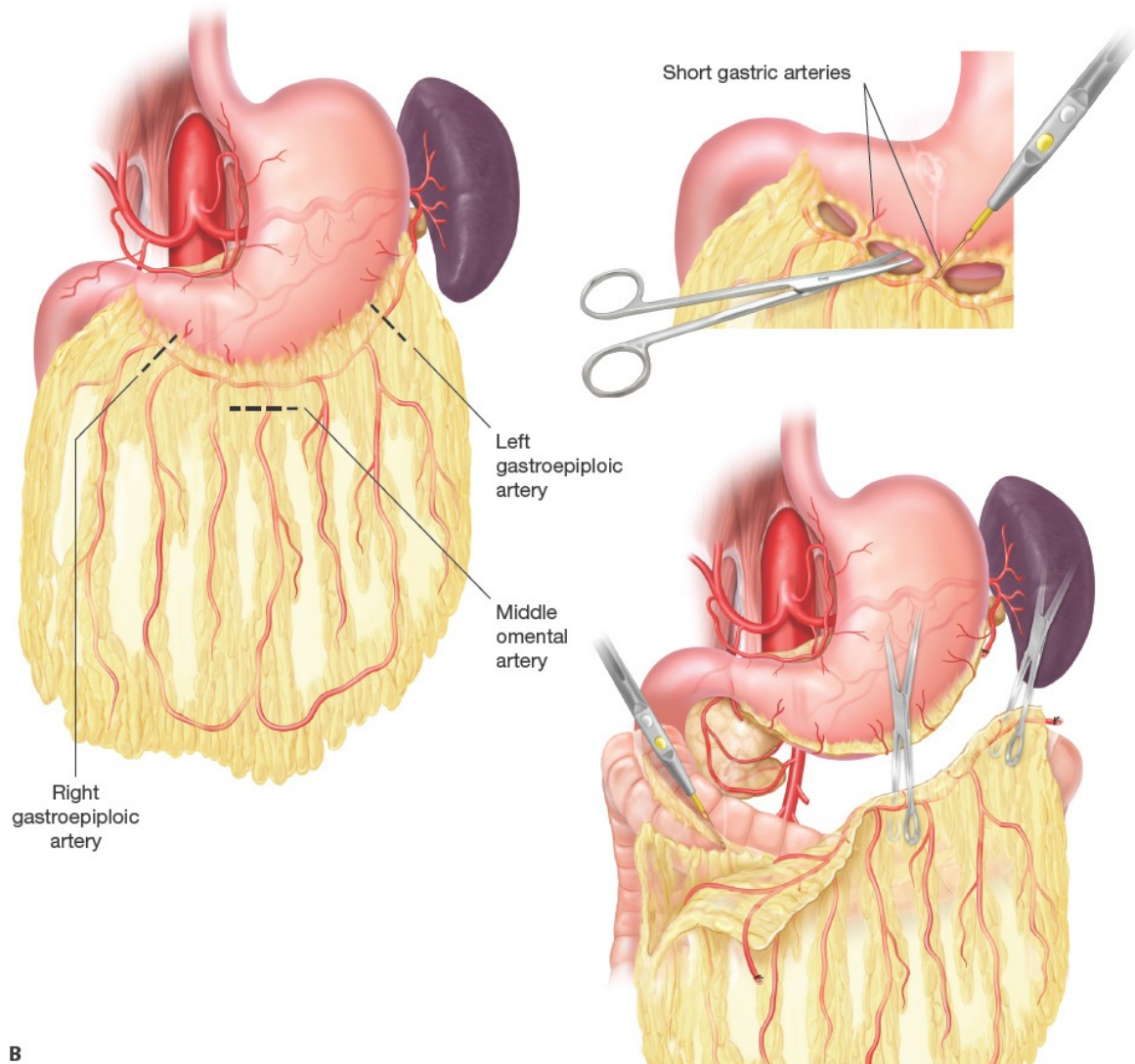
■ Open Harvest of the Omental Flap

- After sterile preparation of the abdomen, incisions are made:
 - Upper epigastric incision is most commonly used and can be made in a transverse or vertical fashion.
 - For better exposure, a complete midline laparotomy incision is considered. This can be done via an extension of the existing thoracic defect or a

separate incision.

- Previous scars are considered for reuse.
- Dissection is continued, rectus fascia is divided, and once the parietal peritoneum is breached, the stomach and greater omentum come into view (**TECH FIG 1A**).
- At times, adhesions may be present and should be released if in the way of flap harvest.
- Commonly, the omentum will be visualized immediately under the peritoneum.
- The greater curvature of the stomach is identified and traced bilaterally along its gastric border.
- Right and left gastroepiploic vessels are identified, as well as their major descending branches to the omentum.
- The omentum is delivered out of the abdominal cavity and flipped upward to expose the posterior attachments of the transverse colon.
- The omentum is separated from transverse colon and great curvature of the stomach in the relatively avascular plane with the help of an assistant who keeps gentle traction on the omentum.
 - Care must be taken to secure the ligature of the short gastric vessels as coagulated vessels and insecure ligatures can dislodge postoperatively when they become distended and cause significant bleeding.
- Omental ligamentous attachments are freed, alongside meticulous collateral gastroepiploic perforating vessel ligation.
 - Any lateral attachments to the duodenum or gastrosplenic ligament are divided.
- Care is taken to avoid any injury to the appendices epiploicae when dissecting in the avascular plane adjacent to them.
 - Any possible colonic diverticula originating from the transverse colon must be avoided.
- Caution is taken to avoid injury to the middle colic vessels and the transverse mesocolon.





B

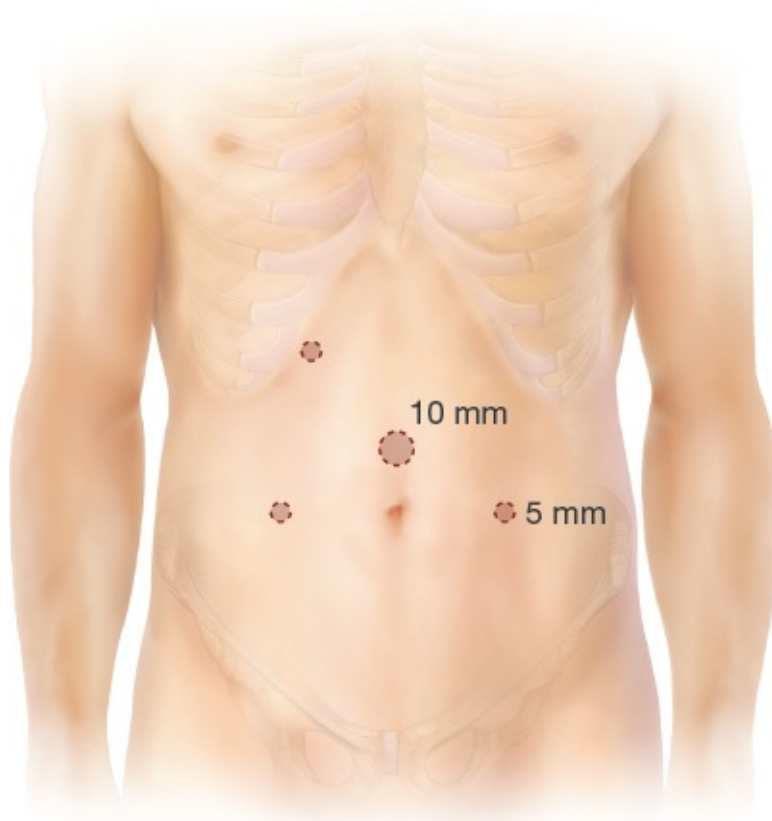
TECH FIG 1 • A. Open approach to omental flap harvest. **B.** Harvest of omental flap and extension technique.

- Once the flap is isolated on its attachment to the stomach, a decision is made whether to harvest the flap based on the right or left gastroepiploic arteries.
 - This depends on the location of the defect as well as the size of the pedicle vessels, especially if it is being harvested as a free flap.
- Skeletonization of the pedicle is often not required or advisable and some perivascular tissue must be spared, to decrease the risk of vasospasm.
- Pedicle can be based on the commonly dominant right gastroepiploic artery originating from the gastroduodenal artery at the gastroduodenal junction.

- Flap harvest based on the right gastroepiploic vessel is rapid because the leaves of the omentum usually are not fused to the body and tail of the pancreas and are easily dissected away.
 - Alternatively, the pedicle can be based on the left gastroepiploic artery or short gastric arteries originating from the splenic artery.
 - The left gastroepiploic artery provides the greatest pedicle length and is more commonly used for extended arch of rotation and flap reach.⁸
 - Elongation of the pedicle technique is performed by division of internal arcades and basing the flap on the right, middle, or left omental branch that arises from gastroepiploic system (**TECH FIG 1B**).
 - Closure of the abdomen should be done in layers including robust rectus fascia closure.
 - A drain should be placed to detect any intra-abdominal hemorrhage.
-

■ Laparoscopic Harvest of the Omental Flap

- After sterile preparation of the abdomen, the laparoscopic ports are placed (**TECH FIG 2**).
- A 10-mm port is placed through an infraumbilical incision, and pneumoperitoneum is achieved.
- A 30-degree angled telescopic camera is then placed through this port, and three additional 2.5-mm ports are placed under direct vision.
 - One port is at the right hypochondrium, another at the right iliac fossa, and the third at the left flank.



TECH FIG 2 • Laparoscopic approach to omental flap harvest.

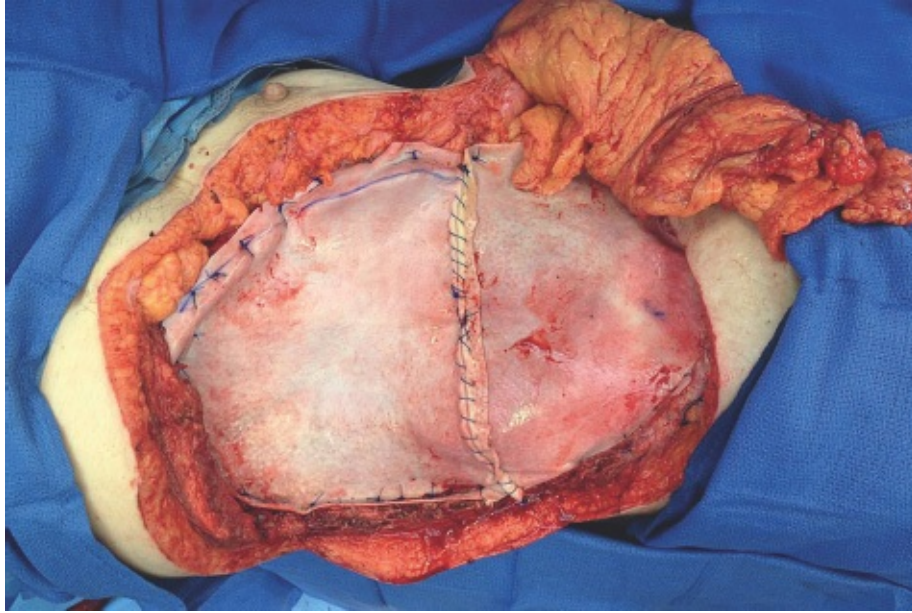
- Although three ports are usually sufficient for instrumentation, additional ports can be added as required.
- The greater omentum is then identified. An instant look inside the abdominal cavity to check if the omentum has sufficient bulk and size, prior to flap harvest, is commenced.
 - Any pre-existing adhesions between the greater omentum and the parietal peritoneum are released with ultrasonic dissection.
- The omental flap is then dissected off the transverse colon.
 - A pair of atraumatic laparoscopic grasping forceps is placed through the right hypochondrium port to pull the greater curve of the stomach cranially toward the right, exposing the transverse colon.
 - The remaining ports facilitate the ultrasonic scalpel and additional atraumatic grasping forceps to pull the transverse colon caudally while dissecting the posterior attachments of the omentum off this structure.

- Once the flap has been isolated on its attachments to the greater curvature of the stomach, it is released from the left edge (for a flap harvested based on the right gastroepiploic artery), carefully ligating the short gastric arteries along the way.
- For delivery of the flap into the thoracic cavity, a communicating diaphragmatic incision measuring about 4 to 5 cm can be made either from the thoracic defect or laparoscopically.
- Care must be taken not to kink the pedicle when the flap is delivered into the defect.
- For external delivery as a free flap, the right gastroepiploic pedicle is divided, and the flap is delivered through an extension of the infraumbilical incision.
- Closure of the port sites can be done in a simple interrupted fashion. A drain should be placed to detect any postoperative intra-abdominal hemorrhage.

■ Transposition of the Omental Flap

Pedicle Transposition

- For extended arc of rotation, a left gastroepiploic artery–based flap is generally considered.⁸
- When transposing the flap, avoid overt pedicle compression against gastroduodenal area to prevent gastric outlet obstruction.
- Transposition to the thorax is done in one of three ways:
 - Extracutaneous tunneling over the costal margin, in which the exposed flap is skin grafted. This is associated with less risk of compression but with a higher infection rate that is contiguous with the abdominal cavity (**TECH FIG 3**).
 - Subcutaneous tunneling over the costal margin. This risks compression on the pedicle, especially when edematous.
 - Through the rectus sheath, facilitated by the laparoscopic approach. Lower hernia rates but risk of diaphragmatic hernia is increased. This is performed either through the diaphragm cruciate ligament on the right, where the liver buttresses the area, or to the left of the falciform ligament.¹³
- A small tacking suture may be placed where the omentum enters the chest wall to prevent pull or extrusion on the pedicle.



TECH FIG 3 • Pedicled omental flap harvest. Thoracic reconstruction for major resection involving all layers of the right thoracic cage. Resection included pleural cavity breach indicating ADM use for structural support. A pedicled omental flap was harvested based on the right gastroepiploic artery.

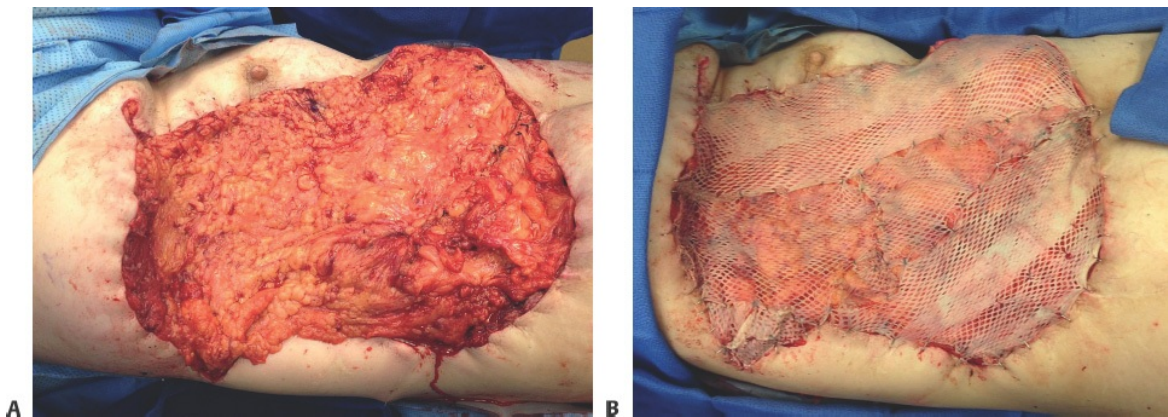
- Adequate pedicle length is ensured to avoid excessive tension on the pedicle during transposition and inseting.

Free Flap Transposition

- The omental flap has a relatively long ischemia time due to its low metabolic demand.
- The dominant right gastroepiploic artery is commonly used.
- Adequate preparation of the defect site and recipient vessels should be done prior to dividing the omental flap pedicle.
- Recipient vessels may include neck, thoracic, aortic, and vertebral arteries and their braches.
- Omentum is transferred and vascular anastomosis is commenced at the recipient site.

■ Flap Inset

- Attention is paid to pedicle positioning to avoid compression, kinking, or twisting, which may compromise blood flow to the flap immediately or early in the postoperative period (**TECH FIG 4A**).
- For the mediastinum and other external chest defects, the omentum can provide volume as well as a large surface area covered by a skin graft (**TECH FIG 4B**).
- Can be folded to fill dead space commonly present in the deep pleural cavity
- Can wrap around vessels or plug bronchopleural fistulas
- Multiple tucking or stay sutures are used to keep the flap in its place and prevent gliding or sliding.
- Drains are recommended for serous fluid accumulation, commonly associated with the omentum flap, and for early recognition of bleeding.



TECH FIG 4 • A. Pedicled omental flap inset. The omental flap covered the entire ADM. The flap was sutured all around for water seal closure. **B.** Skin grafting of the omental flap for complete cover.

PEARLS AND PITFALLS

Preoperative assessment

- Past medical history of abdominal or pelvic surgery should prompt further investigation, and the omentum flap option

	should be reconsidered. ■ Adequate workup and precautions should be taken in patients with significant cardiac disease.
Port placement (for laparoscopic harvest)	■ First port to be placed should be the 10-mm camera port to allow pneumoperitoneum and placement of subsequent ports under direct vision.
Harvest technique	■ Special attention should be given to effective debridement of infected or necrotic nonviable bone and cartilage tissues (eg, sternum, ribs). ■ Laparoscopy allows a “peek” to assess the feasibility and dimension of the omentum flap. ■ Use of nontraumatic grasping forceps. ■ Keep the omentum flap wet at all times to prevent its desiccation. ■ Transillumination of the omentum allows visualization of its vascularity. ■ Minimal manipulation of bowel.
Hemostasis	■ Use of hemostatic ultrasonic scalpel for laparoscopic harvest. ■ Avoid cautery use for vessels. Rather, ligate as you go to decrease the risk of bleeding, hematoma, and injury to vessels of the omental arcade. ■ An intra-abdominal drain should be placed to detect postoperative hemorrhage. ■ Sustained postoperative seroma should be anticipated and drains removed in time.
Delivery and inset of flap	■ An incision in the diaphragm can be used for pedicle transposition but should be wide enough to avoid compression. ■ Prior to ligating the main gastroepiploic vessel, the right and left arteries can be temporarily clamped alternatively to determine omental arch flow. ■ Subcutaneous tunneling should be wide enough (4 fingers’ wide or more) so that postoperative edema will not facilitate compression and venous congestion. ■ Ensure that the pedicle is not kinked or compressed in the process of flap delivery and inset. ■ If used for external coverage, the omental flap can be skin grafted. ■ Sliding of flap postoperatively is a common difficulty and avoided by multiple tucking sutures.

- Gastric outlet obstruction should be thought of when the pedicle is transposed over the gastroduodenal area.
- Be alert for abdominal morbidities following surgery, especially infection and peritonitis.

POSTOPERATIVE CARE

- Immediate postoperative care should include flap care, monitoring, and postabdominal and thoracic surgery precautions.
- A meshed skin graft is advised for externally placed flaps to avoid transudate under the skin graft. A dressing need not be applied to avoid flap compression.
- Clinical monitoring of the omental flap is difficult. Changes within the flap are difficult to see until it is too late.
- If used as a free flap, standard free flap protocols should be instituted including regular flap checks, nothing by mouth (NPO) for the first 24 hours, and bed rest.
- As with any other flap, the 24- to 72-hour postoperative window requires particularly attentive flap monitoring in the form of clinical and/or US Doppler evaluations to identify any signs of pending flap failure.
- Monitoring options include the following:
 - An implantable Doppler for free flap monitoring.
 - Temperature probe placement.
 - A skin-grafted window directly over the omentum facilitates pedicled as well as free flap monitoring for direct flow signal monitoring with the use of a pencil Doppler.
- Postabdominal surgery precautions should include the following:
 - NPO followed by gradual clear fluids working up to normal diet over the first few postoperative days. Commonly, a nasogastric tube is left in place until postoperative day 2 or 3.
 - Monitoring of drain output for early detection of intra-abdominal hemorrhage. The drain can be removed once output is less than 30 mL/d for 2 consecutive days.
 - Adequate pain control. The laparoscopic approach is associated with decreased postoperative pain.
 - Early mobilization of the patient on the first postoperative day is recommended, unless there are other factors preventing this.

- Postoperative antibiotics are given in accordance with abdominal surgery and laparotomy.
- Chest tube with an underwater seal may be indicated for deep thoracic defects involving the pleura. Chest tubes are removed following thoracic surgeon consultation.

OUTCOMES

- Remarkably very few complications are encountered in regard to donor-site morbidities and flap inset.
- Most complications are minor and are addressed conservatively.
- **FIG 3** shows an outcome in one patient after pedicled omental flap for thoracic reconstruction.
- In 135 patients undergoing use of the omental flap for extraperitoneal reconstruction (64 pedicled and 71 free flaps), there were 25 donor-site complications (18.5%).¹ All but one omental flap was harvested via an open technique.

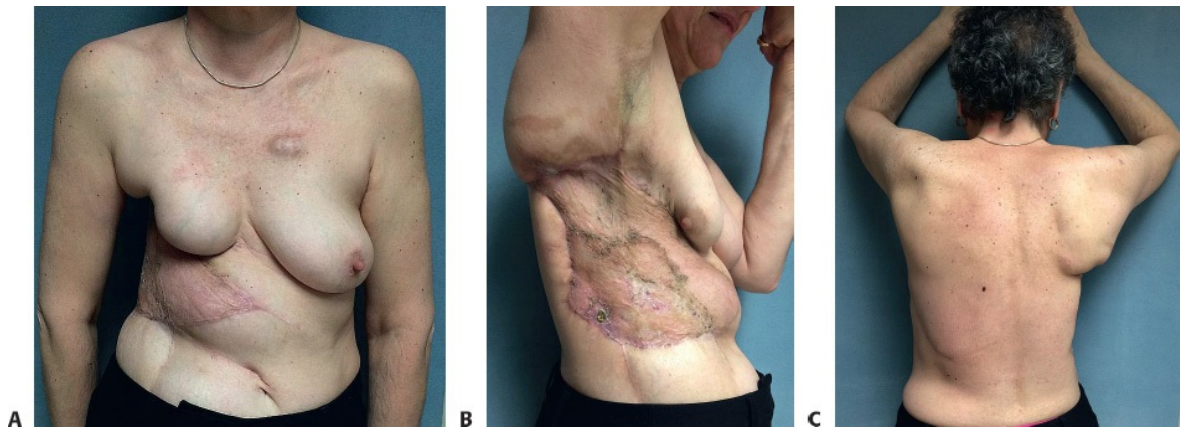


FIG 3 • **A.** Postoperative anterior view of the reconstructed thoracic defect. **B.** Postoperative lateral view of the reconstructed thoracic defect. **C.** Postoperative posterior view of the reconstructed thoracic defect.

- Twenty-six of 53 patients who had undergone previous abdominal surgery required extensive adhesiolysis, with 4 patients sustaining enterotomies.
- Eleven patients (8.1%) had partial flap loss and three patients (2.2%) had total flap loss.

- Factors associated with increased donor-site complications included:
 - Use of pedicled flaps
 - Mediastinitis
 - Advanced age
 - Pulmonary failure
- In a series of nine laparoscopically harvested pedicled omental flaps for chest wall and intrathoracic reconstruction, there were no major intra-abdominal complications postoperatively.¹⁴
- One patient required conversion to a free omental flap due to the detachment of the pedicle, and another patient required conversion to an open harvest technique due to severe abdominal adhesions. One patient had a small transdiaphragmatic hernia treated laparoscopically.
- In a head-to-head comparison of omental flaps vs pectoralis major flaps in the treatment of 33 patients with sternal osteomyelitis, the sepsis-related mortality rate was higher in the pectoralis group (28%) than in the omentum group (0%). The authors concluded that the omental flap conferred greater immunologic advantage as compared with pectoralis major flap.¹⁵
- The open pedicled omental flap harvest technique was used successfully in 27 patients with deep sternal wound infections that had failed previous treatment including pectoralis major flap coverage. There was 1 abdominal wall hernia and 1 persistent fistula in this series.¹⁶

COMPLICATIONS

- In general, postoperative complications associated with chest wall reconstruction include hematoma, seroma formation (fluid transduction), infection, and pneumothorax.
- Skin graft nontake or separation could occur but is mostly only partial and self-resolving.
- If reconstructive plates are used for chest wall stabilization, foreign body reaction, extrusion, and infection can result. This occurs more commonly if the hardware is placed in a radiated field and insufficient soft tissue coverage is the case.
- Donor-site morbidity may include laparotomy-related complications. These include but are not limited to
 - Bowel obstruction
 - Gastric outlet obstruction

- Peritonitis and other infections (eg, abscess)
- Intra-abdominal hemorrhage
- Viscera injury (eg, splenic, liver, bowel perforation)
- Volvulus
- Fascial dehiscence and hernia (eg, epigastric, diaphragmatic)
- Late complications including adhesions and postoperative ileus
- In general, flap-related complications include flap loss secondary to vascular twisting, kinking, excessive tension, and vasospasm, as well as bleeding and infection.
- Specific complications related to the omentum flap include seroma formation (transudation), omental atrophy, flap sliding or migration, and avulsion.

ACKNOWLEDGMENTS

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5 Latissimus Dorsi Flap for Chest Wall Defects

CHAPTER

Essie Kueberuwa Yates and David H. Song

DEFINITION

- Composite defects of the chest wall can arise secondary to oncological extirpation, ablation due to infection, congenital defects, trauma, radiation, or iatrogenic causes such as surgical access and hardware extrusion.
- Methylmethacrylate (in a nonradiated wound bed), bioprosthetic mesh, vascularized bone, local myocutaneous flaps, and free tissue transfer are all routinely used in the reconstruction of chest wall defects.
 - The choice of technique is related to size, extent, and location of the defect and the availability of donor site.
- The latissimus dorsi flap (LDF) is a reliable flap with a robust and predictable vascularity. The proximity of the flap to the chest wall makes it an ideal choice for providing muscle, fat, and skin for use in reconstructing large chest wall defects.
- The thoracodorsal artery system nourishes the LDF and offers the possibility for incorporating multiple tissue types of its single vascular pedicle (chimeric flap).

ANATOMY

- The LD muscle has multiple origins (**FIG 1**):
 - Spinous processes of T7-T12
 - Thoracolumbar fascia

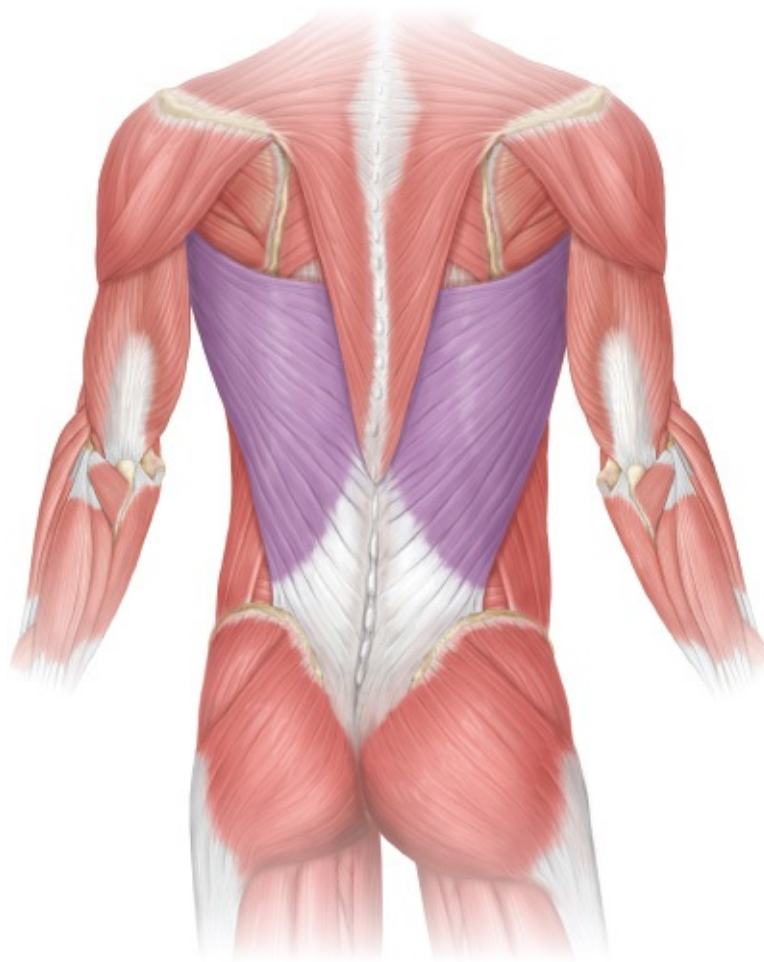


FIG 1 • Latissimus dorsi muscle.

- Posterior third of the iliac crest
- Lowest six ribs
- The LD muscle inserts into the intertubercular groove of the humerus.
- It is a broad flat muscle, which is the most superficial back muscle overlying the paraspinous muscles medially and serratus anterior laterally. It lies deep to the trapezius superomedially.
- The LD is a type V muscle, with the dominant vascular pedicle being the thoracodorsal artery, a terminal branch of the subscapular artery, which arises from the third portion of the axillary artery.
- The thoracodorsal artery runs on the underside of the muscle, and the main pedicle divides into two main branches: an upper horizontal branch that travels medially along the superior border of the muscle and a descending oblique branch that runs inferiorly, parallel to the anterior border of the muscle about

2.5 cm from the edge.

- The bifurcation is predictably found 4 cm distal to the inferior scapular border and 2.5 cm medial to the anterior border of the muscle.
- Thoracodorsal artery perforators exit the muscle and perfuse the subcutaneous tissue, one of these perforators is typically located 8 cm below the posterior axillary fold and 2 cm behind the anterior border of the LD muscle.¹
- Secondary pedicles arise dorsally and mostly perfuse the distal part of the muscle. They are typically found about 5 to 10 cm lateral to the spinous processes and are arranged in a medial row (branches of the lumbar arteries) and a lateral row (branches of the intercostal arteries).
- The largest and most constant of these secondary blood supplies are the branches of the 8th to 11th intercostal arteries. They are typically not useful for large anterior chest wall reconstructions due to their location and short pedicle length.
- These branches can be used, however, when the LD has been previously transected in a standard non-muscle-sparing thoracotomy incision, as the distal portion of the muscle can still be mobilized to provide coverage of limited posterior defects.

PATIENT HISTORY AND PHYSICAL FINDINGS

- When evaluating a chest wall defect, important considerations include the following:
 - Viability and quality of the wound bed (radiated, inadequately debrided; presence of contaminated hardware and large dead spaces result in poor wound healing)
 - Effect of the wound on respiratory mechanics
 - Exposure of vital structures
 - Aesthetics and contour of the chest
- Typically, defects larger than 5 cm or involving more than three ribs require chest wall stabilization in addition to soft tissue coverage.
- In the postirradiated chest wall, larger defects can be tolerated without fixation due to the rigid scarring and fibrosis of tissue.

SURGICAL MANAGEMENT

- The LDF is ideal for chest wall reconstruction because the axis and length of the thoracodorsal pedicle afford this flap an excellent arc of rotation and virtually any part of the ipsilateral chest wall can be reached.

- The most common uses of the LD in chest reconstruction are as a muscle-only flap for intrathoracic obliteration of dead space or as a musculocutaneous flap for coverage of large chest wall defects.²

Preoperative Planning

- When planning chest wall reconstruction with an LD flap, the main considerations are as follows:
 - Ensuring vascularity and availability of donor site. (On occasions, the muscle is transected during thoracotomy.) Some syndromes (eg, Poland) are associated with congenital absence of the pectoralis and LD muscle.
 - Assessing defect size: The thoracodorsal artery provides branches to the serratus muscle, which can be taken in conjunction with the LDF if a larger flap is necessary.
 - Assessment of the need for rigid fixation in addition to soft tissue coverage for composite resections (involving more than three ribs). Vascularized bone can be harvested in conjunction with the LD flap.
 - Appropriate preoperative counseling: The LD is an external rotator of the shoulder, and patients should expect decreased strength and range of motion postoperatively.
- Preoperative markings: With the patient in the standing position, the borders of the latissimus dorsi muscle are delineated (**FIG 2**).
 - Inferior tip of the scapula
 - Anterior border (with the arm elevated, the anterior border extends from the posterior axillary line caudal to the iliac crest).
 - Upper border (with the arm elevated, the posterior border extends from the axilla over the tip of the scapula to the midline of the back).
 - Lower border (curves from the lower midline of the back lumbar region) to the anterior border of the muscle.

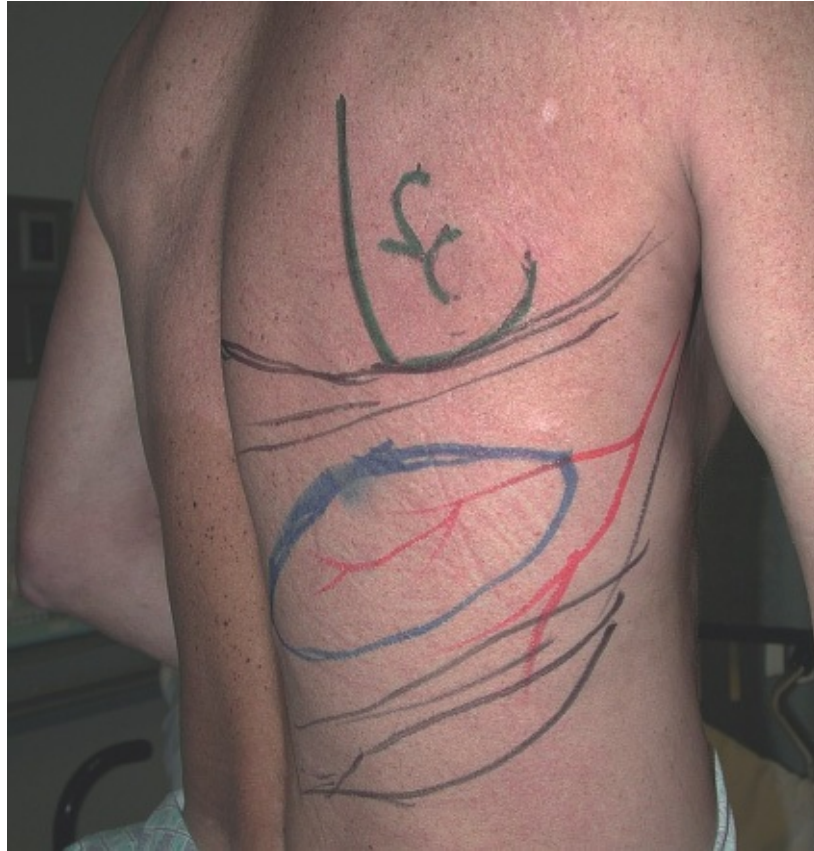


FIG 2 • Preoperative markings.

- The inferior segment of the trapezius is also drawn out as it overlaps the upper medial border of the latissimus as a reminder of this important anatomic relationship.
- Once the limits of the muscle have been identified, the location and orientation of the skin island are planned.
- The size of the skin island is a factor of the defect, and ability to close the donor site primarily.
- The skin island is precisely centered on a dominant perforator that is identified using a handheld Doppler intraoperatively.

Positioning

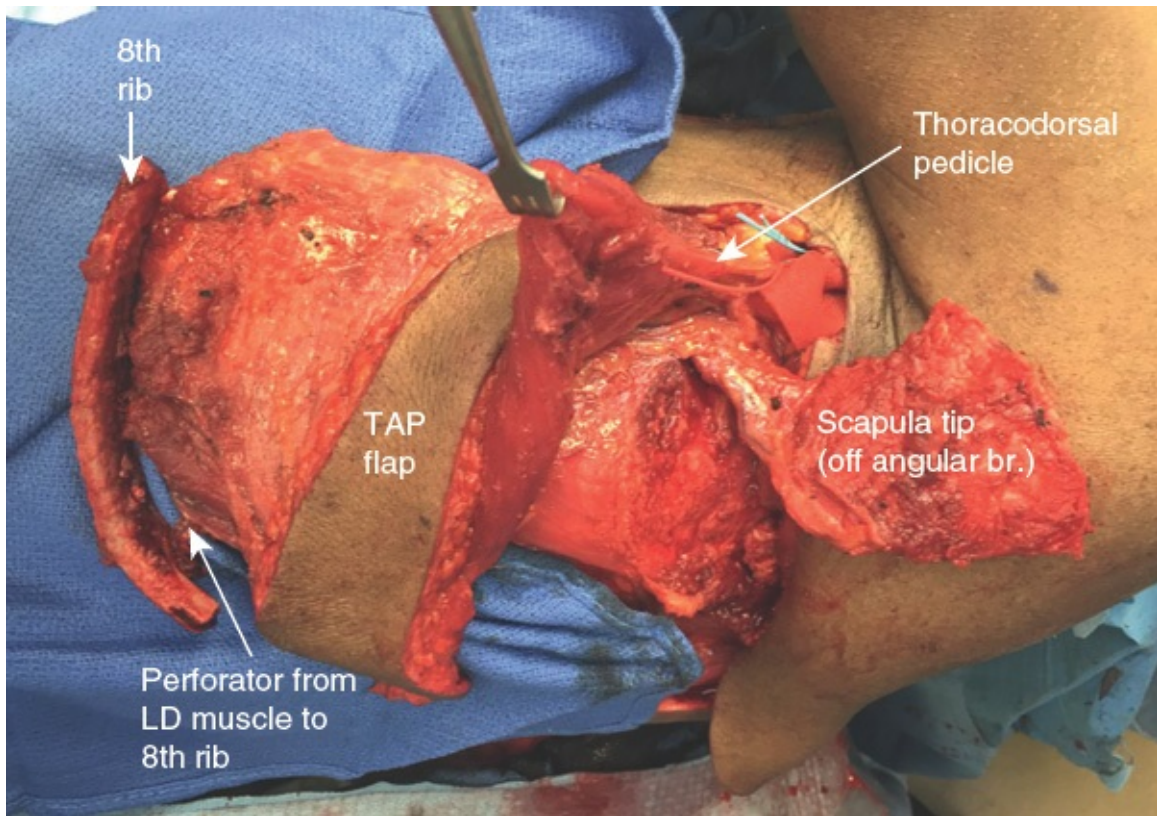
- The LDF is typically harvested in the lateral decubitus position with an axillary support for respiration and with the arm prepped in and the shoulder flexed to 90 degrees.
- A beanbag with appropriate padding can be used, with a pillow placed between the knees and abducted and elevated arm placed on a Mayo stand.

- Lateral decubitus is the preferred positioning for a standard thoracotomy allowing posterolateral and intrathoracic reconstructions to be performed without position change.
- Anterior defects do require harvest, delivery, and closure of donor site, before inset performed when the patient position changes to supine.

TECHNIQUES

■ Flap Elevation

- The skin paddle is incised down through the thoracic fascia to the loose fatty tissue overlying the LD muscle.
 - Caution is taken to bevel out circumferentially for a few centimeters to aid closure without dog-ears and to maximize flap bulk.
- Subcutaneous dissection is carried out inferiorly first, then superiorly keeping a thin layer of loose areolar fat on the muscle until the limits of the muscle are identified.
 - Care is taken to ensure the skin flaps are not too thin.
- The aponeurosis of the trapezius and latissimus muscles is identified, and the LD muscle is separated from underneath it.
- Submuscular dissection is carried down on the medial underside of the LD muscle from superior to inferior.
 - The fascial attachments to the paraspinous muscles are divided, and the lumbar perforators are ligated when encountered.
- Inferiorly, the muscle is divided through its attachments to the iliac crest.
- The anterior border is separated next, again identifying and ligating intercostal perforators and separating attachments from the serratus muscle.
- At this point, the muscle is totally freed and can be flipped upward on its pedicle. (The humeral insertion remains intact at this point.)
 - Any remaining attachments to teres minor or any other deep structures can be identified and divided.
 - The vascular pedicle is visible entering the muscle approximately 10 cm inferiorly from humeral attachment.



TECH FIG 1 • Chimeric thoracodorsal artery perforator (TAP) flap based on the thoracodorsal system. LD, latissimus dorsi muscle. (Courtesy of Lawrence J. Gottlieb, MD.)

- In the case of a chimeric flap, other options involve harvesting the tip of the scapula (off angular branch), serratus muscle/fascia (off serratus branch), and rib based on perforator connections from the LD muscle (**TECH FIG 1**).
- Division of the humeral insertion above the entry of the pedicle greatly facilitates freedom of movement and ease of inset.
- The thoracodorsal bundle is readily identifiable at this stage of the procedure. Division of the nerve at this point minimizes dynamic movements in the flap postoperatively.

■ Dissection of Axillary Tunnel

- The tunnel facilitates the passage of the myocutaneous flap into the chest for

anterior defects.

- Care should be taken to ensure the tunnel has adequate width.
- The tunnel can be dissected from both the chest wall wound (recipient site) and from the donor site (flap side).
- Some surgeons like to predissect the tunnel prior to flap elevation.
- If the humeral origin was divided during elevation, care must be taken not to place tension on the pedicle as it passed through the tunnel.
- The donor site should be closed in layers over closed suction drainage.
- The flap is inset in layers over closed suction drainage

PEARLS AND PITFALLS

Minimizing seroma risk

- Consider quilting sutures for donor site.
- Use at least two large-caliber drains.
- Minimize excessive arm elevation in early postoperative period.

Flap elevation pearl

- If possible, leave the thoracodorsal branch to serratus intact. If you have an injury to the TDA high in the axilla, the serratus branch can nourish the flap via retrograde flow and intercostal communications.

Minimizing donor site morbidity

- If only a small flap is required, consider a TAP flap or latissimus-sparing modification of the traditional procedure.

Stabilization of the chest wall

- Posterior ribs can be elevated with this flap and used in the event when chest wall stabilization with autologous tissue is desired.

Optimizing success in chronic chest wall wounds

- The LDF offers a good option for salvage in a chronic infected wound. Adequate aggressive debridement prior to flap coverage is essential to a successful outcome.

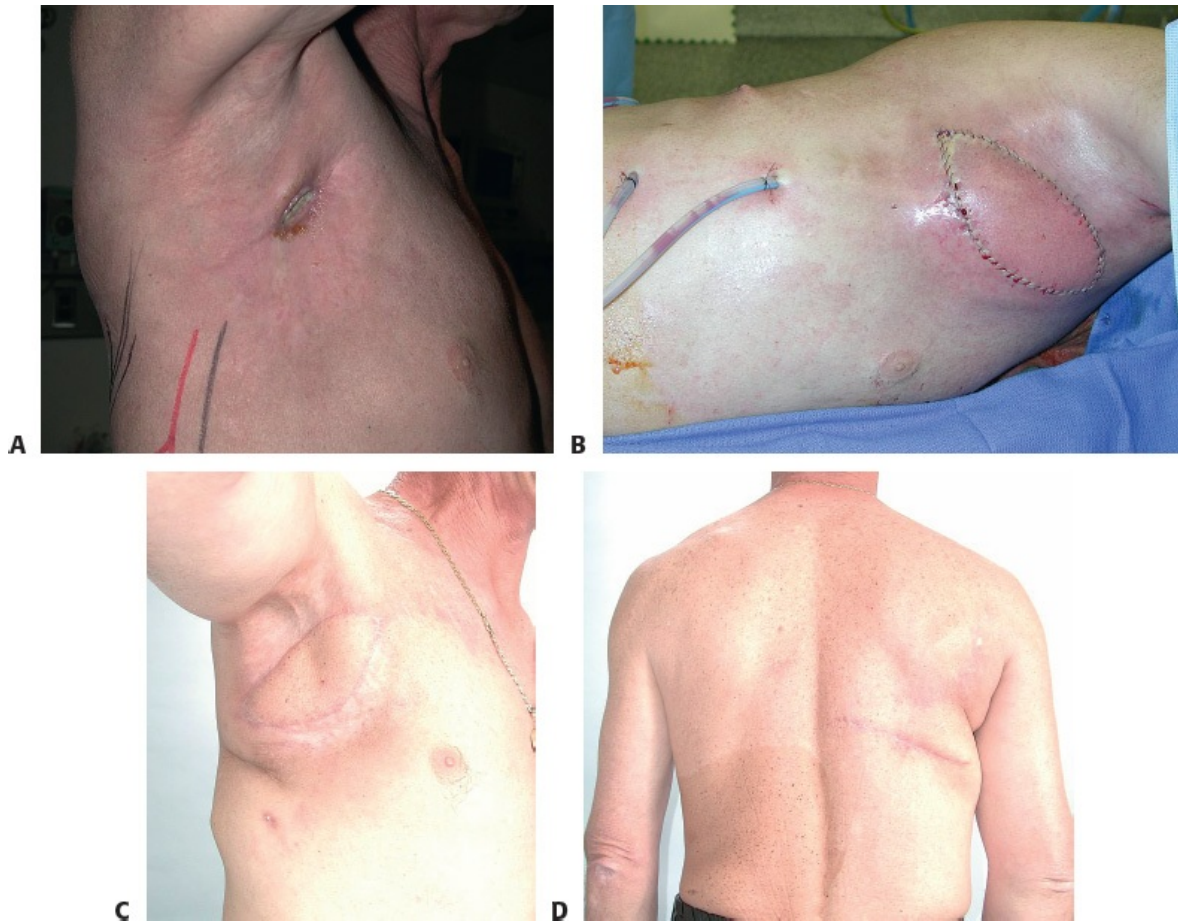


FIG 3 • A. This 53-year-old man had a history of fungating primary adenocarcinoma of anterolateral chest wall after radiation, with open draining wound and osteoradionecrosis of the underlying rib. **B.** After resection and reconstruction with LD flap. **C,D.** Recipient and donor sites, respectively, 6 months postoperatively.

POSTOPERATIVE CARE

- Most patients have an uneventful postoperative course specifically related to the LD flap.
- Early ROM is encouraged to minimize arm and shoulder stiffness.
 - Excess elevation and abduction of the arm are discouraged, however, because of significantly increased seroma formation risk.
- Drains should stay in situ until <30 cc/24-h period is recorded for 2

consecutive days. Drains are often required for many weeks.

OUTCOMES

- In the well-selected patient, the main outcomes for chest wall reconstruction are readily achieved using LDF (**FIG 3**).
- These flaps offer sufficient volume to fill the three-dimensional dead space, buttressing repair of hollow visceral leaks, maintenance of chest wall stability, restoration of aesthetic contour, covering of exposed prosthetic materials with vascularized flaps, and retaining the “right of domain” of abdominal and chest viscera while minimizing donor site functional deficits.³

COMPLICATIONS

- The most common complication from LD flap harvest is donor site seroma formation. Drains are often required for prolonged periods, on occasions up to 6 to 8 weeks.
- In the event of seroma accumulation, repeat in-office aspiration may be required. With time, fluid accumulation eventually stops, leaving behind an empty bursa of varying dimensions.
- Isolated arm strength can be diminished after flap transfer, although this is rarely a significant finding, as the other muscles of the back compensate for the absent muscle.
 - It takes 6 months to a year for the surrounding muscles to be fully compensatory, and patients often describe easy fatigability in activities requiring external rotation and elevation of the arm overhead (eg, swimming, climbing, painting).³
- The vascularity of the LD flap is robust, and vascular compromise or fat necrosis is rare after LD transfer.
 - However, donor site marginal skin necrosis can occur particularly in smokers, which might suggest avoiding excessive undermining.

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6 Serratus Anterior Flap for Chest Wall Reconstruction

CHAPTER

Zachary J. Collier and David H. Song

DEFINITION

- Chest wall deformities arising from congenital malformations and acquired etiologies result in significant physical and psychological sequelae.
- Regardless of the underlying etiology, failure to reconstruct chest wall deformities may result in debilitating respiratory abnormalities, risk of internal organ injury, and psychological ramifications.
- Serratus anterior flap (SAF)
 - SAF was first described in 1979 by Mathes and Nahai and later refined in 1982 by Takayanagi and Tsukie¹ for use as a muscle transposition flap based off of a type III (two major pedicles) vascular supply.
 - The SAF has been employed as a transposition and free flap for reconstructing defects of the upper and lower limbs, trunk, and head and neck.
 - It is a highly versatile small to medium-sized muscle flap that can be neurotized through the sensory branches of the intercostal nerves over the skin paddle as well as incorporated into a larger chimeric design for more complex reconstructions.

ANATOMY

- The chest wall is a complex musculoskeletal system that provides a rigid skeletal encasement for protecting vital organs while maintaining the flexibility to interact with multilayered and vectored musculature to facilitate respiration and upper extremity mobilization.
- The skeletal system is composed of 2 clavicles and 12 paired ribs, which in turn articulate posteriorly with the thoracic vertebrae's costal facets and transverse processes as well as anteriorly with the sternum via costochondral

joints. The 8th to 10th ribs are referred to as “false” ribs as they lack direct sternal attachments, whereas ribs 11 and 12 are termed the “floating” ribs (**FIG 1**).

- The musculature is composed of two main groups—axial and appendicular muscles (**FIG 2**).
 - Most axial muscles can be divided into two subtypes based on their role in respiration—inspiratory (sternocleidomastoid and scalene) and expiratory (rectus abdominis, internal oblique, and external oblique)—although the trilayered intercostals participate in both respiratory processes.
 - The appendicular muscles are required for manipulation of the scapula (trapezius, serratus anterior) and humerus (pectoralis major/minor, latissimus dorsi).
- The serratus anterior originates from the superolateral borders of the first 8 or 9 ribs and inserts onto the costal surface of the medial scapular border to create 7 to 10 distinct digitations or slips (average dimension 10 × 20 cm).²
 - The distribution of serratus digitations is as follows: 7 (13%), 8 (48%), 9 (26%), and 10 (13%).³
- Arterial supply (Mathes and Nahai type III)
 - Superior 3 to 5 slips: The lateral thoracic artery (0.5 to 1.5 mm),⁴ which originates from the axillary artery posterior to the pectoralis minor, follows the inferolateral border of the muscle to supply the first 3 to 5 slips.
 - Inferior 3 or 4 slips: The thoracodorsal artery (2 to 4 mm),⁵ which originates from the subscapular artery, gives off one (40%), two (50%), or three (10%) serratus branches (1.5 to 2.5 mm)⁶ to supply the inferior 3 to 4 slips. The average pedicle length is 11 cm but may be as long as 15 cm if taken to the subscapular artery.³
- Veins: Paired venae comitantes run parallel to their arterial counterparts (**FIG 3**).
- Nerves: Innervated by the long thoracic nerve, which arises from the C5 to C7 anterior rami and passes through the cervicoaxillary canal, it runs posterior to the brachial plexus and axillary artery/vein where it follows the inferior surface of the muscle and eventually diverges on the vascular pedicle as it travels inferiorly.⁶
 - Preserve the first 4 or 5 muscular slips to avoid damage to this nerve, which would produce a winged scapula deformity.
 - Innervation of the optional skin paddle is provided by the lateral cutaneous

branches of the intercostal nerves (**FIG 4**).

PATHOGENESIS

■ Congenital

- Pectus excavatum (PE), pectus carinatum (PC), Poland syndrome, anterior thoracic hypoplasia, pentalogy of Cantrell, asphyxiating thoracic dystrophy, spondylothoracic dysplasia, and sternal clefts

■ Acquired

- Trauma, tumor resections, postoperative complications, wound infections involving musculoskeletal components, and chronic empyemas

PATIENT HISTORY AND PHYSICAL FINDINGS

■ History

- As with any other reconstructive procedure, a thorough evaluation of comorbidities, especially those that place the patient at risk for VTEs (ie, history of VTEs, obesity, diabetes, smoking, Caprini score greater than 8)⁷ or vascular complications, is critical for preoperative medical and anesthesia optimization.

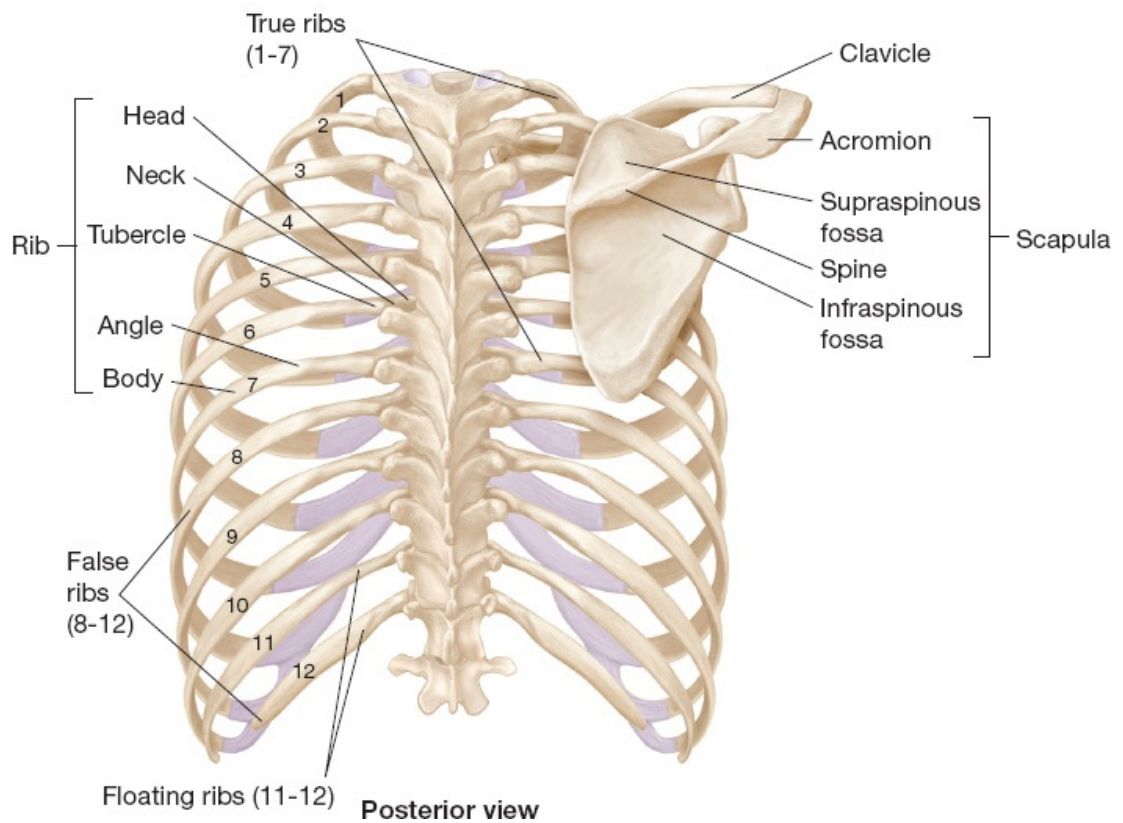
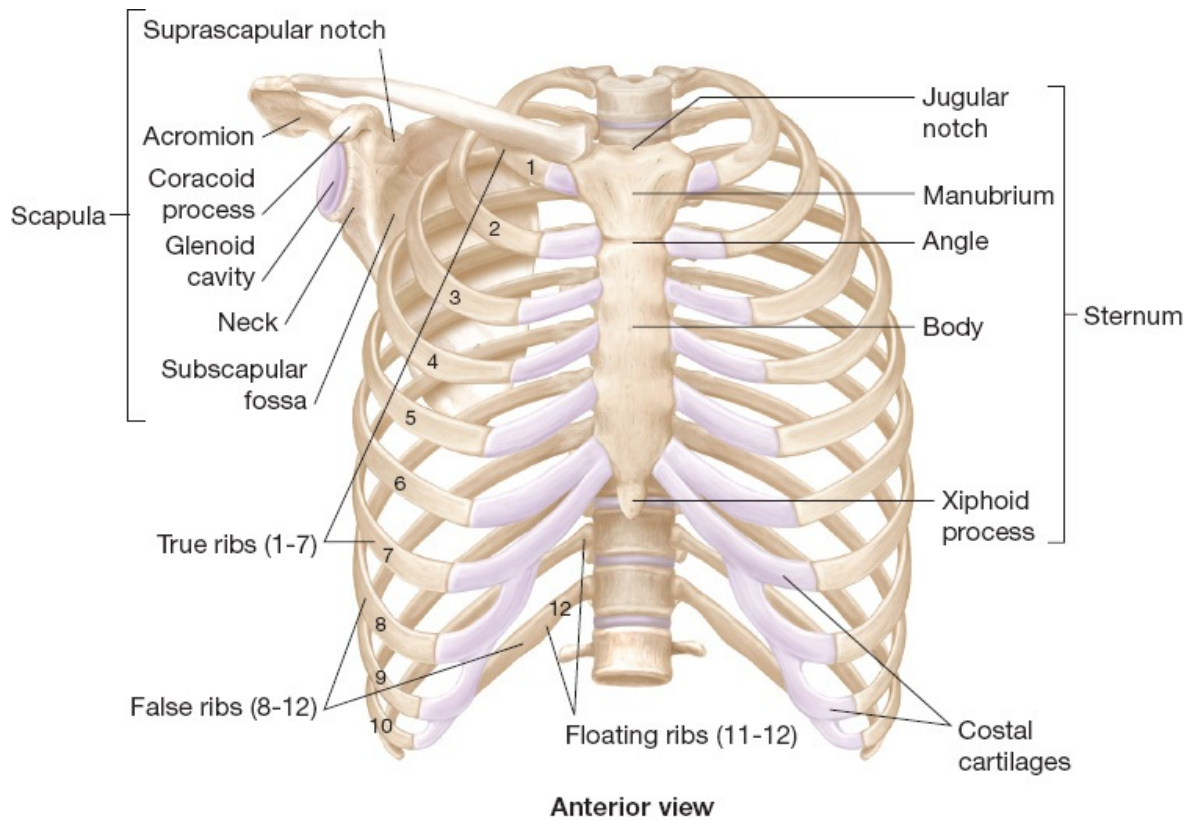


FIG 1 • Skeletal anatomy of the chest wall.

- Congenital: It is important to acquire any genetic workup or syndromic diagnoses in order to identify additional comorbidities and underlying structural abnormalities not readily apparent on physical exam that may complicate or alter the surgical approach.
- Acquired: History of insults to the chest wall soft tissue and skeletal integrity is critical for identifying the full extent of the defect as well as any factors that may influence the treatment plan.
 - Trauma: Consider imaging (magnetic resonance imaging [MRI], computed tomography [CT], vascular imaging) studies if there is a potential for aberrant/obscured anatomy or foreign bodies.
 - Infection: Consider tissue quantifications and cultures to identify any pathologic microbes and to guide preoperative planning regarding plating and/or other hardware utilization.

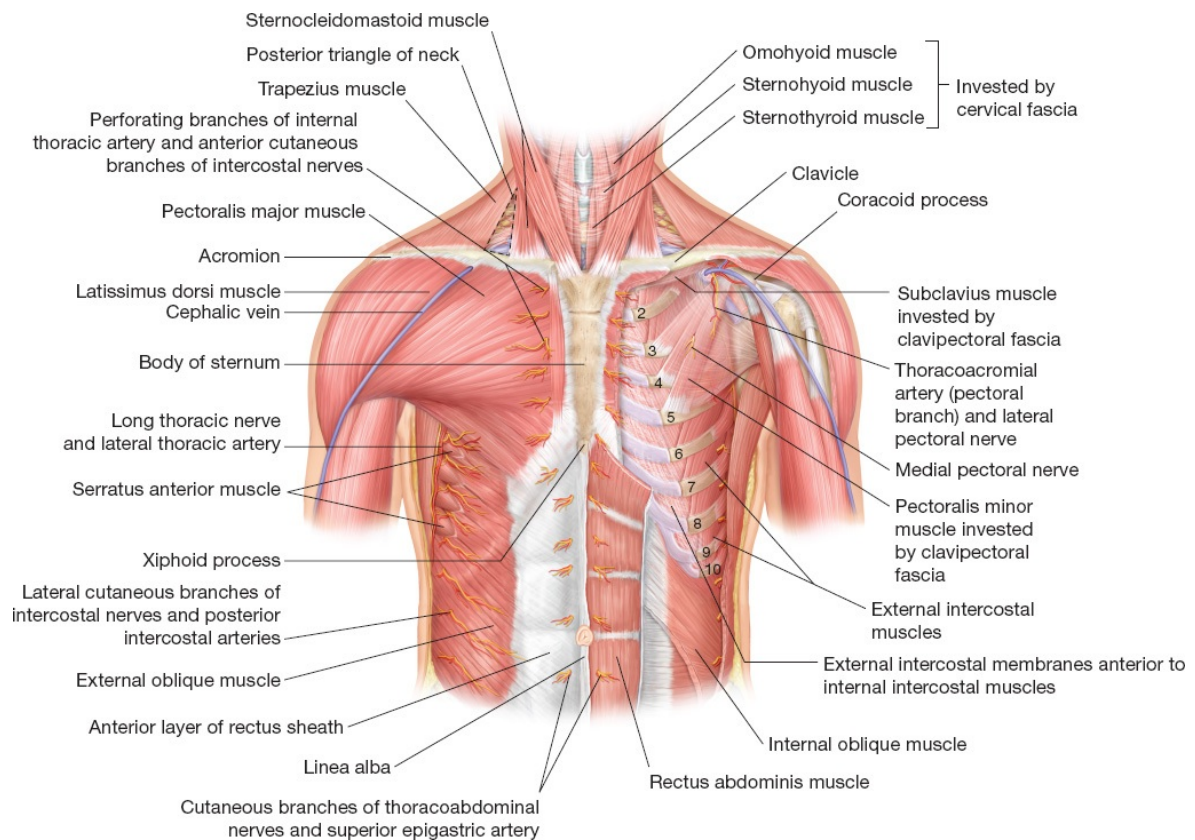


FIG 2 • Musculature and neurovascular anatomy of the

chest wall.

- Oncologic: Ensure clear pathologic margins or identify additional resection requirements and treatment goals respective to tumor type.
- Radiation: Identify plans for postadjuvant radiation therapy to guide reconstructive decisions (ie, local/regional vs free flap design, timing).

■ Physical exam

- In general, identification of defect dimensions and involved tissue types is critical for preoperative planning and flap design.
 - Skin: Note scars or contractures from prior procedures. Identify lacerations for potential utilization as or integration with incision design. Evaluate for skin integrity including turgor, elasticity, and signs of radiation damage or dermatologic disease.
 - Muscle: Assess muscle bulk and dimensions to identify tissue limitations and guide preoperative flap design.
 - Bone: Identify extent of skeletal defects to determine requirements for structural stabilization with plates, grafts, or bone-containing flaps.

IMAGING

- CT or MRI studies may be beneficial in the preoperative evaluation of patients undergoing tumor resection as well as those with trauma to identify the extent of musculoskeletal defects and any complicating foreign bodies.
- Vascular studies such as CT angiography may be warranted if tumor resection or trauma has compromised the natural vascular anatomy or extent of vascular involvement is unknown.
- Dynamic three- and four-dimensional CT imaging can facilitate individualized flap design by identifying angiosome filling patterns up to the subdermal plexus level, recruitment of neighboring angiosomes through communicating branches, and venous drainage.^{8,9}
- As previously mentioned, three main serratus perforator branching patterns from the thoracodorsal artery have been identified in anatomical studies, so CT angiography can be utilized to identify patient-specific anatomical variants for facilitating intraoperative perforator identification and dissection.³

SURGICAL MANAGEMENT

Preoperative Planning

- Location and size of the defect are ideally identified prior to incision to guide decisions regarding flap design (ie, transposition or free flap) and required vascular pedicle length.
- Direct closure of the donor site, stability of the thoracic wall, and protection of the thoracic viscera are all variables that need to be integrated into the decision to utilize a muscle transposition, myocutaneous, or chimeric flap.

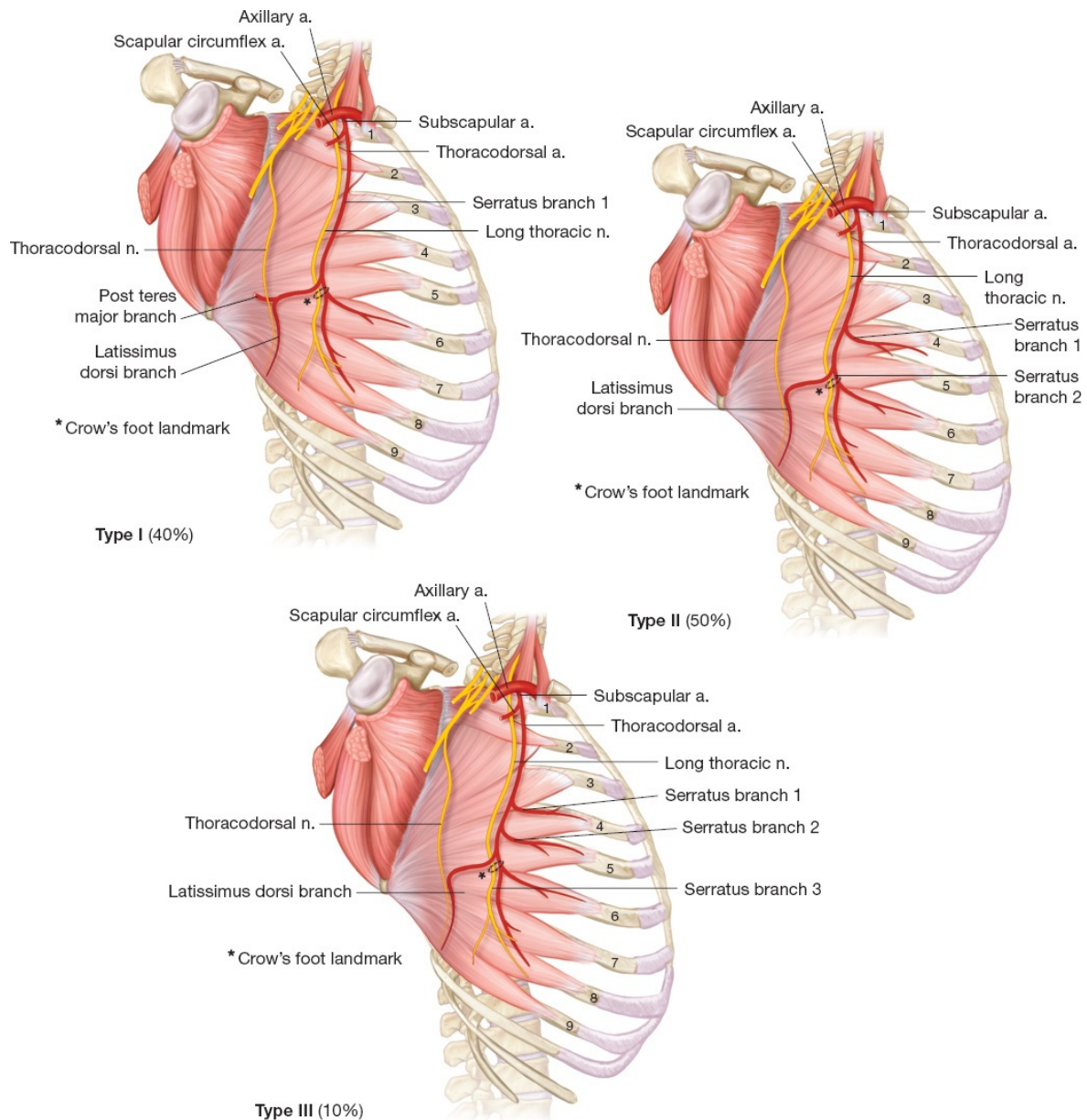


FIG 3 • Vascular branching patterns of serratus perforators from thoracodorsal artery.

- Involved tissue types
 - Skin: Identifying skin involvement is important for determining if a flap with a skin paddle or skin graft is required. The decision to include a skin paddle will alter the dissection to preserve the lateral cutaneous perforators of the posterior intercostals that would otherwise be transected during exposure of the serratus muscle.
 - Muscle: Determine which muscles are involved and the level of functionality

that exists with the current muscular composition.

- If resection, radiation, or infection compromises a muscle that would otherwise be available as flap, this is critical to know prior to taking the patient to the operating room so that a different flap or surgical approach may be chosen.
- Bony defects larger than 5 cm or involving more than 3 or 4 contiguous ribs are likely to benefit from structural support in addition to soft tissue coverage.¹⁰
- A defect's age (ie, acute vs chronic wound) often influences the quality of localized tissue vascularity, extent of fibrosis, and local wound healing capabilities as a result of inflammation-dependent changes in regional "physiosomes."

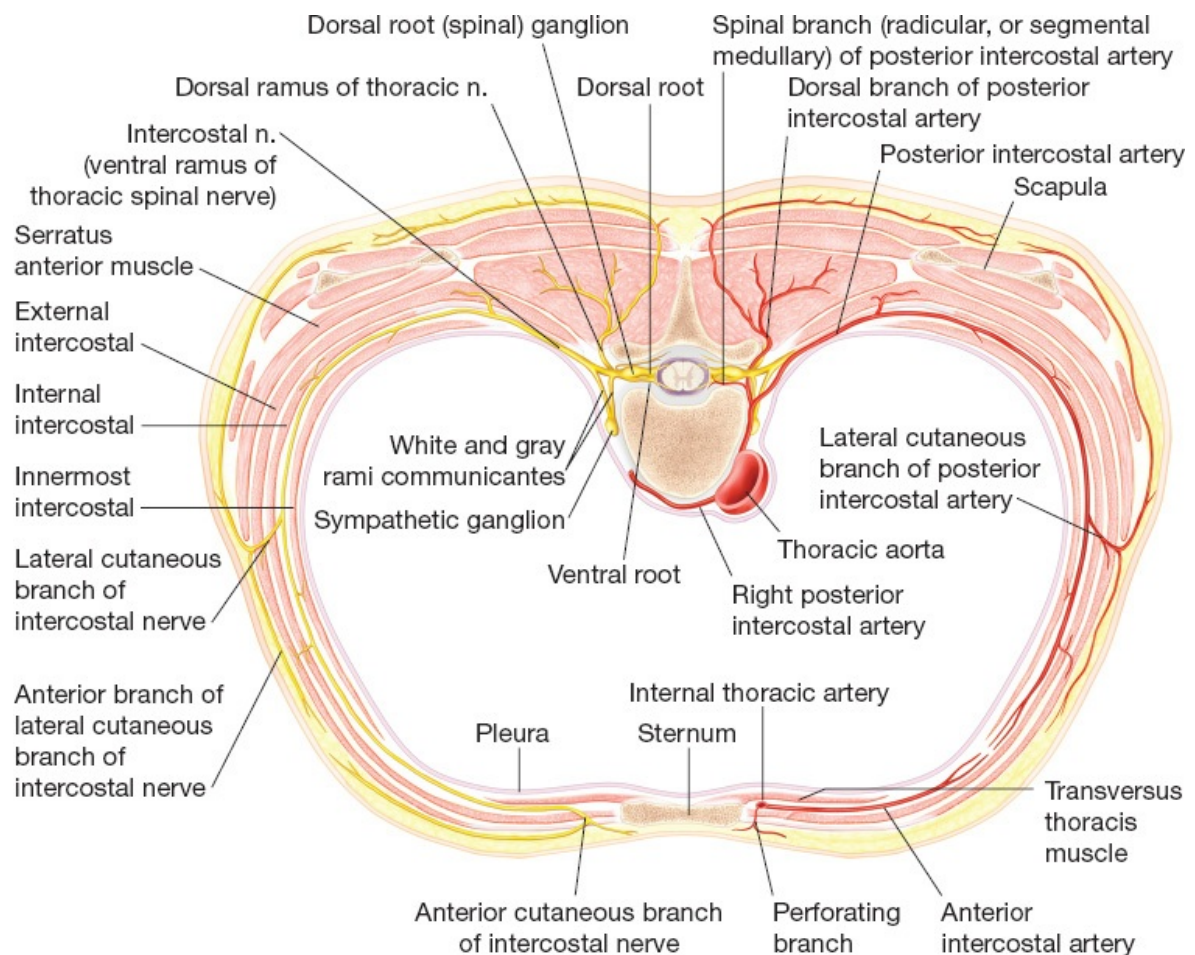


FIG 4 • Thorax anatomic cross section.

- The presence of irradiated skin, previous scars/contractures, localized

infection or inflammation, and acute trauma all influence the regional tissue integrity and subsequently require consideration while determining the reconstructive approach and complexity.

- Patient lifestyle and functional status help to identify the measures to be implemented for preservation of postoperative muscular functionality and the overall type of reconstruction performed.
- Certain activities (ie, boxing, golf, baseball, and swimming) and labor-intensive occupations (ie, construction) depend on the serratus anterior for full functionality, and this must be taken into consideration when choosing the donor muscle.
- Prognosis: Life expectancy and patient-specific goals vary significantly for each patient and, as a result, must be considered when determining the complexity of reconstruction.
- Patient who have had the serratus anterior muscle harvested may have a “winged” scapula and discomfort.
- Those with poorer overall prognoses may be better treated with less complex reconstructive techniques that minimize intraoperative risks while facilitating faster recovery times.

Positioning

- The patient may be placed in partial or complete lateral decubitus position depending on the location of the defect relative to the donor site.
- Defects juxtaposed to the donor site allow for full lateral decubitus positioning with a beanbag setup.

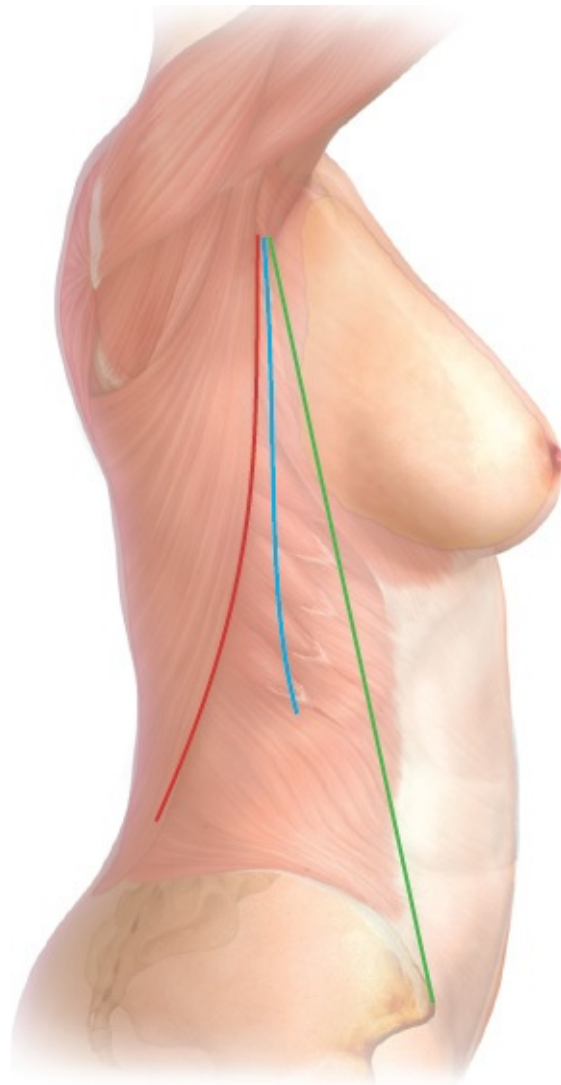
Approaches

- Incisions overlying the anterior border of the latissimus muscle allow ready access to the serratus anterior muscle.
- Transverse or oblique incisions may lend to a more favorable donor site scar.
- Anterior access is necessary to adequately harvest the entire serratus muscle.

TECHNIQUES

■ Landmarks and Markings

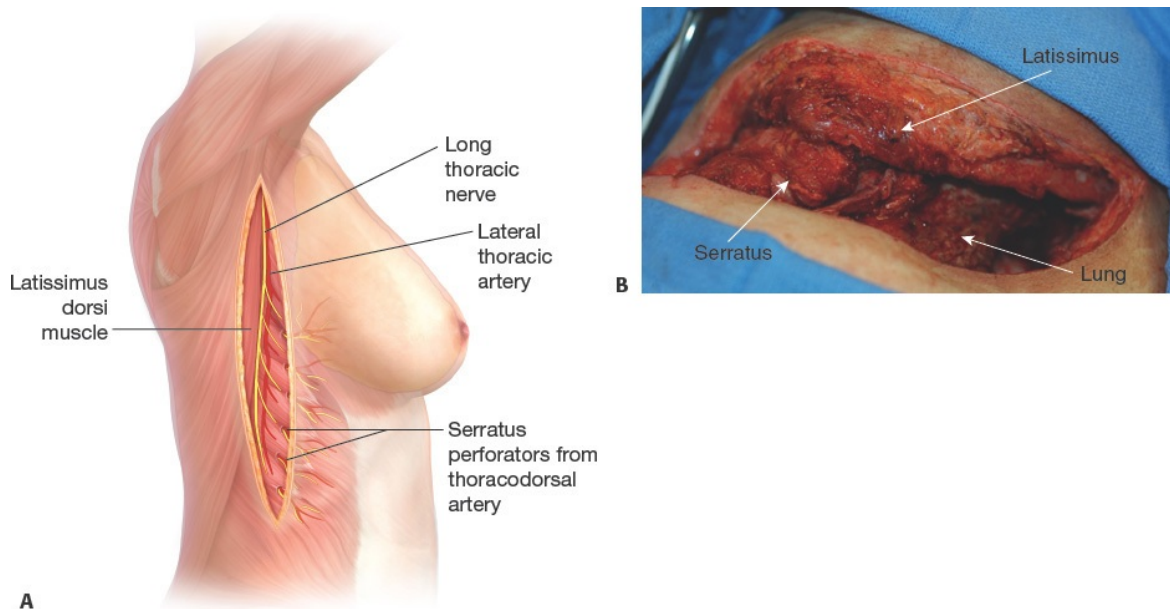
- It is important to identify the anterior border of the latissimus dorsi and the inferior border of the ninth rib to ensure the incision will appropriately expose the latissimus and inferior serratus slips.
- Create a template of the defect to identify the required dimensions for reconstruction.
- Trace the anterior border of the latissimus muscle as well as a straight line from the anterior axillary line to ASIS to delineate the ideal anteroposterior boundaries for the incision (**TECH FIG 1**).
- If a skin paddle is going to be incorporated into the flap design, transpose the defect template into this defined region and identify perforators with US Doppler to optimize the flap position relative to underlying vasculature.



TECH FIG 1 • Preoperative markings.

■ Exposure

- Make a curvilinear incision from the axilla to rib 8 or 9 while avoiding anterior or posterior deviations beyond the previously identified A-P borders. The location and appearance are similar to those of a classic lateral thoracotomy incision.
- Dissect down to the deep fascia overlying the latissimus muscle.
- Following exposure of the anterior projection of the latissimus dorsi, reflect the latissimus posteriorly to expose the underlying serratus anterior muscle while preserving the thoracodorsal neurovascular pedicle (**TECH FIG 2**).
- Dissect out the thoracodorsal artery to identify and preserve the serratus artery branches.
- After isolating the serratus perforators, continue to expose the inferior 3 to 4 serratus slips.
- The long thoracic nerve also travels superficial to the muscle and must be identified to avoid inadvertent damage.

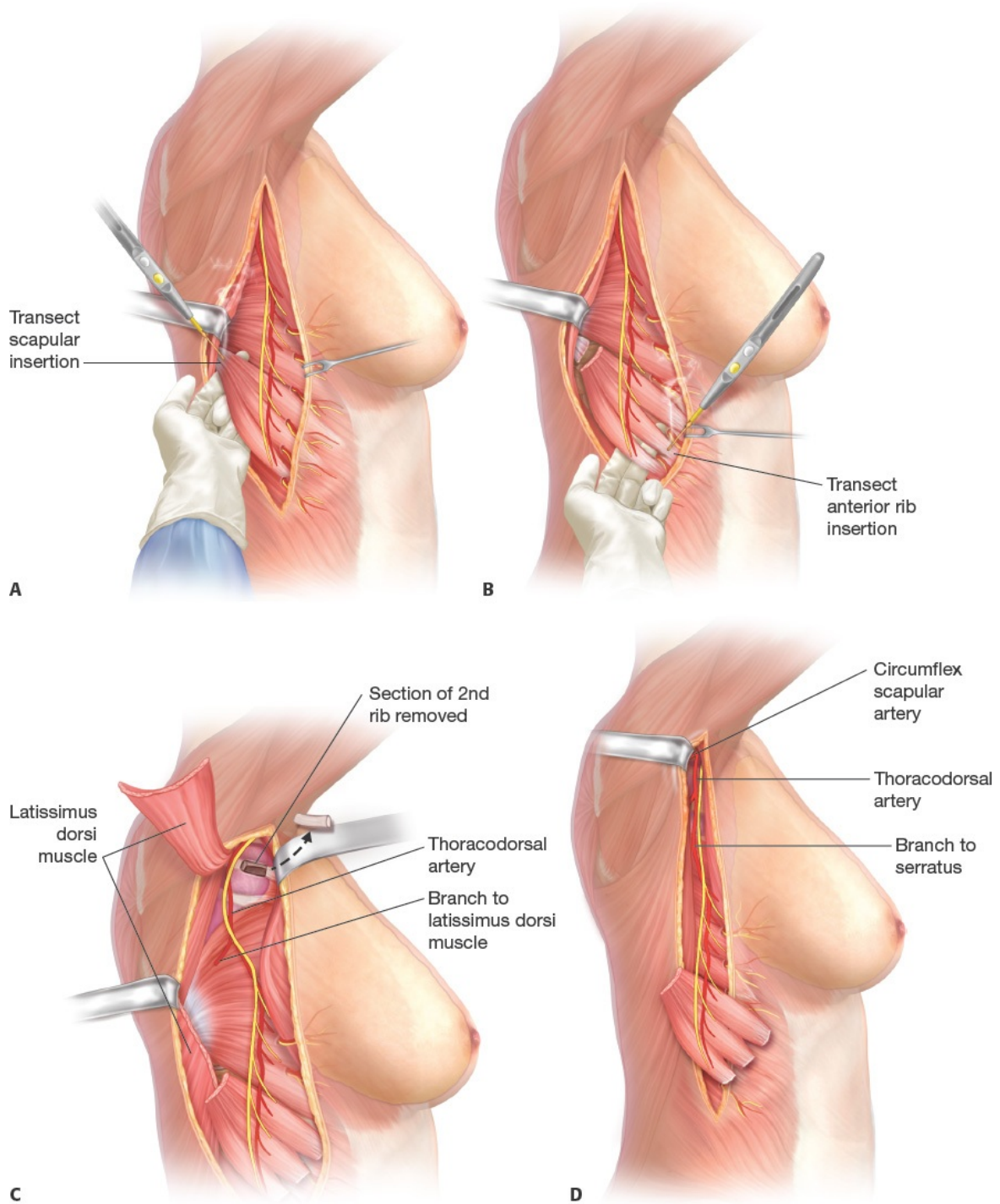


TECH FIG 2 • A. Incision and initial dissection. **B.** Postdissection wound in a patient with a complicated

empyema who underwent open window thoracomyoplasty.

■ Flap Harvest

- Dissect posteriorly and superiorly toward the axilla following the serratus slips to their scapular attachments.
- Identify and preserve the lateral thoracic artery and long thoracic nerve as the dissection travels posteriorly toward the axilla.
- Divide the muscular insertions on the scapula using electrocautery (**TECH FIG 3A**).
- Both the thoracodorsal perforators and lateral thoracic artery can be preserved for flap perfusion or selectively divided depending on the required pedicle length, arc of rotation, and vascular integrity.
- If skeletonizing the pedicle(s), it should be performed cautiously to preserve sufficient perivascular adipose tissue to reduce the risk for vasospasm and avoid damaging the paired venae comitantes that accompany the artery.
- Identify the origin for each slip on the corresponding rib.
 - For a muscle transposition or myocutaneous flap, this costal muscular insertion can be divided for elevation of the serratus muscle (**TECH FIG 3B**).



TECH FIG 3 • **A.** Retraction of latissimus and exposure of serratus. **B.** Serratus flap elevation. **C.** Optional rib harvesting step. **D.** Elevated serratus

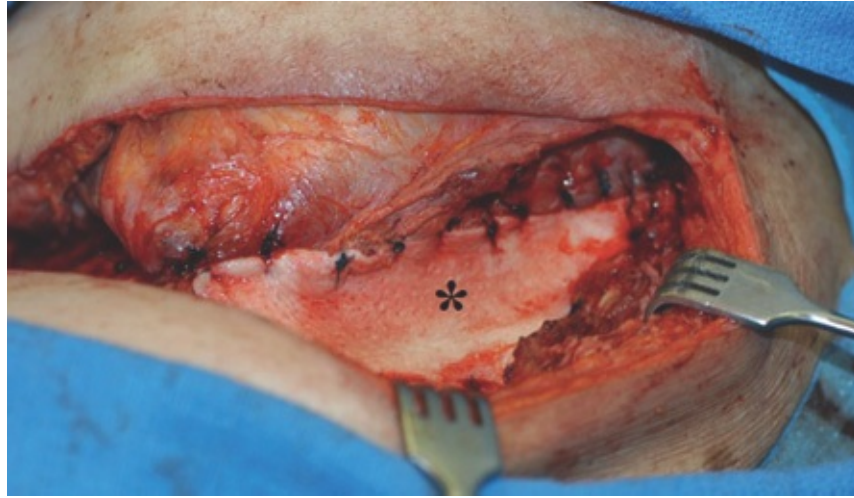
anterior flap on pedicle. **E.** Intraoperative photo of serratus anterior muscle flap elevated on lateral thoracic artery pedicle.

- If the rib is also desired for reconstruction, mark the anterior osteotomy site.
 - Sharply dissect onto the rib after identifying the superior and inferior rib boundaries.
 - Dissect in the subperiosteal plane on the posterior costal border while ensuring the intercostal neurovascular bundle, posterior periosteum, and adjacent pleura remain intact.
 - Perform the anterior and posterior osteotomies to elevate the flap (**TECH FIG 3C**).
- Following flap elevation, continue to proximally dissect the vascular pedicle to the desired length with or without skeletonization depending on inset goals.
 - Up to 15 cm pedicle length and 4 mm vessel diameter are possible if dissection is carried up to axillary insertion for the thoracodorsal-based pedicle (**TECH FIG 3D,E**).
- Ensure constant visualization and isolation of the long thoracic and thoracodorsal nerves to avoid injury.
 - The skin paddle is innervated by the lateral cutaneous branches of the intercostal nerves, which can be readily identified and preserved during flap elevation to preserve sensation to the skin flap.

■ Flap Inset

- Close attention must be paid during skeletonization to preserve some perivascular adipose in the pedicle, which will reduce the risk for vasospasm and pedicle kinking.
- Ensure sufficient pedicle length has been dissected to prevent excessive tension on the pedicle during flap transposition or inseting.
- Maintain awareness of the position in which the vascular pedicles lie to ensure that no kinking or twisting has occurred, which may compromise blood flow to the flap immediately or early in the postoperative period.

- **TECH FIG 4** depicts an intrathoracic transposition insetting.



TECH FIG 4 • Intrathoracic flap insetting and subsequent coverage with acellular dermal matrix (*) for defect reconstruction.

PEARLS AND PITFALLS

Techniques

- Limit harvest to inferior 3 or 4 slips to avoid damage to long thoracic nerve.
- The crow's foot landmark (around 7th to 8th slip) is the point at which the dominant serratus branch of the thoracodorsal artery enters the muscular fascia, crosses the long thoracic nerve, and arborizes anteriorly to supply the inferior slips that will be harvested for the flap.³
- The neurovascular bundle lies superficial to the muscle flap, which facilitates safe dissection from violating the posterior costal periosteum when harvesting a rib.
- The subscapular system can be further modified to create a chimeric flap involving the latissimus dorsi, scapular, parascapular muscle, and scapular spine.
- A skin paddle may also be taken by preserving myocutaneous perforators if needed for defect coverage.

POSTOPERATIVE CARE

- Occlusive-type dressings are preferred.
- Drains are necessary to avoid seroma.
- Local anesthetic block and muscle relaxant can be beneficial to mitigate postoperative pain.
- Thoracic epidural analgesia can also provide extended pain relief.
- Flap monitoring
 - As with any other flap, the 24- to 48-hour postoperative window requires particularly attentive flap monitoring in the form of clinical and/or US Doppler evaluations to identify any signs of pending flap failure.
 - Specific clinical findings point to the vascular etiology and can facilitate more efficient operative interventions.
 - Arterial: Cold, pale, poor capillary refill, and minimal to absent bleeding with pinprick test
 - Venous: Warm, edematous, dusky/purple, and dark blood with pinprick test
 - Newer technology such as ViOptix tissue oximetry may be used to further enhance postoperative flap monitoring. These systems provide continuous flap monitoring with real-time feedback to support clinical decisions regarding flap compromise and the necessity for flap take backs.

OUTCOMES

- Depending on the number of serratus slips harvested, the donor site scar can be made relatively short and well hidden laterally parallel to the adducted arm.
- Limiting the harvest to the inferior 3 or 4 slips and preserving the long thoracic nerve result in good retention of muscular function and overall limited donor-site morbidity.

COMPLICATIONS

- Postoperative complications with chest wall reconstruction include donor and/or recipient site hematoma or seroma formation, infection, and pneumothorax.
- If reconstructive plates are used for chest wall stabilization, extrusion and infection can result if the hardware is placed in a radiated bed or has insufficient soft tissue coverage.
- Flap
 - Failure secondary to arterial or venous congestion is more likely to occur in

cases where there was extensive skeletonization, excessive tension, and/or kinking of the pedicle during flap inseting.

- Donor-site morbidity may include chronic pain, loss of scapular/shoulder ROM or functionality, and winged scapula.

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Section II: Reconstruction of the Abdominal Wall

7 **Hernia Repair With Open Component Separation**

CHAPTER

Ibrahim Khansa and Jeffrey E. Janis

DEFINITION

- Traditional component separation, now termed “anterior component separation,” involves separating the external oblique muscle from the remaining components of the abdominal wall.
- This requires two steps:
 - Incision of the external oblique aponeurosis
 - Delamination of the external oblique muscle from the underlying internal oblique muscle
- A third step (optional) is entry into and development of the retrorectus space.
- “Posterior component separation,” also known as a transversus abdominis release (TAR), is another type of component separation. It requires two steps:
 - Entering and developing the retrorectus space
 - Transection of the posterior lamella of the internal oblique and transversus abdominis
 - Delamination of the transversus abdominis and transversalis fascia

ANATOMY

- The layers of the lateral abdominal wall, from superficial to deep, are the external oblique, internal oblique, and transversus abdominis muscles, transversalis fascia, and peritoneum.
- The segmental intercostal nerves to the abdominal wall musculature travel in

the layer between the internal oblique and transversus abdominis muscles.

- Vascular perforators to the abdominal wall skin emerge from the deep epigastric vessels.
 - They are arranged into a medial and a lateral row.
 - The medial row is dominant, especially the periumbilical perforators.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Assess if any indications for urgent surgery are present.
 - Bowel obstruction
 - Incarceration/strangulation
 - Infected mesh
- Assess effect of hernia on the patient.
 - Ability to carry out activities of daily living
 - Pain at hernia site
 - Difficulty with defecation
- On physical examination, look for:
 - Peritoneal signs
 - Reducibility of hernia
 - Edges of fascial defect
 - All scars on the abdomen (which will affect vascularity)
 - Presence of skin graft
 - Presence of a fistula
 - Presence of an ostomy

IMAGING

- CT scan of the abdomen is useful to delineate:
 - The size, extent, and borders of the fascial defect
 - Whether component separation has been performed previously
 - The integrity of the musculofascial components (may have been previously resected)
 - An estimate of the loss of domain
 - Presence and position of prior mesh, if applicable
 - The thickness of soft tissue between the hernia (sac) and overlying skin

SURGICAL MANAGEMENT

Preoperative Planning

- Assess suitability of the patient for major surgery.
 - Smokers and tobacco users should completely abstain for at least 4 weeks preoperatively and 4 weeks postoperatively.^{1,2}
 - Nutrition should be optimized before surgery (prealbumin greater than 15 mg/dL, albumin greater than 3.25 g/dL).^{2,3}
 - Diabetes should be well controlled ($\text{HbA1c} \leq 7.4\%$).²
 - Body mass index should be 42 or less, and preferably less than 40.²
- After hernia dissection and lysis of adhesions, assess whether component separation is needed:
 - Apply Kocher clamps on the medial edge of the rectus complex on each side.
 - Attempt to simulate midline reapproximation of the rectus complexes by bringing the two sides toward each other.
 - If too much tension is present, which may result in fascial cheese wiring or inability to obtain primary musculofascial reapproximation, start with unilateral component separation and reassess.
 - If still there is too much tension after unilateral component separation, perform bilateral component separation.

Positioning

- Supine with arms abducted 90 degrees and all pressure points padded

Approaches

- Multiple approaches are possible for component separation.
 - Anterior component separation through the hernia defect itself:
 - Open
 - Minimally invasive
 - Anterior component separation through separate lateral incisions: Endoscopic
 - Posterior component separation: Transversus abdominis release (TAR)

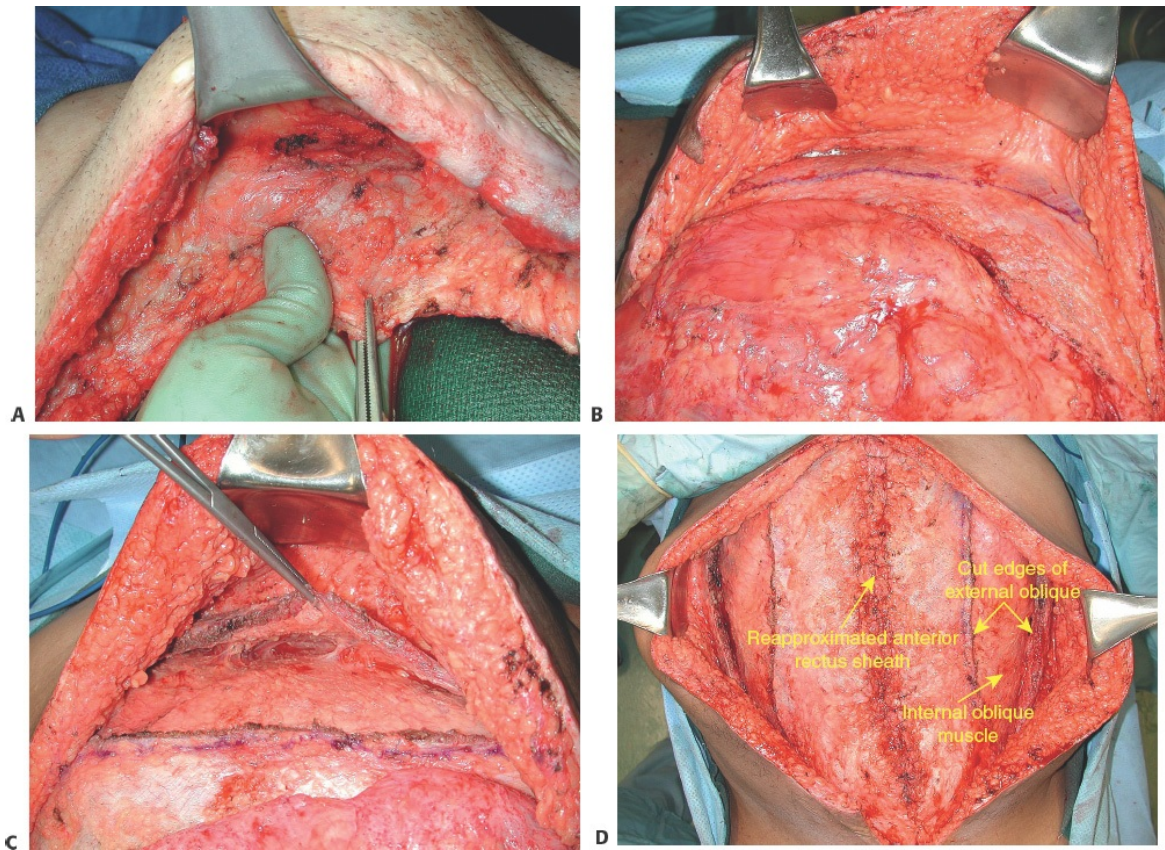
TECHNIQUES

■ Open Anterior Component Separation

- Identify the medial rectus reflection on each side.
- Using Bovie electrocautery, dissect from medial to lateral just above the

anterior rectus sheath along the anterior rectus fascia. Multiple vascular perforators may be encountered depending on the extent of the dissection.

- In the classic open anterior component separation, these perforators are sacrificed and wide skin flaps are developed.
- In more modern perforator-sparing anterior component separation approaches, they are identified and preserved or remain undissected by limited undermining and preservation of composite tissue to decrease complication rates.
- Identify the semilunar line either by palpating the lateral rectus complex margin between your fingers (intraperitoneal) and thumb (extraperitoneal) or by displacing the rectus muscle laterally.
 - This latter maneuver, described by the senior author as the “tube of toothpaste maneuver” (**TECH FIG 1A**), accentuates the indentation of the semilunar line, making it more visible.⁴
- Once the semilunar line is fully exposed, make an incision in the external oblique aponeurosis 2 cm lateral to the semilunar line (**TECH FIG 1B**).
- Enter the plane between the external oblique and internal oblique muscles. This plane is identified by the presence of an avascular layer between the two muscles.



TECH FIG 1 • A. “Tube of toothpaste” maneuver: the rectus complex is displaced laterally in order to accentuate the linea semilunaris. **B.** Marking of the external oblique aponeurotomy in classic “Ramirez-style” open anterior component separation. **C.** Elevation of the external oblique muscle off the underlying internal oblique muscle in an areolar, avascular plane, up to the midaxillary line in classic “Ramirez-style” open anterior component separation. **D.** Closure of the anterior rectus sheath after bilateral classic “Ramirez-style” open anterior component separation. Note the degree of medial advancement obtained.

- Using a blunt dissection instrument (such as a plastic Yankauer suction), bluntly dissect the plane superiorly and inferiorly. Then use Bovie

electrocautery to continue the external oblique aponeurotomy from the iliac crest inferiorly to 6 cm above the costal margin superiorly.

- Superiorly, the aponeurosis is more muscular, and care must be taken to obtain adequate hemostasis as the muscle is incised.
- Apply two Allis clamps to the medial edge of the cut external oblique muscle, and lift it off the underlying internal oblique muscle.
- Place a wide malleable on the internal oblique to push it posteriorly, and use Bovie electrocautery or a spreader-dissector to dissect the plane between the external and internal oblique muscles from medial to lateral (**TECH FIG 1C**).
- This plane should be dissected laterally until sufficient release is performed, varying between the anterior axillary line and posterior axillary line, if needed.
- Near the posterior axillary line, the vascular pedicle to the external oblique muscle will be encountered along its undersurface and should be preserved.
- This technique allows advancement of 5, 10, and 3 cm in the epigastric, waistline, and suprapubic areas, respectively, on each side (**TECH FIG 1D**).⁵
- If needed, the retrorectus space can be entered by incising along the medial rectus reflection, identifying the rectus muscle, and keeping the anterior rectus sheath and muscle together as a complex, as well as dissecting the space between the muscle and the posterior sheath.
- Segmental neurovascular bundles (which enter laterally) should be visualized and preserved.
- This maneuver theoretically adds 2 cm to the amount of possible advancement in addition to the numbers listed above.⁵
- After hernia repair is complete by primarily reapproximating the musculofascia, a closed suction drain should be placed into the space developed between the external and internal oblique muscles.
- Tension-free closure should be performed in layers with absorbable sutures:
 - Three-point sutures incorporating each side of Scarpa fascia and the underlying closed anterior rectus fascia
 - Deep dermal sutures
 - Running subcuticular suture
- Open anterior component separation requires widely undermined skin flaps, which can lead to seroma formation. The risk of seroma can be decreased by:
 - Closed suction drain placement in the midline, as well as at the external

oblique aponeurotomy site

- Progressive tension sutures between the underside of Scarpa fascia and the anterior rectus sheath
- Spraying fibrin glue

■ Minimally Invasive Anterior Component Separation⁶ (Video 1)



Video p5-c007

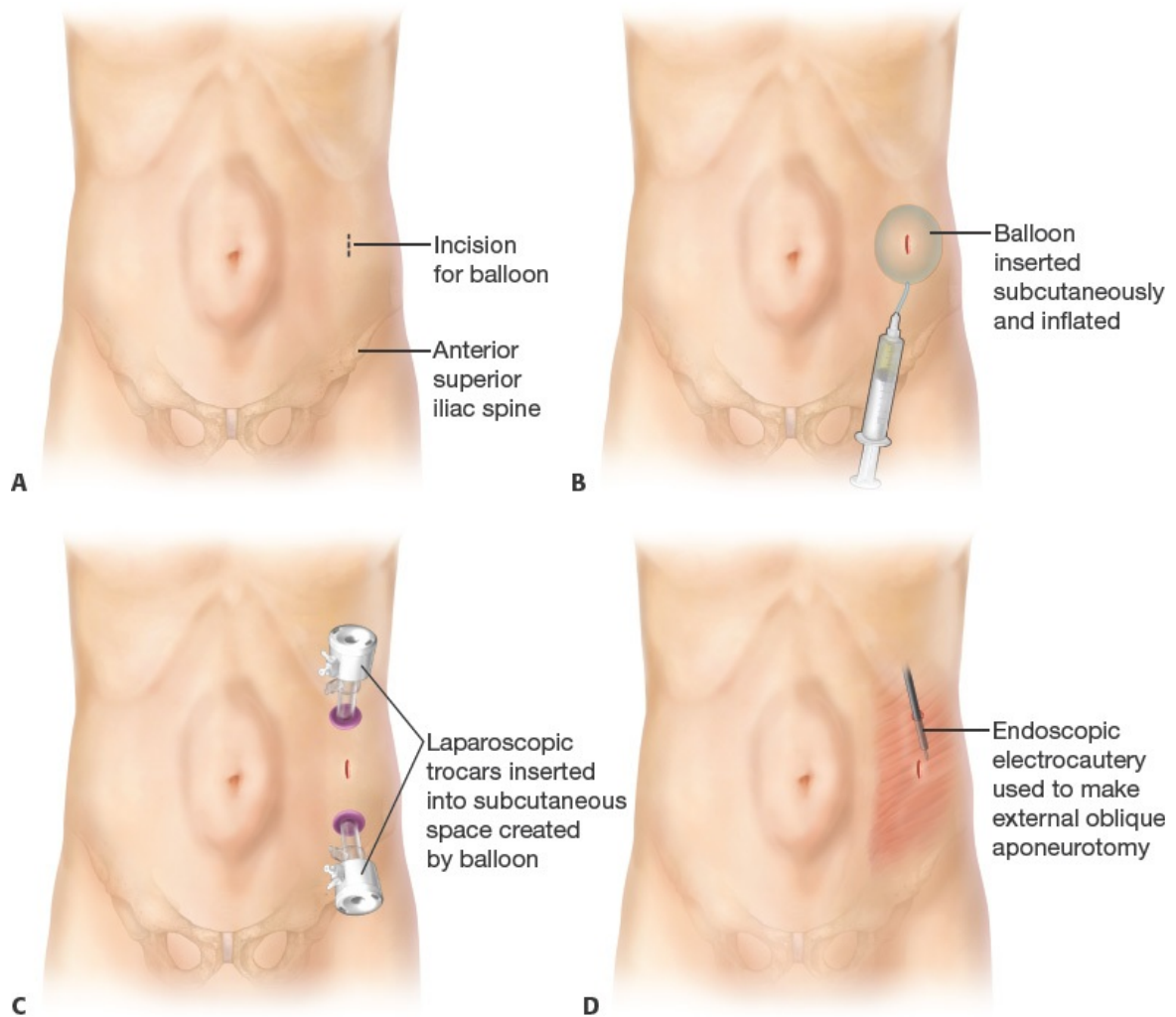
- Identify the rectus complex on each side.
- Using Bovie electrocautery, create a 5-cm-wide tunnel from medial to lateral just superficial to the anterior rectus sheath, located about 4 to 5 cm inferior to the costal margin.
 - This tunnel is meant to spare most vascular perforators to the abdominal wall, especially the periumbilical perforators, by preserving composite tissue.
- Continue medial to lateral dissection within the subcutaneous tunnel until 2 cm lateral to the semilunar line.
 - The semilunar line can be identified using the same “tube of toothpaste” techniques described above⁴ (see **TECH FIG 1A**).
- Once the semilunar line is identified, make a limited incision in the external oblique aponeurosis 2 cm lateral to the semilunar line.
- Enter the plane between the external oblique and internal oblique muscles.

This plane is identified by the presence of a fatty avascular layer.

- Using a blunt dissection instrument (such as a plastic Yankauer suction), bluntly dissect the plane superiorly and inferiorly.
- Now that the trajectory of the anticipated external oblique aponeurotomy is known by transposing the plastic Yankauer suction tip anteriorly, dissect a precise, narrow vertical subcutaneous tunnel overlying the planned location of the external oblique aponeurotomy (2 cm lateral to the semilunar line).
 - This is made with a combination of a narrow Deaver retractor, Bovie electrocautery, and spreader-dissector.
- Then use Bovie electrocautery to continue the external oblique aponeurotomy under direct visualization from the iliac crest inferiorly to 6 cm above the costal margin superiorly.
 - Superiorly, the aponeurosis is more muscular, and care must be taken to obtain adequate hemostasis as the muscle is cut.
- Apply two Allis clamps to the medial edge of the cut external oblique muscle, and lift it off the underlying internal oblique muscle.
- Place a wide malleable on the internal oblique to push it posterior, and use Bovie electrocautery or a spreader-dissector to dissect the plane between the external and internal oblique muscles from medial to lateral.
 - This plane should be dissected laterally, as needed, to anywhere between the anterior and posterior axillary lines.
 - Near the posterior axillary line, the vascular pedicle to the external oblique muscle will be encountered along its undersurface and should be preserved.
- If needed, the retrorectus space can be entered by incising along the medial rectus reflection, identifying the rectus muscle, and keeping the anterior rectus sheath and muscle together as a complex, dissecting the space between the muscle and the posterior sheath.
 - Segmental neurovascular bundles (which enter laterally) should be visualized and preserved.
 - This maneuver theoretically adds 2 cm to the amount of possible advancement in addition to the numbers listed above.
- After hernia repair is complete by primarily reapproximating the musculofascia, a closed suction drain should be placed into the space developed between the external and internal obliques.

■ Endoscopic Anterior Component Separation Through a Separate Incision⁷

- Make a 1-cm vertical incision 5 cm medial to the anterior superior iliac spine, and dissect down to the anterior rectus sheath (**TECH FIG 2A**).
- Create a vertical subcutaneous tunnel over the midaxillary line, using the Spacemaker balloon (Snowden Pencer, Franklin Lakes, NJ) (**TECH FIG 2B**).
- Use the port to insert a 10-mm, 30-degree, angled laparoscope (**TECH FIG 2C**).
- Under direct endoscopic vision, make a 0.5-cm incision 2 cm below the costal margin and another 0.5-cm incision 3 cm superomedial to the original incision.
- Use the additional ports to insert laparoscopic cautery and forceps.
 - Retract the external oblique muscle laterally while performing an external oblique aponeurotomy 1 to 2 cm lateral to the semilunar line.
 - Then dissect in the plane just deep to the external oblique muscle from medial to lateral (**TECH FIG 2D**).
- Modifications of this technique have also been described, with the use of laparoscopic instruments.⁸



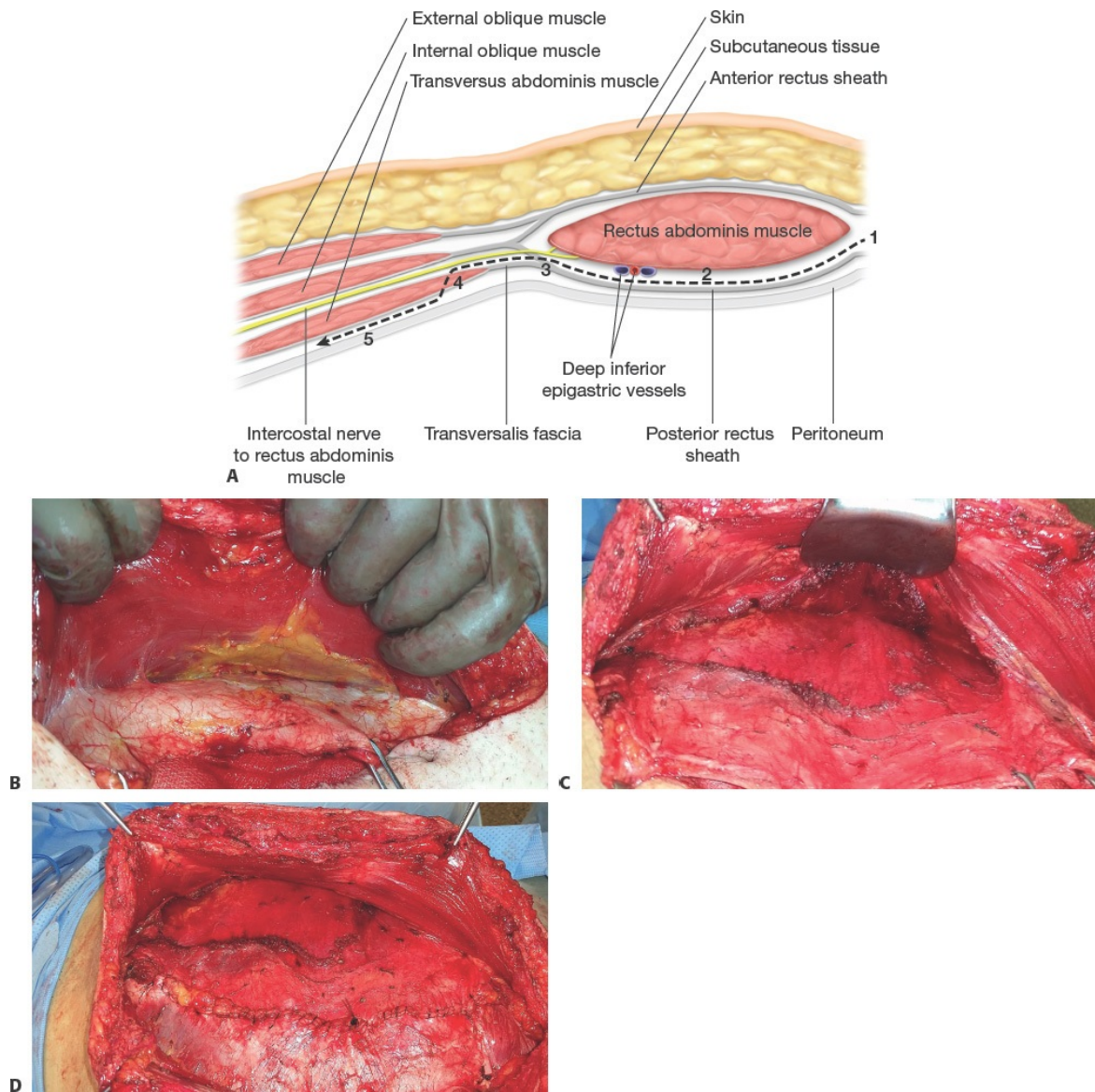
TECH FIG 2 • Endoscopic anterior component separation, as described by Lowe et al.⁷

■ Transversus Abdominis Release^{9,10}

- Identify the medial edge of the rectus complex on each side.
- Use Bovie electrocautery to incise the medial rectus reflection to enter the retrorectus space (**TECH FIG 3A**).
 - Note any small pre-existing rents in the medial aspect of the posterior rectus sheath through which the fibers of the rectus muscle are visible. If present, these constitute an ideal entry point into the retrorectus space.
- Apply a Kocher or Babcock clamp to the anterior rectus sheath/rectus muscle complex and retract it anteriorly and laterally while retracting the

posterior rectus sheath posteriorly and medially.

- Using a combination of blunt dissection (Kittner) and Bovie electrocautery, or with a spreader-dissector, dissect on top of the posterior rectus sheath from medial to lateral, developing the space by elevating the rectus muscle and underlying fat.
- The deep inferior epigastric vessels must be protected during this dissection.
- The retrorectus fat must be elevated with the muscle, leaving behind the shiny white posterior rectus sheath. This facilitates protection of the deep inferior epigastric vessels.
- Continue this dissection laterally until the semilunar line is encountered. Segmental intercostal nerves to the rectus muscle will be visible and should be preserved. Blunt dissection can be performed around the nerves.



TECH FIG 3 • A. Transverse abdominis release steps: (1) enter retrorectus space. (2) Elevate rectus abdominis muscle and fat off the posterior rectus sheath. (3) Incise posterior leaflet of internal oblique aponeurosis medial to the intercostal nerves. (4) Transect transversus abdominis muscle. (5) Dissect extraperitoneal plane deep to transversus abdominis muscle. **B.** Dissection plane in posterior component separation. **C.** Transection of transversus abdominis muscle fibers in transversus abdominis release (TAR)

or “posterior component separation.” **D.** Extended retromuscular plane after TAR. Note the degree of medial advancement obtained.

- Dissect this retrorectus plane superiorly up to the costal margin (or even posterior to it) and inferiorly to the pubic bone.
 - Care must be taken inferior to the arcuate line, as the posterior rectus sheath consists of only the transversalis fascia at this point and is very thin.
- Starting as superior as possible, and 0.5 cm medial to the intercostal nerves to the rectus muscle, incise the posterior lamella of the internal oblique aponeurosis. This will demonstrate the transverse muscular fibers of the transversus abdominis muscle (**TECH FIG 3B**).
- Using a right angle clamp, spread the fibers of the transversus abdominis muscle to separate them from the underlying fascia.
 - Then, using Bovie electrocautery, incise the transversus abdominis muscle. Make sure the transversalis fascia and peritoneum are not injured. A saline-moistened bowel towel protector is also helpful.
- Continue this dissection from superior to inferior until the full length of the transversus abdominis muscle is incised.
- Apply two Allis clamps to the cut edge of the transversus abdominis muscle and enter the underlying avascular plane. This plane can be dissected from medial to lateral using a combination of blunt dissection (Kittner) and cautery (**TECH FIG 3C**).
 - The dissection can be taken superior to the dome of the diaphragm, inferiorly to the pubic bone and Cooper ligaments, and laterally to the psoas muscles.
- The posterior component separation allows advancement of 4 to 8 cm on each side (**TECH FIG 3D**).⁹

PEARLS AND PITFALLS

Techniques

- Anterior component separation is only complete after the external oblique muscle has been completely elevated off the underlying internal oblique muscle laterally to the level of the anterior axillary,

midaxillary, or posterior axillary line, depending on the patient. External oblique aponeurotomy alone does not constitute component separation.

- Minimally invasive techniques for anterior component separation have been proven to have lower rates of wound healing problems compared to techniques with wide undermining.
- When dissecting the retrorectus space, the fatty layer should be elevated with the rectus muscle, leaving behind the white posterior rectus sheath. This is very important to protect the deep inferior epigastric vessels from iatrogenic injury.
- When performing a posterior component separation/TAR, start as superiorly as possible (where the transversus abdominis has the most muscle fibers and is easier to identify) and proceed inferiorly.

Visualization

- When performing minimally invasive component separation, adequate visualization can only be obtained if the surgeons wear a headlight or use a lighted retractor.

Outcomes

- Even in cases in which fascial reapproximation is not possible despite component separation, and where a bridged mesh repair is therefore necessary, the defect size should be reduced using component separation, as this has been shown to reduce recurrence rates.¹¹
- Mesh decreases recurrence rates in all cases and should be used in defects larger than 4 cm.

POSTOPERATIVE CARE

- DVT prophylaxis: Patients should ambulate the evening of surgery and then at least 5 times daily thereafter.²
- Pulmonary toilet: Patients should use incentive spirometry 10 times every hour while awake.²
- Analgesia: The use of neuraxial blocks, intraoperative local anesthetic infiltration in the transversus abdominis plane, and postoperative use of nonopioid analgesics (gabapentin, celecoxib, ibuprofen, acetaminophen) reduce narcotic requirements, which improves mental status and pulmonary function and accelerates return of bowel function.

OUTCOMES

- Minimally invasive techniques of component separation have lower rates of wound healing problems than techniques with wide undermining.
- Ghali et al. compared minimally invasive technique to traditional component

separation and found lower rates of skin dehiscence (11% vs 28%), seroma (2% vs 6%), abdominal bulge (4% vs 14%), and hernia recurrence (4% vs 8%).¹²

- Saulis et al. compared minimally invasive technique to traditional component separation and found lower rates of wound necrosis/infection (2% vs 20%).¹³
- Lowe et al. compared minimally invasive technique to traditional component separation and found lower rates of wound infection (0% vs 40%) and dehiscence (0% vs 43%).⁷
- In cases in which fascia cannot be reapproximated and a bridged mesh repair is planned, component separation should still be performed to reduce the defect size.¹¹

COMPLICATIONS

- Surgical complications
 - Surgical site occurrences
 - Cellulitis
 - Abscess
 - Hematoma
 - Seroma
 - Dehiscence/necrosis
 - Fistula
 - Hernia recurrence
 - Bulge
 - Abdominal compartment syndrome
 - Suspect is intraoperative peak airway pressure increases by 12 mm Hg or more above baseline⁶ or if intraoperative plateau pressure increases by 6 cm H₂O (4.4 mm Hg) or more.¹⁴
- Medical complications
 - Pulmonary (atelectasis, pneumonia, reintubation)
 - Urologic(urinary tract infection)

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8 Ventral Hernia: Component Separation Technique

CHAPTER

Mark W. Clemens and Charles E. Butler

DEFINITION

- The component separation technique is a type of rectus abdominis muscle advancement flap that reconstructs ventral hernia and large abdominal wall defects.
- Component separation is a fascial release of the external oblique fascia with creation of musculofascial advancement flaps.
- The general indications for performing a component separation of the abdominal wall include a deficiency of the abdominal wall fascia, which would require a bridged repair without fascial release.
- Ramirez and colleagues' description of the surgical technique of component separation moves the rectus musculofascia medially, to close midline defect by releasing the external oblique aponeuroses and posterior rectus sheath bilaterally.¹
- Myofascial advancement techniques, or component separation, takes advantage of the laminar nature of the abdominal wall and the ability to release one muscular or fascial layer to enable medial advancement of another.

ANATOMY

- The lateral abdominal wall musculature is composed of three layers, with the fascicles of each muscle directed obliquely at different angles to create a strong envelope for the abdominal contents.
- Each of the muscles forms an aponeurosis that inserts into the linea alba, a midline structure joining the two sides of the abdominal wall.
- The external oblique muscle is the most superficial muscle of the lateral abdominal wall.

- The deepest muscular layer of the abdominal wall is the transversus abdominis muscle with its fibers coursing horizontally. These three lateral muscles give rise to aponeurotic layers lateral to the rectus abdominis muscle, which contribute to the anterior and posterior layers of the rectus sheath.
- The transversus abdominis muscle inserts into the transversus abdominis aponeurosis to form the posterior rectus sheath and continues as a muscular component laterally in the upper abdomen. This feature is important when considering the technical aspects of a posterior component separation.
- At the midline, the two anterior rectus sheaths form the tendinous linea alba. On either side of the linea alba is the rectus abdominis muscle, the fibers of which course vertically and run the length of the anterior abdominal wall.
- The arcuate line, located 3 to 6 cm below the umbilicus, delineates the point below which the posterior rectus sheath is absent and is composed of the transversalis fascia and peritoneum.
- The abdominal wall receives the majority of its innervation from the 7th to 12th intercostal nerves and the first and second lumbar nerves.
- The lateral abdominal muscles receive their blood supply from the lower three to four intercostal arteries, the deep circumflex iliac artery, and the lumbar arteries. The rectus abdominis muscles are perfused by the superior epigastric artery (a terminal branch of the internal mammary artery), the inferior epigastric artery (a branch of the external iliac artery), and the lower intercostal arteries.

PATHOGENESIS

- Indications for abdominal wall reconstruction include tumor ablation, congenital anomalies, and trauma.
- Abdominal defects and hernias may result from genetically impaired collagen formation, deposition, organization with sequelae from injury, failed laparotomy closures, or failed hernia repairs.
- Risk factors for the development of hernias included tobacco use and a strong family history of hernia, which suggests a genetic predisposition.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most common presentation to reconstructive surgeons is an incisional hernia as sequelae to a previous laparotomy.
- There are three general indications to repair an incisional hernia: the hernia is symptomatic, causing pain or alterations in the bowel habits; the hernia results

in a significant protrusion that affects the patient's quality of life; and the hernia poses a significant risk of bowel obstruction (such as a large hernia with a narrow neck).

- Acquired hernias typically occur after surgical incisions and thus are commonly referred to as incisional hernias.
- Epigastric hernias occur from the xiphoid process to the umbilicus, umbilical hernias occur at the umbilicus, and hypogastric hernias occur below the umbilicus in the midline.
- Although not a true hernia, diastasis recti can present clinically as a bulge in the midline. In this condition, the linea alba is stretched, resulting in bulging at the medial margins of the rectus abdominis muscles. There is no fascial ring or true hernia sac. Unless significantly symptomatic, diastasis recti does not need to be corrected surgically.
- Previous rectus abdominis muscle flap harvest does not preclude the future use of component separation techniques.²

IMAGING

- Preoperative computed tomography to examine the defect characteristics and abdominal wall anatomy and vascularity is helpful for surgical planning.
- Computed tomography (CT) allows for visualization of intra-abdominal organs, and the abdominal wall, three-dimensional data sets, and multiplanar reformation capabilities.
- CT scans may assist in detecting fluid collections, bowel obstruction, incarceration, strangulation, and traumatic wall hernias.
- Magnetic resonance (MR) imaging also permits the detection of soft tissue defects and abdominal wall hernias though this modality does not usually offer further sensitivity and therefore may be cost-prohibitive.

SURGICAL MANAGEMENT

Preoperative Planning

- Physical examination should be performed to assess the patient's general condition, the abdominal wall integrity, and the extent and location of any abdominal wall abnormalities.
- The presence of scars that compromise blood supply could become an obstacle to raising reliable tissue flaps.
- Routine laboratory tests and a nutritional workup are advised.

- Patients should be marked in the preoperative holding area, and it is beneficial to evaluate patients in a recumbent and supine position for complete evaluation of abdominal wall defects.
- Markings may delineate anatomical boundaries such as the pelvis, midline, and costal margin as well as the fascial extent of any intra-abdominal defects.
- Bowel preps may be beneficial in patients with anticipated violation of the gastrointestinal tract.
- Intravenous antibiotics are initiated in the holding area.

Positioning

- Patients are placed supine on the operative table, sedated, and intubated.
- The abdomen is widely draped and prepped to expose the patient's flanks and from the pelvis to the midsternal area.
- Patients should receive sequential compression devices and or compression hoses for deep vein thrombosis prophylaxis.
- Patients requiring greater exposure should have room temperatures maintained above 75°F to minimize postoperative infections.

Approach

- All approaches to abdominal wall closure should be aimed at re-establishment of the abdominal domain integrity with complete fascial coaptation.
- All attempts should be made to avoid a bridged mesh repair because there is a clear trend toward higher recurrence rates compared with when the fascia can be reapproximated over a mesh repair.
- Component separation release can be done by open or minimally invasive component separation. A minimally invasive component separation can be performed in various ways, but all of the techniques (to a certain degree) maintain the blood supply to the skin from the underlying rectus abdominis muscles.

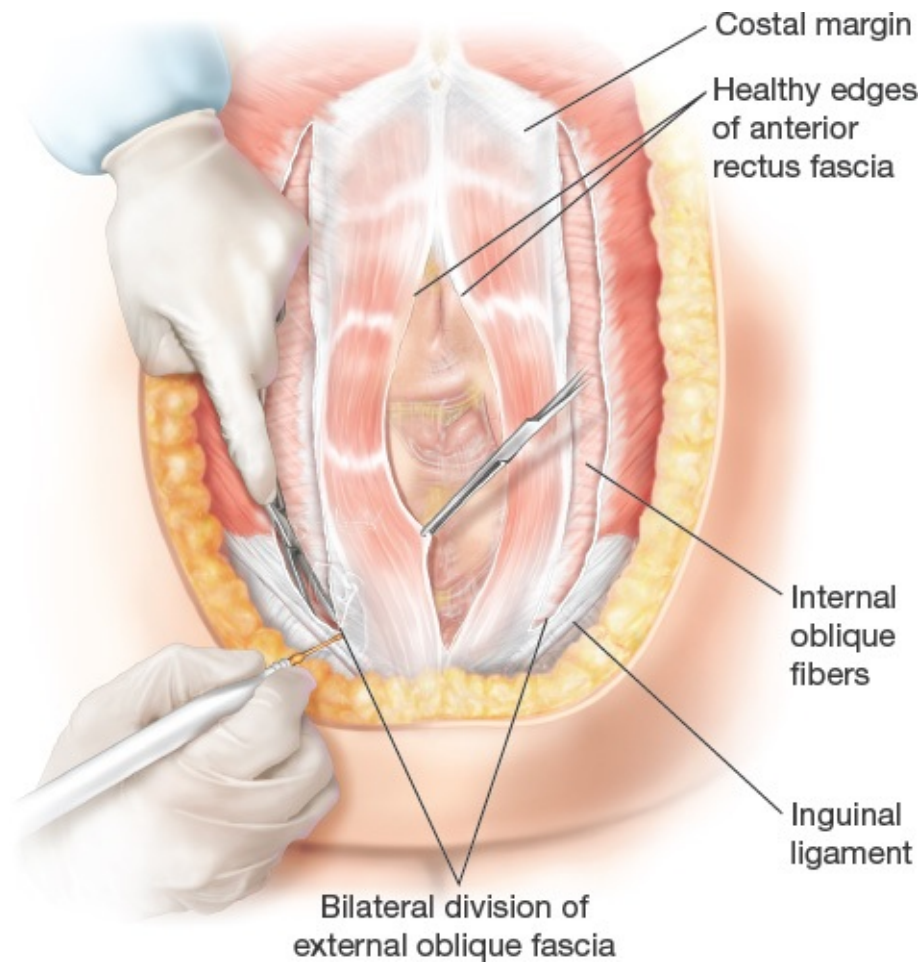
TECHNIQUES

■ Open Component Separation

- An open component separation is performed by raising large subcutaneous

flaps to expose the external oblique fascia³ (**TECH FIG 1**).

- The cutaneous perforators emerging from the anterior rectus sheath are ligated and divided to facilitate exposure of the linea semilunaris in its entirety. These flaps are carried laterally past the linea semilunaris.
- An anatomically precise external oblique aponeurotomy is made 1 to 2 cm lateral to the linea semilunaris on the lateral aspect of the external oblique aponeurosis from several centimeters above the costal margin to the pubis. It is important to confirm that the incision is not carried through the linea semilunaris, as this would result in a full-thickness defect of the lateral abdominal wall, which is challenging to repair.
- The external oblique aponeurosis is then bluntly separated in the avascular plane away from the internal oblique aponeurosis to the midaxillary line, allowing the internal oblique and transversus abdominis muscles with the rectus abdominis muscle or fascia to advance medially as a unit.
- These techniques, when performed bilaterally, can yield up to 20 cm of mobilization in the midabdomen.
- Once the mesh inset and fascial closure are performed, the subcutaneous skin flaps are advanced and closed at the midline.



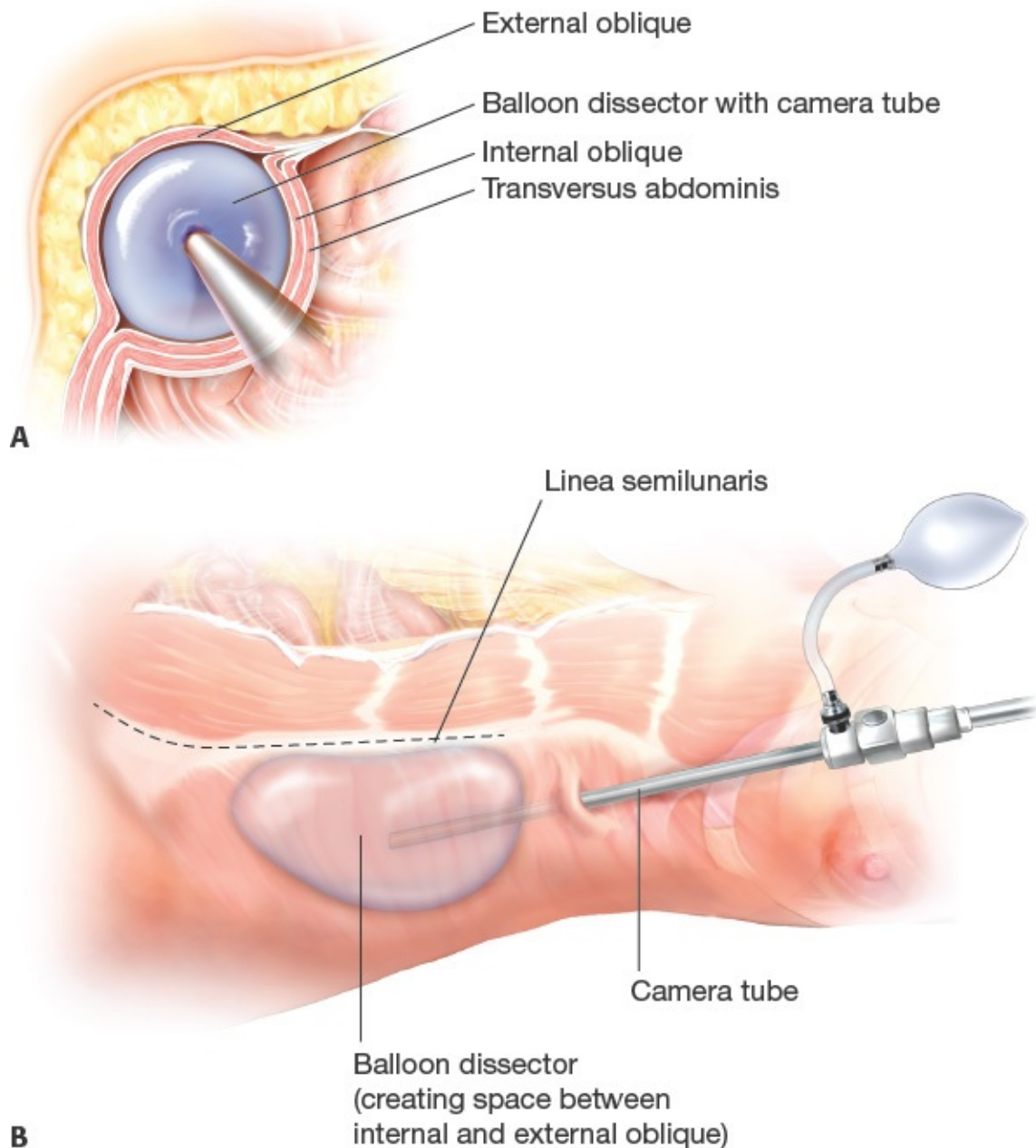
TECH FIG 1 • Open component separation. Subcutaneous flaps are elevated off the anterior rectus sheath to expose the external oblique aponeurosis. The external oblique aponeurosis is released from the inguinal ligament inferiorly to above the costal margin superiorly. This allows exposure of the internal oblique muscle fibers once the external aponeurosis is incised.

- To reduce subcutaneous dead space, interrupted quilting sutures should be placed between the Scarpa fascia and musculofascial repair.
- This technique also decreases shear stress, which is thought to contribute to postoperative seroma formation, and decreases the total drain output, allowing the surgeon to place fewer drains and leave them in for a shorter period.

- After paramedian skin perfusion is critically assessed, a vertical panniculectomy may be performed so that the skin is reapproximated in the midline without redundancy.

■ Laparoscopic Component Separation

- Laparoscopically, component separation is performed through a 1-cm incision below the tip of the 11th rib overlying the external oblique muscle.^{4,5}
- The external oblique muscle is split in the direction of its fibers, and a standard bilateral inguinal hernia balloon dissector is placed between the external and internal oblique muscles and directed toward the pubis (**TECH FIG 2**).⁶
- Three laparoscopic trocars are placed in the space created, and the dissection is carried from the pubis to several centimeters above the costal margin.
- The linea semilunaris is carefully identified, and the external oblique aponeurosis is incised from beneath the external oblique muscle at least 2 cm lateral to the linea semilunaris.
- The muscle is released from the pubis to several centimeters above the costal margin.
- This procedure may be performed bilaterally depending on the width of the defect and the amount of advancement required.



TECH FIG 2 • Laparoscopic component separation. **A.** Access to the external oblique aponeurosis is achieved through a small incision at the costal margin through which a balloon dissector is placed. The external oblique aponeurosis is then divided from the pubis to above the costal margin. **B.** This minimally invasive approach preserves the attachments of the subcutaneous tissue (including myocutaneous

perforators) to the anterior rectus sheath throughout its course.

■ Periumbilical Perforator-Sparing Technique

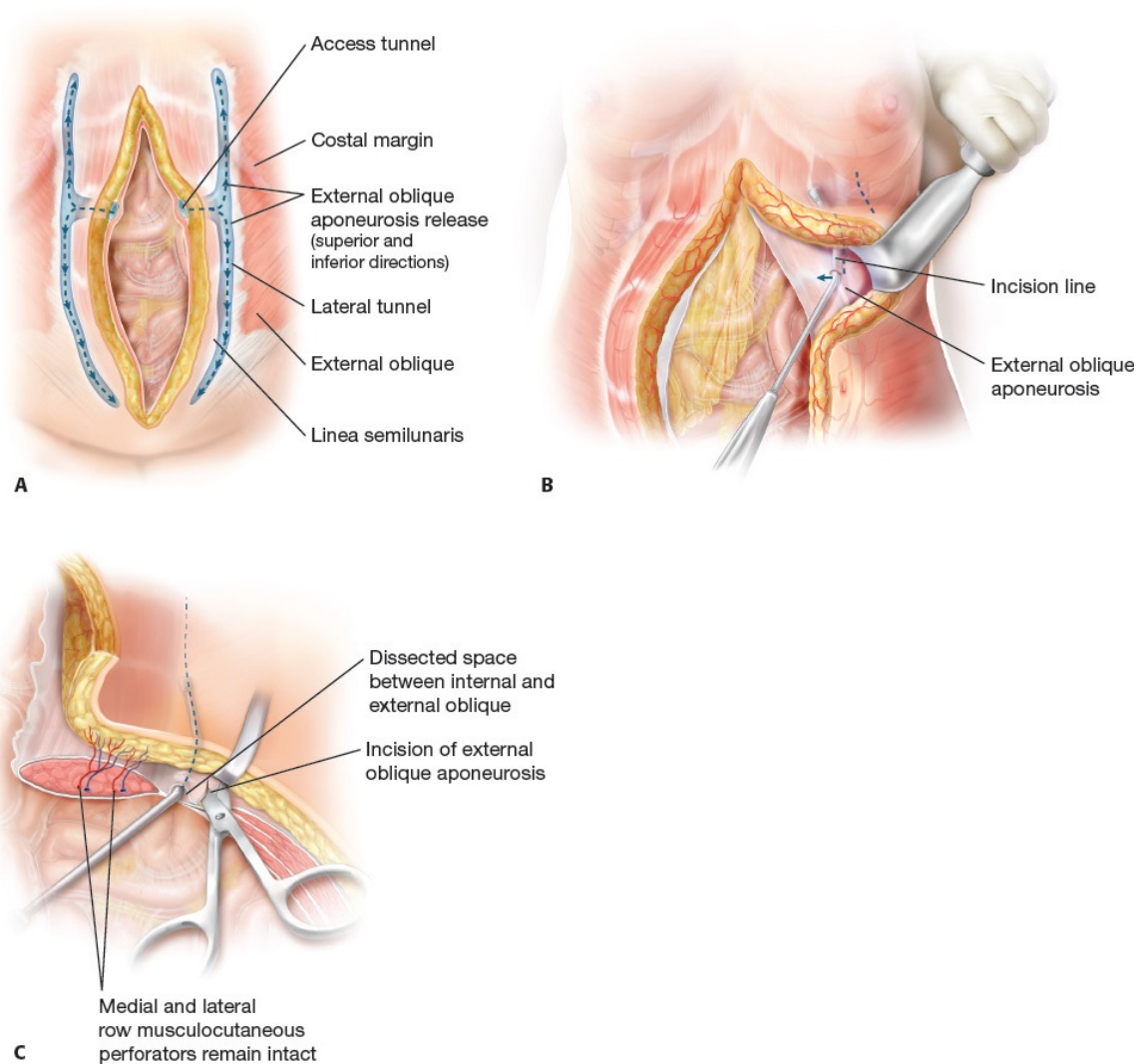
- A periumbilical perforator-sparing technique of component separation may be performed to preserve the blood supply to the anterior abdominal wall skin near the midline and is based primarily on perforator vessels from the deep inferior epigastric vessels.
- Cadaver dissections and radiographic studies confirmed that the majority of these vessels are located within 3 cm of the umbilicus. With preservation of these vessels, ischemic complications involving the subcutaneous flaps are significantly reduced.
- To avoid injury to the periumbilical perforator vessels, a line is marked no less than 3 cm cephalad and 3 cm caudal to the umbilicus.
- The periumbilical perforator tunnels are begun at the epigastric and suprapubic regions. Subcutaneous tunnels are created using lighted retractors to identify the external oblique fascia.
- The superior and inferior tunnels are connected using cautery and retractors while maintaining the subcutaneous attachments of the periumbilical region.
- The linea semilunaris is identified by palpation, and the external oblique is incised 2 cm lateral to this junction.
- The aponeurotomy is extended several centimeters above the costal margin and to the pubic tubercle.
- The external oblique muscle is separated from the internal oblique muscle in an avascular plane toward the posterior axillary line for additional advancement to the midline.

■ Minimally Invasive Component Separation

- The MICS technique is designed to avoid division of the musculocutaneous perforators overlying the rectus sheath and thus maintain perfusion to the paramedian skin.⁷⁻⁹
- After lysis of adhesions and identification of the fascial edges, bilateral, 3-cm wide, subcutaneous access tunnels are created over the anterior rectus sheath from the midline to the linea semilunaris at the level of the costal

margin (**TECH FIG 3A**).

- Through these access tunnels, the external oblique aponeurosis is vertically incised 1.5 cm lateral to the linea semilunaris (**TECH FIG 3B**).
- The tip of a metal Yankauer suction handle (Cardinal Health, Dublin, OH), without suction, is inserted through the opening in the avascular plane between the internal and external oblique aponeuroses, separating them at their junction with the rectus sheath.



TECH FIG 3 • Minimally invasive component separation (MICS). **A.** Access to the external oblique aponeurosis is achieved through a small tunnel from the midline to the supraumbilical external oblique

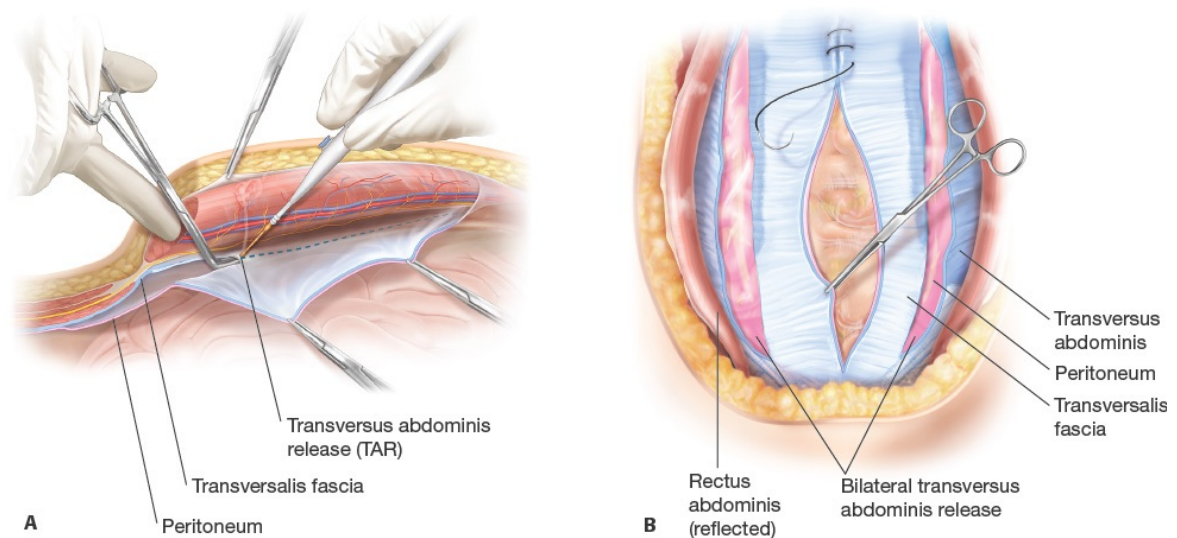
aponeurosis. Vertical tunnels are created dorsal and ventral to the planned release site of the external oblique aponeurosis. Periumbilical perforators and the subcutaneous tissue overlying the anterior rectus sheath are left undisturbed. **B.** The external oblique aponeurosis is then divided from the pubis to above the costal margin. The external oblique aponeurosis in the upper abdomen is released with electrocautery as the muscle is transected at, and superior to, the costal margin. **C.** Scissors are generally used to release the external oblique aponeurosis inferiorly. This MICS approach preserves the attachments of the subcutaneous tissue (including myocutaneous perforators) to the anterior rectus sheath throughout its course.

- The suction tip is advanced inferiorly to the pubis and superiorly to above the costal margin.
- Next, lateral dissection between the internal and external oblique muscles is performed to the midaxillary line (**TECH FIG 3C**).
- Minimal subcutaneous skin flaps are then elevated over the anterior rectus sheath circumferentially to the medial row of rectus abdominis perforator vessels, and a retrorectus or preperitoneal mesh inlay is generally used.
- If a preperitoneal inset is used, the preperitoneal fat is dissected from the posterior sheath circumferentially to allow the mesh to be inlaid directly against the posterior sheath or rectus abdominis muscle (below the arcuate line).
- Mesh is inserted to the semilunar line with no. 1 polypropylene sutures via the horizontal access tunnels and the cranial and caudal aspect of the defect.
- Next, the myofascial edges are advanced and reapproximated over the mesh with sutures placed through the myofascia and mesh.
- Interrupted resorbable 3-0 sutures are placed to affix the posterior sheath to the mesh, thereby obliterating dead space and reducing the potential for fluid collection.

- Closed suction drainage catheters are placed in each component separation donor-site area, in the space between the rectus complex closure and mesh, and in the subcutaneous space.
- The remaining undermined skin flaps are sutured to the myofascia with vertical rows of interrupted resorbable 3-0 quilting sutures to reduce dead space and potential shear between the subcutaneous tissue and myofascia.

■ Posterior Component Separation

- A posterior component separation is based on the retromuscular Rives-Stoppa approach to ventral hernia repair.
- The posterior component separation focuses on transversus abdominis aponeurosis release.
- By incising this myofascial aponeurosis, the surgeon exposes the preperitoneal space. This provides substantial advancement of both the posterior fascial flap and the anterior myofascial compartment.
- The initial release is completed by incising the posterior rectus sheath approximately 1 cm lateral to the linea alba, and the posterior rectus sheath is separated from the overlying rectus muscle (**TECH FIG 4A**).
- The transversus abdominis muscle is incised just medial to the intercostal nerves, and the underlying transversalis fascia and peritoneum are identified (**TECH FIG 4B**). This myofascial release is extended the entire length of the posterior rectus sheath.
- The potential space between the transversus abdominis muscle and the peritoneum is developed as far laterally as necessary, even to the psoas muscle if needed. This plane can be extended superiorly to the costal margin, retrosternally above the xiphoid, and inferiorly into the space of Retzius.
- The posterior sheath is then closed, to completely exclude any mesh from the viscera. An adequately sized piece of mesh is then secured, similar to a standard retromuscular repair but with greater overlap.



TECH FIG 4 • Posterior component separation. A. The initial release is completed by incising the posterior rectus sheath approximately 1 cm lateral to the linea alba, and the posterior rectus sheath is separated from the overlying rectus abdominis muscle. Dissection is carried to the lateral border of the rectus muscle, and the perforating intercostal nerves are identified, marking the linea semilunaris. **B.** Next, the transversus abdominis muscle is incised just medial to the intercostal nerves, and the underlying transversalis fascia and peritoneum are identified. This myofascial release is extended the entire length of the posterior rectus sheath. The potential space between the transversus abdominis muscle and the peritoneum is developed as far laterally as necessary.

PEARLS AND PITFALLS

Abdominal compartment syndrome

- Although every attempt to re-establish the midline is advisable, not all patients can tolerate the intraperitoneal compression required (which can result in intraperitoneal hypertension, pulmonary

	compromise, or abdominal compartment syndrome).
Seroma formation	■ Adequate drainage of the skin flaps should be performed with liberal use of drains and quilting sutures. Resection of a previous hernia sac is important to prevent seroma formation.
Hernia recurrence	■ All means necessary should be employed to avoid a bridged repair as primary fascial coaptation is essential to minimize hernia recurrence.
Mesh explantation	■ Tissue-based bioprosthetic mesh has gained popularity for its lower rates of mesh infection, fistula formation, and mesh explantation than the rates reported with synthetic mesh.
Skin coverage deficiency	■ Pedicled muscle flaps and free flaps are important to assist in soft tissue coverage for large abdominal wall defects.

POSTOPERATIVE CARE

- In general, abdominal wall reconstruction patients have prolonged postoperative healing periods due to the dynamic function and mobility of the abdominal musculature.
- Perioperative management of high-risk patients should include appropriate deep venous thrombosis (DVT) chemoprophylaxis according to the Caprini risk score.
- Sequential compression devices and early ambulation should be utilized with low molecular weight fractionated heparins administered postoperatively.
- Perioperative antibiotics are indicated, and cases with violation of the gastrointestinal tract should be offered broader coverage for anaerobic as well as Gram-negative bacteria.
- For ventral hernia, closed suction drains are used liberally and are kept in place on average 1 to 2 weeks until less than 30 cc/day.
- Abdominal wall reconstruction patients should refrain from strenuous activities and exercises that isolate the abdominal core for at least 6 to 12 weeks.
- Patients may gain comfort from the use of an abdominal binder for 3 months and then with any expected heavy physical activity thereafter.
- Routine follow-up includes a physical examination in an outpatient clinic, often performed weekly for 1 month after discharge, then every 3 months for 1 year, and then annually thereafter.

OUTCOMES

- Estimated incidences of hernia recurrence have a wide range from 2% to 54%, depending on the type of repair (mesh 2% to 36% vs suture repair alone 25% to 54%), patient comorbidities, and surgical technique¹⁰ (**FIGS 1 to 3**).
- The number of prior attempts of hernia repair is predictive of the relative risk of recurrence. In a study of approximately 10 000 patients, 5-year reoperative rate was 23.8% after a primary repair, 35.3% following a secondary repair, and 38.7% after a tertiary repair.
- There are few comparative data to suggest the superiority of one myofascial advancement approach over another, and likely, each has a role in abdominal wall reconstruction. Open component separation often allows tension-free closure of large defects, and recurrence rates as low as 20% have been reported with the use of open component separation and mesh reinforcement in large hernias.

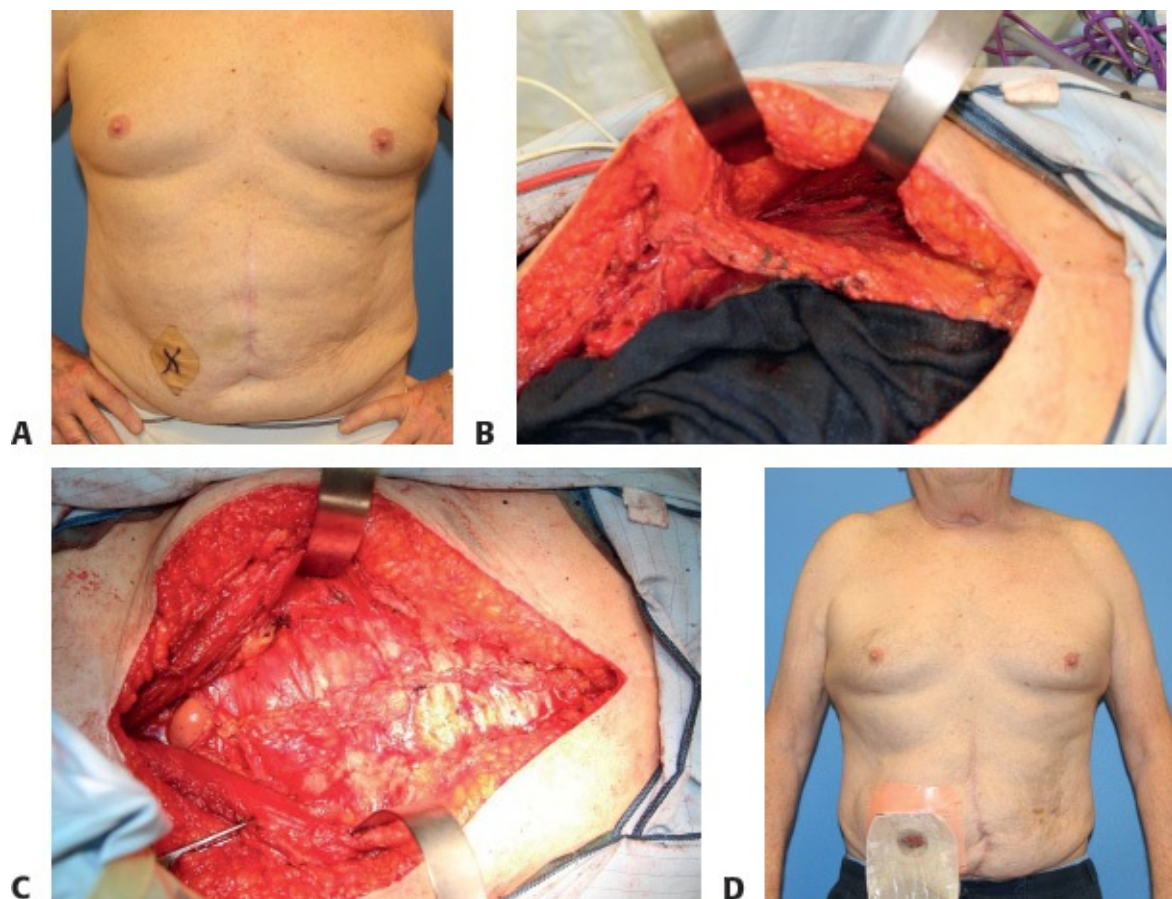


FIG 1 • Abdominal wall reconstruction. **A.** A 67-year-old

diabetic man with a history of bladder cancer resection presented with recurrence invasive into his anterior abdominal wall. Following tumor ablation, he has an intraoperative defect of the abdominal wall 10 × 14 cm in size. **B.** Bilateral minimally invasive anterior component separation was performed (**C**) followed by creation of a retrorectus plane (Rives-Stoppa technique) and closure of the anterior abdominal wall fascia. **D.** Patient 18 months after abdominal wall reconstruction and ileal conduit construction with urostomy.

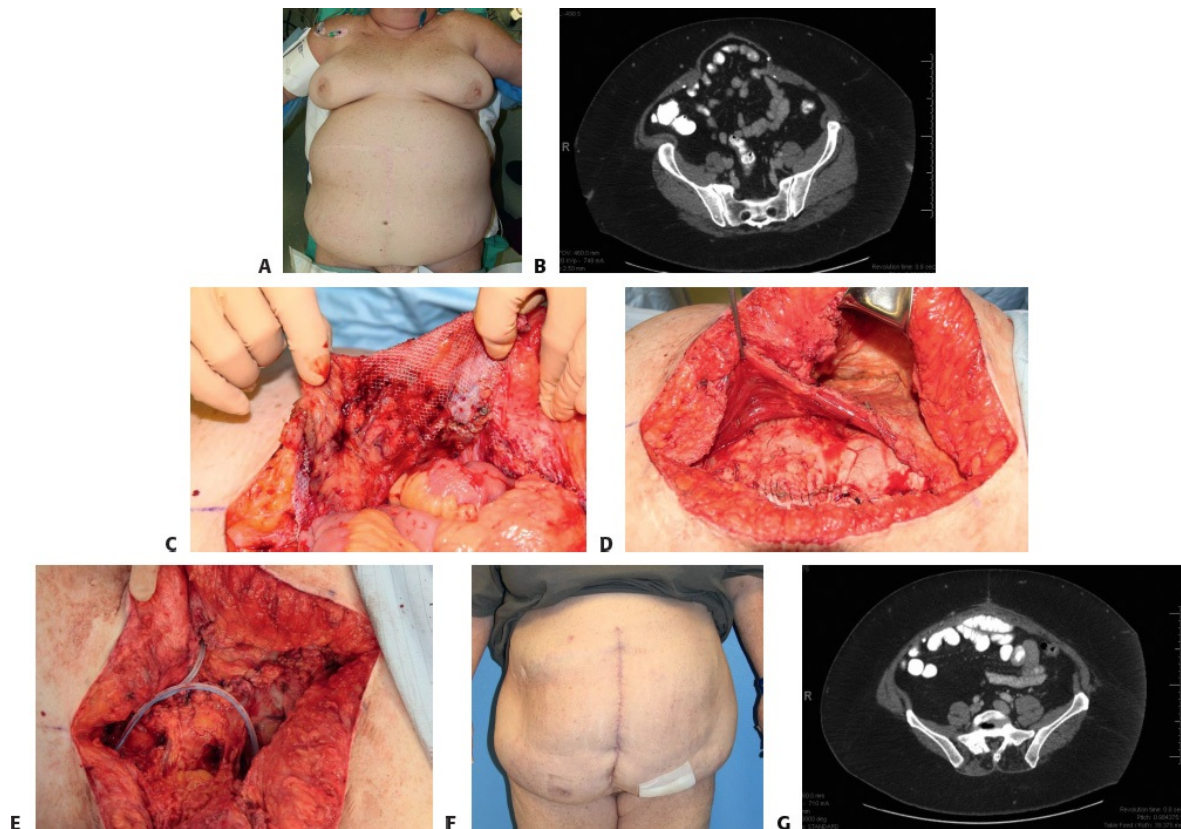
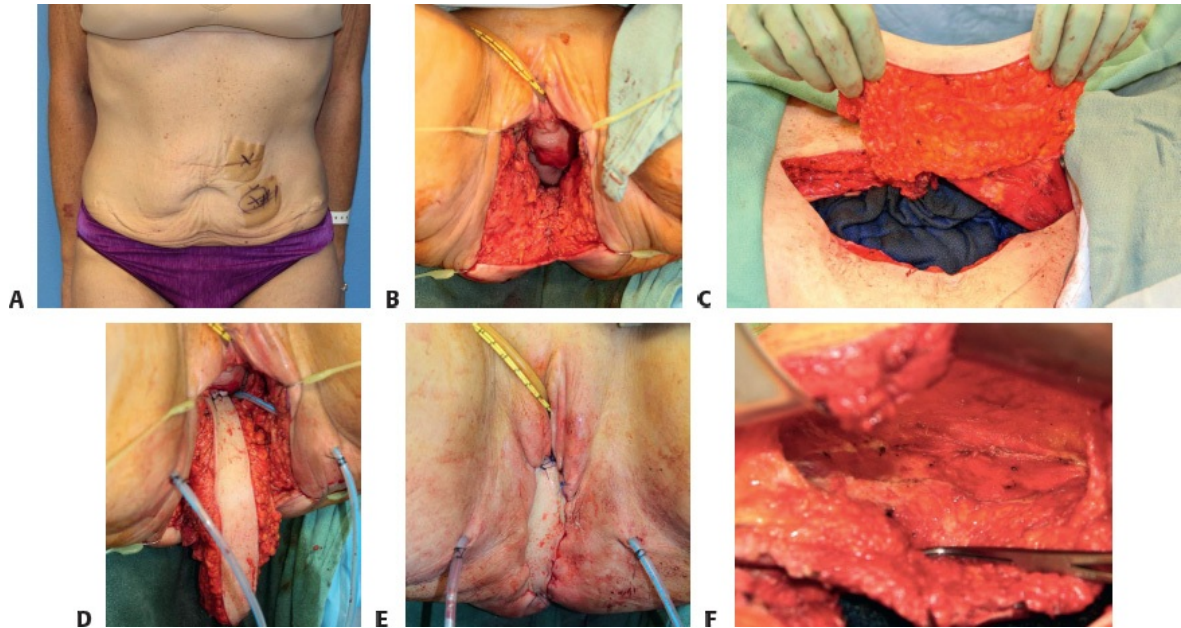


FIG 2 • Hernia repair. **A.** Patient was a 62-year-old woman with a history of colon cancer, morbid obesity with BMI 46, and previous midline hernia repair with mesh reinforcement. **B.** She had a recurrent hernia 12 cm in greatest diameter. **C.** Mesh failure. **D.** Bilateral

minimally invasive component separation was performed, which allowed for complete fascial coaptation **(E)**. **F**. Patient at 1 month postoperatively and by CT scan at 1 year postoperatively **(G)**.



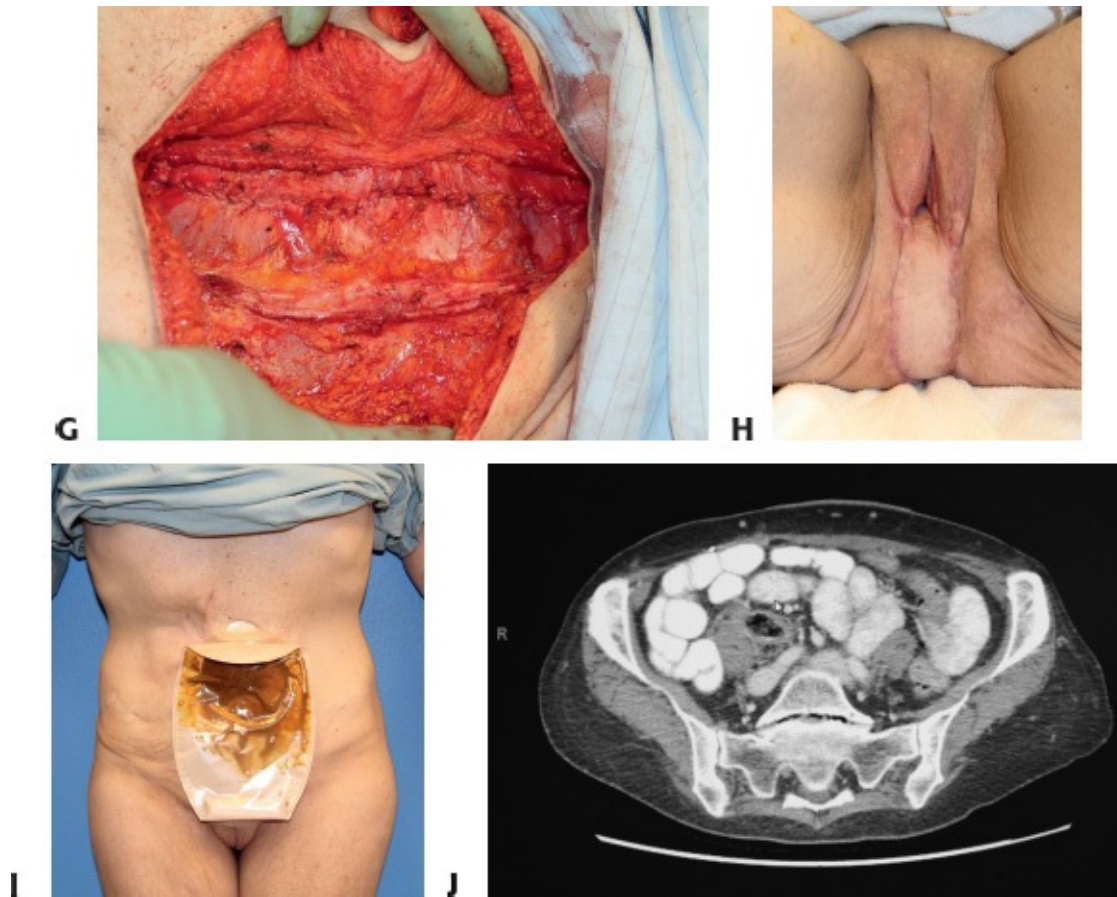


FIG 3 • Pelvic reconstruction and donor-site management. **A.** A 47-year-old woman with invasive cervical cancer required a total pelvic exenteration. **B.** Intraoperative defect. **C.** A pedicled vertical rectus abdominis muscle (VRAM) flap was elevated from the right hemiabdomen and passed through the pelvis (**D**) and inset for reconstruction of the perineum and posterior vaginal wall (**E**). **F,G.** Patient was thin with minimal abdominal wall laxity, and therefore a unilateral component separation was performed to facilitate closure of the VRAM donor site. **H.** This allowed for complete fascial closure. **I.** One year postoperative photo and **J.** CT scan.

■ Comparative data showed laparoscopic component separation to result in a

lower rate of wound morbidity than open component separation. One series reported a significant reduction in wound morbidity with the periumbilical perforator-sparing technique compared with the standard open component separation technique (2% vs 20%; $P < 0.05$).

- A controlled study demonstrated that patients had significantly fewer wound healing complications (32% vs 14%, $P = 0.026$) and skin dehiscence (28% vs 11%, $P = 0.01$) with MICS than with traditional open component separation.

COMPLICATIONS

■ Infection

- In patients with clean-contaminated and contaminated wounds, a prospective multi-institutional study evaluating the role of a porcine ADM to repair abdominal wall defects reported a 34% rate of superficial surgical site infections. In contrast, studies of clean wounds have reported infection rates of 0% to 12%.
- Mesh infections are reported to occur in 0% to 3.6% of laparoscopic ventral hernia repairs and 6% to 10% of open repairs employing mesh.
- The most common organism infecting abdominal wall repair is *Staphylococcus aureus*, seen in up to 81% of cases; this suggests skin flora contamination.
- Gram-negative organisms, such as *Klebsiella* and *Proteus* spp., have been implicated in up to 17% of mesh infections.
- Management of abdominal wall infections is complex and requires patient individualization as well as a knowledge of bacterial susceptibility for a particular hospital.

■ Seroma

- Seroma formation can occur following abdominal wall reconstruction particularly in cases involving large undermined flaps, which create significant dead space.
- If symptomatic, seromas can be aspirated percutaneously or under ultrasound guidance.
- In open ventral hernia repair, drains are often placed in an attempt to obliterate the dead space caused by the hernia and tissue dissection.
- Seroma formation is common after abdominal component separation and muscle flaps of the trunk owing to extensive tissue dissection, and drains may be necessary for up to 4 to 6 weeks.
- Intraoperative techniques, such as quilting sutures, fibrin sealant, and

postoperative abdominal binders, may help to prevent or reduce seroma formation.

■ Enterotomy and enterocutaneous fistulas

- Appropriate management of an enterotomy during a hernia repair is controversial and depends on the segment of intestine injured (small vs large bowel) and amount of spillage.¹¹
- Options include aborting the hernia repair, continuing the hernia repair and repairing the enterotomy with local tissue or bioprosthetic mesh using a primary tissue or bioprosthetic mesh repair, or performing a delayed repair using mesh in 3 to 4 days.
- When there is gross contamination, the use of synthetic mesh is generally contraindicated.
- The treatment of patients with enterocutaneous fistulas (ECFs) is complex and approximately 1/3 of ECFs will close spontaneously with appropriate wound care, nutritional support, and medical therapy.
- Depending on the location of the fistula along the gastrointestinal tract and the volume of output, significant electrolyte disturbances can occur. In particular, proximal high-output fistulas can result in substantial losses of bicarbonate, which must be adequately replaced.
- Diligent protection of the surrounding skin is one of the most important and difficult aspects of ECF management. A dedicated enterostomal nurse is essential to the success of wound management as destruction of local skin can seriously affect eventual reconstructive options.
- In cases in which a fistula is already present, negative pressure wound therapy (NPWT) device can be helpful to isolate a fistula from the surrounding wound and to allow a skin graft to heal.
- In cases of uncontrolled intestinal leakage, a proximal diverting stoma can be lifesaving.
- Nutritional supplementation is one of the most important aspects of reducing deaths related to ECFs. During initial management of an ECF, parenteral nutritional support is preferred. However, once the sepsis is controlled and the patient is stabilized, enteral feedings are initiated.

■ Hernia

- The incidence of incisional hernia is approximately 11% following midline laparotomy.
- Functional problems in hernia patients include poor respiratory effort, loss of abdominal domain, and weak abdominal musculature.

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Abdominal Hernia

9 Reconstruction With Synthetic and Biologic Mesh

CHAPTER

Sergey Y. Turin and Gregory A. Dumanian

DEFINITION

- A hernia is a defect in at least one of the layers of the abdominal wall, permitting intra-abdominal contents such as bowel and fat to protrude past their normal confinement layer of transversalis fascia. This is in contradistinction to a bulge, which is an imbalance between the outward force of the viscera and the containing force of the intact abdominal wall, as seen in denervation injuries or rectus diastasis.
- We will focus on the treatment of incisional hernias in this chapter—hernias due to a defect in the repaired abdominal wall after a prior laparotomy.

ANATOMY

- The key in a hernia defect is the disruption of the continuity of the abdominal wall—depending on the etiology of the hernia and the patient’s surgical history, this may be one or many layers of the abdominal wall. In incisional hernias, this often means a midline defect at the site of the previous midline laparotomy incision (**FIG 1**).
- As shown in **FIG 2**, the abdominal wall lateral to the rectus muscle is intact, and we can clearly see all three layers—the external and internal oblique and the transversus abdominis muscles inserting onto the linea semilunaris. The defect is clearly between the rectus muscles (**FIG 2**).

PATHOGENESIS

- Coughing, the Valsalva maneuver, and contraction of the stomach muscles for postural stability all increase intra-abdominal pressure. This pressure is normally opposed by the abdominal wall, which is a muscular and elastic organ

and can provide inward force to maintain the viscera in their domain.

- When one of the portions of the abdominal wall is unable to oppose the intra-abdominal pressure either due to denervation (as in a bulge) or due to discontinuity of the musculature (as in a hernia), the viscera are forced through that portion by the rest of the competent musculature. The abdominal wall functions uniformly as a pressurized cylinder, whereas sizeable hernias and bulges serve to lower intra-abdominal pressure.
- The abdominal wall is muscular but also elastic. This has great bearing on the choice of reconstructive technique, in that the reconstructed muscular and fascial components must be able to stretch, so they can absorb and dampen the sharp rises in intra-abdominal pressure that come with coughing, sudden exertion, and Valsalva.
- The most successful repairs occur in the most elastic abdomens, whereas a fibrotic, scarred abdominal wall that is unyielding will have more of a tendency for stitches tearing in the postoperative period. A bridging mesh (synthetic or biologic), besides its inherent inability to provide an inward force, is also inelastic and has a compliance mismatch with the intact abdominal wall, leading to a higher rate of dehiscence and suture pull-through, as shown in **FIG 3**.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A full history and physical exam is performed, with a focus on prior abdominal surgeries and the means of closure. Patients are encouraged to obtain all previous abdominal operative reports. The medical history looking for bowel dysfunction and comorbid conditions such as diabetes, cardiac anomalies, and chronic obstructive pulmonary disease is obtained.
- Gestational history is important in order to ascertain if women have had their abdominal walls stretched previously.
- History of weight loss, prior abdominal wall sepsis, or peritoneal dialysis is a factor that will either increase or decrease the elasticity of the abdominal muscles.
- Examine the abdominal wall with the patient both standing and lying down. Attempt to reduce the hernia to assess the degree of bowel adhesions and the compliance of the abdomen.
- Document the scars of previous surgeries. Evaluate rectus diastasis by watching the patient on the descent phase of a sit-up—a maneuver that clearly shows muscle separation in all but the most obese patients.

- Evaluate the skin and subcutaneous tissues for scarring, excess, and wounds because this will need to be addressed for optimal closure.
- Social history is necessary, as return to work issues and help at home after surgery will need to be planned in advance.

IMAGING

- We routinely obtain a CT scan of the abdomen and pelvis using oral contrast to assess the layers of the abdominal wall, any implanted meshes, or biologic materials and measure the size of the defect for all major incisional hernias. If the patient has no kidney issues, we add IV contrast for an optimal study and to obviate the need to explore the abdomen at the time of hernia closure to save dissection time, limit tissue swelling, and avoid possible bowel injury.

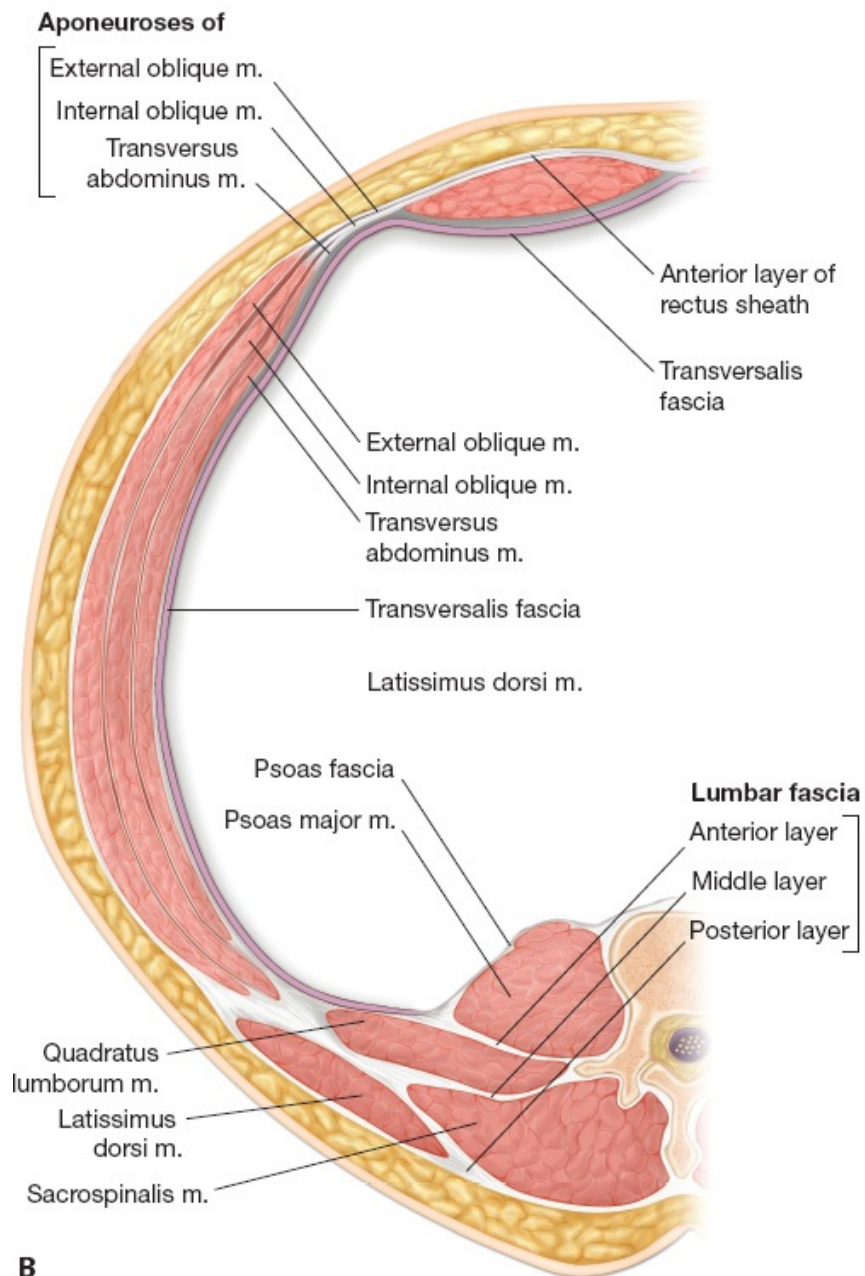
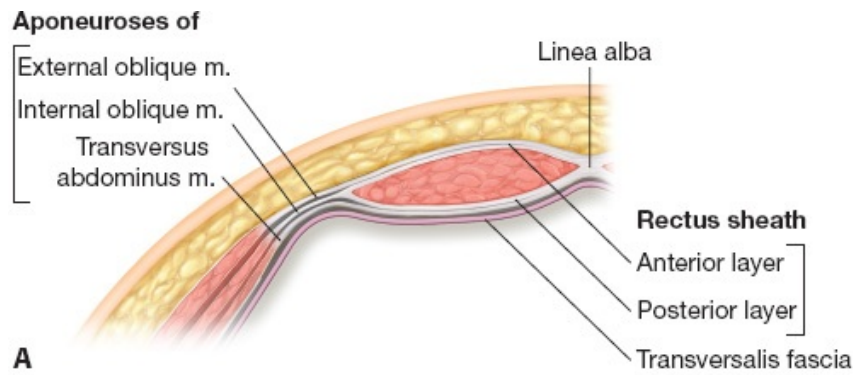


FIG 1 • A,B. Anatomy of the abdominal wall.

NONOPERATIVE MANAGEMENT

- The indications for repair of an incisional hernia are local hernia pain, a history of an obstruction, patient discomfort from an inability to raise core intra-abdominal pressure, unsightliness, and the need for intra-abdominal visceral surgery.
- Small asymptomatic defects can be observed (so long as the patient is not traveling to an area lacking modern medical care), as the risk of surgery approximates the risk of observation.
- For every patient, there should be a comparison of the expected benefits with the magnitude of the procedure required for repair.



FIG 2 • CT Scan demonstrating an incisional hernia.

SURGICAL MANAGEMENT

Preoperative Planning

- These repairs are invasive procedures usually performed on an elective basis, so every patient should be optimized for surgery, including an appropriate perioperative evaluation, nutritional optimization and weight loss, and lifestyle changes such as smoking cessation.
- The Caprini risk stratification model is used to assess the individual patient's risk for DVT/PE and assign chemoprophylaxis if appropriate.
- Perioperative antibiotics are routinely given for 24 hours, and topical antibiotic irrigation is used during the procedure.
- The history and imaging must be reviewed and an operative plan put in place:
 - What incisions have been previously made? What layers of the abdominal wall are no longer continuous?
 - Is there mesh? If so, what kind, how large, and how was it affixed?

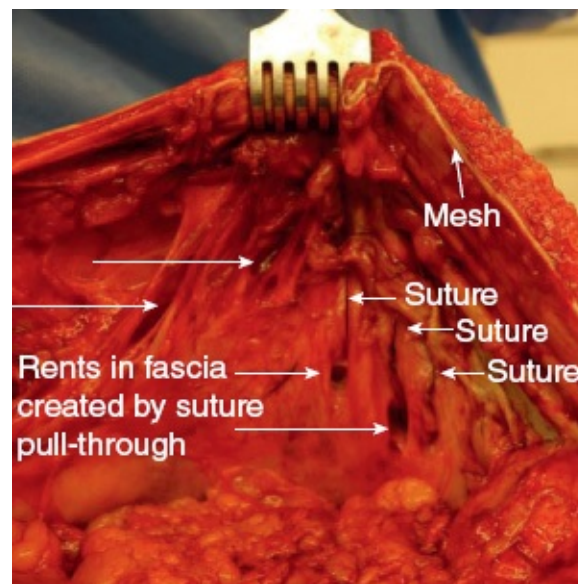


FIG 3 • Suture pull-through or “cheese wiring” due to high focal stress placed by the suture on the tissues.

- Is there a concurrent procedure that needs to be performed (eg, stoma takedown or relocation or other bowel surgery)?
- Assume that some level of adhesiolysis will be required, and backup plans for an enterotomy repair or bowel resection should be in place.

Positioning

- The patient is in a supine position with the arms out to the sides. The field should extend from the xiphoid to pubis and down to the midaxillary line on the sides. Flank defects are repaired in the lateral decubitus position.

Approach

- We use the prior incision for access into the abdominal cavity. In general, the incision must be longer than the prior scar, and so extensions into an unscarred skin are the rule.
- At the end of the procedure, the prior incision, redundant skin and subcutaneous tissue, and hernia sac are excised so that healing will occur with unscarred tissue and so that the soft tissues will lie flat against the abdominal wall.
- For improved aesthetics and healing, the umbilicus is removed and a neoumbilicus created (see umbilicoplasty technique in associated chapter).

TECHNIQUES

■ Laparotomy and Development of Tissue Planes

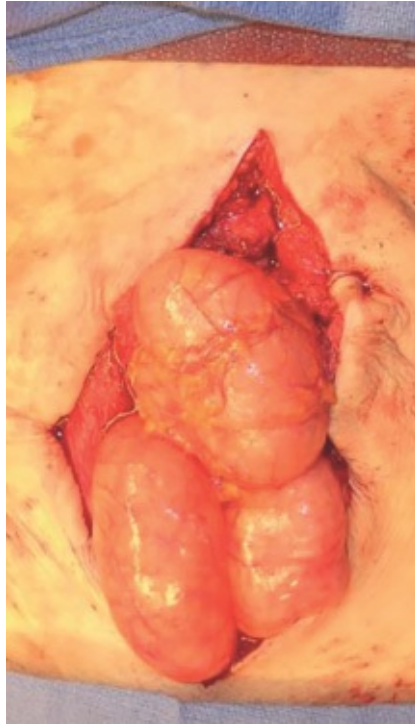


Video p5-c009_02

- Make a generous incision.
- Enter the abdominal cavity immediately rather than trying to preserve the

hernia sac. In general, start where the hernia sac is most mobile and softest, as this is where adhesions will be least. After entry into the abdomen, extend the dissection in either direction until one reaches unscarred tissue, the xiphoid, and/or the symphysis pubis.

- Bowel adhesions to the hernia sac and the peritoneal surface of the abdominal wall should be widely taken down from the anterior abdominal wall, though a full abdominal exploration is not performed (**TECH FIG 1**).
- If there is a mesh, it must be removed completely at this point—it is a foreign body and will not contribute to the closure. We typically split the mesh for ease of dissection and take it off as two “halves.” Alternatively, when there is infected mesh and an enterocutaneous fistula, the mesh is removed “en bloc.”
- Using cautery, dissect through the hernia sac to identify the medial borders of the rectus muscle in their entirety. Clear 4 cm of anterior rectus fascia.
- To assess the need for a components release, the patient should be under general anesthesia and the patient fully muscle relaxed.
 - Grasp the dissected rectus muscles in their midportion with two fingers on either side. If they cannot be brought together to the midline, the patient will require a components release.
 - This occurs in a patient with normal compliance of the abdominal wall with a preoperative CT scan that shows a 6- to 10-cm separation.



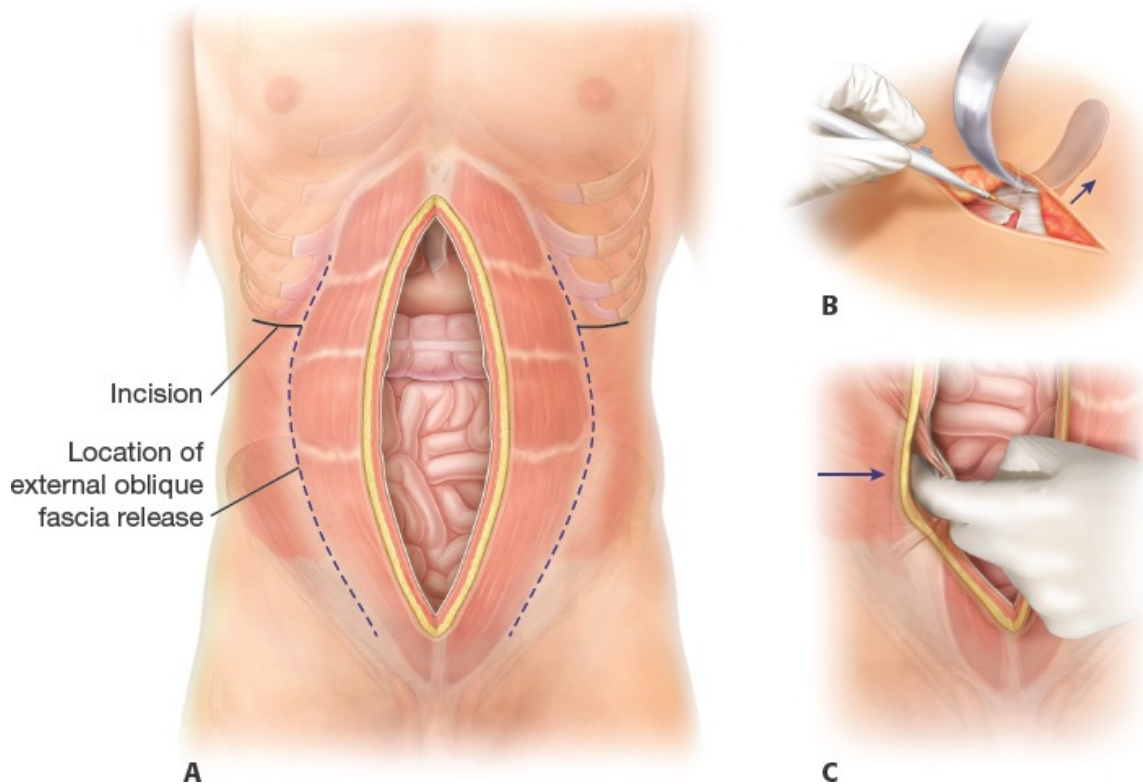
TECH FIG 1 • Midline laparotomy from the symphysis pubis to midepigastrium with division of hernia sac.

■ External Abdominal Oblique Release (Anterior Components Release)



Video p5-c009_01

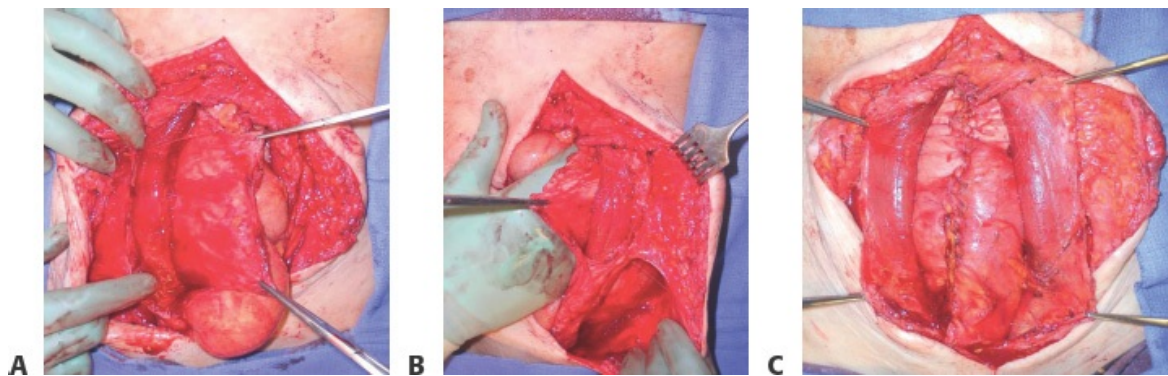
- In cases where a components release is required, palpate the inferior costal margin and make a 6-cm transverse subcostal incision in order to approach the linea semilunaris.
- Using a combination of cautery and spreading with curved Mayo scissors, the anterior-most external oblique fibers are identified as they blend into their insertion into the lateral aspect of the rectus sheath.
- Bluntly dissect a tunnel along the semilunar line going inferiorly and superiorly.
- Using electrocautery, make a small, finger-sized incision in the external oblique muscle just lateral to the rectus sheath. Then, bluntly dissect the plane between the internal and external obliques and use the cautery against your finger to release the external oblique just lateral to the rectus sheath. A narrow Deaver retractor will help visualization.
- These incisions are continued in the tunnels going inferiorly and superiorly from the subcostal incision far above the rib cage down to the anterior superior iliac spine (ASIS). Especially superiorly, a deep fascia of the external oblique exists and should be divided for maximal movement—it is completely distinct from the internal oblique muscle.
- A suprapubic tunnel is brought into continuity with this lateral dissection, all with blunt dissection and remaining near the ASIS to avoid the periumbilical perforators.
- The external oblique release is completed inferiorly with “grabbing” the cut end of the muscle/fascia from the midline tunnel to allow it to be cut under direct vision. Once these releases are complete bilaterally, the rectus muscles should come together in the midline for the majority of hernias (**TECH FIG 2**) (Videos 1 and 2).



TECH FIG 2 • A. Transverse incisions for perforator sparing anterior components release located at the inferior aspect of the costal margins. **B.** Narrow Deaver retractor permitting release of external oblique muscle and fascia over the rib cage. **C.** From the suprapubic midline incision, a dissecting finger creates a tunnel and joins it with the dissections of the lateral incisions. The cut end of the external oblique muscle is captured by the index finger. The dissecting index finger pulls the external oblique fascia into the midline incision to be visualized and subsequently cut.

- This approach to releasing the external obliques preserves the periumbilical perforators that will be supplying the soft tissues overlying the midline closure and has been shown to decrease surgical site occurrences (SSO).
- Choice of mesh remains extremely controversial. General guidelines are that all hernias should be closed with a mesh to distribute forces and to limit suture pull-through.

- Achievement of a “direct supported repair” with closure of biologic tissue over mesh has been shown to decrease hernia rates in comparison with a mesh that bridges a fascial defect.
- For prosthetic meshes, coated meshes against adhesions are generally recommended when placed against bowel, whereas uncoated macroporous meshes with pore sizes greater than 1 mm to limit bridging scar and encapsulation are generally used in the retrorectus and onlay positions.
- Absorbable meshes distribute forces but for only a limited amount of time. Animal experimentation implies that the foreign body response recedes when the foreign body is absorbed. Whether absorbable meshes translate to improved long-term closure remains to be seen. Similarly, biologic meshes are known to incorporate into surrounding tissues.
- Whether a net benefit exists or not of added long-term scar or even tissue regeneration of a fascia is completely unclear at the writing of this chapter.
- The retrorectus space is developed by incising the linea alba to mobilize the posterior rectus fascia (above the arcuate line) and the preperitoneal fat (below the arcuate line) off the rectus muscle for 4 cm. Care is taken to not injure the inferior epigastric vessels, blood vessels supplying this tissue layer, or intercostal nerves entering the muscles on their deep and lateral surface.
- The posterior sheath is then closed with a running 2-0 polydioxanone suture (**TECH FIG 3**).



TECH FIG 3 • **A,B.** Development of retrorectus space.
C. Closure of posterior rectus sheath.

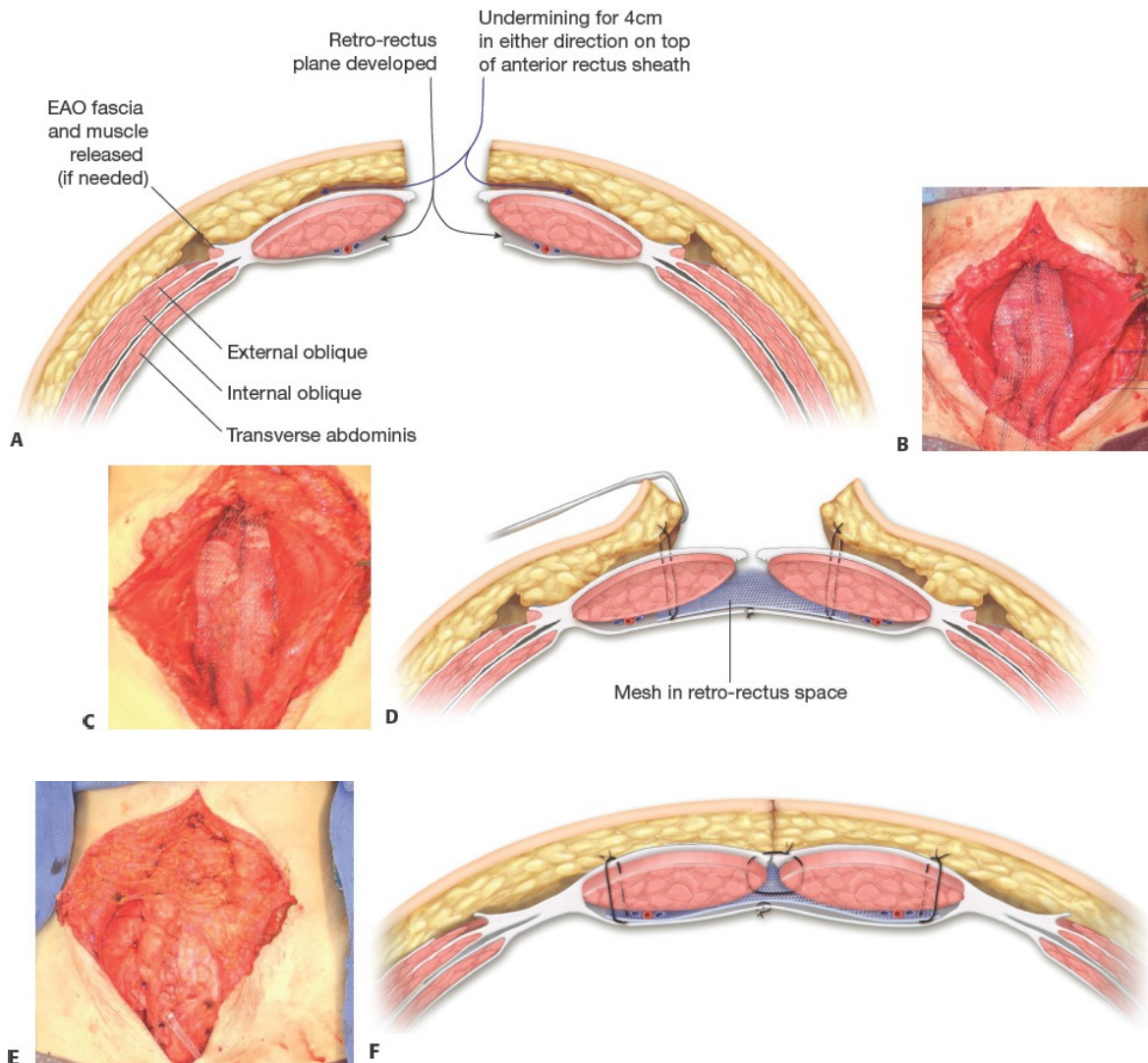
■ Mesh Inset

- The key of the procedure is a well-fixed narrow mesh that is held flat and

tight against the rectus muscles. Wrinkled mesh will not incorporate well into the tissues as a load-sharing component of the abdominal wall. Loose mesh is not load sharing and defeats the purpose of mesh placement.

- Cut a piece of uncoated midweight macroporous polypropylene mesh to a width of 7.5 cm and length equal to the length of the abdominal wall defect. Tension across the narrow width of mesh should maintain macroporosity, as opposed to allowing the holes of the mesh to close down. Macroporous meshes have improved tissue incorporation and biocompatibility in comparison with microporous meshes made of the same material.
- The mesh is then secured in place using #0 polypropylene sutures in an interrupted fashion. These stitches start at the lateral edge of the dissection superficial to the rectus muscle (approximately 4 cm away from medial edge), traverse the muscle and its anterior fascia, then take a small bite of the mesh near its edge before coming back out superficially and tying the knot.
 - Large bites of mesh will distort and wrinkle the mesh, hindering incorporation.
 - Bites should be spaced 2 cm apart or so.
 - The undersurface of the rectus muscle should be well visualized to limit the injury of segmental nerves and blood vessels during placement of these transrectus sutures (**FIG 4A–C**).
- Most techniques in the hernia literature that look to Rives-Stoppa repairs for inspiration use few or no sutures to fix the mesh in place. The mesh is held in place by its size and friction, with medial aspect of the rectus muscles approximated in the midline to cover the mesh.
- Placement of even larger meshes requires the release of the transversus abdominis muscles in what is called the TAR (transversus abdominis release or posterior components) procedure.
- Instead, we promote the use of a well-fixed narrow mesh and believe it has numerous advantages over wide meshes that require additional tissue dissection including less total foreign material, less opening of wide tissue planes, and speed of the procedure. SSO and surgical site infection (SSI) rates for a well-fixed narrow mesh are lower than that for large unfixed meshes in recently submitted data from our institution.
- As the mesh is 7.5-cm wide and the bites are taken 4 cm away from the medial rectus edge on both sides, once the lateral mesh sutures are in place, the medial borders of the rectus muscles should be able to be approximated

with no tension with #0 polypropylene sutures (**FIG 4D–F**).



TECH FIG 4 • A. Illustration of retrorectus mesh position. **B.** Mesh positioning in the retrorectus space with placement of upper transfascial sutures. **C.** Narrow mesh placed flat and tight in the retrorectus space. **D.** Diagram of placement of narrow mesh. **E.** Rectus muscles and anterior rectus sheath closed over the mesh—one can see the lateral suture lines outlining the borders of the mesh and the midline closure of the rectus muscles over the mesh. **F.** Diagram of the abdominal wall reconstruction

construct.

■ Closure

- We place at least 1 drain in the subcutaneous tissues, and for patients with BMI over 30, we place drains in each components release space.
- At this point, we turn our attention to the soft tissues of the abdomen. With the fascia closed, redundant skin and soft tissue are excised and yet still achieving a tension-free closure. This maneuver removes the poorest vascularized tissue and decreases the potential space where fluid can collect.
- We routinely excise the umbilical stalk and reconstruct the depression using “pumpkin-teeth” flaps as described in the umbilicoplasty chapter.
- Closure is performed with polyglactin dermal sutures and either staples or a running subcuticular stitch (**TECH FIG 5**).

Biologic Implant Placement

- In situations where wounds are contaminated and the clinical situation still requires abdominal wall closure, there are numerous options, though none of them are optimal.^{1,2}



TECH FIG 5 • A. Redundant soft tissue after abdominal wall closure. **B.** Markings for soft tissue excision with “pumpkin-teeth” umbilicoplasty flaps. **C.** After soft tissue excision, prior to completion of closure, the umbilicoplasty flaps are approximated at the edge that will be in the deep aspect of the umbilicus. **D.** Preoperative appearance of the patient illustrated above. **E.** Postoperative appearance of the patient illustrated above.

- A bridging piece of biologic mesh can be placed, with the idea of limiting further tissue dissection. These bridging biologics have extremely high failure rates and more likely than not will require a delayed hernia

reconstruction.

- Primary closure of the abdominal wall augmented by a components release, biologics, and retrorectus meshes has all been documented to have recurrence rates in the 20% range.
- Our current management for contaminated closures is to perform a “mesh sutured repair.”
 - Strips of polypropylene 18 to 20 mm wide are introduced through the substance of the abdominal wall and tied as simple sutures.
 - Conceptually somewhere between a suture repair and a planar mesh, these mesh sutured repairs in our hands have demonstrated SSI in the 6% range, SSO to be 18%, and a hernia recurrence rate of 4% with 7.6 months’ follow-up.
- In the interim, we would recommend that, when a biologic mesh is indicated, the surgeon use the technique as laid out above—the principles of flat and tight placement, scar excision, and lateral EAO release all apply in the same fashion. Secure attachment of the mesh is crucial to allow vascularization and integration of the material as quickly as possible. All manufacturer instructions must be followed regarding rehydration of the mesh and optimal tension of inset.

PEARLS AND PITFALLS

Scar is not your friend

- Scar in the subcutaneous tissues, and even more so the scarred edges of the rectus muscles, may seem like strong tissue that can hold a stitch, but it is avascular, is inelastic, and has decreased potential to heal. With time, the suture will simply cheese wire through the noncompliant tissue leading to failure. We routinely excise all scar and make it a priority to close healthy tissue to healthy tissue.

Suture pull-through is the enemy

- Not using enough suture fixation points to spread out the load of the closure along the suture lines will lead to disproportionately high force per unit area in the sutures that are placed, leading to a high risk of cheese wiring through the tissues.

Umbilicus management

- Counsel the patient preoperatively that you may need to remove the umbilicus as part of the closure—if they do want a neoumbilicus,

	plan for the extra time needed for an umbilicoplasty.
Lysis of adhesions	■ As above, make sure that you or a colleague is prepared to deal with bowel adhesions and any intra-abdominal anatomy challenges, as well as the possible enterotomy and need for bowel excision.
Mesh sutured repairs	■ Are efficacious and efficient means to close abdominal wall, though long-term follow-up does not yet exist for this novel closure method. Strips of macroporous mesh 18 to 20 mm wide are passed through the abdominal wall and used as sutures. The strips of mesh use the same concepts of force distribution and reduction of pull-through as tenants of successful abdominal wall surgery. Despite the permanent material, they have been placed successfully in contaminated closures.

POSTOPERATIVE CARE

- Diet management
 - Bowel preps do not decrease SSI or SSO, but a mechanical prep with Dulcolax that does not alter bowel flora may be helpful to reduce visceral volume and pressure during and immediately after surgery. An aggressive antiemetic regimen is necessary to prevent emesis and the associated high abdominal wall stresses. Patients are allowed to eat after passing flatus, typically on POD 3 or 4 for major hernias.
- Activity
 - Patients are up to chair on POD no. 1 and instructed to ambulate on POD no. 2. Patients can ambulate as tolerated thereafter. They can begin nonimpact exercise (walking, swimming, elliptical training) at 6 weeks. They can do isometric abdominal exercise at 3 months and gentle impact exercise at 6 months. They have no restrictions at 9 to 12 months after surgery.
- Foley and UOP monitoring
 - We routinely place and leave a Foley catheter for 24 hours to monitor urine output. A drop-off in urine output in a patient that otherwise appears adequately resuscitated raises concern for abdominal compartment syndrome—a rare but possible complication. Rising intra-abdominal pressure by Foley catheter monitoring, low urine output, and difficulty with ventilation all point toward a compartment syndrome.
- Tidal volume monitoring
 - Returning a large volume of viscera to the abdominal compartment can significantly impair ventilatory capacity by limiting diaphragm excursion.

Pulmonary therapy is necessary during the immediate postoperative state to optimize the patient's respiratory status.

- Valium

- We routinely prescribe diazepam to patients postoperatively to reduce muscle spasms, improve pain control, and off-load the closure.

- Pain management

- We avoid the use of ketorolac given the fairly large dissection. Patients who we anticipate will have pain control difficulties undergo placement of an epidural catheter by the anesthesia pain team for the immediate postoperative period. Use of epidurals may help blunt the body's inflammatory response to surgical trauma but can lead to greater forces on abdominal sutures from greater patient activity.

- DVT prophylaxis

- DVT prophylaxis must be administered as dictated by patient risk stratification on the Caprini score.

OUTCOMES

- In our series of 101 patients who have been treated with a narrow well-fixed mesh as described above, there was a 0% rate of hernia recurrence, SSO of 7.9%, and SSI of 3%. There were no enterocutaneous fistulae, and no meshes required removal. Minor complications included 3 infections, 2 hematomas, 2 seromas, 1 reoperation for a subcutaneous collection, and 5 readmissions within 30 days.³

COMPLICATIONS

- Hematoma/seroma
- Soft tissue infection and prosthetic mesh infection
- Bowel-related complications involving delayed return of bowel function and compartment syndrome
- Medical complications including DVT/PE, pneumonia, UTI, and coronary ischemia
- Abdominal wall pain

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10 Rectus Femoris Flap for Abdominal Wall Reconstruction

CHAPTER

Alexander F. Mericli and Charles E. Butler

DEFINITION

- The rectus femoris muscle can be used as pedicled or free flap for reconstruction of the abdominal wall.
- The flap can be harvested as a myocutaneous or muscle-only flap, depending on the requirements of the defect.^{1–4}
- Several authors have had success employing the flap in an innervated fashion for abdominal defects.⁵
- Depending on the size of the defect, the rectus femoris muscle can be designed as an isolated flap or can be combined with other components of the lateral femoral circumflex vascular axis (vastus lateralis, anterolateral thigh skin and subcutaneous tissue, iliotibial band, and/or tensor fascia lata muscle) for the creation of a subtotal thigh flap.¹ For massive abdominal wall defects, bilateral flaps can be raised.
- As a rotational flap, the rectus femoris muscle will easily reach the lower abdomen, mons, lateral hip, perineum, and groin.
- Although the rectus femoris is recognized as a useful flap, debate continues regarding its associated donor-site morbidity.
- There is disagreement in the literature as to whether the rectus femoris flap is associated with decreased range of motion or strength with knee extension.^{6–8}

ANATOMY

- The rectus femoris is part of the quadriceps muscle complex. It is a bipennate muscle with two distinct muscle bellies (**FIG 1A**).
- It has two separate origins: the anteroinferior iliac spine and the anterior rim of

the acetabulum. The muscle inserts onto the patella along with the other components of the quadriceps complex and both flexes the hip and extends the knee (**FIG 1B**).

- The motor innervation comes from the femoral nerve (L4 nerve root). The sensory innervation to the skin overlying the muscle is from the intermediate femoral cutaneous nerve.
- The vascular supply of the rectus femoris is consistent with that of a type 2 muscle flap, as defined by Mathes and Nahai.
- The major pedicle is a medial branch from the lateral femoral circumflex artery (**FIG 1C**). The branch to the rectus femoris muscle emerges 1 to 2.5 cm distal to where the lateral femoral circumflex artery splits from the profunda femoris artery. The pedicle tends to enter the muscle on its deep and lateral surface. After sending a branch to the rectus femoris muscle, the lateral femoral circumflex neurovascular bundle continues inferiorly, traveling in the septum between the vastus lateralis and rectus femoris muscle, to supply the tissue of the anterolateral thigh flap.
- The minor pedicles are one to three small branches from the superficial femoral artery, distally. Generally, the minor pedicles are not independently sufficient to support flap viability.
- The muscle is bordered by the vastus medialis medially, the vastus lateralis laterally, and the vastus intermedius on its deep surface. The sartorius muscle crosses obliquely over the rectus femoris muscle proximally.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Since the advent of the component separation technique, fascial approximation of defects up to 20 cm wide at the umbilicus can be achieved. Therefore, autologous reconstruction of the abdominal wall using thigh-based flaps is reserved for patients with total or massive subtotal defects of the full thickness of the abdominal wall.
- The etiology of these significant defects is variable and includes malignancy (tumor resection; **FIG 2A**), trauma (damage control of the abdomen or soft tissue loss due to ballistic or blunt injury), and infectious processes (necrotizing fasciitis, full-thickness abdominal wall resection due to extensive enterocutaneous fistula formation; **FIG 2B,C**).

IMAGING

- Imaging studies are not required before performing a rectus abdominis flap for

abdominal wall reconstruction. However, imaging is often present for other reasons and can be utilized to the reconstructive surgeon's advantage.

- Computed tomographic scans of the abdomen and pelvis can be utilized for visualization of the abdominal defect size and associated anatomy.
- Computed tomographic angiography of the lower extremity—if present—can be used to confirm patency of the vascular pedicle (**FIG 3**).

SURGICAL MANAGEMENT

Preoperative Planning

- The patient should be seen preoperatively where a full history should be obtained and physical examination should be performed.
- Special attention should be paid to a past history of any abdominal, groin, or thigh surgeries or injuries.

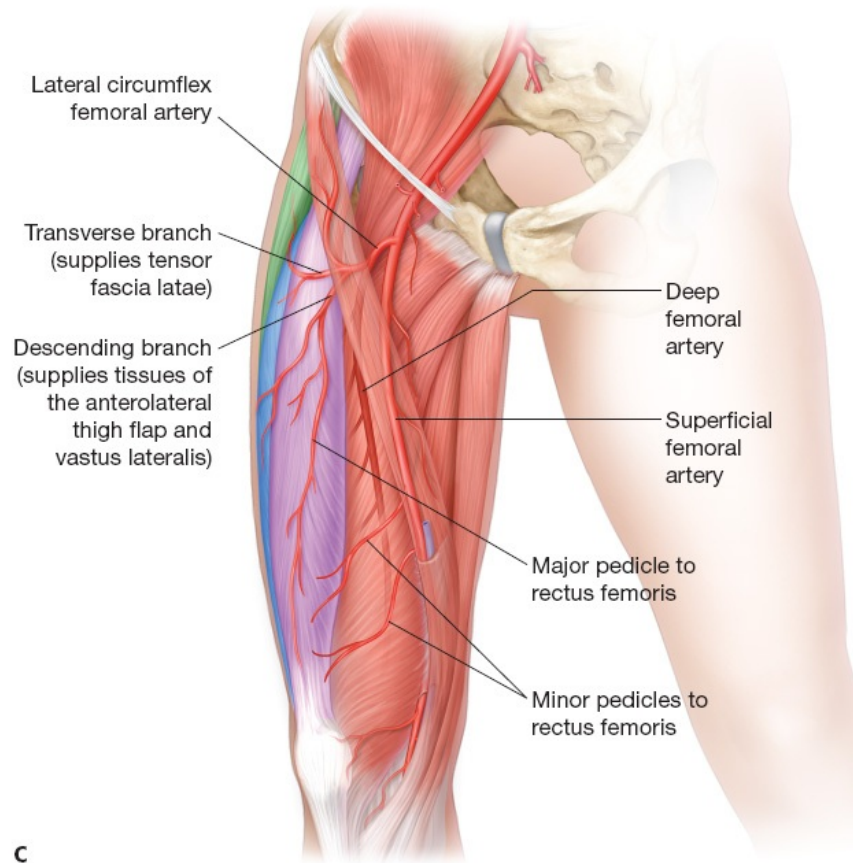
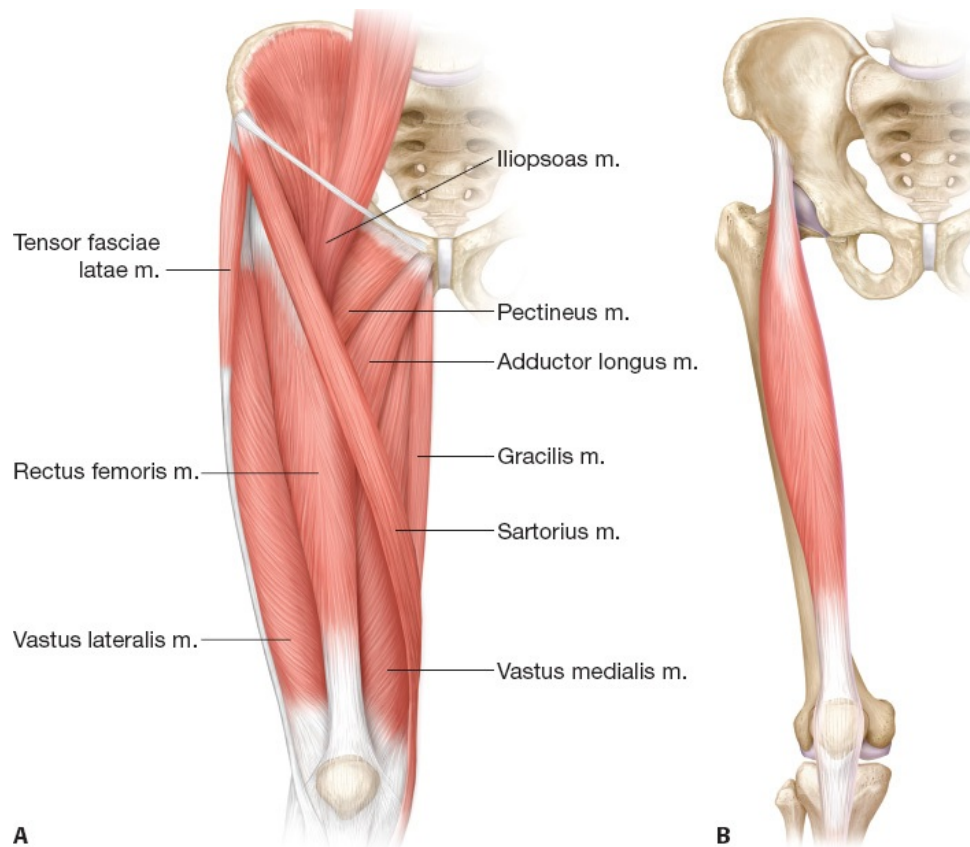


FIG 1 • **A.** Muscular anatomy of the thigh. **B.** The rectus femoris muscle originates from the anteroinferior iliac spine and the acetabulum. It spans both the hip and knee joints, thus serving as both a hip flexor and knee extensor. **C.** The rectus femoris muscle is supplied by the descending branch of the lateral femoral circumflex artery. The lateral femoral circumflex artery also supplies the tensor fascia lata, the vastus lateralis, and the overlying skin, allowing for a subtotal thigh flap to be designed, if necessary. Color code: rectus femoris muscle, purple; anterolateral thigh tissues, blue; tensor fascia lata, green.

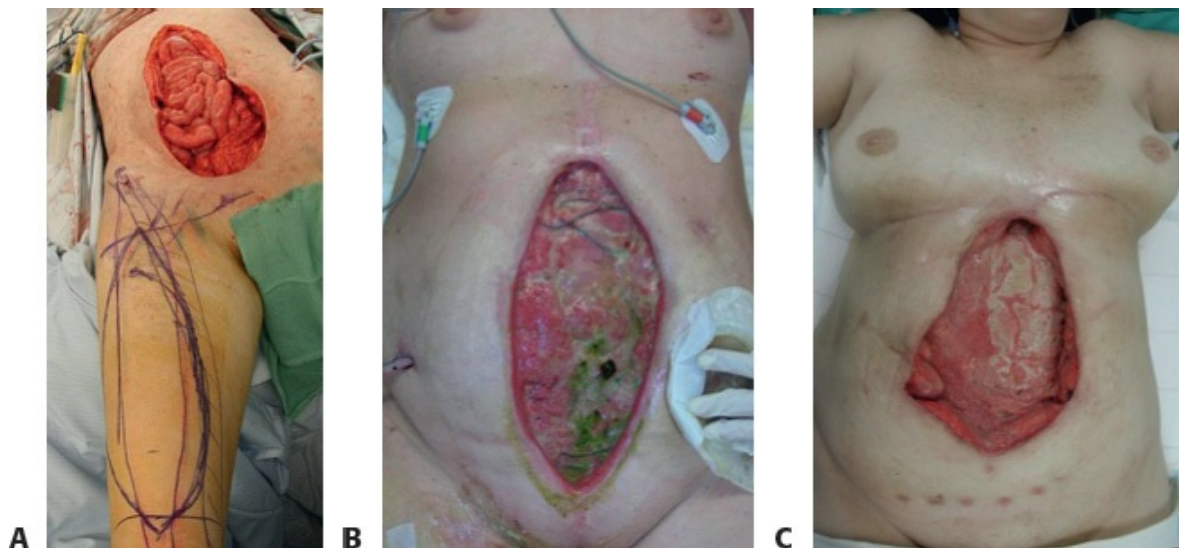


FIG 2 • Abdominal wall defects from various etiologies. Full-thickness defect after oncologic resection (**A**), enterocutaneous fistula and associated soft tissue loss after evisceration (**B,C**). (© Charles E. Butler, MD.)

- If vascular disease is suspected, a computed tomographic angiogram should be considered to verify perfusion of the rectus femoris muscle.
- Reconstruction of the abdominal wall is typically a multisurgeon case involving both reconstructive and general surgeons. General surgeons should

be available to assist with adhesiolysis or any enteral repairs, which might be needed during the exposure.

Positioning

- The patient is placed in the supine position with the bilateral legs internally rotated at the hip.
- The legs are secured in this position at the forefoot with a combination of tape and foam to relieve pressure.



FIG 3 • Computed tomographic angiography demonstrating the cross-sectional anatomy of the thigh.

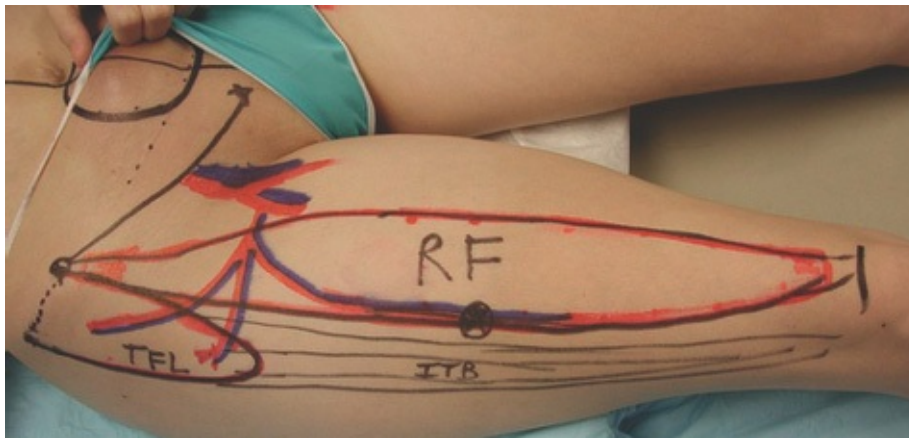
TECHNIQUES

■ Markings

- With the legs internally rotated, markings are placed on the anterosuperior iliac spine and the superolateral border of the patella; a line connecting these two points approximates the lateral border of the rectus femoris muscle.
- A line is extended superiorly from the midpoint of the patella to the

anterosuperior iliac spine representing the central axis of the rectus femoris muscle (**TECH FIG 1**).

- For a muscle-only rectus flap, either one or two incisions are designed along the central axis of the muscle.
- For a more minimally invasive approach, the two-incision technique is used: a short distal incision is planned for the distal thigh to allow disinsertion of the muscle from the patella. This incision is directly overlying the rectus femoris muscle and 6 to 8 cm in length. A separate incision is designed more proximally, over the region of the major pedicle. This incision will allow for more proximal dissection and will facilitate tunneling of the muscle into the abdominal defect, if a pedicled flap is planned.
- If a minimally invasive approach is not necessary, an incision is made over the central anterior axis of the thigh, directly overlying the rectus femoris muscle, from groin to distal thigh.

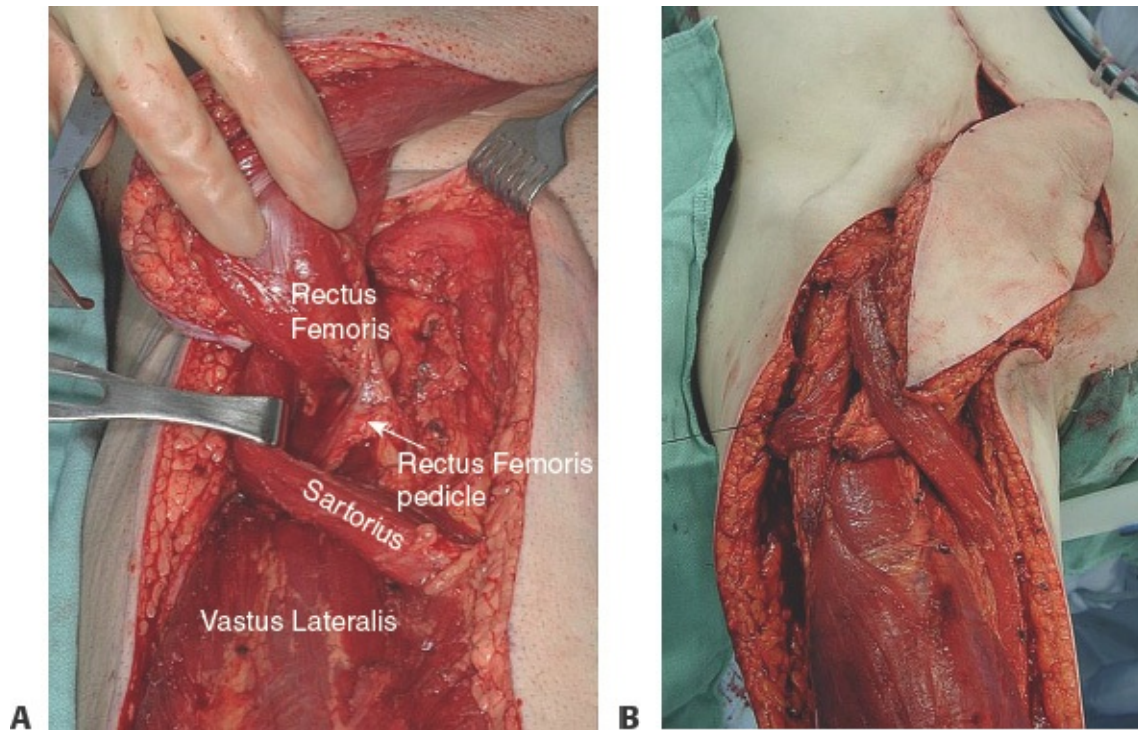


TECH FIG 1 • Surgical markings. RF, rectus femoris; TFL, tensor fascia lata; ITB, iliotibial band. (© Charles E. Butler, MD.)

■ Pedicled Rectus Femoris Flap

- If a skin paddle is desired, it is designed as an ellipse centered over the muscle on the anterior thigh.
- An 8- to 9-cm skin paddle can generally be harvested without the need for skin grafting of the donor site.

- With a large skin paddle, it is useful to suture the edges of the skin to the muscle fascia once the flap is elevated to prevent any shearing of the skin during dissection.
- If no skin paddle is needed, an incision is made distally, along the midanterior line, directly over the rectus femoris muscle. This first incision should be made 4 to 6 cm proximal to the patella.
 - Dissection is carried down through the subcutaneous adipose tissue and through the deep fascia overlying the muscle belly. Blunt dissection is used to free the muscle along its medial and deep surfaces.
 - Laterally and distally, the transition between the rectus femoris muscle and vastus lateralis muscle is often indistinct. This part of the dissection must be performed either sharply or with electrocautery to ensure accuracy; blunt dissection will likely not be possible.
- The distal muscle belly is disinserted from the patella, leaving 2 to 3 cm of tendon with the muscle flap to assist with inseting. The muscle is dissected proximally, freeing it from its medial, lateral, and deep attachments.
 - Several minor pedicles will be encountered entering the muscle's deep surface. These should be clipped and ligated as they are discovered.
- A lighted retractor may aid the surgeon in dissecting the muscle as proximally as possible.
- Either the incision is extended proximally up to the groin or, for a more minimally invasive approach, a separate incision is made overlying the groin, and the disinserted muscle is passed from the distal incision to the proximal incision.
 - The sartorius muscle will be found obliquely crossing over the muscle. The main pedicle enters the rectus femoris muscle on its deep and lateral surface at the level of the sartorius (**TECH FIG 2A**).
- Passing the flap deep to the sartorius will allow for approximately 5 cm of additional advancement (**TECH FIG 2B**).



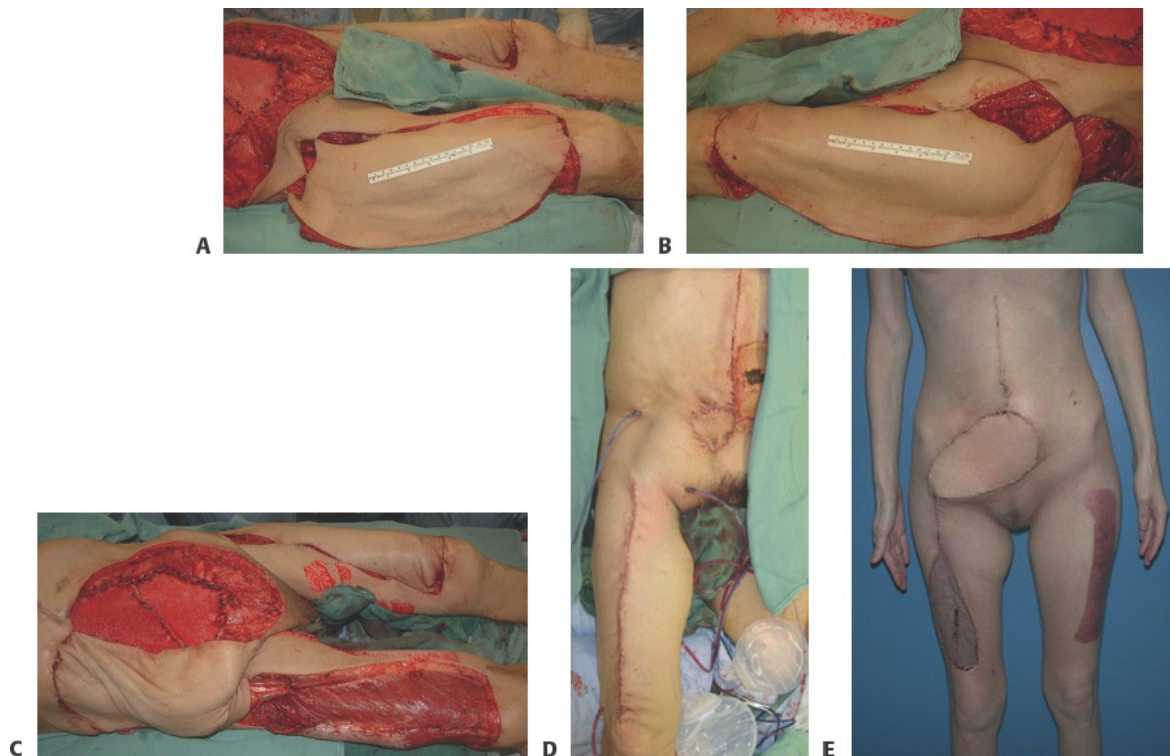
TECH FIG 2 • A. Main pedicle of the rectus femoris muscle (branch coming off the descending branch of the lateral femoral circumflex vessels). **B.** Passing the rectus femoris flap deep to the sartorius muscle in order to allow for greater advancement. (© Charles E. Butler, MD.)

- If the defect does not require skin, the rectus femoris flap can be buried as a muscle-only flap. If skin is required, the flap can either be designed with a skin paddle or a muscle-only flap can be skin grafted.
- Reconstructing the quadriceps tendon complex is an extremely important step of this operation and cannot be underestimated. Doing so will help to minimize the potential donor-site morbidity and loss of terminal knee extension.
 - Buried no. 1 polypropylene sutures are typically used to approximate the vastus lateralis tendon to the tendon of the vastus medialis, thus centralizing the moment arm of the remaining quadriceps tendon. It is not uncommon to extend this tenorrhaphy for 10 to 15 cm proximally.

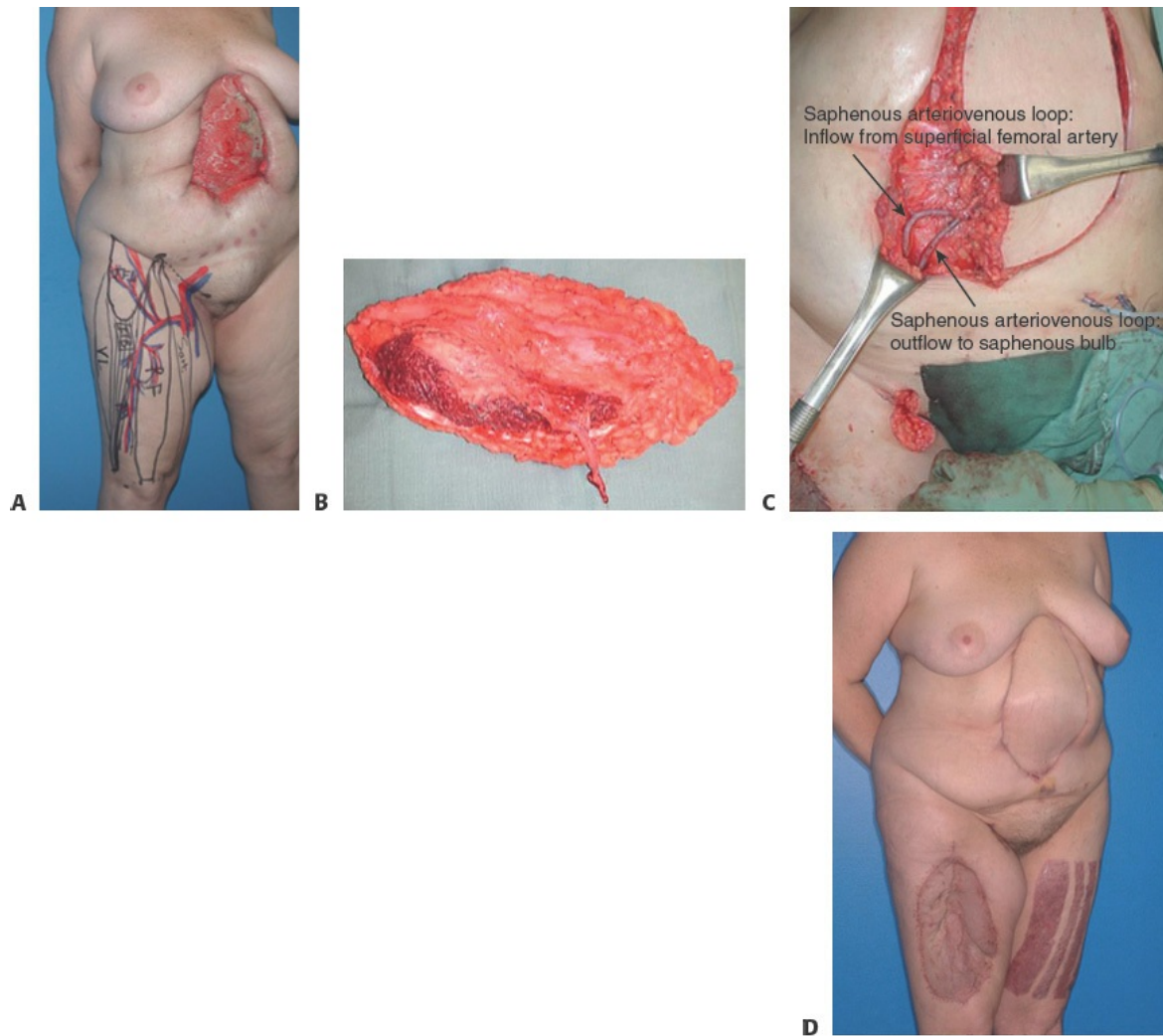
Pediced Subtotal Thigh Flap

- The rectus femoris muscle can be combined with other components of the lateral femoral circumflex vascular tree to create a subtotal thigh flap.
 - The skin paddle possible with this flap is larger than 400 cm² and can be used to reconstruct massive abdominal wall defects. Bilateral flaps can be used to reconstruct the entire anterior abdominal wall¹ (**TECH FIG 3A-C**).
 - The lateral femoral circumflex vessels supply the rectus femoris, vastus lateralis, and tensor fascia lata muscles and the overlying skin. All these structures can be incorporated into the flap, if needed.
- Just as for the rectus femoris flap, the ASIS and patella are marked. A template is made of the defect and its anatomic requirements (area of missing fascia; area of missing skin, dimensions, etc.). The template is then transposed onto the thigh.
- The iliotibial band can be included in the flap to reconstruct any abdominal fascial defect.
 - If an abdominal defect is significant enough to require a subtotal thigh flap for reconstruction, it is unlikely that the iliotibial band will be sufficient in and of itself to reconstruct the associated fascial defect.
 - Therefore, this flap is often combined with a mesh fascial repair for reinforcement of the abdominal wall.¹
- The proximal extent of dissection is the branch point between the profunda femoris and the lateral circumflex femoral artery.
- Similar to the rectus femoris flap, the subtotal thigh flap should be passed deep to the sartorius muscle for an additional 5 cm of advancement. Because of the width of the flap, one or two segmental perforators to the sartorius will likely need to be divided to provide enough room for the flap to pass.
- A pedicled subtotal thigh flap will be able to reach to the level of the umbilicus.
 - If additional length is needed, the flap can be created into a free flap by way of a saphenous vein graft arteriovenous loop (see **TECH FIG 4C**).
- When a partial vastus lateralis muscle flap is included with the distal tendon intact, a vastus medialis to lateralis tenorrhaphy can be done. When the entire vastus lateralis is included in this flap, a vastus lateralis to vastus medialis tenorrhaphy is not possible as it is when only the rectus femoris muscle is used. Therefore, the patient should be counseled preoperatively that loss of terminal knee extension and strength is likely.
 - The patient should be maintained in a knee immobilizer for 6 weeks

postoperatively and may complete a formal postoperative physical therapy program for strength training and range of motion.



TECH FIG 3 • Bilateral pedicled subtotal thigh flaps can be used to reconstruct the entire surface area of the abdominal wall. **A.** Right subtotal thigh flap. **B.** Left subtotal thigh flap. **C.** Right subtotal thigh flap rotated to the abdomen with left subtotal thigh flap reflected to display abdominal defect. **D.** If the flap is less than 9 cm wide, primary closure is generally achieved. **E.** If the flap is wider than 9 cm, primary closure is typically not possible and a skin graft should be used. (© Charles E. Butler, MD.)



TECH FIG 4 • A. Full-thickness abdominal defect and preoperative marking. **B.** Free rectus femoris myocutaneous flap. **C.** Inset of flap to the abdomen via saphenous arteriovenous loop (arrow). Distal saphenous anastomosed end-to-side to superficial femoral artery and venous outflow to saphenofemoral junction. **D.** Final result demonstrating healed flap and skin graft donor site. (© Charles E. Butler, MD.)

- The massive amount of skin taken with a subtotal thigh flap usually necessitates donor-site closure with split-thickness skin grafts (**TECH FIG 3D,E**).

Free Rectus Femoris/Subtotal Thigh Flap

- One significant shortcoming of the rectus femoris and subtotal thigh flaps is the associated short pedicle.
 - This disadvantage can be obviated by means of a free tissue transfer.
- If a free flap is required, but there is a short distance between the recipient vessels and the flap, the branch to the rectus femoris muscle can be transected as it emerges from the lateral femoral circumflex artery. This preserves the anterolateral thigh flap and vastus lateralis muscle for future use.
 - Alternatively, for an additional 2 to 3 cm, the distal lateral femoral circumflex artery can be ligated just distal to the takeoff of the rectus femoris branch, and the pedicle can be transected where it emerges from the profunda femoris.
 - The disadvantage of this maneuver is it prevents future use of the anterolateral thigh and vastus lateralis muscle flap.
- If a subtotal thigh flap is being used, the pedicle is transected in the typical location for an anterolateral thigh flap, where the lateral femoral circumflex artery emerges from the profunda femoris.
- For abdominal wall reconstruction, potential recipient vessels include either of the deep inferior epigastric arteries and their associated venae comitantes.
- Of course, if a patient requires a large flap for reconstruction of their abdominal wall, it is likely that the deep inferior epigastric system is unavailable for use. In this situation, a femoral saphenous arteriovenous loop is a prudent choice (**TECH FIG 4**).
 - The loop is created by transecting the saphenous vein distally and leaving it intact proximally.
 - The distal end of the saphenous vein is then anastomosed in an end-to-side fashion to the superficial femoral artery. The loop is positioned on the abdominal wall adjacent to the flap's vascular pedicle. The loop is divided at its apex to provide both arterial and venous recipient vein grafts.
- Similar to the pedicled subtotal thigh flap and rectus femoris flaps, unilateral or bilateral flaps can be employed, depending on need.

Marking and positioning	■ The patient's legs should be internally rotated at the hip to ensure accurate markings. ■ The flap can be harvested easily in the supine, lithotomy, or lateral decubitus positions.
Flap design and reach	■ The rectus femoris flap can be employed as a muscle-only flap or myocutaneous flap. ■ A skin paddle wider than 8 to 9 cm will usually require skin grafting for donor-site closure. ■ The rectus femoris flap can also be utilized as a chimeric flap, including other elements of the lateral femoral circumflex vascular axis (vastus lateralis, tensor fascia lata, iliotibial band) for increased surface area coverage. ■ The flap should be passed deep to the sartorius muscle for an additional 5 cm of advancement. ■ The flap can reach the lower abdomen as a pedicled flap; if midabdomen or superior abdomen requires reconstruction, the flap should be elevated as a free flap.
Donor-site morbidity	■ Donor-site morbidity is limited to decreased eccentric quadriceps strength. Range of motion is unaffected. ■ Most donor-site morbidity can be obviated by performing a vastus medialis-lateralis tenorrhaphy, requiring a knee immobilizer during the postoperative period, and engaging in a physical therapy regimen.
Postoperative management	■ A knee immobilizer should be worn for 6 weeks postoperatively.
Therapy	■ Physical therapy for quadriceps strength training and lower extremity range of motion can be helpful.

POSTOPERATIVE CARE

- The patient should be placed into a knee immobilizer postoperatively for 6 weeks, which should be worn at all times except when bathing.
- Ambulation is encouraged as early as the first postoperative day with weight bearing as tolerated.
- The affected lower extremity should be kept elevated at all times when not ambulating.

OUTCOMES

- The rectus femoris muscle flap is an effective workhorse flap for abdominal

wall reconstruction (**FIG 4**).

- The donor-site morbidity is low.
- Several authors have reported no loss of knee extension capacity or strength.^{1,6-8}
- The only quantitative assessment found knee range of motion to be unaffected after use of the rectus femoris flap; however, the extension power had decreased 10.3% (concentric contraction) and 19.3% (eccentric contraction). This decrease in strength can be obviated by participation in a postoperative physical therapy regimen.²

COMPLICATIONS

- The rectus femoris muscle is a robust and reliable muscle flap with a low complication profile.
- Published studies cite a 3% to 4% rate of donor-site wound separation and similar rate of donor-site hematoma.¹⁻⁸
- The flap loss rate is negligible as a muscle flap. If the flap is elevated as a subtotal thigh flap, there is a 2% rate of distal tip skin necrosis.¹
- The donor-site morbidity has been detailed in the outcomes section.

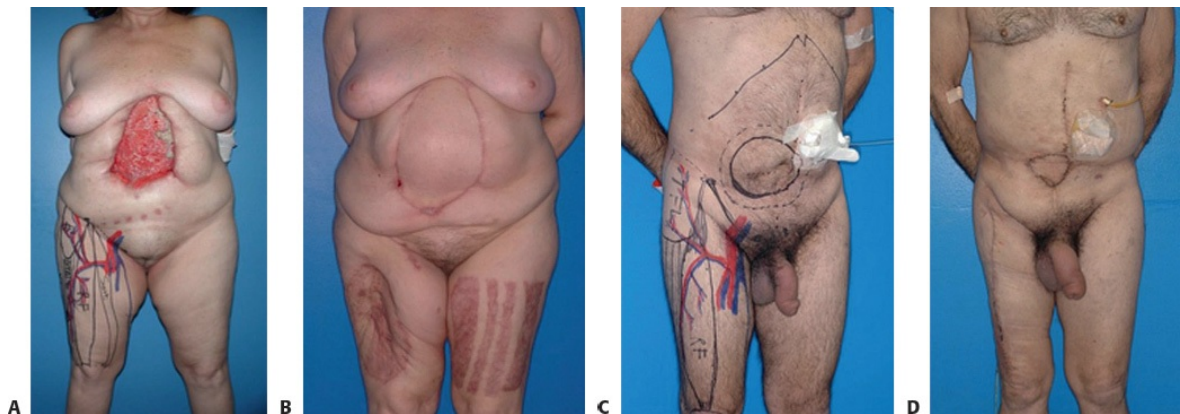


FIG 4 • Preoperative and postoperative photos of two patients who required rectus femoris flaps for reconstruction of the abdomen. **A,B.** This patient had a wide and superior defect, requiring a free flap with skin graft for donor-site management. **C,D.** This patient had a more inferior and narrower defect, allowing for a pedicle flap and primary donor-site closure. (© Charles

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11 Lower Abdominal Wall Reconstruction With Lateral Thigh-Based Flaps

CHAPTER

Dhivya R. Srinivasa and Jeffrey H. Kozlow

DEFINITION

Abdominal wall reconstruction is required when partial- or full-thickness defects of the abdominal wall do not allow for primary fascial and/or skin closure. This situation can arise in a variety of clinical situations, sometimes presenting as an intraoperative consult requiring immediate closure. Defects should be evaluated for missing components of the abdominal wall including the skin, subcutaneous tissue, fascia, and musculature. Reconstruction should aim to close the intra-abdominal compartment while minimizing the risk of future hernia development. Techniques to reapproximate the midline fascia for a ventral hernia are reviewed in a separate chapter. Here, we will focus on restoring soft tissue where it is deficient in the lower abdomen.

ANATOMY

The anatomy of the abdominal wall is most readily described in layers. Most superficial is the skin and subcutaneous tissues. Within the subcutaneous tissues is the Scarpa fascia, a layer of variable thickness that provides some additional support to a repair. The critical component of the abdominal wall is the myofascial layer. This layer includes the paired, vertically oriented rectus abdominis muscles adjacent to the midline along with the internal oblique, external oblique, and transversalis muscles laterally. The investing fascia provides significant strength to the abdominal wall and includes both an anterior sheath and a posterior sheath. The central fascia around the rectus abdominis muscles extends from the oblique musculature. In the upper abdomen, the anterior and posterior sheaths are of similar strength; however below the arcuate

line, the posterior sheath is much weaker as only the transversalis fascia contributes to the fascia deep to the rectus abdominis muscles. **FIG 1** depicts the layers of the abdominal wall.

Blood supply to the abdominal wall derives from multiple vessels with notable overlap in distribution. Centrally, the superior and inferior epigastric systems supply the abdominal wall. This is further enriched by branches from the internal mammary artery, specifically musculophrenic branches, as well as the superficial epigastric vessels. Laterally, the circumflex vessels from the iliac artery (deep and superficial) add to the redundancy in blood supply. Innervation is via subcostal nerves (from T12) and thoracoabdominal nerves from T7-T11. These ventral primary rami branches travel between the internal oblique and transverse abdominal muscles. This is the target for the TAP (transverse abdominis plane) block that is used to anesthetize the abdominal wall in select procedures.

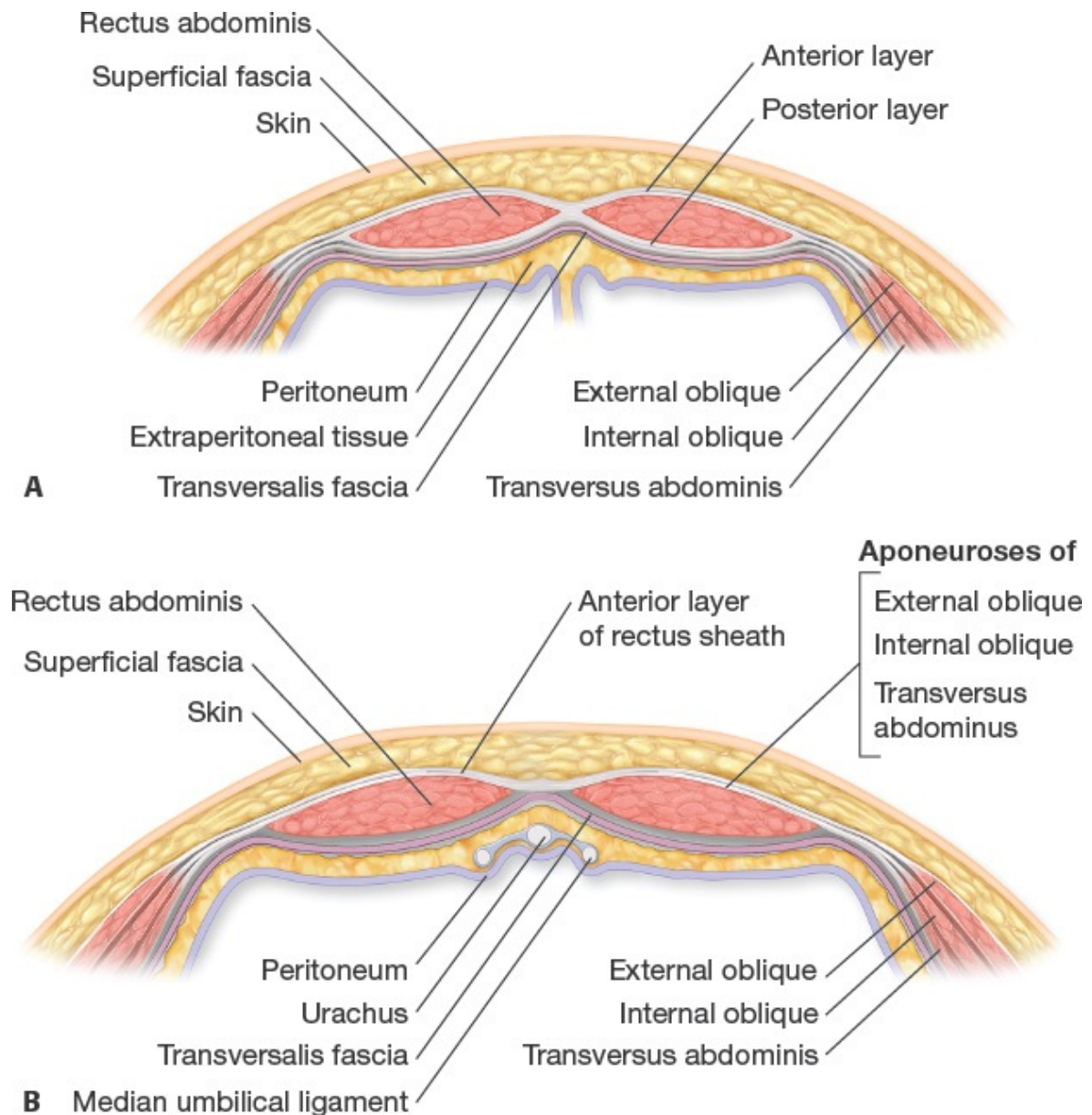


FIG 1 • Layers of the abdominal wall. **A.** Axial view of abdominal wall above the arcuate line. **B.** Axial view of abdominal wall below the arcuate line.

A thorough understanding of the various meshes used in abdominal wall reconstruction (including the various synthetic and biologic materials) is critical for surgeons planning to use these materials. However, details on this topic are beyond the scope of this chapter.

PATHOGENESIS

Abdominal wall defects can arise from a variety of scenarios: trauma, cancer, and hernia reconstruction being the most common. Acquired hernias present as a fascial defect and often require abdominal wall myofascial advancement flaps and/or mesh-related techniques. This chapter will focus on closure of soft tissue defects that arise from traumatic injury and oncologic resections. However, some of the principles used for acquired hernia repair, such as component separation, can also play a role in traumatic and oncologic reconstructions. In trauma, all devitalized tissue should be debrided prior to closure. With respect to cancer, margins should be clear and the need for adjuvant radiation should be considered when choosing a reconstructive technique.

PATIENT HISTORY AND PHYSICAL FINDINGS

In addition to the usual key components of a patient's history, the following specifics should also be documented:

- Prior abdominal surgery
 - Include laparoscopic operations and cesarean sections
- Need for stoma postresection. If an ostomy is planned, the estimated location for the stoma should also be noted.
- History of radiation therapy or planned radiation therapy
- Medical comorbidities that will affect wound healing including diabetes mellitus, steroid use, tobacco use, or connective tissue disorders
- Prothrombotic disease states should be noted and a Caprini score should be calculated. Appropriate venous thromboembolism prophylaxis should be tailored accordingly.¹
- Each patient should be examined thoroughly and all prior incisions should be noted.
- Evaluation of the thigh for adequate tissue to support transfer of the necessary tissue from this area to the abdomen.
 - Incisions within the estimated location of the donor flap should be noted. We also suggest an evaluation of body habitus in this region as thick or thin flaps may be harvested depending on the reconstructive needs.

IMAGING

No specific imaging is necessary for the reconstructive portion of the case. However, most patients will have an abdominal computed tomography (CT) scan, which can be used for planning purposes to understand the anticipated

defect. In oncologic cases, specifically note involvement of the skin, anterior sheath, musculature, posterior sheath, and intraperitoneal or retroperitoneal contents. CT angiography of the thigh can be performed in select cases to evaluate perforator location or regional anatomy in complex situations.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative planning is incumbent on anticipation of the size and depth of the defect. Whether full-thickness abdominal wall resection is necessary will dictate if fascial advancement and/or mesh will be necessary. The location of the defect is also important to note, as it will affect potential flap options. **FIG 2** illustrates various abdominal wall defects and how they can be covered with a thigh-based flap.
- Inguinal defects can often be addressed with ipsilateral tensor fascia lata (TFL) based flaps. These flaps provide strong fascial tissue if needed for reconstruction of the inguinal ligament.
- Lower abdominal (below the umbilicus) and flank defects can be addressed with flaps based off the descending branch of the lateral femoral circumflex system such as the anterolateral thigh (ALT) flap, vastus lateralis, or rectus femoris flaps.^{2,3}
- Midabdominal defects can be addressed with component separation techniques similar to ventral hernia repairs owing to the freedom of the abdominal wall tissue away from the fixed bony pelvis and rib cage.
- Upper abdominal defects are the most difficult as thigh-based flaps will typically not transpose to the upper abdomen without vein grafts.

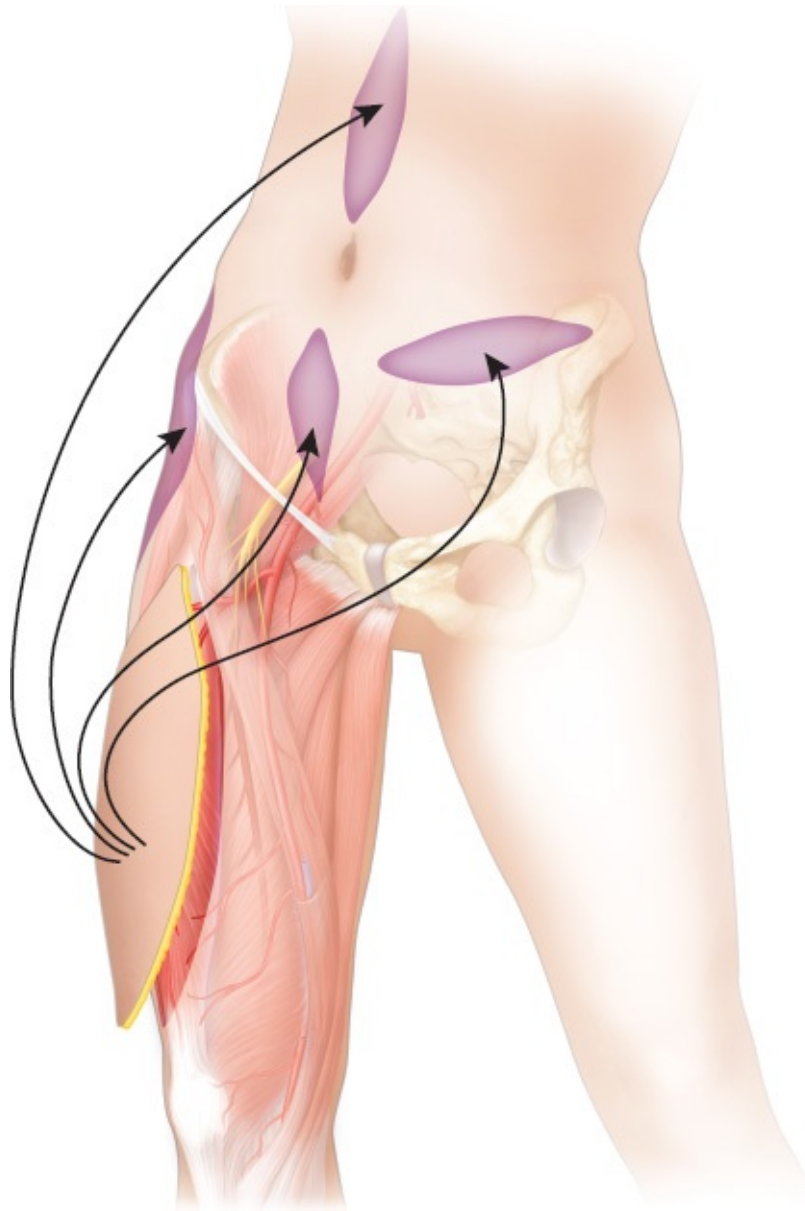


FIG 2 • Lateral thigh-based flaps are a versatile option for a variety of lower abdominal wall defects.

- Preoperative discussion with the patient should include possible donor sites, skin grafting, and potential use of mesh.
- Any planned stomas or existing stomas should be discussed so modifications can be made accordingly. Existing stomas likely pass through the rectus abdominis muscle. Future stomas should be marked preoperatively.
- In cases where primary myofascial repair may be possible, preoperative administration of Botox can be helpful if administered in advance. Typically,

up to 100 units per side can be given at least 1 to 2 weeks prior to surgery to optimize the timing of neuromuscular blockade. The goal is to allow maximal relaxation of abdominal wall musculature in anticipation of myofascial advancement for closure.⁴

Positioning

- The patient will likely be positioned supine for the abdominal portion of the surgery. All of the lateral thigh-based flaps are most easily harvested in the supine position as well.
- A safety belt should be used for all cases, but this most often is placed around the chest area.
- A warming blanket should be placed to optimize normothermic core temperatures during the case.
- SCDs should be placed bilaterally as the critical areas of the thigh need to be prepped only to the knee and do not require intraoperative rotation of the leg.
- The thigh should be prepped circumferentially. The contralateral thigh should also be available in the event skin graft is needed for closure of the defect or donor site.

Approach

- Preoperative markings should be made in the preoperative area, prior to patient positioning in the OR.
- Anatomic Landmarks: The anterior superior iliac spine (ASIS) and the superolateral patella are identified. A line connecting these two points is drawn. For an ALT flap, the midpoint of this line will be near the central axis of the skin paddle. **FIG 3** depicts relevant anatomic landmarks and the axis of the skin paddle.
 - If a TFL flap is planned, the incision can be adjusted superiorly (cephalad).
 - If a rectus femoris muscle flap is planned, the incision can be adjusted medially.
- If an ALT flap is planned, there are two main approaches to identifying perforators and designing the skin paddle:
 - Some surgeons define the “A, B, and C” perforators. The perforators are most commonly found approximately 1.5 cm posterior to the line between the ASIS and superior lateral patella. The center point of this line should be marked as perforator “B.” Perforators “A” and “C” are 5 cm proximal and

distal to “B.”⁵

- Another approach is to draw a 3-cm-radius circle around the midpoint of the axis line, defining the most common location of skin perforators. A Doppler can be used to confirm and mark the location of these perforators. The skin paddle can be centered over these perforators. Most often the perforators are found in the inferolateral quadrant of the circle (**FIG 4**).

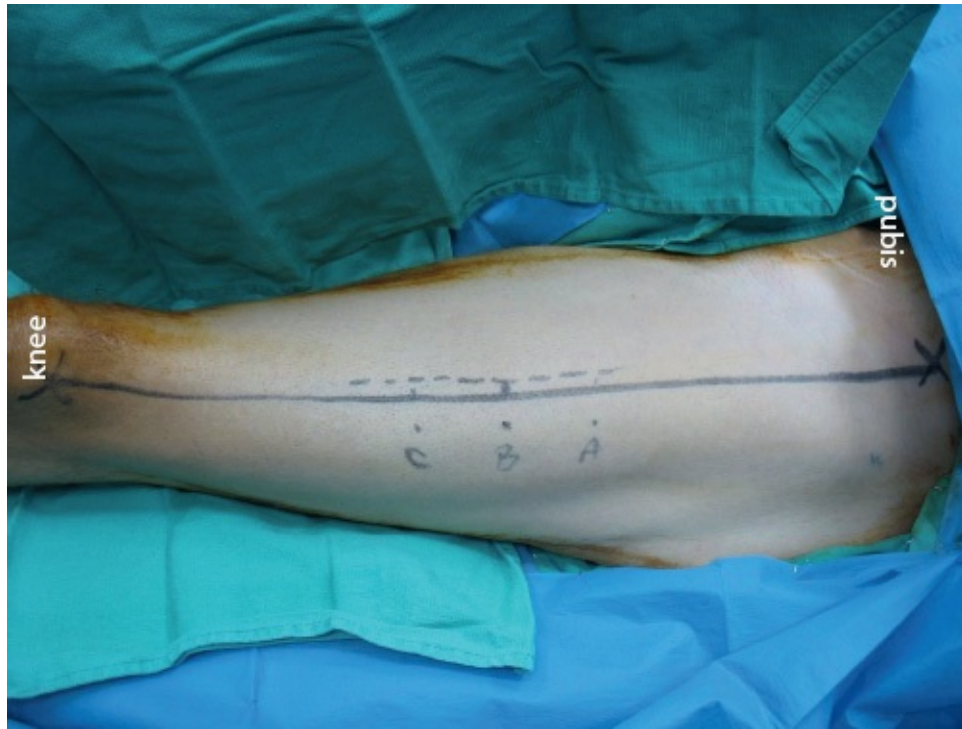


FIG 3 • External anatomic landmarks for an ALT flap from the left leg. The hip is on the right side of the photograph and the knee is on the left side.

- The initial incision for perforator evaluation is drawn 2 cm anterior/medial to the line between the ASIS and superolateral patella. This is also 4 cm anterior to the expected location of the perforators for an 8- to 9-cm-wide flap. The incision is typically ~15cm in length and centered near the region of the expected perforators (see **FIG 3**, dotted line). This initial incision is adjusted accordingly if a TFL or rectus femoris flap is planned.
- The final skin paddle is designed after the full nature of the defect is known and the planned perforators are identified. Delaying the design of the skin paddle after identification of the selected perforators can optimize flap

perfusion and minimize donor-site morbidity.

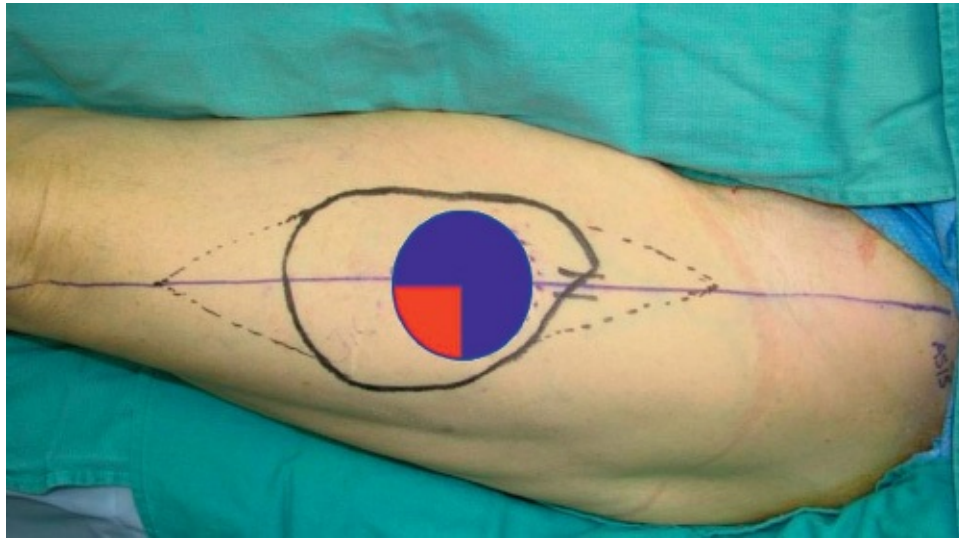
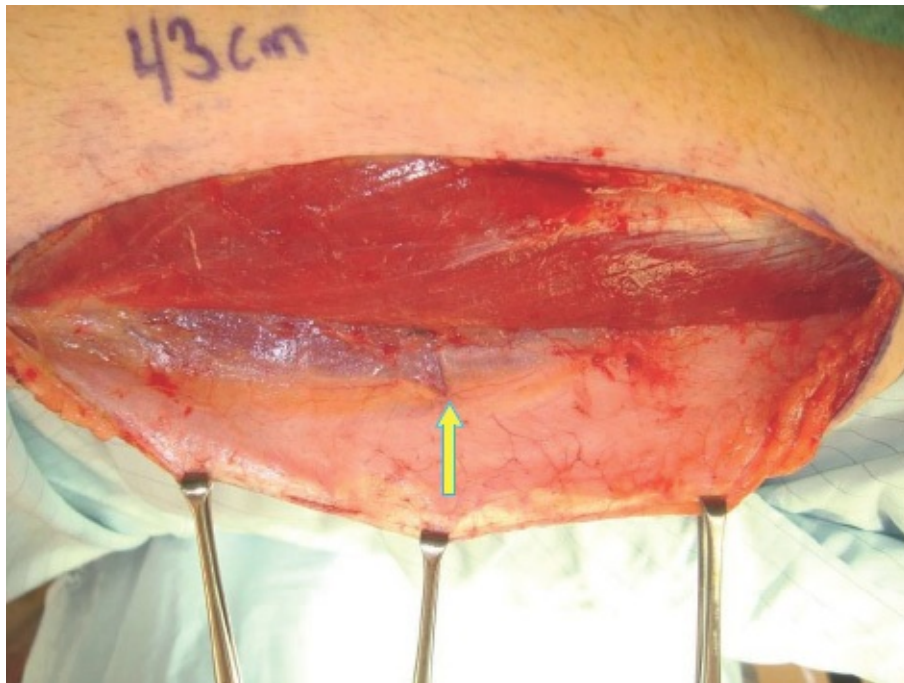


FIG 4 • Perforator location based on center of axis line. The red portion of the circle depicts the most likely location of perforators.

TECHNIQUES

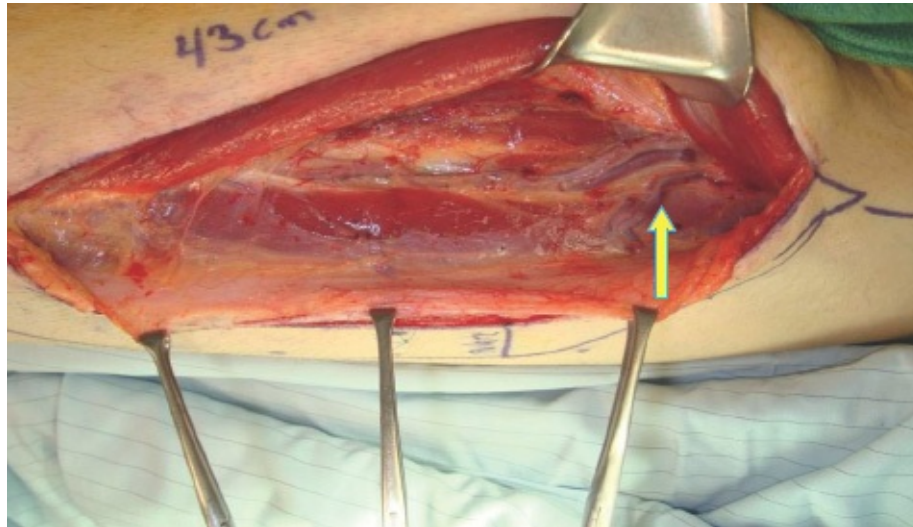
- The patient is marked while positioned supine as described earlier. Toes should be in neutral. Internal rotation of the foot can result in inadvertent rotation of the leg, which would affect markings.
- The marked incision anterior to the perforators is made and dissection is carried down to the fascia. After dissecting through the superficial fascia, care is taken to identify and preserve any medially directed branches of the lateral femoral cutaneous nerve to decrease the extent of postoperative thigh anesthesia.
- In some situations, a suprafascial dissection can be performed with identification of the perforators above the fascia. We prefer including the fascia with the flap for abdominal reconstruction as it provides a robust layer for closure and anchoring of the flap in to the defect.
- The muscular fascia is then incised over the rectus femoris muscle. Three Allis clamps are placed on the fascia, roughly at the A, B, and C perforators, to gently retract the fascia and visualize the subfascial plane.⁵

- It is advisable to place a few sutures to hold the skin edge of the flap down to the fascial edge to avoid pulling the subcutaneous tissue and skin off of the fascia inadvertently.
- Carry the dissection laterally in the subfascial plane until you encounter the septum between rectus femoris and vastus lateralis. A fat stripe is often visible here, denoting the correct plane of dissection and likely close proximity to the perforators. Proximal perforators are commonly septal perforators and more distal perforators travel intramuscular through the vastus lateralis (**TECH FIG 1**).
- Careful dissection is then performed posterolaterally over the vastus lateralis with preservation of any identified perforators.
- After identification of all potential perforators, continue the subfascial dissection behind the perforators as this will make the subsequent posterior flap dissection much easier.
- Next, retract the rectus femoris medially and separate the rectus femoris from the vastus lateralis. Care should be taken to dissect anterior to any septal perforators to avoid injury. Muscular branches to the rectus femoris can be divided (**TECH FIG 2**).



TECH FIG 1 • Allis clamps applied on fascia at the estimated perforator sites. Subfascial dissection has

been performed over the rectus femoris back toward the vastus lateralis, and an initial perforator (*arrow*) has been identified.

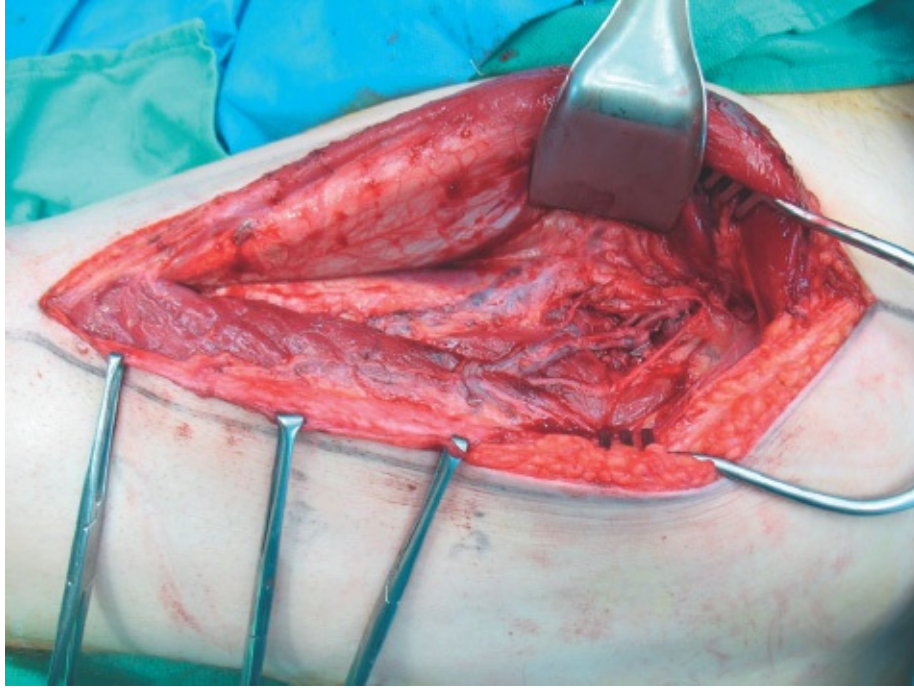


TECH FIG 2 • The rectus femoris muscle of this left leg has been retracted superiorly and an additional septocutaneous perforator (*arrow*) is seen on top of the vastus lateralis.

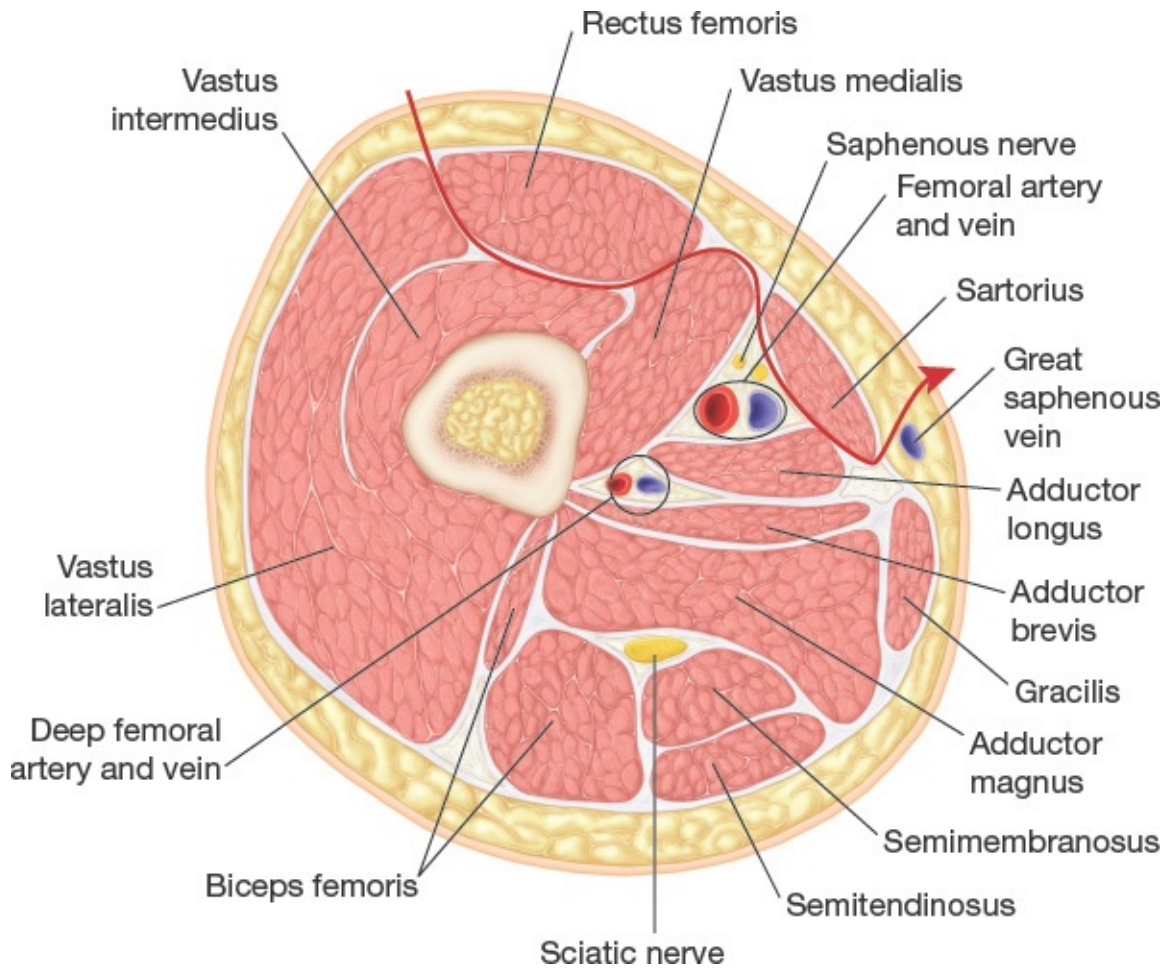
- Deep to the rectus femoris, the descending branch of the LCFA is identified. The investing fascial layer can be opened above the pedicle. This is continued proximally to the origin of the pedicle (**TECH FIG 3**).
- The main branch to the rectus femoris is often near the origin and can often be preserved as well.
- The main motor nerve to the vastus lateralis runs lateral to the main pedicle and can be dissected free to preserve muscle innervation.
- The flap perforators are then selected, and dissection is performed within either the septum or the vastus lateralis, back toward the descending branch of the LCFA. We recommend performing this dissection before clipping other branches of the main pedicle as the perforator course is not always direct to the main pedicle.
- Distal perforators of adequate caliber are preferred due to the subsequent increase in functional pedicle length. However, flaps designed around the “B” or midthigh perforator will adequately reach the umbilicus in most

patients.

- The ALT can be harvested with vastus lateralis muscle if needed. The distal portion of the descending LCFA often runs within the muscle, and one can include the superficial portion of the muscle overlying the pedicle if a chimeric flap is needed.



TECH FIG 3 • Dissection is performed back to the origin of the descending branch of the lateral femoral circumflex trunk.



TECH FIG 4 • The tunnel for the flap should pass below the rectus femoris and sartorius and then through the soft tissue.

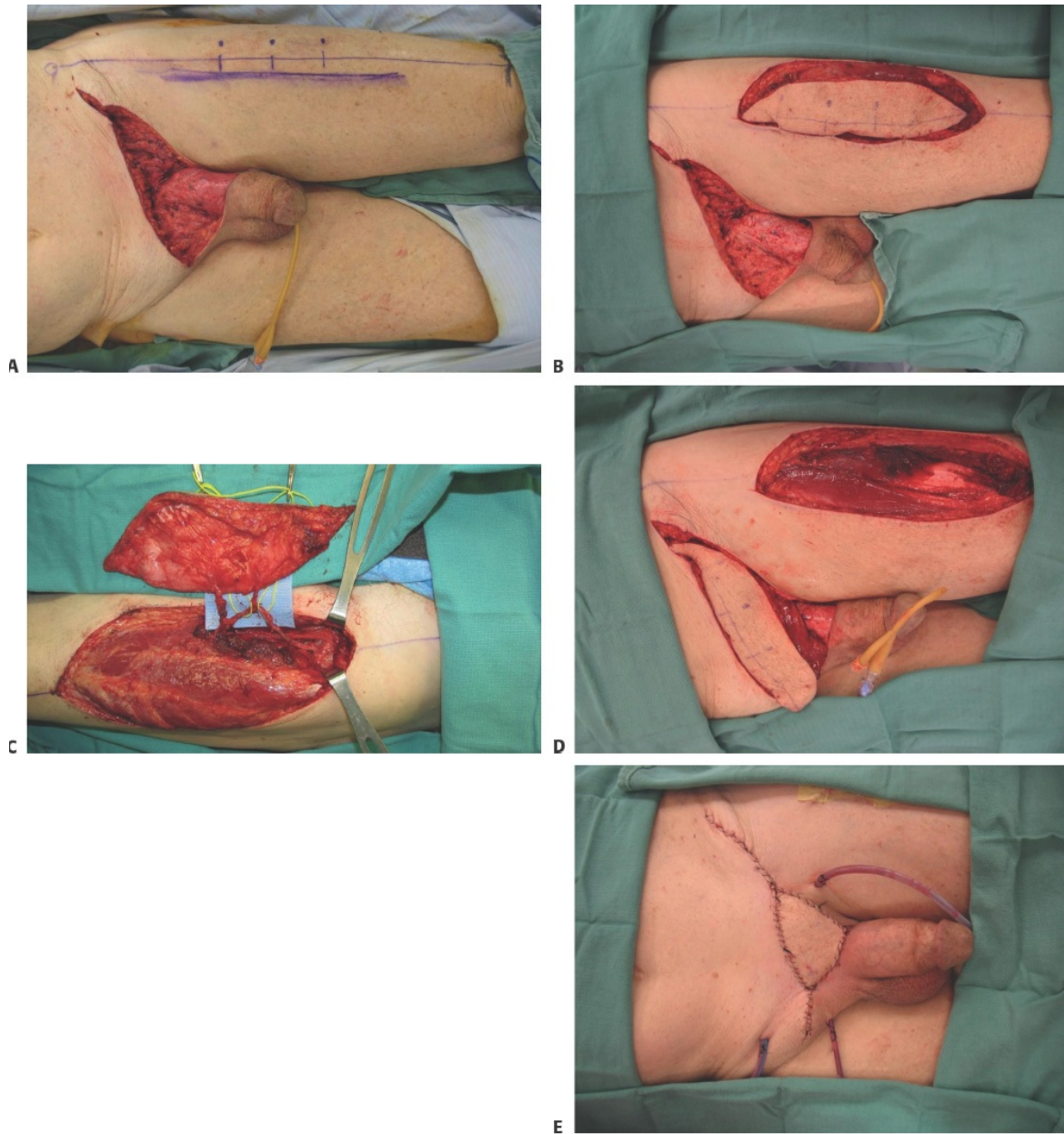
- The anterior incision is then tailor-tacked closed. A flap template is designed base on the abdominal defect. Positioning of the flap around the perforator is based on the defect and planned location for the tunnel between the thigh and the abdomen.
- Flaps up to 9 cm wide and 22 cm long can typically be harvested while still allowing for primary closure of the donor site.
- The posterior incision is then made and dissection is performed through the subcutaneous tissue and muscular fascia with care taken to protect the perforators traveling into the flap. Prior dissection of the subfascial plan behind the perforators from the anterior incision allows for rapid flap elevation at this stage.

- With the distal pedicle now divided, the flap is isolated on only the main pedicle and can be evaluated for perfusion.
- Transposition of the flap from the thigh to the lower abdomen requires a wide tunnel. The typical tunnel is subrectus femoris, subsartorius, and then subcutaneous into the defect (**TECH FIG 4**).
 - The sartorius can also be transected to avoid potential compression in this area.
- The flap is transposed through this tunnel once wide enough to easily accommodate the flap. Note that chimeric flaps will require a much wider tunnel to accommodate the additional muscle bulk.
 - In cases requiring extended reach of the flap, the pedicle of the flap may kink around the vascular branch to the rectus femoris, which can be divided if needed.
- The flap is then inset into the defect using ideally a three-layer closure (the superficial fascia, deep dermis, and external skin) in addition to any abdominal fascia inset.
 - We prefer to use dissolving sutures for the entire inset to avoid the removal of permanent sutures postoperatively.
- The donor site is closed in layers over a drain. A compressive dressing is not placed to avoid compression of the pedicle running across the medial upper thigh.

Resection of Soft Tissue Sarcoma

- Resection of a soft tissue sarcoma left the lower abdominal wall soft tissue defect is pictured in **TECH FIG 5A**. Preoperative markings for a left ALT flap are also shown. The subsequently harvested flap is seen in **TECH FIG 5B** with the vascular pedicle and two perforators seen in **TECH FIG 5C**. The flap is then transposed under rectus femoris and sartorius to the suprapubic defect as seen in **TECH FIG 5D** with final inset seen in **TECH FIG 5E**.
- A vastus lateralis flap in conjunction with a biologic mesh for reconstruction of a full-thickness lower abdominal wall defect following sarcoma resection is pictured in **TECH FIG 6**. There is an acquired defect of the lower abdominal wall with resection of all myofascial layers (**TECH FIG 6A**). After using the omentum to cover the bowel (**TECH FIG 6B**), a piece of acellular dermal matrix was used to close the peritoneum/residual posterior sheath (**TECH FIG 6C**). A vastus lateralis muscle-only flap was planned from the right thigh (**TECH FIG 6D**). After harvest of the vastus lateralis

(**TECH FIG 6E**), it was transposed underneath the rectus femoris, under the sartorius, and then subcutaneously over the inguinal ligament to the lower abdomen (**TECH FIG 6F**). Inset was performed around the myofascial defect with the muscular fascia next to the acellular dermal matrix (**TECH FIG 6G**). The skin was closed primarily in this case.

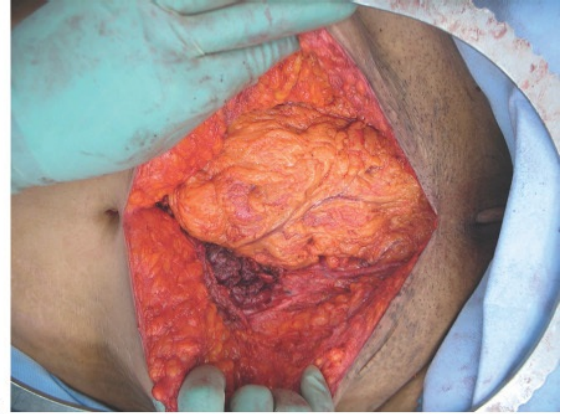


TECH FIG 5 • This suprapubic soft tissue defect resulted from a sarcoma resection. An ALT flap was harvested for closure. **A.** Design of the flap axis, expected location of “A, B, and C” perforators, and the defect. **B.** Harvest of the ALT flap with two perforators. **C.** Vascular pedicle and perforators to the ALT flap. **D.** Transposition of the flap into the defect. **E.** Final inset of the ALT flap with de-epithelialization of the buried

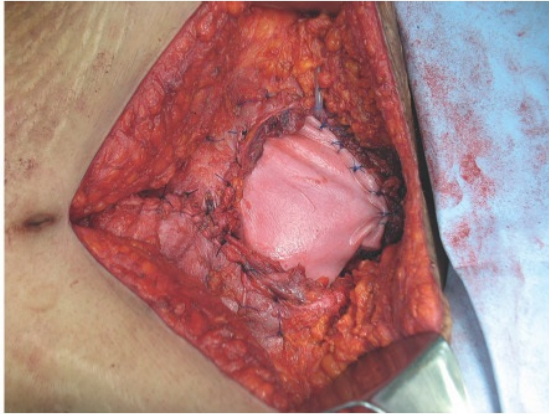
portion of the flap.



A



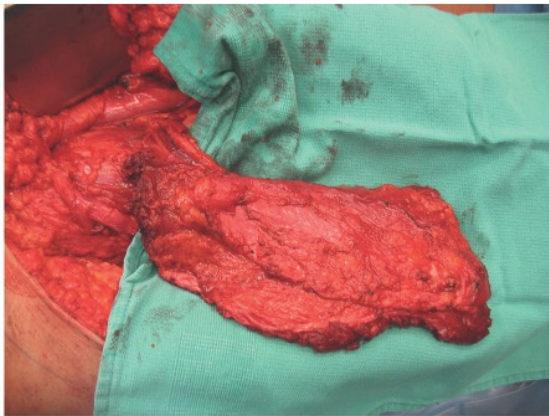
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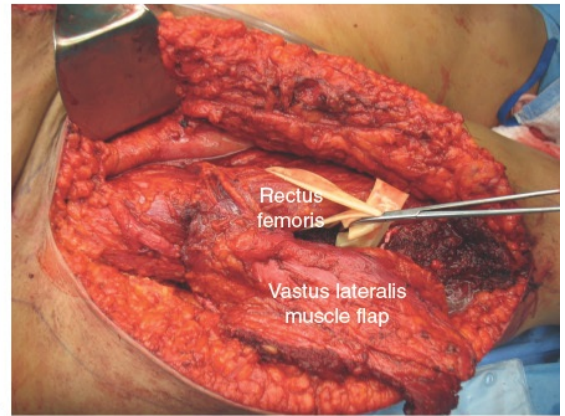
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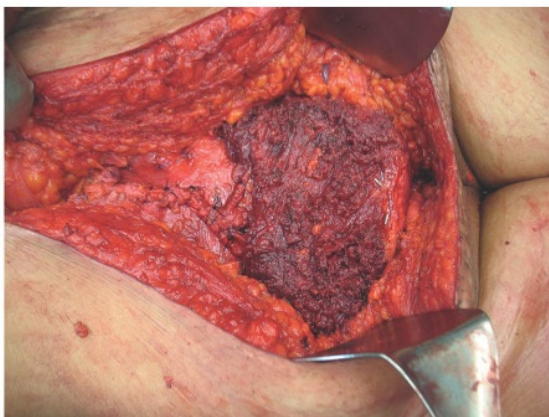
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F



G

TECH FIG 6 • This 9- × 13-cm full-thickness defect of the abdominal is secondary to sarcoma resection. The defect extended from the pubis (*right*) to just below the umbilicus (*left*). **A.** The defect after a bladder flap was used to cover the pubis. **B.** The defect with the omentum protecting the bowel. **C.** A piece of acellular matrix was used to close the peritoneum/transversalis layer of fascia. **D.** Markings for a right vastus lateralis flap. A vastus lateralis muscle flap was then harvested based on the descending branch of the lateral femoral circumflex system (**E**) and transposed under the rectus femoris muscle (with the Penrose drain around the muscle (**F**). **G.** The muscle was then inset into the abdominal wall defect with the fascial side down against the acellular dermal matrix. The overlying skin was closed primarily over the reconstruction.

PEARLS AND PITFALLS

Markings	■ Mark the patient <i>preoperatively</i>. ■ Toes should be maintained in neutral.
Positioning	■ Keep toes at neutral for flap harvest (slight internal rotation of the leg). ■ No bumps under thigh in the OR, as this can distort the soft tissue of the thigh
Skin paddle design	■ For an ALT, cutaneous perforators are most often located <i>1.5 to 2 cm posterior</i> to the axis line; keep this in mind when defining your skin paddle. The incision should be adjusted if other flaps are planned.
Surgical efficacy	■ Harvesting flaps from the right thigh is optimal for right-handed surgeons for dissection of this flap if the defect is midline; otherwise, the leg ipsilateral to the defect should be used if possible to minimize the distance for flap transposition.

Perforator selection	■ More distal perforators should be preserved and more proximal perforators can be sacrificed to optimize pedicle length.
Plan B	■ When using and ALT, expect pedicle variability. Follow the perforators in a systematic fashion. ■ Vastus lateralis and rectus femoris can be taken for additional bulk and/or muscle coverage. ■ If no adequate perforators are located, keep in mind that you can always convert to an anteromedial thigh flap (AMT) before committing to your lateral incision. The lateral incision should over the lateral border of the rectus femoris, as most of the AMT perforators are found there.
Avoid sensory deficits	■ Beware of the descending branch of lateral femoral cutaneous nerve. Preserve as many medial branches as possible to avoid undue numbness in medial thigh.
Tunnel for transfer to the lower abdomen	■ The shortest path for a lateral thigh flap to the lower abdomen is subrectus femoris, subsartorius, and then subcutaneous.

POSTOPERATIVE CARE

- Drain management: Hematomas and seromas can place undue pressure on the flap and pedicle, therefore compromising flow. Pay careful attention to drain output, and any hematomas should be drained operatively.
- Flap monitoring: Nursing staff should monitor the flap overnight, with checks for capillary refill, color, and warmth every 2 to 4 hours. A Doppler stitch can be used if needed. Evidence of congestion or ischemia should be noted immediately. Sometimes, release of sutures can help if undue tension is the source of the problem. Concerns for vascular compromise should prompt operative exploration to evaluate kinking or pressure on the pedicle
- Review the pathology results to confirm margins are negative from the original resection for all oncologic procedures.

COMPLICATIONS

- Flap loss: Complete flap loss is due to compromise of the vascular pedicle. Ideally, this would be discovered soon postoperatively with subsequent operative salvage. However, in the case of irreversible flap loss, the tissue

should be removed and other reconstructive options should be explored.

- Wounds: Recipient site wounds are relatively common and most often can be managed nonoperatively. This would include debridement as needed, local wound care, and close monitoring. The surgeon should avoid the urge to debride aggressively or perform additional procedures as most often, these wounds will heal secondarily.
- Infection: Most infections can be managed with antibiotics. Interventional drain placement is helpful for formed abscesses seen on imaging.
- Hematoma: Hematomas are possible at both the donor and recipient site. Drain output and physical exam are key. Hematomas should be drained surgically.
- Seroma: Late seromas can develop at the donor site. Most can be managed with drains and compression.

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Section III: Body Contouring

12

CHAPTER **Abdominoplasty**

Alan Matarasso and Darren M. Smith

DEFINITION

- Abdominal contour deformity results from relaxation of the abdominal wall and overlying soft tissues with childbearing, weight gain, aging, or a combination of the above.
- Rectus diastasis is the separation of the two rectus abdominis muscles in the midline; this separation, along with stretching of the abdominal fascia, constitutes the deepest anatomical layer responsible for the abdominal contour deformity.
- Lipodystrophy refers to excess adiposity, superficial to the abdominal wall, that contributes to the abdominal contour deformity.
- Skin excess (most frequently present after weight loss or pregnancy) is the most superficial anatomical component of the abdominal contour deformity.

ANATOMY

- The abdominal wall can be discussed in terms of three treatable tissue types, skin, fat, and muscle.
- Skin (from costal margin superiorly to mons pubis inferiorly, with lateral borders defined by the anterior axillary line)
- Fat in the abdominal region is either superficial or deep to the Scarpa fascia. Some surgeons aggressively excise subscarpal fat from the abdominoplasty flap, but this is not generally our practice.
- The rectus abdominis muscles are a paired midline structure that must be assessed in each abdominoplasty patient to determine the need for plication.

- Plication is generally indicated except in men and in the massive weight loss population.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Abdominoplasty patients should be low risk (eg, ASA I) healthy patients.
- Abdominoplasty patients should ideally have completed their childbearing, as future pregnancy will distort the result.
- Massive weight loss patients require heightened vigilance with regard to medical optimization given their unique risk profile.¹
- In addition to ensuring general good health in the abdominoplasty patient, special attention should be paid to venous thromboembolism (VTE) avoidance given the risk of this potentially catastrophic event after this procedure.²
- In a survey of more than 1100 plastic surgeons on VTE occurrence and prevention in their practices, VTE was found to occur most frequently with abdominoplasty and abdominoplasty combined with another procedure (without a significant difference in frequency between the two).³
- Thorough history taking and patient-specific risk reduction strategies based on the literature are critical in VTE avoidance.^{2,4}
- The physical exam should focus on identifying the degree to which the treatable tissues of the abdomen (skin, fat, and muscle) contribute to a given patient's abdominal contour deformity.
- Pre-existing scars should be evaluated with regard to their effect on blood supply to the abdominoplasty flap and to determine the best way to incorporate them into the incision design if they cannot be excised.

IMAGING

- No preoperative imaging is routinely performed prior to abdominoplasty.
- If hernias is suspected based on history or physical exam, an abdominal computed tomogram (CT) is indicated.

SURGICAL MANAGEMENT

- Choice of operation from the abdominoplasty system of classification and treatment⁵ based on physical exam findings with respect to the treatable tissues of the abdomen (skin, fat, and muscle) (**FIG 1**):
 - Type I (liposuction alone): Minimal skin laxity, excess adiposity, minimal rectus diastasis
 - Type II (mini abdominoplasty): Mild skin laxity, excess adiposity, lower

rectus diastasis

- Type III (modified abdominoplasty): Moderate skin laxity, excess adiposity, lower with or without upper diastasis
- Type IV (full standard abdominoplasty with or without liposuction): Severe skin laxity, excess adiposity, complete rectus diastasis
- Patients can be “downstaged” to less invasive options if they cannot accept a given scar or desire minimized recovery time, but it should be explained that a downstaged procedure cannot deliver the same result as the procedure that is indicated by the abdominolipoplasty system of classification and treatment.

Preoperative Planning

- Several red flag patient characteristics emerged from our experience that apply to combining abdominoplasty with any procedure.
- Pulmonary conditions, history of or propensity for VTE, cardiac insufficiency, peripheral vascular disease, hypertension, obesity, bleeding diathesis, smoking, exposure to secondhand smoke, and diseases affecting microcirculation (diabetes, lupus, chronic fatigue syndrome) should be investigated and dealt with prior to abdominoplasty.

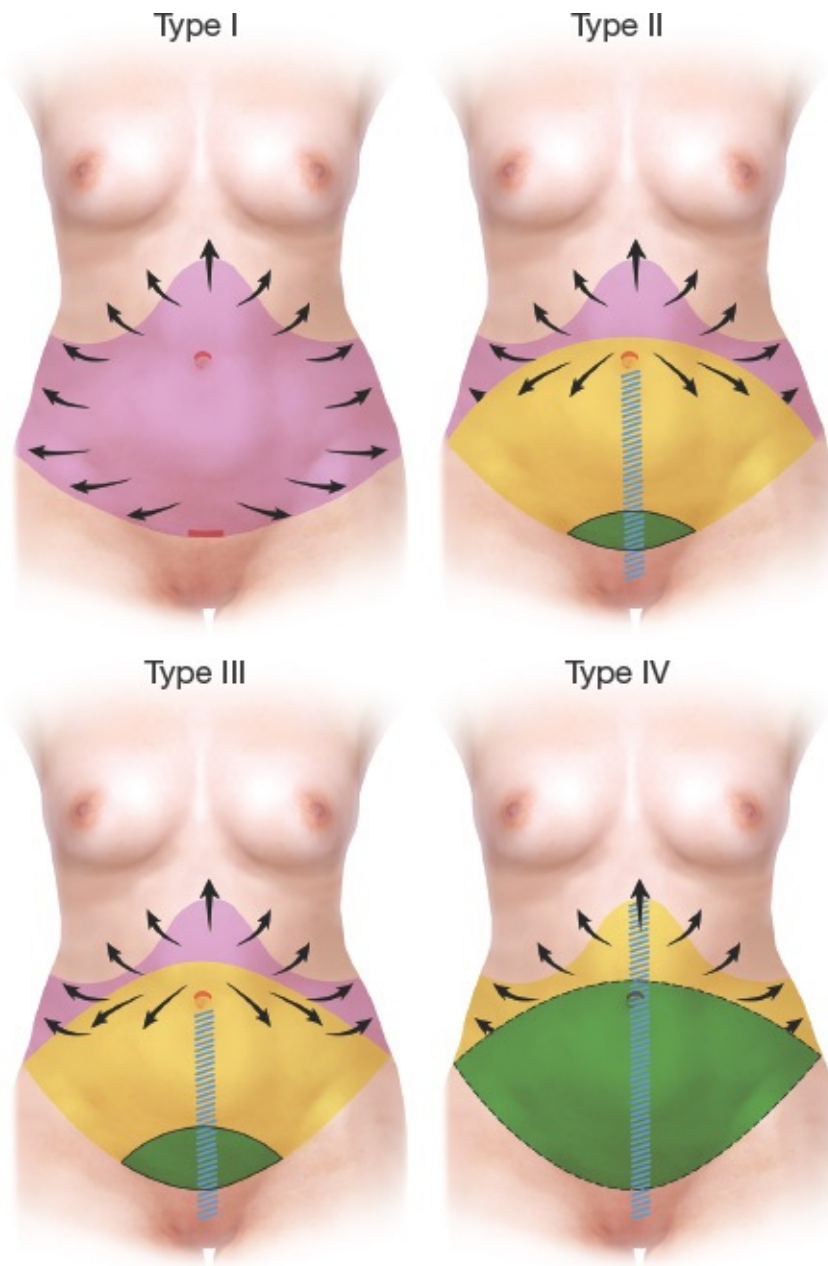


FIG 1 • The abdominolipoplasty system of classification and treatment. Type I, liposuction alone. Type II, mini abdominoplasty. Type III, modified abdominoplasty. Type IV, full standard abdominoplasty with or without liposuction. Types I and II are limited abdominoplasties. Pink, suction-assisted lipectomy; yellow, undermining; green, excision; blue cross-hatching, fascial plication; arrows, transitional area.

- A history of surgical site infections (especially involving methicillin-resistant *Staphylococcus aureus* [MRSA]) should also be addressed.
- With regard to VTE prevention, our patients discontinue the use of all female hormones (including drug-eluting patches and intrauterine contraceptive devices) and nicotine in the preoperative period. They are offered prothrombogenic blood test screening and postoperative venous Doppler testing.



FIG 2 • The Miami beach chair position. The surgeon must verify that the operating table can reach full flexion prior to beginning the case.

- Those at high risk for VTE based on history (Rubin's group offers a good review of criteria with which to assess historical risk⁶) are referred for hematologic workup.
- All of our patients are liberally hydrated and placed in compressive stockings and sequential pneumatic compression devices prior to the induction of anesthesia.
- A history of surgical site infection (especially those involving MRSA) should also be addressed.
- We routinely utilize nostril mupirocin ointment (GlaxoSmithKline, Research Triangle Park, NC) in the perioperative period, along with oral and intravenous antibiotics and antimicrobial body scrubs. Alcohol-based prep solutions are utilized at the time of surgery.

Positioning

- Prior to surgery, it is confirmed that the operating room table can reach a full beach chair position (**FIG 2**).
- The operation begins with the patient in the supine position.
- The symmetry and angle of the arm boards is confirmed, and the arms are secured to the arm boards with a gauze wrap.

Approach

- The operation is performed under systemic anesthesia (spontaneous ventilation general anesthesia, or spinal/epidural) administered by a board certified anesthesiologist in a certified ambulatory surgery facility.
- A Foley catheter is inserted and thromboembolic precautions are taken as discussed above.
- If multiple procedures are to be performed, the abdominoplasty is usually performed last.

TECHNIQUES

■ Abdominoplasty

Markings

- The abdominoplasty incision is marked with the patient wearing their preferred undergarment to ensure it covers the proposed incision.
- The abdominal excision, essentially an ellipse of tissue between the umbilicus and mons pubis, is determined by assessing the ease in which the lower abdominal skin (from umbilicus to hairline) can be excised after grasping the pannus with both hands in an attempt for the fingers to touch the thumbs.
- The pannus is held slightly upward and the lower incision is designed to traverse the natural lower skin crease, slightly below its normal position extending in length to just beyond the lateral skinfolds (noted in a sitting position) and approximately 5 to 7 cm above the vulva cleft.
- The upper incision is demarcated passing over the umbilicus to encompass the old umbilical site and only higher if there is obviously sufficient loose skin, forming an ellipse when joining the upper and lower incisions; a flexible ruler bent to trace the lower incision and flipped along its horizontal

axis can be helpful in designing this incision.

- Bisecting perpendicular lines are marked through it to line up the skin edges for closure.
- The incision for umbilical circumscription is drawn and its four quadrants marked.

Liposuction

- The abdomen is infiltrated with approximately 1 L of superwet anesthesia (1 L Ringer lactate, 1 mL 1:1000 epinephrine, 20 mL 1% lidocaine).
- Liposuction is then performed as indicated.

Verifying Incisions

- The incisions are checked for symmetry by placing 0-silk sutures in the midline at the xiphoid and the mons below the lower incision.
- The sutures are crisscrossed and grasped with a clamp.
- The clamp is then moved to either side of the midline at various points on the upper and lower skin incision lines to confirm symmetry.

Incisions and Dissection

- The abdominoplasty commences by freeing the umbilicus from the rest of the ellipse to be excised during the abdominoplasty.
- The pannus is then prepared for pre-excision in a vest-over-pants fashion by sharply incising the upper limb of the ellipse to the level of the rectus fascia while beveling the cut inward at a 45-degree angle.
- The upper abdominal flap is then completely undermined with electrocautery in a narrow tunnel (inverted V) corresponding to red suction area 3 (the zone of complete undermining) (**TECH FIG 1**).

Selective Undermining and Suctioning

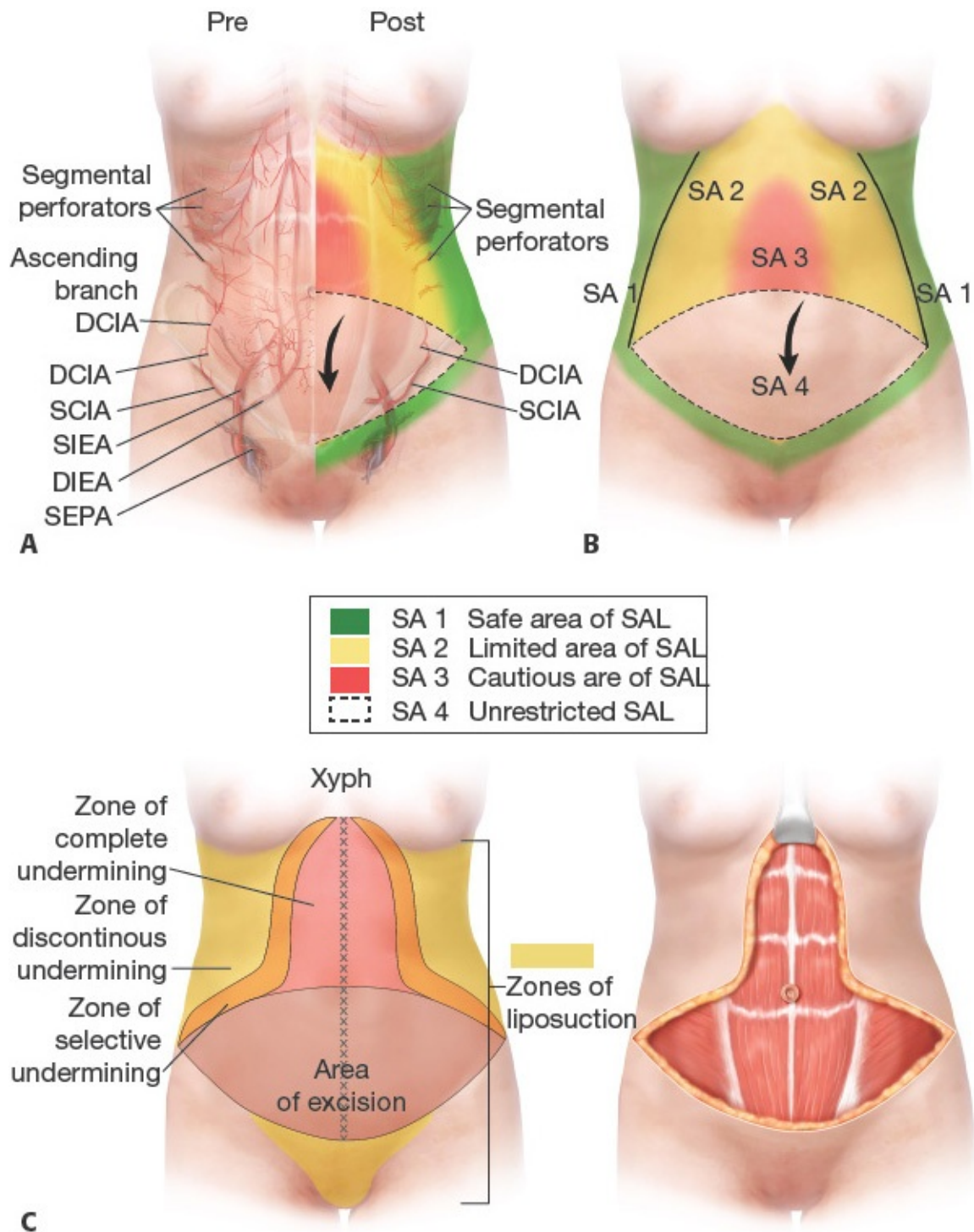
- An intact zone surrounding this tunnel (yellow area in **TECH FIG 1A,B**, which corresponds to suction area 2 or the zone of selective undermining in **TECH FIG 1C**) is undermined as necessary to decrease skin bunching after muscle closure.
- This pattern of dissection maintains intercostal blood supply sufficient to achieve rectus muscle plication.
- Dissecting in this manner maintains a broad intact subcostal perforator blood supply (green area in **TECH FIG 1A,B** or zone of discontinuous undermining in **TECH FIG 1C**, of axial blood supply corresponding to

suction area 1) that has been discontinuously undermined by the liposuction.

- The entire flap can thereby be suctioned during full abdominoplasty, giving rise to the term *lipoabdominoplasty*.
- This operative sequence serves as a standard template and is adjusted according to individual patient needs unless they do not require liposuction, in which case it is not performed.

Confirming Height of Lower Incision

- The operating room table is then flexed and the upper skin flap is pulled over the pannus to verify that it reaches the proposed lower skin incision (**TECH FIG 2A**).
- If the flap does not reach, it can be stretched, further undermined as appropriate, Scarpa fascia scored, or adjustments in the height of the lower incision can be made, if necessary.
- The lower incision is made to the level of the fascia after it has been determined that the upper flap can reach it for closure.



TECH FIG 1 • A. The abdominal blood supply before and after abdominoplasty. **B.** Suction areas (SA) 1 to 4 are determined by these patterns of blood supply. Suction area 4 is not suctioned; it is excised. **C.** The

types of undermining in abdominoplasty can be divided into zones. Complete undermining is performed only as much as necessary to allow for abdominal plication. Note how these zones correspond to the abdominal blood supply detailed in **(A)** and **(B)**.

Excision of the Pannus

- Although some have suggested that leaving a thin layer of fibrofatty tissue on the fascia reduces seroma formation, this is not our practice.
- Special care must be exercised during the dissection in the massive weight loss population as a large pannus can distort the anatomy and bring the spermatochord into the field.
- The pannus is then grasped with Allis clamps and excised en bloc, from right to left.
- An ocular conformer is sutured to the umbilicus to facilitate later identification, and removed when the umbilicus is later exteriorized.
- The surgeon and assistants are actively achieving hemostasis at each step of the operation.

Rectus Plication

- Next, the rectus diastasis is marked in a long vertical ellipse from xyphoid to pubis such that it can be closed without excessive tension (**TECH FIG 2B**).
- The section above and then below the umbilicus is plicated in layers, first with running 0-loop nylon sutures and then a second layer of buried interrupted 2-0 Neuroton sutures.
- Puckering developing in the upper skin flap where it is still attached to the underlying muscle after fascial closure (**TECH FIG 2C**) is gently freed by selective blunt and sharp dissection (zone of discontinuous undermining).
- Small amounts of bunching (resolves in early postoperative period) are tolerated and indeed desirable as this is indicative of preserved lateral intercostal blood supply.

Preparing for Flap Inset

- At least 30 minutes after lidocaine administration and prior to wound closure, Exparel (1.3% bupivacaine liposome suspension, Pacira

Pharmaceuticals, Parsippany, NJ) is injected linearly using a threading technique at strategic submuscular points and in the wound edges.

- The supplied 20-cc single-use vial of Exparel is diluted in 80 cc of preservative-free normal saline; 0.25% Marcaine can be added if desired and safe dosage levels allow.
- The cavity is irrigated, and final inspection and hemostasis are performed.

Closure

- The table is returned to the degree of beach chair position necessary for wound closure.
- Closure commences with placement of a 2-0 Vicryl suture in the midline.
- Staples are used to align the wound edges and minimize dog-ear formation.
- A 2-0 PDO bidirectional barbed suture (Quill SRS, Angiotech, Vancouver, Canada) is run in the deep layers from the Scarpa fascia to the dermis on either side of the midline.
- When most of the wound is closed, the ocular conformer on the umbilicus is palpated below the flap and marked on the skin in the midline slightly cephalad to its natural position.
- A second layer of 3-0 monoderm Quill is run in the subcuticular layer.
- Closed suction drains are placed in the incision (3 to 5 cm from the lateral extent of each side) and are secured with 3-0 nylon sutures.

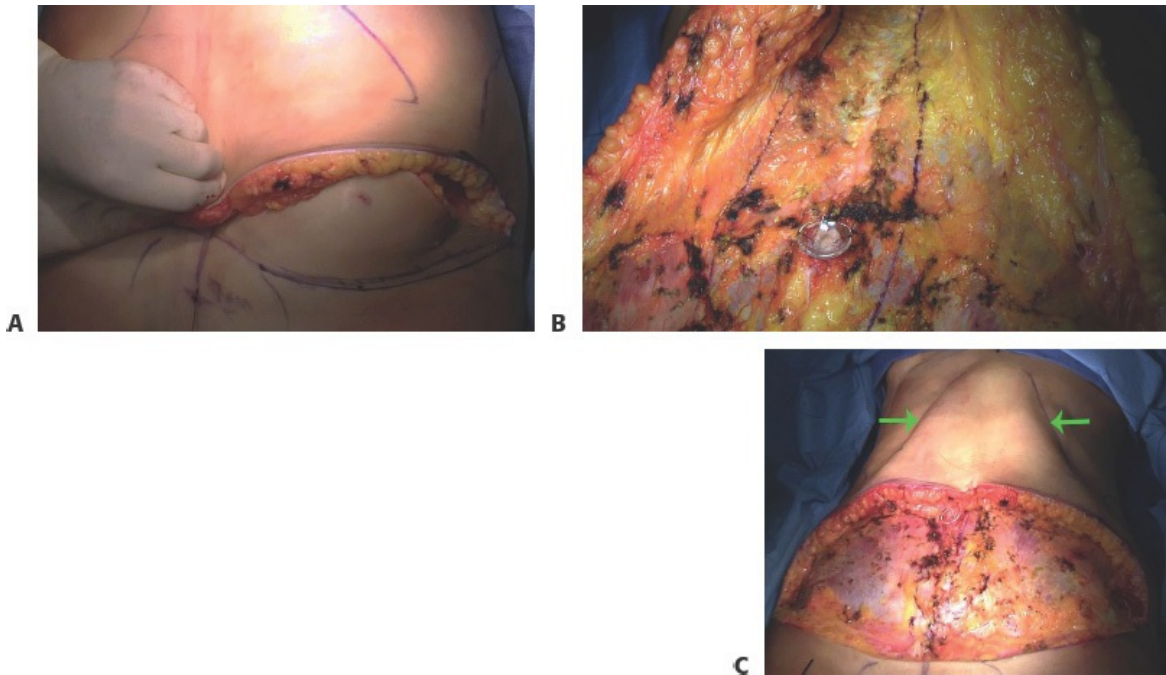
Exteriorization of Umbilicus

- To exteriorize the umbilicus, the patient's midline is verified with the silk marking sutures and by observing the position of the vulva cleft.
- The new umbilical site is determined and marked as a 2.5-cm inverted V in the midline.
- The upper and (more so) lower skin edges of the umbilical opening are defatted.
- The umbilicus is exteriorized and the ocular conformer is removed.
- The umbilicus is sewn to the skin flap with deep absorbable sutures, and the umbilical skin is closed with 3-0 nylon sutures.

Application of Dressings and Binder

- A strip of Xeroform gauze is used to pack the umbilicus.
- The wound is covered with antibiotic ointment, and it is covered with a Telfa dressing.

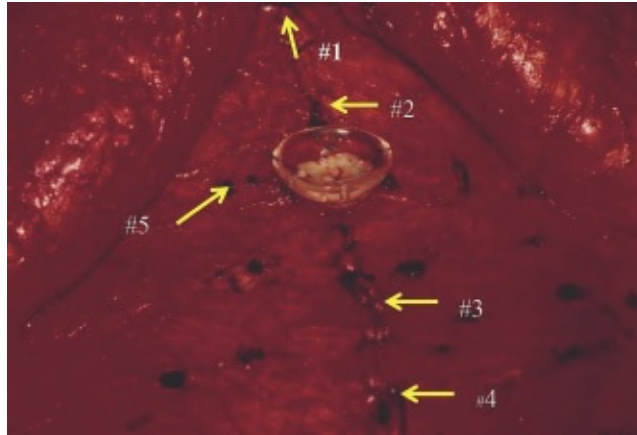
- An abdominal binder can be used if desired.



TECH FIG 2 • A. The upper flap is pulled down to the proposed lower incision before the lower incision is made so that the ability to close is ensured. **B.** The plication is marked as an ellipse above and below the umbilicus, shown here sutured to an ocular conformer. **C.** The *arrows* highlight skin puckering evident after abdominal wall plication. This is released selectively by blunt and sharp dissection (zone of discontinuous undermining).

■ Achieving a Narrower Waistline

- Abdominoplasty patients frequently request a narrower waistline, but this result cannot be guaranteed.
- Appropriate rectus plication will achieve maximal waistline narrowing, although two maneuvers (selective waistline liposuction and, in patients with minimal visceral fat, horizontal waistline sutures) can contribute a modest improvement (**TECH FIG 3**).



TECH FIG 3 • The rectus fascia has been plicated in two layers from xyphoid to pubis. Anatomic landmarks are highlighted: 1, toward the xyphoid; 2, supraumbilical region; 3, arcuate line of Douglas; 4, pubic bulge; 5, level of waistline suture (if indicated).

PEARLS AND PITFALLS

Multiple procedures

- Abdominoplasty is frequently combined with other procedures.²
- If multiple procedures are planned in a surgery, abdominoplasty is usually the last to be performed.

Venous thromboembolism

- Abdominoplasty is the ambulatory plastic surgery procedure most frequently associated with venous thromboembolism; precautionary measures should be taken pre-, intra- and postoperatively.

Hemostasis

- It is prudent for the surgeon and assistants to ensure hemostasis at each stage of the procedure.

Communication

- Review the areas to be addressed with the patient prior to surgery.
- This conversation is critical in maximizing the chances of a positive outcome for the patient and success for the surgeon.

POSTOPERATIVE CARE

- The patient is transferred to a stretcher in the maximally flexed position used for closure.
- Patients should ambulate that day as if using a walker and over the next few days begin to walk fully upright.
- The first 24 to 48 hours after surgery are spent in a hotel-like facility under the care of an experienced registered nurse.
- Blood pressure management, pain control, fluid and food intake, ambulation, hygiene, and pulmonary care are carefully protocolized.
- Drains are removed as early as permitted by character and volume of drainage.
- Patients are inspected frequently for seroma formation, as untreated seromas can result in a variety of sequelae and late contour irregularities such as pseudobursa formation.
- Any concern for thromboembolic events prompts an immediate workup.
- Appropriate pain management is essential not only in enhancing the patient's experience but also in avoiding a host of serious problems such as paralytic ileus and hematoma formation.⁷

OUTCOMES

- Abdominoplasty patients are generally very happy with the result of their operation.
- Perhaps the most common cause of dissatisfaction with abdominoplasty is poor communication between patient and surgeon prior to the operation.
 - It is particularly important to discuss anatomic boundaries with patients so there is a clear mutual understanding of the areas to be treated (eg, soft tissue laxity in the flanks requires a flankplasty) (**FIG 3**).
- Clear communication is essential to ensure that:

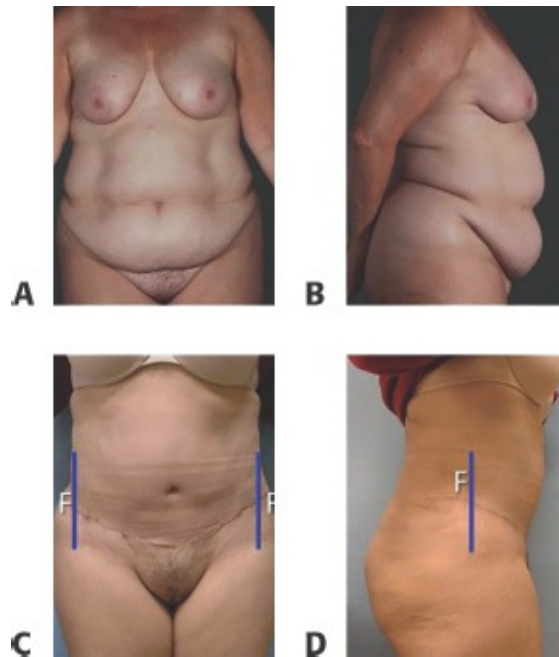


FIG 3 • Preoperative (**A,B**) and postoperative (**C,D**) images of a patient who underwent abdominoplasty with flankplasty. The flankplasty is a prime example of a procedure that underscores the importance of discussing anatomic boundaries with the abdominoplasty patient. To address the flanks (lateral to the vertical lines in **C** and to the left of the line in **D**), the abdominoplasty incision must be extended.

- The proper operation is selected and that if downstaging is to occur, its full repercussions are understood.
- The anatomic limits of the abdomen and surrounding aesthetic units are defined, especially with regard to liposuction to avoid misplaced expectations in terms of areas to be treated.

COMPLICATIONS

- Abdominoplasty carries the highest complication rate (4.7%) of all aesthetic surgery.⁵
- Seroma is the most common complication after abdominoplasty⁵ and is avoided by using closed suction drains and maintaining postoperative vigilance.

- The most dreaded complication of abdominoplasty is pulmonary embolism, which occurs in 0.19% of abdominoplasties, underscoring the importance of the anti-VTE measures discussed earlier.⁵
- Tissue ischemia can be minimized by exercising meticulous technique, an awareness of blood supply, and good judgment in reconciling the extent of liposuction with tension on wound closure.
- Avoidance of tissue ischemia can be further ensured by paying close attention to the method and extent of undermining performed.
- All wounds are examined for signs of ischemia the night of surgery and the next morning.
- If ischemia is noted, any reversible causes such as fluid collection, cellulitis, infections, or wound tension (that can be relieved by suture removal) are addressed.
- If signs of ischemia progress, dimethyl sulfoxide or nitroglycerine ointment may be employed.
- Should frank necrosis evolve, standard wound management principles apply.

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13

CHAPTER Abdominal Panniculectomy

Devra B. Becker

DEFINITION

- Abdominal panniculus derives from the Latin *pannus* (cloth, garment), the diminutive of which is *panniculus* (piece of cloth).
- *Pannus* was used to describe “wrinkled or flabby skin” by the Roman Pliny, but is distinct from the Greek *panus*, meaning swelling (*panus inguinalis*). *Pannus* is defined in modern usage as an abnormal layer of granulation tissue covering the eye or synovial space.
- Panniculus morbidus was described in Petty and colleagues’ 1992 article that reported on eight patients who had restored function after wedge resection.¹
- A symptomatic panniculus can be graded by function²:
 - Grade I: chronic skin problems confined to the lower abdomen
 - Grade II: chronic skin problems around the naval or under a supraumbilical panniculus as well as an infraumbilical panniculus
 - Grade III: abdominal panniculus without chronic skin problem

ANATOMY

- An abdominal panniculus is so defined by redundant skin of the abdomen that can have both horizontal and vertical excess.
- There are three vascular zones of the abdomen as described by Huger.³
 - In Zone 1 (bounded craniocaudally from xiphoid to pubis and laterally by the lateral extent of the rectus sheath), the blood supply is the deep epigastric arcade.
 - In Zone 2 (bounded craniocaudally from a line drawn from the anterosuperior iliac spine [ASIS] to the pubis, and laterally by the inguinal creases), the blood supply is the superficial branches of the circumflex iliac and external

pudendal vessels.

- In Zone 3 (bounded craniocaudally by the costal margin to the ASIS and laterally extending from the lateral rectus sheath to the midaxillary line), the blood supply is intercostal, subcostal, and lumbar arteries.
- Nerve supply to the abdominal wall is segmental and dermatomal, from T7-L1.
- The lateral femoral cutaneous nerve from L2-L3 innervates the anterolateral thigh and travels medial to the ASIS.
- The iliohypogastric and ilioinguinal nerves pierce the internal oblique muscle and travel along the external oblique muscle to provide sensation to the inner thigh and the groin and symphysis pubis.

PATHOGENESIS

- Risk factors for development of abdominal panniculus after bariatric surgery include a higher pregastric bypass body mass index (BMI) and advanced age.⁴

NATURAL HISTORY

- Symptomatic panniculitis is characterized by intertrigo that is refractory to conservative management with desiccants such as powder and topical antifungals.

PATIENT HISTORY AND PHYSICAL FINDINGS

- For patients who have had bariatric surgery, the surgeon should assess the type of bariatric surgery the patient had (restrictive, or restrictive and malabsorptive), time from surgery, total weight loss, and length of time that weight has been stable.
- Nutritional status should be addressed, including protein needs and any micronutrient deficiency.
- History should be assessed for patient reports of functional impairment, particularly with activities that require hip flexion such as cycling or walking up stairs, intertrigal rashes refractory to conservative management with desiccants and antifungals, and back pain.
- Physical exam should include inspection for scars and extent of panniculus, relationship of panniculus to the symphysis pubis, scars, abdominal striae, quality of skin, mons pubis edema and ptosis, intertrigal rashes or ulceration, intertrigal hyperchromia, vertical and horizontal excess, and asymmetry.
- The abdomen should be palpated to assess for hernia, rectus diastasis, skin

elasticity, and extent of subcutaneous fat (**FIG 1**).

- Factors important to surgeons are different from factors important to insurance companies.⁵
- Surgeons value stability of weight for 6 months, and time from bariatric surgery of 18 months, whereas insurance companies value chronic maceration of skinfolds.
- There is no consensus on the most appropriate BMI at which to perform panniculectomy, but postoperative events increase with increasing BMI.
- Panniculectomy can be safely combined with other procedures.
 - In hysterectomy, panniculectomy can decrease wound dehiscence and increase ease of hygiene⁶ without increasing complications,¹⁶ as well as increase exposure of the pelvis.
 - In cases of uterine cancer, concurrent panniculectomy can result in greater total lymph node counts.⁷
 - When combined with hernia repair, it can decrease recurrence.⁸

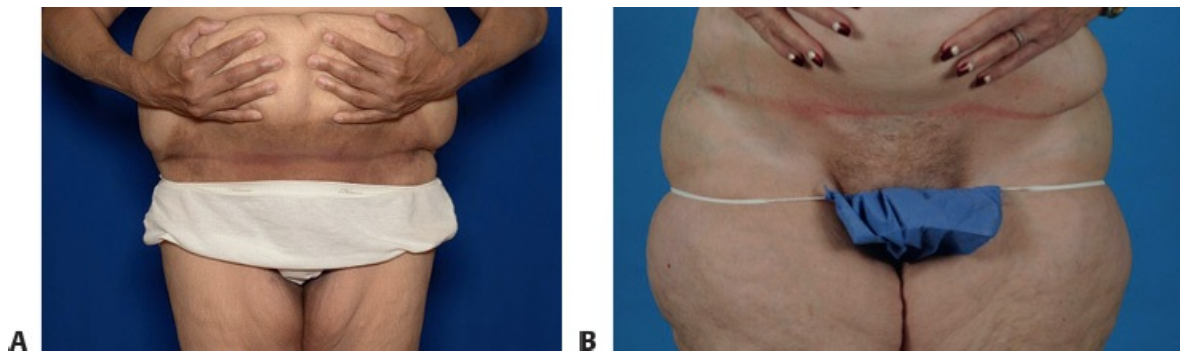


FIG 1 • Physical exam should include inspection as well as palpation. The relationship of the panniculus to the pubis should be assessed, as well as intertrigo. Photographs with the panniculus lifted help to identify hyperchromia and intertrigo.

IMAGING

- Routine imaging is not necessary in the presence of an adequate physical exam, but CT should be obtained in the case of hernia (**FIG 2**).

NONOPERATIVE MANAGEMENT

- Nonoperative management should be aimed at improving function.

- Weight loss, physical therapy for muscle rebalancing, and hygiene for intertrigo reduction are nonoperative strategies that should be trialed for several months.

SURGICAL MANAGEMENT

- If the umbilical stalk is greater than 5 cm or if it is involved in a hernia, it may need to be sacrificed. Discussion of the umbilicus should be frank (**FIG 3**).
- Blood transfusions are often not necessary, but some blood loss is expected. Transfusion rates have been reported from 9% to 12%.⁹
- Risks of the procedure include bleeding, hematoma formation, skin flap necrosis, fat necrosis, and asymmetry.⁹
- If a wedge excision is planned, whether the umbilicus will remain is determined based on its location cephalad to the panniculus.
- The main objective of the operation is to reduce the redundant skin and subcutaneous fat inferior to the umbilicus that creates the panniculus.

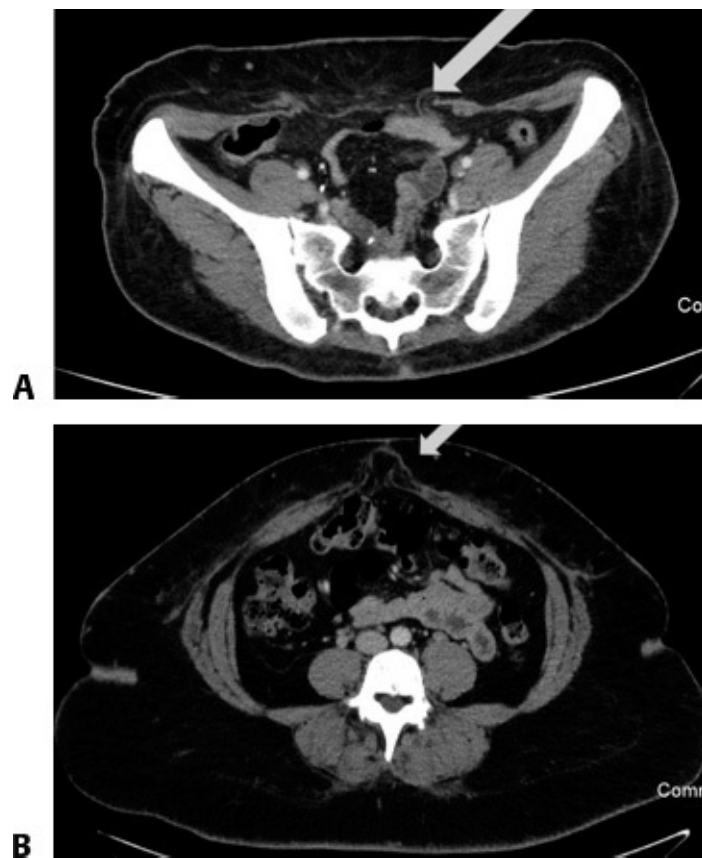


FIG 2 • CT scan can help delineate the extent of a hernia and can help with preoperative planning.

- The luminal diameter of vessels is increased in obese patients, and there is some evidence that the luminal diameter remains increased with massive weight loss.
- Surgeons should be mindful of the larger caliber vessels encountered in panniculectomy, even in massive weight loss patients.
- The ability to close should be determined prior to resection.

Preoperative Planning

- Patients are assessed by Caprini score for deep vein thrombosis (DVT) risk assessment.¹⁰
- CT scans are obtained if there is clinical concern for hernia. If a hernia is present, a combined hernia repair and panniculectomy is planned.
- Patients often have some asymmetry of the panniculus; this is identified and discussed with the patient.
- Best practices in planning panniculectomy in the bariatric population are
 - Ensuring realistic expectations¹¹
 - Allowing for at least 12 months after bariatric surgery to allow for nutritional and metabolic homeostasis
 - Allowing for a stable weight for at least 6 months
- Surgery should be performed by a board-eligible or board-certified surgeon.¹¹
 - Postoperative events have been shown to be lower when the procedure is performed by plastic surgeons compared with general surgeons.⁸

Positioning and Anesthesia

- The operation is performed with the patient in the supine position.



FIG 3 • The umbilicus should be assessed. In this case, the umbilicus is within the panniculus, and the stalk is likely greater than 5 cm. It may need to be sacrificed.

- If the lateral extent of the planned resection cannot be reached in the supine position, the patient is placed on a beanbag for intraoperative adjustment.
- SCDs are placed prior to induction of anesthesia.
 - The authors do not use a Foley urinary catheter unless the operation is going to be longer than 5 hours.
- General anesthesia is used.
- A transversus abdominis plane block can be used as an adjunct.
- Normothermia is important in the operating room. Operative hypothermia is associated with increased seroma formation and blood loss.

TECHNIQUES

■ Abdominal Panniculectomy with Umbilical Transposition

Markings and Incision

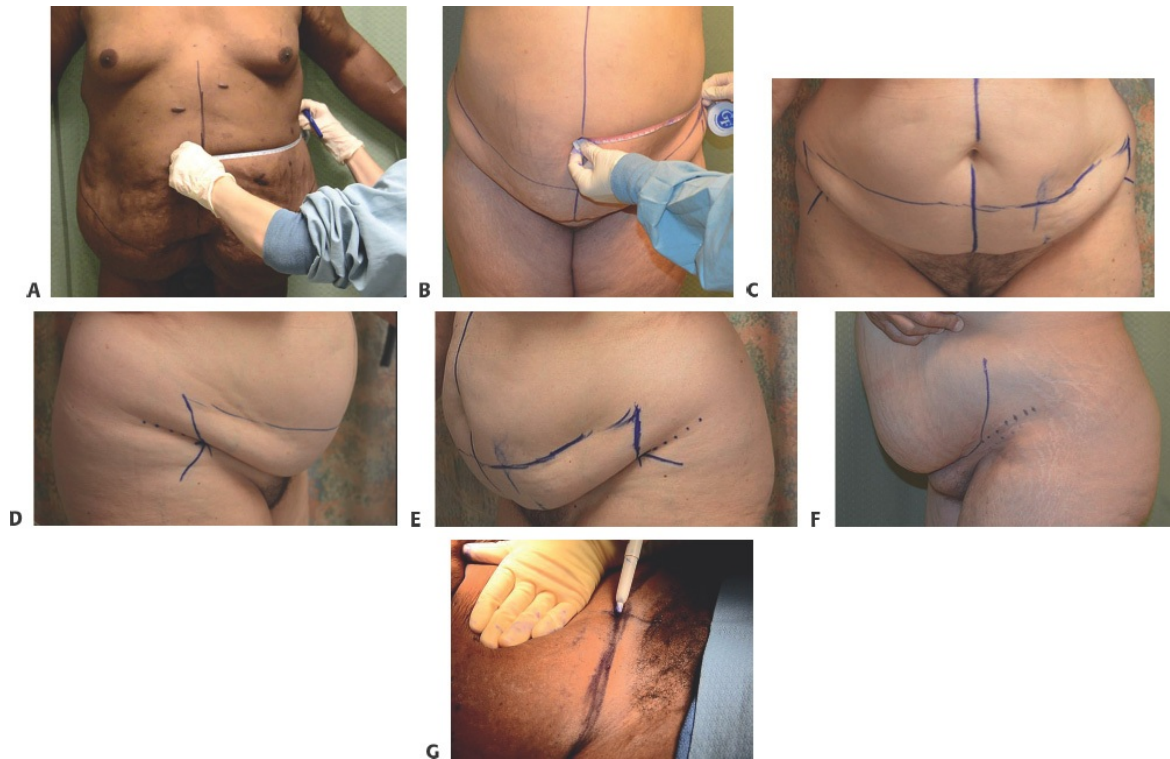
- The patient is marked in the standing position, and the lateral extent of the

panniculus is marked (**TECH FIG 1A,B**).

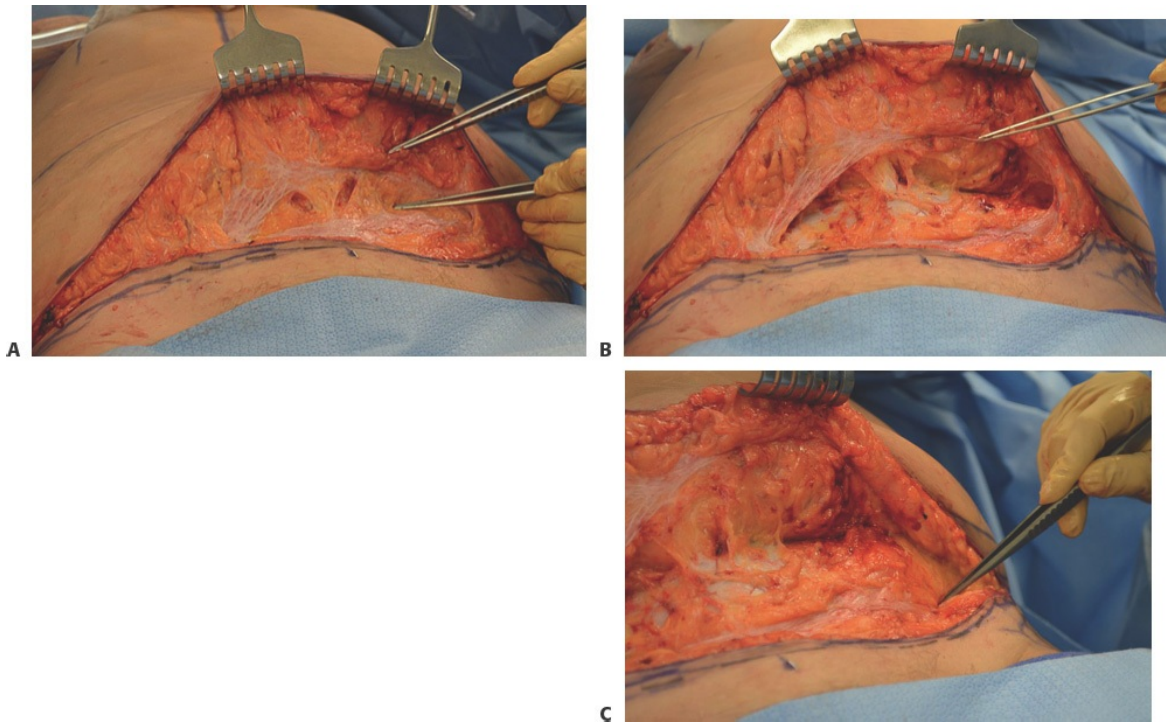
- The authors use a measuring tape to confirm the distance of the lateral extent of the scars from the midline.
- To avoid a dog-ear, an inflection point is made, transitioning the scar from a horizontal vector to a vertical vector (**TECH FIG 1C–F**).
- Use staples to mark the midline cranial to the umbilicus and at the midline of the mons.
- The inferior incision is often placed in the lower abdominal crease.
 - The authors prefer to make the incision slightly cranial to that crease, which avoids a step-off between the abdominal skin and the mons pubis (**TECH FIG 1G**).
- Vessels are cauterized with electrocautery or tied with suture and divided. Vessels within the panniculus can often be large.

Dissection

- Scarpa fascia is identified and divided with electrocautery.
- The fat superficial to Scarpa fascia is often lobular, and deep to Scarpa fascia often has a stromal appearance. The deep fatty layer is often very thin (**TECH FIG 2A,B**).
- The rectus fascia is identified. Although the fascia itself can be skeletonized, we leave a thin layer of tissue over the rectus fascia.
 - Perforators are divided several millimeters superficial to the fascia, because once divided, they will retract, and bleeding can be better managed if they have not retracted within the muscle.
- Leave fat along the ASIS to protect the lateral femoral cutaneous nerve (**TECH FIG 2C**).



TECH FIG 1 • A. The lateral extent of the incision can be measured in both directions from the midline to increase symmetry. **B.** It can also be measured from the umbilicus, which provides a reference on both the mediolateral dimension as well as the craniocaudal dimension, although if the umbilical stalk is long, it may not be midline at the time of measurement. **C–F.** Creating an inflection point can help reduce dog-ears. Shown is the transition medial to the lateral extent or the panniculus. **G.** Marking the inferior incision slightly superior to the fold helps to avoid a step-off between the mons and the abdominal flap.



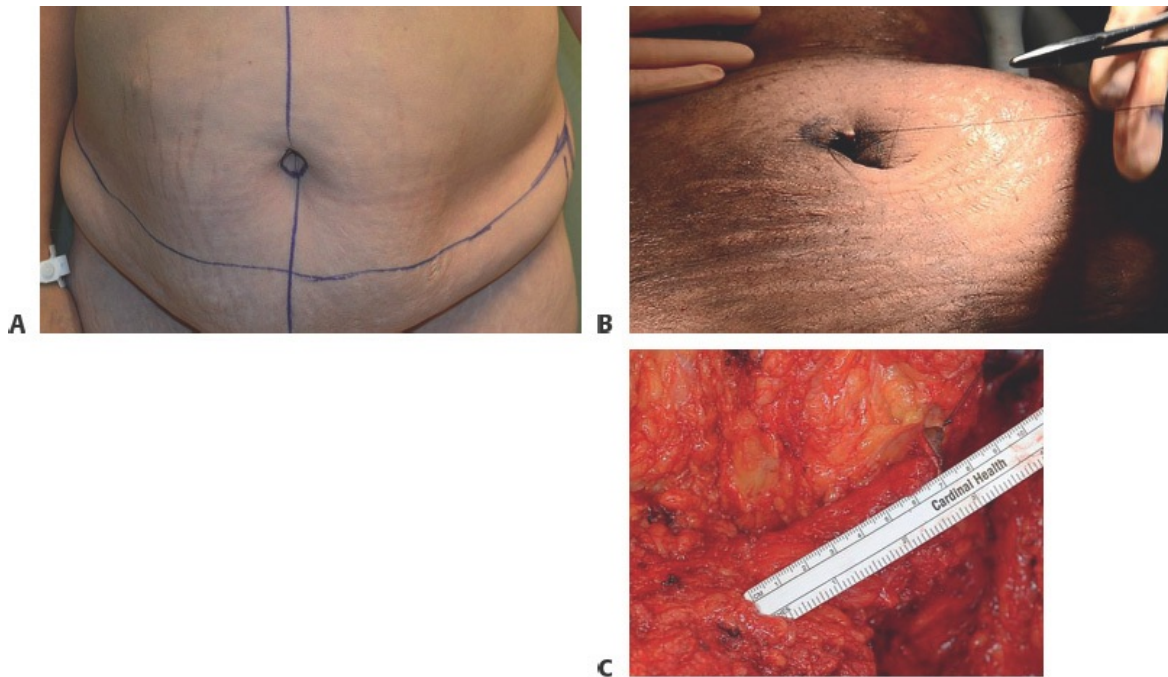
TECH FIG 2 • The fat superficial to Scarpa fascia is more lobular than the fat deep to it, and the deep fatty layer can be thin. **A.** Upper forceps demonstrate fat superficial to Scarpa fascia, and the lower forceps demonstrate fat deep to Scarpa fascia. **B.** The forceps indicate Scarpa fascia. **C.** A layer of fat can be left over the ASIS to protect the lateral femoral cutaneous nerve. It can also be identified visually. Forceps indicate level of ASIS.

Umbilical Transposition

- If umbilical transposition is planned, the dissection is continued cranially until there is approximately 2 cm of subcutaneous fat inferior to the umbilicus to prevent inadvertent disruption of umbilical blood supply.
- Use a surgical marker to mark out the umbilicus. The authors mark in the natural fold of the umbilicus (**TECH FIG 3A,B**).
- The stalk of the umbilicus is separated from the surrounding subcutaneous fat using either Metzenbaum scissors or electrocautery.
- The authors do not skeletonize the stalk, and if the stalk is long, they leave

a generous amount of fat on the stalk to avoid separating perforators (**TECH FIG 3C**).

- Once the umbilicus has been isolated, the dissection continues superiorly to the xiphoid process.
 - The dissection plane becomes more difficult to identify as there is more adherence between the rectus abdominis fascia and the subcutaneous tissue.
- In the case of umbilical sacrifice, the umbilicus is taken as part of the resection specimen, and the stalk is cauterized or tied off.



TECH FIG 3 • **A.** The umbilicus is marked in its natural fold. An umbilicus that is too small can be difficult to clean. **B.** A suture is placed at 12 o'clock to ensure proper orientation at inset and can aid in traction during incision. **C.** When the patient has a long umbilical stalk but the umbilicus is being preserved and transposed, a generous layer of fat can help preserve blood supply.

■ Flap Advancement and Skin Resection

- Once the flap is fully dissected (**TECH FIG 4A**), it is advanced inferiorly and the amount to be resected is determined. If needed, the patient can be placed in a slight reflex position.
- Indocyanine green can be used intraoperatively to assess viability of flaps and can predict wound healing complications.
- The excess panniculus is resected and passed off the table to be weighed.
- If there is a vertical component, the skin can be imbricated with staples to determine a safe amount of resection (**TECH FIG 4B-F**).
- Drains (19-French round hubless channel drains) may be placed underneath the flaps, although progressive tension closure using barbed suture has been demonstrated to be an alternative to drains.
- The receiving bed for the umbilicus is created by measuring the actual size of the umbilicus and drawing a template on the abdominal wall.
 - The template is placed where the umbilicus is positioned when the stalk projects orthogonal to the abdominal wall, and the distance from the mons is measured to ensure that there is adequate skin (**TECH FIG 4G**).

Closure

- The Scarpa layer can be closed using either interrupted or running suture, but it is not always necessary.
- The skin is closed in layers using 3-0 poliglecaprone 25 or glycomer 631 for both the deep dermal and the subcuticular layers.
- The umbilicus is repaired using 3-0 poliglecaprone 25 or glycomer 631 for the deep layers and either 4-0 poliglecaprone 25 or glycomer 631 in a running subcuticular stitch of 5-0 fast as a running baseball stitch.
- All incisions are waterproofed with a cyanoacrylate tissue adhesive.
- An abdominal binder is placed.



TECH FIG 4 • A. The fully dissected flap. **B–D.** If there is a fleur-de-lis component, the skin can be imbricated to determine a safe amount for resection. A marking pen is used to reinforce the boundaries (**E**), and the

staples are removed and the skin is resected **(F)**. **G**. The receiving bed for the umbilicus is placed at the position of the umbilicus as it projects from the abdominal wall. The surgeon places a hand under the flap to demonstrate the location of the umbilicus.

PEARLS AND PITFALLS

Physical findings

- Intertrigo is common and should be assessed. Asymmetry of the panniculus is common and should be identified and discussed with the patient preoperatively.

Technique

- Dog-ears can be reduced by transitioning the direction of the scar at its lateral extent.
- A layer of fat left on the ASIS can help prevent injury to the lateral femoral cutaneous nerve
- When performing an umbilical transposition, marking a receiving bed for the umbilicus based on the measured dimensions of the umbilicus will result in a natural-appearing umbilicus.
- Indocyanine green techniques can be employed to determine flap viability.
- The best position for the umbilicus is along a line drawn between the iliac crests. If the umbilicus is not transposed but remains in situ, a 10-cm flap of skin should remain between the umbilicus and the mons.
- Consider a fleur-de-lis approach if there is both vertical and horizontal skin laxity.¹²

Postoperative

- DVT prophylaxis should be considered.
- Adequate fluid resuscitation is critical, particularly in bariatric surgery patients.

POSTOPERATIVE CARE

- Patient should wear an abdominal binder for 6 weeks.
- Drains should remain until output is less than 30 cc/d.
- Postbariatric patients should have fluid status monitored closely—because of

decreased gastric volume, they cannot orally resuscitate at the same rate as nonbariatric surgery patients.

- Ambulate the day of surgery. Most procedures are performed as outpatient procedures or 23-hour observation.
- Postoperative analgesic medication as needed
- DVT prophylaxis should continue. American Society of Plastic Surgery consensus guidelines are 1 month of postoperative chemoprophylaxis.

OUTCOMES

- Functional outcomes of panniculectomy are often good (**FIG 4**).
- Patient satisfaction is high, regardless of technique used.⁹
- Body image and quality of life are improved after body contouring in bariatric surgery patients.^{13,14}

COMPLICATIONS

- Some studies have shown that postoperative events are correlated with BMIs greater than 30.⁹
- Patients who have had weight loss surgery are at increased risk of postoperative events when compared to patients who have not; the most common events are wound healing problems, wound infection, hematoma, and seroma.¹⁵
- It is unclear if the likelihood of bariatric surgery patients being more likely to have a history of diabetes mellitus, more likely to be smokers, or more likely to have a higher ASA class, is contributory.
- Undiagnosed vitamin deficiency can lead to postoperative events.
- Contour deformity can occur, and scar asymmetry can be seen. Scar asymmetry may be difficult to assess in initial marking, particularly with a large panniculus.
- The skin quality of the massive weight loss patient is not the same as in nonmassive weight loss patients.



FIG 4 • Preoperative (**left**) and postoperative (**right**) views of a patient who had a combined panniculectomy and hernia repair. She noted improved mobility and decreased rashes after the procedure.

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14 Abdominal Panniculectomy in Super Obese Patients

CHAPTER

David J. Rowe

DEFINITION

- Over 60% of the US population is overweight.
- Over 30% is obese by BMI stratification.
- Super obese is classified as BMI greater than 50, super-super obese is BMI above 60.

ANATOMY

- The anatomy of the abdominal panniculus is discussed in Chapter 13.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for a patient with super obese panniculus includes a detailed history as well as documentation of pertinent physical manifestations.
- Physical examination
 - Large abdominal panniculus
 - Intertriginous rashes
 - Chronic infection
 - Ulcerations
 - Fistulous tracts
 - Physical limitation
 - Presence of hernia: difficult given overlying tissue

IMAGING AND OTHER DIAGNOSTIC STUDIES

- If hernia is suspected, CT scan with contrast is warranted (**FIG 1**).
- Preoperative laboratory values: patients who have had previous gastric bypass will need a preoperative workup that will be discussed more in detail in other

chapters. Given the likely comorbidities of the super obese, nutritional parameters may also be evaluated in the workup of all patients.

- Nutritional parameters: albumin, prealbumin
- Lab workup: CBC, basic chemistry

NONOPERATIVE MANAGEMENT

- The primary decision in the instance of panniculectomy in the super obese patient is the possibility of weight loss or gastric bypass prior to surgery.¹
- In the case of panniculus morbidus, the pannus may still be present following weight loss.²
- In the case of combined surgery for cancer extirpation, etc., ideal weight loss may not be achieved.

SURGICAL MANAGEMENT

- Indications for surgery include overhanging panniculus interfering with ambulation and undergoing combined abdominal operations (eg, hysterectomy, tumor extirpation, hernia repair; **FIG 2**).
- Risks to the patient include an increase of overall complication rate given the extremely high BMI, increased risk of prolonged hospitalization, need for further surgical intervention, wound healing complications, and increased bleeding when compared to traditional panniculectomy.

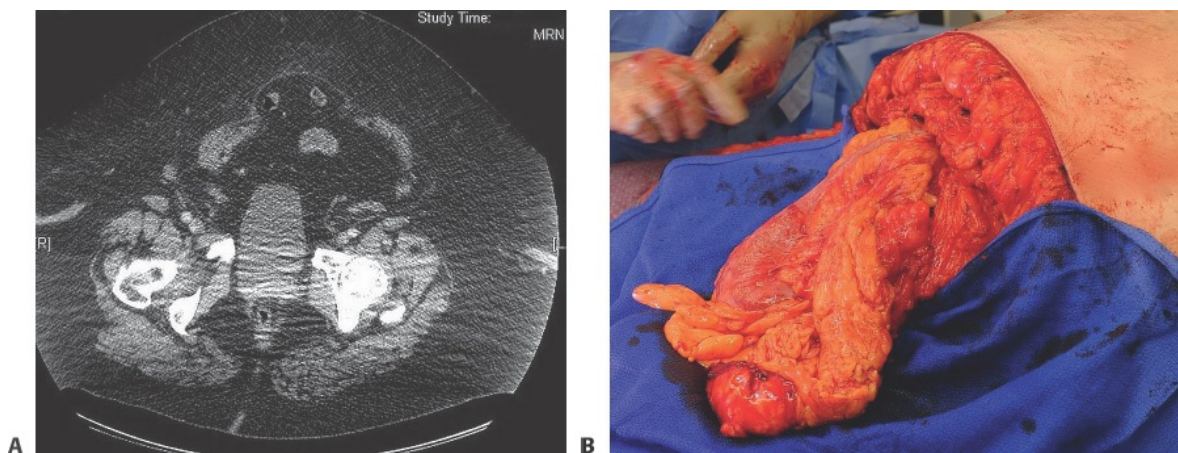


FIG 1 • **A.** Presence of hernia on CT scan. **B.** Intraoperative view of hernia.



FIG 2 • A,B. Morbidly obese panniculectomy. Patient is a 53-year-old woman, BMI 52, with biopsy-proven cervical cancer and need for hysterectomy.

- Given the patient's preoperative risks, surgical intervention may include excision of the panniculus with closure or excision without total closure and use of negative pressure dressings.
- Brown et al. found that in instances of panniculectomy, patients who underwent excision and wound care via vacuum-assisted closure (VAC) therapy required significantly less readmissions and less reoperations.³
- The mons area is usually significantly redundant and must be assessed at this time as well.
- Given the risk of surgery in super obese patients, an anesthesia and medicine clearance is warranted prior to surgery.
- Deep vein thrombosis (DVT) risk assessment via the Caprini score is performed.

Preoperative Planning

- Markings
 - Midline
 - Inferior incision line to accommodate mons lift (if being performed) as well

as general avoidance of attenuated skin at the actual crease. Given the actual size of the pannus, the surgeon may need additional assistance with this marking.

- General area to be resected may also be marked with the understanding that this may change depending on intraoperative findings.
- Patients should be typed and cross-matched prior to the procedure.

TECHNIQUES

■ Preparation and Transection of the Pannus

- Following induction and the administration of weight-based antibiotics, the pannus is prepped for elevation.
- At the most dependent portion of the pannus, several large Steinmann pins are placed through the pannus and attached to a mechanical lift (**TECH FIG 1**).
- A Foley catheter is now placed if it is warranted.
 - Access for the Foley placement is considerably easier following displacement of the large pannus.
- The caudal incision is then marked again approximately 2 to 3 cm above the pannicular crease.
- Sharp electrocautery dissection is performed through the skin; subcutaneous tissue to the abdominal fascia is performed in a caudal to cephalic direction.
- Given the large size of the superficial venous system, care is used in dissection in this plane.
 - The author uses medium and large clip appliers for ligation of these vessels; however, suture ligation may be used as well.
- Attention is then turned to the cephalic incision once visual inspection confirms enough skin to close the incision primarily.
 - In super obese panniculectomy, the umbilicus is usually transected, given the large and tortuous stalk.



TECH FIG 1 • Hoyer lift is employed for retraction. Steinmann pins are placed under sterile conditions and attached to Kocher clamps.

■ Closure

- During closure, two 19-Fr Jackson Pratt drains are used.
- Meticulous hemostasis is performed with patient at the preoperative blood pressure.
- The Scarpa fascia is usually quite attenuated and may be approximated with 3-0 Vicryl suture if an adequate layer is available.
- Skin is closed with 4-0 Monocryl or staples depending on surgeon's choice (**TECH FIG 2A**).
- An incisional VAC may be used to aid healing (**TECH FIG 2B**).



TECH FIG 2 • A. Closure of the skin. Note the continued protuberant abdomen consistent with an abundance of visceral adiposity. **B.** Incisional VAC placement.

PEARLS AND PITFALLS

Physical findings

- Presence of hernia is difficult to clinically evaluate given patient's size. If there is concern, consider CT scan.
- Intertriginous rashes are common and should be assessed prior to surgical intervention.

Hemostasis

- Automatic clip applicators aid in effectively ligating the large vessels found in many of the large pannus specimens.
- Careful evaluation of the dissected area with normalized blood pressure aids in decreasing reoperative rate due to hematoma.

Incisions

- Caudal incision should be made above the pubic symphysis and above any areas of rash. This may decrease the possibility of incision-related infections as well as allow for closure in tissue that has not been overly attenuated.
- Avoid “too low” an incision to decrease the seroma rate given the presence of lymphatic channels in the lateral abdomen/thigh.

Postoperative care

- Consider DVT prophylaxis.
- Encourage early ambulation.

POSTOPERATIVE CARE

- Use of chemoprophylaxis is warranted.
- Ambulation is encouraged early.
- Dehiscence of the skin and fat necrosis are common complications; patients are warned of the possibility of dehiscence, need for reoperation, as well as wound care.
- Depending on the preoperative functioning of the patient and the possible presence of wound healing complications by the time of discharge, some patients may benefit from a stay in a skilled nursing facility.

OUTCOMES

- The primary goal of the morbidly obese panniculectomy may vary depending on the patient population.
 - Restore ability to ambulate
 - Functional access for other surgical interventions

COMPLICATIONS

- Infection
- Fat necrosis
- Skin necrosis
- Hematoma
- Asymmetry of scar

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15

CHAPTER Buttock Lift

Michele Shermak

DEFINITION

- Buttock lift describes excision of lax and/or redundant lower back tissue to improve lift and shape to the buttocks, as well as posterior waist contour. It is the basis for the posterior element to lower body lifting for individuals who have sustained massive weight loss. The procedure may be performed in combination with augmentation of the buttock using fat, autologous flaps, or implants or with lifts of adjacent body regions such as the abdomen or thigh to globally improve the lower body region.

ANATOMY

- The 10 gluteal aesthetic units, identified by Mendieta,¹ while not all in the buttock proper, impact the appearance of buttock (**FIG 1A**):
 - Sacrum
 - Flank
 - Upper buttock
 - Lower back
 - Outer leg
 - Gluteus
 - Diamond zone
 - Midlateral buttock
 - Inferior gluteal/posterior leg junction
 - Upper back
- Anatomic layers of the lower back/buttock (**FIG 1B**)
 - The skin can demonstrate varying degrees of redundancy, vertical excess, laxity, and collagen strength as manifested by striae. Thin skin may have

greater recoil after surgery resulting in exacerbated loosening of the surgical result.

- Subcutaneous fat varies in thickness. A thinner fat layer is more appropriate for buttock lift than a thick one, which might be more suitable for a liposuction contouring procedure or recommendation for weight loss. If subcutaneous fat is limited, an augmentation with autologous flaps, fat, or implant may be considered.
- Scarpa fascia is the pseudofascial plane in the subcutaneous fat that varies in strength and is relied upon for closure and lift and may need more sutures to provide greater tension or better support for weak tissue.
- Subscarpal fat is the layer in which dissection is performed for buttock lift.
- Deep muscular fascia should not be cut during buttock lift. This layer protects the muscles and vital vessels and nerves.
- Muscles of significance in this region include the paired gluteus maximus muscles, which should not be invaded during surgery so all structures deep to the gluteus maximus are not dissected or visualized. Attenuated muscle may account for buttock deflation and may be improved with fat augmentation.
- Circulation of greatest importance is provided by the superior gluteal arterial system and inferior gluteal artery system. Perforators from these arteries should be preserved, particularly when performing autologous gluteal augmentation² (**FIG 1C**).

PATHOGENESIS

- With skin laxity and/or weight loss of varying degrees, individuals can suffer from excess vertical dimension of skin in the lower back with deflation and flatness of the buttock area, an ill-defined infragluteal crease, cellulite, and lack of fullness.
- Ptosis may occur in the buttock and lateral thigh. This is associated with an aged look or with difficulty in wearing clothing.
- Lower backlift/buttock lifting surgery improves the posterior waist and shape and tautness of the buttock, in conjunction with improving adjacent areas, like the upper posterior thigh, outer thigh, and back.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history should be probed for significant weight loss, and if present in the history, the mode and degree of weight loss, as well as nutritional challenges that may exist.

- Weight should be stable at the time of surgery at least 3 months.
- Medical conditions that may impact outcome of backlift surgery should be queried, such as diabetes, peripheral vascular disease, heart disease, sleep apnea, autoimmune and endocrinological disorders, and coagulation disorders and venous thromboembolic history.
- Physical findings should note skin quality and degree of excess and redundancy, as well as adiposity.
- Adjacent body regions such as the upper back, abdomen, and thigh anteriorly and posteriorly are examined to see if addressing these regions will improve overall lower body aesthetics.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative planning depends on patient preference and deformities present.
- Limitations in patient state of health or finances may curtail extensive surgical procedure and mandate a staging plan.

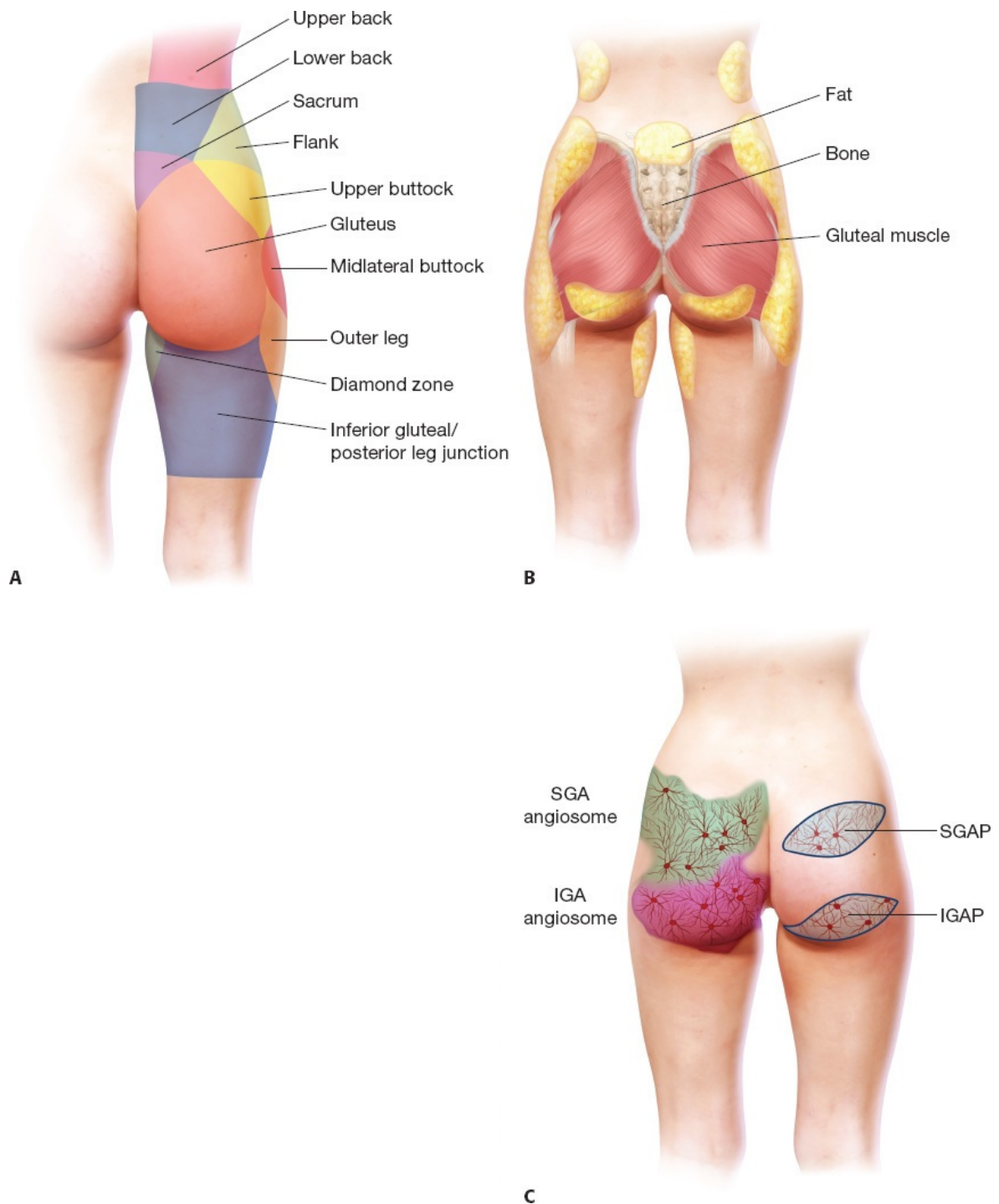


FIG 1 • A. The 10 gluteal aesthetic units are shown. The diamond zone includes the inner gluteal/leg injection. **B.** From superficial to deep, anatomy of the buttocks includes the skin, fat, pseudofascial plane in the fat, muscle fascia, and muscles. The subcutaneous fat

layer may vary in thickness and deposition, and fascial layers may have varying degrees of strength. Thickness of each of these layers affects gluteal contour. **C.** Arterial supply of the gluteal region is primarily provided through the superior and inferior gluteal artery perforators. The autologous flap is primarily supplied by the superior gluteal artery perforator system as it is within the angiosome.

- Buttock lift is typically performed in continuity with abdominoplasty and may be performed either at the time of abdominoplasty or at a later stage.
- Planning and discussing possible augmentation in conjunction with buttock lifting should take place prior to surgery.³
- Prediction needs to be made by the surgeon to determine whether excision of lower back tissue alone will provide adequate improvement to buttock position and contour or if additional tissue in the form of autologous flap tissue or fat graft should be harvested from the tissue that would otherwise be discarded to help amplify and shape a severely deflated buttock.
- Liposuction of the outer thigh also may be considered if it will improve contour and allow greater tissue resection.

Positioning

- Prone positioning is most optimal for buttock lift. It allows a symmetrical, safe, and stable approach.
- The patient is laid on two gel rolls laid horizontally across the OR table, one under the upper chest and axillae, and the other under the lumbar area (**FIG 2**).
- Axillae and elbows are positioned at no greater than 90 degrees to limit traction on nerves and vessels.
- The neck is in neutral position, and the face should be protected in a prone pillow, avoiding any pressure to the eyes.

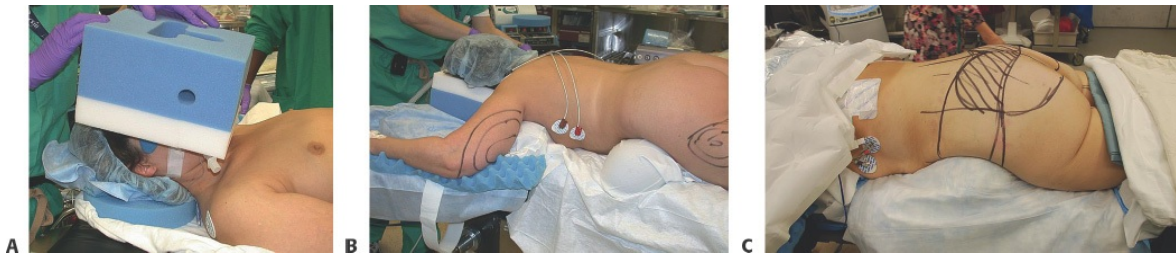


FIG 2 • Prone positioning helps provide the best access to the lower back, allowing symmetrical treatment. Safety measures must be followed to avoid blindness, stroke, neurapraxia, and pressure phenomena. **A.** Face in prone pillow with goggles protecting eyes from pressure and desiccation. **B.** Arms at 90 degrees and bumps under chest and lumbar region. **C.** Bump under lumbar region. Patient is warmed with forced warming blanket intraoperatively.

- These maneuvers in the head and neck limit the risk of kinking of arteries in the neck to prevent dissection and stroke, as well as blindness.
- The legs and arms should be padded with pillows or foam to avoid pressure to superficial nerves.⁴

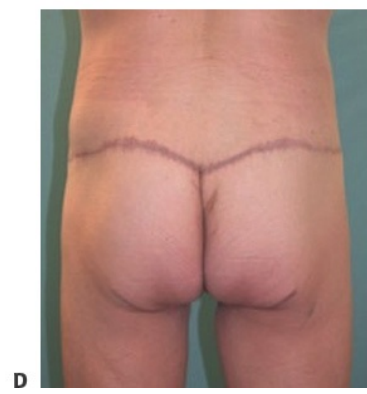
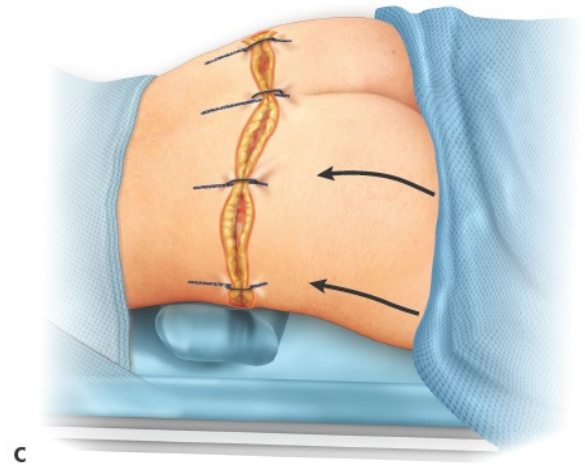
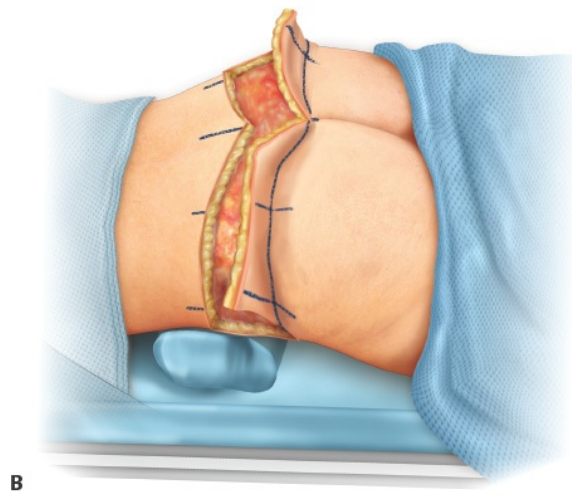
Approach

- Landmarks including the posterior superior iliac crest and sacral depression guide markings for skin removal.
- The buttock down to the infragluteal fold should be marked and prepared in the field.
- Skin undermining and laxity is greatest laterally and extremely limited centrally.
- Markings made preoperatively with the patient standing allow for this and aim to create an incision that resembles a gull wing over the buttock to define and improve aesthetics of the buttock region.

TECHNIQUES

■ Buttock Lift

- The patient is marked while standing.
 - Excision is determined by movement and laxity of the skin, as well as goal of creating a symmetric, curvilinear incision that will border the upper gluteal region (**TECH FIG 1A**).
 - Skin is grasped, and pinching skin closed will guide the marks.
 - Midline should be marked.
 - Little will be excised centrally where there is strong tissue adherence, with increasing removal planned moving laterally.
 - Cross-hatches are made vertically across the proposed excision to aid in approximation.
- The patient is intubated on a stretcher and turned to the prone position with careful padding and protection of all potential pressure points.
- The patient is prepared with Betadine.
- If liposuction is planned in the outer thigh, tumescent solution is infused.
- Incision is made superiorly in skin, through subcutaneous fat to deep fascia.
- Dissection is then directed inferiorly toward the lower marked incision (**TECH FIG 1B,C**).
 - Minimal undermining is performed.
 - Careful hemostasis is performed, and the wound is irrigated.
 - Local anesthetic is injected above and below deep fascia; long-acting Marcaine is preferable.
- Prior to definitively determining the skin excision, if liposuction is going to be performed, it should be performed at this stage, as tissue may mobilize further and allow greater excision.
- Tailor tacking is performed to aid in precise skin removal, using the hatch marks as a guide.
 - The areas are stapled as skin is excised.
 - Tailoring often needs to take place at the sacral hollow in the middle of the incision, closing as a V in the cleft.
- A no. 10 flat Jackson-Pratt drain is placed within the wound and exited out laterally under the incision on each side. It is sutured to the skin.
- The wound is closed. No. 1 braided nylon is used to approximate Scarpa fascia, taking a bite of deep tissue with the fascial layer to close dead space.



TECH FIG 1 • A. The patient is marked while standing. Markings are based on skin laxity as well as incision placement goal through a grasping technique and putting the skin on traction. **B.** Incision is made in the skin to the level of the deep fascia, leaving soft tissue intact, and dissection proceeds inferiorly. **C.** Skin removal is determined with tailor tacking. **D.** Closure of the lower back incision looks like a gull wing over the buttocks.

- The skin is closed with 3-0 monofilament absorbable suture to approximate deep dermis and running 4-0 monofilament absorbable suture as a running subcuticular suture.
- Skin is then better approximated with interrupted 4-0 nylon simple interrupted sutures (**TECH FIG 1D**).
- The wound is washed and dressed with cyanoacrylate glue.
- Attention can then be turned to another body region, such as the posterior thigh or abdomen.

■ Buttock Lift With Autologous Gluteal Augmentation

- The patient is marked standing.
 - A mirror image of the buttocks is drawn within the upper and lower markings of excision.
 - Err on the side of removing less over more to allow for closure over the flaps and avoiding undue tension on the closure or pressure on the flaps.
 - Also err on the side of elevating the lower incision to allow ease of closure over flaps.
 - Incision closure will be more transverse than gull wing at the end of the procedure.
- Cross-hatches are made vertically across the proposed excision, particularly in the midline and along the lateral buttock, to aid in approximation during closure (**TECH FIG 2A**).
- The patient is intubated on a stretcher and turned to the prone position with

careful padding and protection of all potential pressure points.

- After preparing the area with Betadine, the areas marked for the buttock reconstruction flaps are de-epithelialized bilaterally and symmetrically.
- Superior incision marked on the back is made to deep fascia, whereas the lower incision is made to the subcutaneous fat.
- Tissue marked outside the flaps medially and laterally is then resected to deep fascia full thickness around the flaps.
- Deep fascia around the flap is incised, not to muscle, to allow release and movement of the flaps (**TECH FIG 2B,C**).
- Gluteal artery perforator blood supply is based on the superior gluteal artery, and this must be preserved when releasing the fascia around the flaps.
- Dissection of the skin flap over the buttock follows to create a pocket for the flap. Maintain subcutaneous fat on the skin flap and dissect inferiorly as marked to create a pocket for the flap (**TECH FIG 2D**).



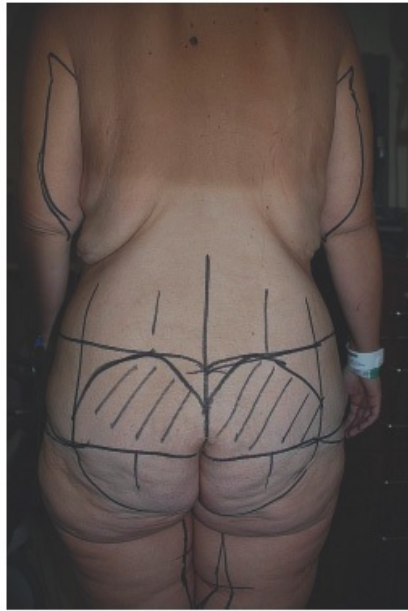
Video p5-c015_01

- Careful hemostasis is performed.
- Local anesthetic is injected above and below deep fascia.
- The flap may then be moved without rotation under the skin.

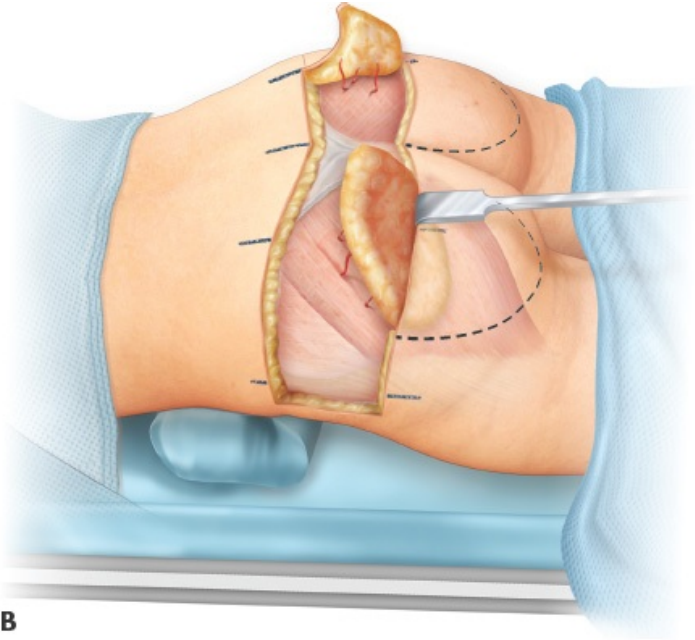


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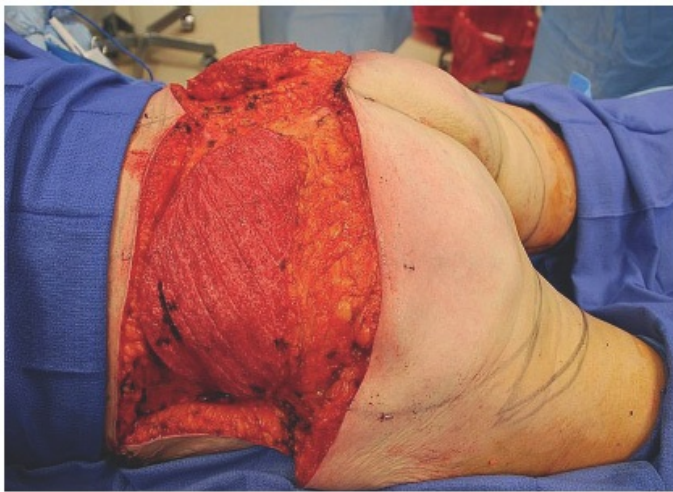
- The flap is tacked into position on deep fascia with 2-0 absorbable braided suture.
- A 10-mm flat drain is then placed on each side in the dead space. It is sutured to the skin (**TECH FIG 2E**).



A



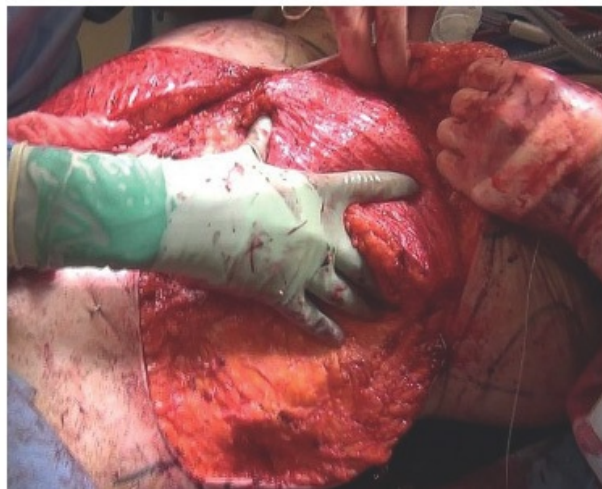
B



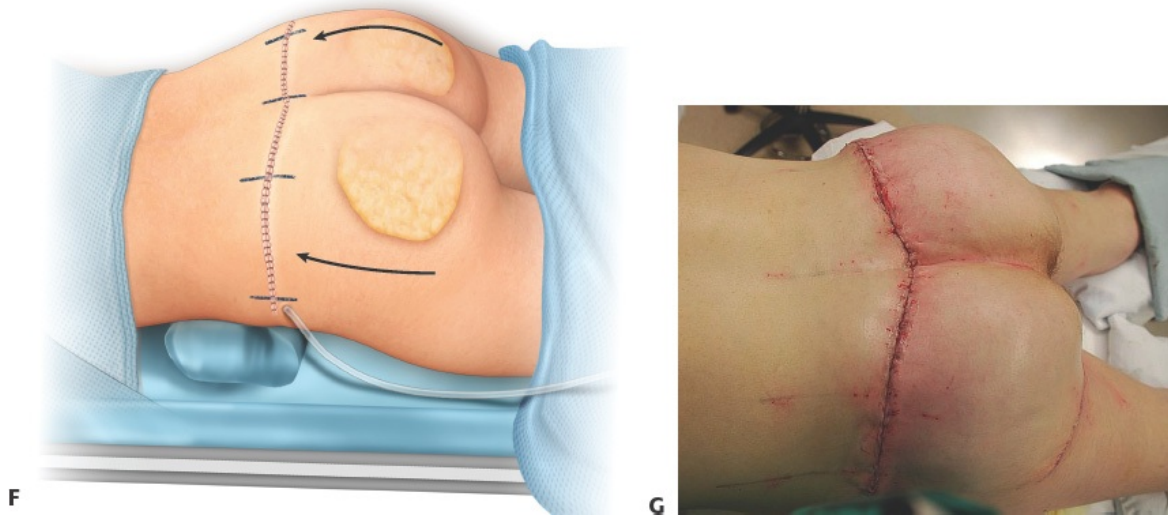
C



D



E



TECH FIG 2 • A. Autologous gluteal augmentation flap is marked in mirror image to the buttocks in the lower back skin excision marked. **B,C.** The tissue marked is de-epithelialized, and tissue between and lateral to the flaps is excised full thickness to deep muscular fascia. **D.** The pocket for the gluteal flap is dissected, maintaining subcutaneous fat under the skin to maintain circulation (see Video 1). The pocket must be dissected inferiorly toward the fold so the flap is not too highly placed. **E.** The flap freely descends under the skin designed for the flap pocket (see Video 2), and the flap is secured in place with 2-0 Vicryl sutures, prior to closing skin. **F,G.** Skin is closed in layers over the flap, with drains in place bilaterally.

- The wound is closed.
- No. 1 braided nylon is used to approximate Scarpa fascia, with 3-0 monofilament absorbable suture to approximate deep dermis and running 4-0 monofilament absorbable suture as a running subcuticular suture.
- Skin is then better approximated with interrupted 4-0 nylon simple interrupted sutures (**TECH FIG 2F,G**).
- The wound is washed and dressed with cyanoacrylate glue.
- Attention can then be turned to another body region, such as the posterior

thigh or abdomen.

PEARLS AND PITFALLS

Optimizing scar

- The best scar results from reduction of tension on the wound, assured by limiting over-resection, and by scar location and symmetry. Without gluteal augmentation, the gull wing scar leads the eye to a focused, well-contoured gluteal region. Maintaining adequate subcutaneous fat on the skin flap for autologous augmentation is critical to avoid wounds.

Optimizing wound healing

- Avoid high-tension closure and proactively address intraoperative issues such as hypothermia and anemia. Wounds are extremely common in the midportion of the incision at the lower sacrum and respond well to gentle cleansing and petrolatum application.

Seromas

- These are not uncommon with this procedure, most often associated with large tissue removal. Maintaining a layer of tissue over deep fascia to assist in lymphatic and venous egress as well as limiting undermining and maintaining drains in place until output is low will best protect against seromas.

To augment or not to augment

- This question needs to be addressed preoperatively as the most optimal tissue for augmentation will otherwise be discarded. This is a judgment call based upon the quantity of existing gluteal tissue: if there is very minimal tissue and significant flattening, then autoaugmentation should take place. This is a much bigger procedure from which to recover and requires hospital overnight stay and monitoring for anemia.

POSTOPERATIVE CARE

- Patients are followed on a weekly basis after surgery to assure optimal wound healing and drain care.
- Drains can be removed when drainage is 30 to 40 cc or less per day.
- Wounds that develop are typically superficial and respond well to gentle cleansing and topical petrolatum, with modification to topical antimicrobial medications for superficial wounds that may be infected, or debridement and packing for deeper wounds.

- Seromas are not uncommon and should be aspirated if there is concern about seroma presence to avoid chronic scar and possible abscess.
- Strenuous activity may be resumed about a month after surgery as long as healing is uncomplicated.
- Longer-term care is provided for scar management, including topical therapies to reduce scar visibility and massage to assist in dysesthesias and edema.
- Compression with a pull-up girdle assists in reducing swelling through the day.

COMPLICATIONS

- Seroma is one of the most common risks with this surgery and is best minimized by maintaining a layer of connective tissue over deep fascia to assure venous and lymphatic drainage, as well as maintaining drain tubes until output is less than 30 to 40 cc/d.
- If a seroma develops, it is best to aspirate with a needle to assure no long-term pseudobursa and scar or abscess. More advanced techniques are helpful with chronic seromas.⁵
- Wound healing problem: Addressing and planning how to compensate for preoperative risk factors like malnutrition, diabetes, peripheral vascular disease and smoking, and downstaging procedures for morbidly obese patients or patients with multiple medical problems.
- Careful surgical technique and attention to maintaining circulation to the tissues and avoiding undue tension optimize wound healing.
- Unsatisfactory scarring is best avoided by minimizing risk of wound healing problems, reducing tension, and closely monitoring postoperatively to innovate scar management depending on progress
- Venous thromboembolism: It is necessary preoperatively to check on any history or elevated risk as per the modified Caprini scale.⁶
- Infection is not common, and risk can be reduced by optimizing surgical conditions like addressing efficiency with reduced operative time and hypothermia, as well as initial dose of antibiotics prior to making incision.
- Seromas can become sources of infection and should be treated.

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16

CHAPTER Circumferential Body Lift

Joseph Michaels and Jennifer Capla

DEFINITION

- A lower body lift is a combined procedure consisting of an abdominoplasty, lateral thigh lift, and buttock lift.
- Addresses the lower truncal skin redundancy in the massive weight loss patient in a circumferential fashion by removing skin excess from the abdomen, hips, lateral thighs, flanks, and buttocks.

ANATOMY

- Excess skin can distort a patient's anatomy.
- Knowledge of the superficial fascial system (SFS) as described by Ted Lockwood is important (**FIG 1**).¹
- The SFS has zones of adherence. Posteriorly, this is to the spine; anteriorly, it is to the lower borders of the pelvis.
- The bony landmarks of the pelvis are commonly used as reference points, specifically the anterior superior iliac spine (ASIS) and the ischium.
- Preservation of the inguinal lymph node basin and knowledge of the course of the lateral femoral cutaneous nerve is important to minimize complications.
- Abdomen
 - The borders are the costal margins and xiphoid superiorly, the pubic symphysis inferiorly, and the ASIS laterally.
 - The blood supply to the abdomen is classically described as three zones (**FIG 2**):²
 - Zone 1: midabdomen supplied by the deep epigastric arcade
 - Zone 2: lower abdomen supplied by the external iliac artery

- Zone 3: flanks and lateral abdomen supplied by the intercostal, subcostal, and lumbar arteries
- Buttocks
 - Landmarks include the posterior superior iliac spine, the ischial tuberosities inferiorly, and the greater trochanter laterally.
 - The gluteal fascia will serve as an anchor point for rotational flaps used to preserve and restore buttock volume.
- Thighs
 - This region overlies the greater trochanter and tensor fascia lata. Anteriorly, it extends to the ASIS.
 - The saddlebag deformity that is commonly seen is a combination of residual adiposity and loose skin.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients generally present with massive weight loss (weight loss greater than 75 lb).
- This can lead to various degrees of skin laxity depending on the extent of weight loss, the rate of weight loss, and the patient's skin elasticity.
- Physical examination is focused on the abdomen, lateral thighs, flanks, and buttock.
- Patients often present with excess skin in the abdomen and may have an intertriginous rash (erythema intertrigo) in the skinfold. There is also commonly mons ptosis. Excess skin extends to the lateral thigh (saddle bag) region and continues onto the buttock. There is often a sense of deflation in the buttock region.
- Abdomen should be evaluated for degree of rectus diastasis, previous incisions, and any associated hernias.

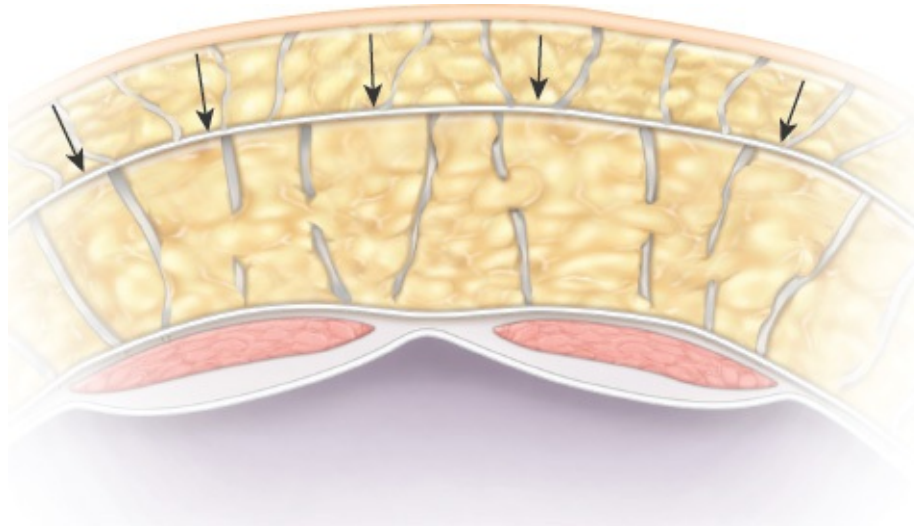


FIG 1 • The superficial fascial system between the superficial and deep fat compartments of the abdomen.

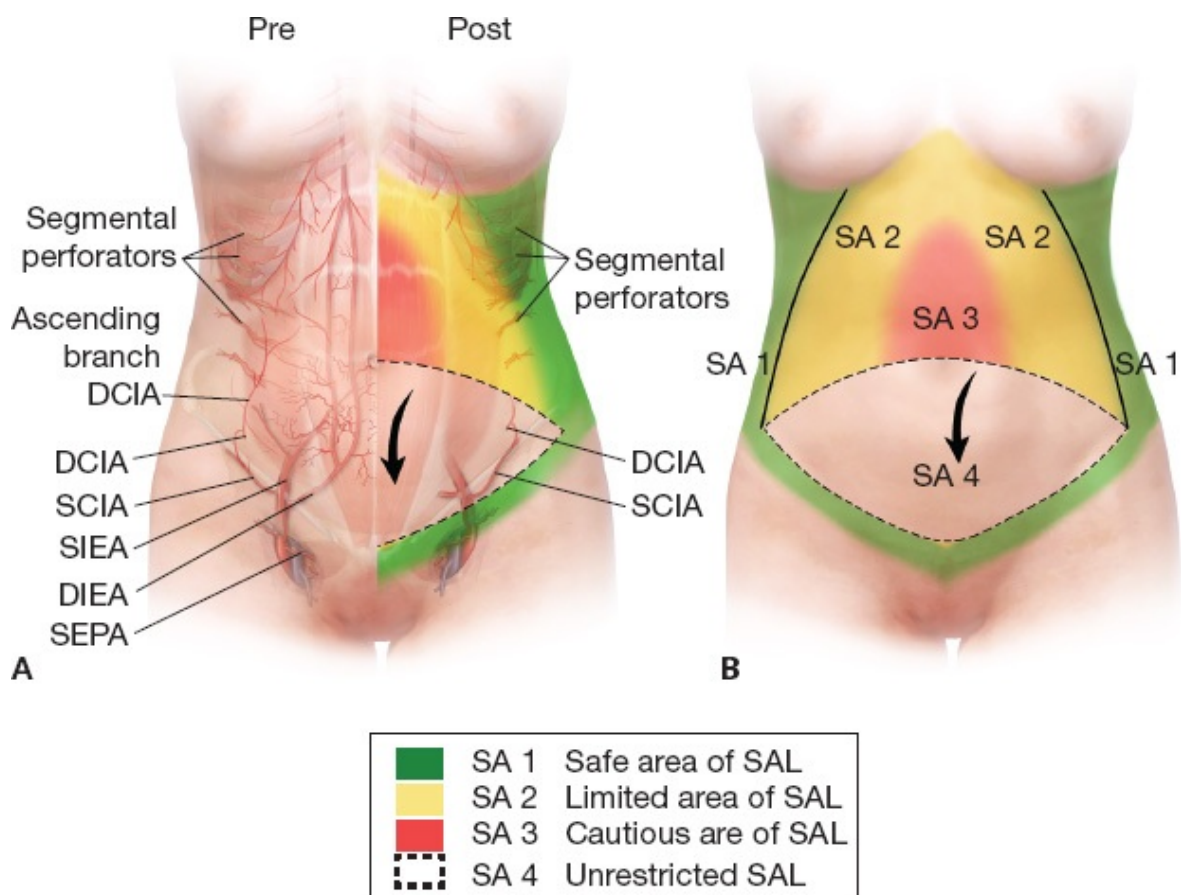


FIG 2 • Blood supply to the abdomen.

IMAGING

- An abdominal CT scan may be helpful if there are any concerns for an abdominal hernia—umbilical, ventral, or incisional. This will allow for better intraoperative planning and the possible need for a general surgeon.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients should be at or close to their goal weight and weight stable for a minimum of 3 months.
- All massive weight loss patients should undergo a full preoperative evaluation in addition to a nutritional assessment.
 - Nutritional assessment is an important factor in wound healing and should include albumin, prealbumin, B₁₂, folate, iron, and total iron binding capacity.
- Understanding and assessing the patient's goals is of primary importance.
- In front of a mirror, with the patient unclothed, the pinch technique can help provide the patient with a sense of how the tissues will translate and what will be achieved with this procedure. This can also be done with the patient lying down and showing them a picture of the projection (**FIG 3**).
- Determine whether the patient needs added volume in the buttock.
 - A lower body lift inevitably will flatten the buttock. Gluteal autoaugmentation is considered in patients who desire increased buttock volume and projection.
- The markings are the key to the procedure.
- Prewarm the operating and all IV fluids to minimize patient hypothermia.

Positioning

- The patient is intubated on a stretcher.
- The patient is transferred to the operating room table in the prone position with appropriate padding.
- Arm boards can be placed on the lower part of the table to widen the bed and to allow for additional abduction of the legs. This will help obtain the maximal lateral thigh lift.
- After the lower body lift is performed, the lateral dog-ears are tucked, stapled, and covered with a sterile dressing.
- The patient is then repositioned into the supine position for the

abdominoplasty portion of the procedure.

Approach

- The determination of whether the patient requires additional buttock volume will ultimately determine the approach for the lower body lift.
- If none is required, this procedure is simply a circumferential removal of skin, also known as a belt lipectomy.
- If increased gluteal projection and volume is necessary, gluteal autoaugmentation or fat transfer will be required.



FIG 3 • Pinch test to evaluate buttock projection for whether autoaugmentation is needed during a lower body lift.

TECHNIQUES

■ Lower Body Lift With Gluteal Autoaugmentation Flaps

Markings (**TECH FIG 1**)

- Patients are asked to bring an undergarment, and upper and lower borders are marked to try and keep the incisions hidden within these lines. Most people wear their undergarments at the level of the anterior superior iliac spine (ASIS).

- The ASIS is also marked, and this height is also transposed to the back as a reference point.
- The next mark is made with the patient lying down. The lower abdominal incision is marked at 6 cm above the vulvar commissure in women or the pubic symphysis in men.
- The patient is then asked to stand up, and the posterior markings are done first. The posterior midline is marked, and the midaxillary line is marked. This represents the lateral extent of the posterior excision.
- In the midline, a mark is placed several centimeters above the gluteal cleft. This point will represent the top of the new gluteal cleft and should lie below the level of the ASIS.
- The superior marking is drawn as a gull wing from the midline mark to a point on the midaxillary line that lies below the ASIS on downward traction.
- A conservative pinch test is performed every 5 to 6 cm up to the superior line. These points are connected and represent the lower posterior marking.
- The area for autoaugmentation is marked. These flaps are designed within the area of resection and nearly encompass the entire area of resection except for the lateral few centimeters over the lateral thighs.
- The patient is then asked to turn around, and the anterior incision is marked with superior traction on the abdomen.
 - The previous marked lower abdominal incision is connected to the lower posterior marking at the midaxillary line.
 - This incision should also remain below the level of the ASIS on upward traction of the abdominal skin.

Gluteal Autoaugmentation

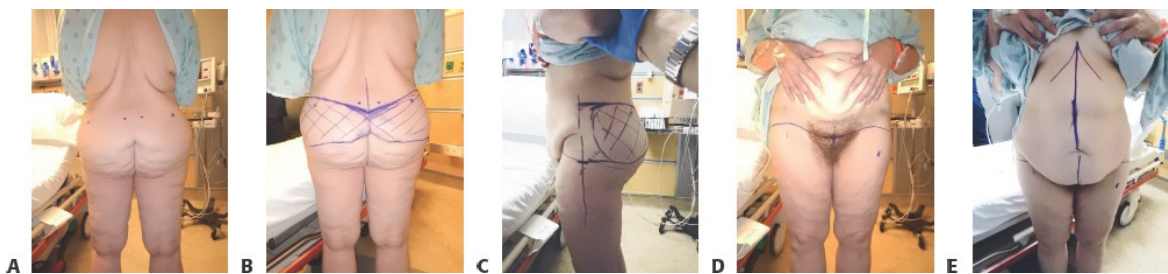
- The procedure starts in the prone position (**TECH FIG 2A,B**).
 - A towel clip is first used to approximate the upper and lower markings to confirm the area of resection. If too tight, adjust the lower marking superiorly.
- The area marked for autoaugmentation is de-epithelialized (**TECH FIG 2C**).
 - The flaps are further dissected with electrocautery to dissect down through the superficial fascial system (SFS) and down to the deep fascia at the superior and inferior margins.
 - Laterally, dissection continues through the SFS until the deep fat pockets are exposed; there is no deep fascia laterally.
- The tissue between the midaxillary line and the lateral extent of the flap is

excised.

- Inferior to the flap, a pocket for the flap is dissected just above the gluteal fascia (**TECH FIG 2D**).
 - The gluteal tissue is elevated from the lateral aspect leaving a broad base to supply the flap.
 - The flap is raised just enough that it can be rotated inferiorly into the pocket to provide the desired projection.
- A Lockwood underminer is used to release the lateral thigh attachments to the greater trochanter allowing for additional upward movement of the lateral thigh and correction of the saddlebag deformity.
 - Liposuction can be used to remove any residual adiposity from this region at this time. Liposuction can also be performed in the lower back region as necessary.
- The SFS is reapproximated with 0-Vicryl sutures. The skin is closed in layers with 3-0 Monocryl (**TECH FIG 2E,F**).
- The lateral dog-ears are temporarily stapled and closed.

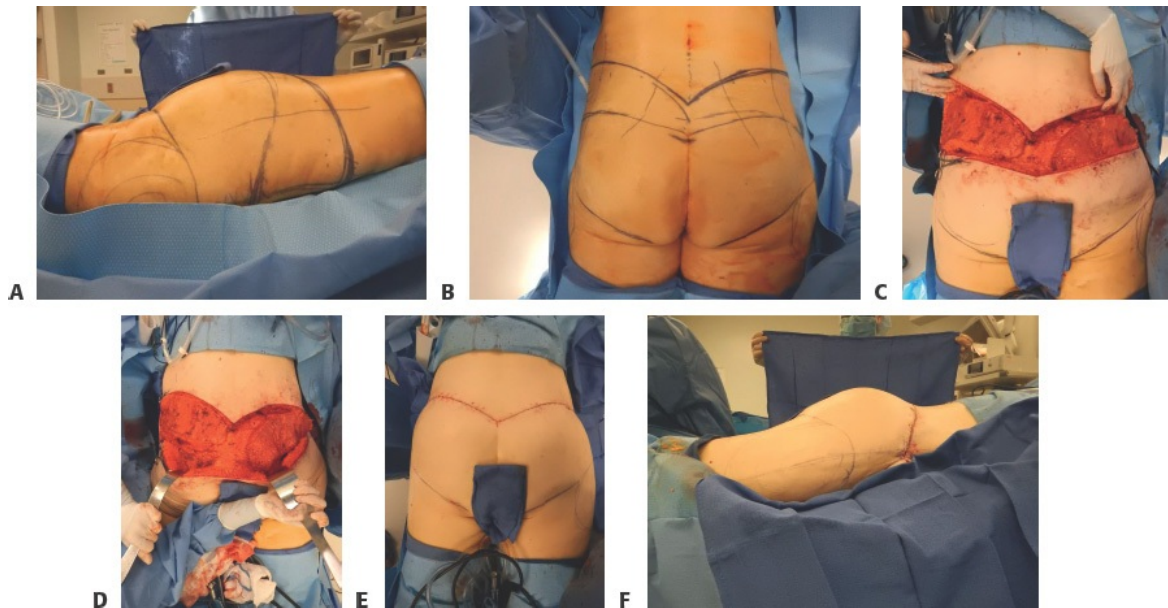
Abdominal Lift

- The patient is transferred to the supine position on the operating room table (**TECH FIG 3A**), dependent areas are again padded, and the patient is sterilely draped.
- The lower abdominal incision is made and connected to the posterior incision laterally.



TECH FIG 1 • **A.** Transposition of ASIS to posterior aspect as a reference point. **B.** Superior and inferior markings of the resection with area of autoaugmentation marked. **C.** Lateral view of the markings showing the extent of the posterior excision,

as well as the lateral aspect of the autoaugmentation flaps. **D.** Anterior markings of the lower abdominal incision connecting to the posterior markings. This line should remain below the ASIS. **E.** Anterior markings with the abdominal skin flap relaxed.

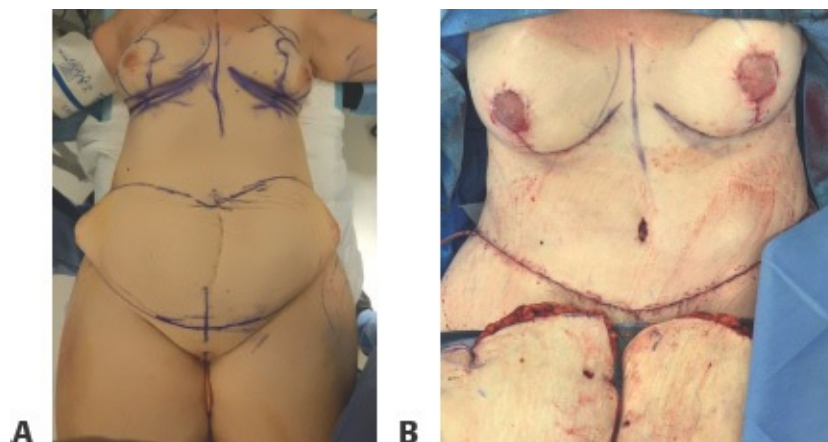


TECH FIG 2 • A,B. Patient in the prone position with superior and inferior body lift markings. **C.** De-epithelialized and dissected buttock flaps. **D.** Pockets made for the inferior rotation of the gluteal flaps. The left side shows the pocket dissected just superficial to the gluteal fascia. The right side shows the gluteal flaps inferiorly rotated and sutured to the gluteal fascia. **E.** Closure of the posterior incision line. **F.** Lateral view after gluteal autoaugmentation showing the change in gluteal projection. Compare with **A.**

- As this incision may lie below the level of the inguinal canal, care must be taken to avoid injury to the inguinal lymph node basin and the round ligament/spermatic cord during elevation of the abdominal flap.
- Care is taken to leave soft tissue on the deep fascia lateral to the rectus

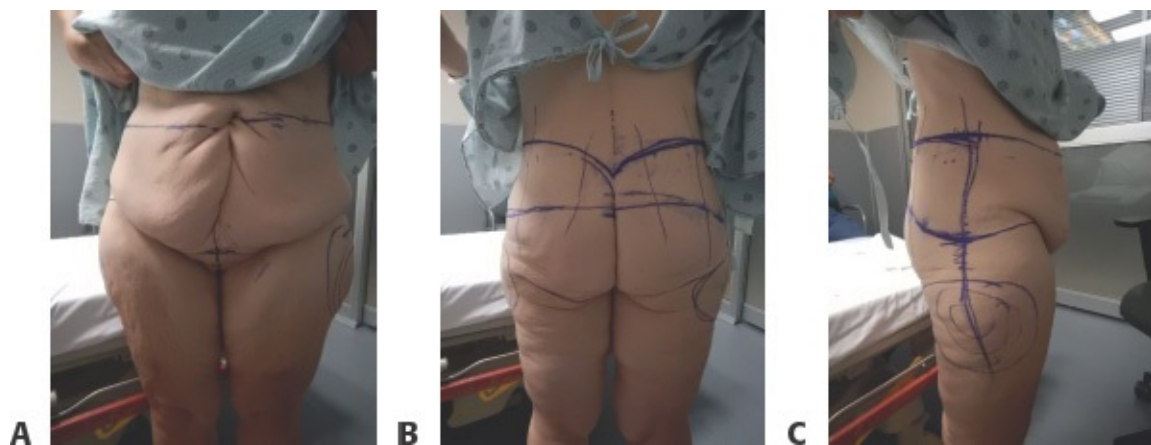
abdominis muscle. This helps preserve lymphatics and decreases the risk of seroma.

- Superior dissection continues to the level of the umbilicus.
 - The umbilicus is circumscribed, leaving adequate perforators, and dissection of the abdominal flap continues up to the level of the xiphoid process and costal margins.
- Any hernias are repaired along with repair of the diastasis recti with permanent sutures (0-Ethibond).
- The patient is sat up in the semi-Fowler position, and the skin excess is marked and excised. The new umbilical position is marked.
- Two no. 15 drains are placed and brought out laterally through the incision. These drains are placed in a crisscross fashion and extend to the opposite side to drain the back.
- The abdomen is closed in a similar manner as the back, and the umbilicus is sutured to the abdominal wall flap with 4-0 Monocryl sutures in layers (**TECH FIG 3B**).
- The markings are similar to the markings described above, except that there are no markings for the autoaugmentation flap (**TECH FIG 4**).
- This procedure is performed similarly to the above procedure except no dermoadipose flaps are dissected to provide added buttock volume.
- For this procedure, the tissue between the superior and inferior incision lines is removed at the level just deep to the SFS. There is no dissection performed outside the areas of resection.
- Posterior closure and the anterior steps are the same as described for the lower body lift with autoaugmentation.



TECH FIG 3 • A. Patient now in supine position. Dog-ears from the back can be seen laterally on the abdomen. **B.** Closed abdomen following completion of the abdominoplasty and lateral dog-ear excision.

■ Lower Body Lift Without Autoaugmentation (also Known as a Belt Lipectomy)



TECH FIG 4 • A. Anterior, posterior (**B**), and lateral views (**C**) of preoperative markings for a lower body lift without autoaugmentation flaps.

PEARLS AND PITFALLS

Lower body lift	■ Creating a dartoid point at the gluteal crease helps to avoid the appearance of the gluteal crease extension above the incision.
Lateral thigh lift	■ Dividing the zones of adherence with the Lockwood underminer allows for a greater pull and redistribution of the tissues.
Mons pubis ptosis	■ In marking the lower abdominal incision, be sure to lift the mons and resuspend at the time of closure.

Staging procedures	■ Do not perform a vertical medial thigh lift or an upper body lift at the same time as a circumferential body lift because of the opposition of vectors on the pull of the tissues.
Lower body lift	■ In the prone position, flex the table 5 to 10 degrees to take the tension off the posterior incision when the patient is in the semi-Fowler position.
Abdominoplasty	■ Preserve tissue on the deep fascia to minimize the risk of seroma.
Lower body lift	■ If patient has very heavy thighs, consider thigh debulking liposuction first to decrease pull on incisions.

POSTOPERATIVE CARE

- Patients should be maintained in the semi-Fowler position.
- Patients should ambulate the evening of surgery.
- Plan for hospital admission for 1 or 2 nights.
- Recommend postoperative venous thromboembolism chemoprophylaxis.
- No lifting over 10 lb for 6 weeks.

OUTCOMES

- Patients will see immediate improvement, but swelling will persist for up to 3 to 6 months.
- Long-term patient satisfaction is high (**FIG 4**).

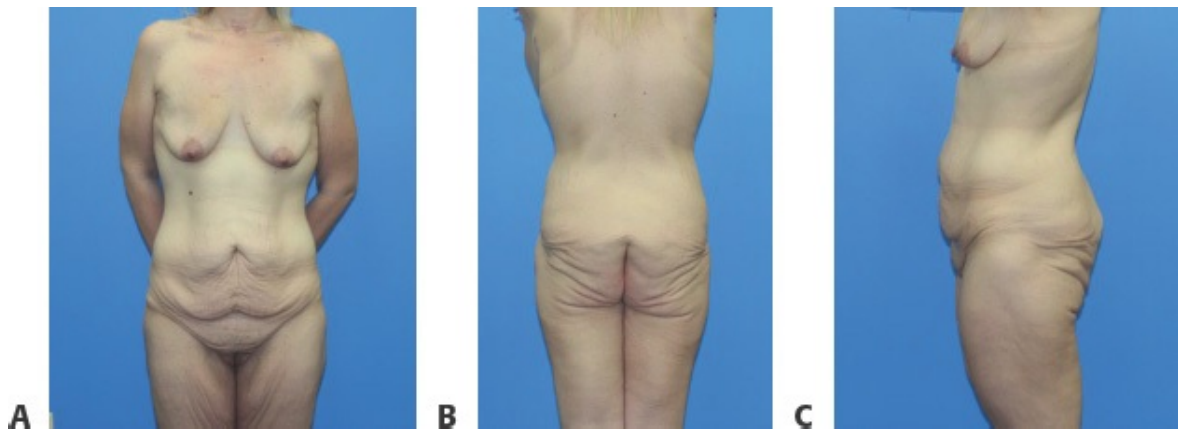


FIG 4 • Preoperative (**A–C**) and postoperative (**D–F**) views of patient who underwent a lower body lift with autoaugmentation.

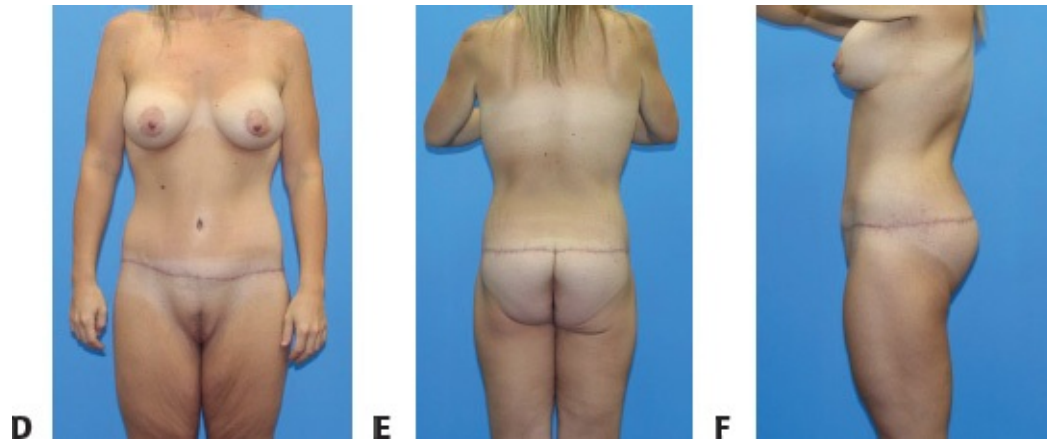


FIG 4 •

COMPLICATIONS

- Seroma
- Wound dehiscence
- Infection
- Scarring
- Hemorrhage
- Residual laxity
- Skin loss
- Residual laxity
- Incomplete correction
- Need for revision
- Venous thromboembolism

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17 Lower Posterior Torso and Buttock Sculpting

CHAPTER

Dennis J. Hurwitz

DEFINITION

- Harmonious sculpturing of a feminine lower back, waist, and buttocks is a new frontier in body contouring surgery. Because less attention has been focused on these regions than the breasts and abdomen, many plastic surgeons need training in advanced approaches to achieve femininity of the lower posterior torso.
- Although the public is increasingly requesting buttock enlargement, adjacent areas such as the flanks, hips, and lateral and posterior thighs should be also addressed when performing buttock augmentation. As there is minimal demand for augmentation of the male buttocks, the male situation will receive limited attention.
- A summary of this author's approach follows:
 - Back rolls with undersized buttocks are treated by third-generation ultrasound-assisted lipoplasty of the torso with lipotransfer to the buttocks in the young overweight female.
 - Posterior torso tissue laxity with flank rolls and buttock ptosis is the indication for lower body lift with de-epithelialized adipose fascial flap buttock augmentation. Liposuction harvest of fat from the flanks and abdomen followed by fat transfer to the inferior buttocks may be helpful to complete the lower torso buttock reshaping.
 - Maximum narrowing of the waist in the older female, especially when none ever existed and the most effective safe correction of oversized love handles in all males is achieved with direct oblique excision of the flanks, ie, a oblique flankplasty.
 - Silicone elastomer implants are reserved for buttock augmentation when

harvestable fat stores are inadequate.

- The drawbacks of commonly accepted approaches have limited their use in favor of innovative solutions to be presented in this chapter.
- Traditional liposuction is rather traumatic when applied to the fibrous posterior torso.
- Hip-hugging circumferential lower body lifts with and without adipose fascial flaps for gluteal buttock augmentation often sag along the lateral gluteal region and fail to narrow bulging waists.

ANATOMY

- A sensuous woman's lower posterior torso, upper thigh, and buttocks and the procedures to create them are based anatomically (see **FIG 1** for an artistic rendering of role of underlying anatomy to feminine shape). The photographic results of the four case presentations of this chapter approximate aesthetic ideal.
- A subtle feminine S-shaped curvilinear midline is centered on the curving lumbar spine. Along with its paraspinous muscular ridges, this concavity bridges the convexities of the lower thoracic spine and sacrum.
- A tapering lower thoracic rib cage narrows to the pelvic brim. This gap is spanned by the latissimus dorsi and external oblique muscles with overlying adipose.

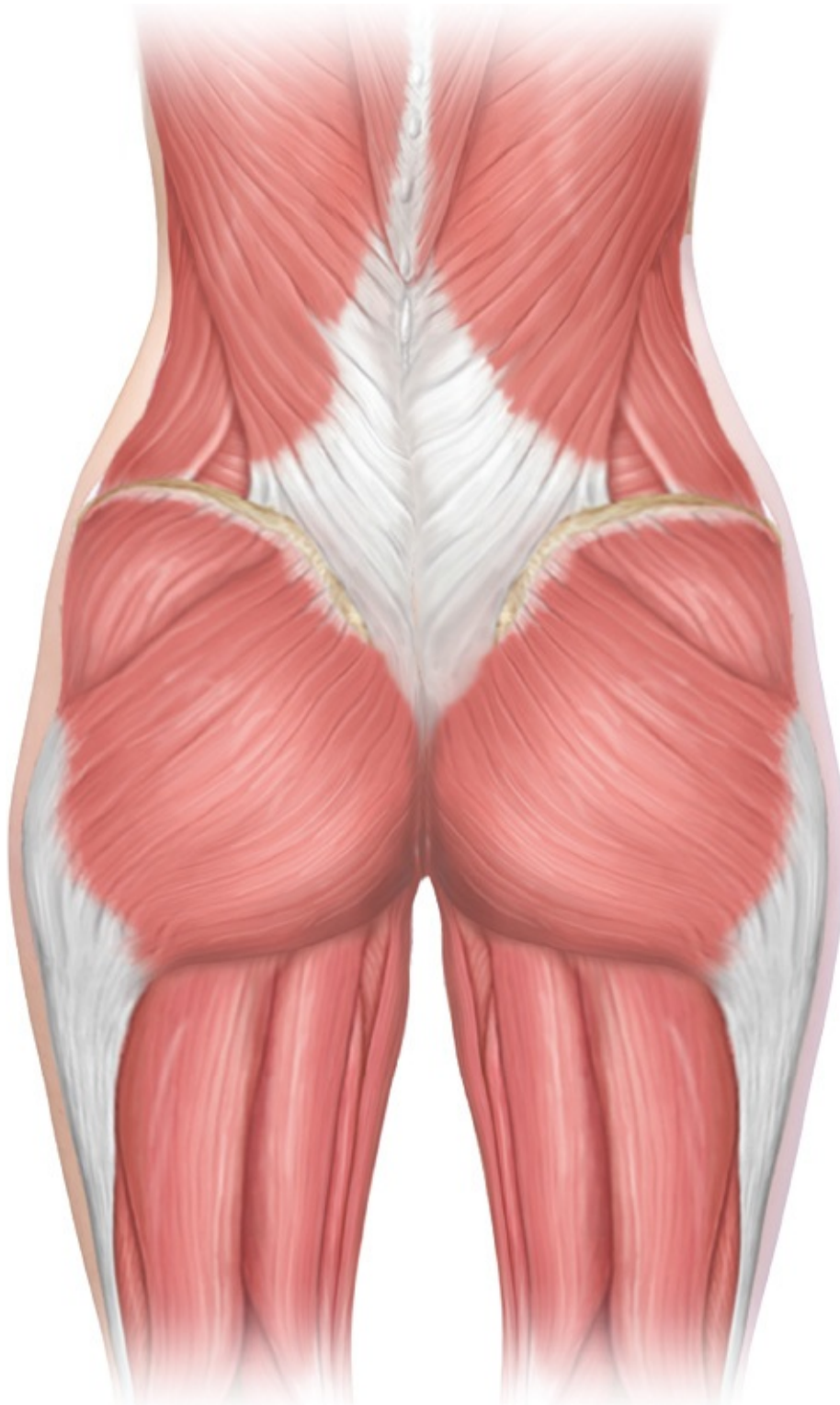


FIG 1 • Anatomy relationships in the aesthetic lower back and buttocks. The musculoskeletal structure and relationships are responsible for the underlying shape

of the lower back, waist, and buttocks. Adipose fullness about the hips and buttocks accentuates femininity. The paramedian vascularity clearly nurtures advanced buttock flaps.

- At an ideal 0.7 transverse diameter, waist-to-buttocks ratio, the waist abruptly expands laterally over the posterior iliac spines to adipose rounded hips that are wider than her shoulders.¹
- The maximal projection of the midbuttocks combines adiposity with the gluteus maximus muscle bulk and lies directly on a horizontal plane to the mons pubis.
- Buttock projection abruptly extends from back lordosis.
- From their widest diameter, lateral buttocks smoothly taper to slightly convex upper lateral thighs.
- Posterior medially, the curved buttocks abruptly end in horizontal folds about the ischial tuberosity to border the upper posterior thighs.
- Within those essential features, there are a variety of sensually pleasing sizes and shapes, but overall, the ideal 0.7 ratio of waist-to-buttock transverse diameter holds true.
- Preserved generous paramedian perforating blood supply allows for high-tension closures and limited mobilization of adipose fascial flaps for buttock augmentation.
- Android body build, massive weight gain and loss, aging, and lower body lifts may result in masculinization and/or undesirable contours.
 - Reducing of the curvilinear midline features
 - Dampening of lumbar lordosis
 - The lower back and waist undulating concavities are straightened and may even bulge.
 - Increased breadth of the back and waist dominates over the narrowing buttocks.
 - Lateral buttocks are flattened and even depressed.
 - Inferior buttock fold separations from the posterior thighs are obliterated.

NATURAL HISTORY

- The shape of the posterior torso and buttocks can be distorted by congenitally flared posterior costal margins, wide and high pelvic rims, localized flank

adiposity, weight gain, weight loss, pregnancy, and menopause.

- Most commonly, aging with weight gain broadens the midtorso, deposits, and transverse rolls and narrows and flattens the buttocks. Buttock ptosis may obliterate the fold at the medial posterior thighs and leave sagging, wrinkled skin.
- Once acquired, increased girth of the flanks is hard to lose through exercise and weight loss, and narrow buttocks rarely expand.

PATIENT HISTORY AND PHYSICAL FINDINGS

- For the back and buttocks, women usually request elimination of sagging back rolls and filling flat buttocks. On occasion, they specifically mention a smaller back, a narrower waist with smooth contours bridging the lower chest and buttocks, and rounder buttocks. More commonly, they complain of sagging abdomen and/or breasts.
- They either ignore the back, waist, or buttocks or simply feel that little can be done to improve bulging or masculine features. Because of that, women considering breast reshaping or abdominoplasty should have their posterior torso, thighs, and buttocks examined. If those areas are sensually alluring, she should be complimented.
- As a rule, in all but morbidly obese patients or after extreme weight loss, the central back is feminine and need no correction. Her figure faults are presented, and if there is interest, the means for their correction are offered.
- In Western Pennsylvania and probably throughout most of America, candidates for body contouring of the back and waist rarely request improvement. Instead, they inquire about breast reshaping and are pleased to learn that the lateral breast roll and upper back can be reduced.
- They request a tummy tuck and are pleased to learn that their waist can be reduced by liposuction or direct excision. A deep and defined waist with rounded buttocks during youth suggests fertility, which is an aphrodisiac.
- With buttock augmentation requests, patients are pleased to learn that fat removed from around the buttocks not only can be processed to augment it but also the perimeter reduction can picture frame buttock prominence. Because their companions better see the posterior view, they tend to be enthusiastic about the anticipated improvement. For some, a lower body lift is the best approach to suspend the thighs and buttocks.
- The examination while standing exposes the entire aesthetic complex.
 - Overall and localized excess adiposity and skin laxity are noted.

- Tightly bound skin expanded by underlying fat is noted as the contour can be improved by liposuction with the expectation of reasonable skin retraction.
- Hanging tissues and rolls are described by location (lateral breast, scapular, midback, flanks, and hips) and magnitude.
- Back rolls are characterized by transverse accumulations of adiposity within loose skin bordered inferiorly by transverse dense fibrous adherence from the dermis to the underlying muscular fascia through relatively thin subcutaneous fat.
- Ptotic rolls, in most over 50 years of age, are best treated with direct or superior excisions.
- Sagging and flat buttocks are congenital, age related, or the aftermath of severe weight loss.
- Laxity with lateral flattening and even indentation are common with aging.
- While pointing out figure faults in front of a full-length mirror aids communication, reviewing standardized digital images is usually less awkward. In either case, lines can be drawn that indicate proposed excisions, liposuction or lipoaugmentation, and resulting scars.

IMAGING

- There are no supportive radiologic or other diagnostic studies.

NONOPERATIVE MANAGEMENT

- If the posterior torso and buttocks are obese, then a weight loss program is indicated.
- There are a variety of noninvasive treatments that apply energy to cause lysis of adipose for reduced volume. Topical treatments of proven but limited and somewhat variable reduced shaping are CoolSculpt, Thermage, VelaShape, Liposonix, and VASER Shape.
 - They are intended to reduce small selected areas over repeated and rather painful treatments. Large contour adipose excess is difficult to reduce.
 - The appeal is nonsurgery and minimal to no downtime.
 - Smartlipo with YAG laser energy leads the list of recognized minimally invasive adipose lysis with some skin retraction, but this costly technology has not been widely embraced among plastic surgeons.
- Recently, minimally invasive treatments with subcutaneous thin probes delivering controlled radiofrequency energy, Thermi and InMode BodyTite, have shown consistent lipolysis with some shrinkage of the lower torso.

SURGICAL MANAGEMENT

Indications

- Patient recognizes correctable deformity of the lower posterior torso and buttocks.
- Patient is reasonable in goals and accepts the therapeutic recommendations and risks.
- Patient is in good health with control of chronic disease.

Preoperative Planning

- Medical, mental, and psychological conditions must be evaluated and acceptable for elective surgery.
- The roles of liposuction, fat grafting, tissue excision, adipose fascial flaps, and silicone implants toward reaching their aesthetic goals
- The functional working order of all equipment with special attention to high-technology instrumentation
- An awareness of the areas to be liposuctioned, lipoaugmented, and excised and the resulting scars
- The trade-off of scars for unwanted contour deformities
- Understanding of the unpredictable quality of scars and the likelihood of faded scars over many years
- The planned areas for liposuction and incisions for skin and fat excisions are drawn on the awake patient either the evening before or immediately prior to the operation.
- Patient understands the unpredictable magnitude of fat graft take.
- Patient understands the risks of implant malposition, exposure, and infection.
- Immediately prior to the procedure, the tissues are pushed together to simulate closures. Excessive width of resection is avoided. When closures are planned over buried adipose fascial flaps, the width of resection is appropriately reduced.
- Following neighboring liposuction and flap undermining, manual assurance of the proper width of resection is made during the operation for the final time with the plan to tangentially resect more tissue if needed to obtain mild tension at closure.

Positioning

- Surgery only on the posterior trunk is performed with the patient prone. The table is airplane towards lateral for deep liposuction of the flanks.
- When an abdominoplasty is part of the plan and fat harvest in the prone position is estimated inadequate for the buttock augmentation, then the operation starts supine with the lipoabdominoplasty followed by a turn prone with strategic placement of gel body rolls to obtain a jack-knife position.

Approach

- Some combination of the following advanced techniques are considered:
 - VASERlipo with optimal probe, mode, power, and cannula selections for extraction and harvesting of fat
 - Lower body lift with adipose fascial flap augmentation
 - Direct oblique excision of flank excess selectively replaces lower body lift.
 - Silicone soft elastomer gluteal implant augmentation

TECHNIQUES

■ VASERlipo of the Posterior Torso With Lipoaugmentation of the Buttocks (Video 1)



Video p5-c017_01

- The demand for gluteal fat augmentation has increased in recent years, with

9993 reported procedures in 2013 and 11 505 in 2014 in the United States.

- VASERlipo is best indicated for flatten buttocks with mild to moderate torso adipose deposits in a previously well-shaped young woman (**TECH FIG 1A-D**).
- The 1 year result of 3500-cc VASERlipo and 300 cc of lipofill of each lateral buttock reveals more pleasing feminine contours (**TECH FIG 1E-H**).

Markings

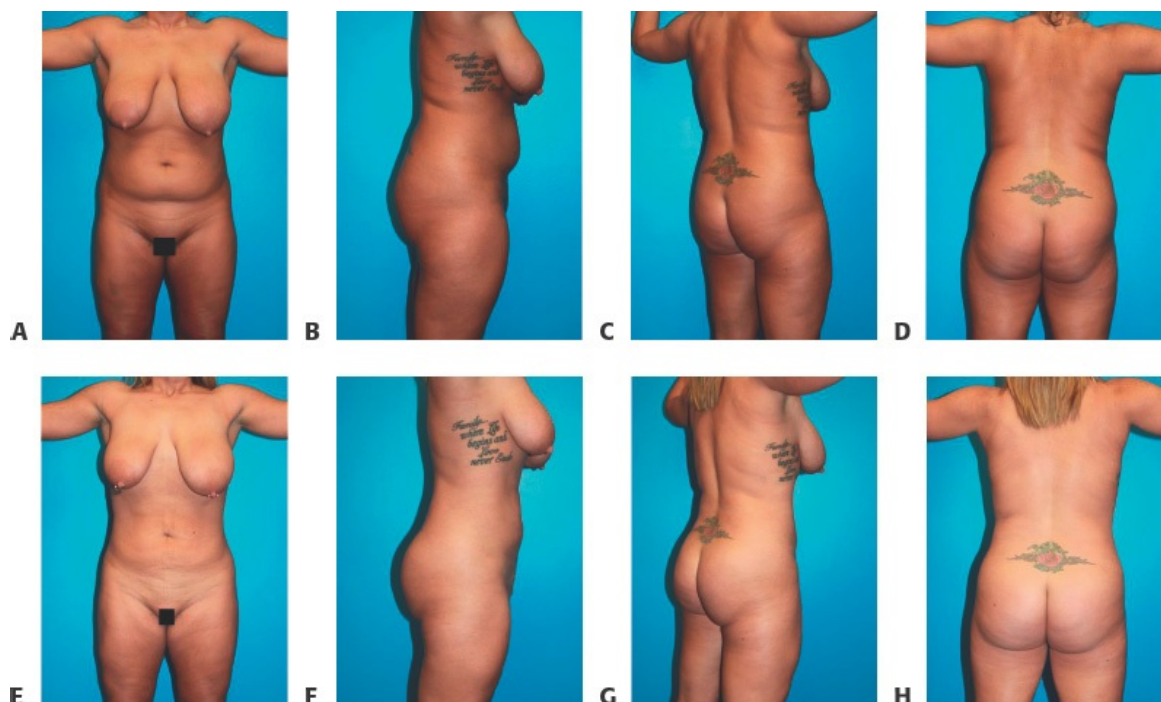
- Through visual and palpable cues, bulging and moderately ptotic back rolls are mapped with purple marker from one to three pluses for the extent of adiposity to be removed via liposuction.
- Excessive removal or etching is indicated in black. Depressed areas, such as adherences, should be avoided and are marked in red. Inadequate and depressed buttock projection is encircled with green marker with dashes indicating the extent of deficiency.

Power-Assisted Lipoplasty

- The densely fibrous adipose of the posterior torso makes traditional suction-assisted liposuction (SAL) arduous and traumatic. Popular power-assisted lipoplasty (PAL) reduces the surgeon's effort but not the damage to the retained tissue.
- Excessive disruption of the connective tissue and neurovasculature intensifies the trauma and disrupts tissue elasticity.
- With large volume removal, the patients are traumatized and intrinsic skin contraction damaged. Recovery can be prolonged for weeks.
- Nevertheless, traditional liposuction and PAL are the most common means of fat shaping and the results can be dramatically excellent.

Fat Emulsification and Harvest

- VASER provides for the preliminary application of internal focused ultrasound. VASER is the acronym for Vibration Amplification of Sound Energy at Resonance.



TECH FIG 1 • A–D. Preoperative frontal, right lateral, right posterior oblique, and posterior view presentation for 4400 cc VASERlipo of the torso, followed by 330-cc lipoaugmentation of each buttock. A 33-year-old woman desires a smaller, more sensual body with buttock roundness. **E–H.** One-year postoperative result of VASERlipo of the torso with lateral lipoaugmentation of the buttocks.

- Resonance is a natural phenomenon referring to the possibility to amplify up to nine times the input resonance versus the energy released. The use of ultrasound frequencies at resonance means that the energy release is most efficient, translating to less power needed to create the same effect, resulting in reduced adverse effects.
- VASERlipo emulsifies fat woven in dense connective tissue, with maximum preservation of supporting structures, neurovasculature, and adipose viability for immediate transplantation to the buttocks.
- Using a multiholed blunt cannula saline with Xylocaine and epinephrine is diffusely and meticulously infiltrated throughout the targeted fat until the tissues are turgid. Through a skin protector, a multiringed ultrasound probe is

uniformly drawn back and forth to disrupt the fat through cavitation of microscopic bubbles introduced through the preliminary infusion of the wetting solution.

- The thrusts are lengthy and slower and more gentle than during typical liposuction. The concept is to achieve an even and thorough disruption of the fat.
- With the energy on, the push through the tissues is met with mild to moderate resistance. The cannula is then pulled back. Disruptive energy is being applied with both the push and pull of the cannula.
- The flattened helping hand stabilizes the skin and adipose, while the thrusting cannula traverses each level, usually from superficial to deep, as if the subcutaneous tissues were laminated.
- Solid titanium probes are available with 1, 2, 3, and 5 rings etched near the distal rounded tip. The greater the number of rings, the more the dispersion of energy. Initial ring selection is made based on the anticipated tissue resistance.
 - Firm or scarred tissue requires one ring, whereas soft fat is rapidly emulsified with 5 rings.
 - When fat is being harvested for lipoaugmentation, the more gentle multiple rings are chosen if possible.
 - Three- and five-ring cannulas tend to have just enough focused energy to traverse the tissue with minimal thrusting force. The power is set at 80%.
 - When the adipose is soft, I prefer the speed of the 5-ringed probe set at 90%.
- The VASER mode, which rapidly alternates ultrasound energy, exudes negligible heat and is preferred when traversing the subdermis.
 - Superficial liposuction with retention of elasticity best leaves skin able to recontour to a smaller volume.
 - When the extracted fat is planned for lipofill, VASER mode is used throughout the procedure.
- Ultrasound is applied approximately 1 minute for every 100 cc of infiltration or until there is no longer resistance to the moving probe.
- Fat for discard is aspirated at one atmosphere (about 22 in. of mercury) through specially vented 3.0-, 3.7-, or 4.6-mm diameter VentX 4-holed cannulas. When the fat is being harvested for lipoaugmentation, the vacuum pressure is lowered to 18 inches of mercury, and a 24-holed grated cannula is

chosen to aspirate fat into a 2200-cc capacity cylindrical glass harvester.

- The 24 two-millimeter openings reduce the vacuum pressure per opening and the size of the adipose particles able to enter each opening. Providing smaller fat packets that can be more easily injected through 1.5-mm diameter Coleman cannulas. When both intakes of the vacuum canister are used, the harvest is quickened and the pressure lowers to 18 in.
- Turning off the vacuum stops the agitation, allowing gravity to separate the denser fluids to the bottom of the canister (**TECH FIG 2**).



TECH FIG 2 • Harvester for aspirated adipose. In-line reusable glass collector with a heavy base traps sterile aspirate. After the suction is turned off, gravity settles the liquid, which is drained through a spout at the bottom. While the remaining fatty emulsion can be syringe aspirated through the spout, we prefer and in this case removed the harvester lid and then poured the contents through a kitchen colander for drainage of excess liquid. The moist fat is then spoon-fed into 10- and 20-cc syringes. Through several stab wound incisions along the designated perimeter, fat is treadlike injected into the buttocks through 8-in.-long blunt Coleman cannulas. Initially, infiltration is fanned throughout the subdermis. Then the fat is evenly injected through the subcutaneous and superficial muscular layers, until a distinct firmness is palpated

throughout the target.

Fat Processing and Injection

- Through a dependent spout, the infranate liquid is released. Then there are two reasonable ways to process fat for injection.
 - Commonly, the canister lid is removed. The fat emulsion is awkwardly poured into a kitchen colander for drainage of the remaining fluid through multiple small holes. Within the open colander, long tissue strands are sliced and diced before the drained fat is spooned into 10- or 20-cc. syringes. The moist fat is pasty and may be difficult to pass through standard Coleman injection cannulas.
 - Alternatively, the decanted adipose slurry is withdrawn through the dependent spout into 20- to 60-cc syringes, which are left standing in a tray. When ready to use, the dependent fluid is pushed out, and the syringe is attached to Coleman cannulas for fat injection. In the demonstration, 3200 cc of fatty emulsion was removed.
- Through stab wounds, fat is injected in a weavelike manner throughout the subcutaneous fat and superficial musculature of the buttocks. As deep, high-tension injections and sharp-pointed cannulas may be the source of fatal venous injections, they are avoided; 600 cc of fat was injected into each buttock.
- The diminution of the back and waist with shapely buttock augmentation is seen one year later (see **TECH FIG 1B,D,F-H**).
- The aesthetic male buttocks are narrow and centrally projecting, suitable for lipoaugmentation that includes infiltration into the gluteal musculature.

■ Gluteal Augmentation Through Lower Body Lift With Adipose Fascial Flaps and Lipotransfer From Flanks to Inferior Buttocks

- Following significant weight loss, sagging, flat buttocks are reshaped with de-epithelialized adipose fascial island flaps isolated within the lower body lift posterior tissue resection.¹ At the same time, reduction of flank adiposity by liposuction not only narrows the waist but also shortens apparent excess buttock height. Fat harvested from the flank is processed and then transferred

to the lower buttocks by injection, where the de-epithelialized adipose fascia flap cannot reach.

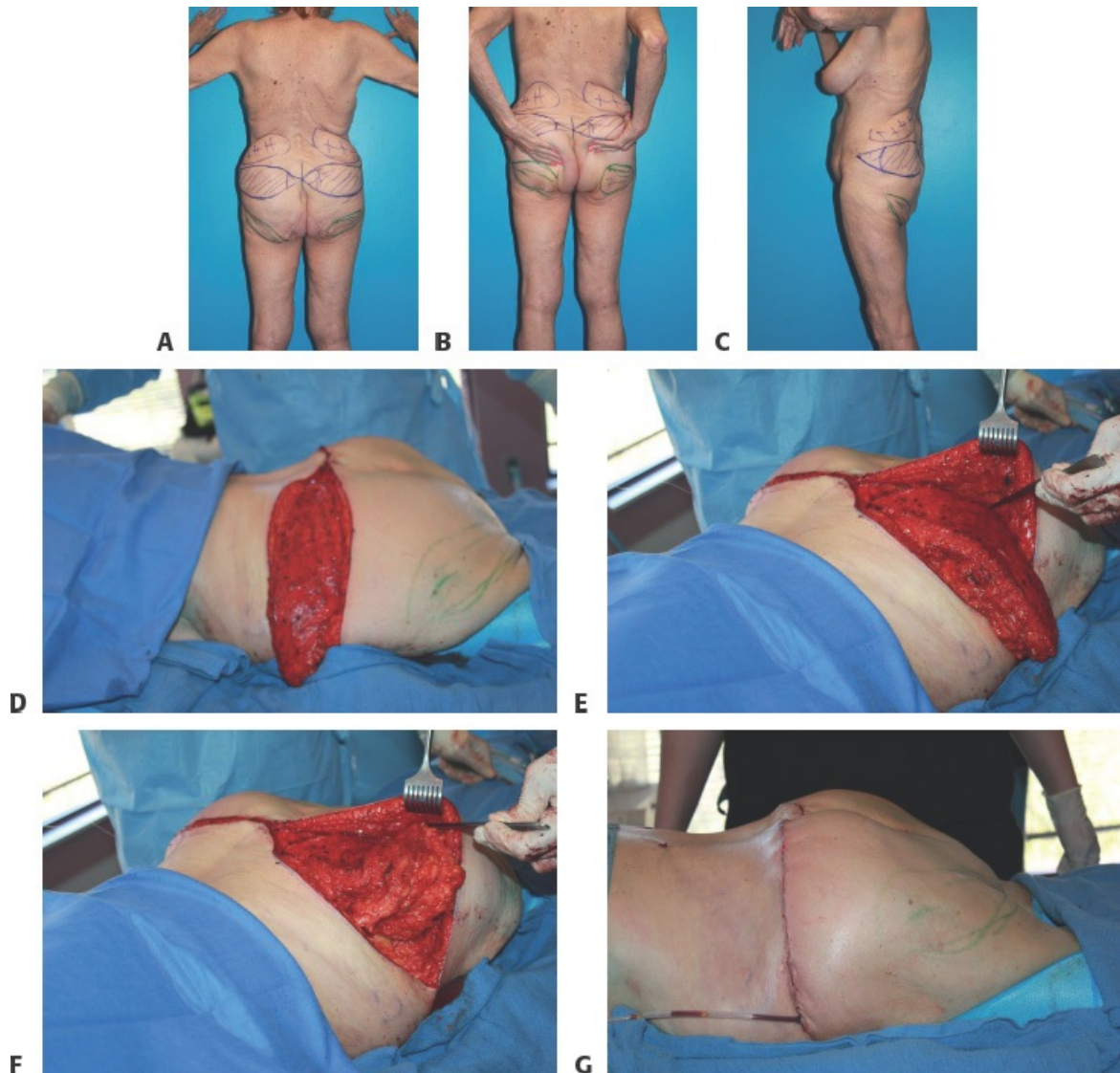
- In this demonstrative case, a prior abdominoplasty has been done many years earlier, and so a circumferential lower body lift was not indicated. Due to a high rate of complications, there is a trend toward performing these two operations independently.²

Island Flap Harvesting and Placement

- A transverse anchor line is drawn along the posterior iliac crests over the lower lumbar midline. The width of resection, as determined by tissue gathering, leaves a transverse curvilinear line along the midbuttocks. Island flaps for augmentation are centered over the superior portion of each buttock (**TECH FIG 3A-C**).
- Reliable double set of paramedian perforator vessels vascularizes the tissues. The anticipated resection distance between the superior and inferior incisions is reduced about 20% to accommodate for the increased subgluteal volume created by the buried augmentation flap.
- The harvested island flaps are de-epithelialized and isolated for positioning under the gluteal skin flap (**TECH FIG 3D**). The perimeter of the flaps is undermined several centimeters. Restricting fascial bands are cut while trying to preserve perforating vessels.
- There are a variety of successful ways to advance the flaps. In this case, the adipose fascial flap was suture advanced to the gluteus muscle as distal under the gluteal skin flap as possible (**TECH FIG 3E**). The lateral fourth of the flaps are completely undermined so that tissue can be either rotated or flipped over the main body of the advanced flap to increase projection (**TECH FIG 3F**). Then the gluteal skin flap is sewn to the lower back and hip anchor incision line in two barbed suture layers (**TECH FIG 3G**).

Completion

- A Jackson-Pratt suction drain is inserted into each buttock pocket. Even a small seroma may allow re-epithelialization of the buried de-epithelialized flap, requiring an operation to decorticate the skin.



TECH FIG 3 • Operative planning for lower body lift with harvest of bilateral adipose fascial flaps, VASERlipo of the flanks, and lipoaugmentation of the lower buttocks. **A,B.** Posterior and left lateral standing views **(C).** A beltlike excision, resembling the infinity symbol, starts at the posterior extent of her abdominoplasty scar. Spanning the posterior iliac crests, the low back side of the excision will anchor the advanced buttock skin flap. The width between incisions, indicated by obliquely oriented cross-hatched lines, is determined by the gap approximation

of the excess upper buttock skin. Within these two incision lines lie the adipose fascial flaps for buttock augmentation. Plus marks within the encircled flanks indicate moderate depth VASERlipo. The inferior buttocks are narrow and deflated with loose skin, which will be lipoaugmented, as designated by the green rectangle, from fat harvested from the flanks. **B.** The same posterior projection of the flanks and buttocks leaves a flattened mega buttocks. **D.** The left side isolated de-epithelialized flap in prone position on operating room table. The flaps are initially deeply de-epithelialized manually or with the assistance of an electric dermatome set to cut thick at 32 000 of an inch thickness. The lower body lift (LBL) incisions form the perimeter of the planned buttock augmentation flaps. Her right LBL with a buried adipose fascial flap has been completed. The stuffed right buttock projects far beyond the unstuffed left. The LBL buttock skin flap needs to be closed over the buried flaps under mild tension. This left adipose fascial flap is isolated on an island pedicle with circumferential undermining. **E.** The flaps are suture advanced to the depths of the dissected space in prone position viewing from the head. After the left flap is fully mobilized, it is sutured advanced with large branded absorbable suture under the buttock undermined flap toward the inferior buttocks. Her right side LBL and buttock plasty have been completed. **F.** The lateral flap extension is flipped over and stacked. Most often, the lateral extensions are completely undermined in order to flip them over the more deeply positioned advancement flaps, providing more projection and lateral fill. **G.** The buttock flap is suture advanced to the lower back

incision. The two-layer closure starts at the midline and progresses laterally with deep bites of double-armed no. 2 PDO Quill. Similarly, 2-0 Monoderm Quill closes the dermis. Compare the competed contour on prone left side with **TECH FIG 3F**.

- The final result in this 77-year-old woman shows a narrow waist with raised buttock and lateral thighs and modest augmentation of the buttocks (**TECH FIG 4**). The generalized skin laxity of the lower back and buttocks has been corrected. Lipoaugmentation of the lower buttocks has reduced the skin sag. Delayed healing of the left transverse suture line has left a depressed scar that may need revision.
- Adipose fascial flaps in men tend to unaesthetically broaden the buttocks and are prone to complications. The low-lying lower body lift tends to excessively depress the upper lateral buttocks. Male hirsutism tends to leave deep hair follicles in de-epithelialized flaps, which may lead to rapid re-epithelialization, which causes intractable seromas. Well-placed suction drains may obviate this complication.



TECH FIG 4 • A. The 6-month result in this 77-year-old patient as seen in posterior and left lateral views (**B**). After a limited dehiscence along the left buttock low back closure, she proceeded to heal with pleasing, hoped-for buttock shape, turgor, and projection, along with a deeper waist. The S-shaped curve from low back to prominent rounded buttocks is agreeable. **C.** Right posterior oblique, before and 6

months (**D**) following her LBL, adipose fascial flaps, VASERlipo of the flanks and lipoaugmentation of the inferior buttocks shows the improve contour best.

■ Oblique Flankplasty With Lipoaugmentation of the Buttocks (Video 2)

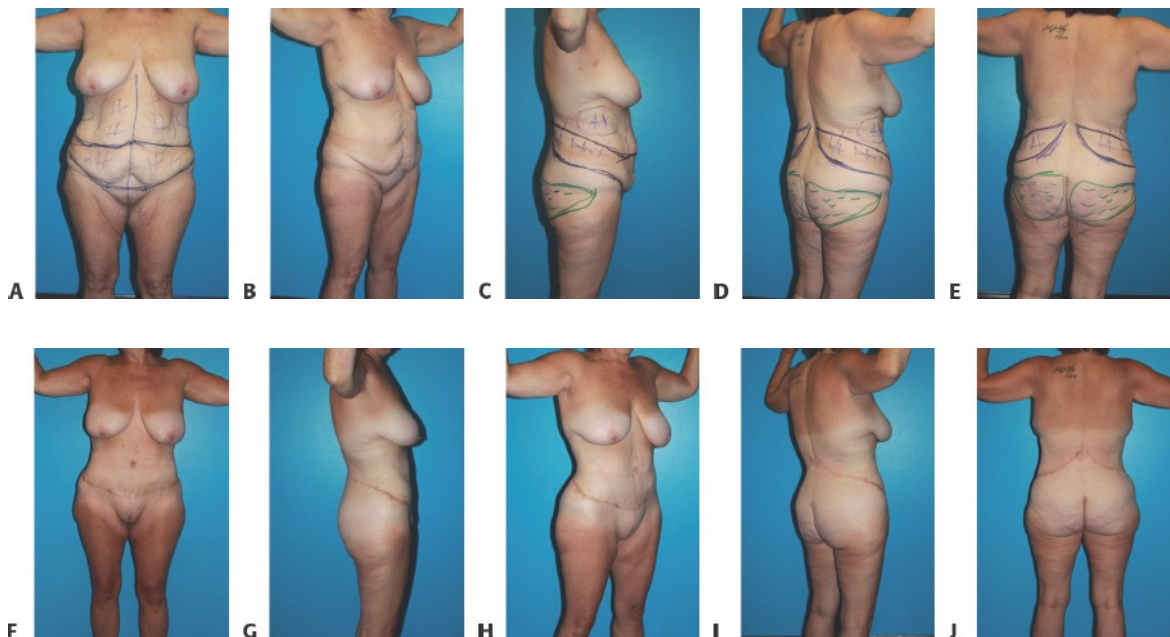


Video p5-c017_02

- Flank rolls widen the waist and lengthen the buttocks.
- When there is skin laxity, liposuction alone cannot adequately narrow the waist. Removing both excess fat and skin narrows the waist and reduces buttock height.
- A full-thickness obliquely oriented flank excision of broad adiposity covered by lax skin creates a narrow waist, especially welcomed when none ever existed. These posterior extensions of an abdominoplasty ascend from between the posterior iliac crests and posterior costal margins. The tapered femininity of the lower costal margin is best exposed through this deep and obliquely oriented resection.
- As the sagging skin along the lateral thigh and buttocks is pulled up with the helping hand, the inferior oblique incision line is drawn from the posterior iliac crests to just short of L1.
- The excess skin and fat are grasped between that line and the posterior costal margin for placement of the parallel superior incision. The two lines taper to

meet near L1 (**TECH FIG 5A-E**).

- The inferior perimeter incision is made vertically down along the iliac crests.
- The superior excision descends vertical to the lumbar fascia. The excision is deep, leaving some fat over the paraspinous muscles, and bares the fascia over the latissimus dorsi and external oblique muscles. The thickness of the specimen can be surprisingly large, like an oversized abdominal pannus.
- A no. 2 PDO Quill suture three-point closure encircling the most superficial subcutaneous fascia edges of the wound to the muscular fascia ensures a tapered deep waist. The quilting aspect of the closure inhibits seroma formation.
- Fat VASERlipo harvested from the excision site is processed to lipoaugment the buttocks.
- The one-year result shows a sensual posterior torso and buttocks in a 68-year-old woman, who is for the first time in her adult life pleased with the appearance of her waist (**TECH FIG 5F-J**). The smooth transitions across her hip heightened the aesthetic appeal.



TECH FIG 5 • A–E. Surgical markings for Oblique flankplasty extension of an abdominoplasty. **F–J.** The result of oblique flankplasty extension of an abdominoplasty. Multiple views show not only deep waists but also curvaceous transitions from the thorax

and buttocks to the waist.

■ Silicone Soft Elastomer Intramuscular Augmentation of the Buttocks (Video 3)

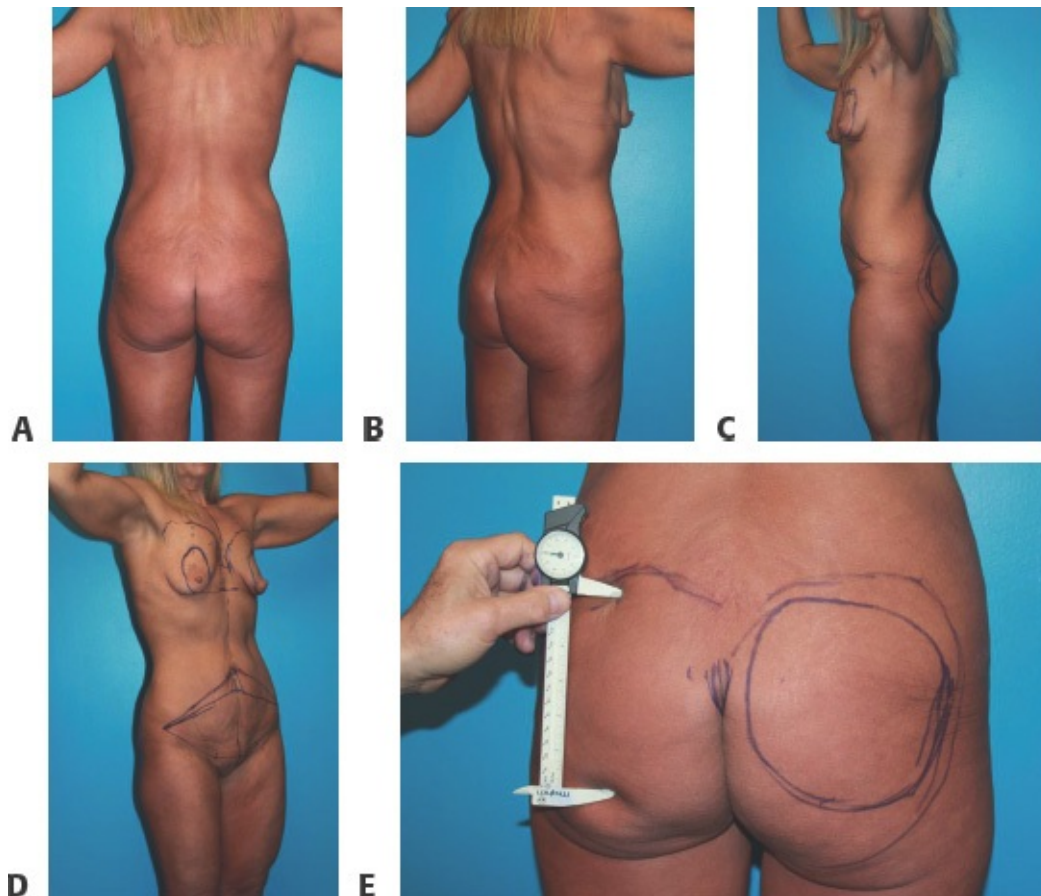


Video p5-c017_03

- Buttock flattening with some skin laxity and normal BMI or less is the indication for implant augmentation of the buttocks. Often, coincidental liposuction of the flanks is performed.
- Based on the patient's desires and anatomy, an appropriate-sized and appropriate shape soft silicone elastomer gluteal implant is selected.
- In closed spaced vertical parallel intergluteal incisions, high intramuscular placement yields the best chance for complication-free aesthetic success.
- The case presentation is a 42-year-old, 5'7", 135 lb self-employed home cleaner, who lost 100 pounds lb through diet and exercise. She is disappointed with her sagging breasts and buttocks as well as generalized loose skin of her torso. She was tormented by her obesity since her adolescence.⁴
- Immediately prior to her buttock implant augmentation, she underwent a 330-cc textured round Sientra implant, Wise pattern implant augmentation mastopexy, and lipoabdominoplasty (**TECH FIG 6A-D**).
- After the gluteal outline is drawn, the perimeter of the chosen implant is outlined immediately inferior to the superior border of the buttocks (**TECH**

FIG 6E).

- A large round implant, 14 cm in diameter and 350 cc in volume, is chosen to augment the central buttocks, take up skin laxity, and partially fill the depressed lateral buttocks.



TECH FIG 6 • Preoperative views with drawings for mommy makeover in a 42-year-old include gluteal implant augmentation. Through diet and exercise, this 5'8" woman has lost 150 pounds and is distressed by deflated breasts and buttocks and generalized sagging skin of the torso. **A.** Unmarked posterior view shows sagging torso and buttock skin. **B.** The left oblique posterior view best shows the flat and sagging buttocks, lower back, and lateral thighs. **C.** Left lateral view shows the markings in profile for correction of sagging breasts, abdomen, and buttocks. **D.** Right

anterior oblique view has markings visible for periareolar mastopexy and 365-cc Sientra textured round implant augmentation and complete abdominoplasty, which will start with the lower of the two superior markings. **E.** In this posterior view, a caliper marks the 14-cm diameter of the implant within the boundary of the left buttocks. Implantech CCBS-NC-3 14 cm in diameter 330 cc. Contour flex gluteal “natural contour” implants were chosen to take up the skin laxity from pelvic rim to lateral gluteal regions without excessive projection. The gluteal implants are drawn extending from the pelvic rim. It is better to keep the placement slightly cephalad as the implants are likely to drop slightly.

Incision and Dissection

- Parallel 6-cm-long vertical incisions are drawn 1.5 cm on either side of the intergluteal cleft. A single midline incision is an alternative approach reserved for the most experienced operators, because without care the intragluteal cleft may be blunted.
- The incision and dissection are completed for one pocket and then the other prior to inserting the implants.
- After the 6-cm gluteal incision is made, dissection proceeds through the medial subcutaneous tissue, to enter the gluteal fascia. A partial-thickness electrocautery incision is made the medial gluteus maximus muscle.
- With the aid of electrosurgery and in-line suction, a tedious intramuscular dissection is continued for the entire pocket for the implant (**TECH FIG 7**).

Implant Insertion

- A plastic ruler cut to the diameter of the selected implant is inserted to assure adequate breadth of the dissected space. Alternatively, a sizer implant is inserted to assure fit. The Implantech buttock implant is pliable enough to roll up for insertion through the 6-cm opening.
- Immediately prior to inserting the implant into the pocket, Betadine-impregnated Ioban sheet is applied over the incision and operative area. The

folded implant is shimmied into the dissected intramuscular space and then unfurled and spread out to precisely fill the intramuscular pocket.



TECH FIG 7 • Intraoperative view of buttock surgery. With her head to the right, the right buttock dissection has been completed and a tail of a buried lap pad is seen. Through a left paramedian 6 cm long incision has been made through skin, and then tediously electrocautery intramuscular dissection is done as exposed by the Richardson retractor.

Completion

- The muscular incision is closed with interrupted absorbable braided suture (**TECH FIG 8A**), followed by two more layers in the subcutaneous tissues and dermis (**TECH FIG 8B,C**).
- Over 6 months, the slightly high positioned and large 14 cm in diameter round implants descend to the desired location.
- Immediately after her 350-cc intramuscular buttock implant augmentation, this 42-year-old woman also had 350-cc gel implant periareolar breast augmentation mastopexy and abdominoplasty. The transformation at 5 months is evident (**TECH FIG 8D-G**).



TECH FIG 8 • A. After placing an Ioban adhesive drape (3M Health Care, St. Paul Minnesota), the gluteal implant was folded, inserted into the dissected intramuscular space, and then unfurled. The carefully preserved muscular cuff is grasped by forceps for interrupted suture closure on the left side. **B.** Immediate intraoperative view of the augmented right buttocks. Compare the height and fullness of the just augmented right buttocks with the left. The 14-cm-

wide implant gently fills the depressed lateral buttocks. **C.** Intraoperative view at the completion of the bilateral implant augmentation. **D.** The 6-month result of the periareolar mastopexy, 365-cc round textured breast implant subpectoral fascia augmentation, complete abdominoplasty, and 355-cc silicone elastomer buttock augmentation. Compare to **TECH FIG 6**. The entire buttocks are well shaped without any surrounding skin laxity. The parallel intergluteal vertical scar are hidden. **E.** Right posterior oblique view shows nicely projecting rounded buttocks that have taken in the slack of the lower back and upper posterior lateral thighs. **F.** Lateral view shows proportionally youthful shape of the breasts, abdomen, and buttocks. **G.** Right anterior oblique view best shows the dramatic figure change with her implants, which along with the abdominoplasty adequately took up the slack. The well-shaped muscular abdomen with a low-lying and level scar complements her muscular upper torso.

PEARLS AND PITFALLS

Aesthetic evaluation

- The buttock evaluation is considered with lower torso and upper thighs. Liposuction about the perimeter of the buttocks enhances buttock appearance and provides donor grafts.

Buttock lipoaugmentation

- First choice when adipose donor sites are adequate. Take is generally very high, but unpredictable. Save potential donor sites.

Buttock adipose fascial flaps

- High rate of delayed wound healing. Avoid over-resecting with tight closure. Early overprojection is lost within months.

Silicone elastomer augmentation

- As implants in America are soft elastomer and not a firm gel, they are placed high and intramuscular to avoid uncomfortable inferior malposition. Minimize wound dehiscence and loss of intragluteal cleft with paramedian incisions.

POSTOPERATIVE CARE

- Immediate postoperative elastic garment that hugs the waist, supports the buttocks, and compresses the upper thighs is fitted according to size.
- Patient may not to lie directly on the incision closure. She may lie directly on the augmented buttocks for up to an hour at a time.
- Suction silicone drains are used after lower back liposuction and alongside adipose fascial flaps but not worth the risk of infection near silicone implants. Meticulous drain care maintains function and exit site cleanliness.
- Extreme hip flexion is avoided.

OUTCOMES

- When properly informed, patients tend to like the outcomes, even when falling somewhat short of expectations.
- Repeat lipoaugmentation for inadequate buttock fullness is anticipated and accepted if performed at reasonable costs.
- Buttock implant failure needs a complete reoperation, which is hard to accept, even when forewarned.
- Adipose fascial flap augmentation, in most instances, settles considerably, causing considerable loss of projection.
- Prolonged secondary healing after adipose fascial flaps may be followed by painful depressed scarring and considerable disappointment.

COMPLICATIONS

- Infection following lipoaugmentation is a difficult and fortunately rare problem to clear, due to the large reservoir of necrotic fat. Numerous small drainage procedures and intravenous administered antibiotics are indicated.
- Forceful injection of fat into the deep gluteal tissues is to be avoided, as sudden death through large vein fat deposits followed by pulmonary embolism has been reported in Latin America.³
- Adipose fascial flaps placed added tension to the lower body lift closure, which may lead to skin and fat necrosis along the closure.
- If limited, debridement is a minor office procedure. When extensive,

debridement has been in hospital under general anesthesia procedure, usually followed by application of VAC.

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18 Gynecomastia Procedures after Massive Weight Loss

CHAPTER

Michele Shermak

DEFINITION

- Gynecomastia technically is defined as enlargement of breast tissue in men. Often with massive weight loss patients, there is pseudogynecomastia, with skin redundancy and ptotic nipple-areolar complex (NAC) position, which might be associated with true breast tissue.

ANATOMY

- In male massive weight loss patients, there may be underlying musculoskeletal deformity with barrel chest. Glandular breast tissue may be present. Skin is excessive vertically and horizontally, with a visible inframammary fold (IMF), and skin excess may extend posteriorly to the upper back. Standard position of the NAC is just lateral to the pectoralis muscle, 20 cm from the sternal notch and 10 cm from midline. With gynecomastia, nipple-areolar position is lower, oftentimes beneath the inframammary fold.

PATHOGENESIS

- Most male neonates have some amount of palpable breast tissue. The next chronological peak for gynecomastia occurs during puberty, with the last peak occurring in men between 50 and 69 years of age.
- Physiological gynecomastia in pubertal male teens is benign and self-limited; on the other hand, several conditions and drugs may induce proliferation of male breast tissue. Most cases result from estrogen excess and/or androgen deficiency as a consequence of different endocrine disorders.
- Thyroid and testicular disease may cause gynecomastia.
- Biochemical evaluation should be performed once physiological or iatrogenic

gynecomastia has been ruled out. Nonendocrine illnesses, including liver failure and chronic kidney disease, are other cause of gynecomastia that should be considered.

- Medications associated with the onset of gynecomastia are spironolactone, cimetidine, ketoconazole, hGH, estrogens, hCG, antiandrogens, GnRH analogs, and 5- α reductase inhibitors.
- Medications probably associated with gynecomastia include risperidone, verapamil, nifedipine, omeprazole, alkylating agents, HIV medications (efavirenz), anabolic steroids, alcohol, and opioids. Cessation of these medications may result in resolution of gynecomastia.^{1–3}

PATIENT HISTORY AND PHYSICAL FINDINGS

- History should be queried regarding potential causes of gynecomastia that may be reversible, such as use of medications or marijuana. Medical history including hyperthyroidism or testicular disease should be checked, in addition to family history of breast cancer. Symptoms such as pain and nipple discharge should be checked.
- Physical examination should emphasize on the chest as well as other body regions elicited on medical history. Examination of the chest wall should focus on symmetry, presence of breast tissue, skin quality, underlying thoracic/skeletal deformities, and any masses on palpation. Testicular physical examination is warranted.
- Examination of the massive weight loss patient may also assess other body regions that may be directly or secondarily addressed at the time of gynecomastia correction.

IMAGING

- Mammogram should be considered in a male with breast asymmetry, palpable mass, or family history of breast cancer.⁴ If there are any suspicious findings on mammogram, ultrasound and MRI studies may follow, with PET/CT if concerns are present for metastatic breast cancer.

SURGICAL MANAGEMENT

Preoperative Planning

- After physical examination and any necessary assessments rule out cancer concern, planning for gynecomastia follows. Lack of skin redundancy and good skin quality lend themselves to limited incision approaches.⁵ Massive

weight loss patients with skin excess, stretch marks, and NAC ptosis require skin reduction techniques and possibly NAC grafting.⁶ Scars associated with skin reduction must be discussed with the patient who should weigh in on the technique chosen.

Positioning

- Positioning for surgery is standard supine with arms lateral to the body at 90 degrees. Sequential compression devices and lower body warming are optimal.

Approach

- Approaches range from liposuction to limited scar with glandular resection and liposuction to skin reduction, glandular resection, and nipple-areolar grafting.

TECHNIQUES

■ Liposuction

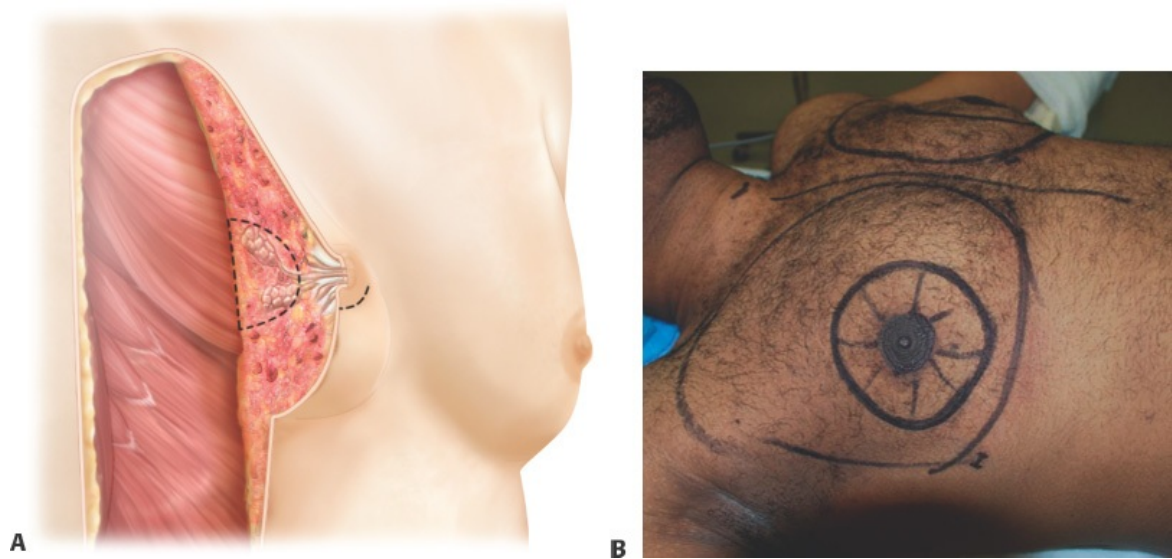
- Patient is marked preoperatively.
- Small stab incisions are created medially and laterally on the inframammary fold (IMF).
- Superwet tumescent liposuction technique is followed, aiming for 1:1 match with tumescent fluid volume instilled and lipoaspirate volume removed.
- After adequate time is allowed for hemostatic effect, liposuction with traditional approach (suction-assisted liposuction [SAL]), power-assisted liposuction (PAL), or ultrasound/VASER-assisted liposuction (UAL) is performed, reducing adipose and glandular elements, with particular attention to treating the IMF and axillary regions (**TECH FIG 1**).



TECH FIG 1 • Liposuction of the chest includes small incisions at the inframammary fold medially and laterally on each side, utilizing preferably PAL or UAL to remove the full tissue and gland.

■ Limited Scar Glandular Resection With Liposuction

- Technique for liposuction of the chest is followed.
- Semicircular incision around the lower NAC is made and the NAC is dissected off of the glandular tissue, maintaining glandular tissue within the NAC to avoid NAC deformity.
- The glandular tissue is completely removed, maintaining appropriate subcutaneous tissue on the chest wall skin.⁵ (**TECH FIG 2**).
- The lateral IMF stab incision may be utilized to place a drain tube.
- The incision is closed in layered fashion with dermal and subcuticular layers.
- The patient is dressed with foam compression and a vest to aid in contour and reduce swelling and bruising.

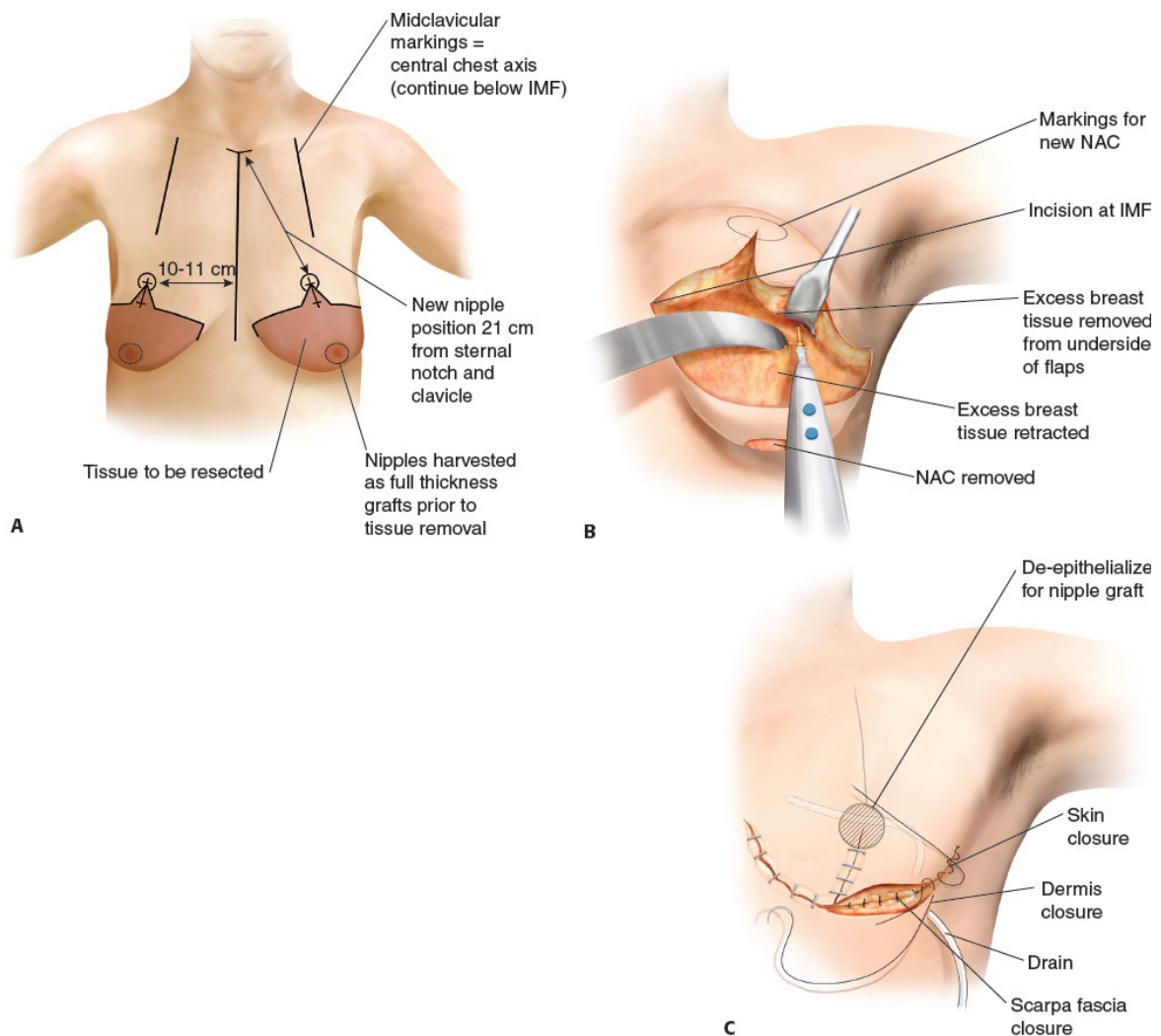


TECH FIG 2 • A. Diagram of resection of breast tissue. This will occur after fat surrounding the *red* area is liposuctioned out. **B.** Markings for liposuction with glandular excision (*outer circle*) include an added incision (marked with a *semicircle*) at the lower edge of the areola from 3:00 to 9:00. The *inner circle* marks palpable breast tissue. Liposuction is performed first, followed by incision of the NAC and glandular

excision. It is important to maintain some tissue behind the NAC to create the most optimal contour.

■ Mastectomy With Skin Reduction After Massive Weight Loss

- Wise pattern is marked on the patient standing, aiming for nipple-sternal notch distance of 21 cm and distance of 20 cm between nipples.
 - The new NAC goal is for small ovoid NAC just along the border of the pectoralis major muscle (**TECH FIG 3A**).
- NAC is harvested to superficial dermis and stored on the side table in saline-moistened gauze.
- Wise pattern breast reduction follows, removing glandular and pseudoglandular tissue while maintaining appropriate-thickness skin flaps (**TECH FIG 3B**).
- A drain is placed and the skin is approximated in layered fashion, including the Scarpa fascia, deep dermis, and subcuticular suture layers.
- The new NAC recipient site is de-epithelialized and the NAC harvested is sutured to the site with interrupted and running no. 4-0 chromic sutures (**TECH FIG 3C**).
- Compression dressing is created over the NAC with nonstick gauze and foam stapled into place.



TECH FIG 3 • A. Markings for Wise pattern mastectomy with nipple grafting for gynecomastia. The NAC is 21 cm from the sternal notch and 10 cm lateral to the midline, and 7 cm is allowed for the distance between the nipple and IMF. **B.** The breast tissue is dissected under the skin flap, which includes the full thickness of the subcutaneous fat layer. The breast tissue is then elevated off the pectoralis fascia after the NAC is harvested and stored, and the breast tissue is removed at the IMF. **C.** The Scarpa fascia is closed with 2-0 or 3-0 interrupted braided absorbable suture, the dermis is closed with 3-0 interrupted

absorbable monofilament suture, and the skin is closed with 4-0 continuous intracuticular monofilament suture. A no. 10 flat Jackson-Pratt drain is placed. After approximating the medial and lateral skin flaps to the IMF, the new NAC position is de-epithelialized and grafted with the NAC harvested earlier in the procedure.

PEARLS AND PITFALLS

Unsatisfactory contour

- Avoid overthinning the NAC and chest skin to create best aesthetic result. Assure if liposuction is performed that the surgeon avoids over- or under-resection and aims for symmetry.

Completely resolve chest fullness

- Aim to add glandular tissue resection to liposuction. Men generally do not like to palpate, let alone see, any chest fullness after surgery. In massive weight loss, the surgeon should consider grafting the NAC rather than maintaining the NAC on a pedicle to avoid residual chest fullness.

Contour takes precedence over scar

- In massive weight loss patients, skin removal is critical to contour. Scars fade over time. Scars range from inframammary scars to anchor incisions to transverse or oblique incisions in the midchest. Scar outcomes may be optimized with patient engagement and counseling.

Individualize care

- Presentation of gynecomastia runs a wide spectrum. Each patient should be evaluated and treated specifically for his or her presentation and scar tolerance.

Other procedures pair well with gynecomastia treatment

- Massive weight loss patients may choose to also undergo abdominoplasty, liposuction, and/or brachioplasty, which may be safely performed together and will complement aesthetic results of the gynecomastia surgery.

POSTOPERATIVE CARE

- Surgery is most often performed as an outpatient.

- Patients are seen within days of surgery at which time any drain tubes are removed.
- After this, patients are seen the following week for suture removal and counseling for optimal scar, which may include compression, topical therapies, and activity limits for 4 to 6 weeks.

OUTCOMES

- Scar therapy is managed and cosmetic outcome should be excellent. There should be no functional deficit (**FIGS 1–3**).

COMPLICATIONS

- Contour irregularity—This may result in need for revisions, which are typically performed under local anesthetic. Focal minimal liposuction or fat transfer may be necessary, as well as excess skin removal. If a liposuction-only technique is performed, patients may be able to palpate or see residual breast tissue after surgery, resulting in patient dissatisfaction and desire to undergo definitive glandular excision in a subsequent surgical procedure.
- Visible scarring—After conservative topical management of scars for 4 months, scar management may require injectable steroid, with consideration for later scar revision under local anesthesia as needed.
- Seroma—If seroma results, this is initially treated with needle aspiration, which may be performed several times. If this does not fully resolve the seroma, a drain may be replaced to more optimally treat residual fluid.
- Infection—This is not common and may be treated with antibiotics, beginning with oral antibiotics that cover gram-positive organisms. Local wound care with topical antibiotics may provide adequate treatment of cellulitis.
- Wound healing problems—Local wound care tends to be adequate, with local debridement as needed and moisture with coverage. Antibacterial topical medications such as mupirocin are helpful if there is cellulitis.

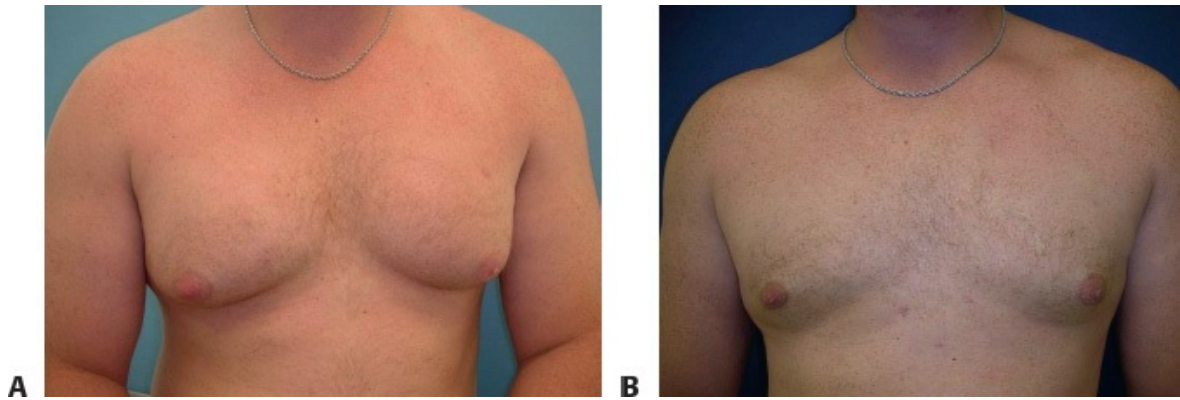


FIG 1 • A,B. Pre- and postoperative photos of a male who underwent treatment of gynecomastia with liposuction.

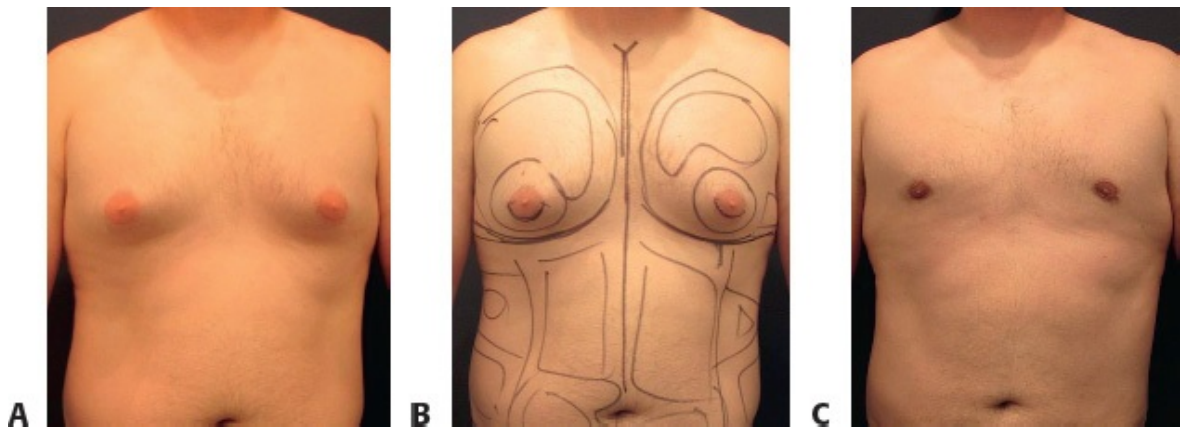


FIG 2 • A-C. Pre- and postoperative photos of a male who underwent liposuction and glandular resection of liposuction. He also underwent liposuction of his torso while being treated for his chest.

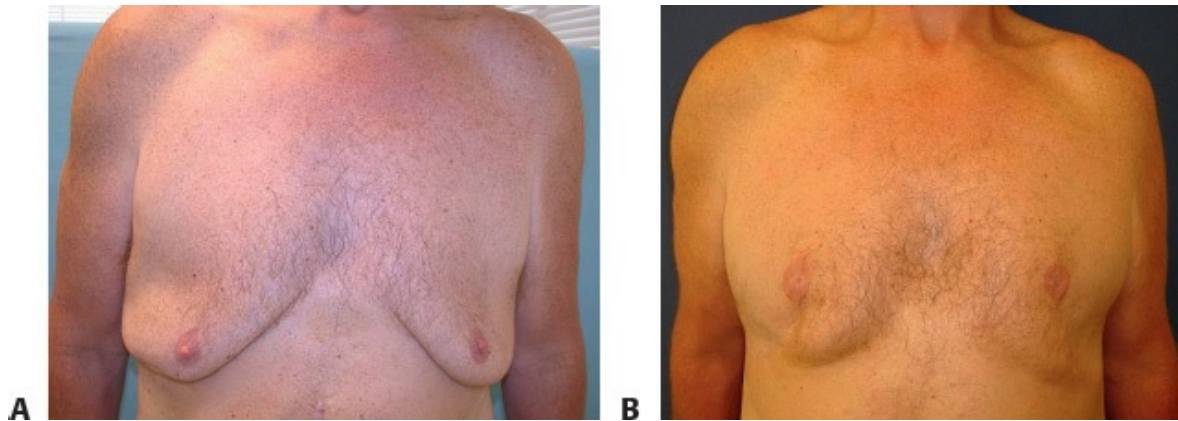


FIG 3 • A,B. Pre- and postoperative photos of a male who underwent Wise pattern mastectomy with nipple grafting after massive weight loss. He also underwent abdominoplasty while being treated for his chest.

- Nipple-areolar pigmentation irregularity—This may occur with nipple grafting and is first allowed a year to improve with moisturizers. If there is residual hypopigmentation, then local excision for small areas or tattoo for larger areas resolves pigment issues.

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CHAPTER Mons Pubis Reduction

Michele Shermak

DEFINITION

- The mons region is defined as a part of the vulvar anatomy, which also includes the labia majora and labia minora.
- Monsplasty is performed as an isolated procedure or in conjunction with abdominoplasty and/or medial thighplasty. The goal of monsplasty is to create a smooth mons with attractive dimensions vertically and horizontally and appropriate fat composition, with harmonious continuity with the abdomen.
- The mons is often affected by massive weight loss (MWL) and pregnancy, with descent of the pubic area, lengthening of the distance between umbilicus and the vulvar cleft, and residual adiposity.
- Although shortening of vertical dimensions and thinning and resuspension of the mons may be performed with abdominal contouring procedures, narrowing horizontal dimension can occur in conjunction with medial thigh lift.
- Monsplasty has been shown to improve hygiene, urinary continence, and confidence in sexuality.

ANATOMY

- The vulva includes the mons pubis, labia majora, labia minora, vaginal vestibule, and bulb of the vestibule (**FIG 1**).
- The mons pubis is superficial to the pubic bone.
- The labia majora are paired cutaneous folds that extend posteriorly from the mons pubis and contain variable fatty tissue. The labia majora converge with the labia minora at the posterior commissure or fourchette.

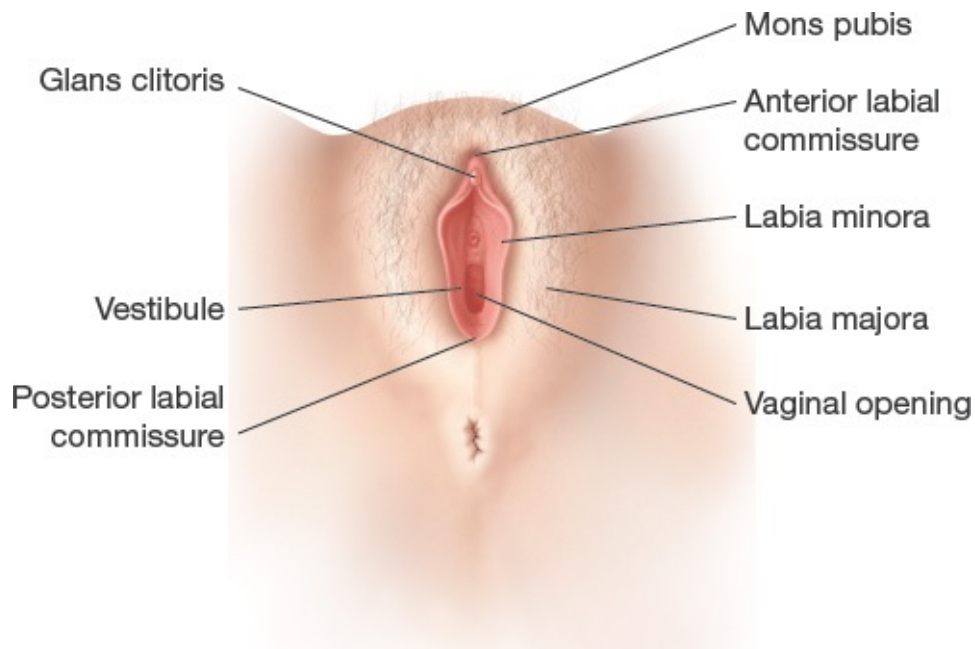


FIG 1 • The female genitalia, with anatomic areas indicated: 1, labia majora; 2, labia minora; 3, mons pubis; 4, clitoral hood; 5, glans clitoris; 6, urethra; 7, vaginal opening.

- The labia minora are cutaneous folds located medial to the base of the labia majora. The visible rounded portion of the clitoris is located near the anterior junction of the labia minora, above the openings of the urethra and the vagina.
- The vasculature of the female external genitalia includes the anterior labial arteries, branches of the external pudendal arteries, the posterior labial arteries, and branches of the internal pudendal artery. The labial veins drain to the pudendal and femoral veins.
- The vulva is innervated anteriorly by the anterior labial nerves and branches of the ilioinguinal nerve and by the genital nerve, which extends from the genitofemoral nerve. The vulva is innervated posteriorly by posterior pudendal branches.

PATHOGENESIS

- Mons pubis and labia majora morphology are impacted by aging, pregnancy, and weight changes that in turn impact fat composition, dimensions, and ptosis.
- The youthful mons pubis is narrow, with good skin tone, and has a moderate amount of fat in the subcutaneous plane to provide padding against the bony

symphysis.

- With age, pregnancy, or weight fluctuations, the mons pubis can appear wide and protuberant with poor skin tone (**FIG 2**). The labia majora may be deflated, and there is ptosis of the external genitalia with increasing distance from the abdomen inferiorly.
- With obesity, the mons becomes increasingly protuberant with a relatively high composition of fat, which often lends itself to surgical correction with liposuction alone. Difficulty with sexual intercourse and maintenance of hygiene as well as discomfort when wearing pants and swimsuits may result. This situation can also impact self-esteem.
- Techniques to correct the protuberant mons and pubic descent with excess skin address these issues with pubic lifting, fat excision and liposuction, and/or elevation and suspension of the fatty layers to the rectus abdominis fascia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The surgical consultation should begin with discussion of patient concerns and desired outcomes. Discomfort or dissatisfaction with sexual intercourse, bladder control, problems with exercise or wearing certain clothing, and hygienic concerns could result in a patient initiating a surgical consultation.
- Medical history should be explored for any medical conditions and history of weight gain or loss and pregnancies, as well as surgical history.

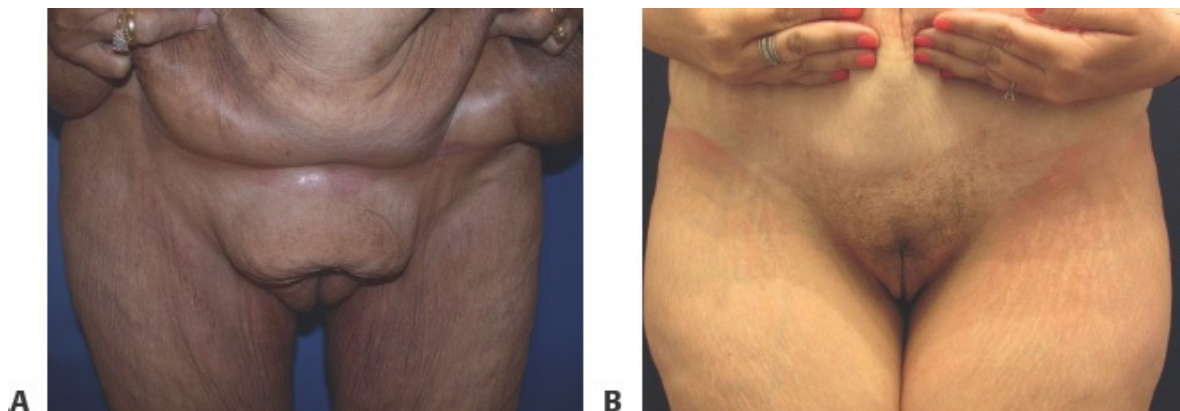


FIG 2 • A. Mons pubis in MWL demonstrates significant ptosis and excess fat. **B.** Abdominoplasty with removal of the upper part of the mons pubis will allow a rejuvenated appearance.

- Physical examination is comprehensive and involves the abdomen as well as the external genitalia.
- A surgical plan is then developed to address patient desires and goals, as well as physical findings, adjusting treatment to health and safety concerns.

IMAGING

- This is not applicable to monsplasty management.

SURGICAL MANAGEMENT

Preoperative Planning

- After history and physical examination, planning for monsplasty takes place. Considerations for the pubic region include fat composition and skin quality and excess, as well as height and width dimensions. In most abdominal contouring procedures, the mons pubis is treated with the abdomen with liposuction.
- With varying degrees of mons distortion beyond excess fatty tissue, excisional procedures including horizontal and vertical wedge excision with or without abdominal or thigh contouring are necessary.
 - Horizontal excision shortens vertical distance and may be performed in continuity with abdominoplasty, allowing 6 to 7 cm of distance between the vulvar cleft and the lower abdominal skin incision.
 - Vertical excisions of the mons and labia majora as a central ellipse or as lateral wedges may be included in medial thighplasty to narrow the mons pubis, by restoring a more youthful triangular configuration.
- Lipoplasty through liposuction or excision in conjunction with central wedge excision techniques allows for thinning a protuberant mons pubis and aids in final contouring to provide better harmony with the abdomen. When contouring of the mons pubis and/or labia majora is complete, the pubic tissues may be suspended up to the fascia of the rectus abdominis to prevent them from recurrent descent.

Positioning

- Positioning for surgery is standard supine with arms lateral to the body at 90 degrees, with appropriate padding and heating for the body to optimize safe surgery without complicated outcomes. Sequential compression devices are mandated as well. Some surgeons like to perform monsplasty in stirrups, which may increase VTE risk.

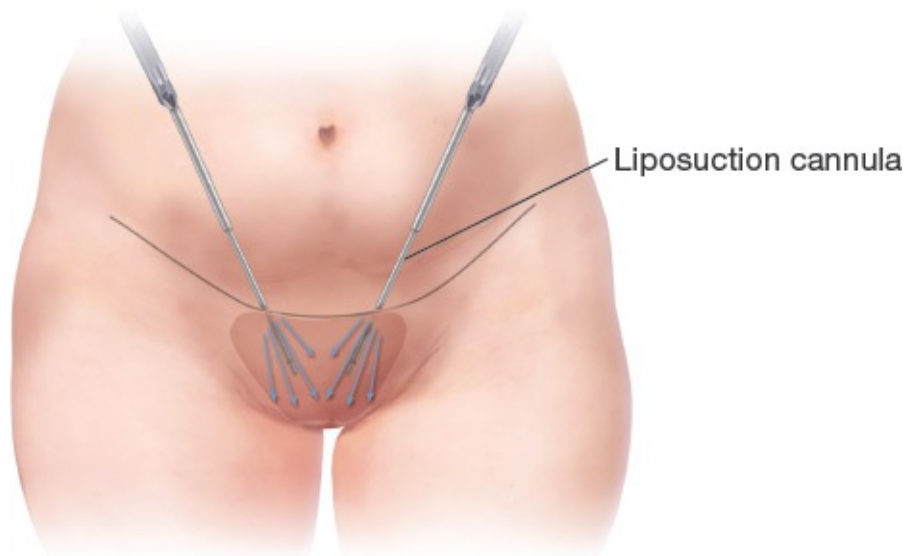
Approach

- Allowing for a distance of 6 to 7 cm from the vulvar cleft to the top of the mons pubis is necessary to avoid distortion and overelevation of the mons pubis. The mons pubis when performed in conjunction with abdominoplasty should strive for the same depth of skin to deep fascia as is present in the abdomen to create harmony between the abdomen and mons pubis.

TECHNIQUES

■ Liposuction

- Patient is marked preoperatively. Small stab incisions are created. Superwet tumescent liposuction technique is followed, aiming for 1:1 match with tumescent fluid volume instilled and lipoaspirate volume removed. After adequate time passes for hemostatic effect, liposuction with traditional approach (SAL), power-assisted (PAL), or ultrasound/VASER-assisted (UAL) liposuction is performed, reducing adipose content (**TECH FIG 1**).



TECH FIG 1 • Liposuction of the mons pubis may be performed with augmented technologies such as ultrasound and power to provide skin tightening.

■ Central Wedge Excision of the Mons Pubis

- Elliptical width is determined for appropriate narrowing of the pubis. Surgical resection includes skin and fat, working the dog-ear inferiorly into the vulvar cleft and avoiding injury to the region of the clitoris (**TECH FIG 2**).

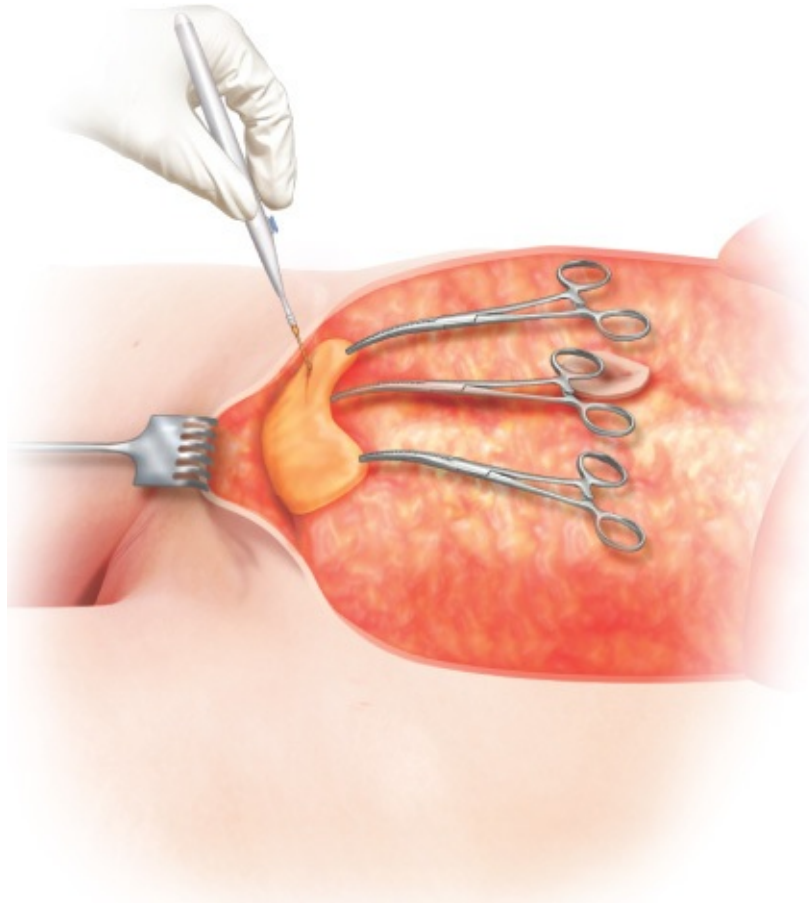


TECH FIG 2 • Central wedge excision is marked, centered around the central vertical axis of the mons pubis and short of the convergence of the labia majora.

■ Horizontal Excision With Lipoplasty and Suspension to the Rectus Fascia in Conjunction With Abdominoplasty

- Markings for abdominoplasty establish 6 to 7 cm of distance between the lower abdominal incision and the vulvar cleft.
- Abdominoplasty proceeds with elevation of the lower skin flap for upper mons excision in continuity with the abdominal skin flap.
- After completion of the abdominoplasty, subcutaneous fat of the mons is excised, leaving a layer of fibrofatty tissue on the abdominal wall and allowing for skin thickness congruent with the abdomen.

- The deep fat on the mons skin flap is then suspended to the rectus fascia with 3 to 4 braided absorbable sutures (**TECH FIG 3**).
- The abdominal incision is closed over drains in layered fashion with superficial fascia, deep dermal and subcuticular layers.



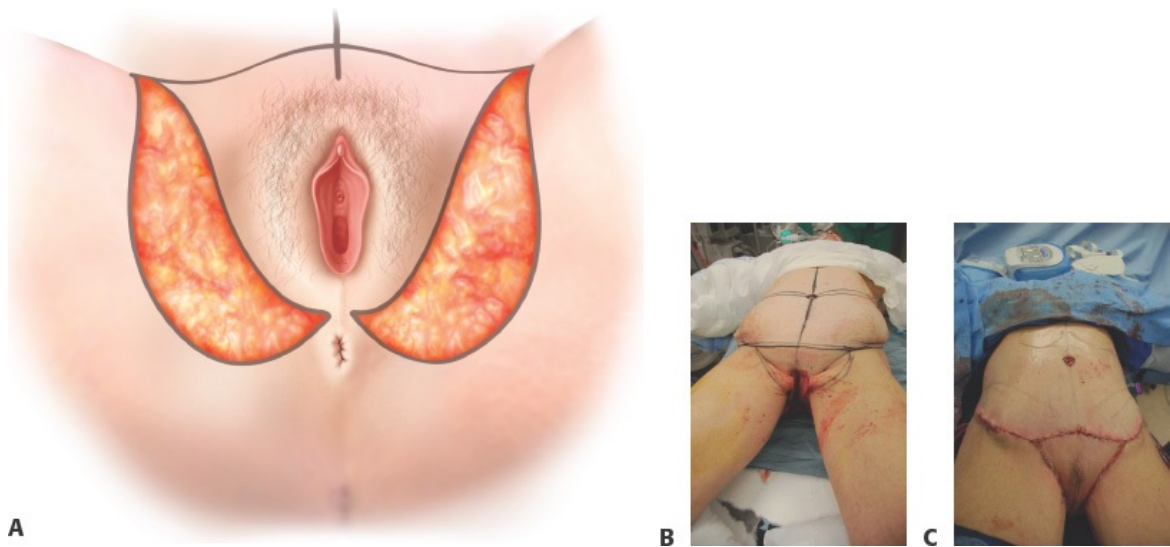
TECH FIG 3 • Horizontal wedge excision of the superior mons pubis in conjunction with abdominoplasty includes defatting of the mons pubis with suspension to the rectus abdominis fascia.

■ Lateral Wedge Excision of the Labia Majora and Mons Pubis in Conjunction With Medial Thighplasty (See Thigh Lift chapter)

- In marking the anterior aspect of the APEX thigh lift or vertical extended

thigh lift into the inguinal region, a central axis is marked on the mons pubis.

- The width of the pubis is determined and should be consistent with dimensions of the underlying bony pubic symphysis, with symmetry of the mons result around the central axis measured and marked.
- In performing the anterior excision of the thigh lift along the inguinal crease, markings along the lateral pubis are commitment excisions, with excision of the redundant lateral pubis and anterior medial thigh dependent on avoiding tense closure and performed in stepwise fashion (**TECH FIG 4**).



TECH FIG 4 • A. Lateral excision of the mons pubis and labia majora is carefully marked preoperatively, in order to create a symmetrical pubis centered around the central axis. **B.** Intraoperative photo of the anterior aspect of medial thigh lift, with pubis markings and extent of thigh lift excision to occur superiorly. **C.** Intraoperative photo of completed medial thigh lift with contoured, thinned mons dimensions.

PEARLS AND PITFALLS

Contour irregularities

- Avoid overthinning and assure uniform treatment,

**and skin laxity
secondary to
liposuction**

recording “ins and outs” of tumescent fluid infiltrated and lipoaspirate removed to create best aesthetic result. Augmented technologies such as PAL and UAL assist in avoiding tunneling deformities and may tighten the skin beyond what is achievable with SAL.

**Horizontal skin
resections rejuvenate
the mons pubis, but
they may descend with
time**

- Suspend the upper mons deep fatty tissue to the rectus fascia with several absorbable sutures to promote prolonged suspension of the mons pubis.

**Avoid asymmetrical or
shortened mons pubis
dimension**

- Asymmetry in skin dimension horizontally or vertically is best avoided through careful preoperative markings, working around a central axis, and allowing for symmetry around the axis and the vulvar commissure. Patient presentation may be asymmetrical, so asymmetrical treatment may be mandated. Using the vulvar cleft as a fixed point, the mons should be no shorter than 6–7 cm to avoid overly high labia majora placement.

**Lateral pubic wedge
excision during medial
thighplasty with vertical
reduction through
abdominoplasty can
lead to a puffy mons
pubis due to
pincushion effect of
circumferential scar**

- Markings should not create overly full or overly shortened pubis at the outset. Lymphatic injury should be avoided and superficial excision leaving tissue above deep fascia and vascular and lymphatic structures helps optimize edema prevention. Pincushion effect is often unavoidable. Compression with foam and a support girdle and massage help. Secondary liposuction may be necessary.

Individualize care

- Presentation of mons pubis and labia majora deformity cover a wide spectrum. Each patient should be evaluated and treated specifically for her presentation, surgery on adjacent areas such as the abdomen and medial thigh, and scar tolerance.

**Avoid damage to the
clitoris**

- Knowledge of external genital anatomy and limiting excision inferior to the superior convergence of the labia majora will help avoid clitoral injury, which is very difficult to fix.

POSTOPERATIVE CARE

- Surgery is most often performed as an outpatient. Patients are seen within days of surgery. After this, patients are seen the following week for suture removal and counseling for optimal scar, which may include compression, topical therapies, and activity limits for 4 weeks. Follow-up may then take place months later for scar management reinforcement.

OUTCOMES

- Scar therapy and compression are managed expectantly, and cosmetic outcome should be excellent. There should be no functional deficit, and in fact there may be improvement in sexual satisfaction and urinary continence.

COMPLICATIONS

- Asymmetry and contour irregularities—Markings are most important to proper symmetry and mons dimensions, and suspension of the mons pubis will protect against recurrent ptosis. Focal liposuction or fat transfer may be necessary, as well as excess skin removal.
- Visible scarring—After conservative topical management of scars for 4 months, scar management may require injectable steroid, with consideration for later scar revision under local anesthesia as needed. The hair-bearing pubis is a setup for hypertrophic and keloid scarring.
- Injury to external genitalia—Surgery should not be performed below the level of the upper pubic symphysis internally, and tissue should be maintained on deep fascia. More superficially, the anterior labia majora converge over the clitoral hood, and the clitoris should be protected from surgical injury.

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20 Upper Arm Lift (Brachioplasty)

CHAPTER

Jennifer Capla and Joseph Michaels

DEFINITION

- A brachioplasty or upper arm lift is a procedure that targets the skin excess from the axilla to the elbow.
- The “hammock”-like effect of loose skin is sometimes known as “bat wings.”

ANATOMY

- With the arm abducted and flexed at 90 degrees, the important landmarks for assessment are from the apex of the axillary crease to the olecranon (**FIG 1**).
- The bicipital groove is the area between the biceps brachii above and the long head of the triceps below.
- In the bicipital groove, below the brachial fascia, lie several important neurovasculature structures including the median and ulnar nerves and the axillary artery and vein.
- In the midportion of the upper arm over the bicipital groove, superficial to the brachial fascia, lies the medial brachial cutaneous nerve.

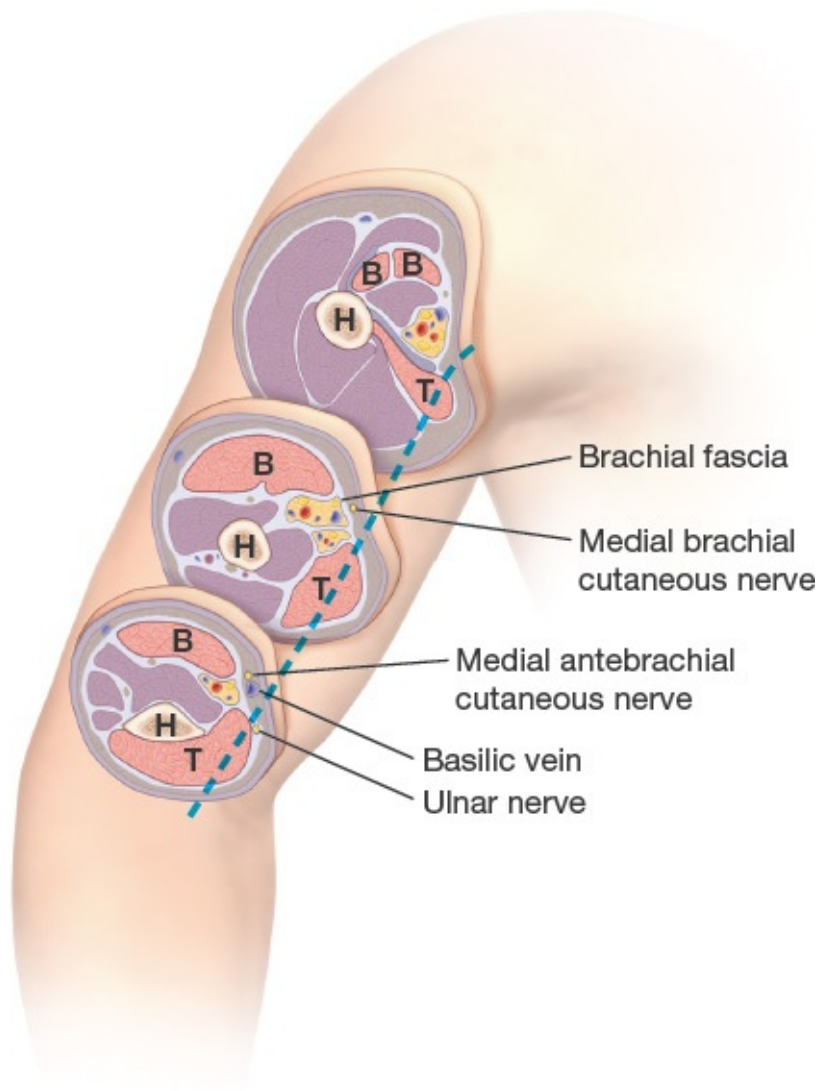


FIG 1 • Arm serial sections over bicipital groove. The blue dotted line approximates scar position in the bicipital groove. B, biceps tendon; T, triceps muscle; H, humerus.

- In the distal portion of the upper arm over the bicipital groove, superficial to the brachial fascia, lies the medial antebrachial cutaneous nerve and the basilic vein.

PATHOGENESIS

- Factors that can produce laxity of the upper arm soft tissue:
 - Significant weight changes

- Aging
- Previous liposuction
- Sun damage
- Despite a good exercise regimen, skin may not retract. This is likely due to weakness of the connections of the superficial fascial system to the axillary fascia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A history of significant weight loss, aging, or previous liposuction can lead to skin excess of the upper arms.
- Patients complain of loose hanging skin of the upper arms that interferes with daily activities, difficulty with finding shirts that fit, and the need to wear long sleeves even in the summer to cover up due to embarrassment of the tissue excess.
- Physical examination:
 - Examine the patient with arms abducted at 90 degrees and the forearm flexed at 90 degrees.
 - Visible skin excess from the axilla to the elbow that drapes like a hammock.
 - Determine residual adiposity vs skin laxity.
 - Assess for any arm swelling or lymphedema.
- Contraindications: chronic swelling from lymphedema or venous incompetence

IMAGING

- No radiologic imaging or diagnostic testing is necessary.

SURGICAL MANAGEMENT

Preoperative Planning

- Assess the patient's goals—in front of the mirror with the arm abducted and flexed at 90 degrees, use the pinch technique to demonstrate what the arm lift will achieve.
- If the patient has significant residual adiposity, an arm lift alone may leave the patient with a heavy arm. Consider liposuction prior to debulk the arm, and then return for an arm lift at a second stage. If the majority of fat is in the posterior compartment of the arm, then liposuction can be combined with the procedure.
- Weight loss patients should be weight stable for a minimum of 3 months.

Nutritional assessment is an important factor in wound healing. Labs should include albumin, prealbumin, TIBC, and folate.

- Managing expectations: Preoperative discussion with the patient about the scar ensures that the patient understands the trade-off. Brachioplasty scars can be red, raised, thickened, and cordlike. Take a black sharpie and mark the approximate position of the scar on the patient. This allows them time to go home and look in the mirror to make sure that they are willing to trade for the scar.
- Scar position: The brachioplasty scar can be positioned in either the bicipital groove or the posterior arm. A patient should be given the opportunity to choose. We prefer the bicipital groove for scar location. There are patients in certain professions, like teachers, who raise their arms a great deal and have opted for the posterior scar.
 - Bicipital groove scar—visible from the front view when the arm is abducted and flexed, but when the arm is down at the patient's side, it is not seen.
 - Posterior scar—not visible from the front or back when the arm is abducted and flexed, but when the arm is down at the patient's side, it can be seen from behind.
- Marking the patient preoperatively is of utmost importance.
- Using the pinch technique, a guide to the excision pattern can be determined. Pay careful attention to the pull in the axilla and the lateral chest wall to ensure that there is no distortion on the chest/breast area.
- If any arm bands are present, then resection may lead to worsening of the bands ("Popeye deformity") that you must make the patient aware of before surgery.
- Speak with your anesthesiologist:
 - IV placement in the hand, not the antecubital fossa
 - Blood pressure cuff on the leg or forearm
 - If performing more than one procedure, it is best to start with the arms. If not, discuss with the anesthesiologist about the possibility of limiting IV fluid to decrease overall swelling until the arm resections are performed.

Positioning

- Patient should be in the supine position with arms abducted laterally at 90 degrees on arm boards.
- Prep arms circumferentially to maintain full mobility and include chest and

lateral chest wall.

- Sterile self adhering wrap (Coband) is helpful to cover any tubing or wiring to maintain a sterile field.

Approach

- Bicipital Groove Scar Brachioplasty.

TECHNIQUES

■ Full Scar Brachioplasty-Bicipital Groove Scar

Marking

- Mark the patient in the standing position with the arm abducted and elbow flexed at 90 degrees.
- Ask the patient to flex the biceps and palpate the bicipital groove.
- Draw a horizontal line from the apex of the axillary crease to a point about 2 cm proximal to the olecranon, marking the final scar position.
- With a marker positioned over your line in place, distract the arm tissue downward to obtain the superior marks.
- The next point is essential to the marking.
 - First mark the apex of the axilla (x).
 - Find a point on the low hanging skin that can be distracted inward and upward to the apex point marked in the axilla. It may take several attempts until it appears right.
 - Once this point is chosen, mark it with a distinguishable circle point and call it (x') (**TECH FIG 1A**).
- While holding the x' point to the axillary apex point (x), do a pinch test at several places in the arm distal to the axilla to mark the estimated lower border.
- The mark in the apex point in the deltopectoral groove (x) is carried inferiorly on the lateral chest, posterior to the lateral pectoralis border to carry out the dog-ear or to excise excess lateral chest wall tissue.²
 - With the arm extended, carry the marking from x' and connect it to the inferior aspect of the above marked axillary marking.
 - The length of this line should be estimated using a pinch technique to

determine where the skin excess tapers. Careful attention to the pull on the chest/breast area should be noted.

- Last, place hash marks perpendicular to the previous marks as a guide to line up the closure. Assess both arms from a distance to ensure symmetry (**TECH FIG 1B,C**).

Liposuction

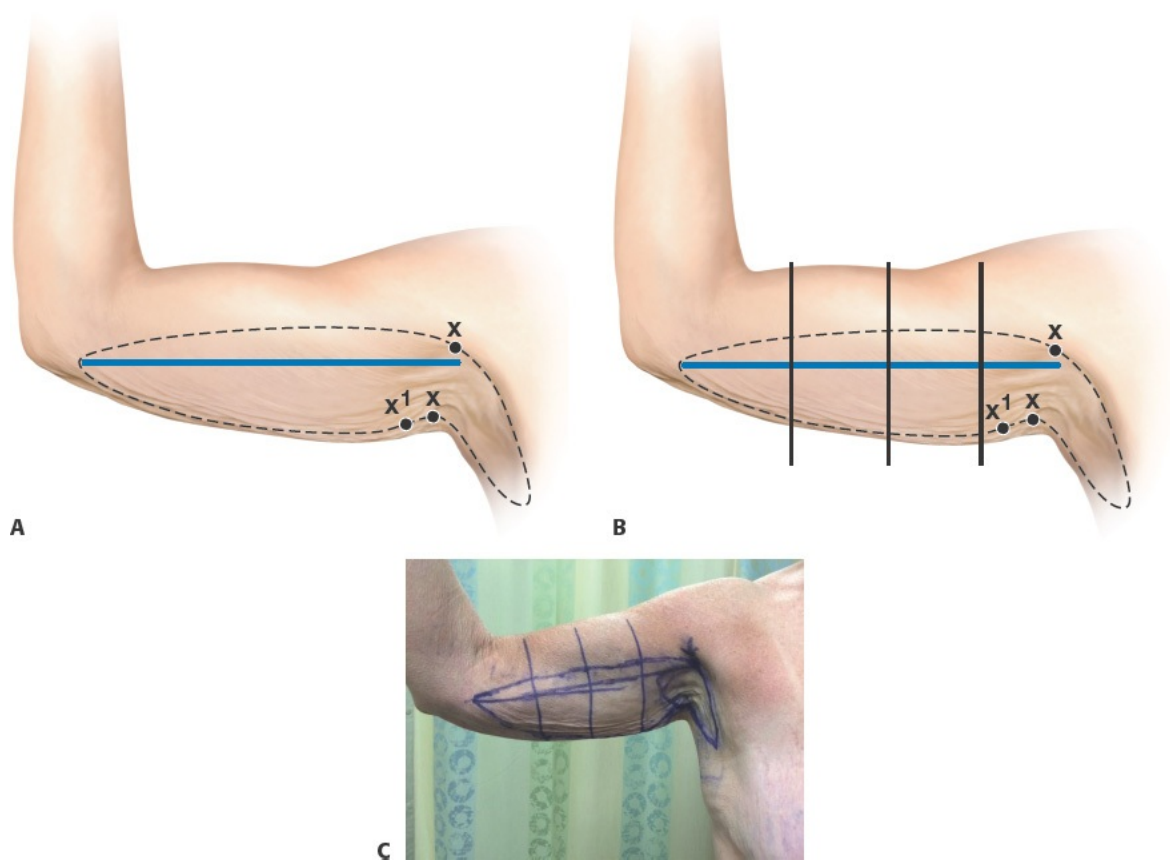
- If combining this technique with liposuction, perform the liposuction of the posterior arm and then begin the excision. Important, do one arm at a time.
- Do not liposuction of both arms first, because the swelling will alter the ability to excise on the other side.

Incision and Flap Elevation

- Infiltrate with local anesthetic.
- Incise the superior portion of the marked incision.
- Elevate a subcutaneous flap above the brachial fascia. Recognize that the arm is a cylinder, so check the thickness of your flap for consistency. It is easy to get too deep.
- Raise the flap just past the inferior border marking.
- In the axilla, stay superficial to avoid injury to underlying lymphatics and neurovasculature structures.
- When approaching the elbow, stay superficial to avoid injury to the medial antebrachial cutaneous nerve. If you see the basilic vein, the nerve will be close.

Resection, Stapling, and Closure

- Once the entire flap is elevated, place two towel clips on the flap and have an assistant distract the flap superiorly and medially.



TECH FIG 1 • Markings for bicipital groove full scar brachioplasty. **A.** Mark bicipital groove (*blue line*). Mark the apex of the axilla (point x). Choose and mark point x' to adequately distract the tissue upward and inward. Distract tissue downward to mark upper line. Using pinch technique, with x' being pulled into x, to mark lower border. **B.** Place hash marks to line up the border. **C.** Preoperative markings.

- Using a heavy forceps, remark the x' point. Make a vertical cut and inset to the high point in the axilla. Place 2 to 3 deep 0-Vicryl sutures from the axillary fascia to the deltopectoral fascia to avoid scar migration out of the axilla.¹
- Resection must be performed in a segmental fashion to ensure closure. Starting at the most distal hash mark, use heavy forceps to mark the inferior excision point. Incise vertically, and staple the point. Continue this for all hash marks.

- Once appropriate tension has been set, mark the remainder of the inferior border and excise.
- Tailor tack the incision with staples. Do not leave the wound open for an extended period as swelling may occur, putting unnecessary tension on the closure or worse off, the inability to close.
- Lift arm up gently off the arm board to assess tension and appearance. Perform the procedure on the contralateral arm. When finished, compare both arms prior to closure for symmetry.
- If placing a drain, bring out from the lateral chest wall. In our practices, we have moved away from placing drains.
- Close the incision in layers.

PEARLS AND PITFALLS

Over-resection

- Always perform excision in a segmental fashion. Failure to do so may lead to an incision that cannot be closed.

Liposuction

- If performing liposuction in combination with a brachioplasty, be sure to do liposuction and the excision immediately afterward on one arm at a time (unless a two-team approach). Otherwise, swelling can lead to decreased ability to excise the desired tissue or can lead to failure to close the arm.

Scars

- Warn patients that the brachioplasty scars can heal red, raised, thickened, and/or cordlike. They can take up to 2 years to mature unlike other scars.

Staging

- For patients with significant residual adiposity, liposuction should be performed as a first stage to reduce the volume and then return for brachioplasty in at least 3 months. If the first stage is not performed, the patient will be left with a heavy arm. If all done in one stage, when the swelling subsides, the patient will likely have residual skin laxity.

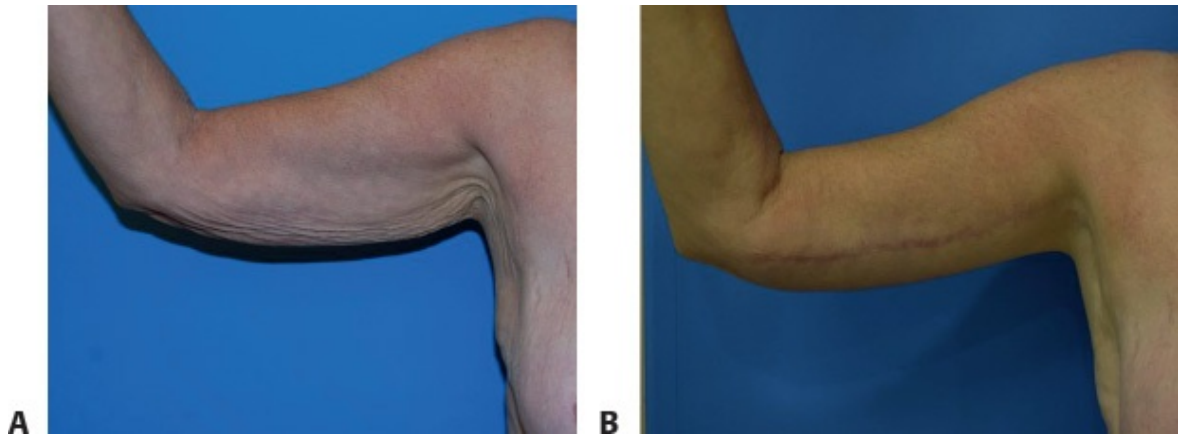


FIG 2 • A,B. Preoperative and postoperative view of male patient.

POSTOPERATIVE CARE

- Place the patient in an arm compression garment for 4 to 6 weeks.
- Keep arms elevated as much as possible.
- Do not exceed 90 degrees at the shoulder for 4 weeks.
- After 4 weeks, the patients can walk their fingers up the wall daily until full extension is reached.
- Begin massage therapy with the product of your liking and consider silicone gel or strips.

OUTCOMES

- Arm contour will immediately be improved (**FIGS 2** and **3**).
- Patient satisfaction with the shape of the arm is high; however, scars can take 1 to 2 years to mature and improve in color and texture.

COMPLICATIONS

- Seroma—fluid collection generally occurs near the elbow and may require serial aspirations in the office.
- Wound dehiscence—generally superficial in the axilla. Treat with dressing changes.
- Hematoma
- Infection
- Poor scarring—may require Kenalog injections.
- Over-resection can lead to failure to close the wound or total dehiscence

postoperatively. Avoid by performing segmental excision at the time of procedure, and do not leave incision open for any meaningful period of time.

- Contracture across axilla—can cause pulling or banding in the axilla. May require a Z-plasty to recruit additional tissue to the area.
- Sensory loss
- Chronic swelling

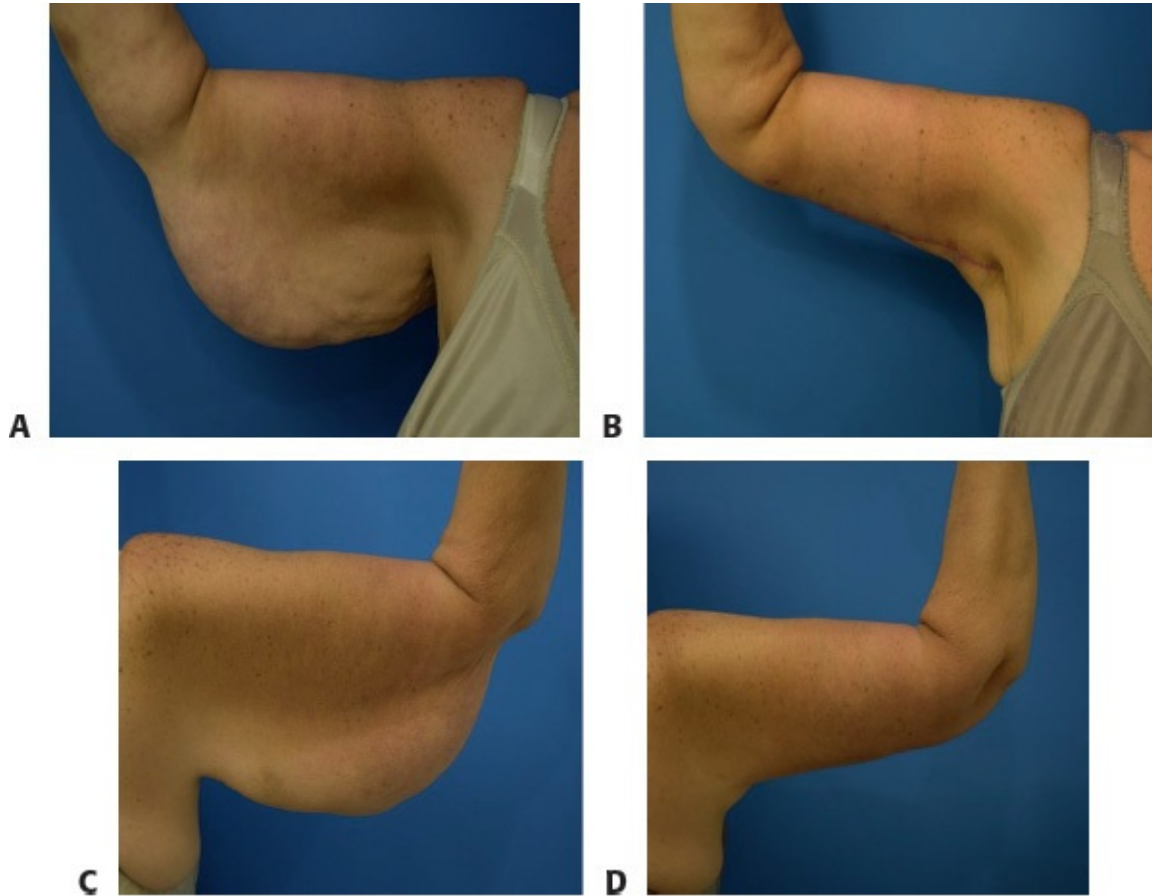


FIG 3 • A–D. Preoperative and postoperative view of female patient.

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CHAPTER Upper Thigh Lift

Michele Shermak

DEFINITION

- Upper thigh lift describes excision of lax and/or redundant thigh tissue to improve tautness, circumference, and/or shape of the thighs.
- This procedure is often included in approaching lower body lifting for individuals who have sustained massive weight loss.
- The procedure may be performed in combination with lifts of adjacent body regions such as the abdomen or back to globally improve the lower body region.

ANATOMY

- Anatomic details of the thigh are shown in **FIG 1**.
- The skin can demonstrate varying degrees of redundancy, vertical excess, laxity, and collagen strength. Thin skin may have greater recoil after surgery resulting in exacerbated loosening of the surgical result. Attention should be focused on the presence of varicose veins, and if there are many, referral to a vascular surgeon is prudent to minimize varicosities prior to embarking on thigh lift.
- Subcutaneous fat varies in thickness.
 - A thinner fat layer is more appropriate for thigh lift than a thick one, which would more optimally lead to a liposuction contouring procedure or recommendation for weight loss.
 - The fat between the anterior thigh and posterior thigh is different: anterior thigh fat is thinner and softer, whereas posterior fat tends to be thicker and fibrous.
- The final scar appearance may be impaired by the difference in fat

characteristics in the medial anterior and posterior thigh with fullness and visibility, particularly if posterior fat is pulled anteriorly.

- Liposuction of the fat to be excised has been described to aid in better visualizing veins and lymphatics; however, liposuction may impair healing, and less is more may be the case here, with improved healing without liposuction performed in the area to be resected.
- Scarpa fascia is the pseudofascial plane in the subcutaneous fat that is located superior to the greater saphenous vein on the inner thigh. The depth of this fascial plane is short in the groin area where penetration can lead to potential injury of the saphenofemoral veins and femoral artery or nerve.
- Deep muscular fascia should be obscured by soft tissue with tissue undermining during thigh lift to help preserve the greater saphenous vein and lymphatics.
- Muscles in this should not be visualized as the muscular fascia is not penetrated; surgery only involves the skin and subcutaneous fat of the inner thigh.
- Patients seeking thigh lift may have superficial dilated varicose veins. The greater saphenous vein is important, because it is within the field of the vertical inner thigh lift and should not be traumatized, as injury may lead to distal extremity swelling. Perforators off the vein are ligated and cut. The saphenofemoral junction is close to the skin surface and may be seen and should be preserved.

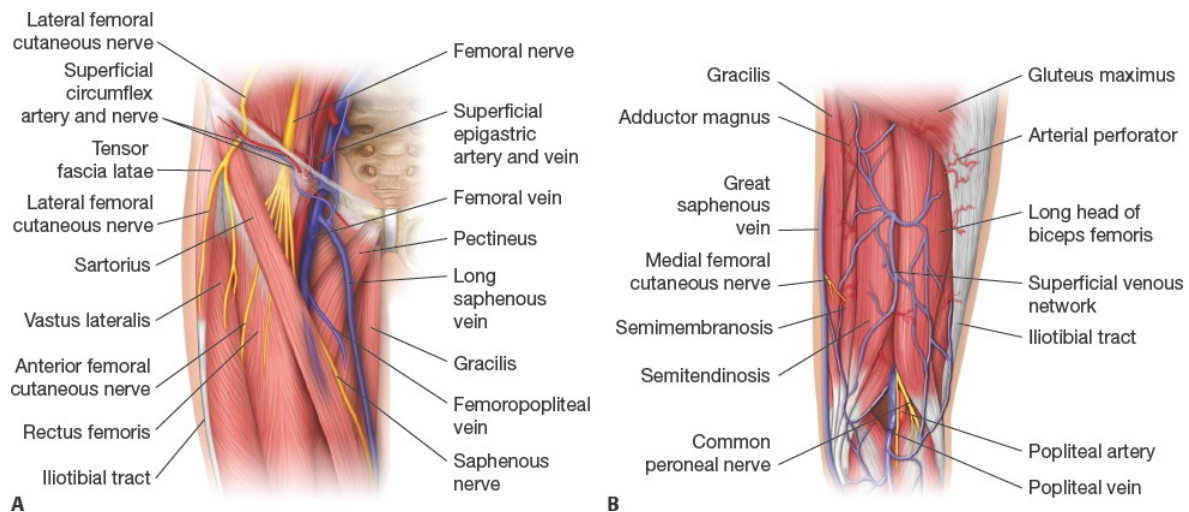


FIG 1 • A,B. Thigh anatomy is notable anteriorly for the saphenofemoral junction at the groin and the lymphatic

collections at the groin and knee. External anatomy—skin quality, fat quantity, and superficial vein and varicosities—is variable in presentation.

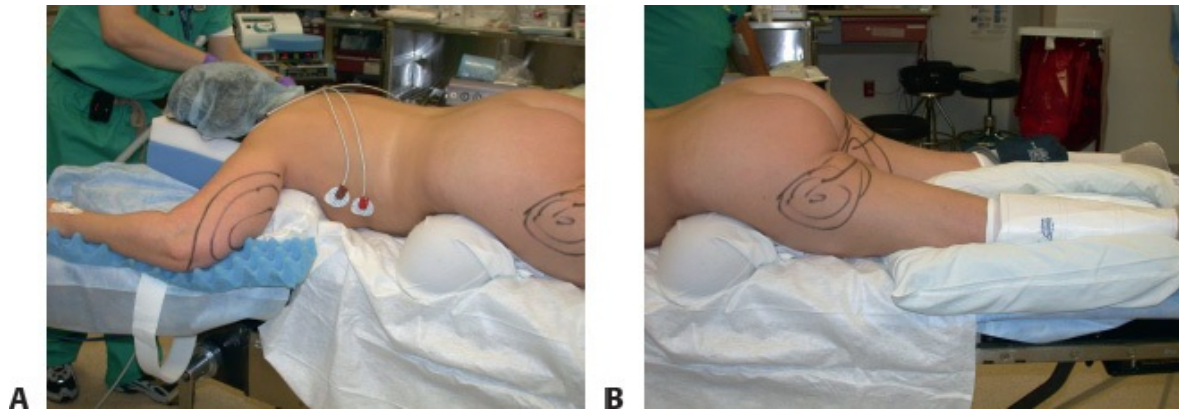


FIG 2 • Prone positioning helps provide the best access to the posterior thigh, when performing APEX proximal thigh lift. Safety measures while the patient is in prone position include the following: **A.** Face in prone pillow with goggles protecting eyes from pressure and desiccation; arms are placed at 90 degrees, and gel bumps are placed under the chest and lumbar region. **B.** Bump under chest lumbar regions and forced warming blanket to avoid hypothermia.

- Dissected thigh tissue is always discarded, so arterial perforators are ligated and cauterized, and no major arteries are within the field of dissection. The femoral artery is close to the skin surface, and dissection should be carefully performed in the groin.
- Dissection deep to superficial fascia may result in injury to lymphatics, which travel close to the saphenous vein. Lymphoceles may develop postoperatively near the knee where lymphatics are dense.

PATHOGENESIS

- With skin laxity and/or weight loss of varying degrees, individuals can suffer from excess skin in the thigh.
- This may be focally limited to the proximal aspect of the inner thigh with

minimal skin change outside of this area, most often seen in younger massive weight loss patients.

- On the other hand, others present with more diffuse, global changes in the inner thigh, with significant attenuation and redundancy of the skin, typically in the older, thinner patient who has experienced massive weight loss.
- A more extended approach to thigh lift in this patient population will reduce circumference and improve skin appearance all the way to the knee.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history should be probed for significant weight loss and, if present in the history, the mode and degree of weight loss, as well as nutritional challenges that may exist.
- Weight should be stable at the time of surgery at least 3 months.
- Medical conditions that may impact outcome of thigh lift surgery such as peripheral vascular disease, varicose veins, venous thromboembolism, diabetes, heart disease, sleep apnea, autoimmune and endocrinological disorders, and coagulation disorders and venous thromboembolic history should be queried.
- Any history of surgery in the groin region must also be addressed, such as that performed for lymph node biopsy.
- Physical findings should note skin quality and degree of excess and redundancy and varicosities as well as adiposity.
- Chronic calf swelling needs to be noted if present.
- Adjacent body regions such as the mons pubis, abdomen, and back are examined to see if addressing these regions will improve overall lower body aesthetics.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative planning with thigh lift includes addressing significant varicose veins ahead of surgery, as well as discussion of different thigh lift approaches with differing scar lengths.
- More focal proximal skin excess and good skin quality lend themselves well to proximal scar along groin crease, which is well hidden.
- More extended involvement to the knee with attenuated skin and cellulite may be better addressed with vertical incision along the length of the inner

thigh.

- With existing calf swelling, the more limited proximal approach is preferable as the more extended thigh lift approach can exacerbate thigh swelling.
- Widened mons pubis may be treated at the time of thigh lift, with inclusion of lateral mons tissue within the zone of resection, paired with liposuction of the mons, as needed (see Chapter 19).

Positioning

- Positioning varies depending on the thigh lift approach.
- The proximal approach requires prone to supine positioning to treat posterior dog-ear and impact of result by extending excision into the infragluteal fold.
- Prone positioning precautions must be followed in the head and neck area and upper body, as well as the gluteal region and thighs.
 - Gel rolls are placed along the upper chest/axilla, and the neck is placed in a neutral position with head resting in prone pillow and eyes off-loaded.
 - Arms at elbow and axilla placed at no greater than 90 degrees with padding under arms and legs to protect pressure points (**FIG 2**).
- The more extended vertical inner thigh excision requires only supine positioning.
 - In the supine position, thigh lift is most easily performed with leg extension bars off the end of the operating room table to allow the surgeon to stand or sit between the legs, which are spread apart from each other.
- Positioning of the thighs in stirrups as seen in gynecological surgical procedures is not necessary and puts the patient at risk for venous thromboembolism (VTE) at the groin with flexion of the hip.

Approach

- Direct excision of the skin excess of the inner thigh is performed.
- Approach must be symmetrical and may include lateral mons pubis to reduce the pubis, which may be widened and full.
- Excision at the lower aspect of the pubis in the groin is most at risk for high tension, so a bottleneck in the excision is created at this point to avoid too much tension and predilection for wound healing problems or pull on the mons pubis or labia.
- Excisions marked should be equivalent bilaterally to aim for best, most symmetrical scar placement, and the ideal scar is hidden when the thighs come

together.

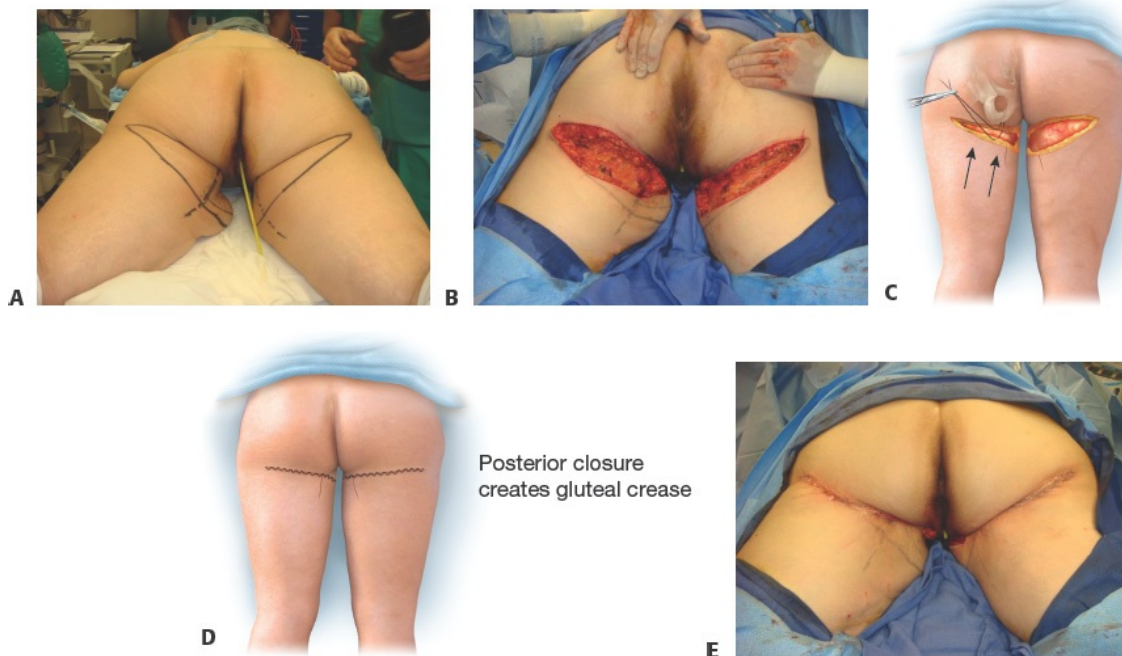
TECHNIQUES

■ Proximal “APEX” Thigh Lift

Posterior Portion

- The patient is marked while standing.
 - Posterior marking is made in the infragluteal fold, which the surgeon may have to choose with buttock deflation and multiple folds. This mark is connected to the anterior groin crease along the mons pubis (**TECH FIG 1A**).
 - A crescent is then marked more distally to define excision, aiming to avoid over-resection.
 - Skin is grasped and pulled tautly upward to determine skin excision.
 - The midline of the inner thigh should be marked vertically, and hatch marks may be marked posteriorly to guide closure.
- The patient is intubated on a stretcher and turned to the prone position with careful padding and protection of all potential pressure points.
- The patient is prepared with Betadine.
- If lower back lift is planned, that procedure should be performed first as the infragluteal fold marking may migrate superiorly and require revision.
- Incision is made in the gluteal fold, through the subcutaneous fat to deep fascia.
 - Vertical incision is made on the medial-most aspect of the thigh at the vertical marking.
 - Dissection is then directed inferiorly toward the lower marked incision (**TECH FIG 1B**).
 - Careful hemostasis is performed and the wound is irrigated.
 - Local anesthetic is injected above and below the deep fascia; long-acting Marcaine is preferable.
- The amount of skin that may be safely excised is determined by pulling up on the skin flap and marking it, adjusting as needed from prior marking.
 - Local anesthetic, preferably long-acting Marcaine, is injected to the deep tissues in the wound.

- A braided no. 1 caliber suture is used to approximate the skin flap up to the ischial periosteum, which is encircled by the surgeon's fingers.
- Proper placement in periosteum is ensured by pulling on the suture and seeing no movement in the buttock.
- Lateral to the ischium, superficial fascia in the fat is approximated to the analogous gluteal fold fascia with 2-0 braided absorbable suture (**TECH FIG 1C**).
- The skin is closed with no. 3-0 monofilament absorbable suture to approximate deep dermis and running no. 4-0 monofilament absorbable suture as a running subcuticular suture.
- The skin is then better approximated with 4-0 nylon simple interrupted sutures (**TECH FIG 1D,E**).
- The wound is washed and dressed with cyanoacrylate glue.



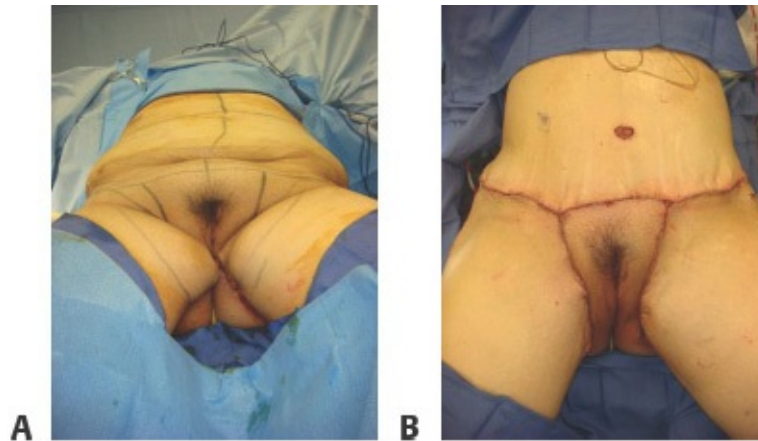
TECH FIG 1 • A. Posterior marking is made in the infragluteal fold, which the surgeon may have to choose with buttock deflation and multiple folds. This mark is connected to the anterior groin crease along the mons pubis. A crescent is then marked to define the extent of excision. The midline of the inner thigh

should be marked vertically, and hatch marks may be marked posteriorly to guide closure. **B.** Incision is made in the gluteal fold, through the subcutaneous fat to deep fascia. Vertical incision is made on the medial-most aspect of the thigh at the vertical marking. Dissection is then directed inferiorly toward the lower marked incision. **C.** Approximation of the posterior aspect of APEX thigh lift depends on deep suspension with multiple permanent sutures to ischial periosteum. **D,E.** Closure is completed superficially and defines the infragluteal crease.

Anterior Portion

- The patient is then turned supine, most safely performed by logrolling onto a stretcher with a roller on it and then pulling the patient back onto the OR bed (**TECH FIG 2A**).
 - Pillows are placed under the legs vertically to elevate the inner thigh up.
 - A small “bump” may be placed between the thighs.
 - The area is sterilized.
 - If abdominoplasty is planned, that is performed first.
- Incision in the inner thigh is continued along the groin crease, symmetric from the mons midline.
- The excision is begun from posterior to anterior in steps to assure there is no over-resection, with undermining of the marked skin quite superficially, by avoiding injury to veins and lymphatics in the groin area.
- The skin is sequentially cut, and the excision is tapered up to the lower abdomen to achieve lift of the upper anterior thigh.
 - Local anesthetic is injected to the wound and along the periosteum.
- The skin flap is approximated to pubic periosteum with no. 1 braided permanent sutures, again taking sufficient bite of periosteum to avoid labial pull and spread.
- More superior to the pelvis, approximation of superficial fascia along the upper groin and abdomen is performed with 2-0 braided absorbable suture, followed by 3-0 monofilament absorbable suture in deep dermis and running 4-0 monofilament absorbable subcuticular suture.

- The area is washed and dressed with cyanoacrylate glue (**TECH FIG 2B**).



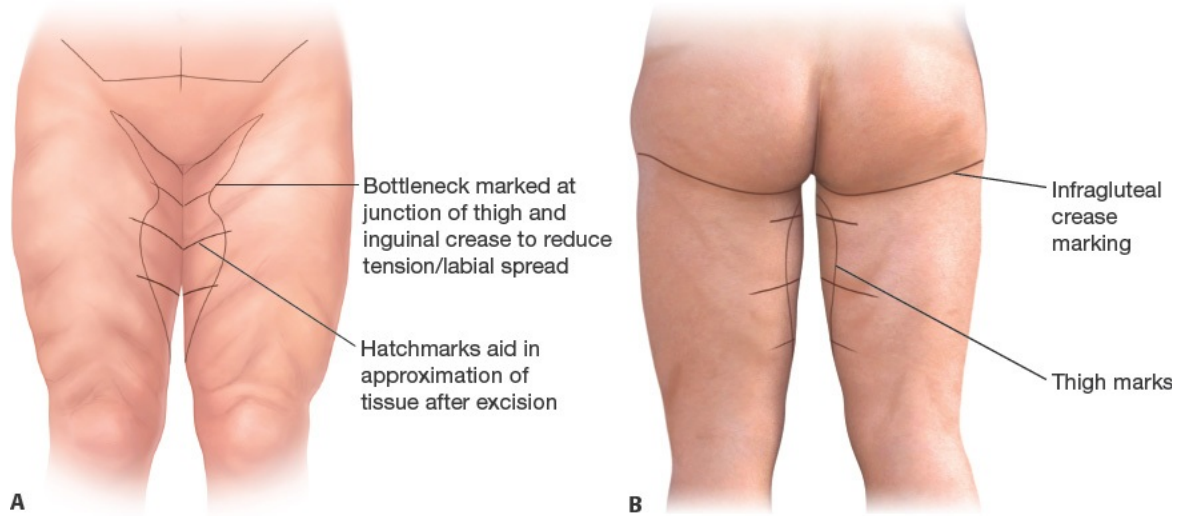
TECH FIG 2 • A. Remaining redundant inner thigh tissue is visible anteriorly in supine position. **B.** The excision proceeds from posterior to anterior with undermining of the thigh skin superficially. The skin flap is approximated to the pubic periosteum with multiple permanent sutures to avoid labial pull and spread.

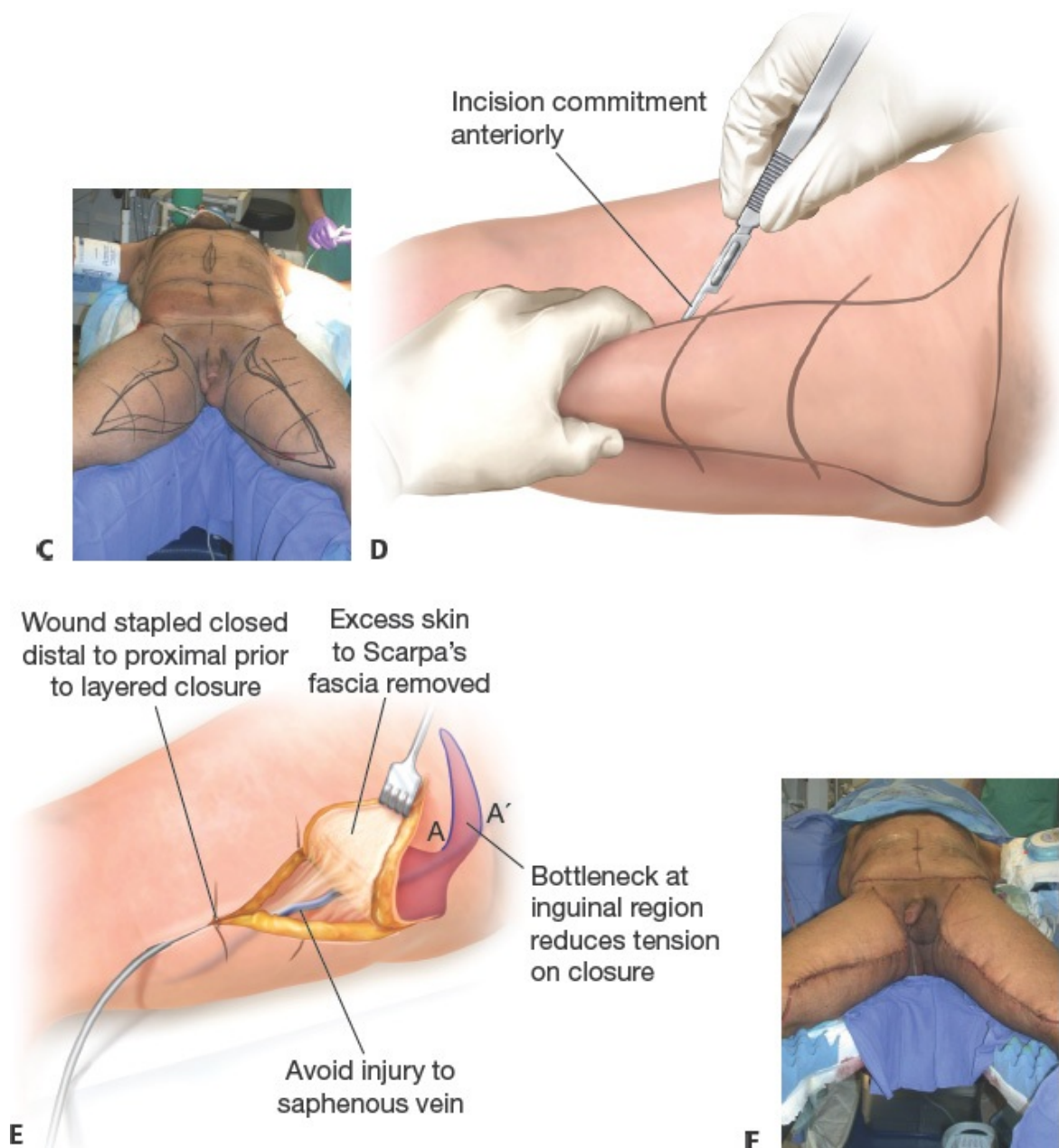
■ Extended Vertical Thigh Lift

- The patient is marked standing.
 - Skin is grasped and pulled taut toward midline of the thigh from the knee to the groin, and this area is marked as an ellipse that tapers distally to the knee and proximally along the lateral groin crease (**TECH FIG 3A,B**).
 - Cross-hatches are made to guide in closure.
- The patient is supine on the OR table, which is ideally fitted with padded leg extension boards, so the legs may be spread and allow a surgeon to stand or sit between them (**TECH FIG 3C**).
 - Sterile Foley catheter is placed, and the patient is prepared with Betadine.
- Skin excision in stepwise fashion from distal to proximal using hatch marks as stop points.
 - The pinch test guides the extent of tissue removal (**TECH FIG 3D**).
 - Depth of excision should be just deep to superficial fascia to avoid injuring

veins and lymphatics.

- Perforating venous branches are ligated with clips. The skin is stapled with each stop point.





TECH FIG 3 • Extended vertical thigh lift. **A,B.** Skin markings. **C.** Patient positioning and markings. **D.** Tissue removal is guided by the pinch test. **E.** Skin excision proceeds in stepwise fashion from distal to proximal using hatch marks as stop points. Excess skin and Scarpa fascia are removed with progressive approximation from distal to proximal. Scarpa fascia is closed with 2-0 interrupted braided absorbable suture.

The incision is closed over a drain. **F.** Closure in superficial fascia within the fat is performed with barbed continuous suture, and the skin is approximated in layers, dressed with cyanoacrylate glue.

- Once the pubic bone is reached, a bottleneck is made with smaller degree of skin excision to avoid tension.
 - Above this point, excision is very thin, skin only.
- A drain is passed from distal to proximal, exiting out the distal incision and fixed to the skin with 3-0 nylon suture (**TECH FIG 3E**).
 - The wound is approximated in the superficial fascial plane in fat with running barbed 0 PDO suture from midincision proximally and distally.
 - The skin is closed with a 3-0 monofilament absorbable suture in deep dermis and running no. 4-0 monofilament absorbable subcuticular suture.
 - The area is washed and dressed with cyanoacrylate glue (**TECH FIG 3F**).
- The leg is wrapped from the toe to above knee with compression wrap to minimize swelling. The incision is protected by ABD pads.

PEARLS AND PITFALLS

Optimizing scar

- The best scar results from reduction of tension on the wound, assured by limiting over-resection and by scar location and symmetry. Without gluteal augmentation, the gull wing scar leads the eye to a focused, well-contoured gluteal region. Maintaining adequate subcutaneous fat on the skin flap for autologous augmentation is critical to avoid wounds.

Optimizing wound healing

- Avoid high tension closure and proactively address intraoperative issues such as hypothermia and anemia. Wounds are extremely common in the midportion of the incision at the lower sacrum and respond well to gentle cleansing and petrolatum application.

Avoiding lower extremity swelling

- Avoid injury to the greater saphenous vein and lymphatic system by staying superficial to deep fascia while excising tissue. Swelling is particularly problematic with the extended vertical approach.

Avoid labial spread	■ Periosteal suspension with multiple braided permanent suture and avoidance of high tension closure are key to avoiding pull along the labia.
Improved efficiency of closure with barbed suture	■ Barbed suture works very well in the thigh because the tissues provide adequate coverage over the barbs. The quality and speed of closure are optimized by barbed suture.
Fluid collection management	■ Fluid collections near the knee are not uncommon with the extended vertical excision, as in the same region as the lymphatics in the leg. Most often, fluid collections are lymphoceles. They may be aspirated and compressed, and particularly, resistant ones can be opened and drained with a Penrose drain.

POSTOPERATIVE CARE

- Patients are followed on a weekly basis after surgery to assure optimal wound healing and drain care for the vertical approach.
 - Drains can be removed when drainage is 30 to 40 cc or less per day.
 - Compression of the leg from the toe to knee assists in preventing calf swelling.
 - If suspicious swelling develops, particularly unilaterally, ultrasound should be performed to rule out deep venous thrombosis.
- Strenuous activity may be resumed 4 to 6 weeks after surgery as long as healing is uncomplicated.
- Longer-term care is provided for scar management, including topical therapies to reduce scar visibility and massage to assist in dysesthesias and edema.

COMPLICATIONS

- Lymphedema: Best minimized by avoiding any interruption of lymphatics or veins. Compression from toe to knee and elevation may help. If swelling is asymmetrical, workup for venous thrombosis should be considered.
- Labial spread: With any procedure that creates some tension with tissue removal and lack of proper suspension of tissues around the mons. Multiple interrupted sutures suspending tissue to periosteum helps reduce risk.
- Wound healing problems are more of an issue with higher weight patients; undermining and adjunctive liposuction should be minimized. Permanent large

caliber sutures around the groin may become infected with wound healing problems, necessitating removal of the exposed suture.

- Unsatisfactory scar: symmetrical treatment with sequential, stepwise tissue excision and avoidance of high tension closure assists in optimizing scar. Irregular contour of the inner thigh with vertical thigh lift is not uncommon as posterior thigh tissue is thicker than the anterior tissues, so it is important to not pull posterior tissue forward.
- Venous thromboembolism: It is necessary preoperatively to check on any history or elevated risk as per the modified Caprini scale. Patients must be encouraged to ambulate after surgery.
- Infection is not common, and risk can be reduced by optimizing surgical conditions like addressing efficiency with reduced operative time and hypothermia, as well as initial dose of antibiotics prior to making incision. Seromas can become sources of infection and should be treated.

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Section IV: Reconstruction of Perineal Defects

22 Vertical Rectus Abdominis Myocutaneous Flap for Perineal Reconstruction

CHAPTER

Sahil K. Kapur and Charles E. Butler

DEFINITION

- The vertical rectus abdominis myocutaneous (VRAM) flap plays a beneficial role in improving postoperative outcomes for patients with defects created following abdominoperineal resection (APR) and pelvic exenteration (PE) surgery.
- Complications following APR and PE are related to large noncollapsible dead space, commonly irradiated dead space, with poor vascularity and bacterial contamination.¹
- The flap provides healthy vascularized tissue to help obliterate the pelvic dead space—created after the resection. It serves as a barrier between the abdominal and pelvic cavity, as well as a source of skin and soft tissue for reconstructing and resurfacing the perineum.

ANATOMY

- The rectus abdominis muscle originates from the 6th, 7th, and 8th costal cartilages and inserts on the pubic bone. It measures approximately 6 cm in width at its origin and 3 cm in width at the insertion.
- It has a dual codominant blood supply (Type III Mathes/Nahai). Superiorly, it is supplied by the superior epigastric artery, a branch of the internal thoracic artery. Inferiorly, it is supplied by the deep inferior epigastric artery a branch of

the external iliac artery.

- The deep inferior epigastric artery originates from the external iliac vessels at a point between the inguinal ligament to about 6 cm above it. The vessel enters the posterior rectus sheath at about the level of the ASIS and the arcuate line (4 to 6 cm above the pubic bone). This artery usually splits into a lateral and medial branch that supplies the lateral and medial row of myocutaneous perforators. Knowledge of perforator anatomy is important when attempting the fascial-sparing approach of VRAM harvest.
- The skin paddle for the VRAM flap is usually designed to include paraumbilical myocutaneous perforators. Extension of the skin paddle superiorly can be carried out without taking additional fascia (extended VRAM flap as described later). This is possible because the intercostal perforators supplying the extended portion have direct perforator-to-perforator connections with the epigastric perforators in the standard skin paddle.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are assessed preoperatively to determine risk factors that would increase complication rates such as obesity, hernia, smoking, steroid treatment, and prior chemoradiation.
- A detailed surgical history is important to ensure that the patient has not had any prior surgeries that could have injured the deep inferior epigastric artery pedicle. Surgeries such as C-sections have a more medially placed scar and generally do not lead to pedicle injury. Prior abdominoplasty surgery is a relative contraindication to the use of a skin paddle because the perforators have been divided.
- Physical examination includes an examination of the abdomen and pelvic region for scars and assessment of hernias.

IMAGING

- Imaging involving CT or MRI is generally available because most patients have undergone an oncologic workup. CT images help determine the amount of diastasis, integrity and bulk of lateral abdominal musculature (in case a component separation is needed), and the presence of hernias.
- No special imaging to assess perforators is necessary for this reconstruction.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients with pelvic or perineal defects benefit from pedicled VRAM flap reconstruction. The flap is based on the deep inferior epigastric artery. A skin paddle is used to provide skin resurfacing of the perineum. It can be de-epithelialized to provide bulk if necessary when the perineal skin is completely closed.

Positioning

- Patients are generally positioned in the lithotomy position by the resecting team. All areas of resection including the perineum and the abdomen beyond the level of the costal margin are prepped into the field.

Approach

- In general, two or more teams are involved. The reconstructive team will begin the operation if a fascial-sparing technique is to be used. The reconstructive team performs the laparotomy and spares the medial aspect of the anterior rectus sheath. Following the oncologic resection, the reconstructive team performs their portion of the procedure.
- The ostomy(s) are matured after the reconstruction is completed and the abdomen is closed.

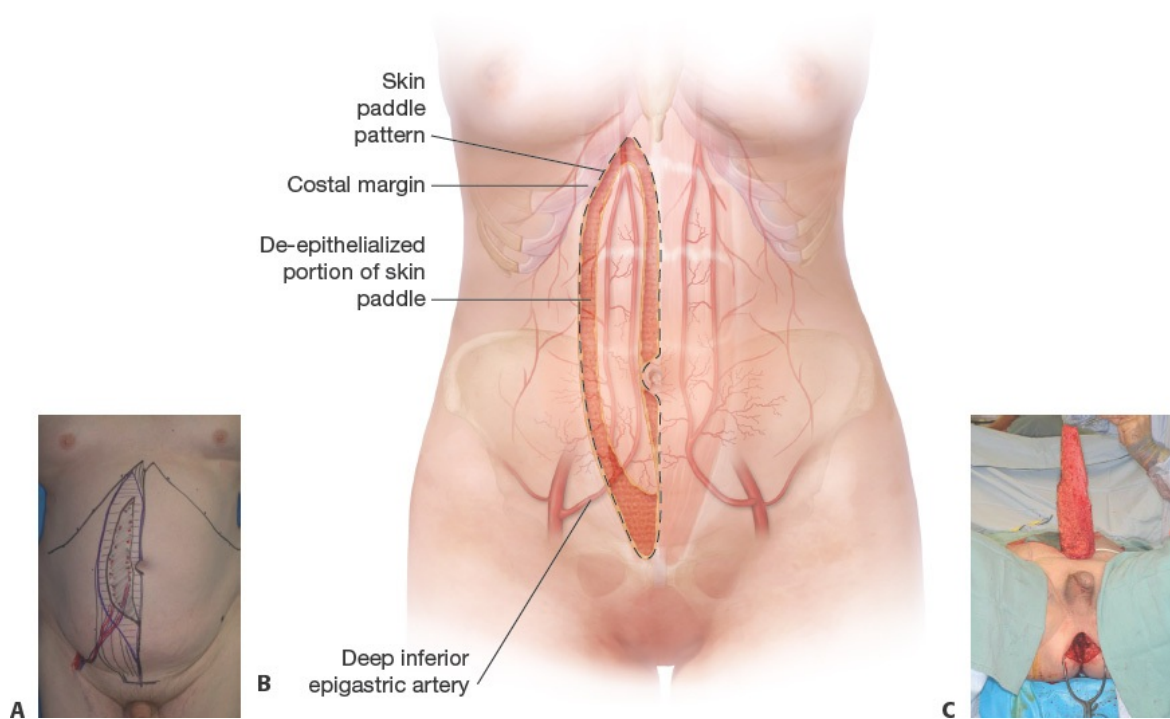
TECHNIQUES

■ Flap Harvest

- Make a midline skin incision, and dissect down to the linea alba (**TECH FIG 1A,B**).
- Once the rectus sheath is identified, begin dissecting laterally, superficial to the rectus sheath, to locate periumbilical and medial row perforators to the skin paddle.
- Incise the anterior rectus sheath 2 to 3 cm lateral to the midline but medial to the medial row perforators.
- Retract the rectus abdominis muscle laterally to expose the posterior rectus sheath.
- Incise the posterior rectus sheath 2 cm lateral to the midline to gain intraperitoneal access. Curve the incision back toward the linea alba at the

arcuate line.

- Advance and suture the posterior rectus sheath to the anterior rectus sheath to protect the rectus abdominis muscle during the resection component of the procedure.
- Resume reconstruction once the resection has been completed. The ostomy is usually passed through the contralateral rectus abdominis muscle and matured by the primary team after the reconstruction and abdominal closure.
- Examine the perineal defect to estimate the bulk and nature of tissue needed. This information is used to decide if a skin paddle will be used or the perineal skin will be closed primarily over the flap.
- Design the skin paddle over the rectus abdominis muscle such that it will reach the defect once the muscle is transposed.
- Release the sutures that were previously placed between the anterior and posterior rectus sheath.
- Complete the soft tissue dissection to isolate the skin paddle.
- Dissect the flap from lateral to medial over the anterior rectus sheath to just lateral to the lateral row perforators.
- Incise the anterior sheath just lateral to the lateral row perforators.
- Dissect the lateral aspect of the anterior rectus sheath from the anterior surface of rectus abdominis muscle using a combination of finger dissection and electrocautery.
- Dissect carefully through areas of muscle inscriptions to prevent damage to the overlying rectus sheath or to the muscle itself.
- Dissect the rectus muscle off the posterior rectus sheath.
- Transect the rectus muscle cranial to the skin paddle and ensure the superior epigastric vascular pedicles are ligated.
- Rotate the flap medially and transpose it into the abdomen and pelvis.
- Ensure that the inferior epigastric artery and vein are dissected free from all soft tissue attachments to prevent compression and kinking of the pedicle.
- Leave the rectus muscle attached at its origin on the pelvis to prevent tension on the pedicle (**TECH FIG 1C**).



TECH FIG 1 • Fascial-sparing approach to the harvest of a VRAM flap. **A.** The inner *solid lines* demonstrate the area of fascia harvested, *red dots* demonstrate the approximate location of perforators, and the area marked by *horizontal lines* demonstrates the area of fascial sparing. **B.** Important landmarks are indicated. **C.** VRAM flap after it has been elevated. The muscle is left connected to its origin at the pubis. (© Charles E. Butler, MD.)

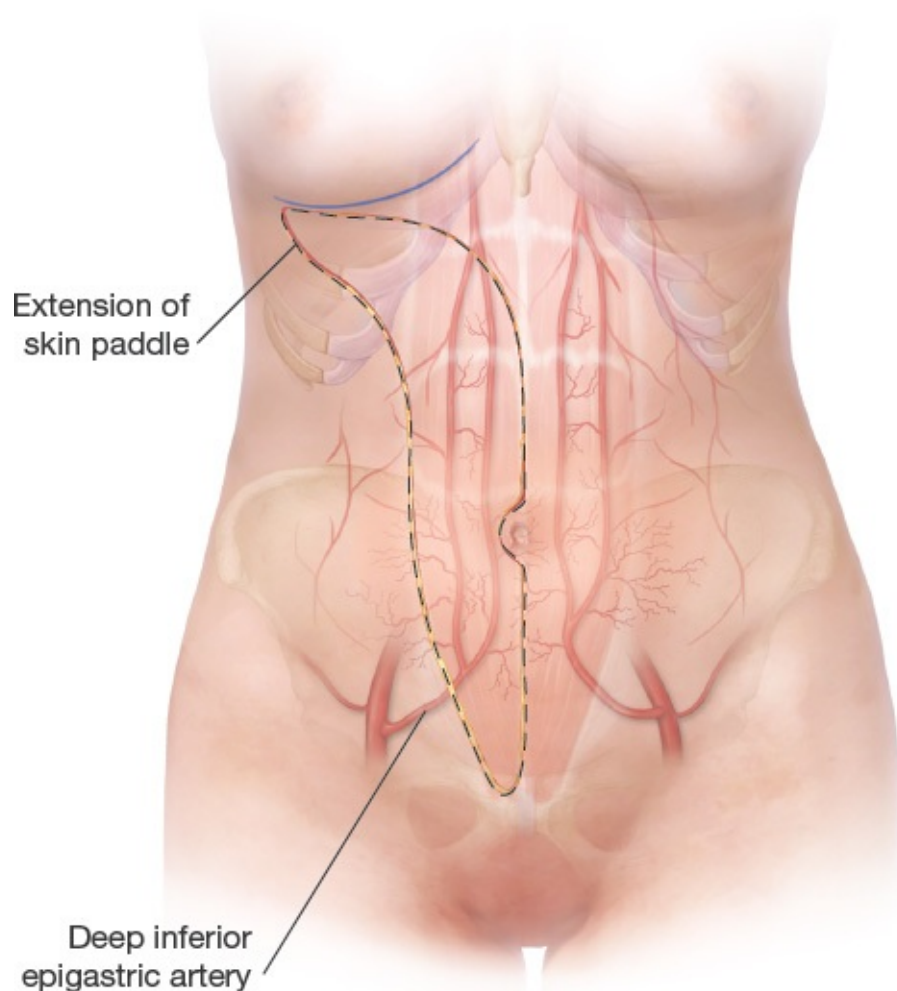
- The above described fascial-sparing approach is not advised when previous midline laparotomies, adjacent hernia sacs, and scarring prevent perforator identification.

■ Extended Skin Paddle Option

- In cases where additional bulk or length is needed, the skin paddle of the flap can be extended in the superolateral direction. Technique is described below:
 - Make a curvilinear incision starting from the superiormost aspect of the

midline incision extending cephalad toward the inframammary fold and laterally toward the posterior axillary line. This line approximately parallels the general direction of the ribs. The inferior aspect of the extended skin paddle is based on the amount of laxity present to close the donor site (**TECH FIG 2**).

- Do not incise any additional fascia with this superolateral extension. The extended portion of the flap is elevated in the subcutaneous plane.

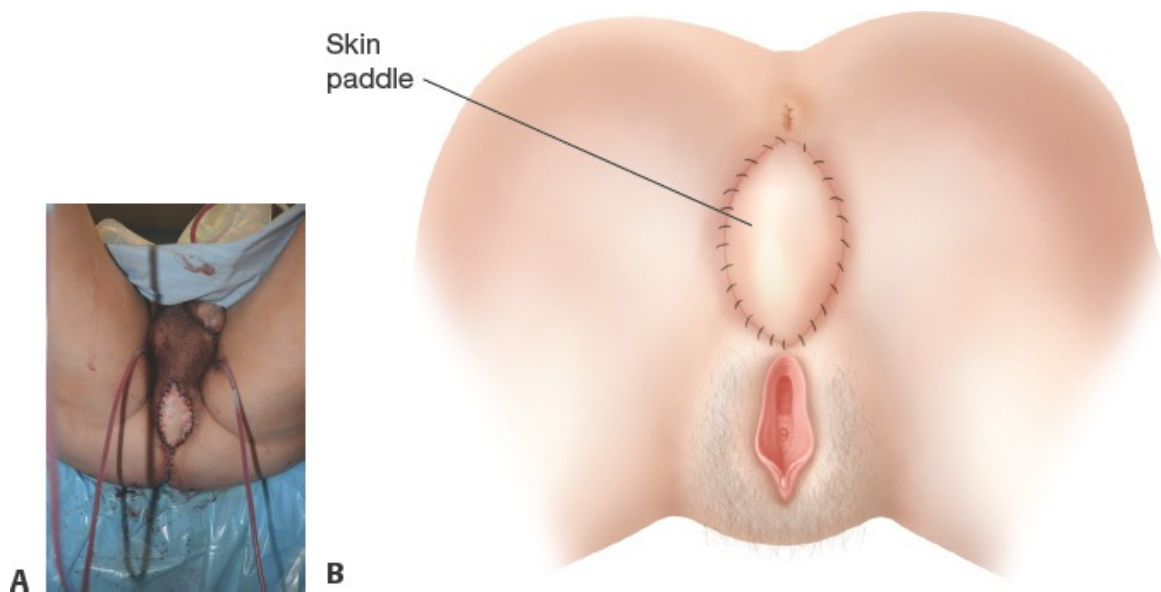


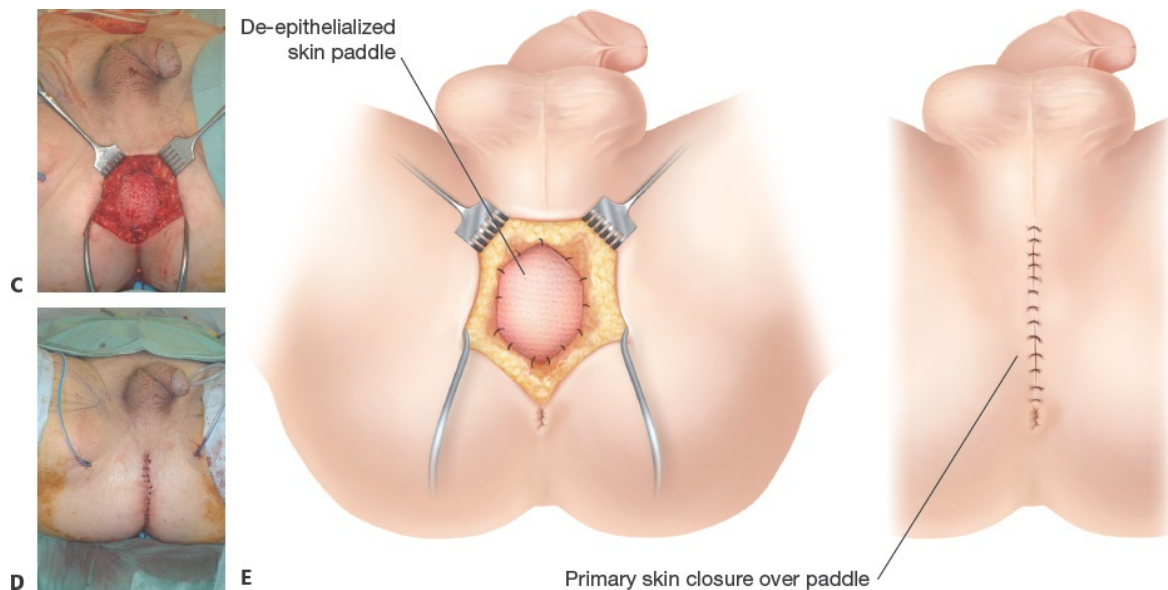
TECH FIG 2 • Skin paddle design of the extended VRAM flap. (© Charles E. Butler, MD.)

■ Flap Inset

- After the flap has been elevated and transposed into the pelvis, place one or two 19-French round channel drains into the pelvic space.

- Inset the flap to maximize dead space fill and minimizes torque on the pedicle. If vaginal reconstruction is necessary then orient the flap with the skin paddle facing anteriorly. The skin paddle is oriented to face the anterior direction, the distalmost tip of the flap ends up posterior.
- De-epithelialize the skin paddle to the dimension necessary to reconstruct the skin defect. Use the rest of the epithelialized portion to close the perineal skin defect (**TECH FIG 3A,B**).
 - When the perineal skin is closed primarily without a skin paddle, the VRAM flap is completely de-epithelialized (**TECH FIG 3C-E**).
- Anchor the flap to remnant tissue in the pelvis using interrupted 2-0 resolvable sutures.
- Close the skin in a vest over pants fashion. Use 3-0 resorbable sutures for buried deep dermal sutures and 3-0 permanent monofilament sutures for the interrupted skin sutures.
- Two round channeled drains are used to drain the perineal space.



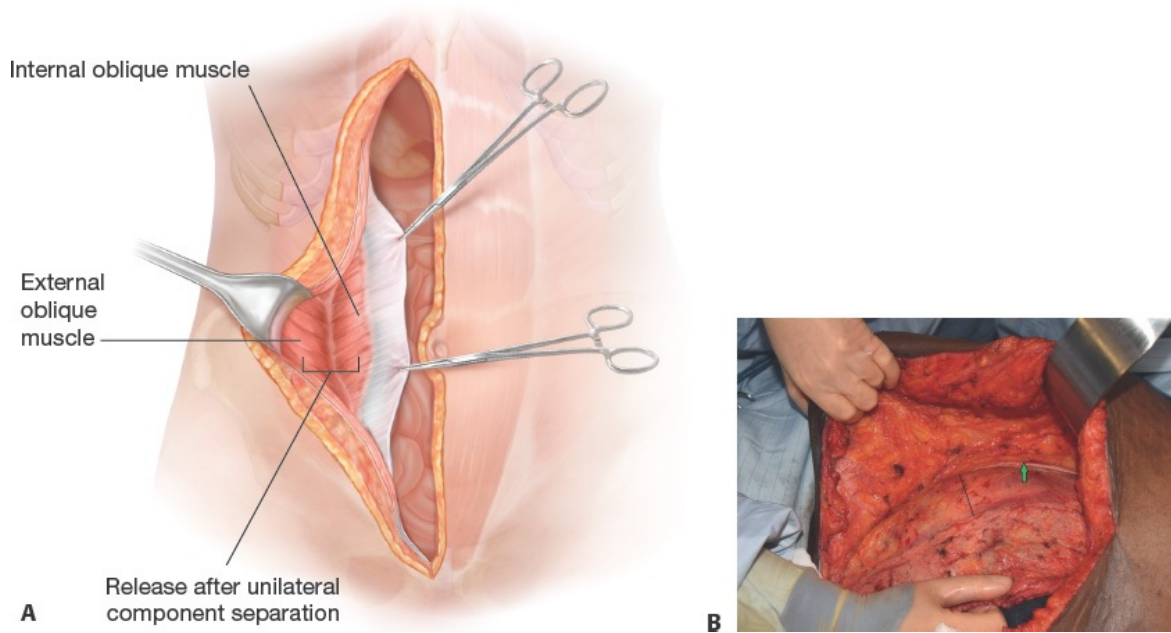


TECH FIG 3 • A,B. Reconstruction of the perineum with a VRAM flap and a skin paddle. (© Charles E. Butler, MD.) **C,D.** Reconstruction of perineum without a skin paddle. **E.** Flap in place with the skin paddle de-epithelialized. Primary closure of skin over the flap. (© Charles E. Butler, MD.)

■ Donor Site Closure

- If primary closure of the rectus sheath is not possible due to excessive tension, perform ipsilateral component separation by incising the external oblique aponeurosis and dissecting between the external and internal oblique muscles. If the fascial integrity is good, component separation will be enough (**TECH FIG 4**).
 - However, if the fascial integrity is poor or the fascial closure is tight then a mesh can be used to reinforce the closure.
- If primary closure is possible without excessive tension, suture rectus sheath using interrupted monofilament suture in figure-of-8 fashion. Include both the anterior and posterior sheath in the closure superior to the arcuate line.
- Place a round channel drain superficial to the rectus sheath to drain the subcutaneous space.
- Approximate the Scarpa fascia with interrupted 2-0 resorbable sutures.
- Approximate the skin with 3-0 resorbable sutures in a deep dermal fashion

followed by a running subcuticular stitch with 4-0 resorbable sutures.



TECH FIG 4 • A. Diagram of open unilateral component separation. **B.** In this operative photograph, the *black line* demonstrates the extent of release. The *green arrow* indicates the fascial edge of the external oblique aponeurosis. (© Charles E. Butler, MD.)

PEARLS AND PITFALLS

Skin paddle design

- Make sure the skin paddle is positioned appropriately such that it will include the periumbilical perforators and reach the distalmost aspect of the defect following muscle transposition.
- If significant amount of bulk at the distal reach of the flap is required, then the extended skin paddle technique should be used as described in the techniques section.

Fascial-sparing technique

- Fascial sparing is not advised when previous abdominal surgery, adjacent hernia sacs, and scarring prevent perforator identification.

Donor-site closure

- Abdominal closure following VRAM harvest should be treated as a formal abdominal wall reconstruction. The scenario is more complex than encountered with a standard laparotomy. The central fascial defect on the side of the VRAM harvest, an ostomy on the contralateral side, and contamination from colon transection increase risk of wound complications and morbidity.

POSTOPERATIVE CARE

- A foam thigh abduction pillow can be used to prevent adduction of the legs and compression of the skin paddle.
- Patients are allowed to ambulate on the first postoperative day. No direct sitting is allowed for the first 3 weeks. Hospital stay ranges from 5 to 7 days.

OUTCOMES AND COMPLICATIONS

- Perineal wound complication rate following APR ranges from 25% to 60%.³
- Patients who undergo primary closure of APR defects have a much higher complication rate than those who undergo VRAM flap reconstruction (44% vs 16%).⁴
- Time to perineal wound healing following wound complication is shorter for patients who undergo VRAM reconstruction compared to patients who undergo primary closure. (Average time: 65 vs 92 days).⁴
- VRAM use is beneficial even if primary closure is possible in patients undergoing APR following chemoradiation. In these cases, patients who receive VRAM reconstruction have a significantly reduced rate of perineal abscess (9% vs 37%), wound dehiscence (9% vs 30%), and need for drainage procedures for fluid collections (3% vs 25%).¹
- Fascial-sparing techniques in VRAM harvest have reduced abdominal hernia rates from 11.5% to 1.5%.⁵
- Component separation technique for donor-site closure leads a threefold lower fascial dehiscence rate and a fourfold lower incisional hernia rate.⁶
- The use of an underlay mesh in patients with poor fascial integrity has also reduced abdominal hernia rates (2.6% vs 5.5%).⁵
- Reconstruction of perineal defects with the use of VRAM flaps has significant advantages over the use of thigh flaps in reducing complication rates (donor-site or recipient site cellulitis, pelvic abscess, and major wound dehiscence).⁷

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23 Gluteal Thigh Flap for Perineal Reconstruction

CHAPTER

David Gerth and Christopher J. Salgado

DEFINITION

- Gluteal thigh flap is an axial fasciocutaneous flap based on the inferior gluteal artery.
- Usually raised as a pedicled flap, but free flap technique has been reported

ANATOMY (FIG 1)

- Blood supply: Descending branch of inferior gluteal artery¹
 - Terminal branch of the internal iliac artery.
 - Course: exits the pelvis through the infrapiriform aperture
 - Supplies the lower aspect of the gluteus maximus muscle and overlying skin through musculocutaneous perforators²
 - These perforators combine with branches of the circumflex femoral arteries and obturator artery to create the cruciate anastomosis.
 - This anastomosis allows the posterior thigh to be adequately perfused even in the case of an absent inferior gluteal artery.

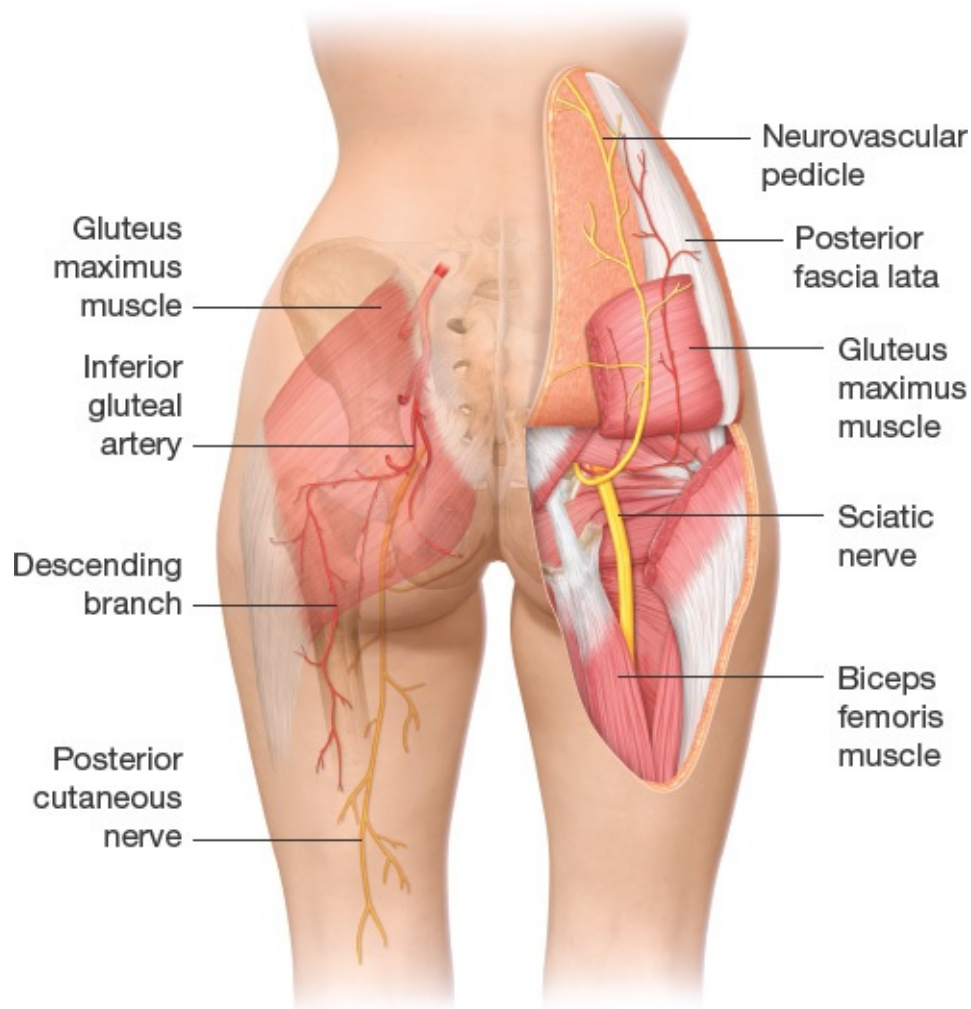


FIG 1 • Relevant surgical anatomy for the gluteal thigh flap. Note the relationship of the posterior femoral cutaneous nerve to the inferior gluteal artery. This classic relationship is not constant, however.

- Recent study has shown that cutaneous branches supplying the distal gluteal and proximal posterior thigh can be more regularly identified.
- 108 of 118 specimens had cutaneous branches derived from the descending branch of the inferior gluteal artery. Ten cases derived from medial or lateral circumflex femoral artery or from the profunda femoris.³
- Pedicle is usually spared during radical pelvic ablations.
- Pedicle is usually outside the area affected by pelvic radiation.⁴
- Venous drainage

- Redundant
 - Deep system
 - Venae comitantes of inferior gluteal artery
 - Venae comitantes of deep femoral perforators
 - Superficial venous system
- Due to substantial drainage, venous congestion rarely occurs.⁵
- Innervation: posterior femoral cutaneous nerves (S1-S3)
 - Many fascicles exit the sciatic foramen along with the inferior gluteal artery.
 - Fascicles converge to form a common trunk with the descending branch of the inferior gluteal artery.⁴

PATHOGENESIS

- Most common: Malignancy
- Infection
- Traumatic injury⁶

PATIENT HISTORY AND PHYSICAL FINDINGS

IMAGING

- No preoperative imaging is necessary.
- Viability of the flap can be assessed intraoperatively via quantitative fluoroangiography (**FIG 2**).

SURGICAL MANAGEMENT

- Goal of surgery
 - The process of perineal repair is especially difficult due to the necessity to preserve the anogenital triangle as well as to provide adequate skin coverage and tissue replacement.
 - Successful repair consists of appropriate reconstruction with vascularized tissue along with proper anogenital repair without leakage of feces or urine.
- Indications
 - Perineal or sacral wounds requiring resurfacing without the need of dead space closure

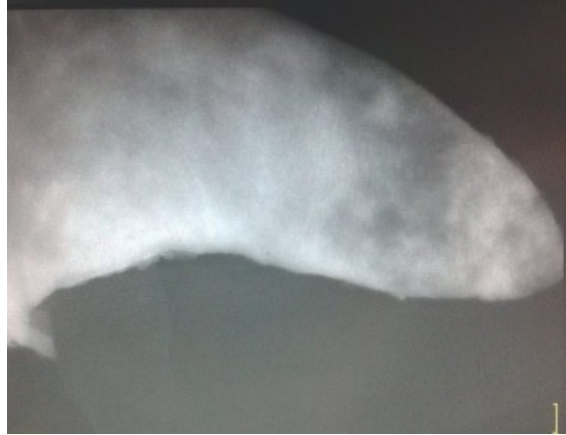


FIG 2 • Intraoperative quantitative fluoroangiography of harvested gluteal thigh flap. The patient is administered indocyanine green (ICG) intravenously, and then, after 3 minutes, the fluoroscope is placed over the flap. Within 120 seconds, adequate perfusion (if present) will register on the imaging. Certain systems may permit quantitation of perfusion relative to surrounding tissues.

- Preoperative planning
 - Before general anesthesia, the patient should be marked in an upright position.
 - The gluteal fold should be identified and marked.
 - The inferior gluteal artery can be located as it exits deep to the gluteus maximus with a mark halfway between the line from the ischial tuberosity to the greater trochanter of the femur. The course of the inferior gluteal artery can be verified with a Doppler probe.
- Positioning (**FIG 3**)
 - The surgeon may position the patient in either prone or lithotomy position. The flap can be harvested in either position; positioning is dependent on location and size of the defect.
- Approach
 - The flap may be harvested as a pedicled rotation flap or as an island flap.
 - Flap size is directly contingent with thigh size and feasibility of donor-site closure.
 - The distal tip of the flap should not extend beyond the popliteal crease to minimize risk of scar deformity and scar contracture.



FIG 3 • Lithotomy positioning for gluteal thigh flap. Bilateral gluteal thigh flaps were harvested in this patient and inset for perineal reconstruction.

TECHNIQUES

- Dissection begins at the distal aspect of the posterior thigh followed by subcutaneous tissue dissection with cauterization.
- The surgeon then dissects the flap distal to proximal. Limit is the inferior border of the gluteus maximus muscle. Proper proximal dissection with inclusion of the vascular pedicle is important for vitality. Care is taken to include the deep fascia within the contents of the flap.
- During flap elevation, the surgeon may place temporary sutures through the fascia and dermis to prevent shearing of the flap during mobilization. In the case of larger defects, bilateral flaps may be raised.⁴
- The posterior femoral cutaneous nerve is not a good reference for pedicle orientation due to its distal arborization.
- Division of the gluteus muscle inferior fibers allows for more proximal dissection of vessels and therefore a greater flap length, although this maneuver is rarely needed.
- Once fully mobilized, a deep subcutaneous tissue tunnel is created between the posterior thigh and the perineal defect. The flap is then passed through the tunnel.
- The surgeon will then mark and de-epithelialize the buried portion of the flap. Once completed, the flap is then inset into the defect.

- While avoiding the proximal vascular pedicle area, drains are placed in the pelvis and donor-site regions.
- Primary closure of the donor site can be performed or in other cases a skin graft may be necessary.⁴



TECH FIG 1 • Elevation of bilateral gluteal thigh flaps. Patient placed in prone position.

PEARLS AND PITFALLS

Technique

- Avoid using the posterior femoral cutaneous nerve as a landmark for the vascular pedicle.
- Divide distal fibers of the gluteus maximus to increase flap pedicle length and arc of rotation.

Postoperative care

- Offload the perineum and the flap with no sitting for 2–3 weeks.
- Use an air-fluidized mattress and frequent turns to decrease risk of pressure sores, especially in the case of a denervated femoral cutaneous nerve.

POSTOPERATIVE CARE

- Due to the location of the flap and the location of the reconstruction as a whole, a 48-hour period of postoperative recovery is recommended before attempting any sort of strenuous leg movements such as walking.⁴
- Patients should not sit at all for the first 2 to 3 postoperative weeks after which

time they can gradually begin to sit again.⁴

- A seating cushion with an open space in the middle may be used to offload the perineum while sitting.
- Patients may experience pain up to several months after the surgery, which may impair their ability to sit.⁷
- Routine drain care is followed, with care taken to observe output once the patient becomes mobile. The surgeon must be vigilant of any signs of infection, such as cloudy or foul-smelling drainage, increased erythema, or pain.

OUTCOMES

- Walton et al. reported their case series of 46 patients, with 8 total complications.
- There were two cases of flap failure:
 - Thrombosed inferior gluteal artery
 - Attempted free flap with subsequent venous thrombosis
- Other case series have reported varying outcomes and complication rates, possibly due to small sample size:
 - Achauer et al. reported two cases of delayed healing in seven flaps.⁷
 - Friedman et al. reported their case series of 27 flaps.⁴
 - Only one failure was reported.
 - 10 of 19 patients experienced delayed wound healing.
 - Saito et al. reported one case of total flap loss and two partial losses in their series of eight patients.⁸

COMPLICATIONS

- Dysesthesia
 - Dysesthesias may result from damage to the cutaneous nerve during surgery.⁷ This loss of sensation combined with the limited mobility after surgery could lead to pressure sores. To decrease the chances of a pressure sore developing, some authors recommend placing patients on a pressure-reducing mattress.
- Flap necrosis
 - Though necrosis can result from either lack of blood flow or infection, it is relatively rare with this flap. Any fistulas that may develop need to be monitored and repaired.⁸
 - When dealing with cancer patients who are undergoing radiation therapy,

skin grafting may be necessary to promote wound healing.⁴

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24 Omental Flap for Pelvic Floor Reconstruction

CHAPTER

Carrie K. Chu and Charles E. Butler

DEFINITION

- Pelvic floor defects may result from colorectal, urologic, and/or gynecologic extirpation (ie, abdominoperineal resection, pelvic exenteration) for oncologic, infectious, inflammatory, or traumatic indications.
- Goals of pelvic floor reconstruction include obliteration of dead space, prevention of pelvic and perineal hernia, avoidance of deep surgical site infection and pelvic sepsis, improved perineal wound healing, replacement of compromised perineal skin if necessary, and vaginal reconstruction when indicated.
- The omental flap can provide readily available vascularized tissue for achievement of many of these reconstructive goals with minimal donor-site morbidity and operative efficiency.^{1–3}

ANATOMY

- The male pelvis is typically narrower throughout, from the pelvic brim through the outlet. The cavity is overall shaped like an inverted cone, in contrast to the wider female pelvis that more resembles a short, wide cylinder.
- The greater omentum, also called the gastrocolic omentum, is a curtain of adipose and lymphatic-rich tissue that extends from the greater curvature of the stomach and drapes over the large and small intestines while folding under itself toward the posterior abdominal wall. The posterior aspect of the reflection apposes the mesentery of the transverse colon (**FIG 1**).
- The vascular supply of the omentum derives from the right and left gastroepiploic arteries. The right gastroepiploic artery is a terminal branch of the gastroduodenal artery, which comes off of the common hepatic artery

originating from the celiac axis. The left gastroepiploic artery is a branch of the splenic artery.

- Along the greater curvature of the stomach, gastric branches arise from both the right and left gastroepiploic arteries onto the anterior gastric wall, and the two vessels communicate in this manner. Multiple branches of these vessels supply the greater omentum (**FIG 2**).
- The flap may be based on either the right or left gastroepiploic artery. The pedicle should be selected based on the likelihood of maximal flap length to reach the pelvis following full mobilization. The right-sided vessel is often positioned more favorably for pelvic coverage.

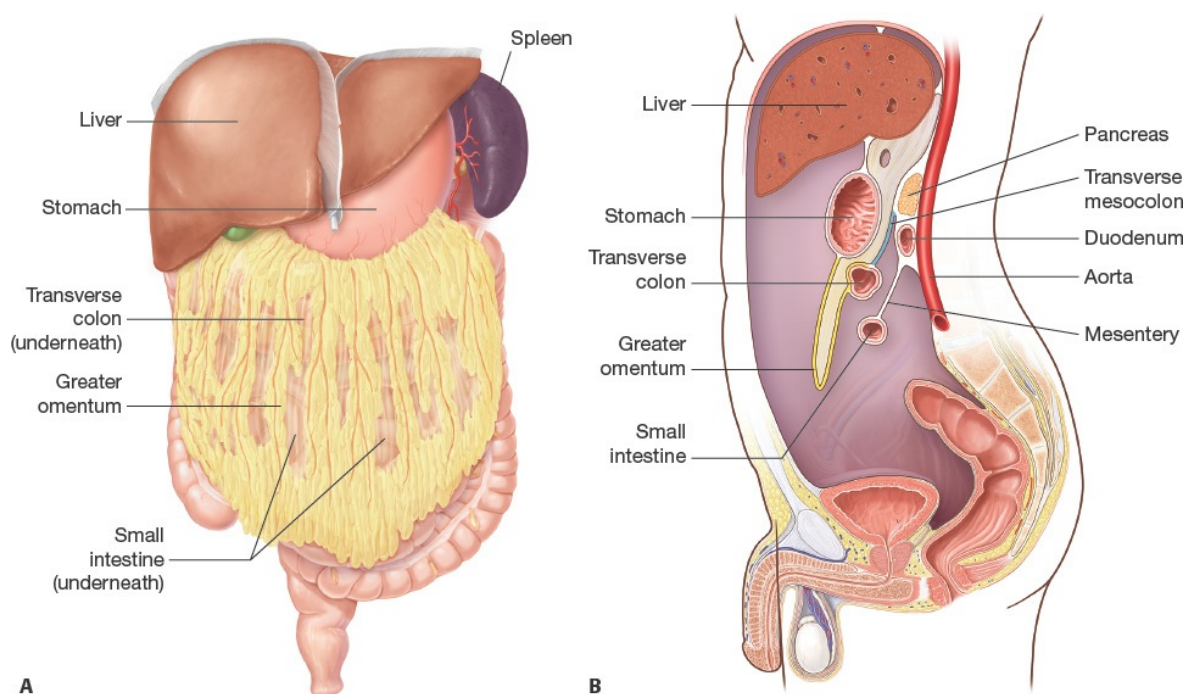


FIG 1 • A,B. The greater omentum extends from the greater curvature of the stomach and drapes over the large and small intestines while folding under itself toward the posterior abdominal wall. The posterior aspect of the reflection apposes the mesentery of the transverse colon.

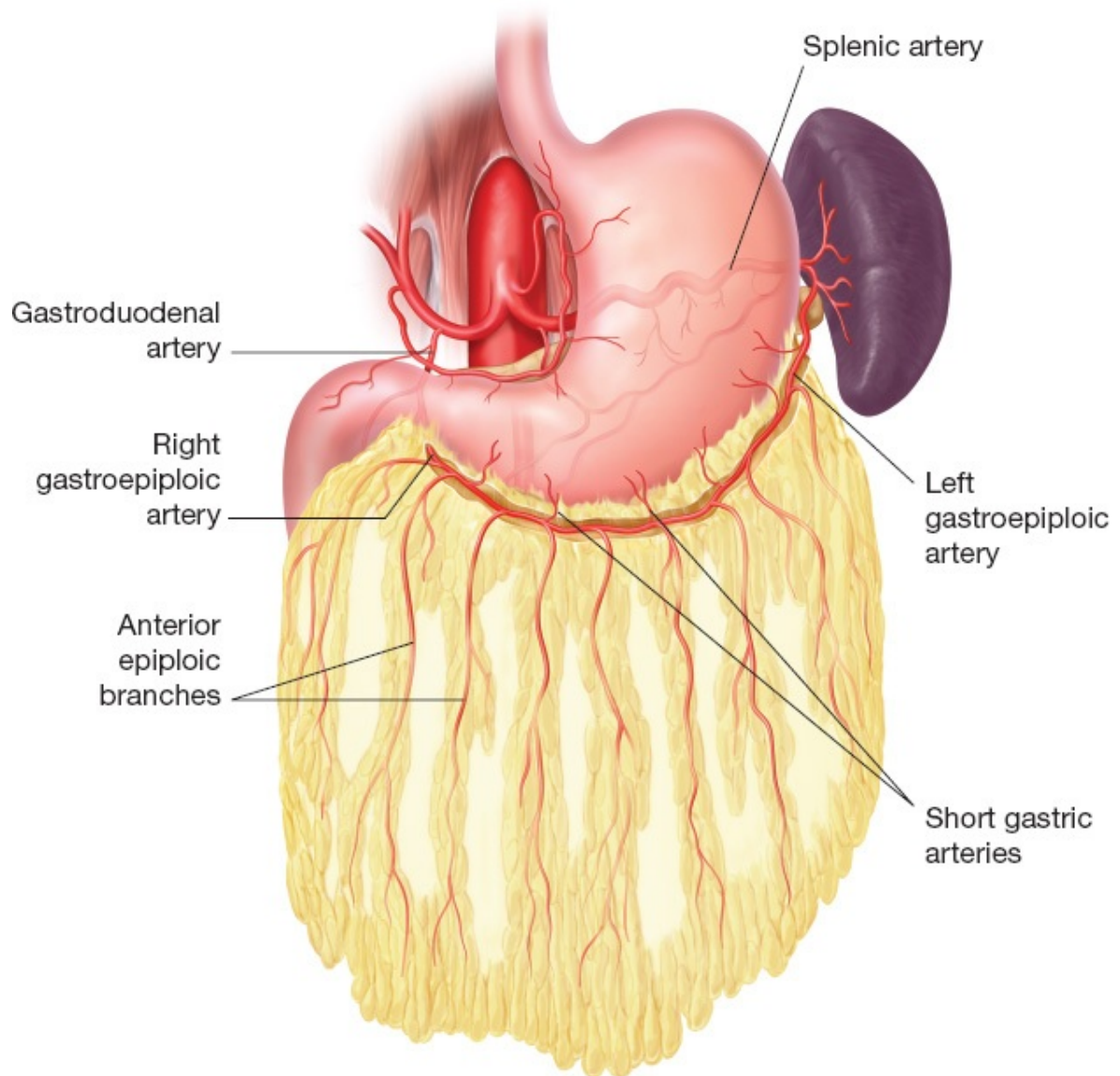


FIG 2 • The vascular anatomy and basis for the pedicled omental flap.

PATHOGENESIS

- Following removal of the rectum, the resultant void in the presacral space and pelvic outlet leaves noncollapsible dead space for fluid accumulation with infectious potential as well as a route for visceral herniation into the perineum. The volume of space is increased with additional resection of the bladder, prostate, uterus, and/or vagina.
- Secondary defects of the pelvic floor may occur from traumatic, obstetric, or iatrogenic etiologies.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Special consideration should be given to the primary disease process and previous abdominal surgical surgery. Dense abdominal adhesions may render this flap unusable. Inflammatory processes or infectious complications may lead to distortion of the omental anatomy. Gynecologic oncologic surgeries often involve partial or total omentectomies. Prior procedures that may have compromised the source vessels of the right and left gastroepiploic vessels, including hepatectomy, pancreaticoduodenectomy, gastrectomy, and splenectomy, should all be noted.
- Physical examination should focus on body habitus, abdominal torso length, abdominal surgical scars, hernias, and evidence of intra-abdominal obesity.
- Pelvic radiotherapy may severely compromise the quality of the perineal skin.

IMAGING

- No routine imaging is necessary for preoperative planning for omental flap harvest. Computed tomography is of limited utility in assessing omental bulk, though well-timed contrast studies may facilitate visualization of branches of the celiac artery, superior mesenteric artery, and proximal gastroepiploic arteries. Magnetic resonance imaging may provide better depiction of omental volume.
- However, abdominal and pelvic cross-sectional imaging is often available as part of the primary disease workup. Review can yield useful information regarding dimensions of the pelvic inlet and outlet as well as the shape and depth of the presacrococcygeal space.

SURGICAL MANAGEMENT

- Omental flaps are most useful for filling of dead space in the pelvic cavity and separation of the intra-abdominal contents from the perineum. When perineal skin replacement is necessary due to disease involvement or radiation injury, omental flap alone will likely not suffice. Consideration should be given to use of a myocutaneous or fasciocutaneous flap instead of or in conjunction with the omental flap, depending on the size of the pelvic cavity.
- The omentum is also suitable for reconstruction of partial vaginectomy defects and can be used in conjunction with skin grafting for this purpose.⁴
- Pelvic floor reconstruction using pedicled omental flaps generally takes place at the time of the primary extirpative procedure. The usefulness of omental flap for secondary pelvic reconstruction in cases of delayed wound healing, pelvic

abscess, or wound dehiscence can be limited.

- There is great individual variability in the bulk and dimensions of the greater omentum. Based on the characteristics of the omentum and the defect anatomy, each patient will require intraoperative evaluation and judgment regarding the appropriateness of this flap for pelvic reconstruction. The omentum may be used in combination with other myocutaneous flaps to accomplish the aforementioned goals.⁵

Preoperative Planning

- No routine preoperative imaging is indicated, but the aforementioned elements in the history and physical should be noted in preparation for surgery.
- Patients should be consented for thigh, gluteal, and abdominal wall donor-site alternatives, as the suitability of the flap is usually unable to be determined until the abdomen is opened.

Positioning

- There are no specific positioning requirements beyond the conventional lithotomy or, less frequently, supine positions used during primary resection, though consideration should be given to prepping of alternative sites in case of inadequate omental mass or reach.

Approach

- A major advantage of this flap is its intra-abdominal location. Exposure beyond the extent performed by the primary surgeon is usually unnecessary. Superior extension of an infraumbilical laparotomy incision is sometimes required.
- In the setting of increasingly common laparoscopic or robotic procedures, the omentum can be similarly harvested using minimally invasive approaches with or without the assistance of a hand-assisted port for retraction.

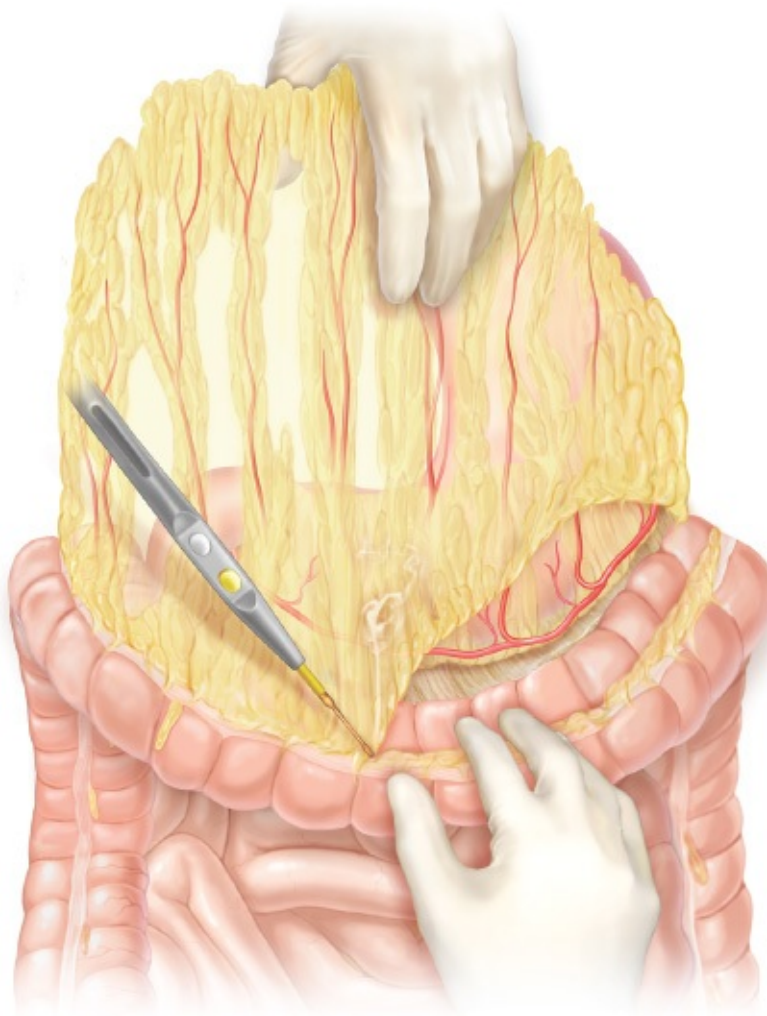
TECHNIQUES

- **Omental Flap Harvest With Right Gastroepiploic Pedicle**

- Omental flaps for pelvic reconstruction are most commonly performed at the time of primary operation. Upon laparotomy, the integrity, mass, and length of the omentum are assessed for suitability for pelvic reconstruction.
- In reoperative cases, omental adhesions to the posterior abdominal wall and/or viscera may be released to preserve flap integrity.
- Following completion of the extirpative procedure, the size of the pelvic space, the dimensions of the pelvic outlet, and the extent of the perineal defect are examined. The ability of the omental flap to be mobilized into the pelvis is assessed.

Dissection

- Dissection of the omental flap begins with its mobilization off the transverse colon mesentery. The assistant gently lifts the transverse colon and retracts it inferiorly while the surgeon begins flap elevation with the cautery. Use of the surgeon's nondominant hand to lift the omentum away from the lesser sac with countertraction against the assistant motion will facilitate visualization of the appropriate plane (**TECH FIG 1**).
- The character of the globular omental fat differs in quality from the thick mesenteric fat, and care should be taken to maintain the avascular plane of separation to avoid injury to the mesentery. On the other hand, violation of the filmy attachments throughout the omentum, especially in thin patients, should be minimized as these can easily result in full-thickness defects through the omentum.
- The surgeon should be cognizant of the course of the middle colic artery, especially in reoperative abdomens, to avoid injury during flap elevation.
- The avascular plane between the omentum and the mesentery is easily taken down with cautery. However, any division of the omental tissue should be cautiously addressed and hemoclips or sutures used generously, as bleeding from the omentum can be insidious.
- As the dissection proceeds more posteriorly, the lesser sac posterior to the stomach is entered.



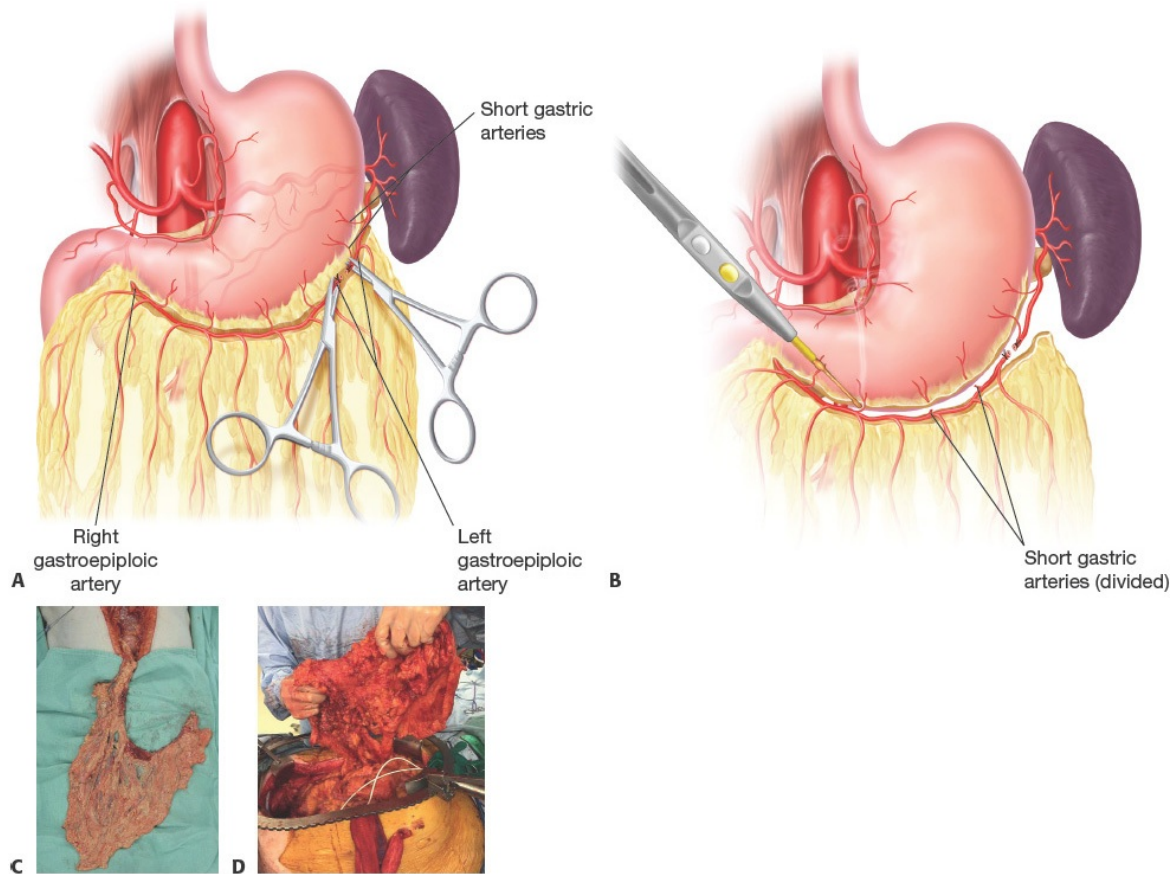
TECH FIG 1 • The omentum is dissected off the transverse colon mesentery through the avascular apposition plane, eventually entering the lesser sac.

- Once the omentum is elevated posteriorly, the mobilization is continued toward the left upper quadrant. Although it might be tempting to maximize the flap harvest in this region to increase flap length, extreme care should be taken to avoid injury to the short gastric vessels, the spleen, and the pancreatic tail. A conservative dissection leaving some omentum in the left upper quadrant is preferred to avoid injuring these vital structures.

Ligation and Division

- As the dissection approaches the proximal aspect of the greater curve, the left gastroepiploic artery will be encountered. Manual palpation can be used

to confirm its position. The artery should be doubly ligated with hemoclips and/or ties prior to division (**TECH FIG 2A**).



TECH FIG 2 • A. The left gastroepiploic artery is divided for a right-sided pedicled flap. **B.** The flap pedicle running parallel to the greater curve is mobilized with the flap. Gastric branches are serially ligated and divided. **C,D.** Fully mobilized omental flaps vascularized by the right gastroepiploic artery. Omental bulk can vary significantly. (© Charles E. Butler, MD.)

- The omentum is then sequentially separated from the greater curvature of the stomach. Serial gastric branches will require ligation and division.
- Bipolar energy-sealing system [Ligasure, Mansfield, MA] and ultrasonic coagulation (harmonic scalpel) are increasingly popular contact hemostatic

tools used during this dissection. When larger vessels in excess of 3 mm are encountered, however, the conventional clamp-and-tie technique should be used as bleeding from one of these stumps can result in delayed catastrophic bleeding (**TECH FIG 2B**).

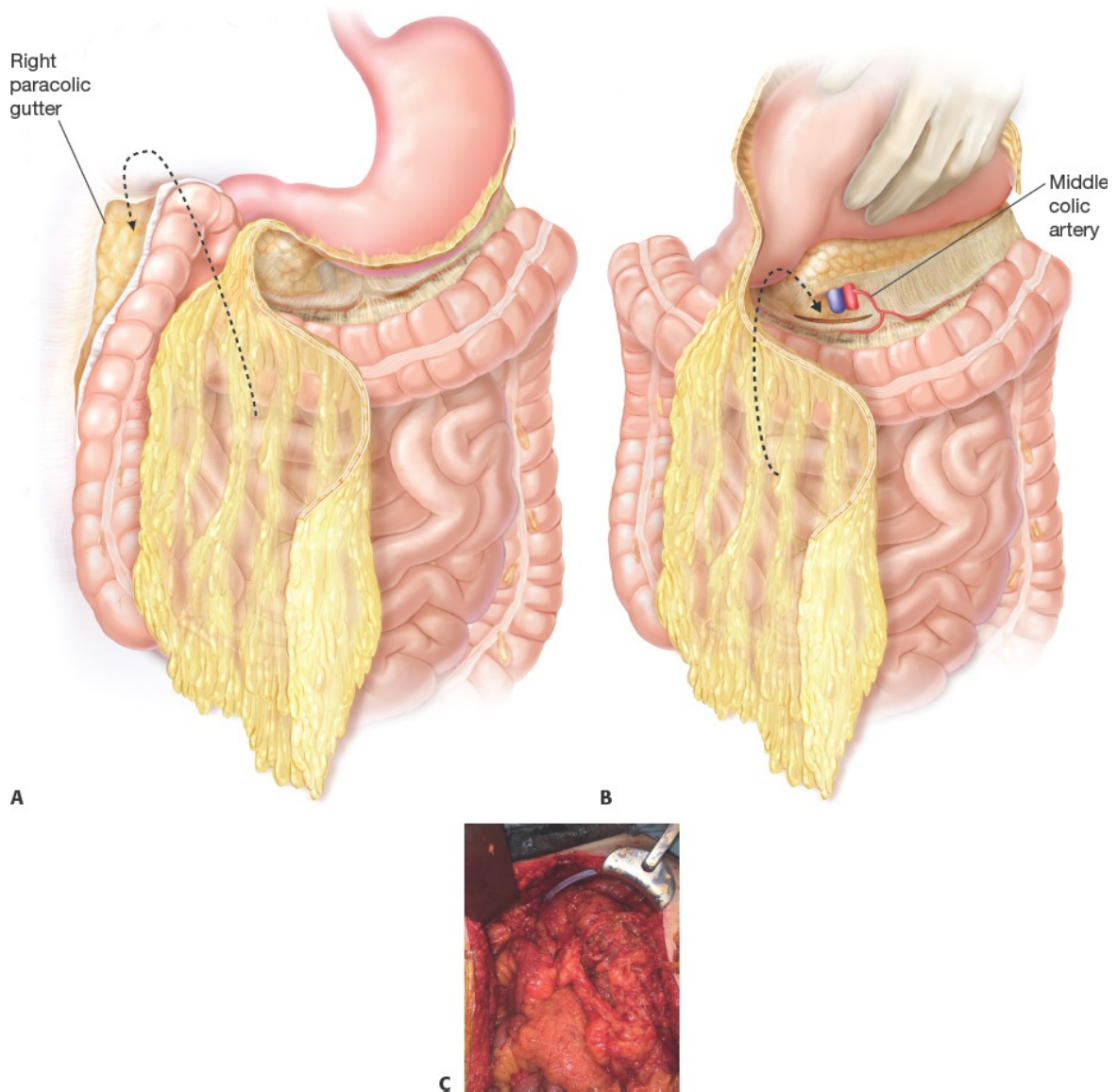
- When the thermal agents are used, meticulous care needs to be taken to avoid collateral injury to the adjacent gastric wall as well as the flap pedicle. The gastroepiploic arcade is located approximately one fingerbreath parallel to the greater curve and can be palpated for guidance.
- If concern arises regarding partial-thickness injury to the gastric serosa, oversewing can be performed due to the thickness of the gastric wall.
- Division is continued until the flap is of sufficient length to reach the pelvis without undue tension. For maximal safe length, the omentum can be safely mobilized just short of the pylorus, where the right gastroepiploic artery comes into direct contact with the stomach. The stomach is well vascularized via the remaining right and left gastric arteries from the lesser curve (**TECH FIG 2C,D**).

Flap Positioning

- A right-sided pedicled flap should generally be passed through the right paracolic gutter (**TECH FIG 3A**). If not already performed by the extirpative surgeon, to facilitate flap positioning, the ascending colon can be mobilized via release along the white line of Toldt.
- Alternatively, passage of the flap can be performed via the retrocolic plane through the transverse mesocolon to the right of the middle colic artery (**TECH FIG 3B**). The resultant mesocolonic defect should be repaired to prevent internal hernia.
- No suture fixation of the omentum is generally necessary in the pelvis. The flap should rest in the dependent position without excessive tension (**TECH FIG 3C**). Placement of the patient into the reverse Trendelenburg position may be useful for positioning.
- If question arises regarding viability of the distal aspect of the flap, options for flap assessment include handheld Doppler and fluorescein angiography.
- Should flap length be inadequate for reach into the pelvis without undue tension, the omentum may be transferred as a free flap using recipient vessels in the pelvis or lower abdomen.
- Additional perineal skin closure or flap reconstruction is performed as

indicated.

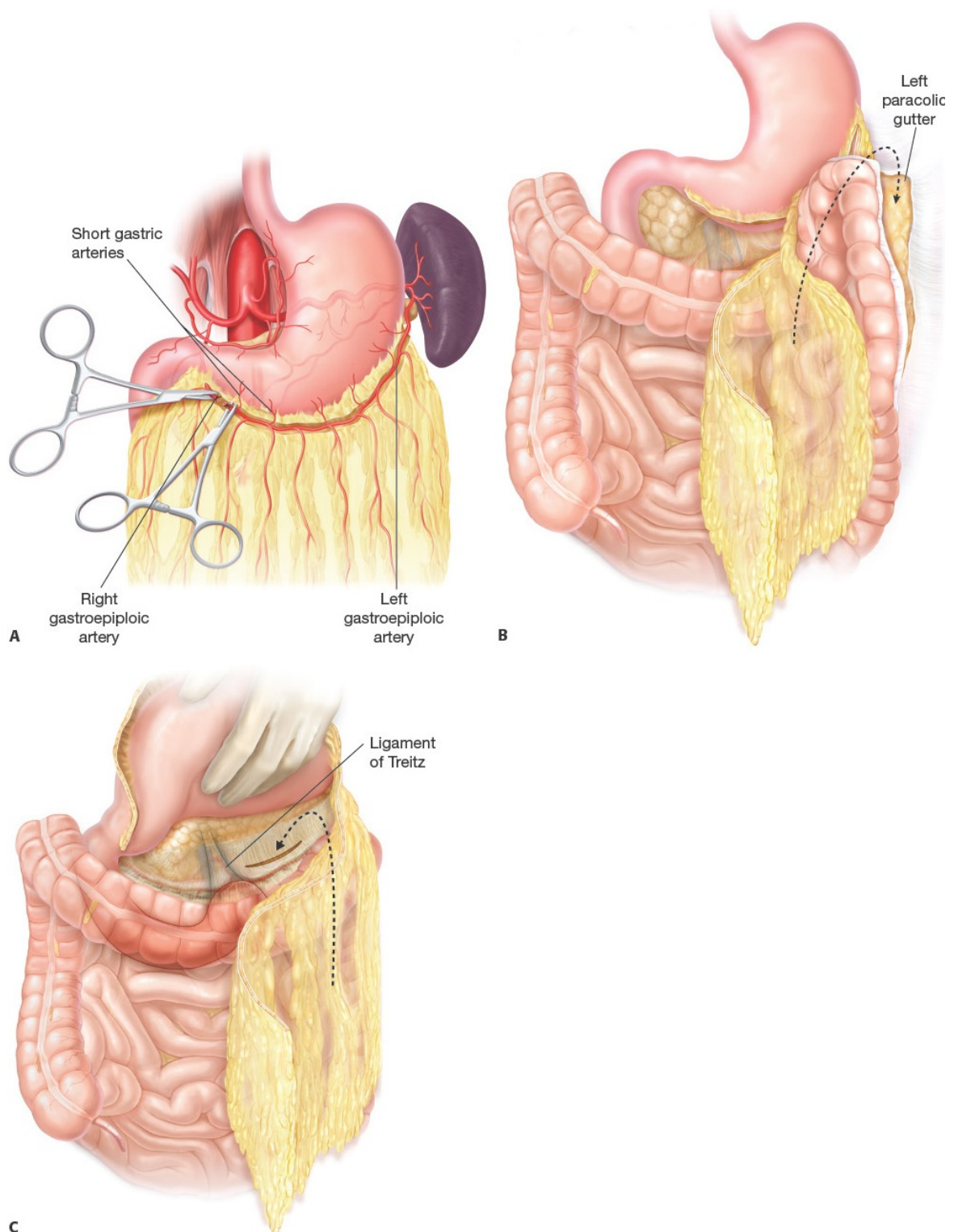
- Laparotomy closure is performed as per routine.



TECH FIG 3 • Inset of a right-sided pedicle flap. **A.** The omental flap may be passed through the paracolic gutter following mobilization of the white line of Toldt. **B.** Alternatively, the flap may also be passed via the retrocolic plane through the transverse or ileocolic mesocolon, across the sacrum, and into the pelvic defect. **C.** The pelvic defect is filled with the omental flap in position.

■ Omental Flap Harvest With Left Gastroepiploic Pedicle

- The flap is generally robust off either pedicle. Use of the left gastroepiploic artery can be required due to altered right upper quadrant anatomy or loss of the source vessels of the right gastroepiploic artery.
- Elevation of the omentum off the transverse colonic mesentery and into the lesser sac is performed in similar fashion as previously described.
- In the right upper quadrant, the flap is separated from the mesocolon of the hepatic flexure. As the gastroduodenal junction and the pylorus are encountered, the right gastroepiploic artery can be palpated. Secure ligation and division should be performed (**TECH FIG 4A**).
- Mobilization of the flap along the greater curvature can then proceed as described above toward the pedicle.
- The left gastroepiploic artery is the largest branch of the splenic artery. The gastric branches off of the left gastroepiploic should be taken down to no more than the middle third body of the stomach to avoid the splenic, short gastric, and pancreatic injuries as aforementioned.
- The mobilized flap can then be positioned along the left paracolic gutter into the pelvis or transmesocolonic as previously described. In the latter case, it can then be transposed to the left of the ligament of Treitz toward the pelvis (**TECH FIG 4B,C**).



TECH FIG 4 • A. For a left-sided pedicle, the right gastroepiploic artery is divided. **B.** Inset of a left-sided pedicle flap. For a left-sided pedicled flap, the flap can

be transposed within the left paracolic gutter. The sigmoid colon and rectum have usually been mobilized. **C.** The flap may also be passed through the transverse colonic mesentery to the left of the middle colic artery and the ligament of Treitz.

■ Laparoscopic Harvest of Pedicled Omental Flap

- Laparoscopic or robotic-assisted pelvic surgery is increasingly common.
 - The omentum can be harvested laparoscopically with one 10-mm periumbilical trocar and three additional 5-mm trocars in the lateral midabdomen to lower abdomen to allow for the concept of triangulation around the operative target with adequate retraction.⁶ In some patients, placement of a hand port may facilitate retraction.
 - The patient is placed into slight reverse Trendelenburg position. The abdomen is insufflated.
 - While the assistant drives the camera with the nondominant hand and provides retraction of the transverse colon toward the patient's feet with a blunt grasper, the surgeon elevates the omentum toward the anterior abdominal wall. The hook cautery may be used to raise the flap off the transverse colon while the surgeons reposition graspers as needed to maintain adequate traction.
 - Once the lesser sac is reached, the omentum is pulled down gently caudally, and a LigaSure or Harmonic device can be used to divide the omentum and to perform the release along the greater curve. Larger vessels are addressed with hemoclips, including the nonpedicle gastroepiploic vessel.
 - During these steps, if a hand-assist port is in place in the lower abdominal midline, the surgeon's nondominant hand may be helpful for caudal retraction of the omentum with manual confirmation of the gastroepiploic arcade location.
 - The flap can then be positioned in the pelvis as needed with the patient in reverse Trendelenburg position.
-

PEARLS AND PITFALLS

Preoperative considerations

- Feasibility of the omental flap for pelvic floor reconstruction is typically assessed intraoperatively. The surgeon and patient should be prepared for alternative options from the abdominal wall, gluteal region, and thighs.

Flap elevation

- Bleeding from the omentum can be difficult to control with conventional electrocautery and can be a source of postoperative hemorrhage. Threshold for secure hemoclip placement or surgical tying should be low.
- Correct use of thermal contact vascular sealing devices may be helpful in flap elevation.
- Awareness of the course of the middle colic artery is essential to avoid inadvertent injury.
- When the right gastroepiploic pedicle is used, mobilization of the omentum within the left upper quadrant should be cautiously and conservatively approached so as to avoid injury to the spleen and pancreatic tail.

Flap inset

- If tension-free positioning within the pelvis cannot be achieved following full mobilization, an alternative flap must be considered. Partial flap necrosis due to excess tension can result in pelvic sepsis and perineal wound breakdown.

POSTOPERATIVE CARE

- Traditionally, the dogmatic practice of nasogastric decompression after omental flap mobilization is thought to decrease gastric distension and manage expected postoperative ileus. Prevention of gastric distention has also been theorized to reduce the risk of hemoclip dislodgement from the ligated stumps of the branches along the greater curve.
- However, enhanced recovery initiatives are now increasingly prevalent. Avoidance of empiric postoperative nasogastric tube use unless strictly indicated is in keeping with the early feeding regimens and prompt patient mobilization that facilitate quicker recovery without compromising patient outcomes.
- If patients become symptomatic with severe nausea, belching, emesis, and/or bloating, abdominal radiograph may be considered for gastric distension. Nasogastric tube insertion should then be performed as indicated.

OUTCOMES

- Comparison of complication rates in patients who were primarily closed following abdominoperineal resection or pelvic exenteration with those in patients who received omental flaps consistently demonstrates improved outcomes in the latter group. In a study of 29 patients with omental flaps either alone or in combination with another flap, and 41 without omental flaps, the incidence of major pelvic complications (abscess, dehiscence, hernia, bowel obstruction, fistula) was greater in the group that did not receive omental flap reconstruction (61% vs 21%, $P < .01$).^{2,7}
- A systematic review of 14 studies (457 proctectomy patients with omental flap and 332 without) with median follow-up of 13.5 months demonstrated superior primary wound healing rate (66.8% vs 50.1%), shorter time to wound healing (24 vs 79 days), and lower wound infection rate (14.4% vs 18.5%) in patients who underwent omentoplasty.

COMPLICATIONS

- Bleeding
- Splenic injury
- Mesocolon injury, including disruption of the middle colic vessels
- Pedicle injury during mobilization along the greater curvature
- Gastric wall injury
- Partial flap loss
- Paralytic ileus
- Pancreatic injury
- Perineal delayed wound healing
- Perineal hernia
- Intestinal obstruction

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25 CHAPTER Posterior Labial Artery Flap for Vulvar and Vaginal Reconstruction

Chris A. Campbell

DEFINITION

- The posterior labial artery flap commonly known as the Singapore flap or pudendal thigh flap is a thin fasciocutaneous flap oriented along the groin crease within the perineum.¹
- The flap's pedicle, the posterior labial artery, is a branch of the internal pudendal artery system.
- Unilateral or bilateral posterior labial artery flaps are commonly used for vulvar resurfacing and vaginal reconstruction.

ANATOMY

- The posterior labial artery flap is inferiorly based with its axis along the groin crease including the thin skin lateral to the labia majora medially and the medial thigh skin laterally.
- The flap's pedicle is the posterior labial artery, which courses above the deep perineal fascia, arising from the perineal artery as it pierces the Colles (superficial perineal) fascia. The perineal artery branches off of the internal pudendal artery that emerges from the pudendal canal located 1 cm medial and inferior to the ischial tuberosity.
- The flap's skin paddle can be up to 15 cm long by 6 cm wide in the adult with the base of the flap even with the posterior edge of the introitus.²
- The posterior labial branches of the pudendal nerve innervate the most posterior aspect of the skin paddle providing sensation to the reconstruction.

PATHOGENESIS

- Vulvar or vaginal defects resulting from resection of squamous cell carcinomas, extensive condyloma, lichen sclerosis, fistulas, necrotizing soft tissue infections, and other cutaneous conditions have been reconstructed with unilateral or bilateral posterior labial artery flaps.
- In the pediatric population, bilateral posterior labial artery flaps have been used for total vaginal reconstruction in cases of vaginal atresia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- When approaching vulvar or vaginal reconstruction, evaluate the abdomen, thighs, and inguinal region to maintain rectus and thigh-based flap alternatives to the posterior labial artery flap, in the event significant tissue bulk is required.
- If the patient has had pelvic radiation to treat malignancy, the exam should focus on the quality of the groin and medial thigh skin to determine if it is within the radiated field. A severely radiated groin crease can increase the risk of partial flap loss and wound healing complications.
- Measure the surface area of vulvar skin or vaginal mucosa that requires resurfacing to ensure that this amount of groin crease skin is redundant to allow for closure of the donor site.

IMAGING

- Computed tomography of the pelvis will be part of the standard preoperative evaluation of patients requiring resection of vaginal abnormalities that will require subsequent reconstruction.
- The posterior labial artery flap lacks bulk and as such is used to resurface the posterior or circumferential vagina or vulvar skin.³ Larger tumors that require pelvic exenteration will need alternative or additional flaps that provide soft tissue bulk in addition to skin resurfacing.

SURGICAL MANAGEMENT

- Unilateral or paired posterior labial artery flaps are used to reconstruct partial or circumferential vaginal defects, respectively, and to resurface vulvar defects with thin pliable skin.
- When total vaginal reconstruction is required, bilateral posterior labial artery flaps are sewn together and rotated into the pelvic defect producing a natural physiologic angle of inclination of the reconstructed vagina.⁴
- Key considerations for use of the posterior labial artery flap include the ability to cover the vaginal or vulvar defect surface area with adjacent available groin

skin within the design of the Singapore flap and whether the skin paddles are within fields of significant pelvic radiation.

Preoperative Planning

- Pathology findings from prior biopsies and imaging studies should be reviewed to confirm the planned extirpation involving the vulva and/or vagina.
- All resections that include the vagina will be preceded by an examination under anesthesia to determine if there has been disease progression and to confirm the planned resection and reconstruction.
- A Foley catheter should be placed to protect urethral structures if total vaginectomy is required and to assist the patient with recovery.

Positioning

- The patient is placed in the lithotomy position on the operating table for both the extirpative portion of the operation and the vulvar and/or vaginal reconstruction with one or both posterior labial artery flaps (**FIG 1A**).

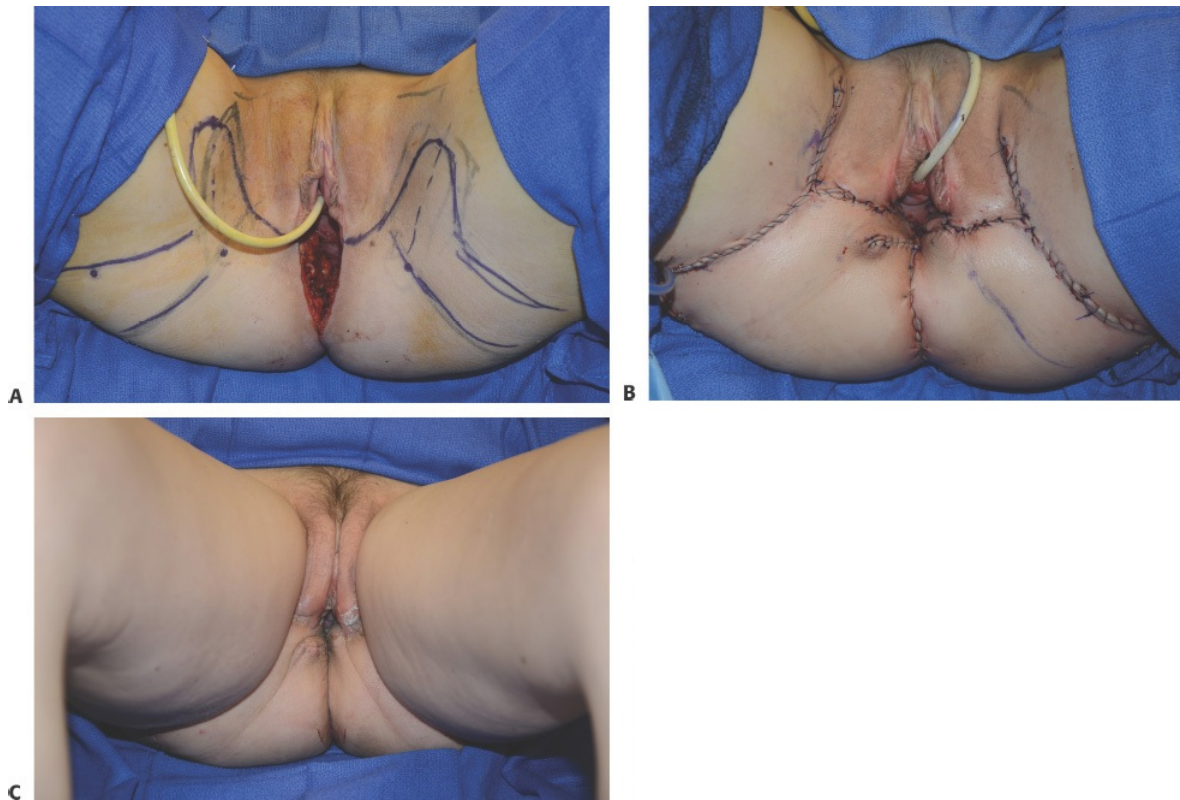


FIG 1 • Operative photos of bilateral posterior labial artery flaps for posterior vaginal reconstruction after

rectal cancer resection. **A.** The patient is in lithotomy position with bilateral posterior labial artery flaps marked. Gluteal advancement flaps are also marked to obliterate the dead space from the abdominoperineal resection. **B.** Bilateral posterior labial artery flaps have been rotated into the pelvic defect to resurface the posterior and lateral surfaces of the vagina. **C.** Six months after surgery with donor-site incisions camouflaged within the groin creases and return of sexual function.

- If other flap options are being considered for vulvar, vaginal, or perineal reconstruction, also prep the thighs down to the knees, lower buttocks, and lower abdomen to include abdominal, buttock, and thigh-based flap options.

Approach

- For vulvar skin defects and vaginal defects where the wound interrupts the posterior introitus, the posterior labial artery flaps are rotated directly into the defect (**FIG 1B**).
- For cases where the labial structures are not interrupted by the resection or in cases of vaginal atresia reconstruction, the posterior labial artery flaps are tunneled underneath posterolateral structures of the introitus as island flaps before inset.

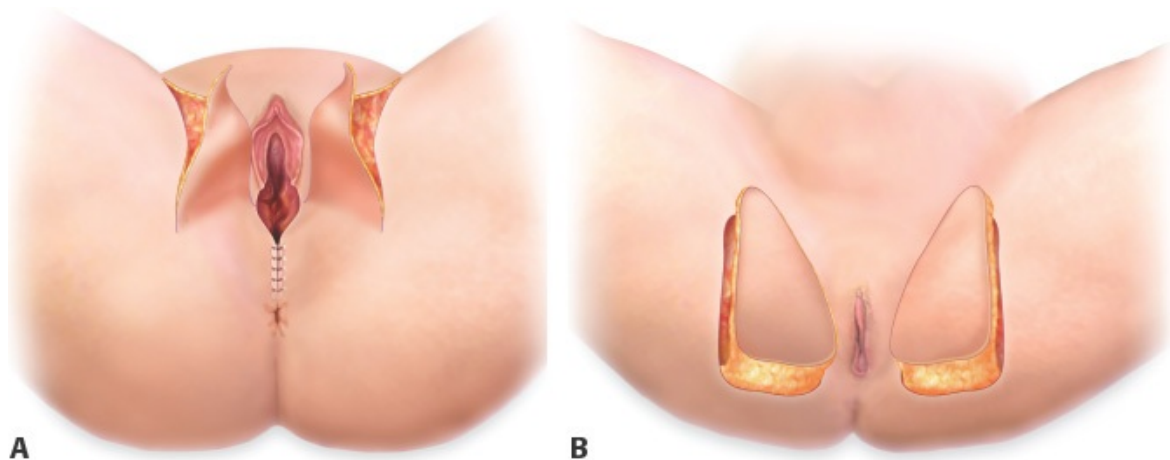
TECHNIQUES

■ Posterior Labial Artery Flap Design

- The flap skin paddle is centered on the groin crease with the base of the flap being set at the most posterior point of the vaginal introitus.
- Maximal flap length has been described as 15 cm in the adult female. A skin paddle that measures 6-cm wide can be closed primarily within the groin crease of the average adult.

■ Posterior Labial Artery Flap Elevation

- Incise the skin of apex and medial and lateral edges of the planned skin paddle passing through subcutaneous fat and the deep perineal fascia and medial thigh fascia.
- Elevate the flap from the anterior tip of the skin paddle and then proceed proximally in a subfascial plane to elevate the posterior labial artery with the flap. This dissection will continue until the posterior edge of the introitus is reached (**TECH FIG 1A**). The transverse fibers of the superficial perineal musculature will provide resistance to further elevation of the deep fascia at this level.
- For flaps elevated as an island flap intended to go underneath an intact edge of the introitus, additional dissection is performed posterior to the skin paddle. Dissect in the subcutaneous plane 4 cm beveling posteriorly to free the proximal edge of the skin paddle for medial tunneling into the defect (**TECH FIG 1B**). Do not violate the fascia on the posterior border of the skin paddle to avoid injury to the pedicle.

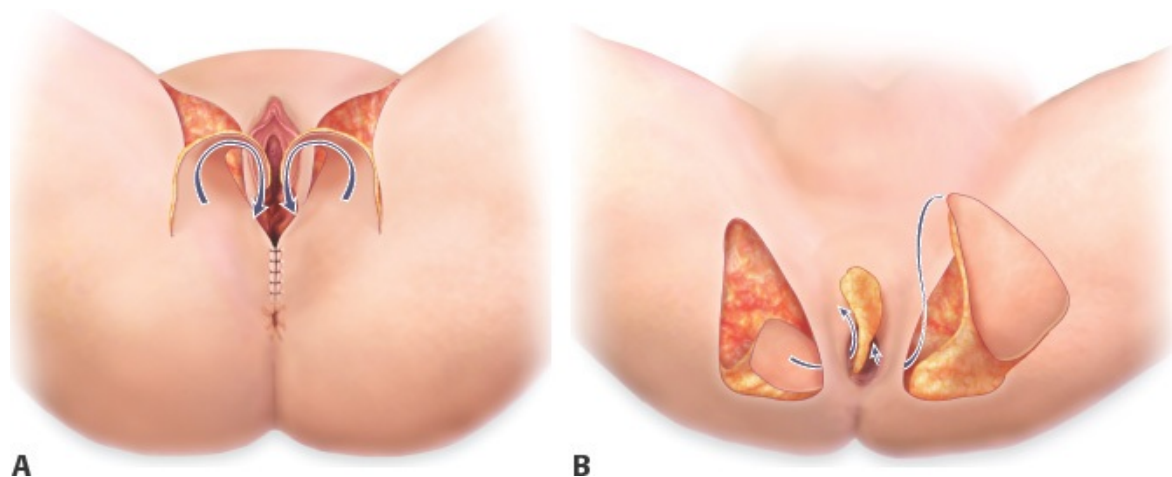


TECH FIG 1 • Bilateral posterior labial artery flap elevation. **A.** Skin paddles of posterior labial artery rotation flaps elevated in a subfascial plane from anterior to posterior stopping at the posterior edge of the introitus. **B.** For the design of bilateral posterior labial artery island flaps, a posterior incision is made through the skin with posteriorly beveled

subcutaneous dissection for 4 cm. This additional posterior dissection allows the flap to be able to be tunneled under the intact posterolateral introitus to reach the pelvic defect.

■ Posterior Labial Artery Flap Rotation

- For defects that include a portion of the introitus, the posterior labial artery flaps are rotated directly into the defect (**TECH FIG 2A**). For vaginal reconstruction where the introital opening is intact, subcutaneous tunnels are created to pass the posterior labial artery flap as an island flap (**TECH FIG 2B**).



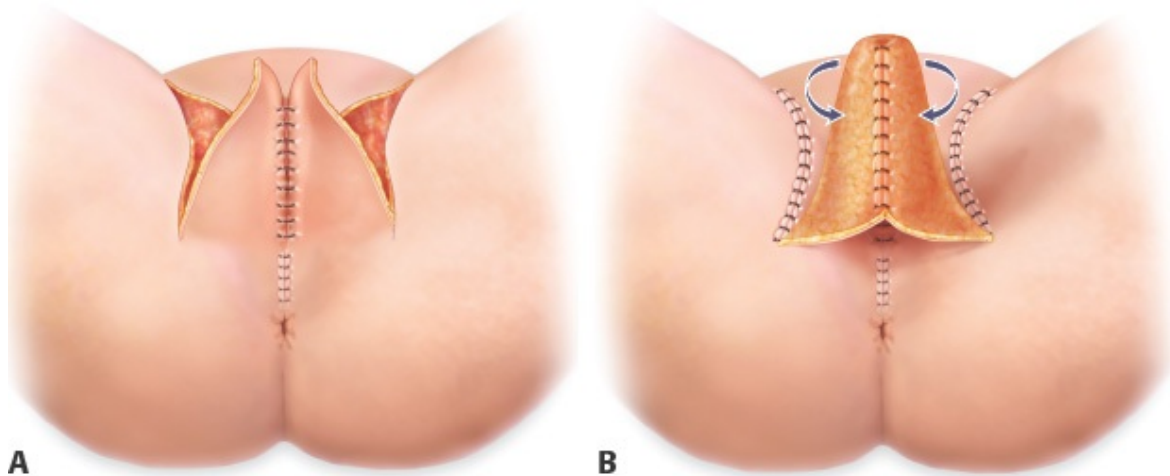
TECH FIG 2 • Bilateral posterior labial artery flap rotation: **A.** Bilateral posterior labial artery rotation flaps will be turned inward to reconstruct the vaginal defect. **B.** Bilateral posterior labial artery island flaps will be tunneled underneath intact skin flaps to reconstruct vaginal defects where the introitus is intact or in congenital cases such of vaginal atresia.

■ Posterior Labial Artery Flap Closure and Inset

- The medial edge of the skin paddles will be sewn to one another to create the posterior surface of the vaginal canal (**TECH FIG 3A**). For defects limited to

posterior vaginal reconstruction, the lateral and distal edges of the combined skin paddle are sewn to the mucosal edges of the defect to complete the reconstruction.

- For total vaginal reconstruction, the lateral edges of the skin paddle are sewn to one another to create the anterior edge of the vaginal canal (**TECH FIG 3B**).
- Finally, the flap donor sites are closed in layers. The incision and resulting scar are camouflaged within the groin crease.



TECH FIG 3 • Bilateral posterior labial artery flap closure and inset. **A.** For total vaginal reconstruction, the medial edges of the skin paddles are sewn together to produce the posterior aspect of the vagina. **B.** The lateral edges of the skin paddles are sewn together to produce the anterior aspect of the vagina.

PEARLS AND PITFALLS

Preoperative evaluation

- It is critical to understand the extent of the planned resection to know if soft tissue bulk is required. Posterior labial artery flaps are thin pliable fasciocutaneous flaps. Therefore, another flap should be chosen for large volume defects.

Physical

- If the groin skin is firm and darkened from prior pelvic radiation,

examination	another flap should be chosen to avoid partial flap loss and wound dehiscence.
Technique— flap elevation	■ The deep perineal fascia overlying the perineal musculature and the deep adductor fascia overlying the medial thigh should be elevated with the flap to avoid harm to the neurovascular pedicle.
Technique— bilateral flap rotation	■ Subcutaneous dissection proximal to the skin paddle is required to allow for appropriate rotation of bilateral island flaps beneath the posterolateral introitus for total vaginal reconstruction. If not performed, the proximal portion of the skin paddles cannot be approximated without tension and will alter the incline of the resulting vaginal angle.
Postoperative care	■ For patients requiring partial vaginal reconstruction in low estrogen states, consult with a gynecologic oncologist to determine if estrogen replacement or inserts may be required to prevent wound healing trouble due to vaginal mucosal atrophy.

POSTOPERATIVE CARE

- Maintain single shoulder's width leg positioning when lying or ambulating for the first 2 weeks after surgery.
- If the reconstruction only involves vaginal reconstruction, then brief episodes of sitting are permitted. A sidesaddle posture of favoring one buttock and then the other is encouraged. If there is also a perineal reconstruction with suture lines posterior to the introitus, then limiting head of bed to 45 degrees or less for 2 weeks without radiation and up to 4 weeks in the presence of preoperative radiation is required.
- The patient should wear dry gauze to the surgical site that is changed frequently to avoid skin maceration. The incision and resulting scar will be camouflaged within the groin crease (**FIG 1C**).
- Daily showering is recommended.

OUTCOMES

- Sexual adjustment after vaginal reconstruction is only successful in about half of women, with problems such as dryness, discomfort, or self-consciousness decreasing success.⁵

COMPLICATIONS

- Partial flap loss at the tip of the flap and wound dehiscence of the posterior vaginal closure and groin crease donor site are infrequent but do occur.

Supportive dressing care is the mainstay of treatment.

- Premenopausal women following chemotherapy and postmenopausal patients with vaginal atrophy who require partial vaginal reconstruction may be more likely to exhibit remnant vaginal narrowing and skin flap dehiscence and may require estrogen replacement orally or in the form of vaginal inserts in the post-op period.
- Foreshortened reconstructed vaginas either due to cicatricial shortening or flap design may contribute to problems with sexual adjustment requiring vaginal dilatation.

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Vertical Rectus Abdominis Flap for Perineal Reconstruction

26

CHAPTER

Dhivya R. Srinivasa and Jeffrey H. Kozlow

DEFINITION

- Perineal reconstruction is often required after oncologic resections for anorectal, gynecologic, and/or genitourinary tumors. Other etiologies including inflammatory bowel disease (IBD), trauma, and necrotizing infections can also be treated in a similar fashion after control of the destructive process.
- The defect can be defined in two components: the internal pelvic outlet defect and the external skin/soft tissue defect.
- Because radiation therapy is an integral component of locoregional tumor management, the surgeon must consider the implications of radiation.
- Although multiple options are available to the reconstructive surgeon, a pedicled vertical rectus abdominis myocutaneous (VRAM) flap is one of the workhorse flaps for reconstruction of the perineum. The VRAM flap allows for harvest of varying combinations of the muscle, fascia, subcutaneous fat, and skin with tailoring of components to the acquired defect. The soft tissues of the VRAM are robust and reliable in anatomy, making this an attractive option for many reconstructive surgeons.

ANATOMY

- The surgeon must be well learned in pelvic and perineal anatomy including the following components:
 - Genitourinary: Bladder, seminal vesicles, and prostate
 - Gynecologic: Ovaries, uterus, cervix, and vagina
 - Colorectal: Rectum, levator muscles, and anus
- **FIG 1** depicts a sagittal schematic of the male and female pelvis.

- In colorectal and perianal resections, the presence or absence of the levator musculature following extirpation can determine the need for pelvic outlet volume to fill the defect and close the pelvic floor. Removal of all the soft tissue in the pelvic outlet will result in a defect that will not collapse down due to the surrounding bony architecture, resulting in postresection “dead space.”
- The abdomen is a readily available donor site for perineal reconstruction. It is remote from the zone of radiation, has a pedicle that originates close to the pelvis, and commonly has lax soft tissue.
- In most cases of perineal reconstruction, the donor site can be closed primarily. Component separation is a useful adjunct if needed to facilitate tension-free primary fascial closure.¹
- The VRAM flap derives blood supply from the deep inferior epigastric artery (DIEA), a branch of the external iliac arterial system as depicted in **FIG 2**. Dissection of the flap pedicle into the pelvis provides maximal arc of rotation. The DIEA and venae comitantes are predictably located on the underside of the rectus muscle, exiting into the pelvis along the lateral aspect of the muscle.

PATHOGENESIS

- Resection of anorectal and urogenital tumors is most often the impetus for perineal reconstruction. Although staging and management can be complex, a significant portion of these tumors undergo surgical therapy along with radiation for curative intent.
- The use of neoadjuvant radiation portends approximately a 60% risk of complications including abscess, wound dehiscence, and enterocutaneous fistula. The introduction of vascularized, nonradiated tissue to the surgical site can significantly decrease the risk of major complications.²
- Subsequent systematic reviews and meta-analyses have confirmed the benefits of local tissue transfer for perineal reconstruction.³
- In female patients, rectal tumors can also invade the posterior vagina requiring an even more complex reconstruction following extirpation. An example of this type of defect is pictured in **FIG 3**.
- Anal tumors are treated primarily with the Nigro protocol, of which radiation is a key component. However, salvage of recurrent disease requires abdominoperineal resection with a wide skin margin resulting in a more significant external defect. Primarily closing the perineal defect is often wrought with complications due to tension, pressure, and radiation injury. Thus, soft tissue reconstruction with regional flaps can improve wound healing

and decrease complications.⁴

- Primary vulvar and vaginal tumors present similar challenges as do anorectal tumors but also require consideration of a functional reconstruction. Vulvar and vaginal tumors can be resected sans radiation, but locally advanced tumors, high-risk tumors, and positive margins can be treated with external beam radiation. Specifically for vulvovaginal reconstruction, restoration of appearance and function has quality of life benefits in addition to decreased wound healing complications.^{5,6}
- IBD, namely Crohn disease, can present with fistulas and recurrent abscesses.
 - Recalcitrant disease that fails medical management is often treated surgically, and abdominoperineal resection is reserved for a severe disease affecting quality of life.

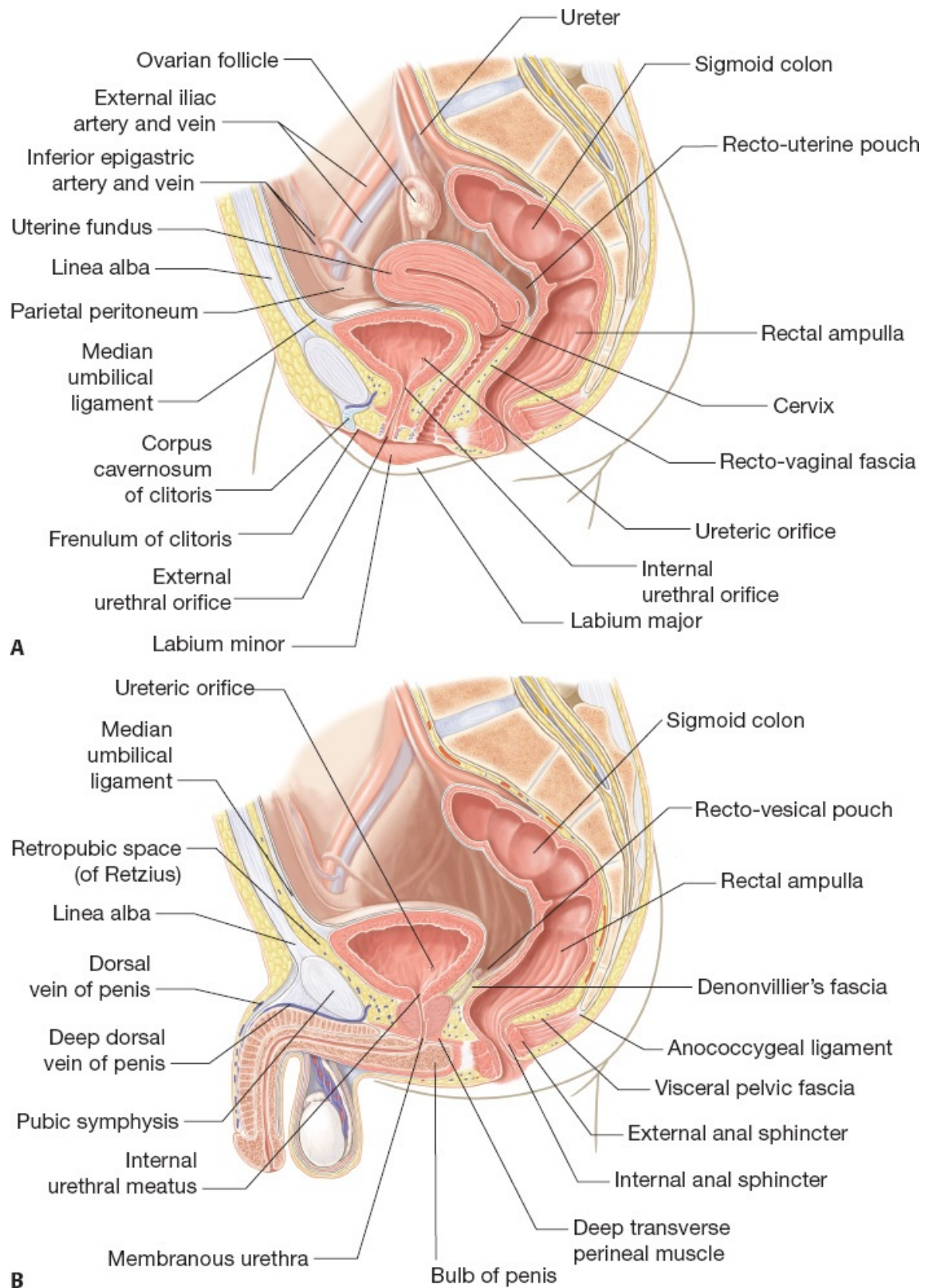


FIG 1 • A. Sagittal view of female anatomy. B. Sagittal

view of male anatomy.

- Inherently, these patients are high risk for wound complications. Most have been on chronic immunosuppressive therapy with corticosteroids and other immune modulators. Further, the tissue has been inflamed for years, with notable friability.
- The introduction of healthy vascular tissue improves wound healing and decreased incidence of major complications.⁷
- Other etiologies for perineal defects include trauma and necrotizing infections, which require full debridement of nonviable tissue prior to reconstruction.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Perineal reconstruction can be performed for a multitude of indications, and a thorough history should include pertinent information to each of these conditions.
- Prior to deciding on a reconstructive plan, the following information should be obtained.
 - Extent of planned defect focusing critically on:
 - Amount of external skin resection
 - Maintenance or resection of the levator complex
 - Vaginal involvement in anorectal tumors
 - Presence of fistulas, which may require extended resection margins
 - History of radiation or planned adjuvant radiation therapy
 - Past abdominal/pelvic surgery including approaches that may have sacrificed the DIEA such as a Maylard approach to gynecologic surgeries.
 - Patient goals: For resections involving the vagina, is restoration of sexual function possible and/or desired?

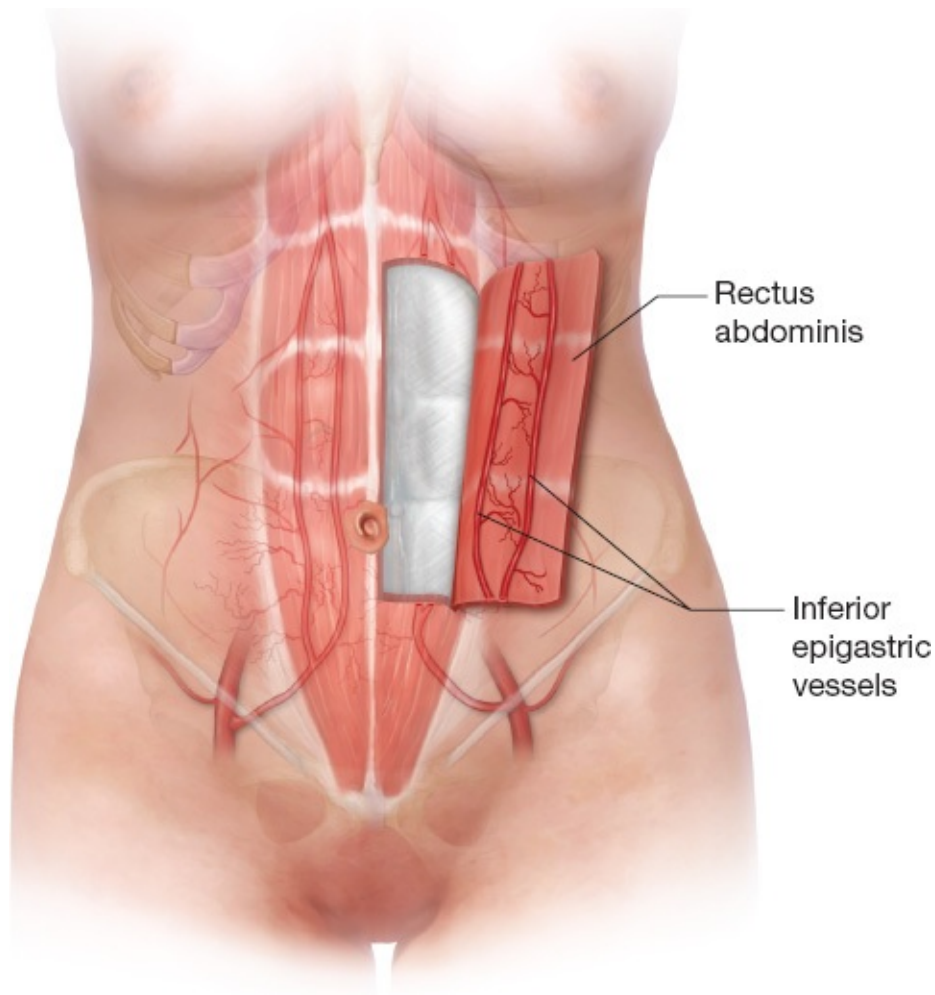


FIG 2 • Vascular anatomy of the deep inferior epigastric vessels.

- Relevant surgical risk factors for delayed wound healing including:
 - Tobacco usage
 - Current or previous steroid use
 - Other immune modulator medications received or planned
- Physical examination should include a thorough examination of the perineum and abdominal donor site.
- Perineal examination should include evaluation of external structures, extent of radiation damage, and an understanding of the planned resection (including margins). Full examination of the genitalia and anus/rectum gives a better understanding of the planned resection, although ongoing radiation treatment may affect this estimate.

- Donor-site examination should evaluate for previous surgical scars, tissue laxity, and skin quality of the anterior abdominal wall. The skin should be adequately lax for primary closure. A “pinch test” of the skin can offer a rough estimate of the maximum skin paddle width that will still be closed primarily. Previous or planned stomas should also be noted, along with the presence of any ventral hernias.



FIG 3 • Intraoperative defect involving the skin of the perineum, pelvic outlet soft tissue, and posterior wall of the vagina.

IMAGING

- Preoperative imaging for cancer staging can offer details on degree of locoregional tumor involvement and necessary margins for resection. Imaging of the abdominal donor site is typically not necessary unless there is concern of DIEA patency.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative planning hinges on clear communication with the surgeon performing the resection. A discussion of planned margins, structures to be removed, the location of stoma(s), and adjuvant cancer therapies should be held prior to planning reconstruction.
- Location of any previous and planned stomas can help guide which rectus is most amenable for flap harvest.

- Discussion on port site locations for laparoscopic surgery is also important. Certain paramedian port sites may injure the DIEA vessel or rectus muscle.
- Delayed reconstruction may be indicated if margins are likely to be positive.

Positioning

- The patient will likely be positioned in lithotomy for the resection. The entire abdomen from below the nipples, including the perineum, and bilateral legs should be prepped to below the knee, exposing the medial and lateral thigh. The exposure should allow for alternative flap harvests as the ability to predict the defect is not always accurate preoperatively.
- Appropriate padding of all pressure points is mandatory. Common peroneal and femoral nerve branches can develop neuropraxias with prolonged lithotomy positioning.
- Bilateral lower extremity sequential compression devices (SCD) should be placed for deep venous thrombosis prophylaxis.
- A safety belt should be used for all cases.
- A warming blanket should be placed on the upper body to optimize normothermic core temperatures during the case.

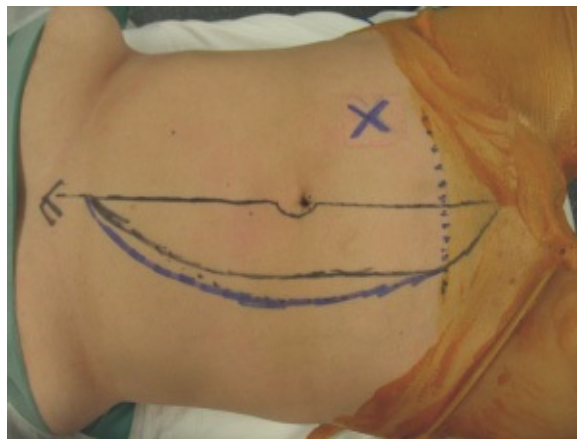
Approach

- Preoperative markings for a vertical rectus flap may not be necessary, but any midline or laparoscopic incisions should be discussed with the oncologic surgeon.
 - If a midline incision is used, it should be placed on the flap side of the umbilicus.
 - If laparoscopic incisions are used, discuss proximity of paramedian incision to the rectus and the deep inferior epigastric vessels. Move these incisions lateral to the rectus sheath if possible.
- If a lower midline incision is used, the fascia (anterior sheath) is incised at the level of the medial row perforators cephalad to the existing incision to preserve as much fascia as possible.
- The final skin paddle is often designed after the full nature of the defect is known. A pinch test can be used to confirm that the skin can be closed primarily, although typically 6 to 7 cm is the most needed and this can be harvested easily from most abdomens.

TECHNIQUES

■ Incision

- The patient does not need specific markings preoperatively; however, incisions should be discussed with the oncologic surgeon.
- When a lower midline incision is used by the resecting surgeon, the cephalad extension of the incision through the fascia can be paramedian, at the level of the medial row perforators. This will allow adequate perfusion to the skin paddle but also preserve the fascia. This requires incision of the anterior sheath only as the muscle can be elevated off the posterior sheath.⁸
- Design the skin paddle according to abdominal skin laxity and the size of the perineal defect (**TECH FIG 1**). This is typically designed such that the medial border of the flap is still in the midline.
- An oblique skin paddle can be used, known as an oblique rectus abdominis myocutaneous flap, or ORAM, which is a semiarticulating skin and soft tissue paddle overlying the muscle. The incision then extends laterally below the costal margin. Here, the periumbilical perforators perfuse the oblique skin paddle and should be maintained as they pass through the rectus.



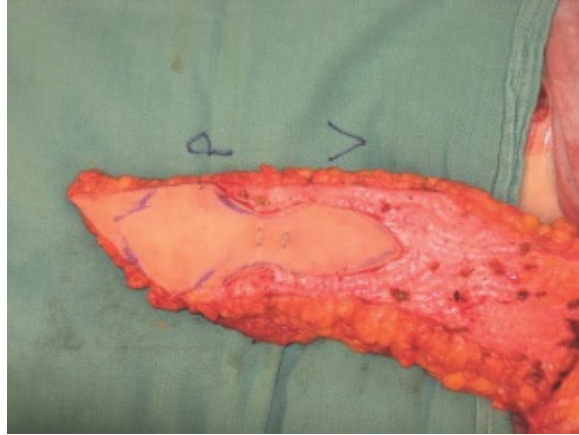
TECH FIG 1 • On-table markings for a VRAM flap. Note that the flap is situated on the contralateral side from the planned stoma. Further, the incision is on the flap side when curving around the umbilicus.

■ Elevation of Rectus and Skin Paddle

- Elevate the rectus from the posterior sheath. Keep in mind that the pedicle runs on the posterior surface of the muscle and should not be injured in this dissection. There will be lateral branches and the motor nerves that also must be divided.
- Transect the cephalad muscle and suture ligate the superior epigastric vessels.
- Once the entirety of the rectus and the overlying skin paddle is elevated, gently free the deep inferior epigastric pedicle as it exits the lateral border of the muscle. It will travel into the pelvis. Here, carefully ligate all small branches to avoid undue bleeding, which can be difficult to control in this region.
 - Incise the posterior rectus sheath for gentle curvature of the pedicle without undue kinking when the flap is passed into the perineal defect.

■ De-epithelization and Transposition of Skin Paddle

- In order to transpose the flap into the pelvis, the posterior sheath must be incised transverse inferiorly so that the pedicle is not kinked with transfer to the pelvis. This division of the posterior sheath is made well below the arcuate line, so there is little effect on closure strength.
 - **TECH FIG 1B** shows the elevated rectus with the skin paddle prior to inset (**TECH FIG 2**). The skin paddle can be de-epithelized inferiorly. For defect requiring both posterior vagina and perineum skin reconstruction, an hourglass skin paddle is designed by de-epithelization. This is best done prior to inset.
- The flap is then transposed into the pelvis with a gentle twist to allow the skin paddle to be used for external reconstruction.



TECH FIG 2 • The skin paddle can be de-epithelialized in an hourglass pattern to allow for combined posterior vagina (V) and perineum skin reconstruction (P). The remainder of the de-epithelialized flap provides bulk to fill the pelvic outlet.

■ Closure

- Abdominal donor-site closure requires approximation of the fascia and skin.
 - For fascial closure, primary tension-free approximation is best. If needed, an anterior component separation can be performed on the contralateral side with or without a mesh to decrease postoperative abdominal bulge or hernia.⁹
- The soft tissue should be closed in layers (Scarpa fascia, dermis, and skin).
- Inset of the flap should allow for tension-free closure as seen in **TECH FIG 1C (TECH FIG 3)**.
 - The muscle should be used to fill the intra-abdominal pelvic defect.



TECH FIG 3 • Inset of VRAM for perineal reconstruction. Part of the skin paddle was used to reconstruct the posterior wall of the vagina. The remainder of the skin paddle was used for the perineal incision.

PEARLS AND PITFALLS

Markings	Incisions should be discussed with the oncology surgeon. The incision should be placed on the side of the flap adjacent to the umbilicus
Spare fascia	The medial extent of the incision can be paramedian; to spare fascia, the anterior sheath can be incised at the level of the medial row perforators
Reduce hernia and abdominal bulge	- Component separation can be used in patients where primary closure without tension is not possible - Fascia-sparing technique
Vaginal defects	The skin paddle can be tubed to reconstruct vaginal defects, whereas the muscle is used to fill in the intra-abdominal defect
Plan B	Alternative flaps should be available and prepped into the field. The thigh is a good alternative donor site (gracilis or ALT)
Tunnel for pedicled VRAM	Release the posterior sheath to allow passage of the flap without kinking

POSTOPERATIVE CARE

- Postoperative restrictions: For perineal reconstruction, it is important that the patient does not place direct pressure on the flap by sitting or lying directly supine. Orders should be written for turns every 2 hours, and the patient can lie on one side or the other, but not directly supine if this would put pressure on the flap. Foam wedges and bumps can be used to offload pressure as well.
- Care should also be taken to avoid hip abduction or complete hip flexion as this can put strain on or kink the pedicle.
- We allow patient ambulation on postoperative day 1 or 2 with the aid of physical therapy. However, sitting is not allowed for 3 weeks postoperatively and gradually advanced with proper cushioning.
- Drain management: Hematomas and seromas can place undue pressure on the flap and pedicle, therefore compromising flow. Pay careful attention to drain output, and any hematomas should be drained operatively.
- Flap monitoring: Nursing staff should monitor the flap overnight, with checks for capillary refill, color, and warmth every 2 to 4 hours. A Doppler stitch can be used if needed. Evidence of congestion or ischemia should be noted immediately. Sometimes, release of sutures can help if undue tension is the source of the problem. Concerns for vascular compromise should prompt operative exploration to evaluate kinking or pressure on the pedicle.
- Review the pathology results to confirm margins are negative from the original resection for all oncologic procedures.

COMPLICATIONS

- Flap loss: Complete flap loss is due to compromise of the vascular pedicle. Ideally, this would be discovered soon postoperatively with subsequent operative salvage. However, in the case of irreversible flap loss, the tissue should be removed and other reconstructive options should be explored.
- Wounds: Delayed wound healing in the perineum is relatively common but can most often be managed nonoperatively. This would include debridement as needed, local wound care, and close monitoring.
- Infection: Most infections can be managed with antibiotics. Interventional drain placement is helpful for formed abscesses seen on imaging.
- Hematoma: Hematomas are possible at both the donor and recipient site. Drain output and physical examination are key. Hematomas should be drained surgically.

- Seroma: Late seromas can develop at the donor site. Most can be managed with drains.

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Gracilis Flap for Perineal and Vaginal Reconstruction

CHAPTER

Ajani G. Nugent, Yasmina Zoghbi, and Christopher J. Salgado

DEFINITION

- Perineal defects reconstructed with gracilis flaps are applied after vulvovaginal resections or more extensive pelvic exenterations with considerable soft tissue loss, dead space, and distortion of the introitus.¹
- Vaginal defects indicated for gracilis flap reconstruction are applied for partial or total circumferential full-thickness portions of the vaginal canal including mucosa and muscle layers.^{1,2}
- The gracilis flap is a highly vascularized muscle or myocutaneous flap that provides regional tissue that has its own independent blood supply, fills in pelvic dead space, and separates abdominal contents from the perineal wound. The gracilis flap is often not in the potential radiation field.^{1,3}

ANATOMY

- The gracilis muscle—one of the adductors of the leg—is found in the more superficial plane of the medial thigh muscles.
- Derived from the Latin word *gracile*, which means slender, the muscle is thin and straplike, measuring roughly 25 cm in length and tapering from superior to inferior from about 6 to 4 cm.⁴
- It takes origin from the ischiopubic ramus and inserts distally via the pes anserinus into the medial tibia inferior to the condyle. The muscle inserts posteromedially to the adductor longus and, along with its tendinous insertion, can be palpated with ease in thinner patients.
- The gracilis axis can be defined by drawing a line from the ischium to the medial condyle of the knee. Alternately, by palpating the adductor longus with the thigh abducted, the gracilis axis can be outlined 2 to 3 fingerbreadths

posterior to the adductor longus.

- The gracilis flap is a type II muscle flap according to the classification of Mathes and Nahai. It has a dominant vascular pedicle from the medial femoral circumflex artery, a branch of the deep femoral system. Two secondary pedicles to the gracilis muscle can be found segmentally proximal and distal to the pedicle.⁵
- The neurovascular pedicle of the gracilis free flap is made up of a single arterial branch arising from the medial femoral circumflex artery, two vena comitantes, and the anterior branch of the obturator nerve.⁶
- On average, the vessel measures 1.6 mm in diameter and passes deep to the adductor longus and superficial to the adductor magnus to enter the proximal third of the gracilis.⁵
- The entry point of the vascular pedicle is typically found 8 to 10 cm inferior to the pubic tubercle.⁶ The proximal attachment of the muscle is often not palpable, and the distal insertion is often used to aid in its identification.
- The anterior branch of the obturator nerve can measure up to 12 cm in length and is found approximately 6 cm from the pubic tubercle.⁵
- The muscle can be divided into two functioning units, owing to its motor nerve dividing into branches innervating the superior and inferior muscle separately.⁷
- Careful attention should be paid to the saphenous vein so that it is not injured during the dissection.

PATHOGENESIS

- Perineal defects
 - Perineal defects necessitating gracilis flap reconstruction are most often the result of extirpative oncologic surgeries but can be the result of infectious processes as well as trauma.¹
 - Perineal malignancies most often occur in the colorectum or cervix and less commonly in the vagina, urinary tract, or anus.¹
 - Total pelvic exenteration for recurrent or locally advanced carcinomas provides a potential oncologic cure that leaves a large pelvic defect.⁸
- Vaginal defects
 - Total circumferential acquired vaginal defects usually arise from perineal malignancies that require pelvic exenterations.¹

NATURAL HISTORY

■ Perineal defects

- Management of perineal malignancies through resection or pelvic exenteration results in pelvic dead space.
- Patients following pelvic exenteration often benefit from muscle or myocutaneous flap reconstruction to obliterate dead space and provide antibiotic delivery to these often large defects with high metabolic demands.¹
- With loss of perineal support, abdominal viscera may fall into the pelvic basin, leading to adhesions, obstructions, fistulas, or perineal hernias.³ Gracilis flap reconstruction aids to decrease the risk of these sequelae.
- Attempts of closing large perineal wounds, especially those previously irradiated, by primary or secondary intention, are at high risk of dehiscence and breakdown.
- Perineal wounds that remain unhealed for over 6 months after surgery are predisposed to developing chronically draining perineal sinuses³ and should be reconstructed with preferably locoregional flaps such as the gracilis flap, if available.

■ Vaginal defects

- Total vaginal resection without flap repair leads to prolonged healing, increased risk for complications, abnormal vaginal anatomy, and inadequate function.⁹

PATIENT HISTORY AND PHYSICAL FINDINGS

■ Wound size

- Evaluation of the defect size and shape is critical in determining if the wound should be managed through primary or secondary intention, debridement and packing, skin grafting, or flap utilization.³

■ Radiation

- Areas that have been previously radiated must be noted as they compromise the surgical site and occasionally may compromise the vascularity of potential flaps.

■ Scars

- Thorough preoperative examination includes evaluation for lower extremity scars, as prior surgery or trauma can influence flap selection.

■ Femoral artery

- With intentions of using the gracilis myocutaneous flap for perineal or vaginal repair, vascular status must be evaluated.

- Physical exam should include palpation of the femoral, popliteal, posterior tibial, dorsalis pedis, and anterior tibial arteries.
- Additional evaluations are capillary refill, skin color and turgor, and Doppler examination if pulses are not detected. Computed tomography angiography (CTA), magnetic resonance angiography, or even angiogram is necessary to ensure patency of arterial inflow. A venous phase with the CTA may be obtained to evaluate the venous outflow as well.
- Expectations
 - Typically, younger, sexually active women desire an anatomically similar, functioning reconstruction of the vagina to both be aesthetically pleasing and permit sexual activity after surgery.¹
 - Conversely, much older patients who may be unlikely to resume intercourse after reconstruction may benefit from a more conservative approach with less risk of complications. Flap obliteration of the perineum without reconstruction of the vagina may yield a quicker and less complicated recovery for the patient.¹ Patients, however, often will request reconstruction of their vaginal canal.

IMAGING

- Imaging in the setting of perineal or vaginal reconstruction using the gracilis flap is generally not indicated in primary cases.
- Angiography, CTA, or MRA may be warranted in patients with a history of vascular disease, bypass graft involving the profunda femoris, multiple surgeries, or radiation.
- Postoperatively, a useful landmark to identify the gracilis flap on CT is the subcutaneous tunnel in the medial thigh that is used to transmit the flap.¹⁰
- If the muscular portion of the gracilis flap is denervated during harvest, it will show changes of atrophy, specifically smaller size and internal fat attenuation on CT.¹⁰ Due to the increased fat content, this change will also be evident on MRI with increased signal on T1-weighted images.
- Changes associated with denervation will also be apparent on T2-weighted MRI due to increased cellular permeability leading to edema within the muscle. This should not be mistaken for inflammation or tumor infiltration within the flap, which would also increase the T2 signal intensity but would generally concurrently enlarge the flap.¹⁰

SURGICAL MANAGEMENT

Preoperative Planning

- As with any reconstructive procedure, a thorough understanding of pertinent local and regional anatomy is crucial, as well as remote anatomy in the event that free tissue options are to be considered.
- The anticipated reconstructive options are primarily guided by the nature of the defect. As such, detailed discussion with the resecting surgeon as it relates to margins and secondary deficits is crucial, in conjunction with review of preoperative imaging if available.
- After the anticipated defect is determined, preoperative optimization should be pursued. These measures include, but are not limited to, control of local infection if applicable with antibiotic therapy, nutritional optimization, and smoking cessation.

Positioning

- For vaginal/perineal reconstruction, the patient is usually in ideal positioning for gracilis harvest, which is usually lithotomy.
- It is important to note the rare, but reported, association of common peroneal nerve injury with prolonged immobilization in lithotomy. As such, appropriate padding of the fibular head should be carried out.
- Other positions ideal for gracilis harvest are supine, with thigh abduction (frog-leg); however, we have often found this position not useful for harvest.
- Rarely, for very posterior defects such as ischial pressure sores, the gracilis may be harvested from prone position.

Approach

- As mentioned above, gracilis harvest can be approached from both an anterior position (lithotomy or frog-leg) and less frequently posterior (prone) position (**FIG 1**).

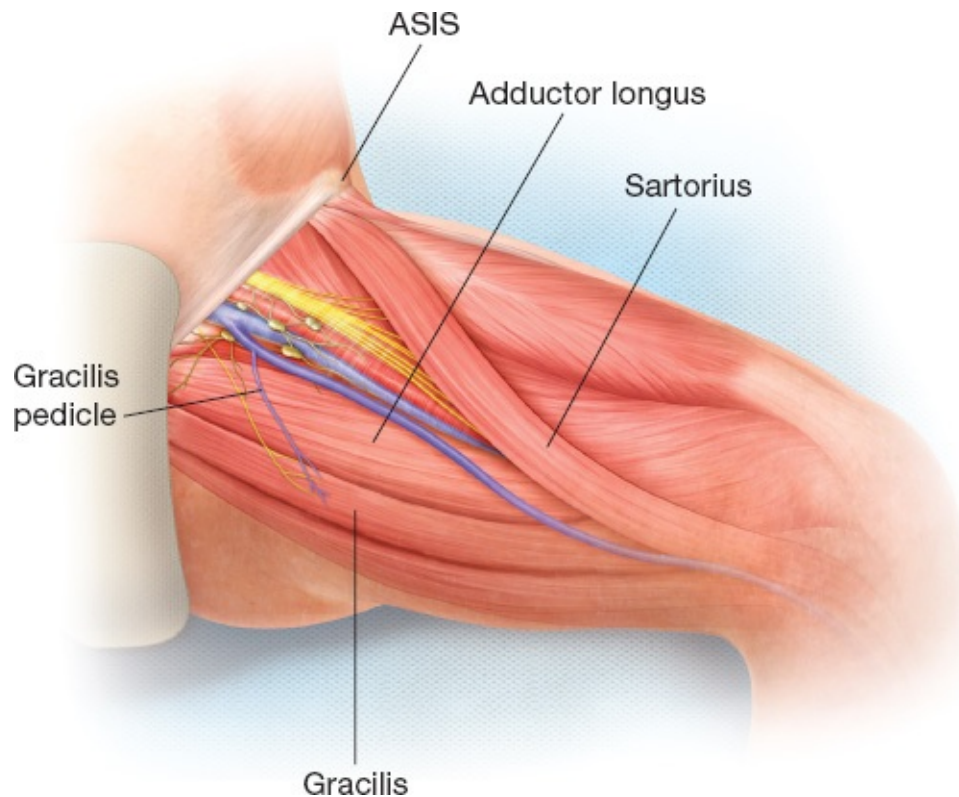


FIG 1 • Gracilis muscle anatomy.

TECHNIQUES

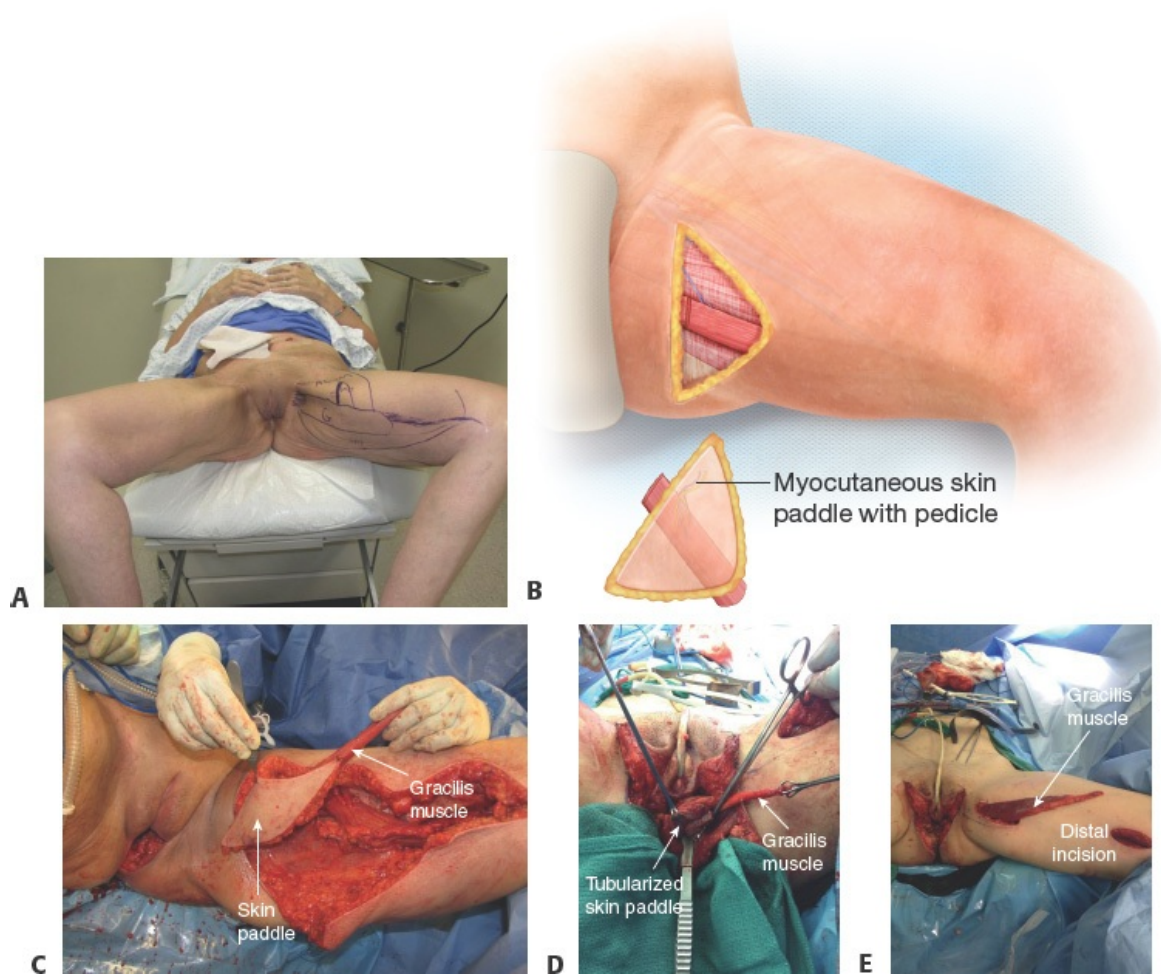
■ Myocutaneous Gracilis Flap

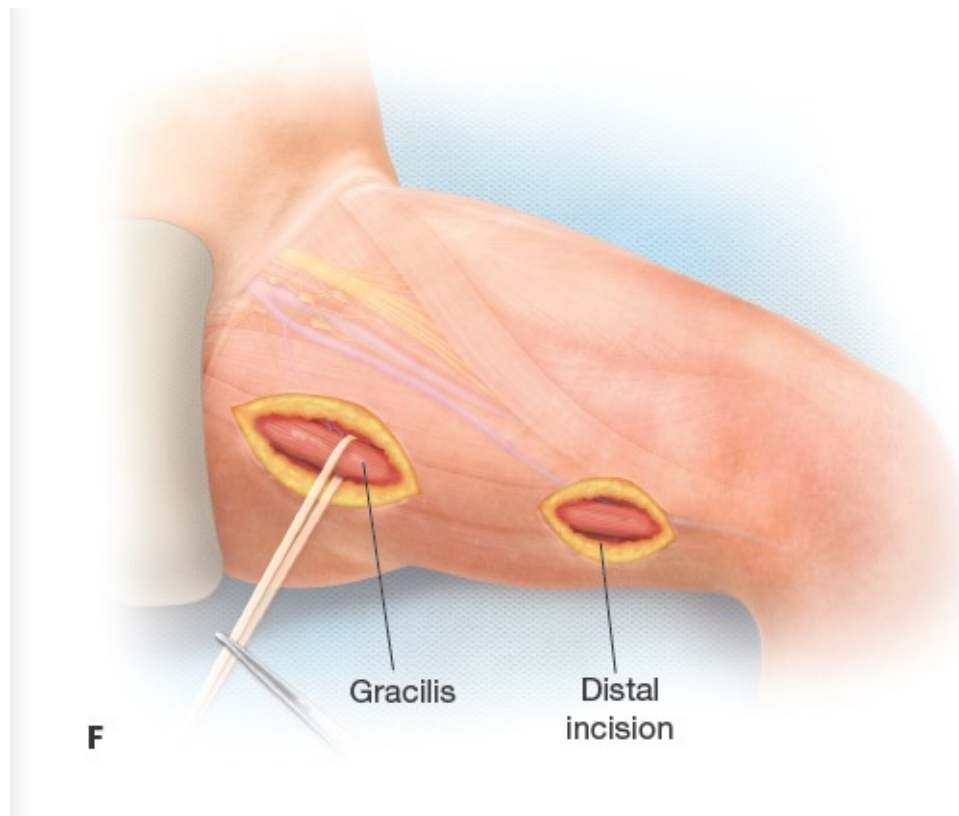
- The skin paddle for the gracilis can be oriented either parallel or perpendicular (transverse) to the gracilis muscle, depending on the reconstructive needs of the flap. Both techniques rely on perforators coming from the proximal aspect of the muscle (**TECH FIG 1A**).
- Once the muscle is delineated, just medial to the palpable adductor longus muscle, an appropriately sized skin paddle is designed. Usually, a skin paddle width of 4 to 6 cm can be closed primarily without difficulty.
- Pencil Doppler is then used to identify the perforators, which will either be musculocutaneous (through the gracilis itself) or septocutaneous (in the septum between the gracilis and adductor longus muscle).
- An anterior incision is made through the skin, subcutaneous tissue, and into the fascia of the adductor longus muscle. Care is taken to bevel the cut away

from the skin paddle and also to be cognizant of the saphenous vein.

- This fascia is then elevated from an anterior to posterior direction, until the intermuscular septum is encountered. Septocutaneous perforators will usually be identified here.
- Attention is then directed to making the posterior incision, once again incising down to the fascia, this time overlying the gracilis muscle. Once again, perforators are identified and preserved.
- The skin paddle is then elevated inclusive of fascia and the intermuscular septum.
- Once the skin paddle is dissected, attention is then directed to raising the remainder of the gracilis muscle.
- A continuation of the anterior skin paddle incision can be made, or a smaller distal incision can be made adjacent to the medial tibial condyle. This secondary incision is usually 3 to 4 cm in length.
- Dissection is carried out to the pes anserinus, at which point the tendons are identified.
- The gracilis can be differentiated from the sartorius muscle here using two techniques.
 - The gracilis is usually all tendinous at this point, whereas the sartorius will be more muscular.
 - If gracilis muscle fibers are present, they will usually be oriented in a longitudinal manner, whereas the sartorius muscle fibers will be oriented in an oblique manner.
- The gracilis tendon is then ligated once pulling on the muscle proximally will lead to tension of the muscle distally.
- A subcutaneous tunnel between the proximal incision and distal incision is created, and the muscle is passed from distal to proximal. This usually requires ligation of at least one minor pedicle coming from the superficial femoral artery. Attention is then directed proximally, where the adductor longus muscle can be retracted laterally and the vascular pedicle (medial femoral circumflex artery) is readily identified running superficially to the adductor magnus muscle.
- The pedicle is dissected from the surrounding fascial attachments as needed for tension-free inset. The flap is now ready to be inset proximally into the defect (**TECH FIG 1B**).
- If the creation of a vaginal canal is necessary, the skin paddle may be folded

on itself as an “alpha-wrap” (**TECH FIG 1C**).





TECH FIG 1 • A. Surface markings of flap in frog-leg position. **B.** Transverse skin paddle. **C.** Myocutaneous gracilis flap ready for inset. **D.** Patient following Abbe-McIndoe procedure for vaginal reconstruction and left gracilis flap for anal sphincter and perineal restoration. **E.** Elevation of left gracilis muscle prior to alpha-wrap of incompetent anal sphincter for functional restoration and perineal reconstruction. **F.** Penrose drain around myofascial gracilis flap prior to distal disinsertion.

■ Myofascial Gracilis Flap

- The gracilis can be harvested as a myofascial flap only as well.
- In situations where epidermal lining is not needed, the pubic symphysis is palpated, and a corresponding line is drawn from there to the medial tibial condyle. This line usually corresponds to the adductor longus, which should be easily palpable as well. The gracilis muscle will be identified

approximately 2 fingerbreadths posterior to this line.

- To prevent inadvertent trauma to the pedicle, an 8- to 10-cm demarcation from the pubic symphysis is made. This corresponds to the most proximal aspect of the harvest incision. Loupe magnification is advised to prevent injury to the pedicle. Identification of the pedicle to allow for maximum release of the muscle if needed.
- The incision is usually carried distally as needed for dissection of the proximal muscle. The incision is carried deep to subcutaneous tissue and fascia, once again, taking care to not violate the saphenous vein.
- The gracilis muscle will be seen as the most medial and thinnest muscle, just medial/posterior to the adductor longus (which will be bigger than the gracilis in this area).
- Dissection proceeds superficially and deep to the gracilis muscle, in a distal manner. As discussed above, a counterincision is then made distally by the medial condyle; dissection is continued accordingly.
- Drains are often placed in the donor thigh after harvest with passive drainage of the reconstructed site.

PEARLS AND PITFALLS

Hematoma	■ Meticulous hemostasis during flap elevation
Partial skin necrosis	■ Ensuring wide inclusion of the fascia and intermuscular septum
Flap loss	■ Meticulous dissection around the primary pedicle (medial femoral circumflex artery)
Postoperative foot drop	■ Proper padding of the lateral fibular head while in lithotomy position

POSTOPERATIVE CARE

- Reports in the literature on the length of follow-up vary, but there is some general agreement of a weekly follow-up for 1 month and twice monthly for the 2nd month until wounds are healed and then every 3 months afterward or as

needed.¹² Median follow-up averages around 15 months.^{13–15}

- Patients should be on bed rest for at least 48 hours. They may not sit up in bed; sitting up puts pressure on the perineal closure and flap, which can delay wound healing.
- We have found air-fluidized beds to be beneficial to prevent pressure on the reconstruction and daily cleansing of the genital area to avoid bacterial overgrowth and infections.
- After 48 hours, they may walk with the help of a physical therapist.
- Gram-positive and Gram-negative antimicrobial therapy is important as well as anaerobic coverage during the hospitalization.
- Dilation with soft vaginal conformers of the vaginal conduit is necessary to prevent stenosis. For total vaginal reconstruction, dilating the reconstructed canal 2 or 3 times daily with a dilator is sufficient.
- On the 2nd postoperative day, Burke et al. recommend starting a program of 3-times-daily perineal irrigation followed by 5 to 10 minutes of forced air-drying using a hair blower set at room temperature.
- The flap should be inspected daily to assess viability and primary healing. A complete examination of the flap, including speculum insertion and digital pelvic examination, should be performed about 1 week after surgery.
- Donor site drains can be removed in 5 days. Sutures should be left intact for about 7 days, and absorbable sutures, which we often use in the immediate genital area, may be left in place.
- Gradual resumption of physical and sexual activity is recommended as healing progresses¹⁶ and is commonly at about 3 months after surgery.
- Hospital stay averages no more than 20 days.¹⁶

OUTCOMES

- Nelson and Butler prospectively analyzed 133 patients who underwent abdominoperineal resection or pelvic exenteration and immediate reconstruction with a pedicled VRAM ($n = 114$) or thigh flap ($n = 19$) between 1993 and 2007.¹⁷
- Thigh flaps were found to have significantly higher rates of major complications (42%), which included major wound dehiscence and pelvic abscess, than VRAM flaps (15%).¹⁷
- Thigh flap donor sites also had higher rates of infection than VRAM donor sites and required longer healing times than did VRAM donor sites.

Furthermore, thigh flap recipient sites had higher rates of wound dehiscence, infection, and longer healing times than VRAM flap recipient sites.¹⁷ The flap remains an excellent option, however, to avoid abdominal donor morbidity and in cases where the abdominal tissue is not usable.

- Casey et al. retrospectively reviewed 99 consecutive cases of vaginal reconstruction—this included 41 VRAM, 13 gracilis, and 45 modified Singapore flaps.
 - The overall complication rate was higher following the gracilis (61.5%) and Singapore flap (46.7%) than with the VRAM flap (31.7%).
 - The flap-specific complication rate was lowest in the VRAM group (22%) compared to the gracilis (53.8%) and Singapore flaps (37.8%).
 - It is important to note that 4 of the 13 gracilis flaps were used as salvage operations secondary to unsuccessful initial reconstruction, as opposed to none in the VRAM or Singapore flap groups.
 - There was no difference in length of stay between the three groups, and sexual function was adequate with all 3 types of reconstruction.¹⁸
- Vermaas et al. reported major and minor complication rates of 43% and 0%, respectively, in their study of reconstructions of 25 abdominoperineal resection and pelvic exenteration defects with pedicled gracilis myocutaneous flaps; however, they only included infection, abscess, hernia, and fistula in their analysis.¹⁴
- In a study on the use of bilateral gracilis myocutaneous flaps to repair total vaginal defects by Pusic and Mehrara, a 10% risk of pelvic abscess and a 10% to 20% incidence of skin loss were identified.¹⁹
- Wilson et al. conducted a review of the literature and found 87 gracilis flaps: 71 for persistent perineal sinus, 5 for fistulating pelvic sepsis, and 4 for deep presacral sepsis. Of all flaps, 31 failed to heal within 12 months (success rate 64.4%).
 - The data suggest that around a quarter of flaps take longer than 3 months to heal.
 - The data did not show any pattern of failure with the pathology or type of flap used (muscle only or musculocutaneous).²⁰ This is a significant improvement to the era prior to flap reconstruction.

COMPLICATIONS

- Possible skin necrosis, which requires surgical debridement to achieve secondary healing, may be seen in the myocutaneous flap.^{12,13}

- There is a lower incidence of skin necrosis when the flap is smaller.¹⁶
- The gracilis myofasciocutaneous advancement flap has great vascular supply to the cutaneous portion of the flap due to the inclusion of perforators from the gracilis muscle and the wide preservation of the fascia above the semitendinosus, semimembranosus, sartorius, and adductor muscles. Small septocutaneous perforators are kept intact, which allows a larger cutaneous territory to be harvested. This prevents the high partial flap necrosis.
- Partial or total flap loss
- Donor site complications include painful thigh wounds, sensory loss, abscess, and separation or infection (ie, local *Pseudomonas aeruginosa* infection).^{14,16}
- Delayed ambulation due to medical complications related to respiratory distress and deep venous thrombosis¹⁶
- Seroma
- Perineal herniation¹⁴
- Perineal infection/abscess
- Perineal fistula
- Hematoma
- Wound dehiscence

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CHAPTER Gender-Affirming Surgery

Katherine M. Gast and William M. Kuzon

DEFINITION

- Gender dysphoria is the incongruence between anatomic sex and gender identity. It is estimated to affect 1.4 million Americans, or about 0.3% of the population. Male-to-female transsexualism is 2 to 3 times more prevalent than female-to-male transsexualism.

ANATOMY

- Male
 - Penis—superficial to deep (**FIG 1**)
 - Skin
 - *Dartos* (superficial) fascia
 - *Buck* (deep) fascia
 - Neurovascular bundle: deep dorsal vein, dorsal artery, paired dorsal penile nerves
 - *Tunica albuginea* (surrounds each corpus individually)
 - Erectile tissue: paired corpora cavernosa, corpora spongiosum surrounds the urethra
 - Arterial supply
 - Internal pudendal artery branches into the perineal artery to the perineum and scrotum.
 - Common penile artery branches to the bulbourethral artery, dorsal artery, and deep cavernosal artery.
- Female (**FIG 2**)
 - Clitoris and clitoral hood

- Labia minora and labia majora
- Urethral meatus, just anterior to vestibule and introitus
- Vagina

PATHOGENESIS

- Considerable evidence now supports a biological basis for determining one's gender identity.¹⁻⁴. Gender dysphoria remains a diagnosis in the DSM-5. It is noted that it is not a mental disorder requiring psychiatric treatment but an incongruence between the biologically determined gender identity and the patient's anatomic sex.
- There are two separate types of gender dysphoria.
 - Gender dysphoria of adolescence and adulthood (ICD10 302.85) often begins in early childhood and persists into adolescence and adulthood.
 - It is important to recognize that gender dysphoria of childhood (ICD10 302.6) is distinctly different. In the majority of these children, gender dysphoria is temporally limited and they will "desist" by adolescence.
 - Because these two scenarios appear to be distinct, considerable expertise is required to diagnose and treat gender-expansive children.
- When gender dysphoria of adolescence and adulthood is confirmed, puberty suppression is now the standard of care for young adolescents who exhibit significant distress with development of secondary sex characteristics. Puberty suppression is reversible and may or may not be followed by cross-hormone treatment.
- It is also important to note that gender dysphoria is distinct from disorders of sexual development (DSD), where there are congenital anomalies of the genitalia and/or are hormonally determined abnormalities of secondary sex development.
 - This has been a source of confusion in the past when DSD children were often assigned the gender most congruent with their anatomy or with the anatomy most easily reconstructed surgically.
 - This resulted in inappropriate assignment of gender with patients opting to surgically transition to their natal gender later in life. These patients were not gender dysphoric.
 - The management of patients with anomalous genitalia or hormonal development requires specialized, multidisciplinary expertise, and patients presenting with a self-reported diagnosis of DSD require appropriate evaluation and referral.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Since plastic surgeons are not trained in the evaluation and management of gender dysphoria, internationally accepted standards of care (SOC) have been published by the World Professional Association for Transgender Health (WPATH). It is imperative that surgeons performing gender-affirming surgery are familiar with these guidelines and that they have in place mechanisms to assure that patients have met SOC before becoming surgical candidates.
- Collaboration with local mental health providers who are familiar with this area is the most practical way of assuring the validity of the letters of readiness required by the SOC.
- If that is not practical, then the surgeon must accept the responsibility of vetting the patient's preparation for surgery, including compliance with SOC.
- The WPATH SOC clinical guidelines address primary care, hormonal therapy, mental health services, and surgical treatment of transgender patients.
- For chest surgery, patients must have one letter of readiness from a mental health professional, and 1 year of estrogen therapy is recommended for breast growth in male-to-female patients who desire breast augmentation.

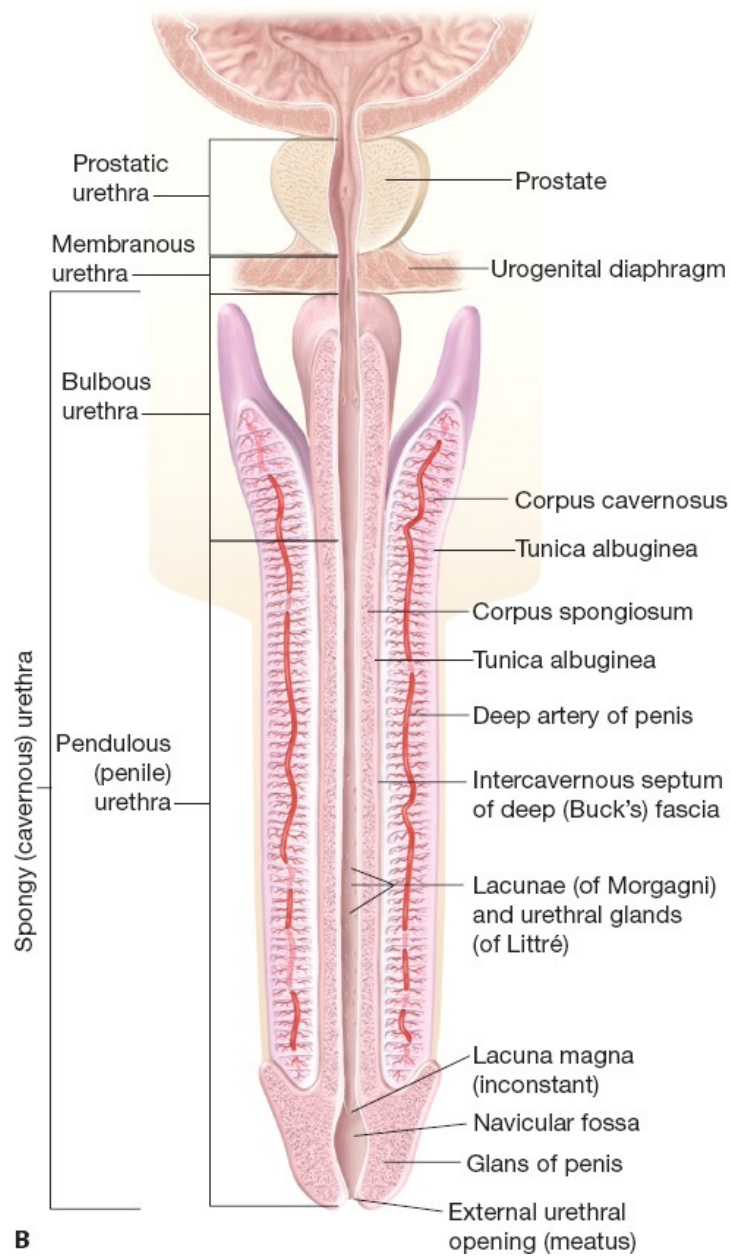
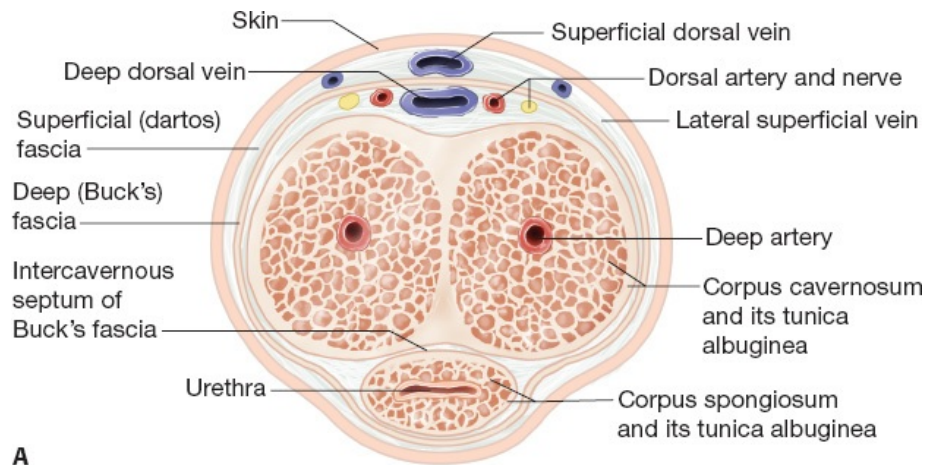


FIG 1 • A. Cross-sectional anatomy of the penis. Note the paired corpora cavernosum and the dorsal lying corpus spongiosum surrounding the urethra. The neurovascular bundle for the neoclitoris flap harvested from the glans is located on the ventral side of the penis and is deep to the Buck fascia. **B.** Longitudinal section of the male urethra.

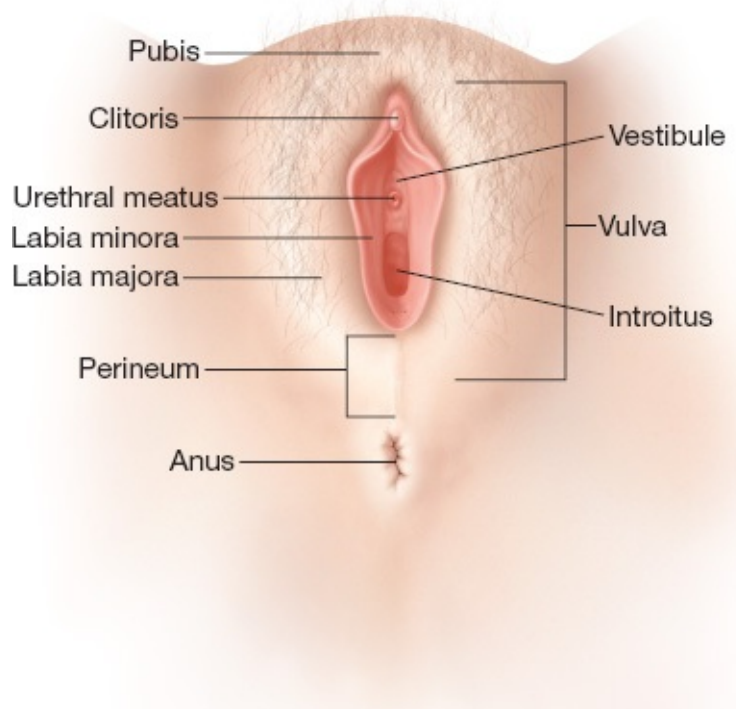


FIG 2 • External female genitalia.

- For genital surgery, or “bottom” surgery, patients must have two letters of readiness, have completed 1 year of hormonal therapy, and have completed 12 months of a “real-life experience” of living in congruent gender in all circumstances.
- Ongoing, regular visits with a mental health professional are recommended. The WPATH SOC are meant to be flexible guidelines and may be modified for individual patients.
- Physical exam of male-to-female patients should document circumcision status, presence of any inguinal hernia, and examination of the testicles and

spermatic cords. The central perineum must be examined for hair growth since this impacts surgical decision-making as described below.

- Physical exam of female-to-male patients should focus on the suitability of free flap donor sites suitable to provide tissue for phallic construction. The radial forearm flap is the most common donor site, so an Allen test of bilateral upper extremities is important. Since the flap must be double rolled into a phallus, the thickness of subcutaneous tissue of the radial forearm flap, the anterior lateral thigh flap, and the superficial circumflex iliac perforator flap should be documented.

IMAGING

- No diagnostic or radiologic studies are indicated.

SURGICAL MANAGEMENT

Penile Inversion Vaginoplasty

Preoperative Planning

- Hair removal: For male-to-female patients undergoing vaginoplasty, electrolysis or laser hair removal must be performed to remove hair of the perineum from anus to base of penis in midline of the scrotum. The reason for this is the perineal flap is used to widen the introitus and line the inferior posterior aspect of the neovagina.
- The perineal flap can be defatted and follicles scraped from the dermis, but this compromises blood supply of the tissue.
- In the event of a rectal injury, well-vascularized tissue over the direct repair is advantageous to prevent rectovaginal fistula.
- Hormone cessation: Estrogen therapy must be held 3 to 4 weeks prior to surgery. Estrogens increase risk of perioperative thromboembolic disease. Hormones are resumed postoperatively when packing is removed and it can be determined that the patient will not require a repeat trip to the operating room. Spironolactone therapy may continue through the perioperative period.
- Bowel prep: A standard bowel prep to cleanse the colon and rectum of stool is performed the day prior to surgery. The patient is kept on a clear liquid diet 24 hours prior to surgery and then nothing by mouth for 6 hours prior to general anesthetic. In the event of a rectal injury, a repair is more durable if stool is not encountered immediately postoperatively.

Positioning

- Patient should be positioned in standard lithotomy position with sequential compression devices on bilateral lower extremities and pressure points appropriately padded. Arms can be tucked at patient's sides with padding at elbow and wrist.
- Patient should be prepped with Betadine including the lower abdomen, penis, scrotum, buttocks, and perineum.

Approach

- Penile inversion vaginoplasty with the penis skin tube lining the neovagina is the most commonly performed technique worldwide. The neovagina is often lengthened with full-thickness skin graft (FTSG) from the scrotum to a goal length of 14 to 16 cm in the operating room. The scrotal skin is fashioned into the labia majora. A portion of the dorsal glans penis is left on a dorsal neurovascular pedicle to create a sensate neoclitoris. Prepuce skin of the penis may be used to construct the labia minora in uncircumcised patients.
- Sigmoid colon vaginoplasty is a technique by which a segment of the colon is harvested by a general surgeon, secured to the sacrum to prevent prolapse, and then brought down into the pelvis and connected to the perineal reconstruction. Diversion colitis, excessive mucous discharge, and prolapse of the intestinal segment limit its widespread adoption as a primary method of vaginoplasty.

TECHNIQUES

■ Penile Inversion Vaginoplasty

Creation of the Perineal Flap

- The perineal flap is located anterior to the anus centered along the midline. The base of the flap is 3.5 cm wide and the flap is 10 cm in length. The flap is triangular shaped and is incised and raised ventral to dorsal with a 1-cm layer of subcutaneous fat, leaving it pedicled posteriorly adjacent to the anus (**TECH FIG 1A**). A vertical incision is then made through the scrotum up to the penile-scrotal junction. Dissection is carried down to the level of the bulbocavernosus muscle. The bulbocavernosus muscle is dissected free from overlying tissue along its length.

- A Foley catheter is placed.
- The origins of the bulbocavernosus muscles from the ischia are identified and dissected bilaterally circumferentially (**TECH FIG 1B**). The base of the bulbocavernosus muscles are clamped and divided on each side; 2-0 Vicryl suture ligatures are employed to control bleeding.
- The prerectal space is then dissected by dividing the plane between the bulbocavernosus and anal sphincter. Sharp dissection through the perineal body using cautery is used initially to the level of the urogenital diaphragm (**TECH FIG 1C**).
- Once the prerectal plane is entered, sharp and then blunt dissection is employed using digital dissection and a sponge stick following the Foley catheter.
- At the level of the prostate, the rectoprostatic fascia (Denonvilliers fascia) is detached from the tail of the prostate, and dissection proceeds anterior to Denonvilliers. This is done bluntly with the aid of a sponge stick, which is advanced slightly and then swept from anterior to posterior. Dissection is carried out to the level of the peritoneum, approximately 15 cm in depth.
- A moist sponge is placed in the neovaginal space. The rectum is filled with half-strength saline-Betadine solution. After 2 minutes, the laparotomy sponge is removed and inspected for Betadine. Bimanual examination with one finger in the rectum and one in the prerectal dissection and direct visualization of the anterior rectal wall is performed to ensure that no rectal injury occurred. The prostate is palpated and any abnormalities noted.
- The levator ani muscles are incised for about ½ cm on each side to widen the space for the neovagina.

Orchiectomy

- Bilateral orchiectomies are then performed in the usual fashion. The testicles are dissected free from the scrotal tissue in the plane just superficial to tunica vaginalis.
- The spermatic chords are dissected to the external inguinal ring.
- The vas deferens is separated from the remainder of the chord and ligated separately with 2-0 Vicryl ties, and the chord is suture ligated with 2-0 Vicryl at the level of the external ring. Careful attention must be paid to avoid retraction of bleeding vessels within the cord into the inguinal canal. The testicles are sent for pathologic examination.

Degloving of the penile shaft

- Two centimeters proximal to the corona, the skin is incised circumferentially and the shaft of the penis is degloved in a plane just superficial to the Buck fascia with Metzenbaum scissors. The prepuce or dorsal penile skin is left adjacent to the glans to serve as a clitoral hood and may be used to construct labia minora in patients who have not undergone circumcision. The penis is degloved to its base, and the penile shaft is pulled through the incision in the perineum used to raise the posterior flap.

Raising the Neurovascular, Neoclitoral Flap

- A “clitoral” flap is now raised from the dorsal area of the glans. A section of dorsal glans penis is marked out in an appropriate shape at the terminus of the dorsal neurovascular bundle. In addition, a portion of the distal dorsal and lateral penile skin is kept intact to serve as a clitoral hood. The 1-cm-wide portion of the glans will serve as the future neoclitoris. This may be shield shaped or M shaped and coned at inset.
- The neurovascular bundle consisting of the dorsal penile arteries, veins, and nerve is raised as a flap by dissecting them off the underlying corporal bodies. Dissection is begun at the midshaft of the penis, incising the Buck fascia along the midaxis of the penis on either side. Dissection is carried to the level of the tunica albuginea.
- The neurovascular bundle is now raised throughout its length from its base at the perineum to the glans portion, raising the Buck fascia and the neurovascular bundle off the underlying tunica using sharp, scissor dissection. The glans portion is then incised and raised with the neurovascular bundle, taking care to include some glans erectile tissue but to exclude the corpus cavernosum.



TECH FIG 1 • A. The perineal scrotal flap is marked with extension of the incision up the raphe of the scrotum. The perineal flap is used to widen the

introitus to prevent a stricture. This area should be depilated prior to operation. **B.** The bulbocavernosus muscle is fully exposed and disinserted from the ischial tuberosities. **C.** The space for the neovagina is created anterior to the rectoprostatic fascia (Denonvilliers fascia). This is done sharply with cautery followed by blunt dissection with a sponge stick being careful to go slowly and gently, using a sweeping motion from anterior to posterior.

Resection of Corpus Cavernosa and Preparation of the Urethra

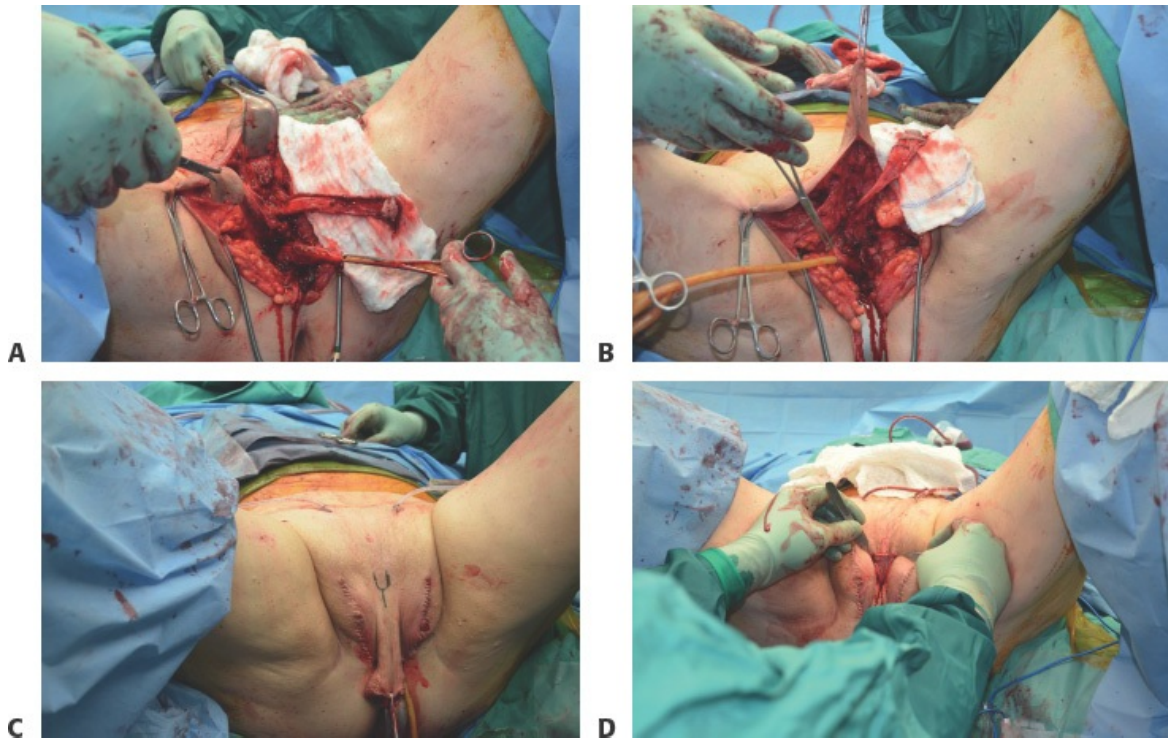
- Dissection of the corpus spongiosum away from the corpora cavernosa is performed in the midline cleft. The corpora cavernosa are then resected bilaterally. This is done to the level of the ischium on each side. Suture ligatures of 2-0 Vicryl are used to control the corporal vascular bundles.
- The corpus spongiosum is dissected up to the level of the urogenital diaphragm. The bulbocavernosus muscle is split longitudinally and the muscle and the spongiosum are dissected off the urethra up to the level of the urogenital diaphragm (see **TECH FIG 1B**). The urethra is cut to leave about 10 cm in length distal to the urogenital diaphragm and the rest is discarded.

Creation of the Vulva and Inset of Neoclitoris

- The neoclitoris is formed by suturing the glans flap into a cone and by enveloping this with the dorsal penile skin as a clitoral hood (**TECH FIG 2A**). This is done with 3-0 Monocryl or chromic sutures. The neoclitoris is now inset. Prior to suturing the neoclitoris in place, the pedicle of the clitoral flap is looped anteriorly into the abdomen and stitched in place bilaterally using interrupted 2-0 Vicryl to prevent kinking, and the clitoris is anchored to deeper structures in the appropriate position using 3-0 Monocryl.
- Blake drains are now placed in the prerectal space dissection and in the lower abdomen and are brought out through separate stab incisions in the pubic hair.
- The penile pullback is now performed. The anchoring points are at the penile-scrotal junction on both sides of the former penile shaft. The degloved

penis shaft is present between these two marks (**TECH FIG 2B**). These two points are then tacked posteriorly to the base of the perineal flap with deep dermal 2-0 Vicryl.

- Once the pullback has been done, an anterior Y-shaped incision is made in the skin anterior to the tube remaining from the degloving of the penis. The anterior portion of the Y is at the location of the neoclitoris, and the posterior portion is at the planned location of the urethral orifice.
- Tacking sutures are placed from the deep dermis of the penile pullback to the periosteum of the pelvis to anchor the central aspect of the new vulva down.
- The urethra is split along its ventral surface to about 2 cm distal to the urogenital diaphragm. Posterior stitches of 3-0 Vicryl in the neourethral orifice are placed between the posterior aspect of the Y-incision and the most anterior aspect of the ventral slit.
- The neoclitoris is inset into its new location using the Y-shaped incision to complete construction of the clitoral hood with the small central Y flap (**TECH FIG 2C**). This is inset using interrupted 3-0 chromic or Monocryl stitches.
- The urethral orifice is then inset using interrupted 3-0 Vicryl stitches from the posterior toward the anterior portion (**TECH FIG 2D**). The most anterior portion of the urethral mucosa abutted the neoclitoris. Careful attention must be made to bury any remnant erectile corpus spongiosa tissue; this will bleed postoperatively if exposed.



TECH FIG 2 • A. The neoclitoral flap is visualized on the right on the surgical sponge. The corpus spongiosum (inferior with Foley catheter in place) has been separated from the paired corpus cavernosa and remaining glans penis. The neoclitoral flap pedicle should be dissected to the pubic symphysis bone. **B.** The corpora cavernosa are amputated at the level of the perineum. Many surgeons prefer to leave a corporal stump and suture the two corpora together to provide a pedestal for the neoclitoris inset. Alternatively, one may choose to resect the corpora back to the ischium. **C.** A Y-shaped incision is made on the anterior most aspect of the penile skin tube for external inset of the neoclitoris and urethra. The penile skin tube is pulled back with anticipated inversion tension to estimate the location. **D.** Urethra inset. The corpus spongiosum is excised from the periphery of the urethra, and the mucosa is split longitudinally

along the posterior surface. It is shaped into a diamond and inset as a fan to prevent a distal urethral stricture.

Creation of the Vaginal Vault

- A vaginal vault lining is constructed by inseting the posterior perineal flap into a longitudinal incision in the penile skin tube with running 3-0 chromic or Monocryl sutures (**TECH FIG 3A**). The labia majora are then constructed by pulling the deep scrotal contents posteriorly and anchoring them to the underlying tissue using interrupted 2-0 Vicryl stitches. The skin portion of the scrotum is then pulled posteriorly and laterally, and an ellipse is removed to create a labia shape. Do not over-resect the scrotal contents or skin.
- The vaginal vault is lengthened using FTSG from the resected scrotal skin (**TECH FIG 3B**). The preserved skin is defatted aggressively and sutured over a stent into a tube 10 cm in diameter and at least 5 cm in length. The size of the skin graft is 5×10 cm, and the tube of skin graft is now sutured to the end of the penile skin tube using 3-0 Monocryl sutures. The total vaginal length is now 14 to 16 cm.



TECH FIG 3 • A. Skin graft sutured to penile skin, prior to inversion. The full-thickness skin graft tube is sutured to the penile skin tube and then inverted and placed into the prerectal space. **B.** Excess scrotal skin excised after constructing the labia majora is defatted on the back table and sutured over a 60-cc syringe to lengthen the neovagina. A skin graft is required in the majority of cases to provide lining for sufficient vaginal

length.

- All remaining wounds are closed with interrupted and running 3-0 chromic or Monocryl stitches, leaving linear incisions on either side along the line of the labia majora.

Placement of Vaginal Pack

- The drains are connected to suction.
- A bacitracin ointment–impregnated vaginal packing is placed to maintain the new vaginal vault in position without undue pressure. The end of the vaginal pack is placed over the urethral and neoclitoral reconstruction in order to provide some dressing.
- The vaginal pack is held in place by through-and-through bolster stitches of 0 Prolene tied over silicone tubing lateral to the labia majora (**TECH FIG 4**).
- The wound is dressed with a perineal pad and mesh panties.
- The patient is taken out of lithotomy position.



TECH FIG 4 • Final dressing. A large vaginal pack is placed in the neovaginal as a bolster for the full-thickness skin graft at the apex and allow adherence of the inverted skin tube. Spanning Prolene sutures with drain tubing prevents pressure on the labia majora skin.

■ Phalloplasty

Preoperative Planning

- There is no “standard” procedure for phalloplasty, and considerable variation in flap choice and in approach (one stage or two stage) is seen between and even within centers.
- Phalloplasty may be performed with radial forearm flap, SCIP flap, anterolateral thigh (ALT) flap, latissimus dorsi myocutaneous flap, or combination of the three to reconstruct an inner epithelialized urethra and outer roll of skin for the phallus.
- The phallus may be constructed from one flap in a “tube-in-a-tube” fashion (radial forearm flap most common), or the urethra and phallic skin may be reconstructed from two separate flaps (radial forearm flap or SCIP flap for the urethra with an ALT flap for the phallic skin most common).
- The choice of donor site is largely dependent on patient’s body habitus and patient and surgeon preference.
- Permanent hair removal on the skin to be used for the neophallus and the neourethra should be completed to lower the risk of urethral strictures and fistulas.
- Allen test should be performed in bilateral upper extremities in preparation for radial forearm flap.

Positioning

- Patient should be positioned supine. If used, the upper extremity should be extended on hand table with sterile tourniquet.

Approach

- The tube within a tube may be accomplished by a double-roll technique of the radial forearm flap, but this is limited by subcutaneous fat thickness on the forearm (**FIG 3**). Alternatively, a thin radial forearm flap may be tubed and then surrounded by a pedicled ALT or SCIP flap in thin patients.
- In all techniques, vaginectomy is performed concomitantly by a gynecologist. It is also common to perform a hysterectomy and bilateral oophorectomy at the time of phalloplasty.

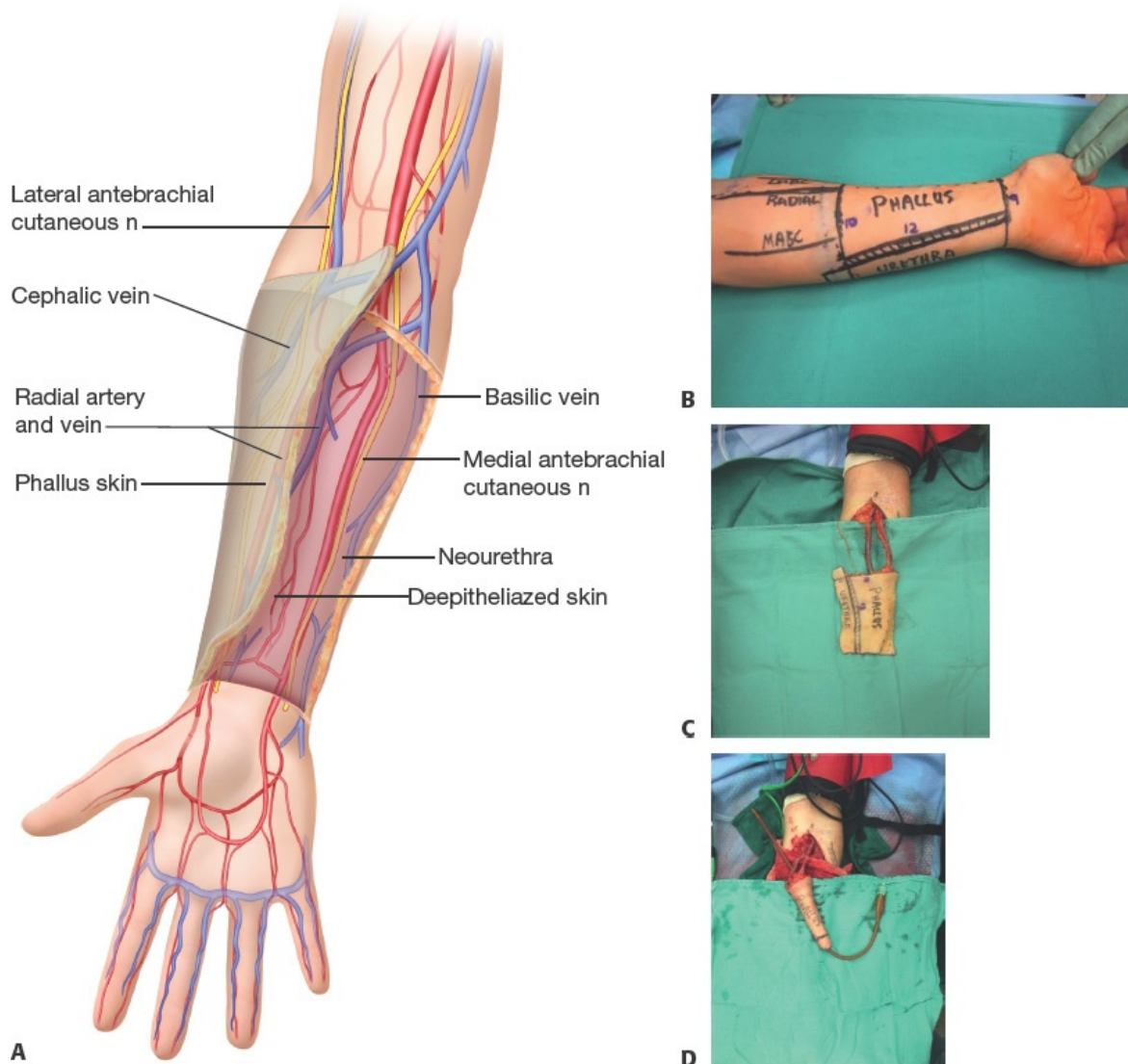


FIG 3 • A. Design of the radial forearm flap with volar ulnar urethra, de-epithelialized area to suture as a tube within a tube, and radial outer phallus. **B.** Markings for radial forearm flap phalloplasty. **C.** Radial forearm flap elevated. **D.** Radial forearm flap tubed on the forearm to create the urethra and phallus.

■ Radial Forearm Phalloplasty

- The patient is placed under general anesthesia in a supine position on the operating table. The perineum, both upper legs, and the left arm are prepped and draped in the usual sterile fashion.

Flap Dissection

- A preoperative Allen test confirmed that there is adequate ulnar artery flow to support the circulation of the hand without any need to reconstruct the radial artery. A radial forearm flap is then marked out over the axis of the radial artery. The flap is at least 20 cm wide and 15 cm long.
- A “tube-in-a-tube” method is used to construct the neophallus with a 3-cm-wide portion in the ulnar aspect (the most hairless part) of the flap serving as a neourethra and the external skin of the neophallus measuring 16×15 cm. The urethral skin strip is left approximately 2 cm longer than the remainder of the neophallus so the urethral coaptation will not lie directly subjacent to an external skin incision.
- The cephalic vein and the associated lateral antebrachial cutaneous nerve (LABC) are marked out, as is the location of the medial antebrachial cutaneous (MABC) nerve. It is sometimes possible to include the basilic vein with the flap for additional venous outflow.
- The arm is exsanguinated and a tourniquet is inflated for less than 120 minutes for this part of the dissection.
- Dissection is begun by incising the margin of the skin paddle of the radial forearm flap and dissecting distally to identify the radial artery and vena comitans. The radial artery and vena comitans are then divided distally at the volar wrist crease. Incisions along the radial and ulnar aspects of the flap are completed, and the flap is raised off the muscle fascia, which is left down.
- Dissection is continued until the brachioradialis on the radial aspect and flexor carpi radialis on the ulnar aspect of the flap are encountered. Proximally, the cephalic vein and its associated LABC are preserved. The MABC is identified and preserved.
- The interval between the brachioradialis and the flexor carpi radialis is opened proximally, and the radial artery and its vena comitans are identified. The flap is now elevated from distal to proximal dissecting at the level of the deep fascia. This preserves the radial artery and its vena comitans within the substance of the flap.
- The radial sensory nerve is dissected out of the substance of the flap on the radial distal aspect of the forearm and is preserved in total. Dissection is carried proximally until the flap is isolated on the two nerves, on two cutaneous veins, and on the radial artery and its vena comitans.
- A large communication between the cephalic vein and the vena comitans is

almost always present in the proximal forearm. Preserving this communication allows a cephalic vein anastomosis to a recipient vein to drain both the deep and superficial venous systems within the flap. All of these structures are dissected proximally up to the antecubital fossa with side branches of all vessels being coagulated or clipped. The radial artery and its vena comitans are isolated right up to their takeoff at the bifurcation of the radial and ulnar vessels.

- The arm tourniquet is released and both the flap and the hand should have excellent perfusion as judged by capillary refill, color, and bleeding from cut edges. Hemostasis is obtained with bipolar electrocautery both the flap and the recipient bed.

Construction of Neourethra

- A neourethra is now constructed around no. 12 French Foley by tubing the ulnar portion of the radial forearm flap. A strip of skin between the urethra and phallus portion of the skin flap is de-epithelialized for suturing. The flap is tubed using interrupted and running 4-0 Monocryl.
- The remainder of the skin portion of the flap is now wrapped around the neourethra creating the external skin portion of the penis. This is sutured with 4-0 Monocryl deep dermal and subcuticular sutures, and the neourethra is sutured to the distal external phallus skin paddle using a running 4-0 Monocryl suture.
- A coronoplasty may be performed now or in a delayed fashion by making an incision 3 to 4 cm from the distal end of the phallus and advancing the distal edge, creating a roll. A narrow ring split-thickness skin graft (STSG) is placed behind the roll proximally, which can be harvested from the area of the flap that has been de-epithelialized.
- The flap is left perfused on the forearm at this time, covered with moist sponge, and attention is then turned to the perineum.
- Concurrently with the flap dissection, a gynecologist or urologist will perform the vaginectomy and preparation of the recipient urethra for anastomosis. A scrotoplasty using the labia majora can be done as well.

Preparation of the Recipient Site

- The recipient site is prepared, dissecting the perineal urethra. The clitoris is de-epithelialized and will be buried at the base of the neophallus. A short midline incision allows dissection of one of the dorsal clitoral nerves for later coaptation with the LABC; the other clitoral nerve is left intact. Because

sensory reinnervation of the neophallic free flap is variable, this preserves a sensate, subcutaneous clitoris as an erogenous location.

- A curvilinear longitudinal incision 12 cm long is now made over the superficial femoral vessels in the left groin. Dissection is carried down, and the superficial femoral vein, any venous side branches, and the saphenous vein are identified and prepared for microsurgery. The saphenous vein generally has a very large side branch just distal to its origin; this should be preserved.
- A subcutaneous tunnel is made between the perineal recipient site and the recipient vessels in the groin. The planned recipient artery is the superficial femoral via end-to-side anastomosis. If the radial artery will not reach, a vein graft can be employed, or better, an AV fistula can be created using the large, proximal branch of the saphenous vein anastomosed end to side to the femoral vein.
- The loop is then divided with the distal end of the loop serving as a vein graft for the arterial revascularization.

Flap Transfer, Vascular Anastomoses, and Nerve Coaptation

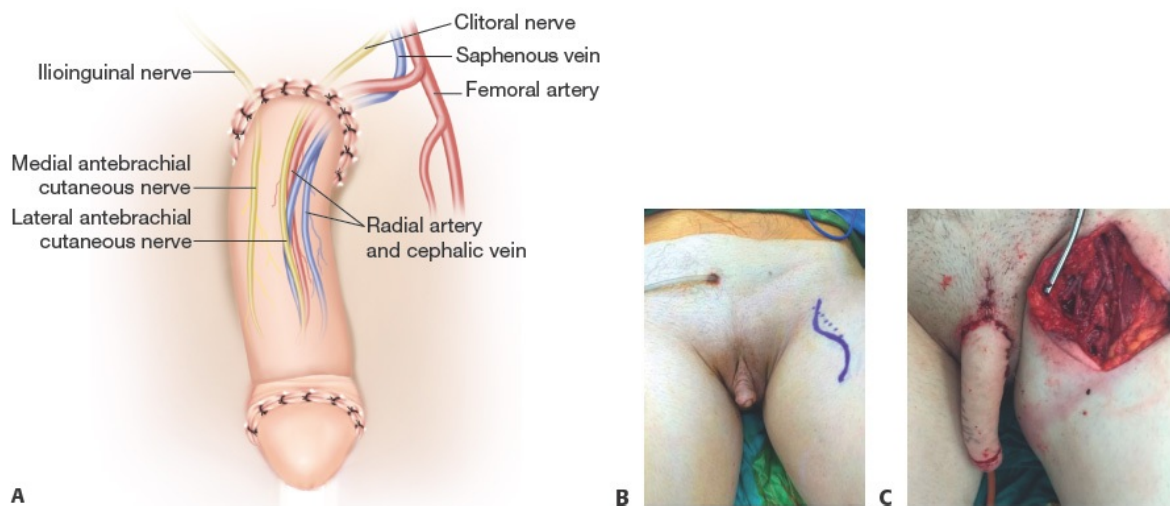
- Attention is turned back to the flap on the arm. The radial artery and its vena comitans are divided after ligacclipping the proximal vessels. The cephalic vein and LABC/MABC nerves are likewise divided.
- The neophallus is transferred to the perineum, and anchoring sutures are placed between the deep dermis portion of the flap and deep Scarpa layer of the suprapubic area. A coaptation of the neourethra in the flap to perineal urethra in the recipient site is performed with interrupted 4-0 Vicryl sutures. Anterior vaginal mucosal flaps, labia minora flaps, or even a gracilis muscle flap may be used to bolster the anastomosis.
- The no. 12 Foley catheter is in the neourethra and left in place for 2 weeks. A suprapubic catheter may or may not be used.
- An end-to-end neural coaptation is performed connecting the MABC to the ilioinguinal nerve and the LABC to one of the previously dissected dorsal clitoral nerves in an epineural fashion with 8-0 nylon sutures. This preservation of the innervated clitoris at the base of the phallus provides the potential for sensory and erogenous reinnervation of the neophallus while preserving a sensate clitoris.
- The recipient vessels are passed through into the right groin dissection through the tunnel made previously. The arterial anastomosis is done end to

side to the femoral artery, possibly aided by vein grafts or an AV loop as described above. The cephalic vein is anastomosed end to end to a side branch of the femoral or saphenous vein.

- The clamps are released, and perfusion in the flap is evaluated by looking for good pulsation in the artery and good venous return. The flap should become pink and bleed from cut surfaces. The lie of the vessels is confirmed to be not kinked or redundant.
- The penile flap is now completely inset by tailoring the surrounding skin to inset the neophallus (**TECH FIG 5**). Inset of the flap is done using interrupted 3-0 Monocryl. The groin wound is now closed using interrupted 3-0 Vicryl stitches in the deep dermal layer and running sutures in the skin. At the end of the procedure, sterile dressings consisting of Xeroform fluff gauze and mesh pants are applied to the neophallus.

Closure of Donor Site and Dressings

- Attention is now turned to repairing the donor defect on the arm. Fascia was left down on the volar compartment with the exception of between brachioradialis and flexor carpi radialis necessary to preserve the radial artery perforators.



TECH FIG 5 • A. Schematic of plan for inset of the radial forearm phalloplasty with anastomosis to the saphenous vein and femoral artery. The lateral and medial antebrachial cutaneous nerves are coapted to the ilioinguinal nerve and one of the clitoral nerves.

One clitoral nerve is left in situ to retain erogenous function of the clitoris, which is now buried beneath the neophallus. **B.** Recipient site planning. This patient has previously undergone metoidioplasty. **C.** Flap inset after urethral anastomosis and nerve coaptations and demonstrating vascular anastomoses.

- The proximal longitudinal exposure incision is closed with interrupted 3-0 Vicryl sutures in the deep dermal layer followed by 4-0 nylon for skin closure.
- A good quality, moderately thick (0.0012"–0.0014" thick) skin graft is harvested from the thigh and is meticulously sutured into the forearm donor site as a sheet graft. This is generally done with 4-0 chromic sutures. Our preference is to place a dressing consisting of Xeroform, mineral oil–impregnated cotton batten, and a form-fitting, well-padded volar short-arm splint maintaining the hand and wrist in the intrinsic plus position, although a tie-over bolster may be used on the skin graft.
- After the dressings are placed on the arm and the Foley is connected to bag drainage, the patient is awakened and returned to the recovery area.

PEARLS AND PITFALLS

PENILE INVERSION VAGINOPLASTY

Rectal injury in vaginoplasty

- The initial dissection through the perineal body, just posterior to the bulbocavernosus muscle, is sharp and performed with cautery.
- Past the urogenital diaphragm, dissection should be performed bluntly with a sponge stick with gentle sweeping motion anterior to posterior.
- Any injury to the rectum should be identified on exam and repaired in two layers.

Raising of neoclitoral flap in vaginoplasty

- There is no defined plane between tunica albuginea and the dorsal penile bundle.
- Dissection begins at the midaxis of the penis and using small

	Metzenbaum scissors carried dorsally in a lateral to medial on both sides. ■ You will notice a difference in fiber direction between bucks (longitudinal along the penis axis) and the more superficial investing fascia (diagonal and transverse). ■ This is tedious.
Placement of vaginal packing	■ Packing should extend into the apex of the neovagina. We use a vaginal pack coated in bacitracin ointment, but many surgeons use metronidazole gel. ■ An entire vaginal pack gauze should fit in the neovagina. ■ Sections of cut suction tubing are used as buttresses over the labia with 0-0 Prolene sutures to tamponade the packing in place.
Hemostasis in vaginoplasty	■ Estimated blood loss for this procedure averages 500 cc. ■ Patients should have two large-bore peripheral IVs and an active type and screen prior to surgical incision.
RADIAL FOREARM PHALLOPLASTY	
Venous congestion	■ Positioning of the neophallus must keep distal aspect elevated. ■ AV fistula may be created in the distal phallus from end of radial artery and large vein.
Urethral fistula or stricture	■ A gracilis muscle flap may be used to bolster the urethral anastomosis at time of phalloplasty if there is significant concern for fistula. ■ Involvement of urologist is recommended for management of persistent fistula or strictures.

POSTOPERATIVE CARE

Penile Inversion Vaginoplasty

- The patient must remain on bed rest overnight until postoperative day 1.
- Examination on POD 1 should document swelling, labial incision integrity, labial skin viability, and neoclitoral viability. After this examination, patients are able to shuffle in their room and sit for limited periods in a well-padded chair, but activity is otherwise limited.
- Surgical drains and Foley catheter remain in place along with the vaginal packing until postoperative day 5 or 6.
- VTE prophylaxis is started 6 hours after surgery.

- Unless a rectal injury was noted and was repaired, patients are advanced to regular diet starting on postoperative day 1.
- Mesh underwear and Kerlix fluff are changed daily and as needed.
- On postoperative day 5 or 6, the vaginal packing is removed, and a speculum exam is performed to assess viability of the neovagina lining. The drains and Foley catheter are also removed at this time. Patients then begin vaginal rinses with 240 cc of normal saline using red Robinson catheter 3 times daily, are taught to perform twice-daily vaginal dilations with small-sized dilators, and are discharged from the hospital.
- Patients are examined again 10 to 14 days later to assess tissue viability and ensure they are managing dilation as instructed.
- Examination 4 to 6 weeks after the procedure should generally find nearly complete healing. At this point, the patient may progress to a larger vaginal dilator, begin relaxing activity restrictions, and return to work.
- Examination about 3 months postoperatively should document full healing before the patient is cleared for penetrative intercourse (**FIG 4**). Patients must understand the need to dilate daily indefinitely or to have penetrative intercourse to maintain vaginal depth.
- Patients must clearly understand that they still have a prostate gland and will still require surveillance for prostate disease as recommended by their PCP.

Phalloplasty

- Patient must remain on bed rest overnight until postoperative day 1.
- Surgical drains remain in for 5 to 7 days. Foley catheter remains in place for a minimum of 2 weeks.
- VTE prophylaxis is started 6 hours after surgery.
- Patients are advanced to regular diet starting on postoperative day 1.



FIG 4 • Postoperative appearance at 3 months.

- Mesh underwear and Kerlix fluff are changed daily and as needed.
- Patients are allowed only very limited, in-room activity for 5 days. After this interval, they are mobilized over a 1- to 2-day period.
- A resting volar splint is kept in place for 5 to 7 days over the split-thickness skin graft on the radial forearm donor site. It is then removed and daily Xeroform dressing changes are performed. A removable splint is fashioned and worn for 3 weeks. After the graft has completely epithelialized, gentle active and passive range-of-motion exercises are initiated.
- Drains in the groin are removed 7 to 10 days postoperatively unless there is unusual high output, which may indicate a small lymph leak. They should then be left in place until output is less than 30 cc/d for 2 consecutive days.
- The Foley catheter remains in place for a minimum 2 weeks and a voiding trial is planned. If the patient is able to spontaneously void, then the suprapubic tube, if used, may be removed.
- The patient is seen 2 weeks postoperatively in clinic to assess surgical incisions, flap viability, and voiding function. They are then seen 3 months postoperatively at which time activity restrictions may be lifted and the patient may return to work.
- Delayed coronoplasty and glans tattooing may be performed after 3 months when all incisions are completely healed. Testicular implants may be placed at this time. Erectile prosthesis, either hydrolic or semirigid, may be placed after protective sensation is achieved in the neophallus, typically 1 year postoperatively.
- Erectile prosthesis may be placed after the neophallus regains protective

sensation, at approximately 1 year. There is a high rate of erosion and ultimate explantation, approximately 50% within 5 years. Semirigid prostheses tend to be better tolerated than hydrolic devices. Necrosis of the phallus during placement of the erectile prosthesis has been described in the literature.

OUTCOMES

Penile Inversion Vaginoplasty

- Published case series have shown that transwomen who have undergone vaginoplasty are able to orgasm and have penetrative intercourse.
- A minority undergo revision labiaplasty to centralize the anterior commissure of the labia.
- With daily dilations, few transwomen need revisionary surgery to lengthen the vaginal vault postoperatively.
- Minor revisionary urethroplasties to address spraying or misdirection of the urinary stream are also moderately common.

Phalloplasty

- The goals of a phalloplasty are to urinate standing up and to provide a phallus for self-image (**FIG 5**).
- After development of protective sensation in 12 to 18 months, a semirigid erectile prosthesis may be implanted for sexual function. However, complications related to prostheses include necrosis of the phallus, infection, extrusion, and need for explantation. Newer prostheses, designed specifically for phalloplasty patients, may improve the complication rate.

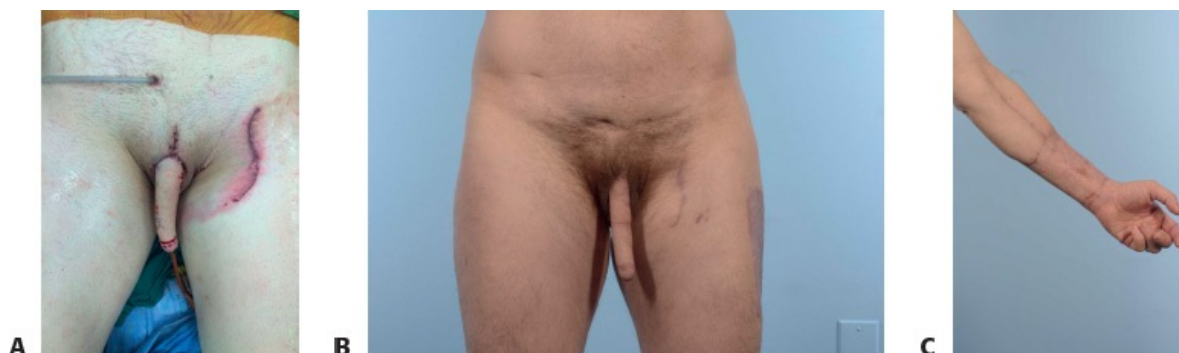


FIG 5 • **A.** Immediate postoperative result showing wound closure and suprapubic catheter. **B.** Appearance of the phallus at 3 months. **C.** Radial forearm flap donor

site at 3 months.

COMPLICATIONS

Penile Inversion Vaginoplasty

- The most feared and serious complication is that of a rectovaginal fistula. We assess for undetected rectal injury using a Betadine enema in the operating room. If there is a tear in the rectum, it is repaired in two layers using 2-0 Vicryl. The patient is then left on a low-residue diet for several weeks.
- If a rectovaginal fistula does develop, it is often managed with diverting ostomy, continued dilation of the neovagina, and watchful waiting. Assistance from a colorectal surgeon is necessary. A gracilis flap interposed between the rectum and neovagina may be necessary.
- Delayed bleeding from the corpus spongiosum deep to the urethral mucosa may be managed with sutures and/or direct pressure. At time of inset of urethra, attention must be paid to bury all erectile tissue under the mucosal closure.
- Delayed wound healing is relatively common, especially at the posterior aspect of the labia majora and inside the neovagina. Most will heal spontaneously without repeat intervention with meticulous hygiene and continued dilation.

Phalloplasty

- Venous congestion of the neophallus may be related to positioning the phallus in the dependent position. It should be elevated continuously for the first several postoperative days. If the phallus remains congested, venous outflow can be augmented with creation of an AV fistula at the distal end of the phallus between the ligated radial artery and vena comitans.
- Urethral fistulas and strictures are common (greater than 50% in many case series) and are difficult to manage. Involvement from a colleague from urology is necessary. Urinary diversion with Foley catheter or suprapubic catheter for an extended period may be necessary.
- If a fistula remains after urinary diversion, superficial circumflex iliac perforator or pudendal perforator flap for coverage may be necessary. Cystoscopy may be required to assess and endoscopically treat urinary strictures.

- Risks of urinary complications should be discussed with the patient preoperatively.

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Section V: Reconstruction of Pressure Injuries

29 CHAPTER **Gluteal Flaps for Sacral Pressure Injuries**

Terri A. Zomerlei and Jeffrey E. Janis

DEFINITION

- Sacral pressure injuries are common in chronically supine patients.
- Patient populations most at risk include those in acute care settings, nursing home patients, and paraplegic populations.
- In addition to unrelieved pressure, the causes are multifactorial and may include incontinence/moisture, friction/shear force, and altered sensory perception.
- Characteristically, the appearance of the overlying skin represents only a small portion of the affected tissue (“the tip of the iceberg”).

ANATOMY

- The sacrum is a large concave triangular bone at the base of the spine that is the fusion of sacral vertebrae S1-S5.
- A pressure injury develops as a result of unrelieved pressure between the sacral bone and the sitting or lying surface.
- The gluteus maximus muscle is a broad, thick, quadrangular muscle that forms the prominence of the buttocks.
 - The gluteus maximus originates along the posterior gluteal line of the ilium and the lateral aspect of the sacrum, coccyx, and sacral ligaments.
 - The superior portion of the muscle inserts along the iliotibial tract of the fascia lata, and the inferior portion of the muscle inserts into the greater

trochanter of the femur.

- It is a type III muscle with two dominant blood supplies, the superior and inferior gluteal arteries.
 - The vessels arise separately from the internal iliac artery.
 - The arteries exit the pelvis with their respective venae comitantes and the superior and inferior gluteal nerves.
- The anatomic landmarks for locating the neurovascular pedicles are the piriformis muscle, the posterior iliac spine, the greater trochanter, and the ischial tuberosity.
- The superior gluteal artery exits above the piriformis one-third the distance from the posterior iliac spine along a tangent from the posterior iliac spine to the greater trochanter.
- The inferior gluteal artery exits below the piriformis just lateral to a point half the distance between the posterior iliac spine and the ischial tuberosity (**FIG 1**).

PATHOGENESIS

- Primary mechanism of pressure injury is cellular ischemia.
 - Tissue pressure greater than the pressure of the microcirculation (32 mm Hg) causes ischemia.
 - If the ischemic period is long enough and repeated frequently, the eventual outcome is tissue necrosis.
- Pressure injuries (decubitus ulcers) almost invariably occur in the tissue over bony prominences in persons not able to change body position frequently.
- Pressure injuries overlying the sacrum are common in chronically supine patients.
- In acutely ill patients, third-space fluid may mechanically compromise the microvasculature.
- Etiologic considerations can be divided in extrinsic and intrinsic factors.
 - Extrinsic factors: Primarily mechanical forces on the soft tissues
 - Friction: Resistance that a surface encounters when moving over another; most often occurs with patient transfers
 - Moisture: Incontinence can lead to skin breakdown.
 - Pressure: Mechanical force that is applied perpendicular to a plane (ie, between a bony prominence and a chair or bed)
 - Shear: Mechanical stress parallel to the plane results in stretching and

compression of the blood supply to the muscles and skin.

■ **Intrinsic factors:** Patient factors that affect the soft tissues

- **Altered level of consciousness:** Results in lack of voluntary movements and protective reflexes that off-load pressure
- **Anemia:** Can contribute to fatigue and weakness which can perpetuate immobility.
- **Autonomic control:** Decreased levels result in spasms, perspiration with increased skin moisture, blood vessel engorgement with resulting tissue edema, and problems with bowel and bladder control.

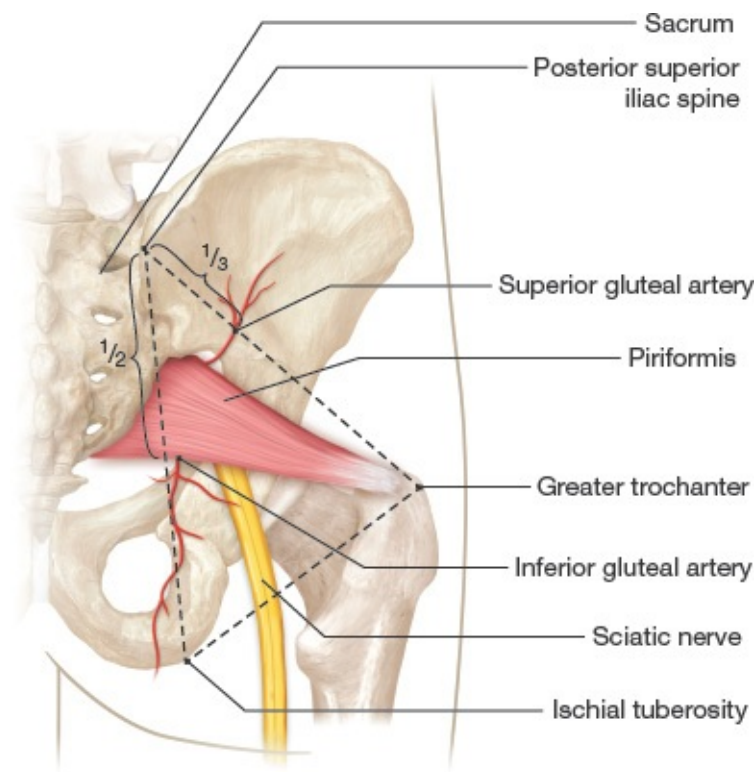


FIG 1 • Sacral anatomy.

- **Age:** Increasing age is associated with increased skin friability and decreased tensile strength.
- **Diabetes:** Poorly controlled blood glucose levels are associated with early recurrence of pressure injuries.
- **Infection:** Profoundly impairs wound healing abilities.
- **Inflammation:** Creates a hostile local milieu resulting in impaired healing, especially in the setting of chronic wounds.

- Malnutrition: Results in wasting and decreased muscle bulk and impairs wound healing abilities
- Sepsis: Can result in decreased tissue perfusion and ischemia
- Sensory loss: Patient is unable to experience the discomfort associated with prolonged pressure over prominences.

NATURAL HISTORY

- Pressure injuries are categorized according to the National Pressure Ulcer Advisory Panel Stages.
- Pressure injuries can progress through the following stages if extrinsic and intrinsic insults are not remedied (**FIG 2**).
- Stage I: Intact skin with nonblanching erythema
- Stage II: Partial thickness skin loss with exposed dermis
 - Presents as a blister, abrasion, or shallow open ulcer
- Stage III: Full-thickness skin loss
 - Subcutaneous fat may be exposed.
 - Tunneling and undermining may be present.
- Stage IV: Full-thickness skin and tissue loss
- Unstageable: Full-thickness skin or soft tissue loss but depth is unknown usually due to the presence of an overlying eschar
- Suspected deep tissue injury: Blood-filled blister or deep purple discoloration of intact skin may indicate deep tissue injury that needs to evolve prior to staging.

HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation of patients with any type of pressure injury includes a detailed assessment of the patient's medical history, social situation, and baseline health status and a comprehensive wound evaluation.¹
- Patient history
 - How long has the pressure injury been present? Acute wounds may respond to conservative treatment, whereas chronic wounds tend to be more recalcitrant.
 - What is the current wound care treatment? Changing local wound care regimens may help with improving the wound.
 - What surgical options have been tried in the past? Obtain any and all operative reports as previous surgeries may limit surgical options.

- Is the patient ambulatory, or wheelchair or bed bound? Some flap procedures are not appropriate for ambulatory patients.
- What type of mattress and turning regimen is currently being used? Airflow mattresses offer the best protection, whereas normal mattresses offer little defense against pressure.
- Is fecal contamination a problem? A dressing or a temporary diverting ostomy may be prudent.
- Are there problems with urinary incontinence? A urinary diversion procedure (ie, suprapubic tube) or indwelling Foley catheter may be indicated.
- Does the patient have spasms? Optimize medications to control spasms.
- Does the patient have any fixed contractures?
- What is the baseline nutritional status of the patient?
- Social history is crucial to obtain in order to understand possible postoperative barriers to care and to thwart recurrence.
 - What is the social support/caregiver situation?
 - Do they have resources for obtaining durable medical equipment (low air loss bed, seat cushion if bed bound or wheelchair bound)?
 - Is there smoking or substance abuse history?
 - Active or prior nicotine use increases risk of poor wound healing.
 - A urine toxicology screen or urine cotinine test may be useful.
 - Is there a history of psychiatric illness?
 - Does the patient follow a specific diet (cardiac, diabetic)?
 - What is their daily protein intake?
 - What is the patient's compliance history?
- Laboratory studies
 - Complete blood count to assess for anemia or active infection
 - Albumin, prealbumin, and total protein to assess protein stores
 - Coagulation panel to assess for coagulopathies
 - Cultures that should be obtained with tissue or bone biopsies as wound swabs have little value due to chronic colonization. Cultures should be sent for quantitative analysis, and if the organism count is greater than 10^5 , consideration should be given to systemic antibiotics and/or staged debridement and reconstruction.
 - Urinalysis

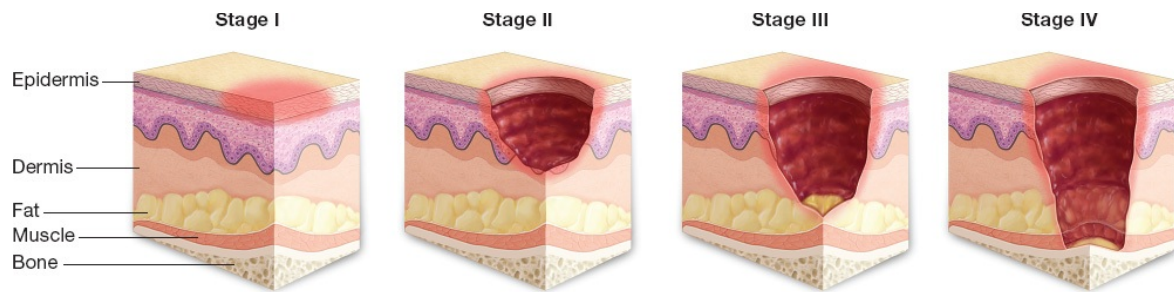


FIG 2 • Pressure injury staging.

■ Physical exam

- *All wounds must be examined manually.*
- Visual wound assessment alone is not sufficient to obtain necessary information about a wound.
- Manually assess the size and depth of the wound, bony prominences, bursa, proximity to the rectum, and presence of tunneling (may need to use long cotton tip applicator to assess tunneling).
- If an eschar is present, the wound cannot be accurately staged.
- A limited bedside debridement may be useful, if the patient can tolerate this, so that the wound can be staged and to facilitate local wound care preoperatively.
- From visual inspection, take note of any previous surgical scars as previous surgeries may preclude the use of a flap secondary to compromised vascular supply.
- Muscle tone and bulk are assessed taking note of any spasticity or contraction of the extremities.
- Assess the patient's sensation in the area of the wound.

IMAGING

- MRI is recommended for all stage IV pressure injuries to evaluate for osteomyelitis.
 - T2 hypersensitivity and low-intensity T1 is sensitive and specific for osteomyelitis (97% and 89%, respectively).
- If MRI is not available or the patient has conditions precluding its use, plain films and CT scan may be used. This imaging can be confirmatory for osteomyelitis but has low specificity.²

DIFFERENTIAL DIAGNOSIS

- Marjolin ulcer
- Burn
- Pilonidal disease
- Neoplasm with bony metastasis
- Soft tissue neoplasm with ulceration
- Chronic surgical wound
- Traumatic wound

NONOPERATIVE MANAGEMENT

- Relieve extrinsic pressure with frequent positional changes.
 - Turn every 2 hours when supine.
 - Lift for 10 seconds every 10 minutes when seated.
- Use proper mattress (low air loss) and cushion for seating and wheelchair (seat mapping).
- Minimize head of the bed elevation (less than 45 degrees).
- Optimize underlying medical status.
 - Address spasticity (baclofen, diazepam, dantrolene).
 - Optimize nutrition—protein intake of 1.5 to 3.0 g/kg/d.
- Local wound care in those who are poor surgical candidates or while optimizing a patient for surgery.
 - Dakin's ¼ strength for a limited time period (days up to 1 week) can be effective in decreasing wound colonization while preserving native tissues.³
 - Limited bedside debridement to remove any wet eschar to facilitate adequate packing and wound care may be warranted.
 - Enzymatic debridement is helpful when the wound has heavy slough.

SURGICAL MANAGEMENT

Preoperative Planning⁴

- The most crucial aspect of the surgical management of sacral pressure injuries is the preoperative and postoperative care.
- Do not operate on patients until their medical status is optimized and the underlying etiology determined.
- Obtain old operative reports to know what prior attempts at closure have been tried.
- Always consider future procedures in the operative planning so as to not “burn

bridges.”

- Review with the patient and all caregivers the postoperative expectations and restrictions to help ensure postoperative compliance.

Positioning

- To minimize repositioning, have anesthesia induced while the patient is supine on stretcher.
 - Ensure that anesthesia provider appropriately protects eyes, face, and endotracheal tube.
- Check OR table to ensure working properly (able to flex and extend at hips) prior to patient transfer.
- Position gel rolls for chest and hips onto OR table.
- Patient gown should be removed.
- With stretcher in locked position next to the OR table and with appropriate resources and careful choreography, roll patient to prone position.
- Pad all extremities with foam or gel pads; toes should be “floating” (consider a Wilson frame).
- Ensure that genitalia are free from compression.
- Arms should be on arm boards in “Superman” position.
- Check EKG pads, monitoring devices, grounding pads, and catheters to make sure they are not placing pressure on the skin and are outside of the operative field.
- Take care that any ostomies, if present, are free from compression.
- Ensure no traction on indwelling catheters.
- Secure patient to bed at both the trunk and lower legs.
- Apply warming blankets or forced air to the upper trunk.
- If the GI tract is still in continuity, an adhesive drape can be applied as a “mud flap” to exclude the rectum from the field.
- OR table can be flexed at the patient’s hip level to improve exposure (**FIG 3**).

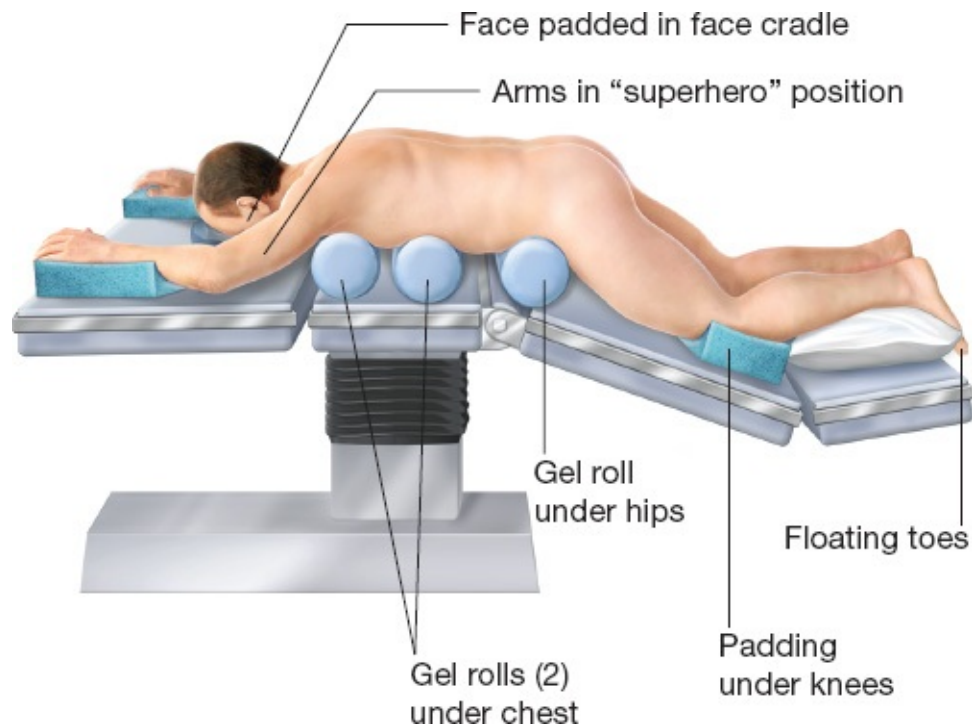


FIG 3 • Prone positioning.

Approach

- Gluteal rotation flap
 - Can be taken from either left or right gluteal area
 - Able to be readvanced as needed in the future
 - Available as a fasciocutaneous or musculocutaneous flap
 - Can be full or segmental (used in ambulators)
 - Musculocutaneous flaps have the advantage of additional bulk and robust blood supply
- V-Y advancement flap
 - Ipsilateral for small wounds
 - Bilateral for larger sacral wounds
- Sliding gluteal flap
 - A fasciocutaneous flap preferred for the ambulatory population
 - Can be unilateral or ipsilateral

TECHNIQUES

■ Excisional Debridement

- Failure to adequately debride can lead to recurrent disease and poor wound healing.
 - Probe wounds prior to debridement so all tunneling is addressed.
 - Infiltration of the peribursal area with a wetting solution (1000 mL of normal saline plus 30 mL of 1% lidocaine, plus 1 ampule of epinephrine 1:1000) can assist with hydrodissection and decrease blood loss.⁵
 - Coating the cavity with methylene blue applied with a cotton applicator can assist with bursa identification and verify the completeness of the debridement.
 - Debridement removes necrotic tissue and biofilm and decreases bacterial count.
 - Converts a chronic wound into an acute wound.
 - Quantitative wound cultures should be obtained following debridement so that postoperative antibiotic coverage can be tailored appropriately.
 - If the completeness of the debridement is ever in question, or the wound is severely contaminated, staged debridement and reconstruction can be performed, although outcomes may be similar to immediate reconstruction.⁶
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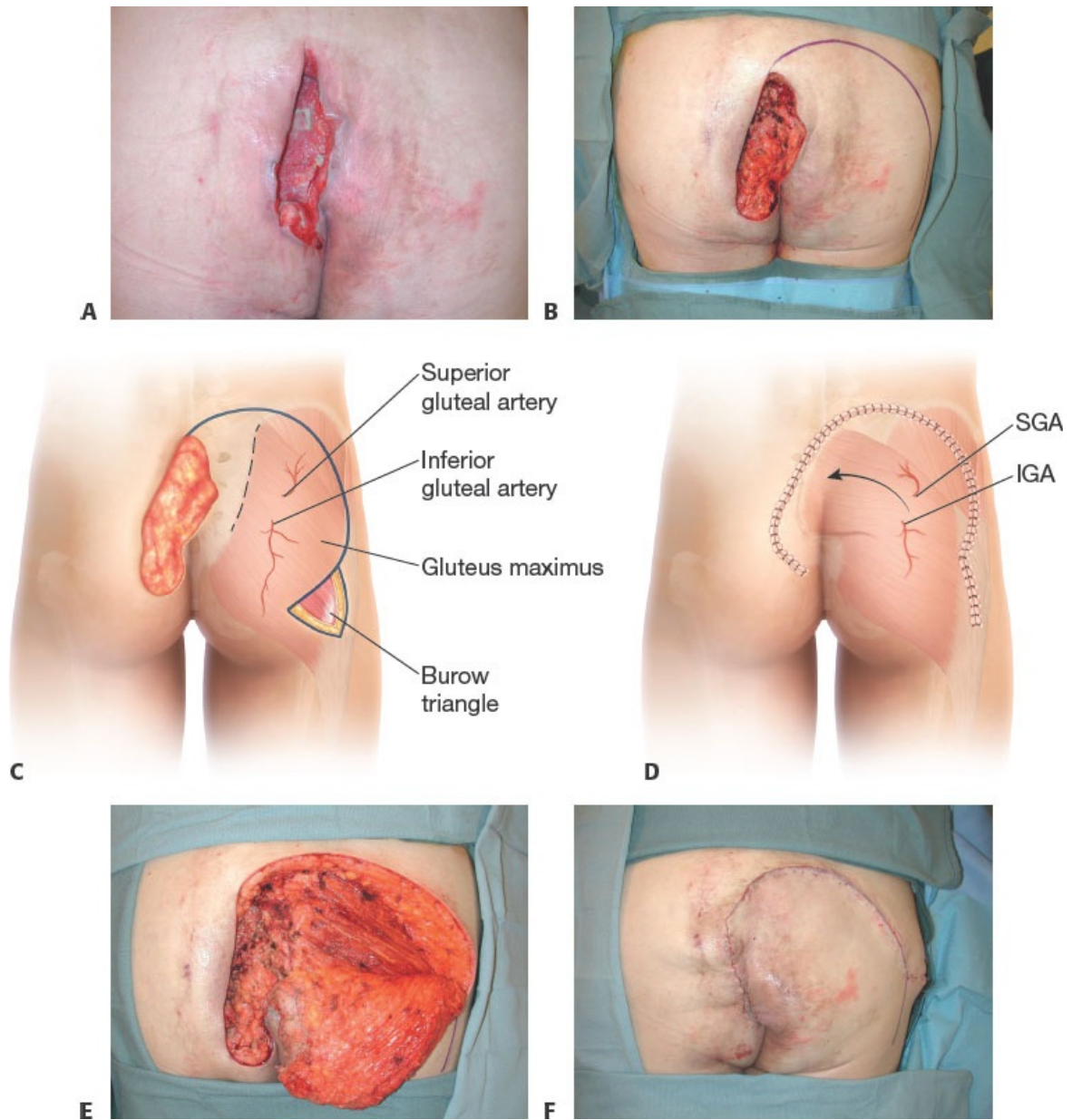
■ Osteotomy

- Because most pressure injuries overlie bony prominences, and underlying osteomyelitis and unhealthy bone are likely, the bony prominence should be removed.
 - The osteotomy should be performed only to lessen the prominence as radical removal may redistribute pressure points to adjacent tissue, result in excessive bleeding, and affect the origin and/or insertion of skeletal muscle.
-

■ Gluteal Rotation Flap

- Prep a wide field with Betadine and drape in the standard fashion (**TECH FIG 1A**).
- Mark key anatomic landmarks:
 - posterior superior iliac spine
 - Greater trochanter

- Ischial tuberosity
- Mark the locations of the vascular pedicles to the gluteus maximus.
 - Superior gluteal artery (SGA): Anticipated location is one-third the distance between the posterior superior iliac spine and the greater trochanter.
 - Inferior gluteal artery (IGA): Anticipated location is half the distance between the posterior superior iliac spine and the ischial tuberosity.
 - A handheld Doppler can be used to confirm location.
- Mark and elevate a larger flap than needed by 2 or 3 cm at least (**TECH FIG 1B**).
- The flap design can incorporate the SGA and its perforators and/or the IGA and perforators, depending on size needs (**TECH FIG 1C–E**).
- For a myocutaneous rotation flap, the incision is made with a scalpel and then deepened through the skin and subcutaneous tissues and muscle insertion with electrocautery.
- Take care to dissect straight down and not to undermine any of the subcutaneous tissue off of the muscle.
- Disinsert the gluteus at the lateral and inferior borders.
- Elevate the gluteus maximus in a superomedial direction in the areolar plane above the gluteus medius.
- Identify and protect the superior and/or inferior gluteal artery.
- Detach the gluteus maximus from its origin at the posterior superior iliac spine.
- Rotate the flap over the sacral defect (**TECH FIG 1F**).
 - A back-cut (Burow triangle) can be made at the inferolateral aspect to rotate tension-free (do not injure the IGA).
- Irrigate and obtain hemostasis.
- Suture the flap muscle to the contralateral gluteus maximus muscle without tension using monofilament long-acting absorbable suture.
- Insert drains into both donor and recipient site.
- Close the skin in layers with suture or suture plus staples.
- The flap can be rerotated at a later date should the need arise.
- A unilateral rotation flap can be used in conjunction with a contralateral V-Y advancement flap.



TECH FIG 1 • **A.** Sacral pressure injury prior to debridement. **B.** Wound following debridement. A right-sided gluteal rotation flap has been marked. **C,D.** Design of the gluteal rotation flap. **E.** A fasciocutaneous rotation flap based on the perforators of the inferior gluteal artery has been raised. **F.** The flap has been inset with absorbable suture. Note the back-cut or Burow triangle.

■ V-Y Advancement Flap

- Mark anatomic and vascular landmarks as described previously.
- Design and mark a skin paddle overlying the gluteus maximus (mark a flap larger than needed).
 - Flap is designed in a triangle shape and can be designed to incorporate the SGA, the IGA, or both (**TECH FIG 2A**).
- Incise the skin sharply, and use electrocautery to dissect down to the muscle beveling out to capture soft tissue.
- Do not undercut the skin paddle with dissection.
- Dissect from lateral to medial in the submuscular space after dividing the muscle laterally.
- Divide the muscle from the origin at the sacrum. Take care not to injure SGA or IGA.
- Once the muscle is fully divided around the skin paddle, the tissue should easily advance medially (**TECH FIG 2B**).
- Place drains into the donor and recipient sites.
- Suture the flap gluteus maximus to the contralateral muscle with absorbable sutures.
- Close the skin and subcutaneous tissues in layers with sutures or sutures and staples (**TECH FIG 2C**).
- The lateral donor site will close primarily (Y).
- This flap can be unilateral or bilateral and can be used in conjunction with a rotational flap.



TECH FIG 2 • **A.** A sacral wound has been debrided, and bilateral myocutaneous V-Y flaps have been designed. **B.** The flaps easily advance to the midline, filling the defect. **C.** The flaps have been inset with

suture.

■ Sliding Gluteal Flap (Fasciocutaneous)

- Mark anatomic and vascular landmarks as described previously (**TECH FIG 3A,B**).
- Design and mark a triangular skin paddle overlying the gluteus maximus (mark a flap larger than needed).
- Cutaneous skin island can reach up to T12 if needed.
- Incise the skin sharply and use electrocautery to dissect down to the muscle by beveling out to capture maximal soft tissue and preserve perforators.
- Do not undercut the skin paddle with dissection.
- Once skin paddle is “islandized,” it should easily move medially.
- Insert drains into donor and recipient sites.
- Close donor and recipient sites with layered sutures or sutures and staples (**TECH FIG 3C**).



TECH FIG 3 • **A.** This ambulatory patient suffered a pressure injury during hospitalization for an acute injury. She developed a chronic wound and osteomyelitis. A fasciocutaneous flap based on the inferior gluteal artery perforators is planned. **B.** Following debridement, the wound is much larger than anticipated. Therefore, bilateral flaps were designed. The area of bone that will undergo ostectomy is outlined in methylene blue. Based on anatomic landmarks, “A” represents the “anticipated” location of the inferior gluteal artery. “R” represents the “real”

location of the artery based on Doppler exam. **C.** The flaps are closed in a V-Y fashion. (Courtesy of R. Chandawarkar, MD.)

PEARLS AND PITFALLS

Preoperative planning

- Evaluate extrinsic and intrinsic factors to determine wound etiology.
- Ensure that the patient is medically optimized prior to their operation.
- Engage social work to ensure that the patient has adequate social support and resources for the postoperative period.
- Consult with appropriate consultants prior to reconstruction (colorectal for diverting ostomy, ID if osteomyelitis).

Positioning

- Attention to choreography and team communication is crucial to position the patient safely in the prone position.

Operative strategy

- Autonomic dysfunction in the patient can create difficulties for the anesthesia team, so communicate with your providers frequently.

- Know the location of the blood supply to the flaps. Use a handheld Doppler if in doubt.

Postoperative care

- Engage a multidisciplinary team including nursing, social work, and other consulting services as appropriate to ensure a safe discharge and to give the patient the “best chance” of preventing reoccurrence.⁷

POSTOPERATIVE CARE

- Patients are hospitalized for 1 to 2 weeks after surgery, and many patients will discharge to a rehabilitation hospital or an extended care facility for several weeks to receive a higher level of nursing care.
- A low air loss mattress should be ordered prior to the surgery and should be available to move the patient onto directly from the operating room table.
- The patient should limit the HOB to less than 10 degrees for 1 week.
- The patient should be repositioned every 2 hours, unless he or she is on an air-

fluidized bed.

- The postoperative dressing should be left in place for 48 hours, after which time a light dressing can be applied to protect against shear and moisture or the wound can be left open to the air to allow for ease of wound monitoring.
- Bladder and bowel function should be controlled to prevent urinary or fecal contamination of the surgical site.
- Spasticity should be prevented with pharmacologic measures.
- Obtain a dietary consultation so that the patient can maintain a positive nitrogen balance.
- Meticulous drain care should be performed in the hospital and taught to all caregivers.
- Obtain an infectious disease consultation for any positive operative cultures to help guide antibiotic selection and duration of treatment.
- Evaluate need for long-term intravenous access for antibiotics.

OUTCOMES

- Recurrence rate is high.
- Local wound/incision problems are common and should be treated with local wound care.
- Anticipate further reconstruction options with every surgical intervention.
- Control for extrinsic and intrinsic factors that contributed to the initial pressure injury formation.

COMPLICATIONS

- Complications are not uncommon in those with significant preoperative comorbidities.
- Hematoma or seroma may occur.
 - If the patient is on anticoagulants, work closely with hematologist to determine when these can be safely held and resumed in the perioperative period.
 - One or more drains should be left under flaps for days to weeks to control for fluid accumulation.
- Small localized incisional breakdown should be treated with local wound care.
- Persistent infection can be minimized with thorough debridement and long-term antibiotics as deemed appropriate by infectious disease colleagues.
- Unless underlying medical problems and extrinsic factors are controlled, the

recurrence rate is high.

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30 Posterior Thigh and Hamstring Flaps for Ischial Ulcers

CHAPTER

John Hulsen and Jeffrey E. Janis

DEFINITION

- A pressure injury is localized damage to the skin and soft tissue typically over a bony prominence.
- They occur as a result of prolonged pressure or pressure in combination with shear.
- National Pressure Ulcer Advisory Panel Stages¹ are shown in FIG 2 in Chapter 32.
- The ischial area is the most frequent site of development and recurrence of pressure ulcers.²
- Soft tissue overlying the bony prominence of the ischial tuberosity is particularly vulnerable to pressure injury especially in the wheelchair-bound/spinal cord injury patient.

ANATOMY

- The posterior thigh is a region bordered by the inferior gluteal fold superiorly, the iliotibial tract laterally, the thigh adductors medially, and the popliteal fossa inferiorly.
- The hamstring muscle group functions to flex, stabilize, and rotate the knee and are not expendable as a group in the ambulatory patient (**FIG 1**).³
 - Biceps femoris
 - Semimembranosus
 - Semitendinosus
- Blood supply of the posterior thigh skin:
 - The profunda femoris artery principally supplies the largest cutaneous area

on the posterior thigh.³

- It originates laterally from the femoral artery, gives off both medial and lateral circumflex femoral arteries, and then continues distally and traveling behind the adductor longus.
 - Medial branches enter into the adductor compartment.
 - Lateral branches (four profunda femoris artery perforating vessels) pierce the adductor magnus insertion and enter the posterior compartment of the thigh.
 - The fourth profunda femoris perforating artery is the termination of the profunda femoris artery.
 - Each profunda femoris perforating vessel perfuses musculocutaneous and/or septocutaneous perforators that contribute to the well-developed fascial plexus of the posterior thigh.
- The inferior gluteal artery principally supplies the cutaneous vascular territory of the lower gluteal region.
 - It originates off the internal iliac artery and exits the pelvis to enter the gluteal region inferior to the piriformis with the sciatic and posterior cutaneous nerves. In 91% of patients, the inferior gluteal artery sends off a descending fasciocutaneous branch.⁴
 - The descending branch of the inferior gluteal artery travels in a common sheath with the posterior cutaneous nerve in 72% of patients.
 - Rather than singularly coursing down the thigh, the descending branch acts as a “relay artery,” being reinforced along its length by myocutaneous and fasciocutaneous branches from the profunda femoris perforating vessels.³
 - Anastomotic branches from the descending branch of the inferior gluteal artery join branches from the medial femoral circumflex artery, lateral femoral circumflex artery, and the first profunda perforating artery to form the cruciate anastomosis (**FIG 2**).⁵
 - Each vessel that unites to form the cruciate anastomosis can provide collateral circulation to the longitudinally directed fascial plexus of the posterior thigh in the absence (or surgical ligation) of one of its constituents.^{3,5}
 - This accounts for the clinical reliability of the multitude of fasciocutaneous flap designs available from the posterior thigh.

PATHOGENESIS

- Pressure ulcers are the result of numerous factors, both extrinsic and intrinsic to the patient, that contribute to the development of a wound.
- Pressure: Greatest areas found over bony prominences
 - Can produce tissue ischemia if applied in excess of 32 mm Hg (skin end capillary bed pressure)
 - The ischial tuberosities are particularly vulnerable to ulceration and recurrence as pressures over this region in the sitting position exceed 80 to 100 mm Hg.
 - Shearing: Sliding deformation of tissue caused by oppositely directed parallel forces
- Friction: Contributes to abrasions and breakdown of the superficial skin barrier
- Moisture: Contributes to maceration of the skin
- Limited mobility: Inability to adequately off-load pressure points, potentially increasing friction and shearing forces
- Altered sensation: Lack of protective sensory input
- Spasticity: Interruption of supraspinal inhibitory pathways that may result in contractures that create new or altered pressure points
- Altered level of consciousness: Unrecognized prolonged pressure with skin maceration/contamination from urine/fecal soilage

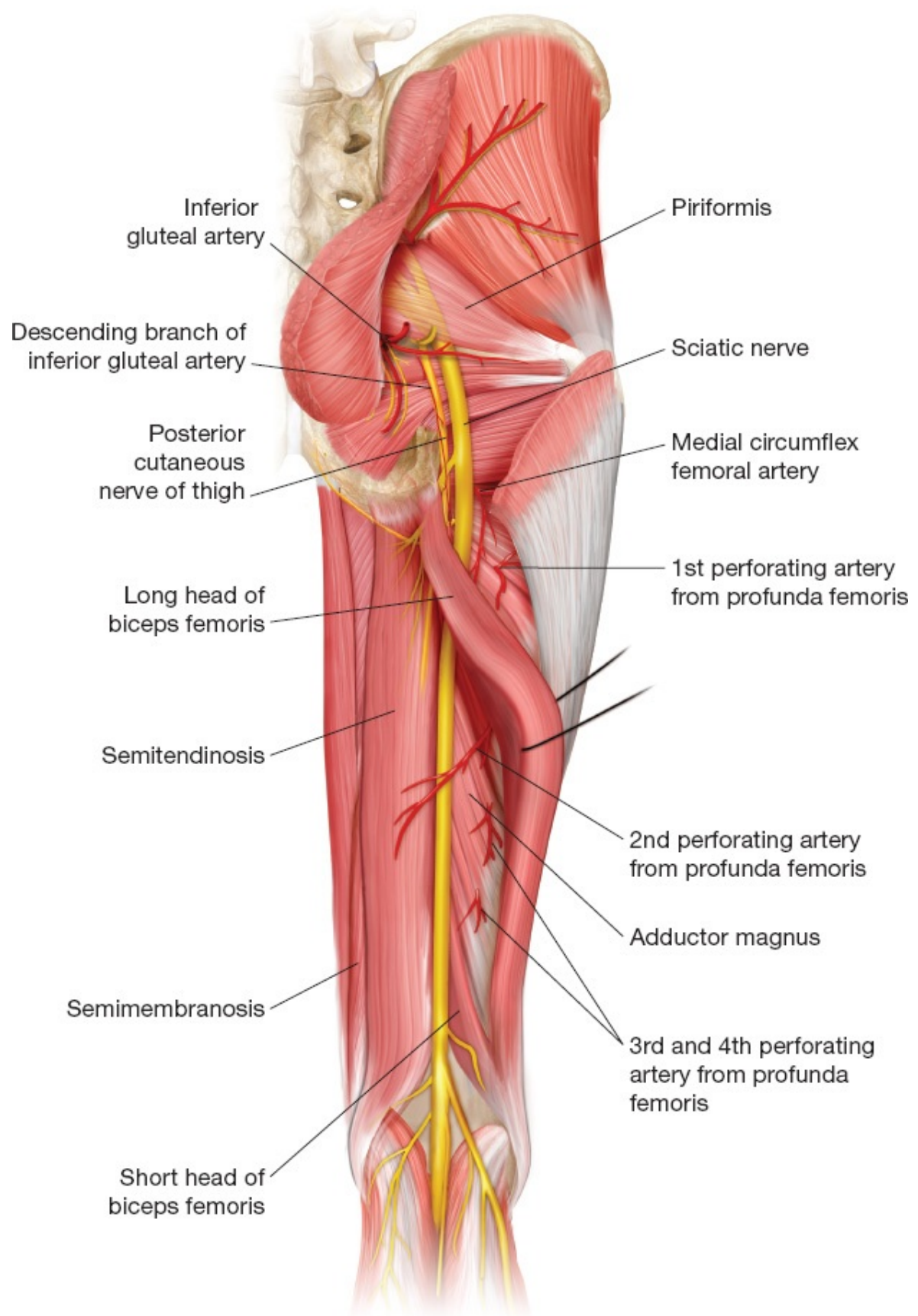


FIG 1 • Key posterior thigh anatomy.

- Tissue tolerance for pressure and shear forces is affected by microclimate, nutrition, perfusion, comorbidities, and condition of the soft tissue.¹
- It is important to recognize, especially in the spinal cord injury patient, that all phases of wound healing are impaired in denervated tissue.

NATURAL HISTORY

- Skin hyperemia is seen within 30 minutes and is characterized by nonblanching erythema that resolves within 1 hour after pressure is alleviated.
- Tissue ischemia develops with sufficient continuous pressure for 2 to 6 hours, causing erythema that requires at least 36 hours to resolve after pressure cessation.
- Deep tissue injury/tissue necrosis can develop after 6 hours of unrelieved pressure and manifests as deep red, maroon, or purple skin discoloration with induration.
- Soft tissue ulceration over bony prominences occurs within 2 weeks after tissue necrosis occurs.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient age, general health/functional status, medical comorbidities, nutritional intake, as well as the circumstances, etiology, chronology, and prior ulcer management should be documented.
- Note any medications or therapy that impairs wound healing such as radiation and steroids.
- Obtain reports from any previous surgical interventions that may influence ulcer reconstructive options.
- Social history including tobacco use and a clear picture of the patient's support system should be obtained.
 - It is critical to identify the etiology that led to reconstructive failure when treating a recurrent ulcer.
 - Lack of compliance with postoperative care, lack of patient motivation, and inadequate resources for home care will doom even the best executed reconstruction and are critical to account for in determining whether a patient is a reconstructive candidate.

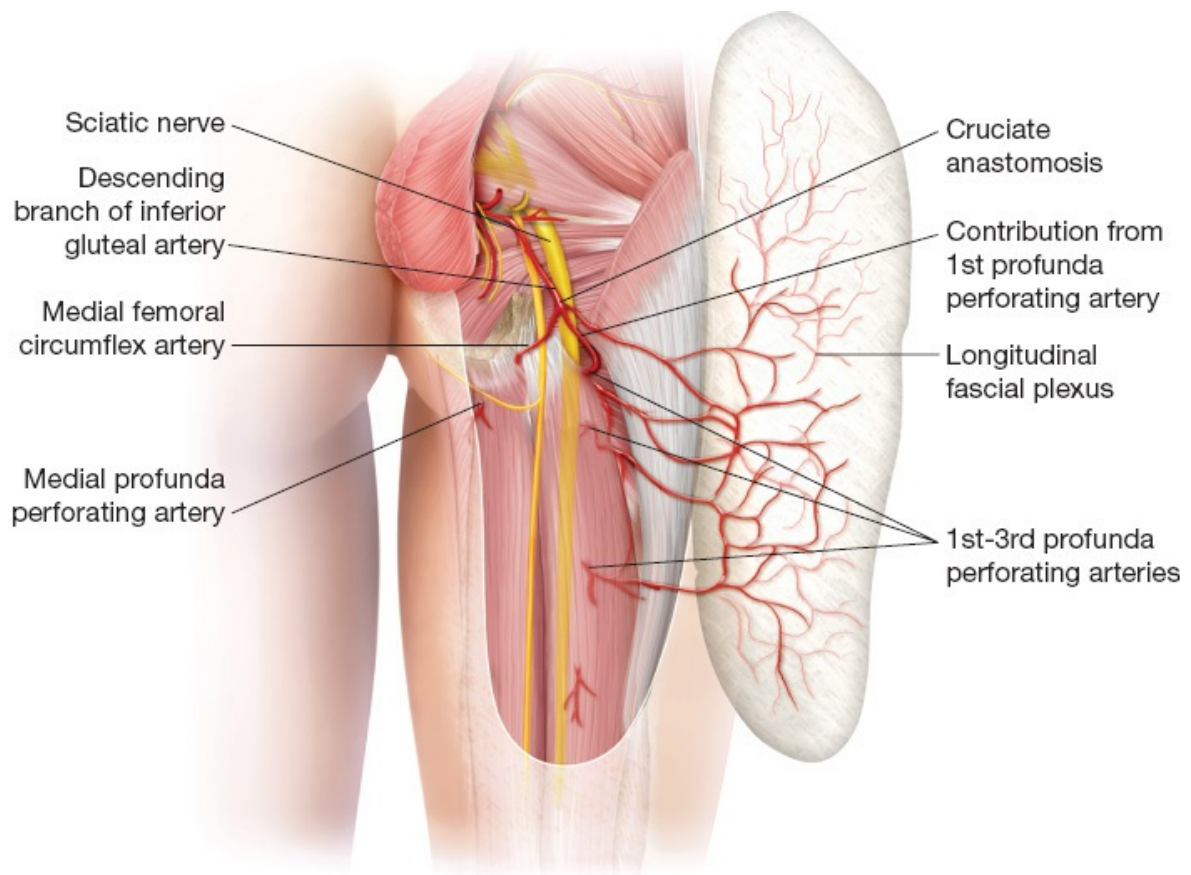


FIG 2 • The crurial anastomosis.

■ Physical examination

- General appearance, BMI, assessment of nutrition status: Does the patient appear well or fragile and emaciated?
- Accurately assess location, dimensions (including tunneling), wound condition/odor, and stage/depth of ulcer.
- Presence of diverting ostomy or suprapubic catheter
- Presence of lower extremity fixed posturing or uncontrolled spasticity
- Evaluate the posterior trunk and lower extremities for surgical scars from previous reconstructions while also assessing potential donor-site muscle bulk (diminished in spinal cord injury).

IMAGING AND OTHER DIAGNOSTIC STUDIES

■ Preoperative laboratory studies

- White blood cell count/differential and hemoglobin/hematocrit
- Inflammatory markers: Erythrocyte sedimentation rate and C-reactive protein

(especially if suspect osteomyelitis)

- Glucose and HgbA1c: Ideally, good long-term glucose control in diabetics with a HgbA1c less than 6%⁶
- Nutrition studies
 - Accurate assessment of the nutritional status of the pressure ulcer patient is often compromised by proinflammatory factors that may preclude the use of typical serum protein values.
 - Ideal, and potentially unattainable, preoperative serum protein levels:⁷
 - Albumin: At least 3.5 g/dL with upward trend
 - Prealbumin: At least 20 g/dL with upward trend
- Unfortunately, there is little evidence that enteral or parenteral nutrition supplementation has any effect on healing existing pressure sores or the prevention of new ulcers.
- Data suggest that anemia, serum protein alterations, and markers of inflammation will actually normalize after surgical treatment of the ulcer.⁸
 - These deficient values are viewed as the result of the ulcer rather than modifiable risk factors to optimize prior to surgery.
- Imaging studies
 - Used to assess for any undrained fluid collection and as noninvasive modality to detect osteomyelitis
 - MRI: 97% sensitive, 89% specific for diagnosis of osteomyelitis in the pelvis⁹
- Pathology/microbiology
 - Diagnostic standard for osteomyelitis is the pathology report of an aseptically obtained bone biopsy.

DIFFERENTIAL DIAGNOSIS

- Stage I to IV pressure ulcer, unstageable wound, or deep tissue injury
- Wound infection
- Acute or chronic osteomyelitis
- Malnutrition
- Muscle spasms
- Fecal and/or urinary incontinence
- Failed previous reconstruction

NONOPERATIVE MANAGEMENT

- Indications for nonoperative management include patients with stage I and II pressure ulcers as well as some patients with stage III and IV ulcers who are not candidates for reconstruction:⁷
 - Unmotivated patient
 - Inadequate home support or outpatient care
 - Comorbidities that place the patient at an unacceptable surgical or anesthesia risk
 - Unreconstructable defect
- In all pressure ulcer cases particular emphasis is placed on the prevention of wound complications and infections, halting ulcer progression, and reducing the risk of additional ulcers.
- If possible, the highest goal is a closed stable wound.
 - A closed wound is not an attainable goal for all patients.
 - The patient's social situation is just as important, if not more so, than any medical or surgical therapy.⁷
 - General treatment strategies for nonoperative management mirror those used in preoperative optimization of the pressure ulcer surgical candidate.
 - Offloading pressure points with specialty beds, seat mapping, and turning protocols every 2 hours.
 - Local skin and wound care to promote moist wound healing without maceration is essential.
 - Many passive and sophisticated active dressings are available; however, evidence is mixed regarding head-to-head superiority.
 - Fever/sepsis usually has a urinary or pulmonary source, not the open wound.
 - Negative-pressure wound therapy may be more comfortable to patients and effective in ulcers that fail to progress or as a bridge to surgery.
 - NPWT functions to increase wound perfusion and formation of granulation tissue while reducing bacterial load
 - A well-balanced diet is best to provide adequate nutrition for wound healing.
 - Supplements are beneficial only if there is a nutritional deficiency.¹⁰
 - Goal is 30 to 35 kcal/kg and 1.25 to 1.5 g protein/kg/d for adults with a pressure ulcer who are at risk for malnutrition.
 - Additional fluid should be provided to patients with heavily exudative wounds to prevent dehydration.
 - Management of muscular spasms helps to prevent new pressure points and

reduces wound-shearing forces.

SURGICAL MANAGEMENT

- The presence of stage III and IV pressure ulcers alone is not an indication for surgical management.⁷
- Optimization of medical comorbidities, modification of risk factors, assuring adequate home support, availability of medical equipment, access to outpatient care, assessment of patient compliance, and motivation to take an active role in self-care are essential for consideration of surgical candidacy.
- The technical intraoperative aspects of pressure ulcer surgery are often the easiest facet of the patient's care.
- Goals of surgical management:⁷
 - Sharp debridement of all devitalized tissue (including complete excision of pseudobursa) to create a healthy bleeding wound bed
 - Osteotomy of devitalized bone to clinically hard bone with pinpoint bleeding and rasped smooth contour
 - Obtain soft tissue and bone biopsies following debridement under sterile conditions when indicated.
 - Provide tension-free soft tissue wound closure and obliterate dead space with judicious selection of large, well-vascularized flaps.
 - Avoid suture lines across pressure/seating surfaces.
- Selection of myocutaneous, fasciocutaneous, and perforator flap reconstruction is dependent on the location and dimensional characteristics of the ulcer, donor-site availability from prior surgery, ambulatory status of patient, and surgeon familiarity/preference.

Preoperative Planning

- Proactive coordination of multidisciplinary postoperative care and clear communication of expectations between the patient and team members prior to surgical intervention.
- Discuss temporary fecal diversion with the patient and general surgery (if incontinent or not compliant with a standard bowel regimen) if wound hygiene is a concern.
- Consider a urology consultation if there is concern for an occult urinary tract leak into the wound or uncontrolled urinary incontinence.
- Communicate in advance to the operating room staff the need for separate instruments for the contaminated debridement, sterile biopsy, and clean

reconstructive portions of the case.

Positioning

- The patient is transferred to the operating room table in the prone position.
- Place the table in a moderate jack-knife position during flap inset to ensure adequate flap length while simulating tensile forces across the closure during the postoperative hip flexion protocol.
- Chest rolls are used to reduce breast and shoulder pressure.
- Assure adequate protective padding over the knees, legs, and feet.

Approach

- Ulcer excision is optimally approached after infiltration of epinephrine containing wetting solution around the pseudobursa/ulcer-healthy tissue interface and coating the cavity with dye.
 - This approach reduces blood loss and facilitates defining the ulcer for debridement.
- Despite attempts to standardize flap terminology, considerable variability exists in published literature and standard textbooks (with limited consensus even among practicing surgeons) regarding what is considered a “posterior thigh flap.”
 - Numerous flaps (with common aliases), varying in type, anatomy, and clinical use are described in **Table 1**.
 - Regardless of nomenclature, it is vital to approach ulcer reconstruction with a sound understanding of the anatomical basis and constraints of each flap design.
 - Tailor flap choice to the patient’s reconstructive needs, available donor sites, intact pedicles, and surgeon experience/preference.
 - Clear communication of your operative plan to the patient, surgical team, anesthesia staff, and rehabilitation team will allow for better coordination of OR resources and postoperative care

Table 1 Posterior Thigh Flaps				
			Use in	

Flap Type	Names and Aliases	Muscles Sacrificed	Ambulatory Patients?	Dom
Fasciocutaneous	Posterior thigh flap	None	Yes	Desc glute; crucia
	Posterior thigh fasciocutaneous flap	None	Yes	1st a perfo
	Gluteal thigh flap Inferior gluteal thigh flap	None	Yes	1st a perfo of inf
	Posterior thigh flap Posterior thigh fasciocutaneous flap Posterior thigh rotation flap V-Y profunda femoris flap	None	Yes	1st a perfo branc (if pre divide
	Posterior thigh flap V-Y posterior thigh flap	None	Yes	Deep fasci perfo comp
Musculocutaneous	Posterior thigh flap V-Y hamstring flap Biceps femoris flap Semicircular hamstring flap	Biceps femoris	Yes (potentially) ^a	1st p profu
	Posterior thigh flap V-Y hamstring flap Semicircular hamstring flap	Biceps femoris Semitendinosus Semimembranosus	No	1st p profu

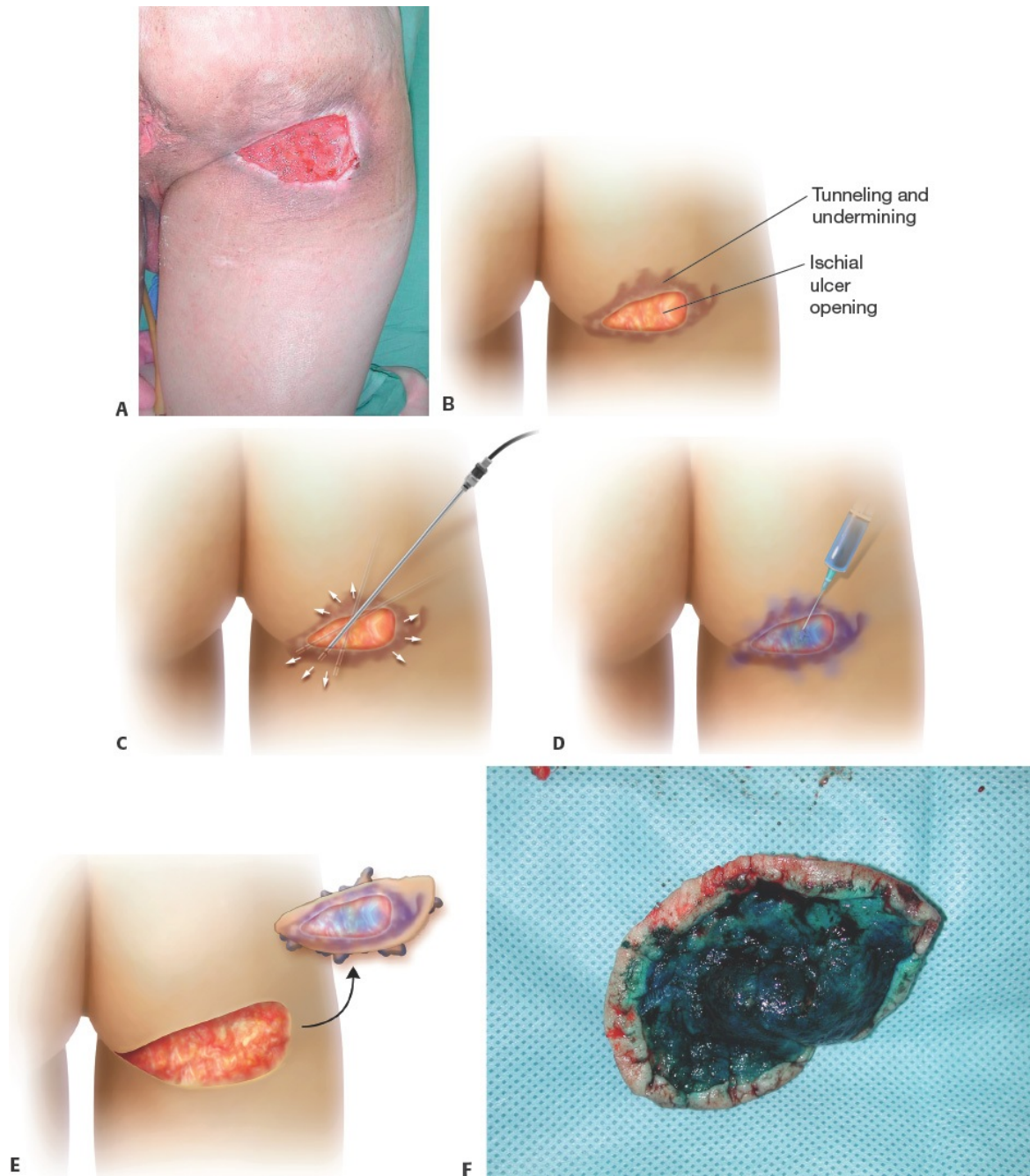
Perforator	Posterior thigh flap Posterior thigh perforator flap	None	Yes	3rd p profu
	Posterior thigh flap Posterior thigh perforator flap Profunda artery perforator Flap PAP flap Adductor flap Adductor magnus perforator flap	None	Yes	1st m femo

^aAs an isolated muscle, it is expendable as a knee flexor except in certain athletic situations.

TECHNIQUES

■ Ulcer and Pseudobursa Cavity Identification, Excision, and Bone

- The patient is prepped and draped with the ulcer cavity and flap donor sites exposed.
- Percutaneous access incisions are made within the rim of the planned ulcer excision as needed (**TECH FIG 1A,B**).
- Warmed wetting solution containing 30 mL of 1% plain lidocaine and 1 mL of 1:1000 epinephrine in 1000 mL of normal saline is injected circumferentially around the entire cavity with a blunt-tipped infiltration cannula (**TECH FIG 1C**).
 - Endpoints of wetting solution infiltration are increased skin turgor and adequate circumferential hydrodissection of the cavity from healthy tissue.
 - Estimation of fluid volume used is 10 mL per 10 cm³ of pseudobursa cavity resection.¹¹
 - The epinephrine is allowed adequate time to achieve full hemostatic effect (no less than 7 minutes).



TECH FIG 1 • **A.** Stage III ischial pressure ulcer with undermining present. **B.** Ulcer opening with undermining and tunneling present. **C.** Infiltration of wetting solution containing epinephrine, “tumescent technique.” **D.** Methylene blue is applied to the tunneling ulcer to identify all tissue to be excised. **E.** Clean, hemostatic wound, free from all

ulcer/pseudobursa tissue. The true extent of the defect is now known. **F.** Pseudobursa and ulcer excised en bloc.

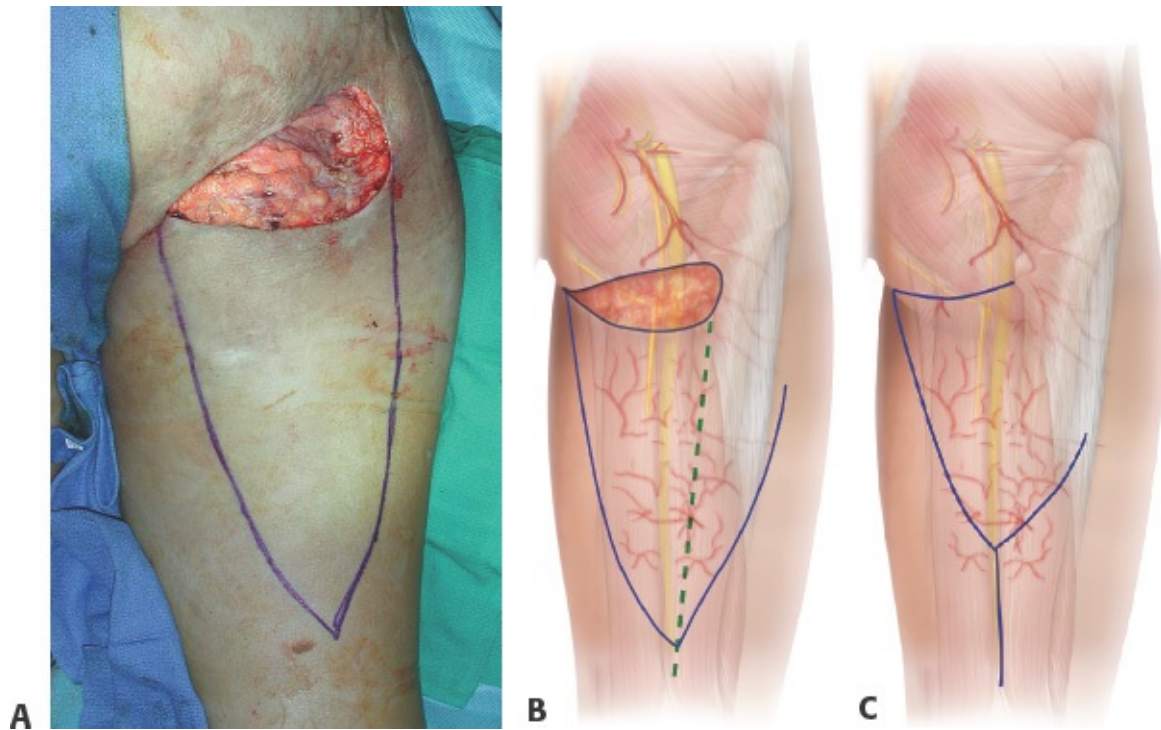
- The entire pseudobursa cavity is then coated with methylene blue dye (**TECH FIG 1D**).
 - Dye is loaded into a 10 mL syringe capped with a 14 g angiocath for clean application into tunneled areas.
- Borders of the ulcer, along a rim of any residual scar, are sharply incised.
- The rim of ulcer is grasped with an Allis or Kocher clamp for countertraction, and excision proceeds sharply through the hydrodissected planes with scissors and/or electrocautery. Endpoints are healthy, soft, bleeding tissue.
- The ulcer and pseudobursa cavity is excised en bloc, defining the new, larger defect (**TECH FIG 1E,F**).
- Osteotomy of exposed bony cortex proceeds, if indicated, using a sharp sterile osteotome.¹² Endpoints are hard, healthy, bleeding bone.
- A sterile rongeur is used to obtain a bone biopsy for culture.

■ Posterior Thigh Fasciocutaneous Rotation Flap With V-Y Closure

- Identify the midpoint between the ischial tuberosity and greater trochanter within the gluteal fold.
- A reference line is drawn from this point down the midaxis of the thigh to a distal point approximately 10 cm superior to the popliteal fossa.⁵
 - The most distal perforators are located approximately 10 cm proximal to the lateral femoral condyle.
- Outline the planned incisions for the V cutaneous island (**TECH FIG 2A**).
 - Medially, a curved line is drawn from the medial border of the ischial ulcer to the distal mark in the midaxis.
 - The lateral line curves cephalad from the distal mark toward the posterior border of the tensor fasciae latae terminating no higher than 10 cm inferior to the ischial tuberosity to preserve the first and second profunda perforators, which supply the flap with or without the descending branch of

the inferior gluteal artery (if present) via the cruciate anastomosis.⁵

- Primary closure of the donor site is possible with flap widths of 9 to 10 cm, otherwise plan for skin grafting.
- Carry incisions through marked outline into subcutaneous tissue and through the deep fascia of the posterior compartment just above the hamstring musculature.
- Begin elevation of the fasciocutaneous flap distally to protect the sciatic nerve, which, in this location, is deep to the biceps femoris.⁵
 - The posterior femoral cutaneous nerve arborizes distally and may not be a reliable reference for initial pedicle orientation.¹³
- The fasciocutaneous unit is easily and quickly raised off the posterior compartment muscles proximally with electrocautery.
 - The fascia is secured to the dermis of the skin paddle with suture to prevent shearing.¹³
- Identify and protect the sciatic nerve as it courses lateral and deep to the long head of the biceps femoris.⁵
 - The profunda femoris perforating vessels are encountered and usually preserved lateral to the sciatic nerve, approximately 10 cm inferior to the ischial tuberosity (**TECH FIG 2B**).
 - Perforators may be preserved or ligated and controlled with hemeclips/cautery if greater length is required and the inferior gluteal system/cruciate anastomosis is patent.
 - If the profunda perforating vessels are sacrificed, the dissection continues cephalad but does not extend superiorly beyond the level of the ischial tuberosity.
- The posterior thigh flap is then rotated into the ulcer/bursa defect.
- Redundant distal portion of the flap should be de-epithelialized and inset into the ulcer dead space and closed in a tension-free manner with long-acting absorbable monofilament suture over closed suction drains.
- The donor site is closed in a V-Y fashion over a drain (**TECH FIG 2C**).

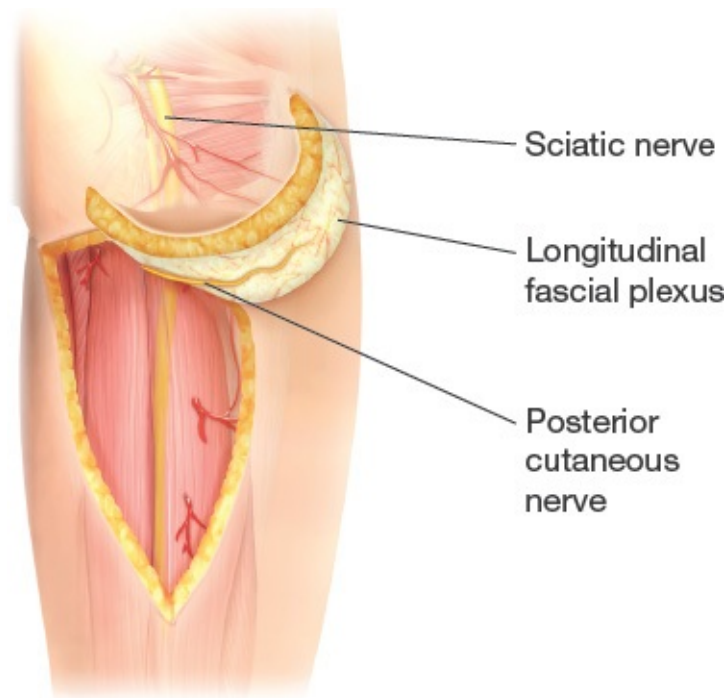


TECH FIG 2 • A. Clean ischial wound, all ulcer tissue excised. Posterior thigh/hamstring V-Y flap outlined. **B.** The profunda femoris perforating vessels are encountered lateral to the sciatic nerve, approximately 10 cm inferior to the ischial tuberosity. **C.** The flap is rotated into the defect, and the donor site is closed in a V-Y fashion.

- If primary closure is not possible, the donor site is closed with a meshed split-thickness skin graft over the intact hamstrings muscle wound bed.

Alternate Techniques

- Designing and raising the entire posterior thigh fasciocutaneous unit, with a distal V or U apex, to the base of the inferior border of the gluteus maximus has been shown to be reliable, as previously described (**TECH FIG 3**).¹³
- This technique relies on the presence of the descending branch of the inferior gluteal artery, and this system must be patent.⁵
- The descending branch of the inferior gluteal artery will supply the entire posterior thigh fascial plexus through the cruciate anastomosis.



TECH FIG 3 • The entire posterior thigh can be raised as a fasciocutaneous unit, the gluteal thigh flap.

■ Hamstring V-Y Flap²

- Identify the midpoint between the ischial tuberosity and greater trochanter within the gluteal fold.
- A reference line is drawn from this point down the midaxis of the thigh to a distal point approximately 10 cm superior to the popliteal fossa.⁵
 - The most distal perforators are located approximately 10 cm proximal to the lateral femoral condyle.
- Outline the planned incisions for the V cutaneous island.
 - Medially, a curved line is drawn from the medial border of the ischial ulcer to the distal mark in the midaxis.
 - The lateral line curves cephalad from the distal mark toward the lateral border of the pseudobursa/ulcer excision defect or the posterior border or the tensor fasciae latae.
- A wide V design that encompasses the entire posterior thigh skin will reliably capture the underlying musculocutaneous and septocutaneous perforators without the concern of centering the skin paddle over the

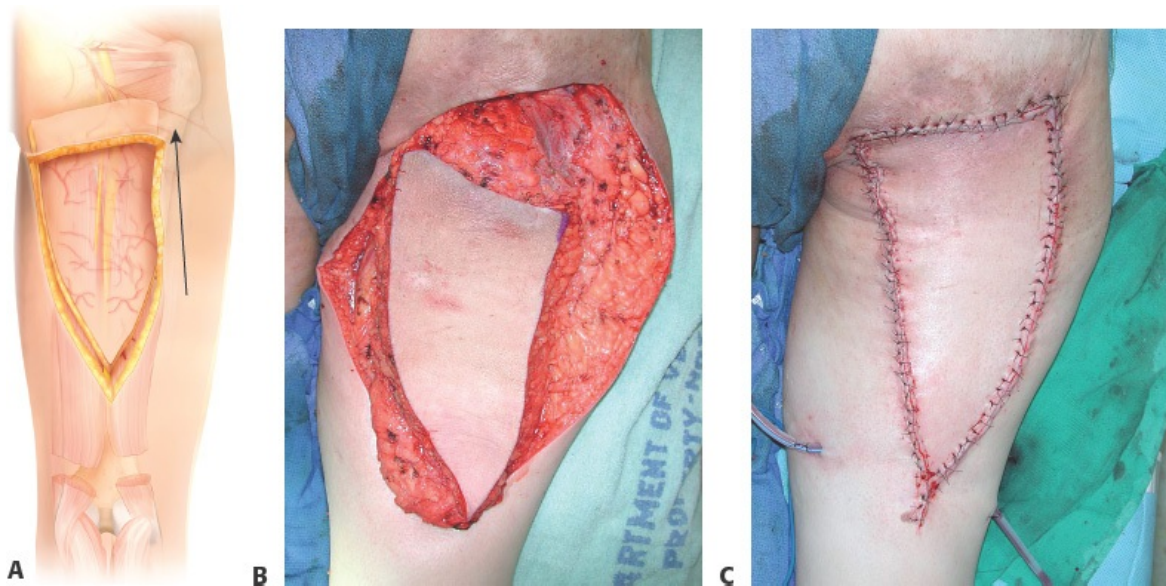
atrophied musculature.

- Note: The posterior thigh muscles may be atrophied and difficult to identify, particularly in the spinal cord injury patient.
- Carry incisions through marked outline into subcutaneous tissue and through the deep fascia of the posterior compartment just above the hamstring musculature.
- Proximally, the hamstring muscle group has often been released from the ischial tuberosity during ulcer excision and limited osteotomy.
 - Separate any remaining attachments, in particular the deeper semimembranosus, with cautery.
- Laterally, identify the distal biceps femoris as it inserts onto the head of the fibula.
 - Divide the long head and deeper short head of the muscle at its musculotendinous junction just distal to the skin island with electrocautery.
- Medially, identify the distal semitendinosus and semimembranosus as they insert onto the medial condyle of the tibia.
 - The semitendinosus is the most posterior tendon of the pes anserinus, the conjoined tendon of the sartorius, gracilis, and semitendinosus.
 - Divide the remaining hamstring muscles at their musculotendinous junction, again just distal to the skin island, with electrocautery.
- Limited blunt undermining is performed laterally and medially to free the hamstrings from the posterior compartment; however, the profunda femoris perforator pedicles need not be skeletonized (**TECH FIG 4A,B**).
- The musculocutaneous unit is easily advanced 10 cm toward the defect.
- Meticulous hemostasis is achieved within the ulcer cavity and around the elevated flap with electrocautery.
- Hamstring muscle bulk and redundant distal fasciocutaneous flap is de-epithelialized and advanced into the ulcer dead space and inset over a drain in layers with long-lasting monofilament suture.
- The cutaneous donor site is closed in layers over a drain in a V-Y fashion (**TECH FIG 4C**).

Alternate Techniques

- Potential skin paddles include medial and laterally based semicircular rotation flaps with primary closure or split-thickness skin grafting of the donor site.

- A standard (deep-based) fasciocutaneous V-Y advancement flap may be used if limited advancement required.
 - Extend the lateral incision to the lateral base of the defect and dissecting down through the deep fascia.
 - Release in the subfascial plane around the cutaneous island borders for no more than 1 to 2 cm, leaving the hamstring musculature intact.
 - The fasciocutaneous unit is advanced into the defect and closed as above.



TECH FIG 4 • **A.** Hamstring complex is divided and the flap is freed to advance proximally. **B.** V-Y hamstring flap elevated laterally and medially following muscle division. **C.** The donor site is closed in a V-Y fashion, supporting the advanced skin island.

PEARLS AND PITFALLS

Patient selection and optimization

- Recognizing and addressing preoperative medical comorbidities as well as extrinsic and intrinsic etiologic factors in a compliant patient will improve chances of surgical success.
- In a young patient with recurrent ischial ulcers and multiple

	risk factors, chances of successful wound closure are essentially 0%. ⁶
Technique	■ Ulcer preparation with tumescent technique and methylene blue aids ulcer identification, dissection, excision, and hemostasis. ■ Multiple flap options for reconstruction have been described; however, none have been shown to be superior. Plan your current flap design with future flaps in mind (including rerotation and/or readvancement).
Nutrition/glucose control	■ Albumin less than 3.5 is a predictor of early ulcer recurrence; however, nutritional parameters may not improve until after ulcer reconstruction despite adequate intake. ■ HgbA1c greater than 6 predictor of dehiscence and recurrence.
Postoperative care/rehabilitation	■ Monitor triggers for autonomic dysreflexia in spinal cord injuries at T6 or higher. ■ Monitor sitting protocol closely for signs of undue pressure. Halt progression when indicated. ■ Coach patient on proper pressure off-loading strategies on an up-to-date seat-mapped chair cushion.
Outcomes	■ Despite medical and surgical advances, pressure ulcer recidivism remains very high. ■ An engaged multidisciplinary team with a standard treatment protocol can improve outcomes and reduce costs. ■ The social/psychological aspects of wound healing in the pressure ulcer population are likely more important than surgery.

POSTOPERATIVE CARE

- The patient is transferred to a pressure off-loading bed in the supine or prone position for a recovery period of flat bed rest.
- There is little consensus on the ideal duration (2–8 weeks) of flat immobilization or ideal setting of convalescence (inpatient hospitalization, acute care rehabilitation, home).
- Preoperative skin care, management of fecal/urinary incontinence, and regimens to control moisture, glucose level, and spasticity are continued throughout the postoperative course for the lifetime of the patient.
- Mobilization is initiated sequentially, with progression to each phase

contingent upon tissue tolerance and uncomplicated wound healing.

- Immediate range of motion therapy for the unaffected limb
- Initiate range of motion therapy on the affected side at approximately week 5 (or nearing the initiation of planned sitting protocol)
- Sitting protocol, ideally in a seat-mapped cushion, is initiated at week 6.
 - Monitored sitting intervals beginning with 15-minute sessions 2 or 3 times a day on day 1.
 - Evaluate the closure for any flap or incision line erythema concerning for undue pressure.
 - Absent incision/flap concerns, may continually progress intervals by 15 minutes each day (day 2, 30-minute intervals; day 2, 45-minute intervals; and so on) until able to tolerate 4 to 6 hours of sitting
- It is essential to coach the patient on adequate repositioning maneuvers when sitting to relieve pressure and maintain tissue perfusion.
 - Side-to-side shifting, lean forward, tilt backs
- Culture-directed antibiotic therapy should be initiated based on results of bone and deep tissue biopsies at the time of surgery.
- There should be clear coordination of outpatient care and social services as well as family member/caregiver education/instructions and follow-up prior to discharge.

OUTCOMES

- Wide variation exists in the reported outcomes for pressure ulcer reconstruction, which is likely attributable to the design of many studies in pressure ulcer literature, length of patient follow-up, and definitions of outcomes.
- Keys et al. assessed the predictors of pressure ulcer reconstructive failure in a retrospective review of 135 patients.⁶
 - 39% recurrence and 16% dehiscence rates were observed; 48% of recurrences occurred within the first year and 76% within the first 2 years.
 - Albumin less than 3.5, age less than 45, and previous same-site surgical failure predicted early recurrence within 2 years.
 - Ischial ulcer, age less than 45, and previous same-site surgical failure predicted late recurrence after 2 years.
 - Poor diabetes control (hemoglobin A1c greater than 6%) was a predictor of return to operating room for dehiscence as well as ulcer recurrence.

- Larson et al. described outcome of a single surgeon experience with a standard protocol of ulcer debridement with immediate reconstruction followed by inpatient hospital admission for 3 weeks in 101 patients.¹²
- Ischial ulcers represented the most common ulcer at 49.7% of the series.
- Recurrence rate of 16.8% and complication rate of 17.3% reported.
- Primary closure was performed in 45.8% of ulcers, the remaining 54.2% underwent flap reconstruction. 17.8% had a V-Y biceps femoris flap and one patient had a hamstring myocutaneous flap.
- Surgery was performed without preoperative consideration of nutritional status or osteomyelitis.
- Outcomes for specific technique of reconstruction (primary closure vs flap reconstruction) or location of recurrence were not provided.
- Sameem et al. reviewed 55 articles in the pressure ulcer reconstruction literature covering each type of flap reconstruction and found no statistically significant difference in complication or recurrence rates between musculocutaneous, fasciocutaneous, and perforator-based flaps.¹⁴
- With no technique superior, consider the advantages and limitations of each approach rather than complication and recurrence rate.¹⁴

COMPLICATIONS

- Cellulitis
- Abscess
- Hematoma
- Seroma
- Urethral injury/leak
- Sciatic nerve injury
- Wound dehiscence
- Partial or total flap necrosis
- Ulcer recurrence

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31 Tensor Fascia Lata Flaps for Trochanteric Ulcers

CHAPTER

Terri A. Zomerlei and Jeffrey E. Janis

DEFINITION

- Trochanteric ulcers are common in chronically bed-bound patients who lie in the lateral position.
- Patient populations most at risk include those in acute care settings, nursing home patients, paraplegic populations and those with hip flexion contractures.
- In addition to unrelieved pressure, other contributing factors include incontinence/moisture, friction/shear force, and altered sensory perception.
- Characteristically, the appearance of the overlying skin only represents a small portion of the affected tissue (“the tip of the iceberg”).

ANATOMY

- The tensor fascia lata (TFL) is a thin, bandlike muscle located in the lateral thigh just distal to the greater trochanter. It functions as a lateral knee stabilizer (**FIG 1**).
- Rectus femoris borders anteriorly
- Biceps femoris borders posteriorly
- Size: The muscle is 5 cm wide, 12 cm long, and 2 cm thick.
- Origin: Anterior 5 cm of the lateral lip of the iliac crest and the lateral aspect of the anterosuperior iliac spine (ASIS). A small portion also originates from the greater trochanter.

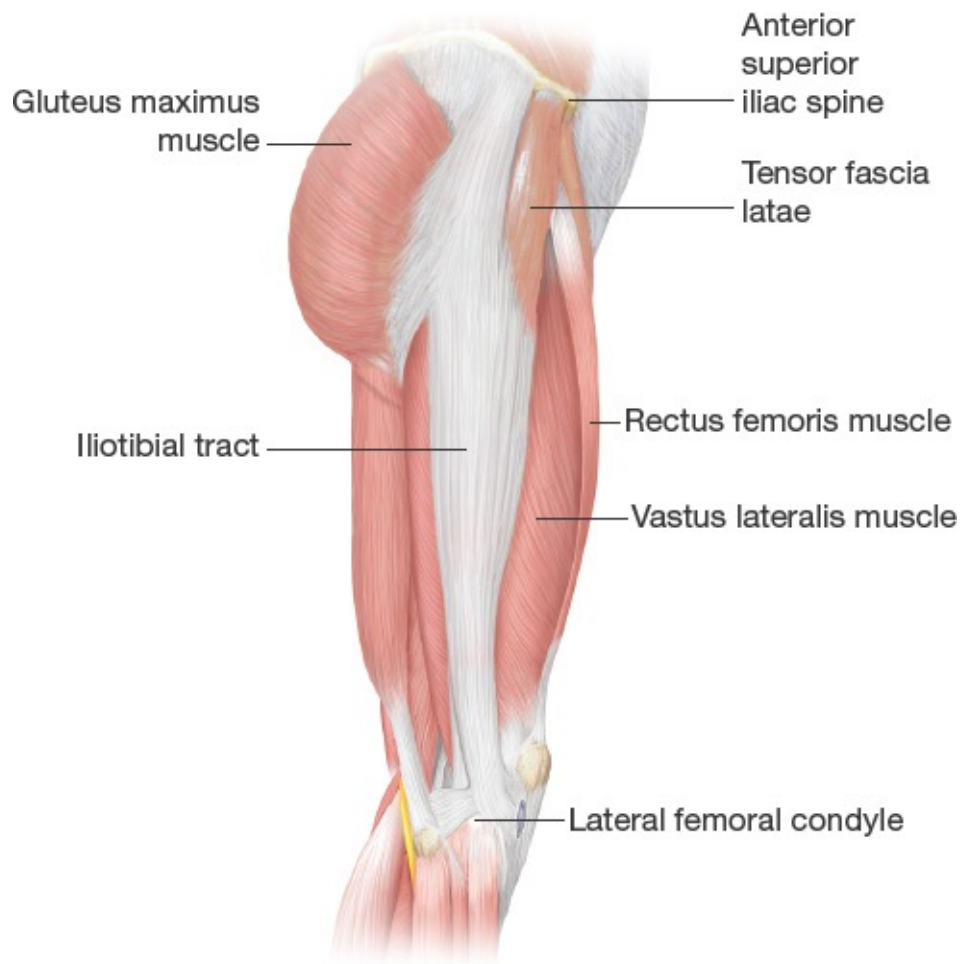


FIG 1 • Lateral leg anatomy.

- Insertion: The fascia lata is an extension of the TFL and inserts into the lateral condyle of the tibia.
- The aponeurosis of the superficial portion of the gluteus muscle, the aponeurosis of the TFL and the fascia lata are commonly referred to as the iliotibial tract.
 - When the iliotibial tract is taut, the knee is held in extension.
 - When tense, the iliotibial tract also stabilizes the hip and knee while standing.
 - Harvest of the TFL flap is associated with minimal functional morbidity.
- The TFL flap is a type I muscle with one dominant pedicle, the lateral circumflex femoral artery (LCFA).
- The LCFA is a branch of the profunda femoris.
- The LCFA passes deep to the sartorius and rectus femoris.

- It gives rise to three branches: the ascending, the transverse, and the descending branches that supply the superior, mid, and inferior portions of the TFL respectively.
- Two venae comitantes travel with the LCFA and join the femoral vein.
- The TFL receives its motor supply from the superior gluteal nerve, which has contributions from L4, L5 and S1. It enters the muscle in the middle third on the posterior aspect.
- The TFL sensory nerve supply is from the lateral cutaneous branch of T12, which provides sensory innervation to the most superior aspect of the muscle and its overlying skin.
- The lateral femoral cutaneous nerve with contributions from L2 and L3 innervates the remaining portion of the skin and muscle.

PATHOGENESIS

- Primary mechanism of pressure ulceration is cellular ischemia.
 - Tissue pressure higher than the pressure of the microcirculation (32 mm Hg) causes ischemia.
 - If the ischemic period is long enough and repeated frequently, the eventual outcome is tissue necrosis.
- Pressure sores (decubitus ulcers) almost invariably occur in the tissue over bony prominences in persons not able to change body position frequently.
- Pressure sores overlying the greater trochanter are common in those with hip flexion contractures who lie in the lateral position.
- In acutely ill patients, third-space fluid pressure may mechanically compromise the microvasculature.
- Etiologic considerations can be divided in extrinsic and intrinsic factors.
 - Extrinsic factors: Primarily mechanical forces of the soft tissues
 - Friction: Resistance that a surface encounters when moving over another. Most often occurs with patient transfers
 - Moisture: Incontinence can lead to skin breakdown.
 - Pressure: Mechanical force that is applied perpendicular to a plane (ie, between a bony prominence and a chair or bed)
 - Shear: Mechanical stress parallel to the plane results in stretching and compression of the blood supply to the muscles and skin.
 - Intrinsic factors: Patient factors that affect the soft tissues.
 - Altered level of consciousness: Results in lack of voluntary movements and

protective reflexes that off-load pressure

- Anemia: Can result in fatigue and weakness which can contribute to and perpetuate immobility. Also affects wound healing capabilities.
- Autonomic control: Decreased levels result in spasms, perspiration with increased skin moisture, blood vessel engorgement and resulting tissue edema, and problems with bowel and bladder control.
- Age: Increasing age is associated with increased skin friability and decreased tensile strength.
- Infection: Profoundly impairs wound healing abilities
- Inflammation: Creates a hostile local milieu resulting in impaired healing, especially in the setting of chronic wounds
- Malnutrition: Results in wasting and decreased muscle bulk and impairs wound healing abilities
- Sepsis: Can result in decreased tissue perfusion and ischemia
- Sensory loss: Patient is unable to experience the discomfort associated with prolonged pressure over prominences

NATURAL HISTORY

- Pressure sores are categorized according to the National Pressure Ulcer Advisory Panel Stages (NPUAP 2016).
- Pressure sore can progress through the following stages if extrinsic and intrinsic insults are not remedied (see FIG 2 in Chapter 29).¹
 - Stage I: Intact skin with nonblanching erythema
 - Stage II: Partial-thickness skin loss with exposed dermis
 - Presents as blister, abrasion, or shallow open ulcer
 - Stage III: Full-thickness skin loss
 - Subcutaneous fat may be exposed.
 - Tunneling and undermining may be present.
 - Stage IV: Full-thickness skin and tissue loss
 - Unstageable: Full-thickness skin or soft tissues loss but depth is unknown usually due to the presence of an overlying eschar
 - Suspected deep tissue injury: Persistent deep red, maroon, or purple discoloration of intact skin may indicate deep tissue injury that needs to evolve prior to staging.

PERTINENT HISTORY AND PHYSICAL FINDINGS

The preoperative evaluation of patients with pressure ulcers includes a detailed assessment of the patient's medical history, social situation, baseline health status, and a comprehensive wound evaluation.²

■ Patient history

- How long has the ulcer been present? Acute wounds may respond to conservative treatment while chronic wounds tend to be more recalcitrant.
- What is the current wound care treatment? Changing local wound care regimens may help with improving the wound.
- What surgical options have been tried in the past? Obtain any and all operative reports as previous surgeries may limit surgical options.
- Is the patient ambulatory, wheelchair bound or bed bound?
- What type of mattress and turning regimen is currently being used? Airflow mattresses offer the best protection while normal mattresses offer little defense against pressure.
- Is fecal contamination a problem? A dressing or a temporary diverting ostomy may be prudent.
- Are there problems with urinary incontinence? Does the patient require temporary or permanent urinary diversion?
- Does the patient have spasms? Are their medications optimized to control spasms?
- Does the patient have any fixed contractures?
- What is the baseline nutritional status of the patient?
- Social history is crucial to obtain in order to understand possible postoperative barriers to care and to prevent recurrence.
 - Social support/caregiver situation
 - Resources for obtaining durable medical equipment (low air loss bed, seat cushion if bed bound or wheelchair bound)
 - Smoking or substance abuse history
 - Active or prior nicotine use increases risk of poor wound healing.
 - Consider urine cotinine testing.
 - Psychiatric illness
 - Diet, specifically amount of protein intake
 - Compliance history
- Laboratory studies
 - Complete blood count to assess for anemia or active infection
 - Albumin, prealbumin, and total protein to assess protein stores

- Coagulation panel to assess for coagulopathies
- Cultures that should be obtained with tissue or bone biopsies as wound swabs have little value due to chronic colonization. Cultures should be sent for quantitative analysis and if the organism count is greater than 10⁵, consideration should be given to systemic antibiotics and/or staged debridement and reconstruction
- Urinalysis
- Physical examination
 - All wounds must be examined manually.
 - Visual wound assessment alone is not sufficient to obtain necessary information about a wound.
 - Manually assess the size and depth of the wound, bony prominences, bursa, and presence of tunneling (may need to use long cotton tip applicator to assess tunneling).
 - If an eschar is present, the wound cannot be accurately staged.
 - A limited bedside debridement is useful to stage the wound and to facilitate local wound care preoperatively.
- From visual inspection, take note of any previous surgical scars because previous surgeries may preclude the use of a flap secondary to compromised vascular supply.
- Muscle tone and bulk are assessed, taking note of any spasticity or contraction of the extremities.
- Assess the patient's sensation in the area of the wound.

IMAGING

- MRI is recommended for all stage IV pressure ulcers to evaluate for osteomyelitis.
- T2 hypersensitivity and low-intensity T1 are sensitive and specific for osteomyelitis.
- CT scan or plain films have lower sensitivity but can be used if MRI not available or patient condition precludes its use.³

DIFFERENTIAL DIAGNOSIS

- Marjolin ulcer arising in a chronic wound
- Burn
- Soft tissue neoplasm with ulceration

- Chronic surgical wound
- Traumatic wound

NONOPERATIVE MANAGEMENT

- Relieve extrinsic pressure with frequent positional changes.
 - Turn every 2 hours when supine.
 - Lift for 10 seconds every 10 minutes when seated.
- Use proper mattress (low air loss) and cushion for seating and wheelchair (seat mapping).
- Minimize head of bed elevation (less than 45 degrees).
- Optimize underlying medical status.
 - Address spasticity (baclofen, diazepam, dantrolene).
 - Optimize nutrition.
- Local wound care in those who are poor surgical candidates or while optimizing patient for surgery
 - Dakin's one-fourth strength for a limited time period (up to 1 week) can be effective in decreasing wound colonization.⁴

SURGICAL MANAGEMENT

Preoperative Planning^{5,6}

- The most crucial aspect of the surgical management of pressures ulcers is the preoperative and postoperative care.
- Do not operate on patients until their medical status is optimized and the underlying etiology determined.
- Obtain old operative reports to know what prior attempts at closure have been tried.
- Always consider future procedures in the operative planning so as to not “burn bridges.”

Positioning

- The preferred patient position is the lateral decubitus position for ease of accessing the lateral thigh.
- Depending on patient body habitus, the TFL flap may be harvested with the patient in the supine position.
- Prior to patient transfer to the OR table, check OR table to ensure working properly.

- Place a “beanbag” body positioner on the OR table if available.

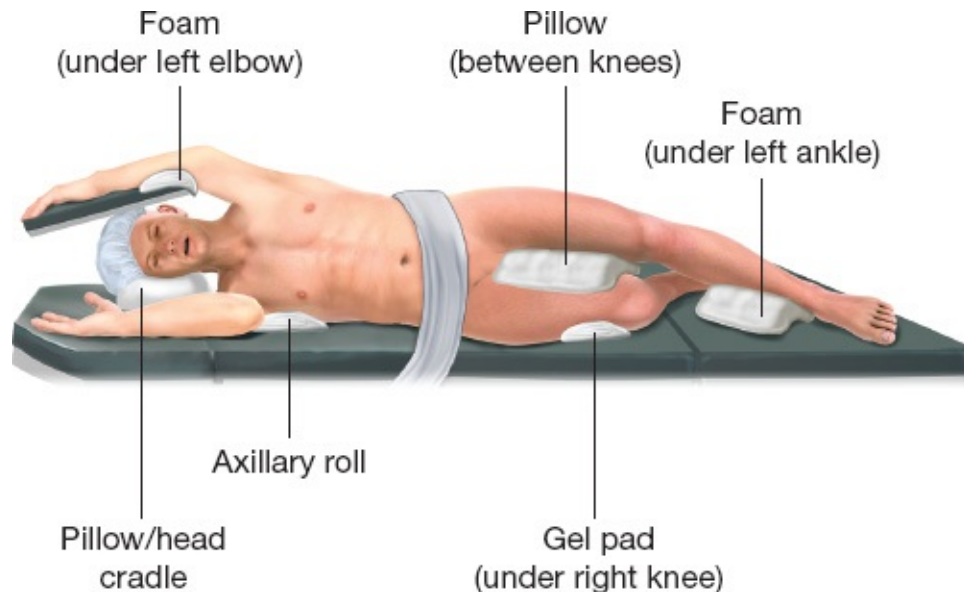


FIG 2 • Lateral decubitus position with appropriate padding.

- Patient is transferred to OR table, monitoring equipment is applied, and the patient is intubated. Ensure that tube is secure and eyes are protected.
- Patient gown should be removed.
- To place in the lateral position, with appropriate resources and careful choreography, the patient is shifted and rolled into the lateral decubitus position with the surgical site facing up (**FIG 2**).
- Make note of all pressure points and pad appropriately.
 - Head is placed in a doughnut or head cradle; ensure ear lobe and helix are not folded or compressed and eyes are protected.
 - The lower arm is placed on an arm board and pillows, or an additional arm board is placed for the upper arm.
 - The arms are secured with straps.
 - Pad the olecranon if needed.
 - A gel roll is placed as an axillary roll.
 - A gel pad is placed between the OR table and the “bottom leg” knee and ankle.
 - Foam or pillows are placed between the knees.
- Place foam or a pillow between the ankle malleoli.

- The beanbag positioner (if available) is “inflated” to help hold the patient in the lateral position.
- Ensure genitalia are free from compression.
- Check EKG pads, monitoring devices, grounding pads, and catheters to make sure they are not placing pressure on the skin and are outside of the operative field.
- Take care that any ostomies, if present, are free from compression.
- Ensure no traction on indwelling catheters.
- Secure patient to bed at both the trunk and lower legs.
- Apply warming blankets or forced air to upper trunk.

Approach

- To provide coverage for a greater trochanter pressure ulcer, the TFL flap is raised and advanced into position as a V-Y advancement flap.
- The flap is raised as a myocutaneous flap.
 - The V-Y advancement places the best perfused and bulkiest tissue into the defect.
 - In most cases, the donor site can be closed primarily.
 - If the flap is greater than 9 cm in width, the donor site may need to be skin grafted.

TECHNIQUES

■ Excisional Debridement

- Failure to adequately debride can lead to recurrent disease and poor wound healing.
- Probe wound prior to debridement so all tunneling is addressed.
- Infiltration of the peribursal area with a wetting solution (1000 mL of normal saline plus 30 mL of 1% lidocaine, plus 1 ampule of epinephrine 1:1000) can assist with hydrodissection and decrease blood loss.⁶
- Coating the cavity with methylene blue applied with gauze or a cotton applicator can assist with bursa excision and verify the completeness of the debridement.
- Debridement removes necrotic tissue and biofilm and decreases bacterial

count.

- Converts a chronic wound into an acute wound.
 - Quantitative wound cultures should be obtained following debridement so that postoperative antibiotic coverage can be tailored appropriately.
-

■ Osteotomy

- Because most pressure sores are overlying bony prominences and underlying osteomyelitis and unhealthy bone is likely, the bony prominence should be eliminated (**TECH FIG 1**).
- The greater trochanter osteotomy should be performed conservatively to lessen the prominence because its radical removal may redistribute pressure points to adjacent tissue, result in excessive bleeding, and affect the origin and/or insertion of skeletal muscle.
- Send a portion of the osteotomy specimen as a bone biopsy to evaluate for osteomyelitis.



TECH FIG 1 • A. Left trochanteric ulcer prior to debridement. This ambulatory patient developed a pressure ulcer while recovering from a major surgery. **B.** Ulcer following debridement and osteotomy. (Courtesy of Noopur Gangophadyay, MD.)

■ Tensor Fascia Lata V-Y Advancement Flap

Markings and Flap Design

- Following debridement and limited osteotomy, begin with marking anatomical landmarks (**TECH FIG 2**).
- ASIS.

- Lateral femoral condyle.
- Draw a line between these two landmarks—this line marks the anterior border of the muscle.
- The LCFA enters the TFL 7 to 12 cm distal to the ASIS.
 - Mark the position of the vascular pedicle.
 - This can be confirmed with handheld Doppler.
- Design the skin paddle so that it is centered over the TFL.
 - Mark a position on the iliac crest that is 3 cm posterior to the ASIS.
 - Draw a line from this point to the lateral condyle; this represents the midaxis of the TFL.
 - Measure a point on the midaxis that is 8 to 10 cm proximal to the lateral condyle—this marks the most distal extent that the flap can be designed.



TECH FIG 2 • TFL anatomical markings and flap design. (Courtesy of Noopur Gangophadyay, MD.)

- The distal one-third of the skin territory is unreliable and the flap design should exclude this area if possible.
- The flap width should be less than 9 cm if primary closure is desired.
- The posterior marking of the flap incorporates the anterior portion of the debrided wound.

Flap Harvest and Inset

- The flap is harvested from distal to proximal.
- After the skin and fascia lata is incised inferiorly, it is helpful to suture these

structures together temporarily to prevent shear.

- Dissection proceeds proximally in the subfascial plane (**TECH FIG 3A**).
- Anticipate the vascular pedicle starting 12 cm distal to the ASIS and proceed slowly when approaching this area.
- The lateral femoral cutaneous nerve is also located near the anterior aspect of the flap near the vascular pedicle; take care not to injure it.
- Near the point that the dissection approaches the pedicle, it is usually possible to advance the flap posteriorly into the defect.
- A back-cut may be necessary to improve the rotation and advancement into the defect.
- Drains are placed into the donor site and the recipient site.
- The flap is inset and the donor site closed with monofilament absorbable sutures and the skin is closed with sutures or staples (**TECH FIG 3B,C**).
- The advancement of the flap into the defect often produces a soft tissue “dog-ear” at the proximal part of the flap. This will flatten with time. Do not attempt to excise at this stage.



TECH FIG 3 • **A.** TFL flap dissection completed in the subfascial plane. **B.** Flap inset. Two drains were used. Donor site is closed primarily. **C.** TFL flap 3 months

postoperatively. (Courtesy of Noopur Gangophadyay, MD.)

PEARLS AND PITFALLS

Preoperative Planning

- Correct any and all extrinsic and intrinsic factors that led to the pressure ulcer development.

- Sacrifice of the TFL could affect function in a patient who is an athlete.

Operative

- Avoid undue tension with flap inset; use a conservative back-cut if needed.

- The distal skin territory is unreliable; avoid excessive flap length.

- Primary donor-site closure is facilitated by undermining the fascia lata anteriorly and posteriorly.

Postoperative Care

- Engage a multidisciplinary team including nursing, social work, and other consulting services as appropriate to ensure a safe discharge and to the patient the “best chance” of preventing recurrence.

POSTOPERATIVE CARE

- Patients are hospitalized for 1 to 2 weeks following surgery, and many patients will discharge to a rehabilitation hospital or an extended care facility for several weeks to receive a higher level of nursing care.
- A low air loss mattress should be ordered prior to the surgery and should be available to move the patient onto the mattress directly from the operating room table.
- The patient should limit the HOB to less than 10 degrees for 1 week.
- The patient should be repositioned every 2 hours, and kept off the surgical site unless on an air fluidized bed.
- The postoperative dressing should be left in place for 48 hours; after that time, a light dressing can be applied to protect against shear and moisture or the wound can be left open to the air to allow for ease of wound monitoring.

- Bladder and bowel function should be controlled to prevent urinary or fecal contamination of the surgical site.
- Spasticity should be prevented with pharmacologic measures.
- Obtain a dietary consultation so that the patient can maintain a positive nitrogen balance.
- Meticulous drain care should be performed in the hospital and taught to all caregivers.
- Obtain an infectious disease consultation for any positive operative cultures to help guide antibiotic selection and duration of treatment.
- Evaluate need for long-term intravenous access for antibiotics.

OUTCOMES

- Recurrence rate is high, especially in those with hip flexion contractures.
- Local wound/incision problems are common and should be treated with local wound care.
- Anticipate further reconstruction options with every surgical intervention.
- Control for extrinsic and intrinsic factors that contributed to the initial pressure ulcer formation.

COMPLICATIONS

- Complications are not uncommon for those with significant preoperative comorbidities.
- Hematoma or seroma may occur.
 - If patient is on anticoagulants, work closely with the hematologist to determine when these medications can be safely held and resumed in the perioperative period.
 - One or more drains should be left under flaps for days to weeks to control for fluid accumulation.
- Small localized incisional breakdown should be treated with local wound care.
- Persistent infection can be minimized with thorough debridement and long-term antibiotics as deemed appropriate by infectious disease colleagues.

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32 Repair of Flank and Lumbar Defects

CHAPTER

Sergey Y. Turin, Chad A. Purnell, and Gregory A. Dumanian

DEFINITION

- A defect in the flank/lumbar region of the abdominal wall can be a challenging problem as there is much discord in the literature regarding its etiology and management. Defined as an inability of the abdominal wall to properly contain the viscera and located lateral to the semilunar line, flank defects are encountered after surgeries requiring retroperitoneal access (transplant, vascular, urologic); these defects occurred fairly frequently, ranging from as low as 8% to 23% in the literature.^{1–4} The etiology of these defects can be of two types—a hernia or a focal weakness of the abdominal wall, usually attributed to denervation injury. A true hernia implies violation of one or more of the layers of the abdominal wall musculature. In contrast, a bulge secondary to denervation injury leading to muscle attenuation and weakness implies continuity of all three layers of the abdominal wall. In our recent review of 31 patients, we found that 55% of patients had a disruption of the internal oblique and transversus abdominis muscles, whereas the external oblique muscle was intact—a type of “partial” hernia often confused with a denervation bulge. In 32%, all three abdominal wall layers were disrupted as true incisional hernias. In the remainder, the three layers of the abdominal wall were intact but had a loss of tone due to denervation—true abdominal wall bulges.
- We present a reliable technique to repair the flank defects that is efficacious for true hernias and can be used for certain denervation injuries.

ANATOMY

- The lateral and lumbar abdominal wall is composed of three load-bearing muscular layers and their respective fascial envelopes—the external and

internal oblique and the transversus abdominis. All three of these can be compromised by an incision for retroperitoneal access. Discontinuity of these layers would lead to a hernia defect. (See the chapter on “Synthetic and Biologic Mesh for Abdominal Wall Defects,” **FIG 1**, for example.)

- The muscles of the abdominal wall are segmentally innervated by the 7th through 12th intercostal as well as the iliohypogastric and ilioinguinal nerves running between the transversus abdominis and the internal oblique muscles. In this plane, they are vulnerable to transection during a retroperitoneal approach for incisions that cross dermatomes. They are also susceptible to focal injuries from retractors, cautery, and abdominal wall full-thickness sutures (**FIG 1**).

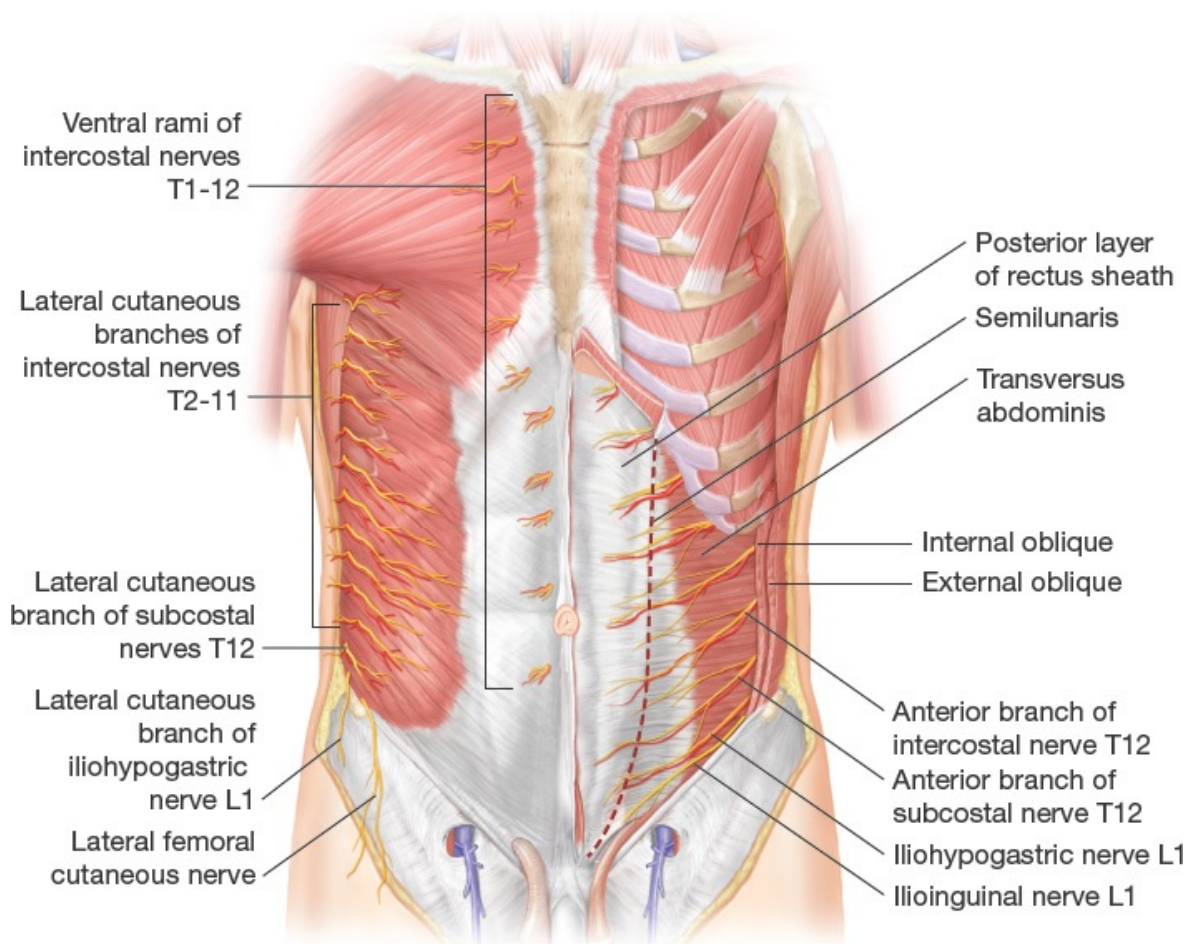


FIG 1 • Innervation of the abdominal wall.

PATHOGENESIS

- True hernias occur when the ultimate tensile strength of the repair is less than the forces applied. Acutely, the sutures can tear through the abdominal muscles during coughs and forceful movements and lead to a dehiscence or evisceration. Chronically, tissue located within the loop of suture becomes scar. When the strength of the scar, sutures, and foreign body reaction to those sutures is less than the forces applied, an incisional hernia develops. In comparison to incisional hernias, flank bulges are due to denervation of the abdominal wall. Narrow zones of denervation with loss of just one or two intercostal nerves during the original surgery do exist, often due to resection of spinal cord roots for exposure or tumors. Alternatively, there can be a large zone of denervation from a profound spinal injury. The larger the zone of injury, such as with a spinal cord injury, the less the techniques in this chapter apply.
- With maneuvers that are intended to stabilize the torso such as the Valsalva maneuver, the viscera instead distend the flank defect and cause a disagreeable and sometimes painful contour irregularity. Patients complain of discomfort due to an inability to raise their intra-abdominal pressure and altered torso mechanics—a loss of “core strength.”
- See the chapter on “Abdominal Hernia Reconstruction” for a discussion of the biomechanics of the abdominal wall and the importance of evaluating abdominal wall compliance when dealing with these defects.

NATURAL HISTORY

- These defects can often be a cause of marked pain and lead to functional impairment with diminished quality of life.⁵ The plastic surgeon will usually see the patient in a delayed setting, with the consultation being prompted by worsening symptoms.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are encouraged to obtain all the previous operative notes, and it is important to record if a rib was resected at the original procedure. Hernias present for many years are more difficult to close than a hernia less than 1 year from the index surgery. It is of great importance to discuss the medical history and comorbid conditions, such as COPD, diabetes, cardiac disease, and any rheumatoid conditions.
- Prior incisions are recorded, and an evaluation of skin quality and abdominal wall compliance is made. The patient is asked to stand as well as to lie in the

lateral decubitus position to clarify the borders and size of the defect. Palpate the bulge with an eye toward feeling any muscle contraction or edge to the defect to gain an idea of whether the remaining muscle is innervated and continuous. Look for incisions of the midline back that denote spine pathology and possible denervation.

- A social history is important to appreciate the stresses on the torso required to return to work or important social activities.

IMAGING

- We routinely obtain a CT scan of the abdomen using oral and IV contrast to assess the layers of the abdominal wall, to measure the size of the defect, and to screen for any other intra-abdominal pathology (such as a recurrent cancer) as dictated by the patient's history. Any midline hernias would be documented (though typically not addressed) at the time of the flank repair (**FIG 2**).

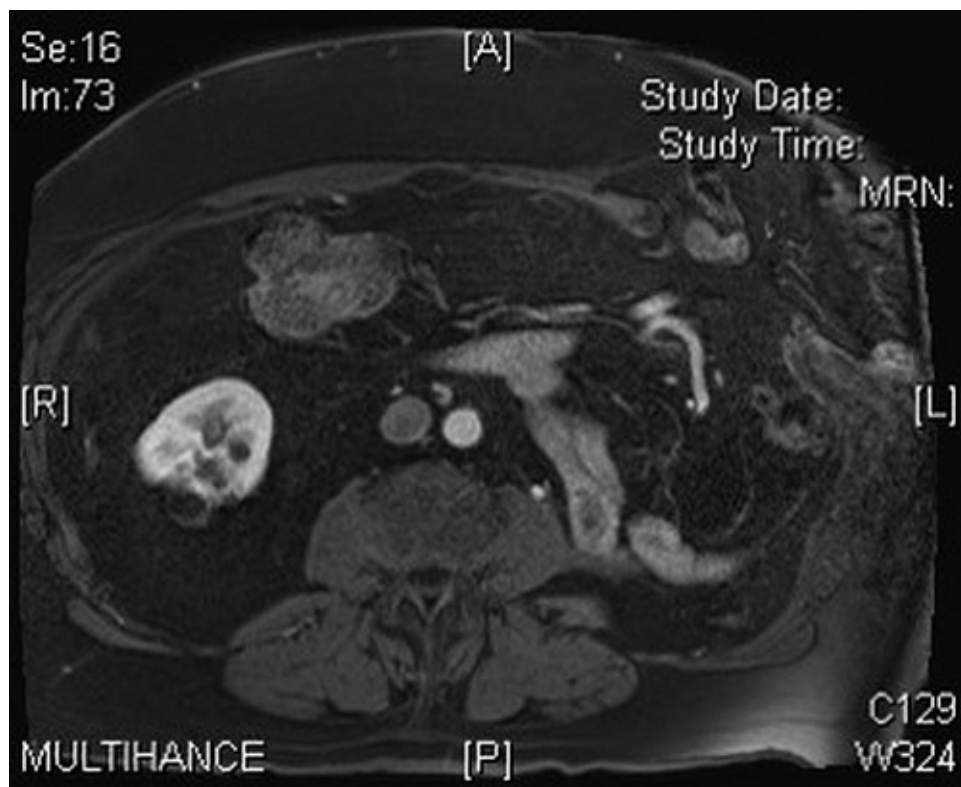


FIG 2 • CT Scan of a patient with a flank hernia.

NONOPERATIVE MANAGEMENT

- If there is adequate soft tissue coverage over the viscera, we counsel the

patient that closure of these large defects is indicated if they are symptomatic and the hernia affects their lifestyle and activities. Given the usually large size of these hernias, bowel incarceration is infrequent. Nonoperative management with binders or fajas is encouraged, but typically is only partially effective, and patients typically do not feel comfortable in these hot and heavy garments. Patients with significant medical problems and patients with large zones of denervation are often encouraged not to have repair in an effort to balance risks and benefits of the procedure.

SURGICAL MANAGEMENT

Preoperative Planning

- Patients are optimized for surgery with smoking cessation, weight loss, and improvement of exercise tolerance. A mechanical bowel prep with clear liquids, magnesium citrate, and bisacodyl tablets by mouth shrinks the bowel and improves the ability to perform the repair without changing the bowel flora.
- Use the Caprini risk-stratification model to assess the individual patient's risk for DVT/PE and assign chemoprophylaxis if appropriate.
- The lateral position required for repair of a flank hernia is not appropriate for other general surgery procedures with a single prepping and draping. Although midline hernias can be repaired simultaneously, we have tended to focus on one defect at a time.

Positioning

- The patient is positioned in a lateral decubitus position with the planned incision over the break in the operating table. (See Figure 3 for example.)
- Appropriate padding for the dependent extremities and an axillary support are placed.
- The operative field should extend from the level of the nipples to the level of the pubis and from the umbilicus anteriorly to the spinal column posteriorly (**FIG 3**).

Approach

- We approach these repairs through the original incision and then trim back any excess soft tissue at the time of closing (**FIG 4**).



FIG 3 • Later decubitus positioning.



FIG 4 • Preoperative markings.

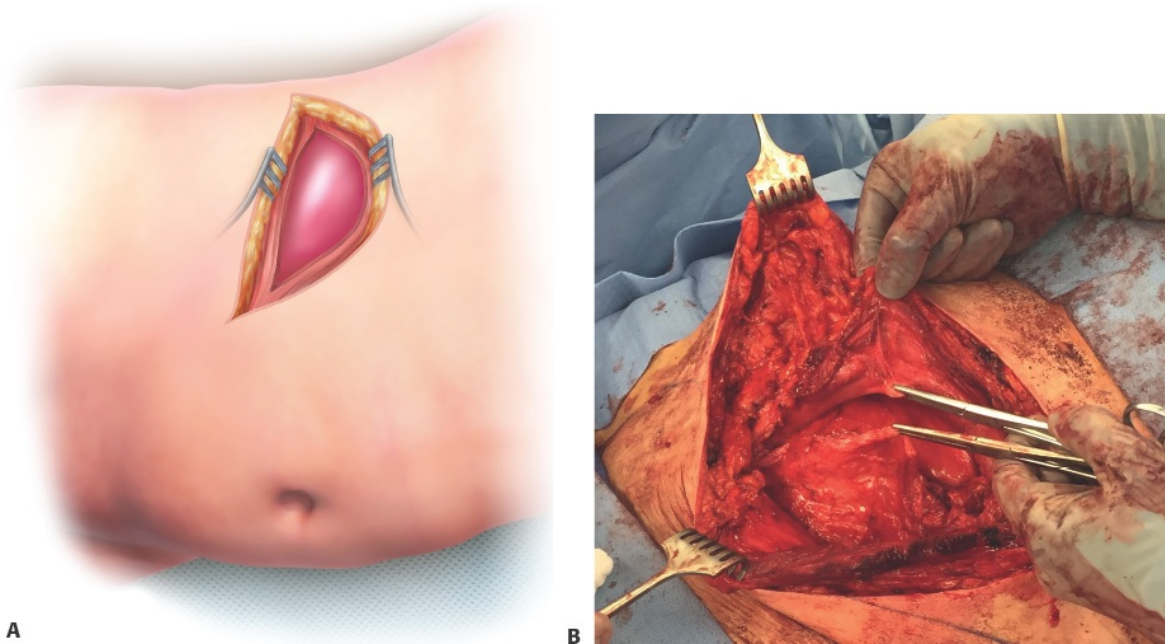
TECHNIQUES



Video p5-c032

■ Approach and Development of Tissue Planes

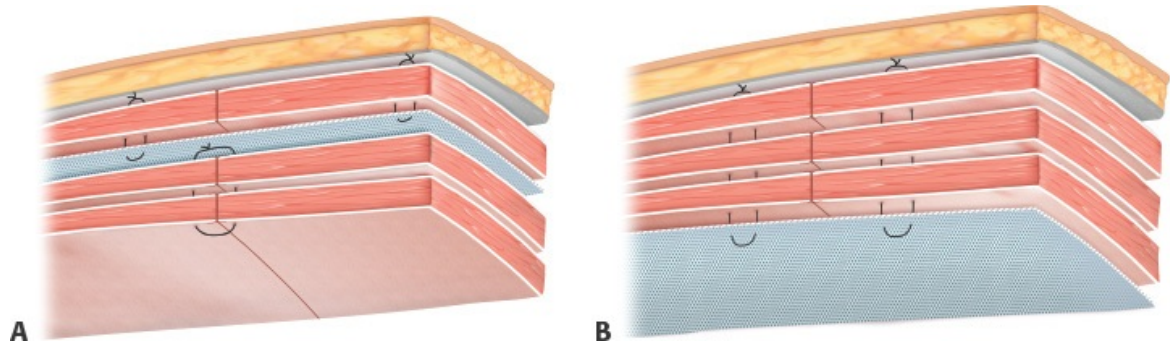
- Make a generous incision through the original scar and extend it to facilitate later skin tailoring (**TECH FIG 1A,B**).
- Incise the abdominal wall and/or hernia sac through the prior scar to enter the abdomen and then clear the inner aspect of the abdominal wall of omentum and bowel. At this point, raise skin flaps cranially and caudally to 4 cm past the level at which the abdominal musculature feels intact by a pinch test. The retracted internal oblique and transversus abdominis muscles can usually be palpated as a thickening of the abdominal wall layers.



TECH FIG 1 • A,B. Incision and exposure of the hernia sac.

■ Determining Plane of Mesh Placement

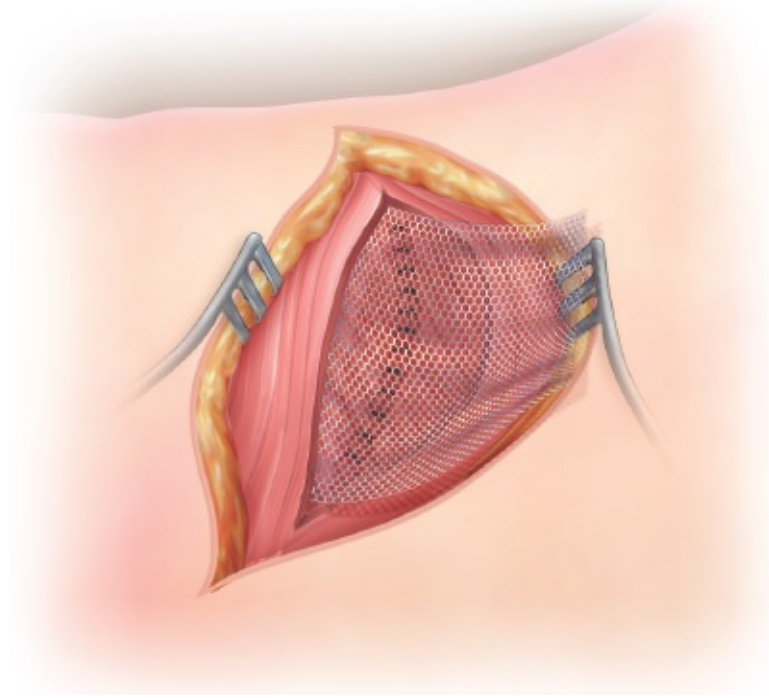
- Grasping this thick aspect of the abdominal wall, assess how easily these two shelves of muscle tissue can be approximated once the operating table is placed in the reflex position. If they can be closed easily and the defect is relatively posterior, the two deep muscle layers are closed and mesh is placed deep to the external oblique as shown in **TECH FIG 2A**.
- If tissue quality is poor and the two deep muscle layers can only be closed with reflex positioning and tension, mesh is placed intraperitoneally as an underlay as shown in **TECH FIG 2B**.
- Mesh sutured repairs use strips of macroporous mesh as sutures to approximate layers of the abdominal wall work especially well in nonmidline defects and are especially helpful where the ribs or the iliac crest limit the ability to place even a narrow strip of mesh. The mesh sutures are introduced through the abdominal wall tissue with a sharp hemostat.



TECH FIG 2 • Mesh placement illustration. **A.** Mesh is placed deep to the external oblique if the deep muscle layers are brought together easily. **B.** Mesh is placed intraperitoneally if there is tension on the closure.

■ Mesh Placement and Muscle Approximation

- The more anterior the defect, the more likely intraperitoneal placement is required. The external oblique muscle and fascia thins at this anatomic area, and renders placement of mesh between the internal and external obliques quite problematic. Regardless of the plane, the technique of mesh placement is the same. We use a 7.5-cm-wide piece of soft midweight polypropylene mesh cut several centimeters longer than the defect with 4 cm bites on either side (**TECH FIG 3**).

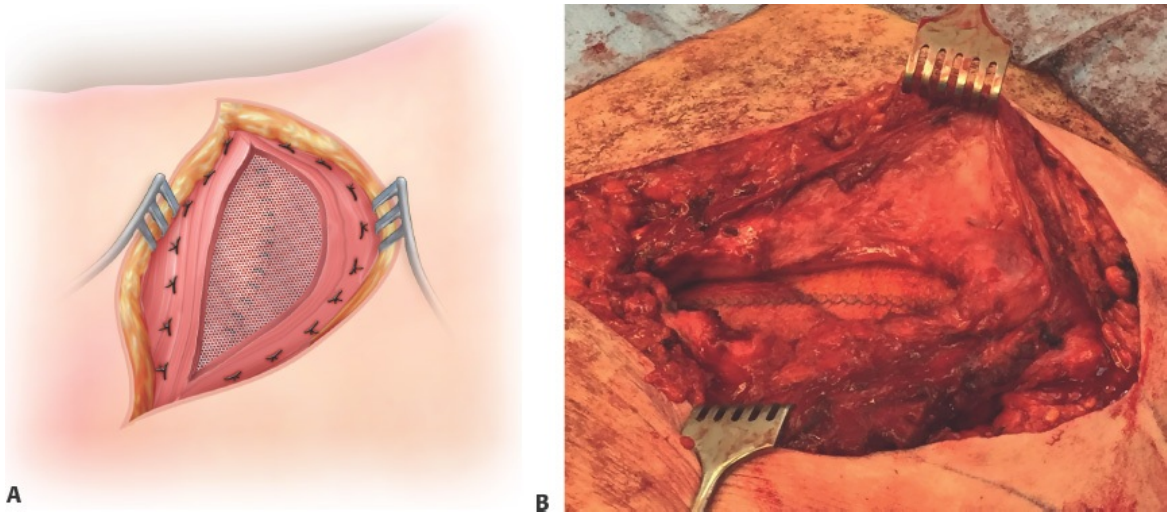


TECH FIG 3 • Mesh placement illustration—here, the internal oblique and the transversus abdominis are closed and the mesh is being placed deep to the external oblique.

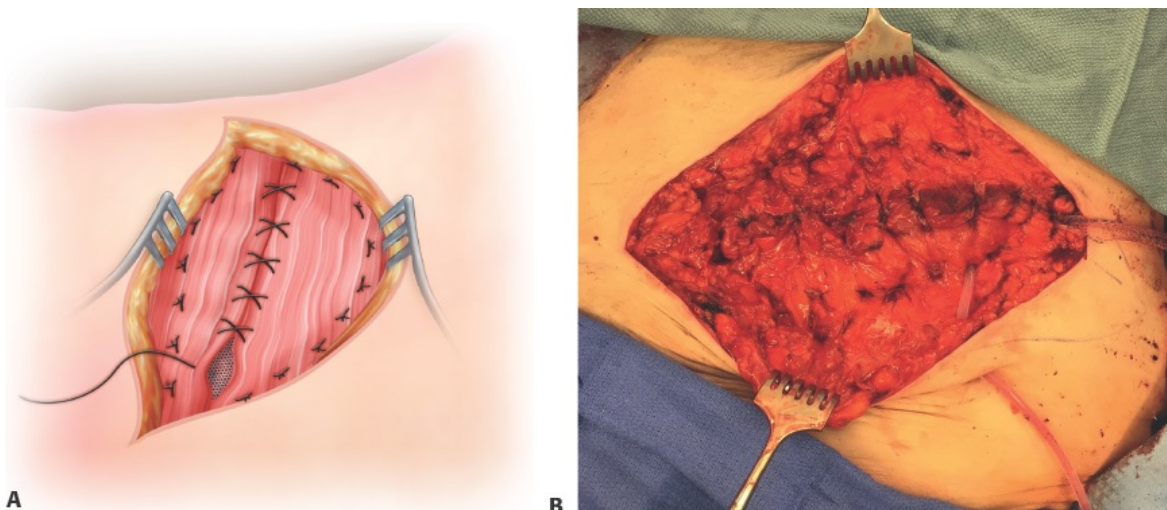
- The mesh must be oriented so that tension across the mesh to close the defect will maintain the mesh pores open and macroporous. If the mesh has a smooth and rough side, place the smoother side facing the bowel if used intraperitoneally.
- When the mesh is placed deep to the external oblique, flex the table and close the internal oblique and transversus abdominis layers using a 2-0 polydioxanone suture.
- Place the mesh in the appropriate layer and then suture the mesh in place using interrupted 0 polypropylene sutures in a horizontal mattress fashion. Use transmuscular bites approximately 4 cm from the edges of the defect and 0.5 cm from the edge of the mesh. The sutures are spaced about 2 cm from each other (**TECH FIG 4**).
- The bites must be taken close to the edges of the mesh to minimize wrinkling of the mesh. We avoid bone anchors, transosseous suturing to the iliac crest, or sutures around ribs when possible. As the mesh is narrower (7.5

cm) than the distance between sutures on each side of the abdominal wall ($4\text{ cm} \times 2 = 8\text{ cm}$), the lateral abdominal musculature falls together without tension along the axis of the mesh.

- Excise any redundant external oblique muscle, and close good quality muscle with figure-of-8 0 polypropylene sutures (**TECH FIG 5A,B**).
- This closure allows the mesh and abdominal wall suture lines to act as a load-sharing construct, distributing the forces of closure. This lowers the forces at each suture-tissue interface and minimizes suture pull-through, which is a primary cause of hernia recurrence.



TECH FIG 4 • A. Diagram of mesh placement. **B.** Narrow mesh sutured into position.



TECH FIG 5 • **A.** Diagram of closure of external oblique over mesh. Closure of muscular layer after mesh placement, creating three load-bearing suture lines. **B.** Patient with closed external oblique over mesh.

■ Closure

- Once the muscular layers of the abdominal wall are closed, redundant skin is excised to reduce dead space. Place one or two drains superficial to the external oblique (**TECH FIG 6**).



TECH FIG 6 • Final result using flexion of the table to facilitate closure

PEARLS AND PITFALLS

Scar does not aid healing	■ Scar in the subcutaneous tissues, and even more so the scarred edges of the oblique muscles, may seem like strong tissue that can hold a stitch, but it is avascular and inelastic and has decreased potential to heal. With time, the suture will cheese wire through the noncompliant tissue leading to failure. We always excise all scar and make it a priority to close healthy tissue to healthy tissue.
Suture pull-through is the enemy	■ Not using enough suture fixation points to spread out the load of the closure along the suture lines will lead to disproportionately high force at the suture-tissue interface, leading to pull-through and surgical failure.
mesh sutured repairs	■ These are efficacious and efficient means to close flank defects, though long-term follow-up does not yet exist for this novel closure method. The strips of mesh use the same concepts of force distribution and reduction of pull-through as tenants of successful abdominal wall surgery.

POSTOPERATIVE CARE

Diet management	We keep the patients NPO until return of bowel function. An aggressive antiemetic regimen is necessary to prevent emesis and the high abdominal wall stress associated with it.
Activity	Patients are instructed to ambulate on postoperative day #1. The same activity protocol exists as for midline hernias.
Pain management	We normally avoid the use of ketorolac given the fairly large dissection. Patients who we anticipate will have pain control difficulties undergo placement of an epidural catheter by the anesthesia pain team for the immediate postoperative period.
DVT Prophylaxis	DVT prophylaxis must be administered as dictated by patient risk stratification on the Caprini score.
Binders	Patients are placed into an abdominal binder to aid wound healing. They wear the binder for 1 month postoperatively to compress the soft tissues to help with healing.
Antibiotics	These are given preoperatively and for 24 hours after

	surgery.
Drains	Drains are removed when the patient has returned to normal activity and output is less than 30 mL/d.

OUTCOMES

■ In our recently published series of 31 patients⁶ treated with the technique described above, 10 patients were found to have a hernia through all layers of the abdominal wall, 17 had a defect in the internal oblique and transversus abdominis with a continuous but bulging external abdominal oblique, and 4 had denervation injury with all the muscle layers in continuity. Mesh placement was intraperitoneal in 19 patients and extraperitoneal in 12 patients. There were no surgical site infections, and with a mean follow-up time of 830 ($\pm$ 1051) days, there were 3 recurrences—2 had small bulges, which were successfully repaired with an additional mesh layer between the internal and external oblique muscles, and one was a small asymptomatic hernia detected on a follow-up CT.

COMPLICATIONS

- Abdominal compartment syndrome
- Hematoma/Seroma
- Infection
- DVT/PE
- Dehiscence

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Section VI: Posterior Trunk Reconstruction

33 Erector Spinae (Paraspinous) Muscle Flap

CHAPTER

Lauren M. Mioton and Gregory A. Dumanian

DEFINITION

- The erector spinae muscle flap is used for coverage of spinal wounds.

ANATOMY

- The erector spinae, also known as the paraspinous muscles, are paired structures comprised of the iliocostalis (most medial), longissimus, and spinalis muscles (most lateral).
- The iliocostalis muscle originates from the sacrum, erector spinae aponeurosis, and iliac crest, with insertions onto the ribs and transverse processes of C6-C4. It contributes to extension and lateral flexion of the vertebral column.
- The longissimus muscle is the largest of the erector spinae with varying portions originating from the sacrum and transverse processes of the lumbar and thoracic vertebra. It inserts into the transverse processes of lumbar, thoracic, and cervical vertebrae. It contributes to extension and lateral flexion of the vertebral column.
- The spinalis muscle originates from and inserts into the spinous process of lumbar and thoracic vertebrae. It aids with extension of the vertebral column.
- The erector spinae muscles are round and large along the inferior aspect of the lumbar region but become thinner more superiorly along the underside of the trapezius.
- They have a convex shape with segmental blood vessels originating from the

thoracic and abdominal aorta, entering on the lateral and deep aspects of the longissimus and iliocostalis muscles. There are typically both lateral and medial vessels entering the erector spinae, and all of the muscle will stay viable just on its lateral blood flow. In the thorax, these vessels travel through the lateral border of the erector spinae to be the minor pedicle of the latissimus muscle.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Past medical and surgical history with attention to the back is necessary. Prior spine incisions, their location, a history of radiation, and a history of prior infections should be sought. A focused physical examination documenting prior incisions and the suppleness of the posterior soft tissues should be performed. A history of spina bifida, a cord lipoma, or lack of fusion of the posterior spinal tube implies a lack of development and/or small size of the erector spinae inferiorly.
- A prior, or planned, lateral approach to the spine may lead to transection of the erector spinae muscles and eliminate it as a flap option.

IMAGING

- No preoperative imaging is warranted in preparation for this flap.

SURGICAL MANAGEMENT

- The erector spinae muscles are no longer functional for spine extension and flexion and seen as expendable following spine fusion.
- It is an appropriate flap for wounds ranging from the high cervical to low lumbar region.
 - It may not provide coverage of high occipital or the sacral recess (between the sacrum and lumbar spine).

Preoperative Planning

- The patient's medical history should be reviewed as prior to any planned surgery.

Positioning

- The patient is placed in the prone position for the erector spinae flap procedure. Arms may be tucked at the patient's side or abducted with elbows at 90 degrees.

Approach

- The spinal wound, especially if chronic in nature, should be appropriately excised and debrided prior to reconstruction.
- Patients who have undergone prior spine surgery may have notable scar tissue in the wound bed. Clearing the surgical bed of this fibrous tissue will reduce the likelihood of postoperative wound complications as well as allow the surgeon to properly identify the erector spinae muscles and dissection planes.
- Spinal closures are performed prophylactically after spine instrumentation to help achieve a durable closure (especially after multiple prior surgeries) and also for treatment of acute postoperative spinal hardware infections. In the latter, the hardware should be assessed for stability and maintained if it feels stable. Switching out of components of the hardware and rendering it less prominent is at the discretion of the spine team. Loose nonincorporated bone graft should be removed, but it is not necessary to remove every piece of bone graft.

TECHNIQUES

■ Erector Spinae Muscle Flap

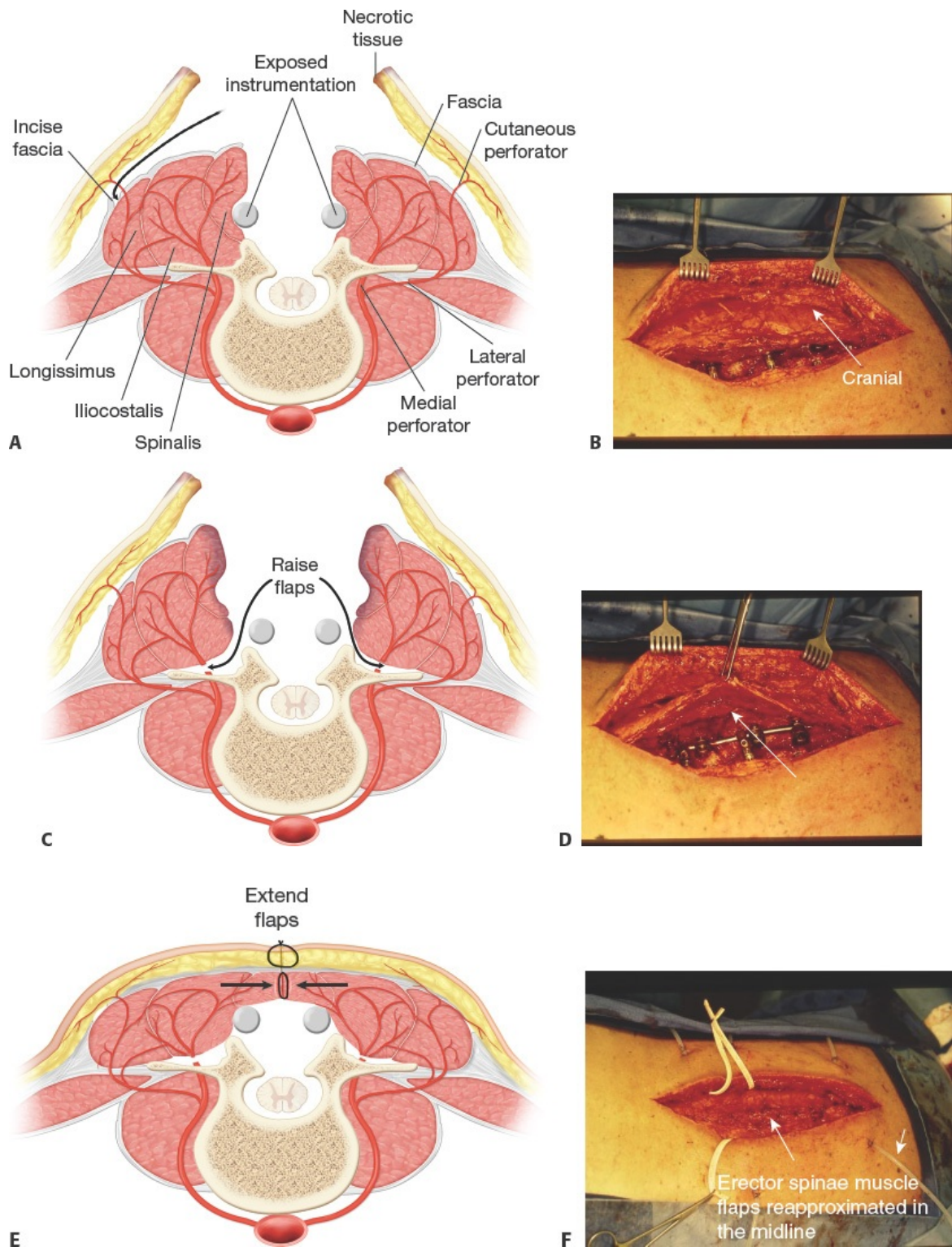


Video p5-c033

- Skin flaps are elevated on either side of the wound either deep or superficial to the thoracolumbar fascia, allowing the latissimus and trapezius muscles to

stay attached to the skin.

- Retractors can be placed on the soft tissues, and cautery can be used to enter the granulation tissue prior to bluntly dissecting in the appropriate plane.
- The cutaneous perforators and dorsal sensory nerves can often be identified and preserved during elevation of the skin flaps.
- Over undermining should be avoided to decrease the change of marginal skin vascularity and to limit dead space.
- When the dissection plane is initially superficial to the thoracolumbar fascia, palpation of the lateral border of the erector spinae should reveal its lateral border clearly. The lateral blood supply enters the muscle along this lateral line, and perforators extending to the latissimus and skin are often identified. Near this lateral border, the thoracolumbar fascia is incised along its length to allow it to mobilize medially (**TECH FIG 1A,B**).
- With the skin still retracted, dissection proceeds along the medial and deep aspects of the erector spinae muscles (**TECH FIG 1C,D**).
 - Division of the medial row of blood vessels entering the erector spinae muscles is necessary for full mobilization of the erector spinae muscles. One places dissecting fingers on the lateral border of the muscle, and one should limit the deep dissection so that the muscle maintains its lateral attachments and lateral segmental blood supply.
 - Following this dissection on both its deep and superficial surfaces allows the erector spinae muscles unfold, changing shape from a rounded muscle mass to a more elliptical form (**TECH FIG 1E**).
- With the tissues fully mobilized, stiff and inflamed tissue along the medial aspect of the skin, subcutaneous tissue, and paraspinal muscles should be sharply debrided.
- The erector spinae muscles should be reapproximated in the midline with two or more drains placed both deep and superficial to muscles (**TECH FIG 1F**).
- Drains should be placed both deep to the muscle closure and between the muscle closure and the undermined skin. The exit sites for the drains should not be on bony prominences of the back. Quilting sutures help to avoid troublesome seromas.
- The overlying skin is then closed with interrupted monofilament sutures.



TECH FIG 1 • A. Cross-sectional anatomy of superficial aspect of dissection for creation of erector spinae muscle flaps. **B.** Superficial dissection

performed in a patient with a postoperative spinal fusion procedure infection. *Arrow* shows incised thoracolumbar fascia. A nerve can be seen passing through the muscle to reach the overlying skin, and it can be preserved. **C.** Cross-sectional anatomy of deep aspect of dissection for creation of erector spinae muscle flaps. **D.** Deep dissection performed in a patient with a postoperative spinal fusion procedure infection. Arrow shows lateral-most dissection along deep surface of the erector spinae muscle. **E.** Cross-sectional anatomy of erector spinae flaps mobilized and approximated in the midline. Note the shape change that occurs in the muscles. **F.** Erector spinae muscle flaps used to close a postoperative spinal fusion procedure infection. Multiple drains placed above and below the muscle closure.

PEARLS AND PITFALLS

- | | |
|------------------|--|
| Technique | <ul style="list-style-type: none">■ Lateral release of the erector spinae muscle alone allows the muscle to move only an estimated 30% of its full potential.■ When proceeding with the medial dissection of the erector spinae muscles, place your nondominant hand on the lateral aspect of the muscle along the lateral row of vessels to ensure they are protected. |
| Outcomes | <ul style="list-style-type: none">■ When the erector spinae muscle closure is of good quality, there should be no need for a second overlying muscle flap. |

POSTOPERATIVE CARE

- The patient is placed under physical activity restrictions based on the location of spinal fusion. These are often coordinated between plastic surgery and spine surgery services.
- Patients with high-level fusions often have upper arm restrictions, including

limitations in shoulder abduction and forward flexion, that are kept in place for 6 weeks.

- The surgical dressing is kept in place for 72 hours following surgery. Once removed, the incision can be left open to the air.
- When appropriate, patients should be walking and working with physical therapy on postoperative day 1, pending approval by the spine surgery team.
- The largest and lowest closures require the patients to be on a pressure-relief bed to allow the skin and muscle flaps to be directly lied on and compressed.
- Drains are left in place until drainage reaches less than 30 cc a day for 2 days in row.

OUTCOMES¹⁻³

- A systematic review of the evidence regarding prophylactic and therapeutic use of flaps for coverage of complex spinal defects revealed that the erector spinae muscle flap was the most commonly used flap for reconstruction of spinal wounds (56% of cases).
 - Use of such flaps in a prophylactic setting in patients undergoing spinal instrumentation with spinal neoplasms led to a markedly decreased postoperative complication rate when compared to those who did not receive prophylactic flap coverage (20% vs 45%).

COMPLICATIONS

- Skin flap or muscle flap dehiscence
- Seroma
- Hematoma
- Abscess
- Hardware extrusion
- Osteomyelitis

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CHAPTER Trapezius Muscle Flap

Lauren M. Mioton and Gregory A. Dumanian

DEFINITION

- The trapezius muscle flap is a reliable option for coverage of the posterior trunk and for defects of the head and neck.

ANATOMY

- The trapezius muscle, which has a unique triangular shape, is the most superficial muscle on the posterior neck and thorax (**FIG 1**).
- It is composed of three parts: descending, transverse, and ascending portions.
 - The descending or superior part originates from the occiput and inserts into the lateral third of the clavicle. It acts to elevate the scapula.
 - The transverse or middle part originates from the spinous processes of the 1st to 5th thoracic vertebra and inserts into the acromion. It acts to retract the scapula.
 - The ascending or inferior part originates from the spinous processes of the 6th to 12th thoracic vertebra and inserts into the spine of the scapula. It acts to depress the scapula.
- There are three arterial supplies to the trapezius muscle. The relative importance and the origin of these vessels are quite variable.
 - The upper one-third of the muscle receives its blood predominantly from the transverse cervical artery, which itself is a branch of the thyrocervical trunk or the suprascapular artery almost 80% of the time. It passes through the posterior triangle of the neck to the anterior border of the levator scapulae muscle before dividing into two main branches.

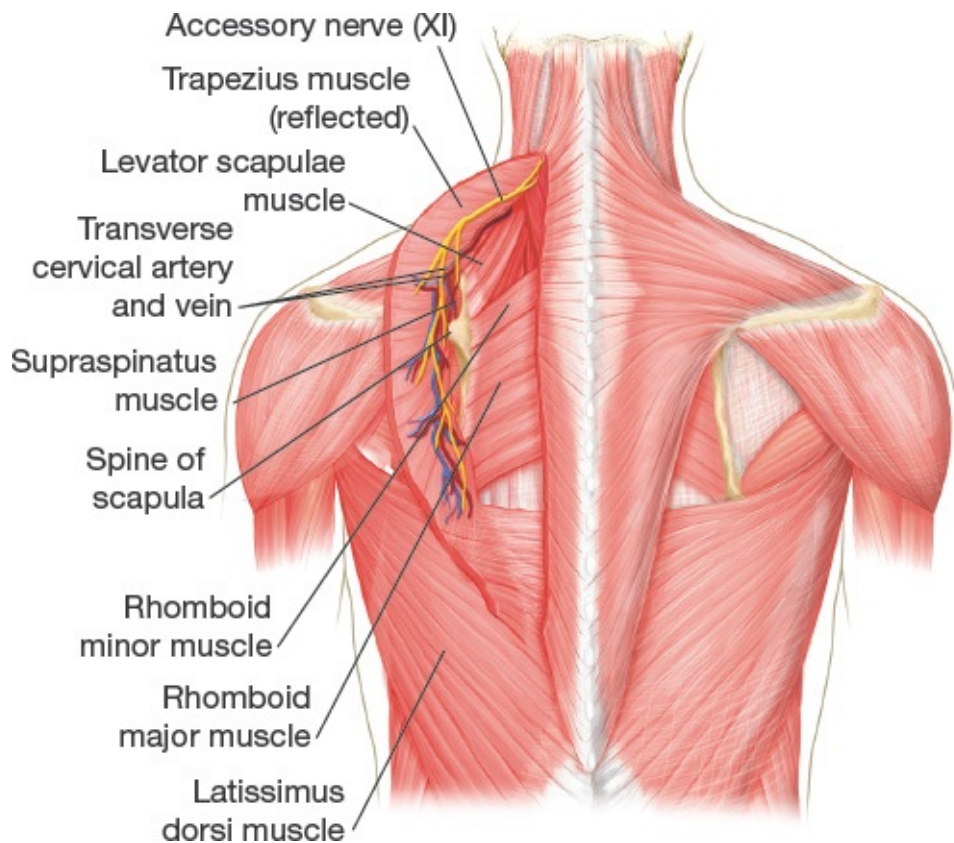


FIG 1 • Regional anatomy of the back.

- The branch entering the upper trapezius is termed the superficial cervical artery, or the superficial branch of the transverse cervical.
- The dorsal scapular artery (DSA) supplies the middle one-third of the trapezius.
- In 75% of cases, the DSA originates off the subclavian artery and passes between the upper and middle (or middle and lower) trunks of the brachial plexus before coursing through the rhomboids.
- A branch emerging from between the rhomboid muscles serves as the perforator to the inferior trapezius. It also supplies the skin paddle above and lateral to the overlying latissimus.
- The third source of blood to the inferior-most trapezius is from segmental, posterior intercostal arteries 3 to 6. Due to these numerous small perforators and a dominant larger perforator, most classify this muscle as Mathes and Nahai type V.
- Dominance of one source vessel tends to cause a lack of development of the adjacent vascular territory.

- The entry point of the transverse cervical is cephalad and medial in location to the entry point of the DSA.
- The trapezius muscle is innervated by the spinal accessory nerve (CN XI).
- It accompanies the superficial branch of the transverse cervical artery in the superior portion of the muscle and the dorsal scapular artery in the inferior portion. It crosses superficial to the superficial cervical artery in a majority of cases.
- The levator scapulae, rhomboid minor, rhomboid major, and latissimus dorsi muscles all lie deep to the trapezius.
- The levator scapulae extend from the 1st to the 4th cervical vertebrae and insert on the superior angle of the scapula.
- The rhomboid minor originates from the spinous process of the 6th and 7th cervical vertebrae and inserts into the medial aspect of the scapula.
- The rhomboid major begins off the spinous processes of the 1st to 4th thoracic vertebrae and inserts into the medial border of the scapula, below the spine of the scapula.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The medical evaluation of patients is based on their pre-existing medical conditions. No special considerations are needed for this procedure. Importance of shoulder abduction for work may lead to the choice of an alternate reconstruction.
- Physical examination
 - The skin is examined for scars or previous incision sites. If a previous radical neck dissection or instrumentation of the subclavian artery has been performed, a preoperative evaluation of the transverse cervical artery and the dorsal scapular artery with duplex ultrasound or even arteriogram may be necessary to determine vascular patency.
 - A functional assessment of the shoulder and arm mobility should be performed with baseline function documented.

IMAGING

- Imaging, such as CT or MR angiography, is often not performed in the preoperative evaluation for a trapezius muscle flap.

SURGICAL MANAGEMENT

- The trapezius muscle flap can be used for coverage of the posterior back or for

soft tissue defects of the head and neck.

- The decision to use such a flap should be based on the location of the defect and tissue required.
- Smaller defects of the posterior trunk that only require the muscle supplied by the dorsal scapular artery (descending branch) can be performed without significant arm dysfunction, as the upper and middle aspects of the muscle remain present to help with shoulder stability. However, mobilization of the entire muscle to reach the neck, face, and anterior trunk is associated with a sizeable donor site morbidity including limited arm elevation and pain. It should only be considered when other flap options have been eliminated, microsurgery is not an option, or the accessory nerve has already been divided during tumor resection.

Preoperative Planning

- Oncologic history, including radiation, should be well documented.
- One should be aware of the location and type of hardware involved.
- Any pulmonary conditions or other baseline medical comorbidities that would prohibit lateral decubitus or prone positioning should be noted.

Positioning

- Patient positioning will depend on the recipient site.
 - Trapezius muscle flap coverage of occipital, posterior neck or spinal wounds can be done in the prone position. The ipsilateral arm should be prepped into the field, and the arms should remain abducted (at 90 degrees) with the shoulder dropped to move the scapula laterally.
 - The patient may be placed in the lateral decubitus position for cases requiring coverage of the anterior head, neck, or axilla. The ipsilateral arm should be prepped in so that it remains flexible and allows the surgeon to manipulate the scapula.

Approach

- The upper trapezius muscle flap is based on the transverse cervical artery and the lower on the dorsal scapular artery. The latter is the more common. The upper (descending) portion of the trapezius based on the occipital artery and the lower-most trapezius based on segmental intercostal perforators are rarely utilized on their own.
- The entire trapezius muscle flap can be based on the transverse cervical artery,

though the most distal aspects of the flap may not remain viable.

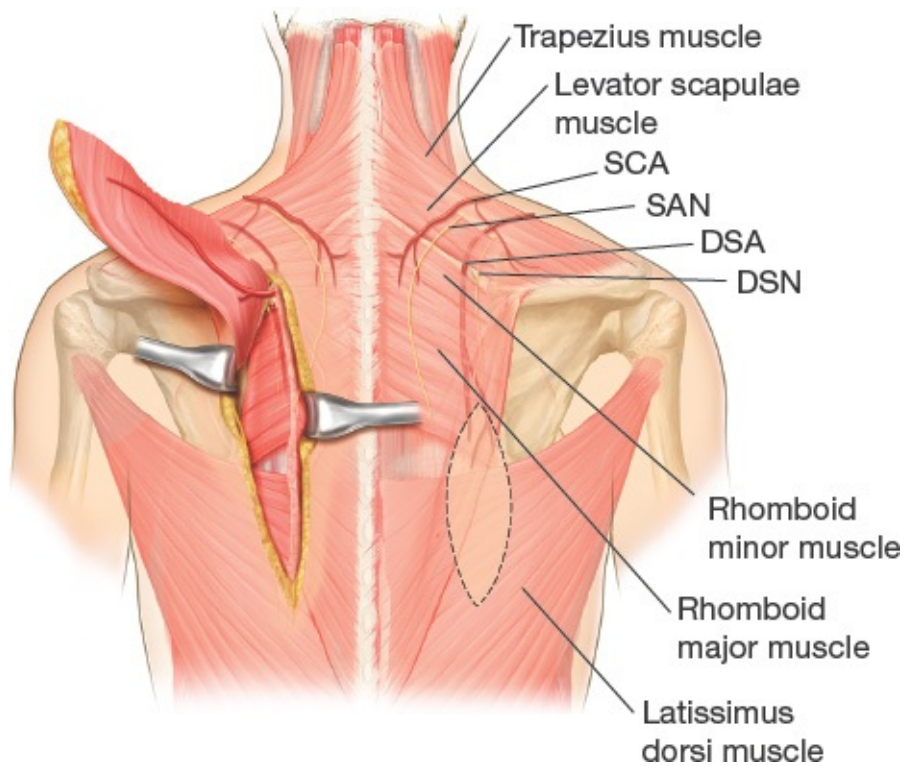
- A trapezius flap based on the branches of the transverse cervical can support the transversely oriented fibers of the muscle and can be harvested as a myocutaneous or osteocutaneous flap if need be.
- This flap can be utilized for soft tissue defects of the anterior neck and lower face, back, axilla, posterior neck, and occipital regions.
- Trapezius muscle flap based on the DSA
 - The inferior segment of the trapezius can be elevated leaving the rest of the muscle alone based on the dorsal scapular artery with limited morbidity. It is ideal for coverage of hardware in the upper thoracic and lower cervical spine area. This flap is ideal for soft tissue defects of the midface and orbital region as well as defects of the anterior neck, lower face, back, axilla, posterior neck, and occipital region.
- Preoperative markings are best done with the patient sitting or standing with the arms adducted, with a clear mark placed over the tip of the scapula and the scapular spine.

TECHNIQUES

■ Trapezius Flap Based on the DSA

- The inferior portion of the trapezius can be isolated and harvested alone based on the dorsal scapular artery (**TECH FIG 1**).
- The lower part of the trapezius muscle and scapula should be marked.
- The medial border of the scapula and the rhomboid muscles are outlined to identify the perforating point of the pedicle artery. A handheld ultrasound Doppler can be used to mark the putative entry point of the DSA into the trapezius. The main pedicle of the inferior trapezius from the DSA enters the muscle 7 to 8 cm on its deep aspect lateral to the midline at the level of the C7 spinous process.
- A skin island, if planned, should be designed so that at least one-third of its diameter overlies the distal border of the muscle. It must not lie more than 10 cm distal to the inferior angle of the scapula. Extensions of skin distal to the muscle are notoriously unreliable, and alternatives to this flap design including skin grafts placed on the muscle flap should be considered.

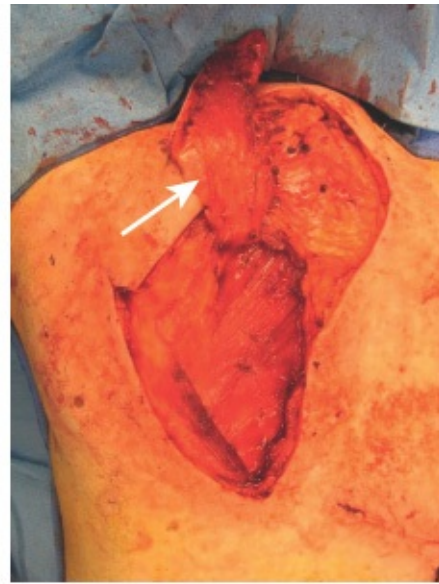
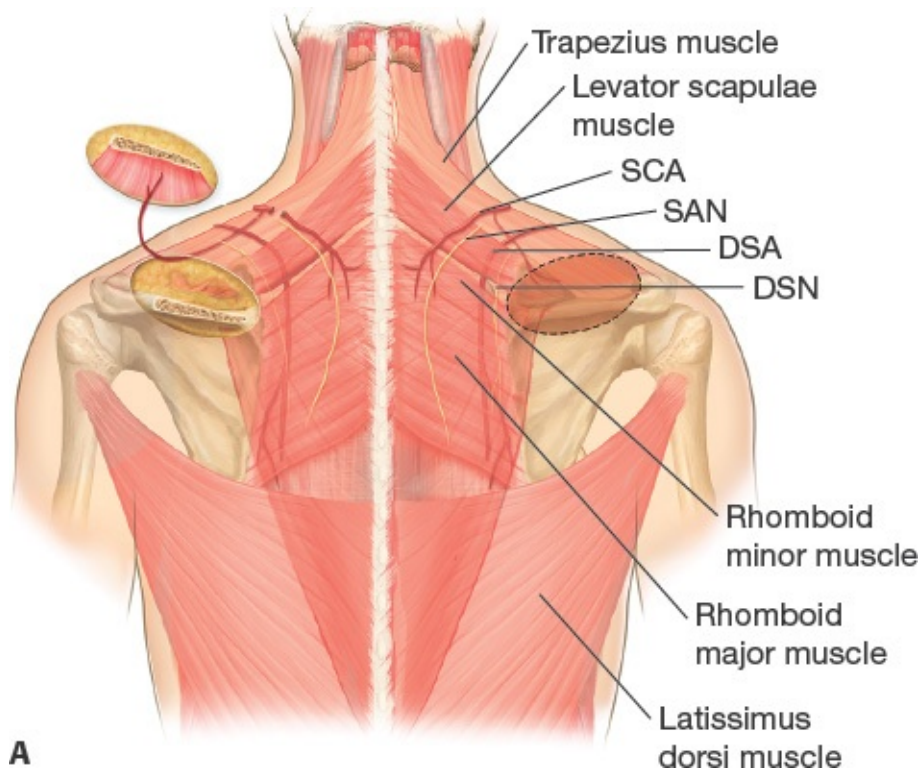
- Identify the distal and inferior triangular portion of the trapezius as it overlies the latissimus dorsi muscle. The crossing muscle fiber directions of these two muscles allow for easier distinction.
- Identification of a blood vessel on the lateral border of the inferior trapezius, termed the superficial dorsal scapular artery, can make more reliable carrying of a skin paddle.
- The skin lying lateral and cephalad to the skin paddle can be elevated off of the trapezius.
- An inferior-to-superior muscle elevation is performed until one reaches this perforator entering the deep substance of the muscle.
- Dissection around the medial attachments may be most unclear given the thickness of the attachments, whereas the lateral border of the muscle is clearly distinct from the deeper back muscles. Therefore, the medial attachments are divided only after the muscle has been elevated off of the back. As one nears the scapular spine, the lateral border also becomes indistinct. It is acceptable to divide the tendinous lateral border of the trapezius rather than continuing to follow it further laterally toward the posterior axially line.
- With the main perforator identified and under direct view, the muscle flap can be turned into an island for greater arc of rotation. The DSA pedicle itself can be mobilized to facilitate movement.
- For extreme cephalad mobilization, the DSA can be temporarily clamped with a vascular bulldog, and flow from the transverse cervical system can be assessed. A viable muscle flap with the DSA clamped can allow for further muscle mobilization up to the transverse cervical vessel to harvest an extremely large flap. Caveats to creation of a flap based on the entire trapezius include the following:
 - The higher the dissection proceeds, the greater the postoperative morbidity due to shoulder drop. The morbidity is attributed to both pain and dysfunction.
 - The donor site should be closed directly, if possible, over a normal suction drain in two layers. Quilting sutures may help to limit troublesome seromas that often accompany muscle elevation.



TECH FIG 1 • Trapezius myocutaneous flap based on the dorsal scapular artery. SCA, superficial cervical artery; SAN, spinal accessory artery; DSN, dorsal scapular nerve.

■ Trapezius Flap Based on the Transverse Cervical (Superficial Cervical Artery)

- A smaller portion of the trapezius muscle, the transverse portion in particular, can be harvested on the superficial cervical artery (**TECH FIG 2**).
- The anterior border of the trapezius muscle; the scapula, including the spine of the scapula; and the acromion are marked. A handheld ultrasound Doppler can be used to mark the position and course of the course of the arteries.
- The acromion should be left intact. If a cutaneous component is planned, the skin island should be marked transversally with the distal aspect overlying the scapular spine. It should not extend over the middle of the scapula to ensure inclusion of the vascular pedicle.
- To allow for direct closure of the donor site, skin islands should not extend beyond 8 cm vertically and 6 cm transversally.



TECH FIG 2 • A. Elevated trapezius myocutaneous flap based on the superficial cervical artery. SCA, superficial cervical artery; SAN, spinal accessory artery; DSN, dorsal scapular nerve. **B.** Incised myocutaneous trapezius flap based on the SCA. The

skin paddle was oriented at the inferior aspect of the muscle. The patient had a cervical wound following excision of a metastatic neuroendocrine tumor. **C.** The trapezius flap inset with a 180-degree twist (arrow). The superficial dorsal scapular artery was not included with this flap, resulting in mild hypoperfusion of the skin paddle.

PEARLS AND PITFALLS

Technique ■ The higher the dissection proceeds along the lateral muscle dissection, the greater the arc of rotation but the greater the postoperative morbidity due to shoulder drop.

Therapy ■ Physiotherapy is needed to strengthen shoulder muscle agonists.

POSTOPERATIVE CARE

- The ipsilateral shoulder should be immobilized in an adducted position for 1 to 2 weeks if the donor site incision is more cephalad in location. Lower incisions, such as those seen with trapezius flaps based off the DSA, do not require immobilization for healing.
- The flap (either muscle or skin island) should be monitored for the first 5 days.
- No particular anticoagulation regimen is warranted.
- It is important to avoid pressure on the pedicle vessels.
- Beds with air cushions may offload pressure on posterior recipient sites, including occipital, posterior neck, and cervical and thoracic spine regions.
- Physiotherapy is recommended to strengthen the muscle agonists.

OUTCOMES

- Donor site function is acceptable when the accessory nerve is preserved and muscle function—the upper and middle parts of the muscle in particular—is maintained.
- Aesthetically, a trapezius myocutaneous flap has an appropriate skin match for

posterior recipient sites but may prove lighter than surrounding skin in anterior head and neck sites. The long scars over the back are often visible and cosmetically unappealing.

COMPLICATIONS

- Loss of scapula stabilization (winged scapula) weakens shoulder and arm elevation.
- Skin necrosis (in cases of skin paddles placed very distally)
- Donor site seroma

SUGGESTED READINGS

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35 Superior Gluteal Artery Perforator Flap

CHAPTER

Lauren M. Mioton and Gregory A. Dumanian

DEFINITION

- The superior gluteal artery flap is relevant to the treatment of pressure ulcers, coverage of the lower lumbar spine, and breast reconstruction.

ANATOMY

- The superior gluteal artery is a continuation of the posterior division of the internal iliac artery (**FIG 1**).
 - It runs between the lumbosacral trunk and the first sacral nerve.
 - It exits the pelvis above the piriformis and immediately divides into superficial and deep branches.
 - The deep branch passes between the gluteus medius and the iliac bone.
 - The superficial branch continues on to supply the upper portion of the gluteus muscle and overlying fat and skin.
- The superior gluteal nerve supplies this flap.
 - It arises from the dorsal divisions of the 4th and 5th lumbar and 1st sacral nerves.
 - It exits the pelvis through the greater sciatic foramen with the superior gluteal vessels.

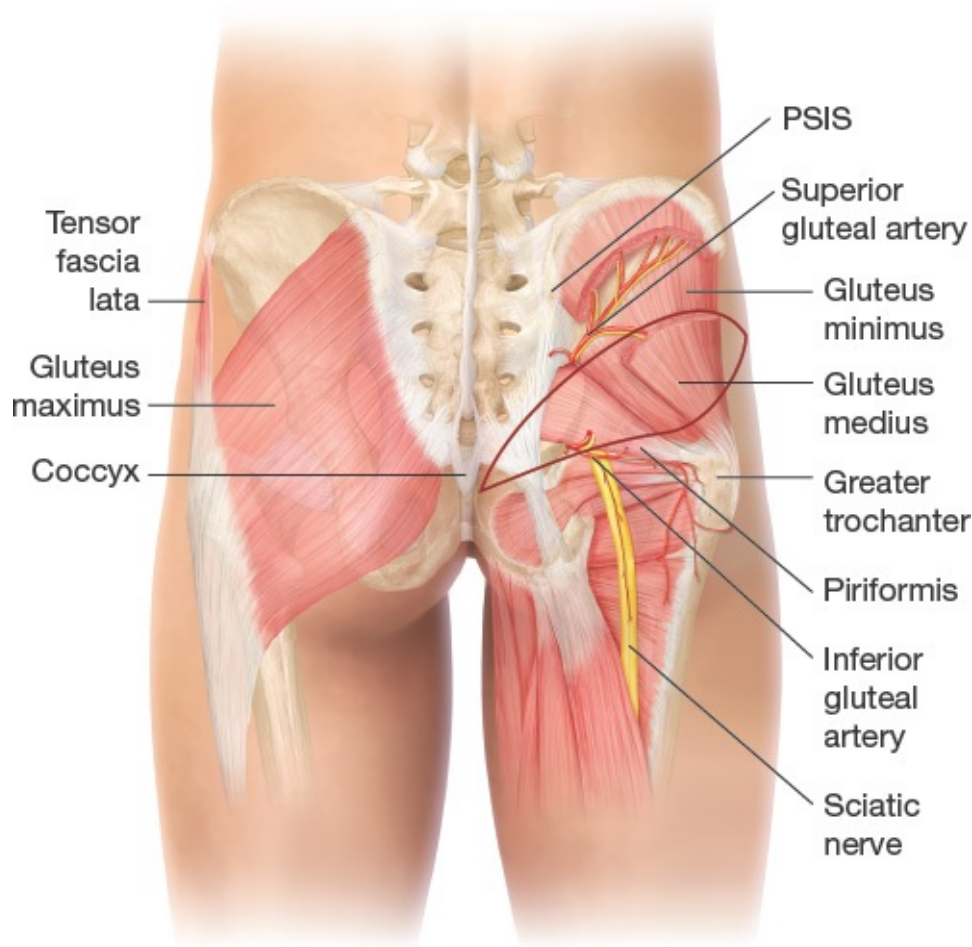


FIG 1 • Anatomic landmarks of piriformis, superior gluteal artery, and superior cluneal nerve.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and physical examination should be performed on the patient in the preoperative setting.
- Prior lower surgery in the gluteal region should be noted as it may preclude the use of the SGAP flap. A history of spina bifida could be associated with lack of formation, small size, or aberrant location of the superior gluteal artery.

IMAGING

- Specific preoperative imaging is not standard workup for SGAP flaps, though it could be performed with a computed tomography angiography.

SURGICAL MANAGEMENT

- The SGAP flap can be used for pressure ulcer reconstruction. Additionally, it is a dependable option for autologous breast reconstruction when abdominal tissue is not available.
- When designing the SGAP flap, the incisions can be in an oblique or more horizontal orientation. A horizontal scar is often deemed more cosmetically acceptable.
- Beveling on dissection creates more dead space and can therefore lead to greater seroma development. Positioning the SGAP more superiorly on the buttock allows for beveling more superiorly and is often associated with decreased revision rates and contour deformities.
- Perforators designed more laterally will lead to longer pedicles.
- The average height and length of the SGAP flap are 10 and 24 cm.

Preoperative Planning

- Patients should undergo additional medical clearance pending their comorbidities.
- The SGAP flap should be avoided in severely obese patients.

Positioning

- Positioning for an SGAP flap depends on the area to be reconstructed.
 - For pressure sore reconstruction or bilateral breast reconstruction, the patient should be placed in the prone position with the arms tucked.
 - In the cases that an SGAP flap is being used for unilateral breast reconstruction, the patient may be in the lateral decubitus position.
 - In both bilateral and unilateral breast reconstruction cases, the patient is subsequently rolled supine for final flap inset. They should be re-prepped and draped during the position change.

Approach

- Markings are placed on the patients in the position that they will be in the OR.
- A line is drawn from the posterosuperior iliac spine (PSIS) to the superior portion of the greater trochanter of the femur. The superior gluteal artery exits the greater sciatic foramen and enters the buttock at the junction of the proximal and middle thirds of this line. The location is confirmed with a handheld Doppler probe.
- Another line is drawn from the PSIS to the coccyx. The intersection of this

line with the superior edge of the greater trochanter helps identify the position of the piriformis.

- Perforators located just superior to the piriformis should be considered for flap harvesting.
- The skin paddle is marked to include these perforators.

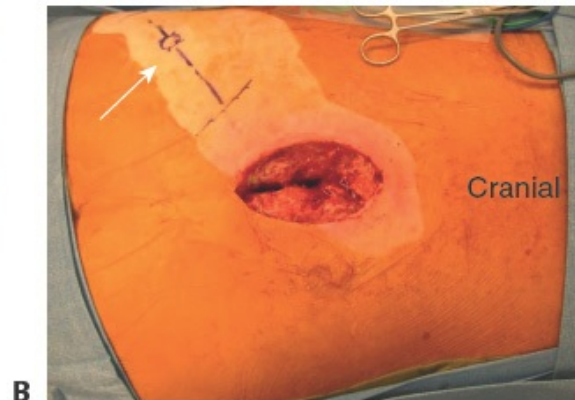
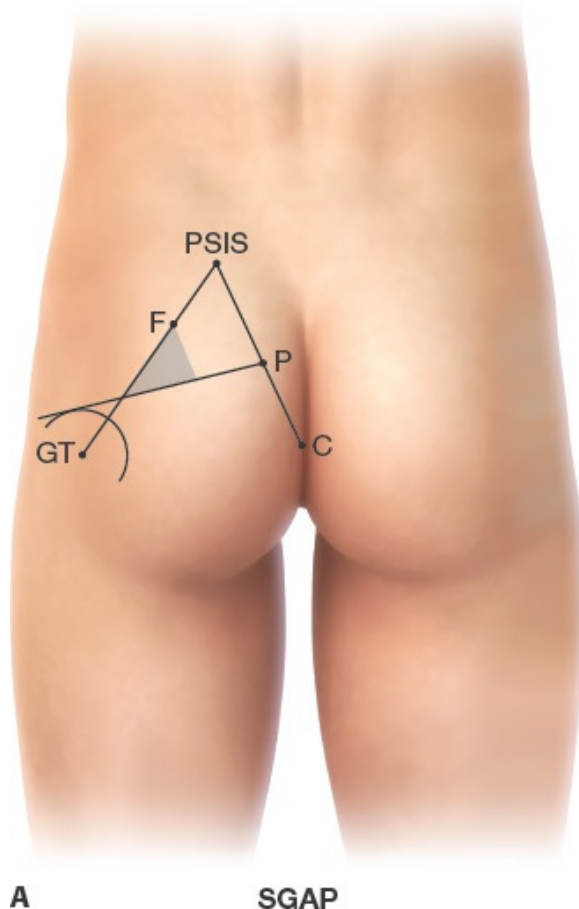
TECHNIQUES

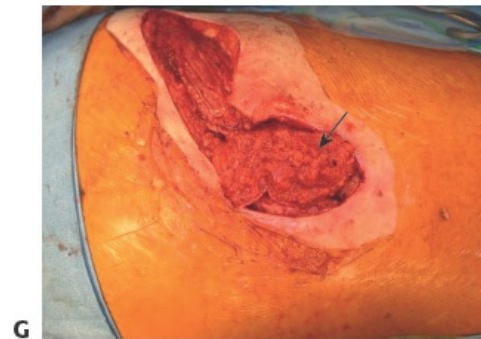
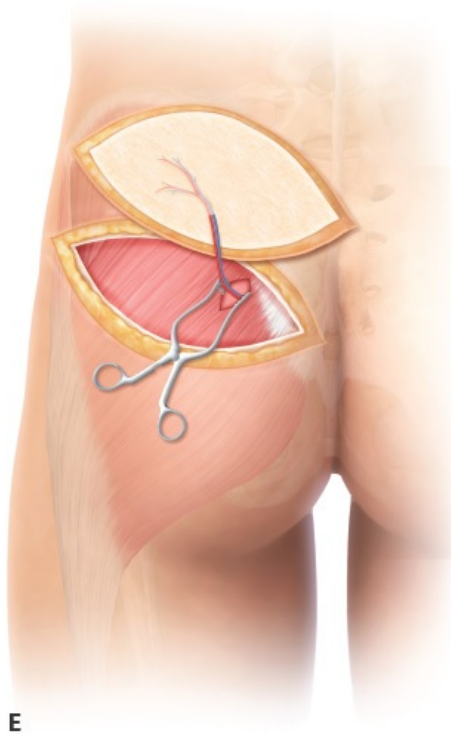
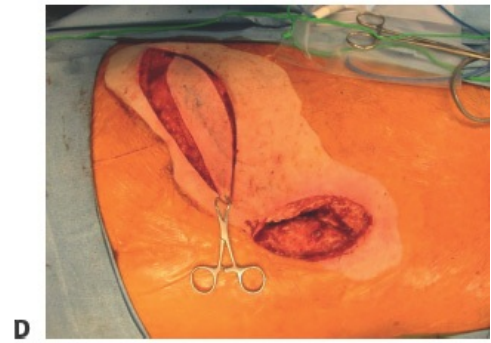
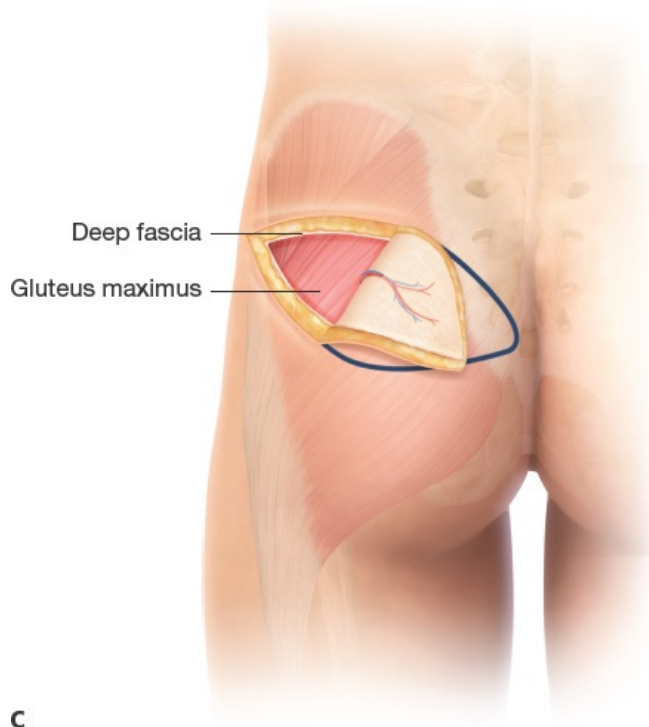
■ Superior Gluteal Artery Flap

- With the patient properly marked, prepped, and positioned, the previously drawn marks are incised (**TECH FIG 1A,B**).
- Electrocautery is then used to divide the fat to the level of the gluteal fascia.
 - The fat can be beveled superiorly and inferiorly to include as much fat as necessary for the reconstruction.
 - Avoid harvesting of soft tissue over the ischium to avoid painful sitting.
- The cluneal nerves are encountered after dissection through the superficial fascia at the cranial aspect of the flap.
- The gluteal fascia is then incised laterally, and dissection proceeds in a subfascial manner lateral to medial (**TECH FIG 1C,D**). The patient should be paralyzed to reduce the likelihood of movement and possible damage to the pedicle during dissection.
- Perforators with an artery of 1 mm or more in diameter are traced through the muscle. The muscle is split longitudinally to reveal the proximal aspect of the perforator.
- The perforator is freed through both blunt and sharp dissection, and the deep aspect of the gluteus maximus and its associated anterior fascia are reached (**TECH FIG 1E,F**).
 - The dissection can terminate at this level for pedicled SGAP flaps with appropriate pedicle length.
 - If a longer pedicle is desired for either a pedicled or free flap, the fascia is incised to expose the subgluteal fat pad. The pedicle is traced as medially as required into the pelvis.
 - There is a delicate vascular network in this region that requires broad exposure and careful dissection. The fascia is strong, rendering blunt

dissection quite difficult.

- The flap is detached from the gluteus muscle in the suprafascial plane, and the pedicle is sectioned off.
- Once the pedicled flap or free flap is placed into the recipient site, the donor site may be closed in multiple layers over a drain (**TECH FIG 1G,H**).
- The skin is undermined and the hip can be extended to reduce tension on the closure.
- The dermal edges of the donor site are often reapproximated with interrupted mattress or simple sutures in patients requiring a SGAP flap for sacral wound coverage.
- When the SGAP is utilized as a free flap for breast reconstruction, the donor site epidermis may be closed with a running subcuticular suture.





TECH FIG 1 • A. Surface landmarks for identification of superior gluteal artery entrance into the upper buttock soft tissues. **B.** Lumbosacral wound 3 weeks

after placement of spinal instrumentation and with postoperative infection. A superior gluteal artery perforator turnover flap is to be used to fill the defect. Arrow points to Doppler signal present on left buttock from the superior gluteal artery system. **C.** Lateral to medial dissection of the flap, bringing the deep fascia of the gluteus muscle with the elevated soft tissues. **D.** Superior gluteal artery perforator flap incised to include pedicle, with distal tip of flap pointed toward the greater trochanter. **E.** Dissection of the pedicle through the gluteus maximus muscle. **F.** Superior gluteal artery pedicle (*arrow*) dissected free from gluteus muscle. **G.** Turnover flap easily reaches and fills the lumbosacral defect. The skin paddle is deepithelialized and inset into the spinal defect (*arrow*). **H.** Skin closed over the flap in the midline and primary closure of donor site.

PEARLS AND PITFALLS

Incision placement

- More horizontal incisions leave fewer contour deformities and are more cosmetically acceptable.

Technique

- Beveling superiorly, inferiorly, and laterally can allow you to obtain more fat and soft tissue. Avoid beveling medially over the ischium.
- More lateral perforators lead to a longer pedicle.

POSTOPERATIVE CARE

■ Free flaps

- The patient will be monitored in the intensive care unit for at least 24 hours with flap arterial and venous Doppler checks every hour.
- Once discharged to a floor bed, the flap will be checked every 4 hours.

- If the patient is ambulatory at baseline, patient is out of bed and ambulatory on the first postoperative day.
- Patients often return to work or normal activity 4 weeks following surgery.
- Pedicled flaps for pressure sore reconstruction
 - The patient should remain inpatient, and pressure should be offloaded from the SGAP flap for 2 weeks. This can be facilitated by the use of a special air mattress or by having the patient in the prone position.

OUTCOMES

- A small retrospective review comparing SGAP free flaps to DIEP flaps for breast reconstruction reviewed equivalent flap and donor-site complication rates.^{1,2}
- Another study comparing functional outcomes after SGAP-based breast to DIEP-based breast reconstruction showed no significant lower extremity functional scores.³

COMPLICATIONS

- Donor Site Complications
 - Seroma
 - Hematoma
 - Contour deformities
 - Donor site pain
- Flap complications
 - Artery or venous occlusion
 - Venous congestion
 - Hematoma
 - Seroma
 - Partial necrosis
 - Infection

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36 Tissue Expansion for Trunk Defects

CHAPTER

Ibrahim Khansa and Jeffrey E. Janis

DEFINITION

- Tissue expansion is the mechanical increase of the surface area of tissue. It relies on two phenomena:
 - Creep: deformation of the tissue in response to stress
 - Stress relaxation: gradual decrease in the amount of force required to stretch the tissue over time

ANATOMY

- In the trunk, the tissues most commonly expanded for wound coverage are the skin and subcutaneous tissue.

PATHOGENESIS

- As the skin and subcutaneous tissue are expanded, all layers get thinner, except for the epidermis, which undergoes cellular hyperplasia via mitosis.¹
- After removal of the tissue expander, all layers return to normal thickness, except the adipose layer, which permanently thins.
- Expanded skin has improved vascularity compared to nonexpanded skin.
- Around the tissue expander, a capsule forms, consisting of collagen and fibroblasts. The zone between the native tissue and the capsule is highly vascular.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Tissue expansion is indicated when there is a local deficiency of soft tissue coverage over a wound, with healthy tissue in the surrounding zone that is able to be expanded.
- Ask about history of radiation, because this makes radiated tissues much more

stiff and difficult to expand and increases the risk of tissue expander exposure, infection, and/or loss.

- On physical examination, look for infection/contamination, as this increases risk of complications with tissue expansion.
- In the lower abdominal wall, regional transfer of tissues from the anterolateral thigh may be a better option for soft tissue coverage than tissue expansion. However, in the epigastric region, those flaps may not have sufficient reach. In addition, the epigastric region often has a scarcity of soft tissue, which increases the usefulness of tissue expansion in this area.

IMAGING

- No imaging is required specifically for tissue expansion.

SURGICAL MANAGEMENT

Preoperative Planning

- Control contamination
 - Mupirocin nasal ointment and chlorhexidine baths for 5 days preoperatively in patients at risk for methicillin-resistant *Staphylococcus aureus* (MRSA) or who are known MRSA carriers.
 - This protocol has been shown to reduce surgical site infections in total joint arthroplasties.²
- Optimize the patient to lower complication rates:
 - Glucose control: Hemoglobin A1c should be $\leq 7.4\%$.³
 - Nutrition: Albumin should be 3.25 g/dL or higher, and prealbumin should be 15 mg/dL or higher.^{3,4}
 - Obesity: BMI should be 42 or lower and preferably below 40.³
 - Tobacco usage: Patients should quit all tobacco products for 4 weeks preoperatively and 4 weeks postoperatively.³
- Tissue expander selection
 - Choose largest tissue expander that can be placed in the pocket.
 - Length of the expander should be at least as long as the defect.
 - Crescentic and rectangular tissue expanders tend to be best suited for abdominal wall defects. Rectangular expanders tend to have the highest yield.⁵
 - Remote port tissue expanders are preferred.

Positioning

- Supine with arms abducted 90 degrees, with all pressure points padded

Approach

- The planned flap movement should be designed before tissue expansion is begun. The incision to insert a tissue expander is usually made very close to the border of the soft tissue defect. This helps minimize the amount of tissue between the leading border of the flap and the wound, which will be discarded, and provide for expansion of uninjured/unscarred tissue to transpose later directly to the defect.

TECHNIQUES



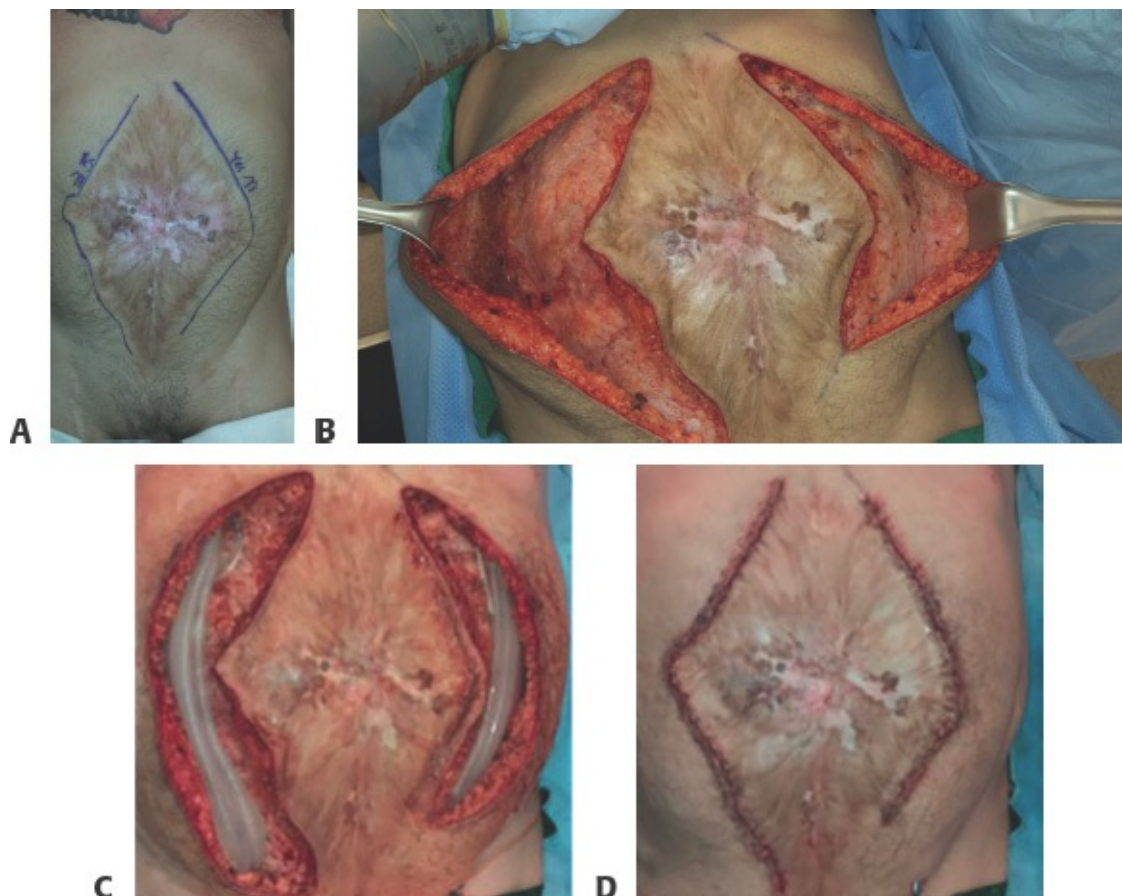
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Subcutaneous Tissue Expander Insertion Into the Abdomen

- Prep the skin with alcohol-containing prep (chlorhexidine and alcohol or iodine and alcohol).^{3,6} If a wound is present, use iodine alone.
- Design an advancement or rotation flap, which, when expanded, will cover the defect. The leading edge of the flap should be along one of the edges of the defect (**TECH FIG 1A**).
- Make an incision within 3 to 5 mm of the edge of the defect. This will serve as the insertion access for the tissue expander and the leading edge of the flap. The incision should not be made immediately at the edge of the wound, as this incision will need to be closed and requires healthy tissue to obtain a closure robust enough to protect the tissue expander (see **TECH FIG 1A,D**). However, minimize the amount of tissue between the edge of the wound and the incision, as this tissue will be discarded.
- Dissect down to the anterior rectus sheath, and elevate the skin and subcutaneous tissue off the rectus sheath from medial to lateral. The length and width of the undermining should correspond precisely to the dimensions of the tissue expander (**TECH FIG 1B**).
- Once the precise pocket is dissected, create an additional small pocket for the remote port. Through the dissected expander pocket, choose a location for the remote port adjacent to the expander. The location should be chosen so that the remote port is distant enough from the expander to avoid expander puncture during fills, where the subcutaneous tissue is thinnest in order to facilitate palpation of the port during fills, and preferably over a bony area to provide support during needle access/insertion during fills. Dissect a small pocket that will precisely fit the remote port. Do not overdissect, as this could result in port migration or rotation.
- Obtain hemostasis and irrigate with warm normal saline and triple antibiotic solution.
- A closed-suction drain is inserted into the pocket through a separate stab incision laterally.
- Use no-touch technique to insert the tissue expander:⁷

- Re-prep the skin with Betadine and allow to dry.
- Use triple antibiotic irrigation (1 g cefazolin, 80 mg gentamicin, 50,000 units bacitracin in 500 cc of normal saline to irrigate the pocket and immerse the tissue expander).⁸
- Only one person touches the tissue expander. That person puts on new talc-free gloves.
- New retractors are used. They should be immersed in triple antibiotic solution before use.
- The skin is retracted using the new retractors, and the tissue expander is inserted into the pocket without touching the skin (**TECH FIG 1C**).
- The remote port can be sutured to the fascia if there is concern that it will rotate or migrate.
- The incision is closed in three layers using absorbable sutures (Scarpa fascia, deep dermis, subcuticular), and dressings are applied (cyanoacrylate or Xeroform) (**TECH FIG 1D**).



TECH FIG 1 • Tissue expander insertion. **A.** The

advancement flaps are designed, with the incisions along the edges of the defect. **B.** Subcutaneous pockets are dissected to precisely fit the tissue expanders. **C.** The tissue expanders are inserted into the subcutaneous pockets. **D.** Meticulous layered closure is performed.

■ Tissue Expander Fill

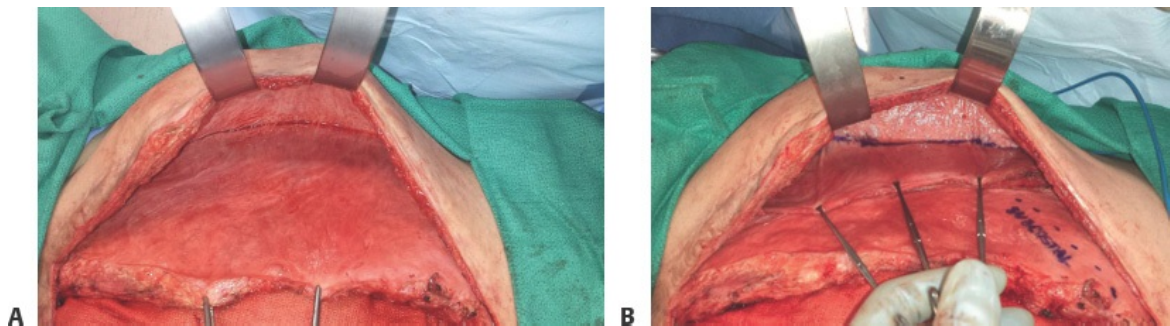
- Filling the tissue expander is begun 2 to 3 weeks after insertion (assuming no wound healing problems). Fills are performed weekly.
- The fill is performed after prepping the skin with chlorhexidine-alcohol. The end points of filling are (a) patient pain and (b) skin blanching.
- Filling is continued until the length of the flap overlying the tissue expander is at least equal to the wound diameter plus the base width of the expander. Judicious overfilling is preferable.

Tissue Expander Removal and Flap Advancement

- The advancement or rotation flap is designed (**TECH FIG 2A**).
- Before excising the wound or the skin graft on bowel, the previous incision (for tissue expander insertion) is recreated along its full length, along with any additional back cuts necessary to advance or rotate the flap.
- The tissue expander and fill port are removed, and the pocket is irrigated with warm normal saline.
- The flap is advanced, transposed, or rotated as designed, and its ability to close the defect is assessed.
- If the flap cannot reach the distal end of the defect, several options are available.
 - In a rotation flap, perform a back-cut, or Burow triangle, in order to increase the rotation of the flap. The triangle should be designed to avoid incising into the base of the flap, which may compromise vascularity.
 - Another maneuver is to incise the fascia underneath the intact skin at the point of maximal tension, which will allow for further excursion.
 - In an advancement flap, undermine farther laterally to increase

advancement. This should be performed carefully as it will decrease the vascularity of the flap. Back-cuts can also be performed unilaterally or bilaterally.⁹

- Perform capsulotomies in the tissue expander capsule. These should be performed perpendicular to the desired direction of advancement (**TECH FIG 2B**). They should be performed carefully, incising through capsule only and avoiding injuring the flap itself. Multiple capsulotomies can be performed, spaced approximately 1 cm from each other. Extrapolating from galeal scoring in scalp reconstruction, the tension should be checked after each capsulotomy, and additional capsulotomies performed if more advancement is needed.¹⁰ Capsulectomies are not recommended, as they can decrease flap vascularity.
- Only excise part of the wound, and leave the remainder for a later serial excision or second round of expansion.
- After the reach of the flap is verified, the wound is excised (partially or fully, depending on flap reach), and the flap is advanced/rotated and inset. A closed-suction drain should be placed under the flap (the capsule will tend to form a seroma unless the pocket is drained).



TECH FIG 2 • Tissue expander removal and skin advancement. **A.** The advancement flap is re-elevated, and the tissue expander is removed. **B.** Capsulotomies perpendicular to the advancement vector can be performed to increase flap excursion.

■ Other Techniques

- Some authors have described expansion of the external oblique,¹¹ of the

internal oblique-external oblique complex,^{12,13} or of the entire abdominal wall musculofascia using intraperitoneal tissue expanders.¹⁴ However, these techniques lead to thinning and attenuation of the musculofascial layer and have not gained widespread use.

PEARLS AND PITFALLS

Planning

- The planned flap movement should be designed before the incision for the insertion of the tissue expander is made.
- Most patients require multiple tissue expanders to be placed. In most cases, one tissue expander can be placed on either side of the wound, and filling of both expanders can be performed concurrently.

Surgical technique

- The capsule is highly vascular. Performing a capsulectomy at the time of tissue expander removal and flap advancement risks skin flap compromise and hematoma formation. Capsulotomies can be performed perpendicular to the desired advancement vector to increase flap excursion.
- Infection and extrusion are major complications that can result in sabotage of the expander-based reconstruction due to need for tissue expander removal. Therefore, meticulous attention to patient selection, sterile technique (both in the OR and during postoperative expansion), and adherence to end points of tissue expansion are paramount.

POSTOPERATIVE CARE

- After tissue expander insertion
 - The drain should be kept in until its output is less than 20 cc/day for 2 consecutive days with the patient ambulatory. This end point may not be reached until tissue expander fills are begun, as the tissue expander starts to fill the dead space.
 - Many surgeons keep patients on antibiotics to cover skin flora while the drain is still present and in contact with the tissue expander. There is no evidence to support or contradict this practice, and the published evidence is inconclusive.^{15,16}
- After tissue expander removal and flap advancement
 - The drain should be kept in until its output is less than 20 cc/day for 2 consecutive days with the patient ambulatory.

OUTCOMES

- Outcomes are generally good, even in the presence of ostomies or enterocutaneous fistulas. These can increase the rate of infection and add morbidity and reoperations. Despite that most patients can usually complete the expansion process successfully.^{17–20}

COMPLICATIONS

- Tissue expander infection
 - If mild cellulitis with no systemic symptoms, attempt treatment with oral or intravenous antibiotics.
 - If severe or with systemic symptoms, requires surgical washout and tissue expander removal.
- Tissue expander exposure
 - Usually requires washout and tissue expander removal. If infection is present, no new expander should be inserted. If no infection is present, a new tissue expander can potentially be inserted after washout.
- Seroma
 - If threatening skin flap viability, aspirate or perform interventional radiology drain insertion
 - If not causing a problem and not infected, can potentially observe and wait for resolution
- Hematoma
 - Requires washout as hematomas that are not evacuated will lead to capsular scarring, which would make flap movement very difficult
- Skin flap necrosis
 - If causing tissue expander exposure, requires washout and debridement and expander removal
 - If occurs after tissue expander removal and flap advancement/rotation, can usually treat with local wound care until demarcated and then may require debridement

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CHAPTER Keystone Flaps

Theodore A. Kung and Peter C. Neligan

DEFINITION

- The keystone flap is a versatile fasciocutaneous flap that transfers available soft tissue to an adjacent defect and can be designed anywhere on the body where perforators are present. It serves as a reliable alternative to more complex forms of reconstruction, such as free tissue transfer, and can be used for large as well as small defects.
- Advantages of keystone flaps include simple and rapid dissection that results in relatively shorter operative times compared to alternative reconstructive options, techniques that are easily reproducible and teachable, and reconstruction with local tissue of similar quality. In addition, although keystone flaps are based on perforating vessels, there is no need to perform a meticulous perforator dissection.
- Appropriate use of a keystone flap over other choices of reconstruction (eg, muscle flap with skin graft, myocutaneous flap, free flap) can minimize donor-site morbidity and facilitate a more expeditious postsurgical recovery.

ANATOMY

- The keystone flap is a fasciocutaneous advancement flap. The donor-site secondary defect is addressed by performing two V-Y closures.
- Knowledge of the location of musculocutaneous and septocutaneous perforators can facilitate design of well-vascularized keystone flaps (**FIG 1**).
- Anteriorly, perforators from the internal mammary, intercostal, and epigastric systems can supply keystone flaps for chest and abdominal reconstruction.
- Posteriorly, midline closures may take advantage of paravertebral intercostal perforators. Multiple perforators arising from the subscapular system may be

used to design keystone flaps for the mid and upper back. Lower back and buttock keystone flaps can include perforators from the posterior intercostal, lumbar, and gluteal systems.

- In upper and lower extremities, numerous perforators from the major longitudinal vessels can supply keystone flaps of various sizes. For larger defects, named perforators can be used to ensure adequate vascularity to the flap (eg, perforators from the descending branch of the lateral circumflex femoral artery), whereas smaller defects may depend on randomly distributed perforating vessels emanating from the underlying fascia and muscle.
- One notable location where keystone flaps may fail is the scalp due to its axial blood supply and relatively unyielding quality.
- In principle, to close a defect with a keystone flap, the volume of the keystone flap needs to be redistributed in order to fill nearly all of the primary and the secondary defect (the total defect size, primary plus secondary, is modestly reduced during closure due to advancement of the wound margins). Thus, the keystone flap is not an ideal choice to fill large concave defects. In those instances, one should consider reconstructive options that provide additional tissue volume.

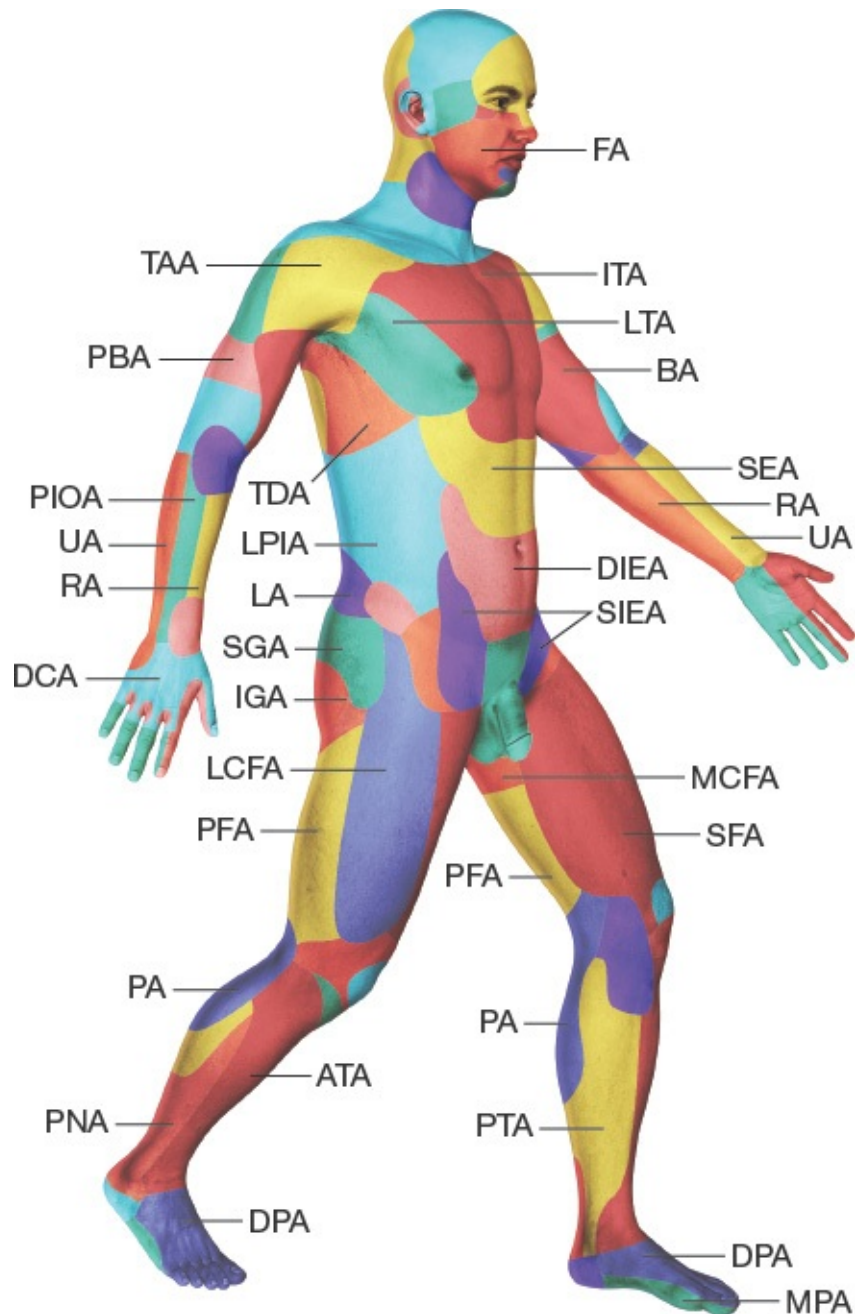


FIG 1 • Keystone flaps may be designed based on knowledge of the location of major perforators and their vascular territories. ATA, anterior tibial artery; BA, brachial artery; DCA, dorsal carpal arch; DIEA, deep inferior epigastric artery; DPA, dorsalis pedis artery; FA, facial artery; IGA, inferior gluteal artery; ITA, internal thoracic (mammary) artery; LA, lumbar arteries; LPIA,

lateral branches of posterior intercostal arteries; LTA, lateral thoracic artery; MCFA, medial circumflex femoral artery; MPA, medial plantar artery; PA, popliteal artery; PBA, profunda brachial artery; PFA, profunda femoris artery; PIOA, posterior interosseous artery; PNA, peroneal artery; PTA, posterior tibial artery; RA, radial artery; SEA, superior epigastric artery; SFA, superficial femoral artery; SGA, superior gluteal artery; SIEA, superficial inferior epigastric artery; TAA, thoracoacromial artery; TDA, thoracodorsal artery; UA, ulnar artery.

- More than one keystone flap can be designed around a defect in order to distribute the tension burden of secondary defect closure.

HISTORY

- As described by Behan in 2003, the keystone flap is a trapezoidal perforator advancement flap. The name is derived from the flap's resemblance to the shape of an architectural keystone within an ancient Roman arch.¹
- The keystone flap has been successfully applied to a vast array of clinical scenarios, including reconstruction of the trunk, head and neck, extremities, and perineum.²⁻⁷
- Multiple variations of the keystone flap have been described. These include the use of more than one keystone flap, a rotational keystone flap, and an omega-variant technique.^{1,8}

PATIENT HISTORY AND PHYSICAL FINDINGS

- The potential use of a keystone flap can be noted preoperatively during physical examination. Patients should be counseled that flap selection is ultimately based upon the dimensions of the defect as well as the laxity of the surrounding tissues. Therefore, other possible reconstructive options should also be reviewed with the patient before surgery.
- For reconstruction after tumor extirpation, knowledge of the necessary surgical margins is helpful to predict if adequate local tissue will be available for design of a keystone flap. Extensive surgical margins commonly result in a wide concave defect that demands a significant amount of volume replacement. On

these occasions, the keystone flap may not provide sufficient volume for coverage.

- The need for preoperative or postoperative radiation therapy should be noted. A keystone flap using soft tissues that have been previously radiated can demonstrate significantly decreased laxity and may not adequately advance into the defect. When postoperative radiotherapy is planned, the well-vascularized keystone flap can be expected to sustain radiation without major complications.

IMAGING

- Imaging studies are not required for successful design of a keystone flap, but oftentimes, preoperative CT scans obtained for surgical planning are helpful to identify perforators.
- Use of a handheld pencil Doppler probe can assist in identifying perforators to help design the keystone flap. Smaller keystone flaps supplied by random perforating vessels may not demonstrate Doppler signals but can still be used successfully.
- Although the viability of the keystone flap can be readily determined by clinical examination alone, if there is any question about the vascularity of the flap after harvest, intraoperative fluorescent angiography can be used to confirm both arterial inflow and venous outflow. A fluorescent dye such as indocyanine green is injected intravenously, and arterial inflow is confirmed within 30 seconds as the dye flows into the keystone flap. After about 20 minutes, venous outflow can also be confirmed by observing the absence of dye within the flap.

SURGICAL MANAGEMENT

- Keystone flaps are commonly utilized in the reconstruction of tumor extirpation defects. These flaps provide durable soft tissue coverage and well-vascularized tissue capable of sustaining adjuvant radiation therapy.
- Some resection defects are quite large and involve full-thickness removal of skin, fat, muscle, and bone (eg, sarcoma excision) (**FIG 2**). Many of these defects would otherwise require the use of a pedicled muscle-based reconstruction method or a free flap. Alternatively, resection defects can be small but located on difficult locations, such as the hand or foot and ankle, where reliable soft tissue coverage is needed to protect underlying tendon and bone (**FIG 3**).

- In the trunk and proximal extremities, where multiple robust perforators are known to exist, the keystone flap should always be a reconstructive option, especially when there is substantial soft tissue laxity adjacent to the defect.

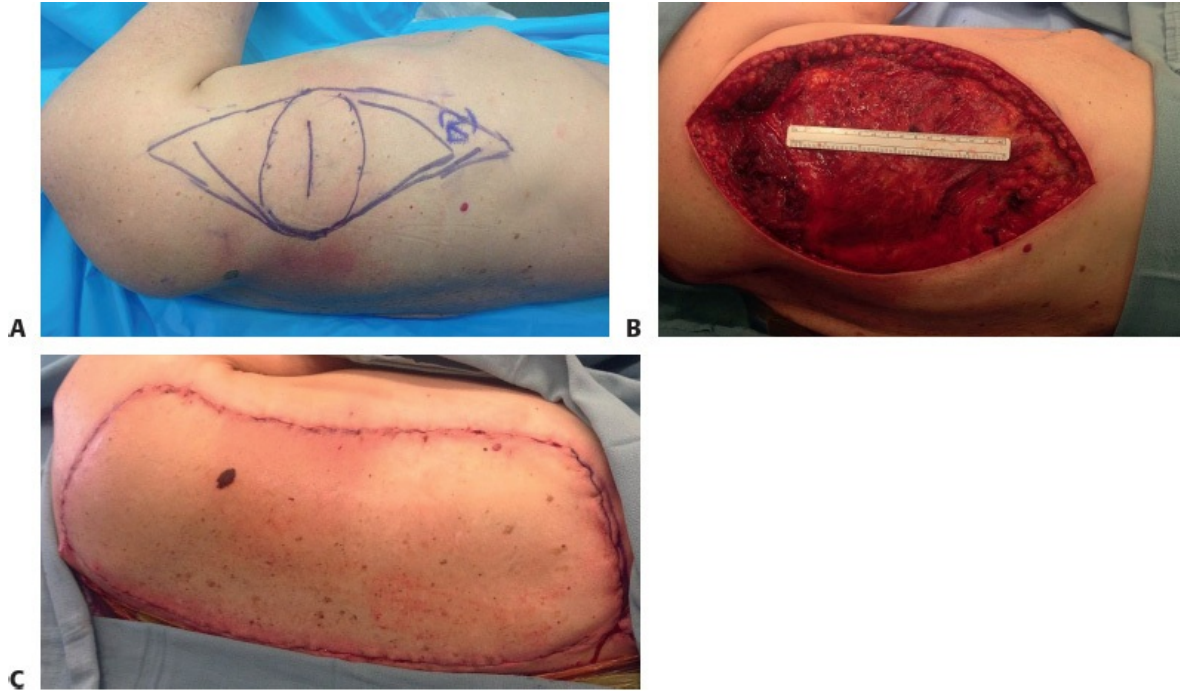


FIG 2 • Wide excision of a sarcoma of the lateral back. A large keystone flap was used to advance skin and soft tissue from a posterior to lateral direction. Adequate exposure is critical to designing a keystone flap of sufficient size to fill such a large defect.

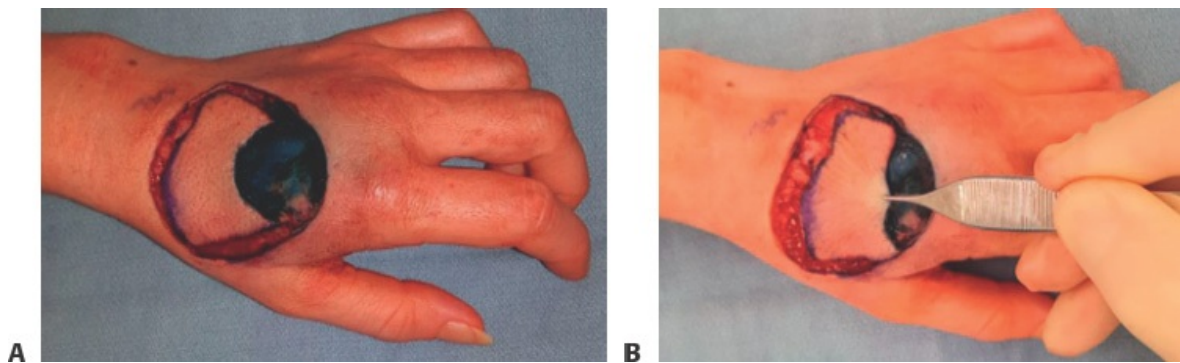


FIG 3 • **A,B.** Smaller defects can also be closed using keystone flaps. A dorsal hand wound resulting from

excision of a melanoma is closed with a keystone flap based on underlying perforators of the dorsal metacarpal arteries. Importantly, no undermining should be attempted to preserve vascularity for smaller keystone flaps.

- For more distal defects, such as those on the hand or foot, a keystone flap may still be used; however, one must be particularly careful not to undermine the flap in an effort to preserve vascularity.
- A keystone flap can be used in conjunction with another local flap to close especially large defects.
- Secondary defects resulting from harvest of another flap can be closed with a keystone flap. For example, when a wide flap containing skin (eg, radial forearm, parascapular, anterolateral thigh, etc.) is needed for reconstruction and the donor site cannot be approximately primarily, a keystone flap can be designed to permit closure of the secondary defect.

Preoperative Planning

- In the vast majority of cases, a keystone flap can be designed based upon knowing the location of key perforators near the site of the defect. Thus, there is rarely a need for dedicated preoperative imaging for the sake of the keystone flap.
- A handheld pencil Doppler probe can be used to confirm the presence of major perforators.
- Alternatively, intraoperative fluorescent angiography can be performed to identify the location of perforators.

Positioning

- When a keystone flap is to be performed after tumor extirpation, coordination with the oncologic surgeon is critical to determine the optimal positioning for reconstruction.
- Adequate exposure of the surrounding tissues is critical to properly design a keystone flap.

Approach

- Design of a keystone flap is individualized to each patient and requires

consideration of the shape and size of the defect, the surrounding soft tissue quality and laxity, and the most favorable placement of scars.

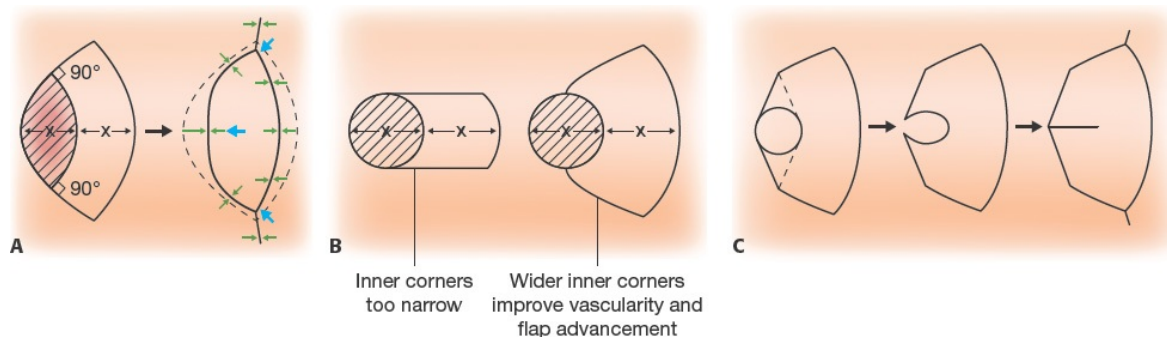
TECHNIQUES

■ Technique for Keystone Flap Design

- The skin and soft tissue around the defect are palpated to determine the areas of maximum laxity.
- Classically, for an elliptical defect, each limb of the keystone flap is drawn at a 90-degree angle to each end of the defect (**TECH FIG 1A**). For a circular defect, these limbs must be designed such that the inner corners of the keystone flap are not excessively narrow in order to optimize vascularity and advancement (**TECH FIG 1B**). Alternatively, a circular defect can be first converted into an elliptical defect, or, the keystone flap may be modified to obviate the need for excision of normal tissue (**TECH FIG 1C**).
- The width of the keystone flap should be equal to or slightly greater than the width of the defect.
- All edges of the keystone flap are incised, and dissection is carried down through the underlying deep fascia. The deep fascia must be completely incised to maximize flap mobility.
- Normally, the perforators that feed the keystone flap are not visualized.
- If adequate mobility permits, the inner corners of the keystone flap may be trimmed away in a rounded fashion.
- Closure begins by placing a stitch at the point of maximum tension. Next, the outer corners of the keystone flap are closed in a V-Y fashion. Finally, the halving principle is used for the remainder of the closure to distribute the tension.
- If there is excessive tightness during closure, several strategies can be considered:
 - Check that the deep fascia at the margins of the keystone flap has been adequately incised.
 - Perform limited undermining of the keystone flap while preserving any visualized perforators.
 - Superficially incise the underlying muscle at the edges of the keystone flap

to gain additional mobility.

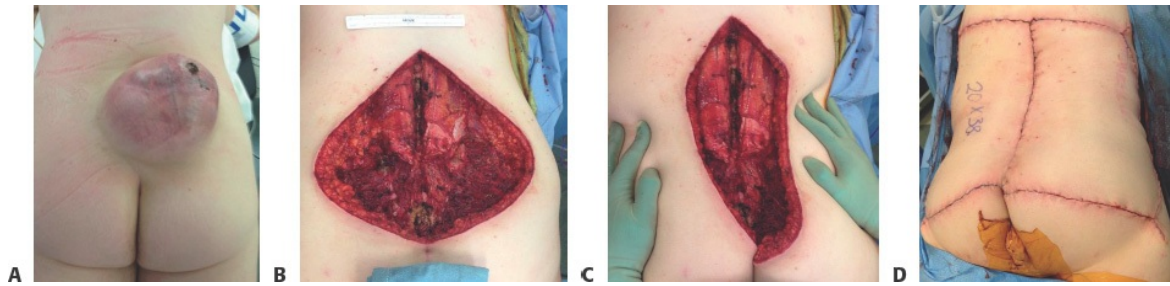
- Undermine the soft tissues surrounding the defect to recruit more laxity at the point of maximum tension.
- Turn the inner corners of the keystone flap toward the defect so that the tips of these corners become the leading edge of the keystone flap. This technique is possible only if the inner corners are sufficiently vascularized (ie, if the tips are not excessively narrow).
- Consider performing a second keystone flap on the other side of the defect.



TECH FIG 1 • A. Keystone flap closure of an elliptical defect. The donor site is closed in a V-Y fashion, and this aids in flap advancement. **B.** With a circular defect, the inner corners of the defect must not be excessively narrow. Wider inner corners will result in improved vascularity and a larger keystone flap, which facilitates flap advancement. If adequate mobility permits, the inner corners may be trimmed away in a rounded fashion. **C.** As an alternative to converting a circular defect into an elliptical defect, the keystone flap may be modified to avoid excising normal tissue.

■ Keystone Flap for Back Reconstruction

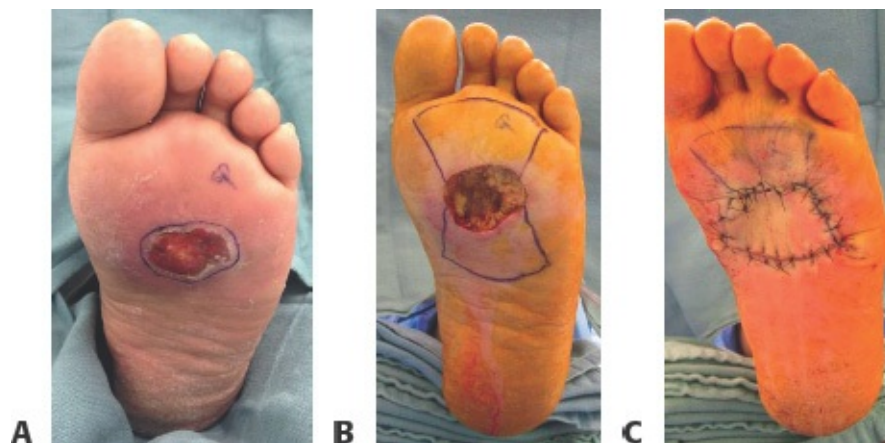
- Midline back defects are especially amenable to bilateral keystone flap closure (**TECH FIG 2**).
- Each flap is supplied by robust perforators, and the advancement requirement for tension-free closure is shared by the two flaps.



TECH FIG 2 • A-D. Excision of a large sarcoma from the midline lower back resulting in a large defect that cannot be reapproximated. Tension-free closure was achieved by performing bilateral keystone flaps.

■ Keystone Flap for Foot Reconstruction

- A keystone flap can be used on glabrous skin of the hand or foot (**TECH FIG 3**).
- In these locations, the skin is firmly adherent to the underlying fascia. Complete release of the fascia is mandatory to maximize flap advancement.
- If necessary, tissue scissors can be used to spread in a vertical fashion perpendicular to the plane of the skin. This technique releases the multiple subcutaneous septa and results in greater flap mobility.

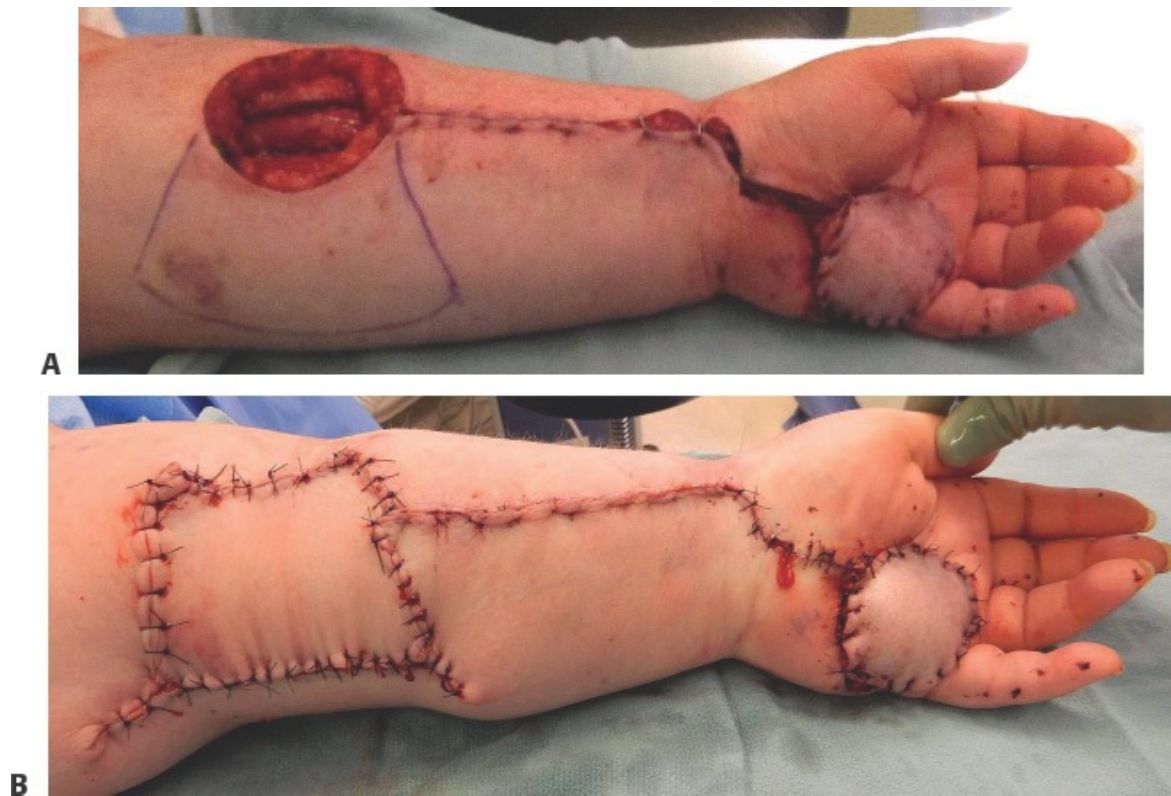


TECH FIG 3 • A-C. An ulcerating plantar foot lesion is excised, resulting in exposure of the plantar fascia. Due to the adherent nature of plantar skin, two opposing keystone flaps were planned. However, after

complete release of the plantar fascia and vertical spreading along the margins of the flap, the defect was successfully closed with only one keystone flap.

■ Keystone Flap to Close a Donor-site Defect

- When reconstruction calls for a large fasciocutaneous or musculocutaneous flap involving a wide skin paddle, the secondary defect may not close primarily.
- As an alternative to skin grafting, which results in poor appearance and may lead to contour deformity, a keystone flap can be designed to fill the donor-site defect (**TECH FIG 4**).



TECH FIG 4 • A,B. A keystone flap can be used to close a secondary defect after harvest of a fasciocutaneous or musculocutaneous flap. A radial forearm flap was harvested for coverage of a palmar hand defect following resection of a sarcoma. The

resultant donor-site defect could not be closed primarily. Therefore, a keystone flap was designed to transfer mobile volar forearm skin and soft tissue to achieve closure of the secondary defect.

PEARLS AND PITFALLS

Design

- The dimensions of the keystone flap must be of sufficient size to close the intended defect.
- The width of the keystone flap must approximate the width of the defect, or else closure may be excessively tight or even impossible.
- A large keystone flap will ensure inclusion of more perforators.
- The V-Y closures of the keystone flap should be designed to maximize advancement of the flap into the primary defect.

Technique

- A handheld pencil Doppler probe may be used to help identify perforators.
- In rare instances, the keystone flap requires cautious undermining. If so, every effort should be taken to preserve perforators.
- Underlying muscle may be superficially incised along the borders of the keystone flap to permit additional advancement, if necessary.
- The first closure stitch should serve to close the primary defect. Subsequently, the secondary defect is closed using the halving principle in order to even distribute tension.

Postoperative

- Patients should be placed on appropriate activity restrictions specific to the anatomic region where a keystone flap was performed. This will minimize the rate of dehiscence.
- Superficial wounds can be treated conservatively with dressing changes. These minor wounds should not delay any planned postoperative adjuvant radiation.

POSTOPERATIVE CARE

- The patient is restricted from any movements that increase tension on the keystone flap, especially along the short axis of the flap. A postoperative splint may be beneficial for a short period of time when the reconstruction is on an

extremity.

- Physical therapy consultation is helpful for some patients after reconstruction of large lower extremity defects.
- Non-weight bearing for about 2 weeks after foot and ankle keystone
- The patient is seen within 1 week after discharge and then for suture removal at the 2-week postoperative visit.

OUTCOMES

- Keystone flaps have been utilized to close a wide variety of defects and boasts a success rate of 97% to 100%.^{2,6}
- Major complications requiring a secondary operation are rare; minor complications commonly involve superficial wound dehiscence that can be treated conservatively.
- Compared to other coverage options, such as muscle-based flaps or free flaps, appropriate selection of a keystone flap for reconstruction can result in shorter operative time, shorter inpatient stay, and shorter time to patient mobilization.

COMPLICATIONS

- Delayed wound healing can occur at points of relative tension along the keystone flap incisions. In the vast majority of cases, these wounds are superficial and can be treated with dressing changes.
- Frequently, planned postoperative adjuvant radiation therapy is not initiated until the reconstruction has sufficiently healed. Superficial wounds should not delay initiation of radiation therapy. For larger wounds, secondary interventions such as split-thickness skin grafting may be considered to hasten wound closure in anticipation of radiation therapy.
- Rarely, keystone flaps may demonstrate venous congestion in the immediate postoperative period. Consider releasing some sutures to relieve tension, application of nitropaste, or the use of leeches. Also, evaluate if patient position and mobility is contributing to the problem.
- Seromas are a rare occurrence after keystone flaps because undermining of the surrounding tissues is generally not necessary.

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38 Treatment of Axillary Hyperhidrosis

CHAPTER

David L. Larson

DEFINITION

- Hyperhidrosis is excessive sweating beyond the normal physiologic response to heat or emotional stimuli.
- Any such sweating is excessive when it so negatively affects the daily life of individuals that their normal interactions with the world around them are compromised.

ANATOMY

- The greatest concentration of eccrine (sweat-producing) glands is in the palms, axilla, and soles of the feet, where only about 5% of the glands are normally active at any one time.¹
- These glands are located in the subcutaneous tissue of the axilla and *not* in the dermis (**FIG 1**)—a fact that is of particular significance when considering the rationale for and effectiveness of axillary shaving in the treatment of hyperhidrosis.

PATHOGENESIS

- Primary hyperhidrosis is not psychological in nature, is not self-limiting, and can significantly impact quality of life (QOL), as validated by QOL scales, showing it to be comparable to end-stage renal disease, rheumatoid arthritis, multiple sclerosis, and severe psoriasis.^{2,3}
- Secondary hyperhidrosis is associated with many *common diseases* (eg, Parkinson's, hyperthyroidism, gout), *conditions* (eg, pregnancy, obesity, menopause), and *drugs* (eg, neuropsychiatric, antimicrobials, urologic) that can cause diaphoresis. Once these etiologies have been ruled out by history and/or

pattern of sweating, a diagnosis of primary or idiopathic hyperhidrosis should be entertained.

NATURAL HISTORY

- Though previously viewed as a benign condition, it is now recognized as a potentially extremely debilitating disease, impairing the social interactions and occupational activities of those affected.
- Affecting 1.4% of the US population, axillary hyperhidrosis generally appears spontaneously in puberty or early adulthood (less than 30 years old). About one-third of these patients will be so negatively affected by the embarrassment, need of frequent change of clothes, and/or malodor that it may eliminate careers such as education, sales, and marketing.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Many patients (over 40%) will not seek medical aid because of embarrassment, the thought that nothing can be done, or misdirection by caregivers (eg, “learn to live with it”).

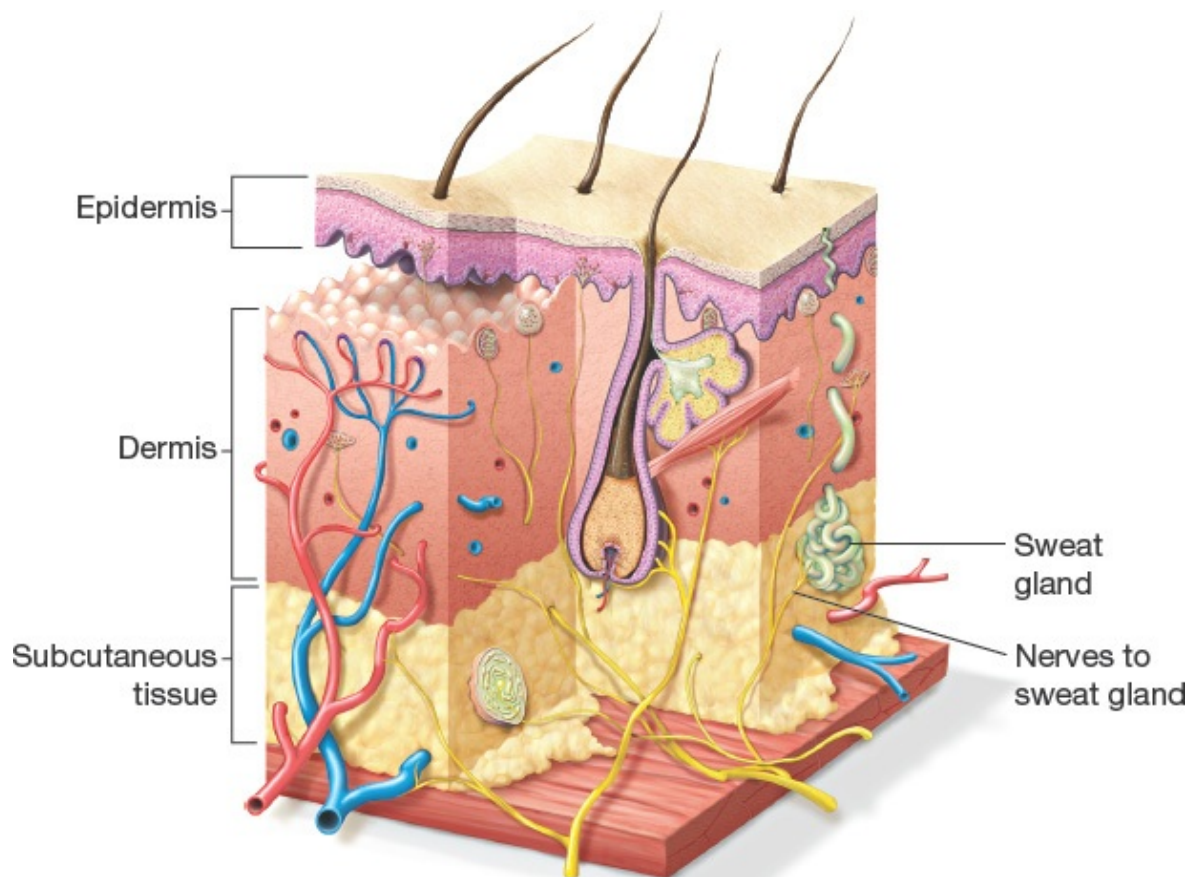


FIG 1 • Anatomy of the skin and its adnexa.

- Diagnosis is made primarily by history, which includes focal, visible, excessive sweating of at least 6 months duration without apparent cause. In addition, there must be at least two of the following characteristics: bilateral and symmetric, impairment of daily activities, at least one episode weekly, onset in youth (eg, 13 to 25 years old), positive family history (usually positive in 25% of patients), and cessation of sweating during sleep. Many times, all of these findings are noted.
- The only physical finding is excessive moisture in the affected area.

IMAGING/DIAGNOSIS

- Diagnosis can be confirmed by measuring the transepidermal water loss ($\text{g}/\text{m}^2/\text{h}$) using a VapoMeter (Delfin Technologies, Stamford, Connecticut) (**FIG 2**).⁴
- Alternatively, the Minor test (starch-iodine test) can be used for confirmation:
 - Clean and thoroughly dry the axilla.
 - Paint the entire underarm with iodine solution or povidone-iodine.
 - Use a makeup brush, sifter, or gauze pad to evenly dust the site with fine starch powder.
 - After 10 to 15 minutes, areas of sweat will turn the mixture dark purple-blue, which should be documented with a photo.

DIFFERENTIAL DIAGNOSIS

- N/A

NONOPERATIVE MANAGEMENT⁵

- Topical antiperspirants: “clinical-grade” topical deodorants have usually been initiated by the patient. Locally applied powder can also be used, but Drysol (prescription item) only lasts 3 to 4 days, is messy, is difficult to apply, and causes local skin irritation.
- Oral anticholinergics: Robinul (1 mg bid and increase 1 mg q 2 weeks until effective) or oxybutynin (2.5 mg daily $\times$ 7 days, then 2.5 mg bid $\times$ 5 weeks) is sometimes effective. Generally, side effects (eg, blurred vision, dry mouth, constipation, etc.) limit the effectiveness, but these should still be the initial treatment.



FIG 2 • VapoMeter provides practical, reproducible, and rapid measurement of sweating in $\text{g/m}^2/\text{h}$ (Delfin Technologies, Stamford, Connecticut).

- Botox injection (50 units per axilla) is very effective but expensive and lasts only 4 to 6 months.
- When conservative management has been used for 2 to 3 months and found wanting, surgical management is justified to both the patient and the insurer.

SURGICAL MANAGEMENT⁶⁻⁹

Preoperative Planning

- As the offending sweat glands are only associated with the hair-bearing area of the axilla, this area is outlined in the holding area of the ambulatory.
- Although it might seem reasonable to consider use of a local anesthesia with sedation, this is not advised. The potential movement of the patient while using a powered, rotating instrument blindly in the axilla is very real. A short, general anesthetic will also expedite the efficiency and ensure the safety of this 60-minute procedure.
- This is, at the very least, a two-person operation. Though the surgeon and a scrub nurse will suffice, an additional assistant will significantly aid in providing the essential maximum lateral tension on the surgical field.
- Following induction, the hair-bearing area is outlined and shaved. Taking care to mark a 1-cm access incision within the axillary fold prior, superficially inject (producing a wheal) about 20 to 30 mL of 0.5 % Xylocaine with 1/200 000 epinephrine within the outlined area (**FIG 3**).

Positioning

- In the supine position, the patient's arms are abducted at about a 100-degree angle and secured.
- The surgeon then preps for surgery concurrent with the patient's prep, hereby adding to the hemostatic effect of the local anesthetic.



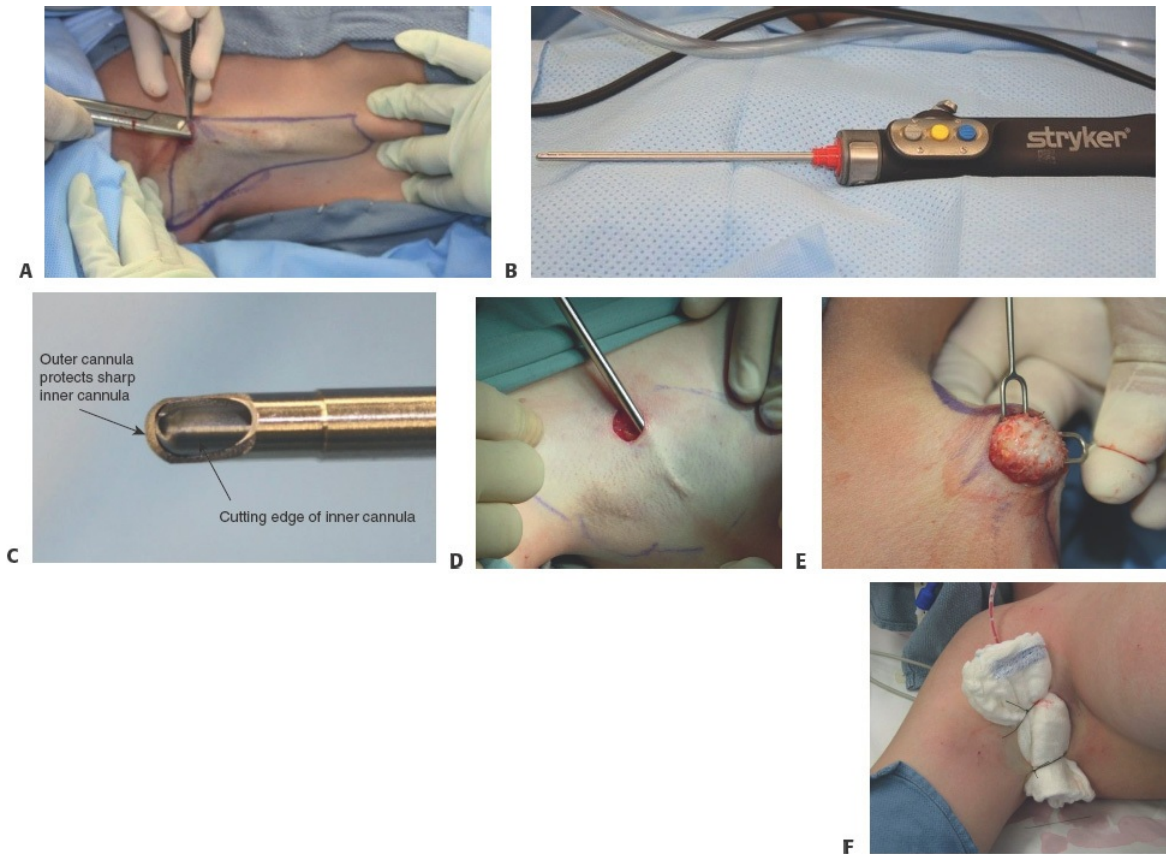
FIG 3 • The hair-bearing area is shaved and injected for local hemostasis, and the 1-cm access incision in the anterior axillary line is marked.

TECHNIQUES

- After draping the axilla, the surgeon takes a place at the head of the table above the arm board and the abducted arm.
- The assistants provide maximal lateral tension to the surgical field to facilitate elevation of the axillary tissue safely and efficiently (**TECH FIG 1A**).
- The previously placed anterior axillary fold mark is incised. Using curved Metzenbaum dissecting scissors, the previously outlined hair-bearing area is elevated in the most superficial subcutaneous plane possible by leaving fatty tissue on the elevated flap. This dissection is typically rapid and bloodless.
- The suction-assisted cartilage shaver, a Stryker CORE Powered Instrument Driver, is brought on to the surgical field (**TECH FIG 1B**). This shaver, commonly used in endoscopic orthopedic cartilage shaving of joints, consists of two concentric metal cannulas, one smaller than the other. At its tip, the

outer larger cannula has a half-opened portion that protects the sharp, inner, oscillating cannula, thus allowing continuous curettage and suction drainage (**TECH FIG 1C**).

- With the handpiece setting placed at its lowest setting (900 rpm or less), the shaving tip is inserted into the previously created subcutaneous tunnel, taking care to ALWAYS hold the open cannula toward the undersurface of the elevated flap and keeping the shaver moving.
- With the flap under maximal tension by the assistants, the shaver is slowly passed in a systematic, gridlike fashion over the undersurface of the flap, thereby aspirating the subcutaneous fat and permanently damaging/aspirating the offending sweat glands (**TECH FIG 1D**). Care must be taken to keep the shaver moving to prevent perforation of the flap by the shaver. The hair follicles are always preserved, as is innervation of the surgical area.
- At completion of the shaving, the skin is everted to verify total removal of the subcutaneous tissue and preservation of the axillary skin (**TECH FIG 1E**).
- Wound suction and external pressure is obtained with placement of a small-caliber drain through the incision and an externally applied surgical sponge (**TECH FIG 1F**). The skin is closed with simple nylon sutures.



TECH FIG 1 • **A.** Maximal lateral tension by assistants greatly facilitates subcutaneous dissection. **B.** The Stryker suction-assisted cartilage shaver. **C.** The double-lumen cannula that provides continuous curettage and simultaneous suction. **D.** Aspiration of the subcutaneous fat. **E.** Eversion of the now shaved axillary tissue reveals the hair follicles devoid of fat tissue, which is synonymous with ablation of the sweat glands. **F.** Secure compression on the flap plus a small drain helps prevent seroma formation.

PEARLS AND PITFALLS

Diagnosis ■ Most patients present with the same, classic history, and signs and

symptoms.

- Any positive starch test or VapoMeter reading greater than 100 mL/m²/h is diagnostic of hyperhidrosis.
- Initially, use nonoperative, conservative approach (anticholinergic).
- Provide insurer with thorough description of symptoms, failure to respond to conservative therapy, and a photo of positive axillary starch test or VapoMeter data.
- This operation is equally effective when the primary complaint is offending malodor +/- sweating.

Technique

- If possible, use two assistants (four hands) to provide lateral traction on the axilla while elevating and shaving the flap.
- Keep moving the shaver while exerting gentle upward pressure on the flap while assistants provide tension.
- If a perforation of the axillary skin occurs, close it with a fast-absorbing suture; it heals quite kindly.
- Using retraction and overhead light, transilluminate the flap to verify a “clean” shaving that preserves only the bulb of the axillary hair follicles.

POSTOPERATIVE CARE

- The external dressing and drain are removed the next day; the permanent sutures are left in place 5 to 7 days, as dehiscence occurs if removed earlier.
- There is very little pain associated with the operation.
- When the dressing is removed, the patient almost always notes total cessation of sweating, which is permanent in greater than 95% of patients.
- Patients should limit arm abduction for one week postoperatively and are typically absent from out-of-home employment about 4 days.

OUTCOMES

- Over 95% of patients have no recurrence of sweating and are quite pleased.
- If sweating does recur, it is usually nominal and managed with conservative methods.
- There is no compensatory sweating (new appearance of hyperhidrosis in another area).

COMPLICATIONS

- There has been one hematoma and one infection in my series. Both responded to conservative measures.

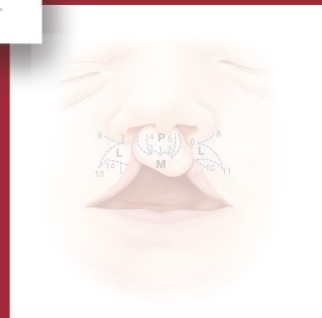
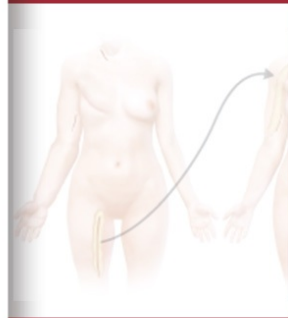
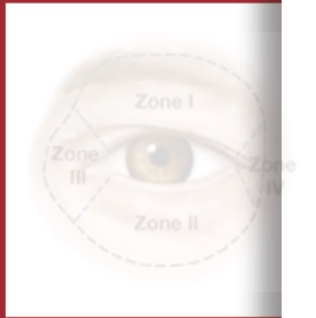
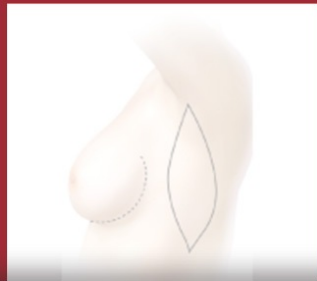
- In the very uncommon occurrence of a recurrence of significant symptoms, the procedure has been repeated without consequence and with a successful outcome (2×/8 years).

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PART 6

Hand Surgery



Section I: Anesthesia and Emergency Procedures

1 Anesthesia and Emergency Procedures

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- Wrist and digital blocks are essential for patient anesthesia in the operating room and during emergency room procedures.
- Nerve blocks assist with postoperative pain control.
- Wide-awake local anesthesia no tourniquet (WALANT) involves local injection of epinephrine with lidocaine for hemostasis and anesthesia instead of applying a tourniquet and sedation. This technique is useful for minor hand procedures as well as tendon surgery.

ANATOMY

- Median nerve
 - At the distal forearm/wrist, the median nerve lies between the palmaris longus (PL) and flexor carpi radialis (FCR) tendons (**FIG 1**).
 - The palmar cutaneous branch (PCB) usually passes subcutaneously between the FCR and PL tendons.

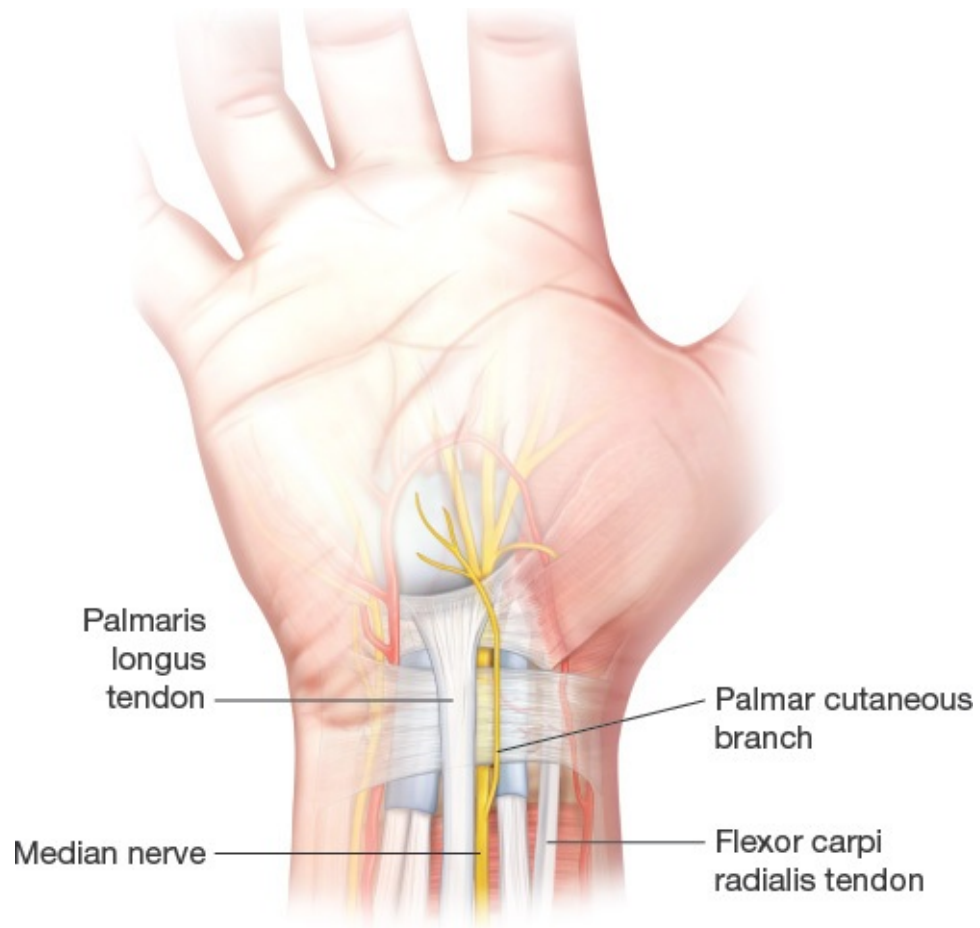


FIG 1 • Median nerve anatomy at volar wrist.



FIG 2 • Ulnar neurovascular bundle anatomy at volar wrist.

- Ulnar nerve
 - At the wrist level, the ulnar nerve is radial and dorsal to the flexor carpi ulnaris (FCU) tendon (**FIG 2**).
 - The ulnar artery is adjacent to the radial aspect of the ulnar nerve.
 - The dorsal cutaneous branch (DCB) originates from the ulnar nerve approximately 5 cm proximal to the ulnar styloid. It crosses from palmar to dorsal near the styloid process.¹
- Superficial branch of the radial nerve
 - The superficial branch of the radial nerve (SBRN) becomes subcutaneous approximately 9 cm proximal to the radial styloid.²
 - At the radial styloid, there are two to three branches of the SBRN in the subcutaneous tissue (**FIG 3**).
- Digital nerves

- Four nerve branches (two palmar, two dorsal) provide sensation to each digit.
- The common digital nerves bifurcate to the proper digital nerves at the level of the distal palmar crease.
- The dorsal digital nerves of the thumb and small finger extend to the tip of the dorsal digit.
- The volar digital nerves supply dorsal sensation distal to the proximal interphalangeal joint in the index, middle, and ring fingers (**FIG 4**).

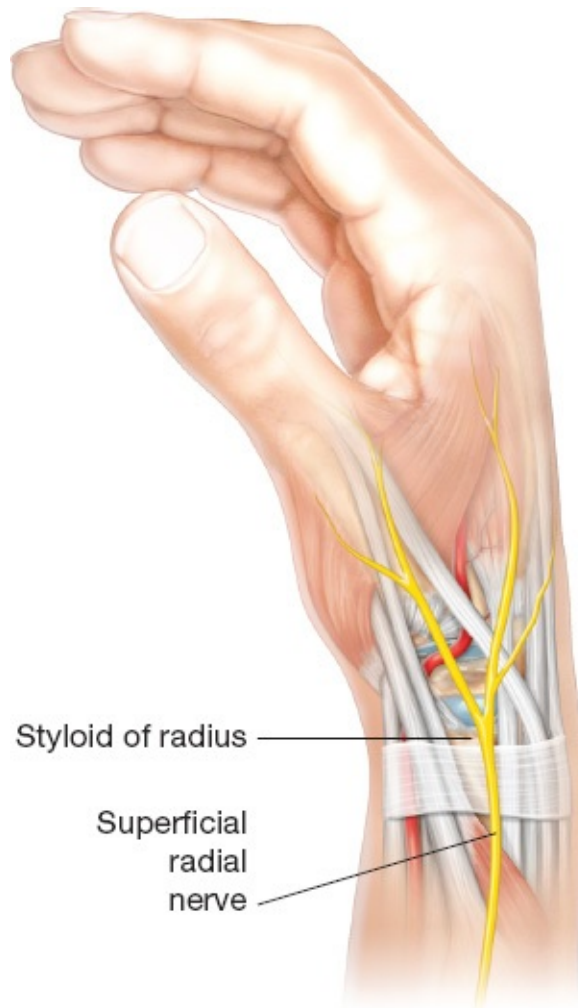


FIG 3 • Superficial branch of the radial nerve anatomy at the radial wrist.

SURGICAL MANAGEMENT

Preoperative Planning

■ Materials

■ Syringe

■ 27-gauge needle

■ Commonly used local anesthetic agents and additives

- Lidocaine is commonly used due to its rapid onset (within 2–5 minutes of injection) and medium duration of action (2 hours for digital block).³
- Bupivacaine has a slower onset of action (5–10 minutes) but longer duration of action (12 hours for digital block).³
- Epinephrine additive induces vasoconstriction, which promotes hemostasis, prolongs duration of anesthesia, and reduces the systemic toxicity of the local anesthetic agent.
- Sodium bicarbonate 8.4% additive buffers the low pH of lidocaine, decreasing injection pain.

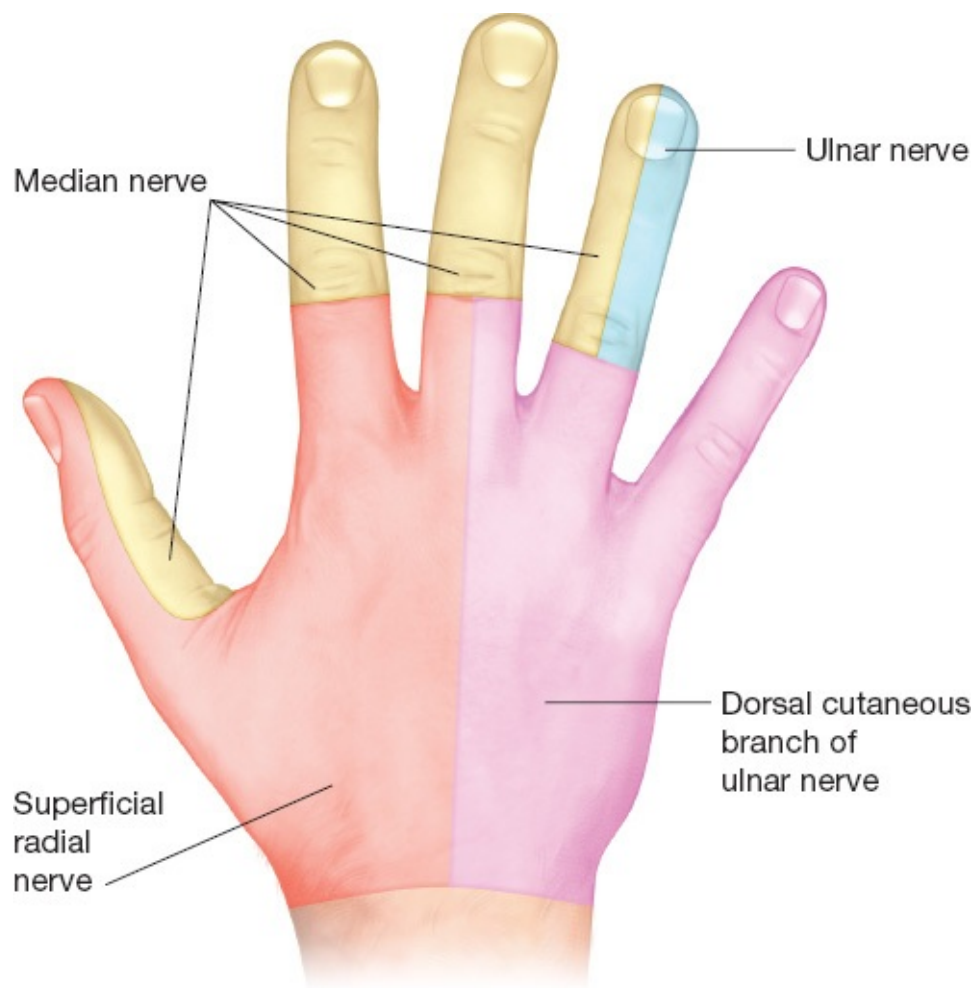


FIG 4 • Dorsal hand sensory innervation.

Positioning

- Whether the procedure is in the operating room or emergency department, the patient should lie comfortably supine to minimize patient movement during the procedure.
- Hand table or Mayo stand.

Approach

- Digital block
 - Volar subcutaneous approach: This is our preferred technique as it only requires one injection and is shown to be less painful than the transthecal approach.⁴
 - Dorsal transmetacarpal approach
 - Transthecal approach
- Wrist block
 - Median nerve
 - Ulnar nerve
 - Superficial branch of radial nerve
- WALANT
 - Use 1% lidocaine with 1:100 000 epinephrine
 - Buffer the lidocaine and epinephrine in a 10:1 ratio with 8.4% sodium bicarbonate
 - Allow adequate time for the vasoconstrictive effect of epinephrine to take effect (25 minutes).⁵
- Volume of injection depends on the site of surgery (**FIG 5**).⁶

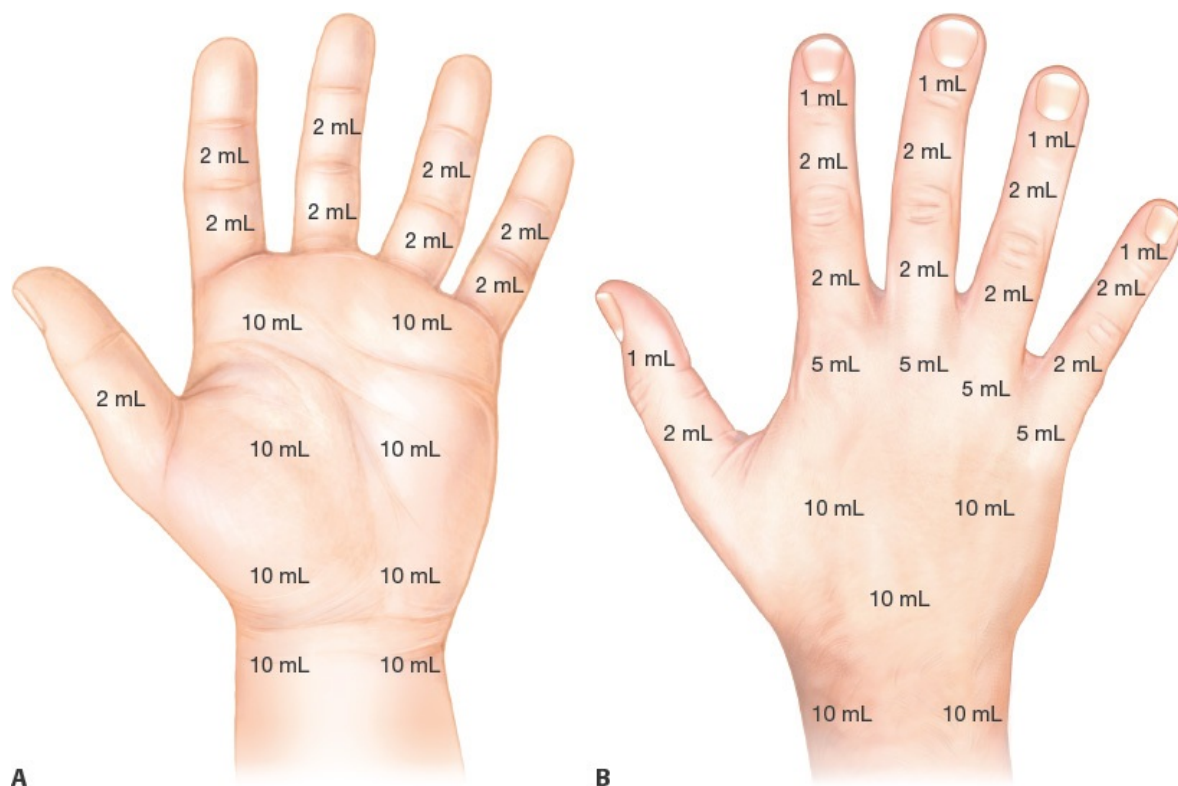


FIG 5 • Palmar **(A)** and dorsal **(B)** hand injection volumes.

TECHNIQUES

■ Digital Nerve Block

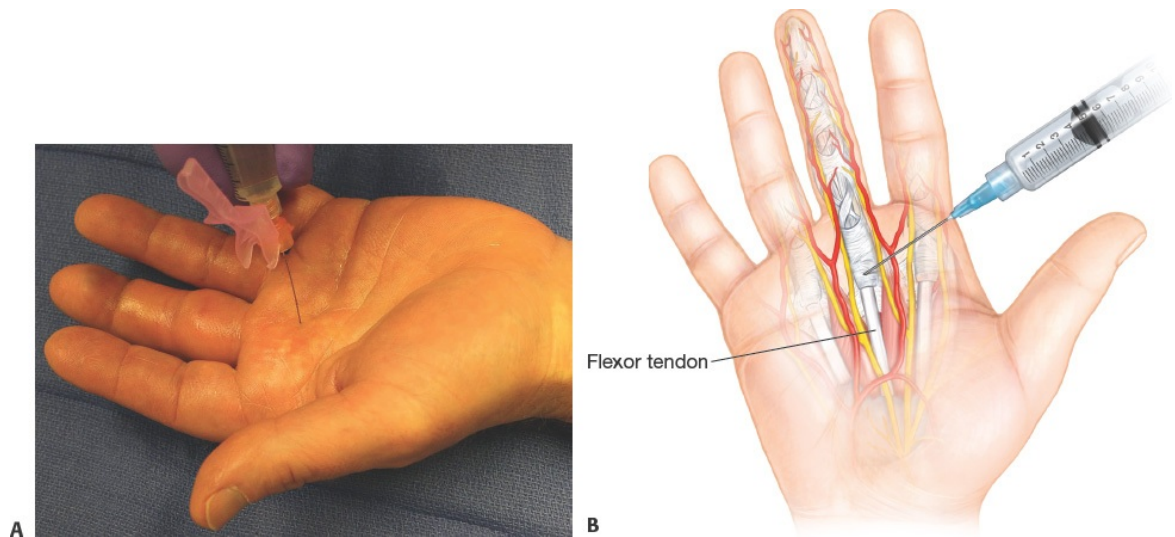
Volar Subcutaneous Block

- Insert a 27-gauge needle at the distal palmar crease at the level of the A1 pulley (**TECH FIG 1**).
- Inject 3 mL of local anesthetic into the subcutaneous tissue. The anesthetic should cause tumescence and flow of anesthetic solution radial and ulnar to the flexor tendon sheath (see **FIG 5A**). If there is significant resistance to injection, withdraw the needle slightly.

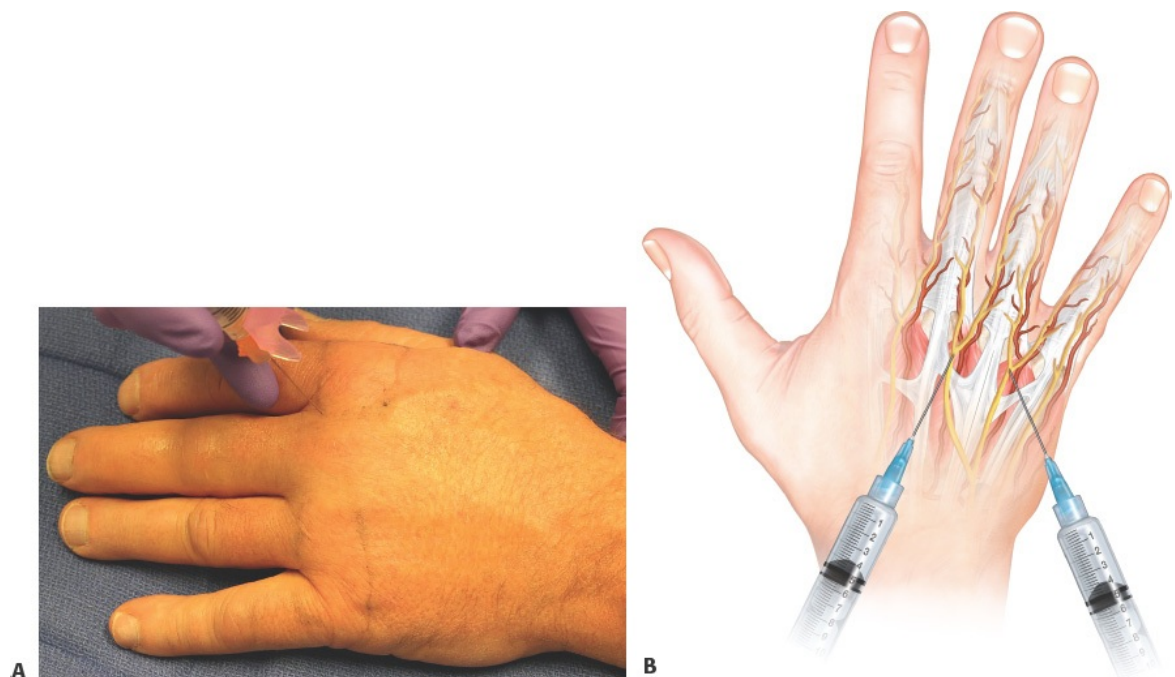
Dorsal Transmetacarpal Block

- Identify the metacarpal head of the digit of interest.

- At this level, introduce a 27-gauge needle from the dorsal web space and advance toward the palm (**TECH FIG 2**).



TECH FIG 1 • Middle finger volar subcutaneous block. Note tumescence radial and ulnar to the flexor tendon sheath in **A**. Note the needle is in the subcutaneous tissue superficial to the flexor tendon sheath in **B**.

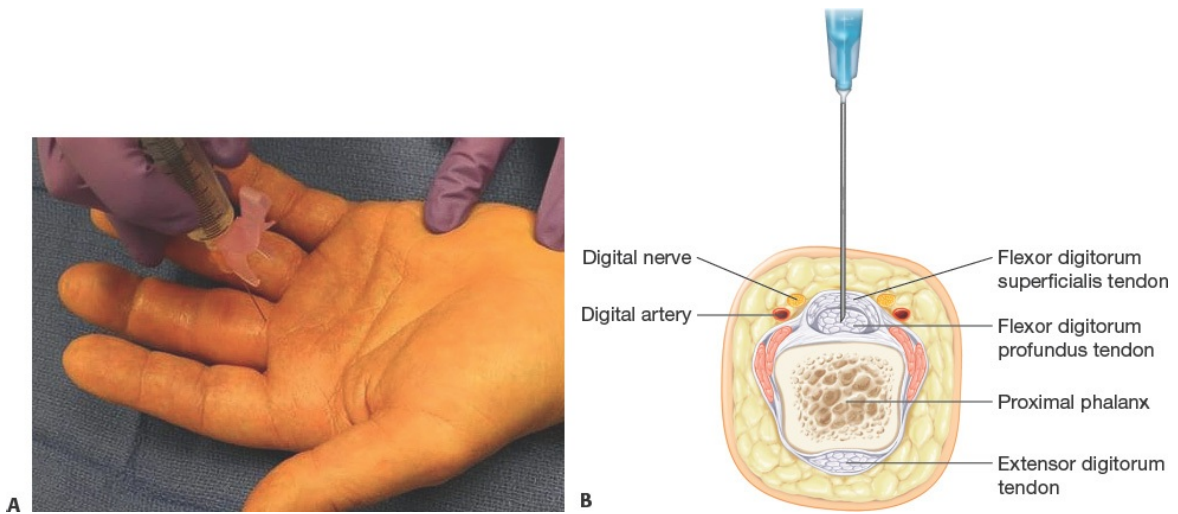


TECH FIG 2 • Dorsal transmetacarpal block.

- Inject 2 mL of local anesthetic into the radial and ulnar web space to anesthetize each digital nerve. Periodically aspirate the syringe to prevent intravascular injection.

Transthecal Digital Block

- Palpate the flexor tendon sheath at the palmar digital crease.
- Insert a 25-gauge needle through the flexor tendon at this level until contact with bone.
- After bone contact, slowly withdraw the needle with gentle pressure on the syringe (**TECH FIG 3**).
- When the needle is withdrawn 1 to 2 mm, anesthetic will enter the sheath.
- Inject 2 mL of local anesthetic.



TECH FIG 3 • **A.** Transthecal digital block. **B.** Cross-section view.

Wrist Block

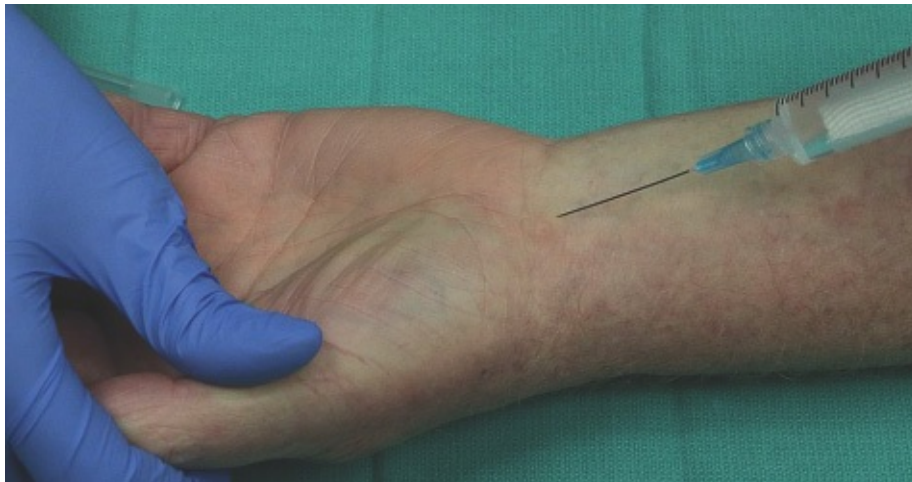
Median Nerve Block

- Identify the FCR and PL tendons at the proximal wrist crease.
- Insert the needle just proximal to the wrist crease and penetrate the flexor retinaculum (**TECH FIG 4**).
 - In the absence of PL tendon, insert the needle on the ulnar side of the FCR tendon.

- Inject 5 mL of local anesthetic around the nerve.

Ulnar Nerve Block

- Identify the FCU tendon at the proximal wrist crease.
- Introduce a 25-gauge needle ulnar and dorsal to the FCU, aiming the needle radially (**TECH FIG 5**). From this approach, the ulnar nerve is encountered first. Avoid pushing the needle too far; the ulnar artery is radial to the nerve.
- Inject 5 mL of local anesthetic around the ulnar nerve, taking care to intermittently aspirate.
- Infiltrate the subcutaneous dorsoulnar wrist with 5 mL of local anesthetic to anesthetize the dorsal cutaneous branch (DCB) of the ulnar nerve.



TECH FIG 4 • Median nerve block at wrist.

Superficial Branch of Radial Nerve Block

- Palpate the styloid process of the radius.
- Insert a 25-gauge needle and inject 5 mL of local anesthetic into the subcutaneous tissue overlying the first through third dorsal compartments.



TECH FIG 5 • Ulnar nerve block at wrist.

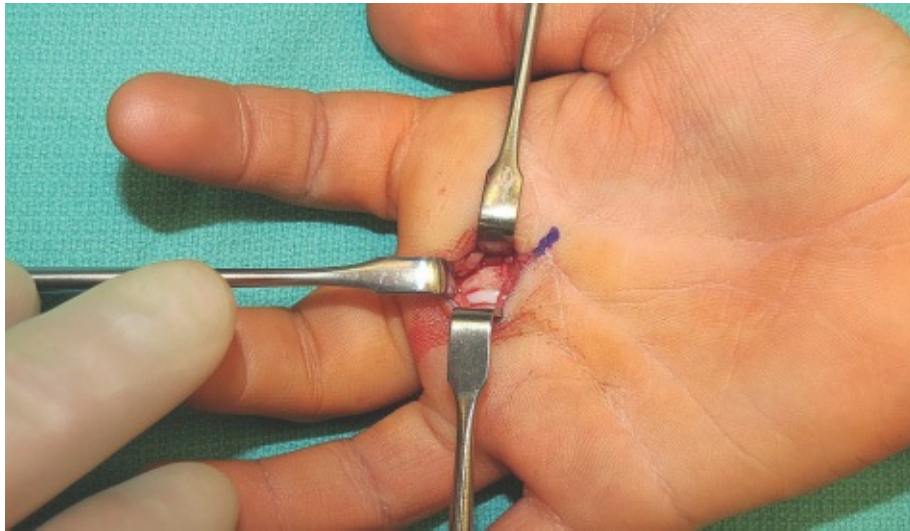
■ **WALANT: Trigger Finger Release Example**

- Prepare a mixture of 1% lidocaine and 1:100 000 epinephrine buffered with 8.4% bicarbonate. For trigger finger, we inject a total of 10 cc locally.
- Warm the local anesthetic solution to body temperature.
- Distract the patient to look away from the injection site.
- Use a 27-gauge needle to inject 0.5 mL of the anesthetic perpendicularly subdermally over the A1 pulley (**TECH FIG 6**).



TECH FIG 6 • WALANT injection for trigger finger.

- Stabilize the syringe and pause until the patient reports he/she does not feel the needle pain.
- Inject an additional 2 mL prior to moving the needle.
- Move antegrade slowly with a tumescent wheal of local anesthetic visible ahead of the needle.
- Prior to incision, wait at least 25 minutes for the vasoconstrictive effect of epinephrine to take place. There is excellent hemostasis without the use of tourniquet (**TECH FIG 7**).



TECH FIG 7 • Trigger finger release demonstrates hemostasis without tourniquet.

PEARLS AND PITFALLS

Physical exam

- Do not forget to carefully document the sensory and motor exam prior to administration of local anesthetic.

Technique

- Avoid intravascular injection by careful intermittent aspiration.
- Palpate the flexor tendon sheath prior to digital block. The flexor tendon sheaths and neurovascular bundles are ulnar to midline in the thumb and radial to midline in the small finger.
- Injection of small boluses of local anesthetic followed by brief periods of observation is a safe way to prevent intravascular systemic toxicity.

- Inject slowly to decrease pain.

Local anesthetic dosage

- The maximum adult dose of plain lidocaine is 4–5 mg/kg.⁷
- The maximum adult dose of plain bupivacaine is 2.5 mg/kg.⁷

POSTOPERATIVE CARE

- Postoperative care will depend on the procedure performed.

OUTCOMES

- A systematic review compared six local anesthetic preparations (lidocaine, lidocaine with epinephrine, bupivacaine, bupivacaine with epinephrine, lidocaine with bupivacaine, and ropivacaine). All provided benefits in digital nerve blocks.³
- Lidocaine demonstrated the shortest mean onset of anesthesia (3.1 minutes), whereas bupivacaine was the longest (7.6 minutes).
- Lidocaine also had the shortest mean duration of anesthesia (1.8 hours), whereas ropivacaine had the longest duration (21.5 hours).

COMPLICATIONS

- Amino esters (chloroprocaine, procaine, tetracaine, cocaine) are more likely to cause allergic reactions than amino amide compounds (lidocaine, bupivacaine, ropivacaine, mepivacaine).
- Systemic toxicity is extremely rare with hand and wrist local anesthesia but can occur with intravascular injection.
- Central nervous system manifestations can include facial numbness, metallic taste, light-headedness, tinnitus, and seizure.
- Cardiac depression can culminate in cardiovascular collapse (ventricular tachycardia or fibrillation).
- Primary therapy in the setting of cardiac arrest involves advanced cardiovascular life support (ACLS).
- Consider intravenous lipid emulsion therapy in the treatment of local anesthetic systemic toxicity.^{8,9}
- Although the authors have never encountered digital infarction with use of epinephrine, it is important to know that local phentolamine injection reverses epinephrine-induced vasoconstriction.¹⁰

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Fasciotomy for Compartment Syndrome of the Hand and Forearm

2

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- Compartment syndrome occurs when interstitial tissue pressure rises to levels that impair blood flow and cellular function.

ANATOMY

- The hand contains 10 muscular compartments as well as the carpal tunnel and digital compartments (Table 1, **FIG 1**).
- The forearm consists of three myofascial compartments: volar, dorsal, and the mobile wad (Table 2, **FIG 2**).

PATHOGENESIS

- If there is swelling within the fascial compartments, intracompartmental pressure will rise.
- Increased compartment pressure can result in tissue ischemia and necrosis.
- Causes of compartment syndrome:
 - Intracompartmental swelling: Bleeding/soft tissue injury from trauma, anticoagulation, infection, high-pressure injection injury, reperfusion injury, intravenous fluid infiltration.
 - External compression: Burn eschar, prolonged syncope with pressure on the limb, tight dressings or casts.
- Major limb replantation/revascularization requires prophylactic fasciotomy due to risk of reperfusion injury and compartment syndrome.

NATURAL HISTORY

- Irreversible muscle damage occurs within 6 to 8 hours of ischemia.

- Rhabdomyolysis from myonecrosis can result in acute renal failure and electrolyte abnormalities.
- Left untreated, permanent nerve deficit and muscle fibrosis of the forearm can result in secondary Volkmann contracture.

Table 1 Head Compartments

Compartment	Muscle	Nerve
Thenar	Abductor pollicis brevis, opponens pollicis, flexor pollicis brevis	Recurrent motor
Hypothenar	Abductor digiti minimi, opponens digiti minimi, flexor digiti minimi	Ulnar
Adductor	Adductor pollicis	Ulnar
Interosseous (7)	4 dorsal and 3 palmar interossei	Ulnar
Carpal tunnel	Flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus (tendons)	Median
Digit		Digital

PATIENT HISTORY AND PHYSICAL FINDINGS

- Understand the mechanism of injury and have a high clinical suspicion—compartment syndrome is a clinical diagnosis.
- Remove any constrictive dressings or clothing.
- Physical exam findings:
 - Tense, swollen compartment, blistering (**FIG 3**)
 - Pain with passive stretch of the compartment muscles
 - Paresthesias
 - Paralysis of the involved compartment muscles develops after nerve paresthesias.
 - Pallor and pulselessness are late findings.

DIAGNOSTIC STUDIES

- Compartment syndrome is usually a clinical diagnosis; diagnostic studies may

complement the diagnosis.

- If there is a history of trauma, plain radiographs are indicated to assess for fracture or dislocation.
- Other advanced imaging (ultrasound, MRI) is rarely indicated. Time-consuming studies should not preclude emergent fasciotomy if there is high clinical suspicion for compartment syndrome.
- Laboratory studies (complete blood count, coagulation panel, basic metabolic panel, creatine phosphokinase, serum and urine myoglobin) are obtained.



FIG 1 • Midpalmar cross-section of hand compartments.

Table 2 Forearm Compartments		
Compartment	Muscle	Nerve
Volar		
Superficial	Flexor digitorum superficialis, pronator teres, palmaris longus, flexor carpi radialis, flexor carpi ulnaris	Median, ulnar
Deep	Flexor digitorum profundus, flexor pollicis longus, pronator quadratus	Anterior interosseous

Dorsal		
Superficial	Extensor digitorum communis, extensor digiti minimi, extensor carpi ulnaris	Posterior interosseous
Deep	Abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, extensor indicis proprius, supinator	Posterior interosseous
Mobile wad	Brachioradialis, extensor carpi radialis brevis, extensor carpi radialis longus	Radial

- If clinical diagnosis is equivocal or the patient is obtunded, compartment pressure measurements should be obtained. We use a commercially available Stryker manometer.
- An acute compartment syndrome is assumed if the compartment pressure is within 30 mm Hg of the diastolic blood pressure.¹ If the compartment measurement is measured under anesthesia, the pressure should be compared to the preinduction diastolic blood pressure.
- If measurements are not consistent with compartment syndrome, close monitoring and repeat clinical examination with serial compartment pressures may be indicated.

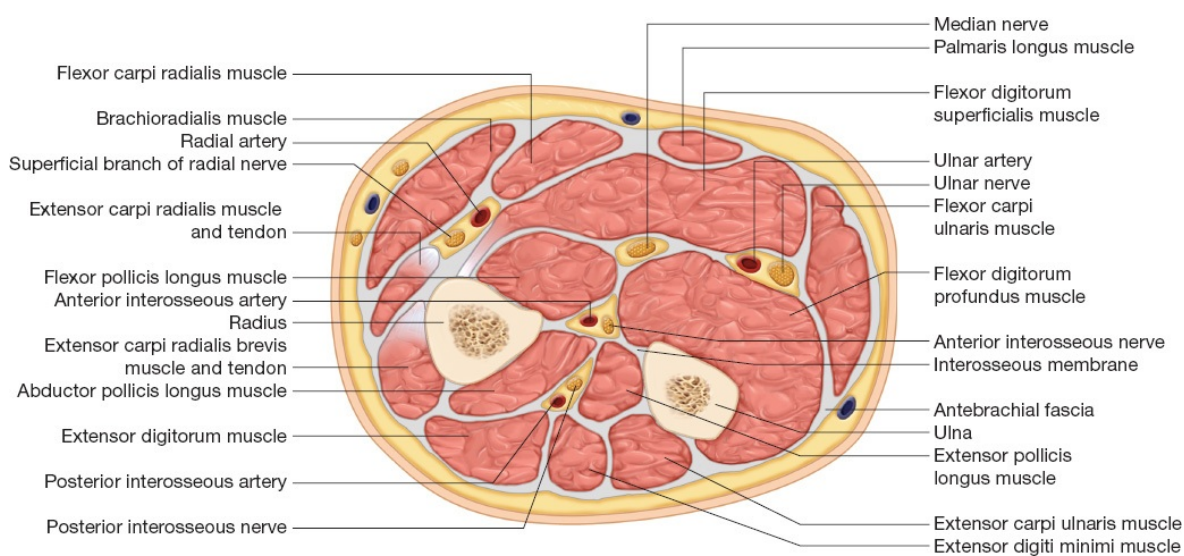


FIG 2 • Cross-sectional anatomy of forearm.



FIG 3 • Forearm gunshot wound with dorsal compartment swelling and skin blistering.

SURGICAL MANAGEMENT

- If there is high clinical suspicion or objective manometric evidence supporting the diagnosis of compartment syndrome, perform emergent fasciotomy.
- The goal of fasciotomy is to reduce compartment pressure and allow for tissue perfusion.

Preoperative Planning

- In the setting of trauma, review radiographs and prepare for skeletal stabilization if necessary.
- Consider reversal of anticoagulation if indicated.

Positioning

- Patient is positioned supine with a hand table.
- A tourniquet is applied to the arm; we do not inflate the tourniquet unless there is difficulty with visualization.

Approach

- The standard approach for the volar forearm involves a curvilinear incision extending from the medial epicondyle to the proximal wrist crease, creating a flap of skin over the distal forearm to cover the flexor tendons and median nerve (**FIG 4A**).

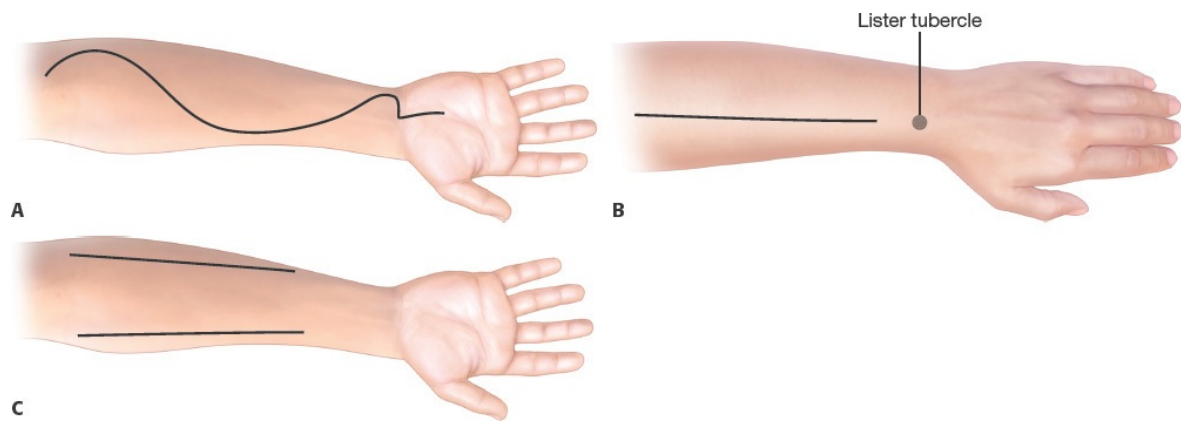


FIG 4 • A. Volar forearm curvilinear approach. **B.** Dorsal forearm longitudinal approach. **C.** Alternative parallel forearm incision approach.

- The dorsal forearm and mobile wad are decompressed through a longitudinal dorsal forearm incision (**FIG 4B**).
- An alternative forearm fasciotomy with two parallel longitudinal incisions (**FIG 4C**)
 - A volar radial incision allows access to the volar compartment and mobile wad without exposure of the median nerve or flexor tendons.
 - An ulnar incision allows access to the dorsal compartment.

TECHNIQUES

■ Fasciotomy of the Hand

Dorsal Hand Compartment Release

- Identify the second and fourth metacarpals dorsally.
- Perform longitudinal incisions on the radial border of the second and fourth metacarpal down to the level of the extensor tendons (**TECH FIG 1A**). Avoid incisions directly over the metacarpals; if the wound is left open, the tendon will desiccate. Avoid injury to the sensory branches of the radial and ulnar nerves.
- The incision over the fourth metacarpal is used to decompress the third and fourth dorsal interossei (**TECH FIG 1B**).

- The incision over the second metacarpal is used to decompress the first and second interossei.
 - Dissect bluntly through the dorsal interossei to decompress the three palmar interosseous muscles.
- Release the adductor compartment through the incision over the second metacarpal.

Thenar Compartment Release

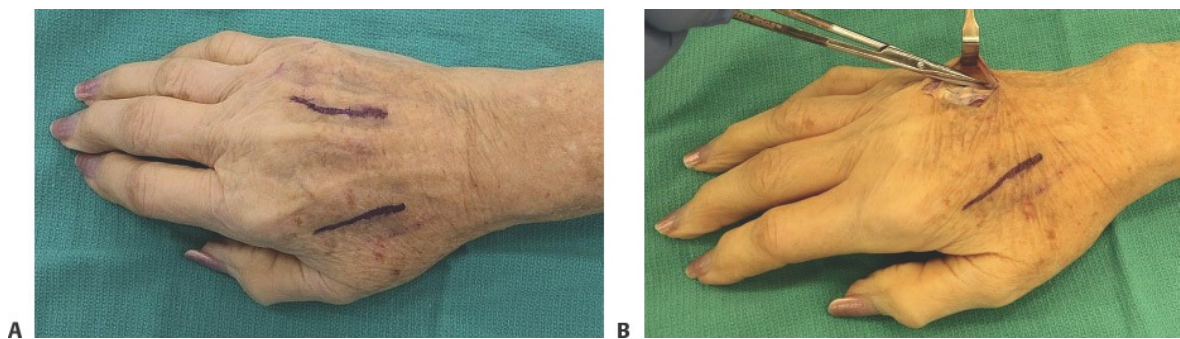
- Palpate the radial border of the first metacarpal and make an oblique longitudinal incision (**TECH FIG 2**, line A).
- Identify the thenar fascia overlying the abductor pollicis brevis (APB) and incise it longitudinally.

Hypothenar Compartment Release

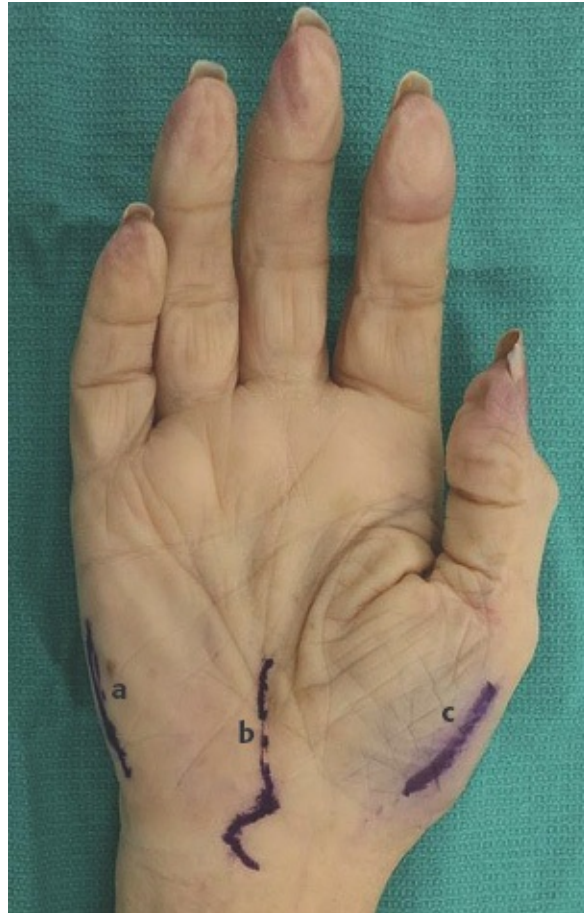
- Make a longitudinal incision just volar to the ulnar border of the fifth metacarpal and hypothenar eminence (see **TECH FIG 2**, line B).
- Identify the hypothenar fascia overlying the abductor digiti minimi (ADM) and incise it longitudinally.

Carpal Tunnel Release

- Make an incision over the carpal tunnel in line with the radial border of the fourth ray between the thenar and hypothenar compartments (see **TECH FIG 2**, line C).



TECH FIG 1 • A. Dorsal hand compartment release incisions. **B.** Decompression of the fourth dorsal interosseous compartment.



TECH FIG 2 • Palmar hand fasciotomy incisions: hypothener (a), carpal tunnel (b), and thenar (c).

- Identify the longitudinal fibers of the palmar aponeurosis and split them longitudinally.
- Longitudinally divide the transverse fibers of the transverse carpal ligament from the level of the sentinel fat pad to the antebrachial fascia, taking care to protect the median nerve and its motor branch.
- This incision may be incorporated into a volar forearm fasciotomy.

Digital Compartment Decompression

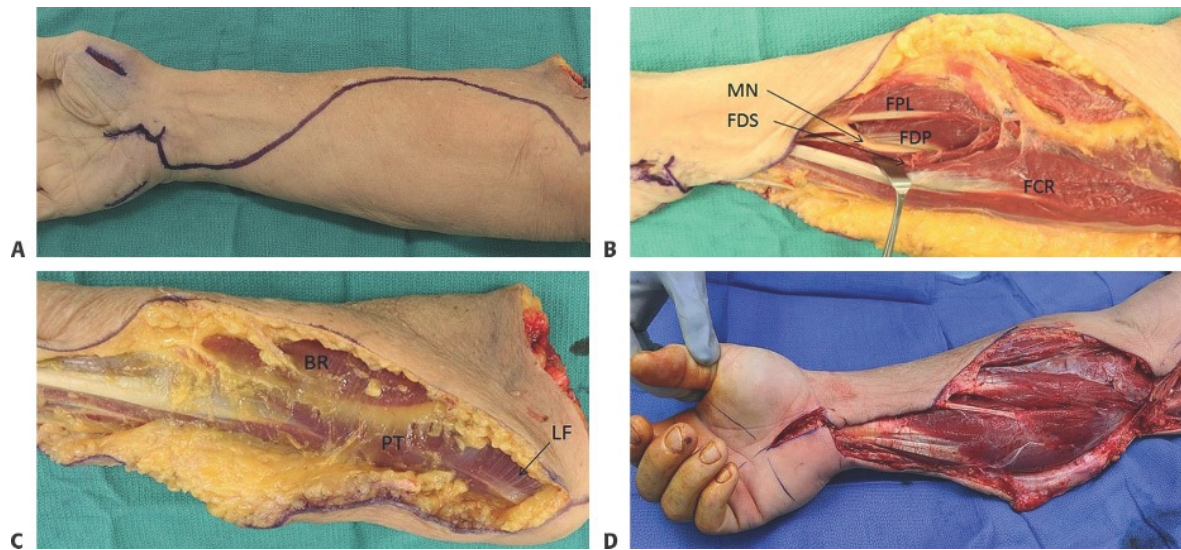
- Approach the digit on its noncontact side (ulnar incision for the index, long, and ring fingers, radial incision for the thumb and small finger).
- Make a midaxial incision (dorsal to the neurovascular bundles) and divide Cleland ligaments.

Wound Management

- Place loose tagging sutures as indicated over the carpal tunnel incision and over any areas with concern for tendon exposure.
 - Apply a bulky dressing and splint in a functional position.
-

■ Fasciotomy of the Volar Forearm with Curvilinear Incision

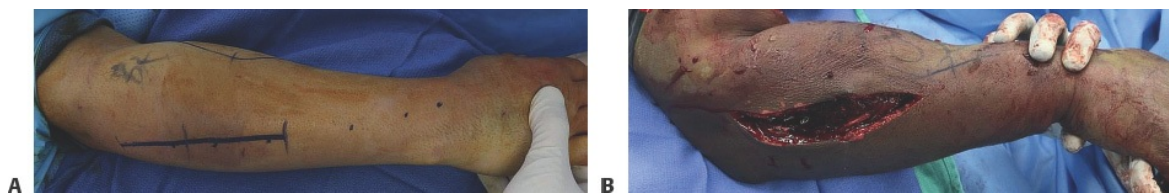
- Design a curvilinear incision from the ulnar wrist crease to the medial antecubital fossa (**TECH FIG 3A**).
- If a carpal tunnel release is performed, extend the proximal carpal tunnel incision ulnarly at the wrist flexion crease.
 - This creates a radially based flap that prevents desiccation of the median nerve and flexor tendons.
- Curve the incision radially in the mid forearm and then toward the medial elbow.
- Release the forearm fascia overlying the superficial and deep compartments of the volar forearm (**TECH FIG 3B**).
- Release the lacertus fibrosus at the medial elbow (**TECH FIG 3C**).
- Inspect each muscle and release individual muscle fascia if necessary.
 - Debride any devitalized muscle.
- The mobile wad can be released through the volar or dorsal incision.
- Loose sutures may be placed to secure skin flaps over the median nerve and flexor tendons. Leave the rest of the wound open, as significant swelling will usually prevent skin closure (**TECH FIG 3D**).
- Apply a loose bulky dressing and splint.



TECH FIG 3 • **A.** Volar forearm curvilinear incision. **B.** Exposure of deep volar muscle compartment. FCR, flexor carpi radialis; FDS, flexor digitorum superficialis; FDP, flexor digitorum profundus; FPL, flexor pollicis longus; MN, median nerve. **C.** Identification of lacertus fibrosus at medial elbow. LF, lacertus fibrosus; PT, pronator teres; BR, brachioradialis. **D.** Clinical image after volar forearm fasciotomy, with significant swelling preventing primary wound closure.

■ Fasciotomy of the Dorsal Forearm

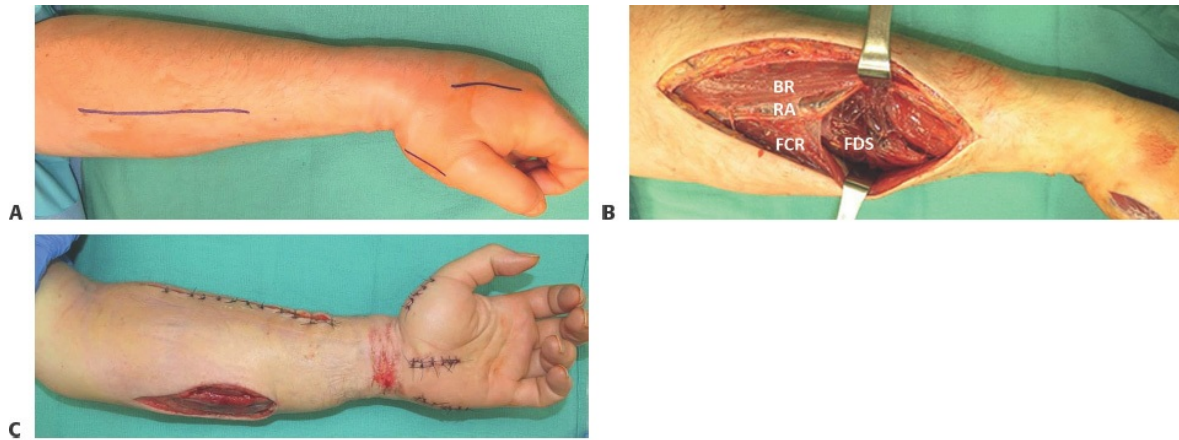
- Re-evaluate for the need for dorsal fasciotomy. After volar forearm and mobile wad compartment release, the dorsal forearm may have been indirectly decompressed.
- Make a longitudinal dorsal incision starting 3 to 4 cm distal to the lateral epicondyle extending toward Lister tubercle (**TECH FIG 4A**).
- Release the fascia over the dorsal compartment and the mobile wad.
- Inspect each muscle and release individual muscle fascia if necessary (**TECH FIG 4B**).
 - Debride any devitalized muscle.
- Perform any secondary procedures such as skeletal fixation.
- The wound is left open. A loose dressing and splint are applied.



TECH FIG 4 • A. Dorsal forearm compartment incision. **B.** Dorsal forearm compartment release and debridement. In this case, devitalized extensor muscle from gunshot wound was debrided.

■ Fasciotomy of the Forearm with Two Longitudinal Incisions

- Make a longitudinal incision on the volar radial forearm along the ulnar border of the brachioradialis (**TECH FIG 5A**).
- Undermine the ulnar aspect of the incision to gain access to the superficial volar forearm fascia.
- Release the underlying volar forearm fascia longitudinally.
- Access to the deep volar compartment is through a volar Henry approach between FCR and brachioradialis (**TECH FIG 5B**).
- Undermine the proximal ulnar aspect of the incision to gain access and release the lacertus fibrosis.
- The mobile wad can be released from the radial aspect of the incision.
- Make a longitudinal incision along the ulnar forearm and release the dorsal forearm compartment (**TECH FIG 5C**).
- Inspect each muscle and release individual muscle fascia if necessary.
 - Debride any devitalized muscle.
- The wound is left open and a loose dressing and splint are applied.
 - This double incision allows decompression without exposure of the median nerve or tendons at the distal forearm.



TECH FIG 5 • A. Alternative volar radial longitudinal incision. **B.** Access to superficial and deep volar compartments. BR, brachioradialis; RA, radial artery; FCR, flexor carpi radialis; FDS, flexor digitorum superficialis. **C.** Ulnar longitudinal approach for dorsal forearm compartment release.

PEARLS AND PITFALLS

Indications	■ Have a low threshold to proceed with compartment release.
Examination	■ Pain out of proportion to injury an early finding in patients with compartment syndrome.²
Technique	■ Attempt to preserve cutaneous nerves and veins whenever possible. ■ Debride any devitalized muscle. ■ Release any restrictive epimysium that can subcompartmentalize muscle groups (flexor digitorum profundus). ■ Do not close fascia. ■ Loose sutures can be used to hold skin flaps over exposed nerve or tendon—initial wound closure should prioritize coverage of neurovascular structures and tendons. ■ Wounds generally should be left open in the acute setting; return for delayed primary closure vs skin grafting or flap coverage as clinically indicated.

Postoperative management

- If there is concern for delayed presentation and muscle necrosis, serial debridement may be necessary.

POSTOPERATIVE CARE

- After initial fasciotomy the limb should be splinted in a functional position.
- Intravenous antibiotics are administered while the wound is open.
- Monitor electrolyte and renal function closely; myoglobinemia can result in acute renal failure.
- Return to operating room is planned within 48 hours for interval debridement and assessment of the wound bed.
- Once the wound bed is stabilized, perform delayed primary closure or split-thickness skin graft (**FIG 5**). Rarely, flap coverage is indicated for exposed tendon or nerve.
- Edema management with elevation and loose dressings proximal to the involved site
- Begin range of motion as soon as reasonable to prevent joint contractures and decrease swelling.

OUTCOMES

- Patient outcomes are dependent on the timing of fasciotomy.
- Early recognition and expedient treatment generally results in favorable outcomes.
- Late recognition and delayed treatment may result in irreversible nerve and muscle injury with limited functional recovery.
- The mechanism and severity of initial injury also influence prognosis.

COMPLICATIONS

- Untreated compartment syndrome will result in nerve dysfunction as well as Volkmann ischemic contracture (**FIG 6**).
- Rhabdomyolysis can result in acute renal failure.
- Incomplete release of the deep volar compartment can result in extrinsic flexor contractures.



FIG 5 • Split-thickness skin graft application to volar forearm.

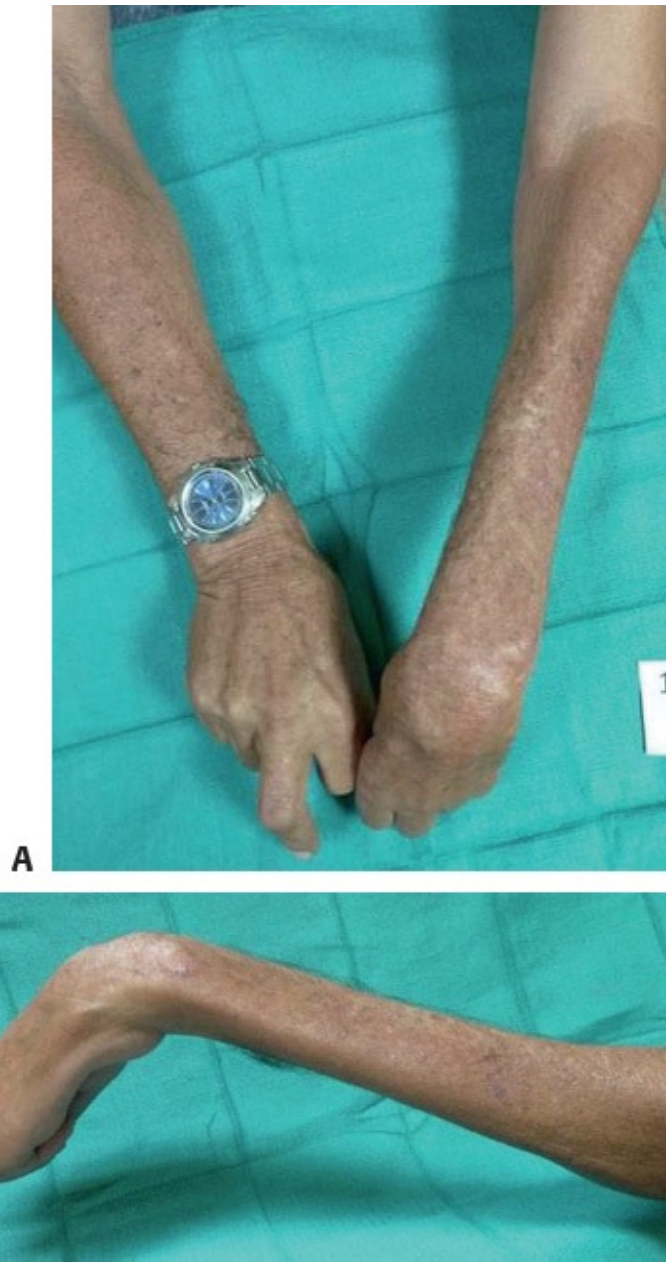


FIG 6 • Untreated compartment syndrome with Volkmann contracture.

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3 Revision Amputation and Shortening of the Digit

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- Fingertip injuries involve trauma to the digit distal to the insertion of the flexor and extensor tendons.
- The primary goal of treatment is a painless fingertip with supple and sensate skin coverage.
- The method of treatment should be individualized to the patient and injury pattern.
- This chapter will focus on revision amputation and shortening of the digit. The principles discussed can be applied to finger amputations more proximal than the fingertip.
- Refer to Chapter 60 for flap coverage options of fingertip injuries.

ANATOMY

- The nail complex (perionychium) consists of the nail plate and surrounding tissues¹ (**FIG 1**):
 - Eponychium: Skin proximal to the nail plate, covering the nail fold
 - Paronychium: Skin lateral to the nail plate
 - Hyponychium: Skin immediately distal and palmar to nail
 - Nail bed: Germinal matrix and sterile matrix
 - Germinal matrix: Soft tissue deep and proximal to nail plate, responsible for majority of nail growth. Distal margin is the lunula.
 - Sterile matrix: Tissue distal to lunula, responsible for nail adherence
 - Nail fold: Consists of dorsal roof matrix and proximal germinal matrix.
 - Lateral matrix horns: The proximal lateral corners of the matrix, formed by the confluence of the germinal matrix, dorsal roof matrix, and lateral nail

fold.

- The terminal extensor tendon insertion on the distal phalanx is approximately 1.2 mm proximal to the germinal matrix.²
- The pulp of the fingertip consists of fibrofatty tissue stabilized by septae extending from the dermis to the palmar periosteum of the distal phalanx.
- The proper digital nerve lies palmar to its corresponding digital artery. The nerve trifurcates at the level of the distal interphalangeal (DIP) joint (**FIG 2**).

PATHOGENESIS

- Traumatic mechanisms of injury: sharp, crush, avulsion

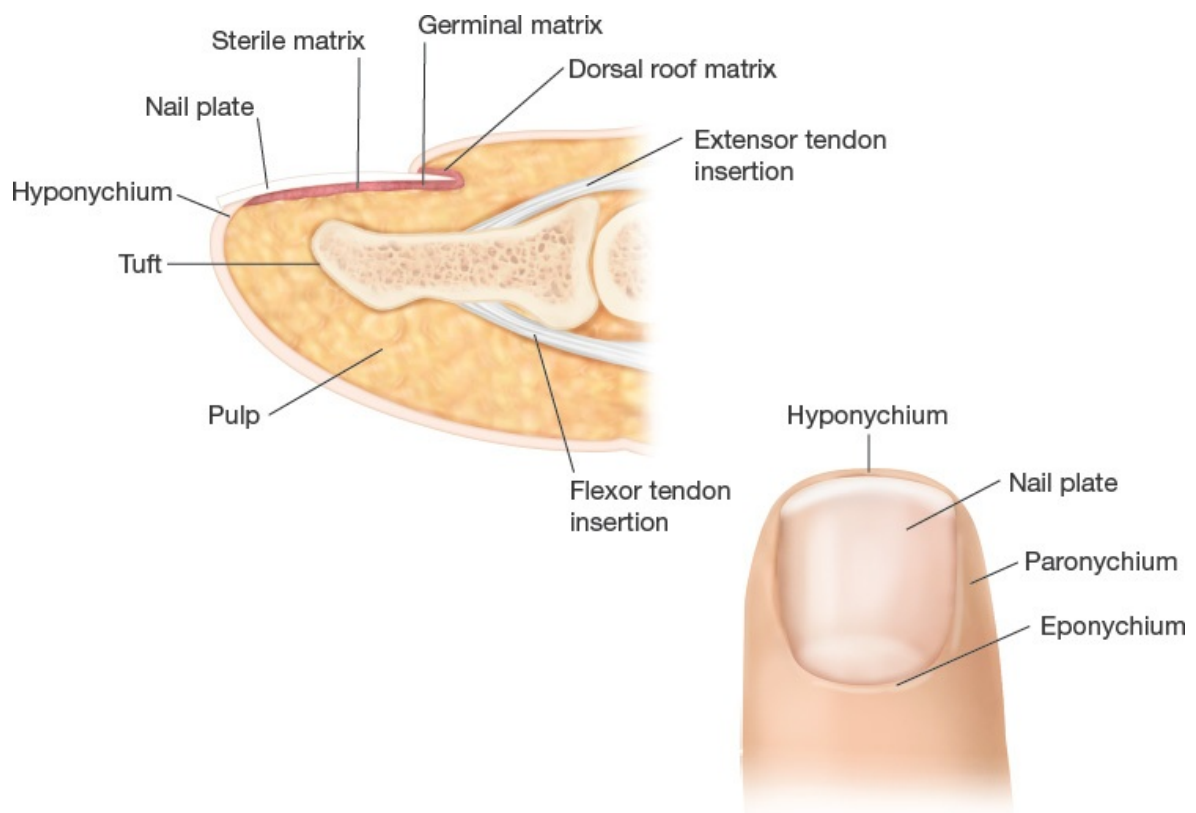


FIG 1 • Sagittal and dorsal views of the distal phalanx and nail complex.

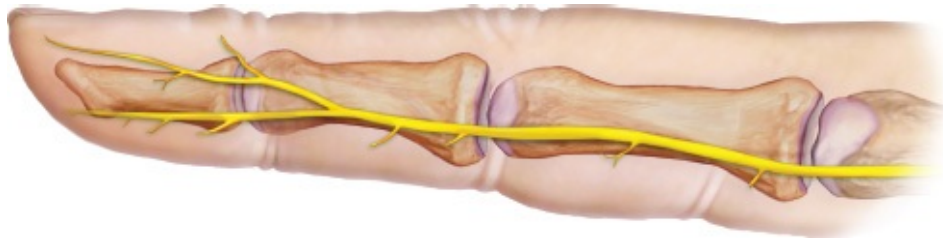


FIG 2 • Digital nerve anatomy. The nerve arborizes at the level of the distal interphalangeal joint.

PATIENT HISTORY AND PHYSICAL FINDINGS

■ History:

- Age
- Handedness
- Occupation
- Medical comorbidities
- Mechanism of injury
- Timing of injury
- Tobacco use
- Tetanus status

■ Physical exam:

- Identify the level of amputation; fingertip vs more proximal.
- Assess for nail bed injury.
- Assess for exposed bone. If there is significant exposed bone, healing by secondary intention will not be successful.
- Morphology of fingertip injury: transverse, dorsal oblique, palmar oblique, radial/ulnar oblique.
- Assess residual soft tissue: Can it be closed primarily with minimal tension?

IMAGING

- Radiographs of the digit

NONOPERATIVE MANAGEMENT

- Fingertip injuries without exposed bone will heal by secondary intention with local wound care.
- Irrigation and primary closure can be considered only if there is adequate skin resulting in a tensionless closure.

SURGICAL MANAGEMENT

Preoperative Planning

- Fingertip and amputations distal to the metacarpophalangeal joint with exposed bone and inadequate soft tissue coverage are candidates for bone shortening and primary closure.
- Amputations at the level of the eponychium and proximal are usually best suited for revision amputation.
- For fingertip injuries with exposed bone involving the midportion of the nail bed, consider flap coverage depending on injury morphology and patient factors (see Chapter 60).
- For finger amputations presenting with an amputated piece, consider replantation (see Chapter 68).
- Uncomplicated finger amputation can be performed in the emergency department.
- If there is a nail bed injury, prepare to repair the nail bed with chromic suture or Dermabond (Ethicon, Inc., Somerville, NJ).³
- If the revision amputation will result in removal of over two-thirds of the nail matrix and/or its underlying bony support, prepare to ablate the nail bed.
- Perform a digital block and gather instruments and dressings prior to starting the procedure.

Positioning

- Patient is positioned supine with hand table or Mayo stand.

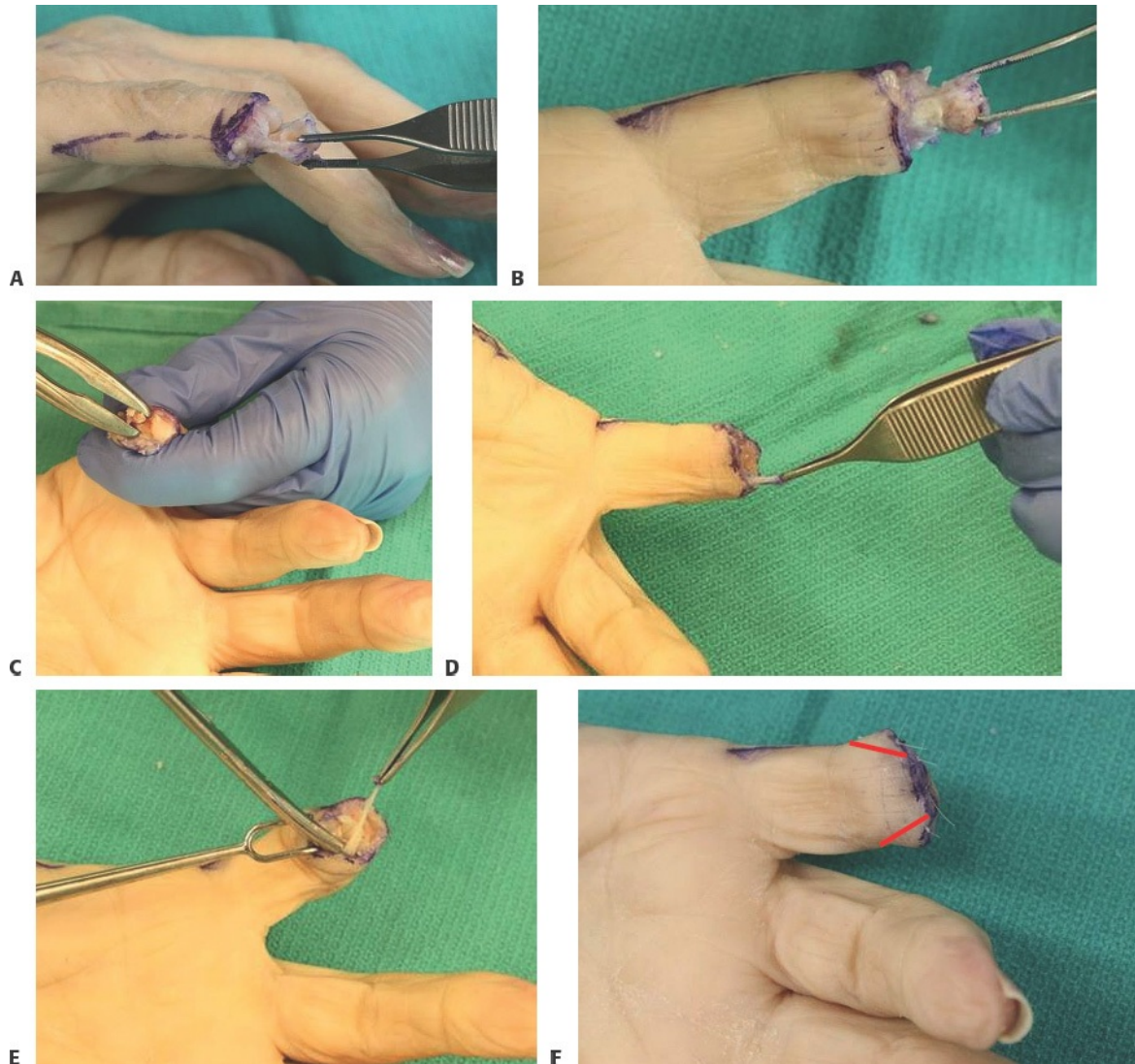
Approach

- Goals of this procedure are a painless, sensate fingertip, preservation of as much length as possible and avoidance of nail dystrophy.
- The decision to proceed with bone shortening and primary closure should take injury characteristics and patient factors into account. For example, if a patient with a volar oblique fingertip amputation is a smoker and a laborer who must return to work as soon as possible, we would recommend revision amputation with shortening and primary closure as opposed to a homodigital island flap or cross-finger flap.

TECHNIQUES

■ Revision Amputation With Primary Closure

- Administer a digital block prior to sterile preparation.
- Apply a finger tourniquet.
- Debride contaminated or devitalized tissue sharply.
- If there is nail matrix involvement, consider ablation vs nail bed repair.
- Mobilize the soft tissue around the level of bony exposure (**TECH FIG 1A,B**).
- Use a rongeur to shorten and contour the bone (**TECH FIG 1C**).
 - Bone should be shortened for tension-free closure.
 - Remove articular cartilage if performing a disarticulation.
- If the amputation is through or proximal to the DIP joint, identify the radial and ulnar digital nerves and shorten them to prevent neuroma being caught in the incision that will be painful (**TECH FIG 1D,E**).
- Reassess skin flaps to ensure tension-free closure and round fingertip by removing the dog ear over either side of the incision to create a round tip rather than a boxy tip.
- Close skin flaps with 5-0 nonabsorbable suture (**TECH FIG 1F**).
- Release the finger tourniquet to ensure adequate perfusion of the skin flaps. If the flaps appear tight or ischemic, consider additional bony shortening.
- Apply a sterile dressing.



TECH FIG 1 • Revision amputation through middle phalanx. **A,B.** Mobilization of the viable soft tissue around the amputation site. **C.** Bone contouring of middle phalanx head at amputation site. **D,E.** Digital nerve identification and shortening to prevent symptomatic neuroma. **F.** Amputation wound closure without tension. The boxy appearance should be rounded by removal of dog ears as marked.

■ Nail Ablation

- If the revision amputation will result in removal of over two-thirds of the

nail matrix and/or its underlying bony support, prepare to ablate the nail bed (**TECH FIG 2A**).

- Administer a digital block prior to sterile preparation.
- Apply a finger tourniquet.
- Remove the nail plate (if it remains) with a Freer elevator and hemostat.
- Make periungual incisions, perpendicular to the radial and ulnar margins of the eponychium, but do not incise through the dorsal roof matrix (**TECH FIG 2B,C**).
- Use methylene blue or a surgical marker to stain the germinal matrix and dorsal roof matrix from within the nail fold⁴ (**TECH FIG 2D**).
- Use a scalpel to raise the eponychial skin from the dorsal roof matrix. Separate these layers to the proximal extent of the germinal matrix (**TECH FIG 2E,F**).
- Avoid injury to the terminal extensor tendon. It inserts on the distal phalanx 1.2 mm proximal to the germinal matrix.²
- Identify the radial and ulnar lateral horns of the matrix, as these define the radial and ulnar limits of ablation.
- Excise the germinal and sterile matrix from the underlying periosteum of the distal phalanx (**TECH FIG 2G,H**).
- The proximal confluence of the lateral nail fold, germinal matrix, and dorsal roof matrix forms a pocket of tissue (lateral horns of the matrix) that should be excised en bloc. All marked tissue should be contained within this pocket.
- Perform bony shortening as indicated.
- Close with 5-0 nonabsorbable suture (**TECH FIG 2I,J**).



TECH FIG 2 • A. Fingertip amputation with significant loss of sterile matrix and bony support. **B,C.** Incisions for nail ablation. **D.** Use of a surgical marker or methylene blue helps define the extent of the nail fold for ablation. DRM, dorsal roof matrix. **E,F.** Elevation of the eponychial skin from the dorsal roof matrix. **G,H.** Nail ablation completed. **I,J.** Wound closure after nail ablation and bone shortening. The closure is contoured by removing dog ears as marked.

PEARLS AND PITFALLS

Preparation	■ Gather all instruments and dressings prior to starting the procedure. ■ Perform the digital block prior to gathering supplies. This allows time for the anesthetic to take effect.
Revision amputation technique	■ If the flexor or extensor tendon insertion is injured, strongly consider DIP joint disarticulation. The residual digit will be more stable with little sacrifice of length. ■ Ensure shortening of digital nerves to prevent painful neuroma formation at the fingertip.
Nail ablation technique	■ Complete removal of the germinal matrix is easier if the dorsal roof matrix is left in continuity with the germinal matrix. This allows for a “pocket” of matrix to be removed en bloc. ■ Handle the thin dorsal eponychial skin with care when elevating from the underlying dorsal matrix.
Wound closure	■ Tension-free closure is a necessity. Shorten bone further if needed. ■ Contour skin edges to minimize dog ears.

POSTOPERATIVE CARE

- A nonadherent soft dressing is applied over the digit.
- Oral antibiotics may be routinely prescribed postprocedure.
- Nonabsorbable sutures are removed 2 weeks postprocedure.
- After revision amputation, hand therapy is useful for fingertip desensitization, contouring, and early motion.

OUTCOMES

- Average static two-point discrimination after revision amputation is 3.8 mm.⁵
- Overall, revision amputation results in better static two-point discrimination when compared to local flaps.
- Good functional outcomes can be expected, with 95% of total active motion preserved.⁵
- Cold intolerance is common after revision amputation, with a 77% incidence.⁵

COMPLICATIONS

- Infection
- Cold intolerance and hypersensitivity are common.
- Painful neuroma
- Poor wound healing may be a result of closure under tension.
- Stiffness can result if early motion is not encouraged.
- Nail remnants may grow at the site of incomplete nail ablation.

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4 Drainage of Septic Flexor Tenosynovitis

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- Pyogenic flexor tenosynovitis is a bacterial infection in the flexor tendon sheath of the fingers or the thumb.

ANATOMY

- The flexor tendon sheath extends from the A1 pulley to the distal interphalangeal joint (**FIG 1**).
- The thumb flexor tendon sheath and radial bursa are contiguous.
- The small finger flexor tendon sheath and ulnar bursa are contiguous.
- The radial and ulnar bursae communicate through the space of Parona, which lies between the fascia of the pronator quadratus and flexor digitorum profundus tendon sheath.

PATHOGENESIS

- Most infections are caused by a penetrating injury to the tendon sheath.
- The most common organism responsible for disease is *Staphylococcus aureus*.¹

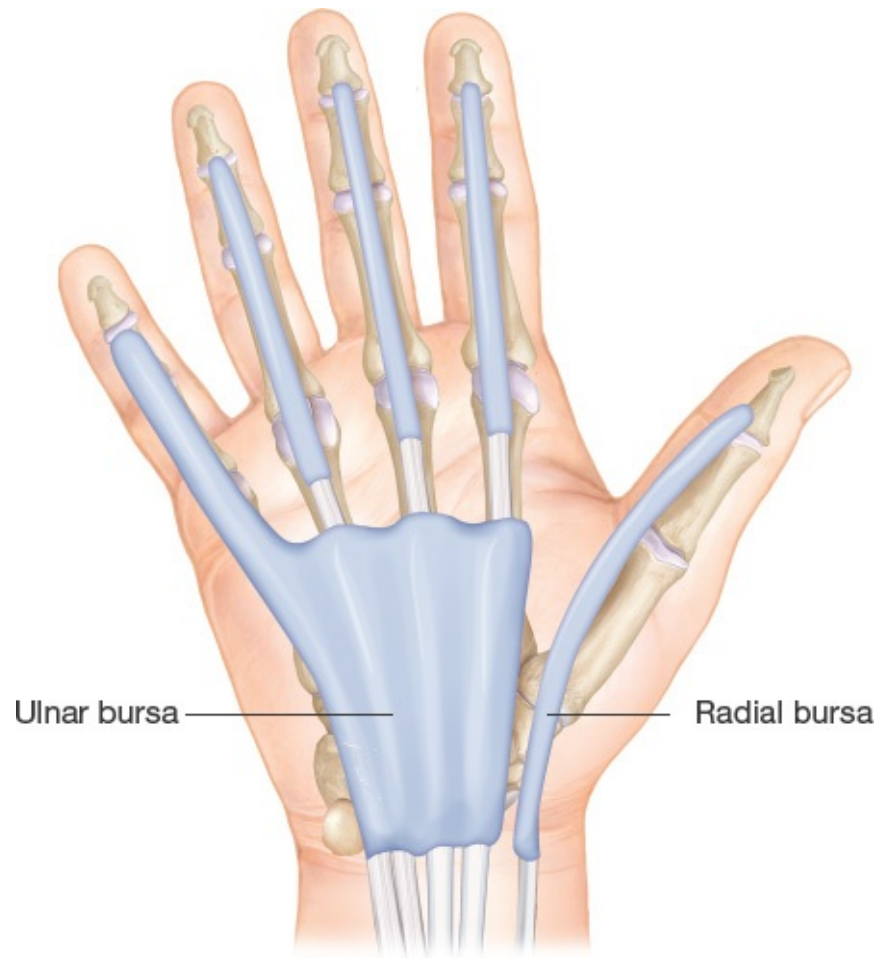


FIG 1 • Flexor tendon sheaths of the hand. There is potential communication between the thumb and small finger sheaths with the radial and ulna bursae, respectively.

- Hematogenous disease can be caused by disseminated gonococcal infection.
- Inoculated bacteria use the synovial fluid within the sheath as nutrition.
 - Bacterial growth leads to increased volume and pressure within the tendon sheath.
- Horseshoe abscess: Thumb or small finger flexor tenosynovitis can extend proximally into the space of Parona and track back up distally the opposite side flexor sheath.

NATURAL HISTORY

- Left untreated, the infection creates adhesions within the tendon sheath,

resulting in stiffness and loss of tendon gliding.

- Increased pressure obstructs extrinsic vincular blood supply to the tendon, contributing to tendon necrosis and rupture.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History of penetrating trauma. Evaluate for puncture wound on the palmar aspect of the digit.
- Assess the timing of injury and onset of symptoms.
- Diagnosis is clinical. Kanavel's four cardinal symptoms and signs are useful in diagnosis¹:
 - Exquisite tenderness along the flexor tendon sheath
 - Semiflexed position of the digit
 - Fusiform swelling of the digit
 - Pain with passive extension of the digit
- Examine the thenar and hypothenar eminences to assess for proximal extension of thumb or small finger tenosynovitis.
- Examine the distal forearm; tenderness or fullness of the volar wrist may indicate extension to the space of Parona (**FIG 2**).

IMAGING

- Radiographs should be obtained to assess for foreign body, pyarthrosis, or osteomyelitis.
- Laboratory evaluation with CBC, ESR, and CRP is helpful to monitor the disease process.

DIFFERENTIAL DIAGNOSIS

- Felon
- Paronychia
- Herpetic whitlow
- Gout
- Local abscess
- Septic arthritis
- High-pressure injection injury



FIG 2 • Thumb flexor tenosynovitis with extension into the space of Parona. Note swelling and erythema in radial volar forearm.

- Nonseptic acute flexor tenosynovitis from an inflammatory process such as rheumatoid arthritis

NONOPERATIVE MANAGEMENT

- Early infection (less than 24–48 hours after inoculation) in immunocompetent patients with mild symptoms may be treated with intravenous antibiotics, immobilization, and elevation.¹
- If symptoms do not improve within the first 12 to 24 hours of antibiotic therapy, surgical treatment is warranted.

SURGICAL MANAGEMENT

- Indications for surgical management:
 - Patients presenting with symptoms for more than 24 to 48 hours
 - Immunocompromised or diabetic patient

- Failure of symptom improvement with nonoperative management.

Preoperative Planning

- Plan for carpal tunnel decompression and extension to the distal forearm if there is concern for proximal involvement.

Positioning

- Supine with hand table
- General anesthesia
- Tourniquet without Esmarch exsanguination

Approach

- Closed tendon sheath irrigation is preferred for acute infections.² The limited incisions prevent tendon desiccation and minimize postoperative scarring.
- Extensile open debridement of the flexor tendon sheath through a longitudinal midlateral incision is used in the setting of subacute or chronic infection with thick purulence and phlegmon. The volar skin should not be disturbed to avoid wound separation, leading to exposure of the flexor tendon sheath that will require flap coverage to avoid tendon desiccation.

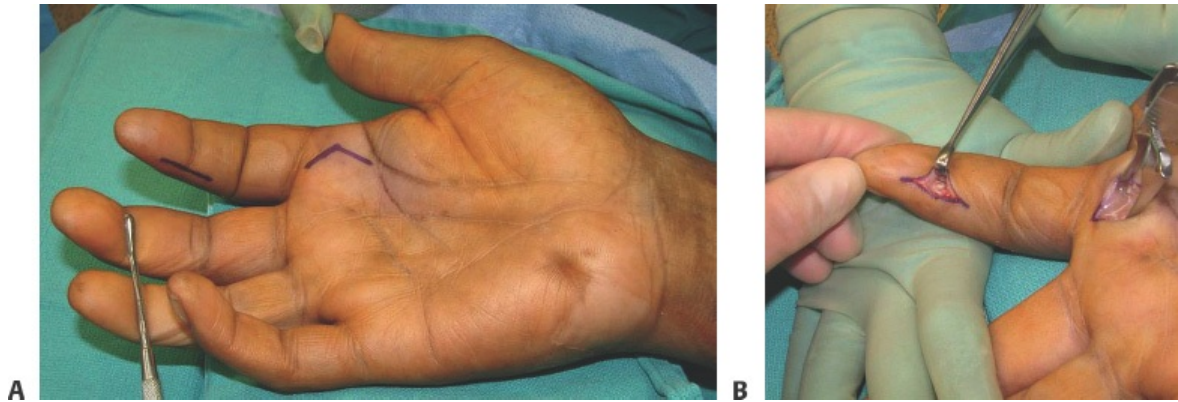
TECHNIQUES

■ Closed Tendon Sheath Irrigation (Acute Presentation)

Debridement and Exposure

- Thoroughly irrigate and debride any wounds.
- Distal exposure of the flexor tendon sheath
 - Make a 1-cm midaxial skin incision on the noncontact side of the digit overlying the A5 pulley (**TECH FIG 1A**).
 - Deepen the incision by dividing Cleland ligaments, dorsal to the neurovascular bundle.
 - Bluntly elevate the volar flap of the incision in order to visualize the A5 pulley of the flexor tendon sheath (**TECH FIG 1B**).

- Incise the A5 pulley longitudinally and send any purulent or cloudy material for culture and sensitivity.
- Proximal exposure of the flexor tendon sheath
 - Make a chevron or oblique incision in the palm overlying the A1 pulley (see **TECH FIG 1A**).
 - Bluntly dissect the soft tissue overlying the flexor tendon sheath, taking care not to injure the neurovascular bundles.



TECH FIG 1 • A. Incision markings for index finger tendon sheath exposure. **B.** Distal portal exposure of A5 pulley. The incision is dorsal to the neurovascular bundle and away from the contact surface of the distal pulp.

- Identify the A1 pulley.
- The A1 pulley does not have to be incised to perform tendon sheath irrigation. However, if there is thickened tenosynovium at this level, debride and send cultures.
- In the thumb, proximal exposure is performed through a thenar crease incision with release of the distal centimeter of transverse carpal ligament. The irrigation catheter is inserted along the flexor pollicis longus tendon.

Tendon Sheath Irrigation

- Place a 16-gauge intravenous catheter or 5F pediatric feeding tube in the proximal flexor sheath under the A1 pulley.
- From the proximal catheter, irrigate the tendon sheath with sterile saline until the effluent is clear (**TECH FIG 2**). We typically irrigate at least 500 mL of

fluid.

- If resistance is met, place a second catheter distally to facilitate irrigant egress.
- If irrigant is exiting through a debrided wound proximal to the distal catheter, irrigate thoroughly and then replace the proximal catheter in the distal aspect of the debrided wound to complete distal irrigation of the tendon sheath. Be sure that the saline is not injected into the subcutaneous tissue to avoid pressure necrosis of the soft tissue.

Wound Management

- Release the tourniquet and achieve hemostasis.
- Place small drains such as a 0.25 in. Penrose in the proximal and distal incisions.



TECH FIG 2 • Irrigation of flexor tendon sheath with pediatric feeding tube.

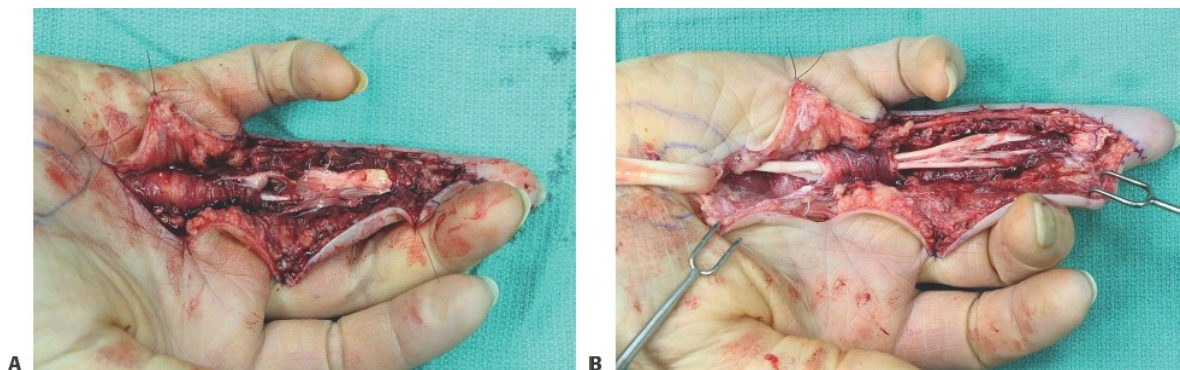
- Loose sutures are placed only to prevent tendon exposure and desiccation. The

wounds should be left open otherwise.

- Apply a forearm-based splint with the hand in resting position.

Open Debridement of Flexor Tendon Sheath (Subacute or Chronic Presentation)

- Thoroughly irrigate and debride any wounds.
- Make a midlateral incision from the distal interphalangeal flexion crease to the metacarpophalangeal flexion crease.
- Elevate a full-thickness palmar flap over the flexor tendon sheath. Extend the incision with oblique Bruner incisions distally and proximally if necessary.
- Identify the proximal extent of the flexor sheath system at the A1 pulley either through a separate chevron incision or by oblique proximal extension of the midlateral incision (**TECH FIG 3A**).
- Debride purulent and unhealthy appearing tenosynovium. Typically, this tissue cannot be washed away with closed sheath irrigation.

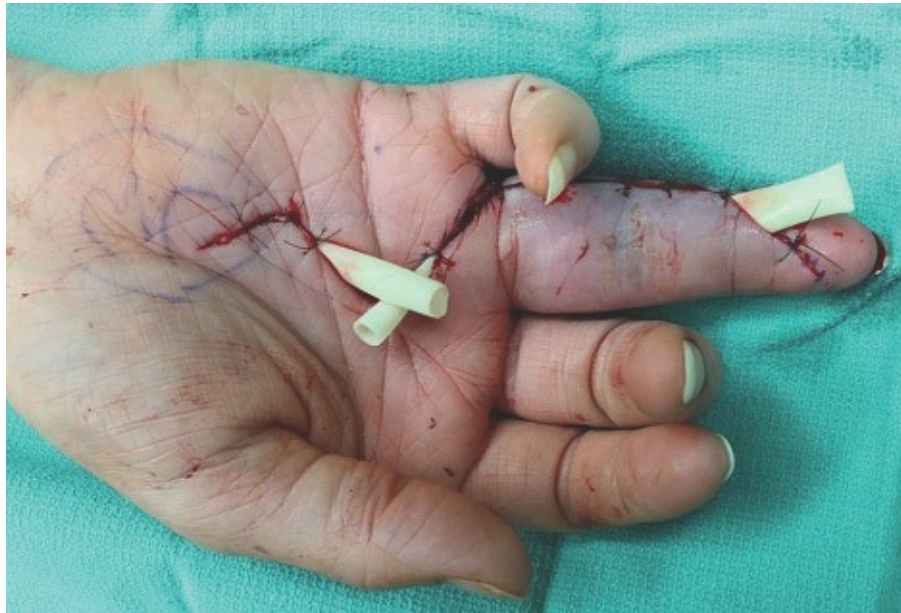


TECH FIG 3 • A. Extensile exposure of flexor tendon sheath in setting of extensive purulence. **B.** Debridement of ruptured necrotic flexor digitorum profundus tendon.

- Necrotic tendon and/or pulley may need to be debrided (**TECH FIG 3B**).
- Send tissue for culture and sensitivities.
- Thoroughly irrigate the wound.

Wound Closure

- Release the tourniquet and obtain hemostasis.
- The palmar flap may be loosely closed over the flexor tendon sheath; compared to a standard Bruner approach, the midlateral approach minimizes the risk of tendon desiccation (**TECH FIG 4**).
- Leave drains in place to allow for fluid egress.
- Apply a forearm-based splint with the hand in resting position.



TECH FIG 4 • Wound closure to cover the flexor tendons.

PEARLS AND PITFALLS

Diagnosis	■ Prompt clinical diagnosis is essential to initiate early treatment.
Incision placement	■ Plan incisions so they may be incorporated into extensile exposures if needed. ■ Avoid injury to the neurovascular bundle. The digital nerve trifurcates at the distal interphalangeal joint crease. ■ Inadequate exposure may fail to drain the infection.
Culture	■ Obtain stains, cultures, and sensitivities for aerobic, anaerobic, fungal, acid-fast bacillus, and atypical mycobacterial organisms.

	■ If a hematogenous source is suspected, obtain blood cultures and gonococcal tests.
Tendon sheath irrigation	■ Avoid high-pressure injection if there is resistance to syringe irrigation. Reposition the entrance and egress catheters if necessary. ■ If there is extensive infection, indicated by thick phlegmon or viscous drainage from the tendon sheath, extensile exposure may be necessary. ■ Continue irrigation until there is clear effluent.
Postoperative	■ Return for interval irrigation and debridement if there is no clinical improvement within 24–48 h.

POSTOPERATIVE CARE

- Elevate the extremity.
- Continue empiric antibiotics while cultures are pending. Include methicillin-resistant *S aureus* coverage.
- Remove the dressing postoperative day one and begin soaks 3 times daily.
- Initiate early motion of the digits to minimize stiffness.
- If symptoms do not improve within the first 24 to 48 hours, return to the operating room for additional irrigation and debridement.
- In the setting of severe infection with persistent infection and/or tendon necrosis, discuss amputation with the patient.

OUTCOMES

- Patients average 70% to 80% recovery of total active motion.³
- Risk factors for failure of surgical treatment resulting in amputation include³:
 - Age over 43 years
 - Diabetes mellitus, peripheral vascular disease, or renal failure
 - Presence of subcutaneous purulence
 - Ischemic changes at presentation
 - Polymicrobial infection

COMPLICATIONS

- Finger stiffness
- Persistent infection
- Digital nerve injury
- Tendon desiccation and rupture

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Section II: Hand Fractures and Dislocations

5

CHAPTER Distal Phalanx Fractures

John R. Fowler and Thomas B. Hughes

DEFINITION

- Distal phalanx fractures can be divided into several main categories (**FIG 1**):
 - Extensor tendon injuries, including soft tissue–only extensor tendon avulsions and “bony mallet” injuries that involve avulsion of a fragment of the distal phalanx. Bony mallet injuries may cause volar subluxation of the distal phalanx.
 - Distal phalanx fractures without involvement of the ligaments or tendons
 - Open epiphyseal fracture with nail bed laceration (Seymour fracture)
- A fracture is present in one-third of all mallet fingers.¹
- Mean age is 30, and the middle finger is most commonly involved.²
- Mallet injuries may be classified using the Wehbe and Schneider classification²
 - Type I: No subluxation at DIP joint
 - Type II: DIP joint subluxation
 - Type III: Epiphyseal injury
 - The types are further subdivided based on the amount of articular surface that is involved:
 - Type A involves less than 1/3 of the articular surface.
 - Type B involves 1/3 to 2/3 of the articular surface.
 - Type C involves greater than 2/3 of the articular surface.

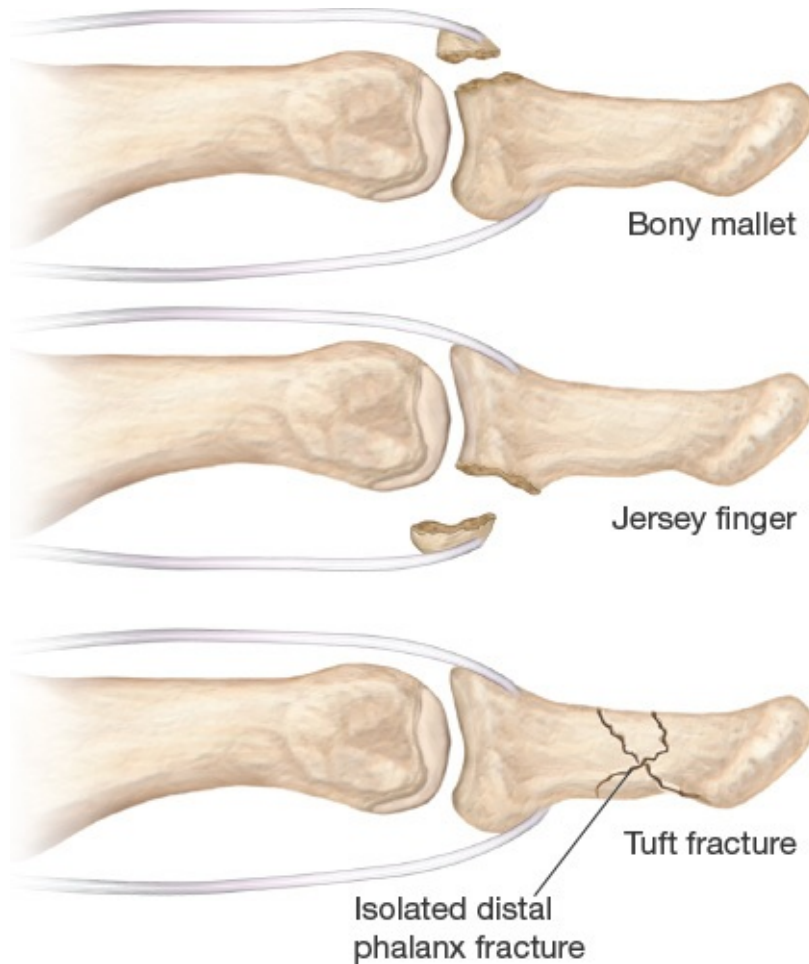


FIG 1 • Type of distal phalanx fractures. **A.** Bony mallet fractures. **B.** Jersey finger—avulsion of the flexor digitorum profundus from the base of the distal phalanx. **C.** Distal phalanx shaft/epiphyseal fracture or tuft fracture.

ANATOMY

- The terminal tendon inserts on the distal phalanx articular edge and has a footprint of approximately 12 mm.³
- The terminal tendon insertion is, on average, 1.4 mm proximal to the leading edge of the germinal matrix.³
- The extensor tendon inserts on the epiphysis, and flexor tendon inserts on the metaphyseal portion of the distal phalanx.⁴ This results in a flexed posture for epiphyseal fractures.

PATHOGENESIS

- The classic mechanism for a mallet injury is a ball striking the tip of the finger, causing eccentric flexion, resulting in tendon rupture and/or distal phalanx fracture.
- Subluxation of the joint may occur with large fracture fragments as the collateral ligaments are attached to the fracture fragment and the flexor digitorum profundus then has unopposed pull.¹
- Biomechanical studies have found that fractures involving less than 43% of the joint surface do not result in joint subluxation, whereas fractures involving over 52% of the joint surface do result in joint subluxation.⁵
- Seymour fractures are more commonly caused by a crushing mechanism resulting in distal phalanx epiphyseal fracture with nail bed laceration.⁴ This is an open fracture that requires immediate debridement, reduction, nail bed repair, and pinning.

NATURAL HISTORY

- Bony mallet injuries without volar subluxation of the joint have excellent healing rates.
- The average extensor lag with nonoperative treatment is 7 degrees.
- Seymour fractures that are not treated with formal irrigation and debridement historically have a high infection rate and risk for osteomyelitis.⁴

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present after a “jamming”-type injury of the finger with a chief complaint of inability to extend the finger at the distal interphalangeal joint.
- The distal interphalangeal joint is often swollen and erythematous. There is a variable amount of nail plate ecchymosis depending on the specific fracture type.

IMAGING

- AP and lateral radiographs of the finger are obtained.

NONOPERATIVE MANAGEMENT

- Conservative treatment in a DIP extension splint is indicated for soft tissue mallet fingers and bony mallet injuries involving less than 40% of the articular surface and injuries without volar subluxation.

- The DIP extension splint is worn continuously for 6 weeks and then only at night for an additional 2 weeks.
- The vast majority of fractures without volar subluxation of the distal phalanx should be treated nonoperatively. K-wire fixation is a secondary solution.

SURGICAL MANAGEMENT

- Indications for surgical management
 - Open fracture (Seymour fracture or open bony mallet)
 - More than 40% articular surface involvement
 - Volar subluxation of the distal phalanx
 - A relative indication is a patient who is a professional (such as a surgeon) who cannot wear an extension splint continuously for 6 weeks. They require pinning, with the pin buried under the skin and removed after 6 weeks.

Positioning

- The patient is placed in the supine position with the arm on a radiolucent table.
- The surgeon sits so that the dominant hand can drill the K-wires retrograde into the finger. For right-handed surgeons, this is at the head of the table.

Approach

- Mallet fingers are treated percutaneously. Seymour fractures require open debridement and pinning.

TECHNIQUES

■ Closed Reduction and Pinning

- First, a closed reduction is performed under live fluoroscopy by hyperextending the distal interphalangeal joint by 5 to 10 degrees.
- If this results in apposition of the bony mallet fragment and distal phalanx, a 0.045 in. K-wire is placed from the fingertip, through the distal phalanx, and across the distal interphalangeal joint (**TECH FIG 1**).
 - The pin can be cut and bent above the skin for removal in the office or buried and removed at a later time.
- If the dorsal bony fragment remains significantly displaced, the finger is

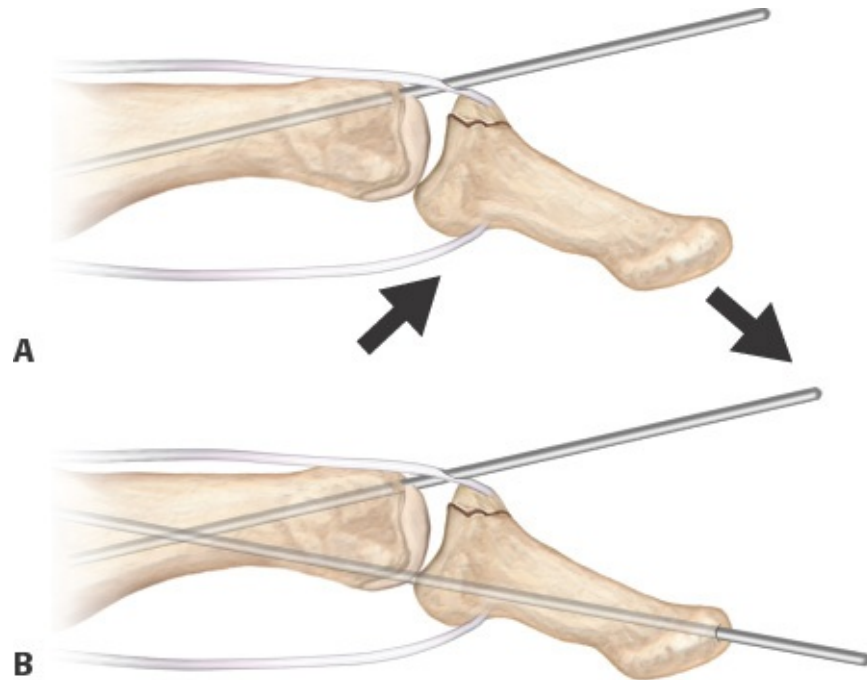
flexed, and under live fluoroscopy, a 0.045 in. K-wire is placed 1 to 2 mm proximal to the avulsion fragment and then drilled into the head of the middle phalanx.⁶





TECH FIG 1 • A. Oblique radiograph demonstrating bony mallet fractures of the small and ring finger distal phalanges. The joint reduced with extension of the distal phalanx, and the avulsion fragments became closely opposed. Postoperative **(B)** and lateral **(C)** AP demonstrate near anatomic overall alignment.

- The finger is then fully extended (**TECH FIG 2A**), and a second 0.045 in. K-wire is placed from the fingertip, through the distal phalanx, and across the distal interphalangeal joint (**TECH FIG 2B**).⁶



TECH FIG 2 • A. After a K-wire is placed just proximal to the avulsion fragment, the distal phalanx is extended to reduce the avulsion fragment to the distal phalanx. **B.** A second K-wire is placed across the DIP joint to hold the distal phalanx in extension.⁶

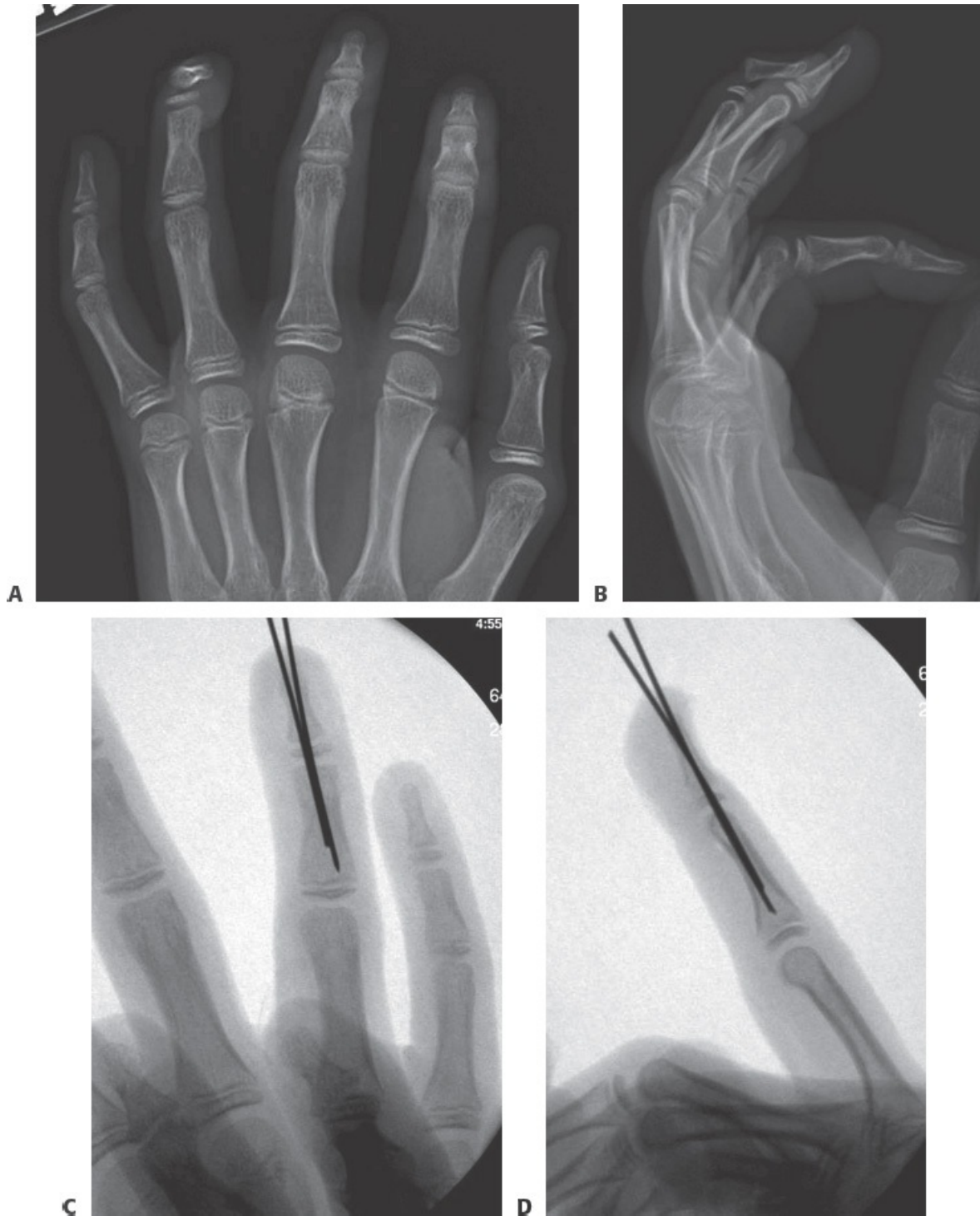
- The starting point for this K-wire is just volar to the nail bed. One must be careful not to be too dorsal because nail deformities can occur if the K-wire is driven through the nail bed.

■ Open Reduction and Internal Fixation

- An H-shaped incision is made dorsally, over the distal interphalangeal joint.
- Thick flaps are raised proximally and distally to expose the terminal tendon.
- The fracture is reduced and held in place with a 0.035 in. K-wire.
- Depending on the size of the fragment, two 1.3- to 1.5-mm mini-fragment screws are placed to stabilize the fracture.
- The reduction is indirect as visualization is blocked.

■ Open Treatment of Seymour Fractures

- The nail bed is carefully removed using a combination of a Freer elevator and a hemostat. Care is taken to not injure the underlying nail bed.
- There is usually a transverse laceration in the nail bed at the level of the germinal matrix.
- It may be necessary to make a longitudinal incision on either edge of the eponychium to lift the eponychium up “like a car hood” to allow better visualization of the germinal matrix.
- The finger is flexed to expose the open epiphyseal fracture. The interposed soft tissue is carefully removed and the bone is well irrigated. Excessive debridement of the bone is not performed as this would risk epiphyseal closure.
- The fracture is reduced and a 0.045 in. K-wire retrograde across the fracture and then across the DIP joint (**TECH FIG 3**).
- The nail bed is repaired using 5-0 chromic suture. The eponychial fold incisions are repaired using 5-0 chromic as well.
 - The nail plate is trimmed, washed, and replaced under the eponychial fold to prevent scarring to the nail bed. Alternatively, the foil wrapper from the chromic suture package is cut in the shape of a nail and placed under the eponychial fold.



TECH FIG 3 • Preoperative AP (**A**) and lateral (**B**) radiographs demonstrating an open distal phalanx epiphyseal fracture. The fracture site was debrided and reduced. **C,D**. Two 0.045 in. K-wires were then drilled

retrograde across the fracture and across the DIP joint for stability.

PEARLS AND PITFALLS

Indications	■ Classic indications include volar subluxation of the distal phalanx and/or a fracture involving more than 40% of the joint surface.
Seymour fractures	■ Early irrigation, debridement, and pinning are essential to successful outcomes. These fractures have a high risk of osteomyelitis if not appropriately treated.
Treatment	■ Attempt to avoid skin incisions and treat percutaneously, if possible, to avoid dorsal skin necrosis.

POSTOPERATIVE CARE

- Patients are immobilized in a DIP extension splint, leaving the PIP joint free.
- Early active motion of the PIP joint is encouraged to prevent stiffness and contracture.

OUTCOMES

- Hofmeister et al.⁷ reported on 24 fingers that underwent extension block pinning at a mean follow-up of 74 weeks.
 - Mean time to union was 35 days.
 - Mean extension was -4 degrees.
 - Mean flexion was 78 degrees.
 - Three fingers had a superficial pin site infection that resolved with oral antibiotics.
 - Two fingers had loss of reduction less than 2 mm.
- Darder-Prats and colleagues⁸ reviewed 22 mallet fractures that underwent extension block pinning at mean follow-up of 25 months. All patients reported a good or excellent result.
- Krusche-Mandl et al.⁹ reviewed 24 patients with Seymour fractures and noted that 23/24 obtained full range of motion and there were no chronic infections. However, 5 patients had distal phalanx growth disturbances and 6 had limited nail dystrophies.

COMPLICATIONS

- The majority of distal phalanx fractures (with the exception of Seymour fractures) should be treated nonoperatively due to the high complication rate associated with operative treatment.
- King et al.¹⁰ reported complications in 41% of operatively treated mallet fractures in their series. The most common complication was dorsal skin necrosis. Other complications included osteomyelitis, pin tract infection, nail deformity, and recurrent extensor lag.
- Stern and Kastrup¹¹ reported a 53% complication rate for operatively treated mallet fractures. The complications included nail deformity, pin infection, and joint incongruity.
- Superficial pin site infections usually resolve with pin removal and oral antibiotics.
- Patients may have persistent extensor lag at the DIP joint despite operative treatment. Additionally, surgical intervention may result in permanent decreased DIP flexion.

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6

CHAPTER Proximal Phalanx Fractures

John R. Fowler

DEFINITION

- Proximal phalanx fractures represent 23% of all hand and forearm fractures.¹
- These fractures can be classified by
 - Location
 - Extra-articular
 - Intracondylar
 - Base/epiphyseal
 - Fracture pattern
 - Oblique
 - Transverse
 - Comminuted

ANATOMY

- The proximal phalanx is the longest phalanx in each finger and has a mild palmar concavity.²
- The head of the proximal phalanx has two convex condyles and a central shallow depression.²
- Proximal phalanx shaft fractures typically assume an apex volar angulation.²
 - The intrinsic muscles insert on the proximal phalanx base.
 - The central slip pulls the distal fragment into extension.
- The extensor mechanism (**FIG 1**) is in direct contact with the proximal phalanx. Therefore, fracture hematoma and resulting fibrosis may greatly inhibit gliding of the extensor mechanism.
- One must consider this close relationship if considering the use of dorsal

hardware.

PATHOGENESIS

- Phalanx fractures occur through several common mechanisms of injury:
 - Axial load (jamming type injury)
 - Rotational torque
 - Medial/lateral angular force
 - Crush or direct blow
- The injury mechanism is important for the type of fracture that is created. Rotational torque typically produces an oblique fracture, while crush/direct blow mechanisms produce a transverse fracture that may have comminution.
- Patient age also plays a role in fracture type and location. Pediatric patients most commonly sustain epiphyseal fractures at the phalanx base, whereas adult patients more commonly sustain transverse or oblique fractures of the phalanx shaft.

NATURAL HISTORY

- Minimally displaced fractures and stable fracture patterns have a high rate of union with minimal long-term loss of function.
- Displaced fractures and unstable fractures may lead to nonunion or malunion, resulting in loss of motion.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history should carefully document the mechanism of injury and time since injury. A higher-energy mechanism of injury may indicate greater surrounding soft tissue damage and the possibility of greater fracture instability. The time since injury is important, especially in pediatric patients, as delay in surgical intervention may preclude closed reduction if significant fracture healing occurs prior to intervention.
- A careful examination of the skin is important to rule out open fracture that would necessitate more urgent surgical treatment.
- The finger is often swollen and ecchymotic from the fracture.

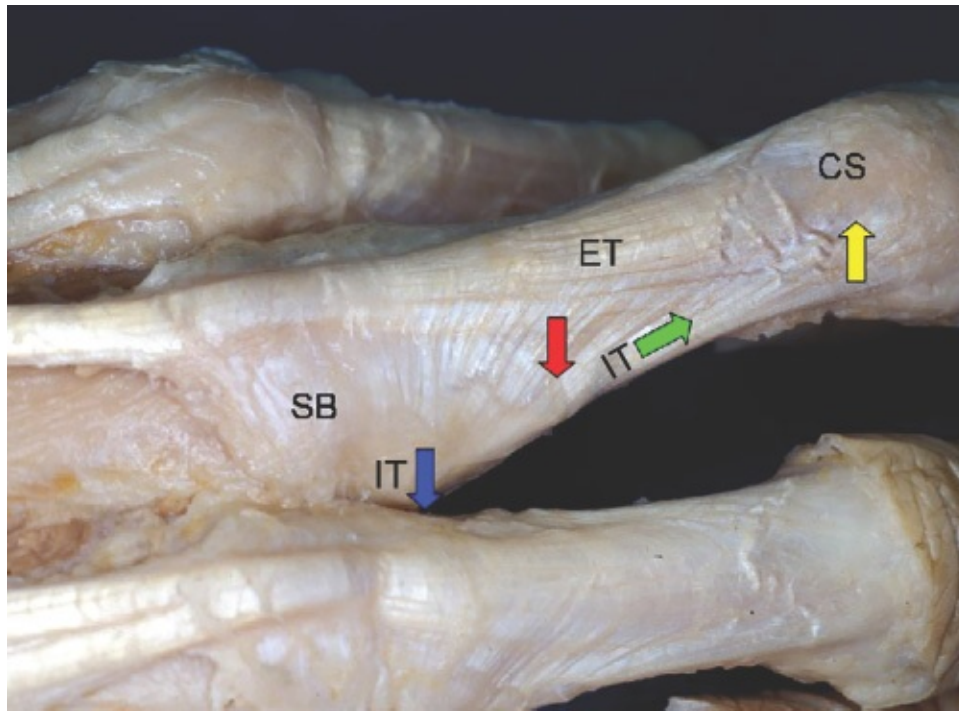


FIG 1 • Extra-articular proximal phalanx shaft fractures typically assume an apex volar angulation (*red arrow*). The lateral band (IT) insertion (*green arrow*) at the base of the proximal phalanx results in flexion of the proximal fragment (*blue arrow*) and the central slip (CS) insertion on the base of the middle phalanx pulls the distal fragment dorsally (*yellow arrow*). SB, sagittal band; ET, extensor tendon. (From Harman TW, Graham TJ, Uhl RL. Operative treatment of extra-articular phalangeal fractures. In Hunt TR, ed. *Operative Techniques in Hand, Wrist, and Forearm Surgery*. Philadelphia, PA: Lippincott Williams & Wilkins, 2011:287.)

- Rotational alignment of the finger should be evaluated by asking the patient to flex the digits. All four fingers should point in the same direction, toward the scaphoid tubercle.
- If patients are unable to adequately flex the digits secondary to pain, the alignment of the fingernails can be compared to the contralateral hand with the fingers in full extension. Rotational malalignment is not well tolerated and

is an indication for surgical intervention.

- Finger extension is carefully evaluated. Apex dorsal angulation of the fracture can result in relative lengthening of the extensor mechanism, resulting in an extensor lag at the proximal interphalangeal joint.

IMAGING

- Standard AP, lateral, and oblique radiographs are obtained.
- Advanced imaging with CT is rarely indicated. CT may be beneficial to evaluate articular congruity for condyle fractures and phalangeal base fractures.

DIFFERENTIAL DIAGNOSIS

- Proximal phalanx fracture
- Contusion
- Collateral ligament sprain/tear
- Arthritis
- Trigger finger
- Infection

NONOPERATIVE MANAGEMENT

- Nondisplaced and minimally displaced fractures without rotational malalignment may be treated nonoperatively with a cast or custom thermoplast splint.
- The risk of prolonged immobilization and resultant stiffness must be weighed against the risks of surgical intervention.

SURGICAL MANAGEMENT

- It cannot be overemphasized that the best surgical option is the least invasive option that provides fracture stability and the opportunity for early range of motion.
 - Extensive exposure may result in permanent postoperative stiffness.
- Percutaneous techniques with near-anatomic alignment may be preferred to open treatment with anatomic alignment.
- Indications
 - Closed reduction and pinning
 - Acceptable alignment can be obtained by closed means.
 - Fracture is stable after pinning.

- Of note, a limited incision to reduce the fracture, followed by percutaneous pinning, is also a treatment option
- Open reduction with lag screws
 - Long oblique fracture with 2:1 ratio of fracture length:phalanx width
- Open reduction with mini-fragment plate
 - Comminution
 - Transverse fracture or short oblique not amenable to lag screws or pinning

Preoperative Planning

- The surgeon should be prepared for both closed and open techniques.
- K-wires and mini-fragment screws and plates should be available.

Positioning

- The patient is placed in the supine position with the affected arm on a radiolucent hand table.
- Most surgical approaches are from the dorsum of the finger, and therefore the palm is placed down on the table.
- The surgeon sits in the axilla (if right handed) or at the head of the bed (if left handed) to allow the dominant hand to be used to place K-wires.

Approach

- For the techniques described in this chapter, the dorsal approach is used.
- Sharp dissection down to the extensor mechanism is performed to develop thick flaps that are not damaged by blunt dissection.

TECHNIQUES

■ Open Reduction and Internal Fixation of Intra-articular Proximal Phalanx Condylar Fractures

- A midlateral incision is made on the side of the condylar fracture.
- Sharp dissection is carried out down to the extensor mechanism and thick flaps are raised.
- The interval between the central slip and lateral band is incised.

- The fracture site is identified and dorsal capsule incised to evaluate the articular surface.
- The collateral ligament is attached to the condyle and is the deforming force.
- The fracture is reduced under direct visualization.
 - This is accomplished by placing a 0.035-in. K-wire in the fragment and using it as a joystick to reduce the fracture. The K-wire can then sometimes be drilled across the fracture site to temporarily stabilize the fracture. However, often the K-wire is at the wrong angle, and a second 0.035-in. K-wire is placed across the fracture site.
 - Caution should be exercised when using tenaculum clamps or towel clips as the condyle fracture fragment is often very small and can be crushed by these larger clamps.
 - I have found that gentle use of a hemostat to hold the fracture while the temporary K-wire is placed across the fracture site is useful and typically does not crush the condyle.
- Two or three (depending on the size of the condyle fragment) 1.2-mm mini-fragment screws are placed across the fracture (**TECH FIG 1**).
- I do not recommend the use of standard lag screw technique for these fractures. I only drill the pilot hole and place a neutralization screw. The fracture fragment is small, and there is little room for error. Multiple passes with the drill can cause fragmentation of the fracture and results in fracture displacement.
- Anatomic reduction is confirmed on orthogonal radiographs.
- The wound is well irrigated and interval between the central slip and lateral bands closed with 4-0 Vicryl suture.
- The skin is closed using 4-0 nylon suture.



TECH FIG 1 • AP (**A**) and lateral (**B**) radiographs demonstrating an intra-articular condylar fracture of the proximal phalanx head. Postoperative AP (**C**) and lateral (**D**) radiographs demonstrate improved articular congruity after open reduction and internal fixation.

■ Closed Reduction and Pinning of Extra-articular Proximal Phalanx Shaft Fractures

- A closed reduction is performed and confirmed on orthogonal radiographs (**TECH FIG 2**).
- The MCP joint is flexed to 90 degrees.
- A 0.045-in. K-wire is taken freehand and placed at the midpoint of the metacarpal head in the AP plane and immediately medial or lateral.
 - In my experience, this starting point is more volar than expected.
- Using a combination of direct feel and fluoroscopy, the K-wire is passed medial or lateral to the metacarpal head and into contact with the base of the proximal phalanx.



TECH FIG 2 • AP (**A**), oblique (**B**), and lateral (**C**) radiographs showing an extra-articular ring finger proximal phalanx shaft fracture with ulnar deviation and apex volar deformity. Postoperative AP (**D**) and lateral (**E**) radiographs showing improved alignment after

closed reduction and percutaneous pinning.

- While holding the reduction, the K-wire is drilled into the phalanx base, across the fracture site, and into the head of the proximal phalanx.
 - Placement of the K-wire within the medullary canal (and not through the phalanx head into the PIP joint) and maintenance of reduction is confirmed using fluoroscopy.
 - This procedure is repeated to place a second 0.045-in. K-wire on the other side of the phalanx.
 - The pins are bent and cut outside the skin for later removal.
-

■ Open Reduction and Internal Fixation of Extra-articular Proximal Phalanx Shaft Fractures With Lag Screws

- A longitudinal incision is made directly over the proximal phalanx. For more distal fractures, the incision is carried distally in a lazy S over the PIP joint, and for more proximal fractures, the incision is carried proximally in a lazy S over the MCP joint.
- Sharp dissection is carried out down to the extensor mechanism and thick flaps raised.
- Fracture exposure can be performed in two ways. I prefer to split the extensor mechanism longitudinally. I feel that this gives the best exposure of the fracture and allows the easiest screw placement. The problem with splitting the extensor tendon is postoperative extensor lag. Alternatively, the interval between the central extensor tendon and lateral bands can be developed.
- The fracture site is identified and fracture hematoma cleared.
- The fracture is provisionally reduced. For oblique fractures, this is often able to be accomplished with the use of a point-to-point tenaculum clamp or towel clamp.
 - Be careful to not overcompress with the clamp as this can cause iatrogenic fracture of the bone.
 - Check rotational alignment.
- A lag screw is then placed perpendicular to the fracture site. The pilot hole is drilled first, followed by the gliding hole. The countersink is then used as well

(TECH FIG 3).

- An additional lag screw is placed perpendicular to the fracture site.
- Finally, a third screw is placed perpendicular to the other two screws.
- The extensor mechanism is closed with buried 4-0 Vicryl sutures.
- Close the skin with nylon sutures.
- Place the patient in splint with MCP flexed to 60 to 70 degrees, PIP and DIP fully extended.

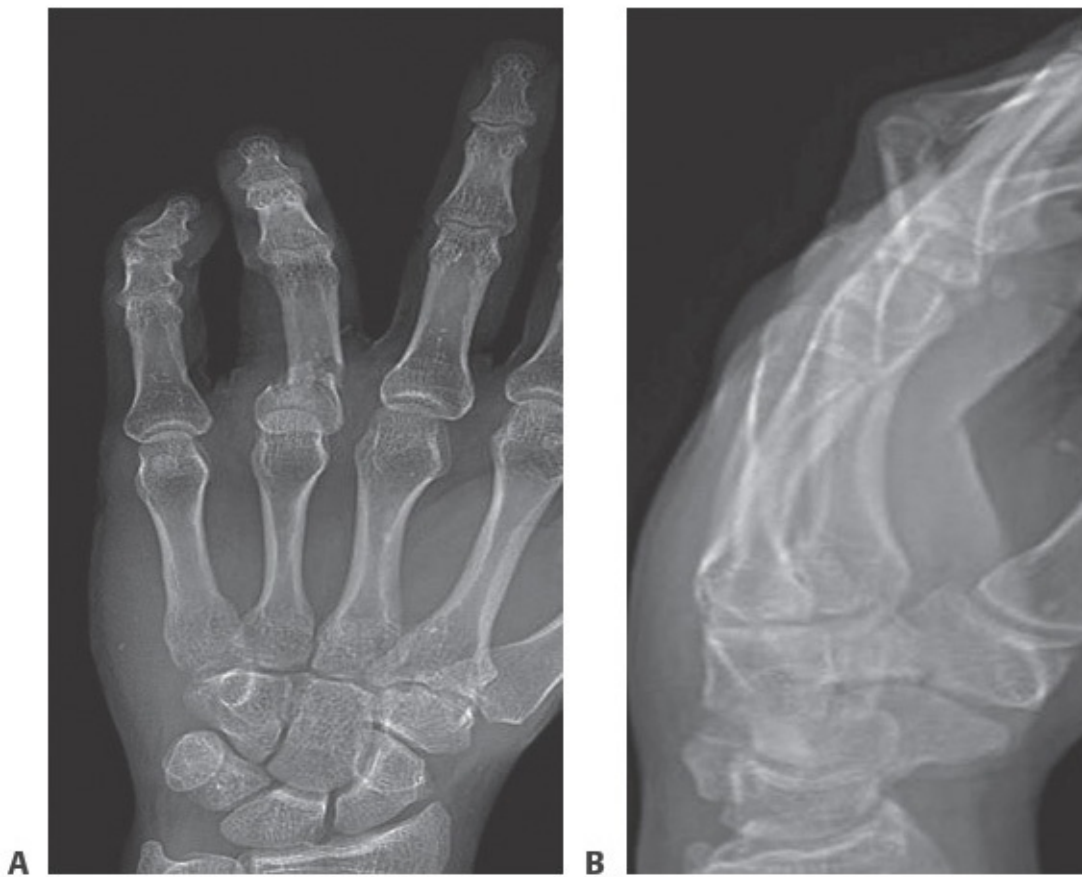


TECH FIG 3 • AP (A) and lateral (B) radiographs demonstrating an extra-articular fracture of the proximal phalanx shaft. Postoperative AP (C) radiograph demonstrates improved alignment after open reduction and internal fixation with a lag screws.

■ Open Reduction and Internal Fixation of Extra-articular Proximal Phalanx Shaft Fractures With Mini-Fragment Plates

- The same approach is used as is described above for lag screw fixation.
- A 1.2 or 1.7-mm mini-fragment plate is chosen based on the size of the proximal phalanx.

- The smallest plate that will offer fracture stability is chosen and hardware prominence against the extensor mechanism may result in decreased range of motion.
- One screw is placed on each side of the fracture and rotational alignment evaluated (**TECH FIG 4A–D**).
- The remaining screws are then placed.
- The extensor mechanism is closed with buried 4-0 Vicryl sutures.
- The wound is closed using 4-0 nylon sutures.





TECH FIG 4 • AP (A) and lateral (B) radiographs demonstrating an extra-articular fracture of the proximal phalanx base. Postoperative AP (C) and lateral (D) radiographs demonstrate improved alignment after open reduction and internal fixation with a mini-fragment plate and screws.

PEARLS AND PITFALLS

Treatment

- Perform the least invasive procedure to achieve fracture stabilization.

Rehabilitation

- Start early ROM to decrease stiffness.

Starting point for K-wires

- The starting point for K-wires is more volar than expected.

Condylar fractures	■ These fractures tend to have relatively little bone. Be careful to not overclamp these fractures as they can fall apart. Additionally, do not try to perform standard lag technique, just place neutralization screws.
Rotation	■ Be sure to evaluate rotation before final hardware is placed and after all hardware is in place. Rotational alignment is critical.

POSTOPERATIVE CARE

- The patient is placed in a plaster splint with the MCP joints flexed to 70 degrees and PIP joints placed in full extension.
- If stable fixation has been achieved, the postoperative splint is removed at 7 to 10 days and the patient placed into a removable thermoplast splint with the MCP joints flexed to 70 degrees and the PIP joints left free to allow early ROM.
- If the fixation is of questionable stability, the patient is placed into a fiberglass cast that places the MCP joints to 70 degrees and PIP joints in full extension.
 - Pins are removed at 4 weeks and ROM initiated.
- At 6 weeks, all immobilization is discontinued and more aggressive ROM is started.

OUTCOMES

- Hornbach and Cohen³ reported on 12 extra-articular proximal phalanx fractures treated with transarticular K-wire fixation.
 - Mean total active motion was 265 degrees and excellent results were obtained in 10 of 12 fractures.
- Faruqi et al.⁴ reported on the outcomes of 50 isolated extra-articular proximal phalanx fractures that were treated with either transarticular or extra-articular cross-pinning.
 - The mean total active motion was 201 degrees in the transarticular group and 198 degrees in the extra-articular group.
 - The mean flexion loss at the PIP joint was 27 degrees.
 - Nearly 33% of patients in each group had an extensor lag greater than 15 degrees.
 - Secondary procedures were required in 6/25 patients in the transarticular group and 2/25 patients in the extra-articular group.
 - Hornbach and Cohen reported on 12 extra-articular proximal phalanx

fractures treated with K-wire fixation at a mean follow-up of 20 months.

COMPLICATIONS

- Stiffness is a nearly universal complication after treatment of proximal phalanx fractures.
- Pin tract infections may occur when percutaneous pins are used.
- Malunion and nonunion may occur but are uncommon.

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CHAPTER Metacarpal Shaft Fractures

John R. Fowler and Thomas B. Hughes

DEFINITION

- A metacarpal head fracture is an intra-articular fracture of the metacarpal that is distal to the metacarpal neck.
- A boxer's fracture is a small finger metacarpal neck fracture.
- Metacarpal fractures constitute 30% of all fractures treated in the emergency department.
- Eighty-five percent of these fractures occur in males¹

ANATOMY

- The metacarpals are concave volarly and articulate distally with the base of the proximal phalanx.
- The metacarpal base articulates with the distal carpal row.
 - The index and middle metacarpal bases articulate with the trapezoid and capitate. There is minimal motion at this articulation.²
 - The small and ring finger metacarpal bases articulate with the hamate. This articulation provides significant flexion and some rotation.²
- The deep intermetacarpal ligament connects the volar plates of each metacarpal, preventing significant shortening in the setting of fracture.³
- Tendon insertions and/or origins may contribute to fracture displacement.
 - FCR inserts on the volar base of the index metacarpal.
 - ECRL inserts on the dorsal base of the index metacarpal.
 - ECRB inserts on the dorsal base of the middle metacarpal.
 - ECU inserts on the dorsal base of the small metacarpal.
 - Interossei arise from the metacarpal shafts.

PATHOGENESIS

- Metacarpal neck fractures are the result of an axial load applied to a flexed MCP joint.
- The most common mechanism of injury is punching a hard object.¹
- Metacarpal shaft fractures can result from axial load, torsion, and/or a direct blow.³
- The ring finger metacarpal has the narrowest shaft and therefore has a higher incidence of shaft fracture from a punching mechanism than do the other metacarpals.¹
- Metacarpal base/CMC fracture dislocations are almost always the result of axial loading.

NATURAL HISTORY

- Pace et al.⁴ compared 23 patients who underwent a closed reduction and casting for an isolated small finger metacarpal neck fracture with 43 patients who did not have a closed reduction.
- Despite improved angulation after reduction, at final follow-up, there was no difference in volar angulation between the two groups.
- Sletten and colleagues⁵ randomized 85 patients with small finger metacarpal neck fractures that had more than 30 degrees of volar angulation to either nonoperative treatment or antegrade bouquet pinning. The authors found no difference in quickDASH, pain, satisfaction, range of motion, grip strength, or quality of life between the two groups. However, the operative group had a higher rate of complications and longer sick leave.
- Every 2 mm of metacarpal shortening results in 7 degrees of extensor lag.⁶

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history often includes an axial load to the hand, usually with the fingers flexed.
- The history should include any history of open wounds or punching the mouth of another person to rule out “fight bite.”
- “Fight bite” injuries require operative treatment to prevent deep infection.
- Special attention should be paid to the rotational alignment of the fingers with flexion.
 - All fingers should roughly point to the distal pole of the scaphoid.
 - Ensure that there is no scissoring.

- Compare to the contralateral hand.
- The flexor tendons and collateral ligaments at each joint should be evaluated to ensure the absence of associated soft tissue injury.

IMAGING

- AP, oblique, and lateral radiographs of the hand should be obtained.
- Volar angulation should be measured on the true lateral view as the oblique view can overestimate true angulation.
- Consideration to CT scan can be given in cases of metacarpal base fractures to more accurately determine subluxation and for intra-articular metacarpal head fractures to more accurately determine the amount of articular step-off and displacement.

NONOPERATIVE MANAGEMENT

- Nonoperative treatment is appropriate for the vast majority of metacarpal neck and shaft fractures.
- Patients without rotational deformity and/or scissoring and without pseudoclawing are placed into a hand-based (neck fractures) or forearm-based (shaft fractures) ulnar gutter splint with the PIP joints left free for early motion
 - The splint is worn full-time for 4 weeks and then discontinued if the fracture site is no longer tender.
- Patients who are likely to be noncompliant with splint treatment are placed in short-arm ulnar gutter casts with the PIP joints left free.

SURGICAL MANAGEMENT

- Indications^{3,7}
 - Metacarpal neck fractures with more than 10 to 15 degrees of volar angulation for the index and middle fingers and more than 40 degrees of volar angulation for the ring and small fingers
 - Metacarpal shaft fractures with more than 10 degrees of volar angulation for the index and middle fingers and more than 20 degrees of volar angulation for the ring and small fingers
 - Any rotational deformity or scissoring of the finger with flexion
 - Pseudoclawing
 - Multiple metacarpal fractures
 - Segmental bone loss
 - Open fractures

Preoperative Planning

- The surgeon should be prepared to perform multiple techniques depending on specific intraoperative findings.
- Fractures that may seem treatable with percutaneous pinning are often deemed to require open reduction internal fixation if an acceptable closed reduction cannot be obtained or if intraoperative findings are more severe than previously thought.
- Consideration should be given to utilization of the technique that results in the least soft tissue disruption while still restoring alignment and stability.

Positioning

- The hand is placed on a radiolucent table
- A forearm tourniquet is used for local-sedation cases and upper arm tourniquet used for regional block/general cases

Approach

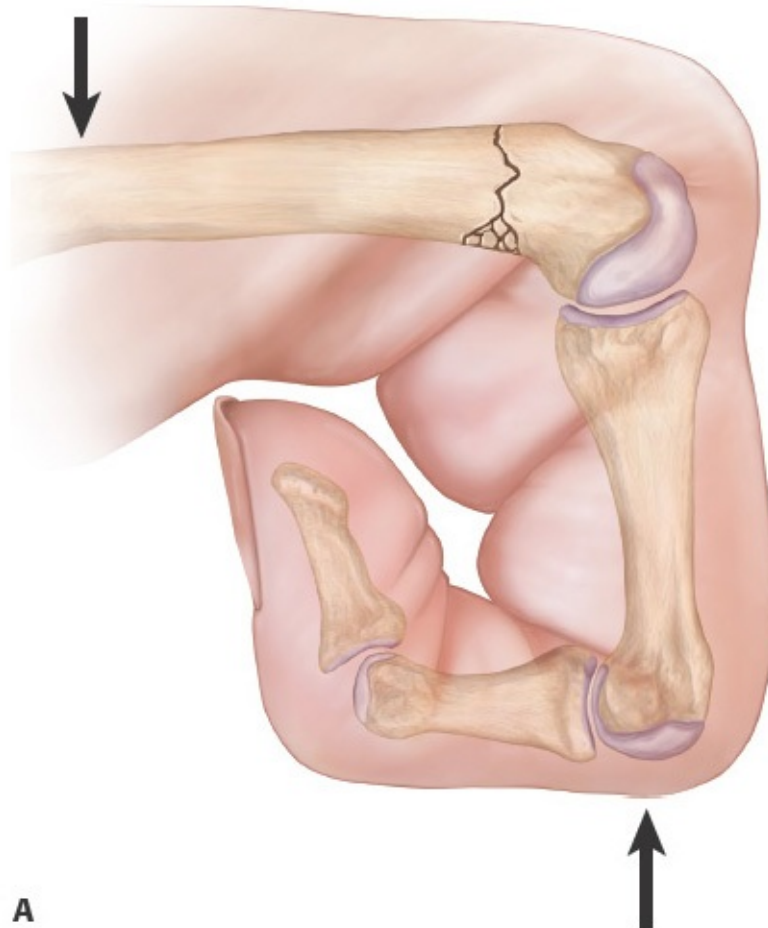
- Open approaches to the metacarpal are almost always dorsally based.
- Adjacent metacarpal fractures can be exposed through a single incision equidistant between the two bones.
- The periosteum is incised and can sometimes be closed over the fracture if lag screws or K-wires are used. This is not usually possible if mini-fragment plates are used.
- For intra-articular metacarpal fractures, the extensor mechanism is split longitudinally to access the articular surface and then closed after fixation is completed.

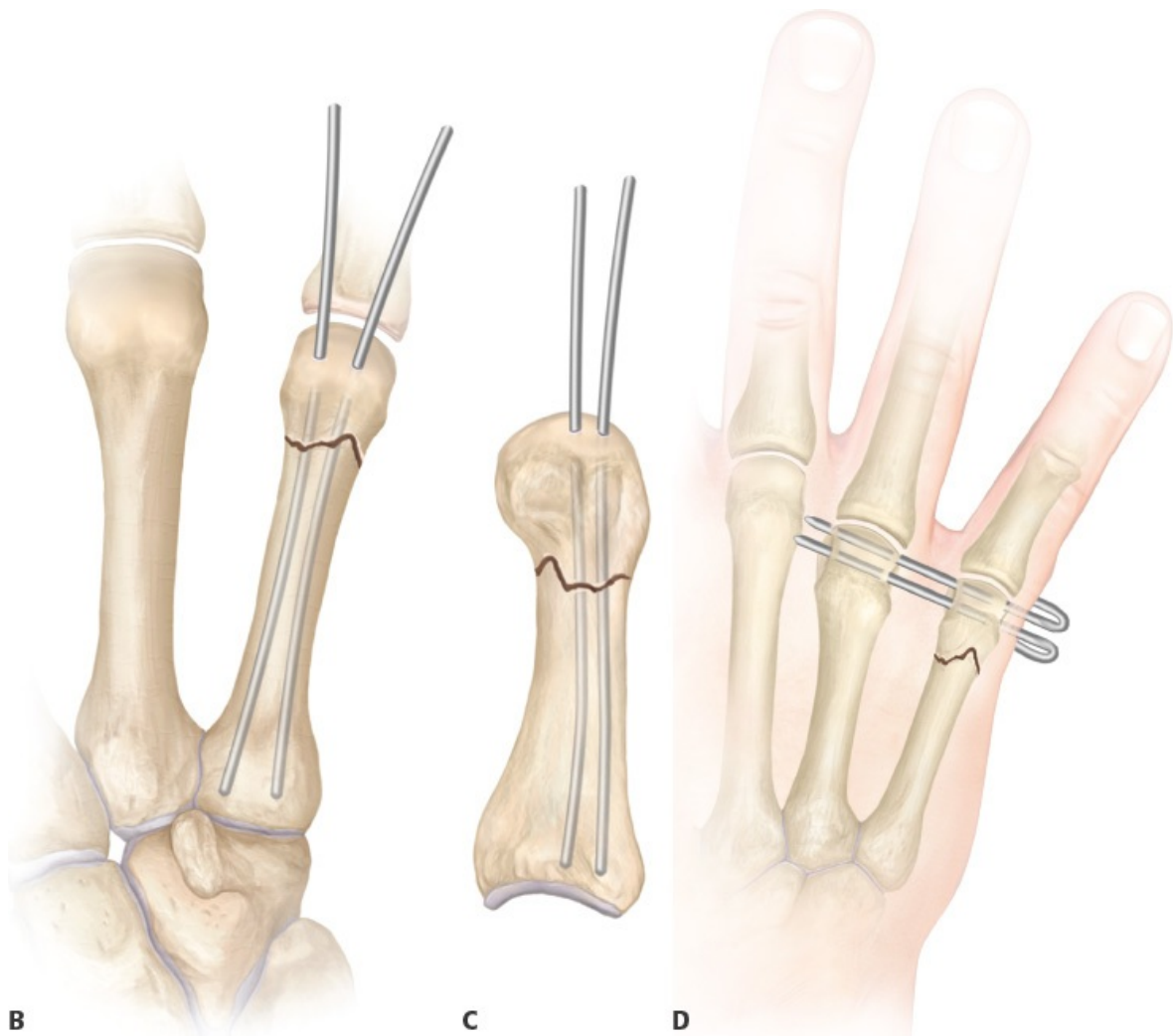
TECHNIQUES

■ Closed Reduction and Pinning of Metacarpal Neck Fractures

- The Jahss technique (**TECH FIG 1A**) is used to perform a closed reduction of the metacarpal neck.
- The reduction is confirmed on the lateral radiograph.

- While the reduction is held by the assistant, a 0.045-in. K-wire is placed into the metacarpal head, just ulnar to the extensor mechanism.
- The K-wire is then advanced across the fracture site and down the metacarpal shaft.





TECH FIG 1 • A. The Jahss technique. The metacarpophalangeal and proximal interphalangeal joints are flexed to 90 degrees and volar to dorsal force is placed on the proximal phalanx head. This reduces the volar angulation of the metacarpal neck fracture. **B,C.** AP and lateral depictions showing two K-wires placed longitudinally from the metacarpal head into the metacarpal shaft on either side of the extensor mechanism. **D.** Transverse pinning of a small finger metacarpal neck fracture to the ring finger metacarpal.

- A second 0.0450-in. K-wire is then placed into the metacarpal head, just radial to the extensor mechanism and advanced across the fracture site, into the

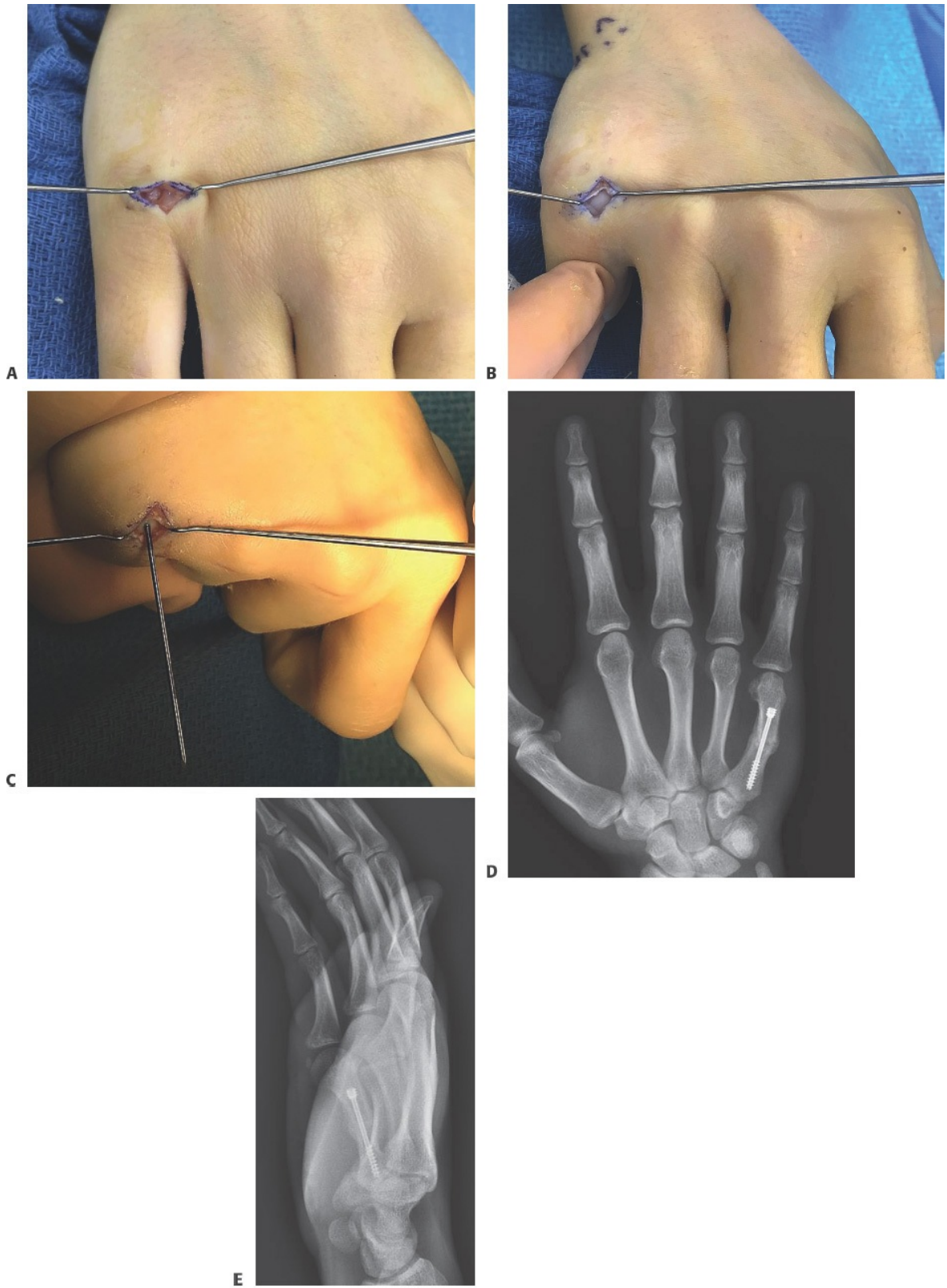
metacarpal shaft (**TECH FIG 1B,C**).

- The reduction and intramedullary location of the K-wires are confirmed using orthogonal fluoroscopic views.
- Alternatively, for border digits, K-wires can be placed perpendicular to the metacarpal shaft and the fracture can be stabilized to the adjacent metacarpal (**TECH FIG 1D**).

■ Open Reduction and Internal Fixation of Metacarpal Neck or Shaft Fractures with Headless Compression Screws

- A 1-cm incision is made dorsally over the metacarpal head (**TECH FIG 2A**).
- The extensor tendon is split and dorsal arthrotomy performed (**TECH FIG 2B**).
- A 1.1-mm K-wire is placed into the metacarpal head and drilled retrograde to the level of the fracture (**TECH FIG 2C**).
 - The K-wire should be in the dorsal third of the metacarpal head on the lateral and not through the articular portion of the cartilage.
 - Consider using a longer K-wire so that you are able to pass the screw and not lose the K-wire into the metacarpal shaft.
- The fracture is then reduced and K-wire driven across the fracture site. Intramedullary location of the K-wire and adequate reduction is confirmed on orthogonal fluoroscopic views.
- A cannulated headless compression screw is then placed over the K-wire (**TECH FIG 2D,E**).
 - We recommend a 3.0- to 3.5-mm screw with the exception of the ring finger because of the narrow diameter of its shaft. For the ring finger, we use a 2.0- or 2.5-mm screw.
 - Measure the width of the intramedullary canal as its isthmus prior to surgery to confirm that it is wide enough (at least 2 mm) to accept an implant.
 - The screw is inserted beneath the articular surface.
 - Attempt to center the screw on the fracture site to maximize compression, although this is difficult for metacarpal neck fractures given their proximity to the joint.
- The extensor split is closed with buried 4-0 Vicryl followed by 4-0 nylon for

the skin.

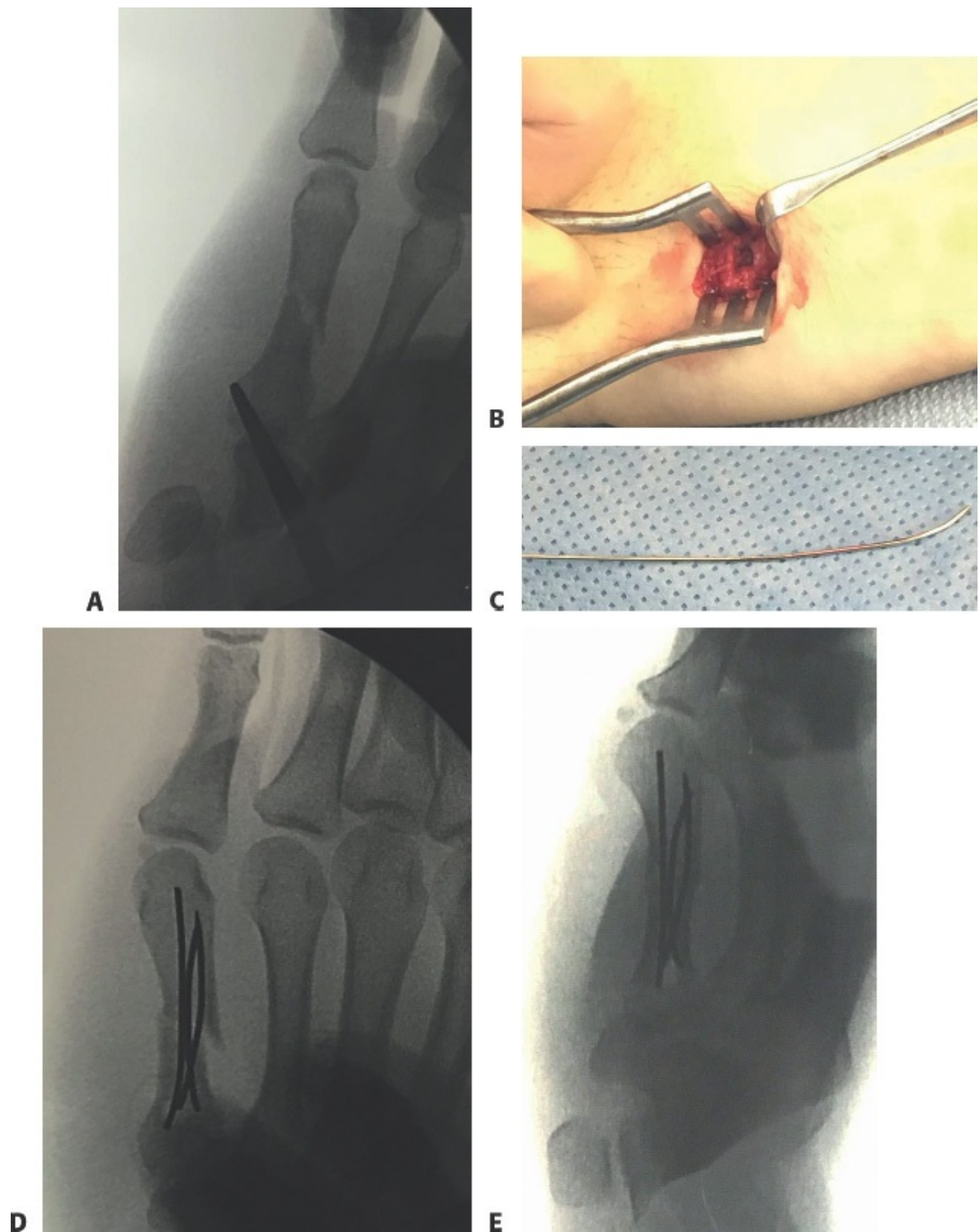


TECH FIG 2 • A. Dorsal skin incision and exposure of

extensor mechanism. **B.** The extensor mechanism is splint and the metacarpal head exposed. **C.** A K-wire is placed in the dorsal third of the metacarpal head and driven retrograde across the fracture site after reduction has been performed. **D,E.** AP and lateral radiographs demonstrating a headless compression screw placed across the fracture site and within the metacarpal shaft.

■ Closed Reduction and Pinning of Metacarpal Shaft Fractures (Bouquet Technique)⁸

- A closed reduction is performed and confirmed on orthogonal radiographs. If an adequate closed reduction cannot be obtained, this technique is abandoned.
- A 2-cm longitudinal incision is made centered on the base of the metacarpal.
- Dissection is carried out down to bone, taking care to protect the extensor tendons.
- A small hole is made on the ulnar aspect of the metacarpal base (**TECH FIG 3A,B**), extra-articularly, taking care to not penetrate the radial cortex. This can be done using an awl or a small drill bit.
- Three round-tip 0.035-in. K-wires are gently bent (**TECH FIG 3C**).
- The fracture is reduced, and each K-wire is placed into the intramedullary canal and drilled across the fracture site and into the metacarpal head.
- The K-wires are placed in divergent directions to form a “bouquet” in the metacarpal head. It is often necessary to get the K-wires in the canal and across the fracture site, then use a needle driver to rotate the pins into divergent directions (**TECH FIG 3D,E**)
- Reduction is confirmed on fluoroscopy.
- The pins are cut outside the metacarpal base, taking care to leave enough K-wire protruding for easy removal.
- The skin is closed with nylon suture.

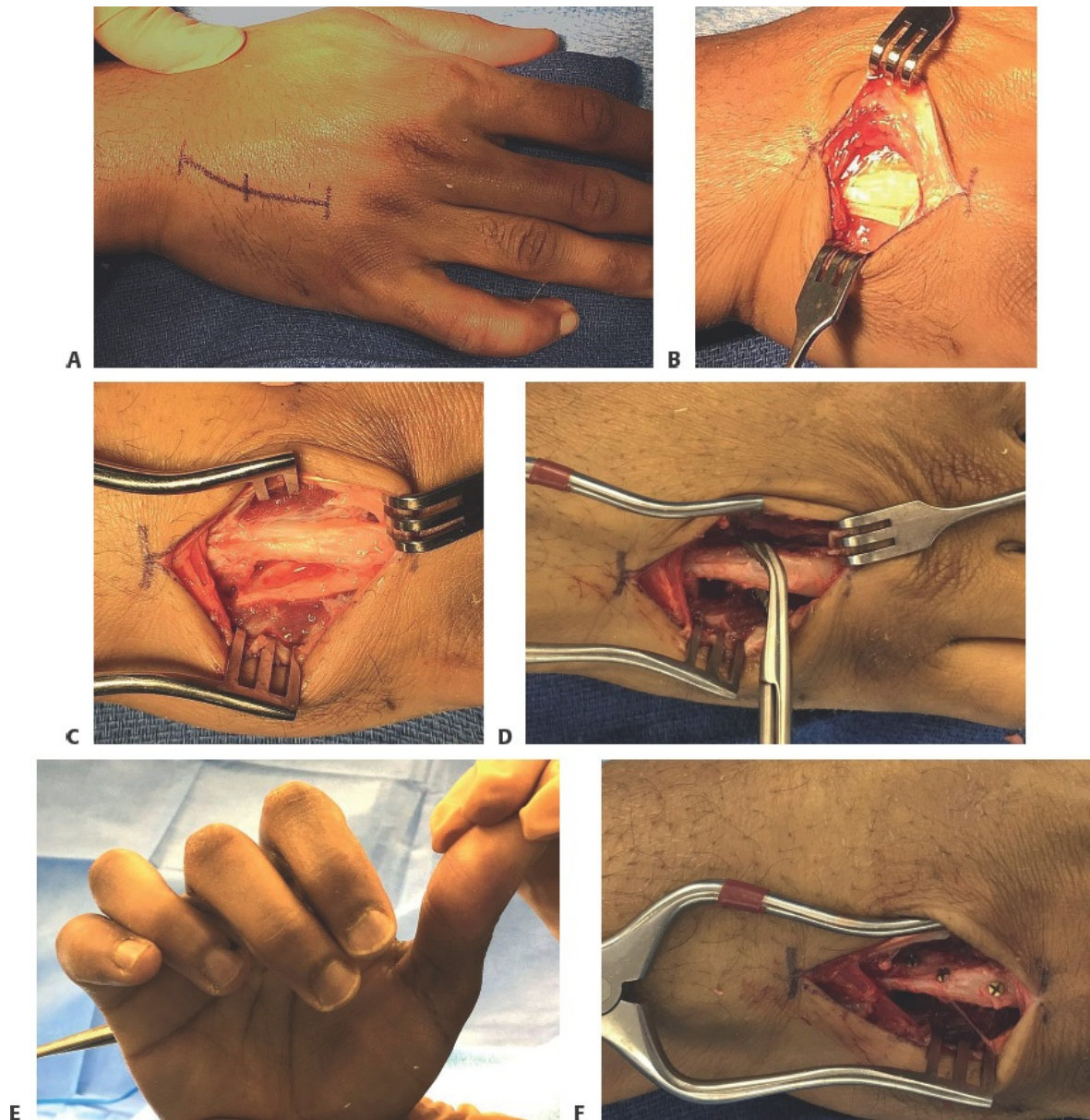


TECH FIG 3 • A. A radiolucent tool is used to locate the entry site for the pins, and the skin is marked with a marking pen. **B.** A 1- to 2-cm incision is made and dissection carried out down to bone. A 2.0-mm drill bit

or curette is used to make a hole in the base of the metacarpal taking care to remain well extra-articular. **C.** The pins are bent with a gentle curve at the tip. **D,E.** Three pins are then placed into the intramedullary canal, and a needle driver is used to rotate them into divergent directions after being placed across the fracture site.

■ Open Reduction and Internal Fixation of Metacarpal Shaft Fractures With Lag Screws

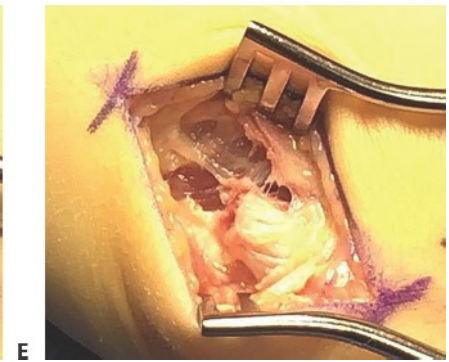
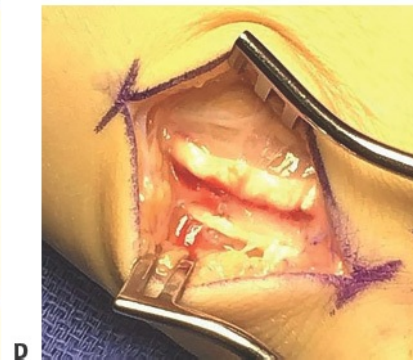
- Open reduction and internal fixation with lag screws requires an oblique fracture line that is at least twice the width of the metacarpal shaft.
- For a single metacarpal fracture, the incision is placed directly over the metacarpal. For multiple adjacent fractures, the incision is placed midway between the metacarpals to allow access to both (**TECH FIG 4A**).
- Dissection is carried out bluntly down to the level of the extensor tendons (**TECH FIG 4B**).
- The tendon is retracted and periosteum incised over the metacarpal.
- The fracture is exposed and debrided (**TECH FIG 4C**).
- The fracture is provisionally reduced. For oblique fractures this can often be accomplished with the use of a point-to-point tenaculum clamp or towel clamp (**TECH FIG 4D**).
 - Care must be taken not to overcompress with the clamp, as this can cause iatrogenic fracture of the metacarpal.
 - Rotational alignment is checked (**TECH FIG 4E**).
- A lag screw is then placed perpendicular to the fracture site. The pilot hole is drilled first, followed by the gliding hole. The countersink is then used as well.
- An additional lag screw is placed perpendicular to the fracture site as well.
- Finally, a third screw is placed perpendicular to the other two screw. (**TECH FIG 4F**).
- Close periosteum over the fracture site if possible.
- Close skin with nylon sutures.
- Place the patient in splint with MCP flexed to 60 to 70 degrees, PIP and DIP fully extended.

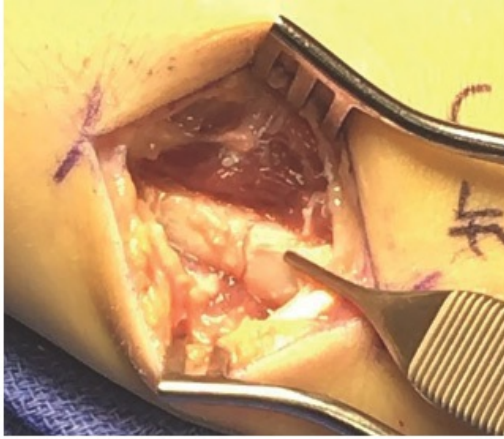


TECH FIG 4 • **A.** A longitudinal incision is made over the affected metacarpal shaft. **B.** Blunt dissection is carried out down to the extensor mechanism. **C.** The extensor mechanism is retracted and fracture site exposed. **D.** The fracture site is debrided of soft tissue and callus and provisionally reduced. **E.** Rotational alignment is confirmed prior to placing screws. **F.** Lag screws are placed and orthogonal radiographs obtained to confirm anatomic reduction.

■ Open Reduction and Internal Fixation of Metacarpal Shaft Fractures With Mini-Fragment Plates

- Open reduction internal fixation with mini-fragment plates and screws may be indicated for transverse fractures or fractures that cannot be adequately reduced and stabilized using percutaneous techniques (**TECH FIG 5A,B**)
- For a single metacarpal fracture, the incision is placed directly over the metacarpal (**TECH FIG 5C**). For multiple adjacent fractures, the incision is placed midway between the metacarpals to allow access to both.
- Dissection is carried out bluntly down to the level of the extensor tendons (**TECH FIG 5D**).
- The tendon is retracted and periosteum incised over the metacarpal.
- The fracture is exposed and debrided (**TECH FIG 5E**).
- The fracture is provisionally reduced (**TECH FIG 5F**).
 - Sometimes it is easier to fix the plate to one side of the fracture and then reduce the fracture to the plate. This is especially true of transverse fracture that are difficult to hold reduced using fracture clamps.
- Place one screw proximally and distally (**TECH FIG 5G**).
 - Check rotation of the finger (**TECH FIG 5H**) and radiographs.
 - If satisfied with alignment and rotation, fill remaining screw holes (**TECH FIG 5I-K**).
- Close periosteum over plate if possible.
- Close skin with nylon sutures.
- Place the patient in splint with MCP flexed to 60 to 70 degrees, PIP and DIP fully extended.





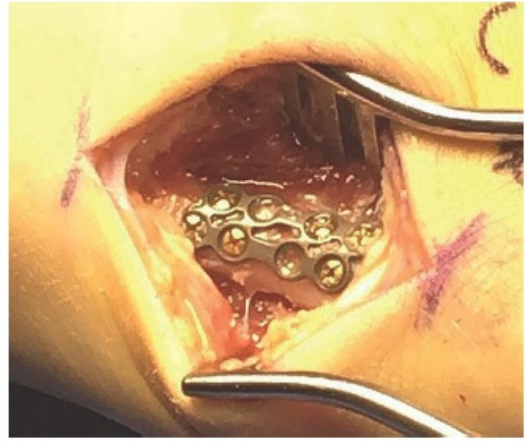
F



G



H



I



J



K

TECH FIG 5 • A,B. AP and lateral radiographs demonstrating displaced metacarpal shaft fractures of the small and ring fingers. **C.** A longitudinal incision is placed over the metacarpal shaft of the affected metacarpal. **D.** Blunt dissection is carried out down to the extensor tendon. **E.** The tendon is retracted and periosteum incised. The fracture is exposed and debrided. **F.** The fracture is preliminarily reduced. **G.** The mini-fragment plate is affixed to the bone proximally and distally with one screw each. **H.** Rotational alignment is evaluated prior to placing the remaining screws. **I.** The remaining screws are placed and orthogonal radiographs scrutinized. **J,K.** Postoperative AP and lateral radiographs after plate fixation.

PEARLS AND PITFALLS

Indications

- Surgical treatment of metacarpal shaft fractures is indicated for rotational malalignment and/or volar flexion of more than 10 degrees for the index and middle fingers and more than 20 degrees for the ring and small fingers.

Rotation

- Once K-wires or screws have been placed, be sure to check rotation by flexing the fingers prior to definitive fixation and/or closure.

Open reduction and internal fixation with mini-fragment plates

- Do not waste time trying to achieve a perfect reduction before plate placement; sometimes it is easier to affix the plate to one side of the fracture and reduce the other side to the plate. Try to minimize soft tissue stripping.

Therapy

- If stable fixation, early ROM can be initiated at 10–14 d.

POSTOPERATIVE CARE

- Patients are immobilized in a nonremovable postoperative splint for the first 10 to 14 days. This splint flexes the MCP to 60 to 70 degrees and ideally leaves the PIP and DIP free for early motion.
- Sutures are removed at 10 to 14 days, and a forearm-based orthoplast splint is fabricated with the MCP joint in 60 to 70 degrees of flexion and PIP and DIP free for early motion.
- At 6 weeks, the splint is discontinued and therapy continued to regain full ROM.

OUTCOMES

- Ruchelsman et al.⁷ reported on 20 patients at minimum 3-month follow-up who underwent limited-open retrograde headless screw fixation of metacarpal neck and shaft fractures. The union rate at 6 weeks was 100%, and all patients regained full composite fist by 3 months and extensor lag resolved by 3 weeks. Mean grip strength improved to 105% of the contralateral side.
- Doarn and colleagues⁹ reviewed nine patients with nine metacarpal fractures treated with retrograde headless screw fixation at mean follow-up of 36 weeks. The union rate was 100% at a mean of 49 days, and mean return to work was 6 weeks. Mean grip strength returned to 95% of the uninjured hand.
- Kim and Kim¹⁰ randomized 46 patients with metacarpal neck fractures to antegrade or retrograde intramedullary pinning. The authors found similar final radiographic alignment, but improved range of motion and DASH at 3 months in the antegrade pinning group.

COMPLICATIONS

- The complication rate depends greatly on the mechanism of injury and the amount of contamination in open injuries.
- Infection
 - The deep infection rate for closed metacarpal fractures treated operatively is 0.5% compared to 2% to 11% for operative treatment of open fractures.¹¹
- Malrotation
 - Rotational deformity can significantly affect hand function.
 - Malrotation of 5 degrees results in up to 1.5 cm of finger overlap with flexion.¹¹
- Malunion

- Volar angulation of the fracture or shortening can result in an extensor lag at the MCP joint.
 - For every 2 mm of shortening, there is 7 degrees of extensor lag.⁶
 - Due to natural hyperextension at the MCP joint, up to 6 mm of shortening may be acceptable in most patients.¹¹
- The rate of nonunion approaches 6% in some series after ORIF.¹²

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Open Reduction for Carpometacarpal Joint Dislocation

8

CHAPTER

John R. Fowler and Robert A. Kaufmann

DEFINITION

- Dislocation of the carpometacarpal (CMC) joint of the fingers may be simple (ligamentous disruption without fracture) or complex (associated with a fracture of the distal carpal row and/or metacarpal base).
- These injuries most commonly involve a dorsal direction of instability with subluxation or dislocation of the metacarpal base occurring relative to the carpal bones. Although rare, volar dislocations have been reported as well.

ANATOMY

- General
 - The index and middle finger CMC joints are more constrained than the small and ring finger CMC joints.
 - The index and long finger CMC joints have 11 and 7 degrees of flexion extension, respectively.¹
 - The ring and small CMC joints have 20 and 44 degrees of flexion extension, respectively.¹
 - This leads to increased incidence of small and ring finger CMC joint dislocations compared to index and middle CMC dislocations.
- Skeletal anatomy
 - The base of the index metacarpal is concave with radial and ulnar condyles that surround the trapezoid. The ulnar condyle also articulates with the long metacarpal and capitate, and the radial condyle has an articulation with the trapezium.²
 - The concave long metacarpal base articulates with the convex capitate and

has a dorsoradial process that increases stability.²

- The ring finger metacarpal base is locked by its articulations with the metacarpal bases of the middle and small finger and the hamate.²
- The small finger metacarpal base has an ulnar slope and articulates with the hamate.²
- Viegas et al.³ classified the shape of the ring finger metacarpal base. The description is based on the number and positions of facets. The clinical relevance of this classification system is unclear.
- Ligamentous anatomy (**FIG 1**)
 - Conflicting descriptions exist in the literature with some authors reporting up to six dorsal and six volar ligaments to each CMC joint⁴ and others reporting only one dorsal CMC ligament.⁵
 - Nakamura and colleagues⁶ dissected 80 cadaver wrists and noted that the anatomy is different depending on which CMC is being studied.
 - The ring and small finger CMC joint have two distinct dorsal ligaments.
 - The index and long finger CMC joints typically have three distinct dorsal ligaments.
 - An intra-articular ligament exists between the long/ring finger metacarpal base and the capitate/hamate. This ligament resists dorsal dislocation even if the other volar and dorsal ligaments are cut.
 - Each CMC joint also has volar ligaments that resist dorsal dislocation.
 - The index and long CMC joints have two deep capsular ligaments that connect the metacarpal bases to the trapezium and two superficial ligaments that connect the metacarpal bases to the capitate.

PATHOGENESIS

- The most common mechanism of injury is punching a hard object with a closed fist.
- Axial mechanical loading through a flexed MCP joint generates a rotational moment that causes a dorsally directed force on the metacarpal base.
- Yoshida and colleagues⁷ found that capitate and hamate fractures were the most common fractures associated with ring and small finger CMC dislocations.

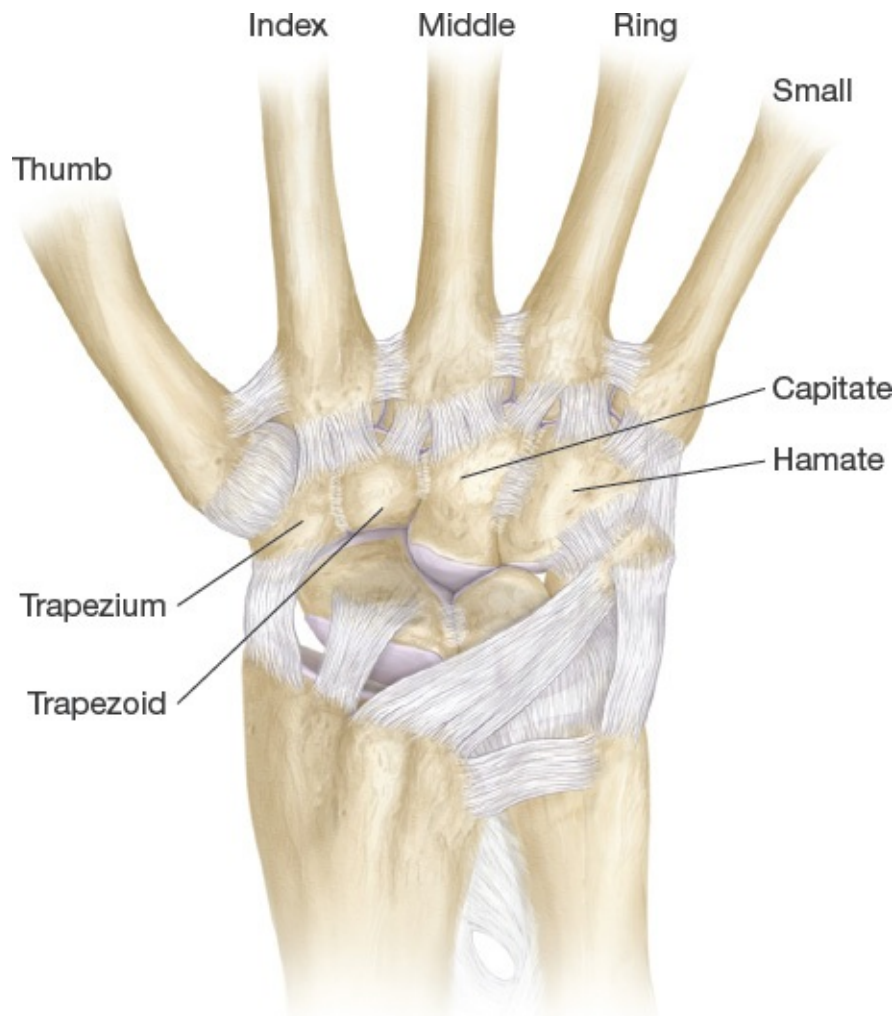


FIG 1 • Dorsal ligaments of the carpometacarpal joints.

- The ring and small finger CMC joints are more susceptible to injury than the index and long finger CMC joints due to increased mobility.⁸

NATURAL HISTORY

- Untreated CMC dislocations and fracture dislocations result in noticeable hand deformity, pain, limited range of motion, and decreased grip strength.⁹

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most patients will present after punching a hard object with a closed fist. Other mechanisms can include an axial load on flexed metacarpals from a fall or motor vehicle accident.
- A thorough skin examination should be performed to rule out other injuries associated with punching, including “fight bite,” which would require urgent

surgical debridement.

- Assessment of the soft tissues is focused on identifying skin disruption and extensor tendon damage.
- There is typically significant swelling, ecchymosis, and the inability to make a composite fist.
- Rotational malalignment is uncommon.

IMAGING

- Standard AP, lateral, and oblique radiographs are obtained (**FIG 2**).
- When a PA radiograph is taken in neutral, the normal CMC joints should have parallel articular surfaces, symmetric width between all CMC joint spaces (1–2 mm), and no overlapping joint surfaces.¹⁰
- Close attention must be paid to the lateral and oblique radiograph to evaluate for dorsal subluxation and/or dislocation of the metacarpal on the distal carpal row.
- On a true lateral radiograph the normal angle between the long axis of the index and small metacarpals should be approximately 10 degrees. Angles near 40 degrees suggest dislocation.¹¹ Comparison to the contralateral side can be useful.
- An oblique radiograph with the forearm pronated 30 to 45 degrees from the PA will allow optimal visualization of the small and ring finger metacarpal base articulations with the distal carpal row.^{11–13} Occasionally, a 15-degree pronation oblique is beneficial to fully assess the injury to the fourth and fifth CMC joints.¹⁴
- In unclear cases, consideration should be given to CT scan to further evaluate the CMC joint.¹⁵

DIFFERENTIAL DIAGNOSIS

- Metacarpal fracture
- Contusion
- CMC dislocation
- CMC fracture dislocation

NONOPERATIVE MANAGEMENT

- Nonoperative treatment may be considered if an adequate closed reduction can be obtained and remains stable. Close follow-up with weekly serial radiographs is recommended to ensure maintenance of the closed reduction.

- An ulnar gutter cast for fourth and fifth CMC injuries and a radial gutter cast for second and third CMC injuries are recommended. It is imperative that the cast prevent CMC subluxation through a dorsal mold. Keeping the MCP joint in no more than 40 to 50 degrees of flexion should prevent recurrence of dorsal subluxation at the CMC joints.

SURGICAL MANAGEMENT

Preoperative Planning

- The surgeon should be prepared to perform both closed and open reduction as needed to obtain a concentric reduction of the CMC joints.
- General or regional anesthesia is obtained.



FIG 2 • PA (A), oblique (B), and lateral (C) radiographs demonstrating dorsal dislocation of the small and ring finger CMC joints.

- A drill and multiple K-wires should be available. A mini-fragment set is required to treat carpal fractures that may require open reduction and internal fixation.
- Intraoperative fluoroscopy is used to confirm adequate reduction and to direct K-wire placement.

Positioning

- The patient is placed in the supine position with the forearm pronated on a radiolucent table.
- The surgeon typically sits at the head of the bed to facilitate placement of K-

wires.

Approach

- The approach to the CMC joint is dorsal and centered directly over the CMC joint. For multiple CMC dislocations, the incision can be placed between the two CMC joints.
- If all four CMC joints are dislocated and open reduction is required, a single incision can be placed over the middle finger metacarpal and thick flaps raised to visualize all four CMC joints.
- The dorsal ulnar and dorsal radial sensory nerves are fully visualized and freed up so that they can be gently retracted during the procedure.

TECHNIQUES

■ Closed Reduction and Percutaneous Pinning

- A closed reduction is attempted with longitudinal traction on the affected metacarpal and dorsal to volar direct pressure on the metacarpal bases (**TECH FIG 1A,B**).
- The reduction is confirmed on AP, lateral, and oblique fluoroscopy images.
- While holding direct dorsal to volar pressure on the metacarpal bases, a 0.045-in. K-wire is drilled from the small finger metacarpal into the ring finger metacarpal, 1 to 2 cm distal to the CMC joint (**TECH FIG 1C**).
 - Familiarity with the location of the dorsal ulnar sensory nerve is imperative to avoid its injury. As a principle, avoiding the most dorsal ulnar region of the fifth metacarpal shaft will avoid injury to this nerve.
 - If the ring finger metacarpal base is also involved, the K-wire is also drilled into the middle finger metacarpal shaft.
- A second 0.045-in. K-wire is placed in similar fashion, 1 to 2 cm distal to the first K-wire.
 - The second K-wire prevents rotation around the first K-wire.
- A third K-wire may be placed from the small finger metacarpal base into the hamate for added subluxation resistance.
- Fluoroscopy confirms maintained reduction of the CMC joints (**TECH FIG 1D-F**).

- The pins are cut below the skin.
- A well-padded volar splint is placed.



TECH FIG 1 • **A.** Photograph of the same injury in FIG 2 demonstrating the dorsal deformity associated with the dorsal dislocation of the metacarpal bases. **B.** Longitudinal traction is placed on the affected fingers and direct dorsal pressure is placed on the metacarpal base to reduced the dislocation. **C,D.** The pins in place

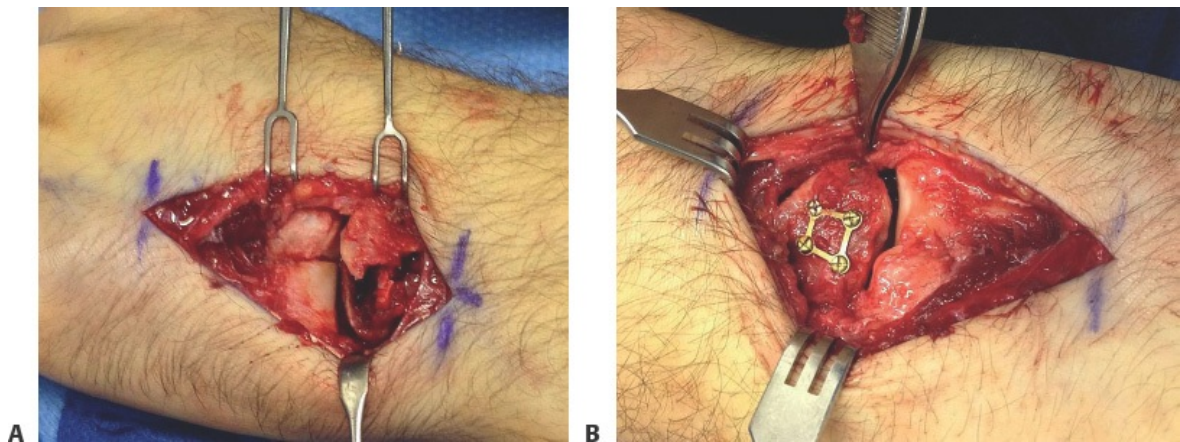
after closed reduction and percutaneous pinning. **E–G.** AP, oblique, and lateral radiographs, respectively, showing placement of the percutaneous pins and reduction of the CMC bases (compare with FIG 2). Note that on the lateral view (**E**), the metacarpals all line up and there is no dorsal subluxation of the small and ring finger metacarpal bases.

■ Open Reduction and Pinning With or Without Internal Fixation of Carpal Fractures

- A closed reduction is attempted with longitudinal traction on the affected metacarpal and dorsal to volar direct pressure on the metacarpal bases.
- If an adequate closed reduction cannot be maintained, an open reduction is performed.
- A longitudinal incision is made in between the small and ring finger metacarpal bases.
- Blunt dissection is carried out to the extensor tendons. The interval between the extensor digitorum communis to the ring finger and extensor digiti minimi is developed.
- The capsule over the CMC joints is incised longitudinally and sharply elevated radially and laterally to allow visualization of the joint.
 - Fibrosis and/or hematoma is cleared from the joint and a reduction performed.
- While holding direct dorsal to volar pressure on the metacarpal bases, a 0.045-in. K-wire is drilled from the small finger metacarpal into the ring finger metacarpal, 1 to 2 cm distal to the CMC joint.
 - Similar to the closed reduction pinning algorithm, pins are placed into the middle finger metacarpal shaft when the ring CMC joint is also injured.
 - If the ring finger metacarpal base is also involved, the K-wire is also drilled into the middle finger metacarpal shaft.
- A second 0.045-in. K-wire is placed in similar fashion, 1 to 2 cm distal to the first K-wire.
 - The second K-wire prevents rotation around the first K-wire.
- An additional K-wire may be placed from the small finger metacarpal base

into the hamate for added stability.

- If there is a sizeable fracture of the dorsal lip of the hamate, this can be addressed using 1.2- or 1.5-mm mini-fragment screws (**TECH FIG 2**).
 - Ensure that the drill does not plunge through the volar cortex of the hamate given the close proximity of the ulnar nerve motor branch to the hook of the hamate.
- Fluoroscopy confirms maintained reduction of the CMC joints.
- The pins are cut below the skin.
- The CMC capsule is closed with absorbable suture. The skin is closed with 4-0 nylon.
- A well-padded ulnar gutter splint is placed.



TECH FIG 2 • **A.** Fracture of the dorsal lip of the hamate. **B.** After internal fixation of the hamate with a mini-fragment plate. For small fragments, mini-fragment screws alone can be used.

PEARLS AND PITFALLS

Radiographs

- Scrutinize the lateral and oblique radiographs to evaluate for dorsal subluxation/dislocation of the metacarpal base. Obtain a CT scan if necessary.

Preoperative workup

- Have a low threshold to obtain a CT scan if necessary.

Fixation	■ At least two K-wires are needed to maintain joint alignment. Ensure that pins gain secure purchase in uninjured metacarpals in order to transmit forces away from zone of injury. Consider third pin directed obliquely from metacarpal into carpal bone to improve biomechanical rigidity of fixation.
K-wires	■ Bury K-wires under the skin for later removal at 10–12 wk. A longer period of fixation is required to allow healing of the dorsal ligaments.
Postoperative immobilization	■ Cast immobilization is recommended for nonoperatively treated injuries. ■ Immobilize unreliable postoperative patients in a cast after sutures are removed.

POSTOPERATIVE CARE

- Patients are placed in an ulnar gutter splint with the MCP joints free.
- Early finger motion is started to minimize stiffness.
- The postoperative splint is removed at 2 weeks and the patient is placed into either a removable thermoplast splint or a short-arm cast. This decision is based on the perceived reliability of the patient. Less reliable patients are placed into casts.
- Radiographs are obtained at 2, 6, and 10 weeks to ensure no further subluxation of the metacarpal base and to evaluate for healing of any carpal fractures that may have been present.
- Buried pins are typically removed in the operating room under sedation and local anesthetic at 10 to 12 weeks.

OUTCOMES

- Zhang et al.⁹ reviewed 20 fracture dislocations of the small and ring finger CMC joints at mean follow-up of 1 year.
 - Mean Michigan Hand Questionnaire score was 98.
 - Patients obtained similar range of motion and grip strength to the contralateral hand.
 - Patients treated without surgery had worse mean grip strength (31 kg vs 45 kg) and worse Michigan Hand Questionnaire score (72 vs 98).
- Gehrman and colleagues⁸ reported on 16 fracture dislocations of the small and ring finger CMC joints and 23 fracture dislocations of the small finger

CMC joint treated with either closed reduction and pinning or open reduction and internal fixation at mean follow-up of 13 months.

- Mean DASH score at final follow-up was 6.0 for small and ring finger dislocations and 7.2 for small finger dislocations.
- Grip strength was 16% less than the uninjured side.
- There were no cases of recurrent dislocation or subluxation.

COMPLICATIONS

- Post-traumatic arthritis may occur despite the surgeon's best effort. This is secondary to cartilage injury during the dislocation event.
- Finger stiffness is common secondary to swelling and pain.
- Recurrent dorsal subluxation/dislocation is uncommon but has been reported.

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Reconstruction of Acute and Chronic Ulnar Collateral Ligament Injuries of the Thumb

9

CHAPTER

John R. Fowler and Robert A. Kaufmann

DEFINITION

- An acute tear of the ulnar collateral ligament (UCL) is defined as an injury that is less than 12 weeks. Acute tears can often be repaired.
- A chronic tear is an injury that is older than 12 weeks. Chronically injured UCLs are often in need of reconstruction.
- The ligament integrity at the time of surgery is the primary determinant of whether a repair or a reconstruction may be performed. Chronic tears, especially in younger patients, can often still be repaired with excellent results. Acutely injured UCLs, particularly Stener lesions, may not be amenable to a repair and might benefit from a reconstruction effort.

ANATOMY

- The thumb UCL has proper and accessory components.
- The proper UCL is tight in 20 to 30 degrees of flexion.
 - The origin is from the metacarpal with the center of insertion 4.2 mm from the dorsum of the metacarpal and 5.3 mm proximal to the articular surface (**FIG 1**).
 - The insertion is on the proximal phalanx with a center of insertion 2.8 mm from the volar surface and 3.4 mm distal to the articular surface.¹
- The accessory collateral ligament is tight in full extension.
 - The accessory collateral ligament is volar to the proper and has an origin on the metacarpal and inserts into the volar plate and proximal phalanx base.

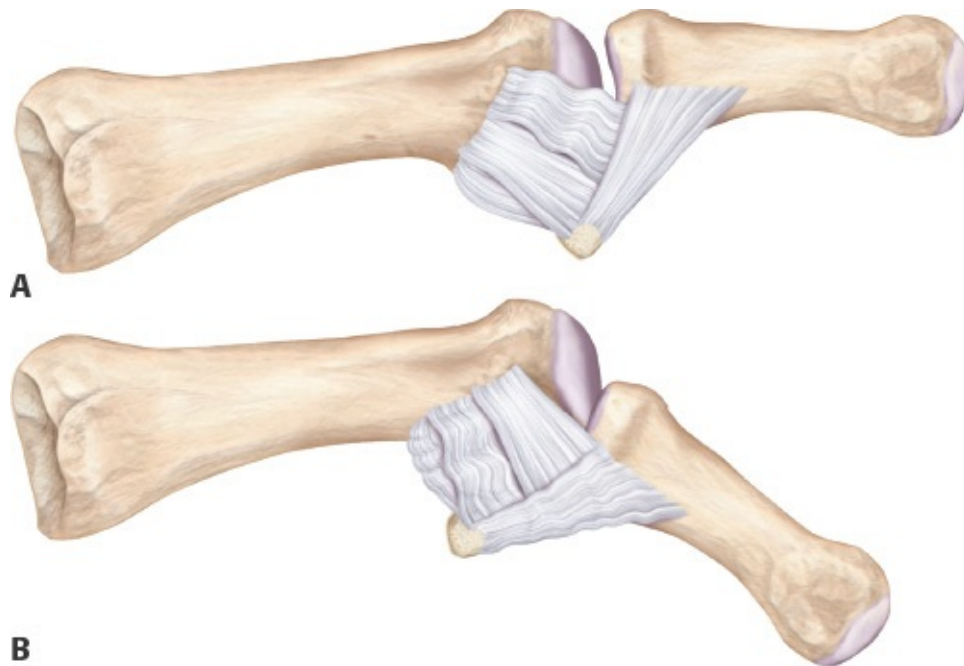


FIG 1 • The anatomy of the ulnar collateral ligament of the thumb metacarpophalangeal (MCP) joint. **A.** In extension, the accessory collateral ligament is taut. **B.** In flexion, the proper collateral ligament is taut.

- The adductor pollicis longus inserts through its aponeurosis into the extensor hood over the metacarpophalangeal (MCP) joint.
- The dorsal capsule of the MCP joint acts as a secondary stabilizer in flexion.²
- The extensor pollicis longus, extensor pollicis brevis, and flexor pollicis longus provide dynamic joint stability.

PATHOGENESIS

- A forceful valgus stress to the thumb results in disruption of the UCL.
 - The ligament may tear and yet not retract substantially from its insertion into the proximal phalanx.
 - A “Stener lesion” is created when the stump of a completely ruptured UCL retracts proximally and then the adductor aponeurosis becomes interposed between the UCL and its insertion on the proximal phalanx³ (**FIG 2**).
- Chronic repetitive valgus stress may result in UCL laxity. Antecedent trauma is likely the sentinel event that caused ligament damage, whose healing was interrupted through chronic reaggravation leading to laxity of the UCL

complex.

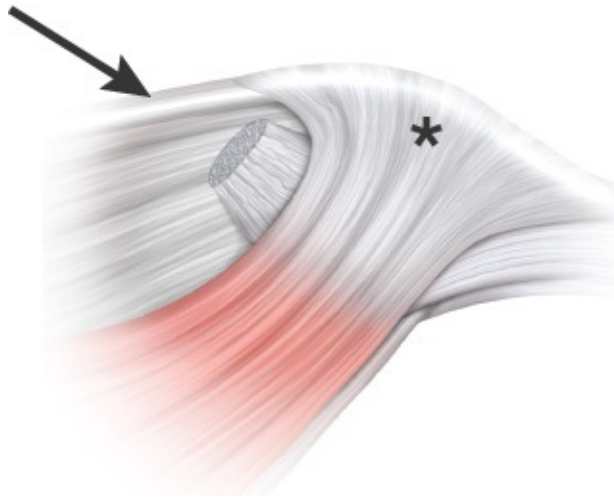


FIG 2 • A Stener lesion occurs when the stump of the ulnar collateral ligament (*arrow*) retracts and the adductor aponeurosis (*) becomes interposed between the ligament and its insertion on the proximal phalanx.

NATURAL HISTORY

- Acute tears of the UCL that do not heal with conservative treatment typically progress to chronic instability.
- Chronic instability results in weakness, pain, and degenerative changes that accompany joint laxity.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with acute injuries typically report a valgus load to the thumb. This may occur during athletic activities, from a fall or from a ski pole or strap.
- The mechanism of injury and chronicity of the injury should be documented.
- Physical examination
 - Inspection: Evaluate for swelling, ecchymosis, alignment.
 - Palpation: Palpate the insertion and origin sites of the RCL and UCL
 - Palpation of fullness over the metacarpal head may indicate the presence of a Stener lesion.
 - Provocative testing
 - Test the accessory collateral in full MCP extension.

- Test the proper collateral in 20 to 30 degrees of flexion at the MCP joint: 30 degrees of deviation or more than 15 degrees compared to the contralateral side is diagnostic for a UCL tear.
- Compare to the contralateral thumb.
- Gross instability with the joint held in MCP extension heralds disruption of both the accessory and proper collateral ligaments and may obviate the need for MRI imaging.

IMAGING

- AP and lateral radiographs of the thumb should be obtained to determine if there is an avulsion fracture of the UCL and to rule out dislocation and/or concomitant fractures of the phalanx or metacarpal. Always review radiographs prior to provocative ligament stress testing to ensure that a nondisplaced avulsion fracture is not displaced through the examination effort.
- Stress radiographs of the thumb may be diagnostic for UCL tear.
- Advanced imaging including ultrasound or MRI may confirm the presence of a complete rupture of the UCL and/or Stener lesion.
 - Ultrasound has an accuracy of approximately 80% for detecting a complete tear of the thumb UCL.⁴
 - MRI has a sensitivity and specificity approaching 100% for complete tears.⁵

DIFFERENTIAL DIAGNOSIS

- Metacarpal or proximal phalanx fracture
- Contusion
- Ligament strain/sprain
- MCP dislocation
- MCP arthritis

NONOPERATIVE MANAGEMENT

- Indications for nonoperative treatment include incomplete or partial tears as well as nondisplaced avulsion fractures.
- Understanding when the injury occurred is important as acute injuries are better suited for nonoperative management.
- Nonoperative treatment consists of immobilizing the thumb MCP joint. A forearm-based thumb spica cast is effective regardless of patient compliance and is recommended, for a minimum of 6 weeks for an avulsion fracture and 8 weeks for a soft tissue injury.

- Patients can elect nonoperative treatment for complete tears; however, healing may be less reliable.
- Landsman et al. reported that 85% of patients with an acute complete rupture of the thumb UCL and who were treated in a cast for 3 months reported no signs of pain or instability.⁶

SURGICAL MANAGEMENT

- Indications
 - Instability greater than 30 degrees with the thumb in 20 to 30 degrees of flexion represents injury to the proper collateral ligament.
 - Instability greater than 30 degrees with the thumb in extension represents injury to both the proper and the accessory collateral ligament.
 - Instability that is 15 degrees greater than the contralateral side
 - Palpation of a Stener lesion (retracted UCL ligament residing proximal to the adductor aponeurosis)
 - A bony avulsion with significant displacement that results in laxity to stress testing
 - Lack of a firm endpoint on examination

Preoperative Planning

- The surgeon should be prepared and comfortable to both repair or reconstruct the UCL.
 - Despite an acute tear, a midsubstance rupture may require reconstruction.
 - Some reported acute injuries actually represent a reaggravation of prior trauma making the UCL untenable for successful reattachment.
- Suture anchors and a drill should be available.
- Presence of the palmaris longus tendon should be established.

Positioning

- The patient is placed in the supine position with the arm on a radiolucent table.
- The surgeon typically sits in the axilla to allow the best visualization of the ulnar aspect of the thumb.

Approach

- The UCL is approached through either a straight or a curvilinear dorsal-ulnar incision.
- If a nonstraight incision is chosen, then the distal aspect should follow a gentle

volar path to facilitate access to the insertion of the UCL on the proximal phalanx.

TECHNIQUES

■ Acute Repair of the Ulnar Collateral Ligament⁷

Exposure

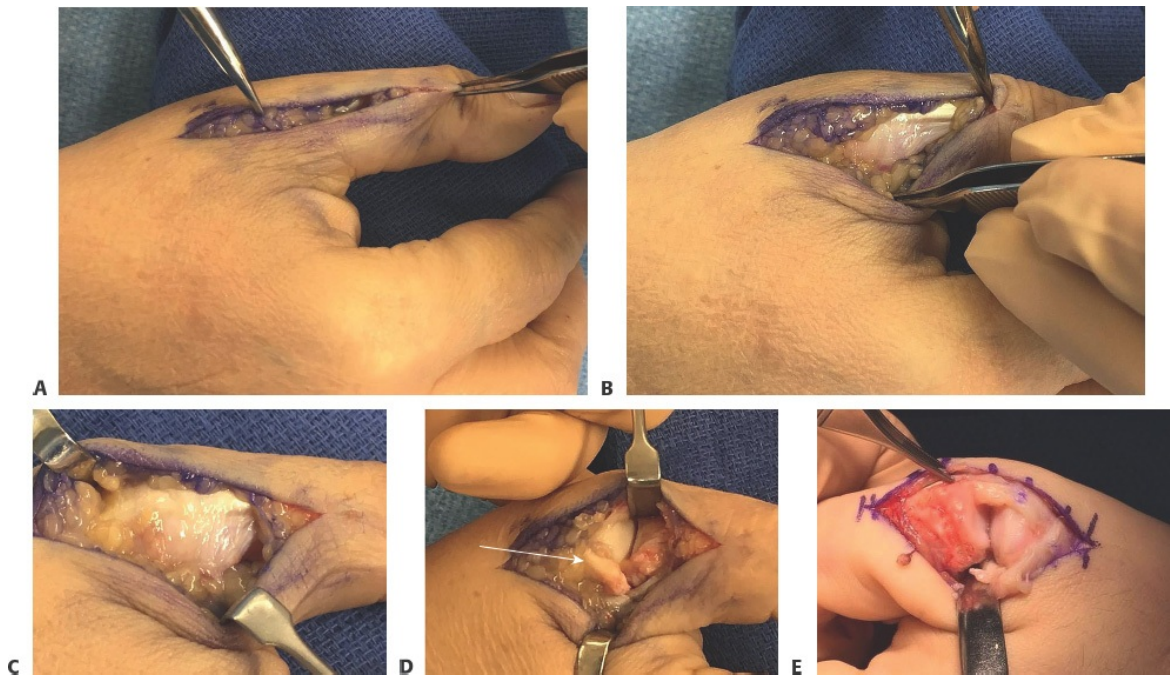
- The incision is centered over the MCP joint (**TECH FIG 1A**).
- Careful blunt dissection is carried out down to the extensor mechanism/adductor aponeurosis. The dorsal sensory nerves are identified and gently retracted (**TECH FIG 1B**).
- The adductor aponeurosis may be incised just off of the extensor pollicis longus or be removed as much as 5 mm. Preserving the distal portion of the adductor aponeurosis as it merges with the extensor pollicis longus facilitates later closure. Leaving the confluence of the adductor aponeurosis and the extensor pollicis longus intact allows for these structures to be closed in a distal to proximal manner essentially “pulling the zipper” in a retrograde manner (**TECH FIG 1C**).
- The aponeurosis is carefully dissected off of the underlying capsule. In chronic injuries, this step becomes more challenging but is often made easier if the adductor aponeurosis is identified in a location slightly more distal than the joint itself and dissected away from the capsule/UCL ligament complex.
- The capsule is then incised and the injured UCL identified (**TECH FIG 1D**). In most cases, the UCL is ruptured/avulsed from the proximal phalanx.
- The articular cartilage is inspected for degenerative changes, which, when present, represent a contraindication to UCL repair/reconstruction (**TECH FIG 1E**).

Suture Placement and Closure

- The proximal phalanx insertion site is debrided to ensure bleeding bone, and a suture anchor is placed at the center of the insertion site (**TECH FIG 2A,B**).
- The stump of the UCL tendon is trimmed back to healthy-appearing tissue

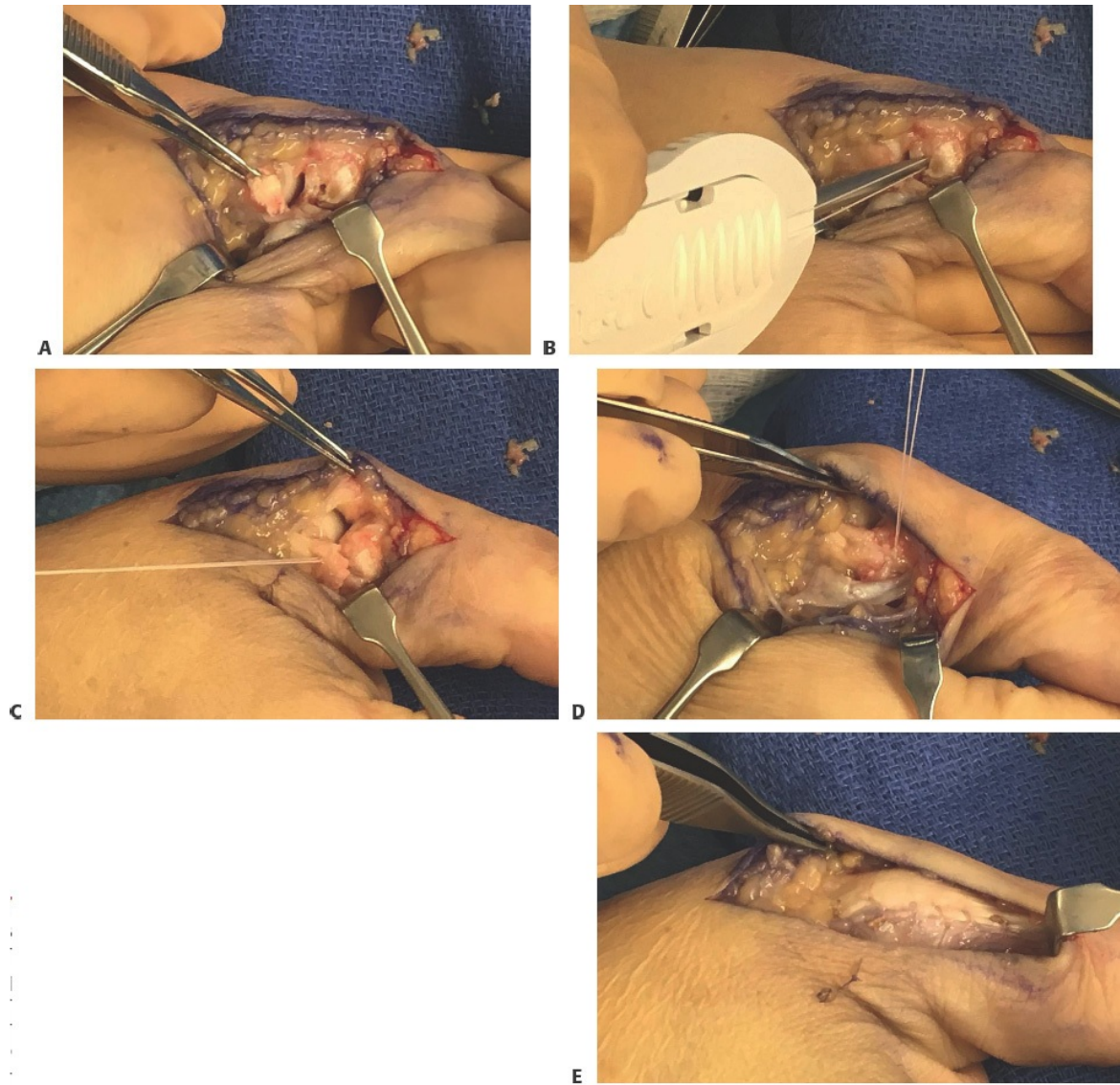
and sutured to the bone using the sutures from the anchor. Additional 3.0 Vicryl sutures are placed between the UCL ligament and the periosteum/capsule that is just distal to the site of ligament insertion. One or two of these sutures can augment the biomechanical integrity of the repair (**TECH FIG 2C,D**).

- The adductor aponeurosis is closed using nonabsorbable suture in a retrograde manner (**TECH FIG 2E**).
- The skin is closed using 4-0 nylon sutures.



TECH FIG 1 • **A.** Planned incision for treatment of ulnar collateral ligament injuries. The curvilinear nature allows access to the insertion of the proper collateral ligament, which is along the volar edge of the proximal phalanx. **B.** The skin is incised and blunt dissection carried out down to the extensor mechanism. Sensory nerve branches may be crossing the incision in this location and must be identified and protected. **C.** The adductor aponeurosis is incised 5 mm from the extensor pollicis longus, leaving a cuff for later repair. **D.** The stump of the ulnar collateral

ligament is identified (*arrow*). Most tears/avulsions occur off the proximal phalanx, but the surgeon must ensure that there is not a midsubstance or proximal rupture. **E.** The joint is inspected for signs of degenerative changes. Degenerative changes are a contraindication to repair and/or reconstruction.

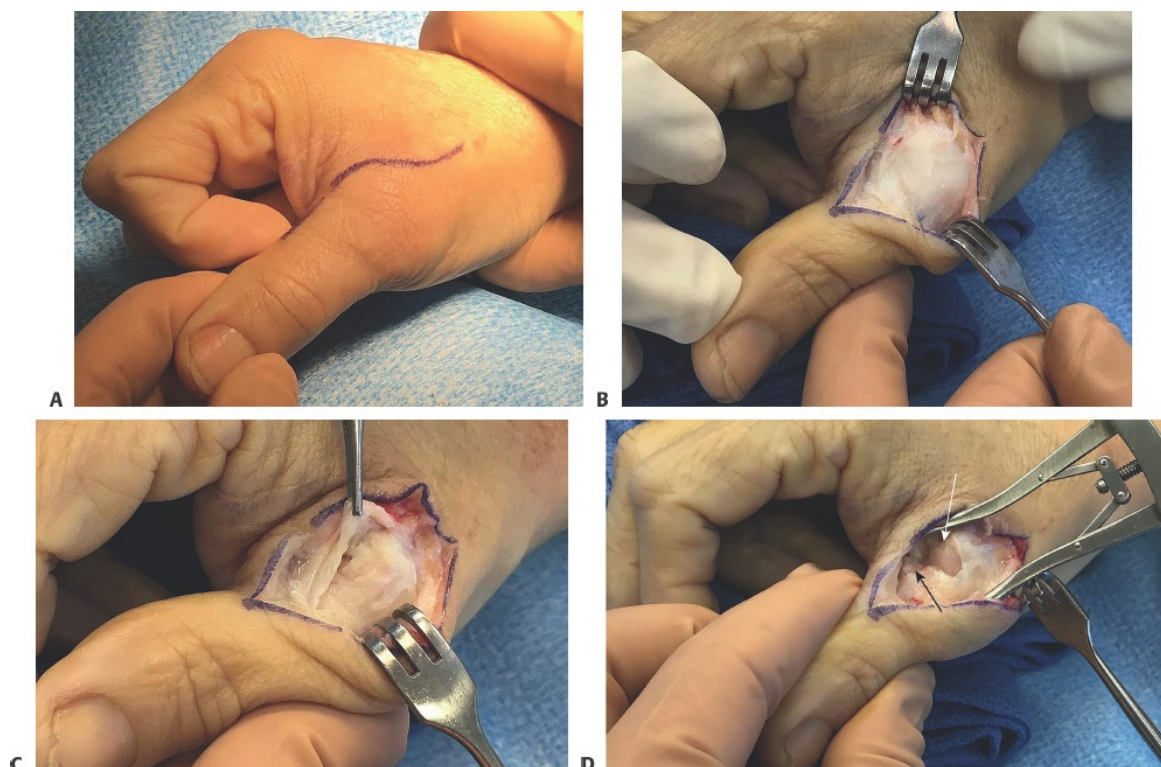


TECH FIG 2 • A. The proximal phalanx insertion site is debrided, and the drill is used to create the hole for the suture anchor. **B.** The suture anchor is placed. **C.** The sutures are passed through the proper ulnar collateral ligament and tied to restore the insertion footprint. **D.** The ulnar collateral ligament is repaired. **E.** Closure of the adductor aponeurosis is performed using absorbable sutures. Care is taken to not suture to the extensor pollicis longus, but rather to the cuff of tissue adjacent to the tendon.

■ Reconstruction of Chronic Tear Using Palmaris Autograft (Tunnel Technique)

Exposure

- The same incision is made for a repair or a reconstruction effort (**TECH FIG 3A**).
- Careful blunt dissection is carried out down to the extensor mechanism/adductor aponeurosis. Dorsal sensory nerves are identified and retracted (**TECH FIG 3B**).
- The adductor aponeurosis is incised just as it would be for a repair and carefully dissected off of the underlying capsule (**TECH FIG 3C**).
- The capsule is then incised and the unrepairable remnant of the ulnar collateral ligament is identified and excised (**TECH FIG 3D**).
- The articular cartilage is inspected for the presence of degenerative change. Significant damage is a contraindication to UCL repair/reconstruction.



TECH FIG 3 • **A.** Planned curvilinear incision for ulnar collateral ligament reconstruction. **B.** Blunt dissection

is carried out down to the level of the extensor mechanism and adductor aponeurosis. Care is taken to identify and protect sensory nerves. **C.** The adductor aponeurosis is incised and carefully elevated off the underlying capsule. A 5-mm cuff of tissue adjacent to the extensor tendons is left for later repair. **D.** In the case of a chronic collateral ligament tear, there is usually very little tendon identified. The origin (*white arrow*) and insertion (*black arrow*) of the proper ulnar collateral ligament are identified and debrided.

Palmaris Tendon Harvest

- A 1-cm longitudinal or transverse incision is made over the distal wrist crease (**TECH FIG 4A**).
- The palmaris longus is isolated and a Ragnell retractor placed under the tendon.
- Traction is placed on the palmaris longus and its course traced proximally.
- A longitudinal or transverse incision is made 10 cm proximal to the wrist crease.
- The palmaris longus is isolated here and transected. Blunt dissection is used to free connections between the underlying tissue.
- The palmaris is pulled through the distal wound and transected distally (**TECH FIG 4B**).



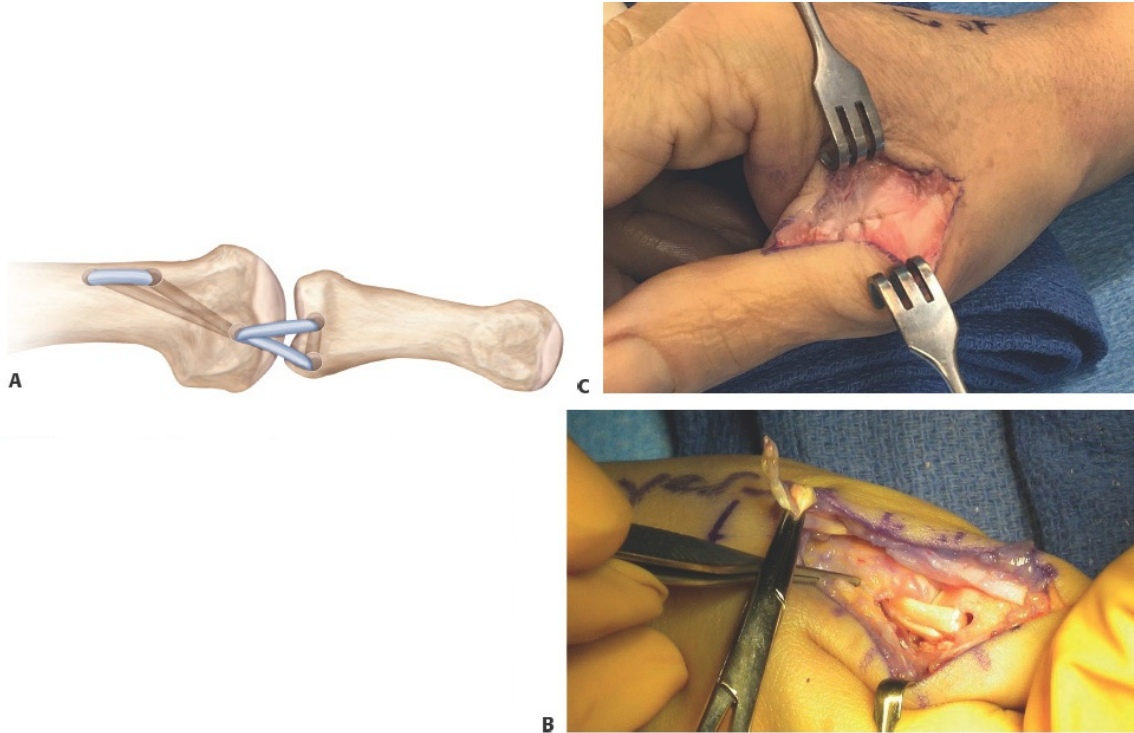
TECH FIG 4 • A. The palmaris longus tendon is palpated and skin incisions planned. **B.** The palmaris

is identified distally and divided. It is then pulled out of the wound proximally and divided to obtain maximum length.

- The palmaris longus should be trimmed to no smaller than 2 to 3 mm in width.

Creating Bone Tunnels and Inserting the Tendon Graft

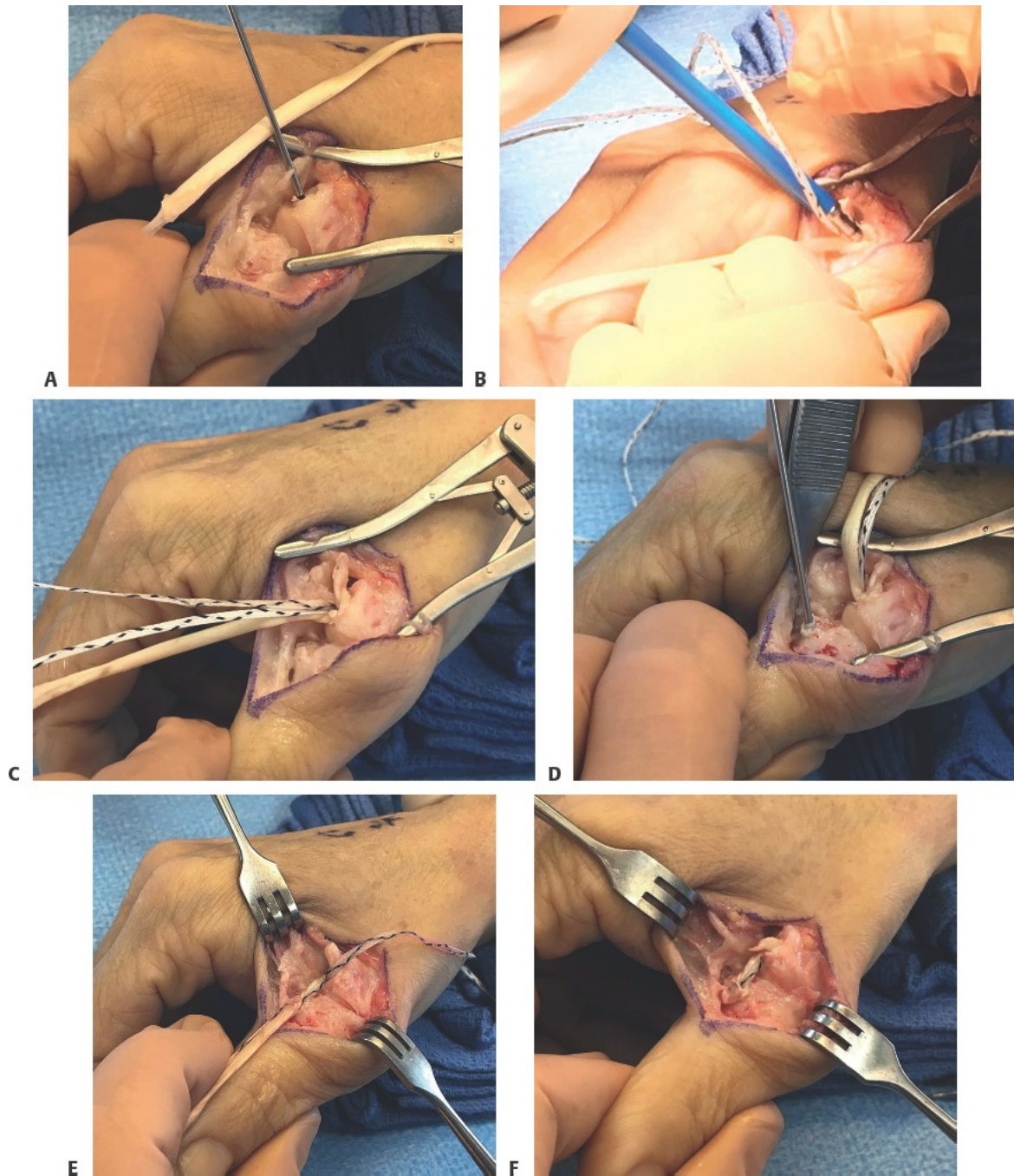
- A 2.0-mm drill bit is used to make a hole at the insertion of the proper collateral ligament on the proximal phalanx (**TECH FIG 5A**).
 - Recognize that the insertion is about 3 mm dorsal from the volar-most edge of the proximal phalanx and about 3 mm distal from the joint line.
- Leaving a generous bone bridge, a second hole is made dorsal to the first hole.
- Proximally, a single hole is made (using the same 2.0-mm drill bit) at the isometric point on the metacarpal head (at the origin of the proper collateral ligament).
- Two additional holes are made more proximal and dorsal to the hole at the proper collateral origin.
 - A curette may be used to both gently enlarge and connect the holes to allow for easier passage of the graft.
- A 4-0 nylon suture or Hewson suture passer is used to shuttle the palmaris autograft through the bone tunnels. The 4-0 nylon needle is secured by the needle driver at its tip and a loop created through which the graft is passed. The same technique can be used to efficiently pass the graft through all of the drill holes (**TECH FIG 5B**).
 - The palmaris is first passed through the tunnels in the proximal phalanx.
 - Both limbs are then passed through the isometric tunnel on the metacarpal head.
- One limb is then passed through its respective tunnel on the dorsum of the metacarpal.
- The MCP joint is reduced and the tendon limbs tightened. The limbs are sutured to each other using a nonabsorbable 3-0 suture.
- The adductor aponeurosis is closed using absorbable suture (**TECH FIG 5C**).
- The skin is closed using 4-0 nylon horizontal mattress sutures.



TECH FIG 5 • A. The bone tunnels are planned to reconstruct the proper collateral ligament. A 2.0-mm drill bit is used to make a hold at the insertion site of the proper collateral ligament. The insertion is approximately 3 mm distal to the articular surface and 3 mm dorsal to the volar edge of the proximal phalanx. A second hole is placed in line with the first hole but 5 mm dorsal. The same 2.0-mm drill is used to make a tunnel at the isometric point on the metacarpal head and then two additional tunnels proximal and dorsal to allow passage of the autograft. **B.** The construct after passage of the graft through the tunnels. The proximal phalanx is to the left and metacarpal to the right. **C.** The aponeurosis is closed using absorbable sutures.

■ **Reconstruction of Chronic Tear Using Palmaris Autograft (Anchor Technique)**

- The aforementioned surgical approach is followed, but instead of using bone tunnels, two anchors are employed.
- A K-wire is placed into the center of the UCL origin on the metacarpal head (**TECH FIG 6A**).
- A 3.5-mm cannulated drill hole is placed over the K-wire to enlarge the hole.
- An Arthrex DX SwiveLock 3.5 mm × 8.5 mm forked tip anchor is used. The palmaris graft is placed over the fork, and the anchor is then seated into the bone. An Arthrex FiberTape suture can be incorporated with the repair for added strength (**TECH FIG 6B,C**).
- A K-wire is placed into the center of the UCL insertion on the proximal phalanx base. The center of the insertion is approximately 4 mm from the dorsum of the metacarpal and 5 mm proximal to the articular surface (**TECH FIG 6D**).
- A 3.5-mm cannulated drill hole is placed over the K-wire to enlarge the hole.
- The palmaris autograft is then placed over the forked tip on a second Arthrex DX SwiveLock anchor (**TECH FIG 6E**).
 - It is important to leave a little bit of slack as the ligament will tighten as the anchor is seated into the bone.
 - Prior to tightening the screw anchor, check stability and range of motion of the MCP joint.
 - Once satisfied with the tension in the graft, range of motion, and stability, tighten the anchor.
- The free ends of the autograft are excised (**TECH FIG 6F**).
- The adductor aponeurosis is closed using nonabsorbable suture.
- The skin is closed in the usual manner.



TECH FIG 6 • **A.** The guide wire is placed at the isometric point on the metacarpal head. **B.** The anchor is used to secure the graft and additional suture into the metacarpal head. **C.** After the graft and suture has been secured. **D.** The guide wire is placed into the insertion site on the proximal phalanx. **E.** The suture

anchor is again used to secure the graft and suture down into the proximal phalanx. **F.** The construct after the extra tendon and suture has been removed.

PEARLS AND PITFALLS

Dorsal sensory nerve	■ Carefully dissect and gently retract the dorsal sensory nerves.
Graft tension	■ When repairing or reconstructing the UCL with bone tunnels, ligament tension may be maximized without overtightening the MCP joint as time-dependent soft tissue properties allow for dissipation of undue graft tension. Thumb stiffness is avoided as long as the MCP joint is flexed 30 degrees while being immobilized in the postoperative setting.
Adductor aponeurosis	■ Leave the distal confluence of adductor aponeurosis with extensor pollicis longus tendon intact so that precise closure may be accomplished. Careful “teasing away” of aponeurosis from UCL/scar/capsule is important to ensure that the adductor aponeurosis maintains its biomechanical integrity when securely reattached to the extensor pollicis longus tendon.
Degenerative changes	■ Degenerative changes are a contraindication to UCL repair and/or reconstruction. A fusion should be performed.
Placement of anchors/tunnels on proximal phalanx	■ Remember that the insertion of the proper UCL is volar, only 3 mm dorsal to the volar edge of the proximal phalanx. Restoration of both proper and accessory collateral ligaments is ensured when bone tunnels are placed.

Postoperative Care

- A well-molded plaster thumb spica cast is placed. Care is taken to avoid any valgus force imparted to the MCP joint.
- The MCP joint is best held in 30 degrees of flexion status post repair or reconstruction effort. Due to “cam” appearance of metacarpal head, the ligament is tighter in flexion and may become unable to stretch out in patients

who are immobilized and then heal in full extension.

- At the 2-week visit, the wound is inspected and patient placed in either a removable thermoplast splint or a short-arm thumb spica cast for an additional 4 weeks.
- Thumb IP joint and finger motion is encouraged.

OUTCOMES

- Operative treatment results in good to excellent results in over 90% of patients.
- Glickel et al. reported on 26 patients who underwent thumb UCL reconstruction using free tendon graft at an average of 3.9 years' follow-up.
 - The authors reported excellent results in 20 patients, good results in 4 patients, and fair results in 2 patients.
 - The operative thumb averaged a 10% increase in laxity compared to the nonoperative thumb and yet retained 80% of its arc of motion.
 - Mild or intermittent pain with heavy use was reported in 8/26 thumbs; the remainder reported no pain.

COMPLICATIONS

- Thumb stiffness particularly when the MCP joint was immobilized in full extension.
- Persistent instability, which is more likely in a repair rather than a reconstruction effort.
- Injury to the radial sensory nerve during exposure and/or retraction.
- Fracture of the metacarpal and/or proximal phalanx when creating bone tunnels or during anchor placement.
- Degenerative changes of the MCP joint over time.

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10 Closed Reduction and Fixation of Bennett and Rolando Fractures

CHAPTER

John R. Fowler and Thomas B. Hughes

DEFINITION

- A Bennett fracture (**FIG 1A**) is defined as an intra-articular base of the thumb metacarpal fracture consisting of a volar-ulnar fragment that is attached to the anterior oblique ligament.¹
- A Rolando fracture (**FIG 1B**) is defined as a comminuted intra-articular metacarpal base fracture.¹ The fracture is often a T- or Y-type pattern.

ANATOMY

- The base of the thumb metacarpal has a saddlelike shape to accommodate its articulation with the trapezium. The articular surface is convex when viewed posterior to anterior and concave when viewed from lateral to medial.²
- The abductor pollicis longus inserts along the lateral edge of the metacarpal base.
- The anterior oblique ligament originates from the volar beak of the thumb metacarpal and inserts onto the trapezium (**FIG 2**).²
- The dorsal ligament complex is the strongest and thickest ligament complex around the thumb CMC joint. It consists of the dorsal radial and posterior oblique subligaments. If the dorsal ligament complex is disrupted, the joint is unstable even if the anterior oblique ligament is intact.²
- The intermetacarpal ligament runs transversely from the index metacarpal to the thumb metacarpal.

PATHOGENESIS

- Bennett fractures are caused by an axial load on the partially flexed thumb

metacarpal.

- The anterior oblique ligament is attached to the volar-ulnar fragment and the trapezium (**FIG 3**). This holds the volar-ulnar fragment in place while the metacarpal base subluxates.
- The metacarpal base is displaced in a dorsal, radial, and proximal direction.
- Bennett fractures are classified using the Gedda classification (**FIG 4**).
- Rolando fractures are the result of an axial load on the thumb metacarpal that has a pilon effect on the articular surface.

NATURAL HISTORY

- As with other intra-articular fractures, articular congruity results in symptomatic arthritis at long-term follow-up.³
- Fractures that are not reduced result in chronic instability, pain, and decreased function.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History should document the acuity of the injury, as chronic injuries may be less amenable to closed reduction.
- Patients typically describe a fall onto the thumb with axial loading. Alternatively, athletes may report a jamming-type injury from either a ball or contact with another player or the ground.



FIG 1 • PA radiographs demonstrating a Bennett fracture (**A**) vs a Rolando fracture (**B**).

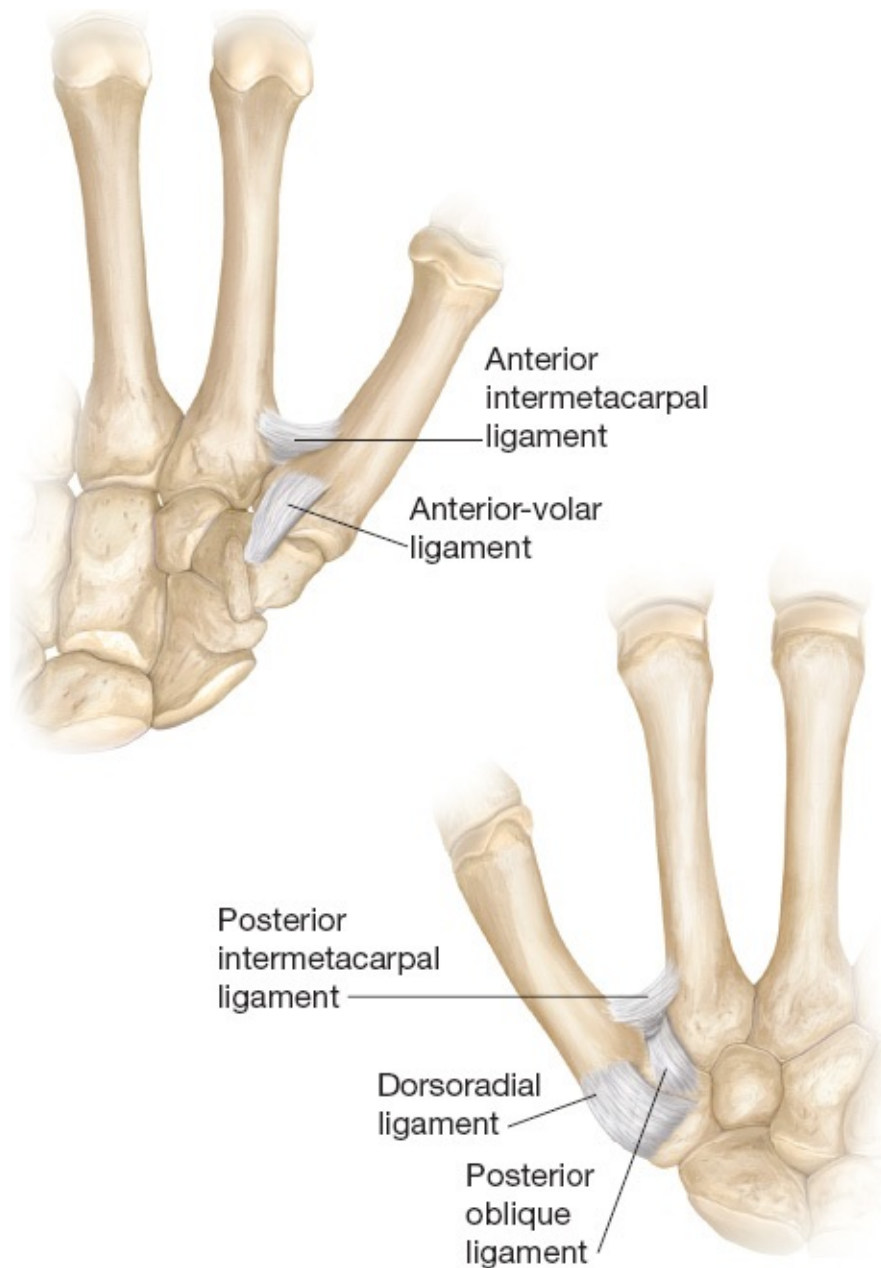


FIG 2 • Anatomy of the thumb carpometacarpal joint with special focus on the anterior oblique ligament and dorsal ligament complex.

- There is often significant soft tissue swelling and ecchymosis around the thumb CMC joint.
- Evaluate the thumb MP collateral ligaments, the EPL, EPB, and FPL.
- Active and passive thumb motion is painful. There may be crepitus of the

CMC joint.

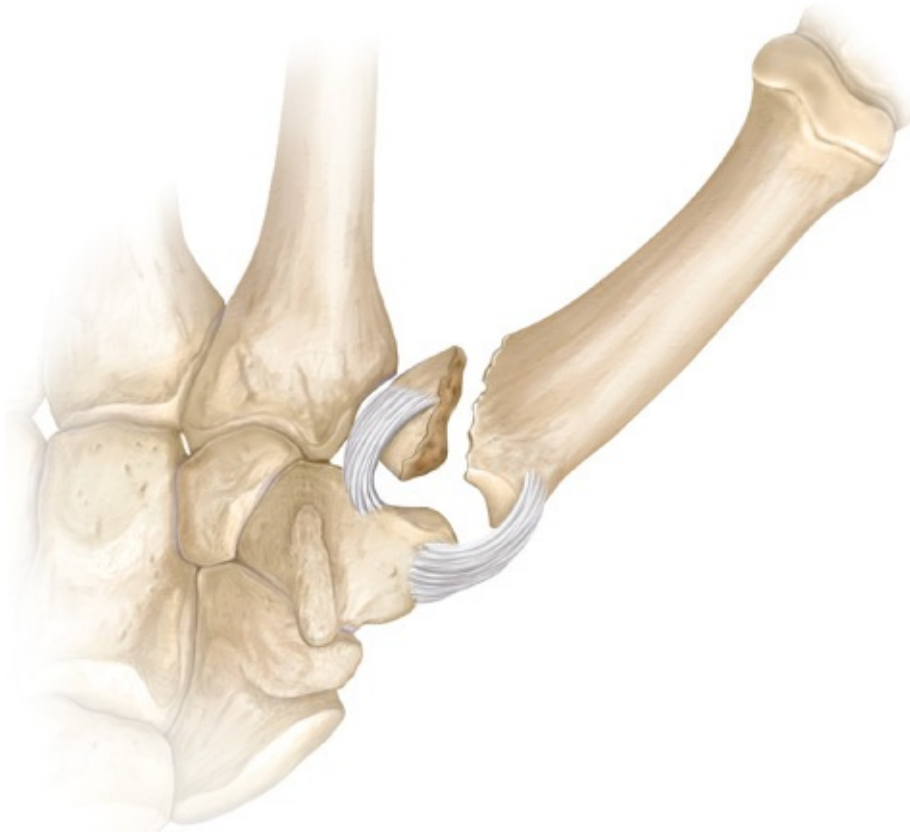


FIG 3 • The deforming forces in thumb metacarpal base fractures result in the characteristic radial displacement of the metacarpal shaft.

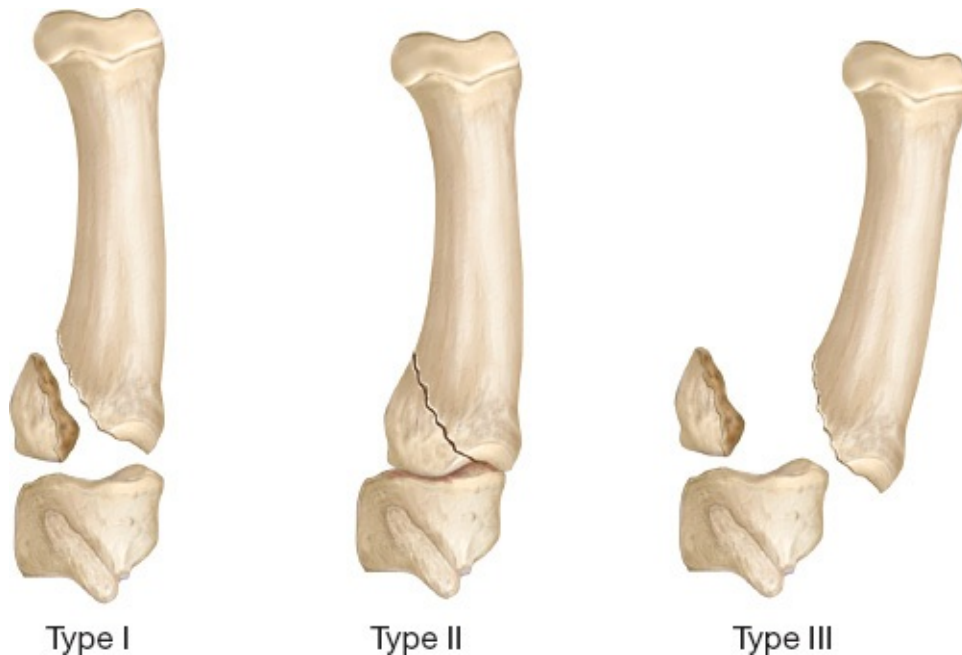


FIG 4 • The Gedda classification for Bennett fractures. Type I: large volar-ulnar fragment with subluxation of the thumb metacarpal. Type II: impaction of the articular surface without subluxation of the thumb metacarpal. Type III: avulsion of volar-ulnar metacarpal with dislocation of thumb metacarpal.

IMAGING

- One must obtain a true AP (Robert's view) and true lateral radiograph (Bett's view) to assess the amount of articular incongruity.¹
- A true AP is obtained by maximally pronating the forearm and placing the dorsum of the thumb on the cassette.
- A true lateral is obtained by pronating the forearm 20 degrees and placing the lateral border of the thumb on the cassette. The x-ray beam is angled 10 degrees distally.
- Computed tomography is not routinely needed for thumb metacarpal base fractures.

NONOPERATIVE MANAGEMENT

- Closed reduction and thumb spica casting is indicated for articular step-off of less than 1 mm.

- Because of comminution and articular incongruity, Rolando fracture is typically not treated nonoperatively.

SURGICAL MANAGEMENT

- Indications for surgery:
 - Articular step-off more than 1 mm⁴
 - Inability to reduce joint subluxation by closed reduction

Preoperative Planning

- The surgeon should be prepared to perform both closed reduction and open reduction as indicated by operative findings.
- Have mini-fragment plating system and K-wires available.

Positioning

- The patient is placed in the supine position with an upper arm tourniquet.
- The surgeon should sit at the axilla and assistant opposite.
- This allows the surgeon the ability to drill K-wires into the index metacarpal or trapeziometacarpal joint.

Approach

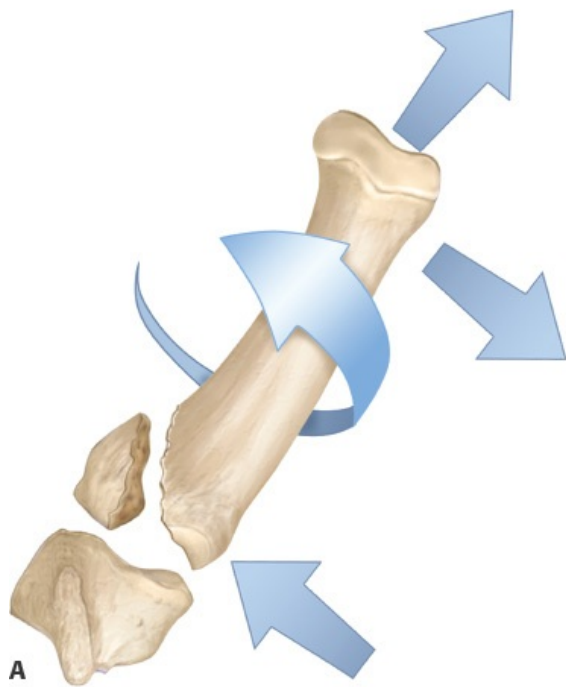
- Fractures that require open reduction and internal fixation are typically approached using the Wagner approach to gain access to the joint and fracture fragments.

TECHNIQUES

■ Closed Reduction and Pinning of Bennett and Rolando Fractures

- Longitudinal traction is placed on the thumb (**TECH FIG 1A**).
- The thumb is then abducted and pronated to reduce the fracture.
- Reduction is confirmed using fluoroscopy.
- A 0.045-in. K-wire is then drilled either into the trapezium or into the index metacarpal (**TECH FIG 1B–D**).
- A second K-wire is used if reduction to the index metacarpal is performed.

- Rolando fractures can also be treated with traction and pinning if alignment can be restored with traction. Pinning of individual fragments is typically not successful because there is often significant comminution.



TECH FIG 1 • A. Illustration demonstrating the

reduction maneuver for Bennett fractures. Longitudinal traction and abduction is performed. The surgeon's thumb places direct ulnar pressure on the base of the metacarpal, and the thumb is then pronated. **B.** PA radiograph demonstrating typical Bennett fracture. **C.** PA radiograph after pinning. **D.** Oblique radiograph after pinning.

■ Open Reduction and Internal Fixation of Bennett Fractures

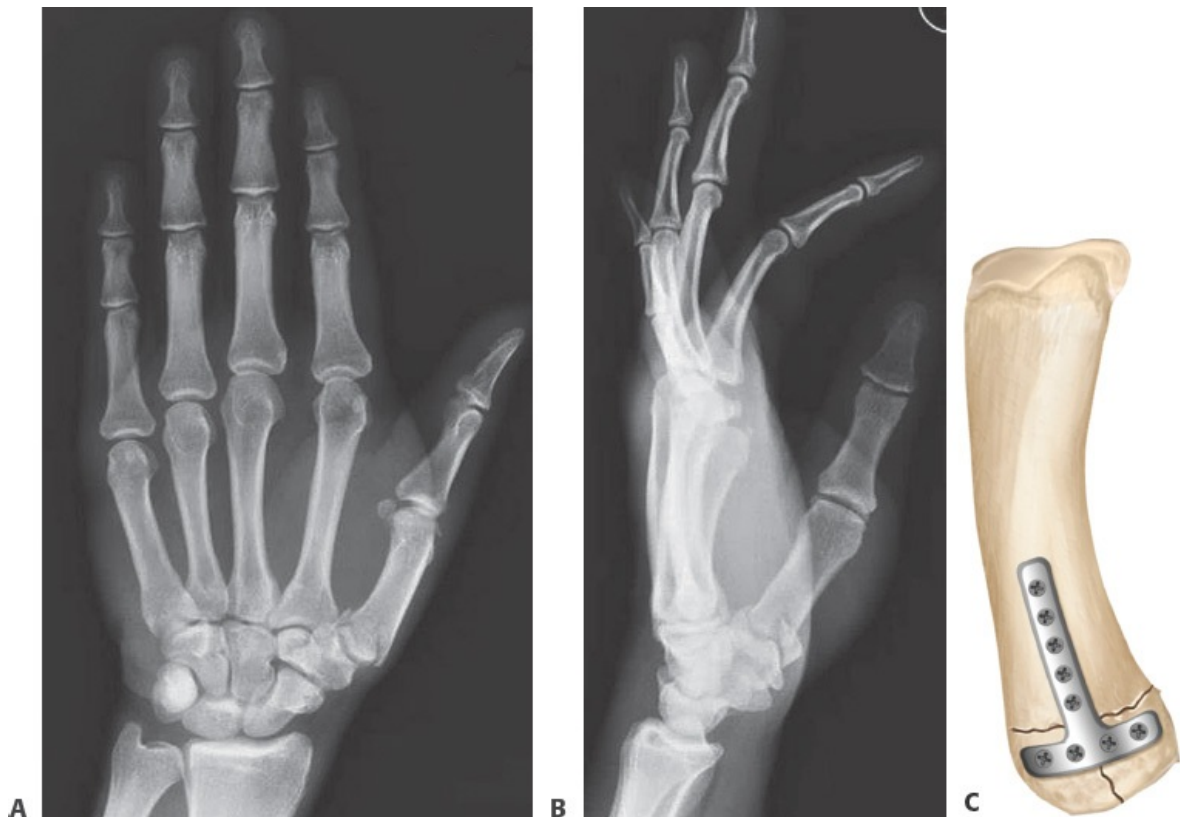
- The Wagner approach is used.
 - The incision is made along the radial border of the thumb between the glabrous and nonglabrous skin.
 - Blunt dissection is performed down to the fascia overlying the thenar musculature. Branches of the palmar cutaneous branch of median nerve and branches of the dorsal radial sensory nerve are identified and carefully retracted.
 - The thenar muscles are elevated off of the metacarpal.
 - A longitudinal incision is made in the thumb CMC joint capsule.
 - Do not strip the individual fragments of their soft tissue attachments.
- The fracture is reduced under direct visualization using ligamentotaxis and/or a fracture clamp and stabilized using K-wires or mini-fragment screws. We prefer to use 1.7-mm mini-fragment screws using a lag technique (**TECH FIG 2**).
 - A K-wire can be placed between the thumb metacarpal and index metacarpal to relieve compression stresses on the fracture site.
- Anatomic reduction of the joint surface is confirmed with direct visual inspection.
- The capsule is closed using nonabsorbable sutures and the skin is typically closed using interrupted nylon horizontal mattress sutures.



TECH FIG 2 • A,B. Preoperative PA and lateral radiographs demonstrating Bennett fracture. **C,D.** PA and lateral radiographs after open reduction and internal fixation with lag screws.

■ Open Reduction and Internal Fixation of Rolando Fractures

- The Wagner approach is used.
 - The exposure is similar to the approach above for Bennett fracture.
 - A longitudinal incision is made in the thumb CMC joint capsule.
 - Do not strip the individual fragments of their soft tissue attachments.
- The fracture is reduced under direct visualization using ligamentotaxis and/or a fracture clamp. A 1.7- or 2.3-mm mini-fragment plate can be contoured and used to stabilize the fracture fragments (**TECH FIG 3**).
 - A K-wire can be placed between the thumb metacarpal and index metacarpal to relieve compression stresses on the fracture site.
 - One or more additional K-wires may be necessary to capture additional fracture fragments or to pin the joint in distraction for stability.



TECH FIG 3 • **A,B.** PA and lateral radiographs demonstrating a Rolando fracture. **C.** Illustration showing placement of a 2.3-mm mini-fragment T-plate

to stabilize the intra-articular fragments.

PEARLS AND PITFALLS

Indications	■ Open reduction and internal fixation is indicated if there is more than 1 mm of articular step off after closed reduction.
Proper imaging	■ Obtain true AP and lateral radiographs to accurately assess articular step-off.
Hardware	■ Ensure that there are no intra-articular screws after ORIF.
Treatment	■ Perform the necessary procedure to restore articular congruity and reduce metacarpal subluxation.
Approach	■ Perform the Wagner approach to visualize the joint surface and directly visualize articular congruity.

POSTOPERATIVE CARE

- Patients are immobilized in a nonremovable thumb spica splint for 2 weeks.
- If closed reduction and pinning is performed, the patient is placed into a short-arm thumb spica cast for 2 weeks.
 - The pin sites are examined at 4 weeks from surgery. If there is no erythema, the pins are left for another 2 weeks.
 - If there is pin site irritation, the pins are removed and patient placed into thumb spica cast for another 2 weeks.
- If open reduction internal fixation was performed, the patient is placed in a thumb spica cast at the 2-week visit for 4 weeks.
- Hand therapy is started at 6 weeks to regain motion and strength.

OUTCOMES

- Middleton et al.⁵ reported long-term outcomes of 62 patients who underwent closed reduction and pinning of Bennett fractures at mean follow-up of 11 years. Mean DASH was 3, and 94% of patients were satisfied with their outcome and none had undergone further surgery.
- Griffiths⁶ followed 21 patients with Bennett fractures treated with closed

reduction and casting and evaluated at mean 6.8 years after treatment. More than half of patients had lost reduction, but there was little correlation between lost reduction and functional disability or symptoms.

- Livesley³ reported on 17 patients at a mean follow-up of 26 years and noted that all 17 had decreased motion and grip strength with radiographic evidence of arthritis and subluxation.

COMPLICATIONS

- Pin tract infections can occur if closed reduction and percutaneous pinning is performed.
- Post-traumatic arthritis with decreased motion and strength may develop despite treatment.
- Superficial sensory nerve injury may occur during open or percutaneous treatment.

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Section III: Joints

11 Volar Plate Arthroplasty of the Proximal Interphalangeal Joint

CHAPTER

James T. W. Saunders and Amy M. Moore

DEFINITION

- Volar plate arthroplasty (VPA) of the proximal interphalangeal joint (PIP) involves the elevation and advancement of the volar plate in an attempt to resurface the fractured articular region of the middle phalanx and reduce dorsal subluxation of the PIP joint.

ANATOMY

- A combination of bony constraints, the volar plate and the collateral ligaments provide stability of the PIP joint (**FIG 1**).
- The concave articular surface of the middle phalanx articulates with the convex condyles of the proximal phalanx, allowing the joint to function as a hinge.
- The volar plate is a fibrocartilaginous structure that originates from the proximal phalanx via two strong checkrein ligaments. It inserts distally to the volar base of the middle phalanx. The volar plate resists PIP joint hyperextension.
- The proper and accessory collateral ligaments are the primary restraints to radial- and ulnar-directed forces. The accessory collateral ligaments, situated volarly, attach to the lateral margin of the volar plate as it crosses the joint.

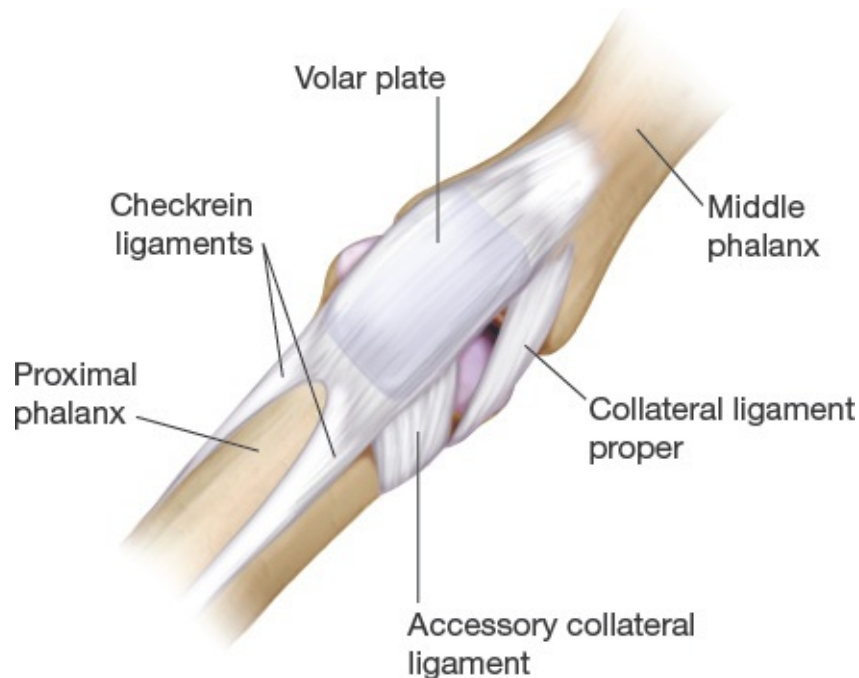


FIG 1 • Anatomy of proximal interphalangeal (PIP) joint. In this view of volar aspect of the joint, note the relationship between the volar plate and collateral ligaments. These structures create stability of the joint and are often injured with PIP joint dislocations.

PATHOGENESIS

- The strong volar plate is frequently injured in dorsal PIP dislocations and/or hyperextension injuries of the PIP joint.
- The most common injury is avulsion of the volar plate from the base of the middle phalanx due to the strength of checkrein ligaments and attachments to the accessory collateral ligaments.
- The distal attachment often avulses a fragment of the base of the middle phalanx (**FIG 2**).
- Disruption of 40% to 50% of the volar articular surface of the base of the middle phalanx can lead to joint instability (ie, dorsal subluxation of the middle phalanx) requiring correction (**FIG 3**).¹



FIG 2 • A. Illustration of volar plate avulsion with dorsal PIP dislocation. **B.** The middle phalanx subluxes dorsally, creating a V deformity of the dorsal joint. **C.** A volar bone fragment is commonly avulsed with the volar plate (*arrow*).

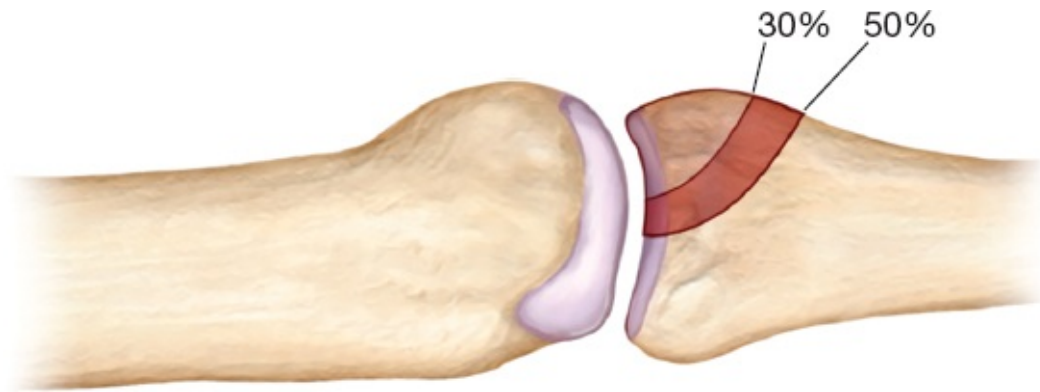


FIG 3 • Fracture stability. Fractures with 50% articular involvement are inherently unstable. Fractures with 30% to 50% involvement are tenuous and need to be evaluated closely for instability. Fractures of less than 30% tend to be stable.

NATURAL HISTORY

- Disruption of the volar plate with or without an associated base of middle phalanx fracture can lead to²:
 - Pain
 - Premature degenerative arthritis
 - Stiffness and loss of PIP joint motion
 - Persistent dorsal subluxation of the joint

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most common cause of acute injury is an axial or dorsal load to the finger leading to a dorsal dislocation. The patients will often report that their finger was “jammed” or “dislocated.”
- Patients most often reduce the joint themselves prior to presentation.
- On physical examination:
 - Patients have ecchymosis, edema, decreased range of motion, and tenderness located to the PIP joint.
 - Repeated dorsal dislocation on flexion of the PIP joint is characteristic of a volar plate disruption.
 - Minimal resistance to hyperextension at the PIP joint is also suggestive of volar plate injury.
 - This is best tested under anesthetic block.

- Always compare to noninjured digits.
- Acute or chronic development of a swan-neck deformity can suggest a volar plate injury.

IMAGING

- Appropriate preoperative radiographic imaging of the affected finger is important to assess bony injury. These include AP and lateral radiographs (**FIG 4A–C**).
- Radiographs in both flexion and extension allow the stability of the joint to be assessed when volar base of middle phalanx fractures exist.
- Preoperative live fluoroscopy is also useful to further assess stability of the joint in real time.
- Complex fractures can be evaluated with a high-resolution CT to evaluate bony fragment size and location (**FIG 4D**).
- In cases of acute or chronic instability without an underlying fracture, signs of arthritic damage or malalignment should be evaluated.

NONOPERATIVE MANAGEMENT

- Nonoperative management for PIP joint dislocations may be considered in those patients with stable injury patterns (less than 30% articular surface involvement).
- Stability may be confirmed with a lateral radiograph of the PIP joint.
- If mild subluxation of the PIP joint exists, the digit should be examined for adequate reduction with the joint blocked in 15 to 20 degrees of flexion using a dorsal blocking splint. If a dorsal blocking splint offers an adequate reduction, conservative treatment can be pursued with close follow-up. If more than 60 degrees of flexion is needed to maintain reduction, surgical intervention should be considered.

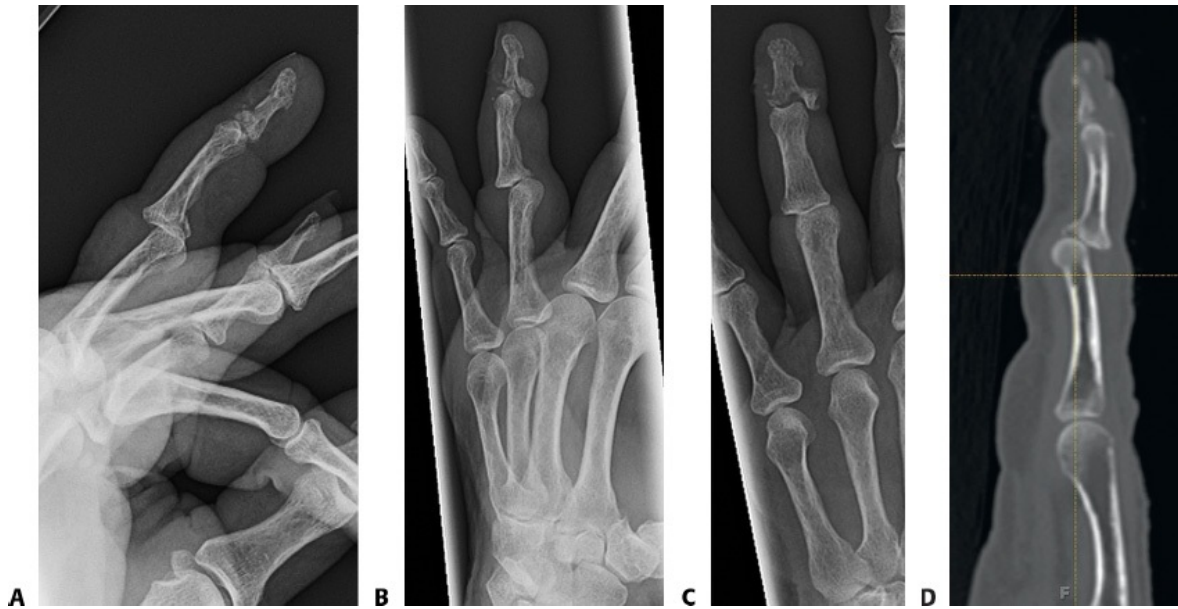


FIG 4 • A–C. Radiographs of the left ring finger demonstrate a fracture-dislocation of the PIP joint with dorsal subluxation. There is also a displaced intra-articular fracture of the distal phalanx. **D.** A CT scan of the affected digit can be obtained to evaluate the size and number of bony fragments involving the middle phalanx.

- Treatment options for stable PIP joints include dorsal blocking splint, buddy taping to a neighboring digit, and early motion. A figure-eight splint or silver ring splint may also be used.

SURGICAL MANAGEMENT

- For most PIP fracture-dislocations, joint reconstruction with a hemihamate arthroplasty (HHA) has largely replaced the use of VPA because of the HHA's ability to restore near-anatomic alignment of the joint. However, the HHA is technically demanding and has a steep learning curve. For inexperienced surgeons, the VPA is a reasonable conservative option.
- Indications:
 - Acute dorsal dislocation injury with gross instability
 - Acute fracture dislocation involving over 30% of the articular surface with subluxation of the middle phalanx.
 - Chronic dorsal subluxation with failed conservative management

- Osteoarthritis of PIP joint³

Preoperative Planning

- Appropriate preoperative imaging is necessary to assess bony joint quality/deformity.
- The dorsal cortex must be intact to perform VPA.
- Articular surface of the proximal phalanx must also be intact.
- General, regional, or local anesthesia can be used.

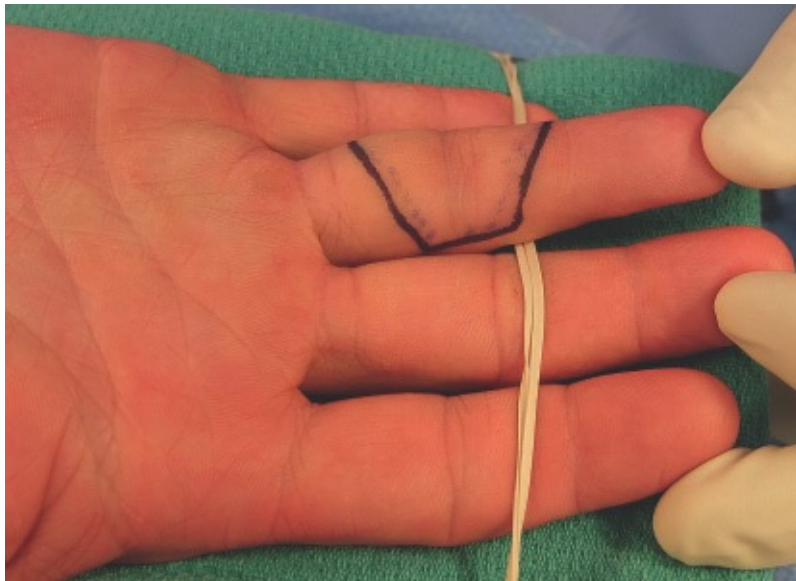


FIG 5 • Skin markings to access the volar aspect of the finger. A traditional Bruner incision is also acceptable.

Positioning

- Patient is placed in the supine position with the affected limb abducted on a radiolucent hand table.
- Tourniquet is placed on upper arm or forearm.
- A malleable lead/aluminum hand may be used to help retract the nonoperative digits.

Approach

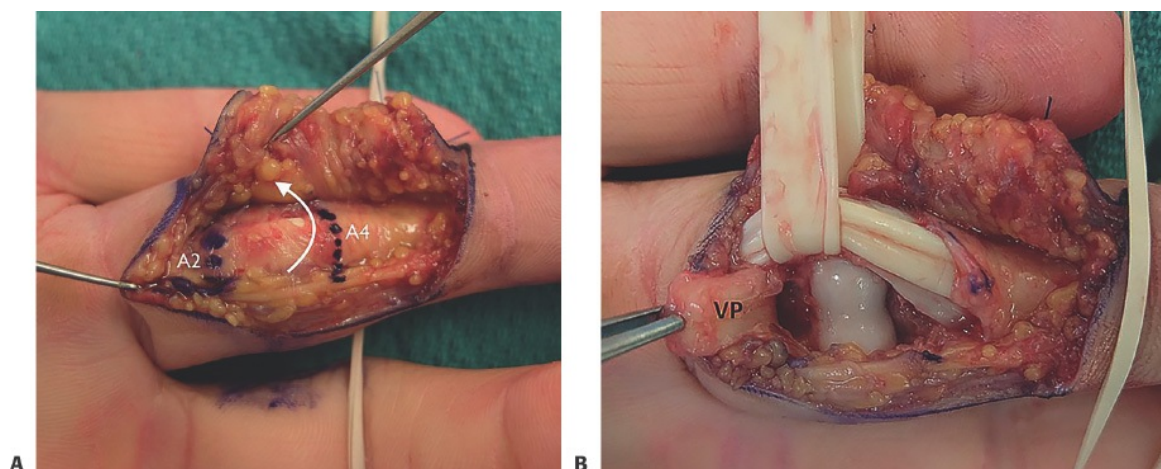
- A volar approach through either a Chevron-shaped or Bruner-style incision is based over the PIP joint (**FIG 5**).

TECHNIQUES

■ Volar Plate Advancement for Base of Middle Phalanx Fractures

Exposure

- Exposure is planned from the A2 pulley to A4 pulley (**TECH FIG 1A**).
- A2 and A4 pulleys are preserved, but the flexor tendon sheath between them is incised and reflected.
- A Penrose drain can then be looped around the exposed flexor tendons to retract them, allowing visualization of the underlying volar plate (**TECH FIG 1B**).
- With the volar plate exposed, the fracture can be visualized by hyperextending the PIP joint.
- Incise and free the lateral margins of the volar plate from the accessory collateral ligaments with a Beaver or no. 15c blade.



TECH FIG 1 • **A.** The distal margin of A2 and the proximal margin of A4 pulleys are identified (*purple dotted lines*), and the flexor tendon sheath is reflected laterally. The pulleys are maintained. **B.** The flexor tendons are reflected laterally and secured with a Penrose drain. The volar plate (VP) is incised and

reflected proximally to expose the joint.

- The distal margin of the volar plate often maintains its attachments to the fracture fragment, which can be sharply excised if necessary.
- If not completely free, the volar plate is then divided transversely as distally as possible to maximize the length of the now proximally based flap.
 - This can be done by first placing a Freer elevator under the volar plate to identify the distal margin and then sliding a no. 15 blade under the volar plate to divide it.
 - It is important to obtain a volar plate flap as long and broad as possible.
- To further hyperextend or shotgun the joint (in cases of joint reconstruction), the collateral ligaments must be released from the middle phalanx at this point.

Preparation of the Middle Phalanx

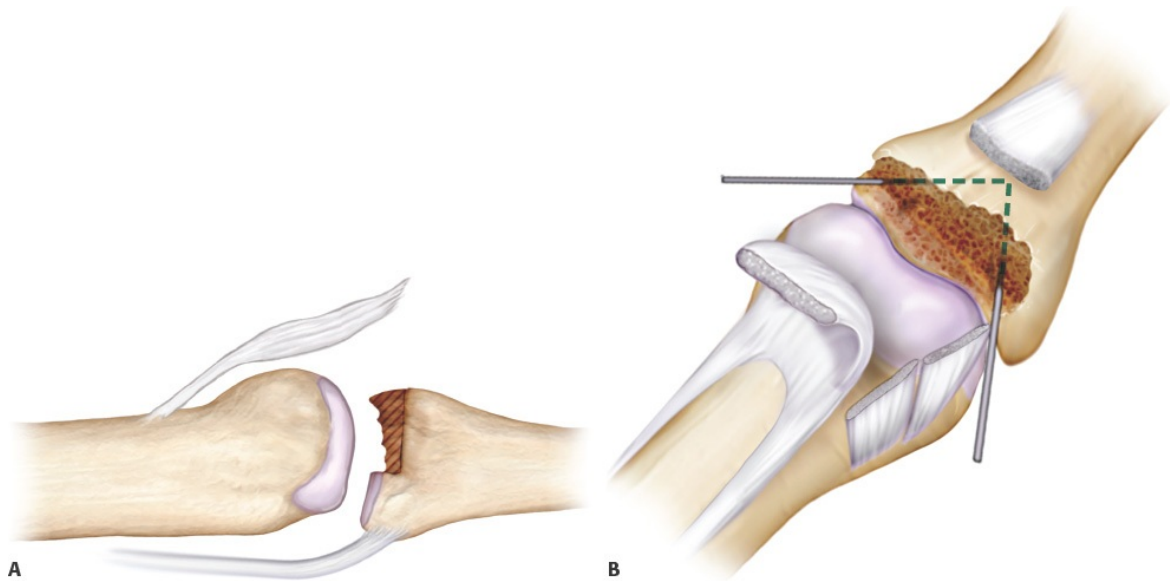
- The middle phalanx is then prepared with a rongeur to make smooth the volar articular surface with careful maintenance of the dorsal articular surface and cortex (**TECH FIG 2A**).
- Two straight Keith needles are drilled through the middle phalanx base from volar to dorsal angling them slightly distally (**TECH FIG 2B**).
 - Each needle is started laterally at the volar margin of the cartilaginous surface and aimed toward the midline dorsally (toward the triangular ligament) to avoid injuring the lateral bands or central slip on the dorsal surface.
 - Flexing the DIP joint as the K-wires are driven will help prevent the DIP joint from being locked in extension if the extensor mechanism is caught with the pull-through suture.
 - In the situation of a middle phalanx fracture, the needles are started at the lateral margin of the remaining intact cartilaginous surface.

Passing and Setting the Suture

- A Prolene or stainless steel suture is passed in a grasping fashion around the fibrocartilaginous portion of the volar plate ending at the distal margin (**TECH FIG 3A**).
- After the needle is removed, the suture ends are fed through the holes in the Keith needles.
- The Keith needles are then manually pulled through the dorsal aspect of the

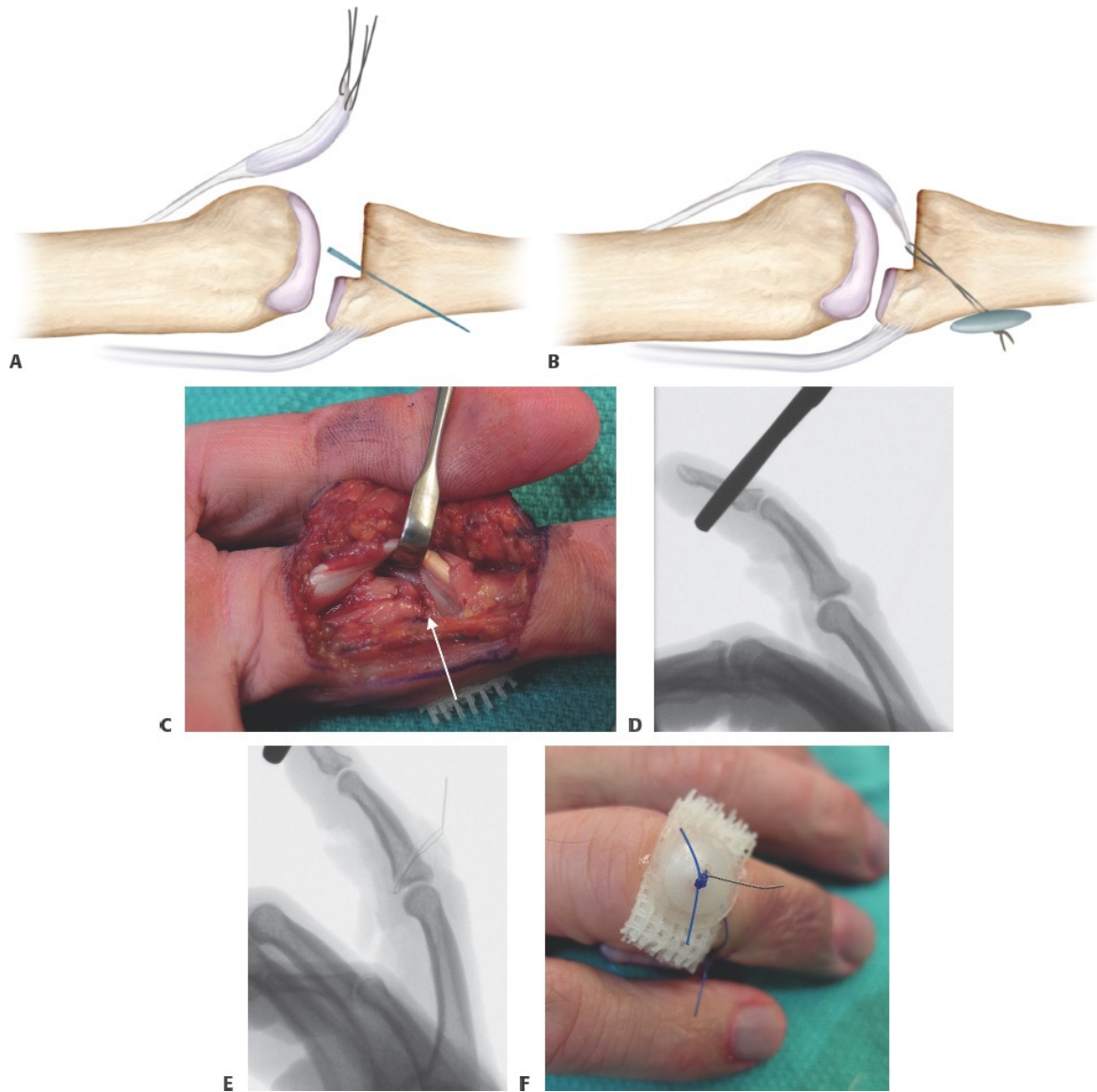
finger using a needle driver.

- If both needles can be brought out through the same hole in the triangular ligament, you can minimize the chance of injuring or entrapping the extensor mechanism.
- The suture is passed through a folded wad of petroleum-impregnated gauze for skin protection before being passed through a button.
- The suture tension is set temporarily over the button with the PIP joint extended to 0 degrees (**TECH FIG 3B,C**).
- Fluoroscopic images are taken to ensure an adequate reduction (**TECH FIG 3D,E**).
- It is important to observe congruent joint surfaces through a full range of motion on fluoroscopy.
- If hinging (gapping over the dorsal cortex) is still present, consider further advancement of the volar plate or releasing the dorsal joint capsule.
- Once satisfied with positioning, the sutures can be permanently secured over the button (**TECH FIG 3F**).
- The lateral margins of the volar plate are then sutured to the adjacent collateral ligament margins to restore three-dimensional stability.
- In the case of a base of middle phalanx fracture, an oblique Kirschner wire is placed to maintain 20 to 30 degrees of flexion and joint congruity.



TECH FIG 2 • A. Preparation of the middle phalanx surface. The volar plate is reflected, and the dorsal

cortex and articular surface are maintained. **B.** The *dotted lines* show the paths of the Keith needles for the pull-through technique. The needles are angled in a volar to dorsal direction toward the midline of the finger. They are also angled slightly in a proximal to distal direction to avoid injury to the central slip dorsally.



TECH FIG 3 • **A.** Lateral aspect of the joint demonstrating the Keith needle placement and locking suture placement of volar plate. **B.** The sutures are pulled through the middle phalanx and secured over a button. **C.** The volar plate is tensioned symmetrically (*white arrow*) to obtain joint congruity. **D.** Lateral radiograph demonstrates dorsal subluxation following a volar base of middle phalanx fracture. The middle phalanx is subluxed dorsally creating a dorsal V sign with overexaggeration of the dorsal joint space.

Approximately 30% of the articular surface is involved in the fracture. **E.** Postreduction radiographs demonstrate restoration of joint congruity using a stainless steel wire with the volar plate arthroplasty. **F.** A petroleum-impregnated gauze strip is used to avoid injury to the underlying skin.

■ Correction of PIP Joint Instability Without a Middle Phalanx Fracture

- The procedure is similar to the volar plate arthroplasty for volar base of middle phalanx fractures with the following differences:
 - A postreduction K-wire can be replaced with a dorsal blocking splint if the reduction is maintained through a full arc of motion allowing for immediate mobilization of the PIP joint.
 - Although the volar plate should still be separated from the collateral ligaments, the collateral ligaments do not need to be divided as the joint is not shotgunned open.

PEARLS AND PITFALLS

Fracture characterization

- Patients with volar base of middle phalanx fractures need radiographs to assess the stability of the joint.
- The dorsal cortex and articular surface must be intact.
- The fracture pattern should be evaluated in flexion and extension preoperatively.
- Volar plate arthroplasty is appropriate for volar base of middle phalanx fractures with greater than 40% of the articular surface involved.

Timing

- Operative management within the acute time period avoids working against scar tissue.

Pull-through wire placement

- Volar placement of the wire and angled distal to central slip is key to an adequate reduction.
- Centralized dorsal placement of the wire will prevent entrapment of the extensor mechanism.

	■ Symmetric tension setting of the volar plate will ensure adequate reduction.
Intraoperative fluoroscopy	■ Joint congruity throughout a full range of motion intraoperatively must be obtained and maintained.
Postoperative care	■ Initiate early guarded range of motion to prevent flexion contracture.

POSTOPERATIVE CARE

- VPA for unstable volar base of middle phalanx fractures:
 - K-wire immobilization of the joint is maintained for 3 weeks.
 - DIP joint ROM is started immediately to promote tendon glide.
 - Active range of motion of the PIP joint is initiated 4 weeks following surgery.
 - Dynamic extension splinting is initiated if full extension has not been reached by 5 to 6 weeks following surgery.
 - The button and suture are removed 5 to 6 weeks following surgery.
 - Buddy taping is initiated once the dorsal blocking splint is discontinued at 6 weeks.
 - Return to sporting activities is permitted at 8 weeks as long as buddy taping is maintained.
- VPA for nonfractured joints with restored congruency:
 - DIP and PIP range of motion is initiated the day after surgery with a dorsal blocking splint in place under the guidance of a hand therapist.
 - The button and suture are removed 5 to 6 weeks after surgery.
 - Buddy taping is initiated once the dorsal blocking splint is discontinued at 6 weeks.
 - Dynamic extension splinting is initiated if full extension has not been reached within 5 to 6 weeks after surgery.
 - Return to sporting activities is permitted at 8 weeks as long as buddy taping is maintained.

OUTCOMES

- Reported outcomes vary greatly, but two long-term follow-up papers demonstrate maintenance of motion and stability of the reconstruction.
- Eaton and Malerich in 1980 reviewed 24 patients over a 100-year period and noted the following²:
 - An average of 95 degrees of motion and a 6-degree flexion contracture if

treated within 6 weeks from a fracture

- An average of 78 degrees of motion and a 12-degree flexion contracture if treated after 6 weeks from the date of fracture
- Dionysian and Eaton reported their VPA results of 17 patients with an average of 11.5 years' follow-up and found⁴:
 - Patients with VPA within 4 weeks of injury maintained total active ROM of 85 degrees.
 - Patients with VPA after 4 weeks of injury averaged 61 degrees of active ROM.

COMPLICATIONS

- Complications are relatively uncommon with reports of patient satisfaction rates as high as 94%.⁵
- Complications can include the following:
 - Redisplacement: Due to failure to achieve a stable reduction or suture failure
 - PIP joint angulation: Commonly due to a failure to recognize or manage an asymmetric fracture pattern
 - DIP joint stiffness: Failure to initiate early DIP motion or capturing the extensor mechanism in the pull-through suture can lead to stubborn DIP stiffness.
 - Flexion contracture: This is the most common complication and is due to splinting or stabilization in excessive PIP flexion or failure to initiate aggressive/hand therapist-supervised hand therapy at an appropriate interval.

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Hemihamate Arthroplasty for the Proximal Interphalangeal Joint Fracture Dislocation

12

CHAPTER

David Wei, Mark A. Vitale, and Amy M. Moore

DEFINITION

- Fracture dislocations of the proximal interphalangeal (PIP) joint are injuries in which the volar lip of the middle phalanx is fractured with accompanying instability of the middle phalanx on the proximal phalangeal head.
- The majority of PIP joint fracture dislocations are dorsal dislocations.
- PIP joint fracture dislocations are classified by their mechanical stability as well as the percentage of joint surface fractured and other radiographic parameters.¹
- The most important radiographic determinant of stability is the percentage of the middle phalangeal articular surface that has been fractured:
 - Disruption of 30% or less of the articular surface is likely to be stable.
 - Thirty to thirty-five percent of articular surface involvement may be tenuous.
 - More than 50% of articular surface involvement is considered unstable.¹
- Other radiographic signs of instability include the dorsal V sign and loss of continuity of the dorsal cortices of the proximal and middle phalanges.^{2,3}
- Evaluation of mechanical stability is also important and can be tested by evaluating range of motion of the PIP joint using live fluoroscopic imaging or with radiographs in both full extension and full flexion (usually under a digital block). Injuries in which the PIP joint subluxates as the joint approaches extension are deemed unstable.
- Hemihamate arthroplasty, originally introduced by Hastings in 1999, is a method of reconstructing the damaged volar base of the middle phalanx by

using the natural contour of the size-matched portion of the distal dorsal articular surface of the hamate.⁴

ANATOMY

- The bony anatomy of the PIP joint allows it to function as a hinge, permitting flexion and extension in the sagittal plane.
- The normal range of motion of the PIP joint is 0 to 120 degrees.
- Stability of the joint is conferred by a combination of bony constraints, the volar plate and the collateral ligaments (**FIG 1**).
- The concave articular surface of the middle phalanx articulates with the convex condyles of the proximal phalanx. There is slight asymmetry between the proximal phalangeal condyles, which causes mild supination of the middle phalanx with flexion.⁵
- The volar plate is a fibrocartilaginous structure that is firmly attached distally to the volar base of the middle phalanx and which originates proximally from the proximal phalanx via two checkrein ligaments. The volar plate resists PIP joint hyperextension.
- The collateral ligaments are the primary restraints to radial- and ulnar-directed forces. They are composed of the proper and accessory collateral ligaments.
- Hemihamate arthroplasty takes advantage of the anatomy of the hamate (**FIG 2A**), which can replicate the volar proximal portion of the middle phalanx (**FIG 2B**), and cadaveric studies have demonstrated ideal suitability as an autologous graft.⁶
- The distal surface of the hamate, which articulates with the base of the fourth and fifth metacarpals, contains a bicondylar facet that is separated by a central ridge.
- The ridge closely replicates the bicondylar facet and central ridge of the proximal portion of the middle phalanx.
- Though the contour of the hamate is more shallow than the contour of the middle phalanx (with the phalangeal radius of curvature ranging from 45% to 61% of the hamate) with proper orientation and tilting of the graft, a stable, congruent joint is achievable.⁶

PATHOGENESIS

- Two mechanisms of injury to the PIP joint have been described: avulsion and impaction shear.⁷

- Avulsion injuries occur when the PIP joint is hyperextended. The volar plate remains attached to the proximal phalanx, and the distal attachment avulses a fragment of the middle phalangeal volar lip (**FIG 3A**).

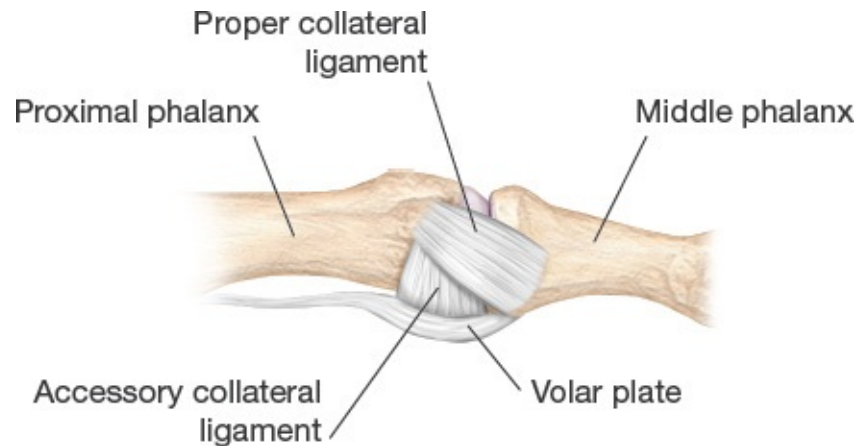


FIG 1 • Anatomy of the proximal interphalangeal (PIP) joint, including the proper (P) and accessory (A) collateral ligaments and the bony anatomy consisting of the convex condylar articular surface of the proximal phalanx (P1), which articulates with a concave articular surface of the middle phalanx (P2).

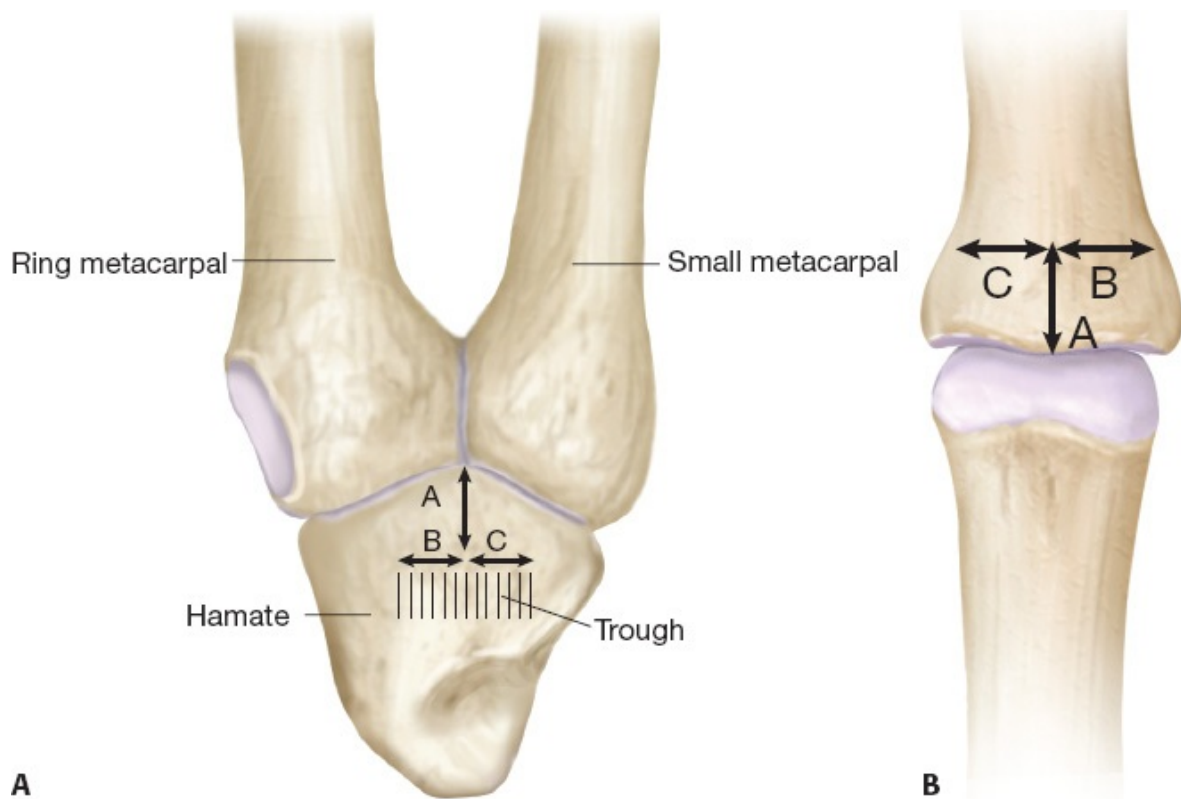


FIG 2 • The distal portion of the hamate bone of the carpometacarpal joint—which consists of a central ridge and bicondylar facet and articular cartilage distally, where it articulates with the articular cartilage of the fourth and fifth metacarpal bases (**A**)—is an ideal match in size, morphology, and dimensions to the volar proximal surface of the PIP joint of the digits (**B**).

- Although avulsion fractures vary in size, there is typically no comminution.
- In impaction injuries, an axial load applied to the digit can drive the middle phalanx into the head of the proximal phalanx, creating a shear force through the middle phalangeal base. This creates a shear fracture of the volar lip.
- In this mechanism because the fractured base is impacted into the head of the proximal phalanx, the metaphyseal bone of the middle phalanx is often comminuted (**FIG 3B**). When the volar fragment is sufficiently large, the buttressing effect of the volar margin of the middle phalanx and the restraint of the volar plate and collateral ligaments is lost, allowing the middle phalanx to displace dorsally.

NATURAL HISTORY

- The natural history of untreated dorsal PIP joint fracture dislocations is loss of motion, pain, and degenerative joint disease.²
- Even with adequate treatment, injury can result in chronic pain, stiffness, and swelling, as PIP joint injuries are relatively unforgiving owing to the combination of bony injury, cartilage damage, soft tissue disruption, and scarring.^{2,8}
- Traditional surgical options for unstable fracture dislocations of the PIP joint include external fixation, volar plate arthroplasty, and fracture fixation via percutaneous methods or open reduction and internal fixation.
 - When more than 50% of the volar aspect of the middle phalanx is injured, these traditional techniques lead to recurrent instability.⁹

PATIENT HISTORY AND PHYSICAL FINDINGS

- A patient's history will typically reveal a specific trauma in which the digit was "jammed" or "sprained"; the patient complains of swelling, pain, and decreased range of motion.
- Physical examination should include a thorough examination of the skin. If surgery is needed and there is a compromised soft tissue envelope, percutaneous pinning or external fixation may be preferred to hemihamate arthroplasty.



FIG 3 • A. Lateral radiograph of a middle finger demonstrating a small volar plate avulsion fracture without any evidence of PIP joint subluxation. **B.** Lateral radiograph of a ring finger demonstrating an impactation injury to the middle phalanx in which the base of the middle phalanx is driven into the head of the proximal phalanx resulting in comminution of the metaphyseal bone of the middle phalanx. This fracture was unstable and required closed reduction with a dorsal blocking splint and ultimately required surgical fixation.

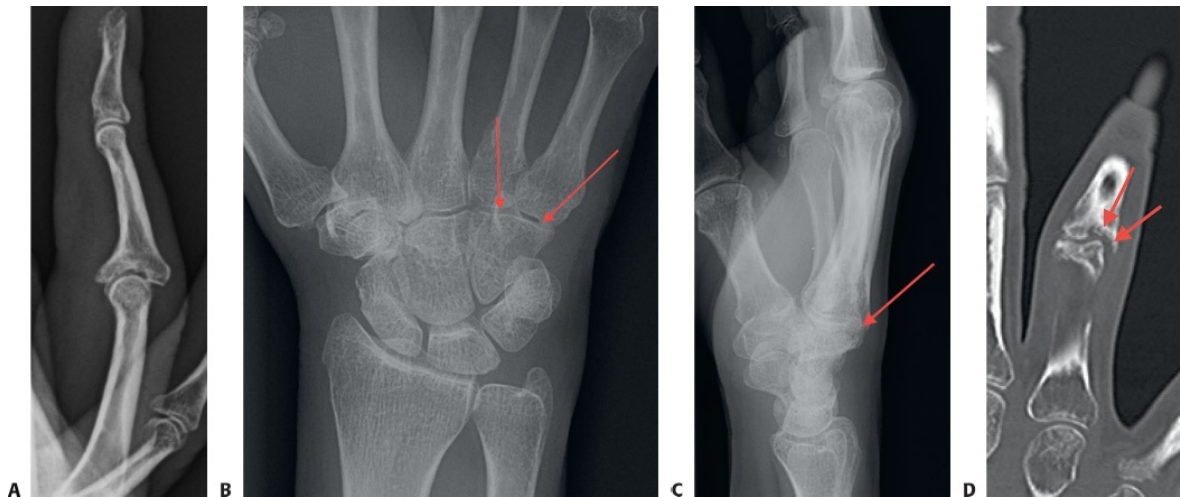


FIG 4 • A. Lateral radiograph demonstrating a patient with a 7-week-old dorsal PIP joint fracture dislocation with involvement of approximately 70% of the articular surface and an intact dorsal phalangeal base. **B,C.** PA and lateral radiographs demonstrating suitability of the ipsilateral hamate bone for a graft without evidence of fracture or degenerative joint disease. *Arrows* indicate location of harvest site. **D.** Coronal slice of a CT scan of the same patient revealing an ulnar-sided middle phalangeal defect with impaction causing ulnar deviation of the digit at the PIP joint (*arrows*). Fine slices via CT imaging allow for preoperative planning to determine how to contour the donor graft from the hamate.

- Physical examination should also include inspection for deformity, swelling, ecchymosis, malrotation, or angulation.
- Check for local tenderness to palpation of the PIP joint and assess the integrity of the flexor and extensor tendons.
- When imaging studies confirm dorsal dislocation, a gentle reduction should be attempted under local anesthetic.
- Once reduced, the joint should be inspected for passive and active stability.

IMAGING

- Basic radiographic imaging (including anteroposterior and lateral radiographs) of both the affected digit and the hand is necessary.
- Lateral imaging of the PIP joint allows evaluation of the amount of articular surface that must be replaced (**FIG 4A**).
- Wrist radiographs confirm that the hamate bone is intact and may serve as potential bone graft donor (**FIG 4B,C**).
- In patients with prior injuries to the base of the ring or small finger carpometacarpal joints, the distal dorsal articular surface should be carefully inspected, and the contralateral hand should be considered for harvest of the hamate bone graft.
- In addition to radiographs, advanced imaging with a CT scan may be helpful in determining the three-dimensional nature of the middle phalanx defect.
- Subtle radioulnar bony deficits, such as impaction and/or comminution may be visualized that are not apparent on radiographs (**FIG 4D**).

NONOPERATIVE MANAGEMENT

- Nonoperative management for PIP joint fracture dislocations may be considered in those patients with stable injury patterns (less than 30% articular surface involvement).
- Stability may be confirmed with a lateral radiograph of the PIP joint in full extension to ensure the absence of any dorsal subluxation.
- Treatment options include dorsal blocking splint, buddy taping to a neighboring digit, and early motion.
- For those PIP joint fracture dislocations that are unstable but reducible with PIP joint flexion of less than 30 degrees, nonsurgical management may be considered.
- A dorsal blocking splint may be used to maintain reduction, and frequent radiographic follow-up is required to ensure the PIP joint remains congruent.
- A figure-eight splint or silver ring splint may also be used.

SURGICAL MANAGEMENT

- Hemihamate arthroplasty is indicated for the treatment of unstable dorsal PIP joint fracture dislocations that are either acute or not amenable to ligamentotaxis or internal fixation, or subacute/chronic dislocations.
- Contraindications of this technique include any fractures involving the dorsal cortex, since the integrity of the dorsal cortex of the middle phalanx is necessary for hamate autograft fixation.

- Other considerations include those fractures with significant extension into the middle phalangeal shaft, as this can affect the positioning and recontouring of the articular surface.

Preoperative Planning

- Lateral radiographs of the PIP joint should be reviewed to estimate the size of the volar articular fragment that needs to be reconstructed.
- CT imaging may be useful in confirming the three-dimensional nature of the fractured volar rim and ensure there is no dorsal cortical fracture or significant distal fracture extension along the volar cortex.

Positioning

- The patient is positioned supine on the operating table with the upper extremity on a radiolucent hand table.
- A malleable lead/aluminum hand may be used to help retract the nonoperative digits.
- The position of the surgeon should take into account the position of the fluoroscopic machine that most easily gives a perfect lateral radiograph of the PIP joint to be taken.
 - One configuration is with the surgeon sitting at the head of the patient with the fluoroscopic C-arm coming from the end of the hand table in the horizontal position and the image intensifier closer to the surgeon. (See Pearls and Pitfalls, below.)

Approach

- A volar “shotgun” approach of the PIP joint is most commonly used and provides excellent exposure. Various skin flaps have been described to accomplish exposure of the volar aspect of the PIP joint.

TECHNIQUES

■ Exposure

- We use a V-shaped Bruner incision, centered at the PIP joint flexion crease with the apex at the radial (the ulnar border could be used too), extending from the palmar digital crease to the DIP flexion crease.

- Raise skin flaps to expose the underlying flexor tendon sheath, and carefully identify both the radial and ulnar neurovascular bundles.
- Create an ulnar-based flap of the flexor tendon sheath by making transverse incisions distal to the A2 pulley and proximal to the A4 pulley, and also along the radial border.
 - Retraction of this flap ulnarly with a proximal and distal retraction suture helps to protect the neurovascular bundle just superficial to it.
- A Penrose drain can be used to retract the flexor tendons, exposing the underlying volar plate.
- Incise both radial and ulnar margins of the volar plate and elevate it from its distal attachment to the proximal phalanx to allow proximal retraction.
 - If the volar plate is still attached to the volar articular fragment, the fragment should be excised.
- Release both collateral ligaments off the proximal phalanx sharply, which may be done by using a knife at the level of the joint and cutting proximally along the contour of the proximal phalangeal head so that the incised collateral ligaments can be redraped over the proximal phalanx to enhance healing.
- Now, the PIP joint may be fully hyperextended (“shotgunned”) open, exposing the entirety of both articular surfaces (**TECH FIG 1**).

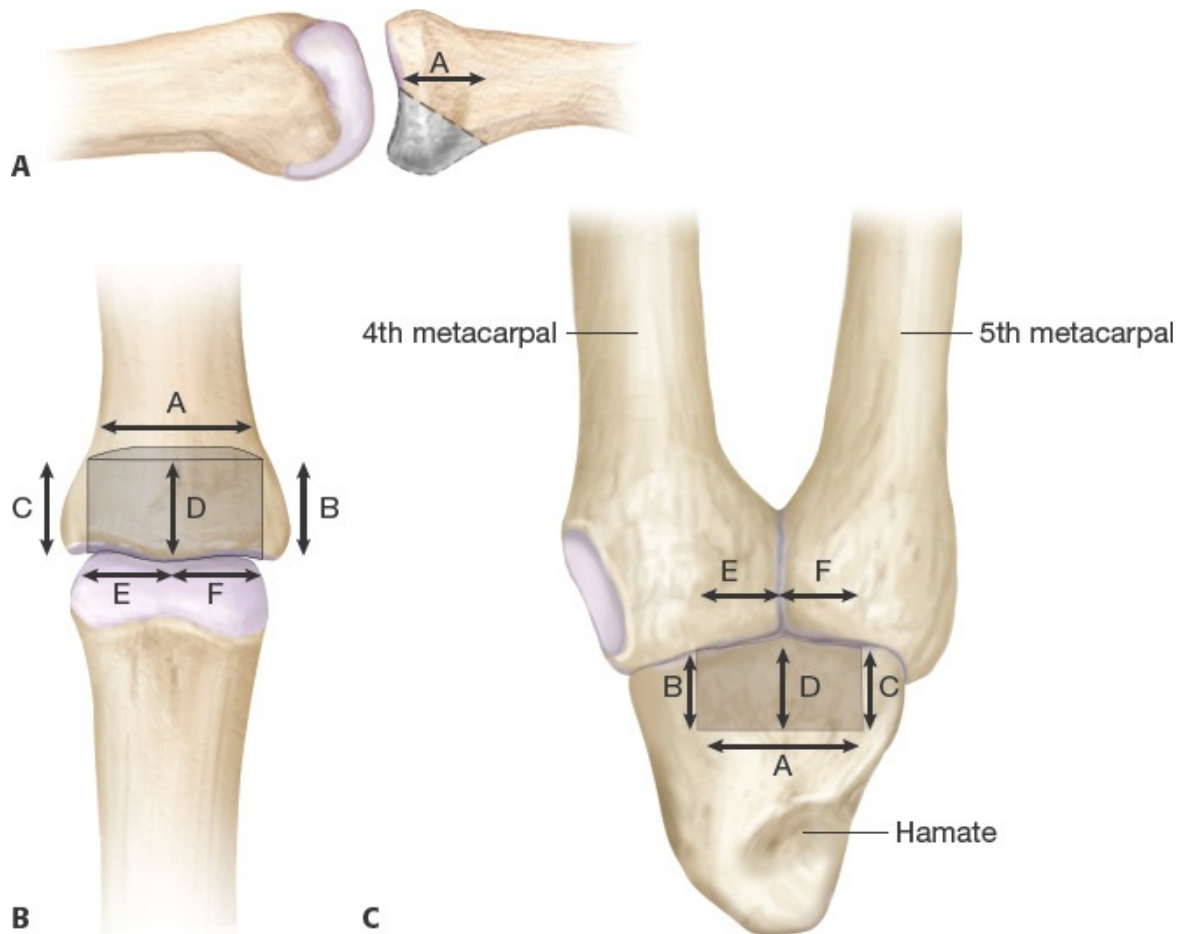


TECH FIG 1 • Shotgun exposure of the PIP joint of the ring finger with a PIP fracture dislocation exposing the

head of the proximal phalanx and the fractured base of the middle phalanx. A small Penrose drain can be used to safely retract the flexor tendon system.

■ Middle Phalanx Preparation

- The base of the middle phalanx should be carefully inspected and correlated with preoperative radiographs and imaging.
- Use a rongeur or oscillating microsagittal saw on the middle phalanx to create a smooth articular interface to accept the hamate autograft.
 - A slow and careful approach during this step is recommended to avoid any excess removal of bone and to prevent fracture of the remaining dorsal bony cortex.
 - If possible, leaving a radial or ulnar bony articular lip may help to provide further stability of the hamate autograft.
- An ideal bone defect is one that begins at the articular surface and slopes toward the remaining intact volar cortex, which helps to cant the hamate graft and ultimately recreate the concave contour of the articular surface (**TECH FIG 2A**).
- The bone defect should be measured in preparation for hamate graft harvesting using either calipers or a small cut piece of a ruler.
- Dimensions that should be noted include the total width, the proximal to distal length, and finally the approximate amount of articular surface that must be recreated (**TECH FIG 2B,C**).



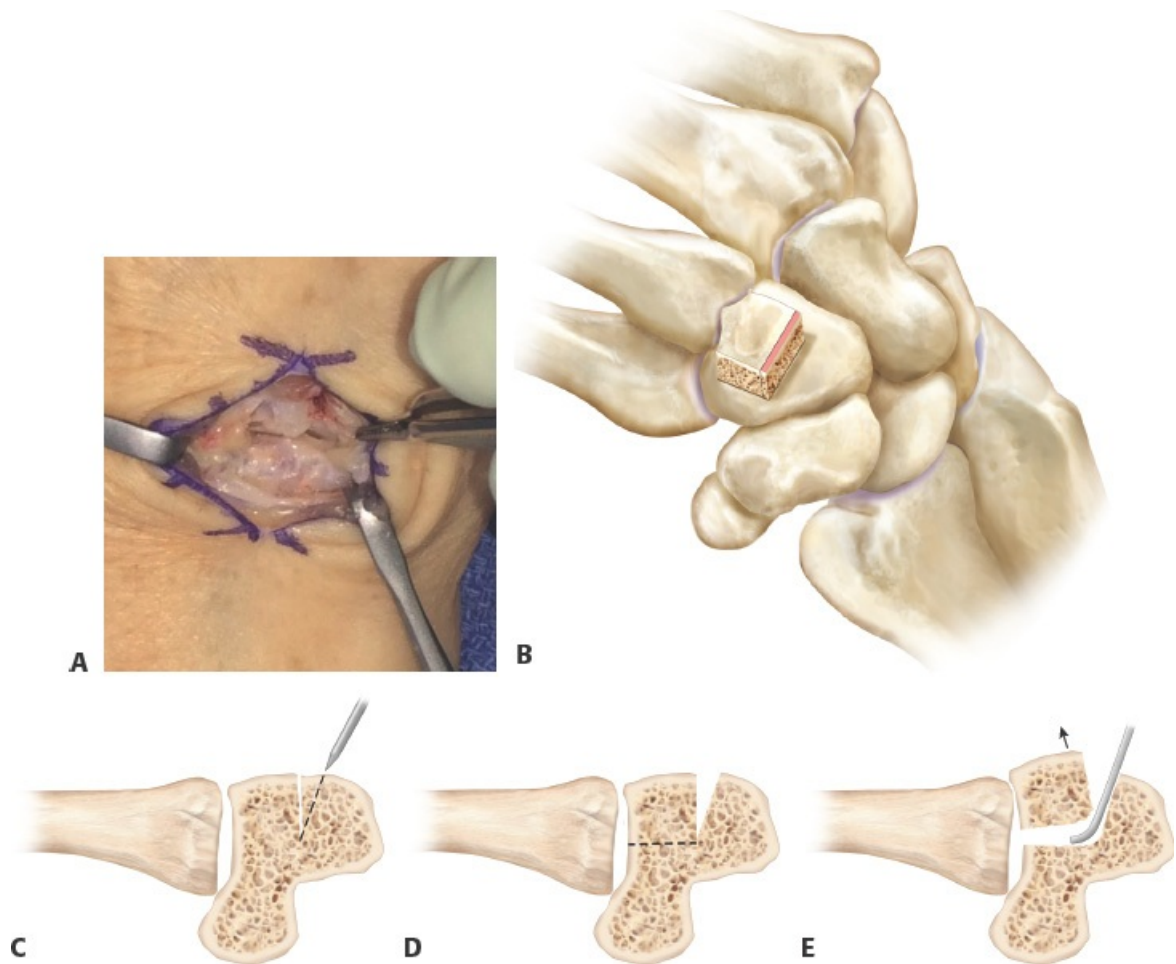
TECH FIG 2 • A. Illustration of the lateral PIP joint demonstrating the preferred bone defect to accept a hemihamate graft, with sloping at the articular surface toward the remaining intact volar cortex. **B,C.** Careful measurement of the dimensions of the missing volar phalangeal base with a caliper or ruler—including the total width, the proximal to distal length, and the amount of articular surface that must be reconstituted from the donor hamate graft—allows for a close match of the graft to its recipient site.

■ Hamate Autograft Harvest

- Identify the ring and small finger carpometacarpal joints using fluoroscopic guidance so the incision may be accurately positioned.

- Use either a transverse or longitudinal incision centered on the carpometacarpal joints.
- Retract and protect any cutaneous branches of the dorsal ulnar nerve as well as the extensor tendons to the ring and small fingers.
- Expose the CMC joints subperiosteally by incising the dorsal capsule longitudinally (**TECH FIG 3A**).
- Find the bony ridge between the ring and small finger CMC facets on the hamate. This will be used as the center of the graft.
- Using the previously measured dimensions of the PIP joint defect, mark the hamate using an indelible sterile marker, erring on the side of harvesting a slightly larger graft than necessary.
- Note that the central ridge on the hamate actually runs at an oblique angle from dorsal to volar. A previous cadaveric study has shown that the hamate has a central ridge and bicondylar facet with articular contours similar to the base of the middle phalanx.⁶
 - To ensure that the ridge remains central and in the correct orientation on the graft, make sure the hand is sufficiently pronated on the table before making any cuts (see Pearls and Pitfalls, below).
- With an oscillating saw or osteotome, make the sagittal and axial plane cuts first, remembering to take into account the loss of bone that can be expected, depending on the thickness of the instrument used.
- Make the coronal plane cut last with a curved osteotome, as this is usually the most difficult cut to make and contributes directly to the concavity of the reconstructed articular surface. Two primary techniques can be used, antegrade or retrograde.
 - In the antegrade approach, a curved osteotome is used transversely along the proximal dorsal surface of the hamate and aimed into the ring and small finger CMC joint blindly. To ensure adequate thickness of the autograft using the antegrade approach, a small slice of bone is removed just proximal to the *axial* plane cut (**TECH FIG 3B**). This extra bone excision will provide room for the curved osteotome to obtain the correct depth of coronal plane cut (**TECH FIG 3C–E**).
 - In the retrograde approach,¹⁰ the ring and small finger metacarpals are forcefully volarly subluxated to reveal the distal articular surface of the hamate, and the saw or osteotome is aimed volar and proximal to make a retrograde coronal cut.

- Alternatively, a modification to this retrograde approach has been proposed¹¹ that exposes the distal articular surface of the hamate by resecting a portion of the ring and small finger metacarpal bases.
- Once excised, the hamate autograft can be further contoured and shaped to fit the recipient site with a fine rongeur.

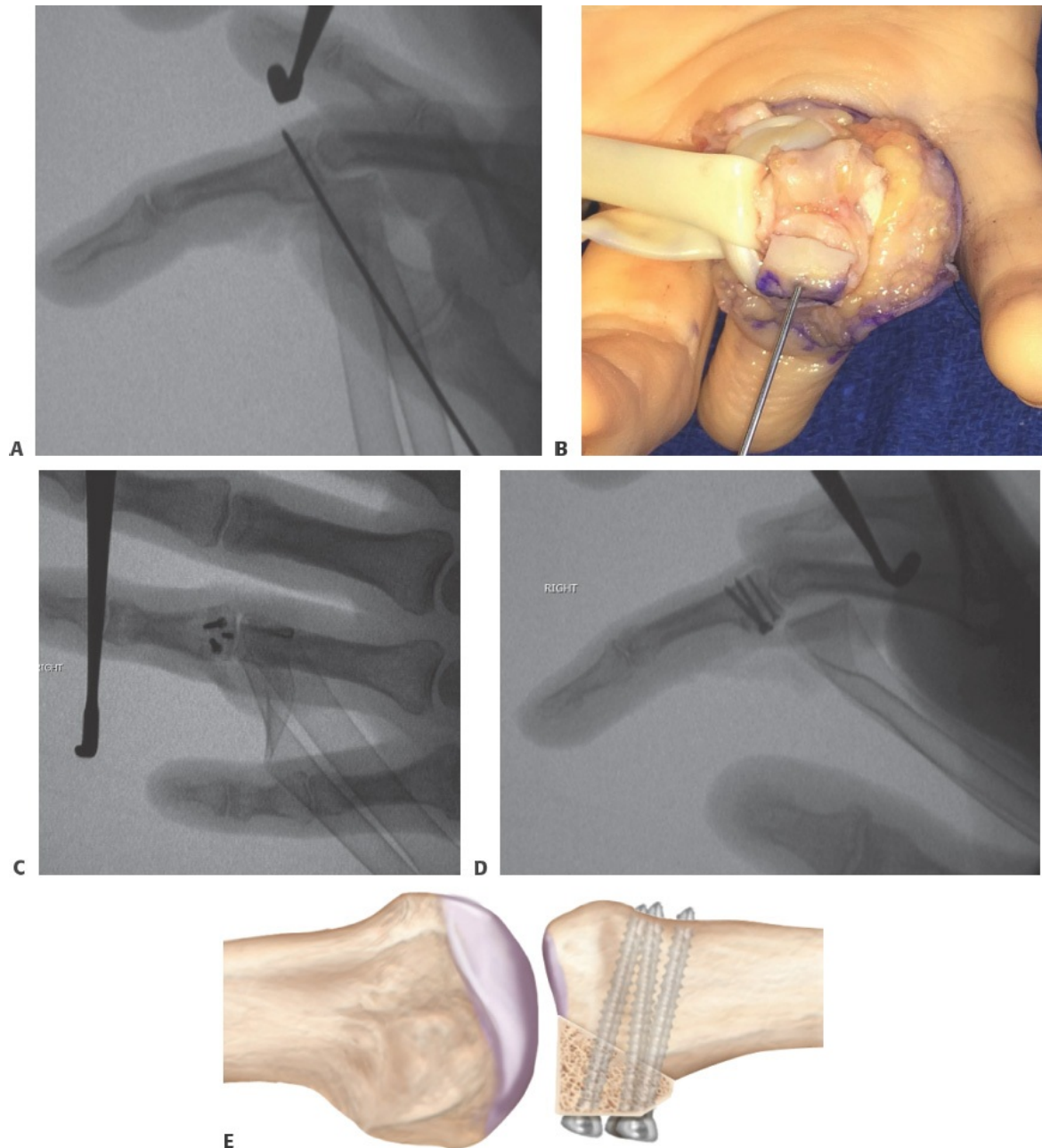


TECH FIG 3 • A. The donor site between the base of the fourth and fifth metacarpal and the dorsal aspect of the hamate can be exposed via either a longitudinal or transverse incision. The graft can be visualized after careful subperiosteal elevation. **B.** The coronal cut of the autograft harvest. To ensure adequate thickness of the autograft using the antegrade approach, a small slice of bone is removed just

proximal to the axial plane cut (indicated in *pink*). **C–E.** This extra bone excision will provide room for the curved osteotome to obtain the correct depth of coronal plane cut.

■ Hamate Graft Fixation and Closure

- Provisionally fix the graft to the middle phalanx using a central 0.028-in. or 0.035-in. K-wire in a volar to dorsal direction (**TECH FIG 4A**).
- If the visual contour of the graft is satisfactory, use two 0.035-in. K-wires to secure both the radial or ulnar aspects of the graft to prevent any rotation (**TECH FIG 4B**).
- If 1.3-mm screws are used, there is no need to redrill, and the 0.035-in. K-wires may simply be replaced with screws.
- Depending on the size of the graft, a combination of two or three 1.0-, 1.3-, or 1.5-mm screws may be used (**TECH FIG 4C,D**).
- Visually verify the concavity of the articular surface, and fluoroscopically verify screw lengths and overall graft positioning. Ideally, screws will be bicortical such that no more than 1 thread length is visible beyond the dorsal cortex to avoid prominence of the screw tips dorsally (**TECH FIG 4E**).
 - Because of the discrepancy of cartilage thickness, a bony step-off visualized on fluoroscopy is not unusual despite visual confirmation of articular congruency; this may be ignored.
- If there is any prominence along the volar cortical surface, the graft may be contoured to match the volar cortex of the middle phalanx using a bur or a rongeur.
- Reattach the volar plate distally, and the flexor tendon sheath flap maybe placed underneath the flexor tendons as an additional layer.



TECH FIG 4 • **A.** Provisional fixation of the hemihamate graft with a 0.035-in. K-wire. This K-wire hole can later be used for one of the screw holes if appropriately positioned. **B.** Using a shotgun approach, the surgeon can align the articular contour between the donor hemihamate graft and the remaining articular surface of the recipient dorsal phalangeal base. Because of slight mismatch in the

width of the articular cartilage of the hemihamate graft and the phalangeal base, which may appear as a step-off on a radiograph or fluoroscopic image, it is more important to visually align the contour of the graft than it is to align the fluoroscopic contour of the underlying subchondral bone. **C.** AP intraoperative fluoroscopic view of final fixation of the hemihamate graft with one 1.0-mm and two 1.3-mm bicortical screws to form an inverted triangle demonstrates correction of preoperative ulnar deviation and good medial to lateral size match of the graft with the native middle phalanx. **D.** Lateral fluoroscopic view shows restoration of PIP joint stability. **E.** Screw fixation of the graft should ideally be bicortical but without more than one thread length of the screws beyond the dorsal cortex of the middle phalanx to avoid dorsal prominence.

PEARLS AND PITFALLS

Autograft contour

- Reconstructing the proper concavity of the articular surface of the base of the proximal phalanx is crucial. Cancellous autograft may be used distally to aid in tilting the graft to create a more concave articular surface.

Hamate autograft anatomy

- The central ridge separating the ring and small finger metacarpal facets on the hamate may not be purely perpendicular to the dorsal surface.
- There are two methods to ensure graft harvest does not result in asymmetry:
 - Be sure to pronate the hand as much as possible such that the central ridge is as perpendicular to the floor as possible. This will help guide your cuts.
 - Fluoroscopy can help verify that the hamate ridge is indeed

	positioned perpendicular to the cut you make. ■ If you do an antegrade osteotomy, first use the saw to remove a very small section of hamate proximal to the graft so that you can harvest a deep enough graft with a curved osteotome when making your final cut in the coronal plane.
Hamate autograft coronal cut	■ The last cut, or the coronal plane cut, of the hamate autograft is the cut that determines the amount of volar-dorsal articular surface harvested.
Radioulnar asymmetry	■ A CT scan may be helpful in determining radioulnar asymmetry of the fracture fragment. When preparing the proximal phalanx, <i>keeping</i> this asymmetry can be helpful, as the hamate autograft may also be asymmetric.
Checking for passive motion	■ After the proximal phalanx recipient site is prepared, make sure passive ROM of the reduced PIP joint is full. If necessary, an extensor tenolysis or joint contracture release should be performed. ■ If this passive motion is not checked until after the autograft is secured, a joint contracture could lead to undue force on the graft and risk graft fixation failure.
C-arm fluoroscopy positioning	■ Obtaining a lateral radiograph of the PIP joint is critical for evaluating the reconstructed joint bony anatomy. Using a C-arm from the end of the hand table in the horizontal position facilitates manipulation and imaging. ■ The shoulder is abducted to 90 degrees, and the elbow is flexed at 90 degrees. With the XR beam horizontal to the floor, the forearm may be easily pronated and supinated until a perfect lateral of the PIP joint is obtained. ■ If a lead hand is used, the other fingers may be fully extended and the shotgunned surgical finger flexed at the MP joint. ■ Alternatively, an elastic bandage may be used to hold all the nonoperative fingers flexed in a fist with the shotgunned surgical finger extended at the MP joint.
Proximal phalanx preparation	■ In order to reconstruct the concavity of the articular surface, it is important to prepare the proximal phalanx such that the graft will be tilted to recreate the cup shape of the volar lip. ■ Creating a slope, rather than a right angle, from the articular surface down to the volar cortex will help with this.
Collateral ligaments	■ The collateral ligament may be repaired to the volar plate for soft tissue coverage and a gliding surface over the bone graft for the flexor tendons.

Postoperative splinting

- A dorsal blocking splint may be used in about 20 degrees of PIP flexion as described in previous published reports, although they may be placed in closer to full extension if the reconstruction leads to a stable joint.

Graft disasters

- Should the graft that was obtained from the ipsilateral hamate be catastrophically contaminated or dropped, consider using the contralateral hamate.

POSTOPERATIVE CARE

- Authors have described various postoperative immobilization protocols including:
 - Use of a 15-degree dorsal blocking splint to protect volar plate repair and avoid postoperative instability⁸
 - Alternately, initial immobilization of the wrist and digit in extension for 3 or 4 days followed by a thermoplast extension splint to avoid a flexion contracture¹¹
 - We prefer to utilize a wrist-based (to protect the hamate graft harvest site) intrinsic-plus splint to include the affected finger and border digits for 1 week until sutures are removed. We then transition to a 15-degree dorsal blocking digital splint vs figure-eight splint initiating active wrist and digital range of motion under the supervision of a hand therapist 1 week after surgery with a home exercise program focusing on active range of motion techniques out of the splint.
- Protective splints are generally discontinued at 6 weeks, followed by initiation of passive range of motion.
- Full unprotected use for heavy lifting and sports is not allowed until bony union is verified by radiographs and clinical exam, which is anticipated at 3 to 4 months.

OUTCOMES

- A prior cadaveric study comparing the biomechanical characteristics of hemihamate arthroplasty vs volar plate arthroplasty found that although both techniques could adequately restore PIP joint stability, use of volar plate arthroplasty led to an increasing flexion contracture as the middle phalanx palmar base deficit increased.¹²
- Williams and coauthors followed 13 consecutive patients with unstable dorsal PIP fracture dislocations treated with hemihamate autograft for 16 months.¹³

On average, 60% of the articular surface was involved on lateral radiographs. Average arc of motion of the PIP joint postoperatively was 85 degrees, VAS pain score was 1.3, grip strength averaged 80% of the contralateral side, and eleven patients were very satisfied with their function.

- Calfee et al. reported on a cohort of 33 patients with a combination of acute and chronic injuries with 4.5-year follow-up.⁸ The average arc of postoperative PIP joint motion was 70 degrees, VAS score rating was 1.4, and grip strength averaged 95% of the contralateral grip strength. Outcomes were modestly better in injuries treated acutely (within 6 weeks of injury) compared to chronic injuries (injuries treated 6 weeks or later from injury).
- Afendras and coauthors reviewed the clinical outcomes of eight consecutive patients who underwent hemihamate arthroplasty at a minimum follow-up of 4 years.¹⁴ The average arc of motion was 67 degrees at the PIP joint, and the VAS rating was 10 (on a 100-point scale), with 91% grip strength compared to the uninjured side.

COMPLICATIONS

- Williams and coauthors reported two patients with recurrent dorsal subluxation out of a total 13 consecutive patients.¹³ The authors postulated the subluxation was due to failure of the volar plate repair and inadequate angulation of the graft such that the articular concave geometry was not sufficiently recreated.
- Others have suggested that adequate restoration of the middle phalangeal base provides sufficient osseous stability to prevent such subluxation and that extension block pinning and formal volar plate repair are rarely needed.^{8,15}
- Two series with long-term follow-up found no instances of subluxation or dislocation.^{8,14}
- One series reported intraoperative fracture of the dorsal cortex of the middle phalanx as a possible complication.⁸
- Flexor tendon pulley insufficiency is another reported complication if the critical A2 or A4 pulley systems that are repaired at the conclusion of the case become incompetent.⁸
- PIP joint flexion contracture has been reported and may potentially be avoided by adherence to a closely supervised postoperative hand therapy protocol.⁸
- Donor site pain in the wrist is an infrequent complication reported in 5% of cases,¹⁵ and cadaveric studies have shown minimal evidence of instability of the fourth or fifth carpometacarpal joints following graft harvest.⁶

- Previous series have shown that radiographic signs of degenerative joint disease of the PIP joint have occurred in close to 50% of cases with long-term follow-up, but this has been observed in the absence of pain or other symptoms with no correlation between loss of joint space and functional outcomes.⁸
- In the patient series by Afendras, two of eight patients developed severe symptomatic arthritis, and two of eight developed mild degenerative changes.¹⁴ The authors speculated that this may be due to nonanatomical mismatch of the joint surface and consequent abnormal load bearing, biologic failure of the graft, or chondral damage from the initial injury.

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13 Thumb Carpometacarpal Joint Fusion With Locking Plates

CHAPTER

John M. Felder and Amy M. Moore

DEFINITION

- Arthritis of the thumb trapeziometacarpal (TMC) joint is common and leads to weakness, deformity, limitation of motion, and pain, particularly with pinch.
- Fusion of the TMC joint produces reliable relief of arthritic pain and a stable position of the thumb for pinch.
- Adequate postoperative thumb motion is maintained through movement at the thumb metacarpophalangeal (MCP) and scaphotrapezial joints.

ANATOMY

- The articular surface of the trapezium with the thumb metacarpal is saddle shaped, permitting a wide range of motion and palmar abduction (abduction perpendicular to the plane of the palm).
- The capsule of the TMC joint must be sufficiently lax to allow the wide range of motion of the thumb but contains key stout ligaments, such as the volar oblique and dorsoradial ligaments, that are critical for joint stability. Attenuation of these ligaments leads to joint incongruity and arthritis.

PATHOGENESIS

- In typical TMC joint osteoarthritis, progressive ligamentous laxity, intrinsic osseous instability, overuse patterns, and articular wear may all contribute to subluxation of the thumb metacarpal from the trapezium with resultant incongruous articulation, cartilage loss, and osteoarthritis.
- TMC joint arthritis may also result from prior fracture of the thumb metacarpal base or trapezium, typically in younger men.

- Fusion of the thumb TMC joint may also be desirable as an alternative to opponensplasty for positioning of the thumb in nerve palsies or brachial plexus injuries affecting thumb opposition.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Any history of nontraumatic radial-sided hand pain, particularly pain localizing to the base of the thumb, may suggest TMC joint arthritis.
- Classically, this disease is most commonly encountered in postmenopausal women.
- Physical examination begins with inspection, which may show enlargement of the thumb TMC joint and prominence of the joint due to subluxation of the base of the metacarpal.
- In advanced disease, metacarpal adduction due to TMC joint subluxation may lead to compensatory hyperextension of the MCP joint, creating the so-called zigzag deformity.
- Maneuvers to elicit joint crepitus or tenderness at the joint include the grind test, palpation of the joint, and the thumb adduction or extension tests (and related tests),¹ which create sheer stress across the joint.
- The CMC grind test is performed by applying an axially directed loading force to the thumb metacarpal and circumducting the thumb. Crepitus or reproduction of pain is considered a positive result.
- For the adduction stress maneuver, the examiner is seated facing the patient. The patient places the affected hand on the examination table with the elbow flexed 90 degrees and the forearm in neutral rotation. The examiner places his or her ipsilateral hand such that the examiner's thumb rests dorsally over the head of the thumb metacarpal. The examiner's contralateral hand supports the ulnar side of the patient's hand to maintain the patient's wrist in neutral position to prevent ulnar deviation of the patient's wrist. The examiner firmly directs an adduction force downward onto the patient's metacarpal head until the patient's thumb metacarpal lies parallel to the midaxis of the index metacarpal or until a firm end point is reached. The re-creation of pain at the TMC joint is considered a positive test.
- The thumb extension test is performed from the same starting position. The examiner places his or her ipsilateral thumb along the radial aspect of the distal thumb metacarpal, 5 to 10 mm proximal to the thumb MCP joint, and extends the thumb until the thumb metacarpal comes to lie in a plane parallel to the palm or until a firm end point is reached. Re-creation of pain at the

TMC joint is considered a positive test.

IMAGING

- Standard PA, lateral, oblique, and Roberts view radiographs of the hand should be obtained. Roberts view of the thumb profiles the articular surface of the thumb TMC joint and provides optimal visualization of the thumb CMC joint. This view requires position of the forearm in maximal pronation with the dorsum of the thumb resting on the film cassette.
- Radiographic staging of thumb TMC joint arthritis² distinguishes between the following:
 - Stage I: Normal radiographs or TMC joint widening with symptomatic pain and laxity
 - Stage II: Mild joint space narrowing, osteophyte formation less than 2 mm
 - Stage III: Significant joint space narrowing or total loss of joint space, osteophyte formation more than 2 mm
 - Stage IV: Stage III also including scaphotrapezotrapezoid (STT) joint arthritis
- Note that this staging system is useful for description of radiographic findings but is not used for prognosis or to guide treatment. Rather, clinical symptoms (eg, pain) direct treatment.

DIFFERENTIAL DIAGNOSIS

- First dorsal compartment (de Quervain) tenosynovitis
- Carpal tunnel syndrome
- Fracture
- STT joint arthritis
- Rheumatoid arthritis

NONOPERATIVE MANAGEMENT

- In the case of the TMC joint osteoarthritis, nonoperative management should always be attempted and consists of hand-based thumb spica splinting, nonsteroidal anti-inflammatory medications, and intra-articular steroid injections.
- In the case of nerve palsy requiring arthrodesis for thumb pinch stability, nonoperative management is not indicated and TMC joint fusion may be elected as a planned part of the reconstructive algorithm.³
- In either case, the patient's tolerance for joint fusion should be tested

preoperatively with a period of immobilization of the TMC joint by rigid splinting before proceeding with arthrodesis.

SURGICAL MANAGEMENT

- Pain interfering with daily activities despite a period of nonoperative management and lack of ability to stabilize the thumb in space for opposition are indications for TMC joint fusion.
- For painful TMC joint osteoarthritis, resection and/or interposition arthroplasty is a reasonable alternative to fusion with similar outcomes.
- Many authors favor TMC joint fusion for younger, higher-demand patients who require greater pinch strength and arthroplasty for older, less active patients.^{4,5}
- Because TMC joint arthroplasty with resection of the trapezium requires a prolonged period of postoperative splinting and therapy and may weaken the thumb for up to 6 months postoperatively, our preference is to perform TMC joint fusion for manual laborers who require a rapid return to work and hand strength.

Preoperative Planning

- Preoperatively, the patient must understand the implications of joint fusion on mobility; this is best demonstrated with a period of preoperative splinting.
- The thumb MCP joint should be assessed for stability prior to proceeding with TMC joint fusion. An unstable MCP joint will preclude stable pinch and, if arthrodesis of the MP joint is required for stability, this in combination with TMC arthrodesis may restrict thumb mobility so greatly as to interfere with thumb function.
- Radiographs should be assessed for osteopenia and be recognized when proceeding with the bony fixation required for arthrodesis. Disuse osteopenia is found with paralytic limbs.
- Radiographs should also be assessed for degenerative changes in adjacent joints such as the STT joint. Severe STT arthritis is a relative contraindication for CMC arthrodesis.⁵
- Surgery may be performed under general, local, or regional anesthesia. We prefer general anesthesia supplemented by local or regional blocks.
- Bone grafting is recommended for successful fusion; bone graft is taken from the distal radius or iliac crest in case of suboptimal contact between prepared bony surfaces.

- Fluoroscopy should be available.
- Power tools and a hand fixation set with locking plates should be requested for this case. We prefer the use of rigid locking plate fixation to traditional plates and K-wires in this procedure as often the bone is of poor quality. Locking plates provide inherent stability for bony fusion.

Positioning

- The patient is positioned supine on the operating room table, with the hand centered on a hand table.
- An upper arm tourniquet and exsanguination should be used for better visualization of neurovascular structures in the field, such as the radial artery and branches of the radial sensory nerve.

Approach

- A volar approach, a modified Wagner approach, or a dorsoradial approach to the TMC joint can be used.
- We prefer the dorsal approach, which requires identification and protection of the radial sensory nerve branches and radial artery but offers better visualization of the joint space and metacarpal, particularly if plate fixation is planned.

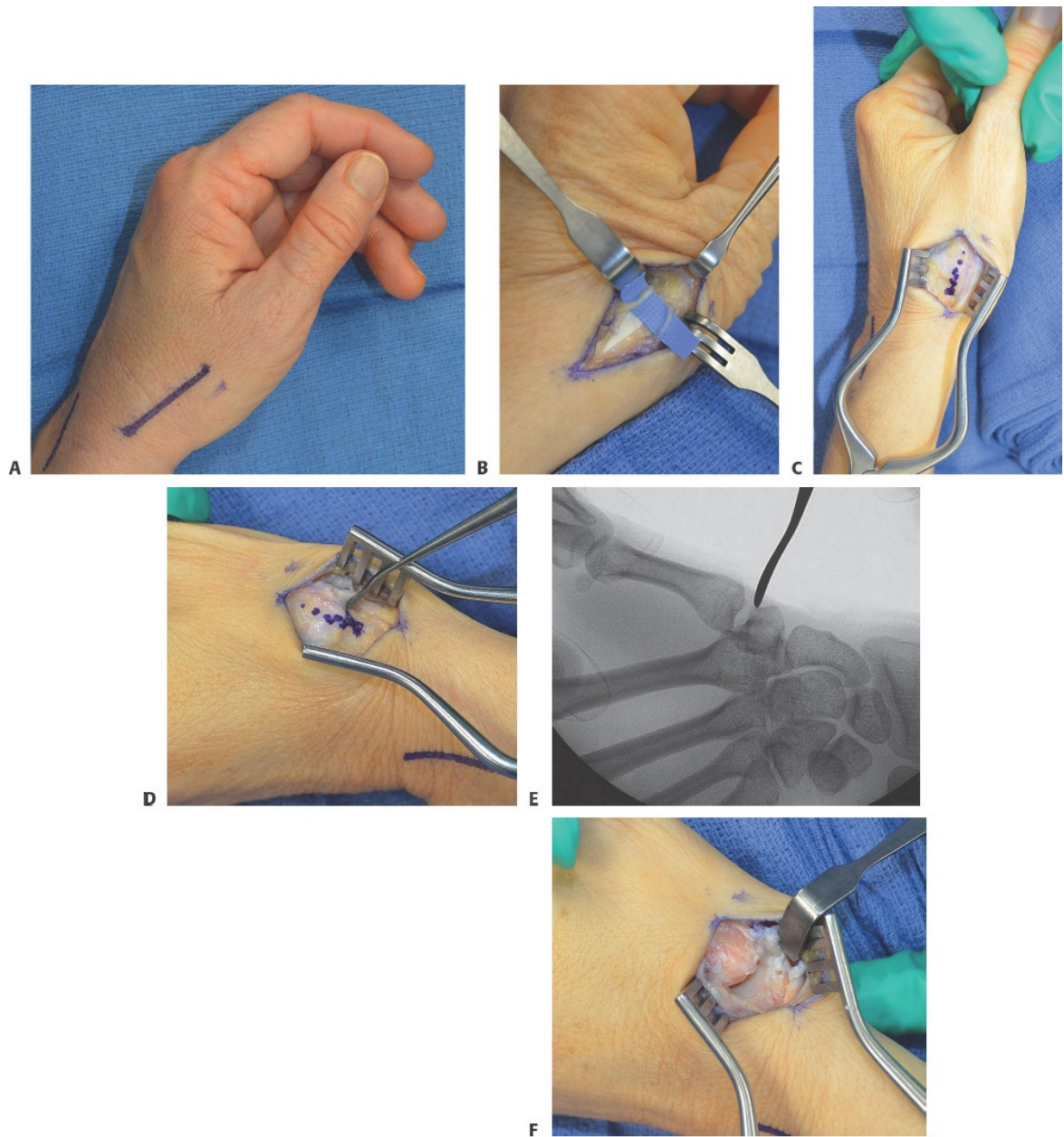
TECHNIQUES

■ Dorsoradial Approach to Thumb TMC Joint Arthrodesis with Plate and Screw Fixation

Exposure

- A longitudinal incision is made from the midpoint of the dorsal surface of the thumb metacarpal to the proximal aspect of the radial styloid (**TECH FIG 1**).
- Superficial branches of the lateral antebrachial cutaneous (LABC) nerve and radial sensory nerve (RSN) are identified and protected (**TECH FIG 1B**).
- The abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons are identified, and the interval between them is opened to create access to the joint (**TECH FIG 1C**).

- The radial artery is protected within the proximal field of dissection.
- The TMC joint capsule is identified in the depths between the APL and EPB tendons. At this point, it is useful to insert a Freer elevator at the presumed TMC joint space (**TECH FIG 1D**) and use fluoroscopy to verify correct position (**TECH FIG 1E**).



TECH FIG 1 • A. Incision is marked between midpoint of thumb metacarpal and radial styloid. **B.** The branches of the radial sensory and lateral antebrachial cutaneous nerves are identified and protected. **C.** The abductor pollicis longus and extensor pollicis brevis tendons are identified, and the interval between them is planned for exposure. **D.** A Freer elevator is used to identify the location of the TMC joint before making a

capsular incision. **E.** Fluoroscopy confirms the correct location of the joint. **F.** The capsule of the TMC joint is incised, and capsular tissue is circumferentially elevated from the thumb metacarpal and trapezium.

- A longitudinal incision is made full thickness through the capsule to elevate the capsule from the metacarpal and the trapezium. An attempt should be made to preserve the edges of the capsule neatly for later closure (**TECH FIG 1F**).
- Elevation of the capsule circumferentially from the metacarpal may cause detachment of the APL tendon insertion and it does not need to be reattached.

Fitting the Metacarpal Base to the Trapezium

- The thumb metacarpal base is delivered into the wound using two small Hohmann retractors.
- Using a rongeur or a slow-running bur, the metacarpal base is denuded of cartilage and subchondral bone, and the proximal medullary bone is fashioned into a ball or cone shape (**TECH FIG 2A,B**).



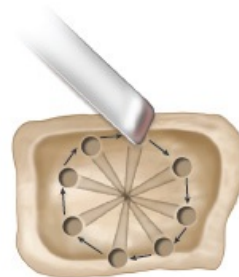
A



B



C



D



E

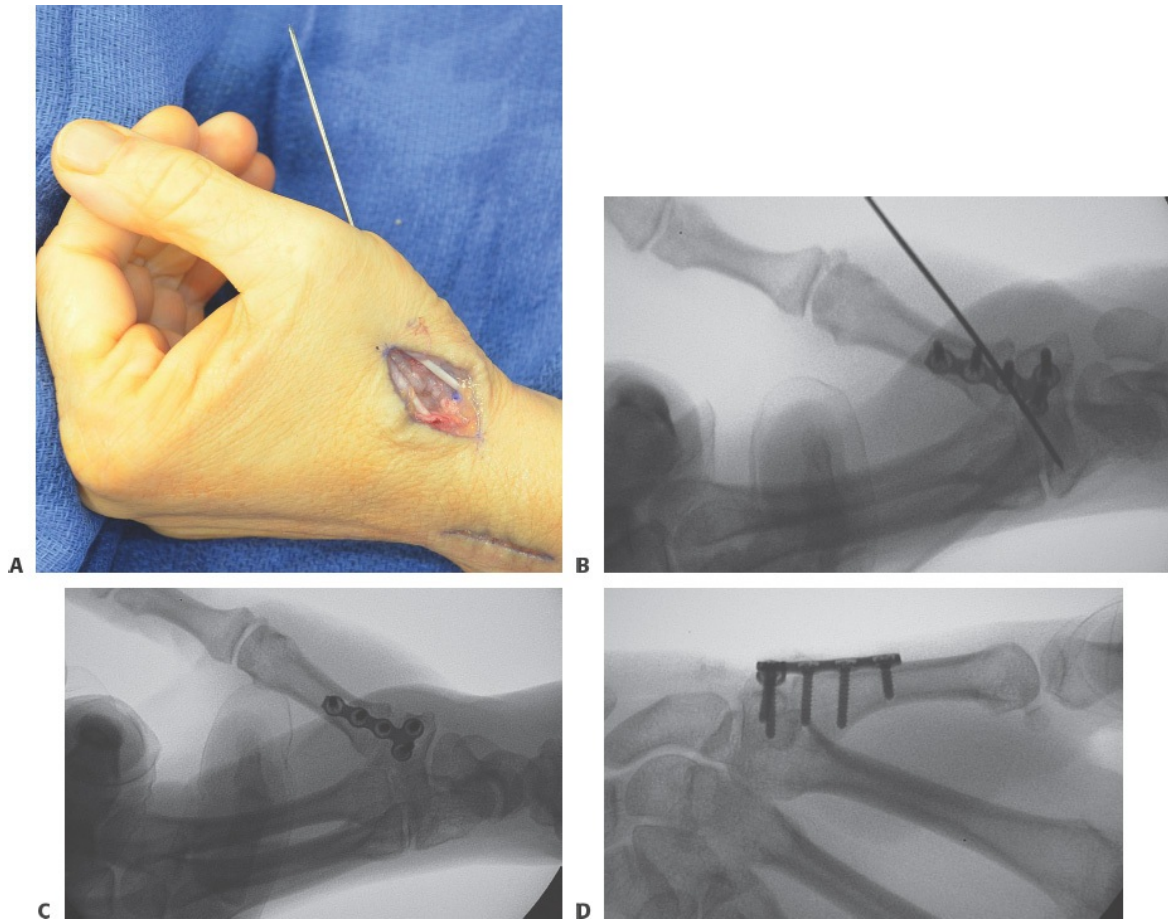
TECH FIG 2 • A. The metacarpal base is delivered into the wound, and a rongeur is used to fashion the medullary bone into a cone shape. **B.** Healthy cancellous bone is visualized. **C.** In preparing the trapezium surface, an option to allow for adequate bony contact is to use a K-wire to drill multiple holes into the trapezium at a 45-degree angle directed toward the center of the bone. **D.** A small osteotome is then used to excavate the central bone to allow the cone-shaped metacarpal base to fit into the trapezium. **E.** The metacarpal is fit onto the prepared surface of the trapezium.

- The articular surface of the trapezium is then removed and the medullary bone of the trapezium is fashioned into a cup shape to accommodate the cone of the metacarpal base. This can be done with a low-speed power bur or by using an awl.
- Another option is to use a K-wire to drill multiple holes angled at 45 degrees toward the center of the trapezium (**TECH FIG 2C**). The holes are drilled sequentially at 2- to 3-mm intervals to create a circle, and the circumscribed cone-shaped fragment is then excavated with a small straight osteotome (**TECH FIG 2D**).⁶
- Attention to detail is important when shaping the surface of the trapezium, as it may be a thin and degenerated bone with relatively little volume to allow for error. It is essential to be certain that the center of the “cone” has been denuded of cartilage or cortical bone and contains exposed medullary bone.
- The metacarpal is fit onto the prepared surface of the trapezium (**TECH FIG 2E**).

Positioning the Thumb and Fixation

- At this point, attention is turned to proper positioning of the thumb. Ideal position is approximately 45 degrees from the coronal and sagittal planes of the hand. Slight pronation of the thumb tip may assist with pinch to the more ulnar digits.

- Proper position is confirmed by seeing that the pulp of the thumb rests on the radial aspect of the index middle phalanx with the fingers in a relaxed, closed fist (**TECH FIG 3A**).
- Positioning should be secured using a K-wire for provisional fixation. This can initially be driven antegrade through the base of the thumb metacarpal toward the MCP joint and then reversed and driven retrograde to secure the base of the metacarpal to the trapezium.
- Once position is visually adequate, bony apposition is checked with fluoroscopy. Any areas of inadequate bony contact should be supplemented with cancellous bone autograft.
- Provisional K-wire fixation is maintained while placing a plate. Our preference is to use a locking 2.3-mm T-plate with the wings of the T placed over the trapezium and the long aspect of the plate extending onto the metacarpal shaft (**TECH FIG 3B**).
- Fluoroscopy should be used liberally to ensure that screws do not penetrate nearby joints (eg, STT) or the FPL tendon sheath. Once fixation is achieved, the K-wire is removed (**TECH FIG 3C,D**).



TECH FIG 3 • A. The thumb is positioned with it resting on the radial aspect of the index middle phalanx with fingers in gentle flexion. A K-wire is used to secure the position prior to plate fixation. **B–D.** A locking T-plate is used to maintain the position of the thumb, and multiple fluoroscopic images are obtained to evaluate the plate position, the contact of the bony surfaces, and the length of the screws to avoid unwanted penetration into the STT joint or flexor pollicis longus.

- The capsule of the TMC joint should ideally be closed with buried suture.
- Supplement general anesthesia with local anesthetic injection before skin closure.
- The skin is closed with horizontal mattress sutures. Take care to avoid

branches of the RSN during closure.

- The hand is dressed with short-arm thumb spica splint, leaving the IP joint free.

■ Dorsoradial Approach to Thumb TMC Joint Arthrodesis With K-Wire Fixation

- This procedure is identical to the above technique except that in place of a plate and screws, three 0.045-in. K-wires are used for fixation.
- This technique is most appropriate for patients with soft bone that will not accommodate a locking plate, such as patients with rheumatoid arthritis. We do not recommend use of K-wire fixation for fusion in patients with osteoarthritis.
- The first wire should follow the planned axis of bone fusion and may be driven using the antegrade (via the exposed TMC joint) followed by retrograde technique.
- The remaining two wires should be driven retrograde through the metacarpal into the trapezium at a divergence of 10 to 20 degrees from the axis of the first wire.
- Wires should not penetrate the STT joint.
- Pins are capped and left outside the skin for office removal at 6 to 8 weeks.
- Closure and dressings are as above.

PEARLS AND PITFALLS

Simulate fusion preoperatively

- Place the patient in a hand-based thumb spica splint for several weeks preoperatively to ensure the patient understands what postoperative motion and hand function will be like.

Preparation of the bone

- Careful preparation of the bone surfaces is essential for positioning and improved bony contact. This involves complete removal of articular cartilage and subchondral bone while maintaining the cup and cone formation of the joint.

Bone graft

- Be prepared to harvest bone graft if needed to ensure excellent

	bony contact between fused surfaces. Our preference is to augment the fusion site with distal radius bone graft.
Nerve branches	■ Take great care to avoid damage to branches of the radial sensory nerve to prevent postoperative pain syndromes.
Position	■ Discuss positioning of the thumb preoperatively with the patient. Ideal position can be estimated by placing the thumb pulp over the index middle phalanx with the fingers resting in a flexed position.

POSTOPERATIVE CARE

- The short-arm thumb spica splint placed in the operating room is maintained for 2 weeks.
- Sutures are removed at 2 weeks, and the patient is placed into a short-arm thumb spica cast.
- If plate fixation is used, the cast is removed at 4 to 6 weeks postoperatively.
- If Kirschner wire fixation is used, the cast and pins are removed at 8 weeks.
- After cast removal, patients are given a custom-fabricated, removable forearm-based thumb spica splint leaving the interphalangeal joint free until definitive signs of bony healing are seen on x-ray.
 - Typically, bony healing on x-ray appears between 12 and 14 weeks (**FIG 1A–C**).
 - A CT scan can be performed to confirm union at 8 to 10 weeks (**FIG 1D**).
- Range of motion is initiated after cast removal with the help of a certified hand therapist (**FIG 1E,F**).

OUTCOMES

- Functional outcomes are typically excellent following thumb TMC joint arthrodesis. Clinically, it may be difficult to tell the difference between the thumb operated upon and the normal thumb.⁶
- Patients and surgeons should expect the operation to relieve the pain of arthritis, improve grip, and restore good stability to the thumb ray.⁴
- With proper positioning of the TMC joint in arthrodesis, compensatory motion of the MCP and STT joints typically allows patients to adduct the thumb to touch the base of the proximal phalanx of the index finger and to oppose the thumb to the tips of all fingers.⁵
- Thumb retropulsion and abduction from the plane of the palm will be decreased when compared with the unoperated side but are adequate to allow

grasp around relatively large objects such as jar lids. Pinch strength is typically equal to the contralateral side.⁷



FIG 1 • Radiographs (**A–C**) and CT image (**D**) confirm healed arthrodesis at 10 weeks. **E,F**. Postoperative photos of patient with left thumb CMC locking plate arthrodesis.

COMPLICATIONS

- Nonunion is the most concerning complication and occurs at a reported rate of

13%.⁸ Nonunion can be minimized by ensuring excellent apposition of cancellous bony surfaces, using bone graft and careful fixation technique. Careful attention to shaping of the cup and cone surfaces and avoiding the use of high-speed, heat-generating power saws may also help to prevent nonunion. Rigid stabilization with plate and screws may shorten casting time, but definitive increased overall union rate over K-wire fixation has not been shown.⁵ Nonetheless, it is our preference to use locking plate fixation over K-wire fixation.

- Hardware-related pain or hardware prominence is a potential complication when using plate and screw fixation that may require return to the operating room.
- Hardware malposition (eg, within the STT joint) is a potential complication that is best avoided by intraoperative use of fluoroscopy in multiple planes.
- Radial nerve neuritis and complex regional pain syndrome are potential complications of this operation that are best avoided by careful identification and protection of nerve branches intraoperatively. However, the surgery should be approached with the knowledge that these complications may occur even despite careful surgical technique.
- Patients may complain of an inability to place the palm flat on a table or with difficulty in placing the hand in a pocket. These concerns are best addressed with thorough preoperative education and splinting.

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Section IV: Wrist Fractures and Carpal Instability

14 Arthroscopic Examination of the Wrist

CHAPTER

Emily Krauss and Amy M. Moore

DEFINITION

- Wrist arthroscopy is a diagnostic and therapeutic tool to evaluate radiocarpal, intercarpal, and carpal pathology. Wrist arthroscopy has been described using both wet (fluid infiltrate) and dry techniques. Treatment applications include arthroscopic surgical procedures and arthroscopic-assisted open procedures.

ANATOMY

- Standard wrist arthroscopy portals are dorsal due to the relative lack of neurovascular structures (**FIG 1**).
- Portals to assess the radiocarpal joint are named relative to their location between extensor tendons. Volar portals, if used to assess the radiocarpal joint, are placed to avoid the major neurovascular bundles. The midcarpal joint can be assessed either by the dorsal midcarpal portals or by the volar radial midcarpal portal. The volar portals are used in select situations to evaluate the dorsal ligaments and are not standard portals for most situations.
- Standard diagnostic arthroscopy ports are described in Table 1.¹
- Portals with special indications are listed in Table 2.¹

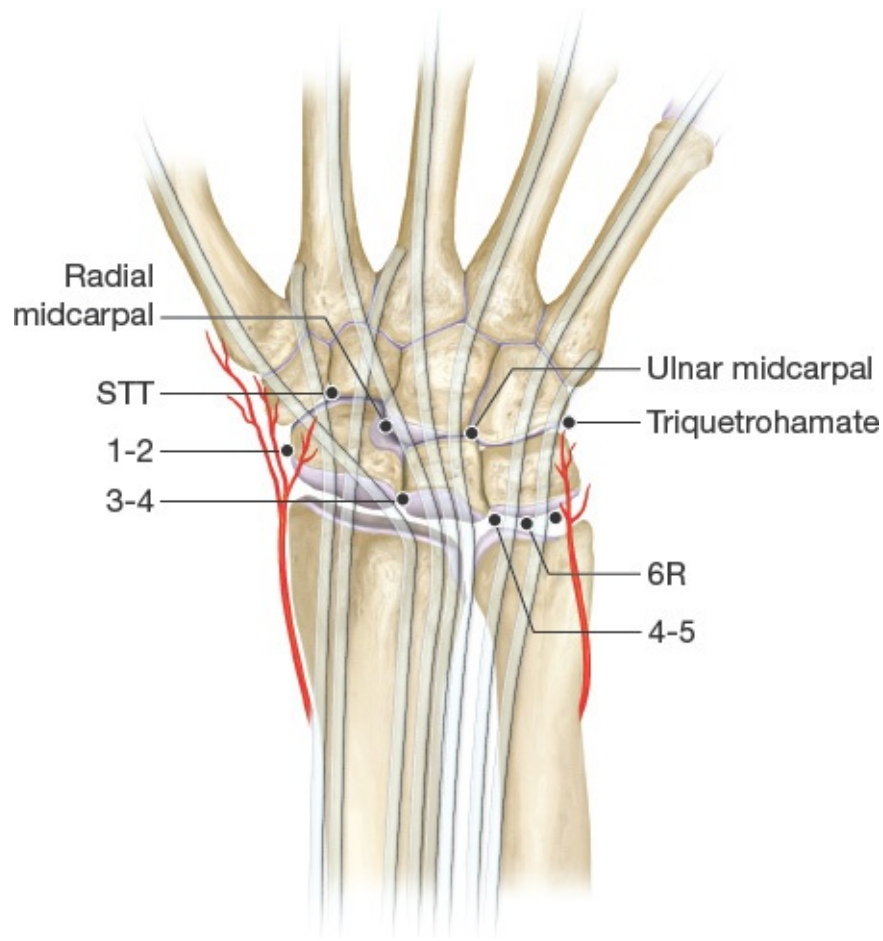


FIG 1 • Dorsal wrist arthroscopy portals.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Wrist arthroscopy is a diagnostic adjuvant to patient history and clinical examination.
- Patient evaluation is not complete without a thorough history of onset, aggravating and alleviating factors, history of trauma, occupational and repetitive motion history, and a complete history of interventions including injections, imaging, and surgical procedures.
- Physical examination should include an evaluation of wrist tenderness, tendinous pathology, carpal instability, distal radioulnar joint (DRUJ) pathology, and reproduction of symptoms with wrist loading. Details of a complete wrist physical examination are essential but beyond the scope of this chapter.

IMAGING

- Plain radiographs including posteroanterior, lateral, oblique, and clenched-fist views of the wrist may contribute to the differential diagnosis.
- A wrist arthrogram to test for triangular fibrocartilage complex (TFCC) tear can be unreliable in ulnar-sided wrist pain (sensitivity of 76%).²
- Wrist arthroscopy continues to be of value as a diagnostic tool in these cases. Arthroscopy is also useful in patients unable to obtain a 3T MRI or in patients suspicious for injury that could benefit from arthroscopic-assisted surgical intervention.

NONOPERATIVE MANAGEMENT

- Wrist arthroscopy is indicated as a diagnostic technique in patients with persistent wrist pain with no response to an appropriate trial of conservative management, including activity modification, splinting, nonsteroidal anti-inflammatories (NSAIDs), and cortisone injection.
- It may also be used as a diagnostic technique to stage the degree of injury (extent of ligament tear and articular wear) or pathology for further surgical planning.

SURGICAL MANAGEMENT

- Diagnostic indications:
 - Cartilage injuries
 - Chondromalacia
 - TFCC injury staging
 - Ligamentous instability (scapholunate interosseous ligament [SLIL] injury, lunotriquetral interosseous ligament [LTIL] injury)

Table 1 Standard Dorsal Wrist Arthroscopy Portals

Portal Name	Anatomic Landmarks	Purpose
1-2	Radial to EPL tendon at dorsum of snuff box	Inflow. Allows access to the radial styloid, scaphoid, lunate, and articular surface of the distal radius
3-4	Distal to Lister tubercle, between EPL and EDC tendons	Used as the main radiocarpal arthroscopic viewing portal

4-5	Distal to DRUJ. Follow ring finger metacarpal proximally, between EDC and EDM	Used as the main instrumentation portal for the radiocarpal joint; allows visualization of TFCC
6R	Radial (R) to ECU tendon	Instrumentation portal, visualize the TFCC and the ulnar wrist ligaments (ulnolunate, ulnotriquetral, and lunotriquetral)
6U	Ulnar (U) to ECU tendon	Outflow; allows access to dorsal rim of the TFCC or for instrumentation when debriding the volar LTIL
Radial midcarpal	In line with second metacarpal proximal to the capitate; identified by a depression between the capitate and scaphoid	Allows visualization of the scapholunate and lunotriquetral articulations, the STT joint, and the distal pole of the scaphoid
Ulnar midcarpal	In line with the 4th metacarpal, 1 cm distal to the 4-5 portal; identified by a depression at the lunotriquetral-capitate-hamate joint	Allows further visualization of the lunotriquetral articulation, distal lunate, and triquetral hamate articulation; used for instrumentation of the articulations

ECU, extensor carpi ulnaris; EDC, extensor digitorum communis; EDM, extensor digitorum minimi; EPL, extensor pollicis longus; DRUJ, distal radial ulnar joint; STT, scaphotrapeziotrapezoid joint; TFCC, triangular fibrocartilage complex.

- Wrist arthritis evaluation (intactness of lunate facet and midcarpal joint in

salvage procedure surgical decision-making)

- Kienbock disease diagnostic staging (using 3-4 portal only to preserve vascular pedicle for a 4-5 extensor compartment artery vascularized bone graft)

■ Treatment indications:

- Ganglion excision
- TFCC tear debridement or repair of foveal tears
- Resection of radial styloid (radial styloidectomy in impingement)
- Ulnar styloid excision
- Proximal hamate excision (proximal arthritis in type II lunate)
- Chondroplasty
- Arthroscopic-assisted fracture reduction
 - Distal radius fractures (comminuted or depressed articular fragments, evaluation of associated scapholunate ligament injuries)
 - Scaphoid fractures (using 4-5 portal for waist and proximal pole fractures)

Table 2 Special Indication Portals

Portal Name	Anatomic Landmarks	Purpose
Scaphotrapeziotrapezoid radial (STT-R)	In line with the index metacarpal just radial to the EPL at the level of the STT joint	Allows visualization and debridement of STT joint
Scaphotrapeziotrapezoid ulnar (STT-U)	In line with the index metacarpal just ulnar to the EPL at the level of the STT joint	Allows visualization and debridement of STT joint
Triquetrohamate	Ulnar to the ECU tendon at the level of the TH joint	Inflow/outflow. Allows visualization and debridement of the TH joint
Volar radial	Radial to the FCR tendon at the proximal wrist flexion crease, essentially through the floor of the FCR tendon sheath	Visualization of the DRCL and the volar aspect of the SLIL, visualization during DRUJ fracture reduction
Volar ulnar	Interval between flexor	Visualization of the

	tendons and flexor carpi ulnaris and the ulnar neurovascular bundle	dorsal radioulnar ligament and volar aspect of the lunotriquetral ligament. Aids in repair or debridement of dorsal TFCC tears
Volar DRUJ port	Accessed through same skin incision of the volar ulnar portal, but the capsular entry is 5 mm to 1 cm proximal to the ulnocarpal capsular entry point	Volar aspect of DRUJ

ECU, extensor carpi ulnaris; EPL, extensor pollicis longus; DRCL, dorsal radial carpal ligament; DRUJ, distal radial ulnar joint; FCR, flexor carpi radialis; SLIL, scapholunate intercarpal ligament; STT, scaphotrapeziotrapezoid joint; TFCC, triangular fibrocartilage complex; TH, triquetrohamate.

- Septic wrist (complete irrigation through radiocarpal and midcarpal portals)
- Dorsal wrist capsular release
- Volar wrist capsular release (standard dorsal portals such as 3-4 and 6R; protect radioscapophcapitate ligament to prevent ulnar translation of carpus, and volar neurovascular structures and tendons can be at risk during release)
- Contraindications:
 - Marked wrist swelling
 - Distortion of surface landmarks
 - Large capsular tears
 - Neurovascular compromise
 - Bleeding disorders
 - Infection
 - Specifically for dry wrist arthroscopy: using thermal probes, lasers, any heat-generating instrument

Preoperative Planning

- Equipment (**FIG 2A**)
 - 2.7-mm, 30-degree-angle scope with camera for the standard wrist arthroscopy and evaluation of the carpus

- 1.9-mm, 30-degree-angle scope with camera for the DRUJ
- Fiberoptic light source
- Video monitor, printer for intraoperative photos, or digital system for direct video recording
- Instrumentation:
 - 3-mm hook probe
 - Motorized shaver for debridement
 - Diathermy unit
- Ancillary equipment:
 - Motorized 2.9-mm bur for bony debridement or resection
 - Suture repair kits including TFCC repair kit or Tuohy needle for facilitating ligament repairs
- Equipment setup (**FIG 2B**)
 - Commercially available wrist arthroscopy traction tower
 - Above-elbow tourniquet
 - Shoulder holder
 - 5- to 10-lb sand bags or weights attached to arm sling for countertraction

Positioning

- The patient is positioned supine on the operating room table with the arm abducted at the shoulder and placed on an arm table.
- An above-elbow tourniquet is placed and the arm rested in a shoulder holder, with 5- to 10-lb weights attached to the arm sling (for countertraction).
- The arm is exsanguinated and the tourniquet insufflated prior to placing the fingers of the examination hand in the traction tower. Total traction force is generally 10 lb (4.5 kg).
- For use of dorsal arthroscopic examination portals, the surgeon sits at the patient's head facing the dorsum of the patient's wrist. For volar portals the surgeon sits over the patient's axilla (**FIG 3**).
- Ensure the arthroscopy camera is white-balanced and that the light source does not rest on the drape or the patient while turned on, as burns can occur.



FIG 2 • A. Arthroscopy equipment. *Top row from left to right:* 22-gauge needle with 5-cc syringe of normal saline, 15 blade scalpel, mosquito or tenotomy scissors, blunt cannula, scope introducer port, 2.7-mm 30-degree arthroscopy, 18-gauge Jelco needle, small arthroscopy shaver, shaver apparatus. *Bottom row from left to right:* 3-mm probe, straight foreign-body grasper. **B.** Intraoperative ConMed Linvatec TractionTower Extremity Traction Device setup with diagram.



FIG 3 • Patient positioning for left wrist arthroscopy. Above elbow sterile tourniquet, countertraction above-elbow straps, traction device with 10 lb of traction. Surgeon sits at patient head for dorsal approach.

Approach

Classic “Wet” Wrist Arthroscopy

- A structured approach to wrist arthroscopy is important for efficiency and good visualization.
- Portals are established by palpating surface anatomic landmarks, prior to inserting a 22-gauge needle into the joint space. If inserting into the 3-4 portal first, the needle should be inserted 10 degrees palmar to account for the volar inclination of the radius.
- The joint is then injected with 5 cc of saline and subsequent aspiration to confirm position within the wrist joint.
- Vertical or transverse (within natural wrist creases) shallow incisions are made

to avoid injury to dorsal sensory nerve branches, and a blunt mosquito or spreading tenotomy dissection is used to dissect the soft tissue down to the wrist capsule.

- The wrist capsule is then pierced (by holding the instrument like a dart) and a blunt trocar fitted with an inflow valve is inserted to introduce the scope cannula into the wrist.
- An 18-gauge angiocatheter can be placed in the 6U portal for sufficient outflow if wet technique performed.
- Structures that should be visualized in any standard arthroscopy include radius articular surface; the proximal scaphoid, lunate, and triquetrum; the SLIL both from radiocarpal and midcarpal; the LTIL both from radiocarpal and midcarpal; the radioscapophcapitate ligament; the ulnolunate (UL) ligament; the ulnotriquetral (UT) ligament; the articular disc of the TFCC; and the radial and peripheral TFCC attachments.
- Diagnostic wrist arthroscopy usually begins with the dorsal 3-4 portal to evaluate the volar ligaments. However, establishing dorsal portals first but beginning the examination using the volar radial portal to visualize the palmar SLIL and dorsal radiocarpal ligament (DRCL) can minimize iatrogenic trauma to the dorsal capsular structures and errors in diagnosis.
- A standard dorsal diagnostic arthroscopic examination uses primarily the 3-4 portal and combinations of the 4-5 portal and 6R to fully visualize the structures. From the 3-4 portal, visualization of the entire radiocarpal joint should be possible, using the 4-5 or 6R portals for probe insertion. 6U is primarily used for fluid outflow or for instrumentation for the palmar LTIL treatment.

Dry Wrist Arthroscopy

- Dry wrist arthroscopy is less commonly performed but has some theoretical advantages. However, with regard to safety with shaving or thermal procedures, we recommend the wet technique.
- Advantages:
 - Avoids fluid extravasation
 - Avoids risk of fluid-associated compartment syndrome
 - Less soft tissue swelling, capsular distention, possibly resulting in less postoperative pain
 - Larger portals and larger instruments
 - Larger portals facilitate more surgical procedures using arthroscopic

technique (eg, partial wrist fusion).³

TECHNIQUES

■ Diagnostic Arthroscopy

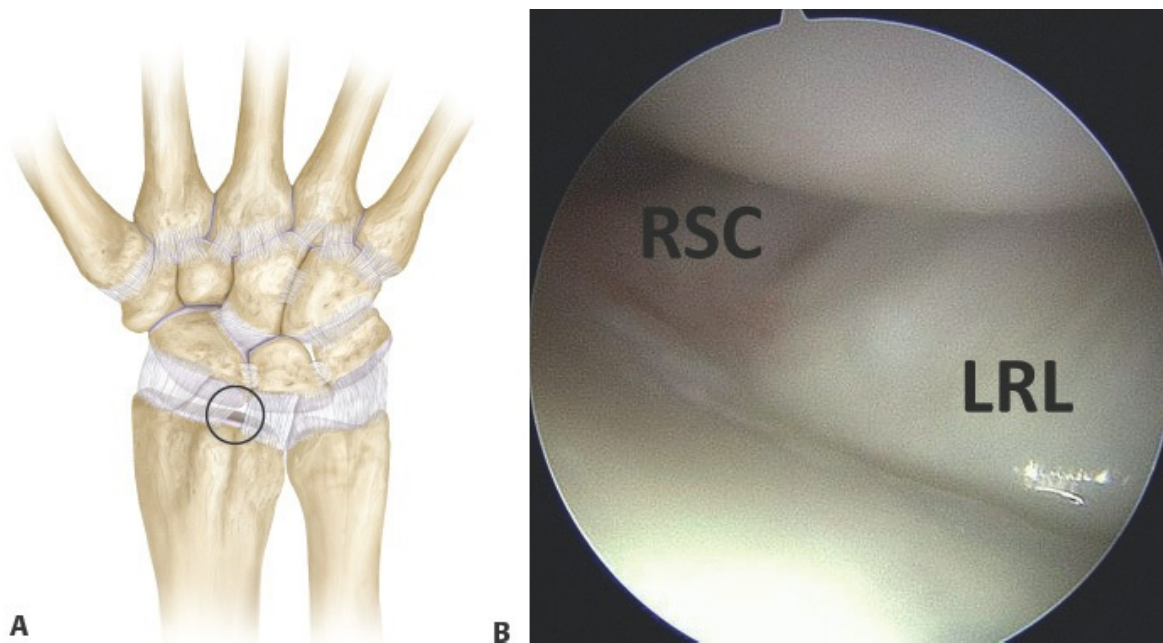
- Begin with the 3-4 portal distal to Lister tubercle between extensor pollicis longus (EPL) and extensor digitorum communis (EDC) tendons.
- After placement of a 22-gauge needle with a 10-degree volar tilt trajectory, inject and aspirate 5 cc of saline to confirm placement within the radiocarpal joint.
- Make a short superficial incision followed by blunt dissection using tenotomy scissors to the wrist capsule and bluntly puncture the dorsal wrist capsule. Gently insert the blunt trocar for the arthroscope (2.7-mm 30-degree angle).
- An 18-gauge angiocatheter can be inserted at the 6U portal for fluid drainage
- The 3-4 portal is a “workhorse” portal of wrist arthroscopy allowing a nearly panoramic examination of the radiocarpal joint.
- Throughout the arthroscopy, evaluation should include articular surfaces, synovitis, loose body identification and removal, and the integrity of wrist ligaments.

■ Radial Structures

- Begin radially to examine the articular surfaces of the distal radius, proximal scaphoid, and proximal lunate. The dorsal aspect of the scaphoid is also visualized. Some features of the DRC joint capsule are also seen radially.
- The radioscapophcapitate (RSC) ligament is seen originating from the tip of the radial styloid and passing distally anterior to the proximal pole of the scaphoid.
- Identify the interligamentous sulcus separating the RSC and the long radiolunate (LRL) ligaments as a landmark for orientation (**TECH FIG 1**). The LRL arises from the palmar rim of the distal radius and passes anterior to the proximal pole of the scaphoid.
- The short radiolunate ligament (SRL) is just ulnar to the LRL, seen as an

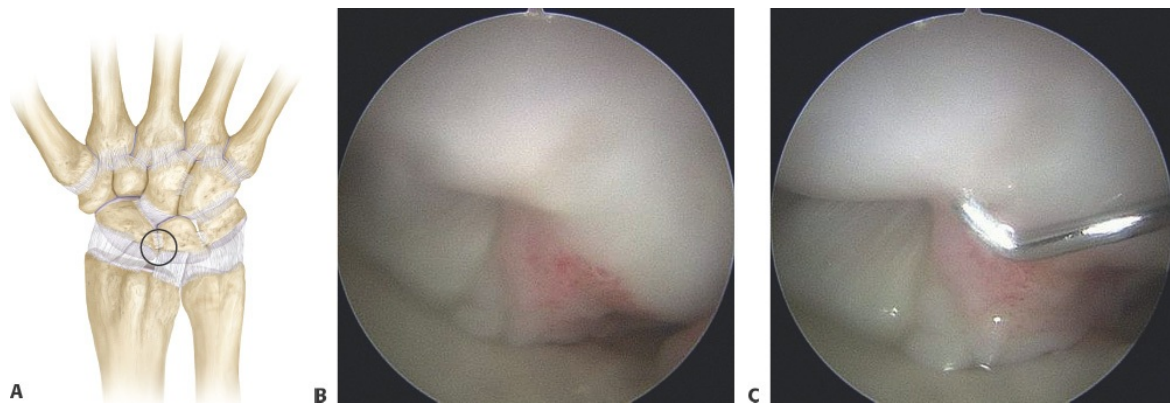
amorphous structure with surface blood vessels. The ligament passes vertically and integrates with the SL ligament in the proximal anterior third.

- The scapholunate ligament can then be seen covering the remaining proximal and distal aspects of the scapholunate joint and is fibrocartilaginous in this section. The ligament is frequently the same color and brightness as the articular surfaces and may be a concave or a convex bulge across the scapholunate joint. The SL ligament should be followed, by lowering the arthroscope parallel to the long axis of the forearm and turning the scope camera, as it courses dorsally to the reflected dorsal radiocarpal (DRC) ligament of the joint capsule. Note any signs of hemorrhage, synovitis, and attenuation (**TECH FIG 2**).
- Just ulnar to the SL ligament, the SRL ligament originates from the volar rim of the radius at the lunate fossa and forms the volar joint capsule, insetting on the proximal lunate. Ulnar and continuous with the SRL is the UL ligament. There may be a perceptible fold between the two ligaments.
- The DRC joint capsule may be visualized dorsally, generally after examination of the LT and TFCC. The DRC is normally generously lined with synovium in this region.
- Table 3 covers the 3-4 portal field of view.



TECH FIG 1 • A. Diagram of a right wrist from dorsal approach, with 3-4 portal view marked. Note the

radioscaphocapitate (*RSC*) ligament radially and the long radiolunate ligament (*LRL*) in the field of view. **B.** Radioscaphocapitate and long radiolunate ligaments as viewed intraoperatively from the 3-4 portal, scaphoid above.



TECH FIG 2 • A. Diagram of right wrist, dorsal arthroscopy, indicating arthroscopic view of the scapholunate (SL) ligament from radiocarpal joint using the 3-4 portal. **B.** Intraoperative view of synovitis of the SL ligament from the radiocarpal joint. **C.** SL ligament probed by 3-mm probe from radiocarpal joint.

Table 3 3-4 Portal Field of View

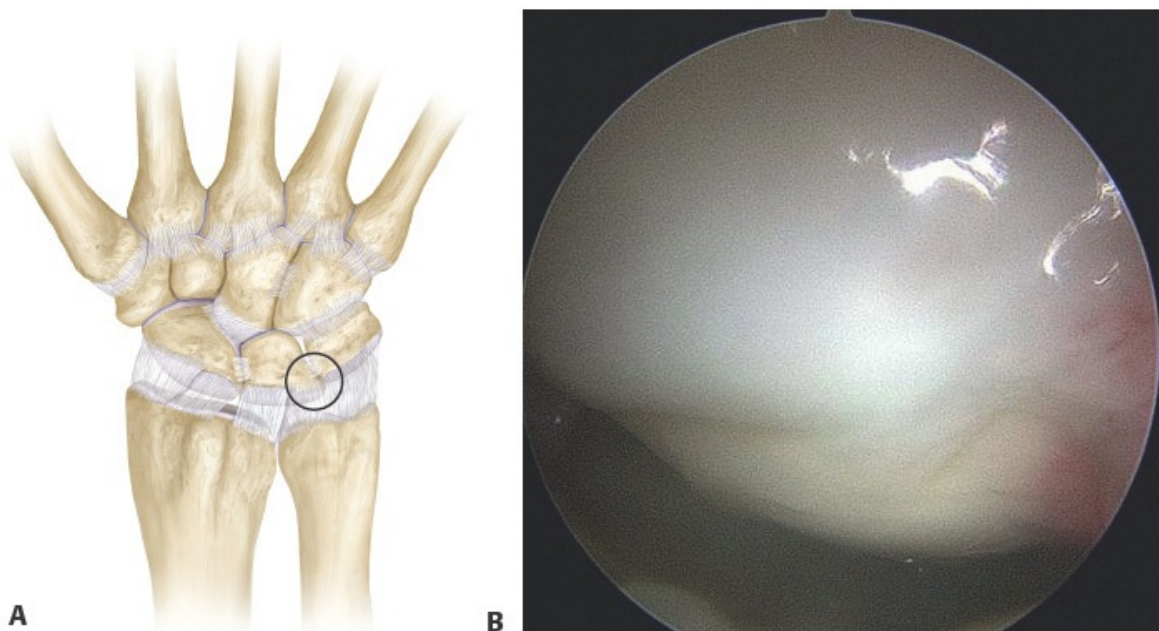
Surface Anatomic Landmark: Distal to Lister tubercle, between EPL and EDC

Portal Field of View

Portal Name	Radial	Central	Volar	Dorsal/Distal	Ulnar
3-4 Portal	Scaphoid and lunate fossa, volar rim of radius	Proximal scaphoid and lunate, dorsal and membranous SLIL	RSC, RSL, LRL, ULL	Oblique views of DRCL insertion onto dorsal SLIL	TFCC radial insertion, central disk, ulnar attachment, PRUL, DRUL, PTO,

■ Ulnar Structures

- A 4-5 portal can also be used to visualize the UL ligament and UT ligaments; however, in most patients, adequate examination can be accomplished by 3-4 portal plus a midcarpal arthroscopy.
- From the radiocarpal joint, immediately ulnar to the UL ligament is the UT ligament inserting on the volar edge of the triquetrum. The prestyloid recess can then be visualized at the junction between the UT and the palmar radioulnar (PRU) ligaments.
- Using the 4-5 portal, the pisotriquetral orifice can be visualized just anterior to the proximal articular surface of the triquetrum. Reposition the arthroscope to visualize the articular surface of the pisiform and the flexor carpi ulnaris (FCU) tendon passing through the orifice.
- Moving dorsally, the proximal region of the lunotriquetral ligament (LT) is localized by identifying the sulcus or concavity in the otherwise convex articular surfaces of the lunate and triquetrum (**TECH FIG 3**). Note any signs of hemorrhage, synovitis, or attenuation.
- Table 4 covers the 4-5 portal field of view.



TECH FIG 3 • A. Diagram of right wrist, dorsal

arthroscopy, indicating arthroscopic view of the lunotriquetral (LT) ligament from the radiocarpal joint using the 3-4 portal. **B.** Intraoperative view of the LT ligament from the radiocarpal joint.

Table 4 4-5 Portal Field of View

Surface Anatomic Landmark: Between EDC and EDM in Line with Ring Metacarpal, Slightly Proximal to the 3-4 Portal

Portal Field of View

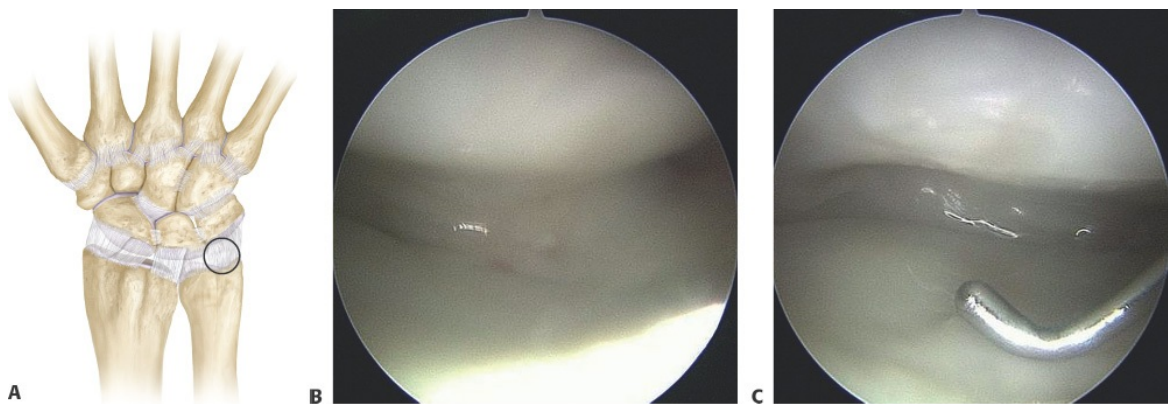
Portal Name	Radial	Central	Volar	Dorsal/Distal	Ulnar
4-5 Portal	Lunate fossa, volar rim of radius	Proximal lunate, triquetrum, dorsal and membranous LTIL	RSL, LRL, ULL	Poorly seen	TFCC radial insertion, central disk, ulnar attachment, PRUL, DRUL, PTO, PSR

■ TFCC Evaluation

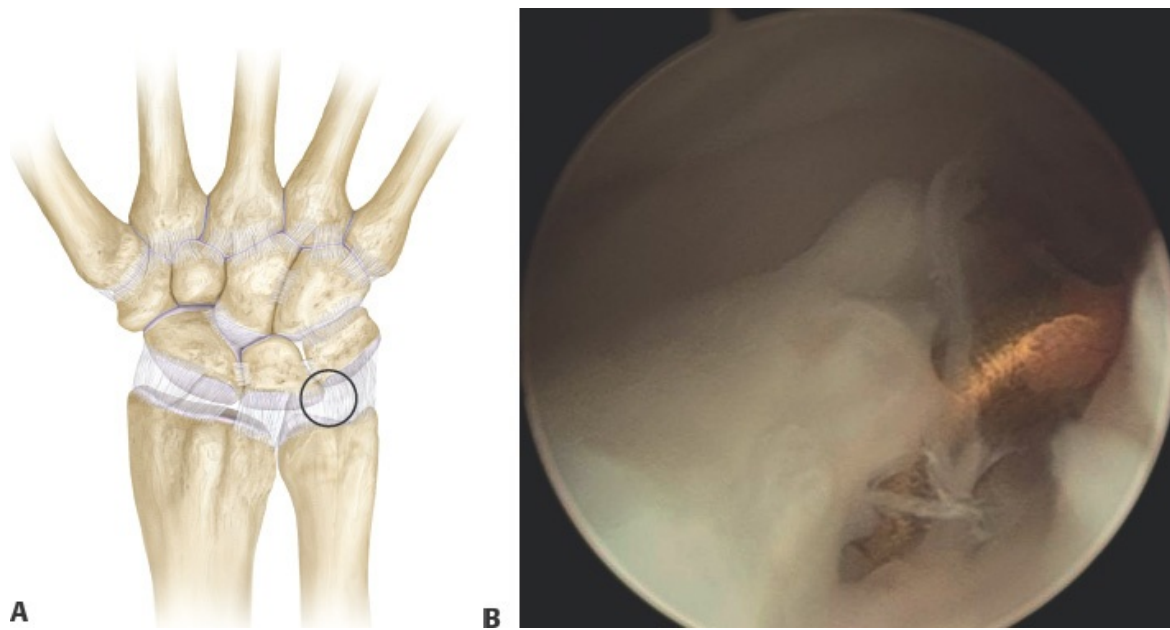
- From the 4-5 portal, the articular disc of the TFCC can be seen proximal, interposed between the dorsal radioulnar (DRU) and palmar radioulnar (PRU) ligaments. The articular disc is fibrocartilage and may be the same color and brightness at the articular surface of the lunate fossa (**TECH FIG 4A,B**).
- A 3-mm probe inserted from the 6R portal can be used to palpate the transition from the articular surface of the distal radius to the articular disc. The probe can be used to estimate the resting tension of the disc by pushing and releasing the probe pressure on the disc. Hypermobility of the articular disc is described as a trampoline sign (**TECH FIG 4C**).
- The dorsal radioulnar (DRU) and palmar radioulnar (PRU) ligaments should be identified as they converge toward their ulnar attachments.
- In patients with ulnar-sided wrist pain, it may be useful to use the volar ulnar portal to assess the palmar LTIL and dorsal radioulnar ligament and the

region of the extensor carpi ulnaris subsheath. This portal also allows for assessment of the radial TFCC attachment.

- TFCC tears can be arthroscopically classified according to Palmer's classification to guide conservative, arthroscopic, or open treatment (**TECH FIG 5**).⁴
- TFCC repair can be accomplished using instrumentation introduced through the 6U portal, although some authors advise open repair, particularly at the ulnar styloid, to avoid injury to the dorsal cutaneous branch of the ulnar nerve at the 6U portal.
- Table 5 covers 6R portal fields of view.



TECH FIG 4 • **A.** Diagram of right wrist, dorsal arthroscopy, indicating arthroscopic view of the triangular fibrocartilage complex (TFCC) using the 3-4 portal. **B.** Intraoperative view of the TFCC articular disc (*bottom*), fovea (*far center*), and lunate proximal articular surface above. **C.** Intraoperative arthroscopic view of a 3-mm probe, inserted through the 4-5 portal, testing an intact TFCC articular disc.



TECH FIG 5 • A. Radiograph demonstrating orientation of arthroscopic view. **B.** Intraoperative arthroscopic view of a 3-mm probe crossing a large peripheral Palmer class 1B TFCC tear.

Table 5 6R Portal Field of View

Surface Anatomic Landmark: Radial Side of ECU Tendon

Portal Field of View

Portal Name	Radial	Central	Volar	Dorsal/Distal	Ulnar
6R Portal	Poorly seen	Proximal lunate, triquetrum, dorsal and membranous LTIL	ULL, ULT	Poorly seen	TFCC radial insertion, central disk, ulnar attachment, PRUL, DRUL, PTO, PSR

■ Midcarpal Arthroscopy

STT Joint

- Midcarpal examination can be performed from either the radial or ulnar midcarpal port or occasionally the scaphotrapeziotrapezoid joint (STT) port.
- When using the radial midcarpal portal, orientation can be quickly established by recognizing the concave surfaces of the proximal row articular surfaces and the dramatically convex articular surface of the head of the capitate and pole of the hamate (**TECH FIG 6**).
- Identify the cleft at the proximal extent of the capitolunate joint.
- Reorient the scope to direct it distally into the dorsal aspect of the midcarpal joint over the STT joint. This is accomplished by dropping the scope into a line tangential to the plane of the forearm.
- Rotation of the arthroscope in this region will visualize the STT joint and the curvature of the distal articular surface of the scaphoid. A cleft can be visualized between the trapezium and trapezoid and the radial aspect of the STT ligament along the lateral aspect of the STT joint.
- Moving the arthroscope proximally from the STT joint, the scaphocapitate (SC) articulation comes into view. The SC joint is a “tight” joint, and transverse fibers of the SC ligament are sometimes seen but not always due to difficulty positioning the arthroscope.

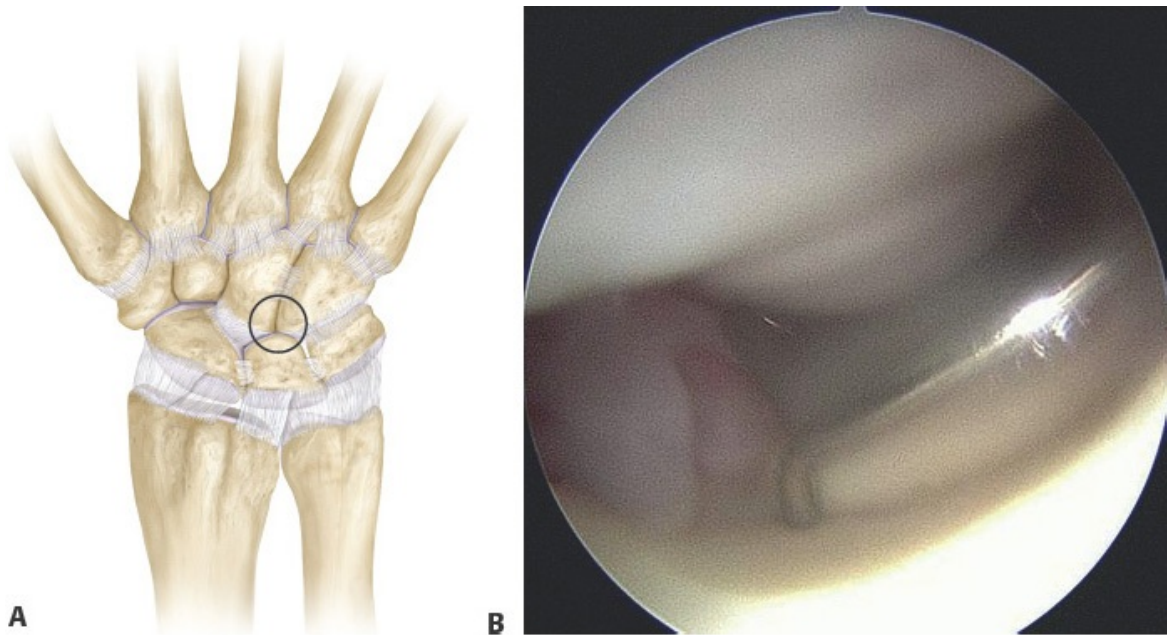
SL Joint

- As the arthroscope is continually drawn more proximally, the distal cleft of the SL joint is visualized. The SL joint should be visualized from at least two portals to change the orientation of view and prevent a false sense of a step-off.
- When visualizing the SL joint, take care to ensure that the arthroscope is not exerting pressure on either the scaphoid or lunate, forcing them out of alignment.
- The SL joint should be evaluated visually and by using a 3-mm probe according to the Geissler grading scale (**TECH FIG 7**).⁵
- Under normal conditions, it is difficult to pass an arthroscopic probe into the SL or LT joint and rotate it. When there is a SL ligament disruption, the scope can enter into the joint space; this is referred to as the “drive-through sign” (**TECH FIG 8**).
- From the midcarpal portals, the volar midcarpal joint capsule, with its generous synovial stratum, can be assessed, as well as the “space of Poirier” by palpating the volar capsule with the probe to detect a groove between the

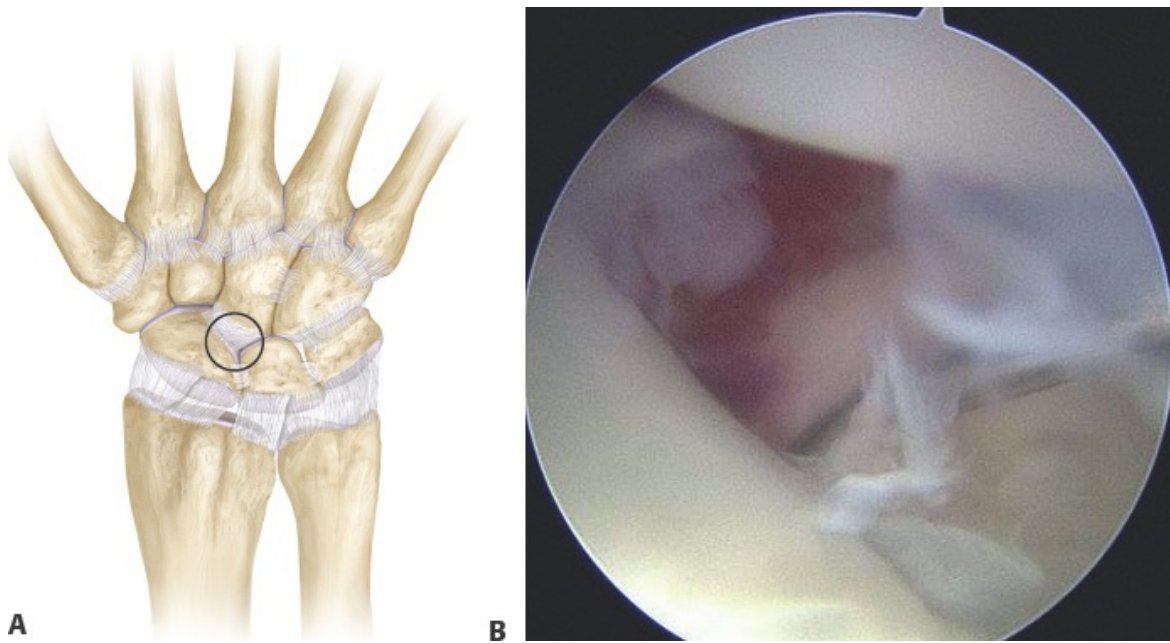
arcuate ligament (RSC and UC) and the lunate.

Ulnar Structures

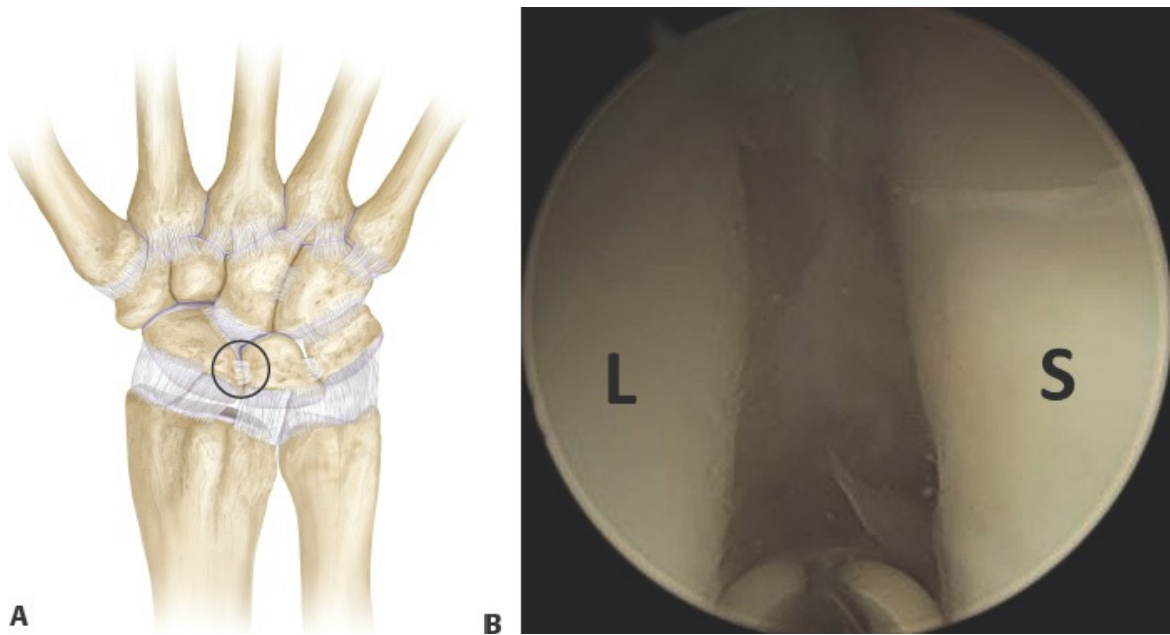
- A complete assessment of the midcarpal joint includes the ulnar structures. Moving the scope ulnarly, the distal articular surface of the lunate can be inspected as well as the LT joint cleft (**TECH FIG 9**).



TECH FIG 6 • **A.** Diagram of the right wrist, dorsal arthroscopy of the midcarpal joint from the radial midcarpal portal. **B.** Visualization of the capitolunate joint allows for orientation in the midcarpal joint.

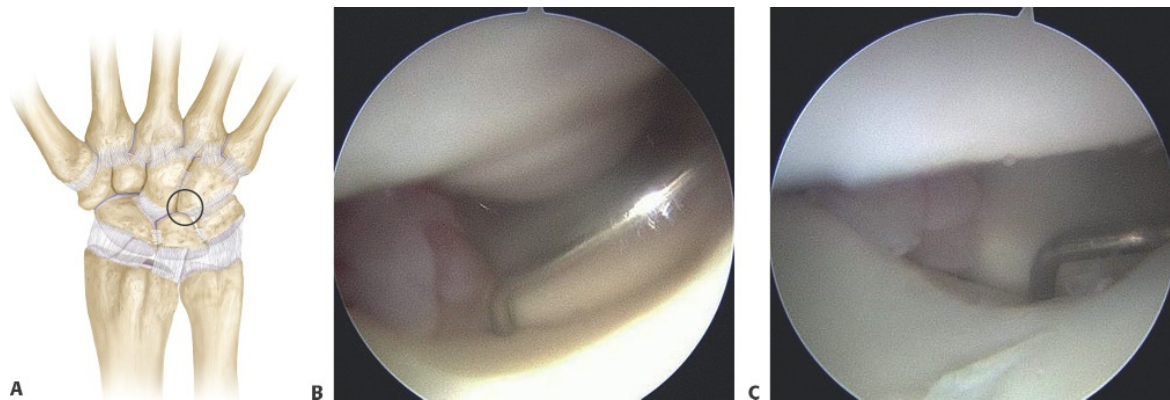


TECH FIG 7 • **A.** Diagram of right wrist, dorsal arthroscopy of the midcarpal joint, indicating arthroscopic field of view of the SL joint from the radial midcarpal portal. **B.** Hemorrhagic synovitis at the scaphocapitate joint.



TECH FIG 8 • **A.** Diagram of the right wrist. **B.** “Drive-through sign” of the SL interval indicating a Geisler-

type IV injury.



TECH FIG 9 • **A.** Diagram of right wrist, dorsal arthroscopy of the midcarpal joint, indicating arthroscopic field of view of the LT joint from the radial midcarpal portal. **B.** Intraoperative arthroscopic view of the capitate and hamate above, and **(C)** a 3-mm probe inserted through the ulnar midcarpal portal testing an intact LT joint.

Table 6 Radial Midcarpal Portal Field of View

Surface Anatomic Landmark: Radial Side of the Third Metacarpal Axis Proximal to the Capitate in a Soft Depression Between the Capitate and Scaphoid

Portal Field of View

Portal Name	Radial	Central	Volar	Dorsal/Distal	Ulnar
Midcarpal radial portal	STT joint, distal scaphoid pole	SLIL joint, distal scaphoid, distal lunate	Radial limb of arcuate ligament, ie, continuation of RSC ligament	Proximal capitate, CHIL, oblique views of proximal hamate	LTIL joint, partial triquetrum

- The LT can be palpated with a 3-mm probe and can also be graded using the Geissler grading scale.⁵

- Further ulnar movement can assess the palmar ligaments (ulnocapitate, triquetrocapitate, and triquetrohamate) after gently scraping the volar capsule synovial stratum.
- By dorsally rotating the scope at this position, the articular surfaces of the distal triquetrum (spiral shaped) and the proximal hamate (elliptical shape) can be inspected.
- Further ulnar movement of the scope will visualize a large joint recess and the “bare area” on the capitate neck and head and the pole of the hamate; however, due to excess synovial tissue, this view is often obscured.
- Tables 6 and 7 cover the radial and ulnar midcarpal portal fields of view, respectively.

Table 7 Ulnar Midcarpal Portal Field of View

Surface Anatomic Landmark: 1 cm Distal to the 4-5 Portal, Aligned with the Fourth Metacarpal, at the Lunotriquetral-Capitate-Hamate Joint

Portal Field of View

Portal Name	Radial	Central	Volar	Dorsal/Distal	Ulnar
Midcarpal ulnar portal	Distal articular surface of scaphoid	Distal lunate	Volar limb of arcuate ligament, ie, continuation of triquetrocapitolunate	Oblique views of proximal capitate, CHIL, proximal hamate	LTIL joint, triquetrum

PEARLS AND PITFALLS

Incisions

- Superficial longitudinal (or transverse) dermal incision followed by blunt dissection with a mosquito (or tenotomy dissection) to protect the extensor tendons and dorsal sensory nerve branches

Portal placement	■ Reposition the trocar if not inserting easily, to avoid chondral injury. Always use the blunt trocar to enter into the joint.
Arthroscopy fluid	■ Normal saline is injected to confirm placement of portals in the wrist, and arthroscopic examination can be performed either with or without fluid. However, use of heat-producing equipment should only be performed with arthroscopic fluid to avoid thermal injuries. We recommend the wet technique.
Inadequate views	■ Synovitis, fractures, ligament tears, and tight wrist capsule may limit the field of view during wrist arthroscopy requiring use of more portals to adequately assess the wrist.
Traction	■ Wrist traction often diminishes throughout the examination and should be readjusted to avoid inadvertent chondral injury from instruments.
Standardization	■ A standard approach to wrist arthroscopy optimizes efficiency and ensures a thorough and complete examination of the wrist.

DRY ARTHROSCOPY

Preventing capsule collapse	■ The valve of the sheath of the scope should be open at all times for air to circulate within the joint; otherwise, the capsule will collapse inward when using suction, obstructing the view.
Limited use of suction	■ Open the suction only when needing to aspirate something, or debris may be stirred up that may stick to the tip of the scope.
Avoiding splashes	■ Avoid using the burs or osteotomes too close to the tip of the scope as minor splashes may block your vision. Minor splashes can be removed by gently rubbing the tip of the scope on the local soft tissue.
Clearing field with saline	■ When a clear field is needed, a syringe with 5–10 mL of saline may be connected to the side valve of the scope and then aspirated with an arthroscopic shaver to get rid of blood and debris. The negative pressure exerted by the shaver will suck the saline into the joint without any pressure on the plunger and prevent extravasation.
Preventing suction clog	■ Periodic saline aspiration from an external basin or by joint irrigation, and systematic joint flushing in some procedures (intercarpal arthrodesis, arthroscopic proximal carpectomy) during prolonged use of burs, which may cause heating of instrument and local burns

POSTOPERATIVE CARE

- Splinting:
 - Diagnostic: 4 to 7 days for comfort.
 - Arthroscopic reduction and scapholunate pinning: sugar-tong splint for 2 weeks, followed by short-arm cast for 8 weeks. Pins are removed at 10 weeks. Removable splint for 2 to 4 more weeks.
 - Open ligament repair with scapholunate pinning: sugar-tong splint for 2 weeks, followed by short-arm cast for 10 weeks. Pins are removed at 10 weeks. Removable splint for 2 to 4 more weeks.
 - TFCC debridement: volar resting splint for 2 weeks, and then begin range of motion exercises.
 - TFCC arthroscopic repair: sugar-tong splint for 2 weeks, followed by above-arm Munster cast for 4 weeks, followed by Munster splint until 45 degrees of nontender pronation and supination was achieved, and then volar resting wrist splint until full rotation achieved.
- Activity modification:
 - After splinting, gentle active range of motion of the wrist is encouraged. Gentle activities of daily living are resumed, but lifting is limited to less than 10 lb based on any repairs that have been performed.
 - Wrist capsule stiffness is a frequent complaint in postarthroscopy patients, and patient education is critical regarding active range of motion and duration of expected stiffness.
 - Gradual strengthening should be encouraged, and involvement of certified hand therapists can optimize recovery.

OUTCOMES

- TFCC tear diagnosis.
 - A recent retrospective review of 908 patients with arthroscopic-confirmed TFCC tears illustrated only a 0.53 to 0.55 positive predictive value of clinical tests and a positive predictive value of MRI of 0.41 to 0.44 in diagnosing a TFCC tear. Arthroscopy is the standard for diagnosing and staging TFCC tears.⁶
- Scapholunate ligament treatment
 - In partial SL ligament tears, 85% treated by arthroscopic debridement have reported satisfactory improvement in symptoms. Only 67% with complete tear reported satisfactory outcomes with debridement alone.⁷

- Arthroscopic reduction and K-wire pinning of SL instability is most beneficial in patients with instability for less than 3 months and a gap of 3 mm or less in the SL interval (83% symptomatic relief compared to 53% symptomatic relief if instability was present for longer, or a greater than 3-mm SL interval gap were present).⁸
- Lunotriquetral ligament treatment.
 - In a small series of LT ligament tears treated with arthroscopic debridement alone, 100% (six patients) with partial injury reported resolution of symptoms after debridement, and 78% (nine patients) with complete tear reported symptom resolution.⁷
- Wrist ganglion treatment
 - A systematic review of arthroscopically treatment volar wrist ganglions reported a recurrent rate of 0% to 20% (mean 6%) and a 7% complication rate. A higher complication rate was reported for arthroscopic treated of volar wrist ganglia in the midcarpal joint as the procedure is technically more difficult.⁹
- Fracture-reduction assistance
 - In case series of acute and nonunion scaphoid fractures, arthroscopy has been shown to aid in the assessment of fracture reduction.¹⁰ In acute scaphoid fractures, one series illustrated median time to union of 62 days and average return to work 21 days after surgery.¹⁰
 - A randomized-control trial of arthroscopically vs fluoroscopically assisted reduction of intra-articular distal radius fractures treated with volar locking plate illustrated no statistical difference in radiographic or functional outcomes, including range of motion (ROM) and disabilities of the arm, shoulder, and hand (DASH) scores, between the two groups.¹¹

COMPLICATIONS

- Most complications are related to injury of the dorsal cutaneous sensory nerve branches, particularly:
 - Superficial radial nerve in the 1-2 portal
 - Dorsal cutaneous branch of the ulnar nerve from the 6U portal
 - Palmar cutaneous branch of ulnar nerve from volar ulnar portal
 - Ulnar neurovascular bundle injury from over-retraction or poor portal placement
- Chondral injury from trochar insertion

- Venous bleeding
- Loss of wrist motion (particularly forearm supination)
- Fluid extravasation
- Infection
- Minor contact burns at the portals and dorsal skin by the full-radius resector and bur may occur in dry arthroscopy
- Meticulous technique is essential to reduce the above complications.

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Ligament Reconstruction for Chronic Scapholunate Dissociation

15

CHAPTER

Mark Morris and Kevin C. Chung

DEFINITION

- Scapholunate instability is the most common form of carpal instability.
- Injury to the scapholunate interosseous ligament (SLIL) and subsequent dorsal intercalated segmental instability (DISI) results in scapholunate advanced collapse (SLAC) if untreated.¹
- Chronic tears generally require reconstruction rather than primary repair.
- Static vs dynamic instability²
 - Static instability: Any or all of the radiographic changes discussed below in the imaging section, seen on plain radiographs
 - Dynamic instability: Normal plain radiographs, but with stress radiographs, any or all radiographic changes are seen.
- Fixed vs reducible deformity
 - Fixed deformity: Static radiographic changes are not passively correctible.
 - Reducible deformity: Static radiographic changes are passively correctible.

ANATOMY

- The lunate, or the intercalated segment, is connected to the scaphoid via the scapholunate ligament and to the triquetrum via the lunotriquetral ligament.
- The scaphoid is inclined to flex, whereas the triquetrum is inclined to extend. Disruption in either ligamentous complex results in intercalated instability.
- The scapholunate ligament is a C-shaped structure that connects the dorsal, proximal, and volar surfaces of the scaphoid and lunate.³ It has three portions (**FIG 1**):
 - Dorsal portion

- 2 to 3 mm thick
- Greatest rupture strength and is responsible for rotational and translational restraint
- Proximal membranous portion
- Volar portion
 - 1 mm thick

PATHOGENESIS

- SLIL disruption occurs when the wrist is forced into extension, supination, and ulnar deviation.⁴
- SLIL injuries range from sprains, partial tears, or complete tears.
- The SLIL usually fails at the scaphoid bone-ligament interface.

NATURAL HISTORY

- With complete rupture of the SLIL, the scaphoid flexes and the lunate is now free to be pulled into extension either by the triquetrum⁵ or because of its own natural tendency due to its shape.⁶ This produces the DISI pattern.
- Left untreated, the DISI deformity results in abnormal radiocarpal contact.
- Flexion and hypermobility of the scaphoid leads to a predictable pattern of degenerative changes, resulting in SLAC wrist.
- SLAC was initially described in three stages but has been more recently described in five stages of degenerative changes:
 - Stage I: radioscapoid
 - Stage II: scaphocapitate
 - Stage III: lunocapitate
 - Stage IV: triquetrohamate
 - Stage V: radiolunate

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients complain of radial-sided wrist pain exacerbated by loading activities, weak grip, swelling, and loss of wrist range of motion.
- Tenderness to palpation in the anatomic snuffbox or over the scapholunate interval, just distal to Lister tubercle
- Pain with extremes of wrist extension and radial deviation
- Diminished grip strength on examination
- Watson scaphoid shift test may be positive in scapholunate dissociation (**FIG 2**).⁷

- The examiner places his or her thumb over the scaphoid tuberosity and the fingers over the dorsal radius. The other hand is used to move the wrist passively from ulnar to radial deviation. The scaphoid is extended with the wrist in ulnar deviation and flexed with the wrist in radial deviation. The examiner applies pressure on the scaphoid tuberosity while moving the wrist from ulnar to radial deviation. This prevents the scaphoid from flexing. If the SLIL is completely torn, the proximal pole subluxes dorsally out of the scaphoid fossa, inducing pain on the dorsoradial aspect of the wrist. When pressure is released, a clunk may occur. This indicates self-reduction of the scaphoid back into its normal position.
- Scapholunate ballottement test may also be positive.
 - The examiner holds the patient's scaphoid between the thumb and index finger. The thumb is placed over the tuberosity, and the index finger is placed over the proximal pole. The thumb and index fingers of other hand are used to hold the lunate. The examiner attempts to move the scaphoid and lunate in opposite directions.
 - This test is positive when it elicits pain.

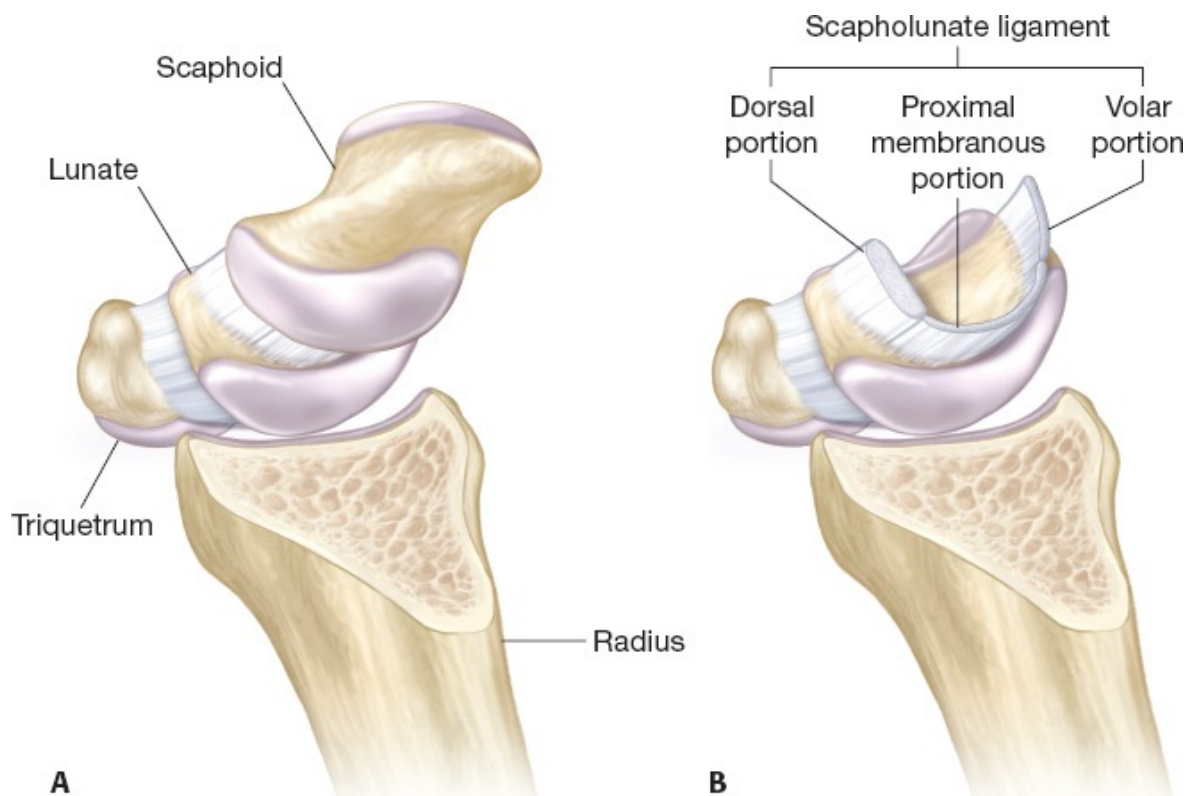


FIG 1 • The scapholunate ligament is a C-shaped

structure that consists of a stronger dorsal portion (2–3 mm thick), a proximal membranous portion, and a volar ligamentous portion (1 mm thick).

IMAGING

- Radiographs may demonstrate the following findings suggestive of SLIL injury:
 - Terry Thomas sign: Scapholunate diastasis of more than 3 mm on standard PA radiographs (**FIG 3A**)⁸
 - Signet ring sign: The presence of a flexed scaphoid on standard PA radiographs produces a cortical hyperdensity that resembles a signet ring (see **FIG 3A**).⁵
 - Angular changes in the carpal bones
 - The normal scapholunate angle ranges from 30 to 60 degrees. An angle over 60 degrees is seen with SLIL injury (**FIG 3B**).
 - The normal capitolunate angle ranges from –15 to 15 degrees. An angle greater than 15 degrees is seen with SLIL injury.
 - The normal radiolunate angle ranges from –10 to 10 degrees. An angle greater than 10 degrees is seen with SLIL injury.



FIG 3 • A. PA radiograph of the wrist showing diastasis of the scapholunate interval (*arrow*). A signet ring sign can also be seen here (*circled*), which is produced when the scaphoid is flexed so the tubercle is superimposed on the waist of the scaphoid. **B.** The scapholunate angle is formed by the intersection of the scaphoid axis (a line drawn between the most palmar point of the distal pole and the most palmar point of the proximal pole) and the lunate axis (a line drawn perpendicular to a line drawn between the most distal palmar and dorsal points of the lunate). A scapholunate angle greater than 70 degrees indicates a DISI deformity.

- Quadrangular lunate: The lunate appears rectangular on standard PA radiographs as it moves into extension.

- Disruption of Gilula lines as the relationship of the proximal carpal row is lost.
- The presence of degenerative changes involving the radiocarpal or midcarpal joints is a contraindication for ligament reconstruction.

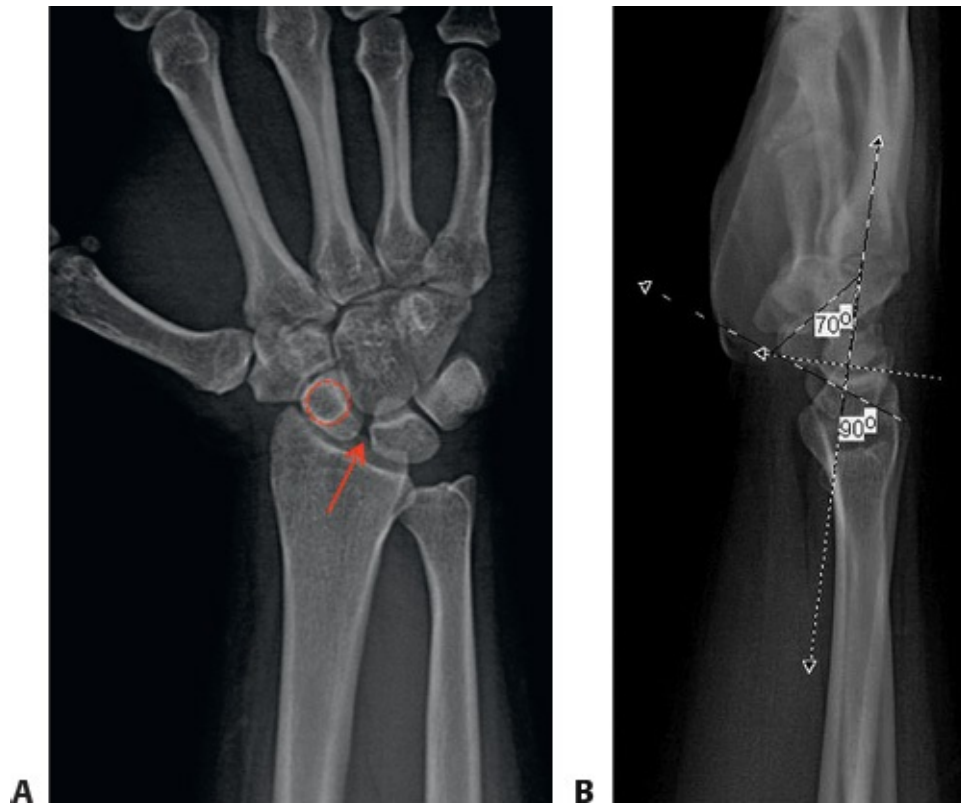


FIG 2 • Watson scaphoid shift test. The examiner uses his or her thumb to apply pressure over the scaphoid tuberosity while using the other hand to move the wrist from ulnar to radial deviation.

- MRI can be performed to identify tears when radiographs are normal.
- The sensitivity of a 3-T MRI ranges from 65% to 89% for complete scapholunate ligament tears. The sensitivity of MRA is reported to be 85% to 100%.
- The sensitivity of both MRI and MRA is poor for partial ligament tears.⁸

DIFFERENTIAL DIAGNOSIS

- Partial SLIL tear

- Radiocarpal arthritis
- Scaphoid fracture
- Keinbock disease

NONOPERATIVE MANAGEMENT

- Nonoperative management of complete SLIL tear is unsuccessful and reliably results in radiocarpal and midcarpal degenerative changes.

SURGICAL MANAGEMENT

- Direct repair is rarely an option for a chronic SLIL tear.
- Capsulodesis is an option for dynamic scapholunate dissociation if secondary stabilizers are intact and there is no cartilage degeneration. Capsulodesis is not indicated in the case of static scapholunate dissociation.
- Ligament reconstruction

Preoperative Planning

- The surgeon can consider diagnostic wrist arthroscopy prior to ligament reconstruction. This will help to better characterize the articular surfaces of the carpal bones, as well as to better delineate the degree of ligament injury.

Positioning

- The patient is positioned supine on the operating table. The operative extremity is draped out on a hand table.
- We prefer to use regional anesthesia for this operation. General anesthesia can also be used.
- A tourniquet is applied.
- An examination under anesthesia is performed. A Watson shift test is done to feel for a clunk.

Approach

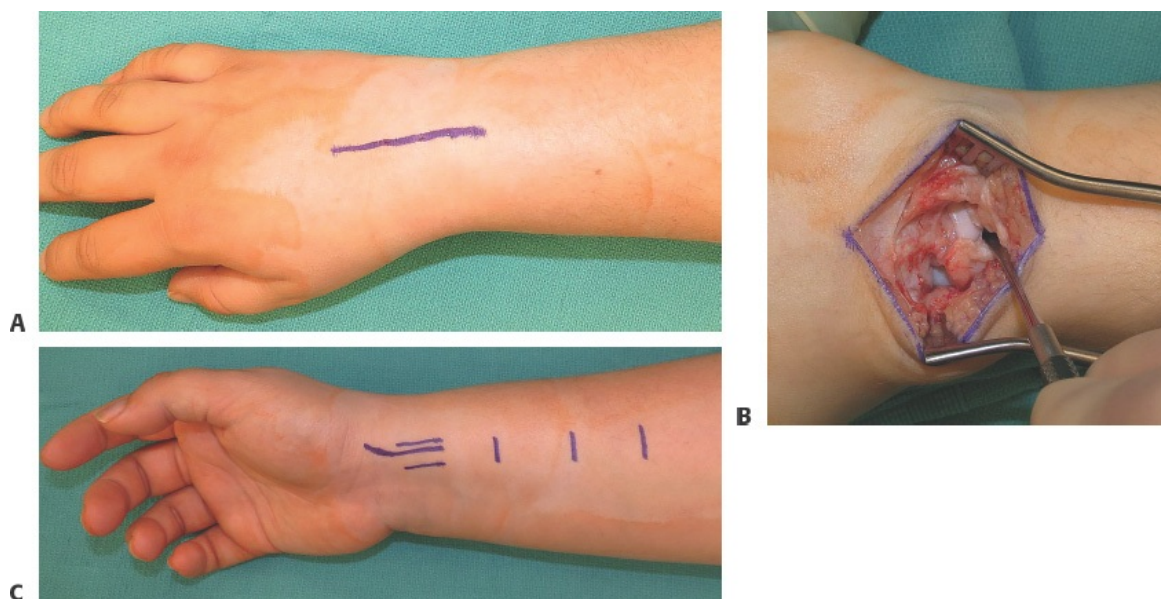
- Volar and dorsal incisions are made.
- The volar incisions are used to harvest the flexor carpi radialis (FCR) graft.
- The dorsal incision is used for most of the reconstruction.

TECHNIQUES

■ Exposure

■ Dorsal

- An 8-cm longitudinal dorsal wrist incision is centered over Lister tubercle (**TECH FIG 1A**).
- The extensor retinaculum over the third compartment is opened, and the extensor pollicis longus (EPL) is retracted radially.
- The dorsal wrist capsule is opened through a longitudinal incision to expose the scapholunate interval (**TECH FIG 1B**).



TECH FIG 1 • **A.** Dorsal wrist incision. **B.** The scapholunate interval is exposed. The Freer elevator in this image is in the scapholunate interval. **C.** Volar wrist incisions.

■ Volar

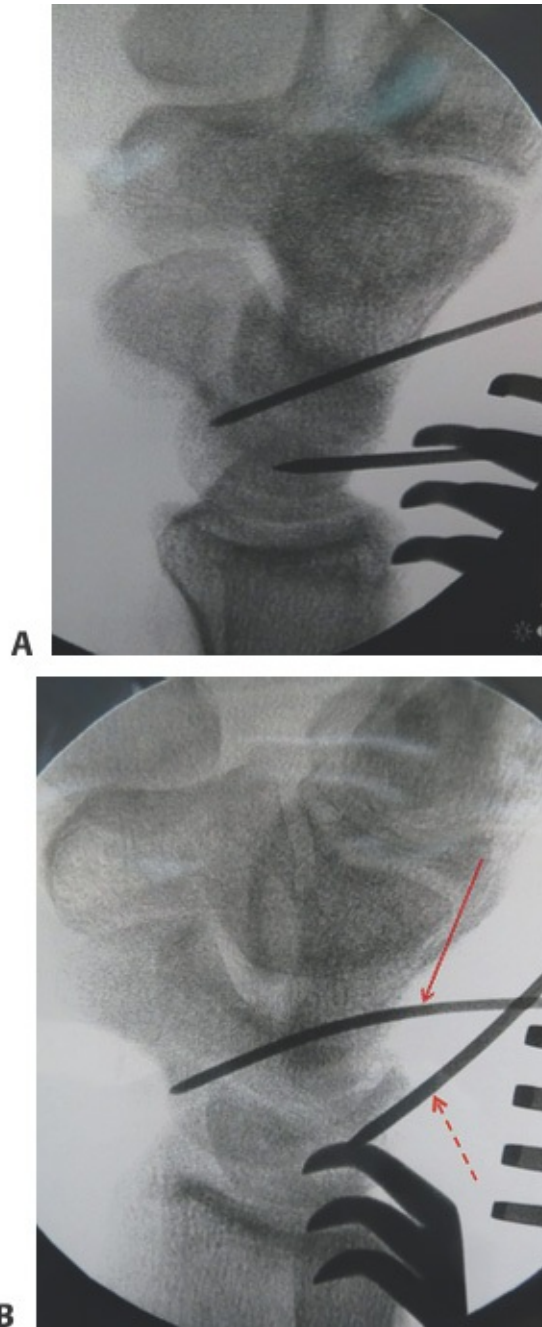
- Three 1-cm incisions are made along the course of the flexor carpi radialis (FCR; **TECH FIG 1C**).
- An oblique Wagner incision is made over the scaphoid tuberosity.
- The radial sensory nerve is at risk with this incision and must be preserved.
- The scar tissue is excised between the scaphoid and lunate.

■ Reduction of Scaphoid and Lunate and Creation of a Bone Tunnel

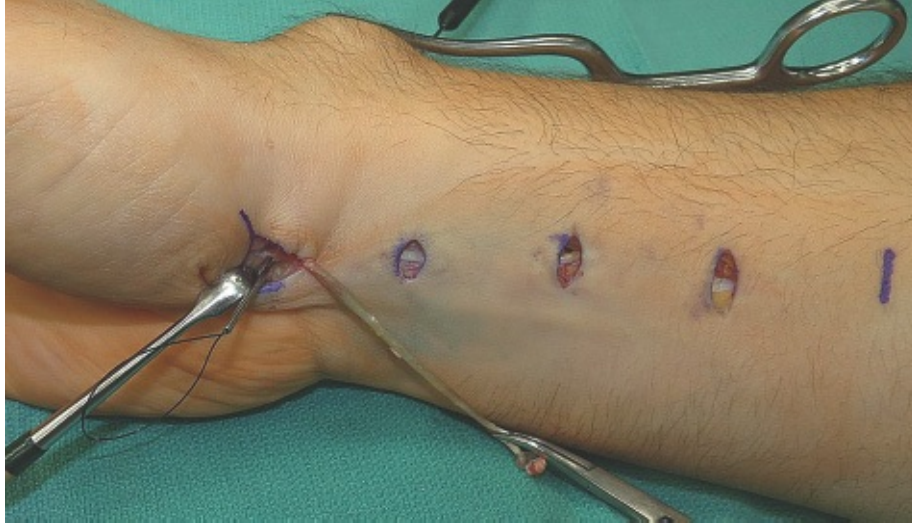
- Two 0.062-inch K-wires are placed dorsally into the scaphoid and lunate. The K-wires are used as joysticks to aid in reduction (**TECH FIG 2**).
 - Threaded wires may provide better purchase of the scaphoid and lunate so joystick wires do not pull out.
- Wires must be drilled away from the anticipated tunnel for the planned ligament reconstruction.
- To correct the DISI deformity, the surgeon must extend the scaphoid and flex the lunate. Direct the scaphoid wire proximally and the lunate wire distally.
- To create a bone tunnel, a K-wire is passed from the scaphoid tuberosity to the dorsum of the scaphoid along its axis.
- A cannulated 2.7-mm drill is passed over the wire from the dorsum to the palmar side.

Harvesting and Passing a Strip of Distally Based FCR Tendon

- A distally based 3-mm-wide by 8- to 10-cm-long strip of FCR tendon is harvested from the radial aspect of the tendon (**TECH FIG 3**).



TECH FIG 2 • A. K-wires are used for reduction of the scaphoid and lunate. **B.** The scaphoid wire is directed proximally to extend the scaphoid (*solid arrow*), whereas the lunate wire is directed distally to flex the lunate (*dashed arrow*).



TECH FIG 3 • The distally based FCR tendon graft is harvested and passed through the scaphoid tunnel.

- The FCR tendon rotates 90 degrees within the sheath at the wrist. It is important to follow the fibers so the tendon is not inadvertently transected. Do not slide the scissors through the tendon fibers; cut along the fibers to maintain the integrity of the tendon.
- A grasping suture is placed at the cut end of the distally based FCR tendon and is then passed through the scaphoid tunnel from volar to dorsal.
- Forcing a wide strip of FCR through the scaphoid tunnel can fracture the scaphoid. It is better to harvest a narrow strip of FCR tendon.

Reduction of the Scapholunate Interval

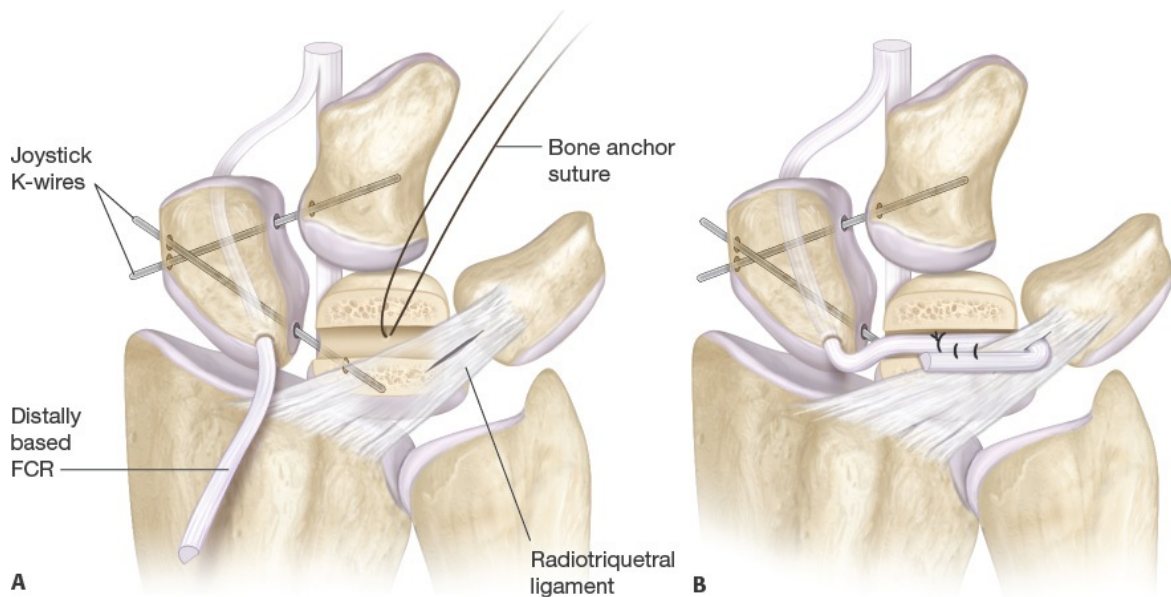
- The scapholunate interval is reduced using the joystick K-wires. The K-wires can only correct the flexion-extension deformities of the scaphoid and lunate. A bone reduction clamp or towel clip is used to reduce the gap between the two bones.
- Reduction is maintained by passing new K-wires across the scapholunate and scaphocapitate joints.
- Confirm reduction of the scapholunate interval with fluoroscopy. Once this is done, the joystick K-wires can be removed.

Securing the FCR to the Lunate and Closure

- A bur is used to make a shallow trough on the dorsum of the lunate.
- The FCR tendon graft is secured to the midportion of the trough using a 1.8-

mm bone anchor suture (**TECH FIG 4A**).

- The remaining portion of the tendon graft is passed through a slit in the distal portion of the dorsal radiotriquetral ligament and is sutured back to itself over the lunate (**TECH FIG 4B**).
- The dorsal capsule is first repaired using 3-0 Ethibond suture.
- The tourniquet is released and hemostasis is obtained.
- The EPL is transposed dorsal to the extensor retinaculum to avoid ischemic rupture that may occur due to postoperative swelling in the EPL sheath. The extensor retinaculum is also closed using 3-0 Ethibond suture.
- Skin is closed using 4-0 nylon suture.



TECH FIG 4 • A. The FCR tendon is secured into the trough in the lunate using a 1.8-mm bone anchor suture. **B.** The remaining FCR tendon graft is sutured back over itself.

PEARLS AND PITFALLS

- Technique**
- Some authors recommend a ligament-sparing capsulotomy to expose the scapholunate interval. To do so, the capsular incision is made in

line with the fibers of the intercarpal and radiocarpal ligaments, and a trapezoid capsular flap is raised.

- The superficial radial nerve and palmar cutaneous branch of the median nerve are at risk with the volar portion of the surgery and should be identified and protected.
- The FCR tendon can be inadvertently transected as it rotates 90 degrees at the wrist. Be careful and follow the fibers rather than blindly sliding the scissors to harvest the graft.
- The scaphoid can be fractured if the surgeon attempts to force a wide graft through the tunnel. The tendon graft should be approximately 3 mm wide.
- K-wires are cut under the skin to avoid pin tract infection. The K-wires are removed in the operating room in 8 wk.

Therapy

- In therapy, initial restriction of radial and ulnar deviation lessens the force on the SLIL ligament reconstruction.

POSTOPERATIVE CARE

- The patient is placed in a volar wrist splint postoperatively.
- The splint and operative dressings are taken down after 10 to 14 days, and the wound is examined. Sutures are removed at this time.
- The patient will remain splinted for 8 weeks.
- After 8 weeks of splinting, the patient is transitioned to a removable volar wrist splint for an additional 4 weeks. Gentle active wrist range of motion is started at this time. We do not send the patient to therapy because injudicious stressing of the wrist to get more motion will disrupt the reconstruction. Our goal is painless motion and whatever motion the patient can achieve is the suitable motion. This expectation must be presented to the patient before surgery; we inform the patient that there is no good wrist operation and all wrist operations trade pain relief for decreased wrist motion.
- Initial restriction of radial and ulnar deviation lessens the force on the ligament reconstruction.
- K-wires are removed 6 to 8 weeks after surgery.

OUTCOMES

- Most patients will have mild to no pain after initial recovery from surgery.^{9–12}
- Most patients feel subjective improvement and would have the operation again.⁹
- Studies have shown a slight loss of wrist motion after surgery (**FIG 4**).

- Total wrist motion averaged 85% of contralateral (uninjured) wrists in one study at an average of 10 years of follow-up.¹¹
- A more recent study of 20 patients with a mean follow-up of 24 months showed that wrist flexion was reduced by a mean of 19 degrees, and extension was decreased by a mean of 14 degrees.¹²

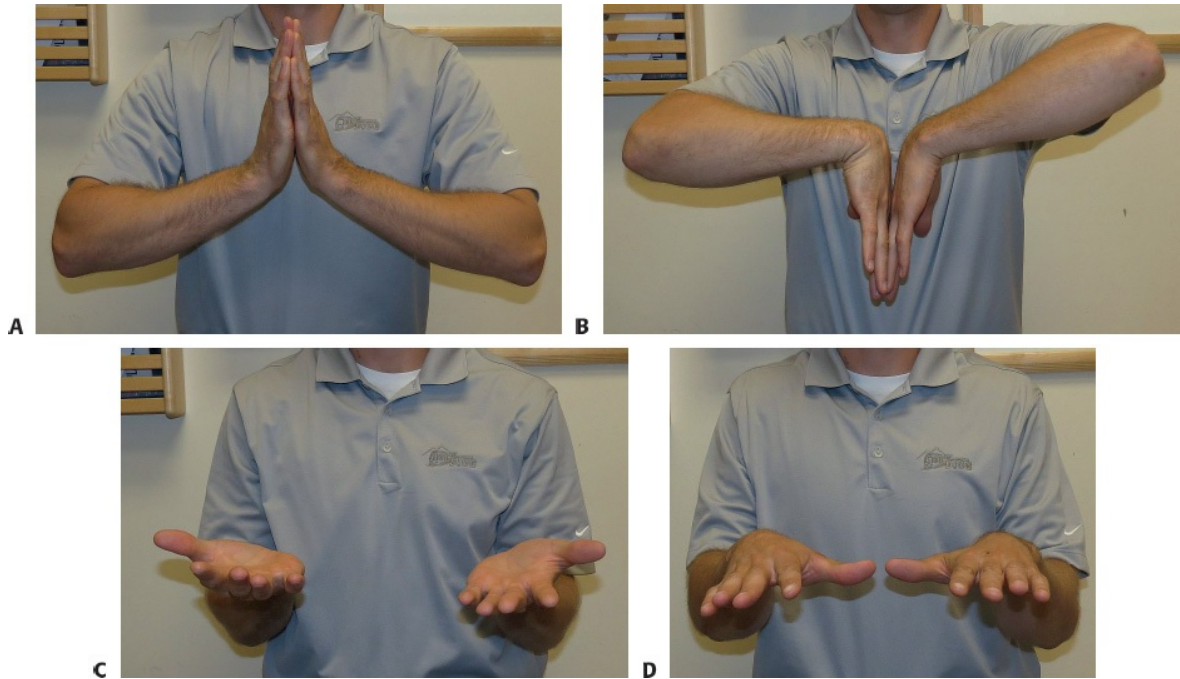


FIG 4 • Five-month postoperative clinical photographs after scapholunate ligament reconstruction with FCR tendon autograft. This patient demonstrates a minor loss of motion of the operative (**left**) wrist, as is to be expected. This loss of motion did not cause him any discomfort or disability. He was very satisfied with his outcome.

- Radial and ulnar wrist deviation has been shown to be 68% and 86% of contralateral wrists, respectively, in one study and equal to contralateral in another.^{9,10}
- Grip strength has been shown to be 78% to 85% of contralateral (uninjured) strength after a modified Brunelli reconstruction.^{10–12}
- Radiographic parameters improve after surgery. In one study, the average

preoperative scapholunate gap was 5.1 mm, which was reduced to 2.4 mm at surgery and was 2.8 mm at final follow-up at an average of 10 years.¹¹

Scapholunate angle has been shown to improve to within normal limits immediately after surgery but may increase again after longer follow-up.¹⁰⁻¹²

- Most patients avoid degenerative changes of the wrist.¹⁰⁻¹²

COMPLICATIONS

- Damage to superficial radial nerve or the palmar cutaneous branch of the median nerve.
- Scar tenderness.⁹
- Complex regional pain syndrome.^{9,10}
- SLAC wrist occurred in 1 out of 19 patients in one study with a mean of 37 months of follow-up,¹⁰ 1 out of 8 in another study with a mean of 10 years of follow-up,¹¹ and 3 out of 20 in another study with a mean of 24 months of follow-up.¹²
- Ligament reconstruction should not be performed in patients who already have degenerative changes on radiographs.

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Lunotriquetral Ligament Reconstruction Using a Slip of the Extensor Carpi Ulnaris Tendon

16

CHAPTER

Mark Morris and Kevin C. Chung

DEFINITION

- Isolated injury to the lunotriquetral (LT) ligament is less common than injury to the scapholunate (SL) ligament.
- LT ligament injury can be found in isolation or in combination with other injuries, such as in the case of a perilunate dislocation.
- The mechanism of LT ligament injury is debated but may be secondary to a dorsally applied force to a palmar-flexed wrist. Perilunate dislocation is thought to occur when the wrist is forced into hyperextension and ulnar deviation.¹
- LT disruption can be the result of acute trauma or secondary to degenerative or inflammatory conditions.
- LT injury ranges from partial tears to complete dissociation. Partial tears or attenuation of the ligament are more common and result in dynamic instability, whereas complete dissociation leads to static collapse.
- Volar intercalated segment instability (VISI) occurs after complete disruption of the LT ligament, dorsal radiotriquetral ligament, and volar radiolunate ligament.
- VISI may occasionally be seen in uninjured wrists, in contrast to dorsal intercalated segment instability (DISI), which is always pathologic.

ANATOMY

- The LT ligament is C-shaped, consisting of dorsal, proximal membranous, and

palmar portions (**FIG 1**). In contrast to the SL ligament where the dorsal portion is thickest and strongest, the palmar region of the LT ligament is the thickest and strongest portion.^{2,3}

- Secondary stabilizers of the LT joint include the ulnocarpal (ulnolunate, ulnocapitate, and ulnotriquetral), midcarpal (triquetrohamate and triquetrocipitate), and dorsal carpal (dorsal intercarpal and radiotriquetral) ligaments (**FIG 2**).
- Complete tear of only the LT ligament will not result in VISI deformity because the secondary stabilizers maintain the lunate and triquetrum in position.
- The scaphoid has a tendency to flex, whereas the triquetrum has a tendency to extend. The lunate, or intercalated segment, is balanced by these two opposing forces.

PATHOGENESIS

- Isolated LT tear is thought to occur when a dorsally applied force is applied to a palmar-flexed wrist. This force causes the dorsal LT fibers to tear. The volar radiolunate ligaments remain intact and tether the proximal lunate on the volar side, leading to palmar flexion.
- Reverse perilunate injuries occur from falling on an outstretched hand with the wrist extended, pronated, and radially deviated. This mechanism can also result in an isolated LT tear, followed by lunocapitate dislocation, and then SL dissociation (**FIG 3A**).⁴
- Perilunate injuries occur when the wrist is forced into hyperextension and ulnar deviation. Mayfield describes four stages of perilunate injury (**FIG 3B**).¹ LT injuries occur in Mayfield III and IV perilunate injuries.
- Inflammatory arthritis or degenerative LT lesions may also lead to instability.

NATURAL HISTORY

- The natural history of LT injuries has not been clearly defined; however, they may lead to degenerative changes of the wrist.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients present with ulnar-sided wrist pain.
- Patients may or may not report a history of trauma.
- Patients may have tenderness to palpation over the dorsal LT joint.

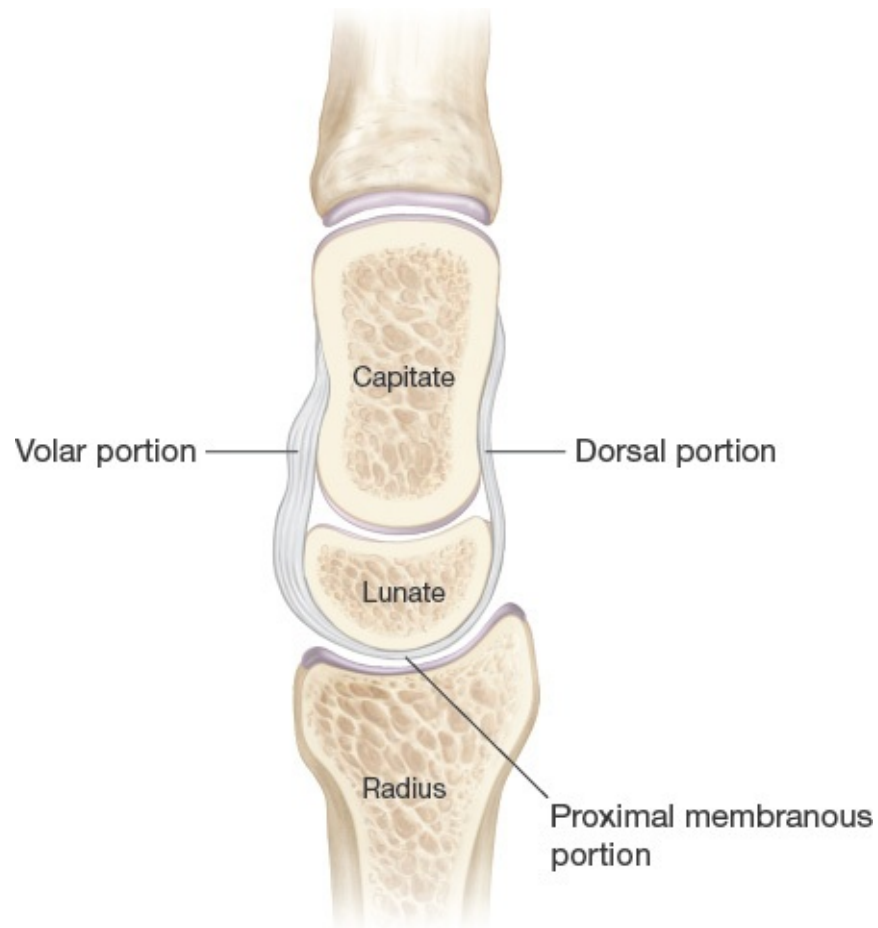


FIG 1 • The lunotriquetral ligament is C-shaped, consisting of palmar, dorsal, and proximal membranous portions. The palmar portion is the thickest and strongest portion of the ligament.

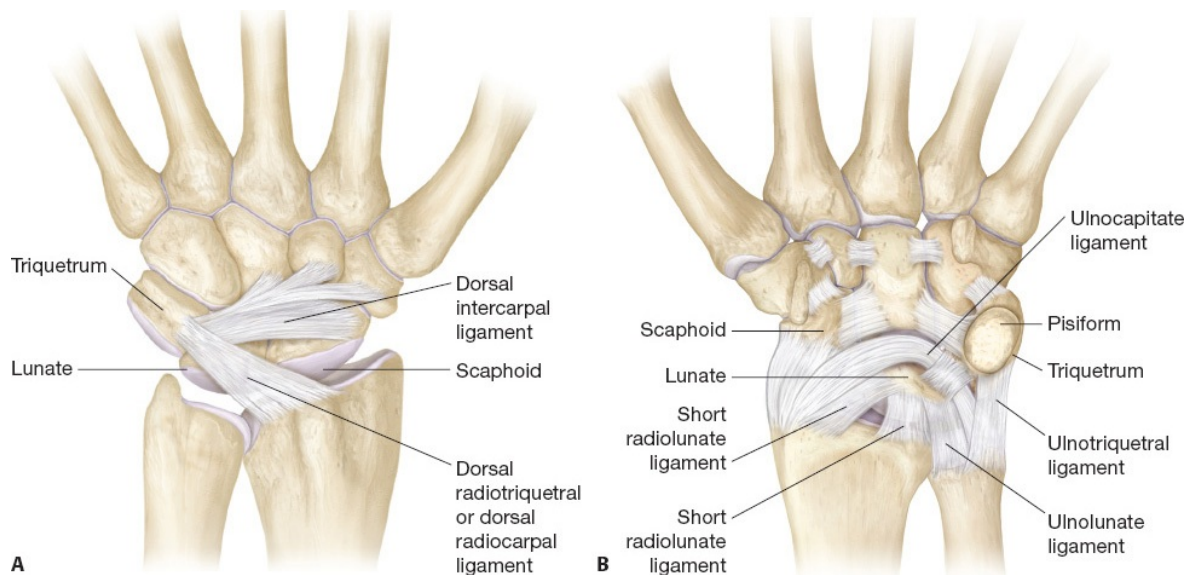


FIG 2 • A. Dorsal wrist ligaments. The important dorsal secondary stabilizers of the lunotriquetral joint are the dorsal intercarpal and dorsal radiotriquetral (also known as dorsal radiocarpal) ligaments. **B.** Volar wrist ligaments. The important volar secondary stabilizers of the lunotriquetral joint are the short and long radiolunate ligaments, the ulnolunate ligament, the ulnocapitate ligament, and the ulnotriquetral ligament.

- LT compression test: Radially directed pressure is applied over the triquetrum. This may elicit pain in patients with LT instability (**FIG 4A**).
- LT ballottement test: The lunate is stabilized with the thumb and index finger of one of the examiner's hands. The other hand is used to displace the triquetrum and pisiform dorsally and palmarly. Pain, crepitus, and joint laxity are seen in patients with LT instability (**FIG 4B**).
- Ulnar deviation with pronation and axial compression may elicit instability and a painful clunk.
- Limited range of wrist motion
- Diminished grip strength

IMAGING

- A PA radiograph may show a break in Gilula lines. There is often a step-off between the lunate and triquetrum.

- It is rare to see a gap in the LT interval on radiographs with LT injuries, in contrast to SL injuries where a gap is seen. Plain radiographs may be normal (**FIG 5**).

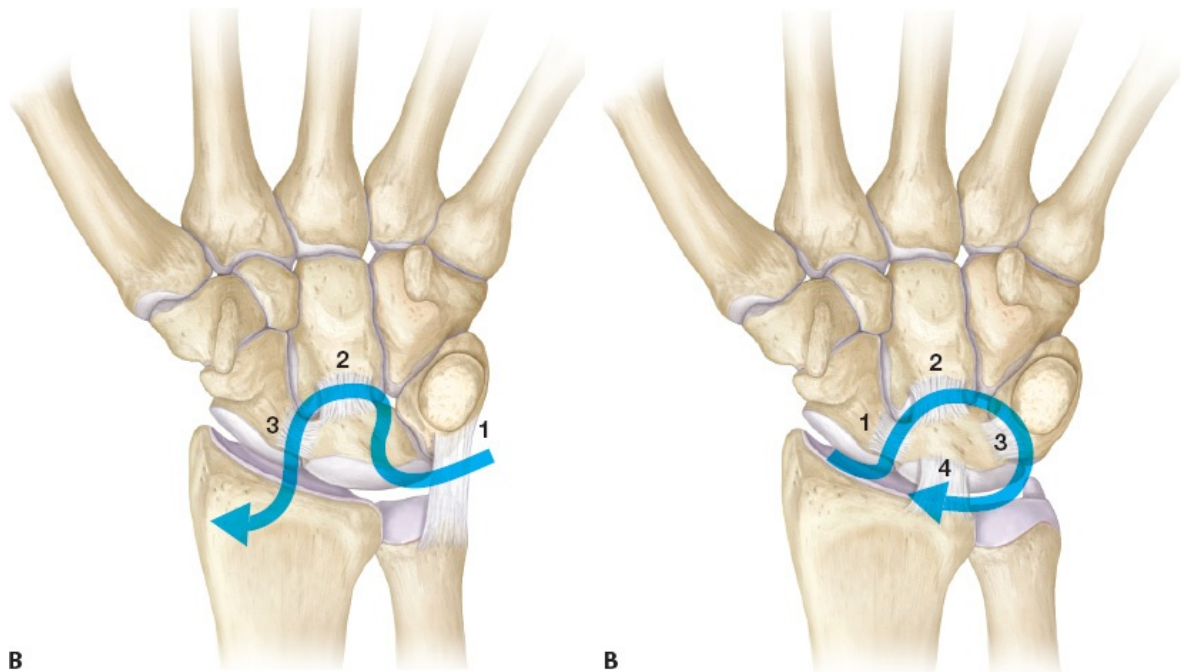


FIG 3 • A. Reverse perilunate injuries start on the ulnar side of the wrist starting with an isolated LT tear, followed by lunocapitate dislocation, and then scapholunate dissociation. **B.** Mayfield's four stages of perilunate injury. Stage 1: Disruption of scapholunate ligament or scaphoid fracture. Stage 2: Lunocapitate dislocation. Stage 3: Lunotriquetral dissociation or triquetrum fracture. Stage 4: Lunate dislocation.

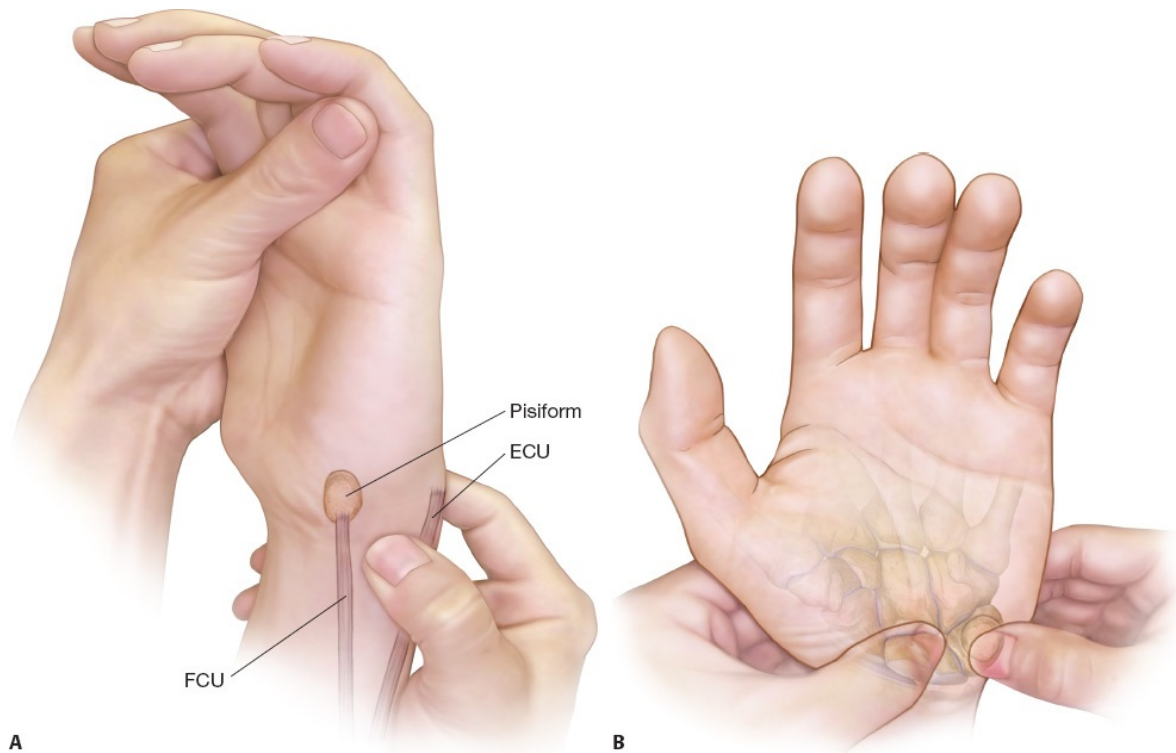


FIG 4 • A. Lunotriquetral compression test. The examiner applies radially directed pressure over the triquetrum. **B.** Lunotriquetral ballottement test. The lunate is stabilized with the thumb and index finger of one of the examiner's hands. The other hand is used to displace the triquetrum and pisiform dorsally and palmarly.

- A lateral radiograph may show a VISI deformity, marked by volar tilting of the lunate. This indicates injury to the LT injury along with injury to the dorsal radiotriquetral ligament (**FIG 6**).
- The SL angle is less than 30 degrees with a VISI deformity.
- The capitolunate angle increases to over 15 degrees with a VISI deformity.
- MRI is not reliable for imaging of LT ligament injuries.

DIFFERENTIAL DIAGNOSIS

- Ulnar impaction syndrome
- Distal radioulnar joint instability
- Extensor carpi ulnaris subluxation

- Triangular fibrocartilage complex injuries
- Pisotriquetral arthritis
- Hook of hamate fracture

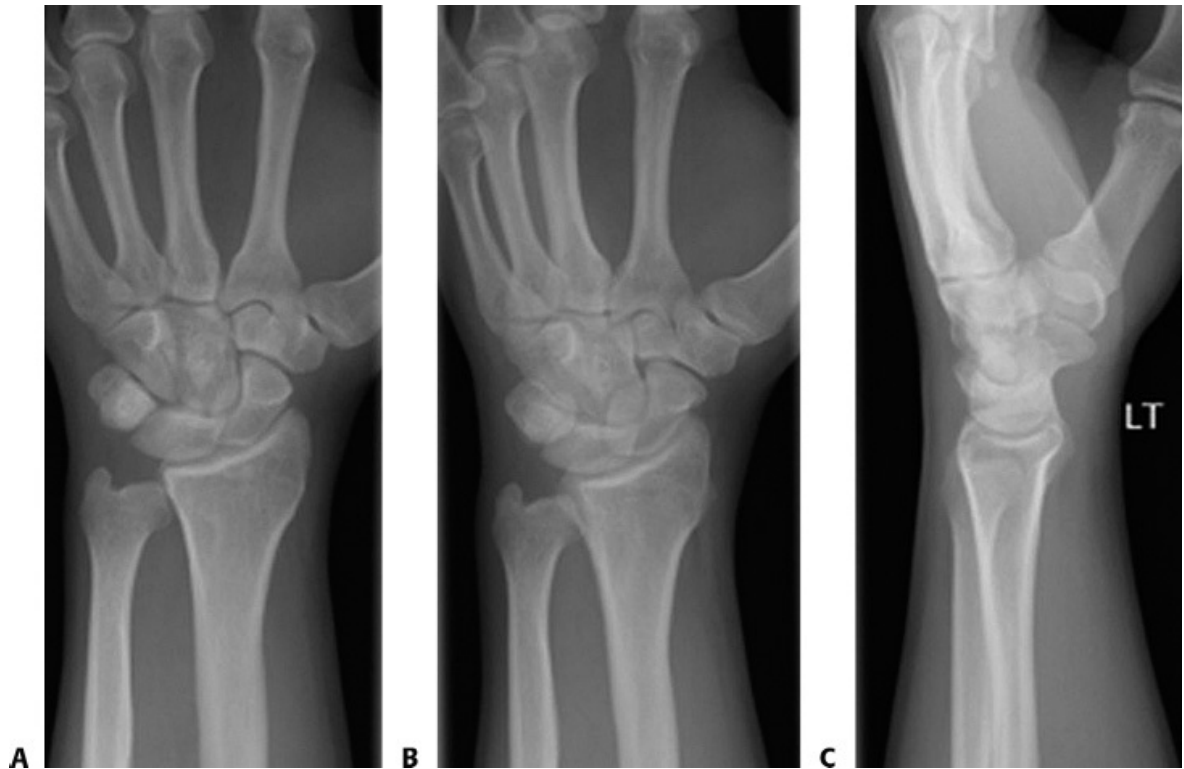


FIG 5 • PA, oblique, and lateral radiographs of a patient with a lunotriquetral injury. There is no apparent widening of the lunotriquetral interval or VISI deformity seen here; however, a lunotriquetral ligament tear was found on wrist arthroscopy after the patient failed nonoperative management.

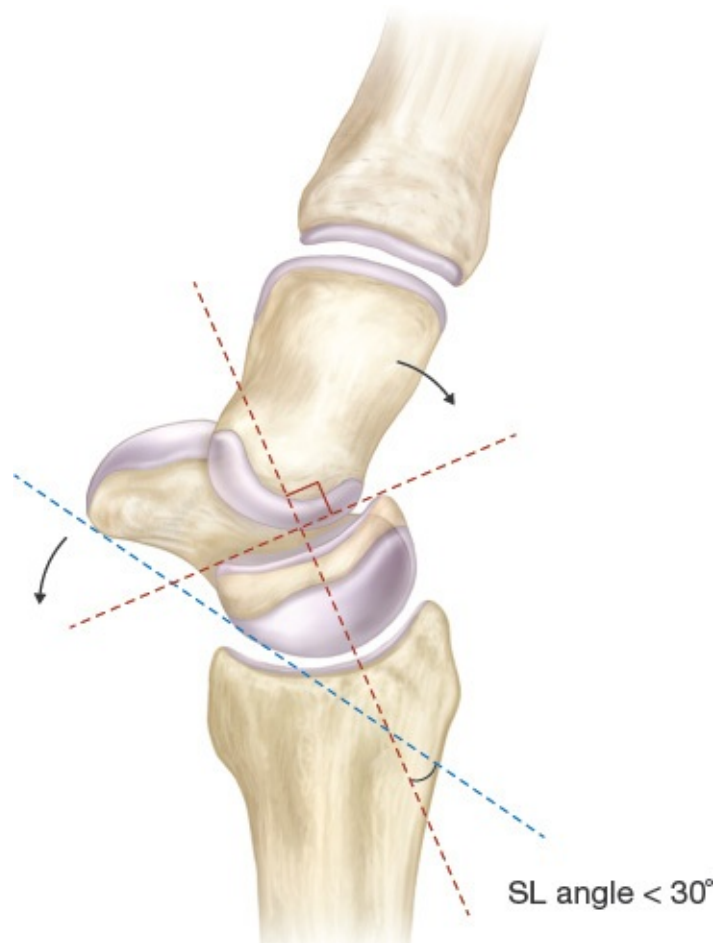


FIG 6 • The VISI deformity is marked by the lunate in a flexed position, which decreases the scapholunate angle and increases the capitolunate angle.

NONOPERATIVE MANAGEMENT

- The appropriate management of an acute LT injury is immobilization in a cast for 8 to 12 weeks. Patients who present with subacute or chronic LT injuries should also be treated first with immobilization, but the timing is less well-defined and can be determined by the patient's symptoms during immobilization.⁵
- Midcarpal injections with local anesthetic and corticosteroids may be a helpful adjunct to immobilization.

SURGICAL MANAGEMENT

- Surgical management is indicated in patients with symptomatic LT

dissociation that is not relieved by nonoperative management.

- The goal of surgery is to restore stability to the proximal carpal row and to realign the lunocapitate axis.



FIG 7 • A dorsal wrist incision is used, centered between the fourth and fifth compartments.

- Ligament reconstruction should be reserved for patients without arthritic changes.
- If degenerative changes are already present, the surgeon should consider arthrodesis or proximal row carpectomy.

Preoperative Planning

- The surgeon can consider diagnostic wrist arthroscopy prior to ligament reconstruction. This will help to better characterize the articular surfaces of the carpal bones, as well as to better delineate the degree of ligament injury.

Positioning

- The patient is positioned supine on the operating table. The operative extremity is draped out on a hand table.
- We prefer to use regional anesthesia for this operation. General anesthesia can also be used.
- A tourniquet is applied.
- An examination under anesthesia is performed to evaluate for a clunk. The distal radioulnar joint can be assessed under anesthesia as well.

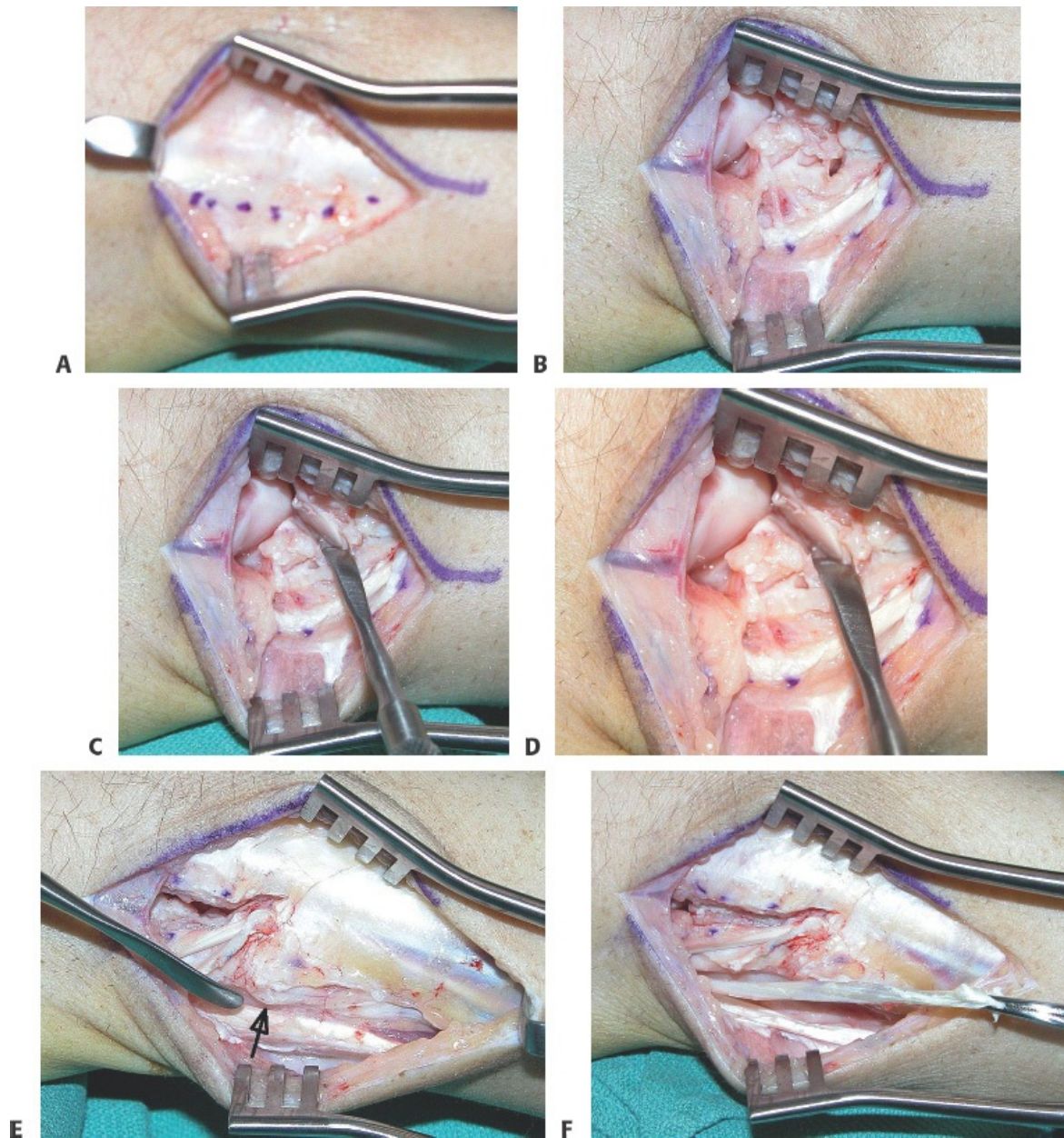
Approach

- A 6-cm longitudinal incision is used, centered over the dorsal wrist between the fourth and fifth compartments (**FIG 7**).
- Alternatively, two incisions can be used—one incision over the dorsal wrist joint, and another proximally over the ECU tendon harvest site.

TECHNIQUES

■ Exposure and Tendon Harvest

- A longitudinal skin incision is centered over the dorsal wrist, between the fourth and fifth compartments.
- The wrist capsule is incised longitudinally (**TECH FIG 1A,B**). The LT interval should now be visible (**TECH FIG 1C,D**).
- Excise scar tissue from between the lunate and triquetrum.
- The ECU tendon is identified in the proximal portion of the incision.
- A distally based slip of ECU tendon is harvested from the radial aspect of the tendon (**TECH FIG 1E,F**).
- The tendon graft should be 3 mm wide by 8 to 10 cm long.
- The strip of tendon graft is dissected to its insertion at the base of the small finger metacarpal.

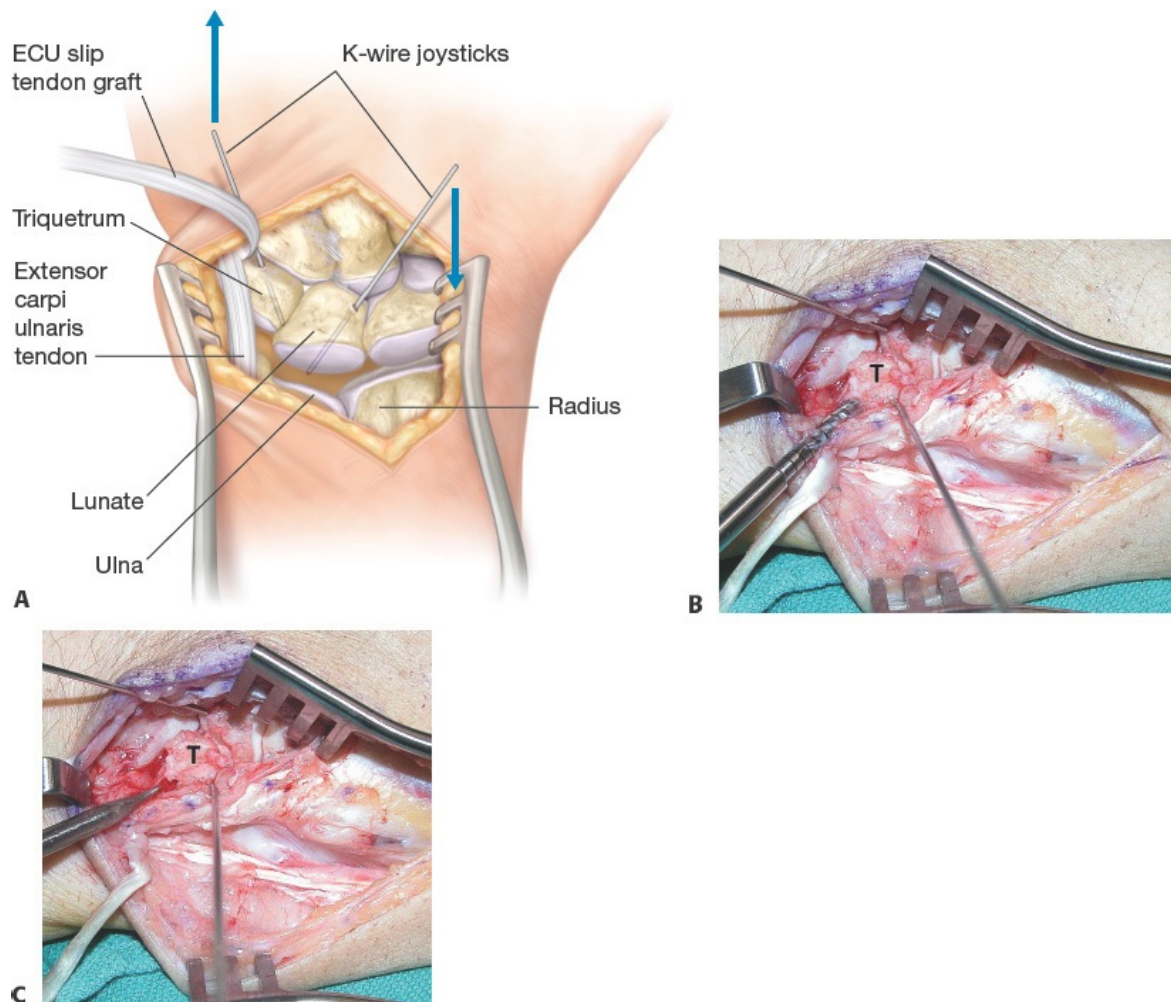


TECH FIG 1 • A,B. Longitudinal incision of the wrist capsule. **C,D.** The lunotriquetral interval is shown here with a Freer elevator. The lunotriquetral ligament here is ruptured. **E.** The intact ECU tendon (*arrow*). **F.** A 3-mm strip of distally based ECU tendon is harvested.

■ Reduction of the Lunate and Triquetrum and

Creation of Bone Tunnels

- Two 0.062-in. Kirschner wires (K-wires) are inserted into the dorsal lunate and triquetrum to be used as joysticks for reduction (**TECH FIG 2A**). Be sure to keep the K-wires out of the way of the planned tunnels in each bone.
- To correct the VISI deformity, the lunate is extended by retracting the lunate K-wire proximally and the triquetrum is flexed by retracting the triquetral K-wire distally.
- To create the bone tunnels, a K-wire is placed in the triquetrum from the distal, dorsal, ulnar aspect toward the proximal, palmar, radial corner. Once acceptable placement is confirmed, a 2.5-mm cannulated drill is used to create a bone tunnel in the triquetrum over the K-wire (**TECH FIG 2B,C**).
- The lunate bone tunnel is then created in similar fashion by placing a K-wire from the distal, dorsal, and radial corner of the lunate to the proximal, palmar, and ulnar corner. A cannulated drill is again used over the K-wire to form the tunnel.
- The tunnels should converge at the volar margin of the LT joint and should remain extra-articular.



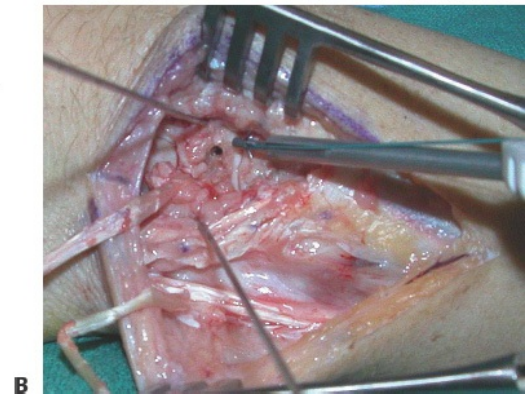
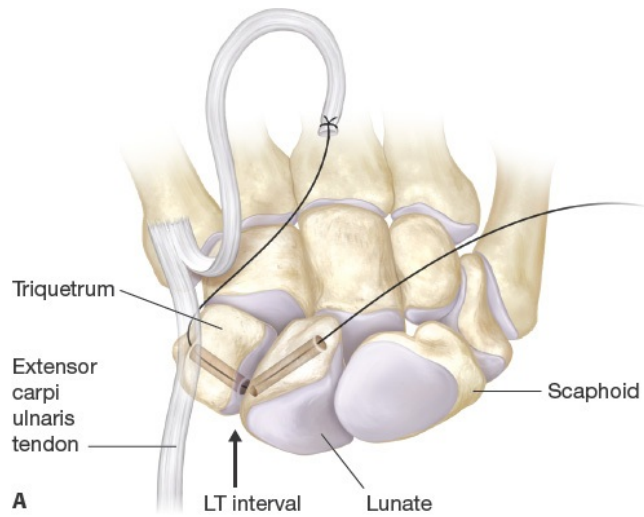
TECH FIG 2 • **A.** Joystick K-wires are placed into the triquetrum and lunate. The *arrows* show the direction of retraction required to reduce the VISI deformity. **B.** A bone tunnel is created in the triquetrum (T) using a cannulated drill. **C.** A microcurette is used to clear cartilage remnants at the exit sites of the tunnels.

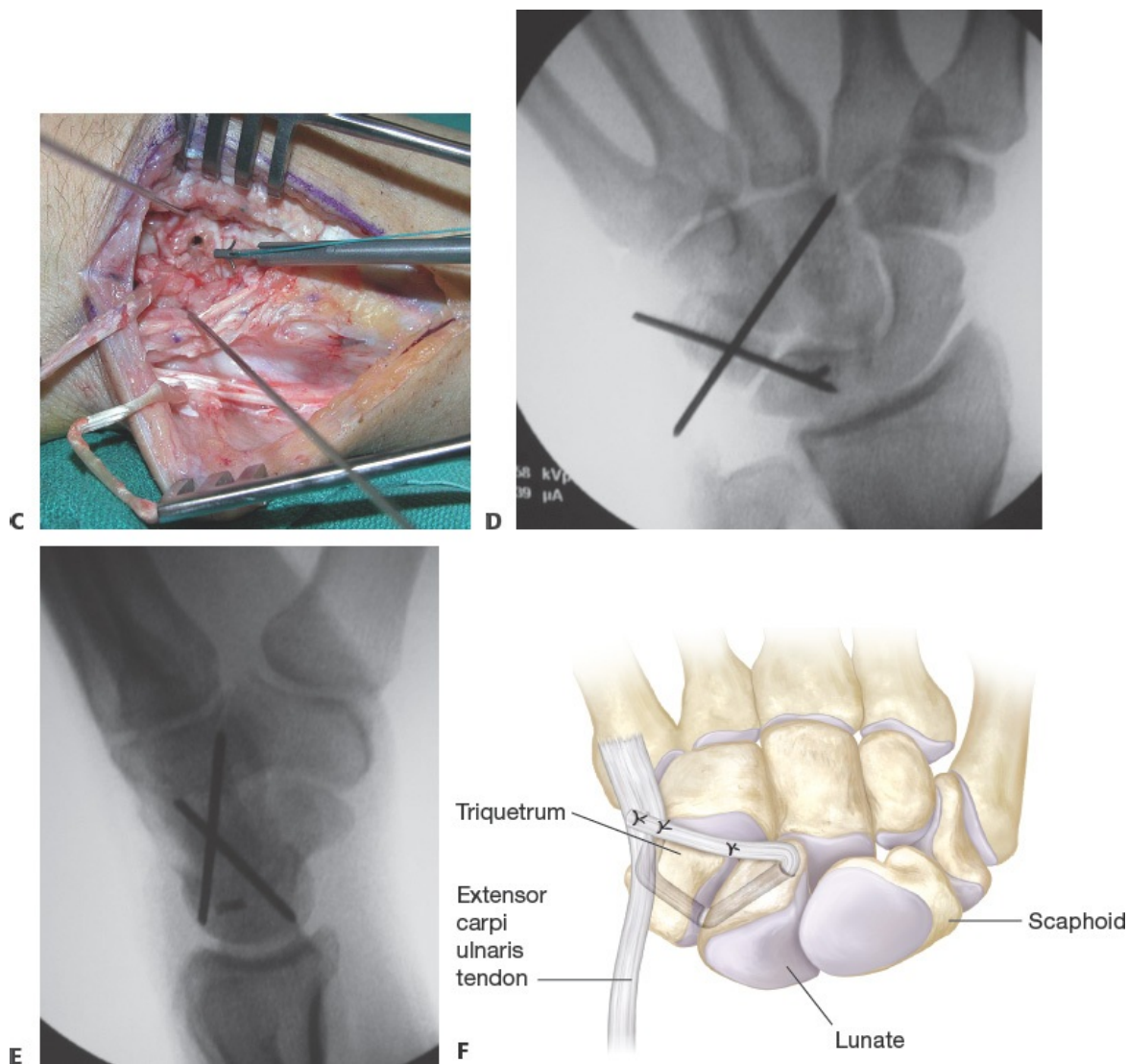
■ Passing and Securing the ECU Tendon Graft

- The tendon is passed through the bone tunnels using a wire or suture. First pass the tendon from the dorsum of the triquetrum to the LT interval and then from the LT interval to the dorsum of the lunate (**TECH FIG 3A**).
- Alternatively, after passing the graft through the triquetrum, a small bone anchor can be used to secure the tendon graft to the lunate (**TECH FIG**

3B,C). The VISI deformity must be corrected with the joystick K-wires prior to fixation with an anchor.

- Next, the ECU graft is secured to itself over the remnant of the LT ligament.





TECH FIG 3 • A. Bone tunnels are made through the triquetrum and lunate. A wire or suture (pictured) is used to feed the graft through the bone tunnels. **B,C.** A mini-Mitek anchor can be used to fix the graft to the lunate. **D,E.** One or two K-wires are inserted to hold the reduction of the lunotriquetral joint. Here, an additional wire was placed through the triquetrum into the hamate and capitellum. **F.** After passing the tendon graft through the triquetrum and lunate, the free end is sutured back to itself.

- First, the VISI deformity is corrected as described earlier with the joystick K-wires.
- The corrected position is held with a third K-wire passed through the triquetrum and lunate (**TECH FIG 3D,E**). The triquetrum should also be pinned to the capitate to fixate the reduced construct; otherwise, the triquetrum may rotate around the single K-wire to lose the reduction.
- The end of the tendon graft is then sutured back to itself using 3-0 Ethibond sutures (**TECH FIG 3F**).

■ Closure

- The wrist capsule is closed tightly with 3-0 Ethibond suture.
- The extensor retinaculum over the fourth and fifth compartments is closed using 3-0 Ethibond suture.
- The joystick K-wires are removed at this time.
- The K-wire traversing the LT joint is left in place and is cut deep to the skin. This is done to avoid pin tract infections from a pin that will be left in place.

PEARLS AND PITFALLS

Technique

- Branches of the dorsal ulnar sensory nerve should be protected. The dorsal sensory branch of the ulnar nerve arises 8 cm proximal to the pisiform and passes dorsal to the FCU and pierces the fascia 5 cm proximal to the pisiform. It reaches the dorsal hand in close proximity to the ulnar styloid process.
- The ECU tendon graft should not be more than 3 mm wide. If it is too wide, it will be difficult to pass through the drill holes in the lunate and triquetrum.
- Joystick K-wires are used to correct the VISI deformity. The lunate wire is placed obliquely from a distal to proximal direction, and the triquetral wire is placed from an oblique proximal to distal direction. The VISI deformity is corrected by making both wires perpendicular to the axis of the forearm.
- An alternative technique to drilling bone tunnels is to use a sharp curved awl. This is less traumatic and may help to avoid fracturing the carpal bones.

- Ulnar shortening osteotomy may be performed at the same time as LT ligament reconstruction in a patient with concomitant ulnocarpal abutment.

Postoperative

- Pain is significantly improved in most patients after this procedure.

Therapy

- Do not be too aggressive with therapy or the repair can fail. Long-term satisfaction is high even though patients do typically lose some wrist range of motion.

POSTOPERATIVE CARE

- The patient is placed in a volar wrist splint immediately postoperatively.
- Incisions are examined and sutures are removed after 10 to 14 days.
- The patient is kept in a volar wrist splint for 8 weeks.
- K-wires are removed after 8 weeks.
- The patient can start gentle range of motion exercises after K-wires are removed. Wrist stiffness is common (**FIG 8**).



FIG 8 • Six-month follow-up after lunotriquetral ligament reconstruction. Although the patient lost some wrist range of motion, he was satisfied with his result.

OUTCOMES

- Shin et al.⁶ demonstrated that patients who had LT ligament reconstruction had lower reoperation rates than did patients treated with direct repair or arthrodesis.
- Shahane et al.⁷ studied 46 patients who underwent LT ligament reconstruction with ECU tendon. After a mean of 19 months of follow-up, 19 patients (41%) had excellent outcomes, 10 (22%) had good outcomes, 11 (24%) had satisfactory outcomes, and 6 (13%) had poor outcomes based on Mayo wrist scores. Forty of 46 patients said that they had substantially improved and would undergo the operation again.

COMPLICATIONS

- Injury to the dorsal branch of the ulnar nerve
- Pisotriquetral pain
- Reflex sympathetic dystrophy
- Residual instability

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17 Fixation of Acute Scaphoid Fractures

CHAPTER

Ketan Sharma, James T. W. Saunders, and Amy M. Moore

DEFINITION

- The scaphoid is the most commonly fractured bone of the carpus.
- *Acute* scaphoid fractures are defined as occurring within 3 to 4 weeks of the inciting event.
- *Displaced* scaphoid fractures are defined as exhibiting more than 1 mm displacement or more than 10 degrees angulation.
- Operative treatment of acute scaphoid fractures remains challenging due to the complex geometry and tenuous blood supply of the scaphoid itself.
- Herbert's system classifies fractures into four types¹:
 - Type A—stable and acute
 - Type B—unstable and acute
 - Type C—delayed unions
 - Type D—established nonunion

ANATOMY

- The scaphoid spans the proximal and distal carpal rows, and serves as an important dynamic link between the two.
- The scaphoid articulates with the radius, lunate, capitate, trapezoid, and trapezium.
 - These numerous articulations mean that over 80% of the surface area of the scaphoid is covered with cartilage and not periosteum.
 - This characteristic limits both ligamentous structural integrity and vascular healing potential.
 - This also means the scaphoid heals predominantly through primary bone healing (intramembranous ossification), which can result in a paucity of

callus formation and weak early union.²

- The scaphoid bone is divided into three regions: the proximal pole, waist, and distal pole (or tubercle [**FIG 1**]).
- The proximal pole of the scaphoid articulates with the distal radius within the scaphoid fossa, and is coupled to the neighboring lunate within the proximal row via the strong scapholunate (SL) ligament.
 - This ligament prevents the scaphoid from falling into a flexed position, and is crucial for carpal stability.
- Vascular supply to the scaphoid is provided through two main branches of the radial artery (**FIG 2**).
 - The dorsal branch supplies 70% to 80% of the total vascularity, enters at the dorsal ridge distally, and supplies the entire proximal pole.

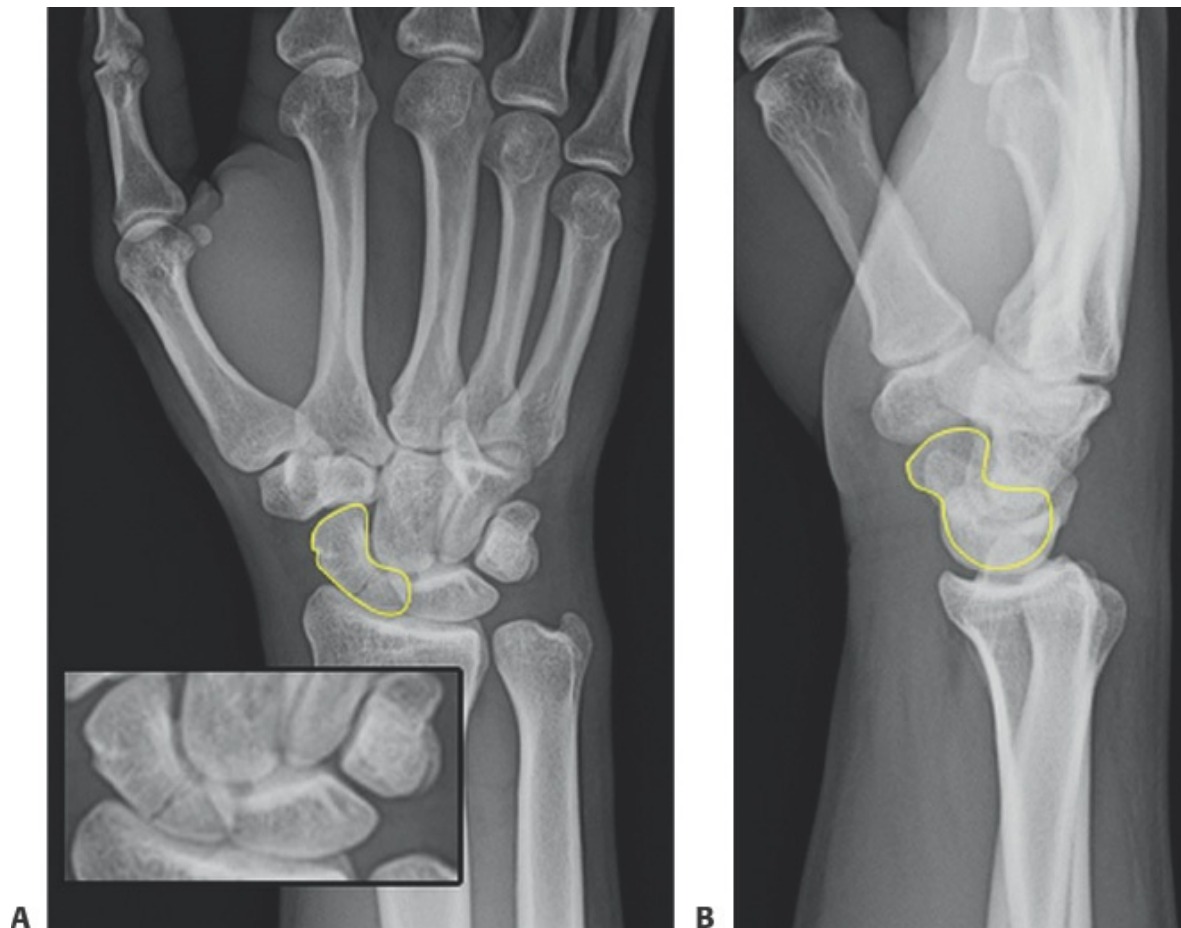


FIG 1 • **A.** PA (**B**) and lateral radiographs showing nondisplaced fracture of the scaphoid waist (scaphoid

outlined in *yellow*; fracture magnified in inset in **A**). The scaphoid is divided into three regions (proximal pole, waist, distal pole) and serves as an important dynamic link between the proximal and distal carpal rows.

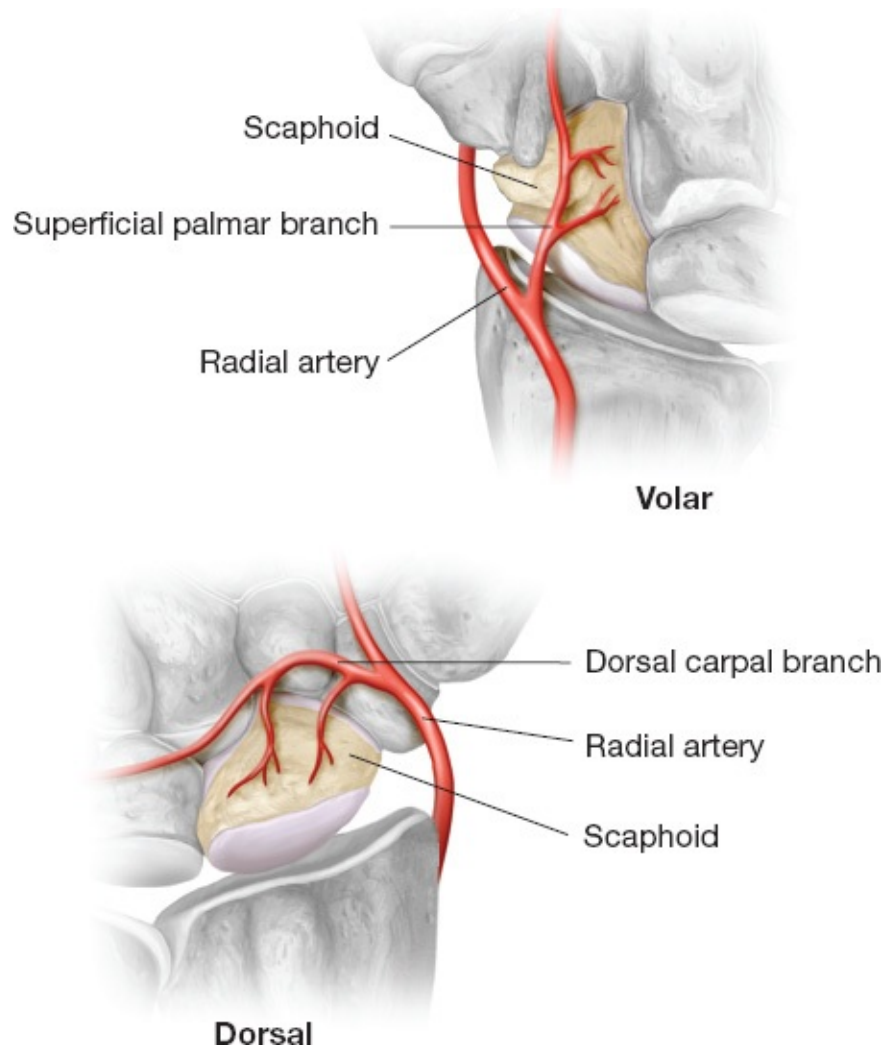


FIG 2 • The scaphoid is supplied by dorsal and volar branches of the radial artery, which predominantly distribute to the proximal and distal poles, respectively. This unique retrograde vasculature has important implications concerning healing of waist and proximal pole fractures.

- The volar branch supplies 20% to 30% of the total vascularity, enters through the tubercle, and supplies the distal pole and distal tuberosity predominantly.³
- The proximal pole receives the majority of its blood supply through retrograde intraosseous vascular flow from these arteries and is therefore susceptible to avascular necrosis (AVN) when this supply is disrupted by the fracture.

PATHOGENESIS

- The most common mechanism of injury of the scaphoid is a hyperextension of the wrist more than 95 degrees, coupled with an ulnar deviation.⁴
- A volar tensile force leads to failure and propagation of a fracture through the body of the scaphoid to the dorsal surface where compression loading occurs.
- Impingement on the dorsal rim of the distal radius during hyperextension may also contribute to waist fractures.
- Proximal pole scaphoid fractures likely occur from dorsal subluxation during forced hyperextension.
- Less commonly, hyperflexion and axial loads may also produce scaphoid fractures.

NATURAL HISTORY

- The natural history of scaphoid fractures remains integral to treatment strategy.
- Healing potential is fundamentally a function of fracture potential and available vascularity.
 - More proximal fractures have poorer blood supply, leading to decreased healing potential, which can produce nonunion or AVN.
 - Fracture displacement disrupts the blood supply and decreases healing potential.
- Fractures displaced more than 1 mm or angulated more than 15 degrees have an increased risk of nonunion.
- Displaced or untreated scaphoid nonunions will predictably progress to dorsal intercalated segmental instability (DISI) type carpal instability, and eventually scaphoid nonunion advanced collapse (SNAC) arthrosis.
 - In patients with a nonunion, up to 97% will demonstrate arthritic change within 5 years of the injury.⁵
- Risk factors for scaphoid nonunion include delayed treatment, inadequate immobilization, proximal fractures, comminution, and concomitant carpal injuries.⁶

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with acute or subacute scaphoid fractures typically present with a history of a high-energy fall or a wrist hyperextension–type injury.
- Patients present with radial-sided wrist pain, swelling, and loss of range of motion (ROM), most predominantly on dorsiflexion.
- Physical examination signs include the following:
 - Wrist edema over the dorsal/radial aspect of the wrist (occasionally accompanied by ecchymosis)
 - Pain on active or passive extension of the wrist localized to the dorsal/radial aspect
 - Focal pain on palpation within the anatomic snuffbox (space between the first and third extensor compartments at the level of the wrist). Always compare to the contralateral side as this is inherently a tender area.
 - Pain on palpation of the scaphoid tubercle volarly
 - Dorsal/radial wrist pain on resisted extension of the second digit
 - Decreased ROM of the wrist
 - Pain on axial loading of the wrist (scaphoid compression test)

IMAGING

- Radiographs should be obtained on any patient suspected of having a scaphoid fracture.
 - Dedicated scaphoid views should be achieved with the wrist in ulnar deviation, an oblique view, a PA view, a lateral view, and a clenched fist view (allows assessment of dynamic instability of the scapholunate ligament).
 - Approximately 25% of scaphoid fractures are not visible on initial radiographs, posing a diagnostic barrier.
 - Any patient with a high clinical probability of scaphoid injury but a negative plain film series either should be splinted for 10 to 12 days before obtaining repeat films or should undergo more sensitive additional imaging (CT or MRI).
- CT scans taken in the axis of the scaphoid offer additional information regarding the architecture or displacement and have utility in diagnosing acute fractures not seen on plain films. They are also useful in assessing for bony union or nonunion after treatment has been initiated (**FIG 3**).
- MRI is helpful in identifying occult fractures in the acute setting. The addition of gadolinium, as a contrast agent, can be used to assess the vascularity of the proximal pole if there are concerns of AVN.

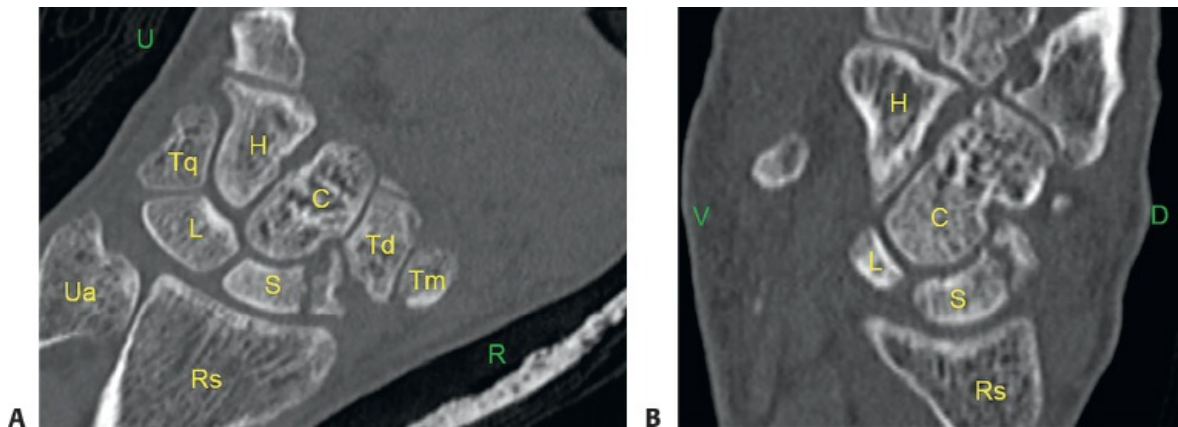


FIG 3 • A. Coronal and **(B)** sagittal CT slices showing a nondisplaced comminuted fracture of the scaphoid waist. Preoperative CT scans can provide additional diagnostic utility especially concerning degree of comminution, and postoperative scans can also allow for superior evaluation of malunion or nonunion. S, scaphoid; L, lunate; Rs, radius; Ua, ulna; C, capitate; H, hamate; Tq, triquetrum; Td, trapezoid; Tm, trapezium; R, radial; U, ulnar; V, volar; D, dorsal.

- A displaced/unstable scaphoid fracture is defined as:
 - Cortical displacement 1 mm or greater
 - More than 10 degrees of angular displacement
 - Comminution at the fracture site
 - Radiolunate angle of more than 15 degrees
 - Scapholunate angle of more than 60 degrees
 - Intrascaphoid angle of more than 35 degrees

DIFFERENTIAL DIAGNOSIS

- Wrist sprain
- Distal radius fracture
- Fracture of other carpal bones
- Ligamentous injury (most commonly, SL)
- Preiser disease (spontaneous AVN of the scaphoid)

NONOPERATIVE MANAGEMENT

- Nonoperative management, in the form of cast immobilization, is effective only in low-risk scaphoid fractures that meet all of the following criteria:
 - Acute fractures (less than 4 weeks old)
 - Nondisplaced
 - Favorable location (distal pole)
- Nondisplaced fractures of the scaphoid waist remain controversial regarding operative vs nonoperative treatment.
 - Nondisplaced waist fractures can be treated nonoperatively with immobilization for 10 to 12 weeks with close follow-up, with union rates as high as 90% in this scenario.¹
 - Patients with a nondisplaced scaphoid waist fracture who wish to mobilize early (highly active persons, athletes, manual workers, or those in high-demand occupations) should undergo operative fixation.
- Nondisplaced and displaced fractures of the proximal pole should be surgically managed to minimize the risk of AVN.
- Splint or cast immobilization should immobilize at least the wrist and thumb CMC but does not need to include the entire thumb.⁷ Above-elbow casting is not needed.
- Nondisplaced distal pole fractures have a high rate of union after cast immobilization for 6 to 8 weeks.
- Union, especially for conservatively treated scaphoid waist fractures, should be assessed with a CT scan to assess for bony bridging at approximately 8 to 10 weeks after the injury.

SURGICAL MANAGEMENT

- Surgical management is best for fractures that are unstable or displaced.
- An open approach is indicated for⁸ the following:
 - Proximal pole fractures
 - A displaced, unstable fracture of the scaphoid waist
 - Associated carpal instability or perilunate instability
 - Associated distal radius fracture. Both fractures can be addressed at one operative time and will allow for early mobility.
- A percutaneous approach is indicated for the following:
 - Nondisplaced fractures of the scaphoid waist
 - A displaced fracture of the scaphoid waist

- Proximal pole fractures
- Percutaneous fixation is technically difficult and has not been shown to have better outcomes. Thus, the authors advocate for an open approach to the scaphoid.
- Both percutaneous and open procedures can be performed from the volar or dorsal approach depending on fracture characteristics.
- In general, fractures of the proximal pole are approached dorsally to allow for antegrade screw fixation and compression across the fracture. This approach maximizes the amount of screw threads distally.
- Scaphoid fractures with associated carpal instability are also approached dorsally to allow for adequate exposure of the proximal carpal row. A K-wire can be placed in the lunate to assist reduction of the proximal scaphoid pole via its attachment through the scapholunate ligament. This assists obtaining and maintaining carpal realignment with scaphoid screw fixation.
- Approaching scaphoid waist fractures, which have a tendency to flex volarly at the fracture site, from the dorsal approach makes reduction more challenging, as the wrist must be flexed to bring the axis of the scaphoid above the dorsal lip of the distal radius. In these cases, a volar approach can be used.

Preoperative Planning

- Imaging studies should be thoroughly reviewed to confirm fracture geometry.
- Required equipment includes
 - K-wires
 - Portable mini-fluoroscopy (“mini C-arm”)

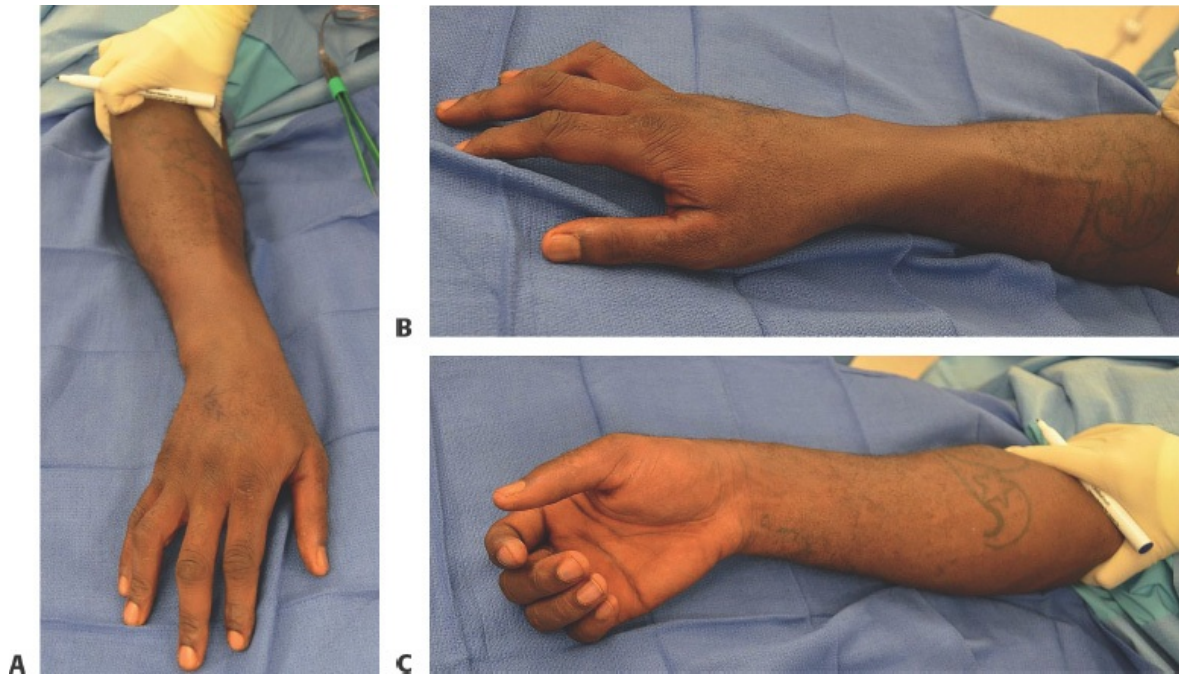


FIG 4 • A. The patient should be positioned supine, with the shoulder abducted to 90 degrees on an arm board. **B,C.** The forearm can then be supinated or pronated depending on the choice of a volar or dorsal approach, respectively.

- Cannulated headless compression screws, in which the differential thread pitch exerts compression across the fracture site¹

Positioning

- Anesthesia should be general or regional.
- The patient should be positioned supine, with the shoulder of the affected upper extremity abducted to 90 degrees on an arm board (**FIG 4**).
- The fluoroscopy unit should be draped and readily available.
- A pneumatic tourniquet should be applied to the proximal upper arm.
- Intravenous antibiotic prophylaxis should be provided prior to tourniquet inflation.
- The upper extremity should be prepped and draped in the standard sterile fashion.
- The upper extremity should then be exsanguinated using an Esmarch bandage, and then the tourniquet should be inflated (to either 250 mm Hg or at least 100

more than systolic blood pressure).

Approach

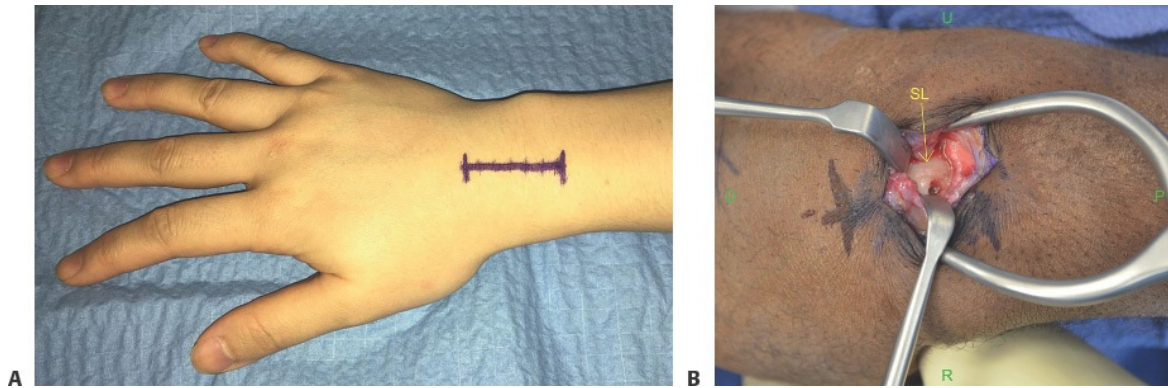
- Scaphoid fractures can be approached from a volar or dorsal approach.

TECHNIQUES

■ Open Reduction and Internal Fixation of Scaphoid Fracture: Dorsal Approach

Exposure

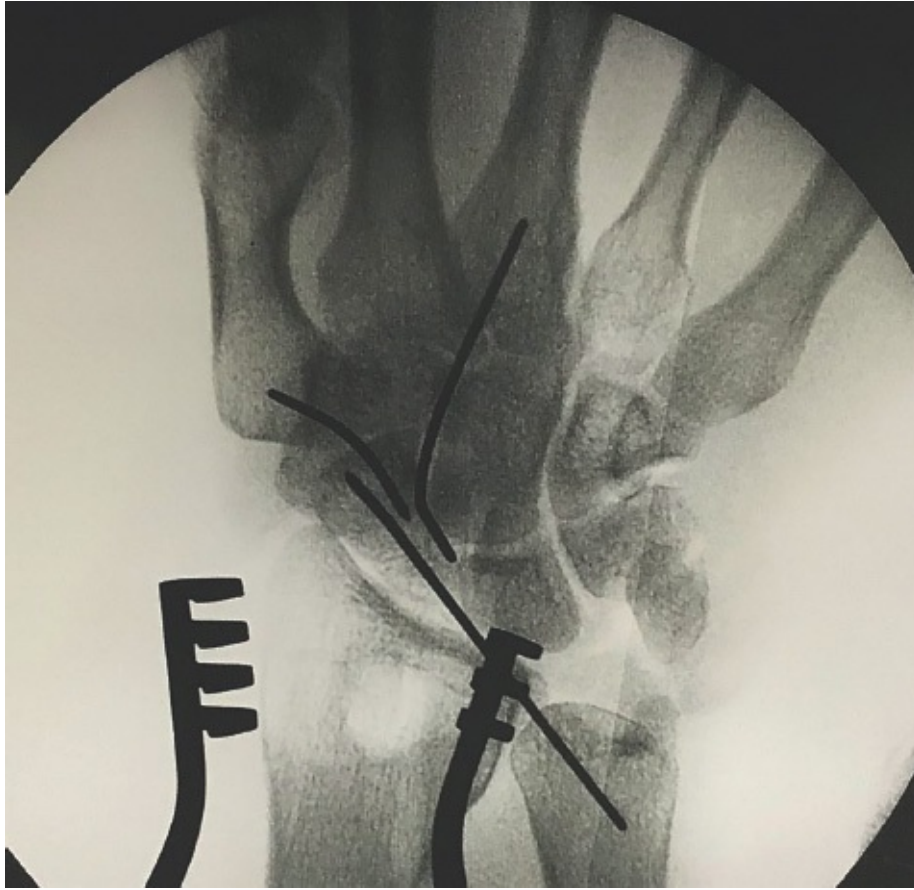
- Make a longitudinal 3- to 4-cm-long incision in the dorsal forearm and hand starting at the ulnar aspect of the Lister tubercle and extending distally (**TECH FIG 1A**).
- Dissect through subcutaneous tissue; elevate skin flaps on either side above level of extensor retinaculum. Identify and protect any crossing radial sensory nerve branches.
- Incise the distal aspect of the extensor retinaculum over the third compartment. Identify the junction of the second and third dorsal compartments.
- Identify and retract EDC ulnarly and ECRB, ECRL, and EPL radially to expose the underlying radiocarpal capsule. The tendons can remain in their compartment but must be identified to avoid inadvertent transection during exposure of the capsule.
- Make a limited capsulotomy to expose the scaphoid. The scaphoid can be approached through a transverse limb just distal to dorsal radius (**TECH FIG 1B**). An inverted T incision can be extended if further exposure is needed.
- Elevate the capsular flap to expose the proximal pole of the scaphoid, the S-L ligament, and the underlying fracture. Be careful to avoid stripping the dorsal ridge vessels entering at scaphoid waist.
- Evacuate fracture hematoma.



TECH FIG 1 • A. Longitudinal approximately 4-cm incision designed along the axis from the Lister tubercle to the long finger metacarpal. This incision is used for a dorsal approach to the scaphoid. **B.** Intraoperative photograph of the dorsal approach depicting scaphoid and intact scapholunate (SL) ligament. Note the position of the buried screw head as well. P, proximal; D, distal; U, ulnar; R, radial.

Fracture Reduction and Fixation

- Apply longitudinal traction on IF and LF to distract the carpus.
- If needed to assist in fracture reduction, insert 0.045-in. K-wires perpendicular into proximal and distal scaphoid fragments (**TECH FIG 2**).
- Reduce fracture; confirm by assessing congruity of radioscaphoid and scaphocapitate articulations.
- Once reduction is confirmed, temporarily fixate with derotational 0.045-in. K-wires. Drill first wire dorsoulnar to central axis of scaphoid, into the trapezium. Drill a second wire, if needed, volar and radial to central axis of scaphoid. Be careful to ensure that derotational wires will not interfere with screw placement and/or prevent compression within the central axis of the scaphoid (see **TECH FIG 2**).



TECH FIG 2 • Inserting 0.045-in. K-wires into proximal and distal fragments to act as “joysticks” may significantly assist in fracture reduction. Also note the placement of a derotational 0.045-in. K-wire for temporary fixation, once the fracture is appropriately reduced. Importantly, this wire should be placed parallel to but not within the central axis of the scaphoid, to avoid interfering with screw placement.

Guidewire Placement

- Guidewire placement should originate at the membranous portion of the origin of the scapholunate ligament. For very proximal fractures, the starting point should be the mid-aspect of the membranous portion of the scapholunate ligament, to be as proximal as possible.
- Flex the wrist, and insert the guidewire down the central axis of the scaphoid. This should be in line with the thumb metacarpal.

- Confirm central axis placement via PA, lateral, and 30-degree pronated lateral radiographs.
- Advance the wire up to the scaphotrapezial joint without entering the joint itself.

Screw Insertion

- Determine screw length via the guidewire. With minimal displacement of the fracture, screw length should be 4 mm shorter than guidewire length to account for the cartilage thickness.
- Advance the guidewire into the trapezium.
- Use the cannulated drill to manually drill over the wire. Be careful to not overdrill the distal scaphoid, which could result in screw migration into the scaphotrapezial joint.
- Remove the drill and insert the screw along the central axis of the scaphoid.
- Remove the guidewire.
- Confirm screw position via radiographs (**TECH FIG 3**).
- Close the radiocarpal capsule and then the extensor retinaculum if completely released, then skin.



TECH FIG 3 • Final confirmation of appropriate screw position via PA (**A**), lateral (**B**), and 30-degree pronated lateral (**C**) radiographs. Note the screw positioning lies within the scaphoid cortex on all views, reducing the chance of undesired prominence.

■ Open Reduction and Internal Fixation of Scaphoid Fractures: Volar Approach

Exposure

- Palpate the tubercle of the scaphoid after radially deviating the wrist.
- Design a 3- to 4-cm incision centered over the palpated tubercle, extending proximally over the FCR tendon sheath and distally over the base of the thumb.
- Incise the FCR sheath and retract the tendon ulnarly, exposing underlying volar wrist capsule.
- Distally, divide thenar muscles over the distal scaphoid and trapezium.
- Incise the volar wrist capsule longitudinally, avoiding injury to the articular cartilage.
- Divide the radiolunate and radioscapnocapitate ligaments in the proximal field to visualize the proximal pole of the scaphoid.
- Use a Freer elevator to expose the scaphotrapezial joint. Limit dissection over the radial scaphoid to avoid injury to dorsal vessels.
- Evacuate fracture hematoma and irrigate.

Fracture Reduction and Fixation

- Apply longitudinal traction to the wrist and reduce the fracture. Consider using pointed reduction forceps or placing 0.045-in. K-wires into proximal and distal scaphoid fragments to assist in reduction.
- Place provisional 0.045-in. K-wire, starting from volar distal to dorsal proximal, for temporary fixation. Ensure the trajectory is not along the central axis of the scaphoid.
- To expose starting position for screw placement dorsally, resect small portion of proximal volar trapezium.
- Place central axis guidewire.
- Determine screw length via the guidewire. With minimal displacement of the fracture, screw length should be 4 mm shorter than guidewire length to account for the cartilage thickness.
- Advance the guidewire into the radius.
- Use the cannulated drill to manually drill over the wire.
- Insert the cannulated screw along the central axis; confirm via PA, lateral, and 30-degree pronated lateral radiographs.

- Repair radiolunate and radioscapohcapitate ligaments.
- Close the volar wrist capsule, then skin.

PEARLS AND PITFALLS

Preservation of scaphoid blood supply

- Avoid dissection on the dorsal ridge of the scaphoid.
- Limit dissection of capsule.

Guidewire positioning

- During dorsal approach, pronate and flex the wrist to ensure appropriate trajectory.
- During volar approach, resect small volar lip of trapezium to expose starting position in distal pole of scaphoid.
- Ensure the guidewire is placed along the central axis.

Screw position

- Assess screw length and prominence intraoperatively via 45-degree supination oblique and pronated oblique radiographs.
- Screw length should be 4 mm shorter than measured length.
- Stop drilling 2 mm short of the distal pole when using the dorsal approach.
- Place the screw in the central axis.
- Bury the headless compression screw beneath the cortical surface of the scaphoid to prevent screw prominence and cartilage erosion.

Small proximal pole fracture

- Consider a smaller screw such as Acutrak Mini to prevent proximal fragment comminution.

Unstable fracture reduction

- Place perpendicular joystick K-wires into proximal and distal fragments to aid in reduction.
- Stabilize fragments prior to screw insertion via derotational K-wires.

POSTOPERATIVE CARE

- Patients should be placed in a volar thumb spica splint.
- Patients should strictly elevate at home to reduce edema and pain.
- Frequent ROM exercises of the digits are crucial to prevent unwanted stiffness.

- At 2 weeks postoperatively, patients should return for suture removal and exchange to a removable forearm-based thumb spica splint. ROM exercises of the thumb are started at this point.
- Fractures that involve the proximal pole, or fractures with significant comminution, should be immobilized for 6 to 10 weeks.
- Radiographs should be taken at the 2-, 6-, and 12-week postoperative time points to assess for fracture healing (**FIG 5**).
- CT scans can be considered to better assess for fracture union at 12 weeks or later if there are concerns about healing.

OUTCOMES

- Outcomes depend on type of treatment, timing of treatment, and location of screw placement.
- A recent systematic review concluded that internal fixation reduces the risk of nonunion compared with cast immobilization (1.7% vs 10%, respectively). However, the two treatments did not differ in terms of eventual postoperative pain, tenderness, long-term grip strength, ROM, functional outcome, and satisfaction, although internal fixation may produce quicker return to function and transiently improved ROM and grip strength.⁹
- Rigid internal fixation theoretically allows for earlier physical therapy, lesser time to union, improved ROM, and quicker functional recovery. This has been corroborated by studies that have showed high rates of union and good overall outcomes using open techniques¹⁰ (**FIG 6**).
- Time to initiation of treatment highly influences union rates:
 - Scaphoid fractures treated before 4 weeks have a significantly higher union rate than do those treated after 4 weeks.¹¹
 - Nondisplaced fractures casted within 3 weeks of injury have a 90% to 100% union rate,¹² whereas those casted between 6 weeks and 6 months from injury demonstrate a 90% union rate, but approximately twice as long duration to achieve a union.¹³
- Central screw placement exhibits more rapid progression to union, in cases of scaphoid nonunion.¹⁴



FIG 5 • A: PA and **(B)** lateral PA and lateral radiographs showing reduced, internally fixed, and united scaphoid waist fracture at roughly 3 months postoperatively.



FIG 6 • Early outcome (at 12 weeks postoperatively) depicting intact grip and wrist flexion/extension.

COMPLICATIONS

- Screw prominence, erosion of the scaphotrapezial articulation, and erosion of the distal radius articular surface are possible if the screw length is not accurately estimated intraoperatively.
- Displaced waist and proximal pole fractures can lead to nonunion and potential AVN.
- Rare but potential other complications include wound infections, hypertrophic scarring, injury to sensory branch of radial nerve, and damage to scaphotrapezial articulation.

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Scaphoid Nonunion: Nonvascularized Bone Reconstruction

18

CHAPTER

Matthew L. Iorio and Jason H. Ko

DEFINITION

- Scaphoid nonunion is defined as failure to heal within 6 months. The incidence of scaphoid nonunion is between 4% and 50%.
 - Nonunion may be evidenced by pain and tenderness at the anatomic snuffbox and scaphoid tubercle, and decreased wrist extension.
- Radiographs demonstrate a wide, sclerotic fracture cleft, potentially with cyst formation (**FIG 1**).
- Unstable nonunions demonstrate loss of the normal length and shape of the scaphoid, often with a dorsal intercalated segmental instability (DISI) deformity.
- When not corrected, carpal instability ensues, and a predictable pattern of degenerative changes known as scaphoid nonunion advanced collapse (SNAC) arthritis occurs.
- The preferred treatment for scaphoid nonunions is internal fixation with autologous bone grafting.
- Nonvascularized bone grafts have been the traditional treatment for scaphoid nonunion, although avascular necrosis (AVN) of the proximal pole is an indication for the use of vascularized bone grafts.

ANATOMY

- Seventy to 80% of the intraosseous vascularity comes from the dorsal scaphoid branches of the radial artery, entering through the dorsal ridge. These dorsal vessels enter the scaphoid waist in a retrograde direction, providing the single dominant intraosseous vessel to the proximal pole of the scaphoid.

- A minor volar contribution comes from radial artery or its superficial palmar branch, which gives off several volar scaphoid branches at the level of the radioscaphoid joint, entering the bone at its distal tubercle.



FIG 1 • Scaphoid waist nonunion characterized by a wide sclerotic fracture cleft with no evidence of bony healing.

- Because of this unique vascular anatomy, the proximal pole of a fractured scaphoid is particularly prone to AVN, especially when the fragment is small.
- A nonunion through the scaphoid waist can lead to progressive flexion of the distal pole and extension of the proximal pole, leading to a “humpback deformity.”
- Treatment and surgical approach will be influenced by whether or not a humpback deformity or DISI deformity is present.
- A proximal pole nonunion will not typically develop a humpback deformity; however, the risk of AVN is higher.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Injury typically involves axial load across a hyperextended and radially deviated wrist.
- Tenderness can typically be found over the distal pole of the scaphoid volarly or along the proximal pole dorsally within the interval between the first and

third extensor compartments.

- Ulnar-to-radial wrist deviation with pressure over the volar scaphoid pole may cause increased pain, as will active assist wrist flexion or extension or resisted pronation.

IMAGING

- Anteroposterior, oblique, and lateral radiographs of the scaphoid should be obtained.
 - Standard scaphoid view involves 30 degrees of wrist extension and 20 degrees of ulnar deviation.
 - Stress views with the fist tightly clenched may demonstrate dynamic instability of the scaphoid or nonunion site.
- Computed tomography (CT) with fine cuts may be beneficial in further characterizing the nonunion site, as well as associated humpback deformity, cyst formation, osteophytosis, and degenerative arthrosis.
 - Increased proximal pole sclerosis or density on imaging may indicate AVN, which, depending on the location of the nonunion, may limit both the ability to obtain viable bone margins as well as reliable fixation and osseous union.
- Magnetic resonance imaging can be used to assess for AVN of the scaphoid proximal pole.
- Evaluation of a potential degenerative posture or malunions of the scaphoid should be measured and documented as part of the initial evaluation. There is some debate as to which is superior in interobserver reliability, though they both function to evaluate deviations of scaphoid posture from a normative comparison in the setting of humpback deformity and collapse.
 - A lateral intrascaphoid angle is obtained by drawing a line perpendicular to the proximal and distal articular surfaces.
 - A normal lateral intrascaphoid angle is 24 ± 5 degrees or less than 3 degrees.¹
 - Increasing flexion results in a humpback deformity, with a lateral intrascaphoid angle greater than 35 degrees.
 - The scaphoid height-to length ratio is evaluated on a lateral or sagittal image. A normal ratio is 0.60 ± 0.04 .
 - For scaphoid length, a baseline is drawn along the volar scaphoid, and the length of the scaphoid is found from the most proximal to the most distal aspect.

- For scaphoid height, the maximum height of the scaphoid was found on a line perpendicular to the baseline.

SURGICAL MANAGEMENT

- Nonvascularized bone graft reconstruction should be considered for the treatment of all scaphoid fracture nonunions that demonstrate no incidence of AVN of the proximal pole.
- Contraindications
 - Progressive pan-carpal arthrosis can follow prolonged scaphoid nonunions in a predictable pattern: SNAC wrist deformity.
 - The presence of radiocarpal or midcarpal sclerosis, with cyst formation, may indicate advanced disease with continued postoperative pain. In this instance, salvage procedures including proximal row carpectomy, limited intercarpal arthrodesis, or total wrist arthrodesis may be more reliable in regard to pain control.
 - Relative contraindications include the patient's suitability for surgery, smoking status, and understanding of the need for prolonged postoperative immobilization and use restrictions.

Positioning

- The patient is positioned supine on the operating room table with a well-padded tourniquet placed on the upper arm.
- General anesthesia or monitored anesthesia care (MAC) can be used, but supplementation with an infraclavicular or interscalene nerve block may markedly improve postoperative pain control.

Approach

- If a humpback deformity is present, a volar approach is used, which provides excellent exposure to the waist and distal pole of the scaphoid.
 - It also provides direct access to the extension osteotomy wedge for direct bone grafting and stabilization.
 - It may be possible that this exposure, by preserving the dorsal ridge vessel, may prevent iatrogenic devascularization of the scaphoid.
- If there is no humpback deformity, a dorsal or volar approach can be used, based on the location of the nonunion. Dorsal approaches are preferred for more proximal nonunions, and volar approaches are preferred for more distal nonunions.

- Either a volar or dorsal approach can be used with a waist nonunion without a humpback deformity.

TECHNIQUES

■ Scaphoid Bone Grafting: Volar Approach

Exposure and Preparation of the Site

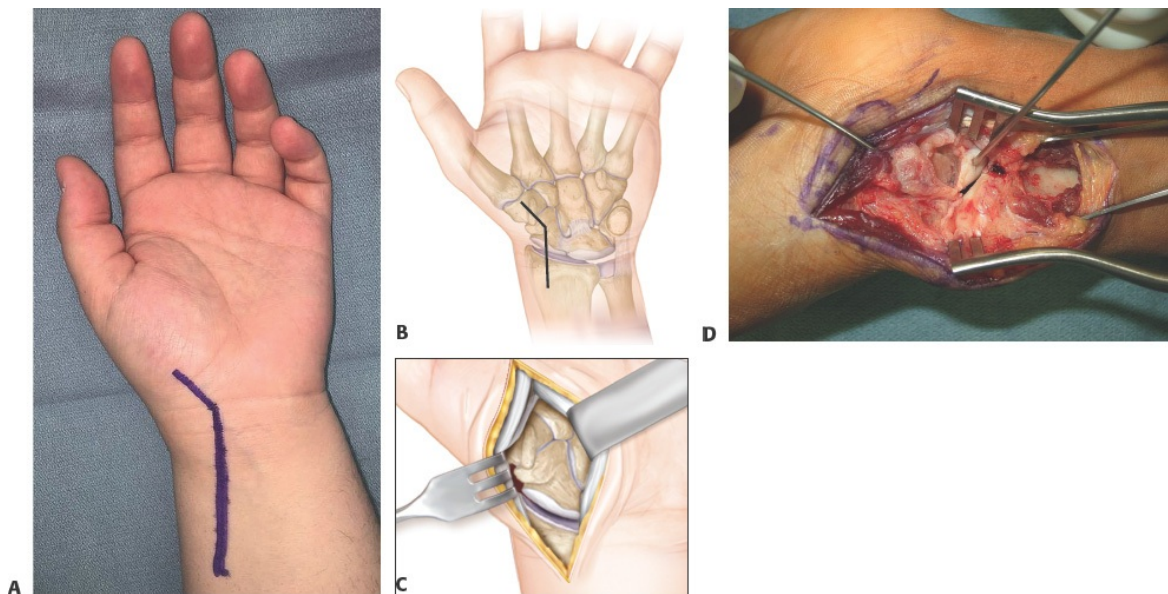
- Under tourniquet control and loupe magnification, a longitudinal incision is made in-line with the flexor carpi radialis (FCR) to the level of the proximal wrist crease, followed by a 60-degree angle at the volar junction of the glabrous skin. This will protect the radial artery and prevent a longitudinal scar across the flexor crease. This is also referred to as the Russe approach (**TECH FIG 1A–C**).
- The deep branch of the radial artery is visualized, and retracted radially.
- An intrasubstance longitudinal incision in the radioscaphocapitate (RSC) ligament can be created for exposure of the volar scaphoid. The incision and exposure should be at least distal to the scaphotrapezium joint, for preparation and visualization of screw placement.
- Following visualization of the scaphoid, 0.045-in. (or larger) K-wires may be placed proximal and distal to the fracture as “joysticks” to retract and see, and correct any humpback deformity that may be present (**TECH FIG 1D**).
- In the event of a malunion, an osteotomy can be performed; however, this should be done judiciously. We recommend only crossing 80% to 90% of the scaphoid waist with the osteotome to prevent penetration of the dorsal cortex and injury to the scaphocapitate joint or the dorsal ridge vessel.
- Disruption of the dorsal scaphoid can create an unstable fracture or make cancellous bone graft placement less secure.
- Following exposure, the nonunion site must be cleared of intervening fibrous material and necrotic bone, but viable cancellous bone should remain. A small dental pick or curette can be useful in this setting.

Obtaining Bone Graft

- If volar distal radius autograft is to be used, the pronator quadratus is incised and dissected subperiosteally to expose the volar cortex of the distal radius

(TECH FIG 2A).

- The site of bone graft harvest should be confirmed with intraoperative fluoroscopy, being careful not to harvest graft too close to the radiocarpal joint.
- A structural corticocancellous bone graft can be obtained either with straight and curved osteotomes or with an oscillating saw.
 - If a saw is used, saline irrigation should be applied during the osteotomies to minimize thermal injury to the bone (**TECH FIG 2B,C**).
- Through the aforementioned cortical window, cancellous autograft can be harvested.
- For most scaphoid nonunions without AVN, distal radius autograft is sufficient.
 - However, iliac crest autograft is the traditional standard for scaphoid nonunion treatment. The anterosuperior iliac spine (ASIS) is palpated, and bone graft should be harvested 2 cm posterior to the ASIS.



TECH FIG 1 • A–C. A volar Russe incision along the FCR tendon with an oblique extension over the scaphoid distal pole provides access to the volar scaphoid. **D.** Through this volar approach, 0.054-in. Kirschner wires used to joystick open the scaphoid fracture nonunion site, correcting the humpback

deformity.

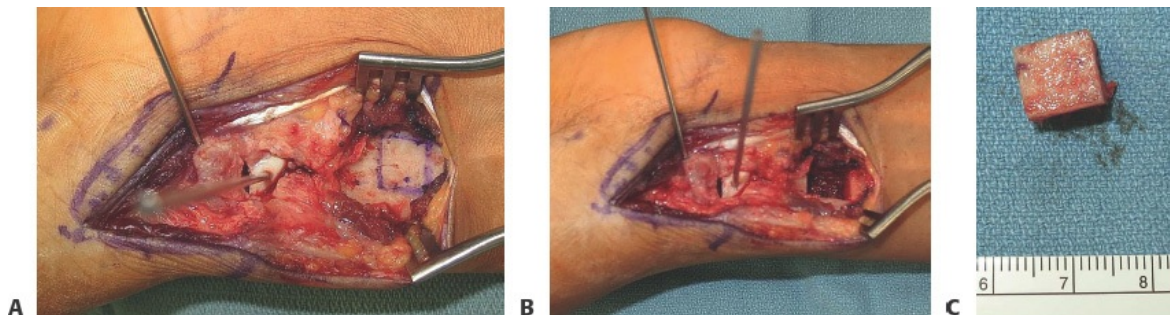
- The skin incision is made posterior to the ASIS, and dissection should proceed with monopolar cautery directly down to the iliac crest.
- Bicortical grafts from the inner table or outer table, or tricortical grafts, can be obtained, typically with an oscillating saw.

Stabilizing the Site

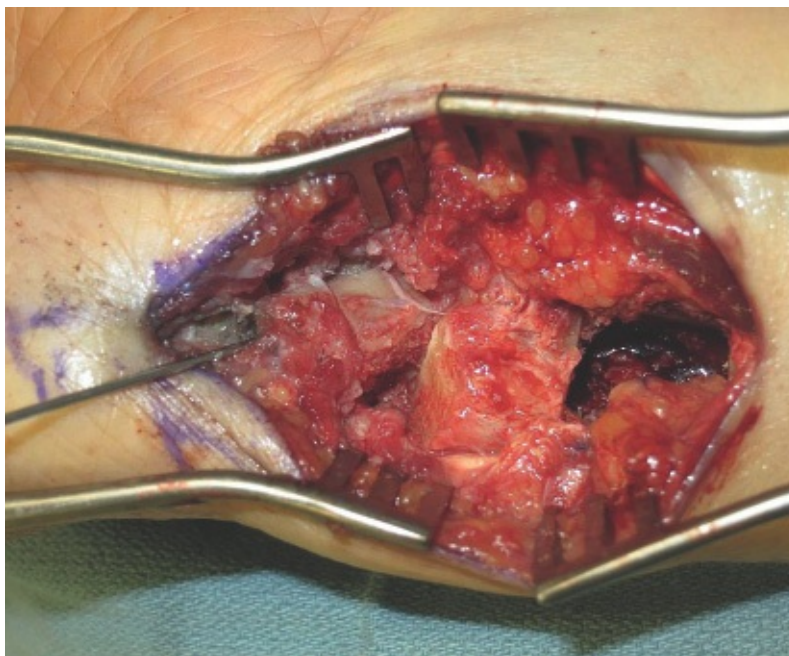
- The nonunion site can then be stabilized by either progressively packing either corticocancellous or cancellous graft into the site, effectively expanding the space and increasing the extension of the distal pole.
- K-wire joysticks can be used to provide an extension force through the fracture, and a longitudinal K-wire can be placed to provide a mechanical restraint to flexion.
 - In our experience, a combination of the two may work best, where the extension is corrected with the K-wires and stabilized longitudinally as best as possible and confirmed with fluoroscopy.
- This wire should be placed slightly off axis to avoid the ultimate trajectory of compression screw placement and directly capture the bone graft.
 - Alternatively, the wire can be placed slightly volar to the bone graft to prevent extrusion during compression.
- If a large cortical defect volarly is present in the extension wedge, a bone graft can be tailored to slightly overfill the space.
 - The longitudinal wire is then backed out just proximal to the fracture, the graft is press fit into the space, and the wire is readvanced (**TECH FIG 3**).

Scaphoid Fixation

- Osteosynthesis is then completed, most frequently with either K-wire or compression screw placement.



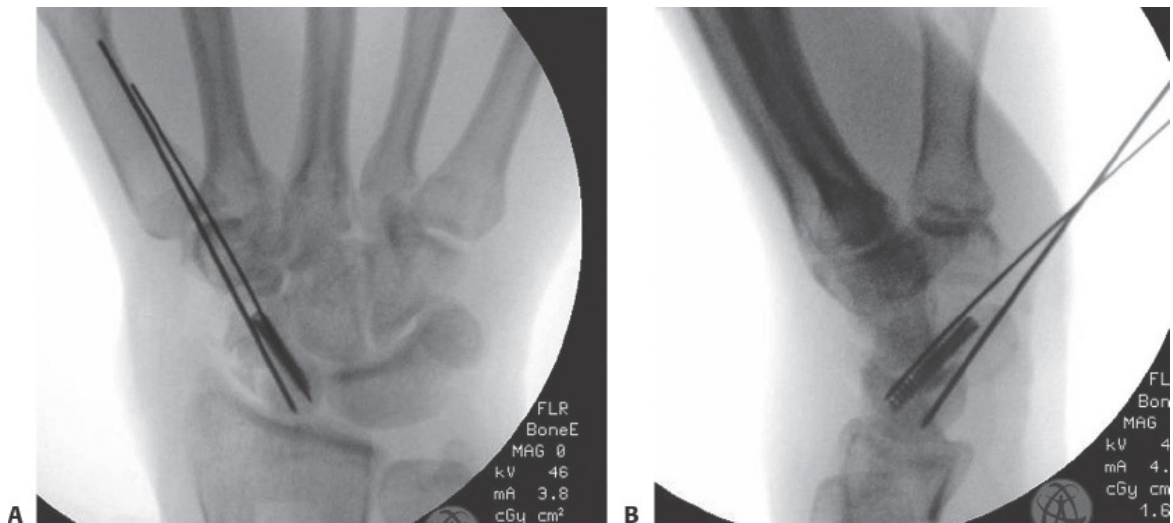
TECH FIG 2 • A. The pronator quadratus has been elevated subperiosteally off the volar surface of the distal radius. The purple markings are used to plan the osteotomies, which were confirmed with intraoperative fluoroscopy. **B,C.** A corticocancellous autograft is harvested from the volar distal radius. This type of graft can be used as a structural graft to correct a humpback deformity.



TECH FIG 3 • Corticocancellous autograft is press-fit into the scaphoid nonunion through a volar approach.

- For compression screw placement from the volar scaphoid, the guidewire can be advanced through either the trapeziometacarpal joint or scaphotrapezial joint, with similar outcomes.
- In the scaphotrapezial approach, however, the volar beak or footplate of the trapezium should be first removed with a rongeur to prevent off-axis screw placement.
- The stabilizing K-wire should be left in place or repositioned if it is blocking the guidewire, to provide rotational control during drilling and compression.

- Following placement of the guidewire, the drill should be advanced with the aid of fluoroscopy to prevent penetration of the far cortex, as this may destabilize the distal screw and lead to screw loosening.
- Screw selection then is performed by drilling to the distal subchondral bone, measuring based off the guidewire, and selecting a screw length 4 to 6 mm shorter than the measured length to ensure that the screw is adequately buried in subchondral bone proximally, without distal extrusion.
- Depending upon the manufacturer, there may be several screw widths to choose from, typically between 2 and 3 mm. This becomes relevant in either revising a prior attempt to heal an acute fracture with a compression screw or expectations in need for nonunion revision. That is, if the widest screw is chosen as the initial fixation and it fails, compression screw fixation may not be an option for salvage given the subsequent bone loss and instability. Therefore, initial fixation should be performed with a narrower screw, in case future revision with a wider screw can be performed (**TECH FIG 4**).

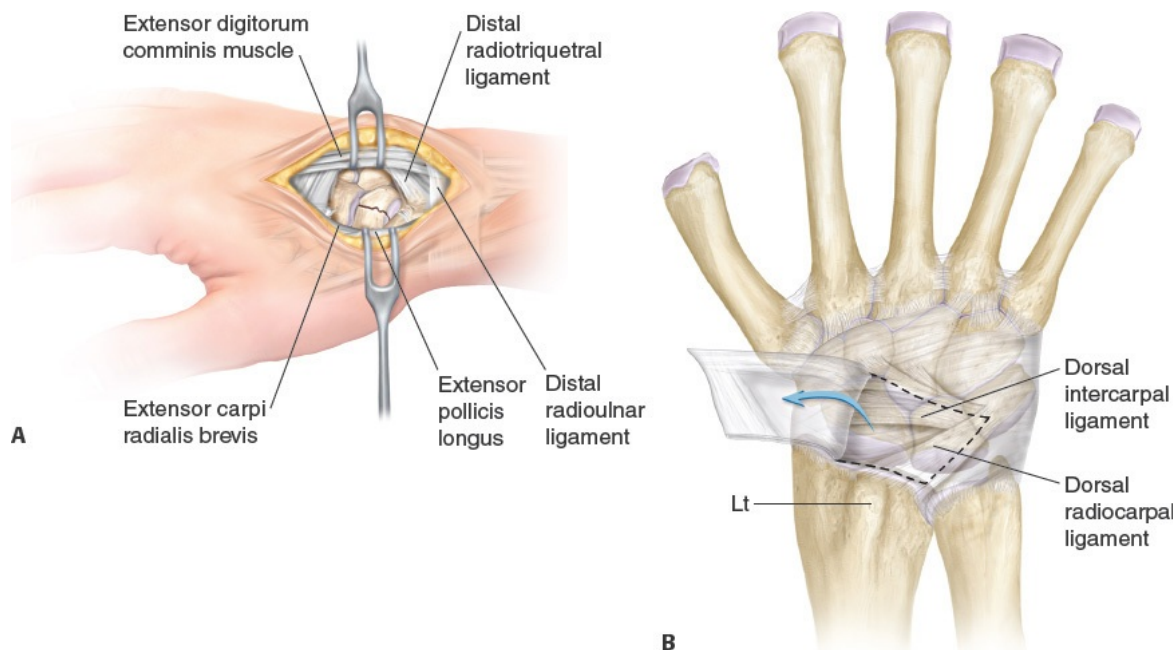


TECH FIG 4 • AP and lateral intraoperative fluoroscopic views of a headless compression screw to provide compression across the corticocancellous bone graft reconstruction. The radial K-wire in the AP view is used as a derotational pin, and the volar K-wire on the lateral view is used to further stabilize the small bone graft.

■ Scaphoid Bone Grafting: Dorsal Approach

Exposure and Preparation of the Site

- Under tourniquet control and loupe magnification, a longitudinal incision is made just ulnar to the Lister tubercle (**TECH FIG 5A**).
- A longitudinal cut or step-cut is made through the extensor retinaculum.
- The third dorsal compartment is released, and the EPL tendon is retracted radially.
- Subperiosteal dissection of the second and fourth dorsal compartments is performed to expose the dorsal distal radius.
- The posterior interosseous nerve (PIN) is located in the floor of the fourth compartment, and during the dorsal wrist approach, a PIN neurectomy can be performed to help minimize postoperative pain.
- A ligament-sparing capsulotomy or longitudinal capsulotomy is performed through the dorsal wrist capsule to expose the proximal scaphoid (**TECH FIG 5**).



TECH FIG 5 • A. A dorsal longitudinal incision just ulnar to the Lister tubercle will give the surgeon access to both the scaphoid nonunion and the dorsal distal radius bone graft site. **B.** A ligament-sparing

capsulotomy is performed parallel to the dorsal intercarpal (DIC) and dorsal radiocarpal (DRC) ligaments, along with a radial extension.

- The nonunion site is exposed and fibrous tissue removed until healthy-appearing cancellous bone is visualized both proximally and distally.
- Care is taken not to disrupt the scapholunate interosseous ligament during the procedure.

Scaphoid Fixation

- As described above, K-wires can be used as joysticks to gain control of the proximal and distal poles, and corticocancellous or cancellous autograft can be packed into the nonunion site.
- Fixation is achieved by headless compression screw, as described above. The derotational K-wire can be left in for temporary fixation.
- In proximal pole nonunions, if there is minimal bone proximally, screw fixation may not be possible, in which case, definitive fixation may be performed with K-wires.
- Allograft bone chips can be used to pack the bone graft donor site.
- With the volar approach, it is important to reapproximate the radioscaphocapitate ligament if it was cut during the procedure. This can be performed with 3-0 polyglactin suture.
- If volar distal radius bone graft was harvested, the pronator quadratus does not need to be repaired.

Closure

- The dorsal capsule is carefully closed with an absorbable suture, such as a 3-0 poliglecaprone-25 or polyglactin suture. The extensor retinaculum is closed with similar 3-0 suture, leaving the extensor pollicis longus tendon superficial to the retinaculum.
 - Depending upon the volume of expected postoperative edema and skin quality, the skin is closed with either deep dermal stitches and a running subcuticular or horizontal mattress stitches with 4-0 nylon.
 - The wrist is immobilized in a well-padded plaster short-arm spica splint.
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PEARLS AND PITFALLS

Scaphoid preparation

- Degeneration of the radioscaphoid facet or post-traumatic arthrosis may predispose to ongoing pain and stiffness and should be considered a potential contraindication to scaphoid salvage techniques.

Distal radius bone graft harvest

- It is important to harvest bone graft 1 cm proximal to the radiocarpal joint to prevent injury.

PIN neurectomy

- During the dorsal wrist approach, the PIN can be identified in the floor of the fourth dorsal compartment and excised to help minimize postoperative pain.

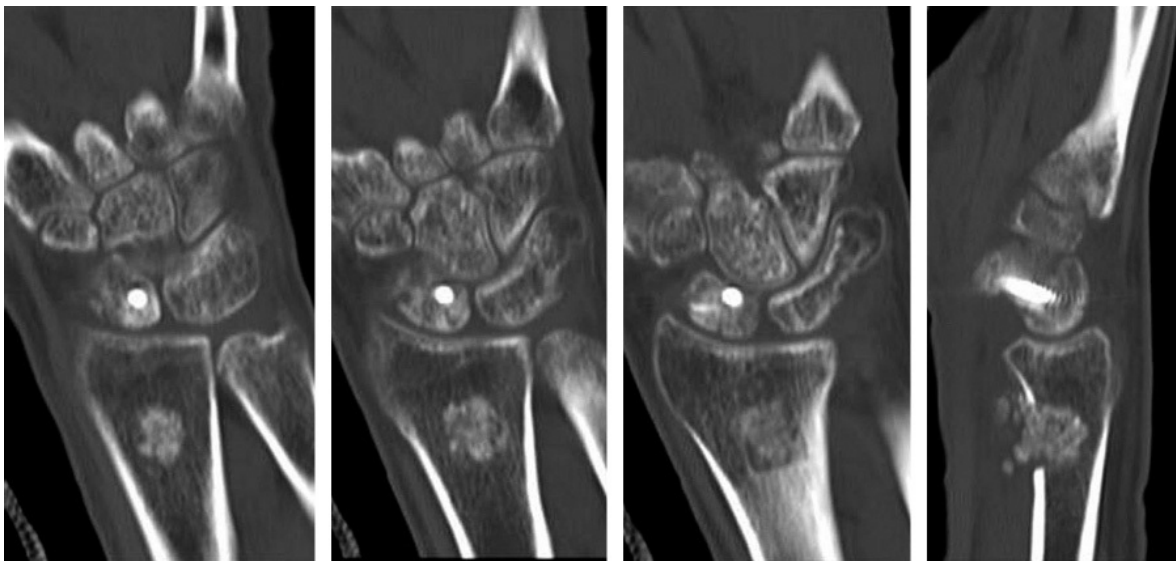


FIG 2 • CT scans obtained 6 weeks postoperatively after volar distal radius corticocancellous reconstruction of a scaphoid waist nonunion demonstrate healing across the proximal and distal autograft sites.

POSTOPERATIVE CARE

- The patient is placed in a well-padded thumb spica splint. At 2 weeks, the splint and stitches are removed and a thumb spica cast is applied.
- Casting is typically continued for a total of 10 to 12 weeks, with cast changes

at 3- to 4-week intervals.

- X-rays should be obtained at each postoperative visit. CT scans can be obtained at the surgeon's discretion any time after 6 weeks postoperatively to determine extent of union (**FIG 2**).
- Exposed K-wires should be removed near 3 to 4 weeks to prevent pin site infections and possible bacterial colonization of the nonunion site. Buried wires can be removed in the office or operating room once union is verified.
- Osseous union is identified by bridging trabeculae on radiographs and absence of fracture site tenderness (**FIG 3**).

OUTCOMES

- In 1936, Matti described the original technique using an iliac crest corticocancellous bone strut as an inlay through a dorsal approach. Russe later offered a modified technique done via a volar approach to spare the blood supply and correct volar collapse. This technique demonstrated union rates ranging from 81% to 97%.²
- The Fisk-Fernandez technique employs a triangular or trapezoidal corticocancellous wedge from the iliac crest or distal radius that is placed as an intercalary structural graft to restore scaphoid length and correct carpal alignment. Such wedge-grafting techniques have demonstrated improved union rates when compared to Matti-Russe inlay grafting technique.³⁻⁶



FIG 3 • Routine x-rays at 10 months postoperatively demonstrate complete healing of the scaphoid

nonunion reconstruction, with pain-free range of motion.

- Sayegh and Strauch performed a systematic review comparing cancellous-only and corticocancellous grafts, reporting cancellous-only grafts provided a shorter interval to union, but corticocancellous grafts were associated with consistent deformity correction and improved Mayo wrist scores.⁷

COMPLICATIONS

- The most common complication is superficial wound or pin site infection, nerve irritation, and complex regional pain syndrome (1.25%).^{8,9}

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Scaphoid Fracture

Nonunion: Vascularized Bone Reconstruction

19

CHAPTER

Matthew L. Iorio and Jason H. Ko

DEFINITION

- Scaphoid fractures are among the most common upper extremity fractures, accounting for 70% of all carpal bone fractures.¹
- Although most scaphoid fractures heal with nonoperative management, the tenuous blood supply of the scaphoid can lead to nonunion in 5% to 10% of cases even with appropriate treatment, and up to 55% of cases when there is displacement on initial injury (**FIG 1**).^{2,3}
- The complications of scaphoid nonunion vary widely, from pain and decrease in function to carpal malalignment, progressive arthrosis, and eventual scaphoid nonunion advanced collapse (SNAC) (**FIG 2**).^{3,4}
- To prevent such complications, surgical advances have been developed to treat scaphoid nonunions, including screw fixation, bone grafting, and, most recently, vascularized bone grafting.⁵
- Vascularized bone grafts (VBGs) have been shown to promote healing and realignment of recalcitrant scaphoid nonunions in addition to re-establishing blood flow in cases with avascular necrosis (AVN).⁶



FIG 1 • Chronic scaphoid waist nonunion with tapered cortical edges.

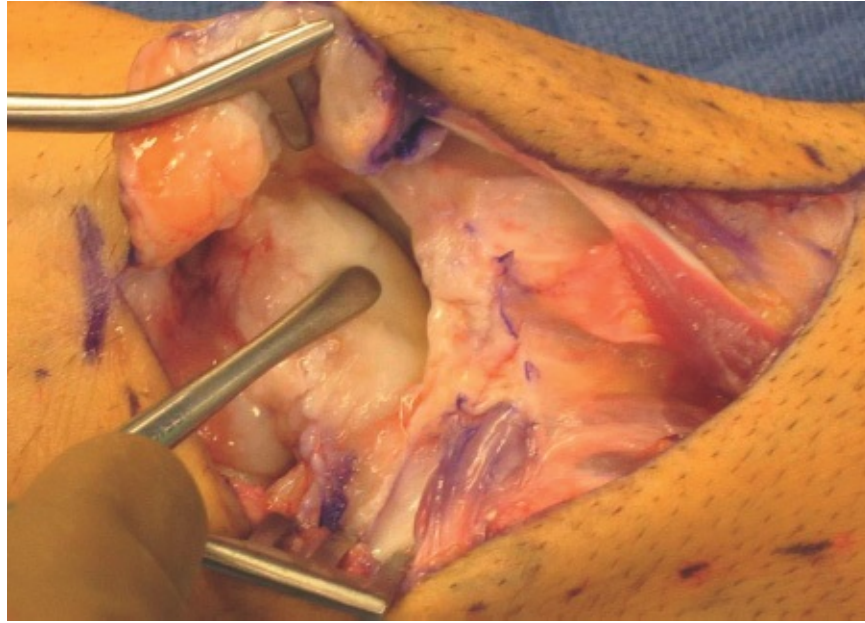


FIG 2 • Radiocarpal joint with avascular proximal scaphoid pole and cartilage fragmentation (Freer elevator).

ANATOMY

- Seventy to 80% of the intraosseous vascularity comes from the dorsal scaphoid branches of the radial artery, entering through the dorsal ridge. These dorsal vessels enter the scaphoid waist in a retrograde direction, providing the single dominant intraosseous vessel to the proximal pole of the scaphoid.
- A minor volar contribution comes from the radial artery or its superficial palmar branch, which gives off several volar scaphoid branches at the level of the radioscapoid joint, entering the bone at its distal tubercle.
- Because of this unique vascular anatomy, the proximal pole of a fractured scaphoid is particularly prone to AVN, especially when the fragment is small.
- Progressive collapse and flexion through the nonunion cause dorsal rotation of the lunate or subluxation of the midcarpal joint leading to a DISI deformity (dorsal intercalated segment instability).

PATIENT HISTORY

- Injury typically involves axial load across a hyperextended and radially deviated wrist.
- Tenderness can typically be found over the volar pole of the scaphoid or along

the dorsal pole within the interval between the first and third extensor compartments.

- Ulnar-to-radial wrist deviation with pressure over the volar scaphoid pole may cause increased pain, as will active assist wrist flexion or extension or resisted pronation.

IMAGING

- Anteroposterior, oblique, and lateral radiographs of the scaphoid should be obtained.
- Standard scaphoid view involves 30 degrees of wrist extension and 20 degrees of ulnar deviation.
- Stress views with the fist tightly clenched may demonstrate dynamic instability of the scaphoid or nonunion site.
- Computed tomography (CT) with fine cuts may be beneficial in further characterizing the nonunion site, as well as associated collapse, cyst formation, osteophytosis, and degenerative arthrosis.
 - Increased proximal pole sclerosis or density on imaging may indicate AVN, which, depending on the location of the nonunion, may limit both the ability obtain viable bone margins as well as reliable fixation and osseous union.
- Magnetic resonance imaging can be used to assess for AVN of the scaphoid proximal pole.
- Evaluation of a potential degenerative posture or malunions of the scaphoid should be measured and documented as part of the initial evaluation. There is some debate as to which is superior in interobserver reliability, though they both function to evaluation deviations of scaphoid posture from a normative comparison in the setting of humpback deformity and collapse.
- A lateral intrascaphoid angle is obtained by drawing a line perpendicular to the proximal and distal articular surfaces.
 - A normal lateral intrascaphoid angle is 24 ± 5 degrees, or less than 3 degrees.
 - Increasing flexion results in a humpback deformity, with a lateral intrascaphoid angle greater than 35 degrees.
- The scaphoid height-to-length ratio is evaluated on a lateral or sagittal image. A normal ratio is 0.60 ± 0.04 .
 - For scaphoid length, a baseline is drawn along the volar scaphoid, and the length of the scaphoid is found from the most proximal to the most distal aspect.

- For scaphoid height, the maximum height of the scaphoid was found on a line perpendicular to the baseline.

SURGICAL MANAGEMENT

- Harvest of the osteocutaneous medial femoral condyle (MFC) microvascular flap provides simultaneous soft tissue and bone for reconstruction, ease of soft tissue recipient closure, and the ability to provide accurate postoperative monitoring of the microcirculation of the flap. Its routine use requires an understanding of the arterial variation of the descending geniculate arterial tree, as well as the blood supply to the overlying skin of the medial aspect of the knee.
- The free MFC corticoperiosteal flap has garnered increasing attention due to its many desirable attributes, including ease of dissection, surgical positioning facilitating a two-team approach, low donor-site morbidity, preservation of all major arteries to the distal extremity, variable size and shape for harvest and in-setting, and osteogenic potential.⁷

Contraindications

- Progressive pan-carpal arthrosis can follow prolonged scaphoid nonunions in a predictable pattern: SNAC wrist deformity.
- The presence of radiocarpal or midcarpal sclerosis, with cyst formation, may indicate advanced disease with continued postoperative pain. In this instance, salvage procedures, including proximal row carpectomy, limited intercarpal arthrodesis, or total wrist arthrodesis, may be more reliable for pain control.
- Relative contraindications include the patient's suitability for surgery, smoking status, and understanding of the need for prolonged postoperative immobilization and use restrictions.

Positioning

- The patient is placed supine on the operating room table, and a well-padded tourniquet is placed on the upper arm.
- General anesthesia or monitored anesthesia care (MAC) can be used, but supplementation with an infraclavicular or interscalene nerve block may markedly improve postoperative pain control.

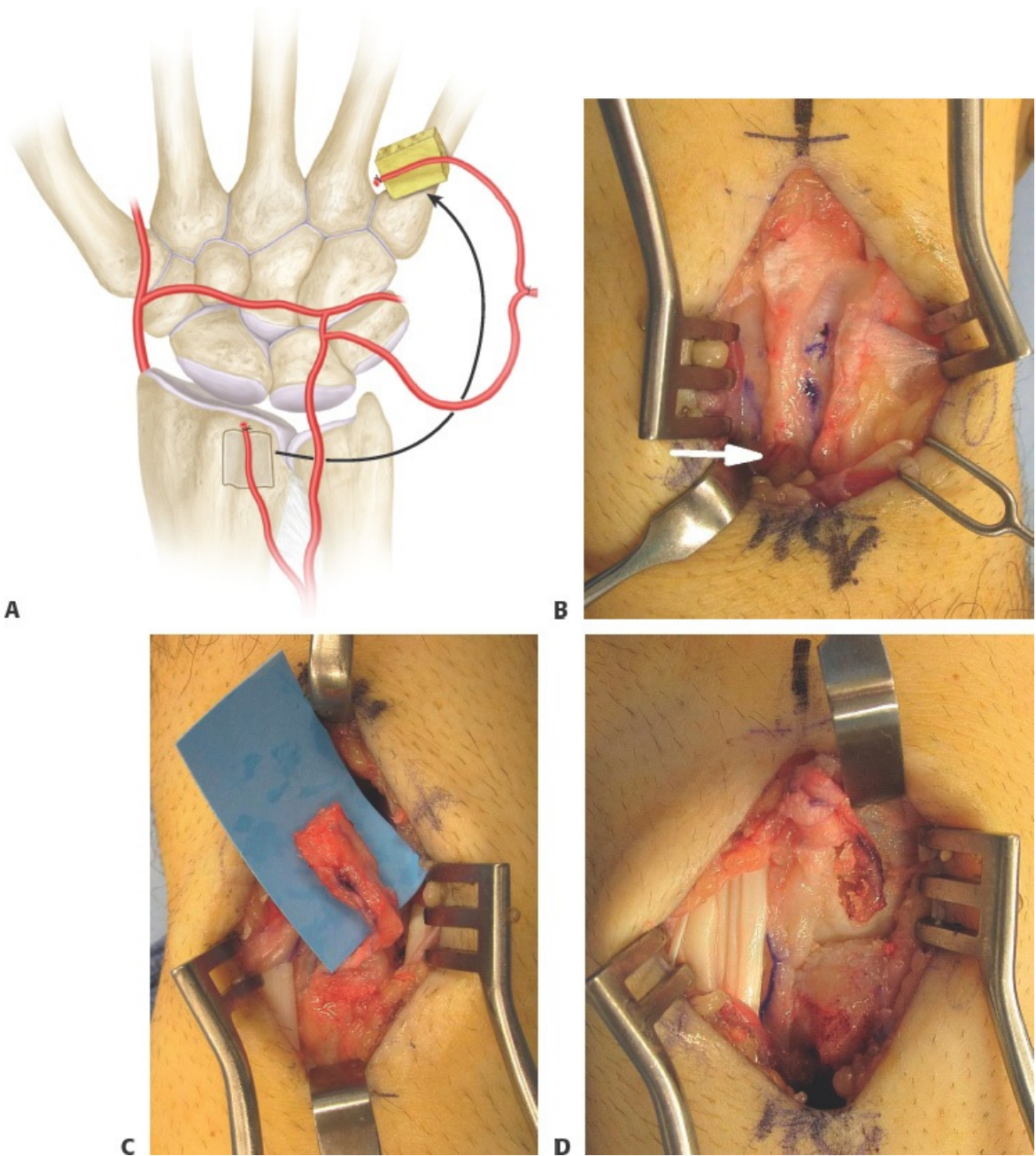
TECHNIQUES

■ Approach to Creation of the Bone Flap

- When there is no humpback deformity, a dorsally based vascularized bone flap from the distal radius, like the 4 + 5 extensor compartmental artery (ECA) flap or the 1,2-intercompartmental supraretinacular artery (1,2-ICSRA) flap, can be used to reconstruct a scaphoid nonunion.
- When a humpback deformity is present in the setting of AVN, however, a structural flap must be placed volarly, so a volar vascularized bone flap or a free MFC (or MFT) flap is required to properly correct the humpback deformity.

4 + 5 Extensor Compartmental Artery Vascularized Bone Flap

- The 4 + 5 ECA pedicle is based on retrograde flow between the anterior interosseous pedicle and the dorsal extensor compartmental arteries (**TECH FIG 1A,B**).
- Under tourniquet control, a standard dorsal approach to the wrist is used for exposure, incorporating prior incisions when appropriate.
- The dorsal radial sensory branches are identified and swept radially to protect them from iatrogenic injury.
- The third extensor compartment is opened and the tendon transposed.
- Retinacular flaps are elevated from the ulnar border of the Lister tubercle, moving radially and incorporating the retinaculum over the second dorsal compartment.
- Just distal to the radiocarpal joint and retinaculum, the fourth extensor compartment and tendons are mobilized from the dorsal capsule, preventing iatrogenic injury to the vascular pedicle.
- The tendons are then retracted ulnarly, exposing the anterior interosseous artery and neurovascular pedicle proximally and its distal anastomotic connections to the fourth and fifth extensor compartmental arteries.



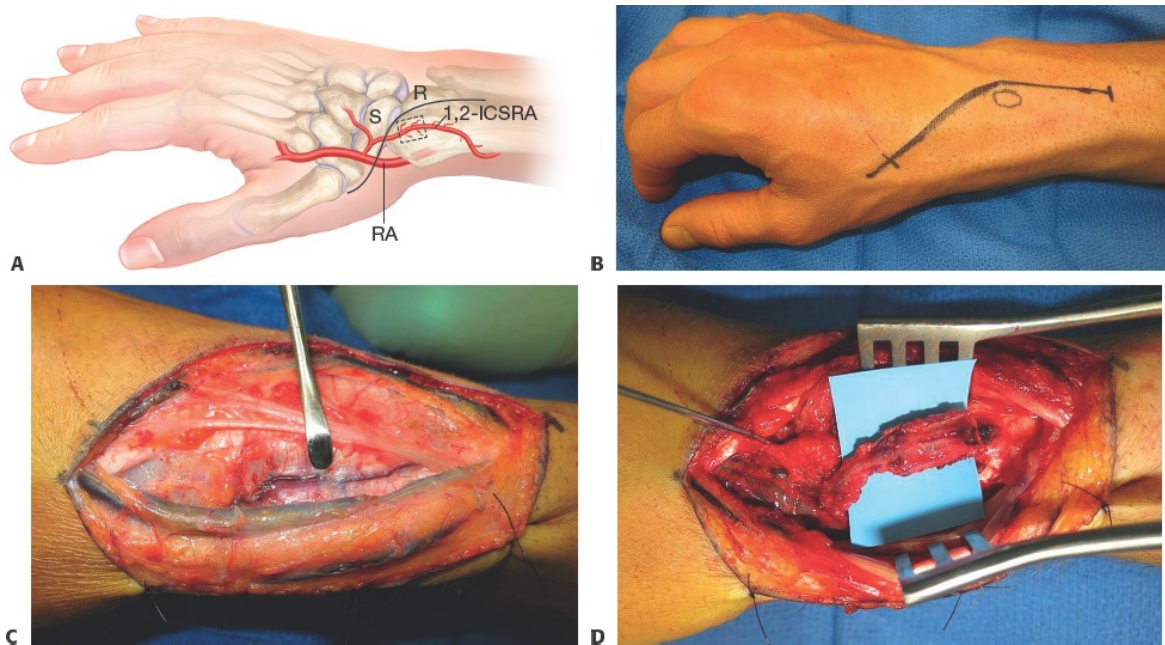
TECH FIG 1 • **A.** Illustration demonstrating the fourth and fifth extensor compartmental artery (4 + 5 ECA) flap and its axis of rotation. **B.** Fourth extensor compartment artery (*arrow*). **C.** Capsular vascularized bone graft distally based on the fourth extensor compartment artery. **D.** Placement of the distally based fourth ECA flap in the proximal pole of the

scaphoid for avascular necrosis.

- Osteotomies are then designed with the vascular pedicle longitudinally centered and the distal transverse cut at least 1 cm proximal to the dorsal ridge of the radius.
- Distal to the site of osteotomy, the pedicle should be elevated with a sharp periosteal elevator or Freer.
- The proximal vessel is clipped, and the osteotomies are performed, taking great care to prevent disruption of the volar radial cortex.
- The flap is then reflected, with a wide cuff of capsular tissue around the retrograde ECA (**TECH FIG 1C,D**).
- The tourniquet can be released at this point to verify perfusion of the bone flap.

1,2-Intercompartmental Supraretinacular Artery Vascularized Bone Flap

- The 1,2-intercompartmental supraretinacular artery (1,2-ICSRA) is distally based from the dorsal continuation of the radial artery into the radiocarpal arch (**TECH FIG 2A**).
- Gentle exsanguination prior to tourniquet elevation can provide some continued turgor of the vascular pedicle, which can improve visibility and dissection.
- Prior dorsal longitudinal incisions can be incorporated when possible into a curvilinear dorsoradial longitudinal incision that follows the course of the EPL tendon (**TECH FIG 2B**).
- The dorsal radial sensory nerve should be identified in the interval next to the cephalic vein and carefully protected.
- Deep to this, the 1,2-ICSRA can be identified on the septum between the first and second extensor compartments, which are incised laterally to include a broad cuff of tissue including the accompanying venae comitantes (**TECH FIG 2C,D**).
- The vertical perforating nutrient branches of the pedicle enter the periosteum at an average of 15 mm proximal to the dorsal radiocarpal joint line.



TECH FIG 2 • A. The 1,2-ICSRA bone flap with curvilinear incision following the course of the EPL tendon. **B.** The incision follows the course of the EPL tendon. **C.** 1,2-ICSRA vascular pedicle highlighted by the Ragnell retractor. **D.** The 1,2-ICSRA vascularized bone flap harvested.

- If desired, a dorsal radiocarpal capsulotomy can be performed to visualize the scaphoid nonunion.
- The proximal vessel is ligated with bipolar diathermy, and the flap is osteotomized with the vascular pedicle longitudinally centered.
- Prior to performing the distal osteotomy, a periosteal elevator should be used to elevate the periosteal sleeve and protect the distally based pedicle.

Superficial Palmar Branch of Radial Artery Vascularized Bone Flap

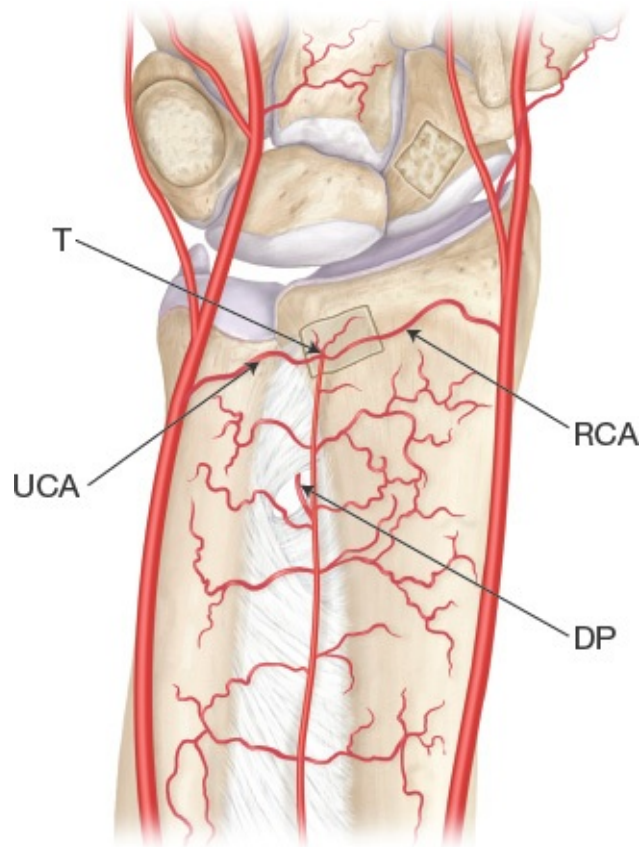
- The superficial palmar branch of the radial artery is a terminal transverse branch of the radial artery that arborizes on the distal cortex of the radius. The branch can be identified and preserved in the standard volar approach to the scaphoid, which may be useful especially in settings of humpback or flexion deformities that are typically approached from the volar wrist (**TECH**

FIG 3).

- Following exsanguination and tourniquet control, a longitudinal incision in line with the flexor carpi radialis (FCR), with a lateral extension (approximately 45 degrees) at the wrist crease along the glabrous skin junction can be used for exposure.
- The superficial palmar branch is then identified in line with the FCR tendon, potentially originating 5 to 8 mm proximal to the radial styloid. It may be useful to identify the proximal radial artery and trace it distally to the takeoff of the palmar vessel, thereby preventing inadvertent injury to the pedicle.
- The posterior sheath of the FCR tendon is then opened, and the volar wrist capsule is identified.
- A longitudinal incision in the radioscaphocapitate (RSC) ligament exposes the scaphoid and facilitates direct tendon repair at the time of closure.
- Following scaphoid preparation, the pronator quadratus is incised longitudinally and transversely to exposure the volar distal radius cortex.
- Care should be taken to harvest the graft at least 10 mm proximal to the volar rim to prevent disruption of the radioscaphoid facet.

Medial Femoral Condyle Microvascular Flap

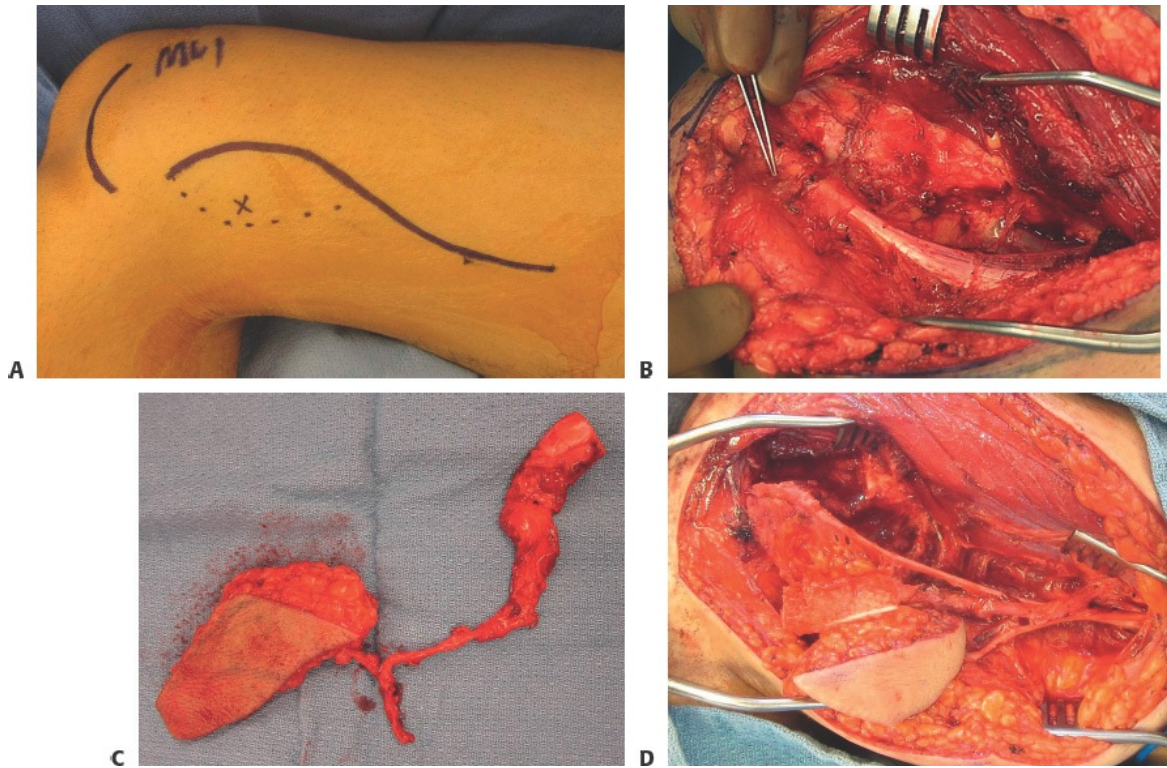
- Flap dissection can be approached with or without the intent of harvesting a skin paddle, regardless of the variations in anatomy.



TECH FIG 3 • Volar vascularized bone flap based on the volar carpal artery.

- A Doppler signal can be routinely located over the apex of the medial condyle of the femur.
- A sweeping, curvilinear incision is created, starting at the Hunter canal and moving in distal and anterior directions to the midpoint between the medial border of the patella and the MFC, just anterior to the location of the Doppler signal (**TECH FIG 4A**).
- The incision then continues distal and posterior, stopping 2 to 3 cm below the joint line and just posterior to the midaxis of the leg.
- This skin incision is continued to the subfascial plane of the vastus medialis muscle, which allows the skin paddle to be rapidly elevated and retracted in a posterior direction as the vastus medialis is dissected in an anterior direction.
- The DGA can then be identified as the medial column of the femur is exposed. Dissecting subfascially ensures protection of all skin vessels that can branch off the distal DGA into the reflected skin.

- Through the fascial plane of the vastus medialis, the branching vessels emitting from the DGA can be identified, and the presence or absence of an SAB and/or DGA-CB is rapidly noted (**TECH FIG 4B,C**).
- Branches to the vastus medialis course in an anterior direction (penetrating the fascial plane) and are ligated.
- At this point, a decision is made regarding the approach for the skin paddle. This skin vessel is preferable because of the speed with which it can be dissected as well as the assurance that the skin and subcutaneous vasculature can be elevated anterior to the sartorius muscle and adductor tendon, keeping the skin and bone segments in the same dissection interval (between the vastus medialis and sartorius muscles).
- If the SAB is selected as the means of supplying the skin segment, it requires a careful distal dissection to determine whether it is supported by skin branches that pass anterior to the sartorius muscle (45%) and in the same surgical interval as the bone component or posterior to the sartorius muscle (55%). If it does pass posterior, it will require a distal elevation of the skin segment and careful passage deep to the sartorius muscle to reunite it with the bone segment before completing the flap harvest.
- After determining the presence or absence of the DGA-CB and the SAB, we prioritize the DGA-CB because of its speed of dissection and ease of visualization.
- If the skin segment is quite large, or if initial dissection reveals that the SAB contributes to the skin perfusion while passing anteriorly to the sartorius muscle, both sources of skin perfusion (SAB and DGA-CB) can be harvested en bloc. Otherwise, the SAB is clamped, and the tourniquet is released. The Doppler signal over the apex of the MFC is again obtained.
- The initial sweeping incision allows many variations of oblique or longitudinally oriented ellipses to be designed, using the initial incision as the anterior border of the skin component, while capturing the Doppler signal for the benefit of postoperative monitoring.
 - Care is taken to harvest this in such a manner that primary closure is simply achieved.



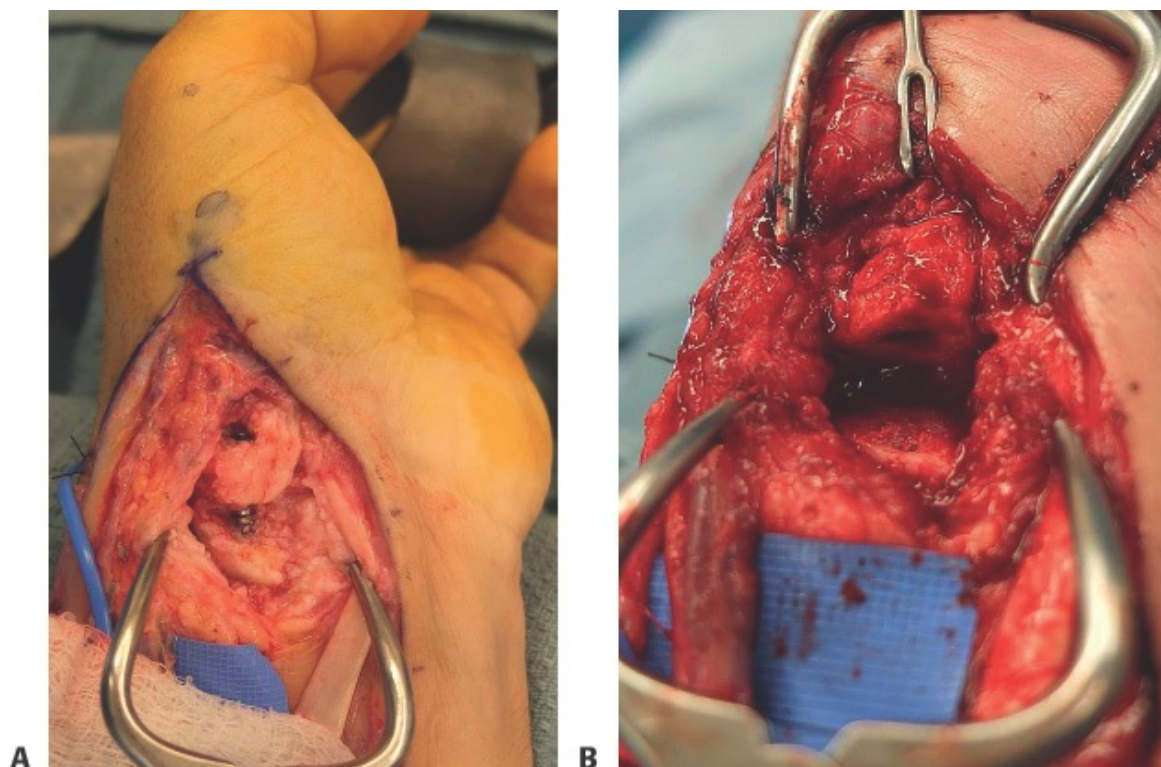
TECH FIG 4 • A. Markings for the medial femoral condyle and trochlea flaps. X marks the Doppler signal routinely located over the apex of the medial condyle of the femur. If a skin paddle is required, a sweeping, curvilinear incision is created at the midpoint between the medial border of the patella and the MFC. If no skin paddle is required, a longitudinal line just posterior to the medial femoral condyle can be used. **B.** In situ relationship of the medial femoral condyle bone flap and skin paddle based on the descending geniculate artery cutaneous branch (overlying sartorius tendon at the tip of the forceps). **C.** Free medial femoral trochlea flap based on the descending geniculate artery. Note the proximal origin of the saphenous artery branch, in this case from the descending geniculate artery, to provide irrigation for a skin paddle. **D.** Medial femoral condyle bone flap and skin paddle following osteotomy and elevation.

- The elevation of the posterior margin of the skin requires making note of the immediate proximity of the DGA-CB to the anterior surface of the adductor tendon.
 - This posterior incision should be carried down to the region posterior to the adductor tendon, giving wide berth to the DGA-CB.
 - When deep and posterior to the adductor tendon, the scalpel is then used to approach the posterior aspect of the tendon and cautiously elevate the DGA-CB off the adductor tendon while maintaining the adductor tendon integrity and preserving the critical DGA-CB.
 - This will enable the entire DGA and its periosteal branches to be preserved undisturbed on the surface of the cortical bone.
 - The bone segment is dissected in the width, length, and depth required, and the flap is then harvested on the common DGA origin vessel (**TECH FIG 4D**).
-

■ Scaphoid Preparation and Fixation

- If cyst formation or bone loss is present without a humpback deformity, a longitudinal 1.1-mm K-wire can be placed radial to the longitudinal axis of the bone to preserve the alignment of the proximal and distal poles.
 - The wire should be placed through the proximal dorsal pole radial and volar to the longitudinal axis of the bone to avoid interference with the placement of a subsequent compression screw or visualization of the fracture.
 - The wire can be advanced antegrade and captured through the volar hand, bringing the proximal edge flush to cartilage cap to prevent injury to the scaphoid facet during manipulation.
 - The proximal and distal poles can then be distracted on the wire to facilitate visualization.
- Fluoroscopy is used to verify the nonunion site.
 - A no. 15 or beaver blade scalpel can be used to gently open the fracture site. Small curettes should be used to remove any intervening cystic or fibrous material (**TECH FIG 5A**).
 - If desired, a 0.8-mm K-wire can be used to sparingly trephine the proximal and distal cancellous surfaces within the fracture, thereby increasing subsequent blood flow to the fracture site.

- The bone flap and nonunion site should be contoured using rongeurs or osteotomes. If an oscillating saw is used, the surgeon should be especially diligent about water cooling the site and preventing heat-induced osteonecrosis (**TECH FIG 5B**).
- If a humpback deformity (flexion of the scaphoid through the nonunion site) is identified, a 1.1-mm K-wire should be placed in the proximal and distal poles to act as joysticks to correct the deformity prior to grafting and final fixation.
- If the nonunion site is expansive, the proximal and distal poles should be packed with cancellous autograft from the bone flap harvest site prior to insertion of the flap and definitive fixation.
- Osteosynthesis can be completed with a headless compression screw advanced from the proximal or distal pole, depending upon the orientation of the nonunion site.
 - Alternatively, K-wires may be used upon the surgeon's preference.
- The dorsal capsule is carefully closed with an absorbable suture, such as a 3-0 poliglecaprone-25 or polyglactin suture. The extensor retinaculum is closed with similar 3-0 suture, leaving the extensor pollicis longus superficial to the retinaculum.
- Depending upon the volume of expected postoperative edema and skin quality, the skin is closed with either deep dermal stitches and a running subcuticular or simply vertical mattress stitches with 4-0 nylon.
- The wrist is immobilized in a well-padded plaster short-arm spica splint.



TECH FIG 5 • A. Scaphoid waist chronic fibrous nonunion with osteolysis. **B.** Preparation of the scaphoid prior to bone grafting, with resection of all fibrous and necrotic bone as visualized by bleeding tissue. Note restoration of the scaphoid distal pole extension from flexion (“humpback deformity”) and the resultant bone void.

PEARLS AND PITFALLS

Scaphoid preparation

- Degeneration of the radioscapoid facet or post-traumatic arthrosis may predispose to ongoing pain and stiffness and should be considered a potential contraindication to scaphoid salvage techniques.
- A radial styloidectomy can be performed as an adjunctive technique in the setting of mild radioscapoid arthrosis or to prevent impingement of the vascular pedicle to the bone flap (**FIG 3**).

- A posterior interosseous neurectomy with distal transection, proximal crush, and transposition may be used during the initial exposure.
- The adherent capsular tissue on the dorsal ridge of the scaphoid should be carefully preserved, as this may represent the blood supply to the scaphoid.
- Following insertion of the bone flap, a 0.8-mm K-wire can be placed just dorsal to the flap to prevent migration or extrusion during application of a compression screw.

4 + 5 ECA; 1,2-ICSRA

- If prior dorsal capsulotomies have been made, the arterial pedicle may have been transected, rendering the 4 + 5 ECA vascularized bone flap unreliable.
- Depending upon the width of the dorsal distal radius, the fourth or fifth ECA may be selected. However, great care should be utilized to prevent violation of the distal radioulnar joint or sigmoid notch when osteotomizing the fifth ECA-based bone flap as it is more ulnarly placed.
- The 4 + 5 ECA bone flap must be osteotomized and elevated prior to full capsular exposure of the scaphoid; therefore, the surgeon should be aware of the potential dimensions of the flap based on preoperative imaging and design the osteotomies to be ample. In comparison, the 1,2-ICSRA should be identified and protected prior to the dorsal radiocarpal capsulotomy, but the bone flap does not need to be osteotomized and elevated prior to exposure of the scaphoid.
- Osteotomies should be made at least 1 cm proximal to the radiocarpal joint to avoid penetration or disruption of the radiocarpal facets.
- Undue traction or injury on the superficial dorsal radial sensory nerve may lead to increased or prolonged postoperative pain.

MFC

- Iatrogenic injury to the saphenous nerve should be avoided by careful identification to the neighboring saphenous artery branch and elevation of the nerve from the proposed skin paddle.
- The skin component is usually elevated first, and attention is then turned to the bone segment. This is because posterior bone cuts will not be readily accessible until the skin paddle and the DGA-CB are reflected in an anterior direction.



FIG 3 • Intraoperative image following resection of the radial styloid and proximal scaphoid pole with preservation of the scaphocapitate articulation.

POSTOPERATIVE CARE

- The patient is placed in a well-padded thumb spica splint. At 2 weeks, the splint and stitches are removed and a thumb spica cast is applied.
- Casting is typically continued for a total of 10 to 12 weeks, with cast changes at 3- to 4-week intervals.
- The authors advocate burying K-wires under the skin, since they are usually left in for 6 weeks. Buried wires can be removed in the office or operating room once union is verified. Exposed K-wires should be removed near 3 to 4 weeks to prevent pin site infections and possible bacterial colonization of the nonunion site.
- X-rays should be obtained at each postoperative visit. CT scans can be obtained at the surgeon's discretion, but the authors recommend 10 to 18 weeks postoperatively to determine extent of union (**FIGS 4 to 6**).
- Osseous union is identified by bridging trabeculae on radiographs and absence of fracture site tenderness.



FIG 4 • Osseous union following MFC vascularized bone flap to the scaphoid waist. The dorsal branch of the radial artery at the wrist was used for inflow to the descending geniculate artery.

OUTCOMES

- Vascularized bone grafting of the scaphoid demonstrates union rates near 90%.⁸
- Across 6 studies (23.1%) involving 124 subjects following vascularized bone grafting to the scaphoid, preoperative pain was 5.20 and postoperative pain was 0.99 (on a 10-point scale), a 79.2% improvement. Two studies (7.69%) used Bach's criteria of pain and activity (BCPA) and Bach's criteria of pain activity limitation (BCPAL).⁹ Across 34 patients, the BCPA improved from 4.32

preoperatively to 1.96 postoperatively, a 54.6% improvement; the BCPAL improved from 4.21 preoperatively to 1.77 postoperatively, a 57.9% improvement.

- Across all studies, regardless of metric, postoperative pain was improved at least 50% after vascularized bone grafting.



FIG 5 • A–C. Radiograph and CT scans showing chronic scaphoid nonunion, with cyst formation and osteolysis. **D–F.** Osseous union is seen following dorsal vascularized fourth + fifth extensor compartmental artery flap and compression screw.



FIG 6 • Osseous union of the proximal scaphoid pole following medial femoral trochlea vascularized bone flap and compression screw.

- Previous studies have demonstrated that the ability to return to work and gainful employment have a significantly positive effect on the perceived health, physical function, and thus quality of life for individuals after injury.
- Vascularized bone grafting serves as a viable option to restore the normal anatomy of the radiocarpal joint and thus re-establish a patient's overall functionality.⁶

COMPLICATIONS

- The most common complication is superficial wound or pin site infection, nerve irritation, and complex regional pain syndrome (1.25%).
- Immediate postsurgical complications are typically only seen in microvascular cases with flap circulatory collapse.

- Errant osteotomies could potentially result in iatrogenic fracture of either the femur or distal radius.

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Open Reduction and Fixation of Acute Perilunate Fracture Dislocation

20

CHAPTER

Grant M. Kleiber and Amy M. Moore

DEFINITION

- Perilunate dislocation refers to a pattern of ligamentous injuries and/or fractures involving the carpus. In a perilunate dislocation, the lunate remains in its anatomic position, and there is dorsal dislocation of the carpus in relation to the lunate.
- In a lunate dislocation, the lunate is volarly displaced outside of the lunate facet.
- Lesser arc injury refers to a purely ligamentous injury pattern.
- Greater arc injury implies at least one fracture in addition to the perilunate dislocation, the most common being the scaphoid and radial styloid.
- In the event of a greater arc injury, the injury pattern and the fractures are described using the nomenclature “trans-[fractured bone]” in addition to “perilunate dislocation.” For example, a perilunate dislocation with a radial styloid and scaphoid fracture would be described as a “transradial styloid, trans-scaphoid perilunate dislocation.”

ANATOMY

- The carpus is constrained by a network of dorsal and volar radiocarpal (extrinsic) and intercarpal (intrinsic) ligaments (**FIG 1**).
- The lunate is constrained by extrinsic ligaments on its volar surface only: the long radiolunate, short radiolunate, and ulnolunate ligaments.
- The lunate is constrained by intrinsic intercarpal ligaments on its radial and ulnar edges: the scapholunate and lunotriquetral ligaments.
- The scapholunate ligament is strongest at its dorsal aspect, whereas the

lunotriquetral ligament is strongest at its volar aspect.

- The space of Poirier is an area of weakness in the volar wrist capsule, allowing the midcarpal joint to expand and contract during wrist motion. It is located between the radioscaphocapitate and the long radiolunate ligaments (see **FIG 1**).

PATHOGENESIS

- The biomechanical forces resulting in a perilunate dislocation are wrist hyperextension, ulnar deviation, and intercarpal supination.
- In a dorsal perilunate dislocation, there is rupture of the scapholunate and lunotriquetral ligaments, causing the carpus to dislocate dorsally off of the lunate.
- The lunate protrudes through the volar wrist capsule through the space of Poirier.

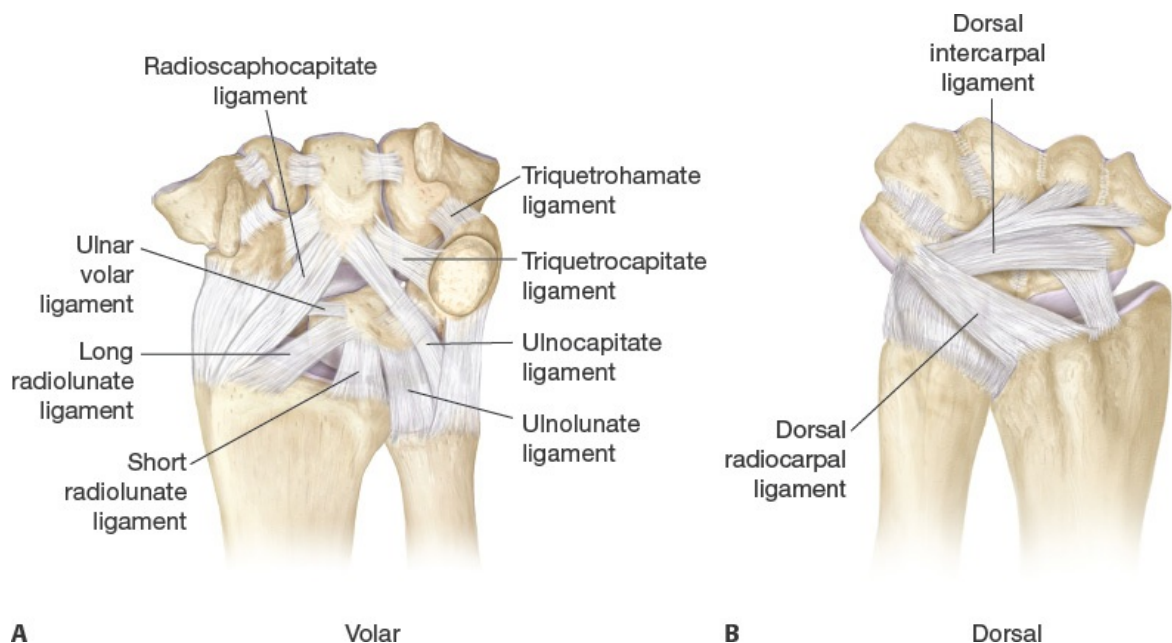


FIG 1 • A: The volar ligaments of the wrist include from radial to ulnar: radioscaphocapitate (RSC), long radiolunate (LRL), short radiolunate (SRL), ulnolunate (UL), and lunocapitate (UC), which overlies the ulnocapitate. Distally, the triquetrohamate and triquetrocapitate ligament stabilize the ulnar carpus (THC). The space of Poirier lies proximal to the arc

between the radial and ulnar volar ligaments. **B:** The dorsal ligaments include the dorsal intercarpal ligament (DIC) and dorsal radiocarpal ligament (DRC).

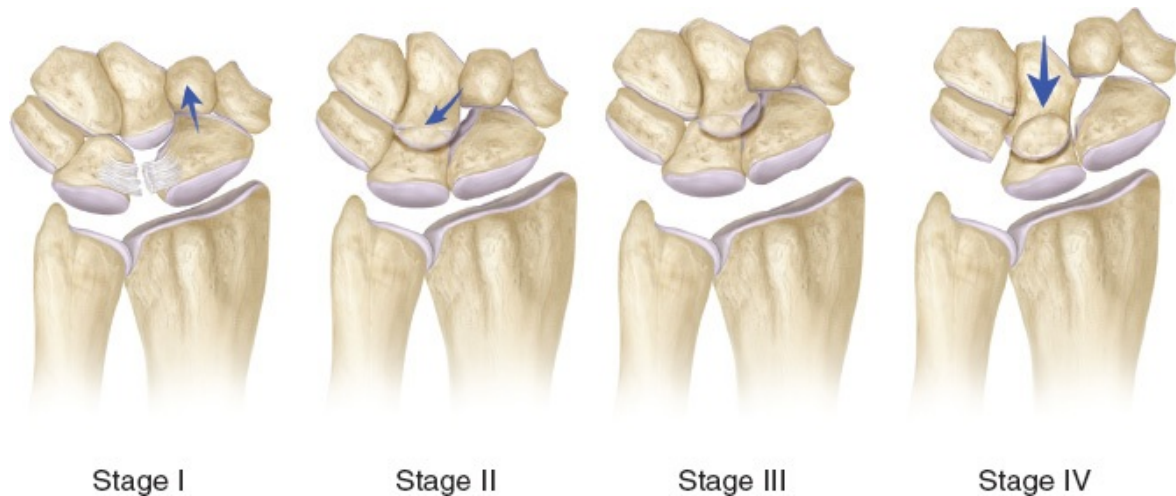


FIG 2 • The Mayfield classification of perilunate injuries proposes a radial-to-ulnar progression of injury. In stage I, the scapholunate ligament is ruptured. Stage II is disruption of the capitulunate articulation. Stage III is disruption of the lunotriquetral ligament and dorsal dislocation of the carpus from the lunate. Stage IV is volar dislocation of the lunate out of the lunate fossa of the radius.

- The short radiolunate ligament typically remains intact in a perilunate dislocation, tethering the volar lunate to the volar lip of the radius.
- Mayfield classified perilunate dislocations as a progression of injury from radial to ulnar around the lunate¹ (**FIG 2**):
 - Stage I: Scapholunate disruption with rotation of scaphoid
 - Stage II: Capitulate dissociation
 - Stage III: Lunotriquetral ligament rupture, dislocation of carpus dorsal to lunate
 - Stage IV: Lunate dislocation: lunate is dislocated volarly out of the lunate fossa.
- In a greater arc injury, there is transmission of force through the bony

structures surrounding the lunate, resulting in at least one fracture in addition to the perilunate dislocation (**FIG 3**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically report a high-energy injury such as a fall from height or a motor vehicle collision.
- A full trauma workup should be initiated depending on the mechanism of injury.

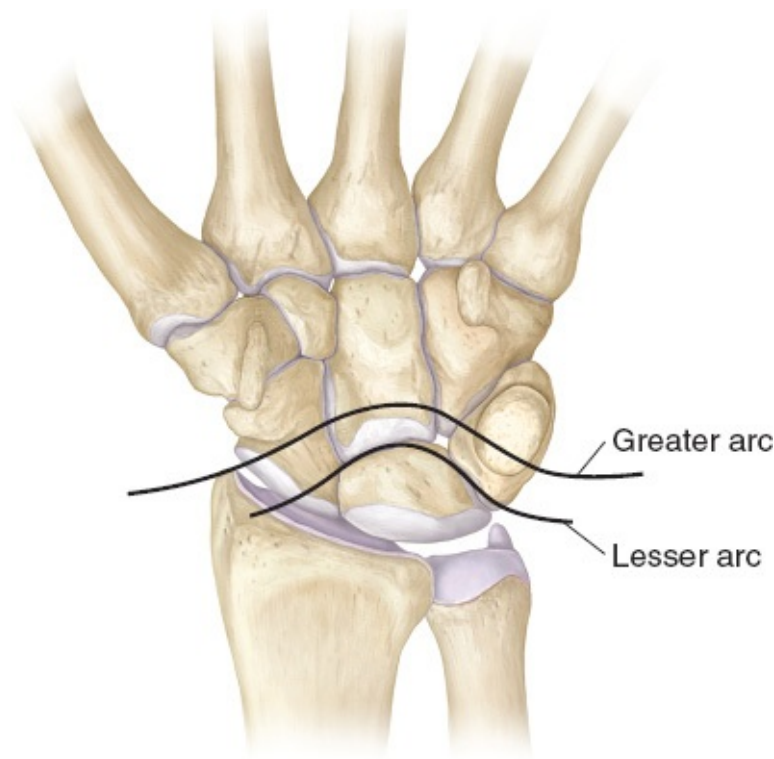


FIG 3 • A lesser arc injury refers to a purely ligamentous pattern of injury, as described in the Mayfield classification. A greater arc injury describes the injury pattern traveling through at least one bony structure, such as the radial styloid, scaphoid, capitate, triquetrum, or ulnar styloid.

- Patients may present with acute carpal tunnel syndrome, with symptoms ranging from paresthesias to severe burning pain in their median-innervated digits.

- The examiner should perform a complete neurovascular examination of the hand including two-point discrimination to document sensory disturbance.
- The wrist is evaluated for edema, gross deformity, and tenderness.
 - Ecchymosis and edema over the volar wrist are often seen.

IMAGING

- Standard three-view wrist radiographs (PA, lateral, oblique) are sufficient for diagnosis in most cases.
- AP views demonstrate irregularity of the carpal rows, with a triangular lunate silhouette superimposed over other bones (**FIG 4A**).
- Lateral views shows the lunate tipped volarly relative to the remainder of the carpus in a “spilled teacup” sign (**FIG 4B**).
- In trans-scaphoid perilunate injuries, the displaced scaphoid proximal pole is seen attached to the lunate (**FIG 4C,D**).
- A CT scan may be helpful to identify and characterize carpal fractures in greater arc perilunate dislocations. Ideally, this study would be performed after reduction of the carpus.

DIFFERENTIAL DIAGNOSIS

- Scapholunate dissociation
- Scaphoid fracture
- Radiocarpal dislocation

NONOPERATIVE MANAGEMENT

- Closed reduction of the lunate should be attempted in all patients using the Tavernier maneuver (**FIG 5**).
- Conscious sedation is recommended for patient comfort and relaxation—facilitating reduction.
- The Tavernier maneuver:
 - The wrist is extended and the lunate is palpated volarly with the examiner’s thumb.
 - Axial traction is placed on the patient’s wrist, and gentle pressure is applied to the volar aspect of the lunate.
 - The wrist is then flexed forward while maintaining axial traction and volar pressure on the lunate. Successful reduction is often accompanied by a palpable “clunk.”
 - Wrist radiographs are taken in traction to verify reduction, and a sugar tong

splint is applied.

- If reduction is unsuccessful, an open reduction should be performed in the operating room in an urgent manner.



FIG 4 • A. AP radiograph of a perilunate dislocation demonstrates disruption of carpal rows and a triangle-shaped lunate (L) superimposed over the midcarpal joint. **B.** Lateral radiograph of a perilunate dislocation demonstrates dorsal translation of the carpus off the lunate, which is flexed forward. In this case, the lunate remains located within the lunate fossa of the radius. **C.**

AP radiograph of a trans-scaphoid perilunate dislocation. The triangular shape of the lunate and disruption of the carpal arcs are demonstrated. **D.** Lateral radiograph demonstrates that in a trans-scaphoid perilunate dislocation the proximal pole of the scaphoid remains attached the lunate. The remainder of the carpus is dislocated dorsally. T, trapezium; Tr, trapezoid; C, capitate; H, hamate; S, scaphoid; Tq, triquetrum; R, radius; U, ulna.

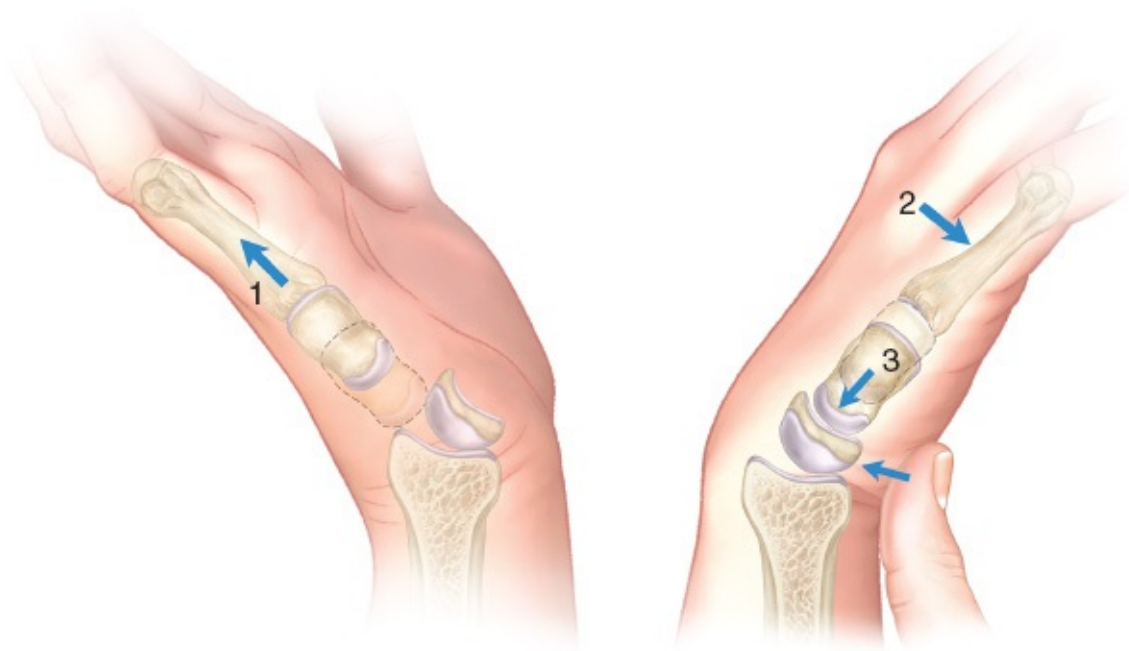


FIG 5 • The Tavernier's maneuver consists of (1) applying distal traction on the wrist while stabilizing the lunate with the opposite thumb. (2) The wrist is then extended and volar pressure is applied on the lunate to prevent dislocation into the carpal tunnel. (3) With traction and the lunate stabilized, the distal carpal row is reduced over the lunate into position with gentle wrist flexion.

SURGICAL MANAGEMENT

- If successful closed reduction is achieved, operative intervention and reconstruction can be performed several days later as a scheduled procedure but ideally within 1 week.
- Irreducible dislocations must be treated urgently to prevent median nerve impingement and devascularization of the lunate and displaced carpal bones.
- A surgical option for irreducible dislocations or for less experienced hand surgeons taking call is to take the patient to the operating room urgently for the volar approach to the carpus. An extended carpal tunnel release is performed to decompress the median nerve followed by open reduction of the carpus and repair of the volar lunotriquetral ligament and capsule. The dorsal approach can then later be performed by surgeons with expertise in the wrist.

Preoperative Planning

- As discussed previously, careful neurological exam should be performed including two-point discrimination to determine the baseline median nerve function.
- Any surgical equipment, such as hardware or suture anchors, should be available.
- A perilunate dislocation can be performed under regional or general anesthesia.

Positioning

- The patient is positioned supine with affected arm on a radiolucent hand table centered on the patient's axilla.
- A well-padded pneumatic tourniquet is placed on the upper arm.
- If an assistant is not available to assist with traction, end table traction with finger traps and 5 to 10 lb of weight will facilitate dissection and reduction during the procedure.

Approach

- A combined dorsal and volar approach is recommended for perilunate dislocations.
- Dorsal approach
 - A 6- to 8-cm longitudinal incision centered over ulnar aspect of the Lister tubercle between the third and fourth extensor compartments provides good exposure. The radiocarpal and midcarpal joints are then exposed using a ligament-sparing capsulotomy, splitting the dorsal radiocarpal and dorsal

intercarpal ligaments (**FIG 6**).²

- The dorsal approach is required in all patients for ligament repair and stabilization.
- Volar approach
 - A standard carpal tunnel release incision is extended across the wrist crease in a zigzag fashion for 2 to 3 cm.
 - The volar approach adds the benefit of open reduction of the lunate under direct visualization, volar lunotriquetral ligament repair, volar capsular repair, and median nerve decompression via the extended carpal tunnel release.

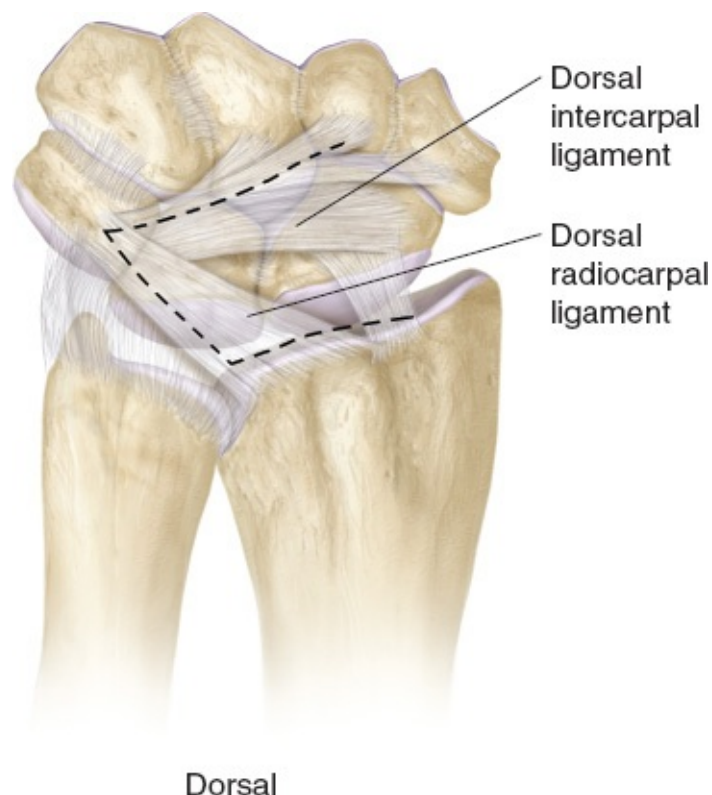


FIG 6 • A dorsal ligament-sparing capsulotomy splits the dorsal radiocarpal (DRC) and dorsal intercarpal (DIC) ligaments, maintaining their fibers in continuity for added dorsal stabilization of the wrist with closure. (From Berger RA, Bishop AT. A fiber-splitting capsulotomy technique for dorsal exposure of the wrist. *Tech Hand Up Extrem Surg.* 1997;1:2-10.)

TECHNIQUES

■ Lesser Arc Perilunate Dislocation

Volar Approach with Extended Carpal Tunnel Release and Open Reduction

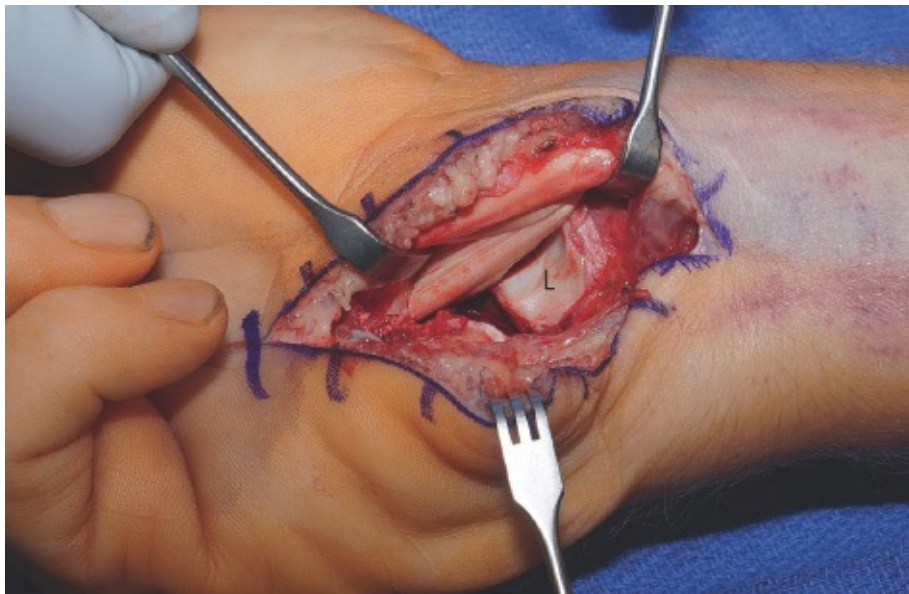
- An extended carpal tunnel incision is made, crossing at least 2 to 3 cm proximal to the wrist crease.
- The transverse carpal ligament is divided along its ulnar aspect to avoid the median nerve, which may be displaced due to presence of the lunate within the carpal tunnel. As the carpal tunnel is released, blood is typically seen in this space.
- The antebrachial fascia is released proximally under direct vision, and the median nerve and flexor tendons are retracted radially.
- The lunate is visualized within the carpal tunnel, protruding from the volar wrist capsule and typically in a flexed position (**TECH FIG 1**). It is gently reduced into its anatomic position with axial traction on the wrist and gentle extension and pressure on the lunate.
- The volar lunotriquetral ligament is visualized and is repaired with nonabsorbable suture.
- The crescent-shaped tear in the volar wrist capsule is also repaired with nonabsorbable suture.

Dorsal Approach with Ligament Repair

Exposure

- The wrist is approached dorsally through a 6- to 8-cm incision centered on the ulnar aspect of the Lister tubercle via the third and fourth extensor compartments.
- Blunt dissection is carried over the extensor retinaculum to raise subcutaneous flaps radially and ulnarly. The radial sensory nerve and dorsal cutaneous branch of the ulnar nerve are identified and protected throughout the case.
- The extensor retinaculum is incised over the EPL tendon, which is transposed out of the retinaculum.

- The extensor retinaculum is then raised off of the fourth dorsal compartment and the second dorsal compartment, entering each through the open third compartment. Self-retaining retractors are placed, exposing the wrist capsule.
- A ligament-sparing capsulotomy is performed to enter the wrist joint, splitting the fibers of the dorsal radiocarpal ligament and the dorsal intercarpal ligament. A radially based capsular flap is raised by extending the proximal incision radially along the dorsal radius (**TECH FIG 2**).^{2,3}
- The scaphoid, lunate, and triquetrum are visualized. Dorsal remnants of the scapholunate and lunotriquetral ligaments are identified. Typically, the ligaments are torn asymmetrically, with a larger piece on one side of the joint.

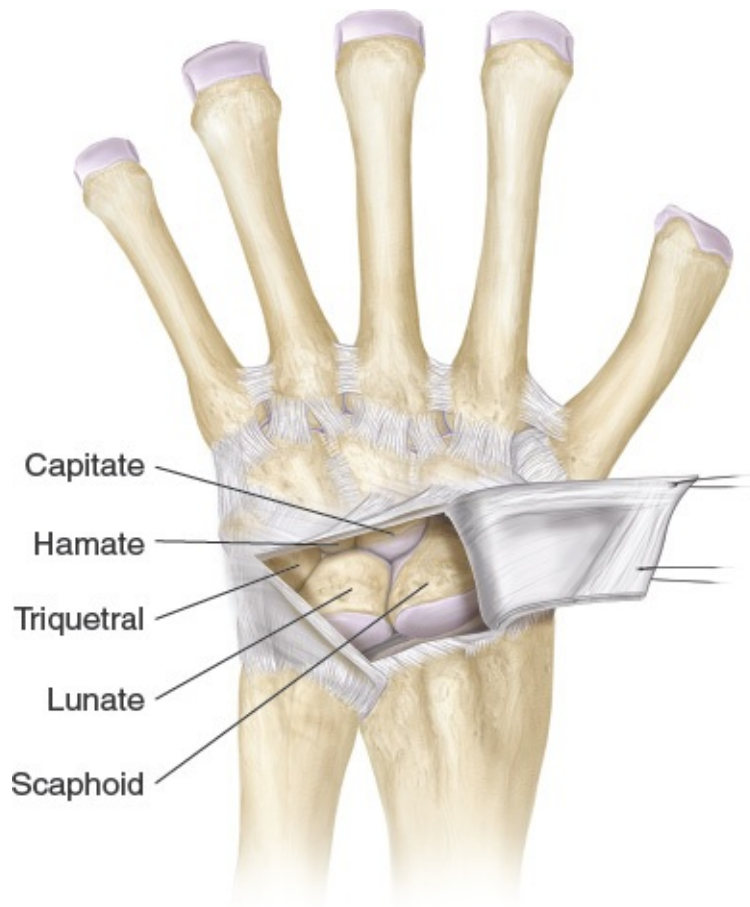


TECH FIG 1 • On volar approach to the wrist, the lunate (L) is seen protruding into the carpal tunnel through a crescent-shaped rent in the volar wrist capsule.

Reduction and Fixation

- Suture anchors are inserted in preparation for ligament repair. The anchor is inserted to the side of the joint with the smaller ligament fragment, so the sutures may be passed through the larger fragment.
- Fluoroscopic imaging and direct visualization are used to ensure adequate placement of the anchors.

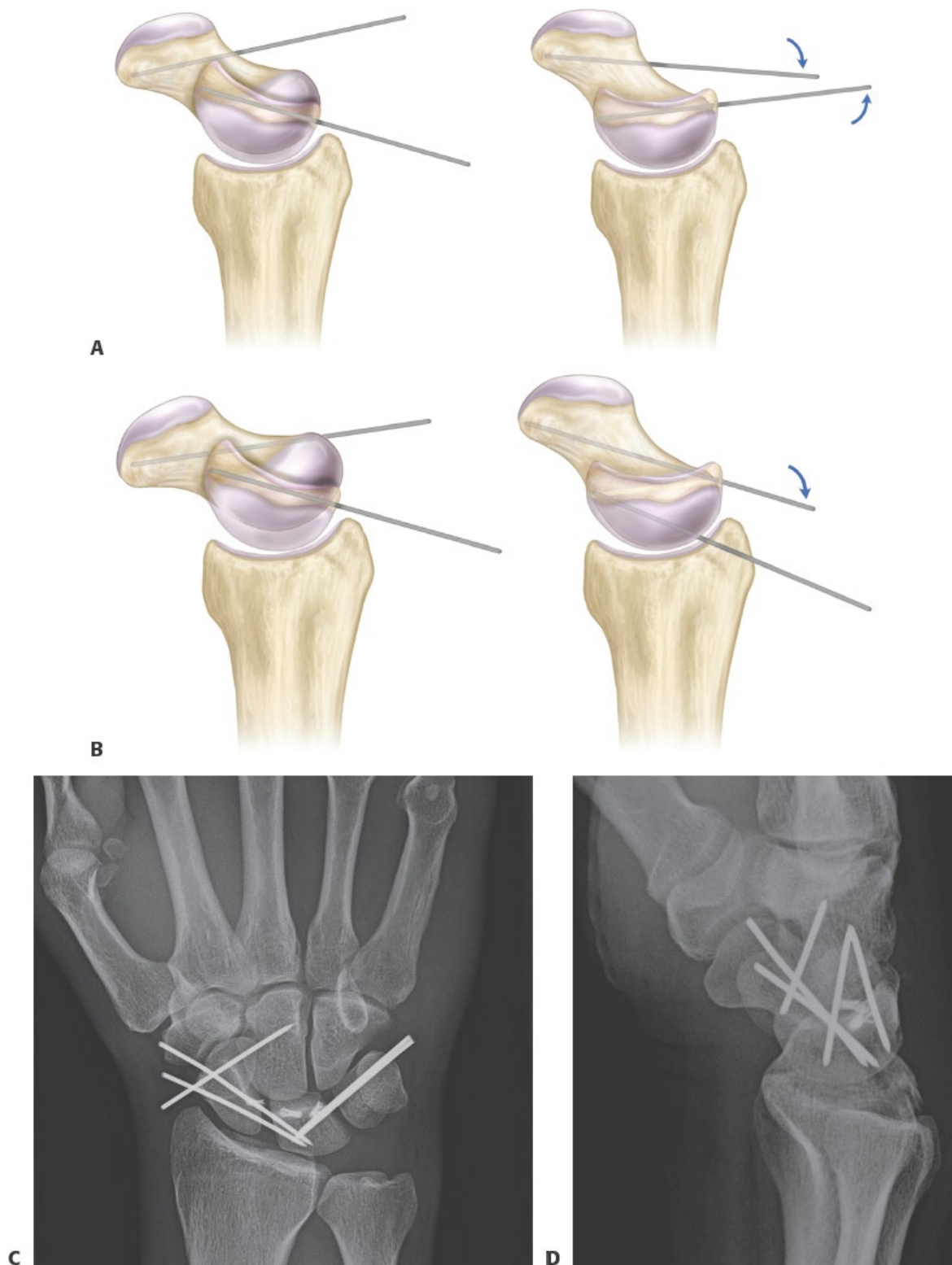
- The scaphoid is typically found to be flexed, and the lunate is extended. To correct the scapholunate angle, a 0.062-in. K-wire is inserted into the dorsum of the scaphoid and the lunate to act as a joystick.
- Using the K-wire joysticks, the scaphoid and lunate are aligned under lateral fluoroscopy to restore a scapholunate angle of 40 to 55 degrees (**TECH FIG 3A**). The K-wires can be provisionally secured together with a hemostat to hold this reduction.
- Another option is to place a radiolunate K-wire to hold the reduced lunate in place and then the scaphoid can be reduced to the lunate using the K-wire joystick (**TECH FIG 3B**).
- The sutures attached to the anchors are now passed through the scapholunate and lunotriquetral ligaments and left untied until intercarpal pins are placed.
- Intercarpal pins are placed using 0.045-in. K-wires. Pins are placed to stabilize the scapholunate interval and the lunotriquetral interval.



TECH FIG 2 • Using a ligament-sparing capsulotomy,

a radially based capsular flap is raised to expose the carpus. (From Berger RA, Bishop AT. A fiber-splitting capsulotomy technique for dorsal exposure of the wrist. *Tech Hand Up Extrem Surg.* 1997;1:2-10.)

- A scaphocapitate pin is placed to stabilize the scaphoid from flexing (**TECH FIG 3C**). Pins are buried beneath the skin to avoid pin-tract infection that invariably will occur when pins are left outside the skin for more than a few weeks.
- AP and lateral fluoroscopic radiographs are taken to ensure adequate reduction of the SL and LT interval, and a scapholunate angle of 40 to 55 degrees (**TECH FIG 3D**).
 - If these films are satisfactory, the suture anchors are tied down.
- The wrist is irrigated copiously with normal saline to ensure no remaining osteochondral debris is present in the articular space.
- The capsulotomy, followed by the extensor retinaculum, is then closed with nonabsorbable sutures.



TECH FIG 3 • A. The scapholunate angle is restored using 0.062-in. K-wire joysticks placed into the lunate and scaphoid. These can be secured together with a

hemostat to hold the reduction temporarily. **B.** Another option is to reduce the lunate and then place a radiolunate K-wire to stabilize the lunate. The scaphoid can then be reduced to the lunate to restore the scapholunate angle using a joystick. **C.** AP radiograph demonstrates that the carpus is stabilized with 0.045-in. K-wires after suture anchors have been placed for reconstruction of the ligaments. Two K-wires are placed in the scapholunate and lunotriquetral intervals. A scaphocapitate (and/or a triquetrocipitate) K-wire can also be placed to stabilize the capitoulunate joint if found to be unstable. **D.** Lateral view of carpus after K-wire stabilization and ligament repair demonstrates restoration of acceptable scapholunate angle.

■ Repair of Greater Arc Injury

Trans-scaphoid Perilunate Dislocation

- Greater arc injuries result in a fracture of an adjacent bone accompanying the perilunate dislocation. The scaphoid is the most common bone involved (**TECH FIG 4A,B**).
- The same volar and dorsal approaches are used as outlined above.
- The scapholunate ligament is most often intact in a trans-scaphoid perilunate dislocation (**TECH FIG 4C**), and the proximal pole of the scaphoid is displaced with the lunate (see **FIG 4D**).
- The scaphoid fracture is reduced under direct vision, aligning the cartilaginous surface of the scaphoid.
 - Joystick K-wires can be placed in the proximal and distal poles to aid in reduction and stabilization.
 - The scaphoid is fixated with a dorsal cannulated compression screw using standard technique, with the caveat that the fracture will be less stable than typical scaphoid fractures.
- Use of distal radius bone graft is encouraged if significant comminution of

the scaphoid is found. The graft can be easily taken from under the Lister tubercle in the same exposure.

- A guidewire is placed for a cannulated screw along the axis of the scaphoid, beginning proximally at the center of the membranous portion of the scapholunate ligament
- An antirotation parallel wire should be placed alongside the guidewire to stabilize the scaphoid fracture for overdrilling the guidewire.
- Most cannulated screw systems have a parallel wire guide for placement of this wire. This step is highly recommended due to the instability of the fracture.





TECH FIG 4 • A. AP radiograph demonstrates a trans-scaphoid perilunate dislocation. In this greater arc injury, there is a scaphoid (S) waist fracture instead of a scapholunate ligament injury. **B.** The proximal pole of the scaphoid remains attached to the lunate (L) and flexes with it. **C.** Image of right wrist demonstrates scaphoid fracture with intact scapholunate ligament (*). **D and E.** AP and lateral radiographs of open reduction and fixation of a trans-scaphoid perilunate injury with K-wire stabilization of the carpus and cannulated screw fixation of the scaphoid. C, capitate; R, radius Tq, triquetrum.



TECH FIG 5 • AP radiograph of a greater arc transradial styloid, trans-scaphoid, transcapitate perilunate dislocation. The distal radius fracture was treated with fragment-specific fixation, and cannulated screws were to repair the capitate and scaphoid fractures.

- The guidewire is measured and overdrilled, and an appropriately sized cannulated compression screw is placed over the wire.
- A scaphocapitate K-wire can be placed to further stabilize the lunocapitate joint as well as reinforce the scaphoid fixation if comminuted.
- The lunotriquetral ligament is repaired with suture anchors in the same manner described above, and the lunotriquetral interval is pinned with 0.045-in. K-wires (**TECH FIG 4D,E**).

Transradial Styloid, Trans-scaphoid, Transcapitate Perilunate Dislocation

- Greater arc injuries result in a fracture of an adjacent bone accompanying the perilunate dislocation. The scaphoid is the most common bone involved, and the technique for fixation of a trans-scaphoid perilunate is outlined above.
- Radial styloid fractures involving greater than one-third of the scaphoid fossa should be repaired to stabilize the volar ligamentous attachments.⁴ This can be performed with cannulated screw fixation or a radial column pin plate. Anatomic alignment of the articular surface is critical.
- Transverse capitate fractures may be managed with cannulated compression screws, allowing the screws to be buried beneath the articular surface (**TECH FIG 5**).

Perilunate Dislocation Reconstruction with Posterior Interosseous Neurectomy

- The terminal branch of the posterior interosseous nerve (PIN) runs in the floor of the fourth dorsal compartment. It provides sensory innervation to the wrist joint.
- Perilunate dislocation and its subsequent reconstruction result in significant capsular trauma to the wrist joint. A PIN neurectomy should be strongly considered as an adjunctive procedure to decrease postoperative pain and improve long-term outcomes.
- The PIN can be consistently found 3 to 4 cm proximal and 1 cm ulnar to Lister tubercle, beneath the tendons of the fourth dorsal compartment.
- The nerve is carefully dissected free from the artery for a distance of 2 to 3 cm. The nerve is crushed proximally with a hemostat and distally 1 to 2 cm is resected. The proximal nerve is then cauterized.
- The proximal nerve end is transposed proximally along the course of the nerve, burying it beneath the forearm musculature to prevent symptomatic neuroma formation.

PEARLS AND PITFALLS

Irreducible perilunate dislocation

- A closed reduction should be attempted in the emergency room under sedation.
- If unable to reduce, open reduction should be performed in the

	operating room in an urgent fashion to decompress the median nerve and improve vascular supply to the displaced carpus.
Median nerve compression	■ Acute carpal tunnel syndrome commonly accompanies perilunate dislocation. These patients should be treated with urgent median nerve decompression and relocation of the lunate through a volar approach. ■ Carpal tunnel release should be performed in all patients due to trauma to the median nerve from the perilunate dislocation.
Technique: Ligament repairs	■ Suture anchors can be use to repair the scapholunate and/or lunotriquetral ligaments. ■ The anchors should be placed prior to the reduction and K-wire fixation of the interval to allow best visualization. ■ Once the interval is reduced and stabilized with K-wires, the sutures can be tied and secured.
Scapholunate angle	■ A normal scapholunate angle between 30 and 60 degrees should be restored, ideally between 40 to 55 degrees. ■ Place joystick K-wires into the scaphoid and lunate to extend the scaphoid and flex the lunate into an anatomic position (see TECH FIG 3A). ■ The lunate can also be stabilized with a temporary radiolunate pin (see TECH FIG 3B).
Posterior interosseous neurectomy	■ A PIN neurectomy should be strongly considered at the time of ligament repair to decrease postoperative pain. ■ The nerve is found in the floor of the fourth dorsal compartment.

POSTOPERATIVE CARE

- The patient is placed in a sugar tong splint for 2 weeks, followed by 8 to 10 weeks of thumb spica cast immobilization.
- K-wires are removed at 8 to 10 weeks. Burying pins beneath the skin results in fewer issues with pin-tract infections, but they may require removal in the OR.
- Gentle range of motion exercises are begun after K-wire removal. Hand therapy is initiated to regain wrist motion.
- A protective removable splint is worn between therapy sessions until pain and range of motion has stabilized. For greater arc injuries, the splint is worn until union is achieved.

OUTCOMES

- Patients should expect decreased wrist range of motion, particularly flexion

and extension, after this significant injury (**FIG 7**). Near-normal pronosupination is typically restored.

- Total arc of motion for flexion/extension is reported from 57% to 83% of the contralateral side.^{5–10}
- A recent retrospective review of 65 cases reported that 85% of patients were able to return to their previous occupation.⁵
- Despite adequate fixation and intervention, most patients (range 18%–92%) develop radiographic signs of radiocarpal and midcarpal arthrosis over time.^{6,11}
- In a study by Forli et al.,⁶ 67% of their patients developed post-traumatic degenerative changes; however, they report that the arthrosis is well tolerated at an average follow-up of 13 years.
- Proximal row carpectomy can be considered as a secondary salvage procedure in patients with avascular necrosis of the lunate or in delayed unrecognized perilunate dislocation.¹²

COMPLICATIONS

- Multiple complications can result from the severe wrist trauma at the time of injury, as well as, from the operative procedure itself.
- Complex regional pain syndrome has been reported to occur in up to 12% of patients.⁵
- K-wire/pin-tract infections can occur.
- Osteonecrosis of lunate or scaphoid has been reported at rate of about 8%.⁵
- Carpal bone nonunion such as in trans-scaphoid perilunate dislocation is rare.^{6,9}

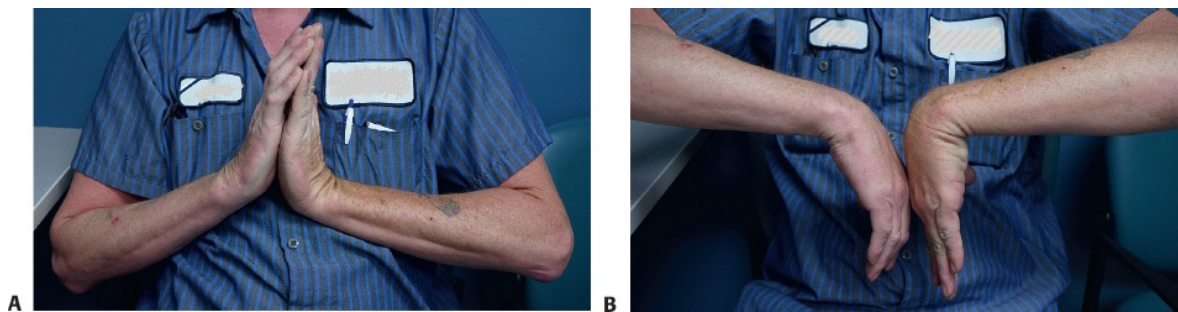


FIG 7 • At 6 months postoperatively, functional extension (**A**) and flexion (**B**) have been restored. However, range of motion is decreased compared to

the uninjured hand.

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Dorsal Capsulodesis for Scapholunate Stabilization with Extensor Carpi Radialis Longus Tenodesis

21

CHAPTER

Mark Morris and Kevin C. Chung

DEFINITION

- Scapholunate (SL) dissociation is the most common cause of carpal instability.
- SL dissociation can result in static or dynamic carpal instability.
 - Static instability: Radiographic changes are seen on standard wrist radiographs.
 - Dynamic instability: Standard radiographs are normal, but signs of instability are seen on stress radiographs.
- Partial SL interosseous ligament tears do not produce radiographic changes and often require arthroscopy for diagnosis.
- SL dissociation left untreated leads to dorsal intercalated instability (DISI) and eventually scapholunate advanced collapse (SLAC).¹

ANATOMY, PATIENT HISTORY, AND PHYSICAL FINDINGS, IMAGING

- See Chapter 15 in the Hand section.

SURGICAL MANAGEMENT

- Dividing the SL interosseous ligament leads to altered radiocarpal kinematics and causes abnormal radiocarpal and ulnocarpal pressure distributions.^{2,3}
- The radioscapoid joint is normally congruent. However, when the scaphoid is subluxed because of SL instability, the load is shifted and abnormal contact points are created, leading to degenerative changes (**FIG 1**).⁴

- The goal of dorsal capsulodesis and extensor carpi radialis longus (ECRL) transfer is to maintain the extended position of the scaphoid in order to restore normal carpal alignment and avoid abnormal radiocarpal contact pressures that otherwise lead to pain and degenerative changes.
- Capsulodesis alone is contraindicated if there is static SL dissociation, whereas ECRL tendon transfer can be performed with static SL dissociation as long as reduction is possible in the operating room. Either procedure is contraindicated if radiocarpal or midcarpal degenerative changes are present.
- Capsulodesis is indicated for predynamic SL instability secondary to an isolated partial SL ligament tear (seen on arthroscopy) and for dynamic SL instability with intact secondary stabilizers and a technically repairable dorsal capsule.
- The main advantage of dorsal capsulodesis over tendon transfer is the technical ease of the procedure.
 - The disadvantage of dorsal capsulodesis is the predilection for attenuation of the repair over time and progressive carpal collapse.⁵ Tendon transfer provides increased strength of repair and the ability to maintain reduction of the scaphoid over time.
 - Additionally, with a capsulodesis, the scaphoid is theoretically still unstable through much of the arc of wrist motion until it reaches the limit of flexion set by the capsulodesis. In contrast, a dynamic transfer should provide an extension force to the scaphoid throughout the entire range of wrist motion.⁶
- ECRL transfer to the scaphoid can be used as an alternative to capsulodesis for treatment of a partial SL ligament tear. ECRL transfer can be performed if the capsule is not technically repairable, which would obviously preclude capsulodesis.
- The ECRL tendon transfer was designed to re-establish a fluid scaphoid slider-crank motion and restore midcarpal kinematics without tethering the scaphoid or limiting wrist flexion.
 - A slider-crank mechanism converts linear motion to rotatory motion or vice versa, such as with a piston and crank shaft of an engine.

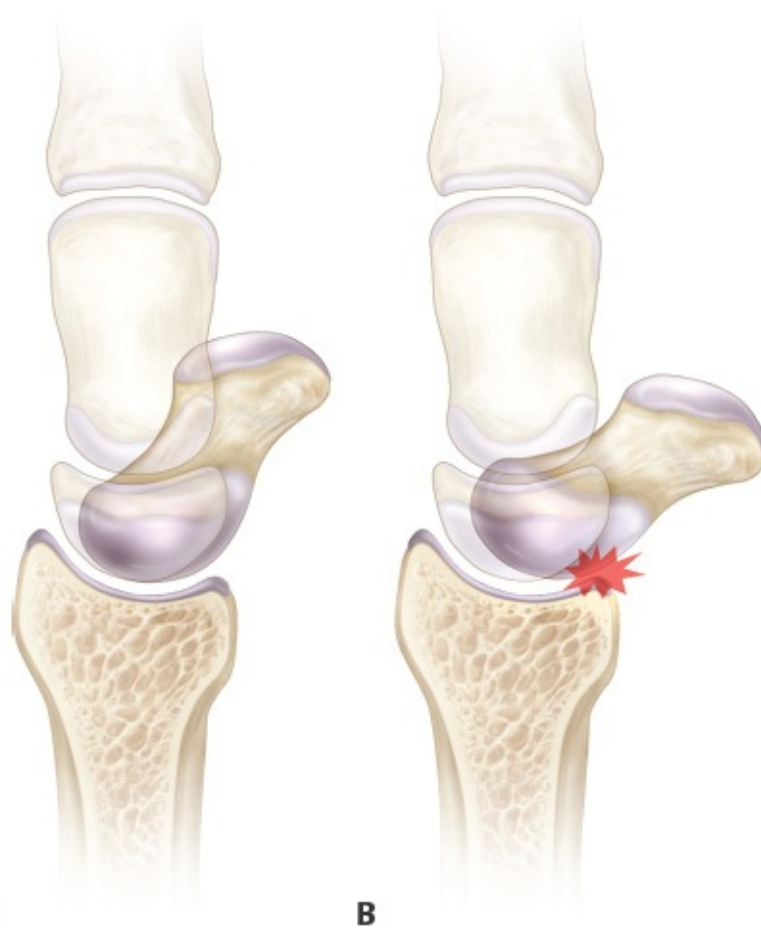


FIG 1 • A. Normal orientation of the scaphoid and radius shows a congruent articulation between the scaphoid and the scaphoid facet of the radius. **B.** An area of abnormal loading of the radioscaphoid joint occurs when the scaphoid undergoes rotary subluxation. Disproportionate loading of the joint leads to degenerative changes.

- The slider-crank model of the wrist described by Linscheid et al.⁷ explains wrist kinematics as a three-bar linkage composed of the radius, lunate, and capitate. The three bars are stabilized by the scaphoid, which acts as the crank. When the wrist is extended, the scaphoid “crank” causes dorsal rotation of the lunate by a dorsally directed compressive force. With flexion, the scaphoid causes flexion of the lunate via a palmarly directed tensile force (**FIG 2**).

- ECRL tendon transfer provides a consistent extension force to the scaphoid throughout the range of motion, as opposed to a dorsal capsulodesis, which acts merely as a checkrein to flexion of the scaphoid. By doing so, the scaphoid is able to influence the kinematics of the wrist throughout the arc of motion rather than just at the point limited by the checkrein.

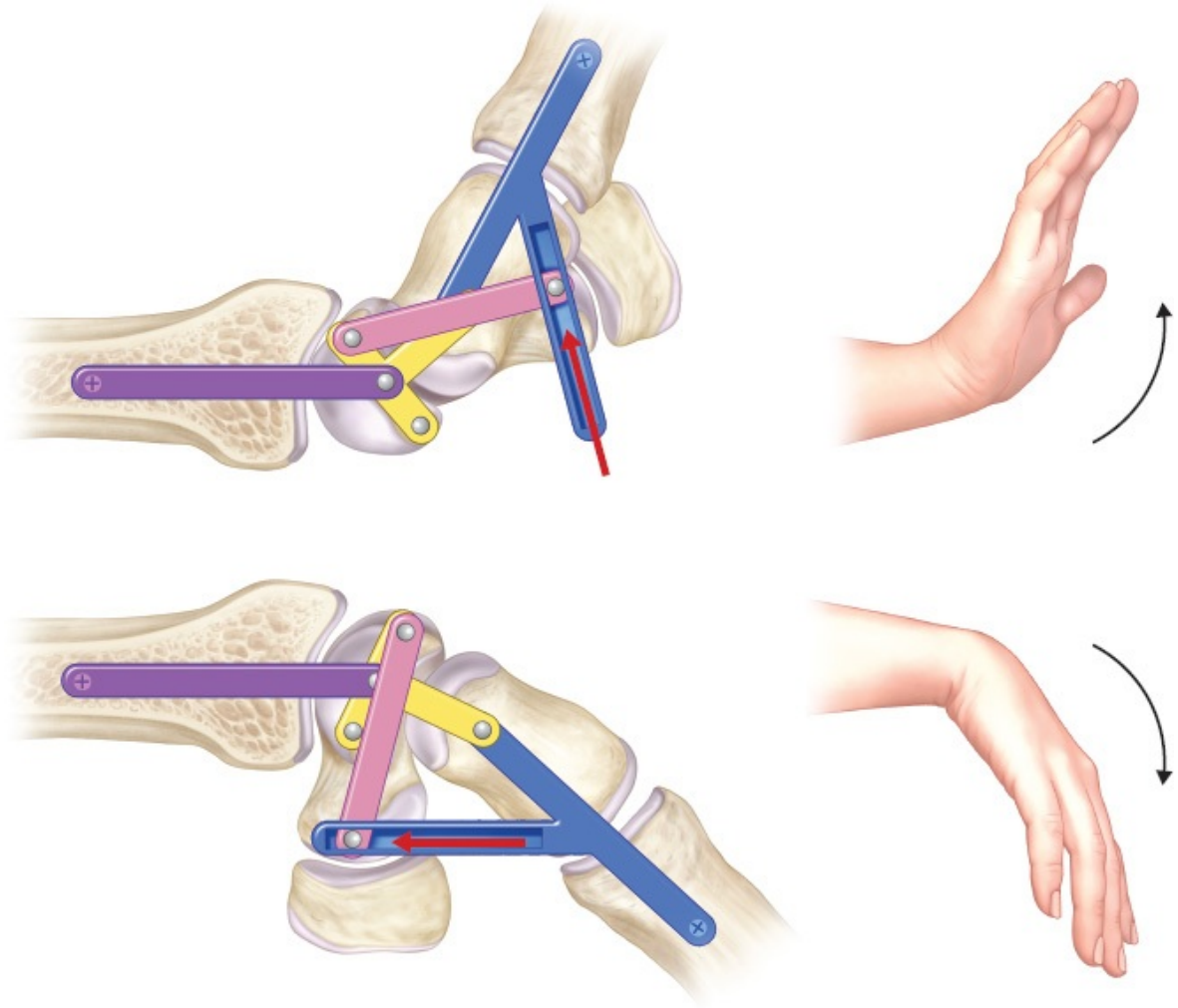


FIG 2 • The slider-crank model of the wrist joint posits a three-bar link between the radius, lunate, and capitate, with the scaphoid acting as the crank. The *red arrows* show the direction of force produced by the crank mechanism—a dorsally directed compressive force with extension of the wrist and a palmarly directed tensile force with flexion of the wrist.

Preoperative Planning

- Wrist arthroscopy has become the standard method of evaluation of interosseous ligament injuries. Geissler grading of ligament injuries as seen during arthroscopy is as follows⁸:
 - Grade 1: Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. No incongruency of carpal alignment in the midcarpal space.
 - Grade 2: Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. Incongruency/step-off as seen from the midcarpal space. A small gap may be seen between the carpal bones but smaller than the width of a probe.
 - Grade 3: Complete ligament tear seen from the radiocarpal joint. Incongruency/step-off of carpal alignment is seen from both the radiocarpal and midcarpal spaces. The probe can be passed through the gap between carpal bones.
 - Grade 4: Complete ligament tear is seen from radiocarpal joint. Incongruency/step-off of carpal alignment is seen from both the radiocarpal and midcarpal spaces. Arthroscope (2.7 mm) can be passed through the gap in the carpal bones. Gross instability with manipulation.

Positioning

- The patient is positioned supine on the operating table. The operative arm is on a hand table.
- Regional or general anesthesia can be used.
- A tourniquet is applied.
- An examination under anesthesia is performed to check for instability.

Approach

- A dorsal approach to the wrist is utilized, centered over the Lister tubercle (**FIG 3**).
- The third dorsal compartment is identified but does not need to be opened in most cases.
- Dissection is performed between the second and fourth compartments to expose the scaphoid and lunate.



FIG 3 • A dorsal incision is centered over the Lister tubercle.

TECHNIQUES

■ Dorsal Capsulodesis for Scapholunate Instability Using Suture Anchors

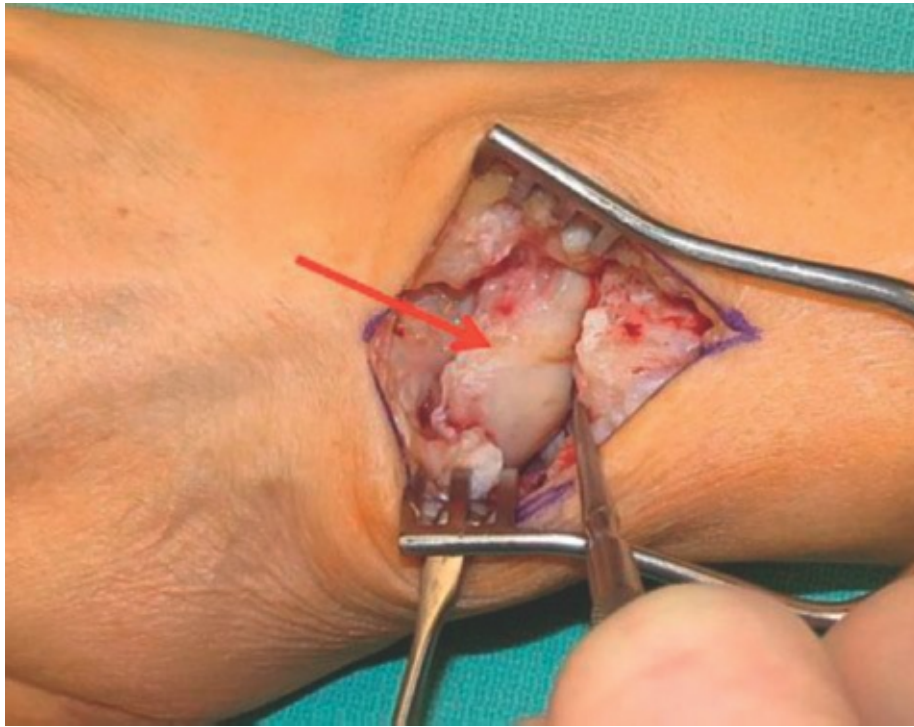
Exposure

- A 6-cm dorsal longitudinal incision is made, centered over the radiocarpal joint in line with the long finger metacarpal.
- Sharp dissection is carried down to the extensor retinaculum.
- Skin and subcutaneous tissue flaps are raised.
- The second and fourth compartments are elevated such that the tendons are maintained within the compartment.
- The wrist capsule is incised longitudinally to expose the scaphoid and lunate.
- The remaining dorsal SL ligament is assessed (**TECH FIG 1**).

Reduction

- Two 0.062-in. K-wires are placed into the dorsal scaphoid and lunate to act as joysticks for reduction.
- The scaphoid wire is retracted proximally to extend the scaphoid. The lunate wire is retracted distally to flex the lunate.
 - Fluoroscopy is used to evaluate the reduction.
- The assistant holds the scaphoid and lunate reduced using the joystick K-

wires while the surgeon drills one K-wire percutaneously from the radial side of the wrist, through the scaphoid and lunate.



TECH FIG 1 • Exposure of the SL joint in this patient shows an intact dorsal SL ligament (*arrow*). This patient had normal wrist radiographs, and SL diastasis on wrist arthroscopy.

- A second K-wire is then drilled through the scaphoid into the capitate to prevent the scaphoid from rotating. This will hold the reduction.

Fixation

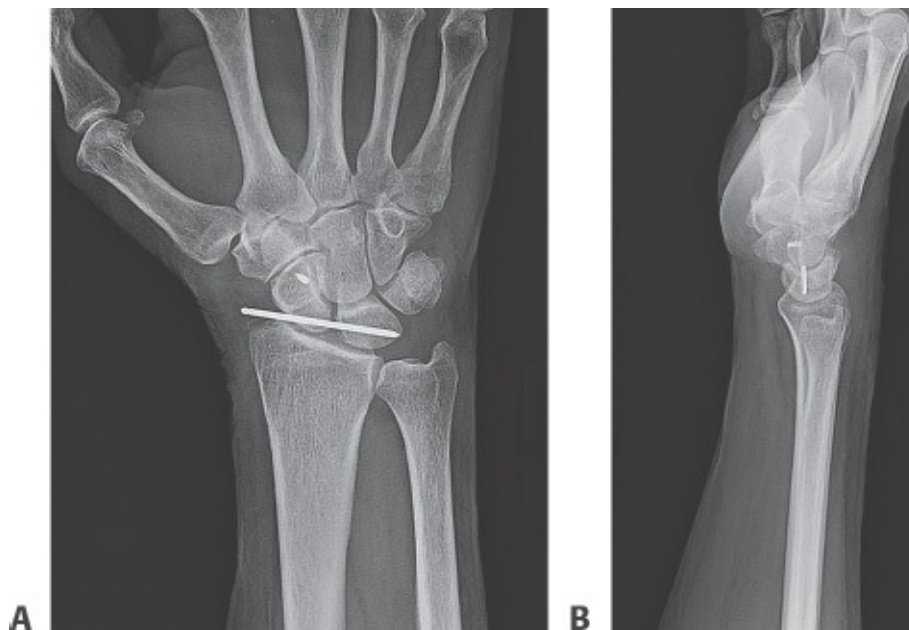
- A curette is used to debride the cortical bone from the distal dorsal scaphoid until cancellous bone is visible. This will provide a more favorable environment for healing the capsule to bone.
- Drill a hole using the Mitek anchor drill into the most distal part of the dorsal scaphoid. The drill hole should be placed adjacent to the scaphotrapezial joint, distal to the scaphoid axis of rotation. Place a 1.8-mm suture anchor (mini Mitek or similar) into the drill hole.
- Secure the dorsal capsule to the scaphoid by passing the suture from the

anchor through the overlying capsule. Tie the suture securely to prevent the scaphoid from flexing.

- Final fixation is assessed fluoroscopically to confirm that the lunate is in neutral position and the carpal bones are aligned correctly (**TECH FIG 2**).
- The dorsal capsule is repaired using 3-0 Ethibond suture.

Closure

- The tourniquet is released and hemostasis is obtained.
- The extensor retinaculum is closed with 3-0 Ethibond suture.
- Skin is closed with a 4-0 Monocryl suture.



TECH FIG 2 • Postoperative AP and lateral radiographs show a suture anchor in the dorsal scaphoid and a K-wire traversing the SL joint.

■ Scapholunate Stabilization with Dynamic ECRL Tendon Transfer

Exposure and Reduction

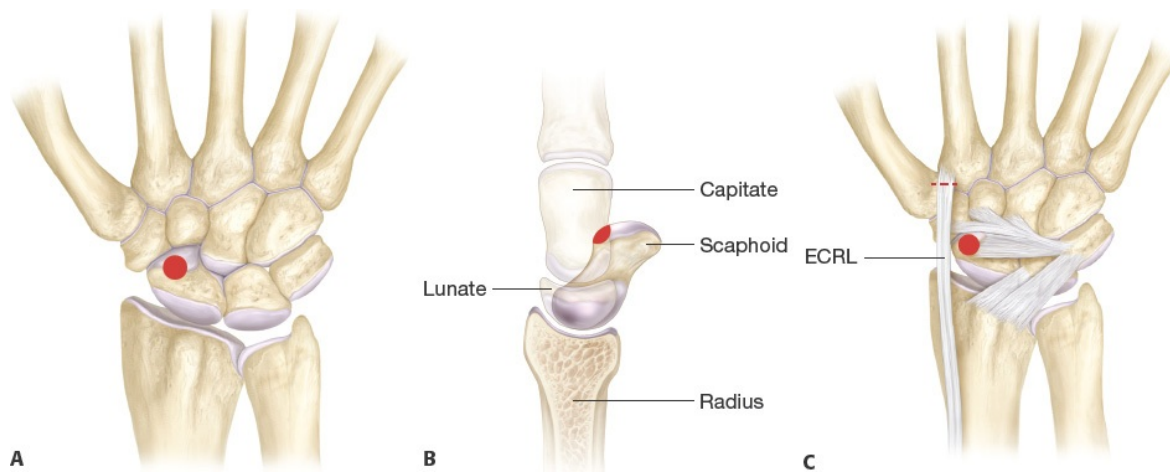
- The skin incision is centered over the dorsal wrist joint between the third and fourth dorsal compartments and extends from the Lister tubercle proximally

to between the index and long finger metacarpal bases distally.

- Expose the ECRL and extensor carpi radialis brevis (ECRB) from the distal edge of the extensor retinaculum to their insertions on the index and long finger metacarpal bases, respectively.
- The extensor tendons are retracted ulnarly to expose the wrist capsule. The wrist capsule is incised longitudinally, just radial to the origin of the dorsal radiocarpal (DRC) ligament proximally and radial to the insertion of the dorsal intercarpal (DIC) ligament distally. This will expose the SL joint and the SL ligament tear.
- Reduce the scaphoid and lunate and pin in place, as described above in the capsulodesis section.

Tendon Transfer

- Prepare the ECRL tendon insertion site at the dorsal distal scaphoid (**TECH FIG 3A,B**).
- A trough is made the dorsal distal scaphoid in the same manner as described in the capsulodesis section, and one or two mini Mitek anchors are placed.
- Anchors can alternatively be placed after the tendon is harvested.
- To harvest the ECRL tendon, it is incised transversely from its insertion on the dorsal base of the second metacarpal (**TECH FIG 3C**).
- The tendon tension should be set to a length that will make it isotonic when docked into the scaphoid—the tendon transfer should provide equal tension to the scaphoid throughout the arc of wrist motion.
 - If the tendon is too short, tension will be too high with wrist flexion.
 - If the tendon is too long, tension will be too light with wrist extension.
- Any adhesions are released so the ECRL has full excursion.
- To secure the tendon transfer, extend the wrist and have the assistant retract the tendon distally to reach the scaphoid while the surgeon ties the tendon down tightly to the anchor. The tendon can otherwise retract during this step.

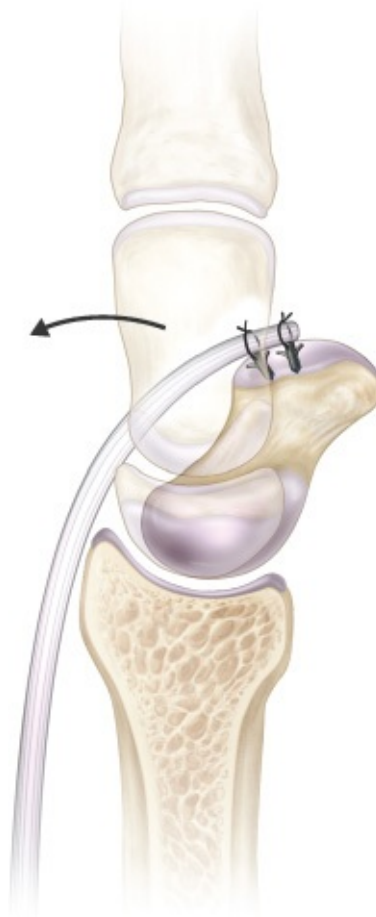


TECH FIG 3 • **A,B.** AP and lateral depictions of the ECRL insertion site in the scaphoid. The *red circles* indicate the area of the dorsal distal scaphoid to be curetted. **C.** The ECRL graft is harvested from the base of the second metacarpal. The *red circle* shows the location of the docking hole. The red line indicates where to transect the ECRL tendon from the insertion site on the index metacarpal base.

- Use two mini Mitek anchors for more secure attachment (**TECH FIG 4**).

Closure

- The dorsal wrist capsule is closed with 3-0 Ethibond suture.
- The tourniquet is released and hemostasis is achieved prior to further closure.
- Skin is closed with a 4-0 Monocryl suture.



TECH FIG 4 • Two mini Mitek anchors secure the ECRL tendon graft, which pulls the scaphoid back into extension.

PEARLS AND PITFALLS

Technique

- When placing joystick K-wires, correction of the deformity will be easier if the scaphoid wire is directed proximally and the lunate wire is directed distally.
- When drilling a hole for a suture anchor, care must be taken to protect the vascular pedicle that inserts at the dorsal ridge of the scaphoid.
- We recommend cutting K-wires under the skin to avoid pin-tract infection. Infection is common when K-wires are left outside of

	the skin for more than 3 weeks.
Postoperative care	■ Wrist range of motion is expected to decrease by about 20%. Despite this, most patients have significant improvement in pain after this surgery.
Rehabilitation	■ Patients are instructed to avoid forceful axial loading of the wrist (especially activities like weight lifting or push-ups) for 6 months.

POSTOPERATIVE CARE

- Postoperatively, the patient is placed into a volar wrist splint for 8 weeks.
 - For capsulodesis, the wrist can be splinted in a neutral position.
 - After dynamic ECRL transfer or tenodesis, the wrist is splinted in 15 to 20 degrees of extension to prevent excessive tension at the ECRL insertion site.
- The wound is examined and sutures are removed (if nonabsorbable sutures are used) after 10 days.
- The K-wires are removed 6 to 8 weeks after the initial surgery.
- After 8 weeks of splinting, the patient is transitioned to a removable volar splint for an additional 4 weeks. Gentle active wrist range of motion can begin at this time.

OUTCOMES

- Dorsal capsulodesis
 - Gajendran et al.⁹ studied 16 wrists in 15 patients who were treated with dorsal capsulodesis for chronic, flexible, static SL dissociation with follow-up of greater than 60 months (average 86 months). At final follow-up, average wrist flexion and extension were 50 and 55 degrees, respectively. Outcomes were also measured with disabilities of the arm, shoulder, and hand (DASH; average score 19), Short Form-12 (average score 78), and Mayo wrist score (average 78). Mayo scores were “excellent” in 38%, “good” in 19%, “fair” in 31%, and “poor” in 12% of patients. Grip strength was statistically unchanged from preoperative to final follow-up. Radiographs at final follow-up showed an average SL angle of 62 degrees, and an SL gap of 3.5 mm. Fifty percent of wrists (8/16) had evidence of arthritis on radiographs. Radiographic outcome did not correlate with subjective pain scores. The authors concluded that although dorsal capsulodesis did not prevent arthritic changes, patient satisfaction and functionality remained high after this surgery.
 - Megerle et al.⁵ did a retrospective study of 59 patients who underwent dorsal capsulodesis, with a mean follow-up of 8.25 years (4.3–12 years). Although

carpal alignment was significantly improved immediately postoperatively, results at long-term follow-up showed a return to preoperative alignment (mean SL angle 70 degrees at final follow-up). Eight patients required a salvage procedure at 2.33 years, and 40 patients had radiographic evidence of arthritis at final follow-up. Mean DASH and Mayo wrist scores were 28 and 61, respectively. The authors concluded that although capsulodesis did not prevent degenerative changes, most patients had acceptable clinical outcomes at long-term follow-up.

- ECRL tenodesis: Bleuler et al.¹⁰ studied 20 patients who were treated with dynamic ECRL tenodesis. All but one patient were satisfied with the functional outcome at short-term follow-up and would undergo the same surgery again if they had the choice. All patients were able to return to their former occupation between 1.5 and 4 months postoperatively.
- Combined ECRL tenodesis with dorsal capsulodesis: De Carli et al.¹¹ retrospectively reviewed 8 wrists in 8 patients who underwent combined ECRL tenodesis-capsulodesis for static SL dissociation with a minimum follow-up of 1 year (average 23 months). Average visual analog scale score (VAS: 0–10) postoperatively was 3. The mean DASH score was 13. Functional results were “excellent” in 2 cases and “good” in 6 cases. All patients lost some of their initial reduction on radiographs, but none had recurrence of carpal collapse.

COMPLICATIONS

- Infection
- Chronic regional pain syndrome
- Damage to the superficial radial nerve
- Loss of wrist range of motion
- Pin-tract infection
- Fracture

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CHAPTER Proximal Row Carpectomy

Patrick Reavey and Amy M. Moore

DEFINITION

- First described by Stamm,¹ proximal row carpectomy (PRC) is the removal of the scaphoid, lunate, and triquetrum, resulting in a neoradiocarpal articulation between the proximal capitate and the lunate fossa of the radius.
- PRC is one of the “motion-preserving” options for the treatment of degenerative carpal arthritis.

ANATOMY

- The proximal carpal row consists of the scaphoid, lunate, and triquetrum, and the distal carpal row includes the trapezium, trapezoid, capitate, and hamate (**FIG 1A**).
- Removal of the proximal carpal row converts a complex link joint to a simple hinge joint between the capitate and distal radius.
- Differences in the capitate and lunate morphology have been described as possible reasons for failure of PRC. However, biomechanical and clinical outcome studies have not demonstrated a significant relationship between carpal shape and failure.^{2,3}
- The carpal bones are linked to the radius and ulna and to each other by a complex network of extrinsic and intrinsic ligaments.
 - The radioscaphocapitate (RSC) ligament extends from the radial styloid across the volar waist of the scaphoid to the capitate (**FIG 1B**).
 - Identifying and preserving this ligament during PRC is crucial to prevent ulnar subluxation of the remaining carpus.

PATHOGENESIS

- A number of conditions can lead to painful radiocarpal arthritis.
- Scapholunate advanced collapse (SLAC) and scaphoid nonunion advanced collapse (SNAC) occur secondary to chronic scapholunate (SL) ligament disruption and scaphoid fracture nonunion, respectively.
 - Both of these conditions result in progressive radiocarpal arthritis that starts between the radial styloid and scaphoid.
 - In later stages, these conditions can progress to a pancarpal arthritis and may involve the lunocapitate joint.
- Kienbock disease is an idiopathic avascular necrosis of the lunate that can lead to varying degrees of intercarpal and radiocarpal arthritis.
- Treatment for each of these conditions varies based on the etiology and stage of disease at presentation. However, once significant arthritis has developed, conservative measures including splinting and steroid injections can minimize pain and improve function.

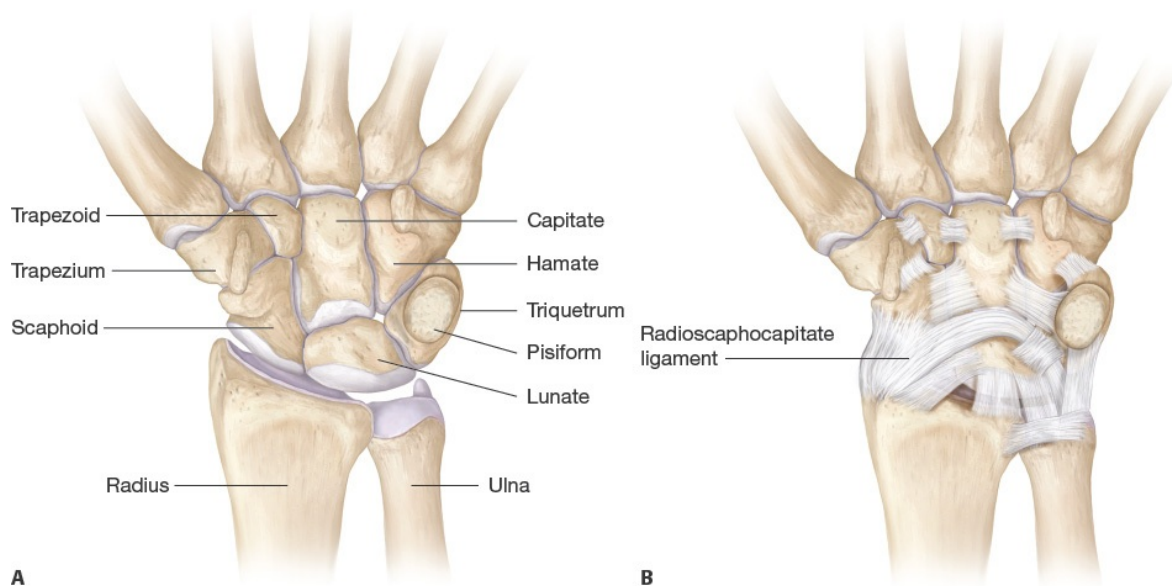


FIG 1 • A. Diagram of the carpus. **B.** Location of volar radioscaphocapitate ligament.

Table 1 Radiologic Staging Systems of Common Degenerative Wrist Arthritidis

Radiographic Stage	Kienboch's	SLAC	SNAC
1	No visible	<i>Arthritis between</i>	<i>Arthritis between</i>

	changes on x-ray, decreased vascularity on MRI	<i>scaphoid and radial styloid</i>	<i>scaphoid and radial styloid</i>
2	Sclerosis of lunate	<i>Arthritis between scaphoid and entire scaphoid facet of radius</i>	<i>Stage 1 + scaphocapitate arthritis</i>
3	A: lunate collapse, no scaphoid rotation B: lunate collapse, fixed scaphoid rotation	<i>Arthritis between capitate and lunate^a</i>	<i>Periscaphoid arthritis</i>
4	<i>Degenerated adjacent intercarpal joints^a</i>	Pancarpal arthritis	

Italics indicate stages appropriate for treatment with PRC.

^aLunocapitate arthritis is a contraindication to PRC, though capsular interposition or osteochondral resurfacing modifications may be performed in the presence of arthritis.

Kienbock, Lichtman classification; SLAC, Watson classification.

- PRC is usually reserved as a salvage operation for patients who have failed surgical treatment of earlier stages of the disease and have also failed trials of conservative management.^{4,5} Table 1 covers staging of each condition and indications for PRC.
- PRC has also been described in the acute treatment of severe radiocarpal or carpal fracture dislocations⁶ but is not recommended in the initial treatment of early SL dissociations.⁷

NATURAL HISTORY

- Carpal arthritis frequently presents with patients complaining of wrist pain, decreased range of motion and grip strength, and inability to perform daily activities without discomfort.
- Many patients will have a distant history of trauma or prior surgical procedures for an acute injury.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Preoperative evaluation of a patient with wrist arthritis should include a detailed history, an assessment of functional limitations, measurement of wrist range of motion, and grip strength.
- History
 - A patient's occupation, age, and interests are key factors in determining if PRC is an appropriate procedure.
 - PRC is generally indicated in patients older than 40 who have low physical demands.
 - Younger patients and manual laborers have less ideal outcomes and higher failure rates after PRC.^{3,8}
 - The operative records from prior surgeries should be obtained and the outcome of any trial of conservative therapy should be elicited.
 - Use of a patient-reported outcome measure (PROM) such as the Michigan Hand Questionnaire (MHQ), disability of the arm, shoulder, and hand (DASH), or Patient-reported Wrist Evaluation (PRWE) can be helpful in determining the patient's baseline functional disability and following postoperative outcomes.
- Physical examination
 - The skin is evaluated for scarring and/or previous incisions.
 - The wrist is evaluated for edema, gross deformity, and tenderness.
- Range of motion and grip strength
 - Active wrist flexion and extension as well as radial and ulnar deviation are measured with the forearm in neutral rotation.
 - Total range of motion as well as the extent of each motion at which the patient experiences pain is determined.
 - Grip strength is measured with a dynamometer.
 - The bilateral wrist measurements are obtained and compared.
- Carpal examination
 - A detailed examination of the carpus is performed to elicit sites of discomfort to palpation and motion.
 - Evaluating for snuffbox tenderness, SL tenderness, and a Watson's is useful when determining the primary pathology leading to carpal arthritis but does not directly impact the decision to perform a PRC.
- Neurovascular examination
 - The examiner should perform a complete neurovascular examination of the

hand.

IMAGING

- Standard three-view wrist radiographs (PA, lateral, oblique) are performed to evaluate for the extent of carpal arthritis.
- Specific evaluation of the lunocapitate joint on PA view is crucial to determining if PRC is an option for the patient because arthritic change at this joint precludes performing a PRC when a normal capitate is needed to articulate with the lunate fossa on the radius.
 - If there is any evidence of lunocapitate arthritis on x-ray, modifications of a PRC may be required (see below in techniques).
 - The patients should also be counseled that they may require conversion to an alternative procedure (ie, wrist fusion) intraoperatively.
- CT scan or MRI may be helpful in evaluating the pathologies that lead to carpal arthritis or the presence of synovitis in the intercarpal joints. However, they are not required prior to performing a PRC as the capitate can be visualized directly early in the procedure with options to perform alternative salvage procedures if necessary.

NONOPERATIVE MANAGEMENT

- Painful radiocarpal arthritis can initially be treated with splinting and/or steroid injections.

SURGICAL MANAGEMENT

- PRC is considered an appropriate salvage procedure if nonoperative measures fail or do not provide durable pain relief.
- Alternative salvage procedures include limited or total wrist arthrodesis.

Preoperative Planning

- As discussed above, evaluating the lunocapitate articulation helps in determining if a patient is a candidate for PRC.
- Mild arthritis of the proximal capitate may not be visualized on radiographs, so all patients should be counseled that they may require conversion to a limited wrist fusion intraoperatively.
- Any implants required for wrist fusion should be available in case they are needed.
- PRC can be performed under regional or general anesthesia.

Positioning

- The patient is positioned supine with the hand over a radiopaque hand table centered on the patient's axilla.
- A well-padded pneumatic tourniquet is placed on the upper arm.
- If an assistant is not available to assist with traction, end-table traction with finger traps and 5 to 10 lb of weight will facilitate dissection during the procedure.

Approach

- A dorsal radiocarpal approach between the third and fourth extensor compartments provides good exposure to inspect the radiolunate and lunocapitate articulations, remove the proximal carpal row, as well as to perform modifications to the PRC procedure or other salvage procedures.
- A volar approach has also been described; however, this requires partial division and subsequent repair of the crucial RSC ligament.⁹ This approach also limits options for alternative salvage procedures and is not recommended by the authors.
- A PRC can be performed arthroscopically,^{10,11} though this requires significant experience with these techniques and may not have long-term benefit to patients when compared to the standard procedure.⁵
- The key steps of a standard PRC are described below. Two modifications of PRC that can be performed in the setting of limited proximal capitate arthrosis are also described.

TECHNIQUES

■ Standard Proximal Row Carpectomy

Exposure

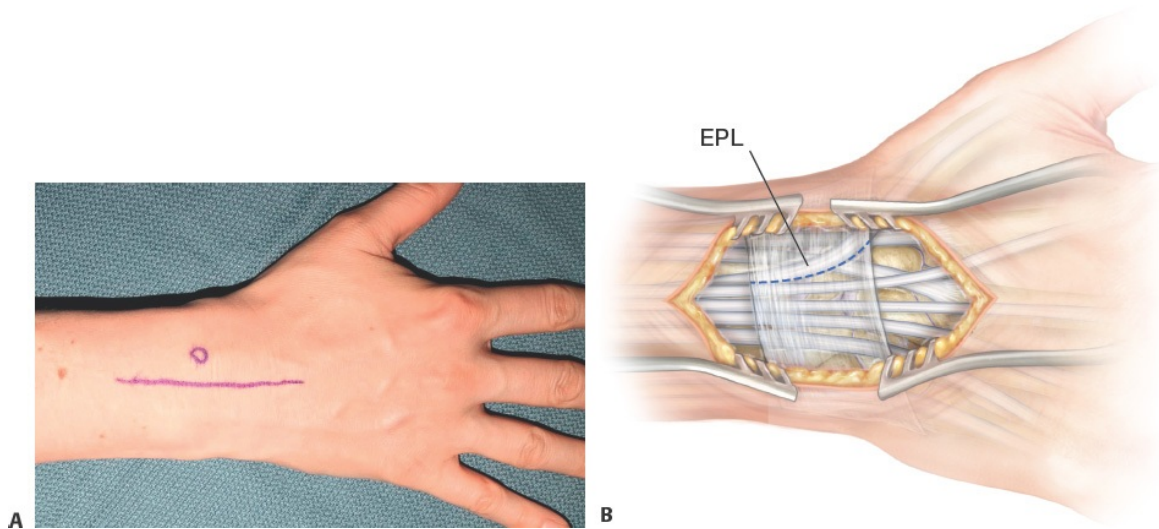
- Exsanguinate the arm with Esmarch tourniquet and inflate the pneumatic tourniquet.
- Make a dorsal longitudinal incision approximately 8 cm in length over the carpus just ulnar to the Lister tubercle (**TECH FIG 1A**).
- Raise subcutaneous flaps ulnarly and radially just above the extensor retinaculum to protect sensory branches of the superficial radial and dorsal

ulnar nerves.

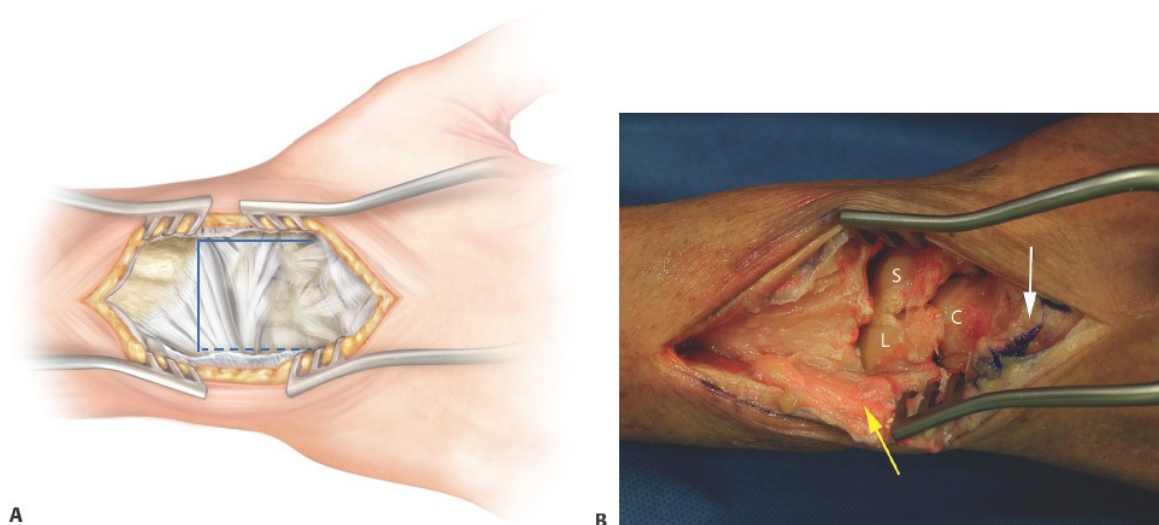
- Identify the extensor pollicis longus (EPL) tendon proximal or distal to the retinaculum and divide the retinaculum sharply along the third dorsal compartment (**TECH FIG 1B**). Externalize and retract the EPL radially so that the EPL does not rupture with swelling around the Lister tubercle after surgery.
- Raise the fourth compartment off the distal radius ulnarly in a subperiosteal fashion, with care not to injure the dorsal ligaments.
- Identify the extensor carpi radialis brevis (ECRB) tendon and place a Weitlaner to retract the ECRB and EPL tendons radially and the fourth dorsal compartment ulnarly.

Capsulotomy

- To enter the carpus, a longitudinal capsulotomy can be made in line with the division between the third and fourth dorsal compartments.
- However, designing an L-shaped capsulotomy provides good exposure for carpectomy and preserves the dorsal capsule for use in an interposition flap if needed (see below).



TECH FIG 1 • A. Incision for dorsal exposure of the carpus. *Circle marks the Lister tubercle.* **B.** Exposure of extensor retinaculum after raising subcutaneous flaps. The retinaculum is divided along the third compartment (*dashed line*).



TECH FIG 2 • A. Markings for L-shaped capsulotomy (solid line). The *dashed line* indicates an incision to convert the capsulotomy into a distally based flap for capsular interposition. **B.** The capsular flap is raised and retracted to expose the carpus (*white arrow*). A portion of the dorsal cuff of capsule has been raised contiguous with the floor of the fourth compartment (*yellow arrow*). L, lunate; S, scaphoid; C, capitate.

- The longitudinal incision should be in line with the native position of the ECRB and connect to a capsular incision along the radiocarpal joint extending ulnarly.
- Leave a small cuff of capsule on the distal radius (**TECH FIG 2A**).
- Use a knife to raise the dorsal capsule off the carpal bones to completely expose the carpus (**TECH FIG 2B**).
- Once the carpus is exposed, inspect the lunate fossa of the radius and the proximal pole of the capitate for arthrosis.
 - If there is some arthrosis of the capitate, a modified PRC may be possible (see below).
 - In the setting of significant arthrosis, PRC should be aborted and the surgical plan changed to limited or complete wrist fusion.
- Once the decision is made to proceed with PRC, the proximal carpal bones are resected.

Bone Removal

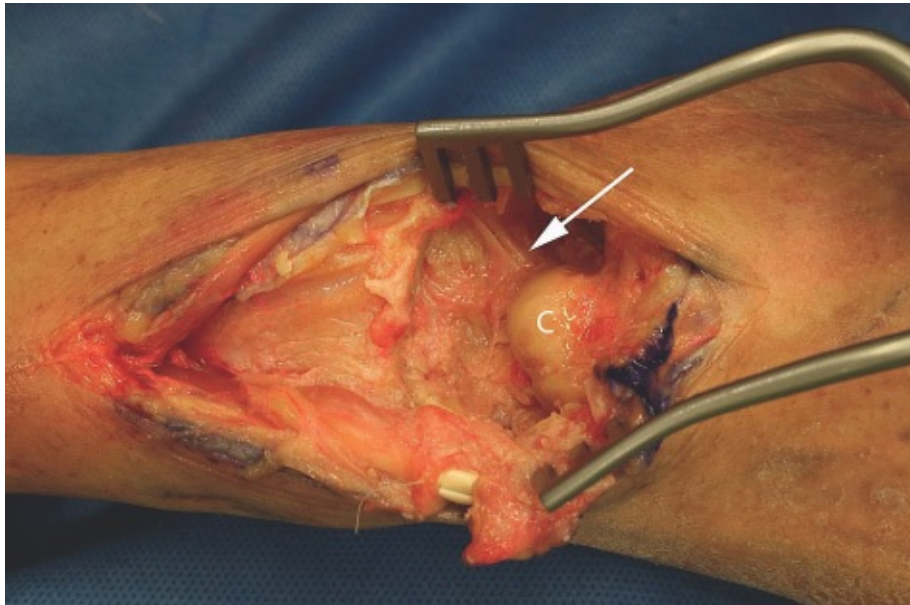
- Place the patient's hand under traction with the help of an assistant or finger traps attached to weights off the end of the hand table. This aids in exposure and creates space between the carpal rows as well as the radius.
- Removal of the proximal row can be done in any order—scaphoid first or scaphoid last. However, there is more room for “error” during removal of the triquetrum, so surgeons with less experience may want to start with the triquetrum excision.
- The general steps to remove each bone is as follows:
 - First, divide any intact dorsal intrinsic ligaments to facilitate independent mobilization of each bone.
 - Use a penetrating towel clamp (or place small threaded Steinman pins or K-wires into the bones) to help manipulate each bone during dissection. Pins are especially useful in the setting of SNAC wrist to separately manipulate and dissect around the proximal and distal poles of the scaphoid.
 - Use a Carroll elevator to bluntly begin the dissection around the volar aspect of each bone. A scraping sensation, as if dissecting subperiosteally, indicates the proper plane.
 - Once enough of the attachments are released, the bone can be torqued to directly visualize the volar ligaments. At this point, sharp dissection with a knife can be used to release the ligaments directly off the bone.
 - Piecemeal resection of the lunate and triquetrum (ie, with a rongeur or osteotome) is acceptable, but not advisable because it makes grasping and manipulating the bones difficult during final volar dissection. Thus, this technique is not recommended for the scaphoid.
- Key aspects of lunate excision:
 - It is crucial not to damage the cartilage on the proximal capitate and lunate fossa of the radius during lunate excision.
 - Hohmann retractors (or similar) should not be used around the lunate during dissection.
 - Consistent traction will provide space to ease dissection around the lunate.
 - Two wet 4 × 4 gauze can be tucked into the lunate fossa and around the proximal capitate to protect these cartilaginous surfaces during removal.
- Key aspects of scaphoid excision:
 - Slow and meticulous dissection along the volar waist of the scaphoid is

imperative to preserve the RSC ligament.

- Until each ligament is clearly visualized, all dissection along the scaphoid should be done bluntly.
- Once the scaphoid has been removed, the intact RSC ligament should be visualized crossing from the radial styloid to the capitate (**TECH FIG 3**).

Completion and Closure

- After completing the carpectomy, fluoroscopy should be used to ensure complete resection. Small, retained portions of the distal scaphoid may not be symptomatic postoperatively,⁵ but any other bone fragments should be removed.



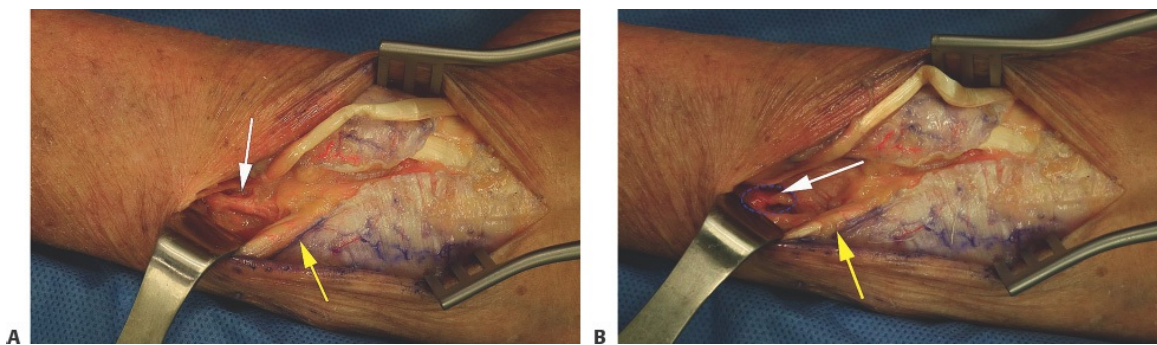
TECH FIG 3 • The proximal row has been resected. Note the thick radioscaphocapitate ligament in the volar capsule (*white arrow*). With forced ulnar translation, the capitate (C) does not migrate past the lunate fossa of the radius.

- Stress the carpus ulnarly to test the volar radiocarpal ligaments.
- If the RSC ligament is adequately preserved, the capitate should not translate past the lunate fossa.
- If the carpus does translate ulnarly, the RSC ligament was likely compromised and the pinning of the neoradiocarpal joint is recommended.

- Seat the capitate into the lunate fossa.
 - Repair the dorsal capsulotomy with a 4-0 absorbable suture.
 - Repair the extensor retinaculum with 4-0 suture leaving the EPL externalized, ie, transposed.
 - Let down the tourniquet and check for hemostasis.
 - A layered skin closure with a running subcuticular 4-0 suture (absorbable or non-absorbable) leaves a minimal scar.
 - Patients are placed into a volar resting splint for postoperative comfort.
-

■ Proximal Row Carpectomy with Wrist Denervation

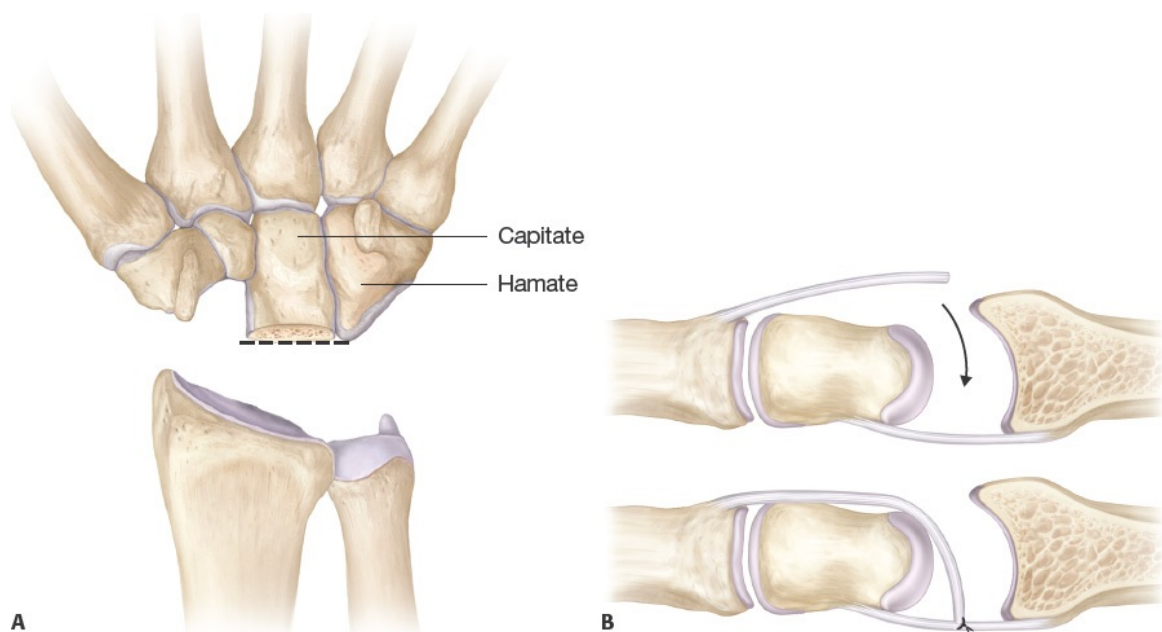
- Neurectomy of the posterior and anterior interosseous nerves may decrease postoperative pain and improve long-term outcomes.⁸
- Denervation can be completed at the beginning or end of the case.
- The tendons of the fourth dorsal compartment are isolated proximal to the extensor retinaculum and retracted ulnarly (**TECH FIG 4A**).
 - The posterior interosseous nerve and artery can be identified on the floor of the fourth dorsal compartment.
 - The nerve is carefully dissected away from the artery, crushed proximally, and resected for a length of 1 to 2 cm. The proximal nerve end is then cauterized.
- The extensor tendons are then shifted radially and the interosseous membrane just proximal to the distal radioulnar joint is identified.
 - A 2- to 3-cm incision is made on the interosseous membrane and the anterior interosseous nerve and artery are identified just volar to the cut membrane (**TECH FIG 4B**).
 - The nerve is crushed proximally, and a 1- to 2-cm length of the nerve is resected with cauterization of the ends.
- After resection of the nerves, the procedure continues as described above.



TECH FIG 4 • A. The posterior interosseous nerve (*white arrow*) is seen on the floor of the fourth compartment, which is retracted ulnarly (*yellow arrow*). **B.** A longitudinal incision has been made in the interosseous membrane (*circled*) and the anterior interosseous nerve is seen immediately below (*white arrow*). The fourth compartment remains retracted ulnarly (*yellow arrow*).

■ Proximal Row Carpectomy with Capsular Interposition

- The Salomon-Eaton modification of the PRC uses a dorsal capsular flap, which is interposed between the capitate and radius and can be performed in the setting of proximal capitate arthritis.^{4,5,12}
- The procedure is performed the same as the standard PRC; however, it is required to perform the initial dorsal capsulotomy so that a distally based capsular flap can be used (see **TECH FIG 2A**).
- After exposure of the capitate and presence of arthritis is confirmed, the proximal row is removed in the same manner as a standard PRC.



TECH FIG 5 • A. The proximal capitate is resected flush with the base of the hamate. **B.** The distally based dorsal capsular flap is sutured around the distal carpal bones to the volar capsule.

- In the traditional Salomon-Eaton procedure, the proximal capitate is then resected with a sagittal saw or osteotome to the level of the hamate (**TECH FIG 5A**). However, resection of the proximal capitate is not required for flap interposition and may result in deleterious injury to the remaining capitate and/or proximal hamate. The authors recommend leaving the capitate as is prior to flap interposition.
- The dorsal L-shaped capsulotomy is converted into a distally based rectangular flap by creating a longitudinal incision in the capsule on the ulnar aspect of the capitate.
- The dorsal flap is then sutured around the proximal capitate to the volar capsule with 4-0 nonabsorbable suture (**TECH FIG 5B**).
- A 0.062-in. K-wire is then inserted in a retrograde fashion from the capitate to the radius to secure it in the lunate fossa.
- As there is no dorsal capsule to close with this technique, closure begins with repair of the extensor retinaculum and proceeds in the standard fashion.

■ Proximal Row Carpectomy with Osteochondral Grafting

- This modification of PRC is indicated for resurfacing limited arthritis (less than 10 mm) of the proximal capitate.¹³ The procedure uses an osteochondral graft harvested from one of the removed carpal bones that is placed into the proximal capitate articular surface.
 - The procedure begins as in the standard PRC.
 - Once the capitate is inspected and found to have a small area of cartilage loss (less than 10 mm), osteochondral grafting can be performed.
 - The proximal row is removed as in the standard PRC; however, at least one of the bones must be removed en bloc to harvest the osteochondral graft.
 - Once the proximal row is removed, the size of the cartilage defect in the capitate is determined and resected with a reamer for a depth of 10 mm.
 - A harvesting dowel of matching diameter is then used to harvest a full-thickness osteochondral graft from one of the removed bones in an area of pristine cartilage, usually on the lunate or triquetrum.
 - The graft is cut down to 10 mm in length and then gently impacted into the defect in the proximal capitate until the cartilage surface is flush.
 - Closure proceeds in the same fashion for a standard PRC.
-

PEARLS AND PITFALLS

Patient selection

- PRC has the longest durability in older patients (older than 40 years) with low physical demands.

Planning

- Patients with evidence of lunocapitate arthritis on radiographs should not be offered PRC.
- Designing the L-shaped capsulotomy in all patients reserves the dorsal capsule interposition flap as a bail-out in cases with mild arthritis encountered intraoperatively.

Technique

- Blunt dissection around the scaphoid is crucial to preserve the RSC ligament.
- Failure to preserve this ligament may lead to poor alignment of the

	capitate and lunate fossa and early failure of the procedure.
Technique	■ Avoid damage to the proximal capitate and lunate fossa of the radius during removal of the proximal row.
Therapy	■ Early motion postoperatively allows for quicker return to of motion without any adverse outcomes.

POSTOPERATIVE CARE

- Patients are seen in the office 2 weeks after surgery and the splint and sutures removed.
- Standard radiographs of the wrist are obtained to confirm appropriate alignment of the radiocapitate articulation (**FIG 2**).
- Patients in whom the RSC was protected and have maintained alignment can begin an early protected range of motion protocol.^{14,15}
- Strengthening of the wrist is reserved until 6 to 8 weeks postoperatively.

OUTCOMES

- Postoperative pain from PRC generally takes 3 to 6 months to resolve.^{3,4,16} However, once recovered, nearly all patients will note a significant decrease in their preoperative pain, and this continues to improve during the first postoperative year.
- Patients can expect to regain between 50% and 85% of their contralateral wrist flexion-extension arc and 75% to 90% of grip strength relative to their contralateral side.^{3-5,8,16,17}
 - Though the range of motion may be less than preoperatively, the decrease in patient's pain provides greater use of the hand, and most patients are extremely satisfied with the results of PRC.
 - Relative to alternative salvage procedures such as four-corner arthrodesis, PRC demonstrates better flexion and extension, though less radial deviation and grip strength.^{12,18}
- Long-term follow-up of PRC patients more than 10 years demonstrates a 10% to 15% failure rate with these patients requiring revision surgery for wrist arthrodesis.^{3-5,8,16,17,19}
 - Younger patients (younger than 40 years of age) and manual laborers have a higher rate of failure,^{3,5} though some authors report that 90% of high-demand patients are still able to function in their occupational capacity.^{15,16,19}
 - All patients will end up with arthritis at the neoradiocarpal joint. However,

most patients will still have good clinical outcomes that do not correlate with the degree of arthritis.^{3-5,8,13,16,19}

- Overall, the results of capsular interposition and osteochondral resurfacing during PRC are similar to those in standard PRC.^{4,5,13}

COMPLICATIONS

- The advantage of PRC is that it has a low complication rate and does not require bony union as in the alternative salvage wrist limited fusion procedures.
- Improper selection of patients may lead to higher failure rates.
- By far the most common complication of PRC is failure to preserve the RSC ligament during dissection. This requires prolonged immobilization postoperatively and leads to a higher likelihood of failure.



FIG 2 • Postoperative **(A)** PA and **(B)** lateral radiographs of a patient after proximal row carpectomy. Note the appropriate alignment of the capitate in the lunate fossa of the radius.

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Section V: Distal Radius Fractures

23

CHAPTER **Distal Radius Fractures**

Shoshana W. Ambani and Kevin C. Chung

DEFINITION

- Distal radius fractures encompass all fractures of the articular and distal metaphyseal components of the distal radius.
- They are the most common fracture of the human skeleton, with an annual incidence of over 640 000 cases in the United States.
- These fractures have a bimodal distribution, with peak occurrences in the 5- to 14-year-old and 75- to 84-year-old populations.
- Fractures of the distal radius distort the normal radiocarpal configuration, changing the biomechanical properties of the wrist joint.
- Nonanatomic alignment due to displaced fractures may lead to degenerative arthritis in the long term.

ANATOMY

- The distal radius has three concave articular surfaces: the scaphoid fossa, lunate fossa, and sigmoid notch (**FIGS 1** and **2A**).
- The dorsal aspect of the distal radius is convex and acts as a fulcrum for the extensor mechanism (**FIG 2B**).
- The extensor pollicis longus tendon passes ulnar to the Lister tubercle, a dorsal landmark on the distal radius.

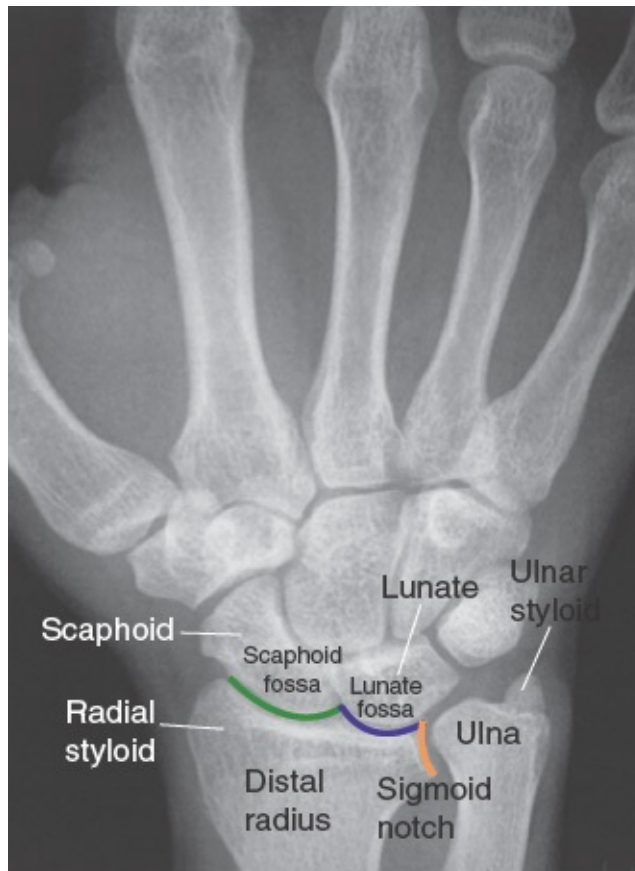


FIG 1 • The distal radius.

- Hand and forearm tendons and musculature are shown in **FIG 3**, and the extensor compartments of the wrist and anatomy of the dorsal wrist capsule are shown in **FIG 4**.
- Important anatomic considerations with regard to surgery of the distal radius are further delineated in the Techniques section of this chapter.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present with tenderness, swelling, and deformity of the wrist after a fall. Such a fall leads to compressive loading on the extended wrist.
 - The term FOOSH, which stands for “fall on outstretched hand,” is a commonly used acronym describing this mechanism.
- Often, the wrist is described as having a “dinner fork deformity” upon examination (**FIG 5**).
- It is important to perform a comprehensive hand and wrist examination while paying particular attention to any median nerve symptoms that would indicate

the presence of acute carpal tunnel syndrome.



FIG 2 • Volar (A) and dorsal (B) surface anatomy of the distal radius.

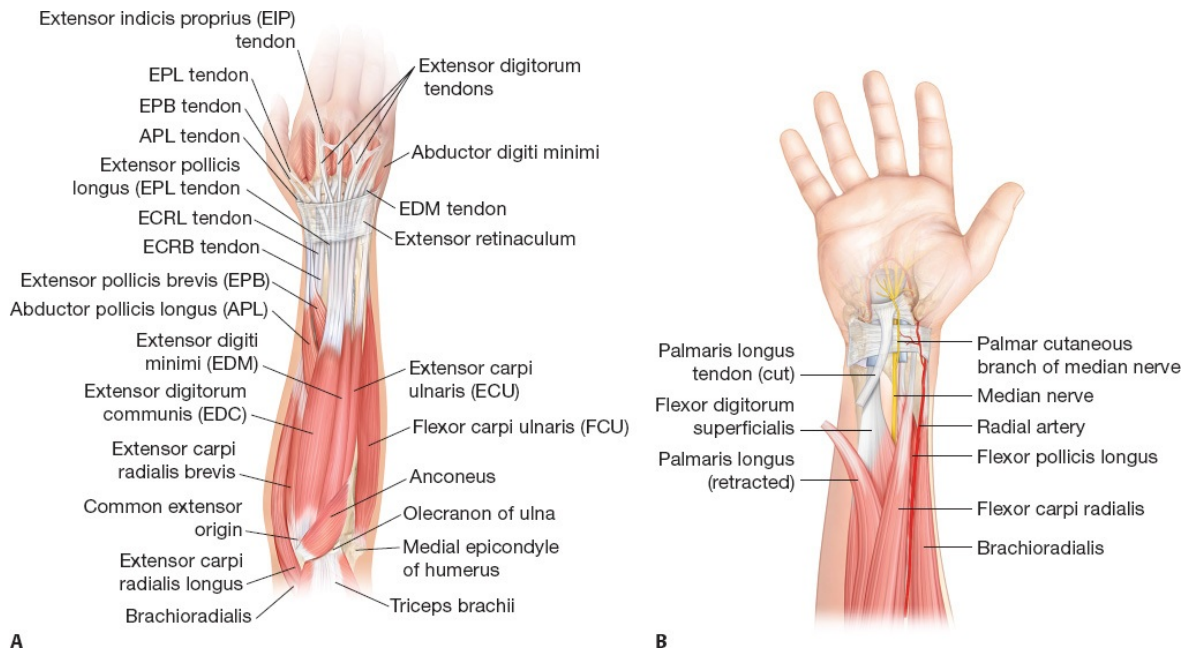


FIG 4 • Dorsal (A) and cross-sectional (B) views of the six extensor compartments of the wrist. C. Anatomy of dorsal wrist capsule.

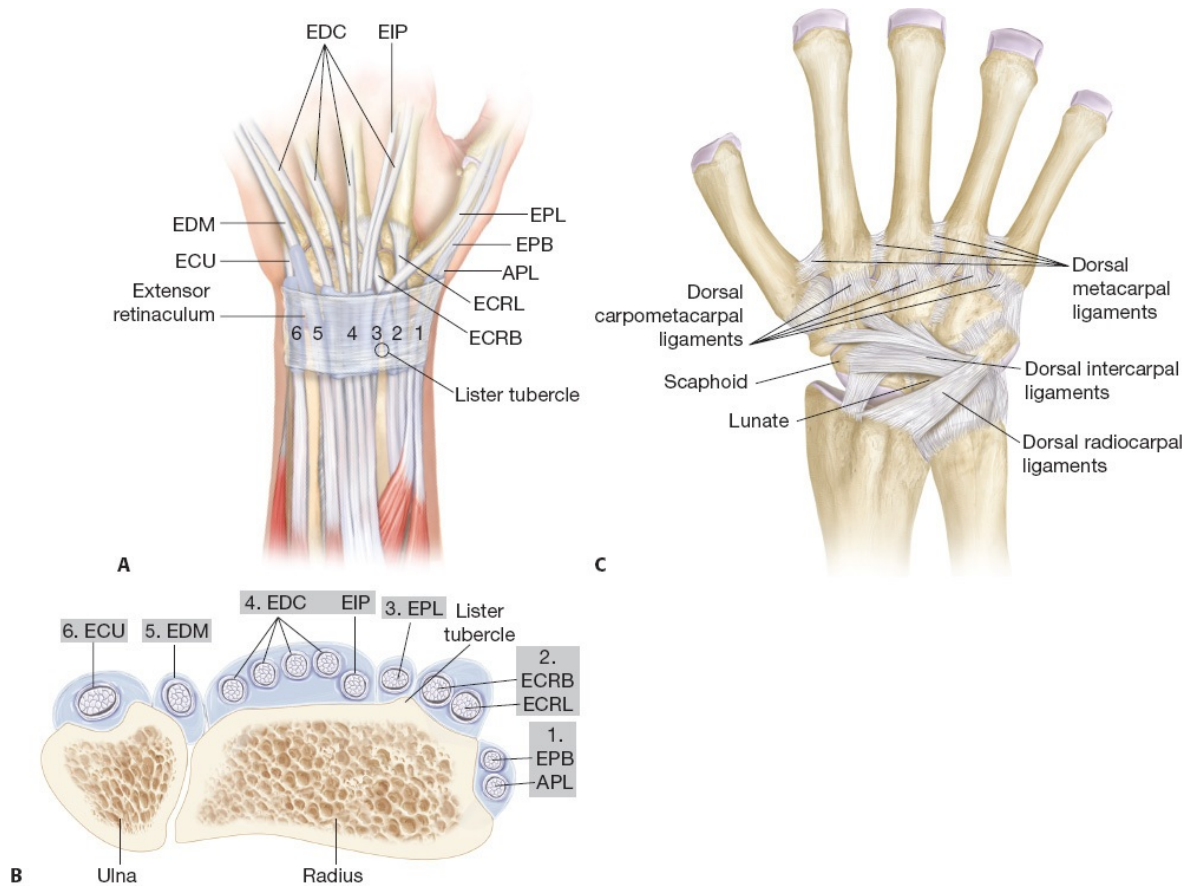


FIG 3 • Tendons and muscles of the dorsal forearm and hand **(A)** and the distal volar forearm and wrist **(B)**.



FIG 5 • Dinner fork deformity.

- Any open injuries should be noted and require urgent debridement.
- The distal ulna should be examined for dorsal prominence or instability, which may be indicative of a concomitant distal ulna fracture or a tear of the

triangular fibrocartilaginous complex (TFCC) ligament.

- The elbow should be examined for tenderness at the radial head and collateral ligaments. Tenderness in this location may be indicative of a radial head fracture, elbow dislocation, or other elbow-related injury requiring attention.

IMAGING

- Standard imaging for all wrist injuries include posteroanterior (PA), oblique, and lateral radiographs.
- On PA view, the distal radius has an average slope of 22 degrees in the radial-to-ulnar plane (radial inclination), with a radial height of about 10 to 12 mm (**FIG 6A**). The congruity of the distal radius articulation with the ulna at the sigmoid notch, as well as the radiocarpal joint itself, must be assessed.
- On lateral view, the distal radius tilts about 12 degrees in the dorsal-to-volar plane (volar tilt) (**FIG 6B**).

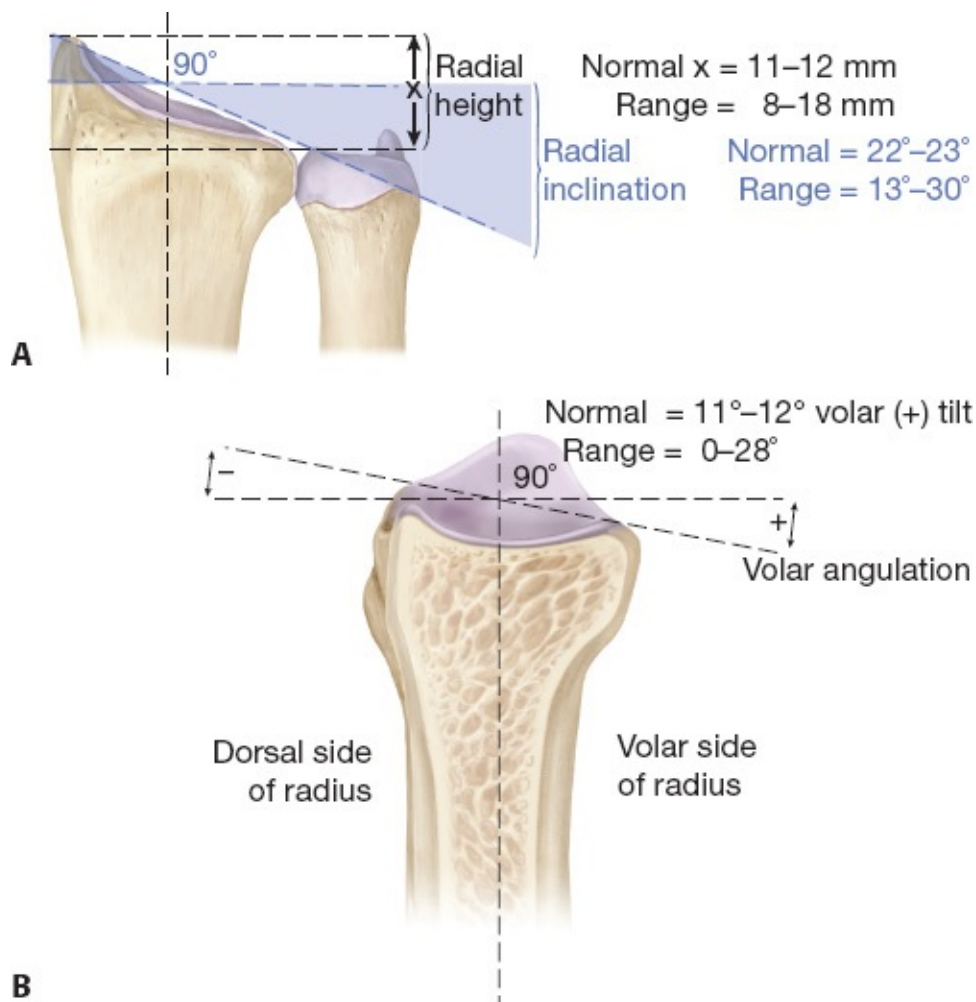


FIG 6 • A. Distal radius radial length and radial angulation. **B.** Distal radius volar tilt.

- If significant intra-articular comminution is present, a computed tomography (CT) scan may provide more information on the location and displacement of fracture fragments to aid in preoperative planning.

DIFFERENTIAL DIAGNOSIS

- Distal radius fractures can be differentiated from other wrist injuries, including the following, by careful examination and review of imaging.
 - Wrist sprain or contusion
 - Radiocarpal dislocation
 - Carpal bone fracture or dislocation, including fractures of the scaphoid
 - Carpal ligament injury, including injury to the scapholunate ligament
 - Fracture of the distal ulna or ulnar styloid
 - Distal radioulnar joint (DRUJ) injury
 - Degenerative arthritis
 - Inflammatory arthritis
 - Septic arthritis
 - Crystalloid arthropathy
- It is important to rule out other concomitant injuries, such as an acute median neuropathy.

CLASSIFICATION SYSTEMS AND EPONYMS

- Once diagnosed, distal radius fractures should be classified as open or closed, displaced or nondisplaced, and extra-articular or intra-articular. The structural elements and angles should be further described for clarity of the fracture pattern.
- Several classification systems exist for distal radius fractures, including the Muller AO, Frykman, Melone, Rayhack, Mayo Clinic, and universal classification systems. Given the plethora of independent classification systems, their use may complicate communication about fracture patterns. It is preferable to describe the fracture pattern directly.
- Eponyms were traditionally used to describe particular distal radius fractures but now only have historical significance. Common eponyms and nicknames include the following (**FIG 7**):
 - A Colles fracture is an extra-articular distal radius fracture featuring an apex

volar deformity with dorsal comminution.

- A Smith fracture, or “reverse” Colles fracture, is an extra-articular distal radius fracture with an apex dorsal configuration.
- A die-punch fracture is an intra-articular depression fracture of the lunate fossa of the distal radius, resulting from a direct load transmitted through the lunate.
- A Barton fracture is an intra-articular shear fracture of the distal radius, involving a fracture dislocation of the radiocarpal joint, either volarly or dorsally.
- A Hutchinson fracture, or “chauffeur’s fracture,” is an isolated intra-articular fracture of the radial styloid. Chauffeurs often sustained injuries from manual crank starters that backfired.

INITIAL MANAGEMENT

- The goal of treating distal radius fractures is to achieve anatomic reduction, thereby maintaining wrist biomechanics.
- Initial management of any distal radius fracture requires closed reduction and immobilization.

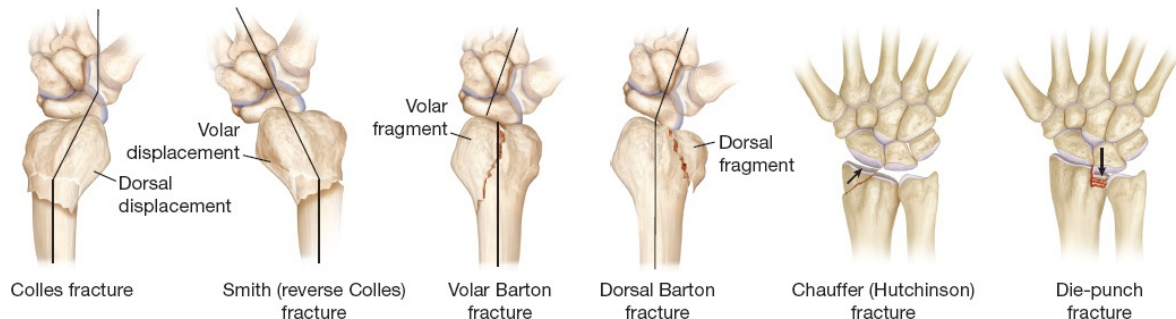


FIG 7 • Eponyms and nicknames for distal radius fractures.

- This can be done with the use of a “hematoma block,” in which local anesthetic such as 1% lidocaine is injected dorsally into the fracture site. In addition, providing the patient with a benzodiazepine can help with muscle relaxation, thus minimizing deforming forces.
- The chance of success can be improved further with the use of continuous intravenous sedation, which provides better muscle relaxation than does a single benzodiazepine dose.

- The patient's index and middle fingers are then placed in finger traps suspended from an IV pole, with the shoulder abducted 90 degrees and elbow flexed at 90 degrees (**FIG 8A**). Weights are applied to the patient's elbow for traction (usually 5 to 15 lb), thereby distracting the fracture site.
- If necessary, a maneuver recreating the injury mechanism to disimpact the fracture site can be performed, followed by a reduction maneuver (**FIG 8B**).
- Notably, with simple distraction and sedation, the fracture often autoreduces without significant manipulation.
- A mini C-arm is employed to determine the adequacy of closed reduction in real time.
- Once reduction is achieved, with the patient still in finger traps, a sugar-tong splint is applied to stabilize the fracture site by preventing wrist flexion-extension and supination-pronation.
- Postreduction films are imperative.

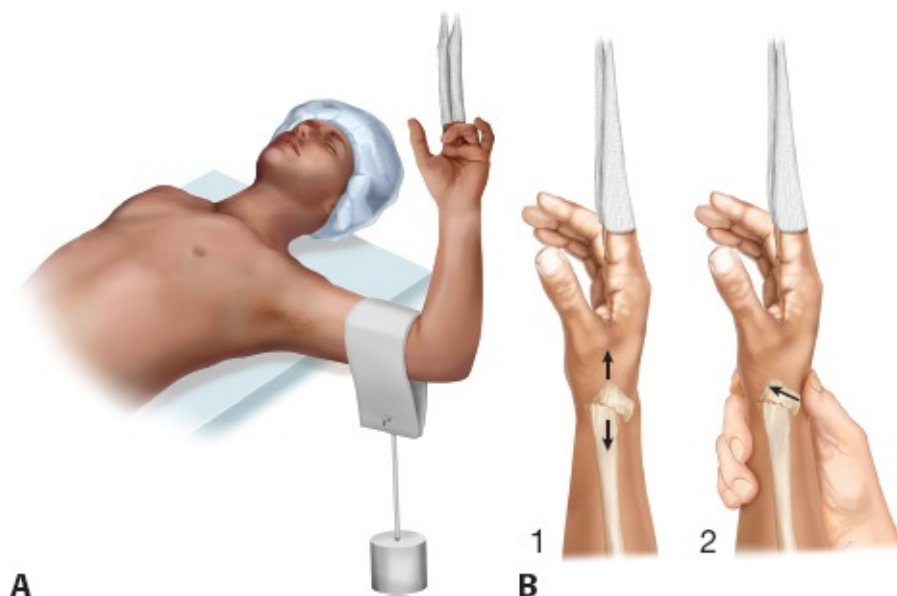


FIG 8 • A. General setup for closed reduction of a distal radius fracture. **B.** Reduction maneuver for dorsal displaced distal radius fractures. First, the wrist joint is placed in traction. Then, the physician's thumb is used to push the distal fragment volarly into alignment.

- If closed reduction is successful, strict immobilization over the next 6 to 8 weeks can lead to adequate fracture healing, obviating the need for surgery.

- An unstable fracture will not be maintained in a splint, however, and surgery should be considered pending patient circumstances.

NONOPERATIVE MANAGEMENT

- Nonoperative management consists of splinting or casting of stable fracture patterns. These are typically nondisplaced or minimally displaced fractures, or fractures that are well reduced.
- The patient's age, medical comorbidities, and functional level should be considered in determining whether or not to pursue nonoperative management vs surgical intervention.
- Patients being treated nonoperatively should be monitored with weekly radiographs for loss of reduction.
 - A volar tilt of 0 to 11 degrees dorsal tilt, radial shortening of 5 mm, and articular incongruity of 1 mm can be tolerated.
- Typically, the patient can be switched to a short-arm cast at 2 to 3 weeks for the remainder of the healing period.
- Early range of motion (ROM) of nonimmobilized joints is essential to prevent contracture. The cast should not extend past the metacarpophalangeal joints to allow finger ROM.

SURGICAL MANAGEMENT

- The goal of treatment is to restore anatomical alignment, thereby maintaining normal wrist biomechanics and decreasing the risk of developing degenerative arthritis.
- Indications for surgery include but are not limited to
 - Articular incongruity more than 1 to 2 mm
 - Radial shortening more than 5 mm
 - Dorsal tilt more than 10 to 20 degrees
 - Extensive comminution
 - Open fractures

Preoperative Planning

- Patient comorbidities must be assessed.
- Healthy patients are often given a regional block with intravenous sedation by the anesthesia team.
- Imaging should be thoroughly reviewed to develop a concrete operative plan.
- If the patient presents with median nerve symptoms, a concomitant carpal

tunnel release should be considered.



FIG 9 • Hand table setup.

Positioning

- Procedures on the distal radius are done on a hand table, with the surgeon seated (**FIG 9**).
- The patient is positioned supine on the operating bed as near to the hand table as possible.
- A tourniquet is placed on the upper arm.

Approach

- Surgical options for the treatment of distal radius fractures include percutaneous Kirschner wire (K-wire) fixation, external fixation, volar plate fixation, dorsal plate fixation, and dorsal bridge plate fixation.
- Percutaneous pinning with K-wires is indicated for unstable, displaced extra-articular distal radius fractures, simple intra-articular distal radius fractures, and displaced distal radius fractures in children and adolescents.
- External fixation uses ligamentotaxis to reduce and stabilize fracture fragments. Indications include unstable, irreducible extra-articular fractures, displaced intra-articular fractures that can be reduced in a closed or percutaneous fashion, and highly comminuted fractures that are openly reduced and fixed with plates or pins but require further carpal unloading to promote

healing. External fixation can be used as an adjunct to other fixation techniques should further stabilization be required.

- Volar-locking plate fixation is indicated for unstable, displaced extra-articular fractures, displaced intra-articular fractures, and volar shearing fractures. The introduction of volar-locking plating techniques has revolutionized the treatment of distal radius fractures by allowing early return of activity and by avoiding the problems of dorsal plating.
- Dorsal plating can be difficult in the presence of dorsal comminution and is associated with a higher rate of postoperative extensor tendon injury, adhesion, or rupture. Dorsal plate fixation is generally reserved for dorsal shear fractures or lunate facet fractures involving the dorsal cortex.
- Dorsal bridge plate fixation is designated for highly comminuted, intra-articular distal radius fractures, including those associated with significant metaphyseal and diaphyseal comminution, in particular subsets of patients:
 - Polytrauma patients with impaired ability to conduct activities of daily living
 - Patients who refuse external fixation for psychological or aesthetic concerns
 - Patients with extensive tendon injuries that will require multiple procedures followed by soft tissue and bony healing over an extended period of time
 - Patients with severe osteoporosis
 - For patients with osteoporosis and severe comminution of the distal radius, the bridging plate serves as an internal distractor that permits healing of the comminuted bone while giving the patient the latitude for self-care, with the bridging plate stabilizing the wrist.
 - At 2 to 6 months, when the distal radius has healed, the plate is removed and the patient can initiate wrist motion to regain mobility.

TECHNIQUES

■ Percutaneous Pinning

Equipment

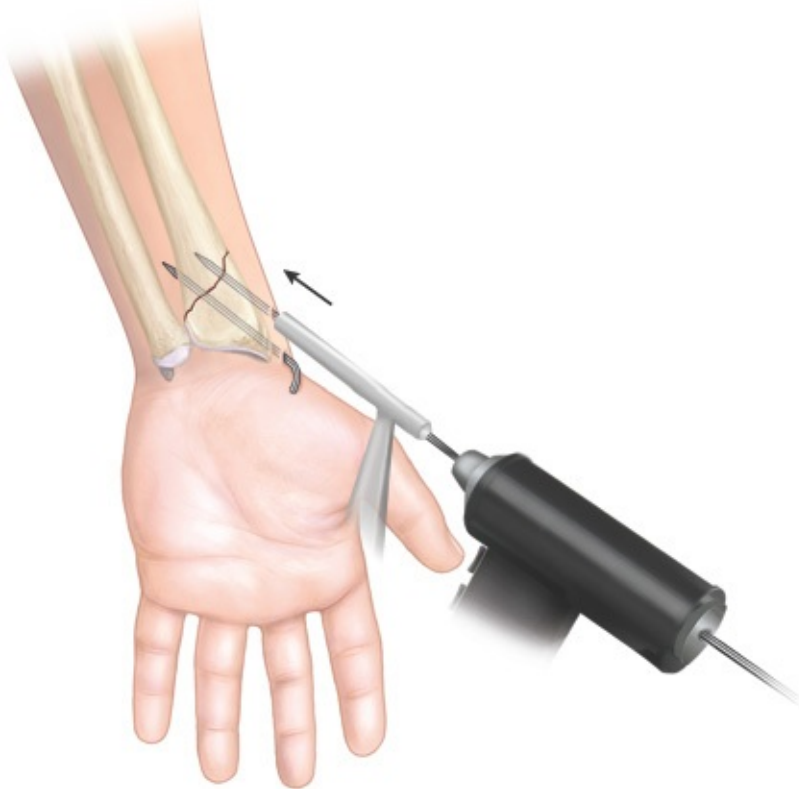
- A tourniquet is not usually needed, although some surgeons advocate for its use to minimize soft tissue swelling during the procedure, thereby allowing improved palpation of bony landmarks.
- The pins are typically 0.062 in. K-wires, which are driven into bone using a

power hand drill (**TECH FIG 1**).

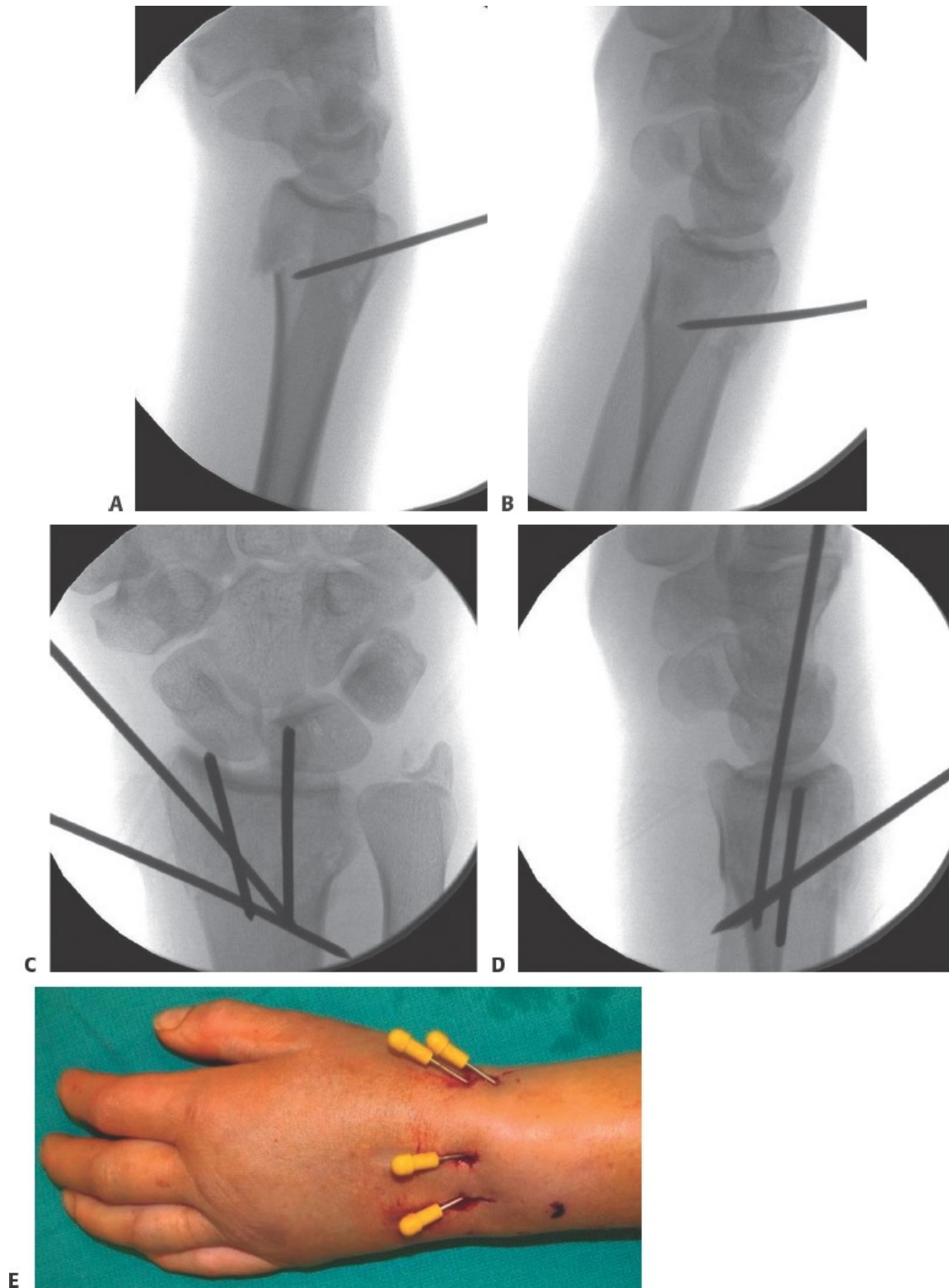
- An intraoperative C-arm is required to assess fracture configuration and pin placement throughout the procedure.

Procedure

- We prefer the intrafocal Kapandji technique for percutaneous pinning of distal radius fractures, particularly if the bone is osteopenic and brittle.
- A K-wire is introduced dorsally into the fracture site as a lever to restore volar tilt (**TECH FIG 2A,B**).



TECH FIG 1 • A power hand drill is used to insert K-wires.



TECH FIG 2 • The Kapandji intrafocal technique. **A.** A K-wire is placed dorsally into the fracture site. **B.** The

distal fragment is levered volarly with the K-wire to achieve reduction. **C,D.** AP and lateral fluoroscopic intraoperative views showing placement of the pins. **E.** K-wire pins in place.

- Once fracture reduction is achieved, one or two more K-wires are driven into the intact volar cortex at the same level, thereby buttressing the reduction. In a similar manner, the fracture can be levered radially to restore radial inclination.
- This is followed by placement of an additional buttressing K-wire.
- Once the fracture is stabilized by this buttressing technique, traditional pinning from the radial styloid and from the dorsoulnar aspect of the radius through the fracture fragments can proceed (**TECH FIG 2C–E**).

Postoperative Care

- Patients are seen 2 weeks postoperatively in clinic for splint takedown, dressing change, and suture removal.
- A removable volar splint is applied.
- Gentle finger, wrist, and elbow ROM is allowed at this time.
- Serial x-rays are obtained at clinic visits to ensure stable bony alignment.
- In adults, K-wires are removed in the office at 5 to 6 weeks.
 - In pediatric patients, K-wires can be removed as early as 4 weeks, depending on radiographic and clinical signs of healing.
- Pin-track infection can lead to early removal of the pin, and if the infection is not treated or recognized, deep osteomyelitis can cause devastating problems.
 - Patients must be taught to clean the pin site meticulously twice a day with hydrogen peroxide on a cotton-tip applicator and then to seal the pin entry site with bacitracin ointment.

■ External Fixation

Equipment

- A variety of external fixator systems for treatment of distal radius fractures exist through different manufacturers. The surgeon must select an external fixator, and the instruction manual must be studied prior to use in the

operating room.

- A tourniquet is useful to help maintain hemostasis during the procedure, particularly if done in conjunction with internal fixation.
- A C-arm is required intraoperatively to assess fracture configuration and pin placement.

Pertinent Anatomy

- The external fixator is placed parallel to the dorsoradial surface of the wrist, using pins at the proximal and distal ends.
 - The distal pins are placed in the second metacarpal.
 - The proximal pins are placed in the radial shaft, approximately 10 cm or one hand's breadth proximal to the radial styloid. This is the location of the abductor pollicis longus (APL) and extensor pollicis brevis (EPB) muscles as they traverse the radial shaft.
- One must have a solid understanding of the dorsal hand and forearm tendons and musculature (see **FIG 3A**) and the extensor compartments of the wrist (see **FIG 4A**).

Fracture Reduction

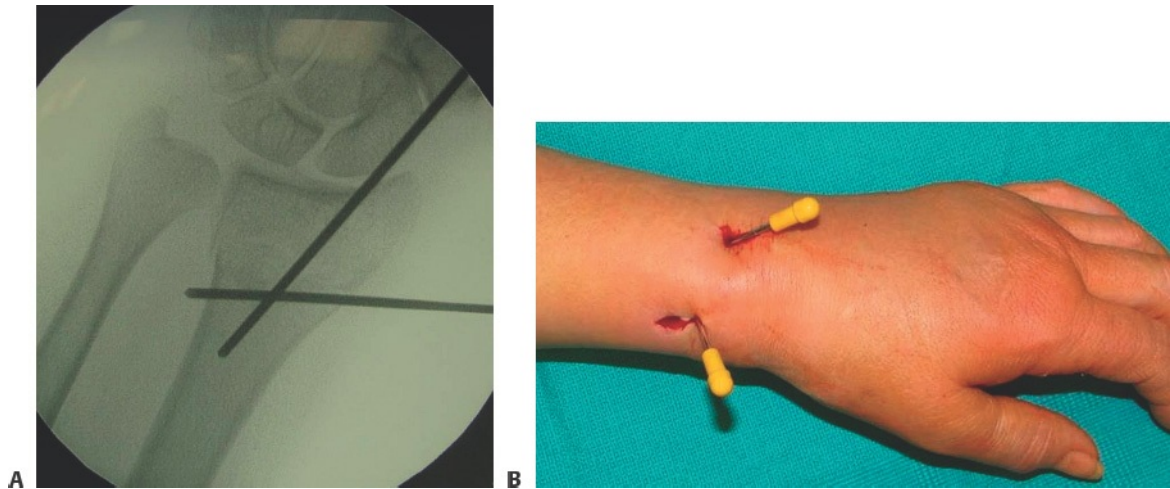
- The forearm is pronated on the hand table.
- The fracture is first reduced under fluoroscopic guidance.
- Percutaneous 0.062 in. K-wires may be placed dorsally as well as through the radial styloid to help maintain the reduction (**TECH FIG 3**).

Pin and External Fixation Frame Placement

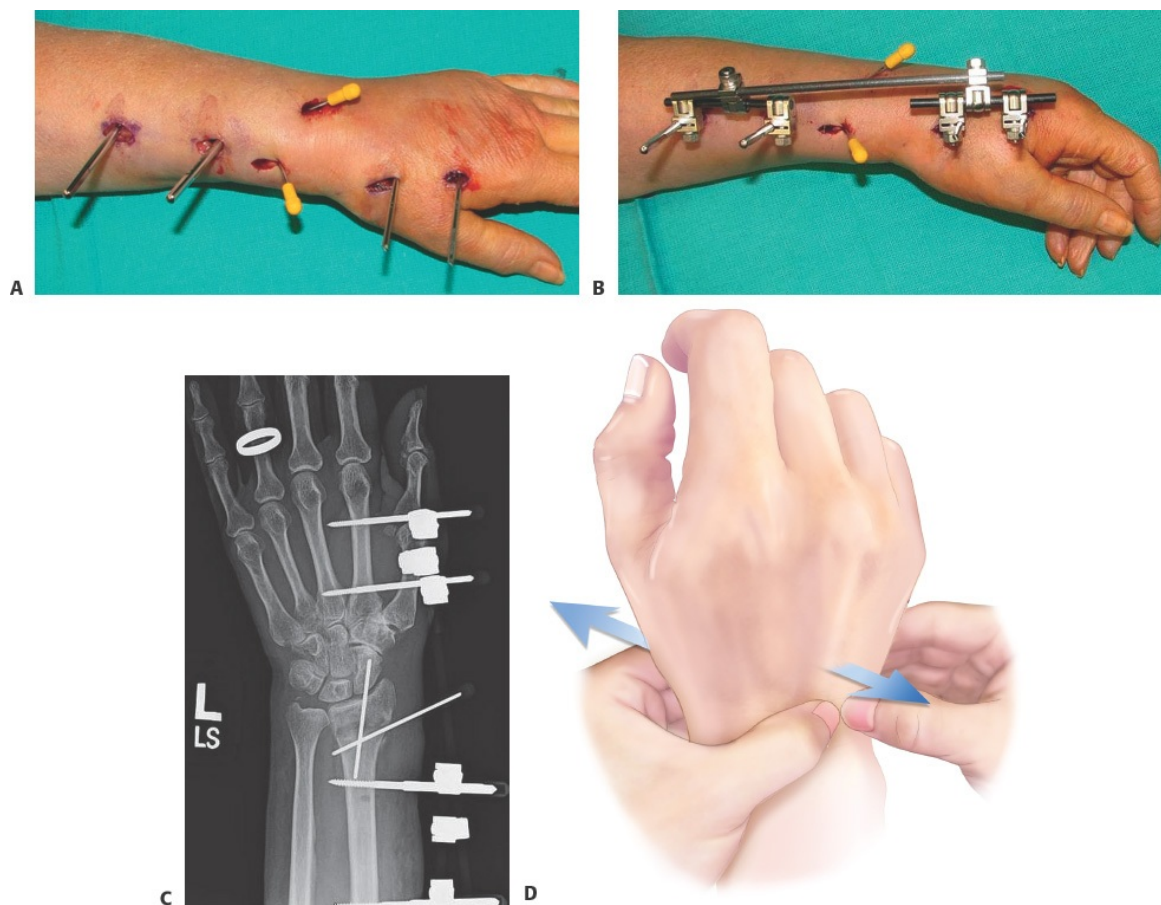
- A 2-cm longitudinal incision is made dorsoradially just proximal to the APL and EPB tendons, about a hand's breadth proximal to the radial styloid.
 - Care is taken to visualize and protect the superficial radial nerve in this area.
- The first pin of the external fixator is inserted into the radial shaft in the deep interval between the extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) tendons.
- Then a 2-cm longitudinal incision along the dorsoradial aspect of the second metacarpal is made, taking care to retract and protect the extensor tendons and first dorsal interosseous muscle.
 - The second pin is placed through this incision.
- The external fixation frame is then slid into place over these initial two pins

and tightened.

- Using the open slots on the frame, the positions of the remaining two pins are marked, one in the metacarpal and one in the radial shaft.
- These pins are then inserted at these locations (**TECH FIG 4A**).



TECH FIG 3 • **A.** Fluoroscopy shows fracture reduction with K-wire pins in place. **B.** Pins in place through small wrist incisions.



TECH FIG 4 • A. External fixator pin placement. **B.** Final placement of external fixator. **C.** Postoperative radiograph. **D.** Testing DRUJ instability.

- The external fixator frame is then further tightened to stabilize the reduction (**TECH FIG 4B,C**).
- At this point, all fingers should have passive flexion and extension, and the wrist should not be placed in excessive flexion or ulnar deviation.
- The DRUJ is also assessed for stability (**TECH FIG 4D**).
 - With the elbow flexed at 90 degrees on the hand table, displacement in the dorsal-palmar direction is tested in neutral position, supination, pronation, and radial deviation. Radial deviation should stabilize the DRUJ unless there is a disruption of the triangular fibrocartilaginous complex (TFCC).
 - DRUJ instability is defined as more than 8 mm of ulnar translation relative to the radius in the dorsal-palmar direction.
 - If unstable, the distal ulna is reduced and pinned to the radius.

- If a large ulnar styloid fracture is noted, this can be fixed with a K-wire.

Completion and Closure

- Simple, interrupted 4-0 nylon sutures are used to close the skin incisions, taking care to avoid injuring the branches of the superficial radial nerve.
- Nonadherent dressings are applied to the pin sites.
- A thick layer of gauze is used to push the skin down from being tented on the pins.
- A volar splint is applied for additional support.

Postoperative Care

- The splint and dressings are removed 7 to 10 days postoperatively to evaluate the pin sites and skin incisions. Sutures are removed.
- Finger ROM is encouraged.
- Nonadherent dressings are applied to the pin sites for the first 3 weeks. If there is drainage, half-strength peroxide is used on a cotton-tipped applicator to clean the sites daily.
- If percutaneous K-wires were placed to stabilize the reduction, they can be removed in the office after 3 to 4 weeks while the external fixator is left in place.
- The patient can shower with the external fixator in place once all sutures and percutaneous K-wires are removed and incisions are dry.
- The external fixator is removed in the office after 4 to 6 weeks once the fracture has healed on clinical and radiographic examination.

■ Volar Plating

Equipment

- A tourniquet is used for this procedure.
- Bipolar cautery is useful for coagulating crossing vessels during exposure.
- A number of volar-locking plate systems exist. The surgeon must select a plating system and review the instruction manual thoroughly prior to use in the operating room. Particular attention must be paid to the distal locking screw trajectory for proper plate placement.
- The C-arm is required intraoperatively to assess fracture configuration and hardware placement throughout the procedure.

Pertinent Anatomy

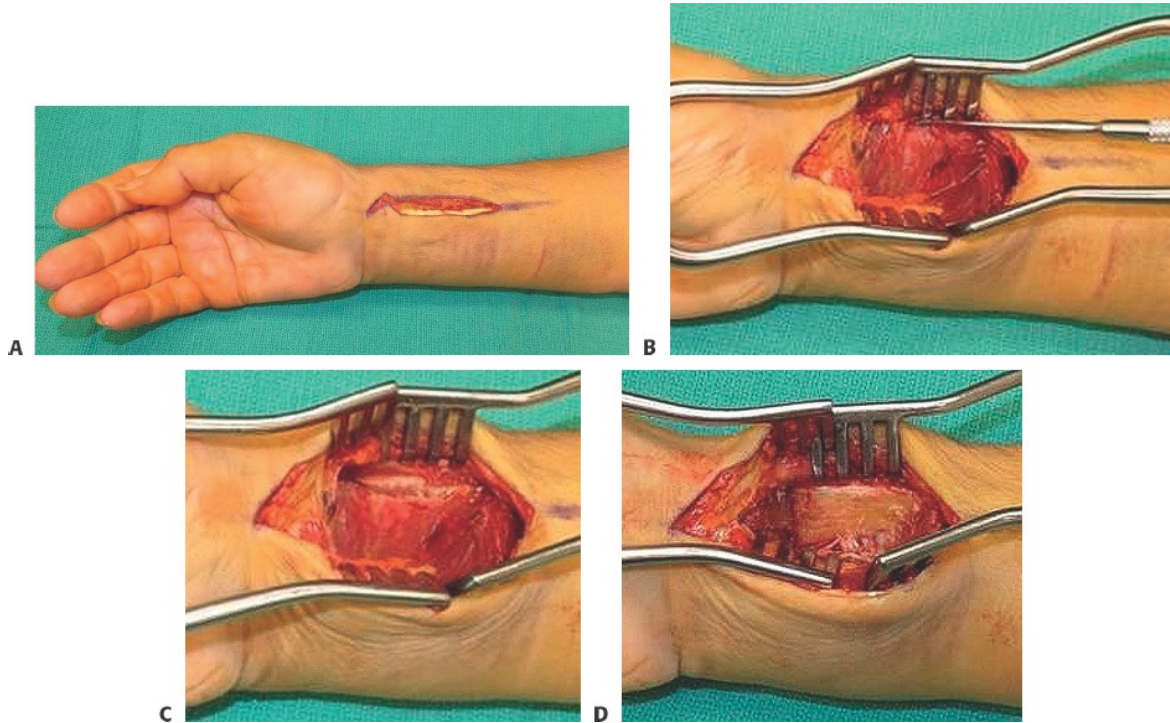
- The surgical interval is between the flexor carpi radialis (FCR) tendon and the radial artery and brachioradialis (BR) tendon (see **FIG 3B**).
- The median nerve lies in the plane between the flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) muscle bellies in the forearm before emerging between FDS and flexor pollicis longus (FPL) more distally, entering the carpal tunnel at the wrist crease just deep to palmaris longus (PL).
- The palmar cutaneous branch of the median nerve arises 5 cm proximal to the wrist crease, between the PL and FCR. Notably, PL is absent in about 15% of the population.
- The FPL muscle overlies the pronator quadratus (PQ) and must be swept from radial to ulnar to expose PQ surgically.
- The PQ muscle is divided along its radial border and elevated to expose the bony surface of the distal radius and the associated fracture.
- The BR inserts into the distal radius and is often released during the procedure to decrease the deforming forces on the distal fragment, aiding fracture reduction.

Exposure

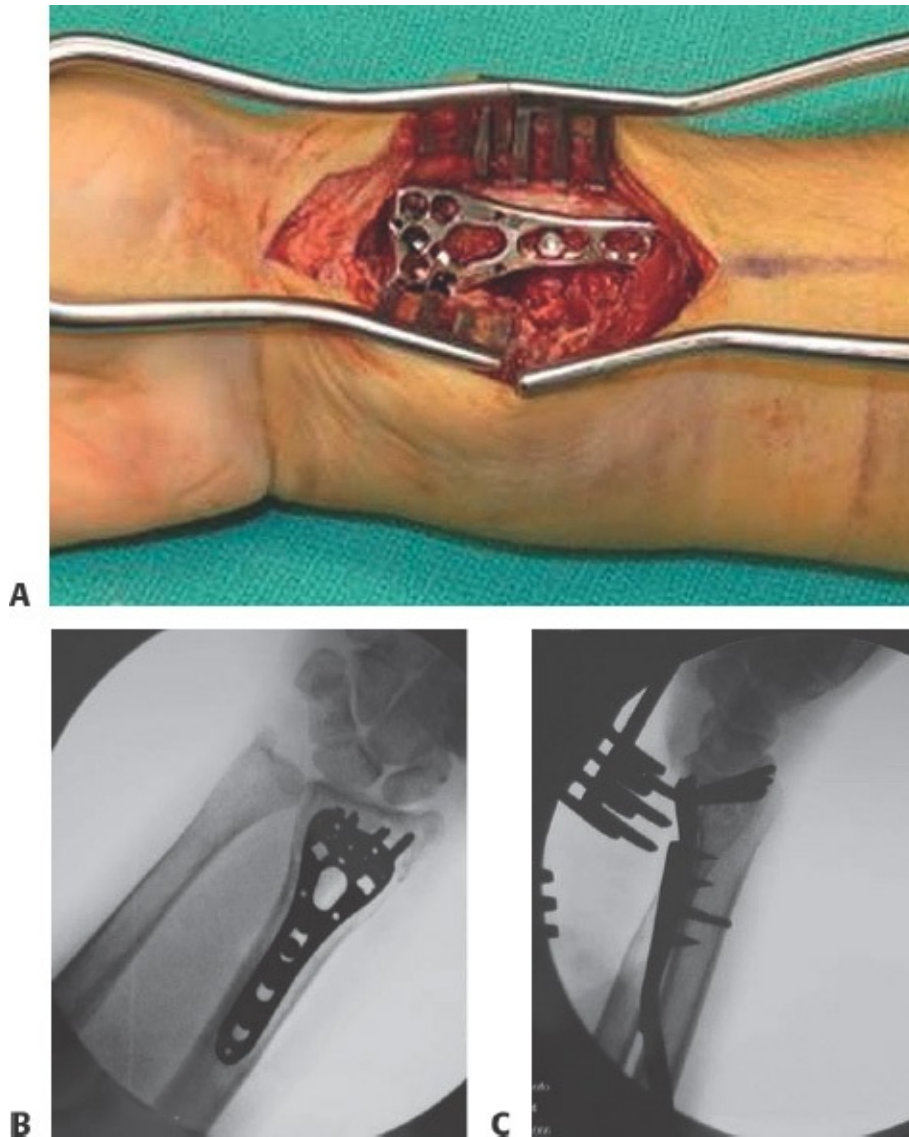
- The forearm is supinated on the hand table.
- A 6- to 8-cm incision is made at the radial aspect of the volar forearm between the FCR and the radial artery, ending just short of the wrist crease. If more distal exposure is required, the incision can be extended with a V-shaped zigzag (**TECH FIG 5A**).
- The FCR tendon sheath is entered, and the dissection proceeds along its radial aspect, to avoid the palmar cutaneous branch of the median nerve that is ulnar to the FCR, through the posterior sheath to expose the FPL muscle belly.
- The FPL is then swept ulnarly, exposing the PQ (**TECH FIG 5B**). The radial artery is also identified and retracted radially.
- An L-shaped incision is made through the PQ, releasing it radially and distally from the radius (**TECH FIG 5C**).
 - The PQ is elevated to expose the fracture site (**TECH FIG 5D**).
- The BR tendon can also be released at this point to further expose the distal fragment, which is usually displaced dorsally.

Fracture Reduction and Plate Fixation

- Next, fracture reduction is performed and may be provisionally held with K-wires.



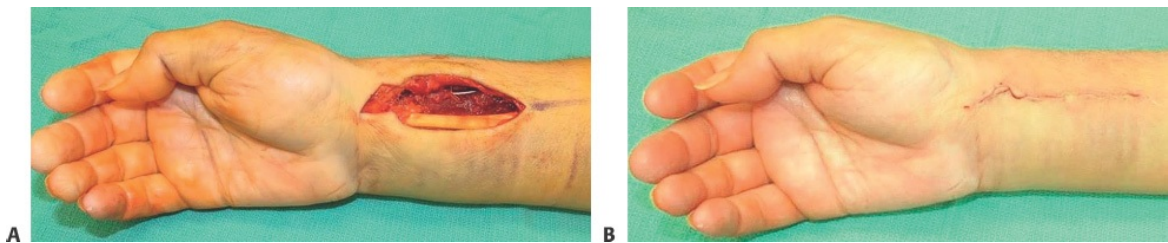
TECH FIG 5 • **A.** Skin incision with FCR exposed. **B.** The PQ is exposed. **C.** The PQ is cut radially and distally in an L shape. **D.** The distal radius is exposed.



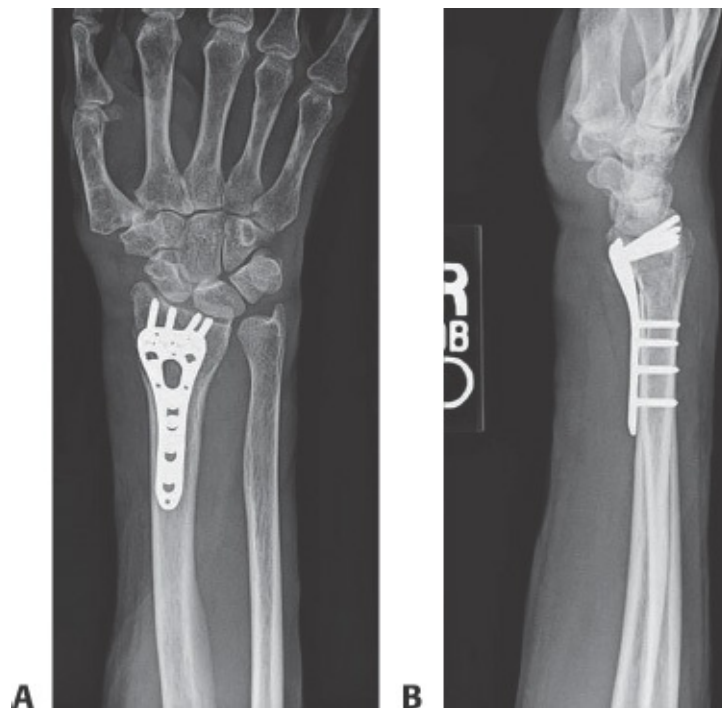
TECH FIG 6 • A. Volar plate placement. **B,C.** Intraoperative fluoroscopic images confirm appropriate plate placement.

- The volar plate is selected and placed centrally and distally on the radial shaft to capture the distal fragment.
- A screw is centrally placed through the elliptical plate hole into the radial shaft.
 - Although sizes can differ based on plating system, typically, a 2.0-mm drill bit is used, allowing for insertion of a 2.7-mm screw.
- Plate placement is then evaluated with C-arm fluoroscopy.

- By loosening the shaft screw, the plate can be shifted proximally or distally as needed.
- Once proper plate placement is achieved, the shaft screw is retightened. A second shaft screw is then inserted.
- With the wrist flexed, the distal screws are then placed, typically with a 1.8-mm drill bit and 2.4-mm screws.
- Locking screws can be used if the fracture is already properly reduced.
- However, if some separation exists between the distal fragment and the plate, a nonlocking screw can be placed initially to draw the bone to the plate.



TECH FIG 7 • A. The PQ is reattached, covering most of the plate. **B.** Skin closure.



TECH FIG 8 • A,B. AP and lateral postoperative

radiographs.

- Once the distal fragment is properly stabilized with a sufficient number of screws, the initial nonlocking screw can be exchanged for a locking screw, if desired (**TECH FIG 6A**).
- At this point, the provisional K-wires can be removed or left in place for 3 weeks if additional support is deemed necessary.
- Fluoroscopy is used to confirm appropriate plate placement (**TECH FIG 6B**).

Completion and Closure

- If the BR was released, it can be reattached with a step-cut lengthening maneuver.
- The PQ is then brought back over the plate and is sutured to the BR fascia using 3-0 Vicryl suture (**TECH FIG 7A**).
- The wound is closed with 3-0 Vicryl suture for the deep dermal layer, followed by a running subcuticular 3-0 Monocryl for the skin (**TECH FIG 7B**).
- A short-arm volar splint is placed for additional support, leaving the fingers free for ROM.

Postoperative Care

- Aggressive finger ROM is initiated immediately after surgery to decrease edema and avoid stiffness.
- The patient is evaluated in the clinic 10 to 14 days after surgery with repeat radiographs (**TECH FIG 8**), at which time gentle wrist ROM is initiated.

■ Dorsal Plate Fixation

Equipment

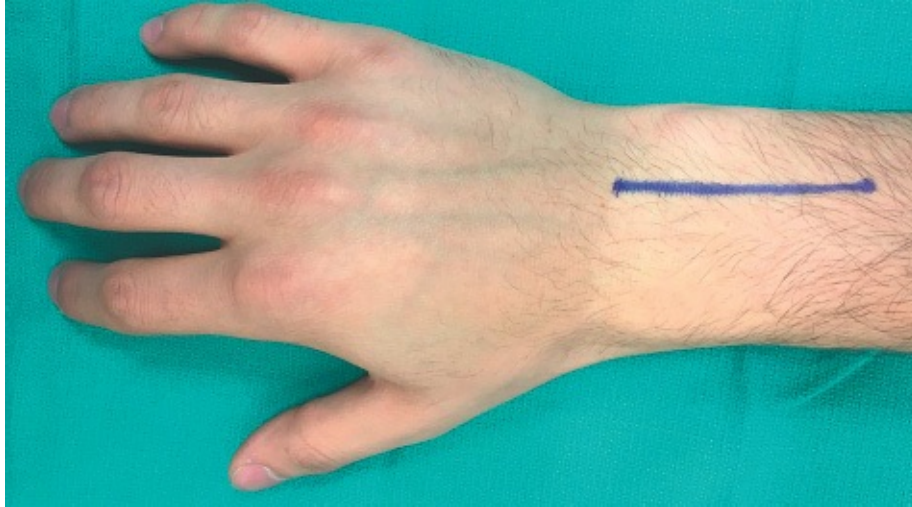
- A tourniquet is used for this procedure.
- A dorsal T- or L-shaped plate of an appropriate length must be selected. This plate is typically a 2.4-mm low-profile plate.
- A C-arm is used intraoperatively to evaluate fracture configuration and assess hardware placement.

Pertinent Anatomy

- The extensor retinaculum divides the extensor tendons into six dorsal compartments and serves to prevent tendon bowstringing (see **FIG 4A,B**).
- The ECRL/ECRB tendons lie in the second extensor compartment.
 - Care must be taken in this area to avoid injury to the radial sensory nerve and dorsal radial artery.
- The extensor pollicis longus (EPL) tendon lies in the third extensor compartment, passing in a groove ulnar to Lister tubercle.
 - It must be released and mobilized to expose the dorsal distal radius.
- The extensor indicis proprius (EIP) and extensor digitorum communis (EDC) tendons lie in the fourth extensor compartment.
 - They are elevated subperiosteally, thereby minimizing tendon contact with dorsally placed hardware.
 - The fourth extensor compartment also contains the terminal branch of the posterior interosseous nerve (PIN), which traverses the floor along its radial aspect and can be sacrificed without clinical import.
- The distal radius articulates with the scaphoid and lunate via two hyaline-covered concave facets.
- The two most important ligaments associated with the dorsal wrist capsule are the dorsal radiocarpal (DRC/radiotriquetral) and dorsal intercarpal (DIC/scaphotriquetral) ligaments (see **FIG 4C**).

Exposure

- A 6- to 8-cm longitudinal incision on the dorsal wrist is made in line with the third metacarpal, just ulnar to Lister tubercle between the third and fourth extensor compartments (**TECH FIG 9**).



TECH FIG 9 • Planned incision on wrist.

- Care is taken to preserve the branches of the superficial radial nerve.
- Full-thickness flaps are raised to expose the extensor retinaculum.
- The third compartment is longitudinally incised, exposing the EPL tendon.
- The EPL tendon is released from its groove, and the retinaculum is divided between the septa of the third and fourth compartments.
- A periosteal elevator is used to elevate the fourth compartment in the subperiosteal plane to expose the bony surface.
- A longitudinal capsulotomy may be required to expose the articular surface, which is performed by releasing the dorsal capsular insertions from the distal nonarticular lunate.
- Once the fracture site and articular surface are exposed, Lister tubercle should be removed with a rongeur to allow the plate to sit flush on the dorsal cortex.

Fracture Reduction and Plate Fixation

- Fracture reduction is then accomplished with provisional K-wire fixation.
- A T-shaped plate is selected and contoured.
- Fluoroscopy is used to adjust the position of the plate proximally or distally as needed.
- Articular congruity is confirmed with fluoroscopy.
- The screws are applied sequentially to finalize plate (**TECH FIG 10**).
- Once the fracture is stabilized, the DRUJ is assessed for instability.

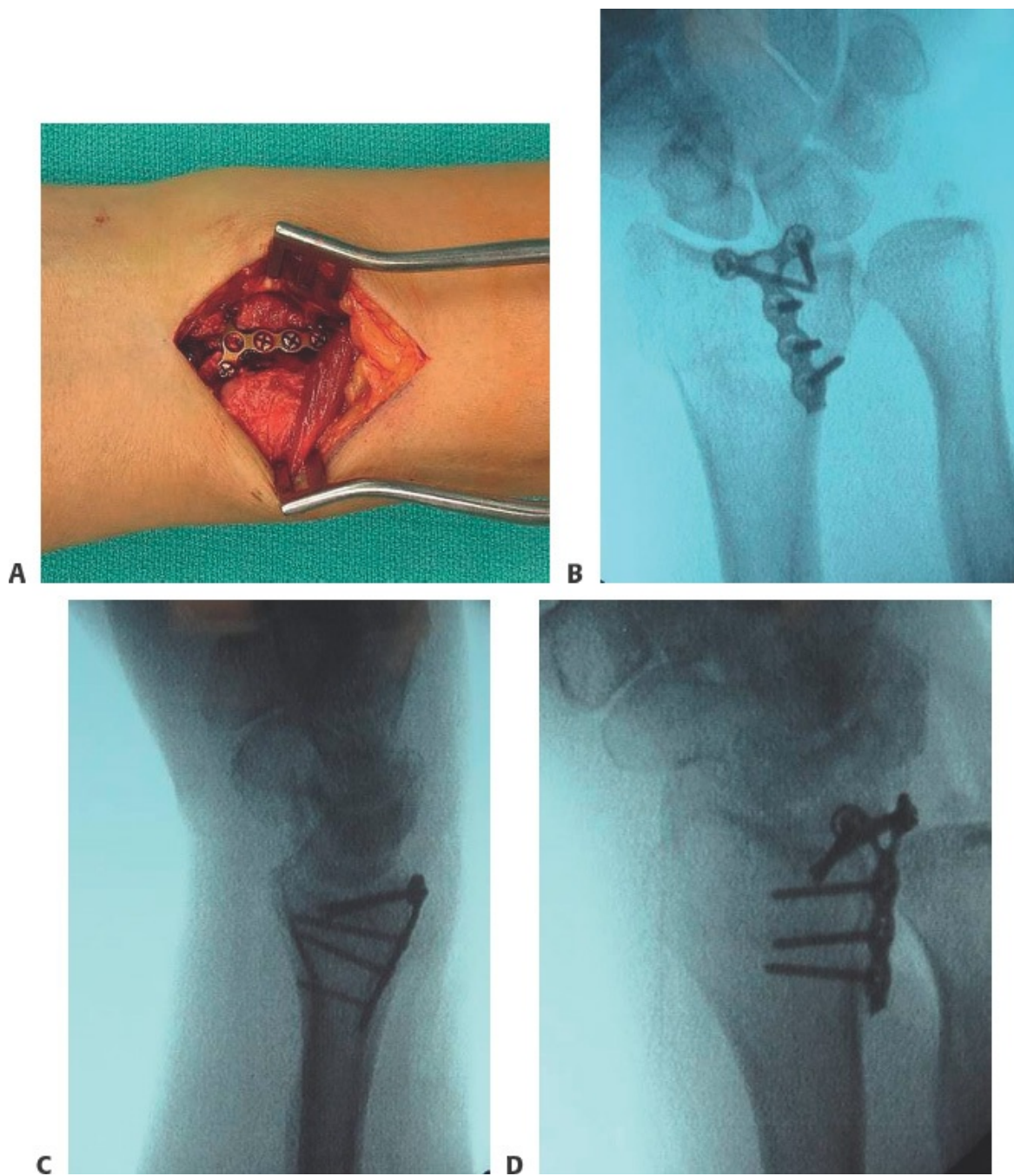
- If deemed unstable, the DRUJ should be pinned percutaneously with the forearm in supination.

Completion and Closure

- The dorsal capsule and extensor retinaculum are closed with 3-0 and 2-0 nonabsorbable suture, respectively.
- The EPL tendon should remain in its new position superficial to the retinaculum.
- The skin is closed with simple interrupted 3-0 nylon suture.
- A volar splint leaving the thumb and fingers free is applied for postoperative comfort.

Postoperative Care

- The splint is removed at the first postoperative visit in 7 to 10 days, and active and passive finger ROM exercises are initiated.
- A removable short-arm volar splint is applied in neutral position, to be removed 5 to 7 times daily for wrist ROM exercises.
- A compression garment is applied for postoperative edema control.
- The splint can be weaned at 4 weeks to allow for activities of daily living.
- Once fracture healing has completed at about 6 to 8 weeks (**TECH FIG 11**), the splint is permanently discontinued.
 - However, if DRUJ instability was addressed in the procedure, the postoperative immobilization period is extended.



TECH FIG 10 • **A.** In situ plate placement. **B–D.** AP, lateral, and close-up lateral fluoroscopic views, respectively, showing final plate placement.



TECH FIG 11 • A–C. AP, oblique, and lateral postoperative radiographs.

■ Dorsal Bridge Plate Fixation

Equipment

- A tourniquet is used for this procedure.
- A distal radius bridge plate of an appropriate length must be selected. This plate is typically a 2.4-mm combination plate with smooth, beveled edges.
 - If such a plate is not available, a 2.7- or 3.5-mm limited contact dynamic compression plate (LC-DCP) can be used.
- A C-arm is used intraoperatively to help plan surgical incisions, evaluate fracture configuration, and assess hardware placement.

Pertinent Anatomy

- Dorsal bridge plate fixation is designated for highly comminuted, intra-articular distal radius fracture (**TECH FIG 12**).
- When placed, the bridge plate passes superficial to the joint capsule and periosteum within the second extensor compartment.

- The extensor tendons overlying the index finger metacarpal must be retracted to facilitate distal fixation of the bridge plate.
- The proximal portion of the bridge plate is placed along the dorsoradial aspect of the radial shaft, adjacent to the BR.

Site Preparation and Exposure

- Fluoroscopy is used to mark the location of the proximal extent of the plate over the radial shaft, which should allow the placement of three screws at least 4 cm proximal to the fracture site.
 - The distal end of the plate should overlie the third or second metacarpal, no farther than the metacarpal neck.
 - These landmarks should guide incision placement.
- Two or three small longitudinal incisions are made dorsally to facilitate exposure (**TECH FIG 13A**).
 - A 4-cm incision is made over the dorsal midshaft of the index finger metacarpal. The extensor tendons are identified and retracted (**TECH FIG 13B**).
 - A second 4- to 6-cm incision is made dorsoradially overlying the radial shaft, just proximal to the EPB and APL muscles. The ECRL and ECRB tendons are identified and the radial shaft is exposed, allowing for placement of three screws at least 3 to 4 cm proximal to the fracture.



TECH FIG 12 • A,B. PA and lateral radiographs showing comminuted intra-articular distal radius fracture.

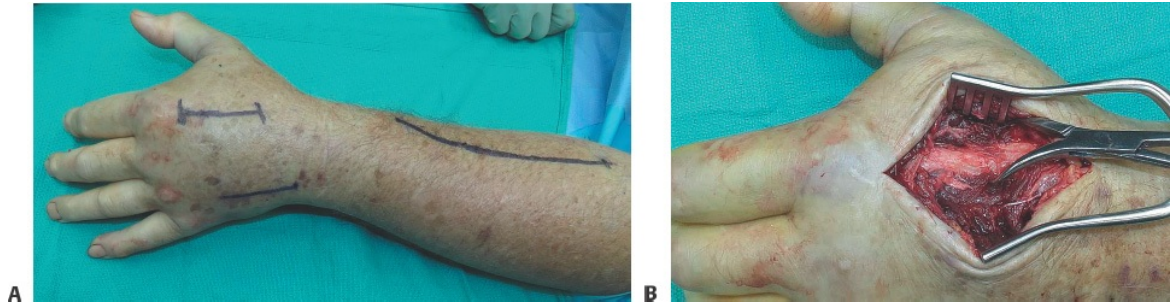
- A third separate 3-cm incision over Lister tubercle may also be made if an articular reduction or metaphyseal bone grafting is needed. The EPL tendon is mobilized to facilitate exposure and reduction.

Placement of the Plate

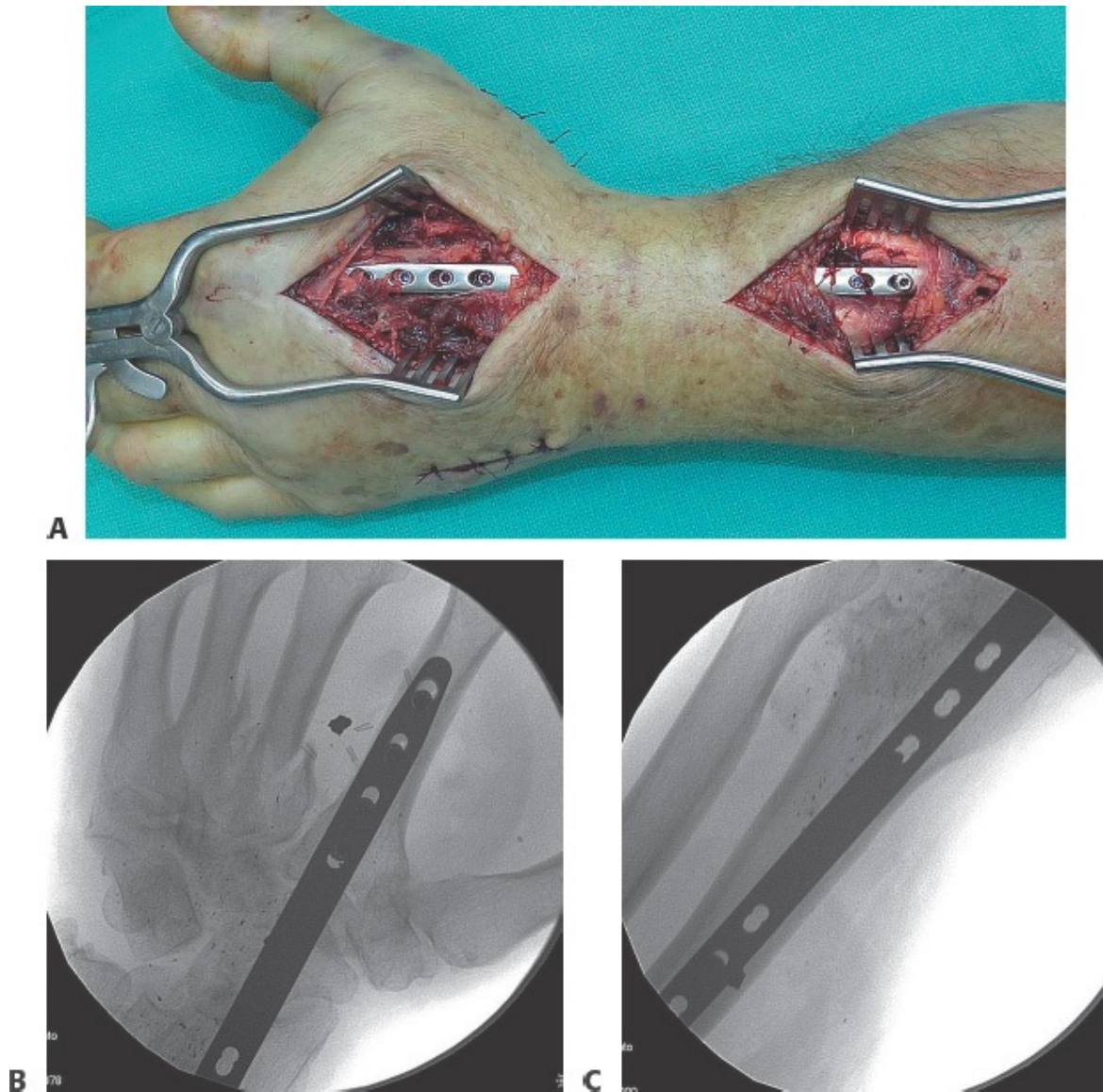
- Metzenbaum scissors are inserted, proximal to distal, along the floor of the second extensor compartment to create a tunnel, ensuring that the periosteum and joint capsule remain deep to the tunnel.
- The plate is then passed from the distal incision to the proximal incision (**TECH FIG 14A**), staying deep to the index finger extensor tendons.
- Manual traction of the wrist is used to obtain provisional reduction of the fracture, restoring radial length and inclination.
- Under fluoroscopy, the plate is aligned centrally over the index metacarpal and radial shaft.
- A bicortical screw is placed in the penultimate hole at the midline of the

metacarpal shaft.

- While traction is reapplied under fluoroscopy to confirm fracture and plate alignment, the proximal end of the plate is clamped to the radial shaft using serrated bone-holding clamps.



TECH FIG 13 • **A.** Planned incisions. **B.** Incision over index finger metacarpal.



TECH FIG 14 • A. Dorsal plate placement. Intraoperative fluoroscopic images showing fixation at the second metacarpal (**B**) and at the radial shaft (**C**).

- Fluoroscopy and clinical assessment are necessary to ensure restoration of radial length, radial inclination, and volar tilt, as well as absence of rotational abnormalities.
- Supination and pronation of the forearm should be assessed to confirm full ROM.
- When plate position is deemed appropriate, three bicortical screws are placed proximally in the radial shaft, securing the plate.

- Two additional bicortical screws are applied to the metacarpal, for a total of three distal points of fixation.
- Fluoroscopy is used to check plate placement (**TECH FIG 14B,C**).

Additional Fracture Reduction and Fixation

- Once the dorsal bridge plate is in place, any diaphyseal fragments amenable to lag screw fixation can be fixated to the radial shaft.
- If any further reduction of the articular surface is required, the third incision (explained above) can be used to release the EPL tendon and pass the plate.
- A dental pick can be used to reduce the articular incongruity.
- If possible, a 2.7-mm cortical screw is inserted through the plate directly under the lunate fossa as a buttress against subchondral collapse.
- Grafting with bone or allograft can also be performed to achieve subchondral and metaphyseal support of the articular reduction.
- K-wires (0.045 or 0.062 in.) can also be placed percutaneously to hold small articular fragments in reduction.

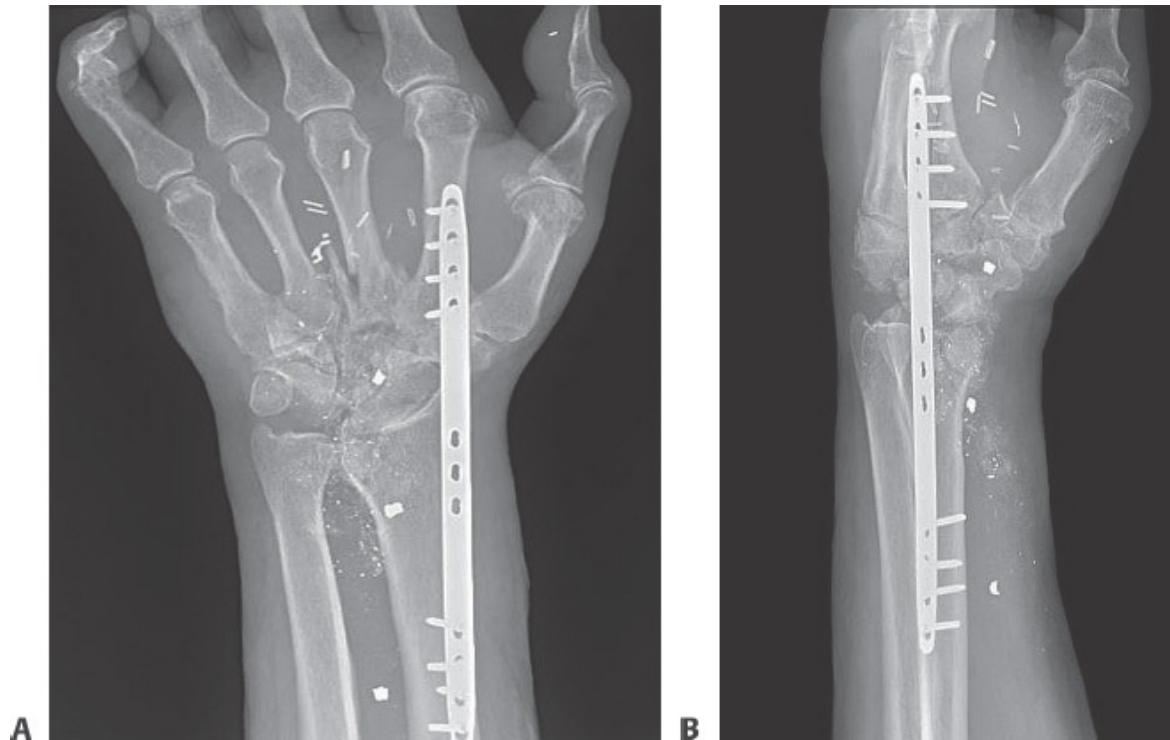
Completion and Closure

- Incisions are typically closed with 3-0 Vicryl sutures for the deep dermal layer, followed by a subcuticular running 3-0 Monocryl for the skin.
- A bulky dressing and volar wrist splint are applied for additional support, leaving fingers free for immediate active and passive ROM exercises.

Postoperative Care

- Active and passive digital ROM exercises are encouraged throughout the healing process.
- The first postoperative visit with radiographic films is at 7 to 10 days (**TECH FIG 15**), at which time a compression garment is applied to control edema, and a thermoplastic short-arm splint is provided.
- If K-wires were placed, they can be removed at 6 weeks.
- Patients may use the operated extremity for activities of daily living.
- Finger ROM, pronation, and supination are encouraged.
- Patients should not lift more than 5 lb. As long as restrictions are maintained, patients may return to work.
- Hardware removal can be scheduled at about 8 to 12 weeks after surgery, once bony healing has been achieved.
- Finger and wrist ROM exercises are initiated immediately after plate

removal.



TECH FIG 15 • **A,B.** PA and lateral postoperative radiographs of dorsal bridge plate in place.

PEARLS AND PITFALLS

PERCUTANEOUS PINNING

General K-wire technique

- Avoid multiple K-wire passes to prevent further fragmentation of fracture pieces, particularly in osteopenic bone.

Percutaneous pinning technique

- For pin placement, the authors prefer using a small longitudinal incision over the radial styloid to avoid skewering branches of the superficial radial sensory nerve and the extensor tendons.
- If the pins are placed percutaneously, caution is advised, as nerves and tendons can be easily damaged.

Adjunctive external

- Consider concomitant external fixation in patients greater than 55 y of age and in younger patients if both the dorsal and volar

fixation	cortices are comminuted.
Over-reduction	■ Avoid over-reducing the fracture fragment, as excessive volar flexion can displace the fragment volarly.
Pediatric distal radius fractures	■ Often, pediatric fractures can be reduced and stabilized with a single K-wire.

EXTERNAL FIXATION

Alignment of external fixator	■ The external fixator should be aligned at about 45 degrees dorsally from the radial midlateral axis. ■ This dorsoradial position for external fixator placement should allow for full thumb ROM, particularly thumb retropulsion, with the fixator in place. ■ Postoperative radiographs can also be obtained without obstruction by the fixator in this position.
General pin placement	■ Pins should be bicortical and stable prior to external fixator frame placement. ■ If the bone is weak and osteopenic, the proximal metacarpal pin may be placed through the second metacarpal base into the third metacarpal base for further stability. However, if the metacarpal pins are placed too deep, the motor branch of the ulnar nerve may be injured. ■ When the proximal pins are placed between the ECRL and ECRB tendons into the radial shaft, the ECRL tendon acts as a protective barrier between the superficial radial nerve and the pins.
Percutaneous approach	■ If the external fixator pins are placed percutaneously, whether in the radial shaft or in the second metacarpal, the superficial radial nerve can inadvertently be injured. ■ The authors prefer using small incisions for direct visualization and protection of the nerve branches.
External fixator frame placement	■ Avoid overdistractive of the frame, as this may lead to wrist stiffness or limited finger ROM. ■ If the external fixator is placed in excessive flexion and ulnar deviation, carpal tunnel symptoms may occur. ■ External fixators can be used to supplement the fixation of highly comminuted distal radius fractures with percutaneous pins or internal plating. External fixation serves to off-load the carpus during the healing process.

VOLAR PLATING

Exposure	■ Avoid soft tissue stripping too far distally on the radius, as inadvertent release of the volar carpal ligaments will result in carpal instability. ■ Mobilizing the radial artery and ligating its ulnar-crossing branches will help to minimize bleeding and permit better exposure of the BR for release. ■ Avoid dissection ulnar to the FCR tendon, as the palmar cutaneous branch of the median nerve can be injured.
Release of the BR tendon	■ Not always necessary ■ Can be useful in fracture reduction ■ Dissection must proceed entirely on bone to avoid damage to the tendons of the first extensor compartment. ■ At the end of the procedure, the BR can be reattached using a step-cut lengthening maneuver.
Fracture reduction	■ A Freer elevator can be used to lever the distal fragment into place. It must be inserted through the fracture site into the dorsal cortex for complete disimpaction of the distal fragment to permit proper reduction. ■ Flexing the hand and wrist can promote reduction. ■ A large towel bump under the hand and distal fragment may be useful in the reduction maneuver. ■ Avoid over-reduction of the fracture, which can lead to volar displacement.
Intraoperative imaging	■ The C-arm is used to assess plate and screw placement. ■ The AP view confirms proper radioulnar placement of the plate. ■ The lateral view confirms proper proximal-distal placement of the plate. ■ A fossa lateral view, which is taken by holding the forearm at 22 degrees from the plane of the hand table, allows visualization of the radiocarpal joint space to ensure no screw penetration.
Screw placement	■ Avoid placing screws that are too long, as they may cause attritional extensor tendon rupture. The distal locking pegs or screws must be about 2 mm short of reaching the dorsal cortex. ■ Avoid screw penetration into the radiocarpal joint and DRUJ. ■ The distal screws are designed for subchondral support (distal row) and for dorsal fixation (proximal row) of the distal fragment.
Reattachment	■ Often cannot be fully reattached due to plate prominence

of the PQ	■ Partial closure allows for some soft tissue coverage of the plate. ■ Avoid inadvertent suturing of the first extensor compartment tendons. ■ Some surgeons do not suture the PQ back into place at all.
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Volar plate removal	■ Approximately 15%–20% of volar plates are eventually removed. ■ Reasons for removal of hardware included tenosynovitis, tendon rupture, pain, and prominent or intra-articular hardware.
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DORSAL PLATING

Exposure	■ Full-thickness flaps are elevated, including skin, subcutaneous tissue, and superficial fascia. These flaps will contain and protect the dorsal sensory branches of the ulnar and radial nerves. ■ Elevating the fourth compartment in the subperiosteal plane minimizes plate contact with the extensor tendons. ■ Small incisions for provisional K-wire placement in the area of the radial sensory nerve are recommended to avoid damaging the nerve branches.
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Dorsal capsulotomy	■ Can be performed to address fractures involving the articular surface. ■ Involves a longitudinal incision that detaches the dorsal capsular insertions from the distal nonarticular lunate. ■ The intercarpal ligaments must be protected. ■ Avoid entering the DRUJ. Radioulnar instability can result if the dorsal radioulnar ligament is divided.
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Lister tubercle	■ The EPL tendon passes in a groove just ulnar to the Lister tubercle. ■ Lister tubercle is removed with rongeurs such that the plate can sit flush with the dorsal cortex and be less prominent.
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Bone grafting	■ Cancellous bone grafting of metaphyseal defects can help support an articular reduction.
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Screw placement	■ Avoid placing screws that are too long, as this can lead to irritation of volar structures.
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DORSAL BRIDGE PLATE FIXATION

Incisions	■ Fluoroscopy is used to guide placement of incisions. ■ By holding the distal end of the plate at the index metacarpal neck-shaft junction, the proximal extent of the plate can be marked over the radial shaft. One must ensure that 3 screws can be placed at least 3 to 4 cm proximal to the fracture.
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	■ A third incision over the Lister tubercle can be made for articular reduction and metaphyseal bone grafting, if necessary.
Dorsal bridge plate placement	■ The plate is placed along the floor of the second extensor compartment, deep to the index finger extensors and wrist extensors and superficial to the periosteum. ■ The plate should not extend distal to the index metacarpal neck. ■ The distal screw must be in the midline of the index metacarpal shaft to avoid rotary displacement of the fracture. ■ Applying traction with the forearm in 45–60 degrees of supination before applying the serrated clamp is helpful to avoid pronation of the distal fragment.
Overdistraktion	■ Defined as a radiocarpal gap greater than 5 mm. ■ Can lead to loss of finger ROM secondary to extrinsic extensor tightness ■ Can lead to development of complex regional pain syndrome (CPRS).
Articular reduction and bone grafting	■ Failure to reduce articular fragments can lead to symptomatic radiocarpal arthrosis. ■ If an articular reduction is performed, bone grafting provides subchondral and metaphyseal support of the reduction. ■ Contraindications to bone grafting: ■ Open fractures with gross contamination ■ Soft tissue defects precluding primary wound closure
DRUJ instability	■ Defined as greater than 8 mm of palmar to dorsal translation of the ulna relative to the radius ■ Should be suspected in cases with large ulnar styloid fractures or displaced ulnar head fractures ■ After bridge plate placement, the DRUJ should be assessed for instability. ■ If DRUJ instability is detected, the forearm should be immobilized in supination for 3–4 wk.
Bridge plate removal	■ Plate removal can be electively scheduled at 8–12 wk after the initial surgery. ■ The plate should stay in place until radiographic osseous healing has occurred. Bridging callous should be seen in both the sagittal and coronal planes. ■ Bony healing may be difficult to visualize with a thick 3.5-mm plate in place. ■ Early removal of the plate can lead to fracture collapse. ■ Late removal of the plate may lead to extensor tendon attrition

and rupture or permanent wrist stiffness.

OUTCOMES

- Excellent long-term outcomes have been reported for all techniques when used in the appropriate patients.¹ Indeed, patient selection is critical.
 - Over the past decade, however, internal fixation has become increasingly popular due to perceived early functional benefits.
- Of the internal fixation options, volar plates are favored over dorsal plates due to fewer tendon-related complications.
- With regard to external vs internal fixation, studies have shown no significant differences in grip strength, wrist ROM, radiographic alignment, and pain.
- Still, the existing literature is heterogeneous with respect to reported outcomes for the treatment of distal radius fractures. As such, a unified approach has been recently proposed to integrate performance, patient-reported outcomes, pain, complications, and radiographs.²
- For the elderly population, management of distal radius fractures has traditionally been dominated by closed reduction and immobilization.
 - Nonoperative management was found to achieve satisfactory functional outcomes despite the presence of fracture malalignment.
 - However, today's elderly population is more active than prior generations, which may indicate the need for more accurate fracture fixation for maintaining function. A multicenter prospective study to further investigate outcomes in this population is currently under way.

COMPLICATIONS

- The overall complication rate after fixation of distal radius fractures has been reported to be as high as 30%.³
- Pin-track or superficial infections associated with external fixation are the most common type of postoperative infection following distal radius fixation, with an overall incidence of 25%.
 - *Staphylococcus aureus* is the most commonly isolated microbe.
 - Nearly all reported infections resolve with oral antibiotics, with or without pin removal.
- Internal fixation of distal radius fractures, whether volar or dorsal, has lower infection rates, only up to 3%.
- Open fractures of the distal radius, regardless of fixation method, are

associated with a higher rate of infection of 44%.

- Clinically relevant extensor tendon injury or rupture is uncommon for both percutaneous pinning and external fixation, less than 1%. The use of small incisions to facilitate direct visualization and protection of important structures during pin placement is generally advocated.
- EPL rupture is, however, a well-documented complication of volar plating, with an incidence of 2% to 9%. It is typically caused by drill bit penetration or prominent dorsal screw tips. EPL rupture can also occur with nonoperative treatment. It is believed that the EPL near the Lister tubercle has poor intrinsic vascularity, and when combined with nutritional interference from hematoma, delayed EPL rupture ensues. Should EPL rupture occur, reconstruction can be performed with tendon grafting or an EIP tendon transfer.
- Extensor tenosynovitis may also occur with prominent dorsal screw tips from volar plating, with an incidence of up to 14%. This is addressed with hardware removal. In particular, dorsal plating is associated with an unacceptably high rate of extensor tendon complications, ranging from 19% to 48%. The advent of ultra-low profile plates appears to have decreased the incidence of such complications.
- Flexor tendon injury is less common than extensor tendon injury following fixation of distal radius fractures and is mostly associated with volar plating.
 - The FPL is the most frequently ruptured flexor tendon.
 - Flexor tenosynovitis may occur and may be treated with implant removal.
 - Some surgeons advocate repair of the PQ as a protective layer between volar hardware and flexor tendons.
- Carpal tunnel syndrome, or median neuropathy, can occur acutely, subacutely, or in a delayed fashion after distal radius fractures regardless of treatment method, operative or nonoperative, with an overall incidence of 8.5%.
 - Some surgeons advocate carpal tunnel release in all distal radius fractures undergoing fixation, whereas others limit this to patients with pre-existing or acute signs of median neuropathy.
- Superficial radial nerve (SRN) injury is most common with percutaneous pinning and external fixation, with an incidence of 4% to 13%. Using small skin incisions to facilitate direct visualization and preservation of the nerve branches during pin placement reduces this risk.
- Complex regional pain syndrome has been associated with distal radius fractures treated both operatively and nonoperatively, with rates ranging from

3% to 25%.

- It is characterized by unexplained pain, swelling, vasomotor instability, and joint stiffness.
- Type I (previously known as reflex sympathetic dystrophy) occurs secondary to a noxious event. Type II (also known as causalgia) is caused by direct peripheral nerve injury.
- The use of vitamin C for CPRS prophylaxis is controversial, but many still advocate it given its low side effect profile.
- Loss of reduction can occur following all forms of distal radius fixation and is most commonly seen with percutaneous pinning, followed by external fixation and subsequently internal plating.
- Internal fixation with plates seems to maintain radiographic parameters better than other fixation methods.
- Reoperation is performed in up to 80% of cases in which loss of reduction is discovered.
- In particular, lunate facet fractures are prone to loss of reduction.
- Some surgeons advocate other fixation methods as an adjunct to plating, such as pins, wires, sutures, or mini-screws.
- Nonunion after distal radius fixation is rare, with an incidence of less than 1%.
 - If nonunion is experienced, revision is indicated with plate fixation and autogenous bone grafting.
- Approximately 65% of patients with intra-articular distal radius fractures go on to develop radiographic evidence of radiocarpal arthritis, regardless of treatment modality.
 - Radiographic evidence of radiocarpal arthritis does not seem to correlate with patient symptoms or functional impairment, however, and functional outcomes seem to be no different from population norms.

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1. Horst TA, Jupiter JB. Stabilisation of distal radius fractures: lessons learned and future directions. *Injury*. 2016;47(2):313-319.
2. Waljee JF, Ladd A, MacDermid JC, et al. A unified approach to outcomes assessment for distal radius fractures. *J Hand Surg [Am]*. 2016;41:565-573.
3. Lee DS, Weikert DR. Complications of distal radius fixation. *Orthop Clin North Am*. 2016;47(2):415-424.

Section VI: Rheumatoid Arthritis

24 Rheumatoid Arthritis of the Hand and Wrist

CHAPTER

Shoshana W. Ambani and Kevin C. Chung

DEFINITION

- Rheumatoid arthritis (RA) is a systemic autoimmune disease characterized by synovial inflammation, which results in progressive joint and soft tissue destruction that leads to deformity and disability.

PATHOGENESIS

- RA is an idiopathic disease affecting about 0.5% to 1.0% of the adult population, with both genetic and environmental factors, which are not fully understood.
- For example, there is a three- to fourfold higher frequency in women compared to men. In addition, patients with the human leukocyte antigen-antigen D related (HLA-DR) allele have a 4 to 5 increased relative risk of RA.¹
- Environmental links have also been made, particularly to smoking, caffeine, silica, and some infectious diseases.
- On a cellular level, autoreactive T cells and inflammatory cytokines have been found to play a critical role in the pathogenesis of RA.^{2,3}
- Tumor necrosis factor (TNF) and interleukin-6 (IL-6), for example, promote inflammatory cell accumulation, production of matrix metalloproteinases, and osteoclast activation, which ultimately results in the destruction of cartilage and bone.

DIAGNOSIS

- The diagnosis of RA is clinical, based on criteria developed by the American College of Rheumatology (ACR, previously the American Rheumatism Association) in 1987 to distinguish RA from other rheumatic diseases (Table 1).⁴
- In general, the diagnosis is made by recognizing a pattern of sign and symptoms, including a history of prolonged morning stiffness that may improve with activity, polyarthralgias, joint swelling, and fatigue.
- Blood work can help exclude the mimics of RA.
 - Anti-cyclic citrullinated peptide (anti-CCP) antibodies have been shown to be more than 90% specific for RA.³⁻⁵
 - Rheumatoid factor (RF), though not necessary to confirm the diagnosis of RA, is associated with more severe joint disease and extra-articular manifestations.
- Examination findings suggestive of RA include symmetrical polyarthritis and rheumatoid nodules.
- Arthrocentesis may be helpful in excluding septic arthritis.
- Radiographs may be obtained, revealing periarticular osteopenia, joint space loss, and erosions.
- In 2010, the ACR/European League Against Rheumatism (EULAR) developed further criteria for diagnosis in an effort to help identify patients who would benefit from disease-modifying antirheumatic drugs (DMARDs) early on before the irreversible effects of RA take place (Table 2).⁶

DIFFERENTIAL DIAGNOSIS

- Viral polyarthritis
- Systemic rheumatic diseases (eg, systemic lupus erythematosus, Sjogren syndrome, dermatomyositis, mixed connective tissue disease)
- Palindromic rheumatism
- Hypermobility syndrome and fibromyalgia
- Reactive arthritis and arthritis of inflammatory bowel disease
- Psoriatic arthritis

Table 1 1987 ACR Criteria for Rheumatoid Arthritis^a

1. Morning stiffness
 - Located in and around joints

• Duration ≥ 1 h before maximal improvement
2. Arthritis of ≥ 3 joint areas • At least 3 joints simultaneously have had soft tissue swelling or fluid, witnessed by a physician • May involve 4 possible joints: PIP, MCP, wrist, elbow, knee, ankle, and MTP joints
3. Arthritis of hand joints • At least 1 area with soft tissue swelling or fluid (wrist, MCP, or PIP joint)
4. Symmetrical arthritis • Simultaneous involvement of same joints on both sides of body • Bilateral involvement of PIPs, MCPs, or MTPs, without absolute symmetry, is acceptable
5. Rheumatoid nodules • Subcutaneous nodules over bony prominences, extensor surfaces, or in juxta-articular regions, observed by a physician
6. Serum rheumatoid factor • Demonstration of abnormal amounts of serum rheumatoid factor by any method for which the result has been positive in less than 5% of normal control subjects
7. Radiographic changes • Includes erosions or unequivocal bony decalcification localized to the involved joints • Osteoarthritic changes alone do not qualify

PIP, proximal interphalangeal; MCP, metacarpophalangeal; MTP, metatarsophalangeal.

^aA patient is diagnosed with rheumatoid arthritis if at least 4 of the 7 criteria are met. Criteria 1 to 4 must have been present for at least 6 weeks.

From Arnett FC, Edworthy SM, Bloch DA, et al. The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. *Arthritis Rheum.* 1988;31(3):315-324.

Table 2 2010 ACR/EULAR Classification Criteria for Rheumatoid Arthritis

Classification Criteria	Score
• Add scores of categories A–D. • A score of $\geq 6/10$ is required for diagnosis of RA.	
A. Joint involvement (any swollen or tender joint on examination, excluding DIPJ, first CMCJ, and 1st MTPJ)	

• 1 large joint	0
• 2–10 large joints	1
• 1–3 small joints (with or without large joint involvement)	2
• 4–10 small joints (with or without large joint involvement)	3
• Greater than 10 joints	5
Note: “Large” joints refer to shoulders, elbows, hips, knees, and ankles; “small” joints refer to MCPJ, PIPJ, 2nd–5th MTPJ, thumb IPJ, and wrists.	
B. Serology (at least 1 test result is needed for classification)	
• Negative RF <i>and</i> negative ACPA	0
• Low-positive RF <i>or</i> high-positive ACPA	2
• High-positive RF <i>or</i> high-positive ACPA	3
C. Acute-phase reactants (at least 1 result is needed for classification)	
• Normal CRP <i>and</i> normal ESR	0
• Abnormal CRP <i>or</i> abnormal ESR	1
D. Duration of symptoms	
• <6 weeks	0
• ≥6 weeks	1

CMCJ, carpometacarpal joint; DIPJ, distal interphalangeal joint; IPJ, interphalangeal joint; MCPJ, metacarpophalangeal joint; MTPJ, metatarsophalangeal joint; RF, rheumatoid factor; ACPA, anti-citrullinated protein antibody; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate.

From Aletaha D, Neogi T, Silman AJ, et al. 2010 Rheumatoid arthritis classification criteria: an American College of Rheumatology/European League Against Rheumatism collaborative initiative. *Arthritis Rheum.* 2010;62(9):2569-2581.

- Polymyalgia rheumatic
- Crystalline arthritis (eg, gout, pseudogout)
- Infectious arthritis

- Osteoarthritis
- Paraneoplastic disease
- Multicentric reticulohistiocytosis
- Sarcoid arthropathy
- Fibroblastic rheumatism

IMAGING

- When evaluating the upper extremities, PA, oblique, and lateral radiographs of the hands should be obtained to assess the condition of the proximal interphalangeal joints (PIPJ) and metacarpophalangeal joints (MCPJ).
- Radiographs of the wrist will further serve to evaluate the distal radioulnar joint (DRUJ), midcarpal joint, and radiocarpal joint.
- Characteristic findings of RA include periarticular osteopenia, joint space loss, and marginal joint erosions (**FIG 1**). Often, these changes are not seen in early disease.
- MRI can be useful in detecting RA before radiographic changes can be detected. MRI can also identify bone marrow edema and synovial hypertrophy, which predict the development of erosive disease.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically present between the third and sixth decades of life. Symptoms begin insidiously and grow over weeks to months. Patients complain of fatigue, malaise, generalized stiffness, and generalized arthralgias or myalgias.
 - In a small subset (10%–15%) of patients, the onset of RA is sudden, with fever, polyarthritis, lymphadenopathy, and splenomegaly developing over days to weeks.
- Inflammation of the synovial tissues (synovitis) develops gradually and often symmetrically in the hands, wrists, knees, and feet. Synovial hypertrophy (pannus) ultimately results in the destruction of ligaments, tendons, cartilage, and bone. Examination of affected joints reveals swelling, tenderness, warmth, and painful motion.
 - In the upper extremity, RA tends to affect the MCPJ, PIPJ, and wrists earlier and more frequently than it does other joints in the body. This is in part due to their high synovium-to-joint surface area ratio.
 - The distal interphalangeal joints (DIPJ) are typically spared from RA.



FIG 1 • Radiographs of rheumatoid hand and wrist showing periarticular osteopenia, joint space loss, and marginal joint erosions. **A.** AP view. **B.** Oblique view. **C.** Lateral view.



FIG 2 • Rheumatoid nodule on elbow.

- Patients may also present with rheumatoid nodules, vasculitis, pericarditis, pleural effusion, interstitial pulmonary disease, peripheral neuropathy, and

keratoconjunctivitis sicca.

- Rheumatoid nodules tend to develop on extensor surfaces or areas of contact pressure, such as the olecranon process at the elbow (**FIG 2**).
- RA also affects the synovial lining of tendons, which can result in carpal tunnel syndrome, tendon rupture, tendonitis, and trigger digits.

Key Findings

- Wrist (carpus)
 - Midcarpal extension
 - Ulnar translocation of the carpus
 - DRUJ instability
 - Caput ulna (ulnar head dorsal dislocation, ECU subluxation, carpal supination)
 - Extensor tendon rupture, Vaughn-Jackson syndrome
 - Flexor pollicis longus (FPL) rupture (Mannerfelt lesion)
 - Carpal tunnel syndrome
- Hand
 - MCPJ and PIPJ arthritic changes
 - MCPJ volar subluxation and ulnar deviation
 - Sparing of the DIPJ
 - Swan-neck deformity
 - Boutonniere deformity

Wrist Joint

- Arthritic radiographic changes are initially noted at the scaphoid waist, the ulnar styloid, and the DRUJ and progress into the radiocarpal and midcarpal joints.
 - In later stages, severe erosion of the volar lip of the distal radius leads to lunate malposition (proximal migration, volar translation, volar angulation) and compensatory midcarpal extension.
- Three patterns of end-stage carpal arthritis can be encountered, depending on the degree of bony destruction and ligamentous instability.
 - First, wrist ankylosis (bony joint fusion) can occur, sometimes in acceptable alignment.
 - Second, the wrist can be arthritic but stable over time with limited ligamentous destruction.
 - Third, the wrist is unstable, characterized by progressive misalignment,

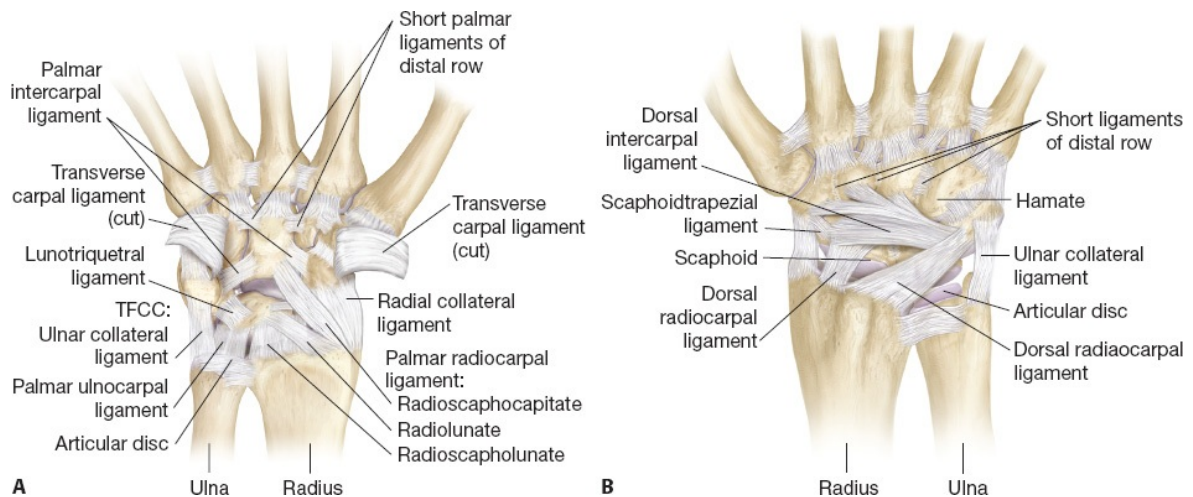
whether ligamentous or bony in etiology.

Carpal Ligaments

- Normal carpal ligament anatomy is shown in **FIG 3A,B**.
- In RA, synovitis attenuates the radioscaphocapitate (RCC) ligament and the scapholunate (SL) ligament, causing ulnar translocation of the carpus.
- At the DRUJ, the triangular fibrocartilage complex (TFCC), including the dorsal and palmar radioulnar ligaments, is also destroyed by synovitis, leading to DRUJ instability and eventual dorsal dislocation of the ulnar head. The extensor carpi ulnaris (ECU) sheath is also destroyed, resulting in volar ECU subluxation and contributing to the supinated and radially deviated posture of the wrist (**FIG 3C**).
- The term *caput ulna* refers to the combination of dorsal ulnar head dislocation, volar ECU subluxation, and carpal supination (**FIG 3D,E**).

Tendons at the Wrist

- Synovitis develops within the extensor tendon compartments on the dorsal aspect of the wrist (**FIG 4**).



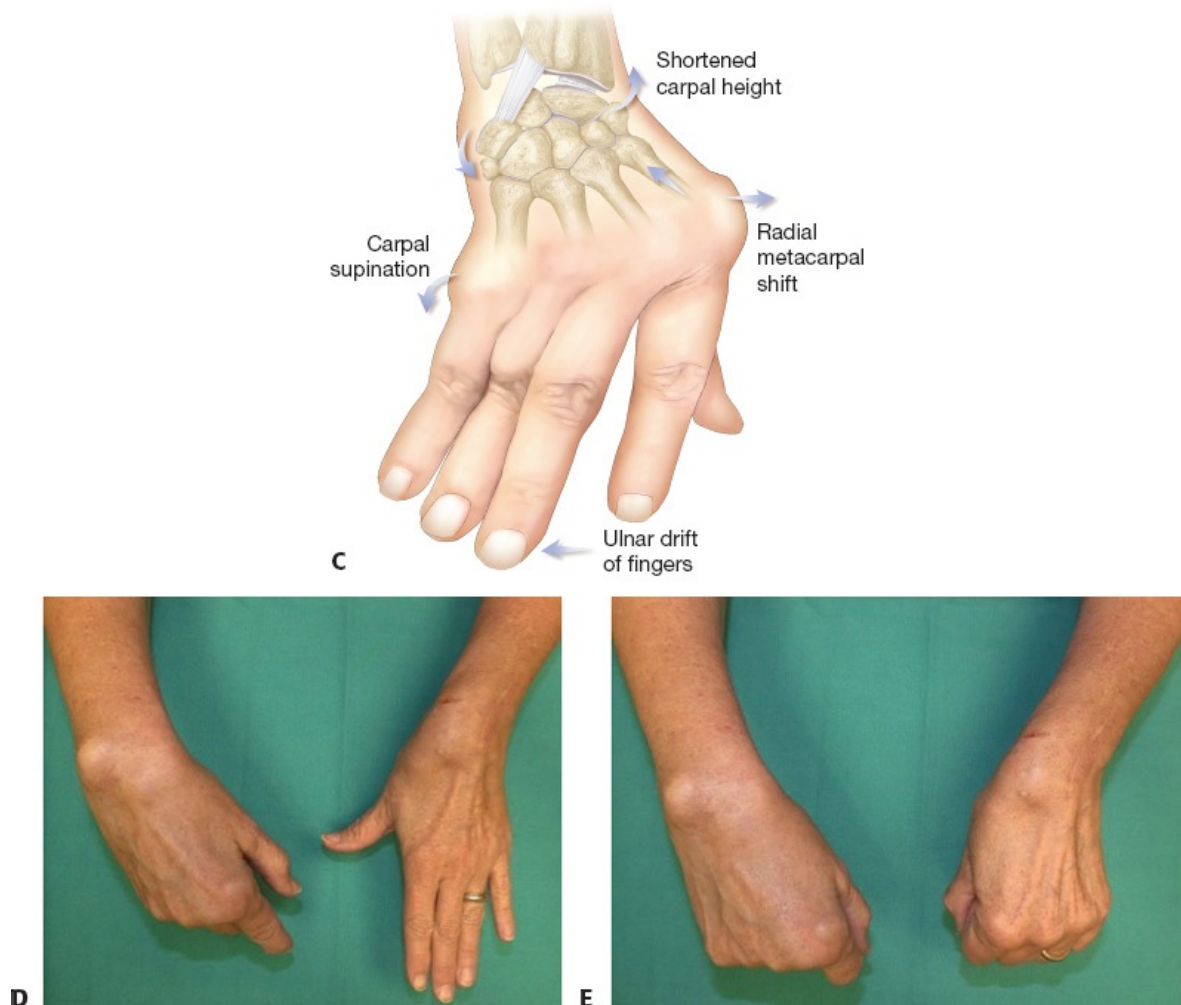


FIG 3 • Palmer (A) and dorsal (B) views of normal anatomy of carpal ligaments and TFCC. C. Wrist changes in RA. D,E. Caput ulna of the right hand.

- Pannus can be seen bulging proximally and distally from underneath the extensor retinaculum, taking on an hourglass appearance.
- Tendon rupture in RA results from direct pannus invasion and/or attritional wear over eroded bony edges.
- In regions where the tendon is covered by tenosynovium (eg, extensor retinaculum, carpal tunnel, and digital flexor sheaths), tendons may be directly invaded by synovial pannus.
- In regions where tendon is closely related to joints (eg, the DRUJ, radiocarpal joint, and PIP joints), underlying proliferative synovitis may cause pressure ischemia leading to tendon rupture.

- Attritional rupture frequently involves the extensor digiti minimi (EDM) at the ulnar head, the extensor pollicis longus (EPL) at the Lister tubercle, and the FPL in the carpal tunnel, which is caused by a flexed, eroded scaphoid. An attritional FPL rupture is termed a *Mannerfelt lesion*.

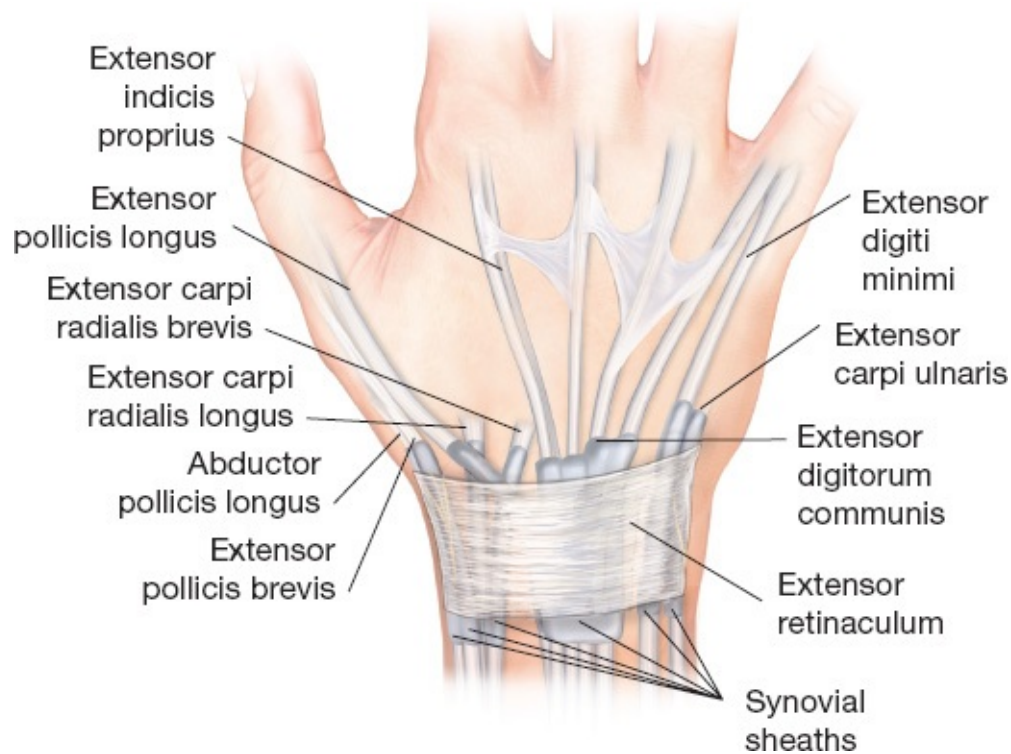


FIG 4 • Extensor tendons of the hand and wrist.

Table 3 Examining the Tendons of the Hand

Tendon	Examination Maneuver	Interpretation and Pearls
Extensor pollicis longus (EPL)	• With the patient's palm flat on a table, ask the patient to lift the thumb off the table.	If able to lift the thumb off the table (retropulsion), EPL is intact.
Extensor indicis proprius (EIP)	• Test independent extension of the index finger with the remaining fingers held in flexion.	It is important to test the integrity of EIP, as it is a common donor in tendon transfer procedures.
Extensor digitorum communis	• With the finger passively placed in extension, ask the patient to maintain the finger	• One must differentiate extensor tendon rupture from (1) ulnar subluxation of the

(EDC)	in extension. If unable to maintain finger extension, there is either a tendon rupture or nerve palsy. • Next, test the <i>tendodesis effect</i> by passively flexing the patient's wrist and looking for concomitant finger extension. If the finger does not extend, tendon rupture is the diagnosis, as the tenodesis effect is preserved in nerve palsy.	extensor tendon over the head of the metacarpal and (2) posterior interosseous nerve (PIN) palsy secondary to elbow synovitis. • Patients with rupture of the EDC to one finger may still be able to extend that finger due to the juncturae connecting it to the adjacent fingers. • Usually, the finger cannot be extended if more than one EDC is ruptured.
Extensor digiti minimi (EDM)	Test independent extension of the small finger with the other fingers flexed.	• Patients may still be able to extend the small finger while extending the remaining fingers through an intact EDC or the juncturae connecting it to the ring finger.
Flexor pollicis longus (FPL)	Holding the thumb MCPJ in extension, ask the patient to flex the thumb IP joint.	• Intact thumb IP flexion indicates an intact FPL tendon.
Flexor digitorum superficialis (FDS)	FDS is checked for each finger by holding the patient's other fingers in extension and allowing the patient to actively flex the finger in question.	• If FDS is intact, the finger will bend at the PIPJ. • It is important to test the integrity of FDS to the ring and long fingers, as they are commonly used in tendon transfer procedures.
Flexor digitorum profundus (FDP)	FDP is checked for each finger by holding the PIPJ straight and asking the patient to flex the DIPJ.	• If FDP is intact, the finger will bend at the DIPJ.

- The most frequently ruptured tendons are the EDM, followed by the extensor digitorum communis (EDC) tendons of the small, ring, long, and index fingers; the EPL; the FPL; and, least commonly, the flexor digitorum superficialis

(FDS) and profundus (FDP) tendons.

- Extensor tendon ruptures often progress from ulnar to radial, eventually affecting all digits, referred to as *Vaughn-Jackson syndrome*. Tendon ruptures occur suddenly, may not be painful, and must be differentiated from volar subluxation of the MCPJ, radial nerve palsy, and extensor tendon subluxation at the MCPJ. Flexor tendon ruptures occur less often.
- A thorough tendon examination (Table 3) is warranted to determine reconstructive options after tendon rupture (Table 4).

Table 4 Tendon Transfer Options for Rheumatoid Attritional Ruptures

Physical Findings	Ruptured Tendon(s)	Reconstructive Options
Lack of small finger extension	• EDM at ulnar head	• End-to-side repair of EDM to ring finger EDC
Lack of small and ring finger extension	• EDM at ulnar head • EDC to small finger • EDC to ring finger	• EIP transfer to EDM and ring finger EDC
Lack of small, ring, and long finger extension	• EDM at ulnar head • EDC to small finger • EDC to ring finger • EDC to long finger	• EIP transfer to EDM and ring finger EDC • End-to-side repair of long finger EDC to index finger EDC
Lack of small, ring, long, and index finger extension	• EDM at ulnar head • EDC to small finger • EDC to ring finger • EDC to long finger • EDC to index	• Long finger FDS to index and long finger EDC • Ring finger FDS to ring finger EDC and small finger EDC/EDM (whichever tendon is more robust)

	- finger • EIP	
Lack of thumb extension (retropulsion)	• EPL at Lister tubercle	• Preferred: EIP transfer to EPL • Alternatives: ◦ ECRL to EPL ◦ EDM to EPL
Lack of thumb, index, long, ring, and small finger extension	• EDM at ulnar head • EDC to small finger • EDC to ring finger • EDC to long finger • EDC to index finger • EIP • EPL at Lister tubercle	• Long finger FDS transfer to EPL and index finger EDC • Ring finger FDS transfer to long and ring finger EDC and small finger EDC/EDM (whichever tendon is more robust)
Lack of thumb IPJ flexion	• FPL in carpal tunnel	• Preferred: BR transfer to FPL • Alternatives: ◦ ECRL transfer to FPL ◦ Long finger FDS transfer to FPL ◦ Thumb IPJ fusion
Lack of independent PIPJ flexion (of any finger)	• FDS (any finger)	• PIPJ synovectomy (to prevent FDP rupture)
Lack of DIPJ flexion (of any finger)	• FDP (any finger)	• Preferred: DIPJ arthrodesis • Alternative: DIPJ tenodesis
Inability to flex PIPJ and DIPJ (of any finger)	• FDS and FDP (any finger)	• Staged flexor tendon reconstruction

BR, brachioradialis; DIPJ, distal interphalangeal joint; ECRL, extensor carpi radialis longus; EDC, extensor digitorum communis; EDM, extensor digiti minimi; EIP, extensor indicis proprius; EPL, extensor

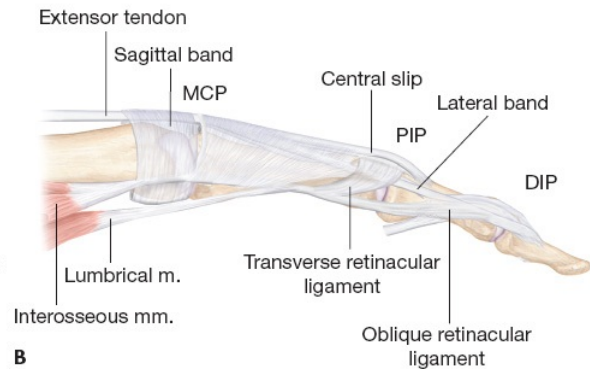
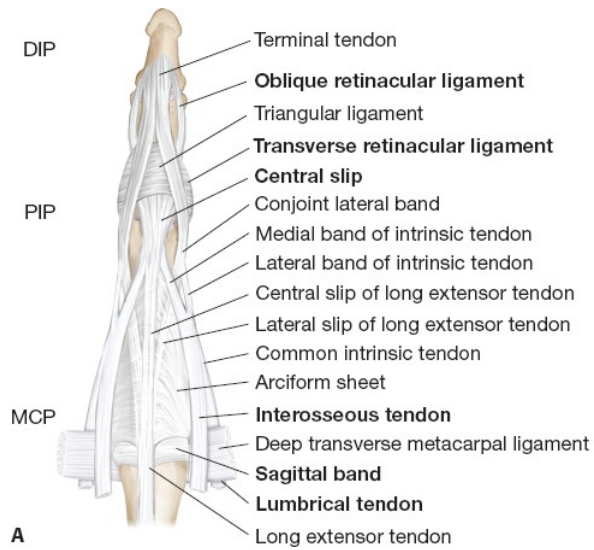
pollicis longus; FDP, flexor digitorum profundus; FDS, flexor digitorum superficialis; FPL, flexor pollicis longus; IPJ, interphalangeal joint; PIPJ, proximal interphalangeal joint.

Carpal Tunnel Syndrome

- Within the carpal tunnel, synovial pannus and tenosynovitis can proliferate to the point of median nerve compression, causing carpal tunnel syndrome.
- Synovitis between the scaphoid and lunate can cause SL ligament rupture and scaphoid collapse with its distal pole protruding into the carpal tunnel.

Joints of the Hand

- In RA patients, the MCPJs and PIPJs are primarily affected, with relative sparing of the DIPJs. Radiographs reveal joint space narrowing from cartilage degradation and marginal bony erosions from pannus invasion. Joint capsules and collateral ligaments are stretched and invaded by pannus as well, leading to joint instability and deformity.
- The radial and ulnar sagittal bands stabilize the extensor tendon over the dorsal midline of the MCP joint (**FIG 5A,B**). When the radial sagittal band is attenuated, the extensor tendon subluxes ulnarly, leading to ulnar deviation of the finger (**FIG 5C**). The MCPJs in RA patients are typically characterized by volar subluxation and ulnar deviation (**FIG 5D,E**). The MCPJ is a condylar joint, allowing for flexion, extension, radial deviation, and ulnar deviation. The extensor tendon is stabilized over the dorsal midline of the MCPJ by the radial and ulnar sagittal bands. The sagittal bands are connected to the volar plate. Because the lateral bands pass volar to the MCPJ and dorsal to the PIPJ, intrinsic muscle contraction through the lateral bands results in MCPJ flexion and PIPJ extension.



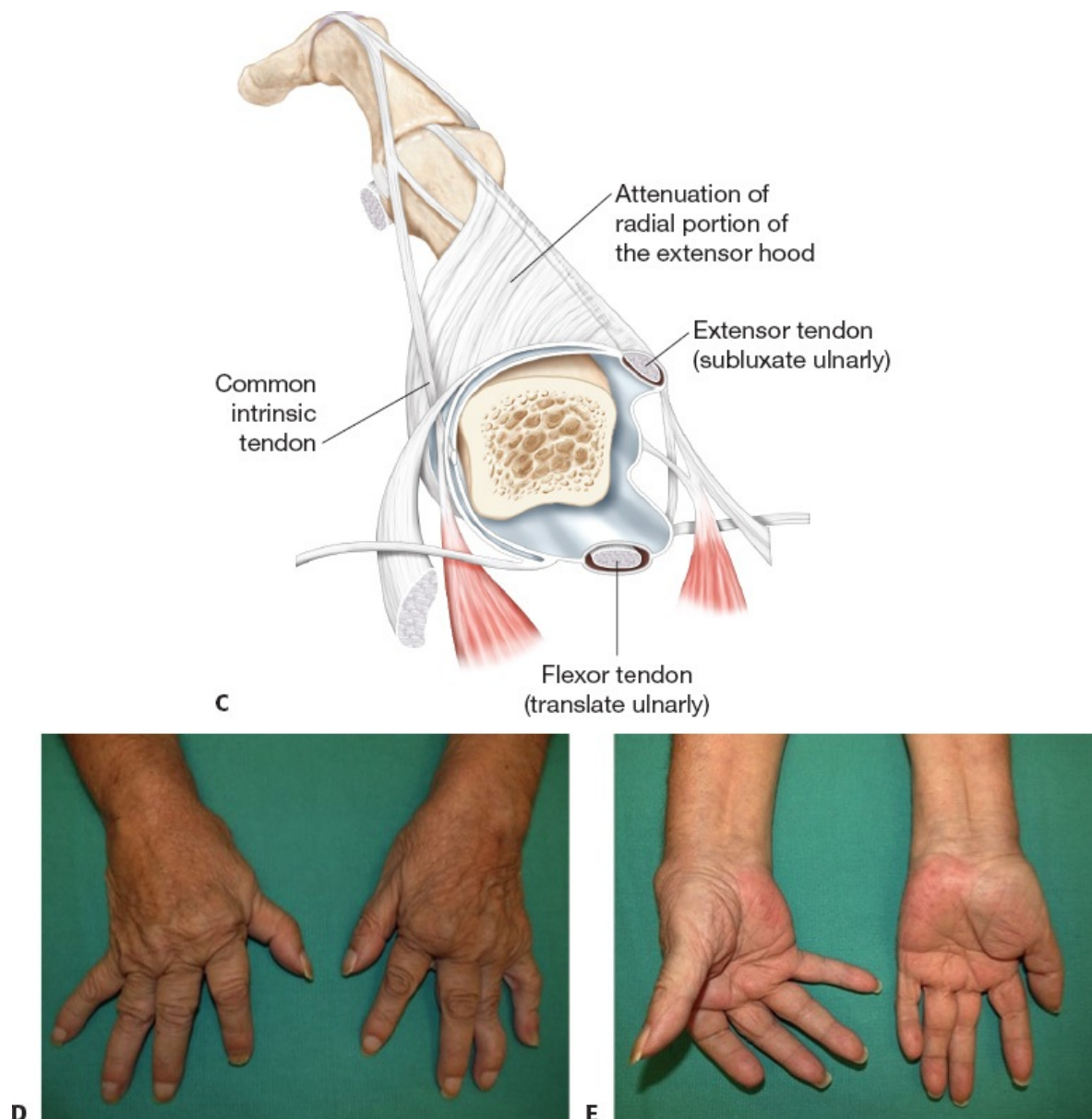


FIG 5 • A,B. AP and lateral views of normal anatomy of extensor tendons of the finger. **C.** Anatomy of ulnar deviation deformity. **D,E.** MCPJ volar subluxation with ulnar deviation of the fingers.

- In RA patients, ulnar deviation at the MCPJ is due to three things:
 - Erosion of the dorsoradial aspect of the joint capsule
 - The radially deviated wrist position causing an ulnar approach of the extensor tendons
 - Attenuation of the radial sagittal bands leading to ulnar subluxation of the

extensor tendons

Swan-Neck Finger Deformity

- The swan-neck finger deformity (**FIG 6**) is characterized by PIPJ hyperextension with DIPJ flexion.
- This deformity is functionally debilitating due to loss of PIPJ flexion, which impedes pinching and grasping.
- Swan-neck deformities can result from pathology at the MCPJ, PIPJ, or DIPJ (Table 5).

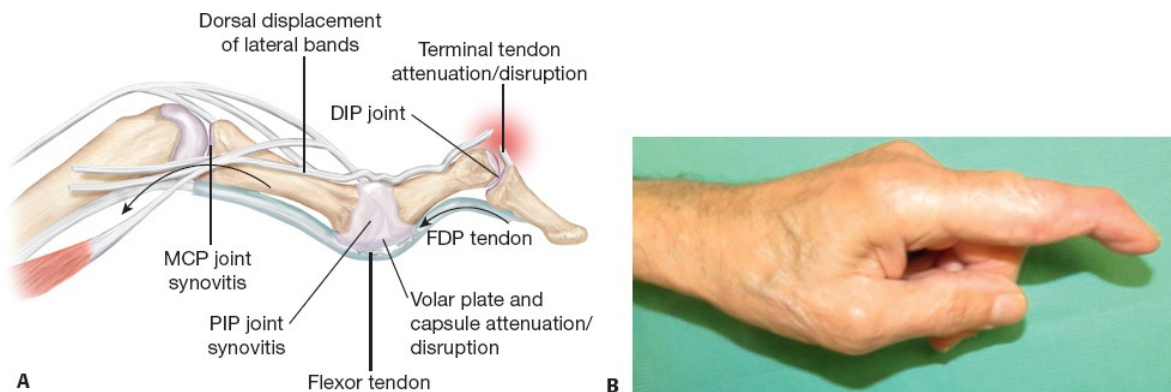


FIG 6 • A,B. Swan-neck deformity.

Table 5 Three Mechanisms Resulting in the Swan-Neck Deformity	
Originating Joint	Mechanism of Swan-Neck Deformity
DIPJ	• Initially, the terminal tendon attenuates or erodes, resulting in a mallet finger. • This leads to increased extension at the PIPJ through the central slip, which is accentuated by MCP flexion. • Further attenuation of the PIP volar plate from synovitis leads to PIPJ hyperextension.
PIPJ	• Initially, the synovial pannus stretches and erodes the volar plate and capsule, allowing for PIPJ hyperextension. • The lateral bands slide dorsally, leading to extra slack in the extensor mechanism. • Slack in the extensor mechanism, combined with tightening of the flexor digitorum

	profundus (FDP) tendon, leads to DIPJ flexion.
MCPJ	• The volarly subluxed MCPJ posture leads to excessive pull through the extensor mechanism. • When the lateral bands migrate dorsally, the resulting tendon imbalance leads to PIPJ hyperextension and DIPJ flexion.

Boutonniere Finger Deformity

- Boutonniere deformities are less common than swan-neck deformities. They are also less debilitating given that PIPJ flexion, and thus, pinch and grasp are preserved.
- The pathology of boutonniere deformities always starts at the PIPJ, where disruption of the central slip at the base of the middle phalanx occurs. The dorsal capsule, transverse retinacular ligament, and triangular ligament also attenuate. As such, the lateral bands sublux to a position volar to the axis of the PIPJ, flexing the PIPJ.
- Hyperextension at the DIPJ occurs because the lateral bands continue to pull distally on the extensor mechanism at the terminal tendon (**FIG 7**).

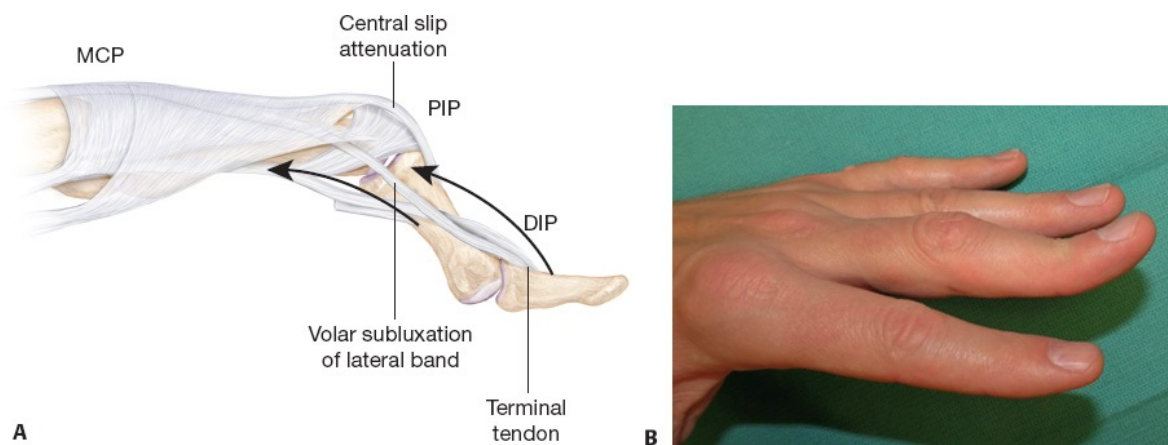


FIG 7 • A,B. Boutonniere deformity.

Thumb Deformity (Types I to V)

- The boutonniere deformity (type I) is the most common thumb deformity in RA patients, characterized by MCPJ flexion, interphalangeal (IP) hyperextension, and radial abduction of metacarpal (**FIG 8**).

- Synovial pannus at the MCPJ erodes dorsally, causing eventual rupture of the extensor pollicis brevis (EPB) tendon insertion and displacing the EPL ulnarly and volarly. This leads to MCPJ flexion and volar subluxation. IP joint hyperextension occurs secondarily and is exacerbated in patients with FPL rupture.
- A type II thumb deformity in RA is less common, characterized by thumb MCPJ flexion and IP extension in the setting of carpometacarpal joint (CMCJ) dislocation or subluxation.
- The swan-neck deformity (type III) is the second most common deformity of the thumb, with MCPJ hyperextension, IP flexion, and a metacarpal adduction contracture (**FIG 9**).
- The volar beak ligament attenuates at the CMCJ, leading to CMCJ subluxation or dislocation and metacarpal adduction. MCPJ hyperextension occurs secondarily as the thumb compensates for the adducted metacarpal and is exacerbated by volar plate attenuation or erosion from pannus invasion.
- The type IV thumb deformity is termed the gamekeeper deformity, which develops secondary to synovial pannus destruction of the ulnar collateral ligament at the MCPJ.
- The type V thumb deformity is similar to the swan-neck deformity, with MCPJ hyperextension and IP flexion, but without the metacarpal adduction contracture.

Trigger Finger

- Trigger fingers in RA patients have a mechanism that is distinct from nonrheumatoid trigger fingers, occurring secondary to synovitis or small rheumatoid nodules in the flexor tendon.
- If the nodule is proximal to the A1 pulley, it can present similarly to a nonrheumatoid trigger digit, with locking in flexion or extension. However, a nodule just distal to the A2 pulley can result in locking in extension or triggering during flexion. Also, multiple nodules or diffuse tenosynovitis can lead to loss of flexion and extension altogether.

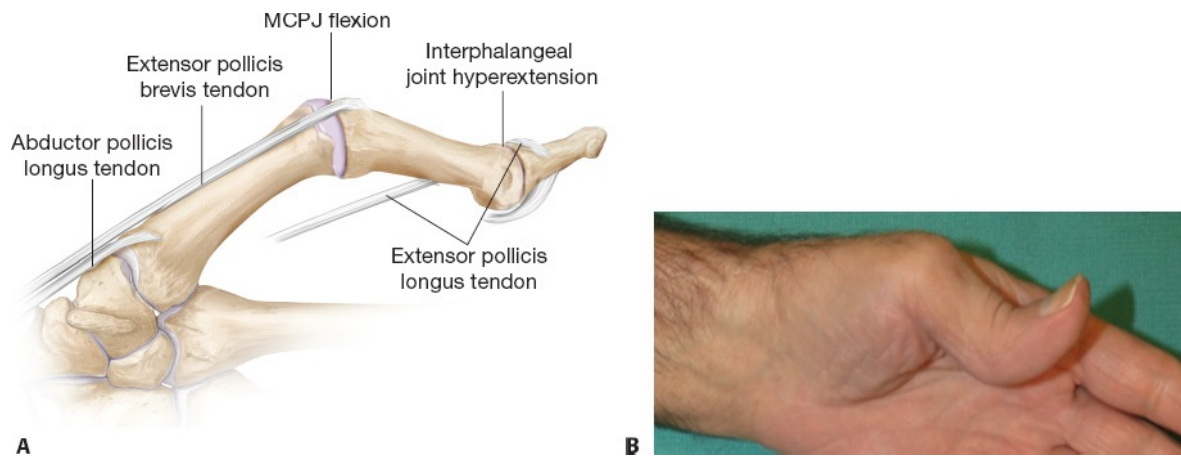


FIG 8 • A,B. Thumb boutonniere deformity.

- Treatment for trigger fingers in patients with RA involves flexor tendon synovectomy through windows in the flexor tendon sheath, along with excision of the rheumatoid nodule, if present.
- The A1 pulley should not be completely released, as doing so would redirect the pull of the flexor tendon and contribute to ulnar deviation.

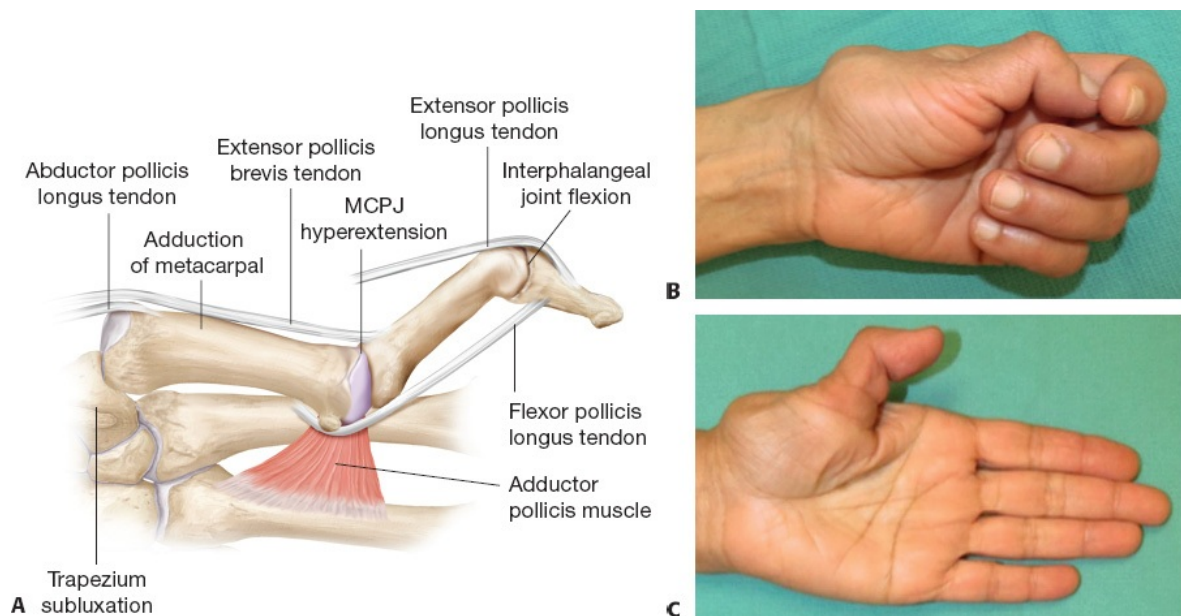


FIG 9 • A–C. Thumb swan-neck deformity.

NONOPERATIVE MANAGEMENT

- The mainstay of RA treatment is medical, particularly with disease-modifying

antirheumatic drugs (DMARDs): glucocorticoids, methotrexate (MTX), conventional DMARDs, and biologic DMARDs.⁷ These medications prevent or reduce joint destruction, maintain or improve function, and can improve other aspects of the patient's general health. The goal of medical management in RA is not only clinical remission but also to prevent joint destruction with early medical intervention.⁶

- Oral glucocorticoids suppress inflammation and preserve joint structure. Glucocorticoids can also be injected into actively inflamed joints for pain relief.
- MTX, a folic acid antagonist, is often considered the first-line therapy for RA treatment, as it has been shown to decrease radiographic progression of the disease. MTX is potentially hepatotoxic, and the patient's liver enzymes should be checked at regular intervals. Since MTX is renally cleared, patients with chronic renal insufficiency should not be treated with MTX.
- Conventional DMARDs include hydroxychloroquine, sulfasalazine, and leflunomide, which are mild anti-inflammatory agents. These can be used single agents in mild RA or in combination with MTX or other agents.
- Biologic DMARDs include anti-TNF agents, such as etanercept, infliximab, and adalimumab. These are often used as second-line therapy for RA and can be added to MTX or other ongoing therapies. Anti-TNF agents are highly immunosuppressive and must be discontinued if an infection is encountered. Other biologic agents include abatacept and rituximab, which are safe when combined with MTX, and can be used if anti-TNF therapy has failed.
- Nonsteroidal anti-inflammatory drugs (NSAIDs) and other analgesics can be used in combination with DMARDs in the symptomatic treatment of pain in RA patients, but they do not have any significant impact on disease progression or function and should not be used as the primary or sole therapy in RA patients.
- Patients with RA should also be monitored for osteopenia and osteoporosis, which are common comorbid conditions in RA and can be accelerated with glucocorticoid therapy.
- Patients should also participate in physical and occupational therapy to maintain joint mobility and function, improve strength and endurance, and enhance cardiovascular fitness.
- Patients should be educated on the safe use of assistive devices, joint protection, and rest.

SURGICAL MANAGEMENT

- Although excellent clinical and radiographic results in patients with mild deformities or tenosynovitis have been obtained since the introduction of DMARDs, patients who develop severe joint deformities, tendon ruptures, and recalcitrant tenosynovitis will require surgical intervention.
- The management of rheumatoid hand problems requires an integrated approach involving both the rheumatologist and the hand surgeon. Once medical management is optimized, the patient can be considered for surgery in an effort to provide pain relief, improve function, prevent disease progression, and improve appearance.
- Common surgeries for the rheumatoid hand include tendon reconstruction, correction of swan-neck deformities, correction of boutonniere deformities, and silicone arthroplasty of the MCP joints.
- Tendon transfers are indicated if there is rupture of the long digital flexor or extensor tendons. A thorough tendon examination (**FIG 10**; see Table 3) is critical in determining the appropriate reconstructive options (see Table 4).
- Although the typical swan-neck deformity involves a flexion contracture of the MCPJ, hyperextension of the PIPJ, and dorsally displaced lateral bands (see **FIG 6**), treatment is based on the flexibility of the PIPJ and condition of the joint cartilage. One must test active and passive PIPJ motion with the MCPJ in extension and flexion in order to evaluate intrinsic muscle involvement.
- The Nalebuff classification⁸ is useful for surgical decision-making (Table 6).
- Flexor tendon adhesions are suspected if PIPJ active motion is not nearly equal to its passive motion. On the other hand, if the PIPJ remains flexible regardless of MCPJ position (type I), a PIPJ extension-blocking splint may be enough to correct the deformity. If PIPJ flexion is restricted with MCPJ extension and radial deviation, ulnar intrinsic muscle tightness is present.
- Reconstructive surgery can be performed for a boutonniere deformity provided that the PIPJ has full passive extension. The Nalebuff classification of boutonniere deformities (see Table 6) classifies this as stage I or II. However, if a severe fixed flexion contracture exists, or if articular destruction is present (stage III), arthrodesis or arthroplasty of the PIPJ is recommended.
- In RA patients, silicone metacarpophalangeal joint arthroplasty (SMPA) is indicated to treat MCPJ contracture, subluxation, or dislocation. However, SMPA is not indicated in patients with other rheumatic conditions such as lupus, in which soft tissue laxity is present without the underlying joint

destruction. In such patients, joint replacement would inevitably lead to joint dislocation due to the absence of healthy supporting ligaments.

- In RA patients with no evidence of MCP joint subluxation or arthritis, soft tissue reconstruction for correction of ulnar deviation finger deformities can be performed using the crossed intrinsic tendon transfer. The ulnar deviation deformity must be passively correctable. As such, this procedure is also useful in patients with lupus who do not have any underlying joint destruction.

Preoperative Planning

- Preoperative evaluation of RA patients is critical in reducing surgery-related morbidity and mortality.
- Many surgeons advocate that all RA patients should be seen in the preoperative anesthesia clinic due to a high incidence of comorbid conditions.
- A thorough evaluation with an electrocardiogram, complete blood count and differential, metabolic panel, chest radiograph, and cervical spine radiographs should be obtained.
- From a cardiac standpoint, RA can be associated with pericardial effusion, constrictive pericarditis, or conduction blocks, thereby impacting cardiac function. In addition, RA patients are at increased risk of coronary artery disease.
- Pulmonary involvement may include rheumatoid nodules, pleural effusions, or interstitial lung disease.
- Long-standing RA can be associated with Felty syndrome (splenomegaly, neutropenia, and secondary thrombocytopenia).
- Cervical spine flexion-extension radiographs are imperative as atlantoaxial instability is common in RA patients, placing patients at risk for spinal cord injury with routine procedures such as endotracheal intubation.
 - Patients with cervical instability should undergo fiberoptic intubation.
 - RA may also involve the cricoarytenoid and the temporomandibular joints, which can further complicate airway management.

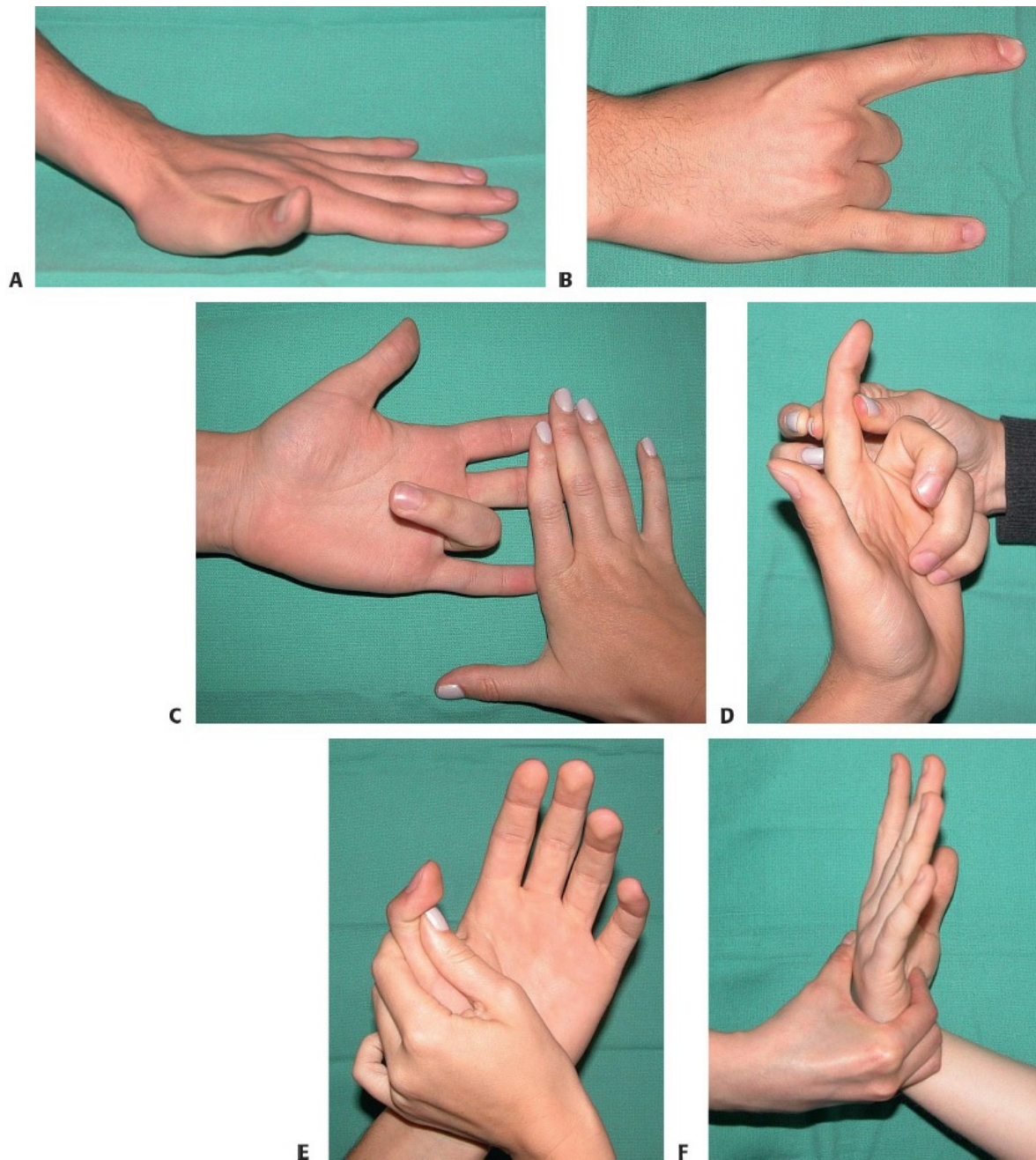


FIG 10 • Tendon examination maneuvers. **A.** Check EPL by placing patient's palm down on tabletop and asking patient to lift the thumb. **B.** Check EIP and EDM by asking patient to extend the index and small fingers only. **C.** Check FDS of each digit by blocking all other digits and asking the patient to bend the digit in question. **D.** Check FDP by blocking the patient's

middle phalanx and asking patient to bend the fingertip. **E.** Check FPL by blocking the patient's thumb proximal phalanx and asking patient to bend thumb. **F.** Check the extensor tendons by flexing the patient's wrist and seeing if the fingers extend (the tenodesis effect).

Table 6 The Nalebuff classification for swan-neck deformities and surgical options

Type	Description	Surgical Goals/Options
I	PIPJ is flexible in all positions of the MCPJ	Must limit PIPJ hyperextension (splint, dermodesis, FDS tenodesis) and restore DIPJ extension (tenodermodesis, fusion)
II	PIPJ flexion is limited in certain MCPJ positions	Intrinsic release and/or MCPJ arthroplasty, in addition to procedures required for type I deformities
III	PIPJ flexion is limited irrespective of MCPJ positions	Restore PIPJ flexion by manipulation, lateral band mobilization, and lengthening of central slip
IV	PIPJ joints are stiff, with poor radiographic appearance	Arthrodesis of PIPJ is preferred, but implant arthroplasty may be considered

DIPJ, distal interphalangeal joint; FDS, flexor digitorum superficialis; PIPJ, proximal interphalangeal joint; MCPJ, metacarpophalangeal joint.

- Perioperative medication management should be discussed with the patient's rheumatologist. In general, corticosteroids can be continued, but patients may require a stress dose at the time of surgery.
- MTX and other conventional DMARDs can generally be continued.
- Biological DMARDs, on the other hand, are typically discontinued for 2 to 4 weeks before and after surgery. Again, discussion with the patient's rheumatologist is imperative.

Positioning

- Patients are positioned supine with the upper extremity abducted on a hand

table.

- Care is taken to provide the appropriate neck support.
- A tourniquet is placed on the upper arm.

TECHNIQUES

■ Tendon Transfers for Tendon Ruptures

Imaging and Planning

- Radiographs of the wrist to evaluate the DRUJ, midcarpal joint, and radiocarpal joint should be obtained.
 - Should these joints be involved, they must be addressed at the time of tendon reconstruction to prevent progressive deformity and rerupture of the reconstructed tendons.
- If tendon rupture is diagnosed, surgical reconstruction is indicated to restore function. Because the ruptured tendon ends are of poor quality, direct repair is usually not possible. Furthermore, myostatic contraction eventually leads to loss of the proximal end of the ruptured tendon, preventing the use of tendon grafts. Tendon transfer is the preferred reconstructive option.
- Depending on the number of ruptured tendons, surgery may involve a simple end-to-side repair to an intact adjacent tendon, or it may require transfer of a new motor-tendon unit (Table 5). It is also important to address the cause of tendon rupture at the time of tendon reconstruction to prevent rerupture.
 - If synovitis is the cause, a synovectomy must also be performed.
 - If joint instability or bony erosion is the cause, a procedure to address this should be performed as well.

Tendon Transfers for Extensor Tendon Ruptures

- After tourniquet inflation, a 6-cm longitudinal incision is made over the dorsal wrist in line with the long finger.
- Skin flaps are raised to expose the extensor retinaculum.
- The retinaculum is incised and elevated using a stair-step design (**TECH FIG 1A**).
 - The stair-step incision effectively lengthens the retinaculum to permit closure over the reconstructed tendons in the presence of swelling.

- Also, if there is eroded bone exposed at the radiocarpal joint, half of the retinaculum can be used as a protective layer between bone and tendon, while the other half is closed over the tendons.
- Next, the septa between the second and sixth extensor compartments are divided, bringing the tendons together, typically revealing hypertrophic synovial tissue encasing the tendons (**TECH FIG 1B**).
- Synovectomy is then sharply performed. Tendons that are invaded by synovial tissue are also completely excised (**TECH FIG 1C**).
- Tendon reconstruction then proceeds based on the tendons involved (see Table 4). All tendon junctures are secured with nonabsorbable braided suture (**TECH FIG 1D**).
- If EPL is to be addressed, a separate incision is made at the level of the thumb metacarpal, to identify the distal EPL tendon (**TECH FIG 1E**).
- The EIP tendon is often weaved into the EPL tendon (**TECH FIG 1F**), thereby restoring EPL function (thumb retropulsion).
- If three or more extensor tendons are ruptured, the FDS is used for the transfer.
 - The FDS tendon is identified through a transverse incision in the distal palm and divided. The proximal end of the tendon is retrieved via a separate longitudinal incision in the distal volar forearm and passed in a subcutaneous tunnel radially in order to reach the extensor tendons on the wrist dorsum.
 - A single FDS tendon can be transferred to up to three extensor tendons. If more than three extensor tendons are ruptured, however, transfer of both the ring and long finger FDS tendons should be considered.
- Once all tendons are addressed, the dorsal wrist capsule is closed using braided sutures. If the capsule is lax, it can be imbricated with these sutures.
- The forearm is placed in supination, and the capsule over the distal ulna is closed tightly with 3-0 braided sutures in a horizontal mattress fashion.
- Next, the extensor tendons are re-examined for laxity.
 - If lax, the extensor tendons can be tightened with horizontal mattress braided sutures.
 - Tension is set with all fingers in fully extended posture, as some postoperative stretching is anticipated.
- The extensor retinaculum is then repaired. If needed, the distal half can be used to augment the wrist capsular repair, placing it underneath the extensor

tendons, and the proximal half is sutured over the tendons, recreating the pulley (**TECH FIG 1G**).

- The tourniquet is then released, hemostasis is achieved, and the skin is closed with 4-0 nylon simple interrupted sutures.
- Fingers are immobilized in fully extended position for 4 weeks, and then active range-of-motion (ROM) exercises are initiated.

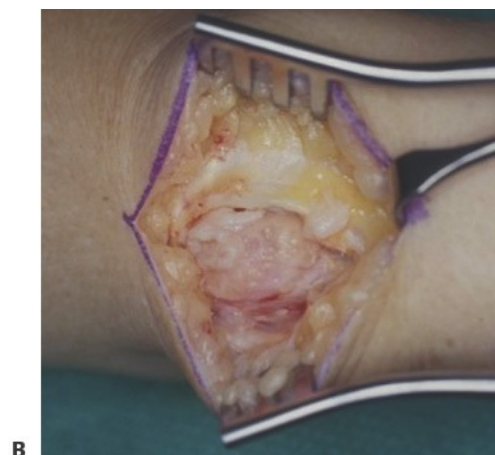
Reconstruction of Ruptured Flexor Tendons

Grafting for FPL Rupture

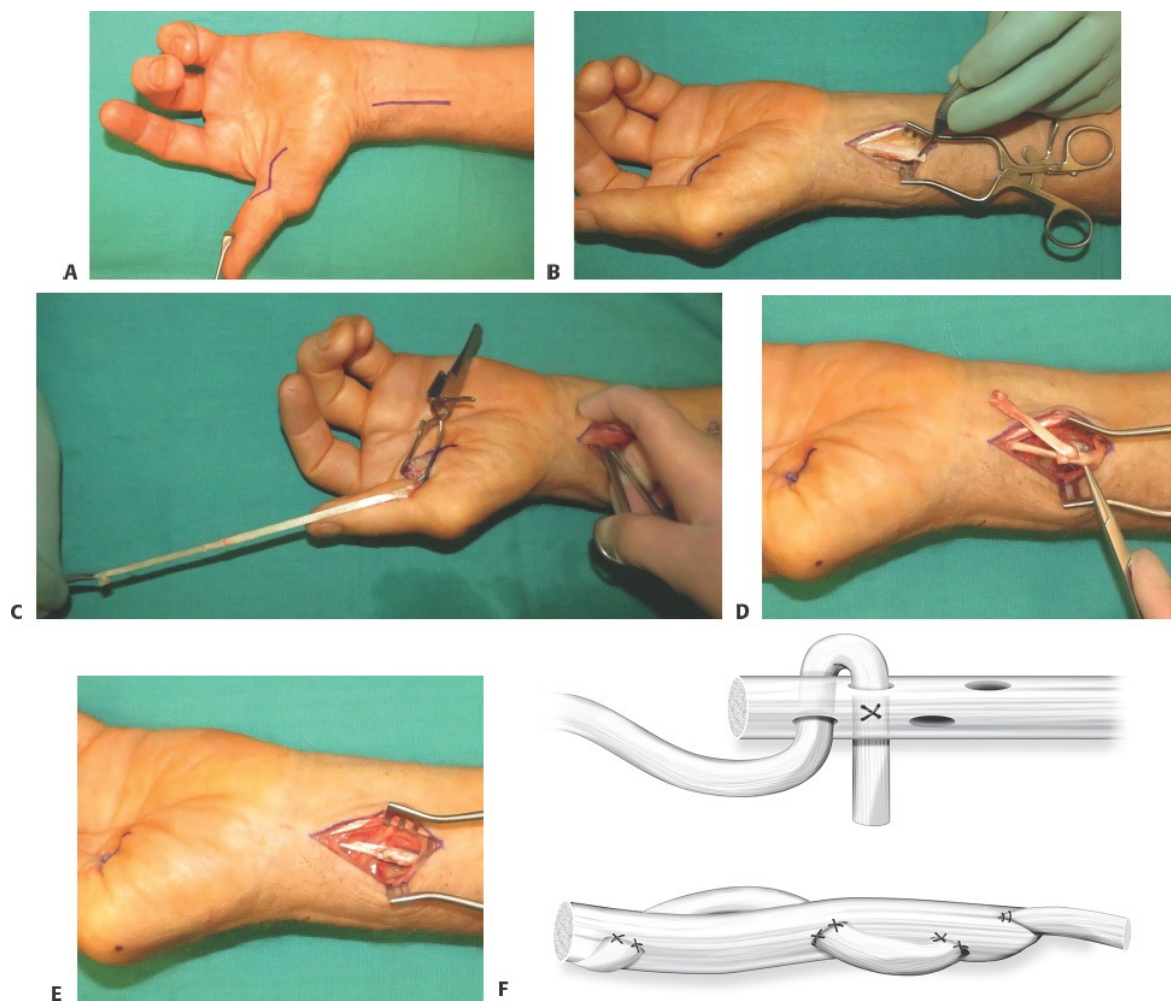
- For the treatment of an FPL rupture caused by attritional wear against an eroded scaphoid (Mannerfelt lesion), exposure of the tendon is performed at the palm-wrist junction, and initially, a flexor tenolysis is performed.
- The osteophyte is then removed with a rongeur, and the capsule is closed to provide a smooth gliding surface.
- If the proximal and distal ends of the ruptured FPL tendon can be found within the palm-wrist incision, a small bridge graft from the palmaris longus (PL) is used in a Pulvertaft weave with 3-0 nonabsorbable braided horizontal mattress sutures (**TECH FIG 2**).
 - As an alternative, a strip of the FCR can be used instead of the PL.

Tendon Transfer for FPL Rupture

- If grafting within the palm or wrist is not possible, a tendon transfer is required. Here, the long finger FDS tendon transfer for FPL reconstruction is described.
 - A zigzag incision is made in the palm and the long finger FDS tendon is identified (**TECH FIG 3A**).
 - The long finger FDS is divided and brought into the palmar wound (**TECH FIG 3B,C**).
 - Through a Bruner incision on the thumb, the flexor tendon sheath is sharply opened and divided transversely, leaving enough tendon distally for suturing.



TECH FIG 1 • Tendon transfer for extensor tendon reconstruction. **A.** Extensor retinaculum with stair-step design. **B.** Hypertrophic synovial tissue encasing extensor tendons. **C.** Extensor tendon ends after debridement (prior to reconstruction). **D.** Extensor tendon reconstruction with sutures in place. **E.** Exposure of EPL through separate thumb incision. **F.** EIP woven into EPL tendon. **G.** Reconstruction of extensor retinaculum (half under and half over the extensor tendons).



TECH FIG 2 • Ruptured flexor pollicis longus tendon reconstruction with PL. **A.** Planned skin incisions. **B.**

Ruptured FPL tendon is identified at the wrist. **C.** FPL with excellent excursion. **D.** FPL is attached to PL. **E.** PL to FPL tendon reconstruction. **F.** Pulvertaft weave.

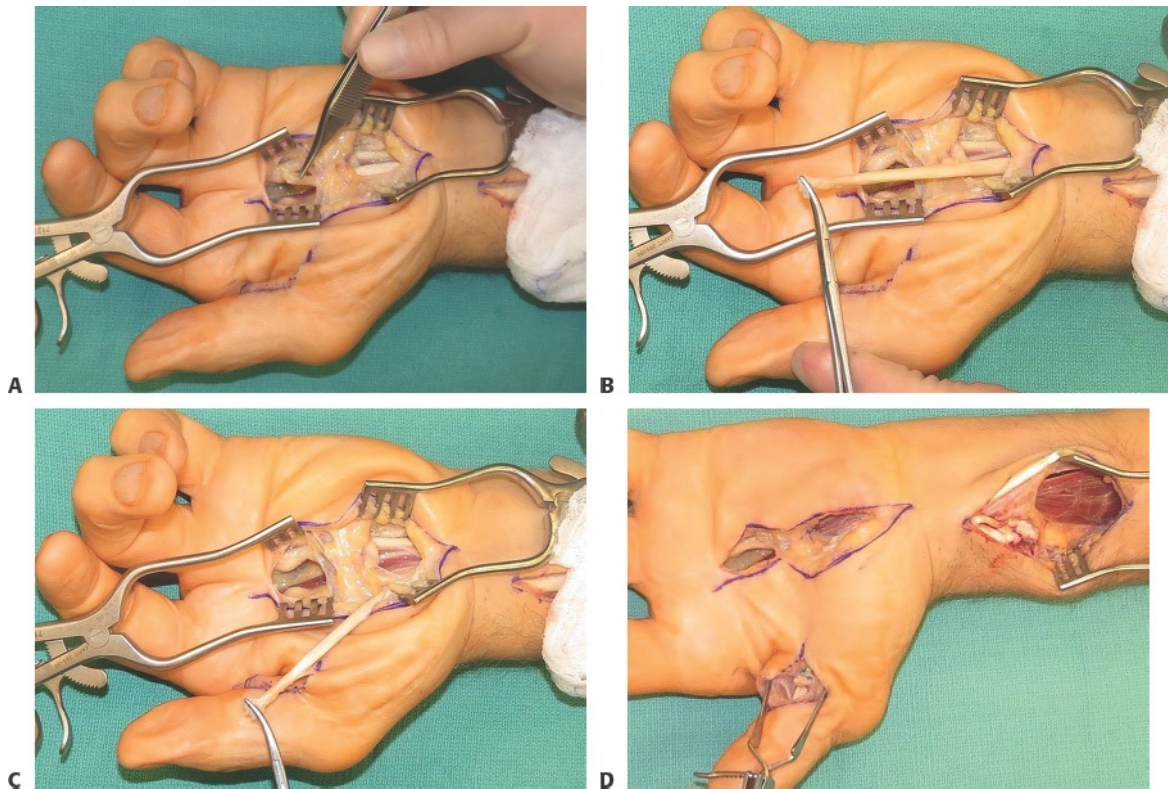
- The FDS is then delivered into the flexor tendon sheath of the thumb using a pediatric feeding tube.
- Nonabsorbable braided suture is then used to sew the FDS tendon to the distal FPL tendon (**TECH FIG 3D**). Tension should be set so that IP extension occurs with wrist flexion, and full flexion into the palm occurs with wrist extension.

Isolated FDS or FDP Ruptures

- If an isolated FDS rupture occurs within the palm or carpal tunnel, an end-to-side suture using a Pulvertaft weave to an adjacent FDS is performed, along with flexor tenosynovectomy and the smoothing of any sharp bony edges.
 - However, if the FDS rupture occurs within the finger, a tenosynovectomy with resection of the FDS should be performed.
- Similarly, if an isolated FDP rupture occurs within the palm or wrist, an end-to-side suture to an adjacent FDP is performed.
- If FDP rupture occurs within the finger, as long as FDS is still functional, the FDP is resected.
- If the DIPJ hyperextends during pinch or grip, DIP arthrodesis is performed as well.

Combined FDS and FDP Ruptures

- If occurring within the palm or wrist, the combination rupture of both FDS and FDP is treated with end-to-side suturing of the FDP to an adjacent tendon.
 - Alternatively, a bridge graft from the ruptured FDS can be used to repair the FDP tendon.
- If both FDS and FDP have ruptured within the flexor tendon sheath, a staged reconstruction should be considered, though outcomes in patients with RA are often disappointing due to limited recovery of motion.
- In patients with IPJ arthritis, the best option is arthrodesis of the PIP and DIP joints in a functional position, with preservation of some finger motion at the MCPJ via the intrinsic system.



TECH FIG 3 • Long finger FDS tendon transfer for ruptured flexor pollicis longus tendon reconstruction. **A.** Long finger FDS is identified through a palmar incision. **B.** The FDS is divided and retracted into palmar wound. **C.** The FDS is transferred from the long finger to the FPL tendon through a Bruner incision on the thumb. **D.** The reconstructed FPL tendon is shown.

■ Postoperative Care

- If tendon transfers are performed for flexor reconstruction, the hand and fingers are immobilized in a dorsal blocking splint to take tension off the transfers for 3 to 4 weeks.
- After this period, ROM exercises are gradually initiated, as guided by the hand therapist.

■ Correction of Swan-Neck Deformity

- It is imperative to understand the anatomy of the extensor apparatus of the finger (see **FIG 5**).

Correction of PIPJ Hyperextension (Type I to III Deformities)

FDS Tenodesis (“Lasso”)

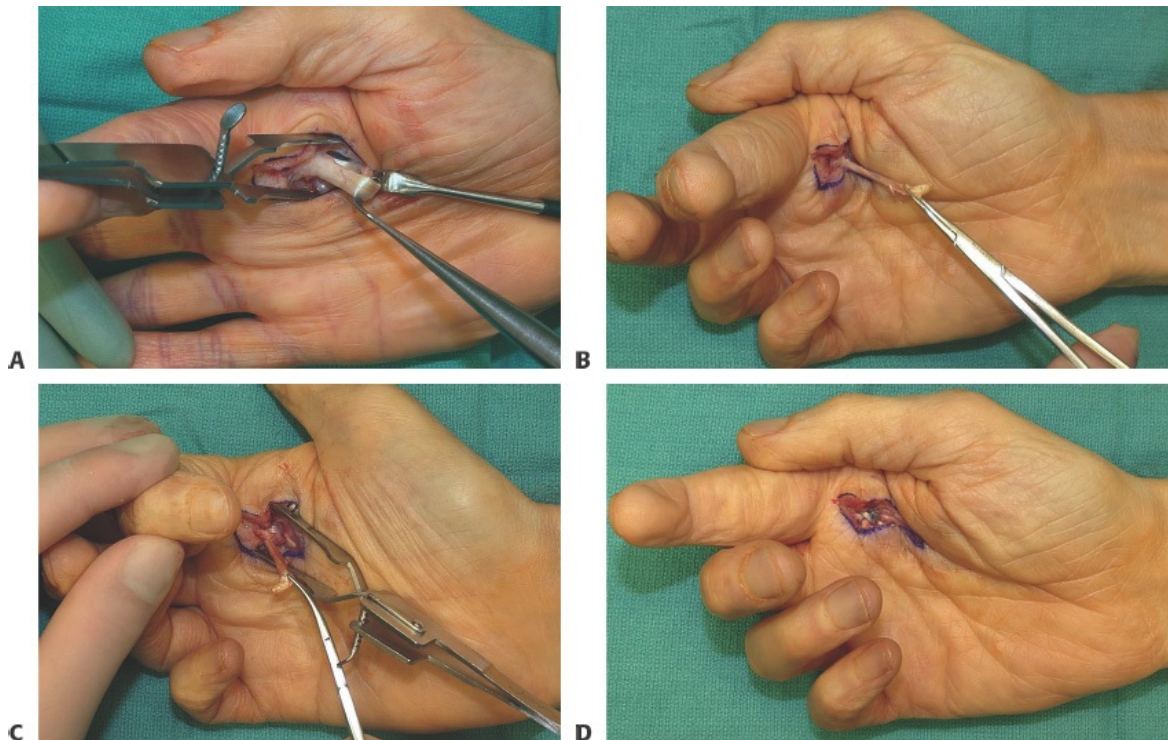
- This is the authors’ preferred technique.
- A slip of FDS is divided proximal to the A2 pulley (**TECH FIG 4A**).
- A hole is made in the distal third of the proximal phalanx, from the volar to lateral surface (**TECH FIG 4B**).
- The FDS slip is passed through the hole, from volar to lateral (**TECH FIG 4C**), and is sutured with the PIPJ at 20 to 30 degrees of flexion (**TECH FIG 4D**).
- This procedure can be combined with removal of a small ellipse of skin at the PIPJ to reinforce the tenodesis, particularly in lupus patients.

Retinacular Ligament Reconstruction

- The ulnar lateral band at the midproximal phalanx is divided and dissected distally (**TECH FIG 5A**).
- It is passed volar to the Cleland ligament, such that the ulnar lateral band can maintain the PIPJ in flexion (**TECH FIG 5B**).
- The lateral band is sutured to the A2 pulley or into the bone of the proximal phalanx to maintain PIPJ flexion at 20 to 30 degrees (**TECH FIG 5C**).
- An extension block pin is placed to protect the reconstruction.

Bone Anchor Repair of Volar Plate

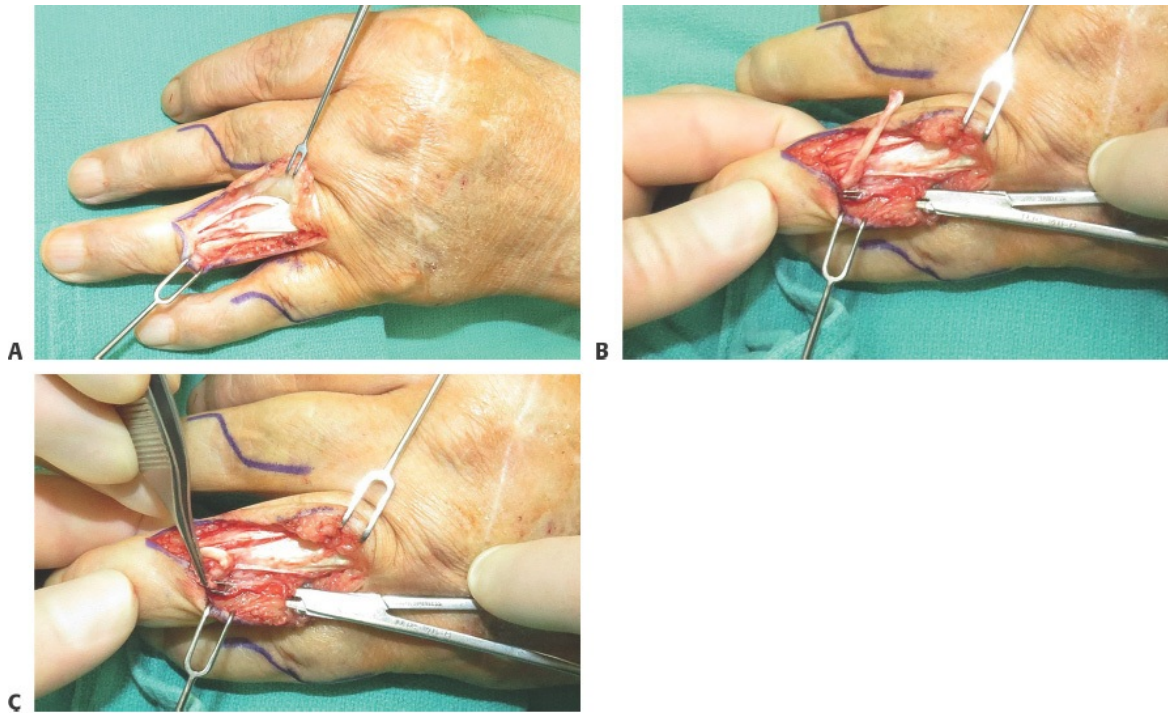
- A Bruner (zigzag) incision is made on the volar finger surface.
- The accessory collateral ligament is identified and incised in order to retract the volar plate and flexor sheath laterally, exposing the head of the proximal phalanx.



TECH FIG 4 • FDS tenodesis for correction of swan-neck deformity. **A.** An FDS slip is divided proximal to A2 pulley. **B.** A hole is drilled in the proximal phalanx (distal third), from volar to lateral surface. **C.** FDS slip is passed through the hold from volar to lateral. **D.** FDS slip is sutured with PIPJ at 15 to 20 degrees of flexion.

- A drill hole is made in the center of the volar surface of the proximal phalanx, approximately 5 to 7 mm proximal to the joint line.
- A bone anchor, which is connected to two needled sutures, such as the Mitek Mini (Mitek Surgical Products Inc., Norwood), is placed into the hole.
- One needled suture is passed from the dorsolateral volar plate, emerging at the central volar plate, and then passed through the edge of the previously divided accessory collateral ligament. The suture is tied with the goal of maintaining 10 degrees of PIPJ flexion.
- The other needled suture is then passed in a similar fashion on the other side and then tied with the PIPJ at about 20 to 30 degrees of flexion.
- Note that this procedure is technically difficult to perform and is not the

authors' preferred technique.



TECH FIG 5 • Retinacular ligament reconstruction for correction of swan-neck deformity. **A.** The ulnar lateral band is exposed at midproximal phalanx. **B.** The ulnar lateral band is passed volar to the Cleland ligament. **C.** The ulnar lateral band is sutured to the A2 pulley.

Correction of DIPJ Flexion Deformity (Type I to IV Deformities)

Dorsal Tenodermodesis of the DIPJ

- A transverse ellipse of skin is excised at the dorsal DIPJ.
- A 3-0 nylon horizontal mattress suture is placed through the skin and underlying extensor tendon in order to close the skin gap. With the DIPJ held in extension, the suture is tied.
- A K-wire is inserted obliquely through the extended DIPJ and is cut off beneath the skin.
- In general, this technique is not preferred because patients have thin skin and tend to experience complications.

DIPJ Arthrodesis

- An H- or Y-incision over the dorsal DIPJ is made to expose the extensor tendon.
- The extensor tendon and collateral ligaments are divided, allowing the joint to be hinged open.
- The joint surfaces are sculpted with a small bur, creating a “trough” distally and a “crest” proximally.
- The bone is fit together, and a compression screw is placed across the joint to support bony fusion. (See chapter on Degenerative Disease of the Hand and Wrist for details).

Correction of a Stiff Swan-Neck Deformity (Type III Deformity)

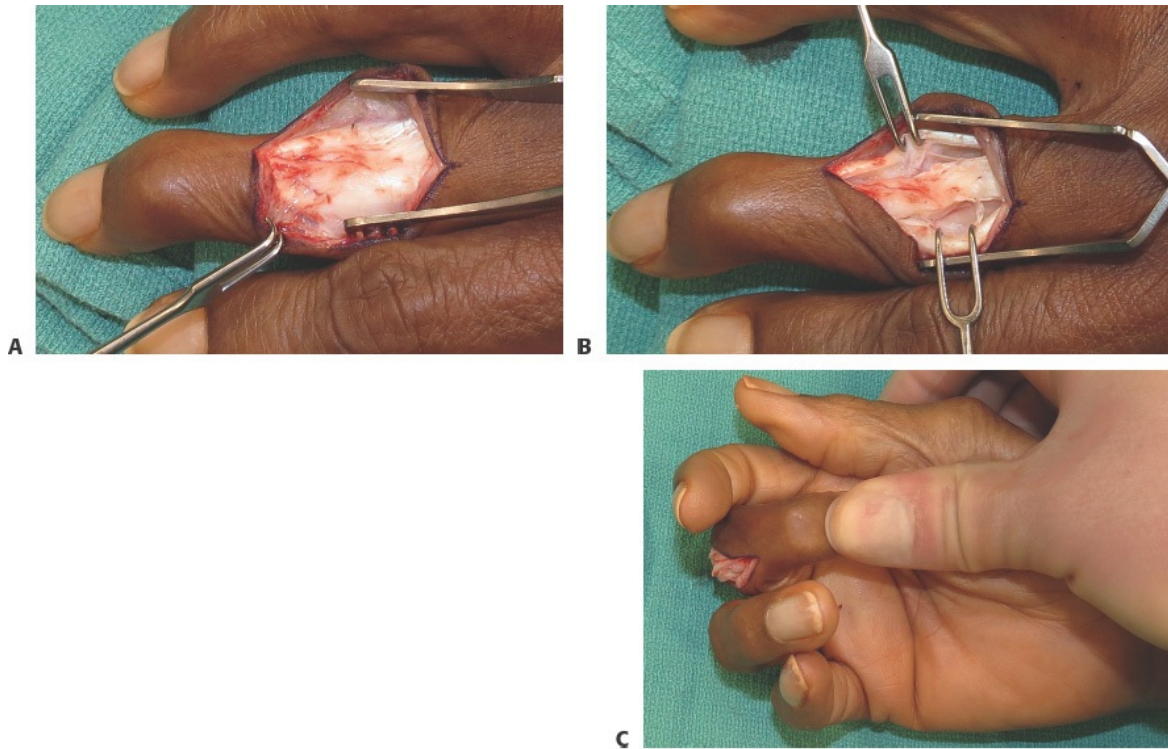
Lateral Band Mobilization

- A curved incision is made over the extensor apparatus overlying the proximal phalanx to the mid middle phalanx (**TECH FIG 6A**).
- The lateral bands are typically found to be dorsally displaced and adherent to the central slip, causing the extension contracture. The lateral bands are sharply dissected from the central slip (**TECH FIG 6B**), distal to proximal, preserving a wide central slip, particularly when the demarcation between the central slip and lateral bands is unclear.
 - A wider central slip can better resist accidental rupture during joint manipulation and is easier to lengthen.
- Next, the PIPJ is flexed to enable the lateral bands to move laterally and volarly (**TECH FIG 6C**).
 - If it is difficult to flex the PIPJ, the dorsal capsule and dorsal aspects of the collateral ligaments may need to be release.
 - Care must be taken to monitor the tension of the central slip during PIPJ manipulation to avoid rupture.

Step-Cut (Z) Central Slip Lengthening

- This procedure can be considered if the central slip continues to restrict PIPJ flexion after release of the lateral bands and attempted PIPJ manipulation. It is generally not necessary, however, because the central slip tends to stretch over time with therapy.
- A Z-incision of the central slip is made, starting 3 to 4 mm proximal to its insertion at the middle phalanx. It is extended 1 to 1.5 cm proximally.
- If not yet performed, the dorsal capsule and dorsal portions of the collateral ligaments are sharply released.

- With the PIPJ in slight flexion, the central slip is then repaired with at least three or four horizontal mattress sutures to prevent rupture during early mobilization.



TECH FIG 6 • Lateral band mobilization for correction of stiff swan-neck deformity. **A.** Exposure of extensor apparatus from proximal to mid middle phalanx. **B.** The lateral bands are identified and separated from the central slip. **C.** The PIPJ is flexed, allowing the lateral bands to fall volarly

■ Postoperative Care

- Active motion is initiated on the 2nd postoperative day.
- A dorsal extension block splint is applied for 2 weeks until the skin has healed. Then, a thermoplastic figure-eight splint is applied for an additional 8 weeks.
- After lateral band mobilization and manipulation of the PIPJ for a type III deformity, the PIPJ should be splinted in flexion in order to stretch the dorsal

soft tissue.

- Patients should continue active flexion exercises, except in cases in which central slip lengthening was also performed.

■ Ligament Reconstruction to Correct Boutonniere Deformity

- Once the patient is made comfortable with a wrist or digital block, a dorsally placed curved incision over the PIPJ is made to expose the extensor apparatus.
- The lateral bands and transverse retinacular ligaments are identified.
- The radial and ulnar transverse retinacular ligaments are sharply divided from their insertions on the volar plate of the PIPJ.
- The transverse retinacular ligaments are then turned over dorsally on either side of the PIPJ and sutured together.
 - Tension of the suture is determined by asking the patient to actively extend the PIPJ.
 - Tension should be set at the near-full extended position.
- Next, active flexion of the DIPJ must be checked. If DIPJ flexion is limited, small transverse cuts into the lateral bands to lengthen them between the PIPJ and DIPJ (overlying the distal half of the middle phalanx) should be made, until the DIPJ can be actively flexed to 30 degrees.
- The PIPJ is then immobilized in full extension with a K-wire for 2 weeks.

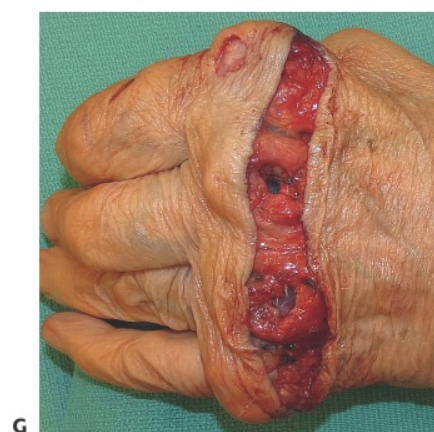
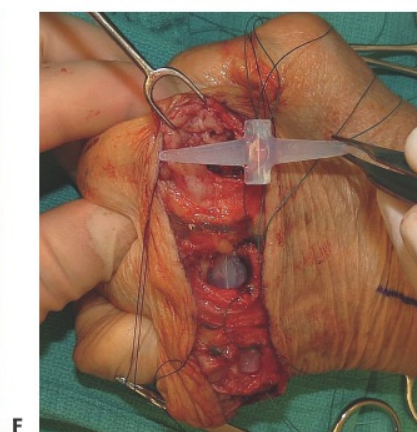
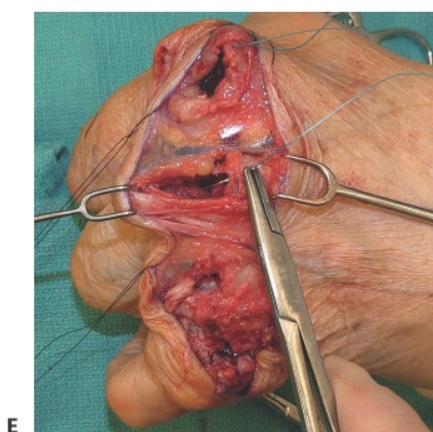
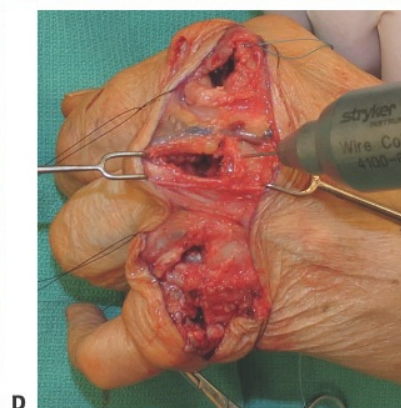
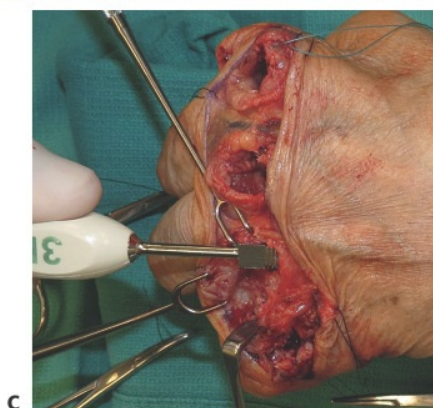
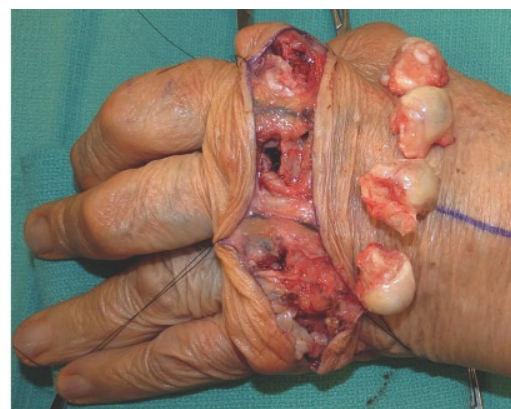
■ Postoperative Care

- Within 3 days of surgery, active DIPJ flexion exercises are initiated, while the PIPJ remains immobilized.
- At about 2 weeks, active PIPJ flexion exercises are begun, while active extension exercises should be avoided.
- To keep the PIPJ in full extension, a daytime dynamic splint and nighttime static splint should be provided.
- The splint is gradually weaned, and active finger exercises are slowly advanced under the guidance of a hand therapist.

■ Silicone Metacarpophalangeal Joint Arthroplasty

- The patient is positioned supine with the extremity abducted on a hand table.
- Under tourniquet control, a transverse incision is made over the heads of the second through fifth metacarpals, taking care to preserve the dorsal veins and sensory nerves (**TECH FIG 7A**).
- The radial sagittal bands are divided to expose the MCPJs. Synovectomy is performed sharply.
- The collateral ligaments are divided at the metacarpal neck, taking care to preserve the radial collateral ligament insertion on the proximal phalanges for later reconstruction.
- With an oscillating saw, the metacarpal heads are resected at the proximal origin of the collateral ligaments (**TECH FIG 7B**).
 - After metacarpal head resection, the fingers are brought into alignment.
 - Using a twisting motion, an awl is used to perforate the medullary cavities of the metacarpals and proximal phalanges (**TECH FIG 7C**).
- Next, sequentially sized broaches are used to enlarge the medullary cavities of the proximal phalanges first, then the metacarpals, since the size of the phalangeal cavity usually determines the implant size to be used.
 - The exception is the ring metacarpal, which is typically narrower than the ring finger proximal phalanx and should thus be prepared first to avoid over-reaming the proximal phalanx.
 - It is important that the broach is inserted straight without twisting, making a rectangular trough to accommodate the shape of the silicone implants.
- The largest implants that will fit into the medullary cavity are then selected.
- Prior to implant insertion, two drill holes are made with a 0.035-in. K-wire on the radial edge of the metacarpal (**TECH FIG 7D**)
 - 3-0 braided permanent sutures are placed through these drill holes to reconstruct the radial collateral ligaments (**TECH FIG 7E**).
- Next, the implants are inserted (**TECH FIG 7F**).
- The radially placed sutures are used to reattach the radial collateral ligament, bringing the fingers into slight radial deviation (**TECH FIG 7G**).
- If still tight, the ulnar lateral bands can be released, though this is usually not necessary.
- The position of the extensor tendons should be re-evaluated. If they cannot be centralized easily, the ulnar sagittal bands may also need to be released.

- Next, the extensor tendons are centralized by imbricating the radial sagittal bands with 3-0 braided horizontal mattress sutures.
- The tourniquet is released, and hemostasis is achieved.
- The skin is closed with absorbable dermal sutures followed by 4-0 horizontal mattress nylon sutures (**TECH FIG 7H**).
- A volar resting short-arm splint is applied.



TECH FIG 7 • Silicone metacarpophalangeal joint arthroplasty. **A.** A transverse incision is made over the metacarpal heads. **B.** The metacarpal heads are resected with an oscillating saw. **C.** An awl is used to perforate the medullary cavities of the metacarpals and proximal phalanges. **D.** Two drill holes are made on the radial edge of the metacarpal. **E.** Sutures are placed through the drill holes. **F.** The silicone implants are inserted. **G.** The sutures are tied down, thereby reconstructing the radial collateral ligament. **H.** Skin closure, improved alignment of fingers

■ Postoperative Care

- The patient is placed in a dynamic extension splint 1 week postoperatively.
 - While in the splint, the patient is to begin active flexion exercises for 6 weeks under the guidance of a hand therapist. The splint is adjusted as necessary to align the fingers.
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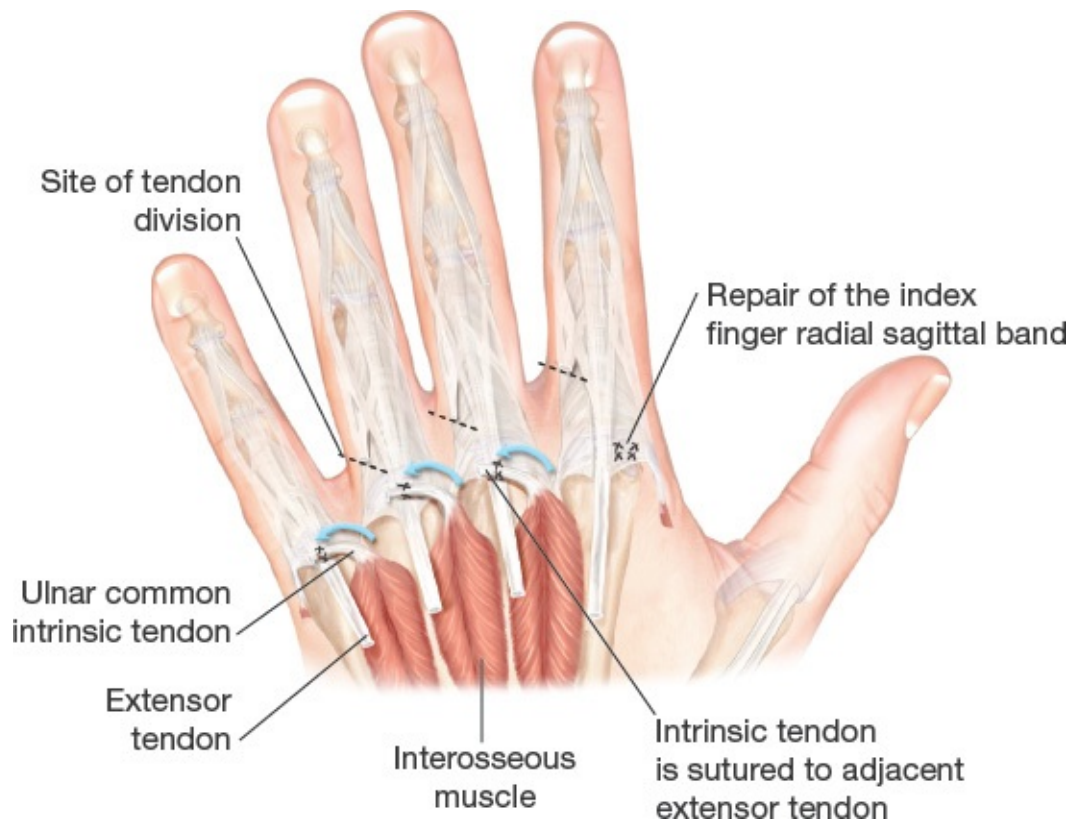
■ Crossed Intrinsic Transfer for Correction of Ulnar Deviation Deformity

Pertinent Anatomy

- The radial and ulnar sagittal bands stabilize the extensor tendon over the dorsal midline of the MCP joint (see **FIG 5A**). When the radial sagittal band is attenuated, the extensor tendon subluxes ulnarly, leading to ulnar deviation of the finger (see **FIG 5C**).
- On the ulnar side of the digit, the common intrinsic tendon is formed by the tendons of the palmar and dorsal interosseous muscles. On the radial side, the common intrinsic tendon is formed by the tendons of the interosseous muscles as well as the lumbrical.
- The common intrinsic tendon then passes volar to the MCP joint and divides into a medial band (which inserts into the central slip at the dorsal base of the middle phalanx) and a lateral band (which inserts at the dorsal base of the

distal phalanx).

- Thus, intrinsic muscle contraction results in MCP joint flexion and IP joint extension.
- In a cross intrinsic transfer, the common intrinsic tendon is divided distally (slanted lines) and sutured to the extensor tendon of the adjacent finger (**TECH FIG 8**).

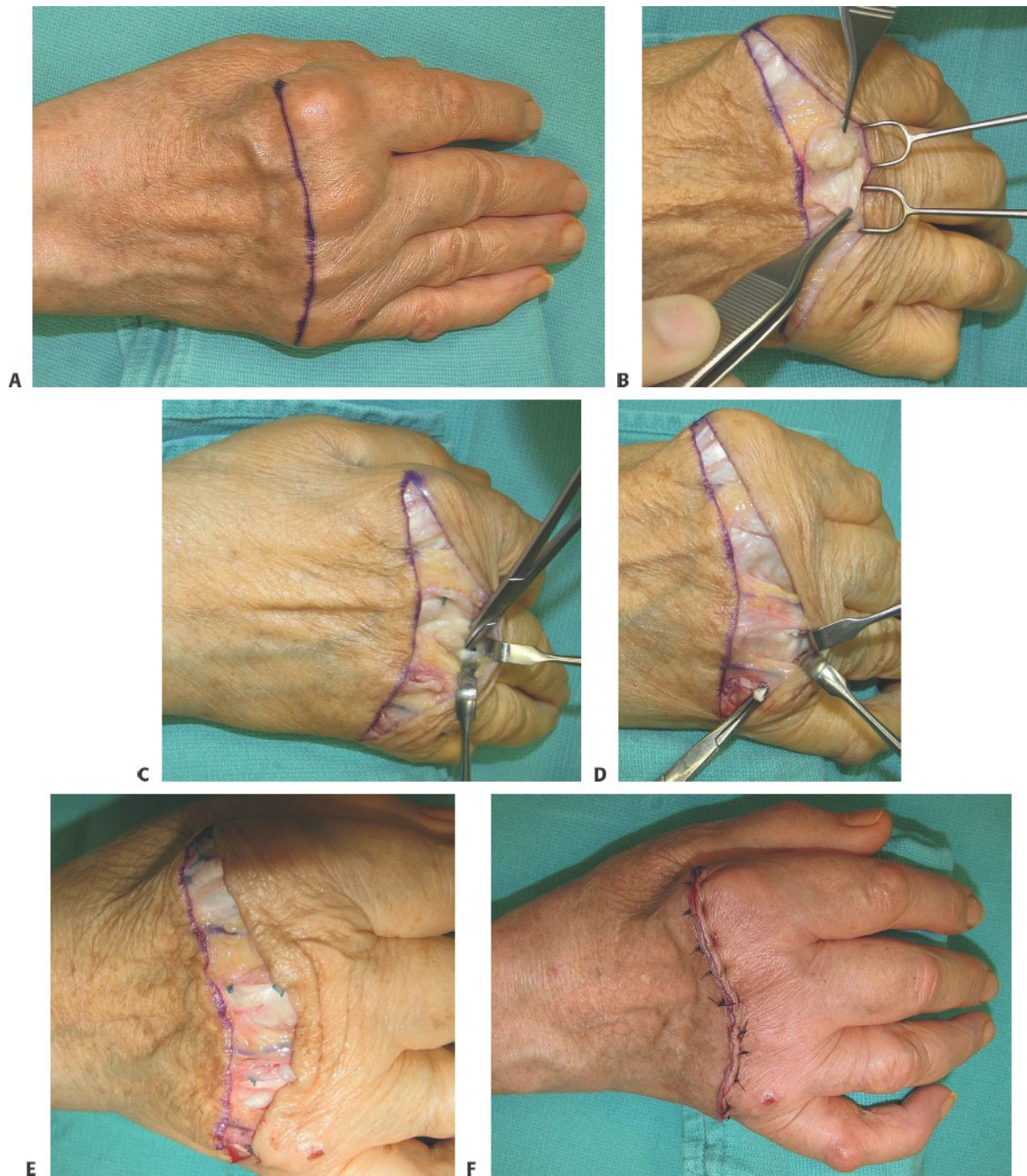


TECH FIG 8 • Cross intrinsic transfer for repair of the index finger radial sagittal band. The common intrinsic tendon is divided distally (*slanted lines*) and sutured to the extensor tendon of the adjacent finger (*arrows*).

■ Transfer Procedure

- Under tourniquet control, the extensor apparatus over the MCP joint is exposed through a lazy-S incision if only one finger is involved or through a dorsal transverse incision over the MCP joints if multiple fingers require correction (**TECH FIG 9A**).

- A longitudinal incision paralleling the extensor tendon is made through the attenuated radial sagittal band (**TECH FIG 9B**).
- The MCP joint is opened. A synovectomy is performed.
- On the ulnar side, the common intrinsic tendon is identified (**TECH FIG 9C**) and divided from its attachment to the extensor mechanism at the midproximal phalanx.
- The tendon is rerouted across the adjacent web space to reach the extensor tendon of the digit ulnar to it (**TECH FIG 9D**). It is then passed through a slit made at the midportion of the extensor tendon overlying the MCP joint and sutured to itself using 3-0 braided nonabsorbable suture.
 - Note that the ulnar common intrinsic tendon of the index finger is used to correct the long finger; the tendon of the long finger is used to correct the ring finger; and the tendon of the ring finger is used to correct the small finger.
- The index finger is then corrected by a double-breasted repair of the radial sagittal band (**TECH FIG 9E**).
- The skin is closed with simple interrupted horizontal mattress sutures (**TECH FIG 9F**).



TECH FIG 9 • **A.** Planned skin incision over the MCP joints. **B.** The attenuated radial sagittal band of the long finger is incised to access the MCP joint to facilitate synovectomy. **C.** The ulnar common intrinsic tendon of the long finger is identified. **D.** The ulnar common intrinsic tendon of the ring finger has been rerouted to the small finger to be sutured to the

extensor tendon. The intrinsic tendon is being held by the clamp in this photo. **E.** Final appearance of multiple cross intrinsic tendon transfers to the long, ring, and small fingers. A double-breasted repair of the radial sagittal band of the index finger is also shown. **F.** Skin closure.

■ Postoperative Care

- A volar hand splint is placed to support the reconstruction with the MCP joint in extension.
- At 10 days, a removable splint is placed.
- At 4 weeks, a gradual mobilization protocol is initiated with protective splinting for another 4 weeks.

PEARLS AND PITFALLS

TENDON TRANSFERS FOR TENDON RUPTURES

Extensor tendon exposure	■ Skin flaps are raised superficial to the extensor retinaculum, taking care to preserve the longitudinal dorsal veins (improves postoperative swelling) and superficial sensory nerve branches. ■ Skin must be handled as gently as possible, as skin quality and vascularity are already impaired by rheumatoid disease and/or medications.
Stair-step incision of extensor retinaculum	■ Facilitates closure of the extensor retinaculum at the end of the case, as swelling under retinaculum is common. ■ Can be useful to shield the extensor tendons from the radiocarpal joint in cases of bony erosion (half the retinaculum is placed under the extensor tendons, and the other half is used to close over them).
Treatment of combined ring and small finger extensor tendon ruptures	■ Treatment options include EIP transfer or end-to-side repair of the ring and small finger extensor tendons to the long finger extensor tendon. ■ EIP transfer is preferred due to the line of pull. ■ End-to-side repair to the long finger extensor tendon results in

	an oblique pull that can cause unwanted abduction of the small finger.
Transferring FDS tendons	■ For extensor tendon reconstruction, a subcutaneous transfer is preferred over a transfer through the interosseous membrane (high risk of adhesions). ■ A subcutaneous transfer on the radial side is preferred over the ulnar side, because the direction of pull helps to correct the ulnar deviation deformity.
Thumb interphalangeal joint (IPJ) fusion	■ Can be considered as long as the MCPJ is stable and functional and the strength of intrinsic muscles is adequate. If not, the patient will not achieve satisfactory pinch strength.
Darrach procedure	■ Defined as the resection of the head of the ulna. ■ May be required if the distal ulna is the source of tendon attrition and rupture. ■ If performed concomitantly with tendon reconstruction, a supination splint should be placed for 4 weeks postoperatively.
CORRECTION OF SWAN-NECK DEFORMITY	
Exposure	■ Avoid injury to the digital nerve at the tip of the flap where it is just beneath the skin by identifying the nerve at the base of the flap.
Dorsal DIPJ tenodesis	■ Generally, soft tissue reconstruction for DIPJ extension is discouraged, and arthrodesis is preferable. ■ However, tenodesis combined with DIPJ pinning for greater than 2 months can create a generally stiff DIPJ allowing for slight motion.
LIGAMENT RECONSTRUCTION TO CORRECT BOUTONNIERE DEFORMITY	
Preoperative management	■ Passive PIPJ mobility is critical to optimize surgical outcomes after correcting a boutonniere deformity. ■ If a severe PIPJ flexion contracture is present, rehabilitation and extension splinting should be performed prior to surgery.
Imaging	■ Radiographs are required to evaluate MCJP, PIPJ, and DIPJ status prior to surgery. PIPJ destruction indicates the need for arthrodesis or arthroplasty, as opposed to ligament reconstruction. ■ MRI may be helpful in identifying synovitis of the PIPJ but is expensive and not usually necessary to make the diagnosis.

Anesthesia: wrist or digital block	■ The surgery is done under a wrist or digital block such that the patient can perform active finger motion during the operation to allow for proper tension setting.
Tension setting	■ The transverse retinacular ligaments are sutured together at the dorsal aspect of the PIPJ when it is in near-full extension. ■ If set too tight, the tension may lead to extension contracture of the PIPJ and DIPJ.
PIPJ contracture	■ If a contracture exists at the PIPJ, the accessory collateral ligament and proximal volar plate should be released to obtain full passive PIPJ extension. ■ Care must be taken to preserve the true collateral ligaments to prevent PIPJ instability.
Achieving DIPJ flexion	■ In some cases, dividing the oblique retinacular ligament is necessary to obtain DIPJ flexion. ■ Avoid releasing the lateral bands too far, as this can result in DIPJ extension lag.
PIPJ synovectomy	■ For patients with active RA, PIPJ synovectomy is required.

SILICONE METACARPOPHALANGEAL JOINT ARTHROPLASTY

Surgical considerations	■ If the patient's fingers are ulnarly drifted without evidence of MCPJ dislocation, soft tissue reconstruction can be performed instead of SMPA. ■ A crossed intrinsic transfer may be performed to correct finger misalignment of the small, ring, and long fingers (see crossed intrinsic transfer for ulnar deviation technique below). ■ For the index finger, the radial sagittal band must be tightened to centralize the extensor tendon, given that there is no ulnar intrinsic tendon available for transfer. ■ Thumb MCPJ laxity is best treated with MCPJ fusion. ■ Patients with wrist collapse and radial deviation of the metacarpals should first have their wrists addressed by fusion or arthroplasty. Not only will this enhance the outcome of SMPA, but also it will prevent early postoperative ulnar subluxation of the fingers after SMPA.
Imaging	■ PA, lateral, and oblique radiographs of the hand and wrist are important in order to evaluate joint alignment, joint congruity, and bony erosions.

Metacarpal head resection

- Resection of the metacarpal heads decreases the tightness of the ulnar intrinsic tendons that contribute to ulnar deviation of the fingers. As such, ulnar lateral band release is usually not necessary.

Preparing the medullary canals for implant insertion

- The medullary canals of the proximal phalanges, which are typically narrower than those of the metacarpals, should be prepared first since they usually determine the implant size to be used.
- The exception to this rule is the ring finger. The ring metacarpal typically has a narrower canal than does the proximal phalanx and should therefore be prepared first to avoid over-reaming the proximal phalanx.

CROSSED INTRINSIC TRANSFER FOR CORRECTION OF ULNAR DEVIATION DEFORMITY

Indications

- The crossed intrinsic transfer may also be considered for lupus patients with ulnar deviation deformities, as they do not have underlying joint destruction.

Surgical tips

- Try to preserve longitudinal dorsal veins during surgical exposure to minimize postoperative swelling.
- Avoid dividing the common intrinsic tendon too proximally, as it may not reach the extensor tendon of the adjacent finger if too short.
- Take care to preserve the neurovascular bundle volar to the common intrinsic tendon.
- Division of the abductor digiti minimi for correction of a small finger ulnar deviation deformity may be necessary.
- A double-breasted repair of the radial sagittal band is facilitated by leaving a 2- to 3-mm cuff of the sagittal band when longitudinally incising it at the beginning of the case.

OUTCOMES

- Tendon transfers in patients with preserved MCPJs reliably achieve restoration of MCPJ extension. However, in patients with volarly subluxed and arthritic MCPJs, arthroplasty and soft tissue reconstruction to restore joint alignment prior to performing tendon transfers are critical for optimizing outcomes.
- In general, tendon transfers for extensor tendon reconstruction achieve good results, though more extension lag is observed when more tendons are involved. For flexor tendons, patients with isolated ruptures in the palm or

wrist have the potential to maintain good finger function, provided that their prerupture finger function was good. However, if preruptured function was limited, outcomes will be poor regardless of the treatment provided.

- Outcomes after the combined rupture of FDS and FDP are also poor, regardless of prerupture finger function or method of treatment.
- To optimize outcomes, correcting the underlying causes of tendon rupture, such as extensor tenosynovitis, rough bony surfaces, and the caput ulna deformity, is critical in preventing the rerupture of reconstructed tendons.
- For advanced swan-neck deformities, the results of surgery can be unpredictable. Still, even if motion is lost, the flexed PIPJ position is functionally preferable to the hyperextended position. As such, as long as PIPJ hyperextension is prevented, there should be no hesitation in performing surgery for advanced swan-neck deformities.
- Patients who undergo SMPA typically gain 30 to 40 degrees of active motion at the MCPJ. Grip strength and pinch strength are unaffected by surgery, while ulnar drift, extension lag, and arc of motion significantly improve (**FIG 11**).
- The crossed intrinsic transfer can provide long-term correction of ulnar deviation deformities but may be associated with decreased active ROM at the MCP joint.

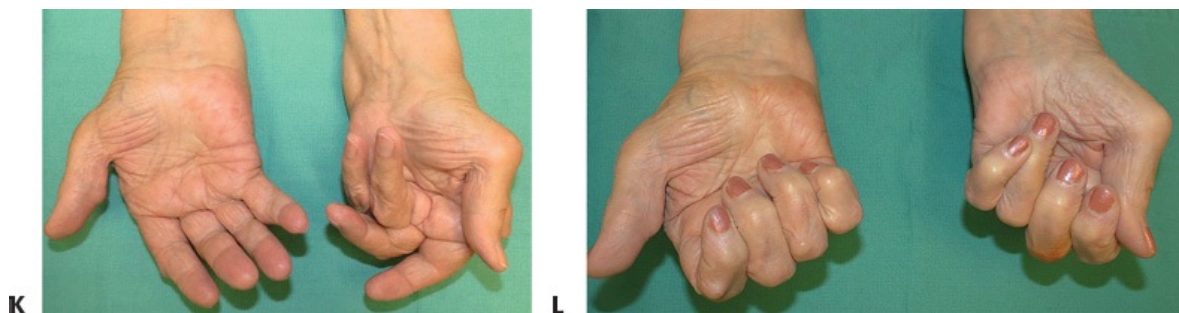
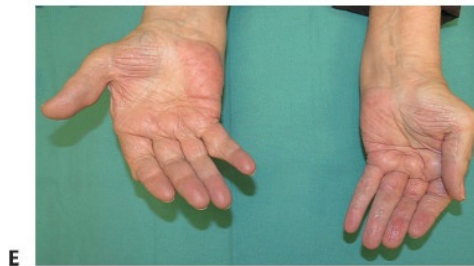


FIG 11 • Results 2 months (**A–F**) and 5 months (**G–L**) after silicone metacarpophalangeal joint arthroplasty.



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Section VII: Degenerative Disease

25 Degenerative Disease of the Hand and Wrist

CHAPTER

Shoshana W. Ambani and Kevin C. Chung

DEFINITION

- Osteoarthritis (OA) is a noninflammatory degenerative joint condition of the hand and wrist that clinically affects 3% to 7% of adults.¹
- The hallmark of OA is the loss of articular cartilage, leading to joint destruction and osteophyte formation (**FIG 1**).

PATIENT HISTORY AND GENERAL FINDINGS

- OA is more common in women and usually presents in patients over 40 years of age.
- Patients generally complain of pain, swelling, and stiffness of the affected joint. Pain is usually activity related.
- Examination confirms swelling, tenderness, limited range of motion (ROM), and decreased function. Crepitus with passive ROM may also be noted.
- Thumb carpometacarpal joint (CMCJ) arthritis often leads to thumb weakness due to pain.
- Examination may reveal a positive grind test, in which pain is produced upon axial compression of the joint.
- Regarding the fingers, patients may display classic Heberden nodes on the dorsal distal interphalangeal joints (DIPJs) or Bouchard nodes on the dorsal proximal interphalangeal joints (PIPJs) (**FIG 2A**).
- Mucous cysts can also present at the DIPJ and cause nail deformities (**FIG**

2B,C).

- Pain with loss of wrist ROM compared to the contralateral side is indicative of wrist arthritis.
- Provocative testing of the distal radioulnar joint (DRUJ) with dorsal and palmar stress (a shuck test) may indicate DRUJ involvement.

IMAGING

- Standard three-view radiographs of the hand and wrist are typically sufficient for evaluation of OA.
 - Further imaging such as CT scan or MRI is usually not routine but may be useful in select situations, such as evaluating the wrist for midcarpal arthritis.
- OA is characterized by narrowed joint spaces due to loss of radiolucent articular cartilage.
 - In addition, osteophytes and loose bodies may be present.
 - Subchondral cysts and sclerosis are signs of more advanced disease (see **FIG 1**).
- Patient symptoms do not always correlate with the radiographic severity of disease. As such, interventions should be based on patient complaints and general goals.

PATHOGENESIS AND ETIOLOGY

- In *primary*, or *idiopathic*, OA, there is no identifiable cause.
 - In *secondary* OA, articular loss is a result of traumatic injury, such as intra-articular fractures, ligamentous injuries that lead to unfavorable articular load-bearing characteristics, or joint infections.
- Generally, OA develops as a result of an imbalance between the destruction and repair of articular cartilage.

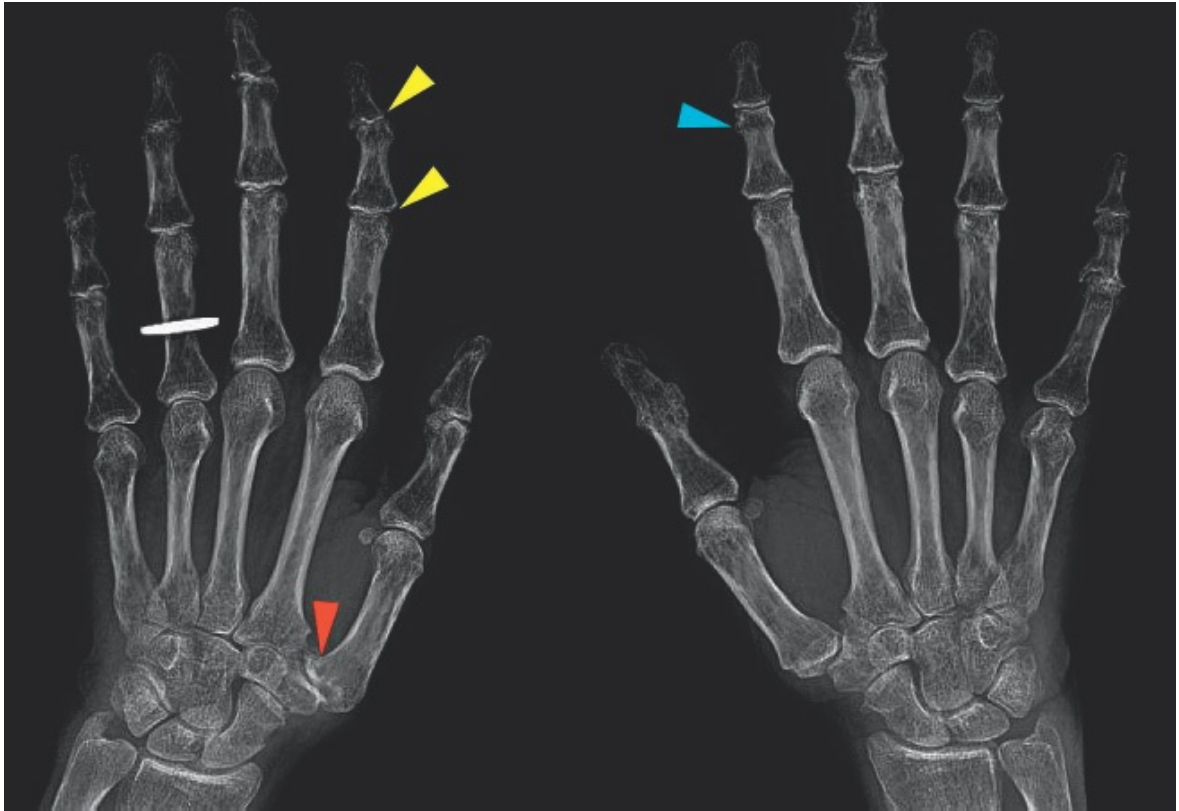


FIG 1 • Radiograph of bilateral hands displays typical characteristics of osteoarthritis, including joint space narrowing (*yellow arrowheads*), osteophyte formation (*blue arrowhead*), and subchondral cyst and associated sclerosis (*red arrowhead*).

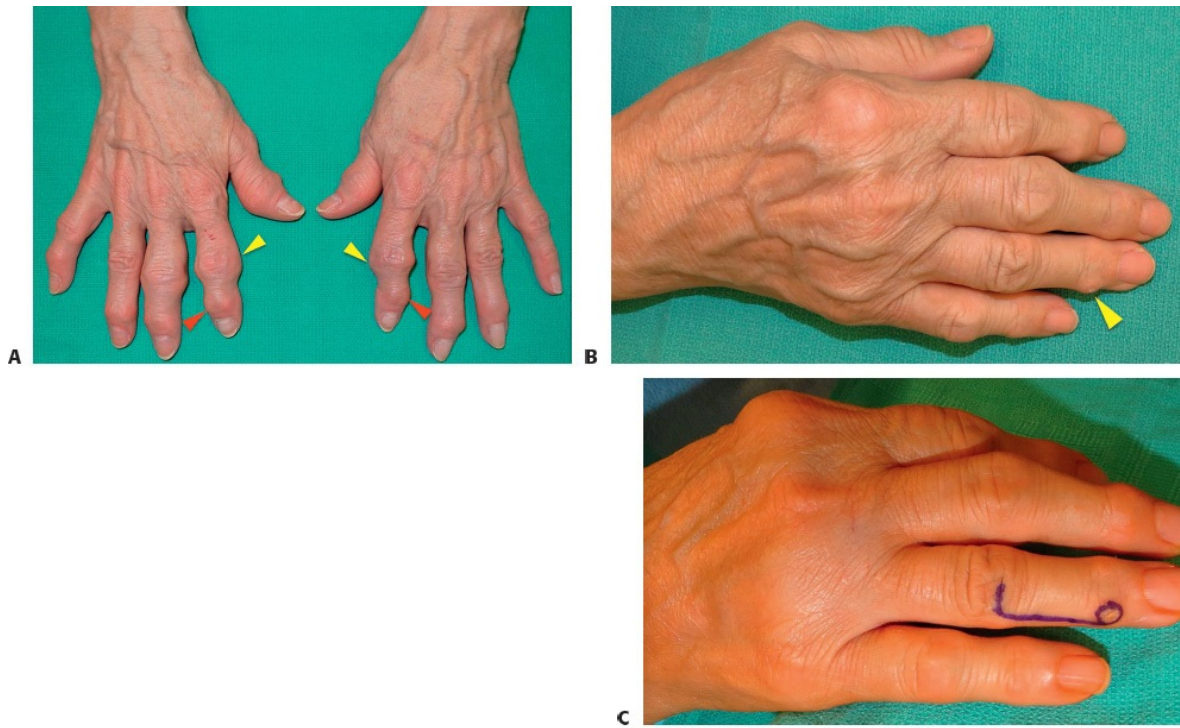


FIG 2 • A. Example of Heberden nodes (*red arrowheads*) and Bouchard nodes (*yellow arrowheads*). **B.** Mucous cyst on dorsal DIPJ of ring finger (*arrowhead*). **C.** A circular incision was used to excise the cyst down to the joint. An osteophyte was removed at the base of the cyst. A skin flap (*marked*) was advanced to close the remaining defect.

- Clefts in the articular surface and a decrease in cartilage thickness eventually progress to exposure of the subchondral bone.
- Bone density increases, as demonstrated by sclerotic changes seen on radiographs, and overly exuberant bone formation may produce osteophytes at the joint periphery. In addition, the synovial membranes become inflamed as cartilage fragments are embedded within them.
- Because of these mechanical factors and pain, joint motion is progressively lost, leading to joint stiffness as the capsule and associated ligaments contract.
- Hand
 - In the hand, OA most commonly affects the DIPJs of the fingers and the CMCJ of the thumb.

- OA then affects the PIPJs and metacarpophalangeal joints (MCPJs), respectively.
- Wrist
 - Scaphotrapezotrapezoid (STT) joint arthritis is one of the most common presentations of idiopathic OA of the wrist.
 - Other causes of primary wrist OA include avascular necrosis of the lunate (Kienbock disease) or the scaphoid (Preiser disease), which can lead to degenerative changes later on.
 - Congenital conditions, including Madelung deformity, can also alter the articular load, leading to wrist OA.
 - Secondary OA is usually trauma related and most frequently develops after distal radius fractures (DRFs), scaphoid fractures, and scapholunate ligamentous injuries.
 - Intra-articular DRFs can lead to a 91% incidence of arthritis if any degree of articular step-off remains after fracture reduction, but only an 11% incidence if a congruent articular reduction is achieved.
 - Extra-articular DRFs can also lead to wrist OA due to the development of abnormal load-bearing patterns across the wrist.
 - Up to 11% of DRFs are associated with instability of the DRUJ, leading to DRUJ arthritis.²
 - Of note, rheumatoid arthritis is the most common inflammatory arthritis to involve the DRUJ.
 - Scaphoid fractures may fail to heal in 5% to 10% of cases, leading to a pattern of carpal instability termed *scaphoid nonunion advanced collapse* (SNAC) arthritis.
 - SNAC wrist typically starts with arthritis at the radial styloid-scaphoid articulation (stage 1) and progresses to the radioscaphoid and scaphocapitate articulations (stage 2) and finally the lunocapitate articulation (stage 3).
 - Similarly, a scapholunate ligament injury can initiate progressive carpal instability and arthritis starting at the radial styloid (stage 1) and progressing to the proximal scaphoid and scaphoid fossa of the radius (stage 2) and finally the midcarpal joint at the lunocapitate articulation (stage 3).
 - This is cumulatively known as *scapholunate advanced collapse* (SLAC) arthritis.
 - The radiolunate joint is typically spared in the SLAC wrist because of the unique congruency of this joint.

NONOPERATIVE MANAGEMENT

- Because there is no cure for OA and no effective method to alter disease progression, the mainstay of treatment is nonoperative and focuses on symptom management.
- Patients may engage in lifestyle modifications, hot and cold therapy, splinting, oral or topical anti-inflammatory medications such as nonsteroidal anti-inflammatory drugs (NSAIDs), or alternative methods such as acupuncture or electrostimulation.
- Steroid injections into the affected joints may provide short-term relief.

SURGICAL MANAGEMENT

Preoperative Planning

- As OA patients are typically older with multiple comorbid conditions, a full medical workup is recommended prior to surgery.

Positioning

- The patient is positioned supine on the operative table and padded comfortably.
- The upper extremity is abducted onto the attached hand table.
- A tourniquet is placed on the upper arm.

Approach

- The indications for surgery in OA patients include refractory pain, loss of motion, and/or joint instability leading to decreased function.
- Surgical methods for the treatment of OA generally involve joint debridement, arthrodesis, arthroplasty, and load-altering procedures.

Fingers

- Because the DIPJs are the most commonly affected joints in OA, surgery typically involves the removal of an enlarged osteophyte and/or excision of a mucous cyst.
 - If the joint is destroyed, arthrodesis at about 5 to 10 degrees of flexion is preferred.
- The PIPJs are treated with arthrodesis or arthroplasty.
- For the radial digits, arthrodesis of the PIPJs with K-wires, screws, or tension banding is preferred in order to provide a strong post for pinch.

- The PIPJ of the index finger should be fused at 25 degrees of flexion, advancing by 5 degrees with each finger ulnarly, if required, for the most functional posture.
- The PIPJs of the ulnar digits require more motion for grip, however, and should be considered for arthroplasty.
 - Silicone arthroplasty provides limited motion to the PIPJs (30–60 degrees) and has a high fracture rate but can easily be revised.
 - Pyrocarbon implants provide greater motion, but implant dislocation may occur, and high complication rates have led to this approach falling out of favor for PIPJs.
 - We have abandoned the pyrocarbon implant in favor of the silicone implant using the volar approach for the PIPJ.

Thumb

- As the second most commonly affected joint in OA, the thumb CMCJ (ie, the trapeziometacarpal [TM] joint) is surgically treated with volar ligament reconstruction, arthroplasty, or arthrodesis.
 - Although the initial treatment may consist of splinting or steroid injections, most patients presenting to surgeons already have sufficient joint destruction to warrant surgery.
- The Eaton classification^{3,4} (Table 1) of TM osteoarthritis describes and categorizes the radiographic progression of the disease. However, surgical planning is based on patient symptoms and complaints, not Eaton classification.
- For early OA (Eaton stage I), which may be characterized symptomatic instability or laxity of the thumb TM joint, volar ligament reconstruction is indicated (Eaton-Littler procedure).
- For Eaton stage II to IV disease, loss of articular cartilage precludes the possibility of joint salvage. Surgical options fall into four major categories:

Table 1 Eaton Classification of Trapeziometacarpal (TM) Osteoarthritis^{3,4}

Stage	Radiographic Characteristics
I	• Normal or slightly widened TM joint • TM subluxation up to 1/3 of articular surface • Normal articular contours
II	

	• Decreased TM joint space • TM subluxation up to 1/3 of articular surface • Osteophytes or loose bodies less than 2 mm
III	• Decreased TM joint space • TM subluxation greater than 1/3 of articular surface • Osteophytes or loose bodies greater than or equal to 2 mm • Subchondral cysts or sclerosis
IV	• Pantrapezial arthritis with stage III features • Involvement of the scaphotrapezial, trapeziotrapezoid, and/or the trapezio-index metacarpal joints

- Trapeziectomy alone
- Trapeziectomy with soft tissue arthroplasty via ligament reconstruction and tendon interposition (LRTI) or an abductor pollicis longus (APL) suspensionplasty
- Arthrodesis
- Prosthetic arthroplasty
- Because of high complication rates with prostheses and lack of outcomes data to show their effectiveness over autologous options, we do not advocate the use of a prosthesis for the thumb TM joint.
- For heavy laborers, thumb TM arthrodesis is preferred for joint stability and strength.⁵ In these cases, the thumb TM joint should be fused at 30 to 40 degrees of abduction, 15 to 20 degrees of extension, and 15 degrees of pronation to allow tip-to-tip pinch.
- In any case, the presence of thumb MCPJ instability or hyperextension greater than 30 to 45 degrees may also warrant concomitant volar plate advancement or MCPJ fusion to avoid failure of the reconstructed TM joint.

Wrist

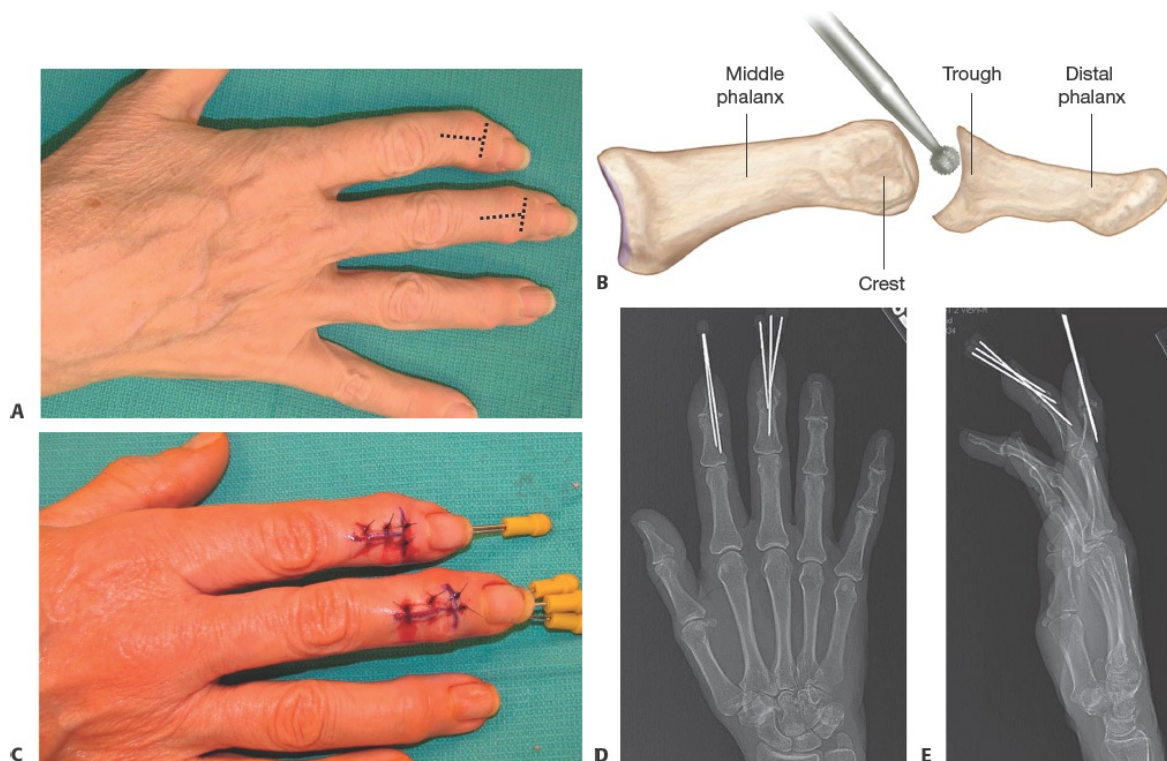
- Surgical treatment of wrist OA is focused on pain reduction. The specific treatment is formulated based on the patient's symptoms, arthritic pattern, and functional demands.
- The selected approach should always account for future additional procedures should the most current option fail.
- In general, surgical options include joint debridement, denervation, arthroplasty, partial vs total wrist arthrodesis, or a combination thereof.

- A radial styloidectomy can be performed for arthritis at the radial styloid.
- Wrist denervation is an option that has been shown to provide partial pain relief in patients and can be considered if selective blocks of the anterior interosseous nerve (AIN) and posterior interosseous nerve (PIN) prove favorable.
- A proximal row carpectomy (PRC), in which the scaphoid, lunate, and triquetrum are removed, is an option when there is no arthritis at the midcarpal joint or radiolunate joint.
- Midcarpal and radiocarpal arthritis can be treated with a scaphoidectomy and four-corner fusion, in which the scaphoid is removed and fusion of the lunate, capitate, triquetrum, and hamate is performed.
- For the arthritic DRUJ, surgical options include resection arthroplasties, including the Darrach procedure, hemiresection ulnar arthroplasty, the Sauve-Kapandji procedure, and prosthetic replacement of the ulnar head or DRUJ.²
 - The Darrach procedure involves resection of the entire distal ulna and has been advocated for low-demand elderly patients.
 - The Sauve-Kapandji procedure preserves the head of the ulna while fusing the DRUJ to prevent ulnar translocation of the carpus.
 - Hemiresection ulnar arthroplasty, in which the radiocarpal joint surface of the ulna is resected while maintaining the triangular fibrocartilage complex (TFCC), is often preferred over the Darrach procedure because of improved postoperative wrist stability. Prosthetic replacement of the ulnar head or DRUJ is a less common option for the arthritic DRUJ.
- In cases of significantly advanced arthritis, wrist arthroplasty or fusion may be the only remaining surgical options.
 - Wrist arthroplasty provides motion at the expense of strength and is considered only in select patients with low-demand wrists or who have fusion of the contralateral wrist. Patients with OA tend to fit this profile, as opposed to those with OA.
 - Total wrist fusion is the ultimate salvage option for all types of wrist arthritis, achieving both pain relief and strength.

TECHNIQUES

■ Distal Interphalangeal Joint Arthrodesis

- The distal interphalangeal joint (DIPJ) is exposed dorsally with a T-shaped incision (**TECH FIG 1A**).
- The extensor tendon is transversely divided, leaving a 5-mm distal stump for later repair.
- The radial and ulnar collateral ligaments are divided, allowing the joint to hinge open.
- Joint debridement is performed using a small rongeur, removing inflamed capsule, ganglions, osteophytes, and residual cartilage.
- A rongeur is used to fashion a concave “trough” at the base of the distal phalanx and a convex “crest” at the head of the middle phalanx until the surfaces align (**TECH FIG 1B**).
- With the joint reduced and compressed at 5 to 10 degrees of flexion, a K-wire is driven through the joint from distal to proximal in a retrograde fashion.
 - A second K-wire is inserted to prevent rotation.
 - The angle is checked with fluoroscopy.
 - A third K-wire may be inserted for further stabilization.
- The extensor tendon is then repaired with a 5-0 absorbable suture, and the skin is closed with interrupted nonabsorbable suture (**TECH FIG 1C**).
 - Soft bulky dressings are applied.
 - The fused joint is supported in a splint for about 6 to 8 weeks until radiographs show bony union (**TECH FIG 1D,E**).
 - At that point, strengthening exercises may be initiated.



TECH FIG 1 • **A.** Skin incision. **B.** Bur is used to create a crest and trough. **C.** Skin closure with K-wires in place. **D,E.** Postoperative radiographs show K-wires in place, fusing the DIPJs of the index and long fingers.

■ Volar Approach to Proximal Interphalangeal Joint Arthroplasty

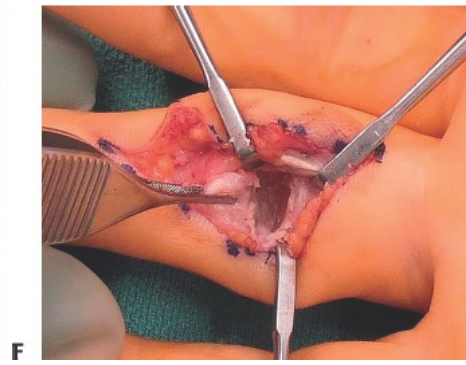
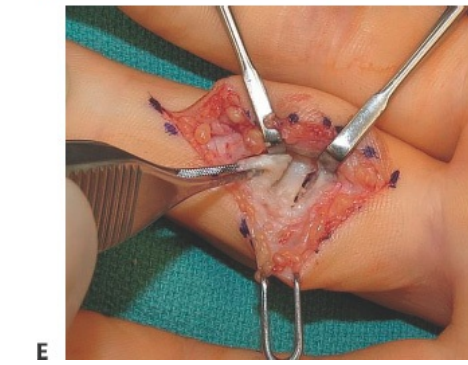
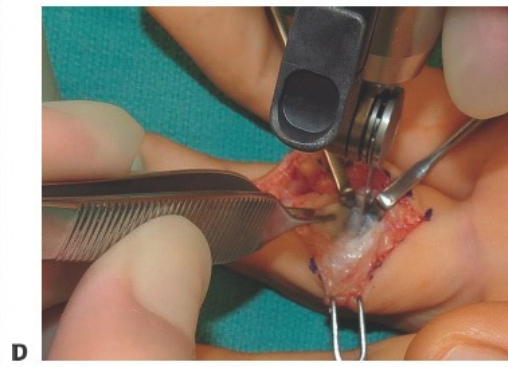
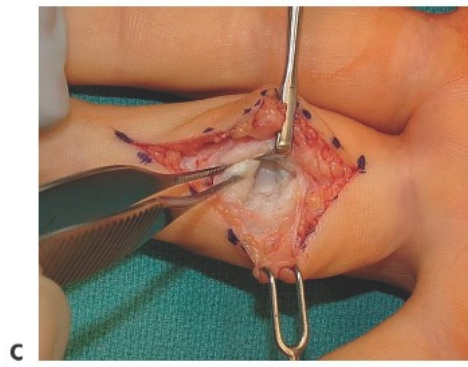
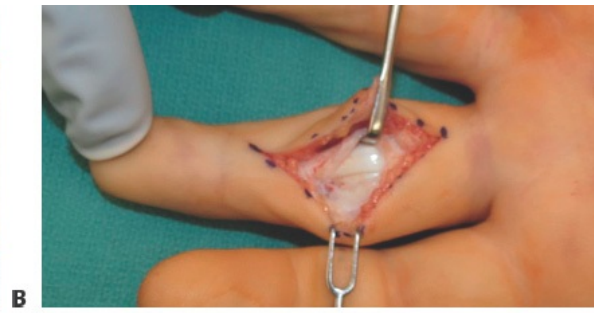
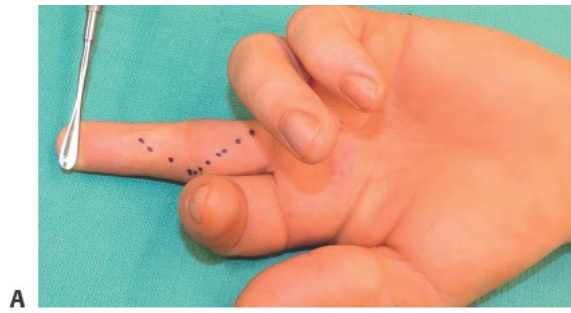
Silicone Implant

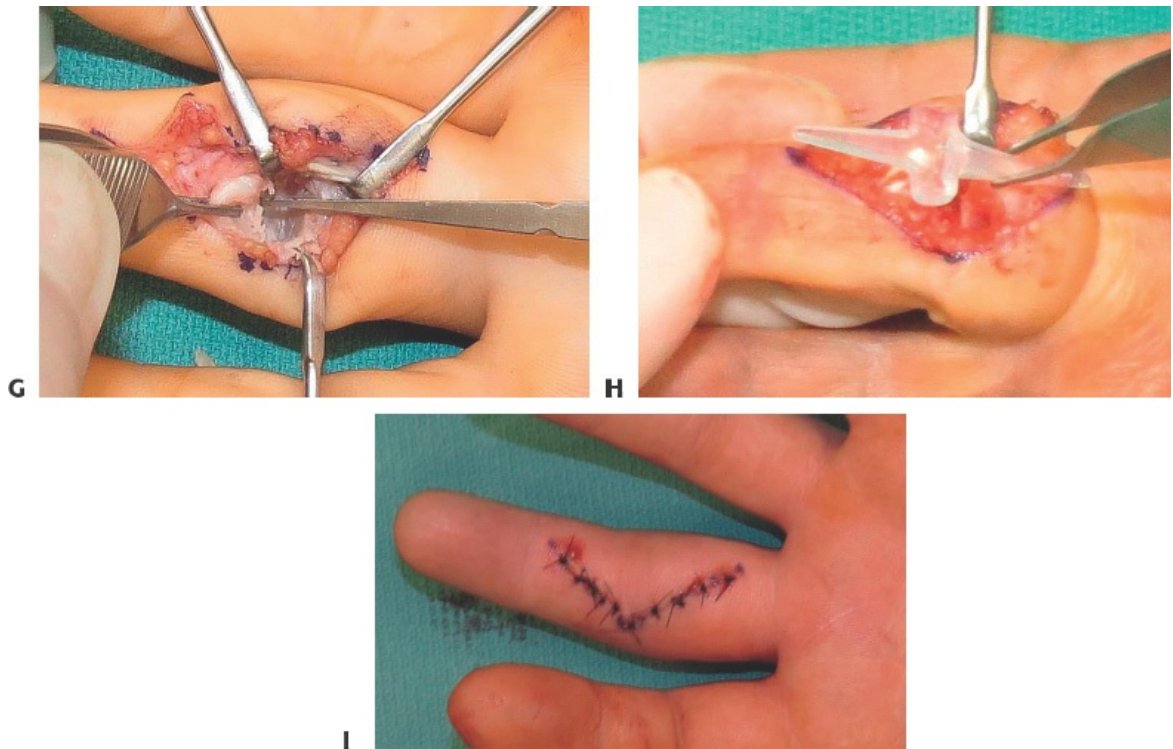
- Patients who do not want proximal interphalangeal joint (PIPJ) fusion for their osteoarthritic pain may consider silicone PIPJ arthroplasty with the understanding that a limited range of motion of 30 to 60 degrees is expected postoperatively.
- Important prerequisites to PIPJ arthroplasty include good bone quality for implant insertion, supple soft tissue coverage, adequate finger sensibility and blood flow, and normal tendon gliding. The best candidate for surgery is a patient with painful PIPJ motion but good stability and normal tendon function.

- We prefer using silicone over pyrocarbon implants given the lower complication rate and the ability to revise the joint more easily if complications arise.
- A V incision over the volar PIPJ is made (**TECH FIG 2A**).
 - Skin flaps are elevated, identifying and preserving the ulnar and radial neurovascular bundles (**TECH FIG 2B**).
 - The A3 pulley is incised and elevated. The flexor tendons are retracted volarly.
 - The volar plate is then incised proximally to expose the arthritic head of the proximal phalanx (**TECH FIG 2C**).
- The head of the proximal phalanx and the base of middle phalanx are excised with an oscillating saw (**TECH FIG 2D–F**).
- The medullary cavity is broached and reamed (**TECH FIG 2G**).
- An appropriately sized implant is then placed (**TECH FIG 2H**).
- Motion at the joint is checked.
- The volar plate is reattached using 4-0 absorbable braided suture.
- The A3 pulley is repaired.
- After skin closure (**TECH FIG 2I**), the hand is placed in a volar splint.
- The patient is seen in the clinic 3 or 4 days after surgery to initiate gentle active range of motion exercises at the PIPJ.
- Splint protection is maintained for approximately 3 weeks to preserve joint alignment and encourage joint encapsulation for additional stability.

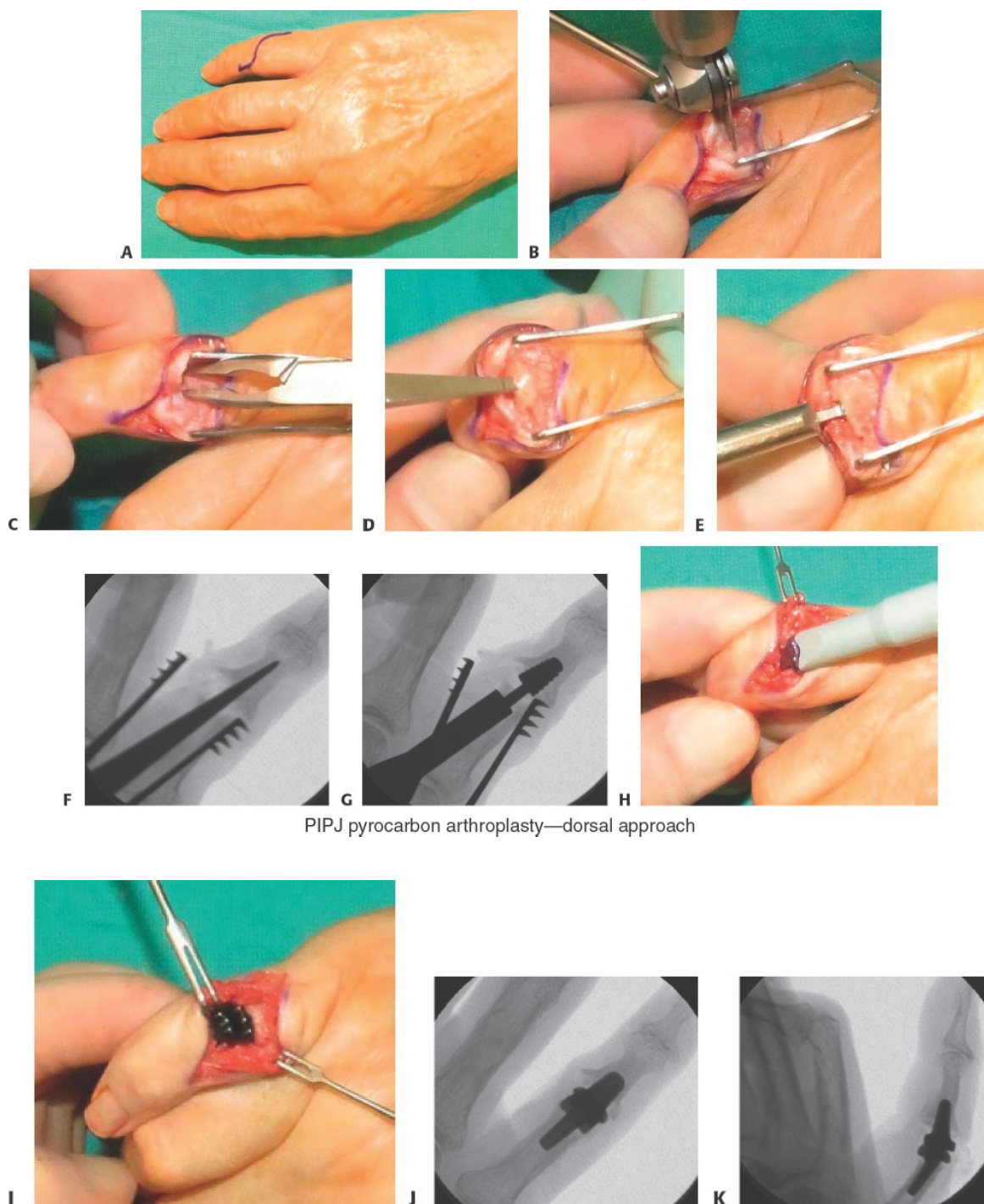
Pyrocarbon Implant

- Steps for PIPJ pyrocarbon arthroplasty through a dorsal incision are shown in **TECH FIG 3**.





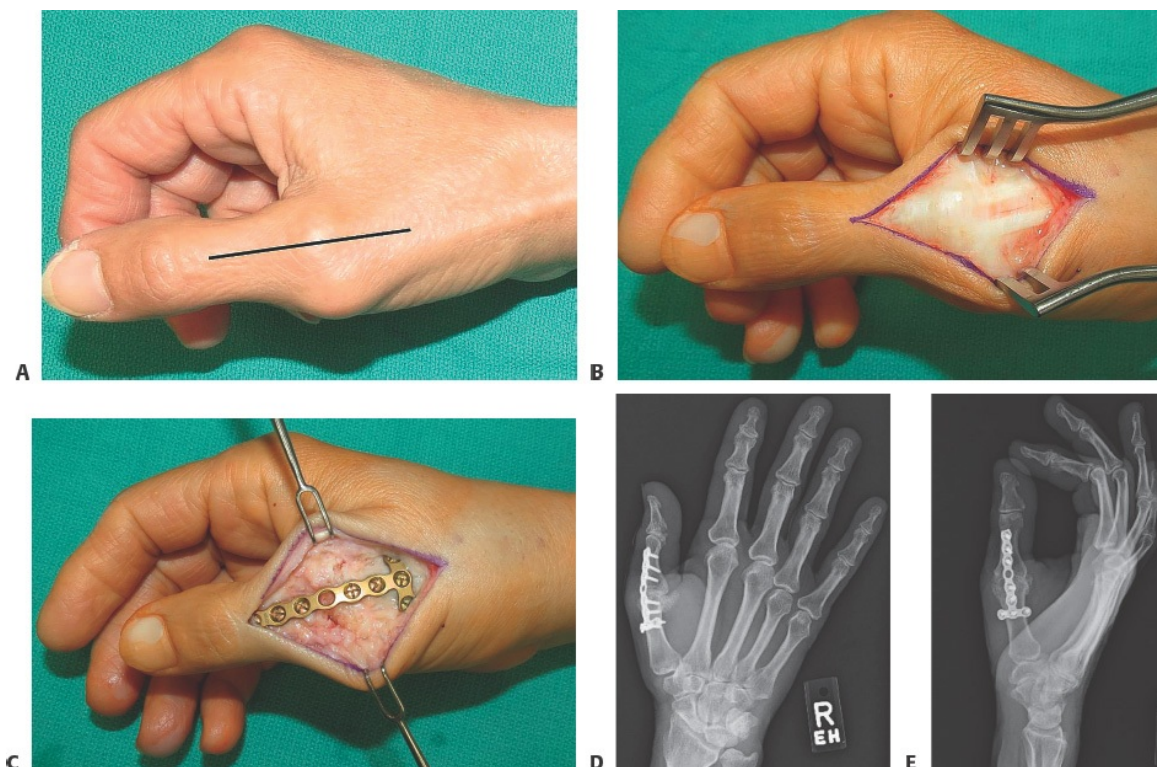
TECH FIG 2 • PIPJ silicone arthroplasty—volar approach. **A.** A V incision. **B.** Skin flap elevation. **C.** Exposure of the arthritic head of the proximal phalanx. **D–F.** Excision of head of proximal phalanx and base of middle phalanx with oscillating saw. **G.** The medullary cavity is broached and reamed. **H.** Placement of implant. **I.** Skin closure.



TECH FIG 3 • **A.** Incision. **B,C.** Excision of head of proximal phalanx and base of middle phalanx. **D,E.** Medullary cavity of proximal phalanx is broached. **F,G.** Fluoroscopy. **H,I.** Implant is seated into the medullary cavity. **J,K.** Fluoroscopy.

■ Thumb Metacarpophalangeal Joint Fusion for Osteoarthritis

- Patients with instability and pain at the thumb metacarpophalangeal joint (MCPJ) due to osteoarthritis are candidates for arthrodesis.
- A plate is used to achieve long-lasting joint stability for patient comfort.
- A 4-cm incision over the dorsum of the thumb MCPJ is made (**TECH FIG 4A**).
 - The interval between the extensor pollicis longus (EPL) and the extensor pollicis brevis (EPB) tendons is entered (**TECH FIG 4B**).
 - The joint capsule is incised to expose the joint.
- The articular surfaces are removed with a rongeur.
- A low-profile T-plate is selected and bent to fit the MCPJ with about 30 degrees of flexion.
- As the bony surfaces are compressed, the T-plate is fixed to the plate with screws (**TECH FIG 4C**).
 - Fluoroscopy is used to check hardware placement.
- The capsule is closed with 4-0 absorbable suture, and the skin is closed with 4-0 nonabsorbable suture.
- A thumb spica splint is placed.
- The patient is immobilized for 6 to 8 weeks or until radiographic union occurs (**TECH FIG 4D,E**).
 - At 2 weeks, the patient can start engaging in light activities of daily living while wearing the splint.

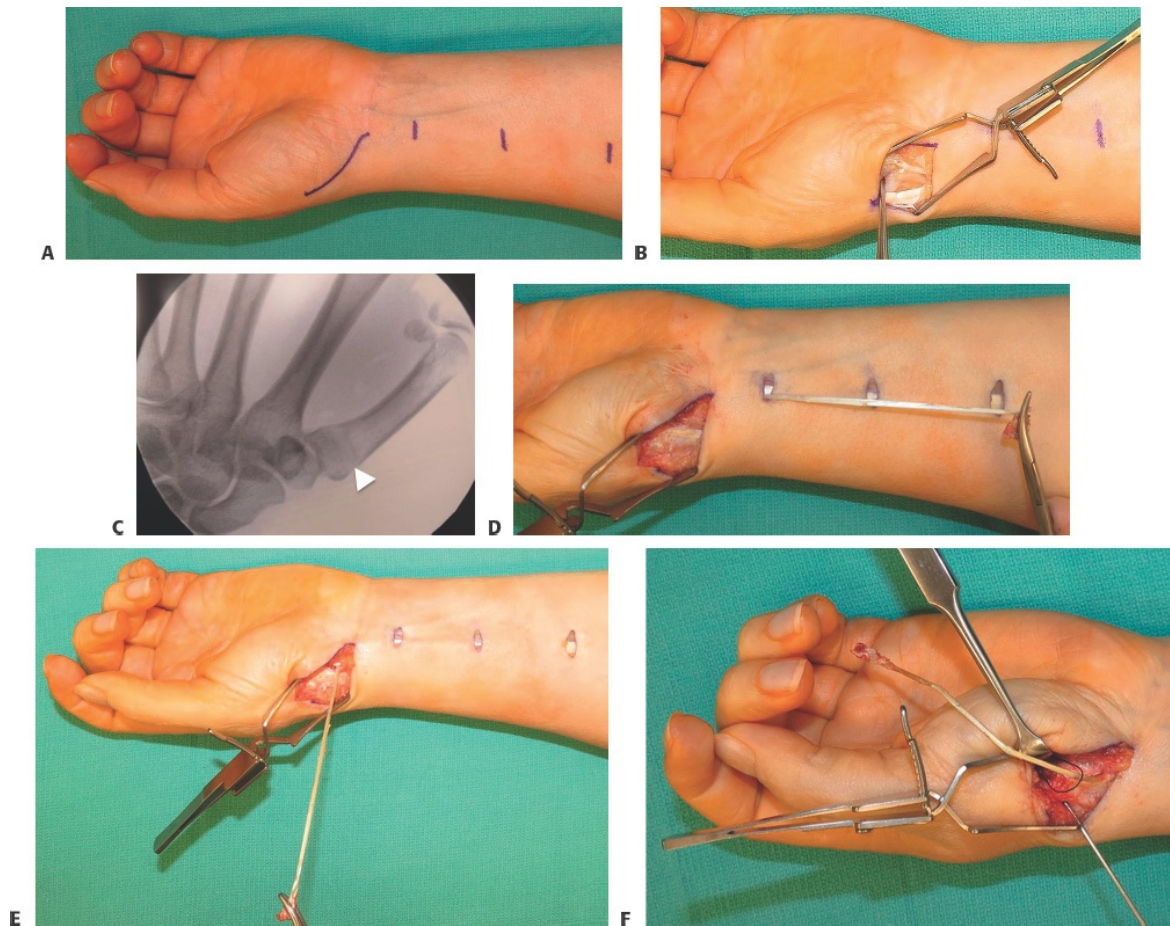


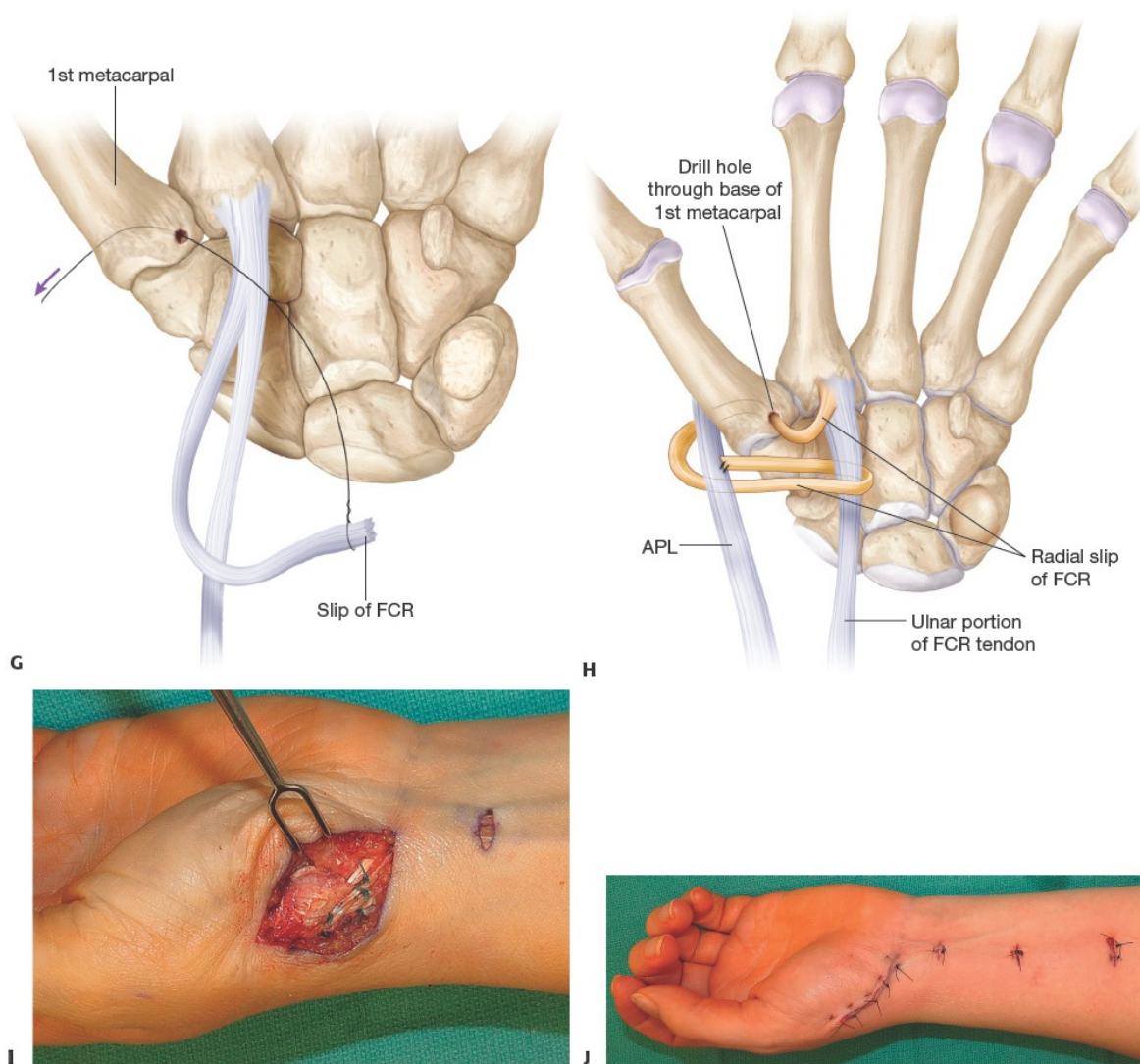
TECH FIG 4 • Joint fusion for thumb MCPJ instability. **A.** Skin incision. **B.** Interval between EPL and EPB. **C.** Plate placement. **D.** Radiograph of fused MCPJ (AP view). **E.** Radiograph of fused MCPJ (lateral view).

■ Reconstruction for Thumb Trapeziometacarpal Instability Using Flexor Carpi Radialis: Eaton-Littler Procedure

- The Eaton-Littler procedure is reserved for thumb trapeziometacarpal (TM) instability in the setting of intact articular surfaces.
- A modified Wagner incision is made at the junction of glabrous and nonglabrous skin along the border of the thenar eminence (**TECH FIG 5A**).
 - The radial edge of the thenar musculature at its insertion on the metacarpal is identified and elevated to expose the metacarpal base and trapezium (**TECH FIG 5B**).
 - The dorsal cortex of the metacarpal base is further exposed through the interval between the EPL and EPB.

- Using a small bur, a hole is made at the base of the metacarpal, from dorsal to volar, starting at about 1 cm from the joint in a plane perpendicular to the axis of the thumbnail (**TECH FIG 5C**).
- The exit site should be at the apex of the volar beak of the metacarpal.
- For harvest of the flexor carpi radialis (FCR), short transverse incisions centered over the tendon are made at 2- to 3-cm intervals proximal to the volar wrist crease.
- The FCR sheath is entered through these incisions to isolate the radial half of FCR, which is transected at about 6 cm proximal to the wrist crease and separated longitudinally from the other half of the tendon (**TECH FIG 5D**).
- At the wrist crease, the FCR slip is traced to its insertion at the base of the index metacarpal.
- The free end of the FCR is brought out through the thenar incision (**TECH FIG 5E**).





TECH FIG 5 • Reconstruction for thumb trapeziometacarpal instability using FCR (Eaton-Littler). **A.** Skin incision. **B.** The trapeziometacarpal joint is exposed. **C.** A hole is drilled through first metacarpal base (*arrow*). **D.** Harvest of radial half of FCR. **E.** The FCR slip is traced to its insertion at the base of the index metacarpal and brought out the thenar incisions. **F,G.** The tendon is directed through the hole at the base of the first metacarpal, from volar to dorsal, using a wire-loop tendon passer. **H.** The FCR is passed through the first metacarpal. **I.** Final

reconstruction. **J. Skin closure.**

- Using a wire-loop tendon passer, the tendon is directed through the hole at the base of the thumb metacarpal, from volar to dorsal (**TECH FIG 5F,G**).
- Under direct vision, the joint is reduced and held in extension and abduction, seating the metacarpal well against the trapezium.
- The tendon is pulled taut and sutured to the dorsal periosteum with a 3-0 braided nonabsorbable suture.
- The tendon is then passed around the metacarpal base, deep to EPB and abductor pollicis longus (APL), through a small spit in the intact FCR tendon proximal to its insertion, and finally back across the joint and sutured to the APL tendon (**TECH FIG 5H,I**).
- Additional sutures are placed at the junction through the FCR tendon.
- The thenar musculature is reattached using 3-0 braided absorbable suture.
 - The skin is closed with 4-0 nylon horizontal mattress sutures (**TECH FIG 5J**).
- A thumb spica splint is placed and worn for 4 weeks, at which point gentle active ROM exercises are initiated.
 - At 8 weeks, strengthening exercises are begun.

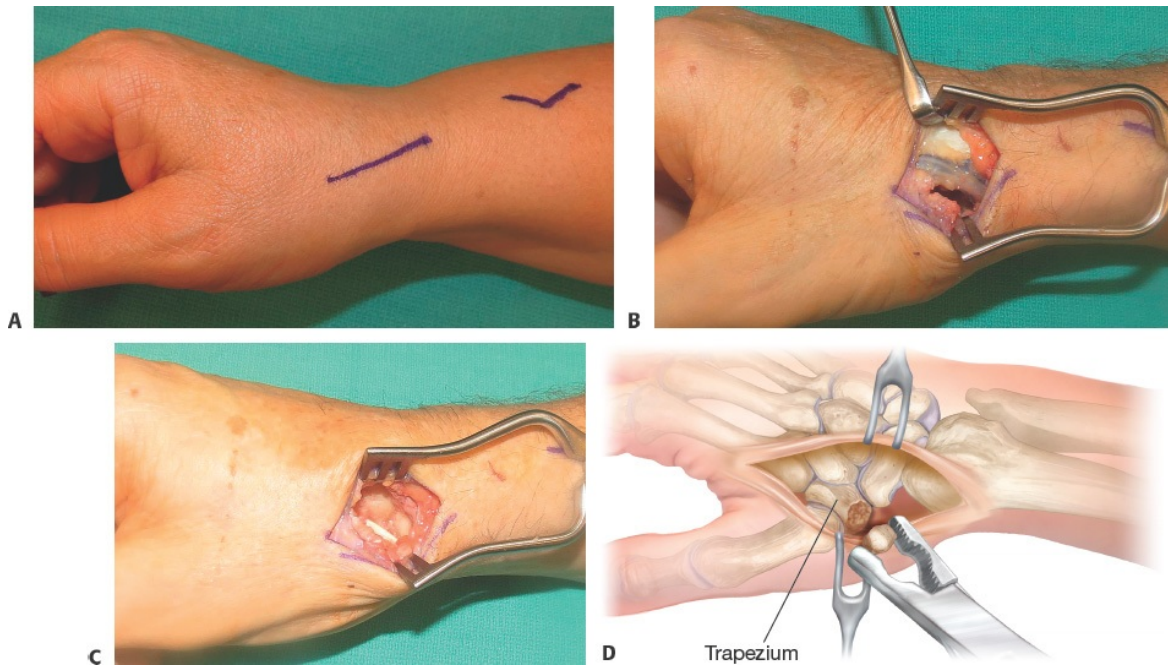
■ Trapeziectomy and Abductor Pollicis Longus Suspensionplasty

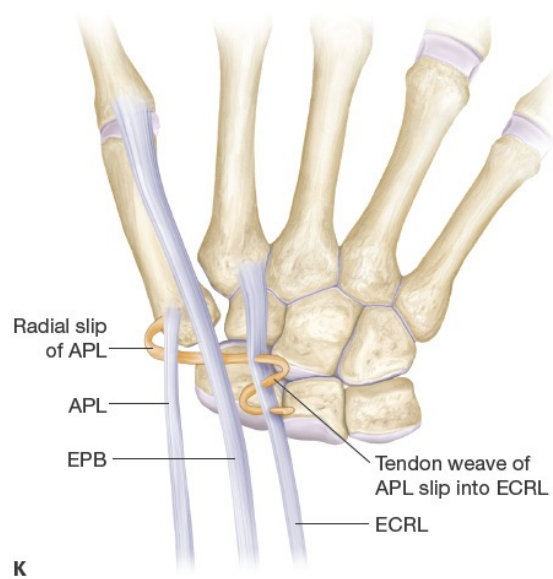
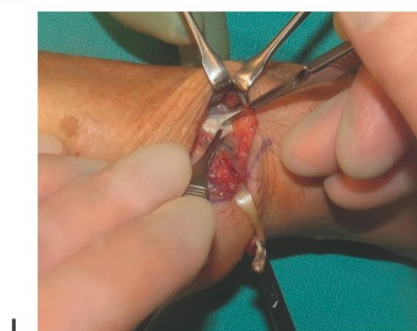
- A trapeziectomy with APL suspensionplasty is our preferred technique for thumb TM (carpometacarpal joint [CMCJ]) arthroplasty, as it is faster and technically easier than the Eaton-Littler procedure yet provides comparable outcomes.⁶
- The first incision is made over anatomic snuffbox and TM joint (**TECH FIG 6A**).
 - The radial sensory nerve branches are identified and retracted. The EPL tendon is found at the ulnar aspect of the anatomic snuffbox.
 - The radial artery is identified in close proximity to the TM joint capsule and is mobilized and retracted inferiorly (**TECH FIG 6B**).
 - The TM joint capsule is incised and sharply elevated to expose the scaphotrapezial joint, the trapezium, and the thumb metacarpal base

(**TECH FIG 6C**).

- The trapezium is cut longitudinally into three pieces using an oscillating saw followed by an osteotome.
 - The pieces are removed with a rongeur (**TECH FIG 6D,E**).
 - Osteophytes and loose bodies embedded in the surrounding soft tissues must also be removed meticulously.
 - Care is taken to avoid injury to the FCR tendon as it passes volar to the trapezium at its proximal radial corner.
- The surface of the trapezoid that articulates with the scaphoid is inspected, and if arthritis is present, a partial proximal trapezoidal resection is performed.
- The second incision is made over the first extensor compartment to identify the musculotendinous junction of the APL, which has multiple slips (**TECH FIG 6F**).
- The most radial slip of APL is divided at this junction (**TECH FIG 6G**), passed under the skin bridge into the thumb incision with a hemostat, and traced to its insertion at the thumb metacarpal base (**TECH FIG 6H**).
- The extensor carpi radialis longus (ECRL) tendon is identified ulnarly where it inserts into the base of the index metacarpal, deep to the EPL tendon.
 - A small incision is made longitudinally in the ECRL tendon (**TECH FIG 6I**).
- The APL tendon is then passed volar to EPL and through the hole in the ECRL into a tendon weave (**TECH FIG 6J**).
- The tension is set such that the thumb metacarpal base is suspended at the level of the index metacarpal base.
- The tendon weave between APL and ECRL is secured using 3-0 braided nonabsorbable horizontal mattress sutures (**TECH FIG 6K,L**).
- The remaining tendon is cut, fashioned into a ball with 4-0 absorbable suture, and placed in the trapeziectomy space (**TECH FIG 6M**).
- The joint capsule is closed with 4-0 braided absorbable suture.
 - The skin is closed with 4-0 absorbable monofilament dermal sutures and a 4-0 absorbable monofilament running subcuticular suture (**TECH FIG 6N,O**).
- A thumb spica splint is placed and worn for 4 weeks.
 - Hand therapy is then initiated for passive and active ROM exercises, with the splint worn between exercises.

- At 6 weeks, light strengthening exercises are begun. At 8 weeks, the splint is weaned and heavy strengthening with grip and pinch exercises is initiated.
- Studies show that patients experience significant improvements in activities of daily living, work, satisfaction, and pain at 1 year postoperatively.







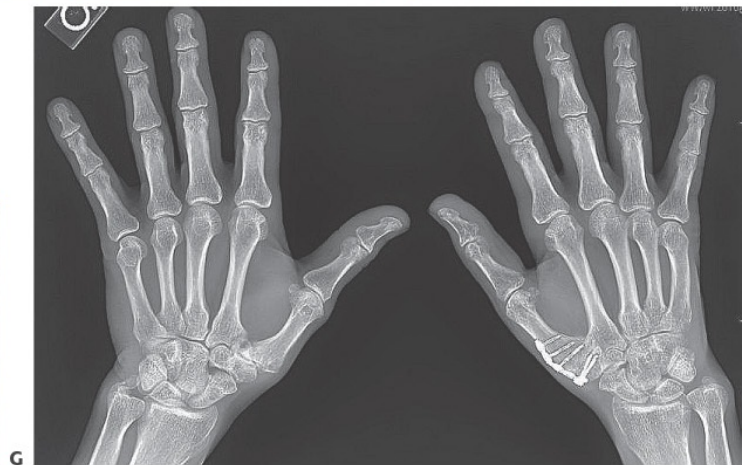
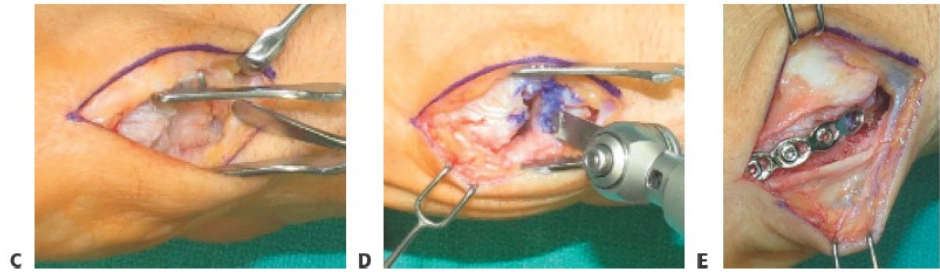
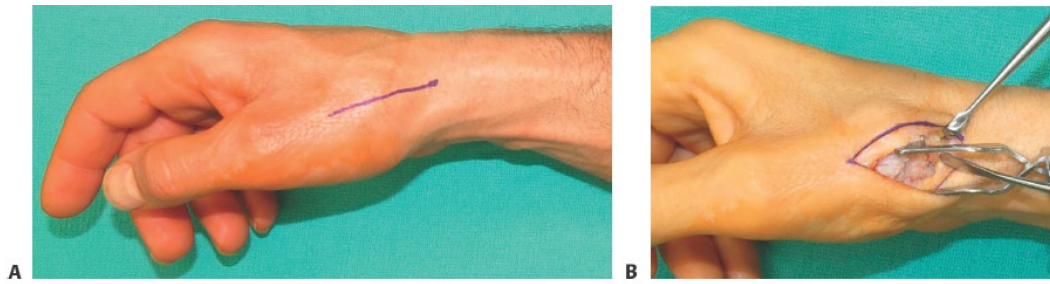
TECH FIG 6 • Trapeziectomy and APL suspensionplasty. **A.** First skin incision. **B.** Radial artery is preserved. **C.** Trapezium is exposed. **D.** A rongeur is used to remove the trapezium. **E.** Trapezium has been removed. **F.** APL is identified via second incision. **G.** The radial slip of APL is divided at the musculotendinous junction. **H.** The slip of APL is brought into the thumb incision and traced to its insertion on the thumb metacarpal base. **I.** A small incision is made in the ECRL tendon. **J,K.** The slip of APL is passed volar to EPB and EPL and through the hole in the ECRL into a tendon weave. **L.** Completed APL tendon weave with ECRL. **M.** The excess APL

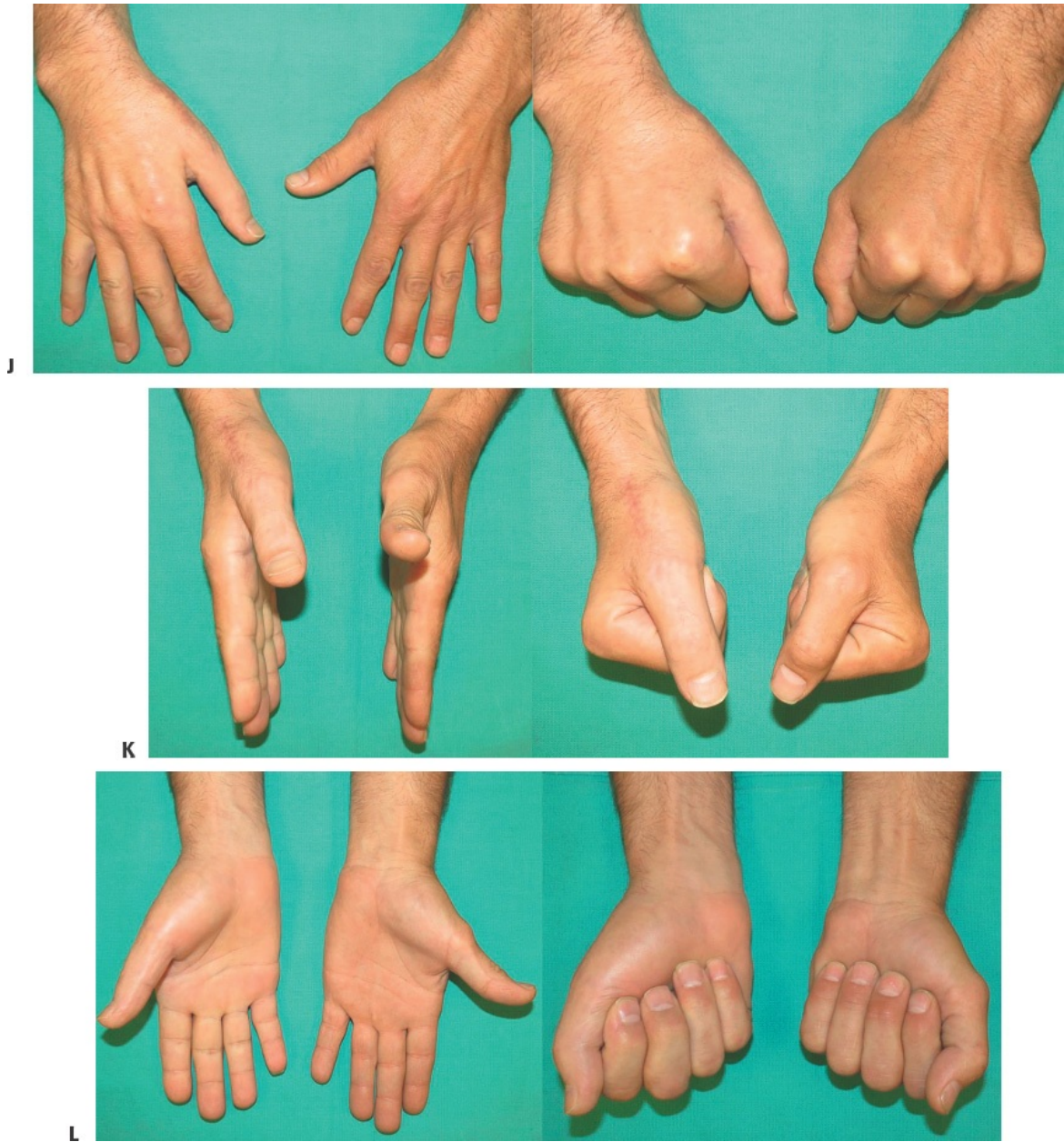
tendon is cut, sutured into a ball, and inserted into the trapeziectomy space. **N.** Skin closure. **O.** Postoperative x-ray.

■ Arthrodesis of the Thumb TM Joint (Thumb CMCJ Arthrodesis)

- Osteoarthritis of the thumb TM joint (ie, CMCJ) can be addressed with joint fusion, particularly in manual laborers who require greater stability than can be achieved with trapeziectomy and ligament reconstruction.
 - Arthrodesis is also indicated in patients with substantial joint laxity and deformity. In the past, nonunion rate is high using the traditional plating system.
 - We have applied the locking plate and screw design for this joint to provide even more rigid fixation that may enhance fusion.
 - Using locking system is the preferred approach to fuse the thumb CMCJ.
- A 4- to 6-cm dorsal longitudinal incision is made over the TM joint at the base of the thumb metacarpal (**TECH FIG 7A**).
 - The interval between the EPL and EBP tendons is entered, exposing the joint capsule. Care is taken to preserve and retract the radial artery.
 - The joint capsule and periosteum are incised, and periosteal flaps are elevated off the trapezium and metacarpal (**TECH FIG 7B,C**).
- Using a combination of rongeur and osteotome, the articular cartilage and subchondral bone are resected (**TECH FIG 7D**).
- A 2.3-mm locking T-plate is selected and positioned with the T-portion centered on the trapezium and the longitudinal portion centered along metacarpal.
 - Screws are applied with the joint in compression (**TECH FIG 7E**).
 - Plate position is confirmed with fluoroscopy.
 - If any bony gaps exist, cadaveric bone graft is applied.
- The periosteal flaps and joint capsule are closed over the plate using 4-0 absorbable braided suture (**TECH FIG 7F**).
 - After skin closure, a thumb spica splint is placed.
- The patient is immobilized in a thumb spica splint for 6 weeks to allow for bony fusion, after which gentle active ROM exercises are initiated (**TECH**

FIG 7G-I).





TECH FIG 7 • Thumb CMC arthrodesis. **A.** Incision. **B,C.** Radial artery retracted and thumb CMC joint identified. **D.** Chevron-type osteotomy made through base of metacarpal and trapezium. **E.** Thumb CMC fusion with Synthes locking T-plate. **F.** Interval between EPB and EPL closed over plate. **G–I.** Six weeks postoperative x-rays. **J–L.** Results 6 weeks postoperatively.

■ Darrach Procedure for Distal Radioulnar Joint Arthritis

- A dorsal incision is made longitudinally over the distal ulna, just proximal to the extensor retinaculum, taking care to preserve the dorsal ulnar sensory nerve (**TECH FIG 8A**).
 - The interval between the extensor carpi ulnaris (ECU) and extensor digiti minimi (EDM) is entered (**TECH FIG 8B**).
 - The periosteum is incised, and radial and ulnar periosteal flaps are raised.
- An oscillating saw is used to resect 2 cm of distal ulna at a 45-degree angle, such that the long end of the oblique cut is in the ulnar border to minimize impingement against the radius.
- The loose ulnar head is sharply excised from its soft tissue attachments (**TECH FIG 8C**).
 - Sharp edges of bone and synovitis within the sigmoid notch are removed with a rongeur.
- Ulnar stump stability is then assessed.
 - If stable, the tourniquet is release, and hemostasis is achieved with cautery.
 - If unstable, an ECU tenodesis is performed.
- Then, with the wrist fully supinated, the dorsal wrist capsule is imbricated with 2-0 braided nonabsorbable horizontal mattress sutures, ensuring that the ulnar is not dorsally prominent in this position.
- The skin is closed with 3-0 absorbable monofilament dermal sutures and a 4-0 nonabsorbable (**TECH FIG 8D**).
- A sugar-tong splint is applied with the forearm fully supinated for 4 weeks, keeping the fingers free for ROM.
 - Gentle active ROM is started at 4 weeks, but if an ulna-stabilizing procedure has been performed, pronation and supination are delayed until 6 weeks (**TECH FIG 8E**).
 - Full activities may be resumed as tolerated at 6 to 8 weeks.



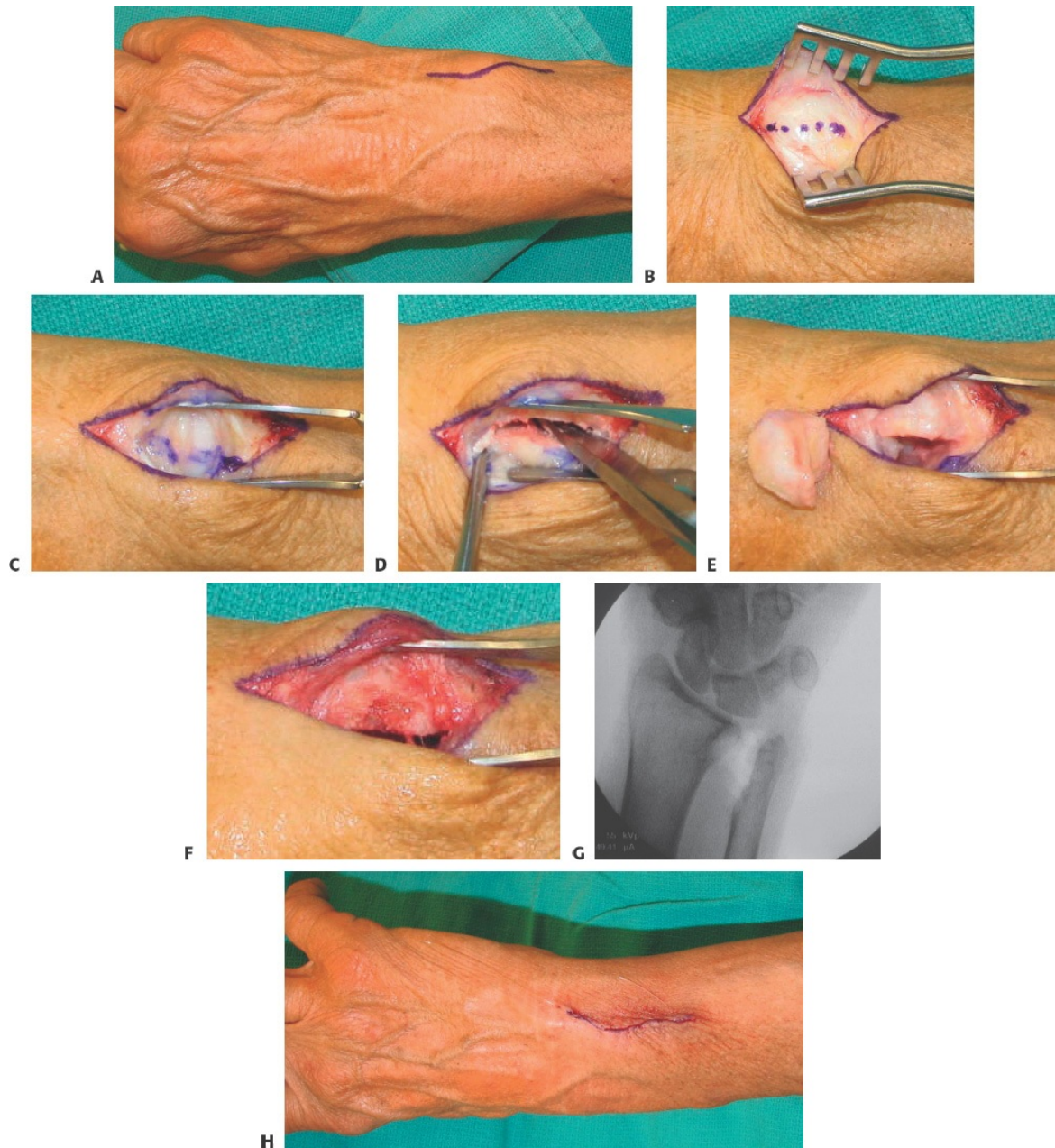
TECH FIG 8 • Darrach procedure. **A.** Skin incision. **B.** Interval between ECU and EDM is entered. **C.** Excised ulnar head (*arrow*). **D.** Skin closure. **E.** Postoperative x-ray.

■ Hemiresection Arthroplasty of the Distal Ulna

- We prefer hemiresection ulnar arthroplasty over the Darrach procedure for patients with wrist pain due to distal radioulnar joint (DRUJ) osteoarthritis, as it is associated with less postoperative wrist instability⁷ and better wrist range of motion, grip strength, and pain relief.⁸
 - In this procedure, the ulnar attachments of the TFCC (triangular fibrocartilage complex) are preserved.
 - Resection of the radial and dorsal margins of the distal ulna is performed such that the resected bone corresponds with the articular surface of the

sigmoid notch.

- This “matched resection” is performed to prevent radioulnar impingement during forearm rotation.⁹
- The distal ulna is exposed in a similar manner as for the Darrach procedure (see above for details) while maintaining the ulnar TFCC (**TECH FIG 9A–C**).
- Using a miniature C-arm, a Freer is used to delineate the dorsal radial cut of the distal ulna to match the curvature of the sigmoid notch.
- An oscillating saw is used to remove this portion of the ulna (**TECH FIG 9D–F**).
- Pronation and supination are checked to ensure no impingement of the distal ulna on the radius.
- The dorsal capsular sheath over the ulna is imbricated to further stabilize the distal ulna using buried 2-0 nonabsorbable braided horizontal mattress sutures.
- After skin closure (**TECH FIG 9G,H**), the extremity is splinted with the forearm in supination.
- The postoperative supination splint is maintained for approximately 4 weeks to stabilize the DRUJ.
 - After 4 weeks, gentle pronation and supination exercises are initiated.



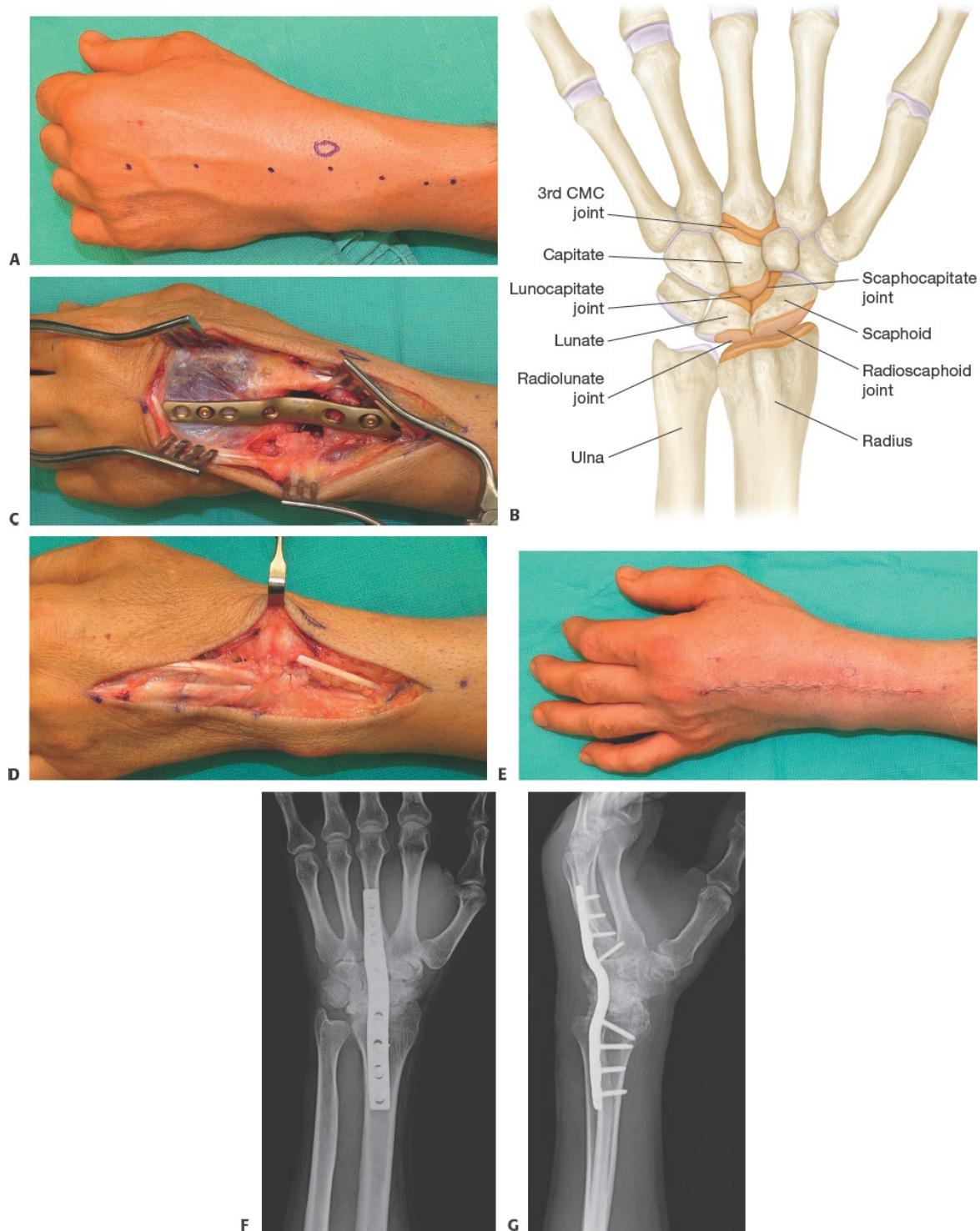
TECH FIG 9 • Hemiresection ulnar arthroplasty. **A.** Incision. **B.** Sheath incision. **C.** Exposure of arthritic distal ulna. **D–F.** Freer and oscillating saw is used to remove distal ulna. **G.** Fluoroscopy. **H.** Skin closure.

■ Total Wrist Fusion

- A dorsal midline incision is made, centered at the radiocarpal joint and

extending from the third metacarpal neck to about 5 cm proximal to Lister tubercle (**TECH FIG 10A**).

- The skin flaps are elevated, taking care to preserve the cutaneous nerves.
- The third extensor compartment is entered, and the EPL tendon is transposed.
- The extensor retinaculum is incised, exposing the second through fifth extensor compartments.
- The posterior interosseous nerve (PIN) is identified on the floor of the fourth compartment and excised.
- The dorsal wrist capsule is incised along the dorsal intercarpal and dorsal radiocarpal ligaments, creating a radially based capsular flap and elevating it off the dorsal triquetrum.



TECH FIG 10 • Total wrist fusion. **A.** Skin incision. **B.** Dorsal wrist anatomy showing areas decorticated and removed of cartilage in preparation for fusion: third CMC, radioscaphoid joint, radiolunate joint,

scaphocapitate joint, lunocapitate joint. **C.** Fusion plate placed. **D.** Wrist capsule and extensor retinaculum are repaired. **E.** Skin closure. **F,G.** PA and lateral postoperative x-rays.

- The dorsal radius, carpus, and third metacarpal are then exposed via a subperiosteal dissection and further decorticated with an osteotome.
- Lister tubercle is removed to allow the plate to seat well on the radius.
- The articular cartilage and subchondral bone are removed from the radioscaphoid, radiolunate, scaphocapitate, lunocapitate, and third carpometacarpal joints to prepare them for fusion (**TECH FIG 10B**).
 - Care is taken to maintain carpal height by avoiding over-resection of bone.
- Soft tissues are released as needed to permit joint reduction and alignment at about 10 degrees of extension and slight ulnar deviation.
- The surface of the radius is contoured to fit the curvature of the fusion plate.
- The prepared joint spaces are filled with the bone graft.
 - For healthy patients, we use cadaveric bone graft, whereas for smokers or those at risk for wound healing delay, we prefer using bone autografts from the iliac crest.
- The fusion plate is applied, spanning from the distal radius to the third metacarpal.
 - A screw affixing the plate to the third metacarpal is placed in a neutral, unrotated position.
- With the wrist joint compressed, the plate is further affixed to the radius (**TECH FIG 10C**).
 - The remaining screws are placed.
 - Hardware placement is checked with fluoroscopy.
 - Full forearm rotation and passive digital ROM should be intact.
- Once the plate is secured, additional bone graft is packed into the prepared joint spaces.
- The wrist capsule is closed over the plate.
 - The extensor retinaculum is repaired, leaving the EPL transposed over the retinaculum.
 - The skin is closed with absorbable monofilament dermal and subcuticular running sutures (**TECH FIG 10E–G**), and a bulky volar wrist splint is

applied.

- Typically, at 2 weeks postoperatively, a removable wrist splint is provided for full-time wear and may be removed transiently for personal hygiene.
- The splint is worn for 3 months.
- However, if the fixation is tenuous or patient compliance is questionable, a postoperative cast should be placed.
- Digital ROM and edema control are encouraged throughout this time frame.
- Upon surgical recovery, patients should expect pain relief, full digital ROM, full forearm rotation, and the ability to complete most activities of daily living.

PEARLS AND PITFALLS

DIPJ ARTHRODESIS

Exposure

- Avoid injury to the germinal matrix of the nail fold.
- If the joint deformity is fixed, adequate soft tissue release must be performed to reduce the joint in an optimal position. This includes release of the volar plate, if necessary.

Shaping the bone

- As an alternative to burring a “crest-and-trough” configuration, the bone ends can be cut with the distal bone at 0 degrees and the proximal bone at the desired angle of fusion.
- Avoid excessive bony removal to preserve length and retain good quality bone for healing.

Other techniques for DIPJ arthrodesis

- The two other most commonly reported techniques for DIPJ fusion include the use of headless compression screws or interosseous cerclage wires. Although evidence is insufficient to support any particular technique, the technique with the least reported complications is K-wiring.¹⁰
- If a headless compression screw is placed across the joint, it should be aimed from proximal to distal and slightly palmar to avoid the nail matrix.

SILICONE PIPJ ARTHROPLASTY

Preoperative assessment of collateral

- The collateral ligaments of the PIPJ must be assessed for stability preoperatively.

ligaments	■ If deficient, the patient may require collateral ligament reconstruction at the time of surgery or may eliminate patient candidacy for arthroplasty.
Finger selection	■ Avoid the use of silicone implants at the index and long finger PIPJs, particularly in young, active patients, because repetitive stresses on the radial collateral ligaments during key or chuck pinch can result early implant failure.
Alternative implants: pyrocarbon	■ Pyrocarbon, or pyrolytic carbon, implants have enhanced lateral stability that makes implantation into the index finger PIPJ more attractive compared to silicone. ■ However, pyrocarbon implants have fallen out of favor due to complication rates as high as 30%. ■ If performed, pyrocarbon PIPJ arthroplasty can be done through a lateral or dorsal approach (see TECH FIG 3A–K).

THUMB MCPJ FUSION

Techniques for thumb MCPJ fusion	■ Thumb MCPJ fusion can be accomplished with a variety of techniques, depending on surgeon preference: ■ Tension band wiring ■ Crossed K-wire fixation ■ Plate fixation ■ Intramedullary implant placement ■ For patients with RA, K-wire placement is the author's preferred technique given that thumb MCPJ fusion is often combined with a number of other procedures dealing with the rheumatoid hand.
Angle of fusion	■ The fused position of the thumb MCPJ should be at about 5–15 degrees of flexion for optimal functionality. ■ Slightly more flexion at 20–40 degrees may be considered in patients at risk for developing/worsening OA at the thumb CM CJ.

THUMB TM LIGAMENT RECONSTRUCTION WITH FCR

Anatomy of the thumb CM CJ	■ The thumb CM CJ is the articulation between the trapezium and the thumb metacarpal. It is also known as the trapeziometacarpal (TM) joint. ■ It is a biconcave saddle-shaped joint that permits thumb flexion, extension, abduction, adduction, and opposition. ■ The volar beak ligament is the primary stabilizer of the thumb CM CJ. It extends from the ulnar base of the thumb metacarpal onto the trapezium.
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Harvest of FCR	■ The radial half of the FCR tendon is harvested. ■ The radial artery and sensory nerve branches must be identified and protected. ■ Injury to the palmar cutaneous branch of the median nerve, which lies 1 mm ulnar to the FCR tendon, must be avoided. ■ Care should be taken to separate the radial half of FCR from the ulnar half as to avoid accidental transection. Scissors should not be used to slide down the tendon and instead to make deliberate cuts from proximal to distal.
Postoperative course	■ Thumb CMCJ stiffness is expected for 4–6 wk after surgery but can last up to 4 mo. ■ Patients can expect near-complete pain relief and minimal progression of degenerative arthritis at the CMCJ provided that the surgery is performed prior to onset of articular cartilage destruction.
TRAPEZIECTOMY WITH APL SUSPENSIONPLASTY	
MCPJ laxity	■ Remember to assess the patient's thumb MCPJ for hyperextensibility during pinch. ■ If laxity greater than 30–40 degrees is present and unaddressed, ligament reconstruction will be stressed by obligatory metacarpal adduction. ■ Hyperextensibility at the MCPJ can be addressed with joint capsulodesis, volar plate advancement, or fusion. We advocate MCPJ fusion in these cases because soft tissue imbrication tends to attenuate over time, whereas fusion has a more predictable outcome.
Carpal tunnel syndrome	■ Up to 43% of patients with TM joint arthritis have concomitant carpal tunnel syndrome. If present, a carpal tunnel release should be performed as well.
Eaton classification	■ The Eaton classification of TM osteoarthritis (see Table 1), which is based on radiographic findings, often does not correlate with patient symptoms.
Radiographs	■ A stress view of the TM joint is useful to assess joint space loss and subluxation in patients with symptomatic joint laxity (Eaton stage I). This is obtained by pressing the thumb tips together with a 30-degree posteroanterior view.
Arthritic involvement of the trapezoid	■ If degenerative changes are present between the trapezoid and the scaphoid, concomitant partial resection of the trapezoid is recommended. This is done to ensure that no contact between

	the scaphoid and trapezoid occurs with axial loading. ■ Traction on the index and long fingers after trapeziectomy will allow visualization and assessment of the scaphotrapezoid joint.
Exposure of the trapezium	■ A dorsal approach provides easy access to the trapezium. ■ Identify and protect these four structures: ■ Radial sensory nerve branches ■ Extensor pollicis longus (EPL) tendon ■ APL tendon ■ Radial artery (located deep to the fatty tissue between EPL ulnarly and APL radially) ■ Thumb traction can help facilitate exposure of the trapezium.

THUMB TM JOINT ARTHRODESIS

Anatomy	■ One must protect the radial sensory nerve during exposure of the thumb TM joint. ■ The radial artery must be protected in the interval between the EPL and EPB tendons where it lies deep to the subcutaneous fat.
Plate selection	■ A 2.3-mm locking T-plate is preferred, with the T-portion centered on the trapezium. ■ Utilization of a locking plate is important in the setting of poor bone stock. The trapezium is often devoid of strong cortical bone necessary to secure traditional screws and plates.
Functional thumb position	■ The thumb should be fixed at 30–40 degrees of palmar abduction, 15–20 degrees of extension, and 15 degrees of pronation. ■ This functional position facilitates tip-to-tip pinch.

DARRACH PROCEDURE

Indications	■ Post-traumatic DRUJ arthritis, rheumatoid arthritis, or osteoarthritis without pre-existing radiocarpal instability in patients who are older and sedentary ■ Caput ulna syndrome with TFCC destruction and painful pronation-supination of the DRUJ ■ Preferred in patients with no ulnar translation of carpus who are at low risk of translation in the future ■ Can be performed concomitantly with partial or total wrist fusion in setting of radiocarpal instability ■ Notably, we tend to avoid the Darrach procedure in osteoarthritis, as it weakens the wrist. We prefer hemiresection
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	arthroplasty of the distal ulna (see Technique no. 8).
Caput ulna syndrome	■ Combination of ulnar head dorsal dislocation, ECU volar subluxation, and carpal supination seen in patients with rheumatoid arthritis ■ The fifth extensor compartment (containing EDM) crosses the ulnar head.
Extent of ulnar head resection	■ The pronator quadratus (PQ) is a dynamic stabilizer of the distal ulna, originating at the distal radius and inserting on the distal ulna. ■ Ulnar head excision should be performed at the level of the sigmoid notch in order to preserve the ulnar attachments of the PQ.
Ulna-stabilizing procedure	■ Prior to closing the wrist capsule, the distal ulna stump is tested for stability with pronation-supination. ■ If unstable, an ulnar stabilizing procedure is indicated (ECU tenodesis): ■ A hole in the dorsal cortex of the distal ulnar stump is drilled with a 3-mm bur. ■ The distally based ulnar half of the ECU is harvested and brought from inside the ulnar canal and out the hole dorsally. ■ The ECU is then sutured to itself with the ulnar stump reduced palmarly and wrist in 15-degrees of extension and 15-degrees of ulnar deviation. ■ The wrist capsule is then closed as described in the text.
HEMIRESECTION ARTHROPLASTY OF THE DISTAL ULNA	
Relative contraindications	■ Hemiresection ulnar arthroplasty should be considered with caution in younger patients because it may lead to loss of support for the ulnar carpus over time. ■ Ulnar-positive variance is a relative contraindication for hemiresection ulnar arthroplasty because it increases the risk of impingement between the ulnar styloid and triquetrum. ■ Other contraindications to hemiresection ulnar arthroplasty include pre-existing ulnar carpal translation (may exacerbate the ulnar translation) and irreparable damage to the TFCC (no benefit over a Darrach procedure).
Technical points	■ Avoid excessive resection of the ulnar head. ■ Preserve the foveal attachments of the TFCC. ■ If necessary, debride the TFCC. ■ Consider ulnar shortening if positive variance is present.

TOTAL WRIST FUSION

Indications	■ Painful wrist with limited ROM due to osteoarthritis, inflammatory arthritis, and post-traumatic arthritis ■ Multiple joint involvement ■ Failed partial wrist fusions or soft tissue reconstructions ■ Carpal instability patterns (eg, SLAC/SNAC arthritis) ■ Contraindications for joint arthroplasty or failed arthroplasty ■ Desire for a one-stage definitive treatment.
Dorsal wrist capsule	■ The wrist capsule can be elevated as a radially based flap (as described in the text) or via a straight midline longitudinal incision. ■ A thick capsular flap should be maintained for good coverage of the fusion plate. ■ The ECRL and ECRB tendons can be released from their metacarpal insertions and used to augment soft tissue coverage of the hardware.
The fusion mass	■ Bony fusion involves the radius, scaphoid, capitate, lunate, and third metacarpal bones. ■ Not included in the fusion mass are the ulnar joints (lunotriquetral and triquetrohamate joints).
Proximal row carpectomy (PRC)	■ Performing a PRC may help to facilitate joint alignment before fusion, particularly in cases of chronic and severe carpal deformity.
Fusion plate	■ A dynamic compression plate is used for wrist fusion and must be contoured appropriately to allow for 10 degrees of wrist extension and slight ulnar deviation. ■ In patients with poor bone stock, locking screw fixation can be used.
Postoperative splinting	■ A supportive wrist splint is applied at the end of the case. ■ Avoid MCPJ extension in the splint, which may result in intrinsic tightness and loss of digital ROM.

COMPLICATIONS

- Inadequate pain relief
- Wound healing delay
- Nonunion
- Hardware failure

- Failure of reconstruction
- Infection
- Need for further surgery

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Section VIII: Nerve Conditions

26

CHAPTER Carpal Tunnel Release

Angelo B. Lipira and Jason H. Ko

DEFINITION

- Compression of the median nerve at the level of the wrist is the most common compression neuropathy, with a prevalence of 1% to 3%.¹
- Patients present with numbness or paresthesias in the distribution of the median nerve (thumb, index finger, middle finger, radial half of ring finger).
- Long-standing carpal tunnel syndrome (CTS) can result in weakness and atrophy of the thenar musculature; sensory fibers are preferentially affected earlier in the process.
- CTS is diagnosed clinically. It is often confirmed with electrodiagnostic studies, which can also indicate the severity of nerve injury.

ANATOMY

- The median nerve provides sensation to the thumb, index finger, middle finger, and radial half of the ring finger, as well as the skin of the thenar eminence via the palmar cutaneous branch. It provides motor function to the thenar musculature via the recurrent motor branch and radial two lumbricals via the proper (first lumbrical) and common (second lumbrical) digital nerves (**FIG 1A**).
- The carpal tunnel is an anatomic space bounded by the transverse carpal ligament (TCL) volarly; the hamate, triquetrum, and pisiform ulnarly; the scaphoid and trapezium radially; and the lunate and capitate dorsally (**FIG 1B**).
- The carpal tunnel contains the median nerve and nine flexor tendons (four flexor digitorum superficialis [FDS], four flexor digitorum profundus, and

flexor pollicis longus).

- The recurrent motor branch innervates the abductor pollicis brevis, opponens pollicis, and superficial head of flexor pollicis brevis. Most commonly, it arises from the median nerve distal to the TCL (extraligamentous, 46%) but may be subligamentous (31%) or transligamentous (23%). Variants that arise from the ulnar aspect of the median nerve and cross over the TCL are at highest risk of injury, particularly in endoscopic techniques.²
- The palmar cutaneous branch usually branches from the radial aspect of the median nerve 5 to 8 cm proximal to the wrist crease and travels distally between the flexor carpi radialis (FCR) and palmaris longus.
- Therefore, thenar sensation is typically preserved in CTS.
- However, the palmar cutaneous branch can also show variation, including a variant where it branches from the ulnar aspect of the median nerve.² The branch becomes superficial at the wrist level and is vulnerable during incisions.

PATHOGENESIS

- Increased pressures within the carpal tunnel lead to vascular congestion, edema, and ischemia of the median nerve.
- Demyelination occurs first, followed by axonal degeneration in more severe cases. Sensory nerve fibers are affected earlier than motor fibers.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient history
 - Patients will often report numbness of the entire hand, rather than localizing it to the median nerve distribution.³
 - Classically, patients will report being awakened by paresthesias and pain, as symptoms often worsen at night because during sleep, the wrist relaxes and is often flexed for prolonged periods of time, leading to elevated pressure in the carpal tunnel. Furthermore, many will sleep with their hands and wrists under the head, which also contributes to nerve compression.
 - They may report weakness or clumsiness in more advanced presentations with motor weakness.
 - Investigate associated conditions including diabetes mellitus, rheumatoid arthritis, obesity, gout, hypothyroidism, and pregnancy.^{1,4}
 - Take a good occupational history, identifying predisposing and repetitive tasks that may contribute to increased carpal tunnel pressure.

- Inquire about past therapies including splinting and steroid injections.
- Physical examination
 - Inspect the hand, looking for atrophy of the thenar musculature and differences in temperature and sweat patterns in the median nerve distribution.
 - Test and document two-point discrimination (static and dynamic) on both the radial and ulnar aspects of all digits (normal values: static less than 6 mm, moving 2–3 mm).
 - Provocative maneuvers are used in an attempt to reproduce the patient's symptoms⁴:
 - Phalen test: The wrists are held in a flexed position for up to 1 minute. Record the time it takes to precipitate their usual symptoms.
 - Tinel sign: The examiner percusses over the median nerve at the wrist. If tingling paresthesias are elicited in the fingers, the test is considered positive.
 - Durkan carpal compression test: Direct pressure is applied over the carpal tunnel with the examiner's thumb. Apply just enough pressure to blanch the overlying skin. Record the time it takes to precipitate their usual symptoms.⁵

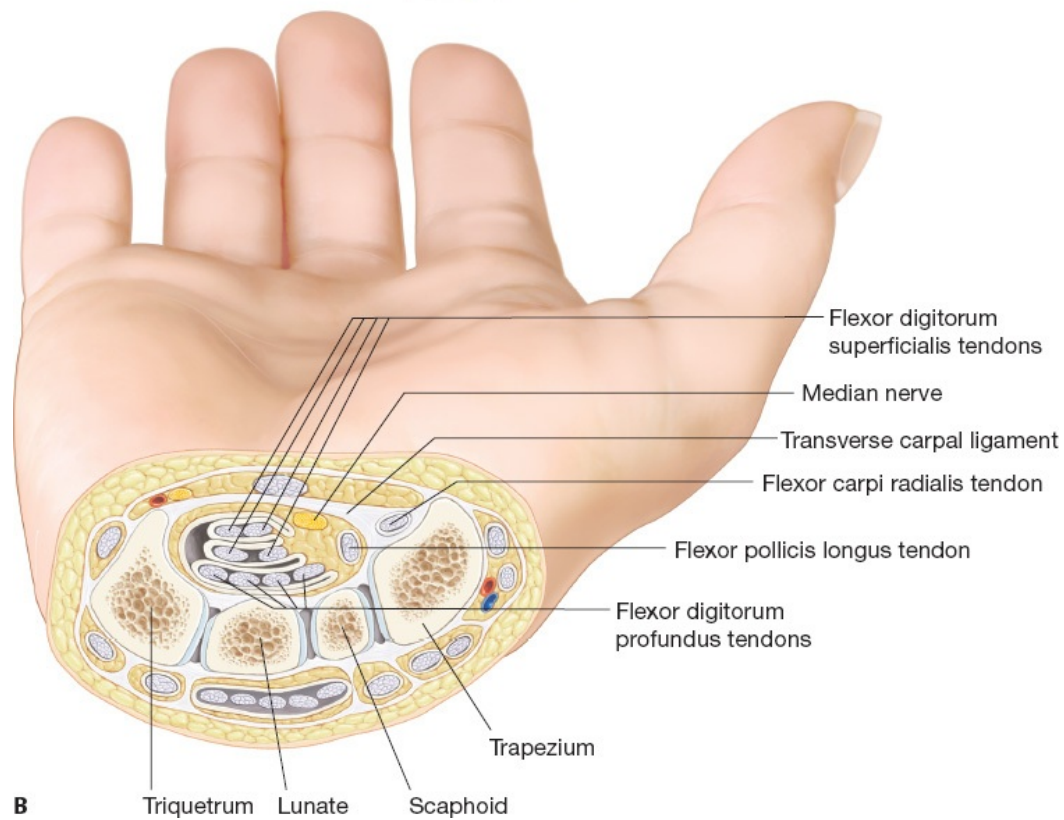
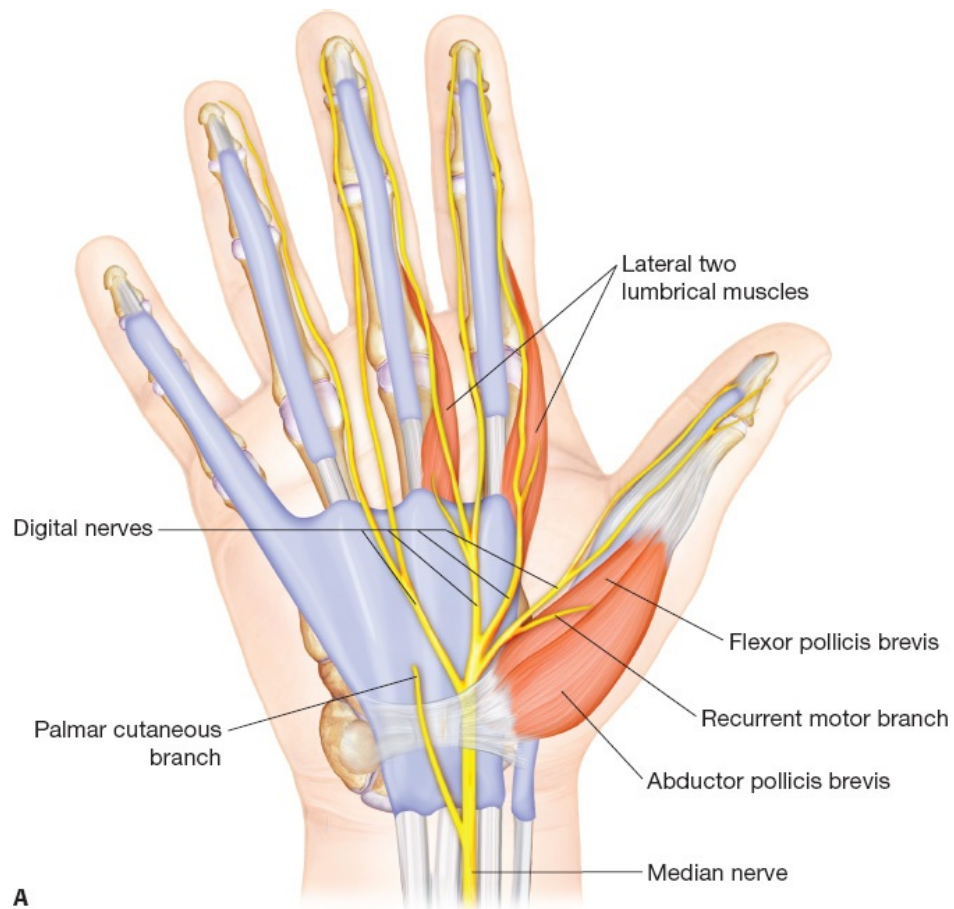


FIG 1 • A. Structures at risk during carpal tunnel release include the palmar cutaneous sensory branch, typically arising ulnarly just proximal to the transverse carpal ligament (TCL), and the recurrent motor branch, typically arising radially just distal to the TCL. **B.** Anatomic boundaries of the carpal tunnel include the TCL volarly; hamate, triquetrum, and pisiform ulnarly; lunate and capitate dorsally; and the scaphoid and trapezium radially. The carpal tunnel contains nine flexor tendons—four flexor digitorum superficialis, four flexor digitorum profundus, and flexor pollicis longus—and the median nerve.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- The diagnosis of CTS is usually made clinically, and electrodiagnostic studies are frequently employed to confirm the diagnosis and rate the severity.
- Imaging is not routinely performed for CTS but may be indicated if there is suspicion of a mass lesion or other rarer presentations.
- Electrodiagnostic studies focus on assessing the conduction velocities and amplitude of the median nerve across the wrist. The ulnar and radial nerve are also often evaluated to compare values in a nerve outside the carpal tunnel and rule out effects of temperature, polyneuropathy, and other factors.
- Nerve conduction studies may demonstrate increased sensory or motor latency (demyelination) and decreased sensory and/or motor amplitude (loss of axons).⁴ Sensory latencies are compared to an unaffected nerve (ulnar or radial) and are generally considered abnormal if the difference exceeds 0.3 to 0.5 ms. Motor conduction is assessed by stimulating the median nerve at the wrist and measuring at the abductor pollicis brevis. Latency of over 4.5 ms is generally considered abnormal.⁶
- The combined sensory index (CSI) is a useful composite value that is obtained by measuring the difference in latency between the thumb, palm, and ring fingers and the ulnar or radial nerve and summing these three values together. A CSI of 1 ms or more is considered abnormal.⁷ Higher CSIs have been associated with greater frequency of symptom resolution following carpal

tunnel release (CTR).⁶

- There is evidence that preoperative electrodiagnostic studies may increase costs and delay time to surgical treatment. Although the American Association of Orthopaedic Surgeons (AAOS), in a prior proactive guideline, recommended electrodiagnostic studies if surgery is being considered, a substantial portion of hand surgeons do not routinely obtain them.⁸

DIFFERENTIAL DIAGNOSIS

- Proximal median nerve lesion (eg, compression from pronator teres, FDS arch, or an accessory muscle such as Gantzer muscle)
- Polyneuropathy
- Central nervous system lesion (tumor, CVA, multiple sclerosis)
- Arthritis

NONOPERATIVE MANAGEMENT

- Nonoperative therapies for CTS include avoidance of provocative maneuvers, wrist immobilization (splinting), nonsteroidal anti-inflammatory drugs (NSAIDs), and corticosteroid injection.
- Wrist braces should hold the wrist in a neutral position. Wrist flexion or extension increases pressure in the carpal tunnel. However, the active position of the wrist is 30 degrees of extension, so neutral splints can make tasks more difficult.
- Although corticosteroid injection leads to transient relief in many patients, the majority will recur within 1 year.⁹ Some surgeons believe that relief with steroid injection is predictive of relief with operative CTR and thus holds diagnostic value.
- Dexamethasone is the preferred corticosteroid, as it appears to be less deleterious than hydrocortisone or triamcinolone if inadvertently injected into the nerve substance.¹⁰

SURGICAL MANAGEMENT

- CTR is commonly performed using both open and endoscopic techniques.
- There is currently no consensus supporting the superiority of one technique over the other.

Preoperative Planning

- Preoperative planning is based on the patient's history and physical exam, as

well as review of electrodiagnostic studies, if available.

- Considerations include conducting unilateral vs bilateral releases, anesthesia plan (local, regional block, sedation), and special considerations in the case of recurrent CTS (see below).
- A recent study showed that patients undergoing bilateral simultaneous CTR have increased difficulties with certain activities compared with unilateral CTR, but self-care was unaffected, and the differences did not persist past two postoperative days.¹¹
- Open CTR can be performed under local anesthetic block with or without sedation or regional block such as Bier intravenous block (**FIG 2**).
 - General anesthesia is not typically required.
- Endoscopic CTR can be difficult to perform under local anesthetic, as the liquid in the carpal tunnel can obscure visualization, so one of the other anesthetic techniques is recommended.
- In cases of recurrent or persistent CTS following CTR, be sure to rule out other etiologies of symptoms, such as cervical radiculopathy, proximal median nerve or brachial plexus lesions, and polyneuropathy.
 - If the patient has hypersensitivity directly over the carpal tunnel without evidence of palmar cutaneous branch injury, or if the median nerve is found to be adherent to the TCL intraoperatively, we consider the interposition of a hypothenar fat pad flap at the time of reoperation.¹²

Positioning

- The patient is positioned supine on an OR table or stretcher, with the operative extremity on a hand table.
- A well-padded, nonsterile tourniquet is placed on the upper arm prior to prep and drape.
- The surgeon is seated with his or her dominant hand more proximal relative to the operative extremity so that they are working distally down the carpal tunnel.
- A sterile folded towel is placed under the wrist to slightly extend the wrist (15–20 degrees), which moves the median nerve away from the TCL.
- For positioning considerations specific to endoscopic CTR, see section below.



FIG 2 • Typical setup for Bier block anesthesia. Note the intravenous line in the dorsum of the hand and the double tourniquet.

Approach

- Techniques can be broadly divided into open or endoscopic. Open approaches include numerous described incisions, including limited incision and minimally invasive approaches.
- Although numerous variations of incisions for open CTR have been described, most agree that it should be in line with the ring finger, thus slightly ulnar to the axis of the median nerve and less likely to cause injury to the palmar cutaneous branch.
- We prefer a 2- to 3-cm longitudinal curvilinear incision, staying 2 mm ulnar to the thenar crease to avoid the palmar cutaneous branch. The distal extent is well short of Kaplan cardinal line, which identifies the location of the palmar arterial arch (**FIG 3**).
- Endoscopic approaches include single-portal¹³ and two-portal¹⁴ techniques.
 - We prefer the single-portal (Agee) technique, and the proximal incision is typically a 1- to 1.2-cm transverse incision placed in the distal flexion crease of the wrist, just ulnar to the palmaris longus tendon (halfway between FCR and flexor carpi ulnaris [FCU] tendons).

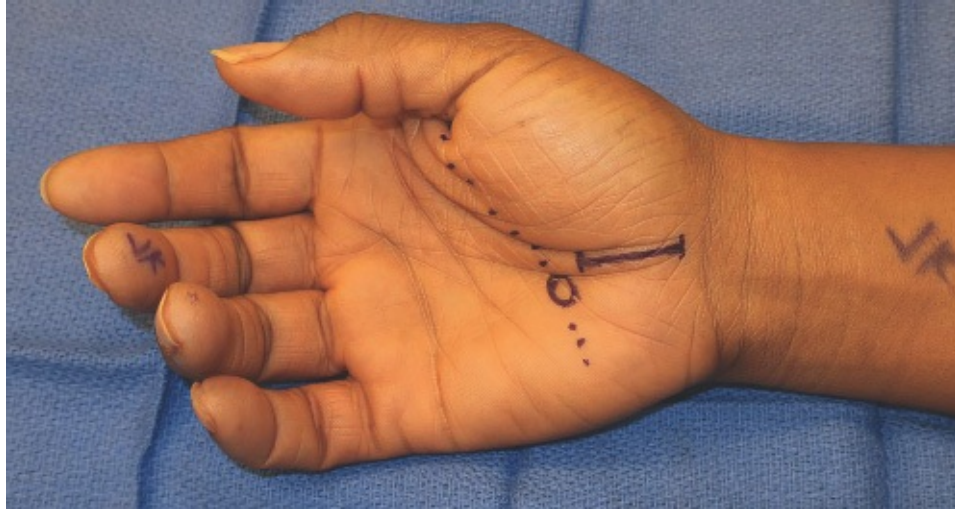


FIG 3 • Incision placement for open carpal tunnel release. It is typically 2 to 3 cm long, in line with the ring finger, and at least 2 mm ulnar to the thenar crease to avoid the palmar cutaneous branch. *Circle* denotes hook of hamate, a palpable landmark. Note incision terminates proximal to Kaplan cardinal line (*dotted line*), which is drawn by extending the ulnar border of the abducted thumb ulnarly and denotes the location of the palmar arterial arch.

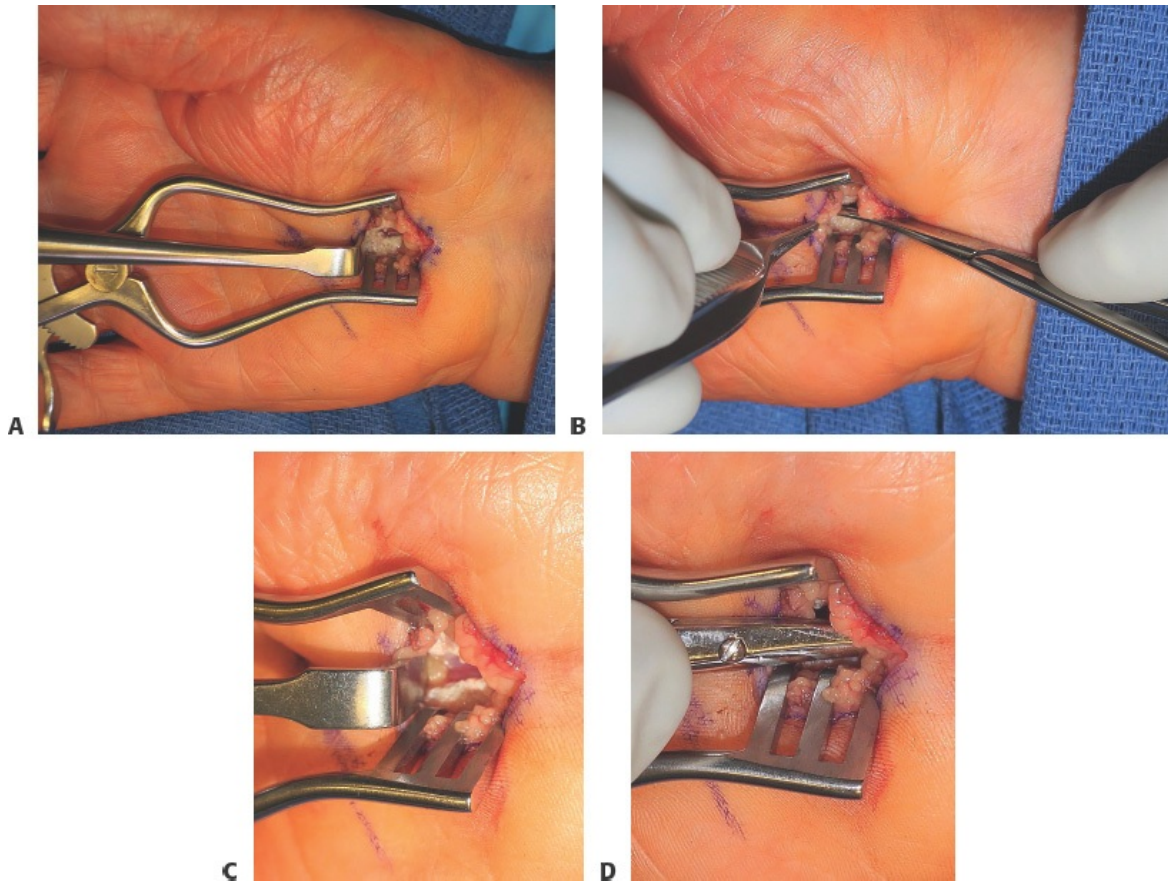
TECHNIQUES

■ Open Carpal Tunnel Release

- Mark a 2- to 3-cm longitudinal curvilinear incision 2 mm ulnar to the thenar crease.
- Exsanguinate the arm with an Esmarch bandage, and inflate the tourniquet to 250 mm Hg (or 100 mm Hg over systolic blood pressure).
- Incise full thickness through skin incision with a 15-blade scalpel.
- An assistant retracts the skin with two Senn retractors while dissection is carried down sharply through the subcutaneous tissues until the transverse carpal ligament (TCL) is encountered. During this dissection, be mindful of ulnar variants of the palmar cutaneous branch that may be encountered

(TECH FIG 1A).

- Using a no. 15 blade, carefully incise the TCL, using a controlled “push,” rather than a slicing motion.
- Once the median nerve is visualized, complete as much of the release of the TCL under direct visualization with the use of a scalpel blade.
- Then use tenotomy scissors to spread both superficial and deep to the TCL, being careful to separate the median nerve (which can be quite adherent) from the deep surface of the TCL. Insert one tine of the tenotomy scissors and divide the TCL distally until the palmar fat surrounding the superficial vascular arch of the palm is reached (**TECH FIG 1B,C**).
- Attention should now be turned toward dividing the proximal TCL and contiguous antebrachial fascia. The surgeon should change positions so that he or she is now seated at the end of the hand table for optimal visualization. Extend the skin incision proximally if necessary (**TECH FIG 1D**).
- Again dissect both superficial and deep to the TCL, separating the median nerve from the deep surface of the TCL. Under direct visualization, release the proximal end of the TCL.
- Continue spreading and dissecting proximally, exposing the deep antebrachial fascia. It is important for the surgical assistant to use two Senn retractors to lift away the skin and subcutaneous tissue to expose the antebrachial fascia proximally. Use tenotomy scissors to release the antebrachial fascia proximally for at least 1 cm proximal to the distal wrist crease.
- Consider lifting the flexor tendons in the carpal tunnel using a Ragnell retractor, and inspect for any mass lesions, such as ganglia, within the tunnel.
- Inject bupivacaine (0.25% with epinephrine) locally into the incision.
- Deflate the tourniquet while holding pressure on the incision.
- Attain meticulous hemostasis.
- Close the incision with 4-0 nylon simple interrupted or horizontal mattress sutures.
- Apply a soft, bulky dressing consisting of nonstick gauze, fluffs, and Kerlix or Ace wrap. Allow for immediate postoperative motion.



TECH FIG 1 • Open carpal tunnel release. **A.** A small self-retaining retractor and a Ragnell retractor provide exposure of the TCL. **B.** After bluntly spreading above and below the TCL, it is divided with the tenotomy scissors. **C.** Distal division of the TCL has been completed to the level of the distal palmar fat. **D.** The proximal antebrachial fascia is exposed by bluntly spreading above and below and then divided with the tenotomy scissors.

■ Endoscopic Carpal Tunnel Release

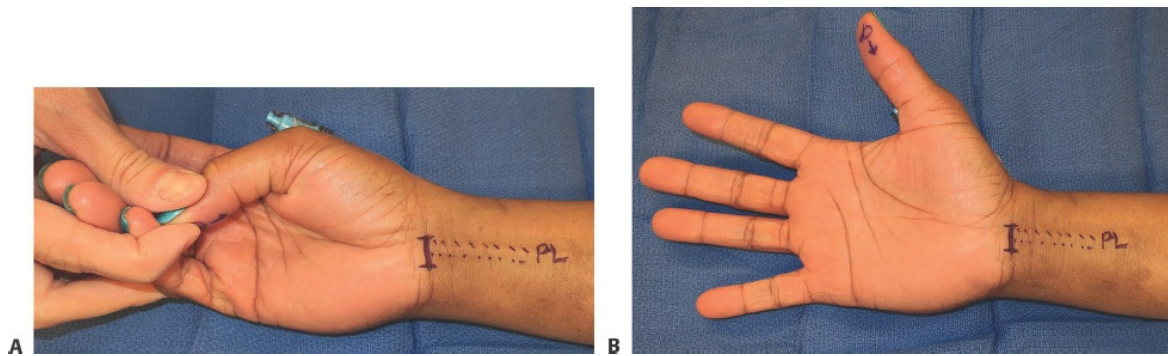
Preparation and Incision

- To avoid fogging of the lens, the lens can be placed in warm water or saline for several minutes prior to use. Otherwise, defogging solution can be applied to the lens immediately prior to use.

- Position the monitor at the distal end of the hand table. Assemble the blade/scope unit and then white-balance the camera (can use a white surgical sponge). Test the camera and endoscopic device blade prior to proceeding. Have defogging solution available on a sponge to defog the lens, if needed. Place a folded OR towel under the wrist to extend it.
- Mark a transverse incision approximately 1 to 1.2 cm in length at the distal transverse wrist crease, slightly ulnar to the palmaris longus (if present) (**TECH FIG 2**).
- Exsanguinate the arm with an Esmarch bandage, and inflate the tourniquet to 250 to 300 mm Hg (or 100 mm Hg over systolic blood pressure).

Accessing the Carpal Tunnel

- Incise the skin with a 15 blade, and use bipolar cautery to coagulate small subcutaneous vessels.



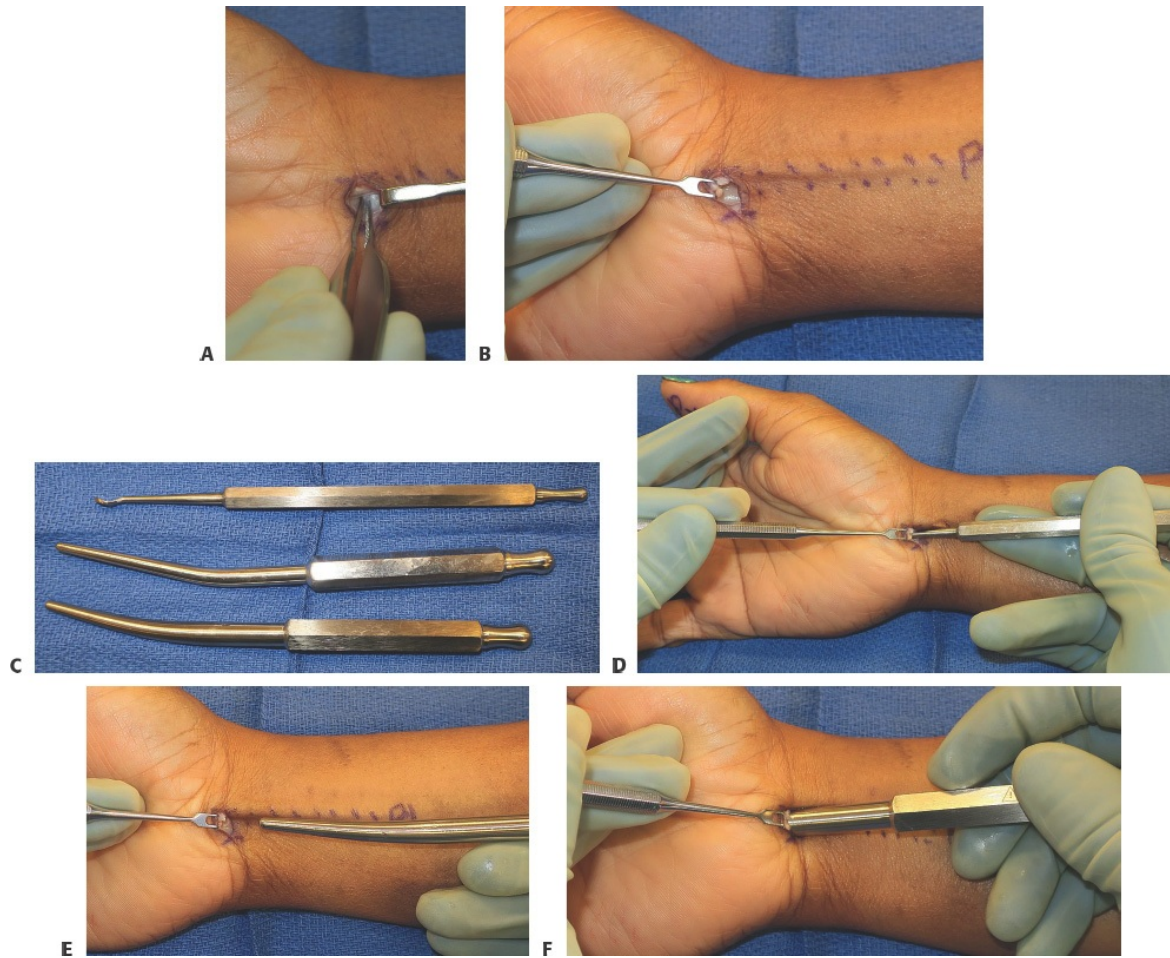
TECH FIG 2 • A,B. Incision marking for endoscopic carpal tunnel release. The palmaris longus tendon (when present) is often palpable when the thumb and small finger are opposed and the wrist flexed. The incision is marked transversely in the distal flexion crease of the wrist, slightly ulnarly translated over palmaris longus (PL, Palmaris longus).

- If excessive fatty tissue is present, perform a direct subcutaneous lipectomy.
- Use tenotomy scissors to release the superficial antebrachial fascia.
- Two Ragnell retractors are then used to bluntly spread through the subfascial tissue to expose the TCL.

- Pick up the TCL with Adson forceps distally (**TECH FIG 3A**), and make a small transverse fasciotomy with a no. 15 blade scalpel until the underlying nerve is visualized.
- Once the fascial incision is large enough to insert the tips of tenotomy scissors, use the scissors to extend the fasciotomy transversely with a single, large spreading motion.
 - Then, make a longitudinal fascial incision along the ulnar aspect of the fasciotomy for about 5 mm to create an L-shaped flap.
- Use a small double-skin hook to lift the L-shaped flap of the proximal TCL (**TECH FIG 3B**).
- With a synovial elevator, using gentle pushing motions (not scraping), clear off the deep surface of the TCL, which helps to effectively push the oft-adherent median nerve away from the TCL.
 - Advance the elevator until it can be passed into the palm and palpated there with your left hand. This should be done in line with the ring finger (**TECH FIG 3C,D**).
- Sequentially introduce two progressively larger sound dilators into the dissected space between the median nerve and the TCL (**TECH FIG 3E,F**).
- Take the light off standby, and again check the blade engagement mechanism and make sure the blade recedes back into the blade sheath upon trigger release.

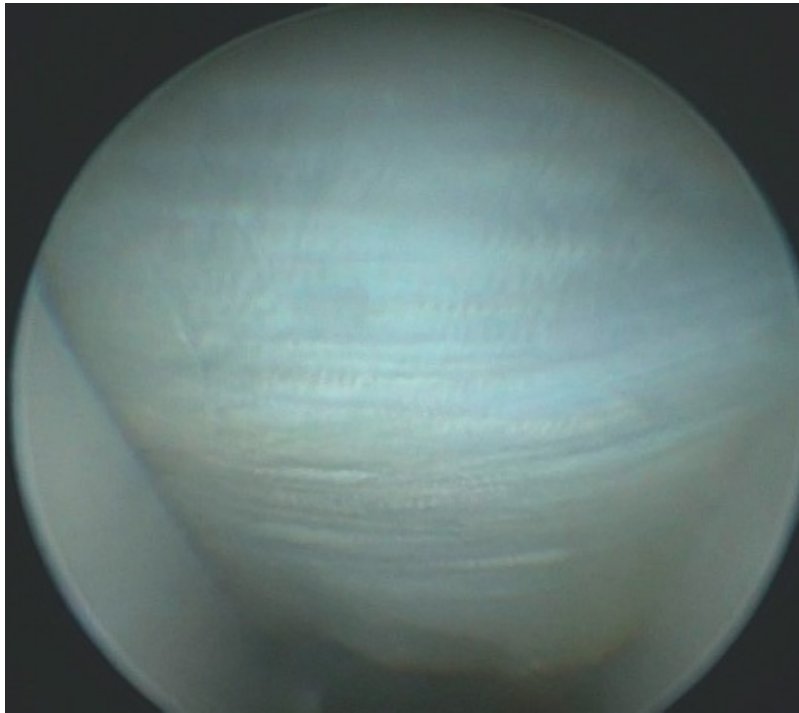
Inserting and Advancing the Endoscope

- Insert the assembled scope and blade in line with the ring finger.
 - Rotate the blade sheath slightly ulnarly while introducing it beneath the L-shaped fascial flap.
- If using hot water to eliminate fogging of the camera, after placing the blade/endoscope unit deep to the TCL, remove the scope from the sheath and immerse it in hot water. Rub it dry with a 4 × 4 Raytec gauze. Turn the room lights down, and reintroduce the scope into the blade unit.



TECH FIG 3 • Accessing the carpal tunnel. **A.** Once exposed, the TCL is grasped with forceps, and a small transverse nick is made with a no. 15 blade. Next, a blunt spread of the tenotomies under the TCL clears the median nerve from its undersurface, and the incision is extended longitudinally along the ulnar aspect to create an L-shaped flap. **B.** A small double hook is used to retract the L-shaped flap. **C.** From top down: synovial elevator, small dilator, large dilator; to be used in that sequence. **D.** Using the synovial elevator, gentle pushing motions (not pulling) clear the synovium from the deep surface of the TCL. **E,F.** The smaller dilator is then passed through the carpal tunnel, followed by the larger dilator. The tunnel is now

prepared for insertion of the endoscopic device.



TECH FIG 4 • Endoscopic view showing the TCL forming the roof of the carpal tunnel, predivision. Note that it has been cleared of adherent synovium. Also note the palmar fat visible at the distal extent of the tunnel.

- If using defogging solution, this step can be skipped.
- Advance the scope until the distal aspect of the TCL is visualized, usually corresponding to the 3.5-cm measurement on the sheath.
- While watching the video monitor, the surgeon's hand that is not controlling the scope can be used to push on the palm repeatedly to determine where the distal edge of the TCL is located, since the tight TCL will minimize motion of the tissues even upon deep palpation.
 - However, the tissue distal to the TCL will “bounce” more easily with palpation (**TECH FIG 4**).

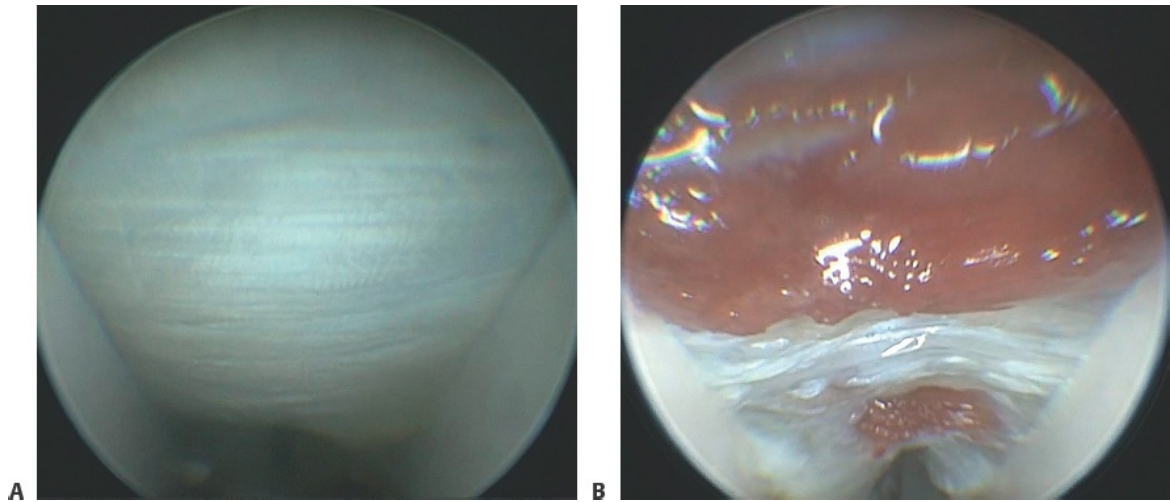
Releasing the Carpel Tunnel and Completion

- Ensure that the hand is completely flat against the towel (with the thenar

eminence firmly pushed down by the assistant) to tighten the TCL while moving the nerve as far away from the blade as possible.

- Engage the blade and slowly pull the scope proximally to cut the distal end of the TCL, stopping at approximately halfway (**TECH FIG 5A**).
 - Disengage the blade and readvance the scope to visualize the distal aspect of the TCL, ensuring no uncut bands remain distally. Any residual fibers can be cut at this time (**TECH FIG 5B**).
- The scope is pulled proximally again, and the blade is engaged again just before reaching the proximal, uncut edge of the TCL.
 - Continue pulling the device proximally to divide the remainder of the ligament while applying pressure to the palm with the hand not controlling the scope, which “pushes” the TCL into closer approximation with the blade.
- The scope can be reintroduced to visualize any residual fibers of TCL, though after release of the TCL, the superficial fat can obscure the view seen on the monitor.
- Remove the scope.
- Introduce closed tenotomy scissors under the cut TCL (superficial to the nerve).
 - Using a bimanual palpation technique, the tips of the tenotomy scissors can be gently run along the deep surface of the palm to determine if any fibers of TCL remain while the surgeon’s other hand follows the tips of the tenotomy scissors on the surface of the palm.
- Attention should now be turned toward dividing the proximal antebrachial fascia, which is a very important part of the endoscopic carpal tunnel release.
 - The surgeon should change positions to be seated at the end of the hand table for optimal visualization.
- Retract the skin and fat above the proximal superficial and deep antebrachial fascia using a Ragnell retractor, and divide the antebrachial fascia proximally with tenotomy scissors for approximately 2 cm.
- The incision can be approximated with 4-0 nylon suture in a simple or horizontal mattress fashion.
- Infiltrate a 0.25% bupivacaine with epinephrine into the incision, along with the area of the released TCL and antebrachial fascia.
- Apply a soft dressing of fluffs and a 4-in. Kling wrap.
- Apply firm pressure at the incision site through the dressing while deflating

the tourniquet.

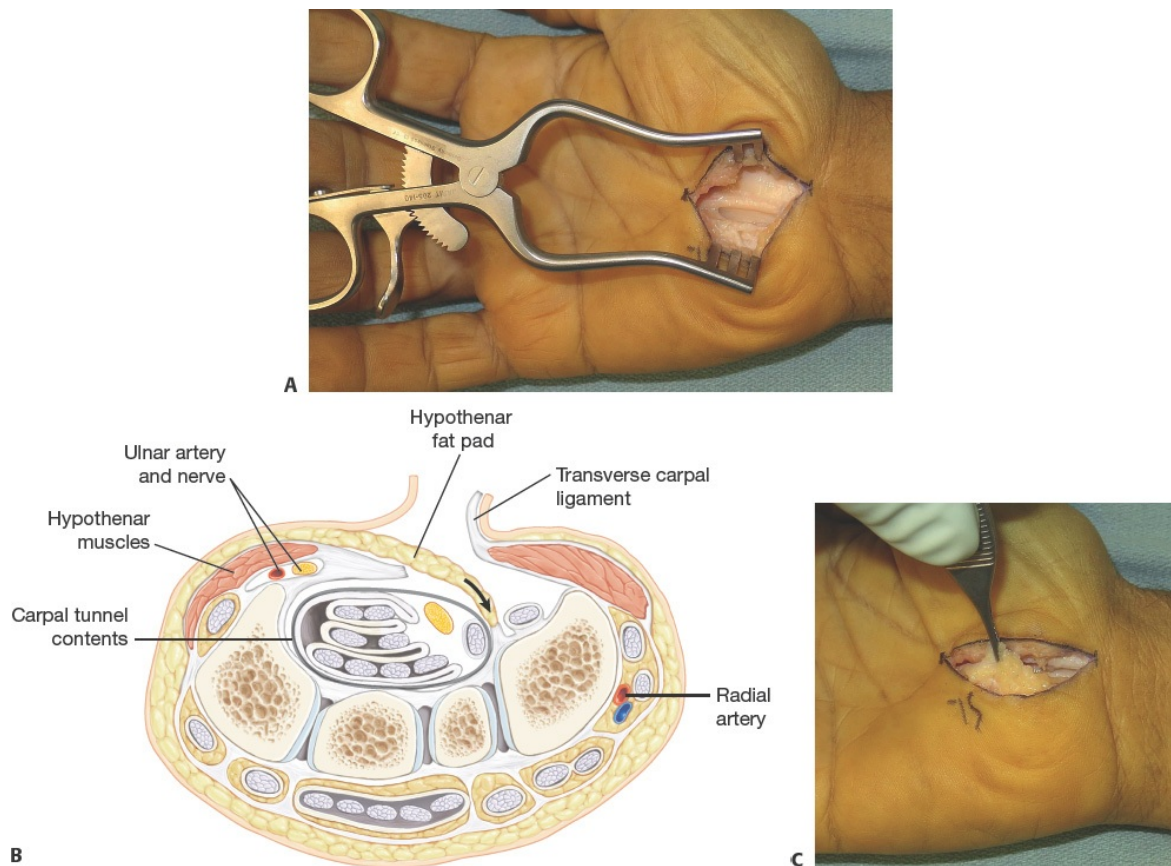


TECH FIG 5 • A. With the blade engaged, division begins at the distal extent of the TCL by slowly withdrawing the device. **B.** Following the initial pass of the blade, much of the TCL has been divided, exposing the overlying pink palmar fascia. Note the band of intact TCL that must be divided with a second pass.

■ Hypothenar Fat Flap

- In cases of recurrent or recalcitrant carpal tunnel syndrome (CTS), excessive scar formation may contribute to entrapment of the nerve. The hypothenar fat flap is a technique to interpose healthy, vascularized tissue over the nerve to prevent recurrence from aggressive scar formation.
- Exsanguinate the arm with an Esmarch bandage, and inflate the tourniquet to 250 mm Hg (or 100 mm Hg over systolic blood pressure).
- Make a linear incision just radial to the hypothenar eminence, and carry dissection down to the carpal tunnel to identify the median nerve.
 - Typically, the hypothenar fat flap is used for the treatment of recalcitrant CTS, so the incision can be made through the previous surgical scar (**TECH FIG 6A**).
- Perform external neurolysis of the median nerve.

- Using sharp dissection, develop a subdermal plane over the adipose tissue of the hypothenar region, being cautious not to make the cutaneous flap too thin. Carry this dissection to the dermal insertion of the palmaris brevis¹² (**TECH FIG 6B**).
- Perform deep dissection under the fat pad, directly over the hypothenar musculature, until the ulnar nerve and artery are visualized.
- Check if the flap has been sufficiently mobilized to be advanced to the radial wall of the carpal tunnel (**TECH FIG 6C,D**).
- If not, carefully perform additional dissection, being careful to preserve the vascular pedicles of the flap and the ulnar neurovascular structures.
- Retract the carpal tunnel contents ulnarly, and place the hypothenar fat pad flap volar to the median nerve and deep to the radial leaf of the TCL. Place horizontal mattress sutures through the flap and into the radial wall of the carpal tunnel. Tag these sutures and sequentially tie them once all have been placed.
- Irrigate the wound and deflate the tourniquet. Achieve meticulous hemostasis.
- Approximate the skin using 4-0 nylon suture in a simple interrupted or horizontal mattress fashion. Apply dressings as described above.



TECH FIG 6 • Hypothenar fat pad flap. **A.** The carpal tunnel has been released, the median nerve has been neurolysed, and a subdermal plane has been developed over the adipose of the hypothenar region. **B.** The hypothenar fat pad flap must be mobilized sufficiently to reach the radial wall of the carpal tunnel. The subdermal plane is developed to the dermal insertion of palmaris brevis, and the deep dissection is carried out just over the musculature until the ulnar neurovascular bundle is visualized. **C.** The elevated hypothenar fat pad flap, prior to inset.

PEARLS AND PITFALLS

Incomplete release	■ Be sure to adequately release the distal TCL in the palm to the level of the palmar fat pad, and the antebrachial fascia for 1–2 cm in the forearm. In endoscopic CTR, check for bands of undivided TCL by palpating with closed tenotomy scissors.
Palmar cutaneous branch injury	■ Make incision ulnar to axis of ring finger. Look out for ulnar cutaneous branch variant.
Recurrent motor branch injury	■ Subligamentous and transligamentous variants are at increased risk specifically with endoscopic CTR. Rare variant that exits median nerve ulnarly and curves distally around TCL is highest risk. ²
Superficial palmar arch injury	■ Located 2–26 mm from the distal edge of TCL, contained in palmar fat pad ¹⁵
Radially located ulnar artery	■ In some patients, the ulnar artery is located radial to the hook of hamate, making it vulnerable during CTR. ¹⁵
Visualization on endoscopy	■ Watch the monitor closely at all times while the endoscopic device is entering, exiting, or within the carpal tunnel.
Anesthesia	■ Endoscopic release is very difficult with local anesthesia, as the liquid anesthetic obscures visualization.

POSTOPERATIVE CARE

- We do not use postoperative splinting, but rather a soft dressing that the patient removes after 24 to 48 hours. We encourage use of the hand right away to encourage nerve gliding and prevent adhesion formation.
- We do not routinely refer our patients to hand therapy postoperatively. Therapy can be useful in specific cases such as desensitization for abnormal postoperative hypersensitivity or if there is stiffness or immobility.

OUTCOMES

- A Cochrane systematic review found that both surgical and nonoperative treatments of CTS are effective, but surgery produces a longer-lasting relief of

symptoms than nonoperative therapies.

- Surgical release yields continued improvement for around 12 months postoperatively, whereas improvements from nonoperative therapies plateau at around 3 months.¹

COMPLICATIONS

- Postoperative recurrence has been reported in 3% to 20% of cases.^{16,17}
- Etiologies of persistence or recurrence include incompletely released TCL, abundant scar formation from a number of causes, neuropathy of other etiology (eg, polyneuropathy), and psychosocial factors.¹⁶
- Serious complications are rare but include injury to the median nerve, recurrent motor branch, or palmar cutaneous branch.
- Other complications include painful or hypertrophic scar, hematoma, infection, and wound healing problems.

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CHAPTER Ulnar Tunnel Syndrome

Mary Claire Manske and Jason H. Ko

DEFINITION

- Ulnar tunnel syndrome, first described by DuPont et al. in 1965, is a compressive neuropathy of the ulnar nerve at the wrist that presents with a variable constellation of sensory and motor symptoms, depending on the site of nerve compression within the ulnar tunnel.¹
- The ulnar tunnel is commonly referred to as Guyon canal after Jean Casimir Felix Guyon, a French surgeon who first described this anatomic space in 1861.²

ANATOMY

- The ulnar tunnel is a fibro-osseous canal that extends from the proximal edge of the volar carpal ligament to the hook of the hamate and the fibrous arch of the hypothenar muscles distally.
- Medially, it is bordered by the pisiform, flexor carpi ulnaris (FCU), and abductor digit minimi; laterally, it is limited by the hook of the hamate, transverse carpal ligament, and extrinsic flexor tendons.
- The roof of the ulnar tunnel is composed of the volar carpal ligament, palmaris brevis, and hypothenar fascia; the floor is formed by the transverse carpal ligament, pisohamate ligament, pisometacarpal ligament, and opponens digiti minimi³ (**FIG 1A**).
- The contents of the ulnar tunnel include the ulnar nerve, ulnar artery and venae comitantes, and fat. The ulnar nerve is ulnar and dorsal to the ulnar artery.
- In the distal forearm, the ulnar nerve travels volar to the flexor retinaculum before entering the ulnar tunnel. Although variations exist,⁴ the ulnar nerve bifurcates within the tunnel into superficial and deep branches approximately 6

mm distal to the distal pole of the pisiform.

- The superficial branch innervates the palmaris brevis and then continues as a sensory nerve, providing sensation to the hypothenar eminence, small finger, and ulnar side of the ring finger.

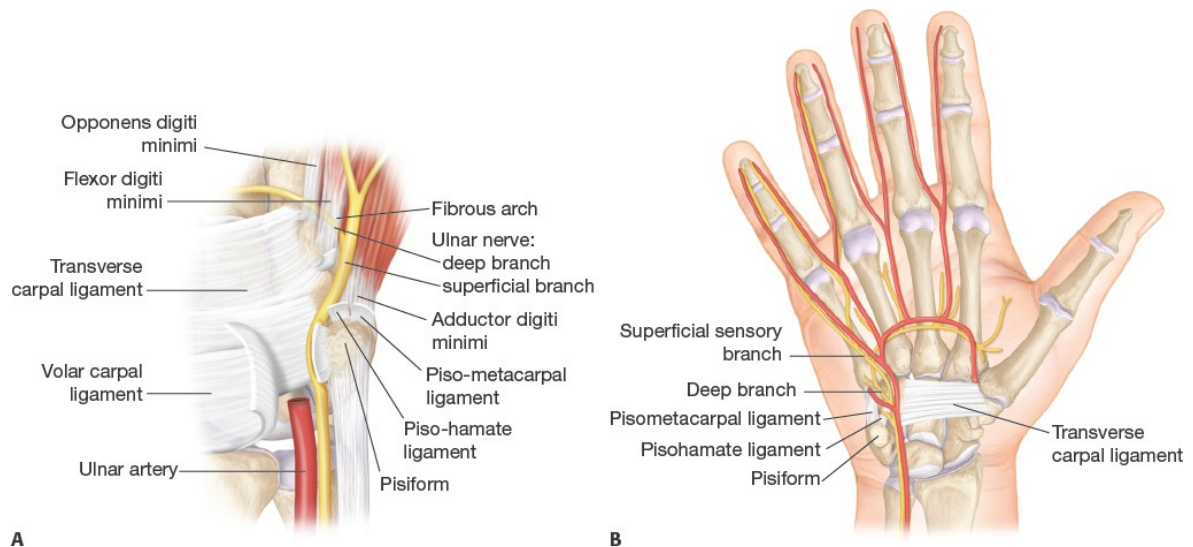


FIG 1 • A. Anatomy of the ulnar tunnel. The ulnar tunnel is defined dorsally by the transverse carpal ligament; volarly by the volar carpal ligament; ulnarly by the pisiform, FCU, and ADM; and radially by the hook of the hamate. **B.** Anatomy of the ulnar nerve in the ulnar tunnel. The dorsoulnar fibers of the ulnar nerve become the deep motor branch innervating the intrinsic hand muscles, while the volar-radial fibers provide sensory fascicles to the small finger and ulnar side of the ring finger.

- After passing through the ulnar tunnel, the deep motor branch of the ulnar nerve runs through the pisohamate hiatus just distal to the ulnar tunnel, which is bordered by the pisohamate ligament dorsally and by the fibrous arch of the hypothenar fascia volarly. The deep motor branch curves around the hook of the hamate to innervate the abductor digiti minimi (ADM), flexor digiti minimi, opponens digiti minimi, interossei, third and fourth lumbricals, adductor pollicis, and flexor pollicis brevis (**FIG 1B**).

- The ulnar nerve at the wrist has been divided into three zones, which can be used to correlate clinical symptoms to the site of compression.^{2,5,6}
- Zone I: From the proximal edge of the volar carpal ligament to the bifurcation of the ulnar nerve into motor and sensory branches. Compression in zone I results in intrinsic muscle weakness and sensory deficits over the hypothenar eminence and small and ring fingers.
- Zone II: From just distal to the bifurcation to the fibrous arch of the hypothenar muscles and contains the deep motor branch of the ulnar nerve. Compression in this zone presents with ulnar-innervated intrinsic motor weakness and intact sensation in the ulnar nerve sensory distribution.
- Zone III: Also begins just distal to the bifurcation and includes the sensory branch of the ulnar nerve. Compression at this level results in diminished sensation in the volar aspect of the small finger and volar ulnar ring finger.

PATHOGENESIS

- Many cases of ulnar tunnel syndrome are idiopathic.⁷ Space-occupying lesions, aberrant musculature, carpal tunnel syndrome, and acute and chronic trauma have also been implicated in the pathogenesis of ulnar nerve compression at the wrist.
- Space-occupying masses in the ulnar tunnel are reported to cause compression of the ulnar nerve or its branches, including ganglia, lipomas, ulnar artery thrombosis, ulnar artery pseudoaneurysm, hemangioma, osteoarthritis and rheumatoid arthritis, edema, proliferative synovitis, and bony deformity.
- Hypertrophic hypothenar muscles or anomalous muscles (hypothenar adductor) may cause ulnar nerve compression.
- Carpal tunnel syndrome may cause compression of the ulnar nerve distally, as increased pressure in the carpal tunnel is transmitted to the adjacent ulnar tunnel.
 - Seventy-one percent of patients with ulnar tunnel syndrome have a concomitant diagnosis of carpal tunnel syndrome.⁷
- Fractures and dislocations
 - Hook of hamate fractures: Fracture displacement or associated hematoma and edema may compress the ulnar nerve.
 - Dorsally displaced distal radius fractures and other carpal fractures can cause ulnar nerve palsies secondary to traction on the ulnar nerve or edema.
- Chronic compression

- “Handlebar palsy” in long-distance cyclists who place prolonged pressure on the hypothenar area
- Chronic repetitive microtrauma or vibration
 - “Hypothenar hammer syndrome” in patients who use high-impact vibratory equipment with the wrist extended (eg, jackhammer) results in direct trauma to the ulnar artery leading to thrombosis, which may compress the ulnar nerve and/or cause ischemia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History and physical examination findings may be purely sensory, purely motor, or mixed sensory and motor, depending on the location of pathology.
- History
 - Sensory complaints: numbness and/or paresthesias in small and ring finger
 - Patients with ulnar tunnel syndrome do not present with sensory disturbance over the dorsal aspect of the hand, given that the dorsal sensory branch of the ulnar nerve supplying this area branches from the ulnar nerve proximal to the ulnar tunnel.
 - Cold intolerance or pain in the ring and small fingers
 - Motor deficits: clumsiness, loss of coordinated hand function, weakness of pinch and grasp, clawing
 - History of trauma
 - Acute: direct blow or sports injury (consider fractures, dislocation)
 - Chronic: use of power tools, cycling (consider ulnar artery thrombosis, pseudoaneurysm, or compression)
 - Comorbid medical conditions: rheumatoid arthritis, osteoarthritis, diabetes mellitus, carpal tunnel syndrome
- Physical Examination
 - Inspection: intrinsic muscle atrophy/wasting or clawing; mass or fullness; ecchymosis, swelling, or other evidence of trauma; compare to contralateral upper extremity
 - Palpation: tenderness may indicate fracture; identify presence of a mass (ganglia, lipomas)
 - Sensory exam: decreased sensation to light touch in small and ulnar ring finger; Semmes-Weinstein monofilament or two-point discrimination test
 - Motor exam: intrinsic motor weakness, index finger abduction (assessment of the first dorsal interosseous muscle), or the cross-finger test (asking the

patient to cross the middle finger over the index finger to assess the first volar and second dorsal interossei)

■ Special motor tests

- Froment sign: Positive test when patient is unable to use adductor pollicis for lateral pinch. Instead, patients compensate with the median nerve innervated flexor pollicis longus to flex the thumb interphalangeal joint. Positive test indicates dysfunction of ulnar nerve motor fibers, although it does not localize the site of the lesion.
- Jeanne test: Test is positive, indicating ulnar motor neuropathy, when the patient hyperextends the metacarpophalangeal joint to compensate for weak adductor pollicis during lateral pinch.
- Wartenberg sign: Inability to adduct the small finger secondary to paralysis of the third palmar interosseous muscle. Positive test indicates an ulnar motor neuropathy.

■ Vascular exam: palpation of radial and ulnar artery pulses, bruits, or thrills; Doppler examination of radial and ulnar artery; Allen test to assess ulnar artery patency

■ Provocative tests: Tinel and Phalen test over pisiform (Phalen test over pisiform is more sensitive than Tinel for ulnar tunnel syndrome)⁸

■ Must rule out alternative sites of nerve compression: cubital tunnel syndrome, carpal tunnel, cervical radiculopathy, thoracic outlet syndrome

IMAGING

■ Electrodiagnostic studies are indicated in nearly all patients with a suspected diagnosis of ulnar tunnel syndrome. The need for additional imaging is determined by the suspected structural etiology of the patient's ulnar tunnel symptoms; bony pathology requires x-ray and/or CT scan; vascular pathology should be evaluated with ultrasound or contrast arteriography; soft tissue masses should be worked up with an MRI. In addition, elbow or cervical spine imaging (x-rays, MRI) may be indicated if there is concern for more proximal pathology.

■ Electrodiagnostic studies are useful to confirm and localize ulnar nerve entrapment.

- Conduction velocity of the ulnar nerve across the elbow and the wrist can determine the location of ulnar nerve entrapment (elbow, wrist, zone I, II, or III).
- The most sensitive electrodiagnostic study for ulnar tunnel syndrome is the

distal motor latency to the first dorsal interosseous combined with conduction velocity across the wrist (90% sensitivity).⁹

- Zone I lesions are characterized by decreased sensory responses and prolonged latency to the first dorsal interosseous and ADM. Zone II lesions show prolonged latency to the first dorsal interosseous (and possibly hypothenar muscles) with normal sensory findings. Zone III lesions show only decreased ulnar sensory responses without motor deficits.¹⁰

■ Radiographic studies

- Posteroanterior, lateral, and oblique views of the wrist are useful when fracture or dislocation is the suspected etiology of the patient's ulnar nerve symptoms.
- A 30-degree supinated oblique view with the thumb abducted or carpal tunnel view is useful when there is clinical concern for pisotriquetral joint pathology or hook of the hamate fracture, respectively.
- The indication for obtaining a CT scan in the setting of ulnar tunnel symptoms is similar to that for x-rays. CT scan is particularly useful in detecting hook of hamate fractures.
- Magnetic resonance imaging is useful for identifying and localizing soft tissue masses, aberrant musculature, vascular anomalies, and hook of hamate fractures.
- Ultrasound has similar indications to MRI but is less costly.¹¹
- Arteriography serves as the standard for evaluating ulnar artery pathology (eg, thrombosis, pseudoaneurysm).¹²

DIFFERENTIAL DIAGNOSIS

- Cubital tunnel syndrome or proximal compression of the ulnar nerve
- Carpal tunnel syndrome
- Cervical radiculopathy
- Neuromuscular disorders (Charcot-Marie-Tooth, amyotrophic lateral sclerosis)
- Malignant peripheral nerve sheath tumors
- C8-T1 brachial plexopathy
- Central nerve system lesion
- Poliomyelitis

NONOPERATIVE MANAGEMENT

- Nonoperative management consisting of activity modification, rest, and a short

course of bracing in a neutral wrist splint may be considered in patients without motor symptoms.

- Activity modification for ulnar tunnel symptoms secondary to hypothenar eminence compression. Cyclists with handlebar palsy may modify the position of their handlebars to prevent the compression of the ulnar base of the palm.
- Patients with hypothenar hammer syndrome without thrombosis and symptoms of digital ischemia may attempt nonoperative intervention, consisting of the following:
 - Smoking cessation, avoidance of trauma, protective gloves, change of occupation, cold avoidance, and calcium channel blockers¹³
- Cortisone injections are not indicated for ulnar tunnel syndrome because inflammation is rarely the cause of ulnar tunnel syndrome and there is a high risk of neurovascular injury when injecting into this confined space.

SURGICAL MANAGEMENT

- Indications:
 - Failure of nonoperative intervention
 - Loss of two-point discrimination
 - Presence of intrinsic muscle weakness or atrophy
 - Severe electrodiagnostic abnormalities
- Operative intervention for ulnar tunnel syndrome consists of ulnar nerve decompression through the distal ulnar tunnel. Additional procedures may be performed as needed to address the causative pathology.
 - Space-occupying mass requires mass excision in addition to ulnar nerve decompression in the ulnar tunnel.
 - Ulnar artery thrombosis or aneurysm should be treated with artery reconstruction and ulnar nerve decompression.
 - Ulnar tunnel syndrome secondary to carpal tunnel syndrome often improves with carpal tunnel release alone, and additional release of the ulnar tunnel is not recommended.
- Optimal outcomes are achieved when all sources of pathology are addressed.

Preoperative Planning

- Indications for operative intervention include failure of nonoperative intervention, motor weakness or loss of two-point sensibility in the ulnar nerve distribution due to ulnar nerve compression distally, or severe electrodiagnostic

changes involving the ulnar nerve at the wrist.

- Electrodiagnostic studies should be reviewed to confirm the precise location of ulnar nerve compression and appropriate site of decompression.
- Relevant imaging studies must be reviewed to allow the surgeon to address all etiologies of ulnar nerve symptoms.

Positioning

- Patients are positioned supine on a well-padded operating table with the affected limb on a hand table.
- The operating table is turned so that the hand table faces the center of the room.
- A nonsterile tourniquet is applied to the affected upper extremity.

Approach

- A volar approach to the ulnar nerve at the wrist is the most direct approach and allows accesses to the relevant pathology.

TECHNIQUES

■ Ulnar Tunnel Release and Ulnar Nerve Decompression

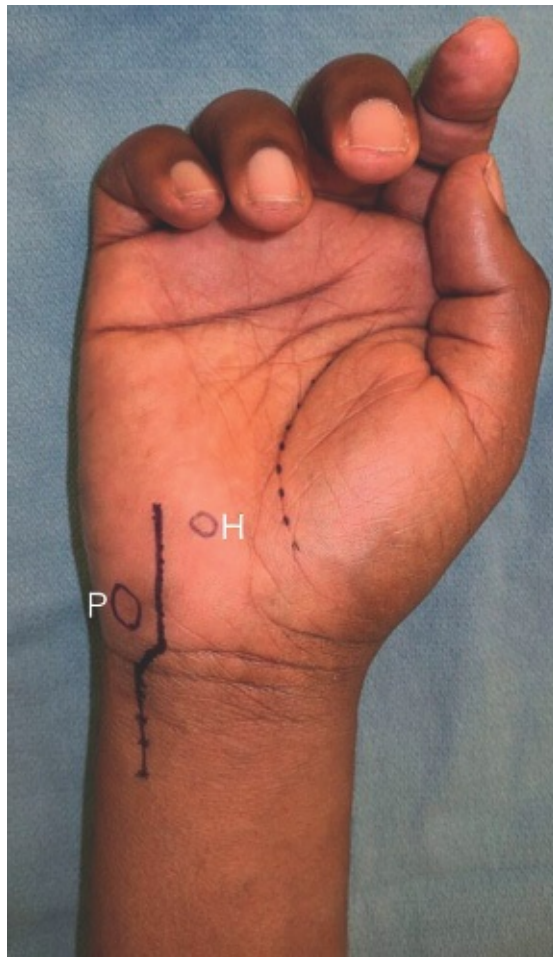
Exposure

- Operative limb is elevated and exsanguinated with an elastic bandage immediately prior to tourniquet elevation.
- Alternatively, or in addition to a tourniquet, 0.25% bupivacaine with epinephrine can be injected into the planned incision site for postoperative comfort and intraoperative hemostasis.
- Identify landmark for incisions: The pisiform is easily palpated in the ulnar base of the palm. The hook of the hamate is located 1 cm distal and 1 cm radial to the pisiform and can be palpated.
- A no. 15 blade scalpel is used to make a 4-cm longitudinal or curvilinear incision through the skin paralleling the thenar crease between the pisiform and hook of the hamate, approximately 6 mm ulnar to the thenar crease (**TECH FIG 1**).

- To extend proximally into the forearm, the incision should cross the wrist crease obliquely and may continue proximally adjacent to the flexor carpi ulnaris tendon.
- To extend the incision distally into the palm, the incision may be extended in a zigzag or Bruner fashion.

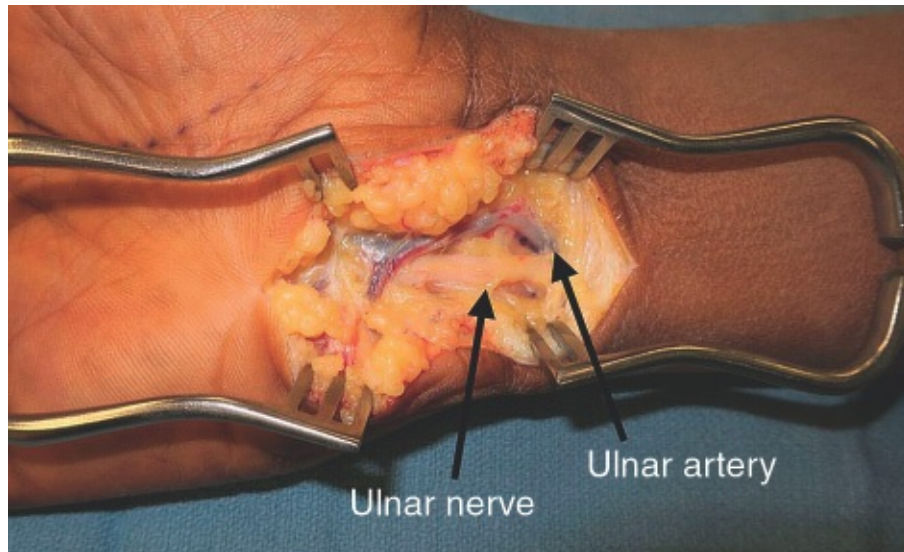
Dissection

- Tenotomy scissors are used to dissect through the subcutaneous tissue, and gentle skin retraction is provided by two double-prong skin hooks.



TECH FIG 1 • Incision for ulnar tunnel release. In the palm, a longitudinal incision is centered between the pisiform and hook of the hamate. The incision crosses the wrist flexion crease obliquely before extending proximally adjacent to the flexor carpi ulnaris (FCU)

tendon. *P*, pisiform; *H*, Hook of hamate.



TECH FIG 2 • In the forearm, the ulnar neurovascular bundle is identified deep to the antebrachial fascia between the FCU tendon and tendons of the finger flexors. At this location, the ulnar nerve is deep and ulnar to the artery.

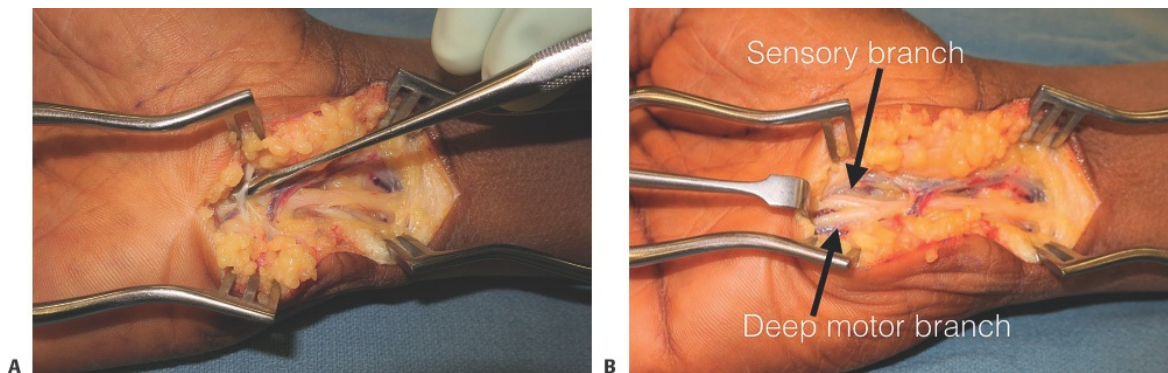
- A cutaneous branch of the ulnar nerve crosses the distal aspect of the incision in 15% of patients. Care must be taken to identify and protect this nerve to avoid a painful neuroma if injured.
- Dissection continues until the volar carpal tunnel and palmaris brevis are identified.
- Proximally in the forearm, the ulnar neurovascular bundle is identified deep to the antebrachial fascia between the flexor carpi ulnaris and the finger flexor tendons. The ulnar nerve is located ulnar and deep to the ulnar artery (**TECH FIG 2**).

Ulnar Nerve Decompression

- The ulnar nerve is carefully dissected from proximal to distal, through the ulnar tunnel.
- The volar carpal ligament and palmaris brevis (roof of the ulnar tunnel) are incised, staying ulnar to the hook of the hamate, so as not to inadvertently

enter the carpal tunnel.

- Within the ulnar tunnel, the ulnar nerve is gently retracted medially to identify and decompress the deep motor branch.
- To identify the deep motor branch, locate the oblique fibers of the proximal edge of the hypothenar fascia. Immediately proximal to this leading edge, 1 to 2 mm of the deep motor branch is visible as it dives deep to the hypothenar fascia to enter the pisohamate hiatus and curves around the hook of the hamate.
- A small blunt elevator may be placed deep to the proximal edge of hypothenar fascia to protect the deep motor branch, and this fascia is then released (**TECH FIG 3A**).
- The deep motor branch is then followed around the hook of the hamate, and all tendinous bands of the hypothenar musculature must also be divided (**TECH FIG 3B**).
- If the deep motor branch is compressed more distally in the palm, it may be followed along the interosseous fascia (deep to the flexor tendons and superficial palmar arch) to its terminus in the adductor pollicis.



TECH FIG 3 • A. A Freer elevator has been placed beneath the leading edge of the hypothenar fascia. **B.** The sensory branch and deep motor branch of the ulnar nerve have been decompressed.

- Within the canal, care must be taken to protect the small vessels running with the motor branch.
- After releasing the ulnar nerve and the deep motor branch, the floor of the ulnar tunnel is evaluated for masses or anomalous muscles, which are then

excised. In the case of a ganglion cyst, the stalk of the cyst is identified and ablated at its origin.

- After the ulnar nerve and its distal branches have been decompressed, the wound is thoroughly irrigated with sterile saline and the tourniquet deflated. Meticulous hemostasis is achieved with bipolar electrocautery.

Wound Closure and Dressing

- The incision is closed with 4-0 nylon suture in a horizontal or simple interrupted fashion.
- If local anesthetic, such as 0.25% bupivacaine, has not previously been injection, it may be injected into the incision site at this time for postoperative comfort.
- A nonadherent dressing is applied directly to the wound, and a sterile, bulky soft dressing is placed.
- Typically, a splint is not needed, unless a ganglion cyst was excised or the dissection was extensive.

PEARLS AND PITFALLS

Diagnosis	Evaluate for extrinsic sources of compression based on suspected pathology. ■ Osseous pathology: radiographs, CT ■ Vascular pathology: Ultrasound, contrast arteriogram ■ Soft tissue mass: MRI
Incision	■ Fifteen percent of patients have a cutaneous branch of the ulnar nerve in the distal aspect of this incision. Avoid injury to the nerve here to prevent a painful neuroma.
Entering the ulnar tunnel	■ Stay ulnar to the hook of the hamate to avoid entering the carpal tunnel.
Identification of the deep motor branch	■ Identify the oblique fibers of the hypothenar fascia at the proximal edge of the hypothenar muscles and carefully release these fibers to expose and decompress the ulnar motor branch.
Release of	■ Ensure complete nerve decompression, including complete release

**the deep
motor branch**

of the tendinous bands of the hypothenar muscles.

Hemostasis

- Preserve the small vessels running with the deep motor branch to avoid having to cauterize vessels adjacent to the nerve.
-

POSTOPERATIVE CARE

- Apply a soft bulky dressing to the wrist postoperatively, and active range of motion can be initiated immediately to minimize scarring around the nerve.
- The bulky surgical dressing is removed on postoperative day 1 or 2 and replaced with a clean gauze dressing or bandage, if necessary.
- Night splinting with the wrist in a neutral position may be used for 2 weeks for patient comfort.
- Strengthening exercises may be initiated at 4 to 6 weeks. Patients may gradually increase activities as tolerated at this time.

OUTCOMES

- There are limited data on the outcome of ulnar tunnel release and decompression.
- Murata et al. retrospectively reported their outcomes in 31 patients with ulnar tunnel syndrome with a variety of causes treated with ulnar tunnel decompression.⁷
 - The authors reported improvement in subjective symptoms and two-point discrimination in all patients (from a preoperative mean of 7.0 and 6.9 mm in the ring and small fingers, respectively, to 5.4 and 5.3 mm postoperatively), although no statistical analysis was provided.
 - Five patients had persistent symptoms in the ring and/or small fingers.

COMPLICATIONS

- There are few studies reporting the type and incidence of complications of ulnar tunnel release.
- Potential complications include the following:
 - Incomplete relief of symptoms (persistent numbness, weakness)
 - Iatrogenic injury to the ulnar nerve or artery branches, especially to the deep motor branch as it enters the pisohamate hiatus
 - Hematoma resulting from injury to vascular plexus around the ulnar nerve branches and failure to achieve hemostasis prior to wound closure

- Wound infection
- Wound dehiscence
- Meticulous hemostasis, careful dissection, and knowledge of the ulnar nerve and artery branching anatomy and its variations are helpful in avoiding complications.

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CHAPTER Cubital Tunnel Syndrome

Mary Claire Manske and Jason H. Ko

DEFINITION

- Cubital tunnel syndrome is symptomatic ulnar nerve dysfunction resulting from a combination of compression, traction, friction, and nerve instability at or near the elbow.
- The cubital tunnel is a fibro-osseous canal through which the ulnar nerve passes at the level of the medial elbow and is thought to be the most common site of nerve pathology.

ANATOMY

- The ulnar nerve is composed of fibers from the C8 and T1 nerve roots, although additional contributions from the C5, C6, C7, or T2 roots are common.
 - It arises from the medial cord of the brachial plexus and enters the arm by passing deep to the pectoralis major muscle, medial to the brachial artery.
- At 8 to 10 cm proximal to the medial epicondyle, the nerve pierces the medial intermuscular septum from anterior to posterior and descends through the arm along the posterior aspect of the medial intermuscular septum.
 - At this location, there is often a thick fascial band (the internal brachial ligament) spanning from the medial intermuscular septum to the medial head of the triceps, commonly referred to as the arcade of Struthers (**FIG 1**).
- The ulnar nerve travels posterior to the elbow via the cubital tunnel to enter the anterior forearm. The cubital tunnel is a fibro-osseous space bordered by the medial epicondyle anteriorly, the olecranon posteriorly, the oblique and posterior bands of the ulnar collateral ligament medially (the “floor” of the tunnel), and Osborne (or arcuate) ligament laterally (the “roof” of the tunnel).

Within the cubital tunnel, the ulnar nerve commonly provides articular branches to the elbow and motor branches to the flexor carpi ulnaris (FCU) (between 1 and 4 branches, arising from 4 cm proximal to the elbow to 10 cm distal to the medial epicondyle). The ulnar nerve provides motor branches to the ulnar two flexor digitorum profundus, which arise approximately 3 cm distal to the medial epicondyle.

- After passing through the cubital tunnel, the ulnar nerve travels deep to the fibrous aponeurosis of the FCU to pass between the two heads of the FCU and into the forearm along the undersurface of the FCU into the distal forearm.

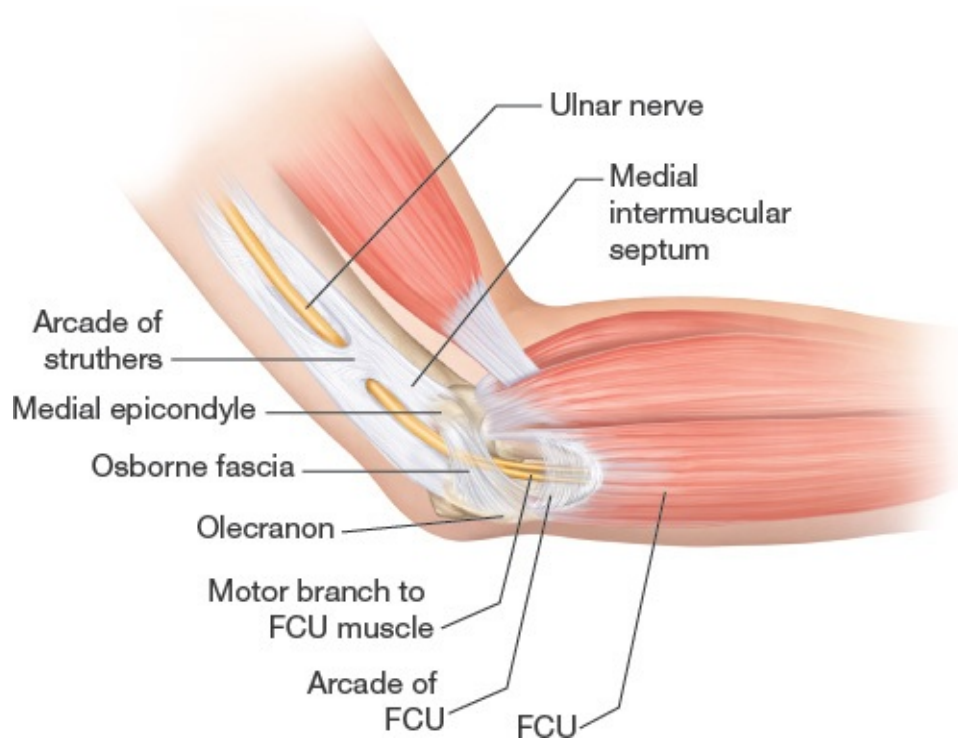


FIG 1 Anatomy of the cubital tunnel.

PATHOGENESIS

- Four pathogenic mechanisms have been implicated in cubital tunnel syndrome: compression, traction, friction, and instability.
- Compression: The ulnar nerve may be compressed anywhere along its course, but the most common clinical sites of compression are the arcade of Struthers, the median intermuscular septum, medial epicondyle, anconeus epitrochlearis (if present), the cubital tunnel, and the deep flexor-pronator aponeurosis

- The cubital tunnel is round and spacious with elbow extension but narrows and becomes elliptical with the elbow flexed, decreasing the volume of the tunnel by 55%.^{1,2}
- Decreased cubital tunnel volume results in a four- to fivefold increase in extra- and intraneural pressure of the ulnar nerve.³
- Both blood flow and axonal transport are impaired with external nerve compression; as pressure increases, the nerve tissue thickens and nerve conduction is impaired.^{1,4-6}
- Less common sources of ulnar nerve compression include soft tissue masses (eg, ganglia, tumors), hypertrophic synovium, cubitus valgus, and osteophytes.
- Traction⁷: The course of the ulnar nerve around the medial epicondyle places tension on the ulnar nerve where it crosses the elbow and enters the forearm.
 - The ulnar nerve elongates by 4 to 8 mm when the elbow is flexed. This stretch is further increased with the shoulder abducted and the wrist extended.
 - Stretch of the ulnar nerve results in both reduced blood flow and impaired conduction.
- Friction: Although the nerve naturally experiences some traction and excursion with elbow motion, repetitive elbow motion or subluxation of the nerve can cause traction neuritis, inflammation, and endoneurial edema, decreasing the nerve's ability to glide smoothly.¹
- Instability: Subluxation of the ulnar nerve out of the cubital tunnel or over the medial epicondyle may result in elbow pain, a snapping sensation, numbness, or intrinsic motor weakness.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Sensory
 - Numbness and paresthesia in the ring and small finger
 - Dorsoulnar hand numbness helps differentiate cubital tunnel syndrome/proximal ulnar nerve compression from ulnar tunnel syndrome at the wrist.
 - Presence of numbness or paresthesia in the medial forearm distinguishes C8 radiculopathy from cubital tunnel syndrome.
 - Depending on severity and chronicity, numbness may be intermittent or constant.

- Motor
 - Hand clumsiness, loss of dexterity
 - Weakness of pinch and grip
 - Inability to adduct or abduct the fingers
 - Intrinsic muscle atrophy, clawing of the ulnar two digits, with severe ulnar nerve compression
 - Pain in the medial elbow or forearm
- Physical exam
 - Inspection: Intrinsic muscle atrophy/wasting or clawing; compare to contralateral upper extremity
 - Palpation: Medial elbow tenderness; subluxation or perching of ulnar nerve over medial epicondyle with elbow flexion and extension
 - Sensory exam: Decreased sensation to light touch in small and ulnar ring finger; decreased sensation over dorsoulnar hand. Semmes-Weinstein monofilament or 2-point discrimination test
 - Motor exam: Intrinsic motor weakness indicates compromise of ulnar motor nerve fibers. Assess by testing index finger abduction (first dorsal interosseous muscle) or performing the cross-finger test (asking the patient to cross the middle finger over the index finger to assess the first volar and second dorsal interossei).
 - Additional motor tests:
 - Froment sign: Positive test when patient is unable to use adductor pollicis for lateral pinch. Instead, patients compensate with the flexor pollicis longus, which is innervated by the median nerve, to flex the thumb interphalangeal joint. Positive test indicates dysfunction of ulnar nerve motor fibers, although it does not localize the site of the lesion.
 - Jeanne test: Test is positive, indicating ulnar motor neuropathy, when the patient hyperextends the metacarpophalangeal joint to compensate for weak adductor pollicis during lateral pinch.
 - Wartenberg sign: Inability to adduct the small finger secondary to paralysis of the third palmar interosseous muscle. Positive test indicates an ulnar motor neuropathy.
 - Provocative tests:
 - Tinel sign at elbow: Percussion over ulnar nerve at medial epicondyle reproduces paresthesias in ring and small finger in patients with cubital tunnel syndrome.

- Elbow flexion test: Elbow flexion, forearm supination, and wrist extension for 3 minutes elicit paresthesia in ulnar nerve distribution in patients with cubital tunnel syndrome.
- Pressure provocation test: Manual pressure over ulnar nerve in cubital tunnel elicits ulnar nerve paresthesia.
- Scratch collapse test⁸: Examiner scratches the skin over the compromised ulnar nerve while the patient performs sustained resisted shoulder external rotation with the arms adducted and the elbow flexed. A positive test is indicated by brief loss of ability to maintain resisted external resistance (ie, collapse).
- Must rule out alternative sites of nerve compression:
 - Guyon canal (tenderness over hook or hamate or pisiform)
 - Cervical radiculopathy (neck pain, Spurling test, more proximal motor and sensory involvement)
 - Carpal tunnel syndrome (thenar atrophy or weakness; sensory disturbance in radial-sided digits; Tinel, Phalen, Durkan test positive over carpal tunnel)
 - Lower brachial plexus lesion
 - Thoracic outlet syndrome (Roos test, Adson maneuver)

IMAGING

- Electrodiagnostic testing is useful to confirm a diagnosis of ulnar nerve dysfunction, localize the site of compression, and quantify the severity.
- The following criteria are used to diagnose cubital tunnel syndrome electodiagnostically⁹:
 - Absolute conduction velocity less than 50 m/s
 - Decreased conduction velocity of greater than 10 m/s across the elbow
 - Decreased amplitude of at least 20%
 - Absent sensory response
 - Evidence of motor atrophy
- X-rays should be obtained selectively when there is clinical concern for an osseous abnormality causing ulnar nerve compression.
- Elbow radiographs are useful in suspected cases of elbow osteoarthritis, rheumatoid arthritis, trauma, or cubitus valgus deformity
- Chest radiographs may identify a cervical rib causing thoracic outlet syndrome or a Pancoast tumor (suspected in patients with ulnar nerve

symptoms, shoulder pain, and history of smoking)

- On ultrasound, patients with cubital tunnel syndrome have an increased cross-sectional area of the ulnar nerve compared to patients without cubital tunnel syndrome.
- Ulnar nerve cross-sectional area of 0.10 cm^2 or higher on ultrasound of the ulnar nerve within 4 cm of the medial epicondyle is 93% sensitive and 98% specific for cubital tunnel syndrome.¹⁰
- Morphologic and signal changes in the ulnar nerve have been observed on MRI in cubital tunnel syndrome.
- MRI has been reported to be both sensitive and specific in diagnosing cubital tunnel syndrome but is not routinely used.^{11,12}

DIFFERENTIAL DIAGNOSIS

- Cervical radiculopathy
- Ulnar tunnel syndrome
- Lower brachial plexopathy
- Motor neuron disease (eg, amyotrophic lateral sclerosis, Charcot-Marie-Tooth)
- Guillain-Barré syndrome
- Diabetic neuropathy

NONOPERATIVE MANAGEMENT

- Initial treatment of cubital tunnel syndrome in patients without constant numbness or motor atrophy is nonoperative.
- Nonoperative treatment consists of patient education, activity modification (discontinue triceps exercises, pad medial elbow when resting on a hard surface), postural modification (avoidance of prolonged elbow flexion or resting medial elbow on a hard surface), night splinting (to prevent the elbow from flexing beyond 40 to 50 degrees during sleep), and/or nerve gliding exercises.¹³
- The recommended duration of nonoperative treatment is 3 months in patients with mild or moderate symptoms and 6 weeks in patients with severe symptoms.
- A comprehensive course of nonoperative intervention has been shown to resolve symptoms in 42% of patients with mild cubital tunnel syndrome, 34% of patients with moderate symptoms, and 20% of patients with severe symptoms.¹⁴

- Steroid injection is not recommended, as this has not been shown to provide any benefit in the treatment of cubital tunnel syndrome and presents a risk of nerve injury.¹⁵

SURGICAL MANAGEMENT

Preoperative Planning

- Indications for operative intervention include failure of nonoperative intervention, muscle atrophy or weakness, loss of two-point sensibility in the ulnar nerve distribution, or severe electrodiagnostic changes involving the ulnar nerve in the proximity of the elbow.¹⁶
- Assess stability of ulnar nerve preoperatively, as this guides surgical intervention; patients with ulnar nerve instability are not candidates for in situ decompression.

Positioning

- Patients are positioned supine on a well-padded operating table or stretcher.
- The operative extremity is positioned on a hand table. The patient's shoulder should be placed as close to the hand table as possible.
- We recommend against the use of a nonsterile tourniquet, as this may encroach upon the surgical field when anterior transposition is required.

Approach

- A direct approach to the ulnar nerve on the medial side of the elbow is utilized.

TECHNIQUES

■ In Situ Cubital Tunnel Decompression

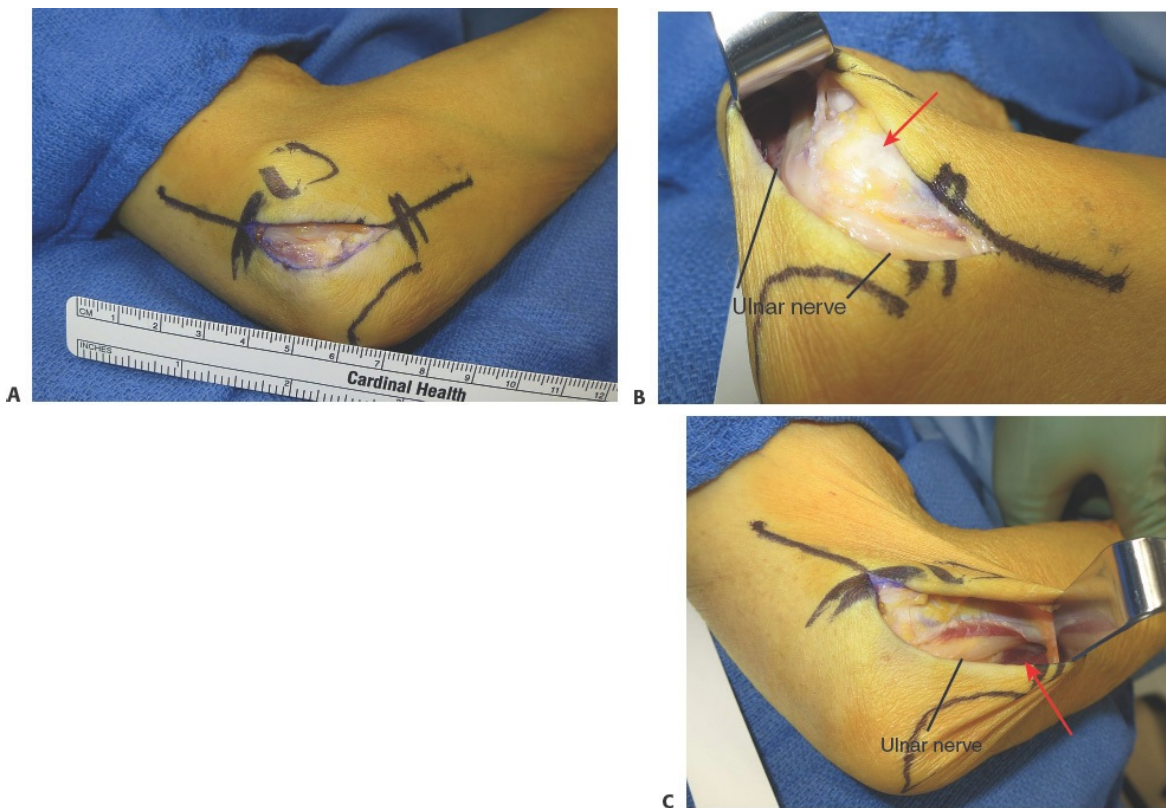
- After the operative limb is prepped and draped, a surgical marking pen is used to mark the medial epicondyle, olecranon, and medial intermuscular septum. If a tourniquet is used, a sterile tourniquet should be applied to the upper extremity as proximally as possible. An alternative to the tourniquet is to inject the planned incision subcutaneously with local anesthetic containing epinephrine.
- If a tourniquet is used, the extremity is exsanguinated with an elastic

bandage and the tourniquet elevated to 250 mm Hg.

- A 3- to 5-cm incision along the course of the ulnar nerve midway between the medial epicondyle and olecranon is made with a scalpel just through the dermis (**TECH FIG 1A**).
- The subcutaneous tissues are dissected with tenotomy scissors in line with the skin incision down to the level of the deep brachial fascia proximally and the antebrachial fascia distally.
- Care must be taken to identify and protect branches of the medial antebrachial cutaneous (MABC) nerve, which lie within the subcutaneous fat just over the muscle fascia from 6 cm proximal to 6 cm distal to the medial epicondyle.¹⁷
- The ulnar nerve is identified proximally, deep to the deep brachial fascia and posterior to the medial intermuscular septum.
- The fascia overlying the ulnar nerve proximally is released, beginning 8 cm proximal to the medial epicondyle (**TECH FIG 1B**).
- The nerve is followed distally, releasing the overlying fascia bands to decompress the nerve. Specific structures released include the arcade of Struthers, deep brachial fascia, Osborne ligament, and deep flexor-pronator aponeurosis. Care is taken not to dissect around the ulnar nerve circumferentially.
- The deep flexor-pronator aponeurosis should be released for a minimum of 4 cm distal to where the ulnar nerve enters the forearm between the two heads to the flexor carpi ulnaris (FCU).
- With blunt digital dissection, a finger should be passed along the course of the ulnar nerve as it passes deep to the flexor-pronator mass to ensure that all constricting bands of the deep flexor-pronator aponeurosis have been released (**TECH FIG 1C**).
- Following decompression, the ulnar nerve is not displaced from its bed, nor is a neurolysis performed.
- The elbow is taken through its full arc of motion, and the stability of the ulnar nerve is assessed.
 - If the nerve subluxates or perches on the medial epicondyle, an anterior transposition should be performed.
 - In addition, evaluation for any residual points of ulnar nerve compression should be performed. In particular, the medial intermuscular septum should be examined to ensure the nerve does not kink on the septum with elbow

range of motion; if it does, that section of the medial intermuscular septum should be excised, with care to cauterize or ligate the branches of the profunda brachii artery that cross the septum.

- If a tourniquet has been used, it is released and meticulous hemostasis obtained with bipolar electrocautery.
- The skin may be injected with local anesthetic if this was not performed previously.
- The dermis is closed with a 3-0 absorbable suture in a buried interrupted fashion. The skin is closed with an absorbable monofilament suture.
- A bulky soft dressing is applied and elbow range of motion is initiated within the first few days postoperatively. Patients are permitted to perform light activities of daily living (eg, dressing, self-care, feeding) but no heavy lifting or sports for 2 weeks.



TECH FIG 1 • **A.** A 3- to 5-cm incision is made along the course of the ulnar nerve centered between the medial epicondyle and the olecranon. **B.** The fascia overlying the ulnar nerve proximally is released,

beginning 8 cm proximal to the medial epicondyle (*red arrow*) and proceeding distally. **C.** The deep aponeurosis of the flexor-pronator mass is released over the ulnar nerve, as it dives between the two heads of the FCU (*red arrow*). (Proximal is to the left and distal to the right in all parts.)

■ **Transposition of the Ulnar Nerve**

- Typically, in situ decompression of the ulnar nerve is the first-line treatment for cubital tunnel syndrome.
- However, if there is subluxation of the ulnar nerve, subcutaneous or submuscular transposition of the ulnar nerve may be indicated at the time of decompression.
- For the treatment of recurrent cubital tunnel syndrome, subcutaneous or submuscular transposition of the ulnar nerve is the treatment of choice.
 - Submuscular transpositions are usually reserved for patients who have failed previous subcutaneous transposition.
- The operative extremity is prepped and draped in the usual sterile fashion.
- A sterile tourniquet may be applied to the operative extremity as proximally as possible. An alternative to the tourniquet is to inject the planned incision with local anesthetic containing epinephrine.
- A surgical marking pen is used to mark the anatomic landmarks: medial epicondyle, olecranon, and medial intermuscular septum.
- If a tourniquet is used, the limb is exsanguinated with an elastic bandage and the tourniquet is elevated to 250 mm Hg.
- A 10-cm incision is made over the course of the ulnar nerve centered between the medial epicondyle and olecranon. Proximal to the medial epicondyle, the incision is made along the palpable course of the medial intermuscular septum. Distally, the incision follows the course of the ulnar nerve as it travels between the two heads of the FCU.
- An ulnar nerve decompression is performed as described above for in situ ulnar nerve decompression.
- A half-inch latex-free Penrose drain is placed around the nerve to allow it to be manipulated atraumatically. The ends of the Penrose drain are sutured

together with 4-0 nylon suture.

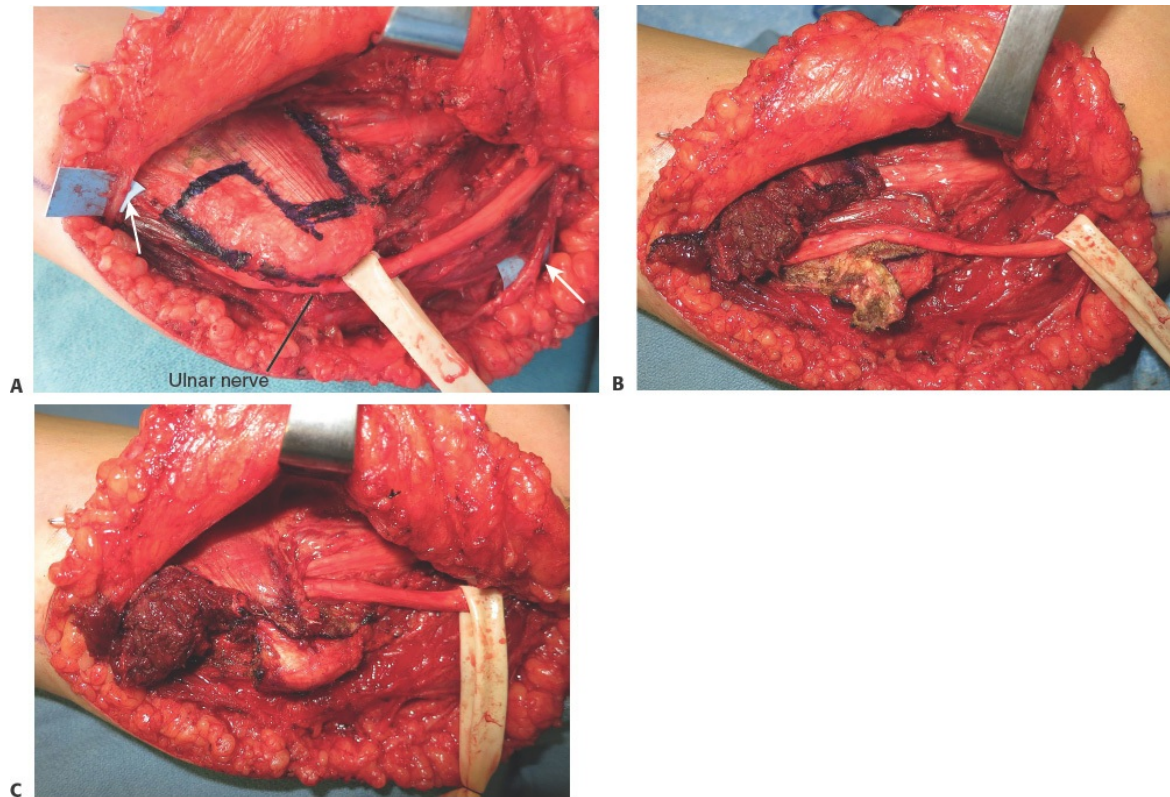
- We recommend against using a vessel loop around the nerve or placing a hemostat clamp on the Penrose drain, as both of these may cause unnecessary trauma to the nerve and increase the likelihood of a neurapraxic injury.
- Using tenotomy scissors, the ulnar nerve is circumferentially dissected to free it from surrounding tissues and the bed in which it rests.
- The longitudinally running superior ulnar collateral vessels that accompany the nerve should remain with the nerve as distally as possible, but it is necessary to ligate the vessels as they penetrate the FCU muscle belly.
- To avoid compression of the nerve by the medial intermuscular septum after it is transposed, the distal segment of the medial intermuscular septum should be excised from its insertion on the humerus. Branches of the profunda brachii artery cross the septum, and these need to be ligated or cauterized.

Submuscular Transposition of the Ulnar Nerve

- The subcutaneous tissues are elevated off the flexor-pronator fascia.
- A step-cut is made in the flexor-pronator fascia, such that the anterior musculofascial flap is distally based and the posterior fascial flap is proximally based on the medial epicondyle.
 - The flaps should be approximately 3 cm in length to avoid compression on the ulnar nerve when the flaps are coapted (**TECH FIG 2A**).
- The posterior fascial flap is carefully and sharply elevated from the underlying muscle with a scalpel or tenotomy scissors, with care not to disrupt the base of the fascial flap.
- The anterior musculofascial flap is elevated full-thickness, including the superficial head of pronator teres and the common flexor tendon, using monopolar cautery.
 - This allows the anterior musculofascial unit to slide distally, creating a trough for the ulnar nerve, once transposed.
- Within the muscle of the flexor-pronator mass, there are stout fascial septa that need to be excised to prevent them from compressing the ulnar nerve when it is transposed.
 - Care must be taken to identify FCU motor branches of the ulnar nerve that may cross these septa.
- Monopolar electrocautery is used to dissect through the flexor-pronator

muscle in line with the elevated posterior flap to provide a deep muscular bed in which the ulnar nerve may rest.

- Using the Penrose drain, the nerve is gently transposed anteriorly and laid in the previously created muscle trough (**TECH FIG 2B**).
- If the nerve is tethered by motor branches to the FCU, these branches may be separated from the main nerve for up to 6 to 8 cm to allow greater excursion of the ulnar nerve as it is transposed.
- The entire course of the ulnar nerve is examined to ensure there are no points of nerve compression or crimping after it has been transposed.
 - In particular, ensure that all soft tissues proximally have been released, that the nerve is not kinked as it crosses the medial intermuscular septum, and that it is not bending over the superficial or deep flexor-pronator fascia distally.
- Stout, nonabsorbable braided suture is used to coapt the ends of the flaps that were raised from the flexor-pronator fascia, effectively lengthening the musculofascial unit.
 - Figure-of-eight or horizontal mattress suture can be used (**TECH FIG 2C**).
- The elbow is taken through a range of motion from full extension to full flexion.
 - The nerve is inspected to ensure it does not fall out of its bed in the muscle or subluxate posterior to the medial epicondyle.
 - Any dynamic points of compression are also identified and released as necessary.
- If a tourniquet is used, it is now deflated. Meticulous hemostasis is obtained with electrocautery.



TECH FIG 2 • **A.** A step-cut is made in the flexor-pronator fascia to create an anterior distally based myofascial flap and a posterior proximally based fascial flap. *White arrows* indicate medial antebrachial cutaneous nerve. **B.** Full-thickness myofascial flaps are elevated to create a trough in the muscle bed into which the ulnar nerve is transposed. **C.** The ends of the fascial flaps are sutured together to prevent posterior subluxation of the ulnar nerve and effectively lengthening the musculofascial unit. (Distal is to the left and proximal to the right in all parts.)

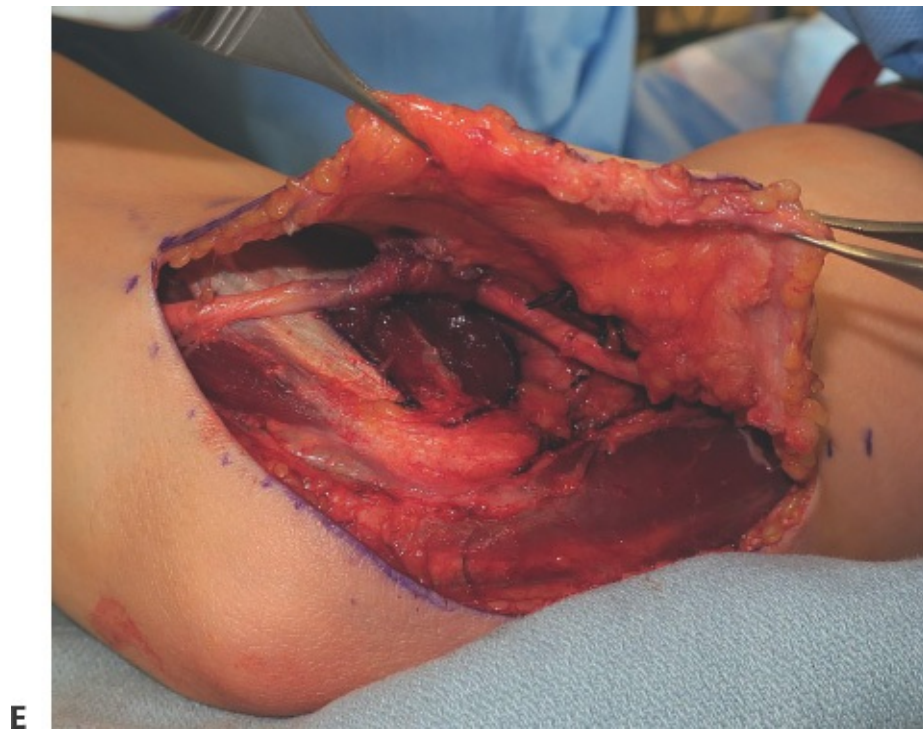
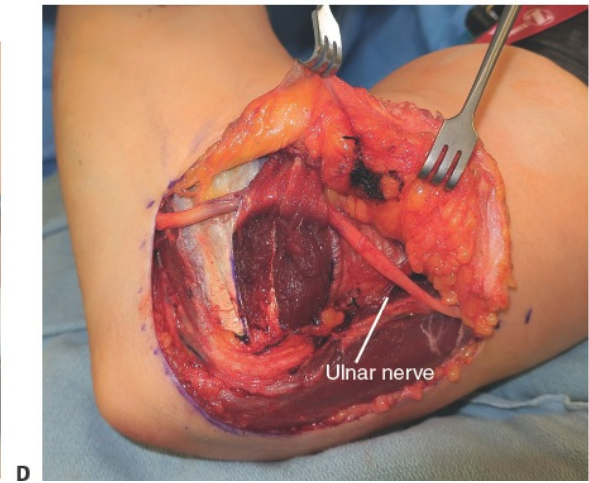
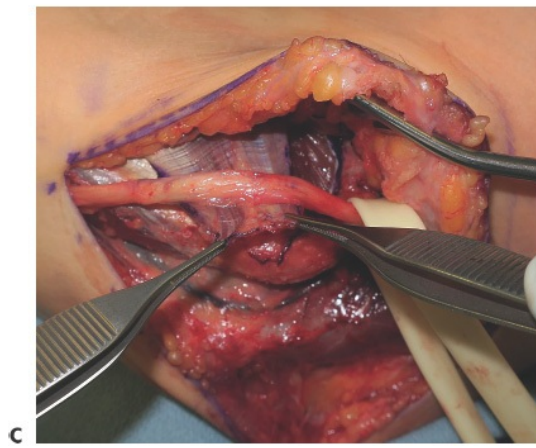
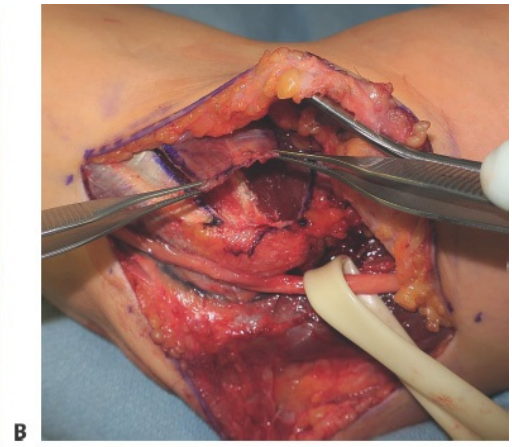
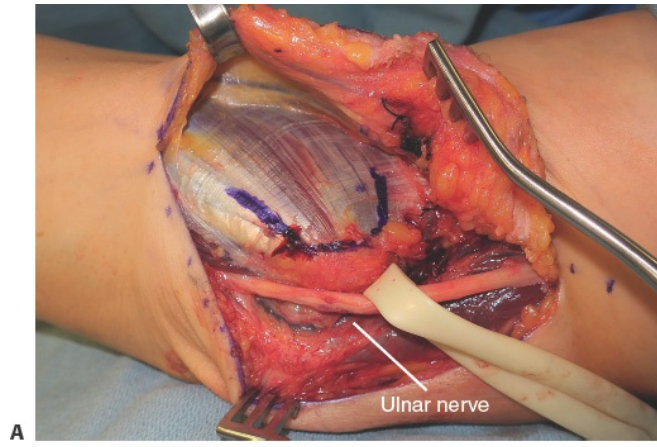
- The wound is thoroughly irrigated with normal saline.
- The wound is closed with deep dermal buried interrupted sutures using an absorbable suture material. The skin is closed with a running subcuticular absorbable monofilament suture or a nonabsorbable monofilament in a simple or horizontal mattress fashion.
- A sterile soft dressing is applied to the wound, followed by either a soft

compression dressing or a posterior slab long-arm plaster splint, which remains in place for 2 weeks.

- It is important for the patient to be able to perform gentle active range of motion of the elbow in the immediate postoperative period.

Anterior Subcutaneous Transposition of the Ulnar Nerve

- The subcutaneous tissues are elevated off the flexor-pronator fascia.
- An anteriorly based flap of flexor-pronator fascia is sharply elevated from the medial epicondyle and underlying musculature with a scalpel blade or tenotomy scissors.
 - The fascial flap should be approximately 3 cm in length to avoid compression of the ulnar nerve (**TECH FIG 3A,B**).
- Using the Penrose drain, the nerve is gently transposed anteriorly and positioned superficial to the fascial flap (**TECH FIG 3C**).
- If the nerve is tethered by motor branches to the FCU, these branches may be separated from the main nerve for up to 6 to 8 cm to allow greater excursion of the ulnar nerve as it is transposed.
- The entire course of the ulnar nerve is examined to ensure there are no points of nerve compression or crimping after it has been transposed. In particular, ensure that all soft tissues surrounding the nerve proximally have been released, that the nerve is not kinked as it crosses the medial intermuscular septum, and that the nerve is not compressed by the flap in its transposed position.
- The fascial flap is approximated to the deep dermis on the underside of the anterior skin flap, and that point on the superficial surface of the skin can be marked with a marking pen (**TECH FIG 3D; VIDEO 1**).
- Stout, nonabsorbable braided suture is used to suture the free end of the fascial flap to the deep dermis on the underside of the anterior skin flap. Figure-of-eight or horizontal mattress suture may be used.
 - The flap is approximated quite anteriorly so that when the anterior skin flap is then brought down for closure, the fascial flap acts as a “hammock” for the ulnar nerve, keeping it anterior to the medial epicondyle (**TECH FIG 3E**).



TECH FIG 3 • **A.** An anteriorly based flap of flexor-pronator fascia is designed to form a sling for the transposed ulnar nerve. **B.** The fascial flap then elevated from the medial epicondyle and underlying musculature. **C.** The ulnar nerve is transposed anteriorly over the fascial flap. **D.** The fascial flap is sutured to the dermis of the anterior skin flap to function as a “hammock” for the transposed ulnar nerve to prevent posterior subluxation. **E.** The nerve is evaluated throughout the full range of motion of the elbow to ensure that the nerve does not kink, subluxate, or become compressed in its transposed position. (Distal is to the left and proximal to the right in all parts.)

- The elbow is taken through a range of motion from full extension to full flexion.
 - The nerve is inspected to ensure it does not fall out of its bed in the muscle or subluxate posterior to the medial epicondyle.
 - Any dynamic points of compression are also identified and released as necessary (Video 2).
- If a tourniquet is used, it is now deflated. Meticulous hemostasis is obtained with electrocautery.
- The operative field is thoroughly irrigated with normal saline.
- The incision is closed with deep dermal, buried, interrupted sutures using an absorbable suture material.
- The skin is closed with a running subcuticular absorbable monofilament suture or a nonabsorbable monofilament in a simple or horizontal mattress fashion.
 - If an absorbable subcuticular suture is used, Steri-Strips are applied to the incision.
- A sterile bulky soft dressing is applied to the incision, which remains in place for 2 days.
 - After postoperative day 2, it is important that the patient continue to use a

compression dressing to minimize postoperative edema.

- Patients are instructed that they may gently move their elbow and use the extremity for activities of daily living.

PEARLS AND PITFALLS

Superficial dissection

- Care should be taken to preserve branches of the medial antebrachial cutaneous nerve to avoid causing a painful neuroma. These branches cross the medial arm from 6 cm proximal to 6 cm distal to the medial epicondyle.

Deep dissection

- A Penrose drain is loosely looped around the ulnar nerve to manipulate it atraumatically during dissection and transposition.

Hemostasis

- Meticulous hemostasis must be obtained to prevent a hematoma, which could compress the ulnar nerve or lead to wound dehiscence.

Iatrogenic compression

- Secondary points of compression may be introduced after ulnar nerve transposition if care is not taken to release them; in particular, the medial intermuscular septum, the deep septa of the flexor-pronator musculature (with submuscular transposition), and the fascial flaps holding the nerve transposed should be inspected to ensure no compression is present.

Nerve stability

- Inspect the position of the ulnar nerve throughout the full range of motion of the elbow to ensure the nerve does not rest on or subluxate posterior to the medial epicondyle.

POSTOPERATIVE CARE

- In situ decompression or subcutaneous ulnar nerve transposition
 - Patients are placed in a bulky soft dressing, which may be removed on postoperative day 2. They may begin showering at that point, but it is important to continue the use of a compression wrap to minimize postoperative edema.
 - Patients may move the operative extremity and perform activities of daily living postoperatively. Heavier activities (ie, more than “coffee cup” weight bearing) are prohibited. Patients may move the elbow and forearm as pain permits. Patients are encouraged to move their wrist, hand, and digits to

prevent postoperative edema and stiffness.

- Submuscular transposition
 - The use of a bulky soft dressing vs a long-arm splint is at the discretion of the surgeon.
 - It is important for gentle range of motion of the elbow to begin immediately in the postoperative period to minimize scarring along the ulnar nerve.
 - If a long-arm splint is used, it remains in place for 2 week postoperatively. Patients are encouraged to move and use their digits while the splint is in place.
 - If a soft dressing is used, it should remain in place for 2 weeks.
- When the incision is well healed (usually around 2 weeks postoperatively), sutures may be removed if nonabsorbable suture were used. Patients whose incisions are closed with subcuticular absorbable sutures and Steri-Strips are instructed that the Steri-Strips will fall off on their own.
- All patients may allow the incision to get wet in the shower but are restricted from immersing the incision in baths and pools for another week.
- Patients may engage in unrestricted activities as tolerated at 2 weeks postoperatively as long as the incision is well healed.

OUTCOMES

- In situ decompression, subcutaneous transposition and submuscular transposition have all been shown to be effective in the treatment of cubital tunnel syndrome.
 - Most patients experience objective and subjective improvement in sensation, strength, and pain, although persistent subjective sensory abnormalities are common, regardless of surgical technique.
 - Patients express high satisfaction with the outcome of surgical intervention with all procedures.
 - Multiple meta-analyses have demonstrated no difference in outcome in terms of clinical outcomes or conduction velocities.

COMPLICATIONS

- New elbow pain
- Scar tenderness
- Medial elbow and forearm numbness
- Hematoma
- Infection

- Persistent or recurrent symptoms
- The rate of revision surgery following in situ decompression is reported between 3% and 19%.^{18,19}

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29 Radial Tunnel Decompression

CHAPTER

Joseph Pirolo and Jason H. Ko

DEFINITION

- Radial tunnel syndrome (RTS) is a pain syndrome caused by compression of the radial nerve and its branches in the proximal forearm.
- Generally characterized by lack of muscle weakness and electrodiagnostic findings

ANATOMY

- The radial tunnel is the space through which the radial nerve and its branches pass in the proximal forearm.
- The tunnel extends approximately 5 cm from the radiocapitellar joint to the proximal edge of the supinator muscle.¹⁻³
- Tunnel boundaries¹⁻³
 - Radial: brachioradialis (BR), extensor carpi radialis longus (ECRL), and extensor carpi radialis brevis (ECRB)
 - Ulnar: brachialis, biceps tendon
 - Floor: radiocapitellar joint capsule, supinator
- Radial nerve branches and sites of compression
 - The radial nerve branches proximal to the superior border of the supinator and forms the radial sensory nerve (RSN) and the posterior interosseous nerve (PIN).
 - The PIN has multiple potential entrapment sites^{2,4-6}
 - Arcade of Frohse (proximal tendinous edge of supinator)
 - Proximal edge of ECRB
 - Radial recurrent vessels (leash of Henry)

- Radiocapitellar joint capsule and osteophytes
- Supinator distal edge

PATHOGENESIS

- Compression of the radial nerve, PIN, or SBRN by one or more anatomic structures at the radial tunnel, which can be secondary to aberrant anatomy, mass effect, trauma, arthrosis, or idiopathic
- Pathogenesis and pathophysiology of RTS is poorly understood and controversial owing to the fact that it is a compressive neuropathic pain syndrome with no reliably identifiable motor, radiologic, or electrodiagnostic findings.
- Although the PIN is a motor nerve, it does contain group IIA and IV fibers, which have been associated with temperature and nociception.⁷ Given that these are not evaluated in standard electrodiagnostic testing, one possibility is that they may contribute to the pain syndrome even though nerve conduction velocities remain normal.
- Occupations that require heavy tool use in full elbow extension have been identified as a risk factor for development of RTS.^{8,9}

PATIENT HISTORY AND PHYSICAL FINDINGS

- History
 - Patients complain of pain and fatigue in the proximal dorsal forearm.
 - Pain may radiate and can be aggravated by activities loading a rotated forearm or extended wrist.¹
 - Muscle weakness is either absent or secondary to pain.¹⁰
 - Sensory disturbances are usually absent.
- Physical exam
 - The primary finding is localized tenderness over the radial nerve 5 cm distal to the lateral epicondyle.¹¹
 - Provocative tests include pain with resisted forearm supination and/or resisted active extension of the middle finger.¹⁰
 - The “rule of nines” test has been proposed to help localize tenderness to the radial tunnel and help differentiate from other nearby sources of pain. In this test, the proximal volar forearm is divided into nine squares and tenderness with the lateral column marking out the radial tunnel.¹²
 - Examination must take into consideration several other possible sources of proximal forearm pain, especially lateral epicondylar tendinopathy, in which

tenderness is located more proximally over the epicondyle.

- **Electrodiagnostic studies**
 - The results of standard nerve conduction velocity (NCV) and electromyography (EMG) studies are typically normal.
 - Although several modifications to standard NCV testing have been proposed, including testing latencies in different forearm positions and testing motor latencies to different motor groups, these have not been widely adopted in clinical practice.^{13,14}
 - Electrodiagnostic studies may be useful to help rule out cervical radiculopathy or other concomitant entrapment neuropathy.

IMAGING

- Plain radiographs are typically nondiagnostic for RTS but can identify radiocapitellar arthrosis, which can lead to a distended, synovitic joint capsule and extrinsic compression at the radial tunnel.
- Magnetic resonance imaging (MRI) is not routinely helpful in the diagnosis of RTS. One study comparing MRI in 25 patients with RTS found that 52% had either edema or denervation atrophy of the supinator, whereas 28% had other aberrant anatomy such as nerve swelling, thickened ECRB, or prominent recurrent vessels.¹⁵
- The combination of the patient's history, physical exam, and MRI can also help to delineate radial tunnel from lateral epicondylar tendinopathy.

DIFFERENTIAL DIAGNOSIS

- Radial tunnel syndrome
- Lateral epicondylar tendinopathy
- PIN syndrome
- Cervical radiculopathy
- Biceps tendinitis or local muscle strain
- Osteoarthritis of the radiocapitellar joint
- Synovial impingement of the elbow
- Wartenberg syndrome

NONOPERATIVE MANAGEMENT

- Nonoperative treatment using anti-inflammatories, splinting, and activity modification should be exhausted prior to consideration of operative treatment and may lead to resolution of symptoms.¹⁶

- Although evidence for steroid injections is limited to a single small trial, it may be considered for patients with ongoing symptoms who are poor surgical candidates or those who do not want to consider surgery.¹⁷
- When a local anesthetic is mixed with the steroid injection, this can serve as a diagnostic aid and is considered successful if both pain symptoms are temporarily alleviated and a motor block of the PIN is achieved.

SURGICAL MANAGEMENT

- Operative radial nerve decompression is indicated for those patients who have failed to improve after prolonged nonoperative treatment.
- Intravenous regional (Bier block) and axillary block regional are preferred methods of anesthesia.
- Three commonly described dorsal surgical approaches to release potential compression points along the radial tunnel have been described.
 - ECRB-extensor digitorum communis (EDC) interval
 - ECRL-BR interval
 - BR transmuscular splitting approach
- The authors prefer the ECRL-BR interval for the following reasons:
 - It avoids muscle splitting.
 - It allows for easy identification of the radial nerve, PIN, and the sensory branch of the radial nerve to ensure all are free from compression.
 - There is some evidence to support more reliably successful outcomes with decompression of the SBRN, which is best addressed through this interval.^{18–20}
 - The most common complication of radial tunnel decompression is neuropraxia of the SBRN, which is best identified and protected in this interval.^{20–23}
 - The interval is easily identifiable when marked out in the preoperative area by having the patient flex the elbow against resistance.

TECHNIQUES

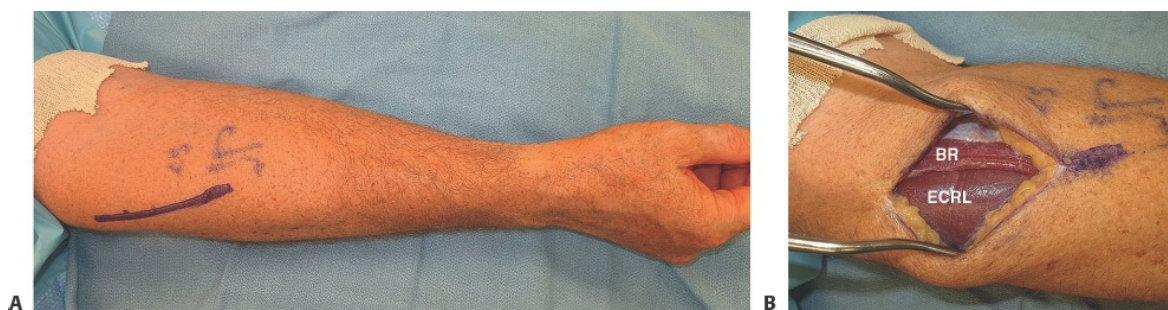
■ **Radial Tunnel Decompression**

Exposure

- In the preoperative area, ask the patient to flex the elbow against resistance to help mark out the interval between BR and ECRL.
 - This causes brachioradialis (BR) to become prominent while the extensor carpi radialis longus (ECRL) is relaxed, making the interval much easier to locate.
- A straight longitudinal or lazy-S incision is made through the skin and dermis (**TECH FIG 1A**).
- Care is taken to identify and protect the posterior cutaneous nerve of the forearm and any posterior branches of the lateral antebrachial cutaneous nerve.
- The fascia overlying BR and ECRL is incised and the interval is developed (**TECH FIG 1B**).
 - BR fascia is thinner, and thus, the BR muscle belly will appear as a brighter red color.
 - The dorsal ulnar edge of BR is also thinner, coming to a tapered edge and lying superficial to the more dorsal central aspect of the ECRL.
 - This interval should open easily and with mostly blunt dissection. If extensive sharp dissection is required, the surgeon has likely strayed out of the appropriate interval.

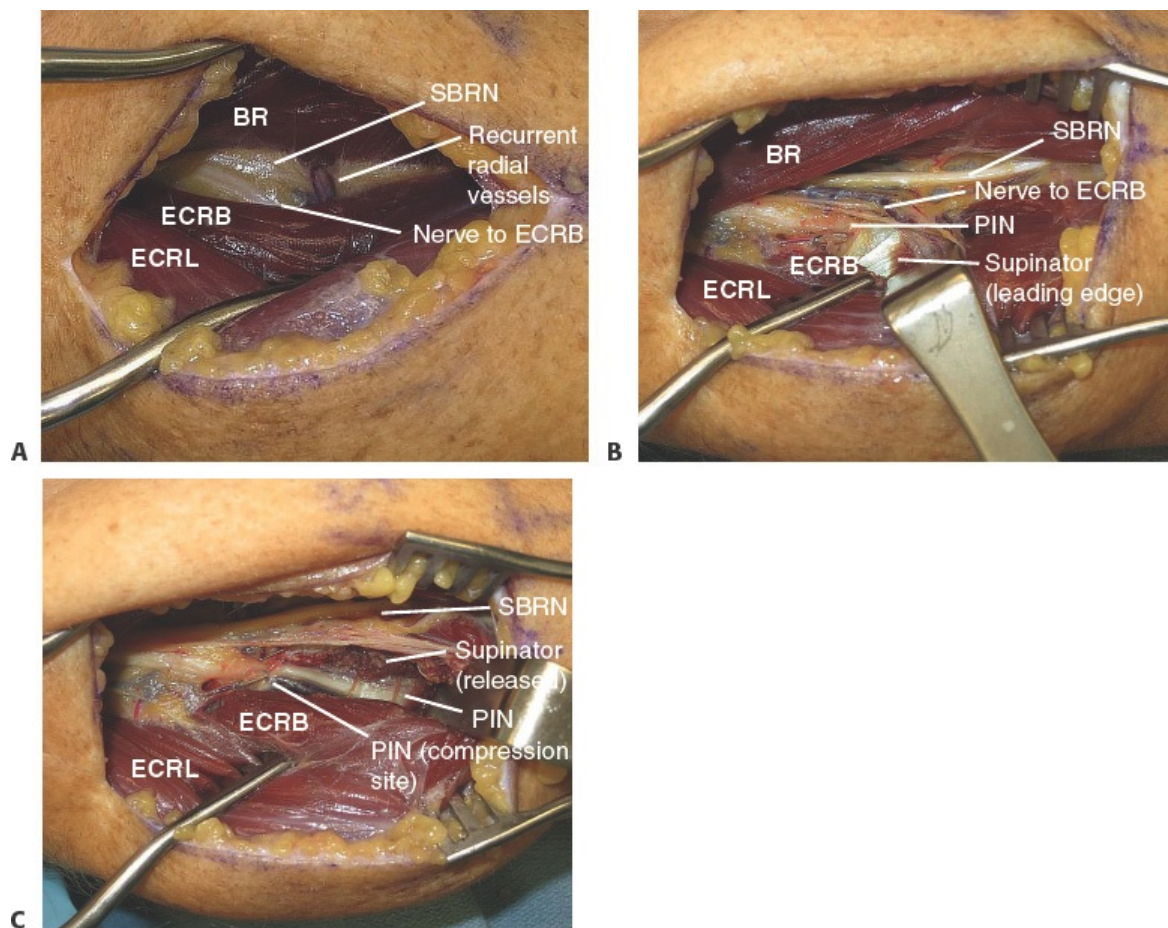
Release of Entrapment

- Coming down between BR and ECRL will bring the surgeon to a layer of fat containing the SBRN.



TECH FIG 1 • **A.** Proposed incision over the dorsal proximal forearm marked out at interval between brachioradialis and extensor carpi radialis longus. **B.** Superficial interval between brachioradialis (BR) and extensor carpi radialis longus (ECRL). Note the

thinner edge of BR and the more rounded, dorsal central aspect of ECRL.



TECH FIG 2 • A. Intermediate interval between extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) ulnarly and brachioradialis (BR) radially. The radial recurrent vessels (leash of Henry) course through and over the radial nerve branches (PIN, SBRN, nerve to ECRB). **B.** Deep interval after limited external neurolysis of radial nerve branches, ligation of crossing vessels, and release of proximal edge ECRB reveals the tight, tendinous leading edge of supinator (arcade of Frohse) directly compressing the PIN. **C.** Release of

the supinator reveals a chronic compression deformity of the PIN. (For all parts, proximal is to the left, distal to the right, radial to the top, and ulnar to the bottom.)

- Follow the SBRN proximal, and you will encounter the radial recurrent vessels (leash of Henry) (**TECH FIG 2A**).
 - They must be ligated with suture or clips.
 - Dissecting more proximally within this interval, follow the SBRN and you will encounter the posterior interosseous nerve (PIN) and the nerve to extensor carpi radialis brevis (ECRB).
 - Meticulous care to dissect and control crossing vessels is essential.
 - Release any constricting fascial bands over the SBRN as this may increase the likelihood of success.^{18–20}
 - At this point, you will have identified the SBRN, nerve to ECRB, and the PIN (**TECH FIG 2B**).
 - From radial to ulnar, the orientation will be SBRN, nerve to ECRB, and PIN.
 - The PIN will be larger in caliber and coursing distal and ulnar.
 - The SBRN and nerve to ECRB will be parallel to one another.
 - Follow the PIN distally and release the overlying ECRB fascia, which can be a point of compression.
 - After ECRB fascia has been released, you will encounter the supinator fascia (arcade of Frohse), which must be released (**TECH FIG 2C**).
 - As ECRB has been implicated in lateral epicondylar tendinopathy, release of the ECRB tendon may be helpful for patients with concomitant “tennis elbow.”
 - Check proximally and distally to ensure no further entrapment points exist.
 - Proximally, fibrous bands over the radial head can sometimes be found.
 - If used, the tourniquet is released to ensure adequate hemostasis.
 - Close the skin using a dermal layer with 4-0 absorbable suture followed by a subcuticular layer using 4-0 absorbable suture.
 - A long-arm, soft bulky dressing is applied using a thin layer of gauze, sterile cast padding, and a very lightly compressive wrap.
-

PEARLS AND PITFALLS

Preoperative marking	■ Marking out the BR-ECRL interval in the preoperative holding area with the patient flexing the elbow against resistance can make surgical orientation much easier.
Hemostasis	■ Meticulous care to control crossing vessels throughout the case is a part of the decompression, can save time when the tourniquet is let down, and will prevent postoperative hematoma formation.
Adequate exposure	■ A minimal exposure can lead to inadequate visualization of all compression points and necessitate excessive retraction on the muscular interval, as well as the SBRN, leading to known complications.
Decompression of all radial nerve branches	■ External neurolysis of the radial nerve, nerve to ECRB, PIN, and SBRN is important to maximize likelihood of success.

POSTOPERATIVE CARE

- Immediate active digital, wrist, and forearm motion is allowed, but with limited weight bearing until the 2-week clinic follow-up.
- The dressing is removed 2 days after surgery.
- The wound is checked and any external sutures are removed at 2 weeks.
- Strengthening allowed at 3 weeks and patients are expected to be back to normal work activities by weeks 4 to 6.

OUTCOMES

- No level 1 evidence exists to guide expected outcomes following radial tunnel release.
- Patients who have had “successful” outcomes following radial tunnel release varies widely in the literature from 32% to 97%^{19,21,22} prompting controversy as to the effectiveness of the procedure.
- Known risk factors that lower expected success rates of radial tunnel decompression include
 - Concomitant lateral epicondylitis²²
 - Multiple entrapment neuropathies²²
 - Workers compensation/litigation²²

- A recent study by Lee and colleagues found good results in 86% of patients with isolated RTS, whereas this number dropped to 57% in patients with multiple entrapment neuropathies and 40% in patients with associated lateral epicondylar tendinopathy.²²
- A thorough examination of available literature makes it clear that appropriate patient selection based on clinical history, exam, and diagnostic workup is crucial to success in the treatment of RTS.

COMPLICATIONS

- Complication rates have been reported in a portion of available retrospective reviews and case series; however, the anticipated rate of these complications is difficult to determine.
- Some reported complications include
 - SBRN neurapraxia or hyperaesthesias^{20–22}
 - Paresis of common digital extensors^{21,23}
 - Postoperative hematoma²¹
 - Complex regional pain syndrome²⁰
 - Infection²⁰

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Primary Nerve Repair and Nerve Graft for Traumatic Nerve Injuries

30

CHAPTER

Sonya Paisley Agnew and Jason H. Ko

DEFINITION

- In the setting of acute nerve injuries, the surgeon should abide by the following principles when performing a nerve repair or reconstruction:
 - Debridement of the injured nerve ends to healthy fascicles
 - Correct alignment of fascicles when possible
 - Delicate handling of neural tissue
 - Tension-free repair or reconstruction
 - Prevention of fascicular outgrowth at the coaptation site
- The level of injury, zone of injury, primary nerve function (motor vs sensory), and functional significance of the injured nerve (eg, “critical” nerves such as the ulnar digital nerve to the thumb vs “noncritical” nerves such as the ulnar digital nerve to the long finger) will guide choice of treatment.
- Options for repair include primary repair with or without a conduit vs reconstruction with nerve grafts (autograft vs allograft).¹ Consideration should be given to techniques for bolstering the nerve coaptations (eg, fibrin glue, nerve wraps, nerve tubes).
- The most commonly used techniques for nerve coaptation are an “epineurial repair,” which is suturing of the epineurium with no direct manipulation of the fascicles, and a “grouped fascicular repair,” which requires reorienting the fascicles and directly placing sutures into the perineurium of the fascicles (**FIG 1**).
- No studies have documented superiority of one coaptation technique over the other.

ANATOMY

- An understanding of fascicular anatomy of mixed major peripheral nerves can improve the outcomes of nerve repair by aligning proximal fascicles with their distal targets—matching proximal motor fascicles to distal motor fascicles and proximal sensory fascicles to distal sensory fascicles, whenever possible.
- This topographical orientation has been described for major mixed nerves, including the median and ulnar nerves, which can help with fascicular alignment when treating lacerations at various levels in the forearm and hand.²
- Anatomic fascicular orientations that have been well-established in the literature¹:
 - Median nerve in the forearm (**FIG 2**)
 - The motor branches lie peripherally (in the radial and ulnar aspects of the median nerve), with sensory fascicles located centrally. The recurrent motor fascicle is a separate, distinct fascicle 10 cm proximal to the radial styloid and located radially.
 - Median nerve at the wrist level (see **FIG 2**)
 - Recurrent motor fascicles are located within the volar and radial aspect of the nerve.
 - Digital sensory fascicles are located dorsally along both the radial and ulnar aspects of the nerve.
 - The ulnar nerve in the forearm (see **FIG 2**)

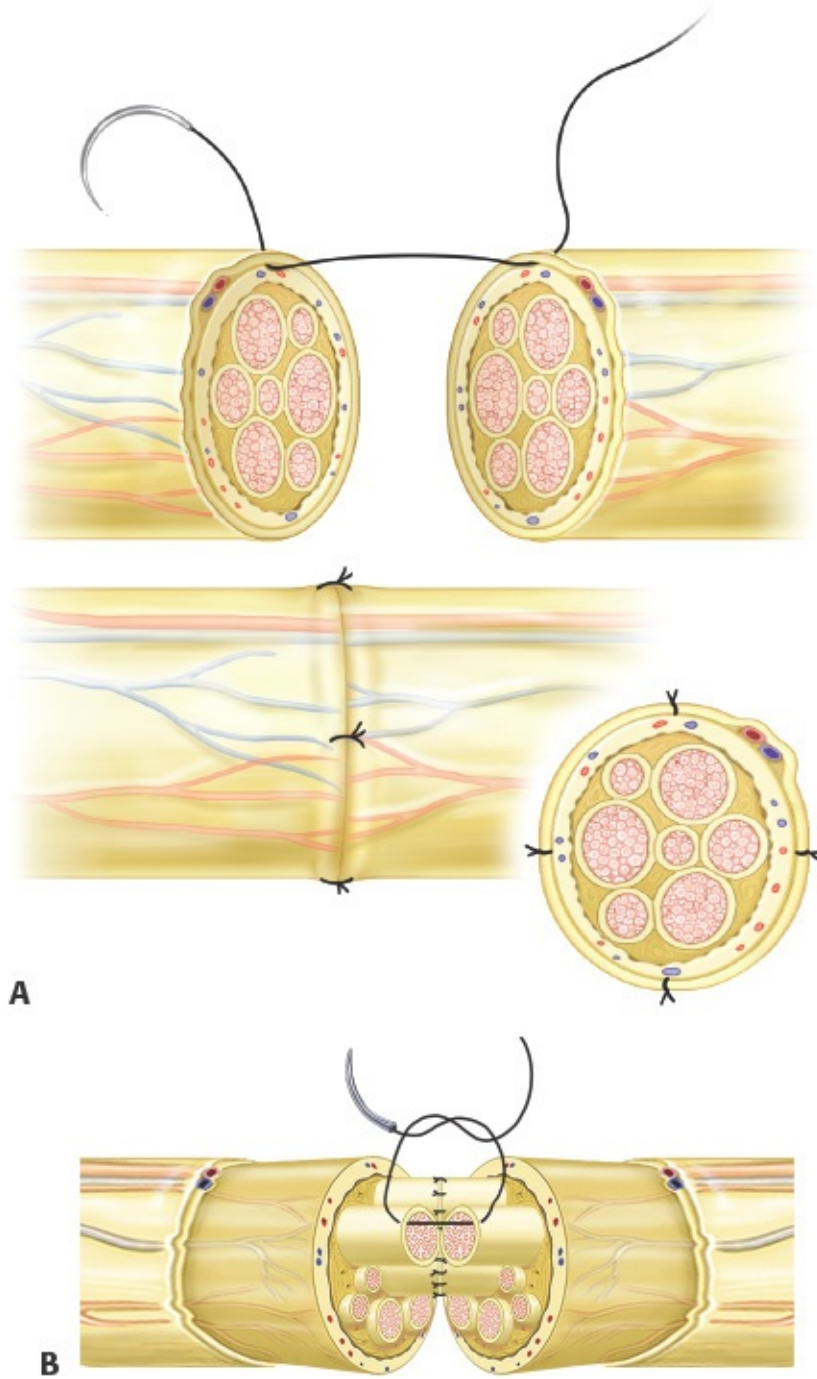


FIG 1 • Nerve coaptation techniques. **A.** Epineurial repair. **B.** Grouped fascicular repair.

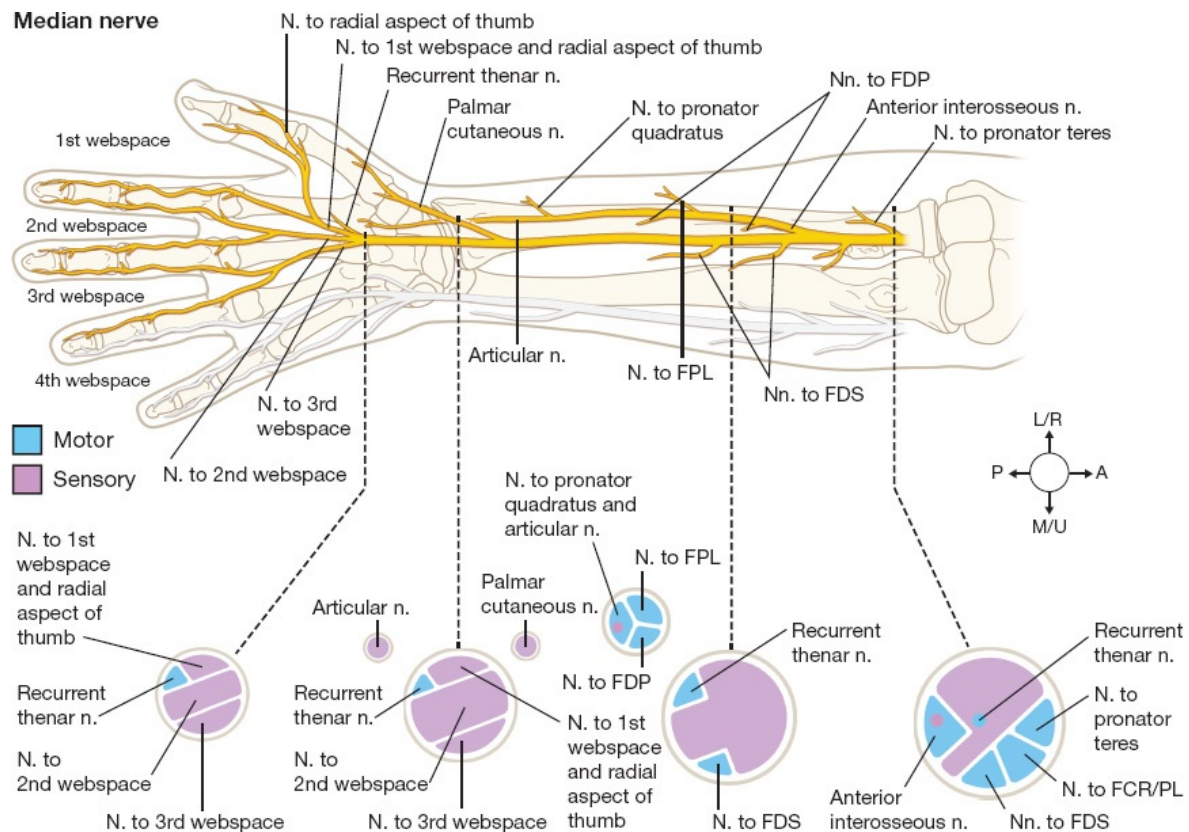


FIG 2 • Intraneural topography of the median nerves at various levels.

- Dorsal sensory branch of the ulnar nerve is located in an ulnar position within the nerve and separates from the main nerve 5 to 8 cm proximal to the radial styloid.
 - The intrinsic motor fascicles lie dorsal to the digital sensory fascicles and are distinct 9 cm proximal to the ulnar styloid.
 - In the proximal forearm, the motor fascicles (intrinsic and flexor carpi ulnaris [FCU]/flexor digitorum profundus [FDP]) are centrally located, and the sensory fascicles are superficial.
 - At the wrist level, the ulnar nerve motor branch is dorsal and ulnar relative to the sensory fascicles—the motor fascicles can be seen as separate and distinct up to 9 cm proximal to the ulnar styloid.³
- Grouped fascicular repair should be used in larger mixed nerves, such as the median nerve at the humeral level.³
 - Care should be taken to avoid bulky perineurial sutures that may become an obstacle to axonal regrowth.

- The less the ends of the nerve are manipulated intraoperatively, the less scarring there will be at the coaptation site.
- Microsutures should be used to repair the epineurium for all nerve repairs. The coaptation sites can be augmented with fibrin glue at the discretion of the surgeon.
- Tension should be avoided at all cost when performing a nerve coaptation. In the authors' opinion, rather than repairing a nerve under tension, the surgeon should reconstruct the nerve with an interpositional nerve graft (autograft or allograft) to achieve a tension-free construct.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Physical exam:
 - A thorough motor examination and evaluation of sensation by two-point discrimination or Semmes-Weinstein monofilament testing will help to localize the nerve injury and adequately counsel the patient regarding postoperative expectations.
 - The location of a Tinel sign will help to pinpoint the site of nerve injury in the acute setting, and an advancing Tinel sign can be used to measure nerve regeneration over time.
 - In the acute setting, the sensory examination may be unreliable due to pain or neurapraxia.
- History: When obtaining the patient's history, certain factors are important for preoperative planning and counseling, including the following:
 - Patient age: Nerve regeneration occurs more rapidly in younger patients. The potential for nerve recovery decreases with age and should be addressed preoperatively with the patient. Older individuals are more likely to have delayed and/or incomplete recovery.
 - Chronicity of injury: In a delayed nerve repair, the surgeon should be prepared for retraction of the proximal nerve stump, in addition to neuroma formation, which may necessitate the use of nerve grafts.

IMAGING

- Ultrasound may be helpful in determining the presence of neuroma-in-continuity or complete laceration of the nerve. It offers the advantage of allowing static and dynamic assessments of the nerve and associated structures.
- MR neurography can also be used to evaluate larger nerves, but it is less effective at visualizing smaller nerves in the palm and fingers.

- Other imaging modalities are not commonly used for traumatic nerve injuries. Operative exploration is the primary method of diagnosis and treatment.

SURGICAL MANAGEMENT

Preoperative Planning

- The patients should be monitored closely to determine the extent of peripheral nerve injury.
 - A penetrating injury with acute nerve deficit warrants operative exploration.
 - A blunt or closed injury with acute nerve deficit may justify a period of monitoring to rule out neurapraxic injury.
- Sharp injury: If addressed acutely, primary nerve repair is possible. Nerve wraps or conduits can be used as adjuncts, if there is minimal tension at the repair site. If primary repair is under tension, then interpositional nerve graft should be used for reconstruction instead.
- Crush injury: The surgeon should be prepared for a broad zone of injury with extensive injury to the nerve. Nerve grafting will most likely be necessary, and the surgeon should consider delayed repair so that the zone of injury in the nerve can be better assessed as the soft tissue heals.
- Poor soft tissue cover: It is important for the surgeon to perform local or distant soft tissue flaps to achieve a stable, well-vascularized soft tissue envelope over the site of a nerve injury. Stable overlying soft tissue is a prerequisite for successful nerve repair or reconstruction.
- Timing: Neuromuscular function disappears 3 to 5 days after nerve transection,⁴ whereas nerve action potentials remain for 7 to 9 days after injury.⁵ After this time period, the use of intraoperative stimulation to aid in fascicular identification is not possible.

Positioning

- Supine positioning
- For distal nerve injuries in the upper extremity, a well-padded tourniquet is placed on the proximal arm.
 - The authors recommend tourniquet use to maintain a bloodless field, which will more easily identify peripheral nerves, especially in the setting of substantial scarring.
 - However, if intraoperative motor nerve stimulation will be performed, the tourniquet should be released within 30 to 40 minutes to avoid tourniquet

neurapraxia.

- The hand table should have a stable base to limit motion during microsurgery.
- If sural nerve grafts are indicated, one or both legs are circumferentially prepared, and a thigh tourniquet should be used. It may be beneficial to harvest the sural nerve from the contralateral leg, which allows a bump to be placed under the contralateral hip.

Approach

- Bruner incisions to cross wrist and digital creases are employed to avoid straight-line incisions across joints.
- For sural nerve harvest, stair-step incisions may be used to decrease the overall length of the harvest site (**FIG 3**). However, longitudinal incisions directly over the entire length of sural nerve can be performed. Endoscopic sural nerve harvest techniques can also be employed.
- Nerve repair and reconstruction requires identification of injured nerve ends. Bruner or mid-lateral incisions should be used to expose the injured nerve(s) on the volar aspect of the palm or fingers. Bruner extensions should be used across all volar joint creases in the upper extremity. Dorsally, longitudinal incisions can be made over joint surfaces.
- Tenotomy scissors should be used to dissect the proximal and distal ends of the injured nerve(s) as atraumatically as possible. Overlying fascia or compression points should be released for better mobilization of the nerve ends.

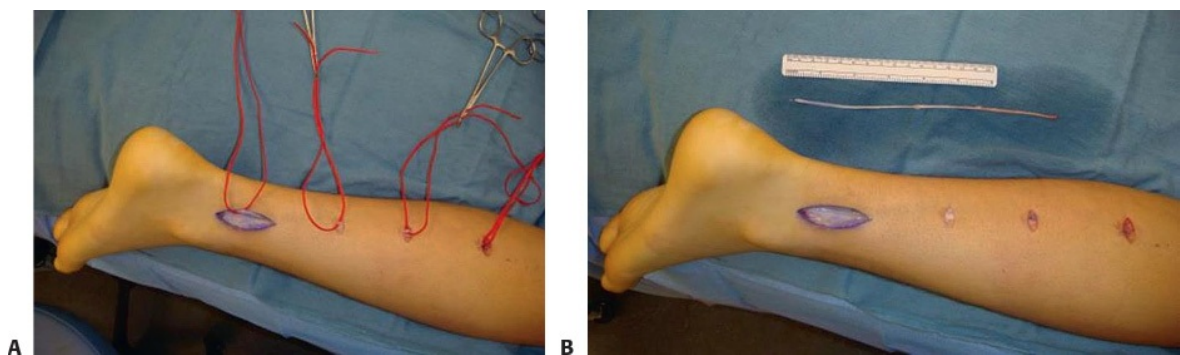
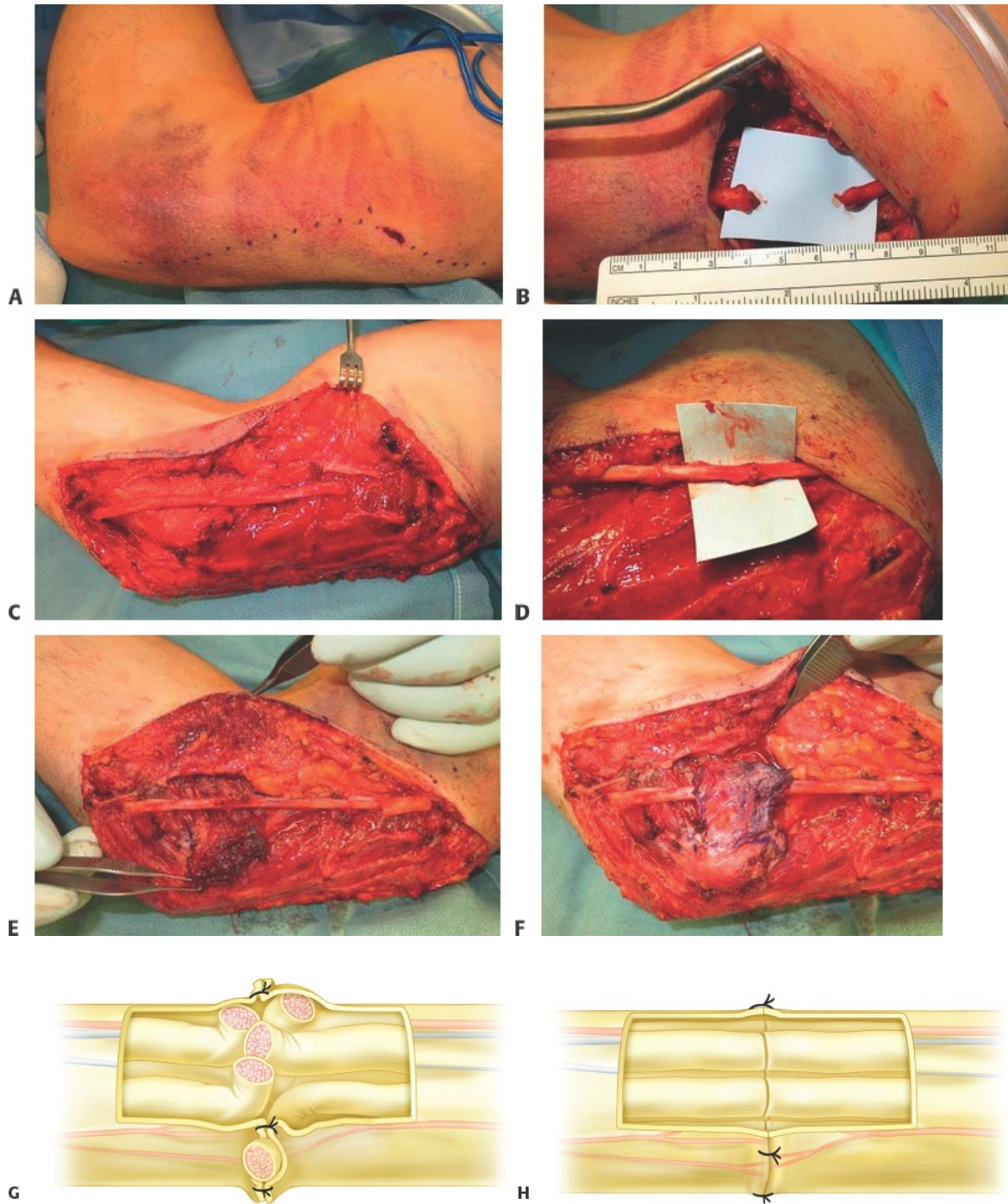


FIG 3 • A,B. Stair-step sural nerve harvest.

TECHNIQUES

■ Primary Nerve Repair

- A direct repair is indicated in a sharp laceration when the nerve ends may be brought together with no tension.
 - Traumatized fascicles should be sharply debrided to healthy-appearing ends and oriented (in cases of larger nerves) appropriately.
 - If the nerve ends cannot be approximated without any tension, direct nerve repair should not be performed—nerve grafting should be used instead.
 - If nearby joints (eg, fingers, wrist, elbow) have to be flexed down to help minimize tension on the nerve repair, the primary nerve repair is too tight and should be abandoned.
- Lining up epineurial vessels proximally and distally can be used to help with orientation at the time of nerve repair. This will make pairing up the proximal and distal fascicles easier.
- Use of an operating microscope is recommended,⁶ and 8-0 or 9-0 nonabsorbable monofilament suture should be used for epineurial repair to orient proximal fascicles to their distal targets (**TECH FIG 1A–F**)
- Fascicles that are “outpouching” should be tucked into the epineurial repair and trimmed back if necessary (**TECH FIG 1G,H**).
- A piece of surgical glove, Esmarch bandage, or silicone background can be used like a “burrito” to wrap around the repair into which fibrin glue is applied to bolster the repair. After the fibrin glue has set, the burrito wrap is removed.
- At this point, the surgeon should consider releasing any potential distal compression points (eg, the transverse carpal ligament distal to a median nerve repair in the distal forearm; Guyon canal release after an ulnar nerve repair at the wrist).

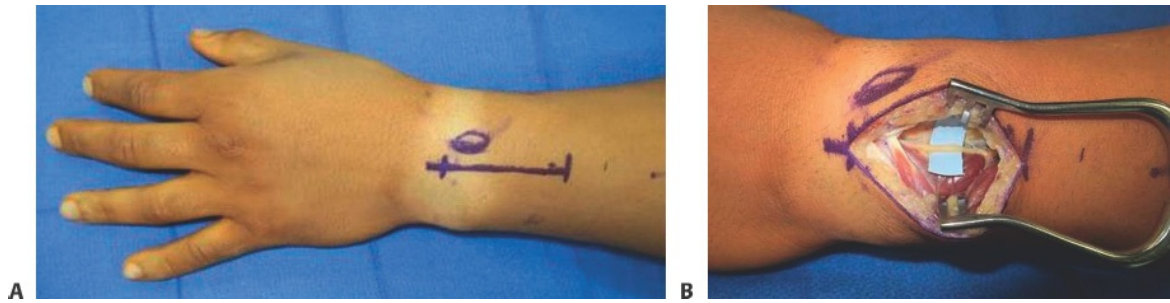


TECH FIG 1 • Ulnar nerve repair proximal to the elbow. Anterior transposition can be performed to reduce tension on the nerve coaptation. **A.** Gunshot wound with suspected ulnar nerve injury. Dotted marks outline possible incision location. **B.** Exploration

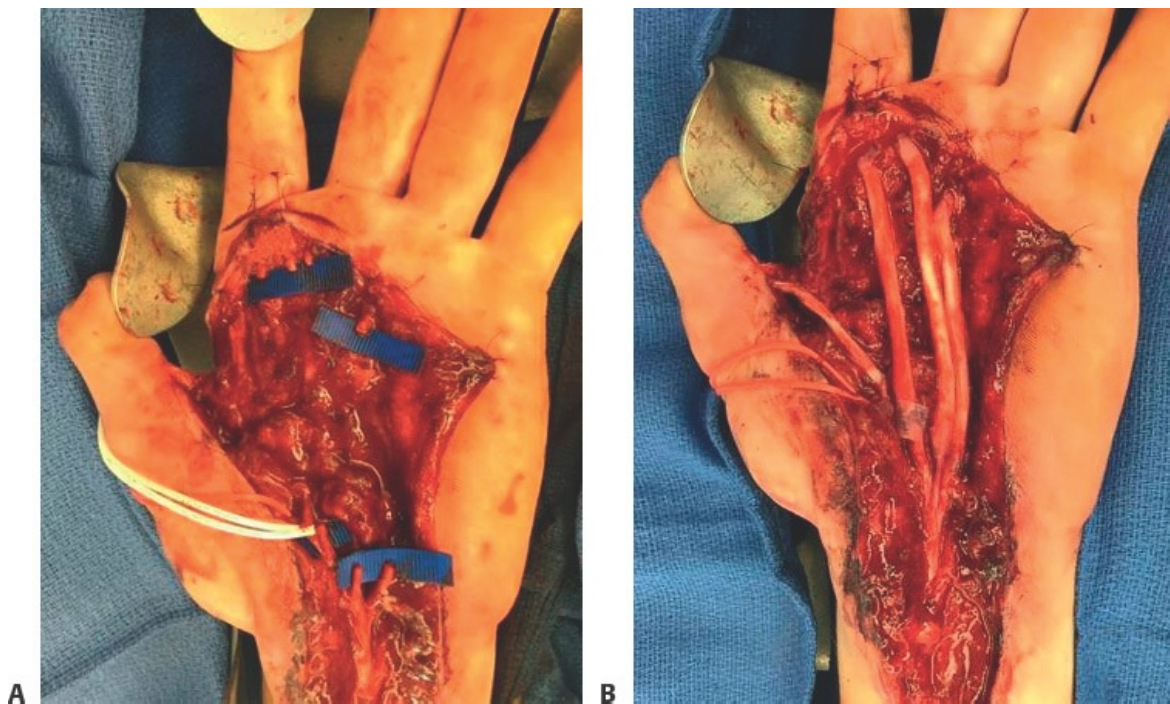
reveals a complete ulnar nerve transection proximal to the elbow. **C.** Anterior transposition of the ulnar nerve has been performed by extending the skin incision distally and completely releasing the ulnar nerve from the cubital tunnel. **D.** Anterior transposition of the ulnar nerve allows for tension-free primary nerve coaptation. **E.** Fascial sling of the flexor-pronator was elevated sharply anterior to the medial epicondyle. **F.** The fascial sling is sutured to the deep surface of the anterior skin flap. **G.** Outpouching of the fascicles should be avoided to prevent aberrant axonal regeneration. **H.** The fascicles should be trimmed and aligned to maximize regeneration.

■ Repair in the Setting of a Small Nerve Gap in a Small Caliber Nerve

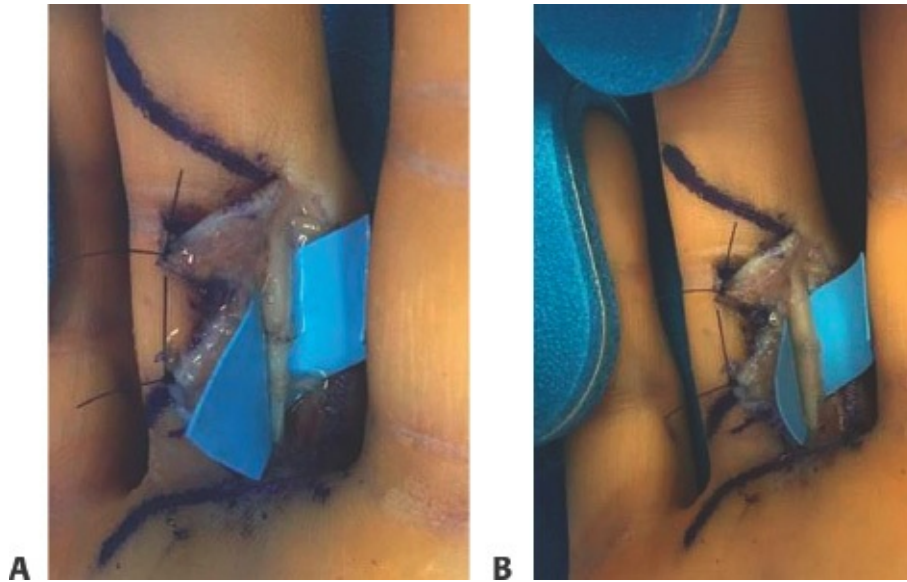
- When the ends of a nerve cannot be brought together without tension despite proximal and distal mobilization, use of a nerve graft is indicated.
- For digital nerve gaps, lateral antebrachial cutaneous (LABC) nerve, medial antebrachial cutaneous (MABC) nerve, and posterior interosseous nerve (PIN) are suitable sizes for autograft (**TECH FIG 2**). These have the additional benefit of using a donor site in the same surgical area as the nerve reconstruction.
- Alternatively, processed nerve allograft (PNA) of varying lengths and diameters are available as an off-the-shelf option with no donor site concerns (**TECH FIG 3**).
- The proximal and distal ends of both repair sites can be bolstered with absorbable polyglycolic nerve tubes, fibrin glue, or xenogenic wraps (**TECH FIG 4**).



TECH FIG 2 • Posterior interosseous nerve harvest in the dorsal wrist. **A.** Incision site. **B.** Isolation of nerve.



TECH FIG 3 • **A.** A 5-cm nerve gap in the median nerve at the level of the carpal tunnel. **B.** Repair with processed nerve allograft.



TECH FIG 4 • Direct digital nerve repair (A) and after wrapping with xenogenic nerve wrap (B).

■ Repair of Larger Nerve Gaps or Larger Caliber Nerves

- When a large gap in a nerve exists, either cable grafts or processed nerve allografts are indicated.

Sural Nerve Harvest Technique

- The sural nerve can be harvested in the supine position with a well-padded sterile tourniquet on thigh and the knee flexed.
 - A sterile sandbag and/or an assistant can keep the knee flexed and hip internally rotated.
- If a single sural nerve is to be used, harvesting the contralateral sural nerve will allow a bump or pillows to be placed under the contralateral hip to help gain better access to the posterolateral aspect of the leg, especially more proximally where the sural nerve is deeper.
- If bilateral sural nerves must be harvested, the surgeon should consider performing the sural nerve harvest in the prone position, which would most likely require an intraoperative position change to access the upper extremity.
- Surface landmarks for sural nerve harvest—the lateral malleolus and anterior edge of the Achilles tendon—are marked.

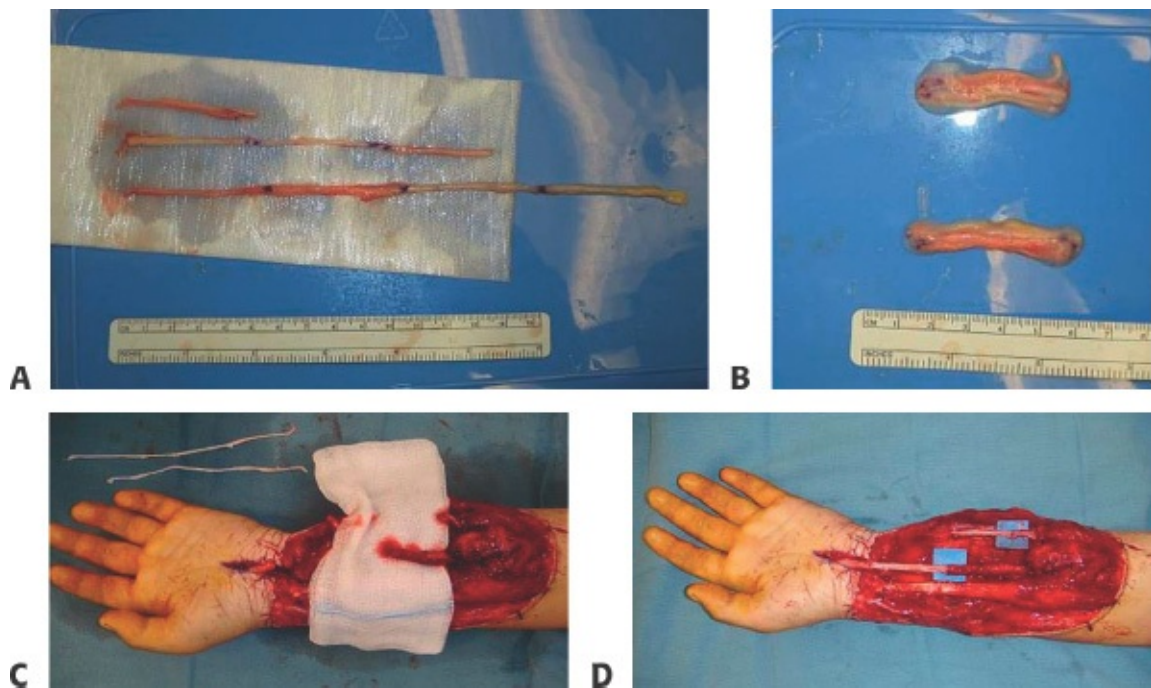
- **FIG 3** depicts the step-cut technique for sural nerve harvesting.
 - The sural nerve is easily located 2 cm superior and posterior to the lateral malleolus. Distal to the malleolus, the nerve begins to branch and becomes significantly smaller.
 - The lesser saphenous vein is intimately associated with the nerve and can be protected or ligated.
 - Gentle traction is placed on the nerve to determine the more proximal incisions.
 - The intervening skin bridges should be short enough that undue traction is not necessary to free the nerve from the surrounding soft tissue.
- The dissection proceeds proximally to the junction of the medial and lateral sural nerves in the mid-leg, where the medial branch pierces the gastrocnemius fascia, and the lateral sural nerve continues superficially.
 - The dissection can continue easily toward the origin of the lateral sural nerve from the common peroneal nerve or the medial sural nerve in between the two heads of the gastrocnemius muscle.⁷
- Approximately 30 cm of sural nerve can be harvested from one leg.
- A suture or surgical marking pen can be used to signify the proximal end so that the graft is reversed when brought to the recipient site.
 - Graft reversal prevents theoretical loss of axonal regeneration down small side branches and into surrounding soft tissues.

Graft Preparation

- For large defects, multiple sural cables should be prepared, and the number used depends on the number of large groups of fascicles within the injured nerve, in addition to the total length of sural nerve harvested.
- The nearby joints (fingers, wrist, elbow) should be maximally extended when measuring the nerve graft and length of nerve graft needed.
 - This will allow the nerve graft to be placed under no tension, even with early postoperative motion.
- After the length of the nerve defect is measured, the number of cables required is determined by the number of larger groups of fascicles visible that can be matched to accept individual grafts.
- The cables are brought together on a separate operating room table and rolled into a “burrito” as referenced earlier, followed by augmentation with fibrin glue.
 - This technique has been referred to as the “super nerve” technique (**TECH**

FIG 5A,B).

- The ends are sharply transected, exposing the grouped fascicles, and one end is coapted to the proximal recipient nerve defect with 8-0 or 9-0 nonabsorbable monofilament suture with the aid of an operating microscope.
- Identical preparation is done for the distal end of the cable graft, and the graft is inset in a similar fashion to the distal recipient nerve (**TECH FIG 5C,D**).
- The central portion of the cable graft is gently draped into the soft tissues with space between the cables to allow for revascularization.
- The upper extremity is taken through a full range of motion to verify that the nerve reconstruction is under no tension.



TECH FIG 5 • A,B. Preparation of multiple sural nerve cable grafts on the back table prior to reconstruction—the “super nerve” technique. **C,D.** Ulnar and median nerves grafted with sural nerve cable grafts.

Nerve gap	■ Avoid tension and have low threshold to perform nerve grafting.
Fascicular orientation	■ When possible, align fascicles at the time of repair.
Positioning	■ Repair and grafts should be tensioned to allow for “safe” positioning of the fingers/wrist/digits. Flexed postures to accommodate primary repair should be avoided at all costs. When in doubt, use a graft.

POSTOPERATIVE CARE

- For direct nerve repairs, splinting in a position that keeps the nerve repair under no tension should be considered for 2 weeks.
- For nerve reconstructions under no tension, splinting for 2 weeks is optional. A soft dressing is recommended when there is no tension.
- If immobilization is used, range of motion (ROM) begins at 2 weeks.
- Nerve regeneration begins after a period of 30 days and from this point on continues at a rate of 1 mm/d, 1 in./mo, and 1 ft./y.
 - The surgeon should follow the patient for signs of distally migrating sensory recovery and strength testing for motor reinnervation.
- Based on the distance from repair site to distal nerve endings, the surgeon can calculate at what point the patient should begin to experience noticeable recovery, and follow the Tinel sign along the path of the nerve.
 - If the Tinel sign ceases to cross the repair site, consideration should be given to repeat exploration, neurolysis, possible neuroma excision, and grafting.

OUTCOMES

- Positive predictors of sensory recovery include age and time since repair, and data show trends consistent with better outcomes for sharp injuries.
- There is no association between delay in repair and outcome for sensory injuries.⁸
 - For mixed nerve injuries, time to repair is critical as the motor endplates will cease to function after 18 to 24 months, and worse outcomes are seen after a delay in repair of more than 6 to 12 months.⁹
- Similarly, the distance from the injury to the target muscle is an important determinant of outcome.
 - The surgeon may calculate the distance from the injury from the target muscle and determine the time it will take for reinnervation to commence.

- A commonly reported “satisfactory” result is seen as recovery of M4 (active movement against resistance) or M5 (full power) for motor, and sensation S3+ (static two-point discrimination of 7–11 mm).¹⁰
- When grafting is required, the results of allograft and autograft nerve appear at this time to be equivalent.

COMPLICATIONS

- Complications of nerve repair are primarily inadequate recovery of sensation or motor function and neuroma formation.
- For inadequate sensory recovery, exploration with neurolysis and possible neuroma excision and grafting may be indicated, although there is no urgency to perform this.
- For suboptimal recovery of motor function, either nerve or tendon transfers may be indicated depending on the nerve injured and the time since injury.

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31 Tendon Transfers for Median Nerve Injury

CHAPTER

Rafael J. Diaz-Garcia and Kevin C. Chung

DEFINITION

- Median nerve palsy refers to the loss of motor control and sensation of the hand in the distribution of the median nerve.
- Low median nerve palsy refers to the loss of motor control and sensation of the hand in the distribution of the median nerve. Loss of sensation is the greatest deficit, because it encompasses 70% of the palmar surface. Loss of thenar function, particularly opposition, warrants reconstruction consideration.
- High median nerve palsy has significantly greater disability than does low median palsy due to the variable loss of function in the forearm, which can include pronation and flexion of the thumb, index, and long fingers.

ANATOMY

- The median nerve is a mixed nerve composed of fibers from the C5 through T1 roots, forming as a confluence of the lateral and medial cords of the brachial plexus.
- It travels with the brachial artery in the upper arm, between the biceps brachii and brachialis. It crosses anteriorly to the vessel as it reaches the antecubital fossa. It enters the forearm between the two heads of the pronator teres, innervating it.
- The median nerve travels between the flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) in the forearm. It gives off a branch, the anterior interosseous nerve, to innervate the flexor pollicis longus, the radial ½ of FDP, and pronator quadratus.
- The median nerve proper innervates the flexor carpi radialis, FDS, and palmaris longus.

- The palmar cutaneous branch arises 5 cm proximal to the wrist joint, supplying the skin of the thenar eminence.
- The median nerve passes superficially in the carpal tunnel, before giving the recurrent motor branch from the central or radial portion of the nerve. It usually passes distal to the transverse carpal ligament. It passes through the transverse carpal ligament up to 7% of the time.¹ The motor branch goes to the opponens pollicis, abductor pollicis, and the superficial head of the flexor pollicis brevis.
- The sensory branches provide sensation to the radial 3½ digits of the hand.
- Martin-Gruber and Riche-Cannieu connections represent anomalous innervation patterns between the median and ulnar nerves, which may complicate the findings on exam.

PATHOGENESIS

- The pathogenesis of median nerve palsy is most frequently due to compression, attributed usually to long-standing carpal tunnel syndrome.
- Median nerve lacerations happen most commonly at the wrist due to the superficial position of the nerve.
- Lipofibromatoma of the median nerve can be seen in pediatric cases.²
- Systemic conditions such as Charcot-Marie-Tooth disease can also cause median neuropathy.³
- The pathogenesis of high median nerve palsy is most frequently caused by trauma, which can happen from injuries extending from the brachial plexus to the forearm.
- Compression can also cause high median nerve palsy, though it is much more frequently the cause of low median nerve palsy. Sites of proximal compression include the pronator teres, lacertus fibrosis, and supracondylar process.

NATURAL HISTORY

- Compressive causes can have insidious onset symptoms over the period of years or even decades.
- Traumatic cases have a clearer history because of the abrupt onset of sensory disturbance that is noticed by the patient.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Acute injury
 - Patients present with a history of trauma and often a laceration, usually in the

volar wrist.

- Patients present with diminished sensation in the radial 3½ digits of the hand and a positive Tinel sign at the level of injury. There is greater functional loss with high median nerve palsy. There is a loss of opposition, flexion of the thumb through long fingers, and potentially pronation.
- Palmar abduction may still be present from the intact abductor pollicis longus.
- Chronic compression
 - Patients present with pain, numbness, and paresthesias of the radial 3½ digits.
 - In carpal tunnel syndrome, symptoms may be exacerbated during sleep or activities that require wrist flexion, such as driving or keyboard use.
 - They often complain of “clumsiness” or difficulty with fine motor functions.
 - The most notable finding on physical exam in long-standing low median palsy is thenar atrophy.
 - In pronator syndrome, symptoms may be exacerbated with compression of the proximal forearm over the pronator teres.
- Inability to make an “OK” sign with the thumb and index finger reflects pathology involving the anterior interosseous nerve.
- Lack of pronation reflects pathology proximal to the elbow

IMAGING

- Initial workup for acute median nerve palsy may warrant x-rays to determine if there are any fractures or dislocations in the extremity associated with the acute trauma.
- Nerve conduction studies and electromyography may be helpful in the workup of compressive median neuropathy, helping to determine the level of the lesion.
- Motor and sensory latencies are often increased with chronic compression of the median nerve. Fibrillation potentials indicate denervation of the muscles tested and axonal loss.
- MRI of the brachial plexus may be warranted if there is concern for a lesion at this level.

DIFFERENTIAL DIAGNOSIS

- Carpal tunnel syndrome
- Isolated median nerve injury
- Anterior interosseous syndrome
- Pronator syndrome

- Cervical radiculopathy
- Leprosy
- Charcot-Marie-Tooth disease
- Brachial plexus lesion

NONOPERATIVE MANAGEMENT

- Nonoperative management is indicated in the setting of a brachial neuritis (Parsonage-Turner syndrome), presenting with anterior interosseous nerve dysfunction.
- Work modification may be warranted in a patient with compressive neuropathy secondary to over use in pronator syndrome.
- Thumb adduction contractures must be prevented or treated prior to tendon transfers, as maximum passive motion must be acquired before any tendon transfers.

SURGICAL MANAGEMENT

- There are three key functions that tendon transfers must address in the setting of high median nerve palsy:^{9,10}
 - Thumb opposition
 - Flexion of the thumb
 - Flexion of the index and long fingers
- Occasionally, lack of pronation may require biceps rerouting. However, shoulder abduction can often compensate for this deficit enough to not be an issue.
- Unlike nerve transfers, tendon transfers do not have a firm time period in which they must be performed. Tendon transfers can be delayed while awaiting potential nerve recovery.
- The common principles of tendon transfers are as follows:
 - Joint contractures should be treated prior to any transfers.
 - Each muscle transfer should target one specific function.
 - Transferred tendons should glide through a smooth and scar-free surgical site.
- Thumb opposition cannot be reconstructed using FDS or palmaris longus in the setting of high median nerve palsy, as it would be in low median nerve palsy. Examination should be able to determine whether these muscles are functional.⁸
- In isolated low median nerve palsy, all reconstruction options are available. In

general, using the extensor indicis proprius is our first choice given the negligible donor morbidity and excellent tendon excursion. The Camitz transfer (palmaris longus) is a good option for elderly patients with long-standing carpal tunnel syndrome. It is simple to execute at the time of carpal tunnel release but creates more palmar abduction than true opposition. The Huber transfer (abductor digiti minimi) is reserved for children and for combined high median and radial nerve palsies.

Preoperative Planning

- Tendon transfers should be delayed until after potential nerve recovery is completed.
- Clinical exam of the patient will allow the surgeon to decide what functions must be recreated and what donor muscles are available for each function.

Positioning

- The patient is placed in the supine position with a tourniquet on the upper arm.
- The OR lights are positioned with one projecting from proximally and one distally from the operative site.

Approach

- Like with all tendon transfers, one should plan for the tendons to glide through a smooth and scar-free wound bed and each transfer should be for one function. If there is scarred tissue along the path of the transfer, it must be replaced by soft supple tissue either through serial scar excision or a flap procedure.

TECHNIQUES

■ Low Median Nerve Injury: Reconstruction of Thumb Opposition

Palmaris Longus to Abductor Pollicis Brevis (Camitz Transfer)

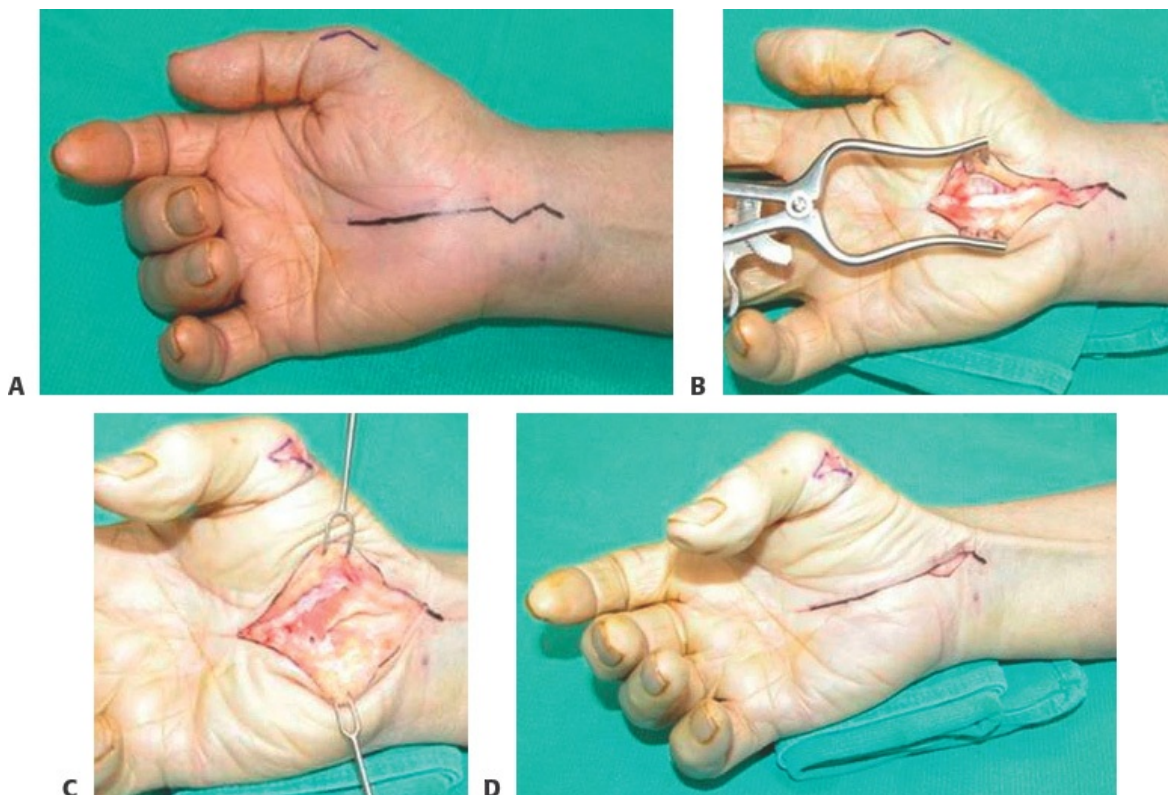
- Confirm the presence of a palmaris longus (PL) tendon and design a longitudinal incision, from the distal wrist crease to the proximal palmar crease, with a Bruner design over the wrist joint (**TECH FIG 1A**).
- Dissect the palmaris longus distally, taking a patch of palmar aponeurosis

along with the tendon (**TECH FIG 1B**).

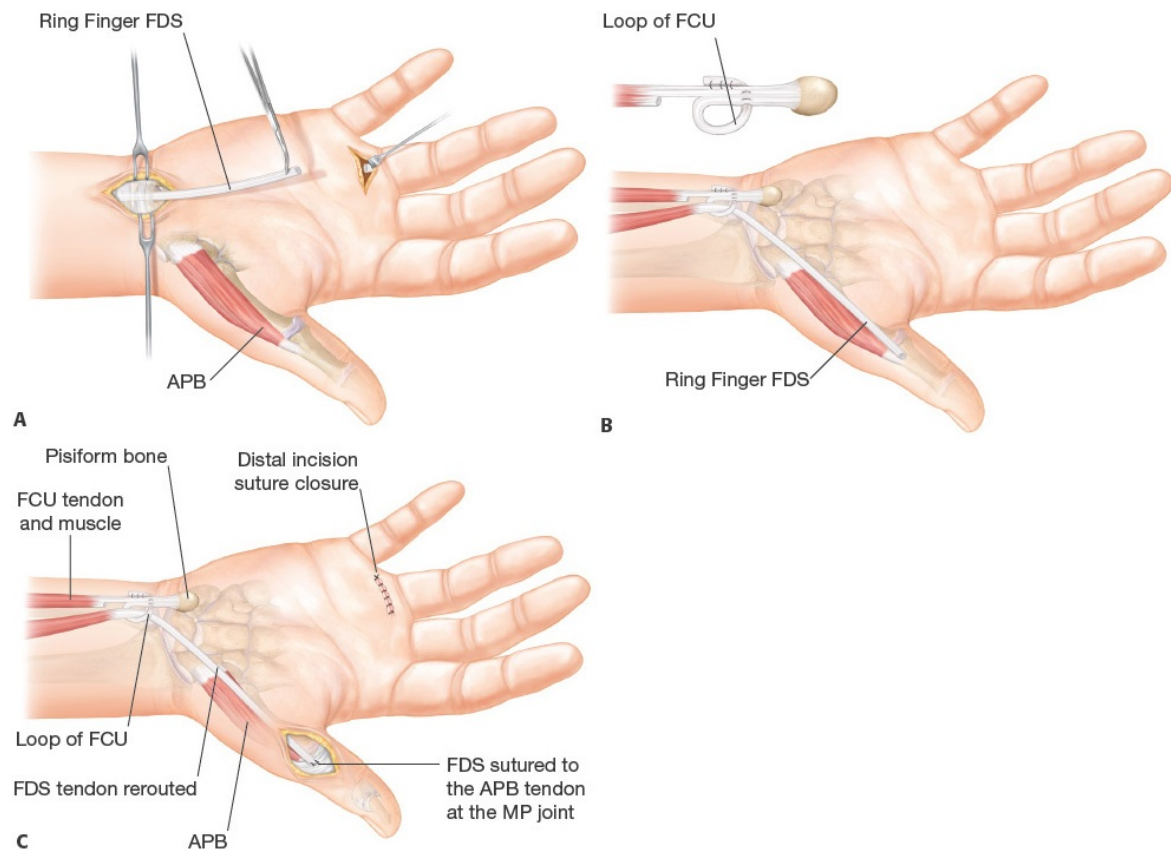
- Make an incision over the dorsoradial aspect of the thumb metacarpophalangeal (MCP) joint.
- Create a subcutaneous tunnel between the PL tendon and the MCP joint with blunt dissection.
- Pass the PL tendon to the thumb incision and suture it to the abductor pollicis brevis (APB) tendon (**TECH FIG 1C,D**) and extensor hood.

Flexor Digitorum Superficialis to Abductor Pollicis Brevis (Bunnell Transfer)

- A transverse incision is made over the ring finger A1 pulley (**TECH FIG 2A**).
- The A1 pulley is exposed and divided longitudinally, preserving the neurovascular bundles.
- The flexor digitorum superficialis (FDS) is divided proximally to the bifurcation with proximal longitudinal traction.
- A Bruner or longitudinal incision is made over the ulnar wrist, just radial to the flexor carpi ulnaris (FCU) tendon and near its insertion.



TECH FIG 1 • A. Design of incisions for PL transfer to AP. **B.** Exposure of PL at insertion into palmar fascia. **C.** PL tendon is sutured to APB, creating palmar abduction. **D.** PL tendon is sutured to APB, creating palmar abduction.



TECH FIG 2 • A. Tendon anatomy for FDS to APB (Bunnell) transfer. **B.** Looping of the FCU tendon to create a pulley for transfer. **C.** Passage of FDS tendon through the FCU pulley for suture to the APB tendon.

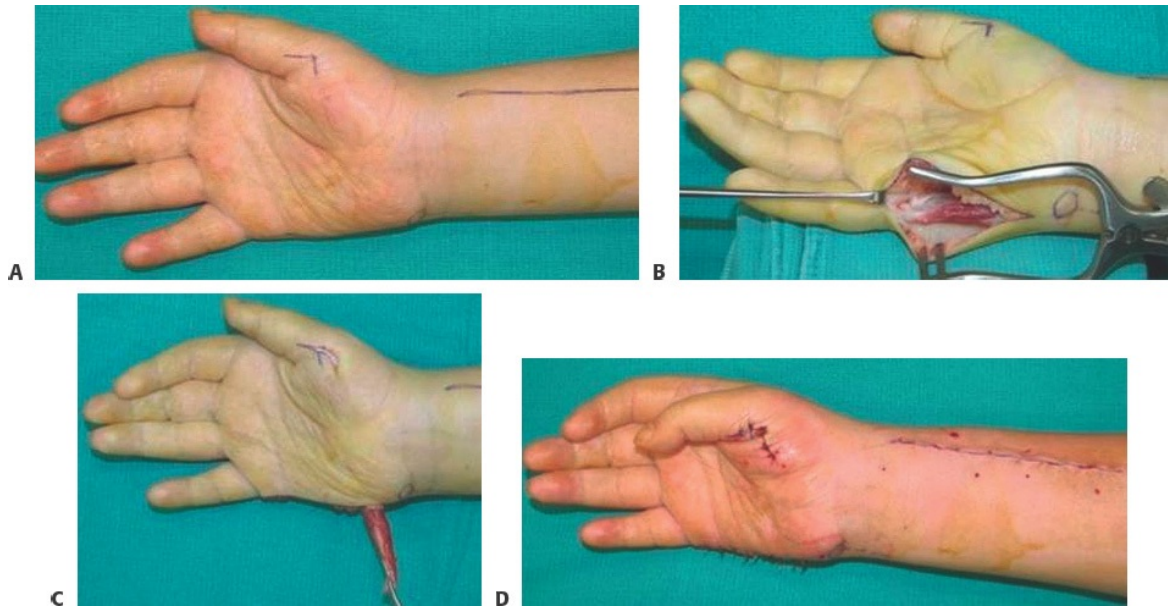
- The radial half of the FCU tendon is divided and separated from the ulnar half longitudinally.
- The distally based FCU tendon is sutured to itself at the insertion site, creating a pulley (**TECH FIG 2B**).
- A longitudinal incision is made along the radial aspect of the thumb MCP

joint.

- A subcutaneous tunnel is created from the thumb incision to the wrist incision.
- The FDS is passed through this pulley and then through the tunnel to the thumb, where it is sutured to the APB tendon and extensor hood with braided suture (**TECH FIG 2C**).

Abductor Digiti Minimi to Abductor Pollicis Brevis (Huber Transfer)

- A Bruner or curvilinear incision is made from the ulnar aspect of the small finger to the radial border of the hypothenar eminence (**TECH FIG 3A**).
- The abductor digiti minimi (ADM) is dissected distally, protecting the ulnar neurovascular bundle to the small finger. It is freed from the underlying flexor digiti minimi, if present (**TECH FIG 3B**).
- The ADM is released from its insertion site on the small finger proximal phalanx with a portion of the lateral band to increase its length.
- From distal to proximal, mobilize the muscle toward and eventually off of the pisiform. Preserve the neurovascular bundle, which comes from the deep and radial surface of the muscle (**TECH FIG 3C**).
- Make an incision along the radial aspect of the thumb MCP joint and use blunt dissection to create a subcutaneous tunnel in the palm, superficial to the transverse carpal ligament.
- Pass the ADM through the tunnel to the thumb and suture it to the APB tendon and extensor hood with permanent braided suture (**TECH FIG 3D**).



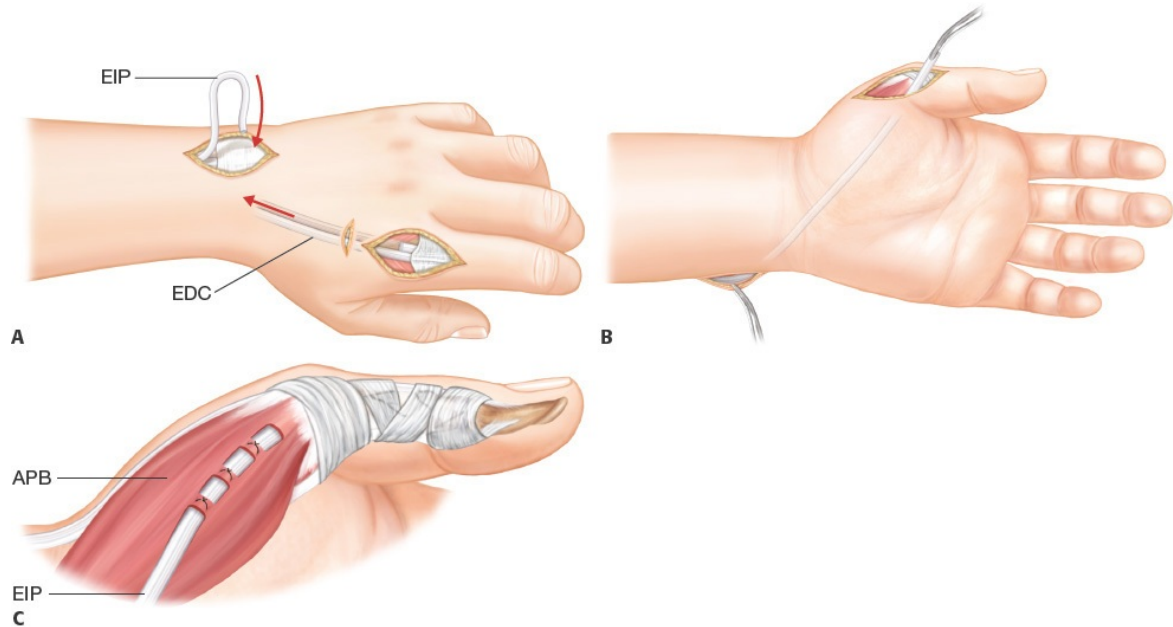
TECH FIG 3 • **A.** Design of incisions for ADM transfer to APB. **B.** Exposure of ADM along hypothenar eminence. **C.** Dissected free ADM muscle, all the way to pisiform. **D.** Final position after transfer, creating both palmar abduction and opposition.

■ High Median Nerve Injury

Reconstruction of Thumb Opposition: Extensor Indicis Proprius to Abductor Pollicis Brevis

- A small longitudinal incision is made along the dorsoulnar aspect of the index MCP joint (**TECH FIG 4A**).
- The extensor indicis proprius (EIP) tendon is identified as the ulnar tendon and released from the index finger extensor hood with a small slip of extensor mechanism. The rent is repaired with permanent suture.
- A longitudinal incision is made over the dorsoulnar wrist, just proximal to the ulnar styloid.
- Dissection is carried radially from this wrist incision to find the EIP tendon, just distal to the extensor retinaculum. The distal aspect of the fourth extensor compartment is divided to fully mobilize the tendon.
- A small incision is made along the radial pisiform and a longitudinal incision along the radial aspect of the thumb MCP (**TECH FIG 4B**).

- A subcutaneous tunnel is created from the dorsal wrist incision to the pisiform incision, attempting to stay deep to the ulnar sensory nerve branch. This tunnel is then dissected from the pisiform to the thumb incision.



TECH FIG 4 • A. Release of EIP tendon for passage and radial dissection to locate and retrieve EIP tendon for transfer. **B.** Creation of a subcutaneous tunnel from the radial pisiform incision to the longitudinal thumb incision. **C.** EIP suture to APB tendon with braided permanent suture.

- The EIP tendon is passed from dorsal to volar, around the pisiform, and then to the thumb incision. It is sutured to the APB tendon and extensor hood with braided permanent suture (**TECH FIG 4C**).

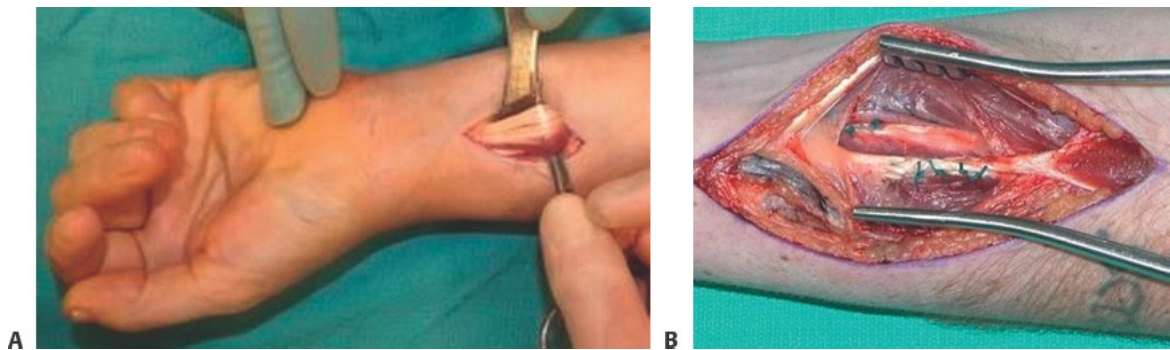
Reconstruction of Index and Long Finger Flexion: Flexor Digitorum Profundus Side-to-Side Transfer

- A longitudinal incision is made over the distal third of the forearm.
- The flexor digitorum profundus (FDP) tendons are identified, deep to the median nerve (**TECH FIG 5A**).
- The FDP tendons are synchronized to recreate the digital cascade, and one

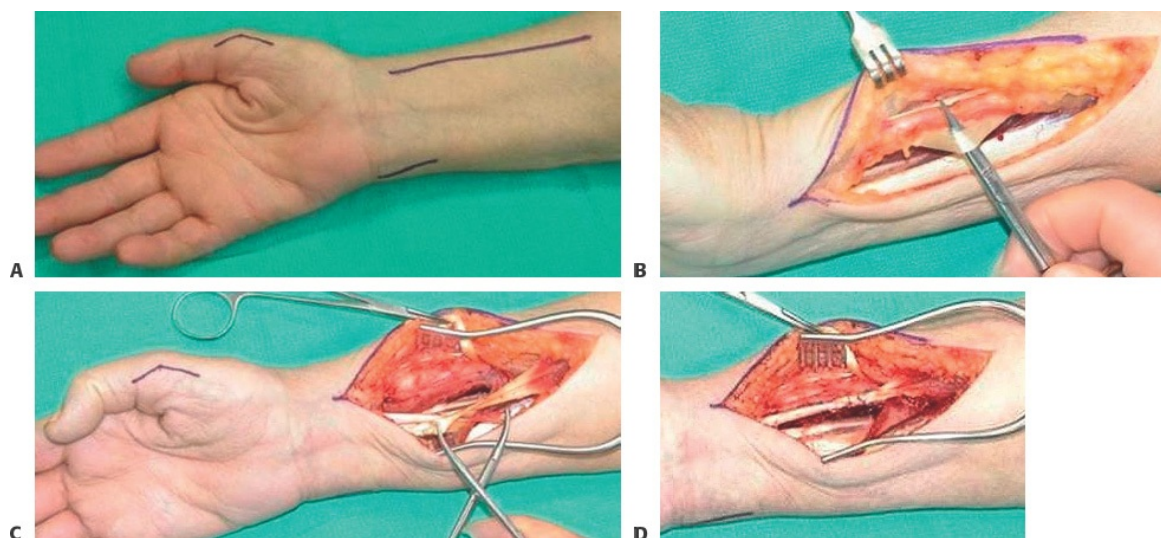
sutures the index through small finger tendons with two rows of braided permanent sutures (**TECH FIG 5B**).

Reconstruction of Thumb Flexion: Brachioradialis to Flexor Pollicis Longus

- A longitudinal incision is made along the distal third of the forearm. The same incision for the FDP transfer can be used (**TECH FIG 6A**).
- The brachioradialis (BR) is released from the radial styloid insertion and mobilized proximally to maximize the excursion (**TECH FIG 6B**).
- The FPL tendon is located under the flexor carpi radialis, in the deep volar compartment.
- The BR is weaved into the flexor pollicis longus (FPL) with multiple passes, after optimizing tension (**TECH FIG 6C,D**). Wrist extension should result in maximal thumb IP joint flexion and lateral pinch.



TECH FIG 5 • A. The FDP tendons are localized beneath the median nerve in the distal forearm. **B.** Tension is set between the radial two tendons (median innervated) and ulnar two tendons (ulnar innervated), recreating the digital cascade.



TECH FIG 6 • **A.** Design of incisions for high median nerve tendon transfers. **B.** Exposure of BR along insertion onto radial styloid. **C.** Tension is set between the BR and FPL. **D.** Final position of thumb after transfer, judging tenodesis with wrist flexion and extension.

PEARLS AND PITFALLS

Preoperative evaluation

- Critically assess donor muscle availability and strength.
- Determine patient goals and potential for additional nerve recovery.
- Release any areas of nerve compression for pain control, even if motor recovery is unlikely.

Thumb opposition

- Thumb should be in full opposition and IP joint flexed with wrist extension and should relax with wrist flexion.
- Ensure that subcutaneous tunnel is of ample size to allow easy tendon gliding.

Finger flexion

- Improvement in finger flexion may not improve grip strength given no additional motor units.

POSTOPERATIVE CARE

- Patient is usually splinted with the thumb in full opposition and wrist in flexion immediately after surgery. The fingers are free to move to maintain motion.
- At the first postoperative visit, an orthoplast splint is fabricated to maintain thumb opposition and slight wrist flexion. At 3 weeks, gentle active range of motion is commenced several times a day. Passive range of motion is started at 6 weeks. Strengthening is started at 8 weeks.
- A knowledgeable hand therapist plays an important role in the surgical outcomes.
- Early active range of motion for opposition transfers has been advocated by some surgeons, with quicker recovery and no evidence of pullout of the transferred tendon.⁴

OUTCOMES

- Most median nerve palsy patients can perform normal activities of daily living with their hand after complete recovery from surgery. The tendon transfers combine proper direction of action, pulley location, and force for success.⁵
- Extensor indicis proprius (EIP) opponensplasty is generally efficacious, with 88% of patients with excellent results—ie, 75% function of the opposite, normal thumb.⁶ It works best in the setting of supple hands.⁷ EIP is not synergistic with thumb opposition, so retraining can be more difficult than FDS transfers.

COMPLICATIONS

- Suboptimal results may be a result of choosing a weak motor for transfer or incorrect vector of pull.
- Tendon adhesions can result from prolonged immobilization, particularly if using a pulley to reroute the force of the muscle.
- Tendon ruptures can be prevented with patient education and progressive therapy advancement.

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32 Tendon Transfers for Ulnar Nerve Injury

CHAPTER

Rafael J. Diaz-Garcia and Kevin C. Chung

DEFINITION

- Ulnar nerve palsy refers to the loss of motor control and sensation in the distribution of the ulnar nerve.
- Low ulnar nerve palsy refers to isolated loss of intrinsic hand function, whereas high ulnar nerve palsy refers to the additional loss of half the flexor digitorum profundus (FDP) and flexor carpi ulnaris (FCU).

ANATOMY

- The ulnar nerve is a mixed nerve composed of fibers from the C8 and T1 roots via the medial cord of the brachial plexus.
- It lies posteromedial to the brachial artery in the upper arm, prior to piercing the intramuscular septum 8 to 10 cm proximal to the medial epicondyle. It has no branches in the arm.
- It passes through the cubital tunnel into the forearm, running between FCU and FDP, innervating the former and 0.5 of the latter.
- Approximately 6 to 7 cm proximal to the ulnar styloid, the dorsal sensory branch leaves the main nerve to innervate the dorsoulnar hand and dorsal proximal phalanges of the small and ring fingers.
- The ulnar nerve continues into the hand through the Guyon canal at the wrist, splitting into a superficial sensory branch and a deep motor branch. The sensory branch supplies innervation to the small finger and ulnar half of the ring finger. The motor branch supplies the hypothenar muscles, ulnar lumbricals, interossei, adductor pollicis, and the deep head of flexor pollicis brevis.
- Martin-Gruber and Riche-Cannieu connections represent anomalous

innervation patterns between the median and ulnar nerves, which may complicate the findings on exam.

PATHOGENESIS

- The pathogenesis of ulnar nerve palsy is most frequently secondary to trauma. Injury may come in the form of a laceration along its course, an axonotmetic injury, or an avulsion of the roots. Proximal injuries that involve the medial cord may also have sensory disturbances in the arm or forearm due to involvement of the medial brachial and antebrachial cutaneous branches.
- Systemic conditions such as Charcot-Marie-Tooth disease, leprosy, and syringomyelia can cause ulnar neuropathy as well.¹ Systemic conditions are unlikely to present with isolated ulnar nerve symptoms.

NATURAL HISTORY

- With prolonged ulnar nerve palsy, secondary deformities of the hand will develop with attenuation of the central slips and flexion contractures of the interphalangeal joints.
- The disability and deformity is directly related to the degree of the nerve injury. If tendon transfers are being considered, nerve recovery is unlikely.

PATIENT HISTORY AND PHYSICAL FINDINGS

- It is important to identify the cause and timing of ulnar nerve palsy to determine if the pathology can be reversed. Acute repair of lacerated nerves, nerve transfers, and decompressions should be done sooner rather than later to prevent irreversible loss of the motor end plates in the innervated muscles.
- Tendon transfers are indicated when no further recovery of the nerve or the ulnarly innervated muscles is expected.
- Working from distal to proximal, testing muscle and sensory function can help localize the level of the lesion. The first dorsal interosseous is the last muscle innervated by the ulnar nerve. Involvement of only motor function implies a lesion in the deep motor branch, distal to the Guyon canal. Loss of sensation along the dorsoulnar aspect of the hand implies a lesion proximal to the takeoff of the dorsal sensory branch. Loss of distal interphalangeal (DIP) flexion of the ring and small fingers implies high ulnar nerve palsy, due to involvement of the FDP. Loss of sensation along the medial arm or forearm implies a lesion in the brachial plexus.
- There are many eponymous physical findings found in ulnar nerve palsy, most

of which are functional losses of intrinsic hand muscles:^{2,3}

- Froment sign: hyperflexion of the IP joint of the thumb when attempting forceful adduction, due to substitution of flexor pollicis longus (FPL) for adductor pollicis
- Jeanne sign: hyperextension of the metacarpophalangeal (MCP) joint of the thumb as a reciprocal result of over use of FPL
- Wartenburg sign: abduction of small finger due to paralysis of intrinsics with unimpeded abduction by extensor digiti minimi
- Duchenne sign: hyperextension of the MCP joints and flexion of the PIP joints, secondary to paralysis of ulnarly innervated interosseous and lumbricals
- Masse sign: flattening of the metacarpal arch
- Pollack sign: loss of DIP flexion of the ring and small fingers in high ulnar nerve palsy
- The Bouvier maneuver is a preoperative test to assess IP joint extension if MCP hyperextension is blocked. In theory, a positive Bouvier—that is to say, intact IP extension with MCPs held in flexion—implies that addressing MCP hyperextension with a static procedure should correct claw deformity. In reality, static soft tissue procedures tend to stretch out and most patients would do best with a dynamic tendon transfer.⁴

IMAGING

- Initial workup for an ulnar nerve lesion usually warrants nerve conduction studies and electromyography to determine location and extent of injury.
- MRI of the brachial plexus may be warranted if there is concern for a lesion at this level.

DIFFERENTIAL DIAGNOSIS

- Isolated ulnar nerve compression
- Isolated ulnar nerve injury
- Traumatic lower plexopathy
- Cervical radiculopathy
- Leprosy
- Syringomyelia

NONOPERATIVE MANAGEMENT

- An occupational therapist can be helpful in the nonoperative management of

ulnar nerve palsy.

- An anticlaw splint (dorsal blocking at the MCP joint with IP joints free) can be used to preserve extensor integrity while the nerve recovers or as a long-term functional orthosis.
- Flexion contractures must be prevented or treated prior to tendon transfers, as maximum passive motion must be acquired before any tendon transfers.
- Fixed flexion contractures should be addressed with serial casting, if needed.

SURGICAL MANAGEMENT

- There are three key functions that tendon transfers must address in the setting of ulnar nerve palsy:
 - Thumb adduction to recreate key pinch
 - Improved grip by addressing claw deformity and MCP hyperextension
 - Flexion of ring and small finger DIP joints, in those with a high ulnar palsy
- Unlike nerve transfers, tendon transfers do not have a firm time period in which they must be performed. Tendon transfers can be delayed while awaiting potential nerve recovery.
- The common principles of tendon transfers are as follows:
 - Joint contractures should be addressed prior to any transfers.
 - Each muscle transfer should address one specific function.
 - Transferred tendons should glide through a smooth and scar-free surgical site.
- Thumb adduction can be addressed with either extensor carpi radialis brevis (ECRB) or flexor digitorum superficialis (FDS), with the former being our preference. Transfers for adduction require a pulley distal to the pisiform for the transfer to be effective.
- Claw deformity of the fingers can be addressed with either static or dynamic procedures. For static procedures to be indicated, the Bouvier maneuver must be positive. Static procedures prevent hyperextension of the MCP joint but often stretch out over time unless the joint undergoes arthrodesis.⁵ Dynamic procedures use FDS, ECRB, extensor carpi radialis longus, or flexor carpi radialis. The FDS transfers are preferable because they do not require tendon grafts, which may be prone to adhesion. High ulnar nerve palsy precludes use of the FDS tendons in the ring and small finger for transfers.

Preoperative Planning

- Tendon transfers should be delayed until after potential nerve recovery is

completed.

- Clinical exam of the patient will allow the surgeon to decide what functions must be recreated and what donor muscles are available for each function.

Positioning

- The patient is placed in the supine position with a tourniquet on the upper arm.
- The OR lights are positioned with one projecting from proximally and one distally from the operative site.

Approach

- Like with all tendon transfers, one should plan for the tendons to glide through a smooth and scar-free wound bed and each transfer should be for one function.
- To recreate the intrinsic function of the hand, the transferred tendons should pass volar to the axis of the MCP joint prior to inserting on the dorsal extensor apparatus.

TECHNIQUES

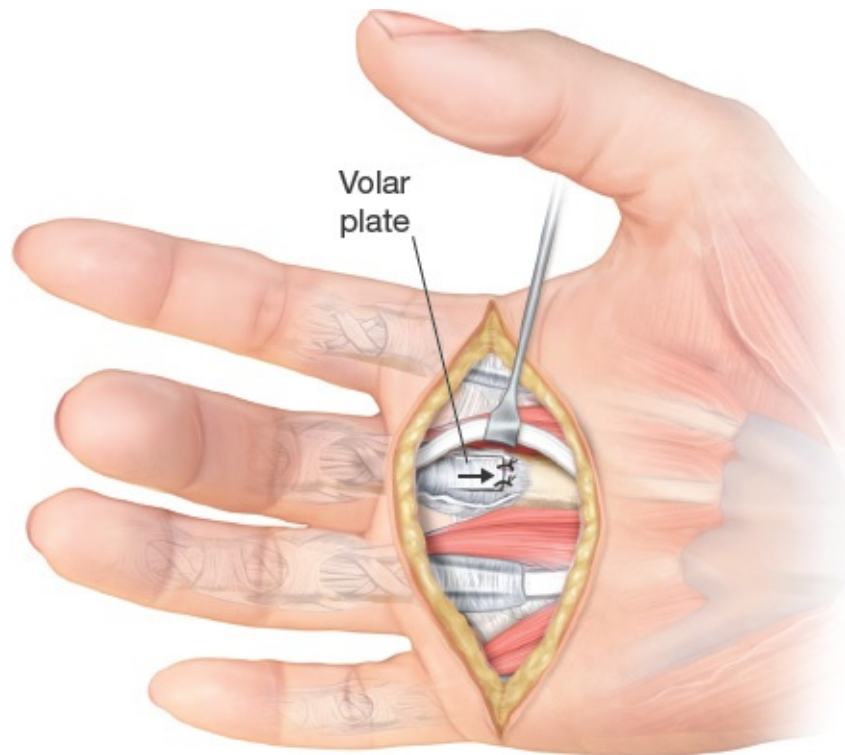
■ Claw Deformity of Digits

Metacarpal Capsulodesis^{6,7}

- Indicated only with a positive Bouvier maneuver
- An incision is made in line with the distal palmar crease, over the A1 pulley of the ring and small fingers.
- The A1 pulley is exposed and released longitudinally, protecting the neurovascular bundles and exposing the volar plate of the MCP joint (**TECH FIG 1**).
- A distally based, rectangular-shaped flap of volar plate is created by releasing the proximal attachment off the metacarpal.
- A 30-degree flexion contracture is created with the volar plate advanced proximally, and bone anchors are used to maintain position of the joint.
- As noted before, this procedure can be technically difficult to perform because the exposure is limited and the volar plate cannot be advanced easily. This type of soft tissue reconstruction does stretch out rather quickly. A truly predictable static procedure is MCP joint fusion.

Flexor Digitorum Superficialis Lasso

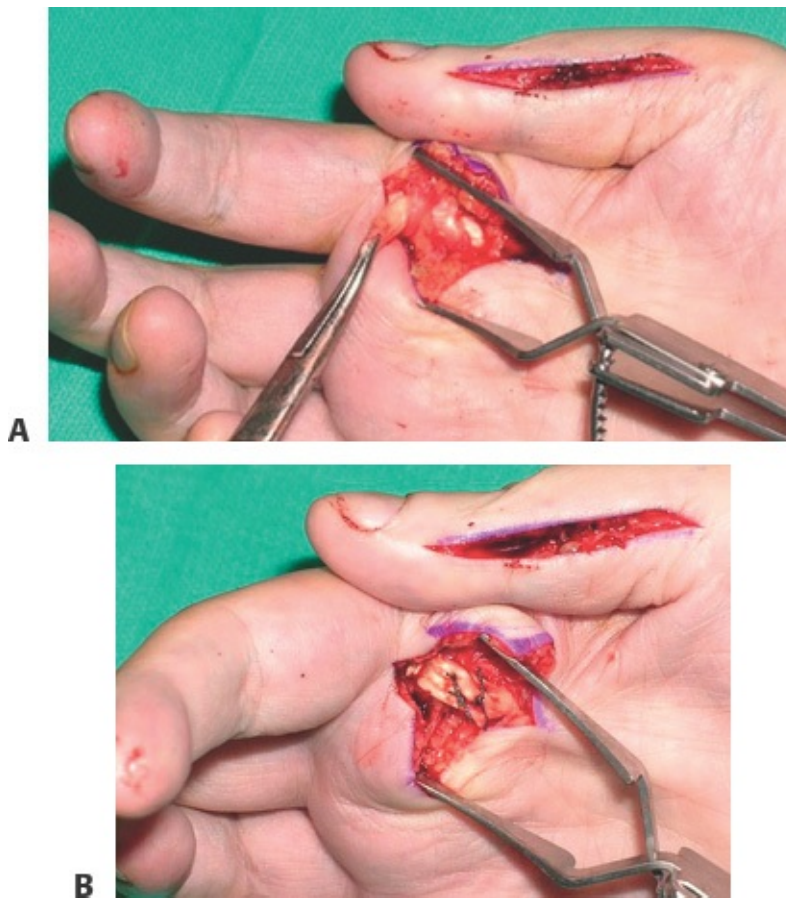
- An incision is made in line with the distal palmar crease, over the A1 pulleys of the ring and small fingers.
- The A1 and A2 pulleys are exposed, preserving the neurovascular bundles.
- The FDS insertion is preserved to reduce the likelihood of a swan-neck deformity. The FDS is released at A2 pulley and sutured back to itself proximal to the A1 pulley, creating a tendinous loop (**TECH FIG 2A**).
- Set the tension with the MCP joint at 40 to 50 degrees of flexion with the wrist at neutral, recreating the usual digital cascade of the hand (**TECH FIG 2B**).
- The FDS middle finger can be split into four tails in a more proximal incision and similarly tensioned at each A1 pulley.



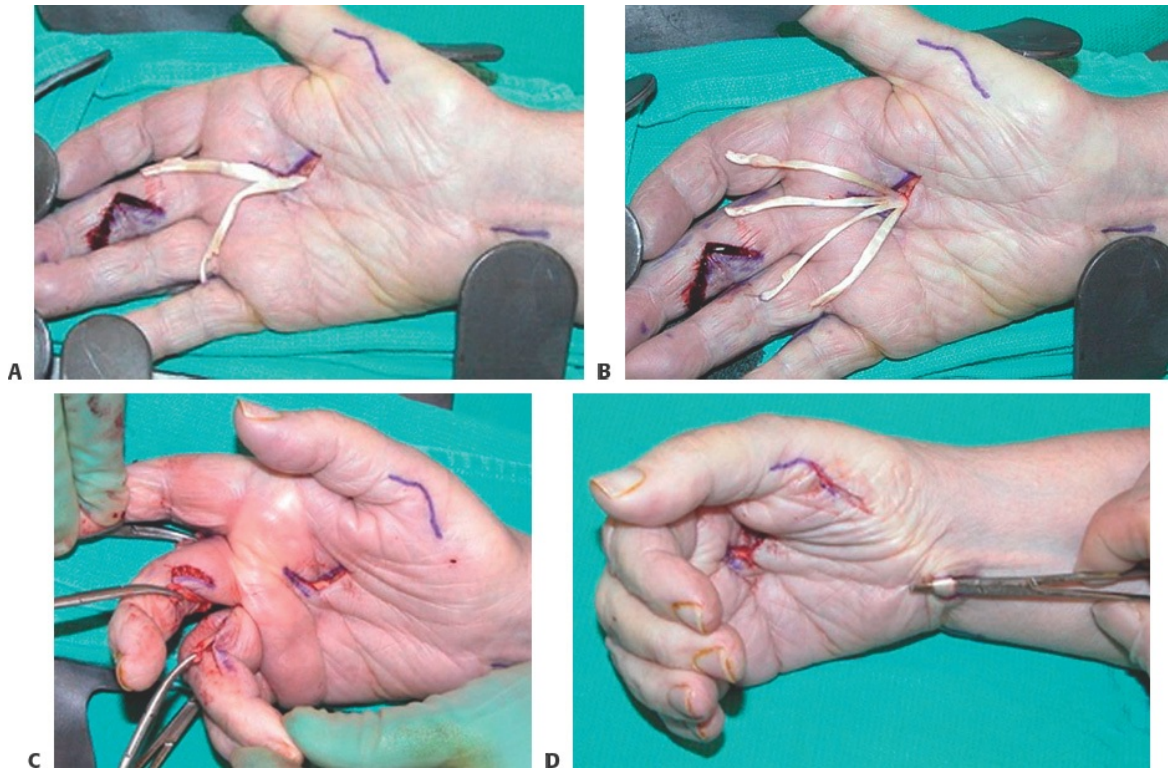
TECH FIG 1 • A1 pulley is released longitudinally and a rectangular-shaped flap of volar plate is created. Flexion contracture is created with the proximally advanced volar plate and bone anchors maintain position of the joint.

Stiles-Bunnell Transfer of FDS to Lateral Bands^{8,9}

- One FDS tendon can be used to power two digits or four digits. The ring and small finger FDS is not used in the setting of high ulnar nerve palsy to preserve flexion of the ring and little fingers when the FDP to these two fingers is paralyzed.
- A Bruner incision is made over the proximal phalanx between the A2 and A3 pulleys. A separate longitudinal incision is made over the proximal phalanx between the glabrous and nonglabrous skin to expose the radial lateral band (**TECH FIG 3A**).
- The FDS is divided just proximal to the insertion and split into four slips as proximally as possible (**TECH FIG 3B**).



TECH FIG 2 • A. FDS tendon is released at distal edge of A2 pulley via Bruner incision. **B.** FDS tendon is sutured back to itself to create a flexion contracture at MCP joint.

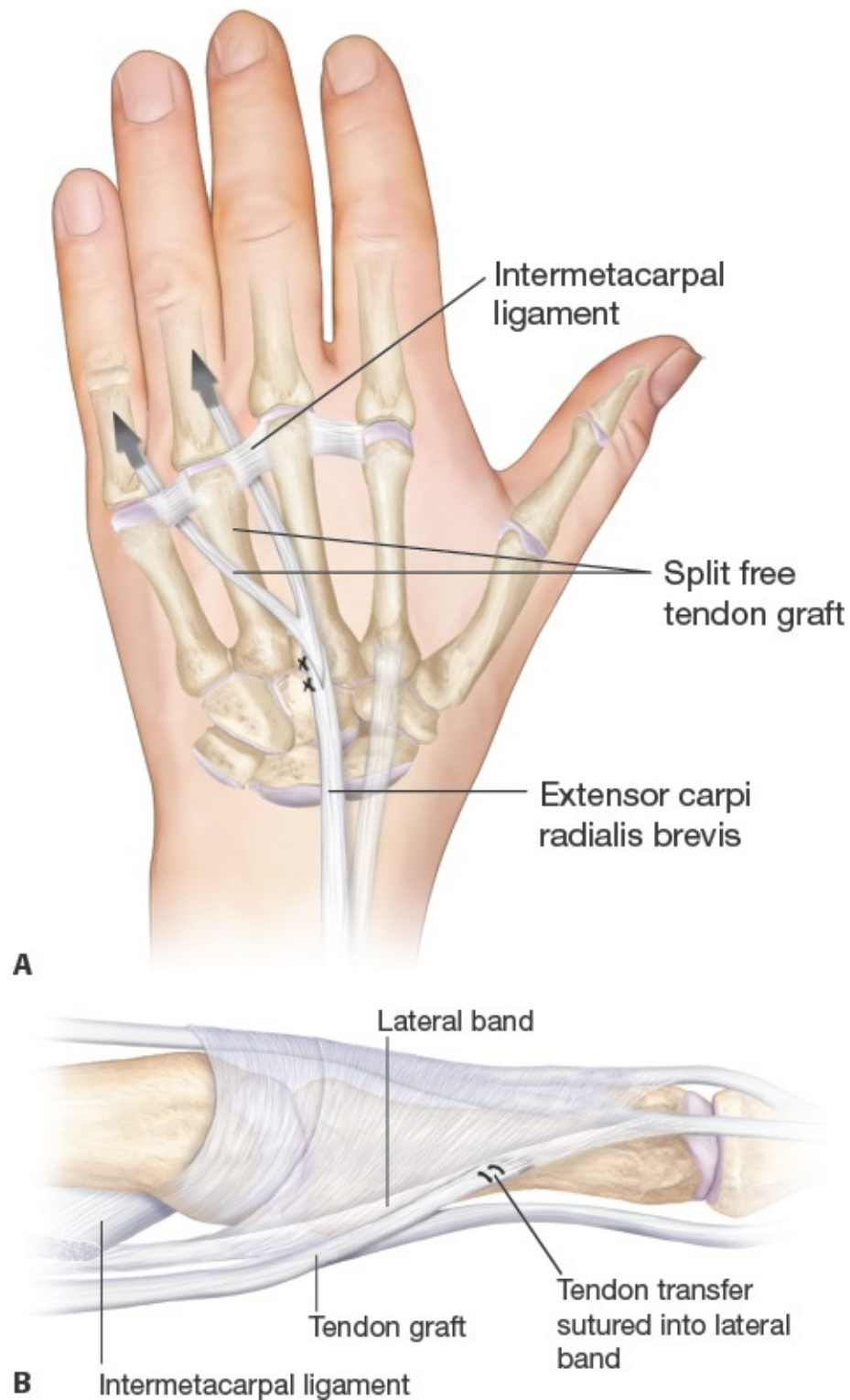


TECH FIG 3 • **A.** The FDS of the middle finger is released from the insertion on middle phalanx. **B.** Four tails are created for transfer to the digits. **C.** FDS is transferred to the lateral bands of each digit, radial of the middle-small and ulnar of the index. **D.** Final position after transfer shows MCP flexion composite with FDS pull.

- FDS slip is passed through lumbrical canal, deep to the neurovascular bundle, with a tendon passer or hemostat to the radial aspect of the middle through small fingers and the ulnar aspect of the index. It is key to stay palmar to the deep metacarpal ligament to maintain the force palmar to the axis of rotation (**TECH FIG 3C**).
- FDS slips are attached to the lateral band with the wrist at neutral, trying to recreate the digital cascade. MCP flexion should be at 50 to 70 degrees and IP joints in full extension (**TECH FIG 3D**).
- Passive wrist flexion should result in full MCP extension.

ECRB to Lateral Bands With Tendon Graft^{9,10}

- ERCB is used when the FDS is not available, for example, high median and ulnar nerve palsy when the reinnervated median nerve muscles are too weak to transfer.
- A small transverse incision is made over the third metacarpal base, through which the ECRB is transected at its insertion.
- The ECRB tendon is retrieved proximal to the retinaculum through a separate incision.
- Incisions are made at the metacarpal necks in the second/third metacarpal interval and fourth/fifth metacarpal interval.
 - Excising a small window of paralyzed interosseous muscle creates a path for each tendon graft.
- Longitudinal incisions are made over the proximal phalanges of the index through small fingers, exposing the lateral bands.
- A tendon graft is passed volarly to the intermetacarpal ligament and through the intermetacarpal windows.
- The tendon grafts are sutured to the radial lateral bands of the middle through small fingers and the ulnar lateral band of the index.
- The grafts are sewn to each other and then to the ECRB (**TECH FIG 4**).
 - Tension should be done with the wrist in full extension and the fingers in an intrinsic-plus position.
 - MCP extension should happen with wrist flexion.

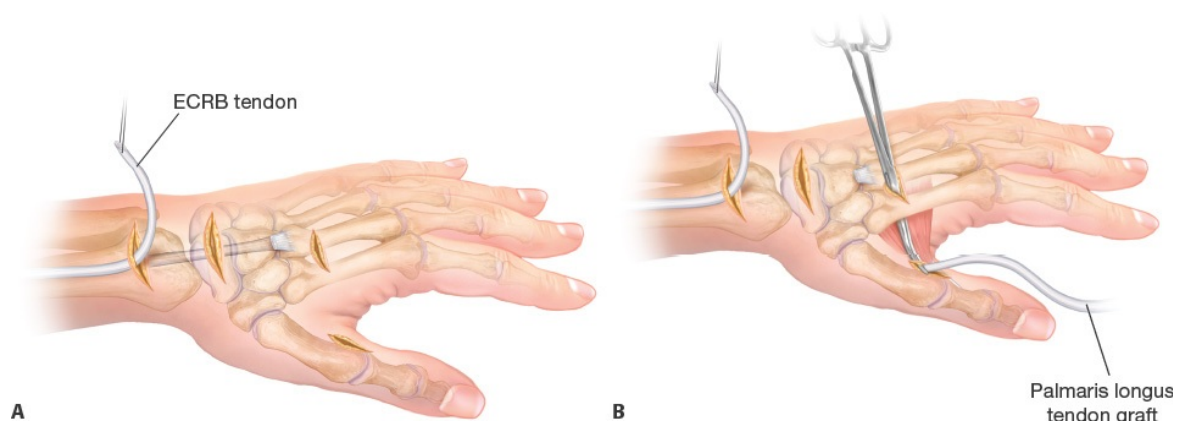


TECH FIG 4 • A. Tendon graft is passed volarly to the intermetacarpal ligament and through the intermetacarpal windows. **B.** Tendon grafts are

sutured to the radial lateral band of the middle finger and the ulnar lateral band of the index finger. Tendon transfer is sutured into the lateral band.

■ Restoration of Thumb Adduction: ECRB to Adductor Pollicis With Tendon Graft

- A small transverse incision is made over the third metacarpal base, through which the ECRB is transected at its insertion.
- The ECRB tendon is retrieved proximal to the retinaculum through a separate incision.
- A path for the tendon graft is created between the third and second metacarpals, incising skin and excising a small window of paralyzed interosseous muscle.
- A longitudinal incision is made along the ulnar aspect of the thumb MCP joint, exposing the adductor aponeurosis.
- A tendon graft (often palmaris) is passed deep to the adductor pollicis and through the window between the metacarpals (**TECH FIG 5**).
- The graft is tensioned so that the thumb is adducted past the index metacarpal when the wrist is at neutral. In dorsiflexion, the thumb is abducted, and in palmar flexion, it should lie firmly against the palm.

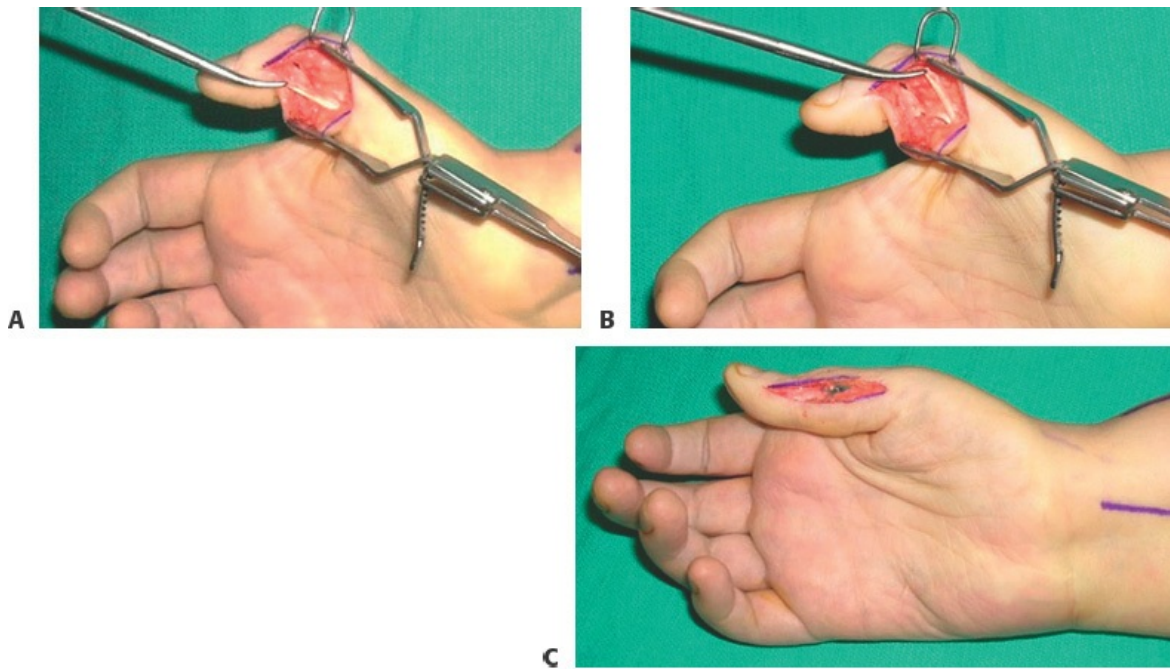


TECH FIG 5 • A. A transverse incision is made over the third metacarpal base and the ECRB is transected at insertion. The ECRB tendon is retrieved proximal to the retinaculum through another incision. **B.** The

palmaris longus tendon graft is passed to the adductor pollicis.

■ Thumb Stabilization: Split Flexor Pollicis Longus (FPL) to Extensor Pollicis Longus (EPL) Tenodesis

- The muscle imbalances of the ulnar paralyzed hand, particularly due to the loss of the adductor pollicis, result in greater flexion of the IP joint and less of the MCP. This creates a Z-deformity in about 60% of patients.¹¹
- A radial incision is made over the proximal phalanx of the thumb.
- Preserving the oblique pulley, the FPL and EPL are exposed.
- The radial half of the FPL is released from the distal insertion and weaved into the EPL (**TECH FIG 6**).
- The interphalangeal joint is kept in extension with a 0.045-in. K-wire.



TECH FIG 6 • **A.** The radial half of the FPL is released from the rest of the tendon at the insertion site. **B.** This radial slip is transferred dorsally. **C.** Final position after transfer shows IP joint stabilization.

■ Restoration of Finger Flexion: Flexor Digitorum Profundus (FDP) Side-to-Side Transfer

- High ulnar nerve palsy results in paralysis of the ulnar 0.5 of FDP, affecting motion of the DIP joints of the ring and small fingers and thus grip strength.
- Side-to-side transfer is an easy way to address this with the median nerve innervated portion of the muscle.
- A longitudinal incision is made over the distal third of the forearm.
- The FDP tendons are identified, deep to the median nerve.
- The FDP tendons are synchronized to recreate the digital cascade, and one sutures the long through small finger tendons with two rows of braided permanent sutures.

PEARLS AND PITFALLS

Preoperative evaluation

- Critically assess donor muscle availability and strength.
- Determine patient goals and potential for additional nerve recovery.
- Determine the integrity of the PIP central slip with the Bouvier maneuver.

Thumb adduction

- The thumb may have joint instability that requires additional procedures such as capsulodesis or arthrodesis.

Addressing claw deformity

- Static transfers usually stretch over time and should be reserved for combined nerve injuries.
- Transfers must pass volar to the MCP joint to address hyperextension.
- Dynamic transfers should be sewn into lateral bands if Bouvier maneuver is negative.

POSTOPERATIVE CARE

- The patient is usually splinted with the MCP joints in 60 to 70 degrees of flexion and the IP joints in full extension (intrinsic plus position) for a total of 4 weeks. Active range of motion exercises are then commenced, with a dorsal blocking splint at the MCP joint.

- Passive range of motion is started at 6 weeks. Strengthening is started at 8 weeks for the adductor plasty and 10 weeks for the intrinsic transfers.
- A knowledgeable hand therapist plays an important role in the surgical outcomes.
- Early active range of motion has been advocated by some surgeons, with quicker recovery and less pain.^{12,13}

OUTCOMES

- Outcome studies are difficult to compare due to the heterogeneity of the patient populations.
- Static reconstructions often stretch. Less than 50% of the hands treated with capsulodesis see long-term improvement in regard to clawing.¹⁴
- Wrist extensor transfers to the lateral bands restore grip strength most effectively, with the highest efficacy in those with short-standing paralysis.¹⁵ However, the need for tendon grafts and scarring through the interosseous muscles makes them less favorable.^{16,17}
- FDS transfers are most efficacious in addressing claw deformity, with minimal improvement in grip strength.^{15,18}

COMPLICATIONS

- Complications are more common with the intrinsic transfers due to the delicate balance in the extensor mechanism.
- Transfers may be ineffective due to poor tensioning and may need surgical revision to tighten the insertion.
- Transfers that are too tight can often be addressed with passive range of motion exercises to stretch the transfer.
- Harvest of FDS results in a swan-neck deformity fairly commonly, with the incidence ranging from 15% to 85%.^{15,19,20}

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33 Tendon Transfers for Radial Nerve Injury

CHAPTER

Rafael J. Diaz-Garcia and Kevin C. Chung

DEFINITION

- Radial nerve palsy refers to the loss of motor control and sensation of the hand in the distribution of the radial nerve.
- Loss of extensor function of the wrist and digits is the greatest deficit, as the sensation loss is of little consequence in prehension because it is on the dorsum of the hand. Loss of wrist extension affects grip strength.

ANATOMY

- The radial nerve is a mixed nerve composed of fibers from the C5 through T1 roots, forming as a terminal branch of the posterior cord of the brachial plexus.
- It travels initially in the posterior compartment of the arm, where it gives off multiple branches to the three heads of the triceps while coursing along the spiral groove of the humerus. It passes through the intermuscular septum into the anterior compartment, where it lies between the brachialis and brachioradialis (BR), innervating the latter.
- The BR, extensor carpi radialis longus (ECRL) and, at times, extensor carpi radialis brevis (ECRB) are innervated by the proper radial nerve prior to its entering the supinator, where it then divides into its two terminal branches.
- The superficial branch of the radial nerve provides sensation to the radial dorsum of the hand and fingers except for the small finger and ½ of the ring finger.
- The deep branch of the radial nerve innervates the supinator and becomes the posterior interosseous nerve (PIN) as it exits, innervating ECRB, extensor digitorum communis (EDC), extensor carpi ulnaris (ECU), abductor pollicis longus (APL), extensor pollicis brevis (EPB), extensor pollicis longus (EPL),

and extensor indicis proprius (EIP).

- Order of innervation is consistent, with EPL and EIP as the last two innervated muscles. This is helpful with clinical examination at time of injury and monitoring recovery.

PATHOGENESIS

- The pathogenesis of radial nerve palsy is most frequently due to traumatic injury, which can happen from injuries extending from the brachial plexus to the forearm.
- Idiopathic and compression causes are rarely seen.
- Radial nerve injury is most commonly seen with humeral shaft fractures, given its location in the spiral groove.¹⁻³

NATURAL HISTORY

- The mechanism of injury is an important predictor of potential recovery.
- Open, high-energy, and penetrating injuries should be explored early, as they have demonstrated poor recovery with nonoperative management.⁴

PATIENT HISTORY AND PHYSICAL FINDINGS

- A patient with radial nerve injury will present with potential loss of elbow extension, wrist extension, digital extension, thumb extension, and thumb abduction.
- The BR and ECRL are preserved in PIN palsies, as they are innervated proximal to the elbow.
- Tenodesis on physical exam can differentiate extensor tendon injury vs nerve palsy.

IMAGING

- Initial workup for acute radial nerve palsy may warrant x-rays to determine if there are any fractures or dislocations in the extremity associated with the acute trauma.
- Nerve conduction studies and electromyography may be helpful in the workup of radial nerve palsy, helping to determine the level of the lesion. Axonal loss is evident 3 weeks after injury.
- MRI of the brachial plexus may be warranted if there is concern for a lesion at this level.

DIFFERENTIAL DIAGNOSIS

- Extensor tendon laceration/rupture
- Isolated radial nerve injury
- Cervical radiculopathy
- Volar subluxation of the MCP joint (in inflammatory arthritis)
- Brachial plexus lesion

NONOPERATIVE MANAGEMENT

- Hand therapy is essential to educate the patient in a home exercise program to maintain motion and prevent contracture while waiting for nerve recovery.⁵
- Patients should be given a wrist splint for support to counteract the unopposed wrist flexors. Hand intrinsic muscles can provide some digital extension.

SURGICAL MANAGEMENT

- The goals of reconstruction depend on the level of injury of the radial nerve.
 - Injuries in the arm require reconstruction of independent wrist extension, finger extension, and thumb extension.
 - Injuries in the forearm of the PIN will spare the ECRL and sometimes the ECRB, which preserve wrist extension.
- Donor muscles include the pronator teres (PT), flexor carpi ulnaris (FCU), flexor carpi radialis (FCR), flexor digitorum superficialis (FDS), and palmaris longus (PL). The different reconstructions are usually referred to by which transfer is used for reconstruction of digital extension.
- Tendon transfers should be delayed until after potential nerve recovery is completed. However, unlike median or ulnar nerve transfers, sometimes radial nerve transfers are done at the time of nerve repair/reconstruction to minimize need for bracing.

Preoperative Planning

- Clinical exam of the patient helps the surgeon decide what functions must be recreated and what donor muscles are available for each function.
- Hand and wrist joints should be as supple as possible.
 - Wrist motion, particularly flexion, is an important characteristic for radial nerve transfers. That is because additional excursion is obtained with wrist flexion to help the FCR or FCU to fully extend the fingers.
 - If there is significant wrist stiffness, one should consider FDS to EDC transfers for better excursion of the transfer.

Positioning

- The patient is placed in the supine position with a tourniquet on the upper arm.
- The OR lights are positioned with one projecting from proximally and one distally from the operative site.

Approach

- Like with all tendon transfers, one should plan for the tendons to glide through a smooth and scar-free wound bed and each transfer should serve one function.
- If there is scarred tissue along the path of the transfer, it must be replaced by soft supple tissue either through serial scar excision or a flap procedure.

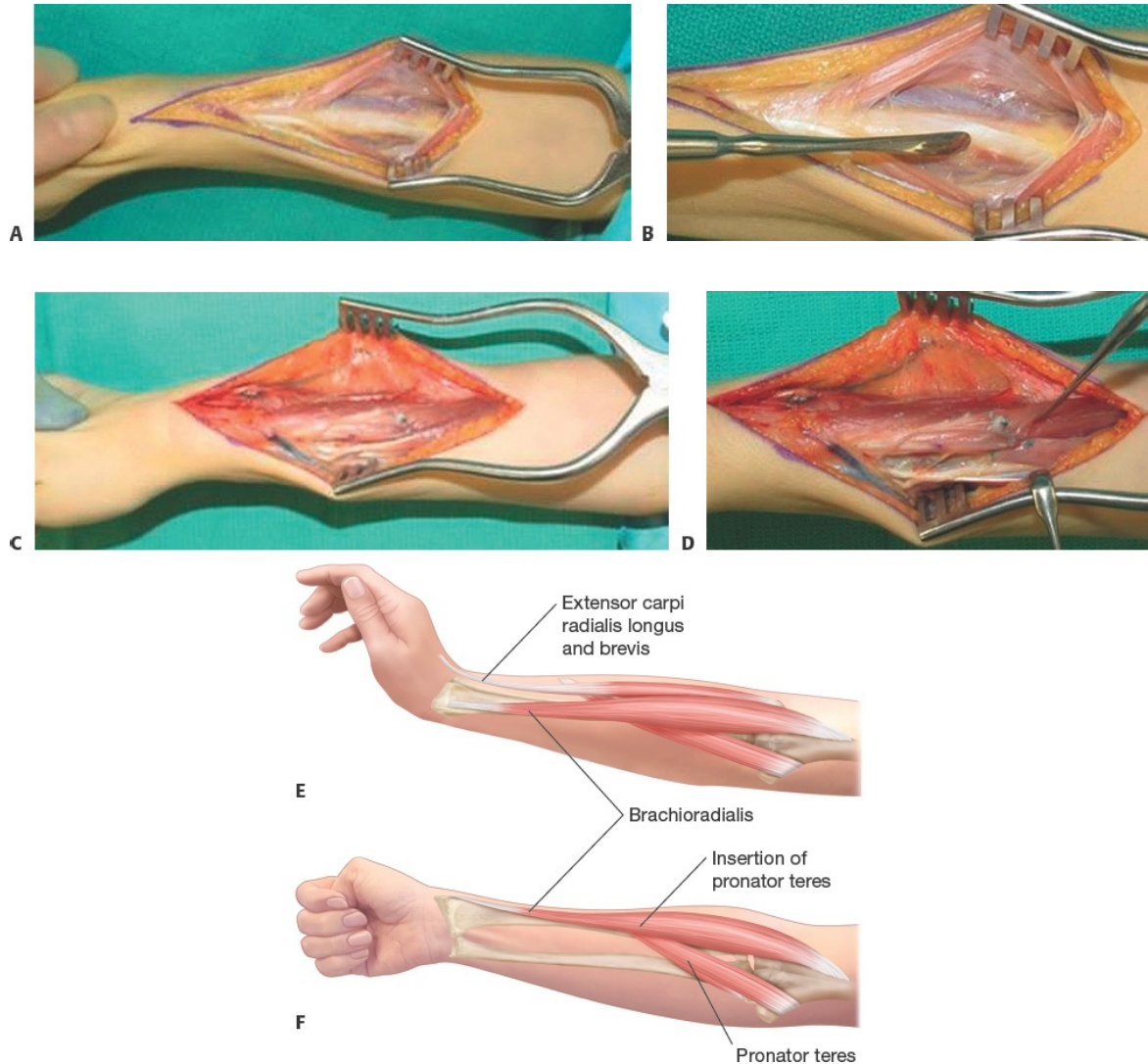
TECHNIQUES

■ Reconstruction of Wrist Extension: Pronator Teres to Extensor Carpi Radialis Brevis

- A radial-sided longitudinal incision is planned over the midpoint of the forearm to expose both the PT and the second extensor compartment (**TECH FIG 1A,B**).
- The pronator teres (PT) is identified inserting on the radial shaft, deep to the brachioradialis (BR) and radial artery.
 - Additional length is acquired by harvesting a strip of distal periosteum along with the distal tendon.
- The proximal PT is freed of its attachments to the other volar muscles to improve the excursion.
- The extensor carpi radialis brevis (ECRB) is localized just distal to the musculotendinous junction. A smooth path is created over the BR and the superficial radial nerve.
- The PT is passed over the BR to the ECRB. The ECRL can also be incorporated into the tendon transfer, but this is typically not done.
- If the ECRL and ECRB has no chance of recovery, the tendon transfer is done in the end-to-end fashion, rather than end-to-side to provide maximum excursion. Tension is set.
- A Pulvertaft tendon weave is done using 2-0 braided nonabsorbable sutures.
- The wrist tendons are reconstructed first to facilitate setting tension for the

fingers and thumb.

- The wrist should be at a neutral posture after the tendon transfer is secured.
- Each end of the tendon is grasped with a clamp to set the tension, and if the tension is too loose, horizontal mattress sutures are used to “fine-tune” and tighten the transfer (**TECH FIG 1C–E**).



TECH FIG 1 • A,B. The PT is identified where it inserts on the radial shaft, deep to the brachioradialis. **C,D.** The PT is woven through ECRL and ECRB tendons just distal to the musculotendinous junction. **E,F.** Path of the transfer.

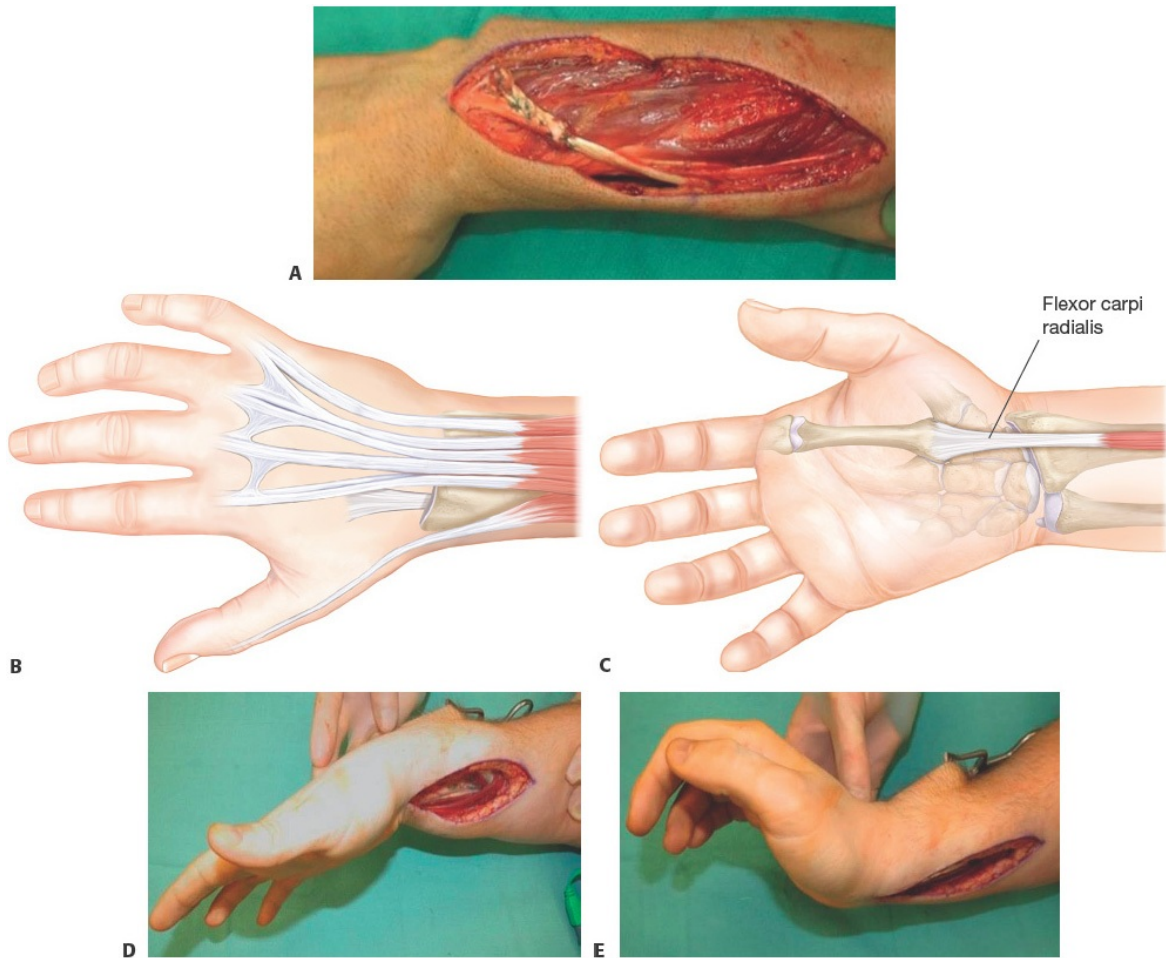
■ Reconstruction of Finger Extension

Flexor Carpi Radialis to Extensor Digitorum Communis^{6,7}

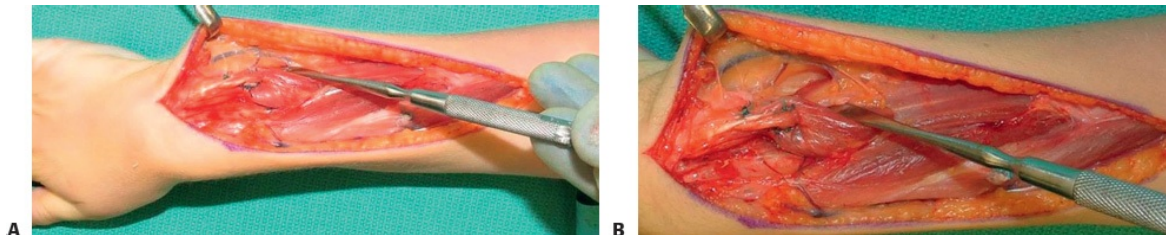
- A longitudinal volar incision is used to expose the flexor carpi radialis (FCR) and palmaris longus in the distal forearm.
 - The distal tendon is transected at the distal wrist crease.
- There are two paths of transfer of the FCR.
 - A subcutaneous tunnel in a radial direction to the dorsum of the wrist. This is our preferred transfer, as the path is created for the EPL as well.
 - A tunnel through the interosseous membrane (IOM) to the dorsum of the wrist. This has a more direct line of pull but has a higher incidence of postoperative adhesions.
- Point of insertion on each tendon is chosen to recreate the normal digital cascade by detaching each finger tendon and suture it along the path of the FCR.
- Pulvertaft weaves are held in place with nonabsorbable sutures (**TECH FIG 2A–C**).
- Final tension is set to achieve the tenodesis posture: 30-degree wrist extension is accompanied by 90 degrees of finger flexion; 30 degrees of wrist flexion is accompanied by full finger extension (**TECH FIG 2D,E**).

Flexor Carpi Ulnaris to Extensor Digitorum Communis^{8–10}

- A longitudinal incision is made over the distal aspect of the flexor carpi ulnaris (FCU) tendon at the pisiform.
 - The ulnar neurovascular bundle must be identified and protected.
- The FCU is freed from its surrounding attachments to achieve sufficient excursion.
- A broad subcutaneous tunnel is created in an ulnar direction toward the dorsum of the wrist.
- A dorsal incision is made to expose the extensor digitorum communis (EDC) and release the proximal extensor retinaculum.
- Pulvertaft weaves are held in place with nonabsorbable sutures (**TECH FIG 3**).
- Point of insertion and tensioning is done similarly to the FCR transfer.



TECH FIG 2 • A. The FCR to EDC is completed via a subcutaneous tunnel along the radial side of the wrist. **B,C.** Relationship between the FCR donor and the EDC tendons. The transfer can be either subcutaneous or transinterosseous membrane. **D.** Full digital extension is seen with slight wrist flexion. **E.** Full digital flexion is possible with wrist extension.

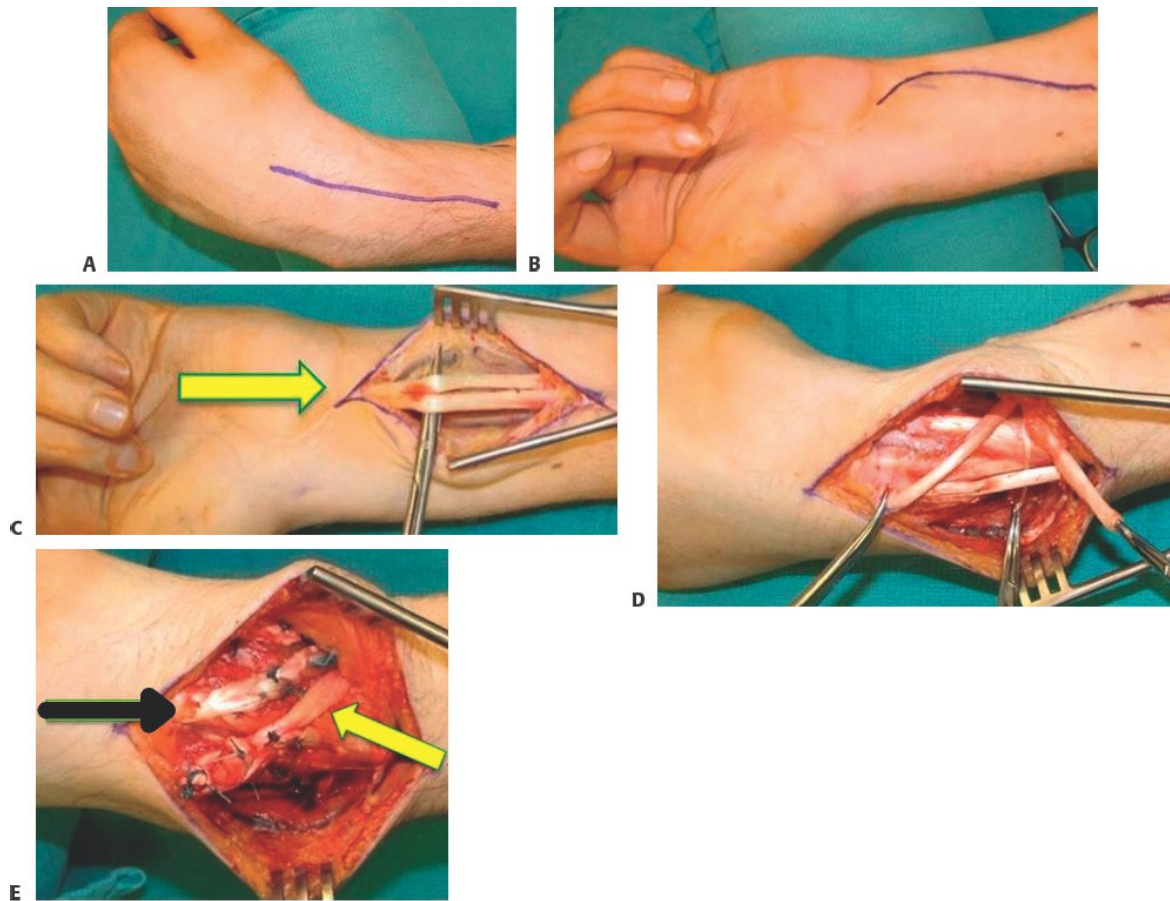


TECH FIG 3 • The FCU to EDC is completed via a

subcutaneous tunnel along the ulnar side of the wrist. Care is kept to ensure there is no injury or compression to the dorsal ulnar sensory branch. The distal FCU muscle can be debrided if it makes the weave too bulky.

Flexor Digitorum Superficialis (FDS-IV) to Extensor Digitorum Communis¹¹

- FDS to EDC transfer is best suited for patients with poor wrist motion preoperatively.
 - The better excursion of the FDS (70 mm) results in better digital extension.
 - In most patients, wrist motion from tenodesis compensates for the limited excursion of the wrist flexors.
- The FDS tendon is released from the ring finger just proximal to the carpal tunnel via a volar wrist incision.
 - Alternatively, it can be released at the PIP joint through a Bruner-style incision if greater tendon length is needed in the case of tendon rupture or loss.
- For radial nerve palsy, when the extensor tendons are intact, the FDS is transected at the wrist and will be transferred dorsally to attach to the extensor tendons proximal to the extensor retinaculum.
- It is retrieved from the volar forearm incision used to harvest the other tendons.
- The FDS to the long finger is transferred to the index and thumb extensor tendons, coordinating both these digits for precise pinch (**TECH FIG 4A–C**).
- The IOM is exposed proximal to the pronator quadratus.
- Making sure to not disrupt the central band of the IOM, an opening is made to allow for the tendons to pass from volar to dorsal (**TECH FIG 4D**).
- Dorsally, the FDS-IV is transferred to the EDC long through small fingers with a Pulvertaft weave.
- This transfer is grouped in this fashion to coordinate the ulnar digits in power grip.
- Tension is set with the wrist at 30 degrees of extension and the MP joints at full extension (**TECH FIG 4E**).



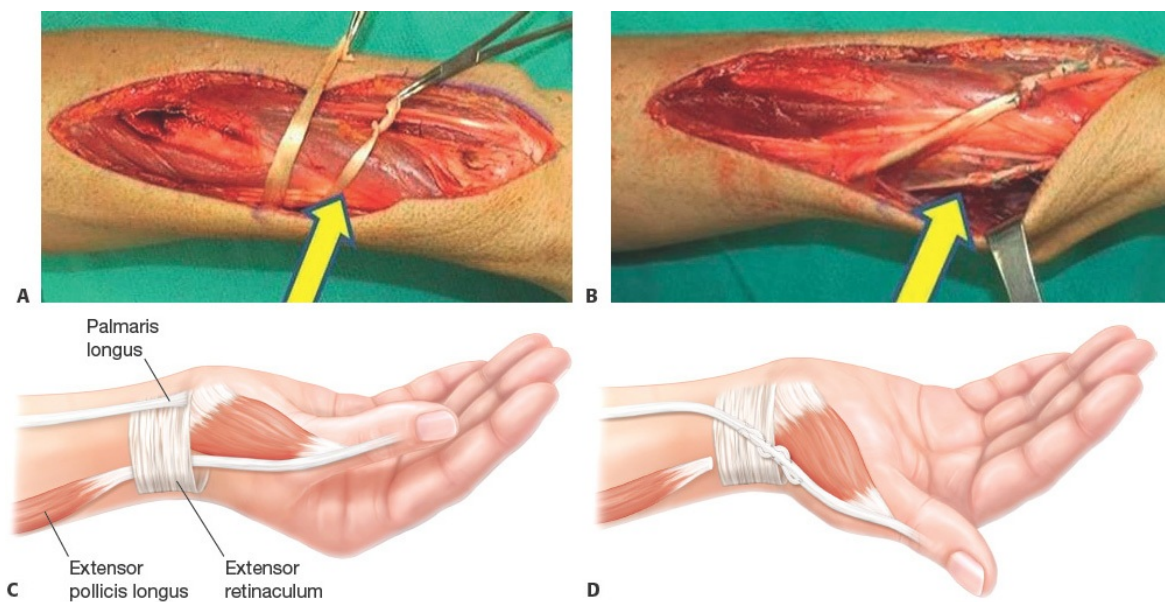
TECH FIG 4 • **A,B.** Dorsal and volar incisions, respectively, are designed for exposure of tendons. **C.** The FDS to the long and ring fingers are divided just proximal to the carpal tunnel. **D.** The tendons are passed from volar to dorsal via the interosseous membrane. **E.** The FDS-IV is woven into the EDC tendons (*yellow arrow*), and the FDS-III is woven into the EPL and EIP (*black arrow*).

■ Reconstruction of Thumb Extension: Palmaris Longus to Extensor Pollicis Longus

- Palmaris longus (PL) is identified through the volar incision used to expose FCR. It is freed from its surrounding attachments to maximize excursion.
- A subcutaneous tunnel toward the thumb is created below the radial artery

and cutaneous nerves along the radial aspect of the wrist (**TECH FIG 5A**).

- If nerve recovery is not expected, the extensor pollicis longus (EPL) tendon is released proximally through the dorsal incision.
- If nerve recovery is expected and transfer is being used as a temporizing measure, the EPL is kept in continuity but released from the third compartment to improve the vector of pull of the transfer.
- A Pulvertaft weave is done between the PL and EPL tendons.
- Tension is set with the thumb fully extended with the wrist in neutral.
- Transfer is secured with nonabsorbable suture (**TECH FIG 5B–D**).



TECH FIG 5 • A. FCR and PL can both be harvested from the same radial incision. **B.** FCR is woven to EDC and PL is woven to EPL. **C,D.** Transfer of PL to EPL.

PEARLS AND PITFALLS

Preoperative evaluation

- Critically assess donor muscle availability and strength.
- Determine patient goals and potential for additional nerve recovery. Tendon transfers for wrist extension and thumb extension may be

done even with expected recovery.

- Because wrist flexors do not match excursion of finger extensors, preoperative assessment can help determine working range of transfer and how to set tension.¹²

Finger extension transfer

- Choice between FCR and FCU for digital extension is not straightforward. Neither matches excursion, though FCU has greater force. However, loss of FCU may result in loss of “dart thrower’s motion.”
- Interosseous membrane passage must allow for easy tendon gliding. Prone to greater adhesions.

POSTOPERATIVE CARE

- The patient is usually splinted with the wrist in 30 to 40 degrees of extension and the MP joints in full extension. The interphalangeal joints can undergo passive range of motion, as the intrinsic hand muscles drive their extension.
- At the first postoperative visit, an Orthoplast splint is fabricated to wrist and MP extension. At 3 weeks, gentle active range of motion of the wrist is commenced several times a day. Integration of digital extension is added as wrist motion improves. Passive range of motion is started at 6 weeks. Strengthening is started at 8 weeks.
- A knowledgeable hand therapist plays an important role in the surgical outcomes.

OUTCOMES

- Most radial nerve palsy patients can perform normal activities of daily living with their hand after complete recovery from surgery.
- With restoration of wrist extension, grip strength is 40% to 50% of the contralateral side and digital extension is 34% to 75% of normal.^{12–14}

COMPLICATIONS

- Suboptimal results may be a result of choosing a weak motor for transfer or incorrect vector of pull.
- Radial deviation can result from use of FCR. PIP joint hyperextension or flexion contractures can result from use of FDS tendons.
- Tendon adhesions can result from prolonged immobilization, but tenolysis should not be considered until at least 9 months out from surgery.
- Tendon ruptures can be prevented with patient education and progressive

therapy advancement. Transfer attenuation may require revision.

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34 Tendon Transfers for Combined Median and Ulnar Nerve Injury

CHAPTER

Kate Elzinga and Kevin C. Chung

DEFINITION

- Combined median and ulnar nerve injuries cause major impairment of the upper extremity. The ability to perform fine pinch and power grasp is lost. The volar and dorsoulnar hand is insensate. The balance between the flexor and extensor muscle groups of the upper extremity is absent. Prehensile function is greatly reduced.
- Low median and ulnar nerve injuries are the most common combined nerve injury of the upper extremity. Nerve lacerations should be repaired acutely. In the case of a delayed nerve injury presentation or incomplete recovery following nerve repair, tendon transfers can be used to augment function.
- Tendon transfers can be combined with nerve transfers and free muscle transfers to help maximize the function of the injured upper limb. However, in combined nerve injuries, the number of nerves available for transfer is also limited.
- For a successful tendon transfer, a redundant tendon is harvested for transfer, minimizing donor-site morbidity while restoring a lost function. Finding an appropriate donor tendon is more difficult in combined nerve injuries compared to isolated nerve injuries; a greater number of tendons are affected, which results in multiple functional deficits while fewer intact tendons remain for transfer.
- Sensory deficits are also greater in combined nerve injuries (**FIG 1**). Reconstructive outcomes are inferior in combined nerve injuries compared to single nerve injury injuries.
- Donor-site morbidity must be carefully considered prior to tendon harvest for

transfer in combined nerve injuries. These patients have a limited number of tendons available for transfer. The patient's individualized goals must be carefully considered. A personalized reconstructive plan is created to best restore the patient's function.

- The patient's physical exam is central in formulating the operative plan. Missing functions, as well as available donor tendons, are documented. Once the functional deficits and available donors have been determined, the donors are matched to the deficits for reconstruction.
- Following the principles of tendon transfers optimizes patient outcomes:
 - Expendable donor
 - Straight line of pull
 - One muscle for one function
 - Similar force of contraction
 - Adequate excursion
 - Synergism
 - Skeletal stability
 - Stable, supple soft tissue bed
 - Full passive range of motion (ROM)
- Synergistic transfers are the most intuitive for patients to learn and offer the quickest return of function. Wrist extension is synergistic with finger flexion, whereas wrist flexion is linked with finger extension.
 - Compared to single nerve injuries, following a combined nerve injury, achieving synergy can be more difficult.
- Ideally, tendon excursion of the donor tendon should match that of the recipient tendon to best restore the biomechanics of the upper extremity. The wrist flexors and extensors have 3.3 cm of excursion, the finger extensors have 5 cm of excursion, and the finger flexors have 7 cm of excursion.¹
- Staging of procedures is important. Only tendon transfers that can be rehabilitated with hand therapy together should be performed at the same time. Multiple surgeries may be required.

ANATOMY

- Proximally, the median nerve innervates the pronator teres, flexor carpi radialis (FCR), palmaris longus (PL), and flexor digitorum superficialis (FDS).
- The anterior interosseous nerve (AIN) originates from the median nerve 6 to 8 cm distal to the medial epicondyle. It innervates the flexor digitorum profundus (FDP) to the index and middle fingers, flexor pollicis longus (FPL), and

pronator quadratus.

- The median nerve continues distally to provide motor innervation to the lumbricals to the index and middle fingers and the thenar muscles (abductor pollicis brevis [APB], flexor pollicis brevis [FPB], and opponens pollicis) and sensory innervation to the thumb, index, middle, and radial half of the ring finger.
- A low median nerve injury, distal to the origin of the AIN, causes the loss of thumb opposition and sensory deficits in the volar-radial hand.
- A high median nerve injury affects all of the muscles listed above. In addition to thumb opposition and sensory deficits, forearm pronation is lost, wrist flexion is weakened, flexion of all four proximal interphalangeal (PIP) joints as well as the index and middle finger distal interphalangeal (DIP) joints is lost, and thumb flexion is lost.
- The ulnar nerve innervates, from proximal to distal, the flexor carpi ulnaris (FCU), FDP to the ring and small fingers, hypothenar muscles (abductor digit minimi [ADM], opponens digiti minimi, flexor digiti minimi), lumbricals of the ring and small fingers, dorsal and palmar interossei, deep head of the FPB, and adductor pollicis (AdP). The ulnar nerve provides sensory innervation to the ulnar ring and bilateral small fingers.

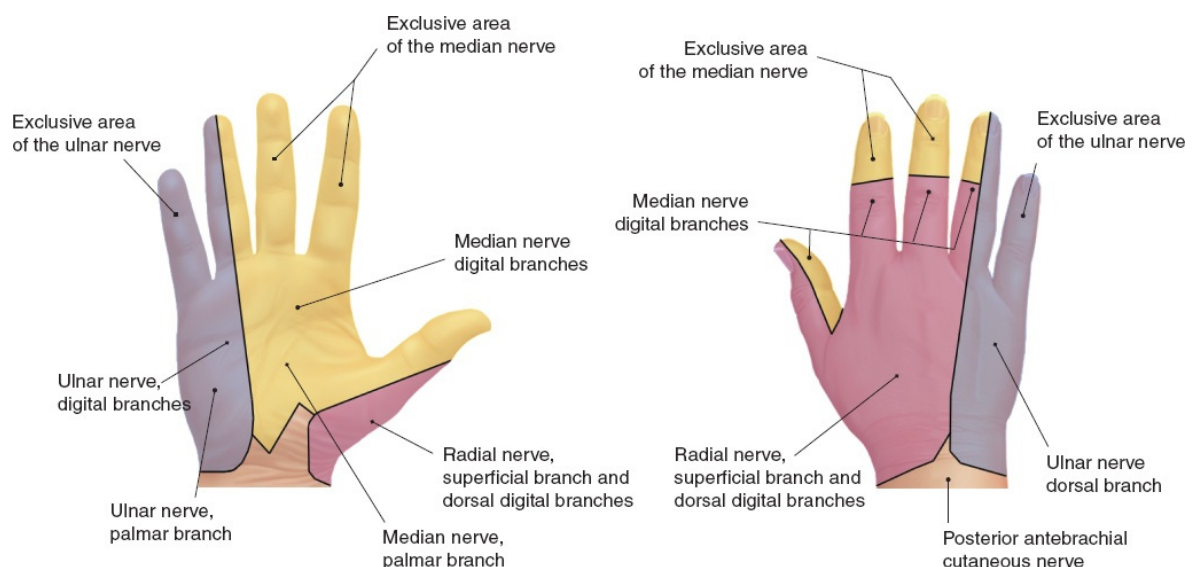


FIG 1 • Following a combined median and ulnar nerve injury, sensory deficits are profound in the hand. All volar hand sensation is lost. Dorsal sensation over the index and middle fingers distal to the PIP joints and

over the entire ring and small fingers is also absent.
Yellow, median nerve; *blue*, ulnar nerve; *pink*, radial nerve.

- A low ulnar nerve injury denervates the intrinsic muscles (hypothenar muscles, lumbricals ring and small fingers, interossei, deep head of FPB, AdP) of the hand.
- A high ulnar nerve injury occurs more proximally and denervates the extrinsic muscles (FCU, FDP ring and small fingers) of the hand in addition to the intrinsic muscles.
- Connections are common between the ulnar and median nerves, occurring in 9% to 27% of forearms^{1,2} and 83% of hands.³ However, connections between the radial nerve to either the median or the ulnar nerve have not been reported. In combined median and ulnar nerve injuries, motor and sensory deficits are profound and complete.
- A combined low median and ulnar nerve injury leads to the loss of thumb opposition and hand intrinsic function (thenar and hypothenar muscles, lumbricals, interossei). Forearm pronation, wrist flexion, and finger flexion are preserved. Hand sensation remains intact in the distribution of the superficial branch of the radial nerve over the dorsoradial hand only.
- In addition to the deficits of a low combined palsy, a combined high median and ulnar nerve injury results in the loss of forearm pronation, wrist flexion, finger flexion, and thumb flexion.
- The radial nerve innervates, from proximal to distal, the triceps, brachioradialis (BR), extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB), supinator, extensor carpi ulnaris (ECU), extensor digitorum communis (EDC), extensor digit minimi (EDM), abductor pollicis longus (APL), extensor pollicis longus (EPL), extensor pollicis brevis (EPB), and the extensor indicis proprius (EIP).
- Expendable radial nerve-innervated tendons for wrist and hand reconstruction include:
 - The BR can be transferred if the biceps and/or brachialis are intact to maintain elbow flexion. The biceps and brachialis muscles are innervated by the musculocutaneous nerve and are not affected by median and ulnar nerve injuries.
 - Two of three of the ECRL, ECRB, and ECU can be harvested. One of these

tendons must be preserved to maintain wrist extension.

- The EIP and EDM can be transferred if the EDC is intact to maintain extension of the index and small fingers.
- The EPB can be harvested if the EPL is intact to provide thumb extension.
- The APL has multiple slips. As long as one slip of the APL is preserved for thumb abduction, the additional slips can be harvested for transfer.

PATHOGENESIS

- Lacerations to the volar wrist are the most common cause of combined low median and ulnar nerve injuries. The median and ulnar nerves are at increased risk in the distal volar forearm because of their superficial location here compared to their location deep to the muscles in the proximal forearm and arm.
- More proximal injuries, typically resulting from sharp mechanisms, can result in high combined nerve injuries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Selection of appropriate donor tendons for transfer is critical to restore function while minimizing donor-site morbidity.
- A comprehensive history and physical examination is performed to determine the patient's functional deficits and their reconstructive goals.

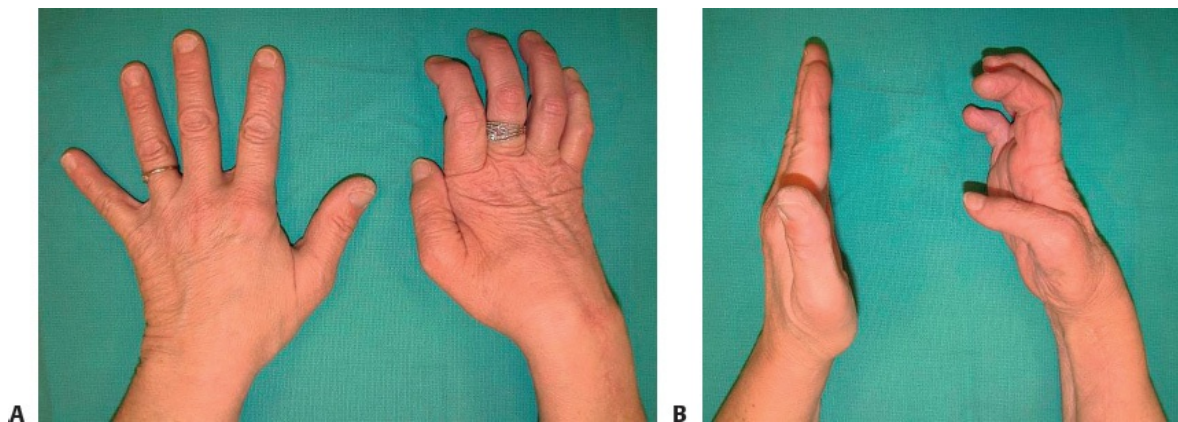


FIG 2 • This patient had a low combined median and ulnar nerve injury of the right hand. A claw hand deformity is viewed from dorsal **(A)** and lateral **(B)**. The finger MCP joints are extended, and the IP joints are flexed.

- The patient's age, handedness, occupation, and avocations are documented.
- Limitations in activities of daily living, recreation, and work are discussed.
- The patient's goals are explored, including their plans for return to work, their availability and willingness to undergo secondary procedures and hand therapy, and the importance of appearance.
- Discussion with the patient's hand therapist provides further insight into the patient's deficits and can help prioritize reconstructive goals. Reconstruction is focused on providing the most functional benefit to each individual patient.
- The patient's compliance with therapy and their anticipated ability to retrain transferred tendons is assessed by the therapist and considered when determining the reconstructive plan.
- Important considerations from the patient's past medical history include smoking, diabetes mellitus, peripheral vascular disease, connective tissue disorders, arthritis, Dupuytren disease, and previous hand injuries.
- On physical examination, a claw hand deformity is more apparent in a low median and ulnar nerve palsy than in a high injury (**FIG 2**).
 - In low injuries, FDS and FDP innervation remain intact causing unopposed flexion of the interphalangeal (IP) joints of the fingers due to the denervation of the interossei and lumbricals. The loss of the intrinsic muscles of the hand also leads to a hyperextension deformity of the metacarpophalangeal (MCP) joints due to unopposed extension through the extrinsic finger extensors.
- The Bouvier test is used to assess if the extensor mechanism is functioning normally. The patient's MCP hyperextension is blocked and then he or she is asked to extend their PIP joints (**FIG 3**).
 - If the MCP flexion facilitates the patient's active PIP joint extension, the test is positive and the claw is defined as "simple," because by procedures to keep the MCP joints flexed, the PIP joints can extend via the extrinsic extensor tendons. However, the word "simple" is a misnomer because other than fusion of the MCP joints in flexion, all the soft tissue procedures applied to flex the MCP joints will stretch out over time.
 - If the patient cannot extend their PIP joints, the test is negative and the claw is "complex." Etiologies of a complex claw include central slip attenuation, central slip adherence to the PIP joint, and volar subluxation of the lateral bands.

IMAGING

- If the patient's clinical history is suspicious for arthritis, plain radiographs are

taken of the hand and wrist to assess the joints. Painful arthritic MCP and IP joints are better reconstructed with arthrodesis than with soft tissues procedures such as tendon transfers. Wrist arthrodesis is typically avoided to maintain wrist tenodesis.

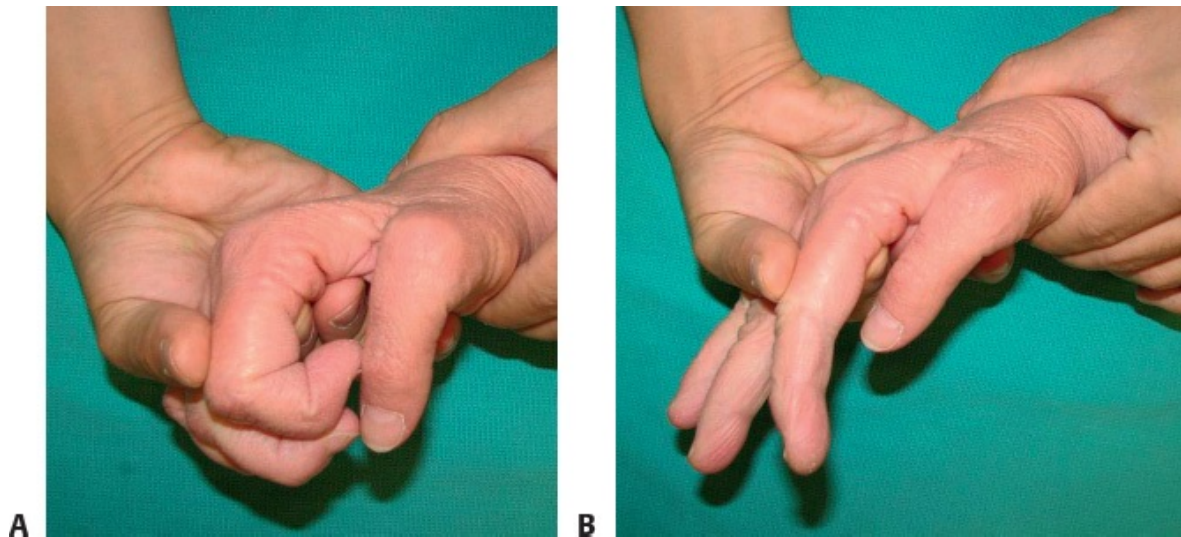


FIG 3 • The Bouvier test is used to assess the extensor tendon mechanism in claw hand deformities. **A.** The examiner holds the MCP joints in flexion to passively correct the MCP hyperextension deformity. **B.** The patient is then asked to extend the PIP joints. If the patient is able to extend, the extensor mechanism is functioning properly and the claw is designated “simple,” as shown here. If the patient cannot extend the PIP joints, the claw is designated “complex.”

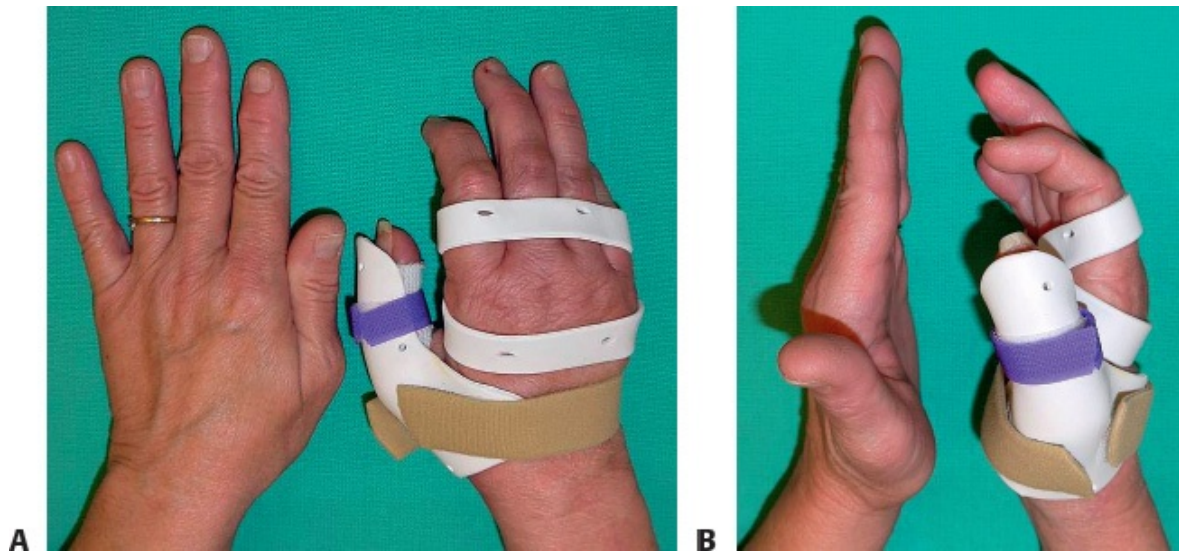


FIG 4 • Thermoplastic splints can be used to correct a claw hand deformity and unopposed thumb extension in combined median and ulnar nerve injuries. Here, the anticlaw splint corrects the patient's simple claw; correcting her MCP hyperextension permits active extension of her IP joints. The dorsal blocking thumb splint prevents the hyperextension deformity of the thumb at the carpometacarpal, MCP, and IP joints.

- Electrodiagnostic studies can be used to assess recovery following incomplete nerve injuries and after nerve repair to aid in planning for tendon transfers.
- Donor muscles can be tested if there is concern of their integrity. Donor muscles lose one medical research council grade of strength when transferred; grade 5 muscles are normal strength and are preferred as donors.

NONOPERATIVE MANAGEMENT

- Hand therapy is essential to maintain supple joints prior to reconstruction. A tendon transfer will not restore active ROM if the joint is stiff and incomplete passive ROM is present.
- Passive ROM should be optimized prior to surgery.
- If necessary, joint contracture release is performed prior to tendon transfer.
- Patients can be taught how to use wrist tenodesis to improve their hand function.
- Wrist flexion and extension can increase the amplitude of finger extension

and flexion by 2.5 cm, respectively.¹

- Preoperative splinting can be used to correct a patient's thumb and finger MCP joint hyperextension following a combined median and ulnar nerve injury (**FIG 4**).
- If the patient finds the splints helpful, surgical intervention—including thumb MCP arthrodesis and index, middle, ring, and small finger MCP volar capsulodesis or arthrodesis—is indicated.

SURGICAL MANAGEMENT

- Tension of the tendon transfer is critical for restoration of function while preventing the loss of ROM of other joints. In general, when suturing the tendon transfer, the joints are positioned as though the donor muscle is contracting and the transferred tendon is secured under tension.
- To minimize rupture rates, tendon transfers are best secured using three Pulvertaft weaves.⁴ The donor tendon is divided distally and the recipient tendon is divided proximally to facilitate adequate tendon weaving.
- The tendon transfer tension is set with one Pulvertaft weave and then wrist tenodesis is checked to ensure adequate passive ROM. Adjustments in tension can be made with the second and third Pulvertaft weaves.
- Tendon transfers can be performed in an end-to-end or end-to-side fashion.
 - End-to-end suturing facilitates a direct line of pull and is used if the recipient tendon is not expected to have any spontaneous recovery, for example, after complete denervation from an unrepaired nerve transection.
 - If the nerve has been repaired and some muscle recovery is expected, the tendon transfer is performed in an end-to-side fashion to augment existing function.
- A direct line of pull maximizes the power of the tendon transfer. If a direction change is unavoidable, the tendon should be passed around a fixed structure that behaves as a pulley, for example, the EIP tendon around the distal ulna to abduct the thumb.

Preoperative Planning

- When selecting a tendon for transfer, any resulting weakness must be considered. One tendon must remain intact to perform the donor's original function.
- Tendon gliding occurs best in a supple, stable soft tissue bed. If needed, scar contracture releases and flap reconstruction are performed prior to tendon

transfers to permit optimal tendon gliding and to minimize tendon adhesions.

- A stable platform with adequate bone and joint stability is required prior to tendon transfer. If required, arthrodesis of select joints is performed prior to tendon transfer.
- A thumb MCP arthrodesis can be helpful to correct severe thumb hyperextension following the loss of thumb flexion in a median nerve palsy. The MCP is fused in 15 to 20 degrees of flexion and 15 degrees of pronation using headless compression screws, a dorsal plate, or tension band wiring.
- Wrist fusion permits all three wrist extensors (ECRL, ECRB, ECU) to be harvested for transfer; however, this is not typically recommended because it will eliminate wrist tenodesis, which augments the excursion of the remaining tendons.

Positioning

- The patient is positioned supine with the arm extended on a hand table.
- A tourniquet is placed on the upper arm.

Approach

- Loupe magnification is helpful. Incisions are planned prior to inflation of the tourniquet.
- We prefer to use 3-0 polyester suture for our tendon transfers. Two sutures are placed to secure each Pulvertaft weave.

TECHNIQUES

■ Low Combined Median and Ulnar Nerve Palsy

Thumb Opposition

- In a low combined median and ulnar nerve injury, the ADM is denervated, but the FDS, PL, and EIP maintain their innervation and can be used as donor tendons for an opponensplasty. Only the EIP is available in high combined median and ulnar nerve palsies.
- The EIP is our preferred tendon transfer. It has minimal donor-site morbidity and has sufficient length to reach the APB insertion without a tendon graft.
- If the EIP is being used to restore another function of the hand following a

low median nerve injury, the ring finger FDS is our second choice for an opponensplasty.

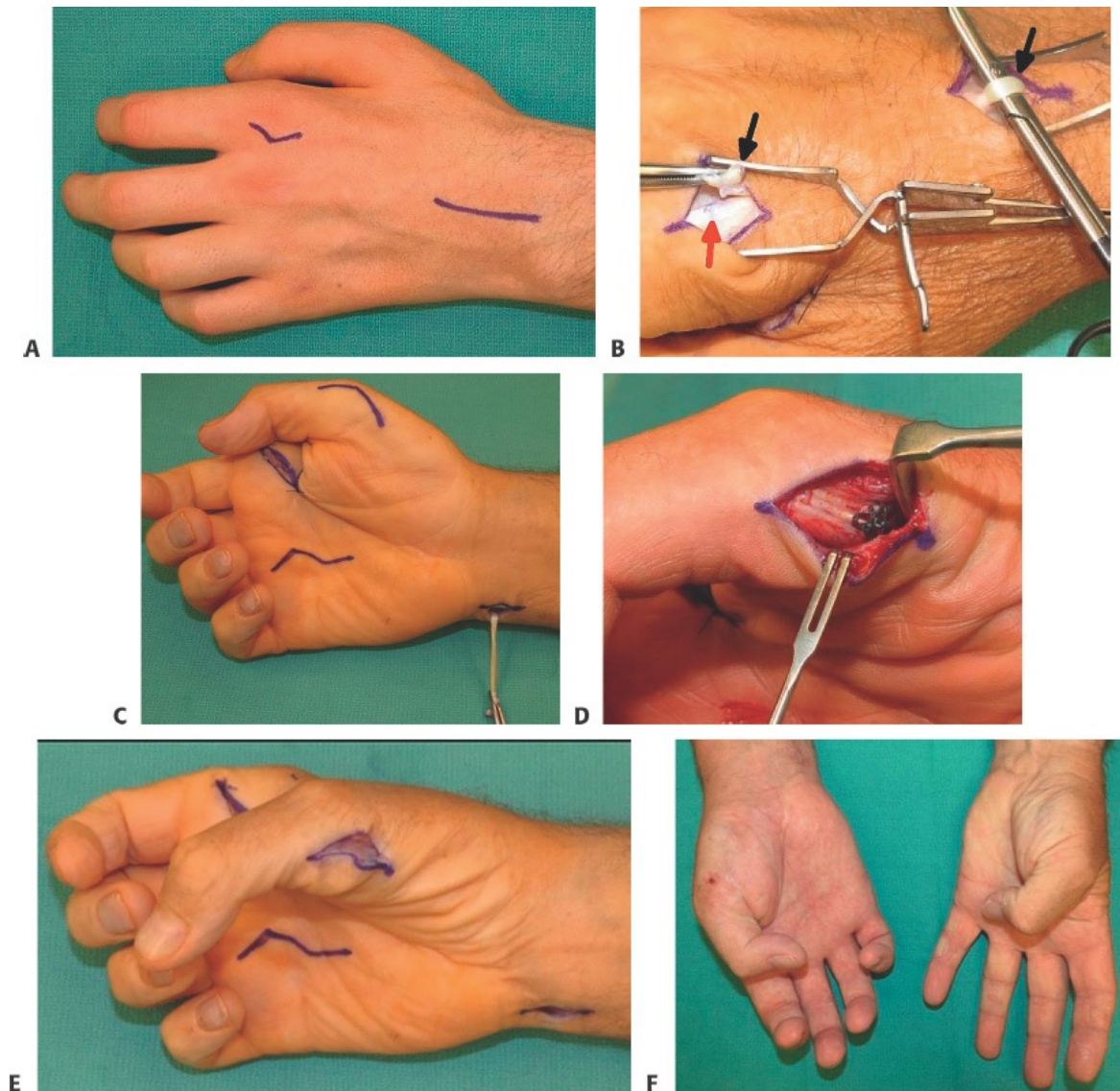
- The ADM is only transferred in cases of congenital hypoplastic thumb or in combined median and radial nerve injuries.
- The PL is primarily used as an adjunct in elderly patients with severe carpal tunnel syndrome and thenar wasting. This tendon transfer provides more thumb abduction than true opposition.

Low Injury: Ring Finger FDS to APB Tendon Transfer

- The FDS is harvested and retrieved via transverse incisions first at the base of the proximal phalanx and then proximal to the carpal tunnel.
- A pulley is created by passing the FDS through a window in the transverse carpal ligament to reroute it obliquely across the palm.
- The FDS is secured to the APB at its insertion on the radial base of the proximal phalanx of the thumb.

Low or High Injury: EIP to APB Tendon Transfer

- The EIP is divided distally over the dorsal index finger MCP joint using a transverse or a V-shaped incision (**TECH FIG 1A**).



TECH FIG 1 • A. Two incisions are used over the dorsal hand and wrist for EIP harvest. The EIP is first identified over the index finger MCP joint using a transverse or a V-shaped incision. Next, it is identified over the dorsal wrist through a longitudinal incision distal to the extensor retinaculum. **B.** The EIP (*black arrows*) is divided for transfer over the index finger MCP joint. It is located ulnar to the EDC tendon (*red arrow*) in most patients. Next, it is retrieved over the dorsal wrist. **C.** The EIP is rerouted around the ulnar wrist, proximal to the pisiform, and then tunneled

subcutaneously to the APB insertion on the radial base of the proximal phalanx of the thumb. **D**. The EIP is secured to the APB tendon at its insertion using three Pulvertaft weaves secured with 3-0 polyester suture. **E,F**. The position of the right thumb is improved following opponensplasty, shown here at the end of the surgery (**E**) and at the 2-month follow-up visit (**F**).

- The EIP is located ulnar to the EDC in most patients (**TECH FIG 1B**); anatomic variations of the EIP and EDC over the MCP joint exist in 19% of patients.⁵
- The distal stump of the EIP can be sutured end to side to the index finger EDC tendon to prevent an extensor lag of the index finger.
- The EIP is retrieved over the distal wrist, using a longitudinal incision distal to the extensor retinaculum (**TECH FIG 1B**)
- It is then rerouted around the ulnar side of the hand, superficial to the FCU, using an incision proximal to the pisiform (**TECH FIG 1C**).
- After placement through the pulley, the EIP is tunneled through the subcutaneous tissue of the palm, volar to the neurovascular structures, to the APB tendon on the radial base of the proximal phalanx of the thumb.
- The EIP is sutured into the APB with the wrist in neutral and the thumb maximally palmarly abducted (**TECH FIG 1D-F**).
 - Setting tension is unnecessary because the EIP will barely reach the APB; wrist flexion may be required to suture the tendon in place.
 - After the tendon juncture has healed, the wrist is slowly brought to neutral position.

Thumb Adduction: ECRB to AdP With Tendon Graft

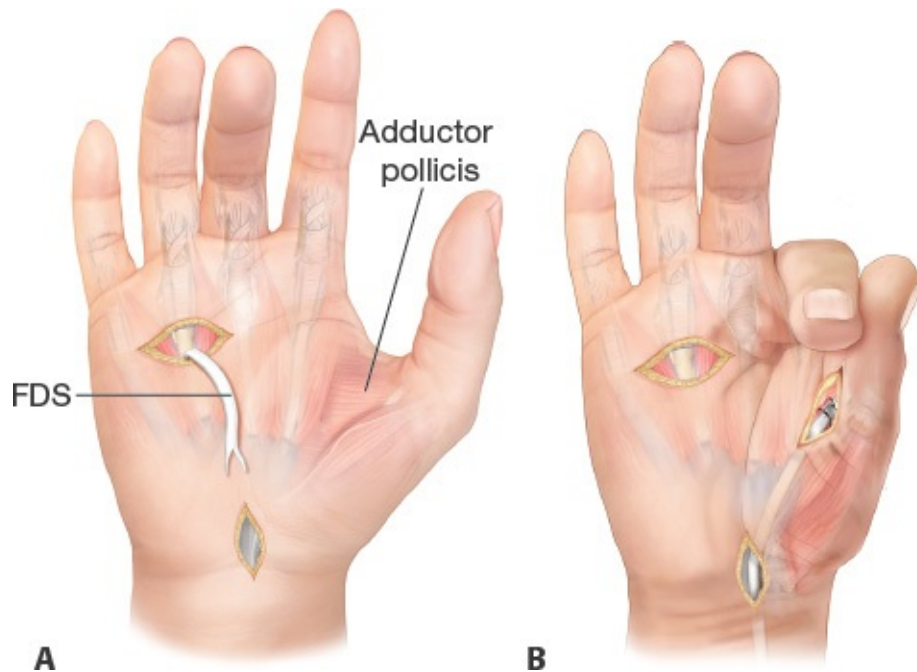
- Thumb adduction and pinch can be restored by transferring a tendon to the adductor pollicis (AdP) near its insertion on the ulnar base of the proximal phalanx of the thumb.
- The FDS from the ring finger or the ECRB are commonly transferred; the ECRB must be extended using a tendon graft to reach the AdP.

Low Injury: FDS to AdP Tendon Transfer

- In low median and ulnar nerve injuries, the FDS to the ring finger can be transferred to the AdP. The FDP to the ring finger is intact in these injuries and maintains finger flexion.
- The FDS is divided distal to the A1 pulley using an incision over the volar base of the ring finger proximal phalanx.
- The FDS is then retrieved through a second incision ulnar to the thenar crease at the base of the palm and is passed to the AdP insertion subcutaneously and sutured to the AdP through a third incision over the ulnar base of the thumb proximal phalanx.
- Tension is set with the wrist in neutral, the thumb adducted against the index finger, and the FDS at its resting length (**TECH FIG 2**).⁶

Low or High Injury: ECRB to AdP Tendon Transfer

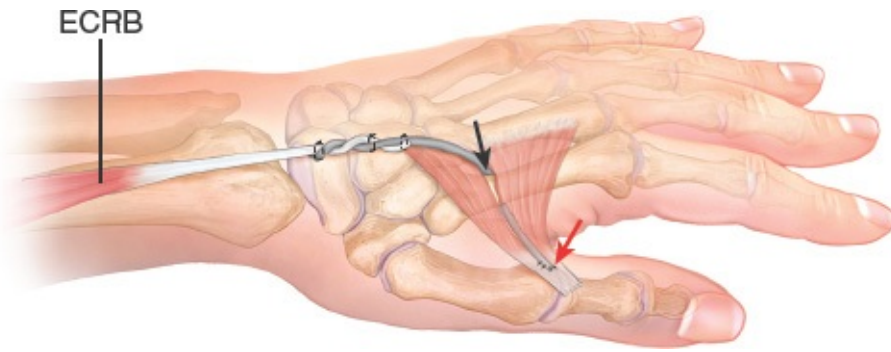
- The ECRB is divided at its insertion over the dorsal base of the middle finger metacarpal.
- Using a second incision proximal to the extensor retinaculum, the ECRB is retrieved proximally.
- A third incision is used to expose the AdP over the ulnar base of the proximal phalanx of the thumb.
- A tendon graft is secured to the AdP and then passed through the intermetacarpal space between the index and middle finger metacarpals from the volar to the dorsal hand using a fourth incision longitudinally over the proximal third of the second intermetacarpal space.
 - This graft is passed deep to the flexor tendons and superficial to the AdP.
- The tendon graft is secured to the distal ECRB over the dorsal wrist with the wrist in neutral and the thumb adducted against the index finger (**TECH FIG 3**).



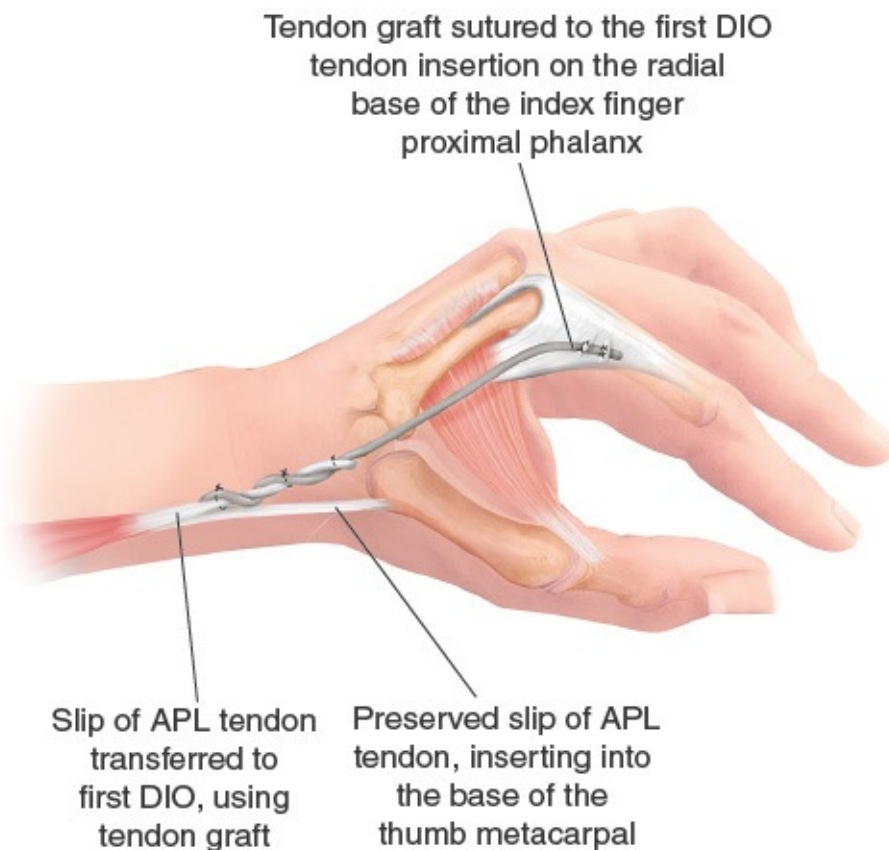
TECH FIG 2 • The ring finger FDS tendon is harvested at the base of the finger **(A)** and then rerouted for transfer to the adductor pollicis tendon on the ulnar proximal phalanx of the thumb **(B)** to restore thumb adduction following an ulnar nerve injury.

Index Finger Abduction: APL to First Dorsal Interosseous With Tendon Graft

- In 84% of people, the APL tendon has multiple tendinous slips⁷; up to 14 slips have been recorded.⁸ An accessory slip of APL can be harvested as a donor tendon in patients with multiple slips. In the 16% of patients with a single APL tendon, half of the APL tendon can be harvested longitudinally for transfer.
- A slip of the APL can be transferred to the first dorsal interosseous (DIO) tendon near its insertion on the radial index finger metacarpal to restore index finger abduction for pinch.
- A tendon graft is required for the APL to reach the first DIO tendon (**TECH FIG 4**).
 - The palmaris longus, plantaris, extensor digitorum longus (to the second, third, or fourth toes), or flexor digitorum longus (to the second, third, fourth, or fifth toes) can be used as a tendon graft.



TECH FIG 3 • Thumb adduction can be restored by transferring the ECRB to the adductor pollicis near its insertion on the ulnar base of the proximal phalanx of the thumb (*red arrow*), using a tendon graft. The graft first secured distally, passed through the second intermetacarpal space (*black arrow*), and then secured to the ECRB tendon proximally.



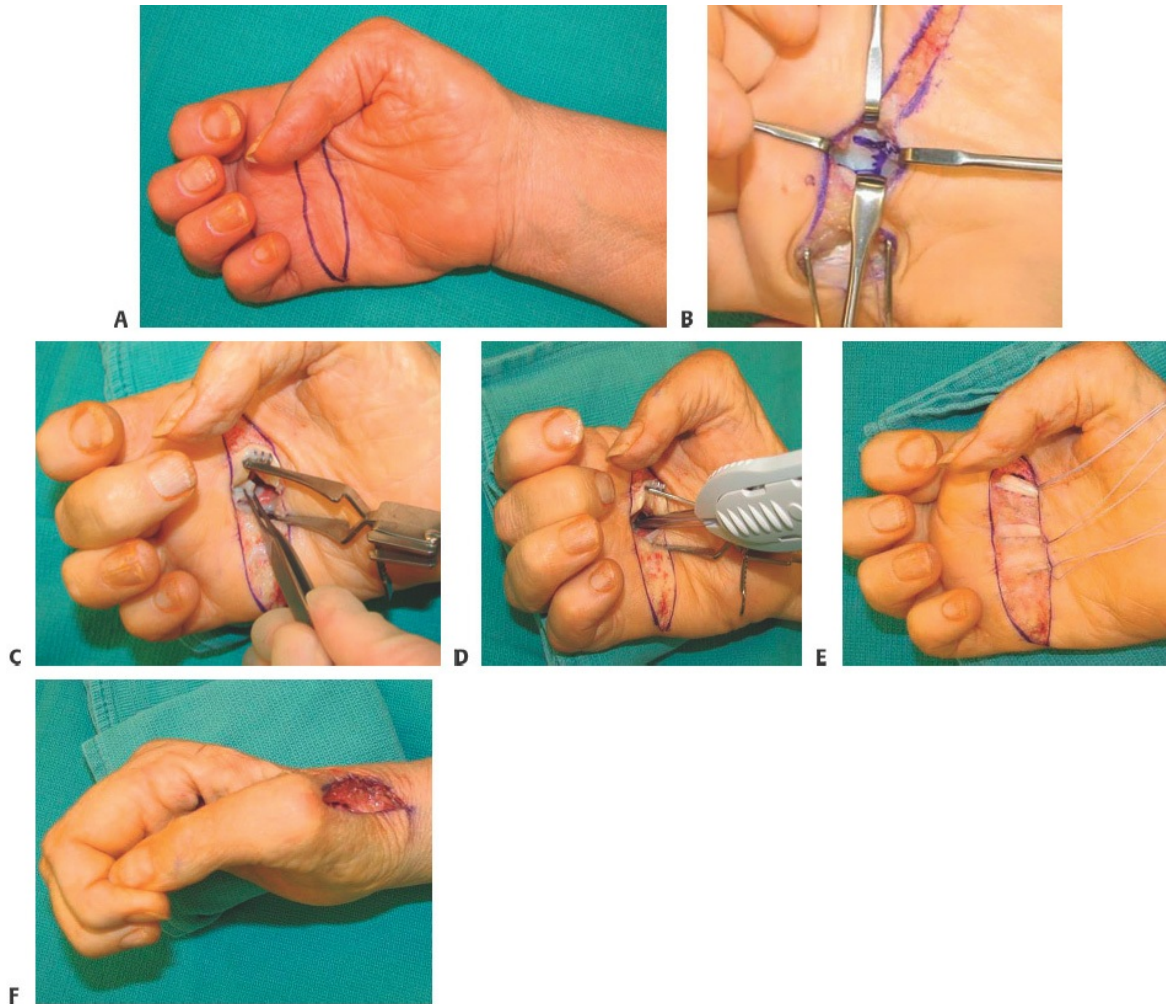
TECH FIG 4 • To restore index finger abduction and

pinch, a slip of the APL is transferred to the first DIO. A tendon graft is necessary for the APL to reach the insertion of the first DIO on the radial base of the index finger proximal phalanx.

- A slip of APL is harvested from its insertion on the radial aspect of the thumb metacarpal base using a longitudinal or V-shaped incision.
- A midlateral incision is made over the radial base of the index finger proximal phalanx to identify the first DIO.
- The tendon graft is secured to the first DIO and then passed proximally over the dorsal hand in the subcutaneous tissues to the proximal incision, where it is secured to the APL tendon.

Finger Clawing: FDS (Low Injury) or ECRL (High Injury) Tendon Transfer to the Lateral Bands of the Index, Middle, Ring, and Small Fingers

- For a simple claw, MCP joint hyperextension can be treated via static procedures such as volar MCP capsulodesis (the volar plate is detached and advanced proximally and secured with a bone anchor to the volar metacarpal to maintain the MCP in 45 degrees of flexion) (**TECH FIG 5**) or the Zancolli lasso (the FDS is divided over the distal proximal phalanx, removed from under the A2 pulley, turned proximally volar to the A1 pulley, and sutured to itself over the MCP joint).



TECH FIG 5 • A. This patient had a simple claw identified using the Bouvier test. MCP volar capsulodesis was performed for the index, middle, ring, and small fingers to correct the MCP hyperextension deformity. A volar incision was made over the volar MCP heads. The excess skin was marked for resection here. **B.** The index finger volar plate is shown here, with its proximal extent outlined with a purple marker. **C.** The proximal volar plate was elevated and then advanced proximally and secured to the metacarpal using a bone anchor to maintain the MCP in 45 degrees of flexion to correct the MCP claw hyperextension deformity. **D.** One bone anchor was

used to secure each proximal volar plate proximally to the volar metacarpal. The four bone anchors were placed **(E)**, and then each volar plate was advanced proximally and secured using the bone anchor suture to hold the MCP joints in 45 degrees of flexion **(F)**.

- Restoration of MCP joint flexion in a simple claw permits the patient to extend their IP joints through their extrinsic extensors (EDC, EIP, EDM). The main drawback of these soft tissues procedures is their tendency to stretch out over time.
- Our recommended long-term solution is to fuse the MCPJ in flexion (**TECH FIG 6**) or to perform a dynamic tendon transfer.
- In a complex claw, both MCP joint flexion and IP joint extension reconstruction are required. A dynamic tendon transfer is used. A four-tailed middle finger FDS (low injury) or ECRL (low or high injury) is commonly used as donor tendon for transfer in complex, and simple, claw hands.
 - If used, the ECRL must be extended with a tendon graft to enable it to reach the clawed digits.
- Tendon transfers in a simple claw are inserted into the A2 pulley to restore MCP joint flexion only.
- In a complex claw, the insertion is into the lateral bands over the proximal phalanx to restore both MCP joint flexion and IP joint extension.
- The tendon is passed from the distal palm, volar to the deep transverse metacarpal ligament, to the lateral bands of the affected digits.
- The tendon is secured to the ulnar lateral band for the index finger and to the radial lateral band for the middle, ring, and small finger.



TECH FIG 6 • A. To correct this patient's simple claw deformity of his index, middle, ring, and small fingers following a combined high median and ulnar nerve injury, MCP joint fusions were performed. The MCP joints could be passively flexed, but not actively. **B.** Dorsal incisions were used over the MCP joints. Two K-wires were used to fuse each of the patient's MCP joints in 45 degrees of flexion, as shown here on the PA radiograph (**C**), lateral radiograph (**D**), and lateral clinical photograph (**E**). The K-wires were removed 8

weeks postoperatively. The patient's MCP hyperextension deformity was corrected with MCP joint arthrodesis of the left index, middle, ring, and small fingers, shown here 4 months postoperatively with the fingers in extension **(F)** and flexion **(G)**.

Small Finger Abduction (Wartenburg Sign) Correction: EDM Tendon Transfer

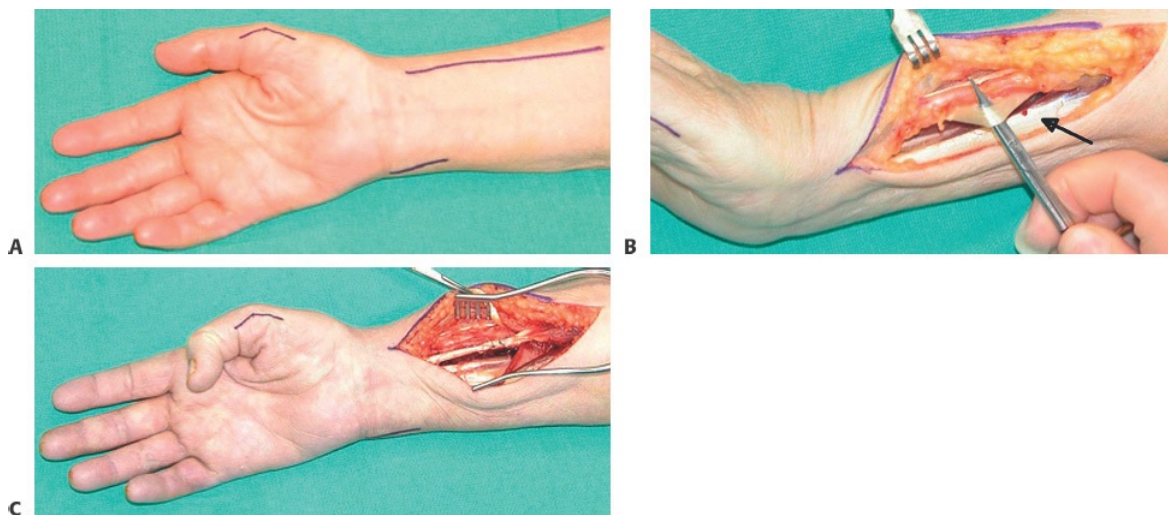
- In a low median and ulnar nerve palsy, the abduction deformity of the small finger occurs due to the ulnar pull of the EDM on the small finger without opposition due to the deinnervation of the third palmar interosseous.
- To correct the ulnar deviation of the small finger, the ulnar half of the EDM is divided from its insertion on the dorsal proximal phalanx of the small finger and then passed volar to the deep transverse intermetacarpal ligament from the dorsal to the volar hand.
- If there is no clawing, the EDM can be sutured to the insertion of the radial collateral ligament of the small finger MCP joint.
- If there is clawing of the small finger, the EDM tendon is passed under the A2 pulley and sutured back to itself to correct the MCP hyperextension deformity.

■ High Combined Median and Ulnar Nerve Palsy

Thumb Flexion: BR to FPL Tendon Transfer

- To restore flexion of the thumb, the BR, ECRL, or ECRB can be transferred to the FPL.
 - We prefer to use the BR, it is the most expendable of these three tendons; its harvest results in minimal donor-site morbidity. This reserves the ECRL for transfer to the FDP for finger flexion and maintains the ECRB as the only remaining wrist extensor.
 - The ECRB is the preferred wrist extensor to preserve because it is the most centrally located over the dorsal wrist.
 - Preserving the ECRL only can lead to radial deviation of the wrist with extension. Similarly, preserving only the ECU can lead to ulnar deviation in extension.

- To transfer the BR, an incision is made over the volar-radial distal radius to identify the insertion of the BR onto the radial styloid as well as the FPL (**TECH FIG 7A**).
- The BR tendon is harvested distally with a 2-cm periosteal extension from the distal radius to increase its length (**TECH FIG 7B**).
- The superficial branch of the radial nerve must be carefully protected; this nerve is the only source of sensation to the hand in patients with combined median and ulnar nerve injuries.
- The BR is freed proximally off of the radius to maximize its excursion, moved volarly, and secured to the FPL proximal to the carpal tunnel (**TECH FIG 7C**).



TECH FIG 7 • A. In a patient with a high median nerve injury, an incision is designed over the volar-radial distal radius to identify the BR, FPL, and FDP. The BR is transferred to the FPL to restore thumb flexion. **B.** The ECRL (isolated on scissors) is identified for transfer to the FDP for finger flexion. (Pulling the ECRL causes wrist extension.) The BR (*arrow*) is identified for transfer to the FPL to restore thumb flexion. **C.** The BR is secured to the FPL proximal to the carpal tunnel, restoring thumb flexion.

- The tendon transfer tension is set with the elbow flexed at 90 degrees, the

wrist in 20 degrees of extension, the forearm fully pronated, and the thumb pulp and PIPJ of the index finger opposed.⁹

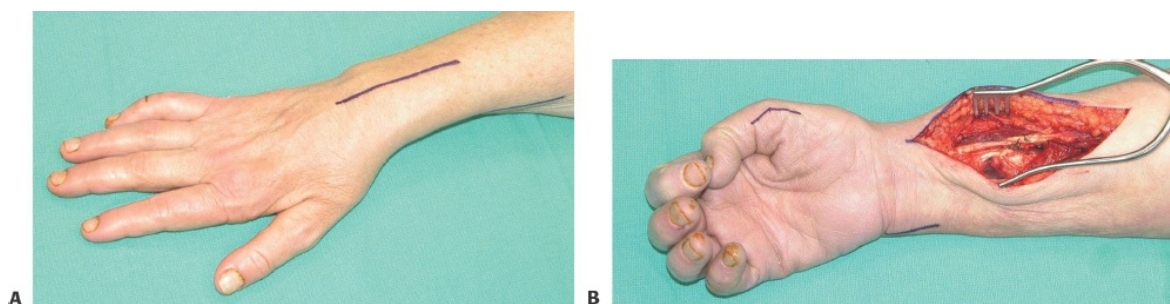
- The position of the elbow affects the degree of thumb flexion once the transfer has healed. When the elbow is extended, thumb flexion is stronger than when the elbow is flexed.

Finger Flexion: ECRL to FDP Tendon Transfer

- To restore finger flexion, the ECRL can be transferred to the FDP around the radial side of the wrist.
- An incision is made over the dorsal base of the index finger metacarpal to expose the ECRL insertion (**TECH FIG 8A**).
- The ECRL is divided near its insertion and then rerouted subcutaneously around the radial border of the forearm and sutured into the four FDP tendons proximal to the carpal tunnel using a second incision (**TECH FIG 8B**).
- The tendon transfer is secured to restore the flexion cascade of the digits; the tension is set progressively tighter from the index to the small finger.

Forearm Pronation: Rerouting the Brachioradialis Tendon

- Forearm pronation is lost following a high median nerve injury.
- To re-establish pronation, the biceps tendon insertion can be rerouted around the neck of the radius.¹⁰ Alternatively, the BR can be rerouted and the interosseous membrane can be released if tight.¹¹

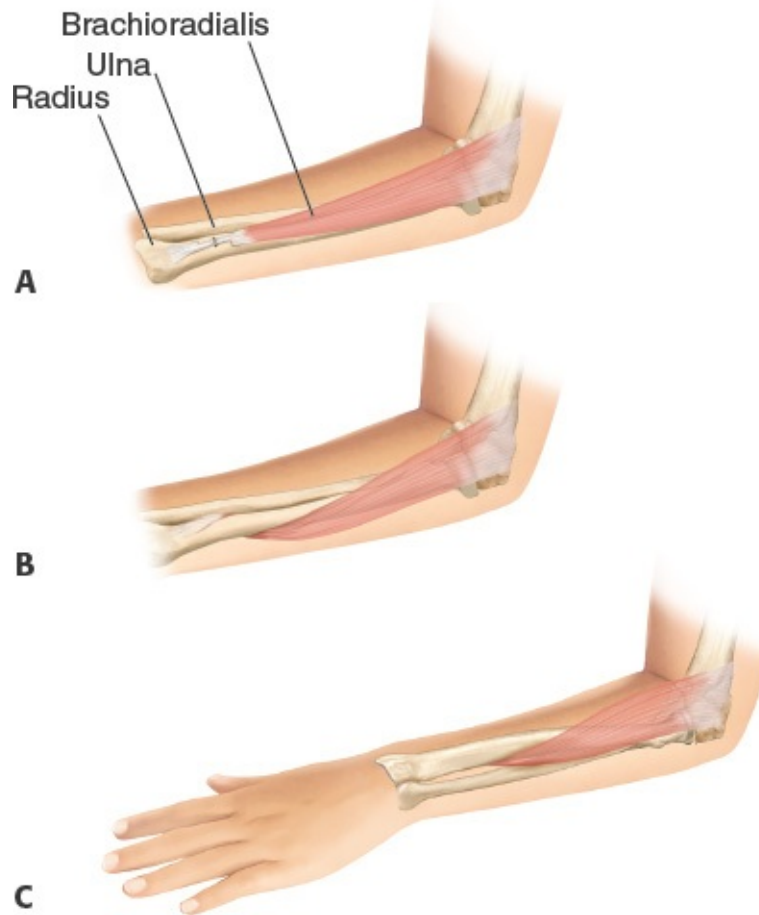


TECH FIG 8 • A. Over the dorsal wrist, an incision is made to identify the ECRL. The ECRL is rerouted around the radial wrist and transferred to the FDP to restore finger flexion. **B.** The ERCL is secured to the FDP, restoring flexion of the index, middle, ring, and small fingers.

- We prefer to reroute the BR, it is less technically challenging than biceps rerouting and it provides greater active pronation than other techniques.
 - Biceps rerouting can cause an elbow flexion contracture.
- To reroute the BR, an incision is made over the volar distal third of the radius. The BR is elevated off the radius at its distal insertion and elevated proximally. It is extended 5 cm distally using Z-lengthening.
- The BR is then passed between the radius and ulna through the interosseous membrane, proximal to the pronator teres, from volar and ulnar to dorsal and radial.
- The elbow is placed in 90 degrees of flexion and the forearm is fully pronated. The BR tendon is secured to the dorsoradial distal third of the radius (**TECH FIG 9**).

Sensory Nerve Transfers

- In combined median and ulnar nerve injuries, all volar hand sensation is lost.
- To restore protective sensation, a branch of the superficial radial nerve can be transferred to the distal median nerve.
- Alternatively, a first dorsal metacarpal artery flap can be used to provide sensation to the volar thumb. A branch of the superficial branch of the radial nerve is contained within this innervated flap.



TECH FIG 9 • To restore forearm pronation, the BR can be rerouted around the radius. **A.** The BR tendon is extended 5 cm distally using Z-lengthening. The BR is elevated distally from its insertion on the radius, passed through the interosseous membrane (**B**), and then secured to the dorsoradial radius with the elbow flexed 90 degrees and the forearm in full pronation (**C**).

PEARLS AND PITFALLS

Physical findings

- Creating a chart is helping in determining an individualized surgical plan. The patient's main subjective functional complaints

	are listed in the first column. In the second column, the patient's objective physical examination deficits are listed. In the third column, the patient's intact, innervated tendons are documented; these are further classified into expendable tendons available for transfer and nonexpendable tendons that must be preserved to prevent donor-site morbidity. ■ The donor tendons are then matched to the functional deficits and the surgical plan is reviewed with the patient. ■ It is beneficial for the patient to meet with a hand therapist prior to tendon transfer surgery for preoperative teaching; rehabilitation protocols and expectations are reviewed.
Technique	■ Proper intraoperative tension setting and postoperative immobilization are necessary to optimize the outcomes of tendon transfers. ■ Wide-awake surgery using local anesthesia can facilitate intraoperative assessment of the tendon transfer tension.
Postoperative	■ The joints crossed by the tendon transfer are immobilized for 4 wk. ■ ROM exercises for the shoulder and unaffected joints of the upper extremity should be resumed immediately postoperatively to minimize stiffness.
Therapy	■ Some authors advocate for early active ROM exercises following tendon transfers secured with 3 Pulvertaft weaves to minimize adhesions. In these cases, tendon gliding exercises are started on postoperative day 2 under the guidance of a hand therapist.¹²

POSTOPERATIVE CARE

- Following a tendon transfer, we prefer to immobilize the affected joints for 4 weeks to permit tension-free tendon healing; casting or splinting is used.
- Above elbow immobilization is used in transfers crossing the elbow. For example, for the BR to FPL transfer, immobilization holds the elbow in 90 degrees of flexion and the wrist slightly flexed or in neutral. Following tendon transfers to correct clawing, the MCP joints are immobilized in flexion and the IP joints in extension.
- ROM exercises are started 4 weeks postoperatively, starting with active ROM and followed by passive ROM. Mobilizing one joint at a time minimizes tension on the tendon transfer.
- 6 weeks postoperatively, muscle retraining and resistance exercises begin.

- 8 weeks following surgery, strengthening exercises begin and splints are weaned.
- At 12 weeks postoperatively, free unrestricted activity can be resumed.

OUTCOMES

- The balance of the flexors and extensors of the hand and wrist is critical for optimal function.
- The transfer of radial nerve-innervated hand and wrist extensors to restore hand and wrist flexion aids in restoring the function of the hand by re-establishing active hand and wrist flexion while weakening hand and wrist extension, improving the overall balance of the hand and wrist.

COMPLICATIONS

- Thorough discussion with the patient, careful physical examination, and thoughtful planning are required to optimize the function of the upper extremity following combined median and ulnar nerve injuries.
- The patient is counseled that his or her volar and dorsoulnar hand will remain insensate following tendon transfers. Worse outcomes are seen in patients with decreased sensation compared to those with intact sensation. Following sensory nerve injury, visual and auditory cues are required to permit the patient to use their injured hand; tactile sensory feedback is absent. Sensory nerve transfers can be performed to restore protective sensation. Ideally, nerve repair at the time of the injury is performed to permit motor and sensory recovery over time.
- Transferred tendons can rupture if placed under excess tension, if inadequately sutured during surgery, and if not sufficiently immobilized after surgery. If rupture occurs, immediate exploration and primary repair are recommended.
- Adhesions frequently form where tendons cross each other and in scarred tissue beds. Frequent, intensive hand therapy is used to optimize passive ROM in these cases. If passive ROM exceeds active ROM, a tenolysis may be beneficial. Tenolysis is performed no sooner than 3 months following the tendon transfer. Patient compliance is critical; daily hand therapy exercises are started 2 days after tenolysis to maintain intraoperative active ROM gains.
- Multiple long incisions are used for tendon transfers; patients must be counseled about postoperative scarring prior to reconstruction. Postoperatively, scar massage and sun avoidance are recommended for scar management.

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35 Distal Anterior Interosseous Nerve Transfer to Motor Branch of Ulnar Nerve

CHAPTER

Shelley S. Noland and Jason H. Ko

DEFINITION

- Ulnar nerve palsy severely limits hand function with loss of dexterity, pinch and grip strength weakness, and claw formation.
- Ulnar-innervated intrinsic muscle recovery after high ulnar nerve injury (above elbow) is poor.
- Distal transfer of the anterior interosseous nerve (AIN) to the motor component of the ulnar nerve can preserve motor endplates and restore motor function.

ANATOMY

- Ulnar nerve
 - After exiting the cubital tunnel, the ulnar nerve enters the forearm between the two heads of the flexor carpi ulnaris (FCU).
 - It travels between the FCU and flexor digitorum profundus (FDP) muscles and gives off the dorsal sensory branch 9 cm proximal to the wrist crease.
 - At the Guyon canal, it enters the hand and divides into the deep motor branch and the sensory branch.
 - Internal topographical anatomy
 - Topographical anatomy is critical to the success of this procedure.
 - The ulnar nerve has a discrete fascicular pattern.
 - At the level of the mid-forearm, the three components are the ulnar-sided sensory component (dorsal sensory branch), the middle motor component (intrinsic motor function), and the radial-sided sensory component (digital ulnar sensation) (**FIG 1**).

■ Median nerve

- After exiting from underneath the lacertus fibrosus, the median nerve travels through the pronator teres.
- It courses between the flexor digitorum superficialis (FDS) and the FDP and gives off four motor branches in the proximal forearm.
- It enters the hand at the carpal tunnel and divides into the recurrent motor branch and sensory branches.
- Anterior interosseous nerve
 - Branches from the median nerve 3 cm distal to the intercondylar line
 - Contains fascicles to the flexor pollicis longus (FPL), FDP (index and middle finger), and pronator quadratus (PQ)
 - Exits the median nerve on the dorsal radial aspect (**FIG 2**)

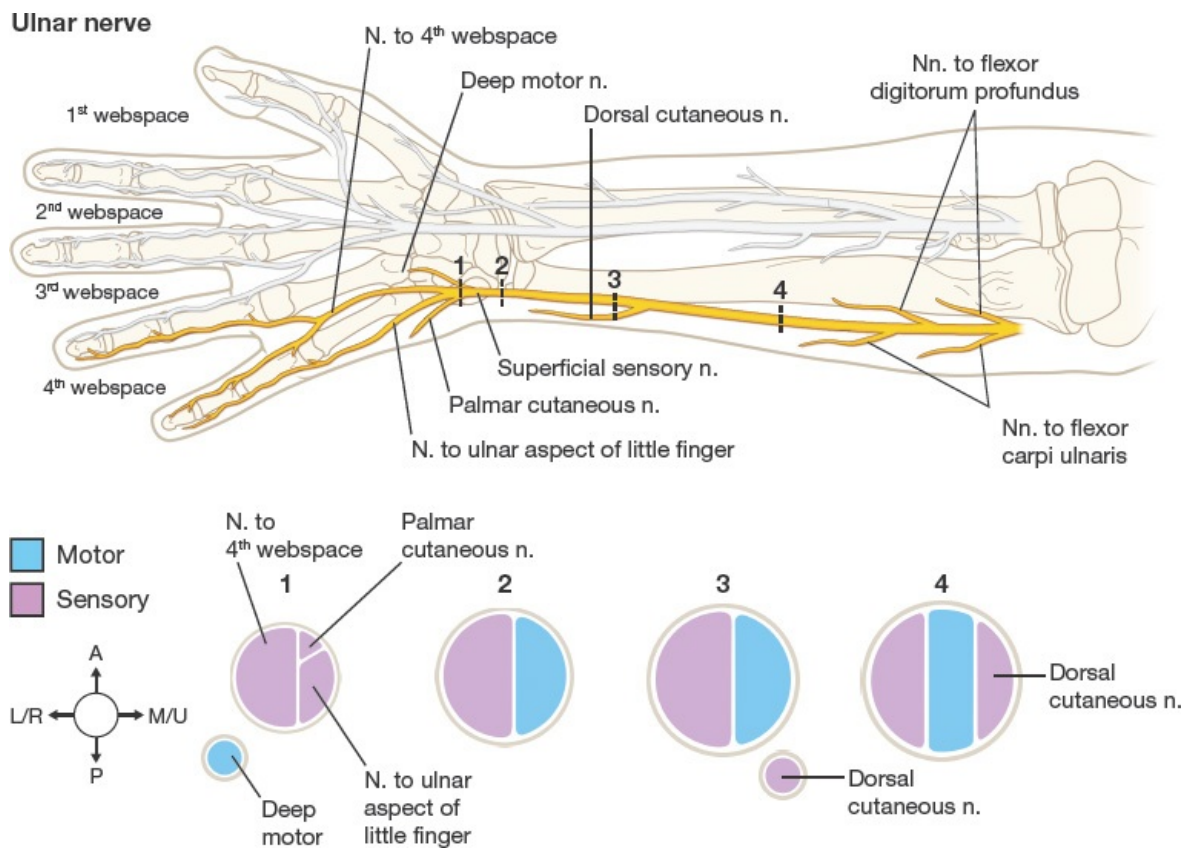


FIG 1 • Internal topography of the ulnar nerve. A, anterior; P, posterior; L, lateral; R, radial; M, medial; U, ulnar.

nerve distributions.

- Perform full motor exam of bilateral upper extremities by documenting strength in relevant muscles, clawing of the fingers, intrinsic atrophy/wasting, and presence of Froment (thumb interphalangeal flexion with pinch) or Wartenberg signs (abducted posture of small finger).
- Perform provocative maneuvers including elbow flexion test and compression at the Guyon canal.

IMAGING

- Obtain nerve conduction studies (NCS) and electromyography (EMG) to help with localization of lesion and to assess severity of ulnar neuropathy.
- NCS may demonstrate a conduction block at the cubital tunnel or Guyon canal.
- EMG can identify the presence and quality of fibrillations, positive sharp waves, and motor unit potentials.
- In setting of trauma, traditional x-rays are recommended to evaluate for fracture, dislocation, or foreign body.
- In setting of tumor, formal imaging studies such as CT or MRI are warranted as appropriate.

DIFFERENTIAL DIAGNOSIS (OPTIONAL)

- Cervical radiculopathy
- Cubital tunnel syndrome
- Guyon canal compression
- Shoulder injury
- Thoracic outlet syndrome
- Polyneuropathy
- Other systemic neuropathy

SURGICAL MANAGEMENT¹⁻³

- Distal AIN to motor branch of ulnar nerve transfer should be considered in patients with isolated high ulnar nerve injuries or lesions (above elbow).
- Patient must have intact median nerve and AIN function.

Preoperative Planning

- Patient counseling regarding the timeline of recovery is critical (1 mm/d).
- Need to coordinate care with a hand or physical therapist for postoperative

motor re-education.

Positioning

- The patient is positioned supine on operating table with the affected arm extended and supinated on an armboard.

Approach

- The entire procedure is completed through a single incision designed longitudinally or zigzag over the course of the FCU and ulnar neurovascular bundle in the distal 1/3 of the volar forearm (**FIG 3**).

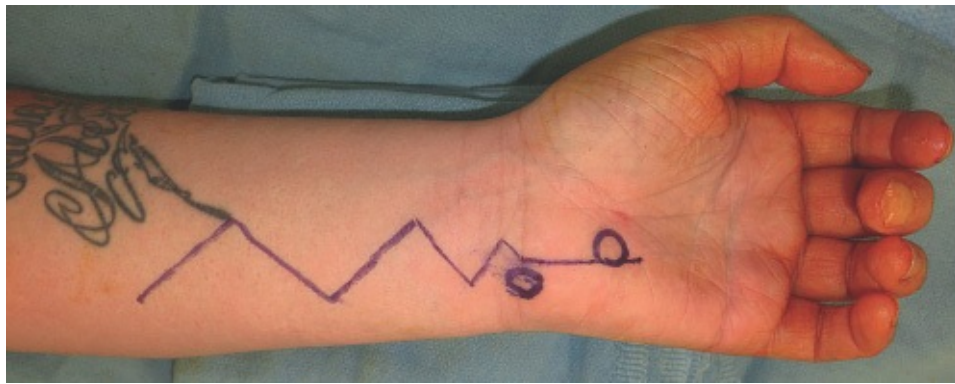


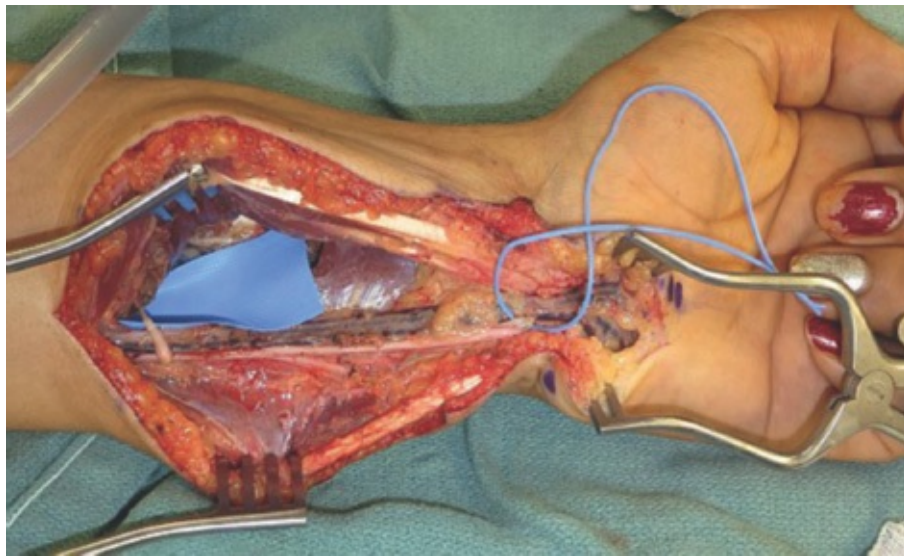
FIG 3 • Surgical approach for AIN to ulnar motor nerve transfer.

TECHNIQUES

■ Distal Exposure Including Identification of the Motor Component of the Ulnar Nerve

- A longitudinal incision is made in the distal 1/3 of the volar forearm over the course of the flexor carpi ulnaris (FCU) and ulnar neurovascular bundle including a short zigzag segment across the wrist crease.
- The pisiform and hook of the hamate are marked, and a longitudinal incision between them is made to approach the Guyon canal. Sharply dissect the overlying fascia at the level of the wrist crease, exposing the ulnar neurovascular bundle.

- The ulnar neurovascular bundle is identified and retracted ulnarly.
- The deep motor branch is released by dividing the leading edge of the hypothenar musculature off of the hook of the hamate.
- The motor branch is then identified and traced proximally. Either manual or visual neurolysis can be performed to identify the motor component of the ulnar nerve 9 cm proximal to the wrist crease.
- The motor component of the ulnar nerve is marked with a vessel loop 9 cm proximal to the wrist crease (**TECH FIG 1**).



TECH FIG 1 • Identification of the motor component of the ulnar nerve (vessel loop).

■ Proximal Exposure Including Identification of the Anterior Interosseous Nerve

- Through the same incision, identify the finger flexors and retract them radially to identify the pronator quadratus (PQ) muscle. Some muscle fibers of the flexor digitorum profundus (FDP) may have to be released to gain better visualization of the proximal PQ and anterior interosseous nerve (AIN).
- At the proximal edge of the PQ, identify the AIN entering the muscle.
- Carefully divide the PQ with bipolar cautery for 1 to 2 cm (proximal to distal) superficial to the AIN to maximize AIN length for transfer (**TECH**

FIG 2).

- Divide the AIN distally just prior to its branching point, which is typically at the halfway point of the PQ.

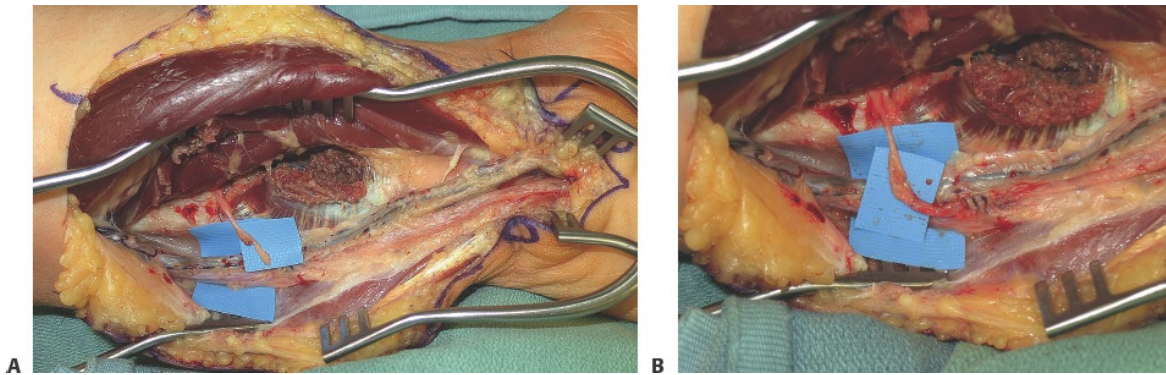


TECH FIG 2 • Division of the pronator quadratus to reveal the distal extent of the AIN (upper *blue* background).

■ End-to-End Transfer of the AIN to the Motor Component of the Ulnar Nerve

- Transfer the AIN ulnarly across the PQ to the ulnar nerve 9 cm proximal to the wrist crease (**TECH FIG 3A**).
- Ensure adequate length to perform transfer with no tension.
- Divide the motor component of the ulnar nerve as proximally as necessary to ensure adequate length to perform transfer with no tension.
- Intrafascicular dissection of the ulnar motor fascicle distally will allow for a tension-free coaptation.
- Perform neurorrhaphy with a microscope using 9-0 nylon suture (**TECH FIG 3B**).
- Evaluate the neurorrhaphy site while performing a full pronation-supination arc to ensure no tension at any forearm position.
- Close skin in standard fashion, and either a soft dressing or volar wrist splint

is placed.

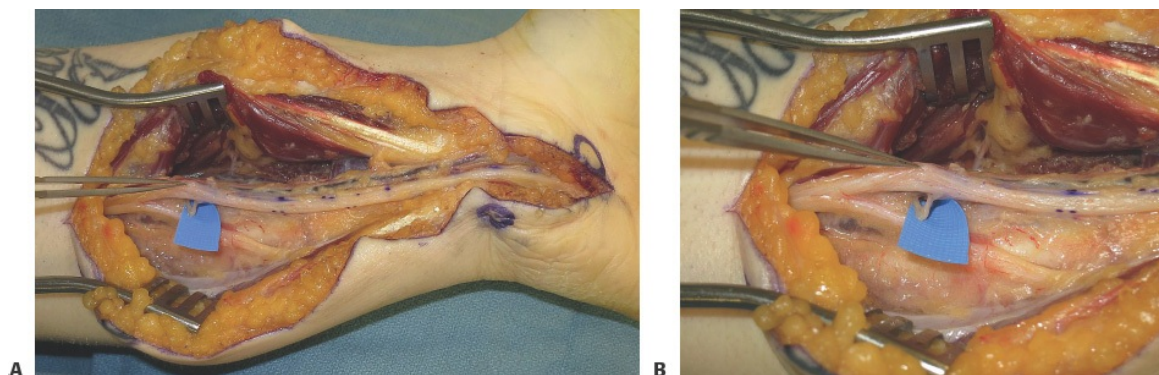


TECH FIG 3 • **A.** Division of the AIN. **B.** End-to-end neurorrhaphy of AIN to motor component of ulnar nerve.

■ Reverse End-to-Side AIN to Ulnar Motor Nerve Transfer⁴

- Consider reverse end-to-side transfer in patients in whom ulnar nerve recovery is ultimately expected. Also, in high ulnar nerve injuries where distal intrinsic recovery is possible, the distal reverse end-to-side AIN nerve transfer can be performed to help “babysit” the motor endplates in the hand until the more proximal regenerating axons can reach the hand.
- When performing a reverse end-to-side nerve transfer, the skin incision should be longer, and the ulnar nerve exposure should be more proximal. To obtain a tension-free reverse end-to-side nerve transfer, the AIN will have to be transferred more proximally to reach the ulnar nerve than in an end-to-end transfer.
- Instead of dividing the ulnar motor component, create epineurial and perineurial windows in the motor component of the ulnar nerve.
- Transfer the AIN to this epineurial/perineurial window ensuring no tension.
- Perform neurorrhaphy of the AIN to the side of the ulnar motor component with a microscope using 9-0 nylon suture (**TECH FIG 4**).
- Evaluate the neurorrhaphy site while performing a full pronation-supination arc to ensure no tension at any forearm position.

- Close skin in standard fashion, and either a soft dressing or volar wrist splint is placed.



TECH FIG 4 • A,B. End-to-side neurorrhaphy of AIN to motor component of ulnar nerve.

PEARLS AND PITFALLS

Nerve transection	■ Remember that the Donor nerve (AIN) is always cut Distal and the recipient nerve (ulnar motor branch) is always cut proximal.
Guyon canal release	■ It is important to perform a full Guyon canal release to prevent a distal conduction block on the recovering nerve.
Reverse end-to-side transfer	■ Consider a reverse end-to-side transfer in patients in whom ulnar nerve recovery is ultimately expected.
Tension	■ Ensure no tension on neurorrhaphy site while observing a full pronation-supination arc.
Postoperative rehabilitation	■ Ensure that you have a hand therapist knowledgeable in motor re-education for optimal outcomes.

POSTOPERATIVE CARE

- If a splint was used, the postoperative splint can be removed and gentle range of motion can be initiated 1 week after surgery.

- Once postoperative pain has subsided at 3 to 4 weeks, the patient begins motor re-education under the care of a knowledgeable hand therapist.

OUTCOMES

- There are limited outcomes data for this procedure, but most case series report return of intrinsic function within 1 year of surgery.

COMPLICATIONS

- The most common complications are infection, bleeding, and lack of reinnervation of the intrinsic musculature.

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36 Nerve Transfers for High Radial Nerve Palsy

CHAPTER

Shelley S. Noland and Jason H. Ko

DEFINITION

- High radial nerve palsy limits hand and wrist function with loss of wrist, finger, and thumb extension.
- The presence of a wrist drop significantly decreases finger flexion power and grip strength.
- The inability to open the hand to initiate grasp makes tasks of manual dexterity difficult.
- Distal transfer of median-innervated nerve branches to branches of the radial nerve can preserve motor endplates and restore motor function.

ANATOMY

- Radial nerve
 - Originates from the posterior cord of the brachial plexus
 - Courses between the humerus and the triceps and innervates the triceps muscle
 - Travels in the spiral groove posterior to the humerus and exits through the lateral intermuscular septum about 10 cm proximal to the lateral epicondyle
 - Passes between the brachialis and brachioradialis (BR) and gives off the following branches:
 - BR muscle branch
 - Extensor carpi radialis longus (ECRL) muscle branch (at the level of the interepicondylar line)
 - Enters the forearm by passing anterior to the lateral epicondyle and gives off the following branches (**FIG 1**):
 - Radial sensory nerve (RSN) branch, which courses underneath the BR

- Extensor carpi radialis brevis (ECRB) muscle branch (about 3 cm distal to the interepicondylar line)
- Supinator muscle branches (1–2; just proximal to the leading edge of the supinator)
- Continues as the posterior interosseous nerve (PIN) and innervates all hand and wrist extensors
- Median nerve
 - Originates from the medial and lateral cords of the brachial plexus
 - Courses anterior and medial to the brachial artery
 - Travels between the brachialis muscle and the medial intermuscular septum
 - Gives off the pronator teres (PT) muscle branch at the level of the interepicondylar line
 - Courses under the lacertus fibrosus, through the superficial and deep heads of the (PT), and underneath the tendinous arch of the flexor digitorum superficialis (FDS) and gives off the following branches (see **FIG 1**):

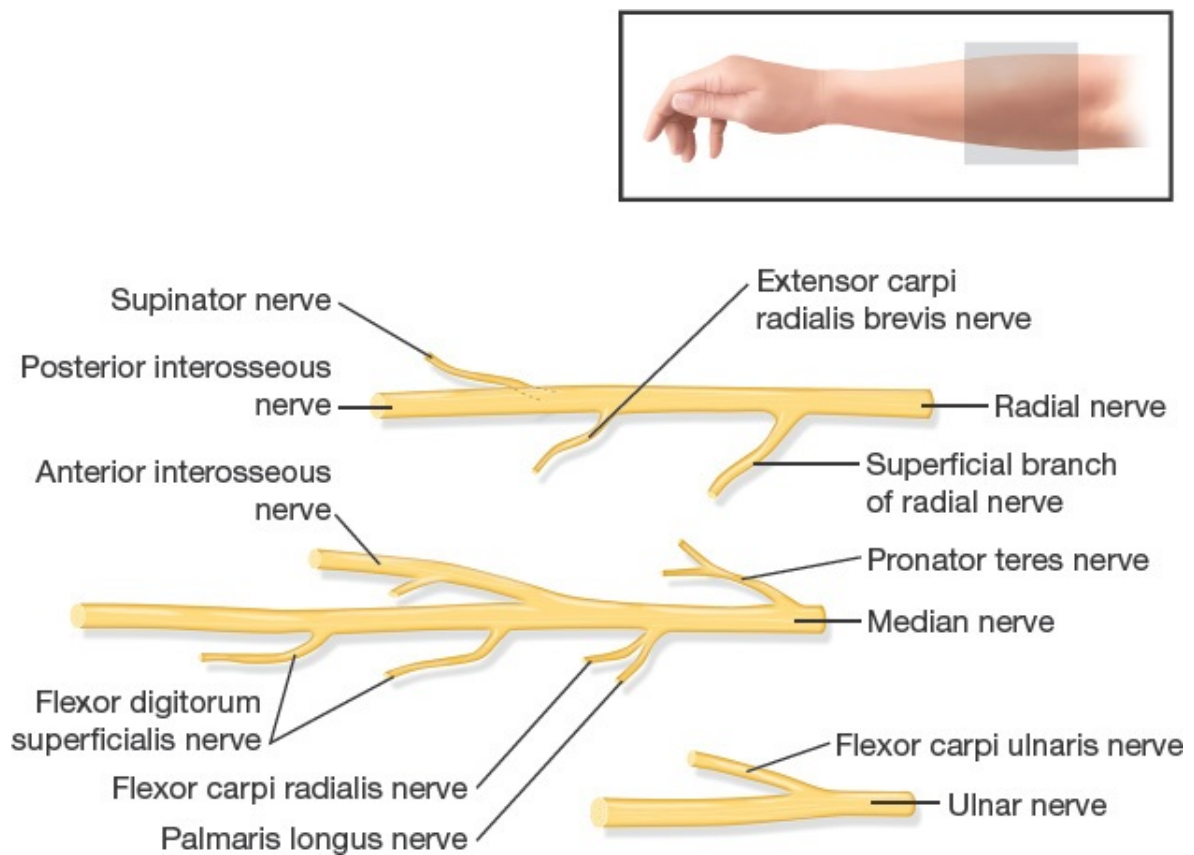


FIG 1 • Anatomy of the median and radial nerves in the

forearm.

- FDS muscle branches (2–3) from the ulnar side of the median nerve
- Flexor carpi radialis (FCR) muscle branch
- Palmaris longus (PL) muscle branch (if PL is present)
- Anterior interosseous nerve (AIN) from the dorsal radial side of the nerve
 - Branches 3 cm distal to the intercondylar line
 - Contains fascicles to the flexor pollicis longus (FPL), flexor digitorum profundus (FDP; index and middle finger only), and pronator quadratus (PQ)
- Palmar cutaneous branch in distal forearm
- Enters the hand at the carpal tunnel and divides into the recurrent motor branch and sensory branches

PATIENT HISTORY AND PHYSICAL FINDINGS

■ History

- Obtain history of trauma, tumor, or other injury to the affected extremity.
- Ask location, timing, frequency, and duration of sensory symptoms including numbness and tingling.
- Rule out other causes of symptoms such as cervical spine, shoulder, or brachial plexus issues.
- Elicit a history of the etiology of the radial nerve palsy.
- Determine the timeline of injury.

■ Physical examination

- Perform full motor exam of bilateral upper extremities.
- Assess for a Tinel sign along the course of the radial nerve.
- Perform a full motor and sensory examination of the entire affected extremity.
 - Determine the level of the injury.
 - If the patient has a wrist drop, it is likely a high radial nerve palsy occurring prior to the innervation of the ECRL and ECRB (**FIG 2**).
 - If the patient can extend the wrist, he or she likely has a PIN palsy with preservation of ECRL and ECRB function.
 - Perform full sensory exam of bilateral upper extremities documenting 2-point discrimination and/or Semmes-Weinstein monofilament testing in all

nerve distributions.

- Sensory disturbances in radial nerve lesions typically involve the dorsal radial aspect of the thumb and hand.
- Ensure that the injury is isolated to the radial nerve.
 - Test and record function in your potential median-innervated donor nerves including branches to the FCR, FDS, and PL.
 - Test and record function in the median-innervated muscles that may need to be used for tendon transfers in the event there are no nerve transfer options including the PT, FCR, and PL.

IMAGING

- Obtain electrodiagnostic studies to assist with localization of the injury and to assess severity of the radial nerve palsy.

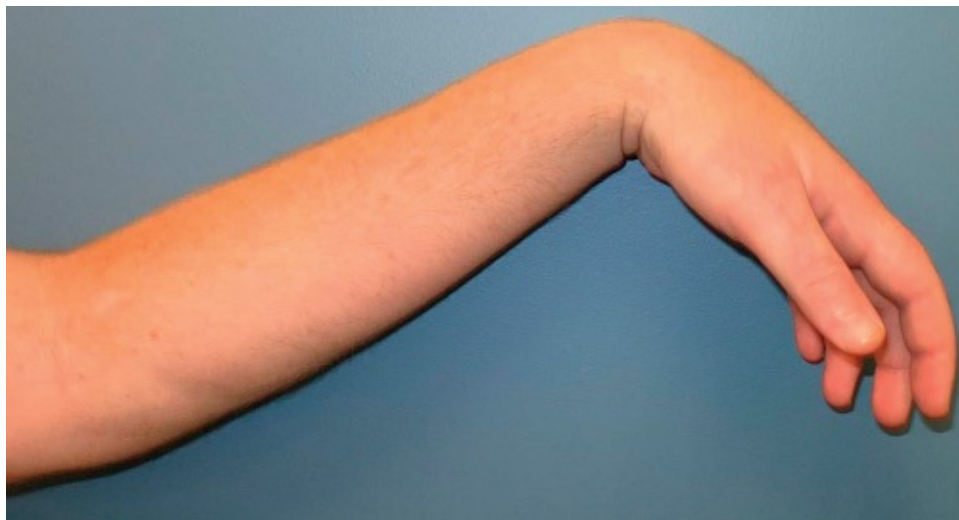


FIG 2 • Example of wrist drop.

- EMG can identify the presence and quality of fibrillations, positive sharp waves, and motor unit potentials. This can be followed over time to determine reinnervation status.
- In setting of trauma, traditional x-rays are recommended to evaluate for fracture, dislocation, or foreign body.
- In setting of tumor, formal imaging studies such as CT or MRI are warranted as appropriate.

SURGICAL MANAGEMENT¹⁻³

- Patients should be monitored from the time of injury for reinnervation of wrist, finger, and thumb extensors.
- Patients with no evidence of clinical or electrical reinnervation at 6 to 9 months should be considered for nerve transfers. Alternatively, tendon transfers can be performed in a delayed fashion and will be discussed in Chapter 39 (**FIG 3**).
- The most common nerve transfers for high radial nerve palsy are
 - FCR to PIN
 - FDS to ECRB
 - Lateral antebrachial cutaneous nerve (LABC) to RSN
- Typically, there are redundant motor branches to the FCR and FDS, so using a single-donor nerve branch will still leave some function of the FCR and FDS, which can still be used to power a tendon transfer if the nerve transfer is not sufficient.

Preoperative Planning

- Patient counseling regarding the timeline of recovery after nerve transfers is critical (1 mm/d).
- Need to coordinate care with a hand or physical therapist for postoperative motor re-education

Positioning

- Patient is positioned supine with the arm extended on a hand table.
- Tourniquet can be used if donor exposure and identification can be accomplished within 30 to 40 minutes.
 - After 30 to 40 minutes, tourniquet neurapraxia may preclude the use of nerve stimulation.

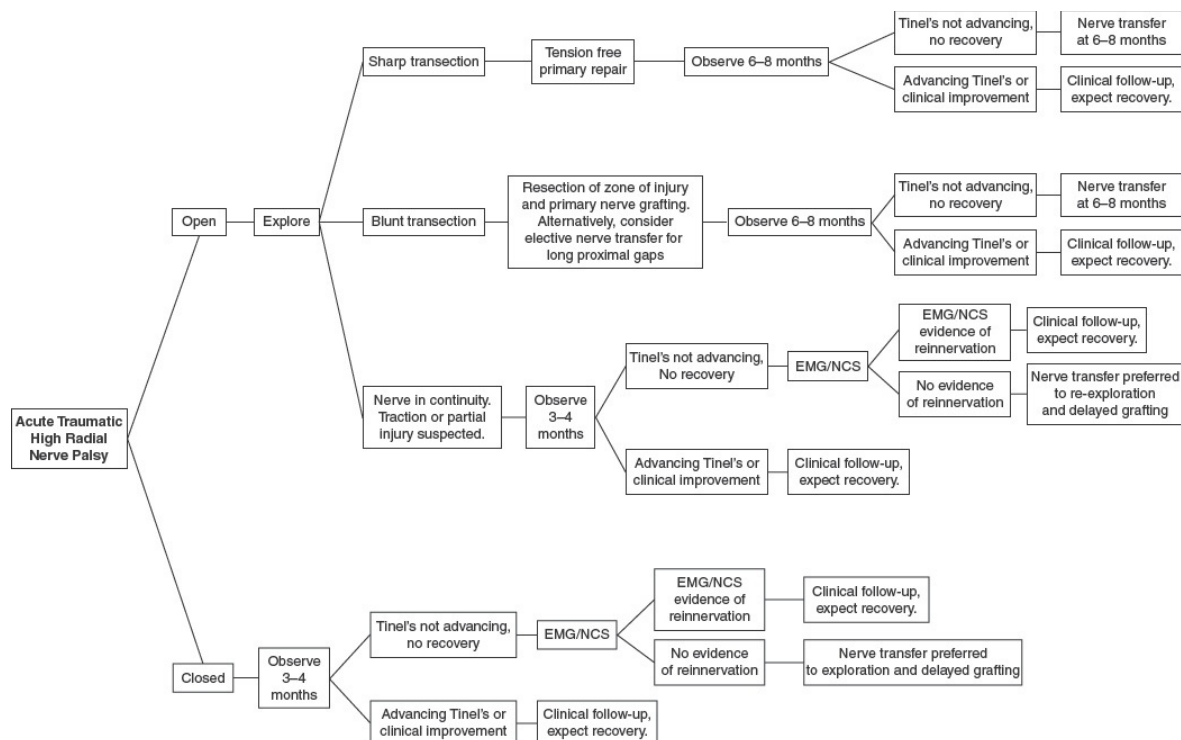


FIG 3 • Algorithm for the management of high radial nerve palsy. Reprinted from Pet MA, Lipira AB, Ko JH. Nerve transfers for the restoration of wrist, finger, and thumb extension after high radial nerve injury. *Hand Clin.* 2016;32(2):191-207 with permission.

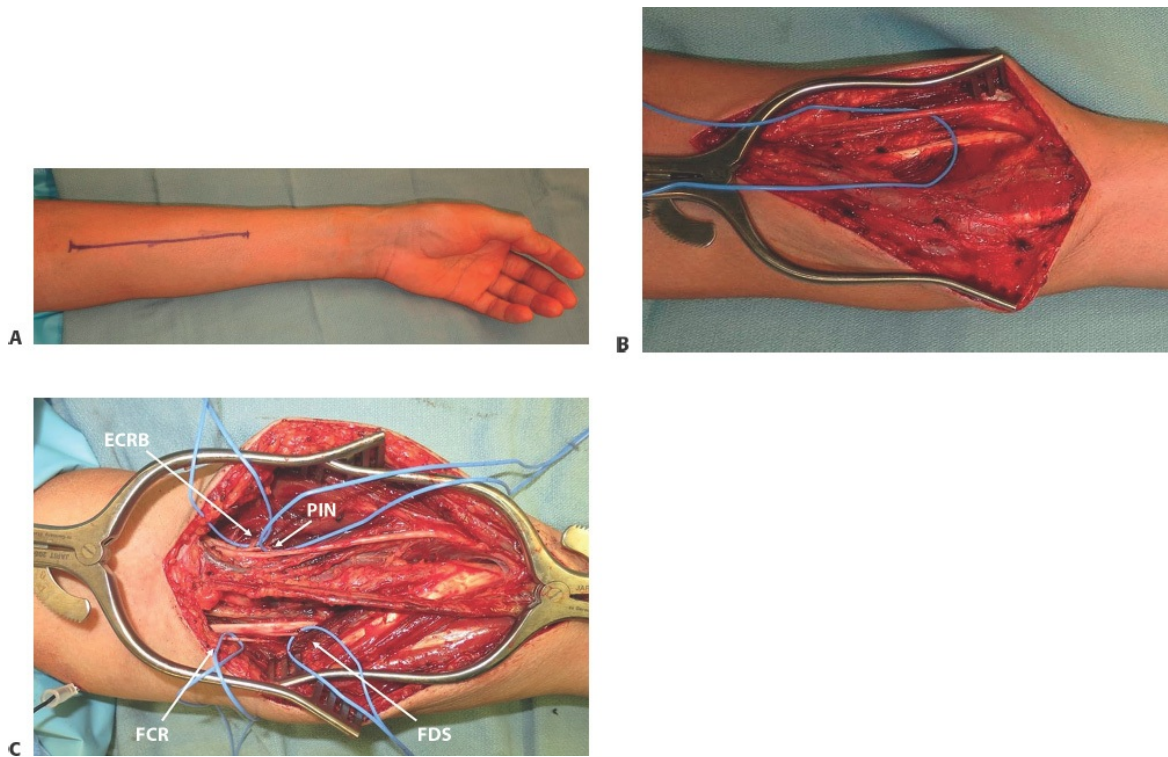
TECHNIQUES

■ Identification, Decompression, and Dissection of the Median Nerve

- A straight incision from the lateral antecubital fossa along the medial aspect of the BR to the midpoint of the forearm is utilized, which provides exposure of median and radial nerves (**TECH FIG 1A**).
- Identify and protect the LABC nerve that runs with the cephalic vein.
 - Identify and retract the BR to identify the RSN and radial vessels beneath (**TECH FIG 1B**). This provides visualization of the PT tendon.
- If PT to ECRB tendon transfer will be performed, the skin incision is

extended distally to visualize the insertion of the PT on the radius.

- The insertion of the PT is elevated with a strip of periosteum as distally as possible, and subperiosteal dissection is performed distal to proximal at this stage for later tendon transfer.
- Because it takes 6 to 9 months to begin to see motor recovery after these nerve transfers, the PT to ECRB tendon transfer acts as an immediate treatment for wrist drop, which can be quite debilitating for patients.
 - This tendon transfer works well and acts as an internal splint until motor recovery occurs.
- If the PT to ECRB tendon transfer is not performed, step-lengthening of the PT tendon should be performed at this point.
 - This allows the superficial head of the PT to be reflected medially, exposing the deep head of the PT.
- Release the deep head of the PT to expose and decompress the median nerve in the proximal forearm.
- Identify and release the tendinous edge of the FDS to further decompress the median nerve and allow direct visualization of the nerve branches.
- Identify the median nerve and dissect it distally to identify the following branches (**TECH FIG 1C**):
 - PT, PL, FCR, FDS, AIN
 - Use of a nerve stimulator will help confirm branch identity.
 - It is helpful to loop each branch with a vessel loop in preparation for later transfer.

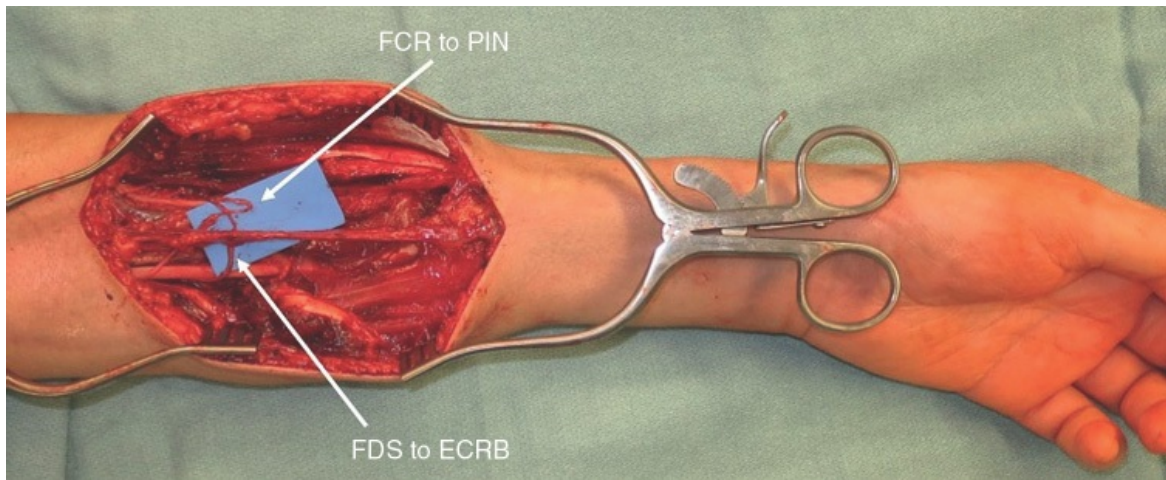


TECH FIG 1 • **A.** Approach for median to radial nerve transfers. **B.** Identification of radial sensory nerve. **C.** Identification of median nerve branches, including flexor carpi radialis (FCR) and flexor digitorum superficialis (FDS), along with radial nerve branches, including extensor carpi radialis brevis (ECRB) and posterior interosseous nerve (PIN).

■ Identification, Decompression, and Dissection of the Radial Nerve

- Retract the BR laterally and follow the RSN proximally until the main radial nerve is identified.
- Divide the transverse radial recurrent vessels that overlie the radial nerve (“leash of Henry”).
- Dissect the radial nerve distally and identify the following branches (**TECH FIG 2**).
 - ECRB branch: This branch is small and directly radial to the RSN.

- PIN branch: This branch is larger and radial to the ECRB branch. This branch dives deep to the supinator muscle.
- Use of a nerve stimulator will help confirm branch identity.
- It is helpful to loop each branch with a vessel loop in preparation for later recipient of nerve transfer.
- Release the tendinous leading edge of ECRB and supinator muscles (arcade of Frohse).
- This is important for maximal mobilization of recipient nerves.



TECH FIG 2 • Coaptation of flexor carpi radialis (FCR) to posterior interosseous nerve (PIN) and flexor digitorum superficialis (FDS) to extensor carpi radialis brevis (ECRB) nerve transfers.

■ Mobilization and Transection of the Donor and Recipient Nerves

- Mobilize FCR, FDS, and LABC branches as distally as possible and transect them distally.
 - This will facilitate a tension-free neurorrhaphy.
- Mobilize PIN, ECRB, and RSN branches as proximally as possible and transect them proximally.
 - This will facilitate a tension-free neurorrhaphy.

■ Transfer FCR to PIN

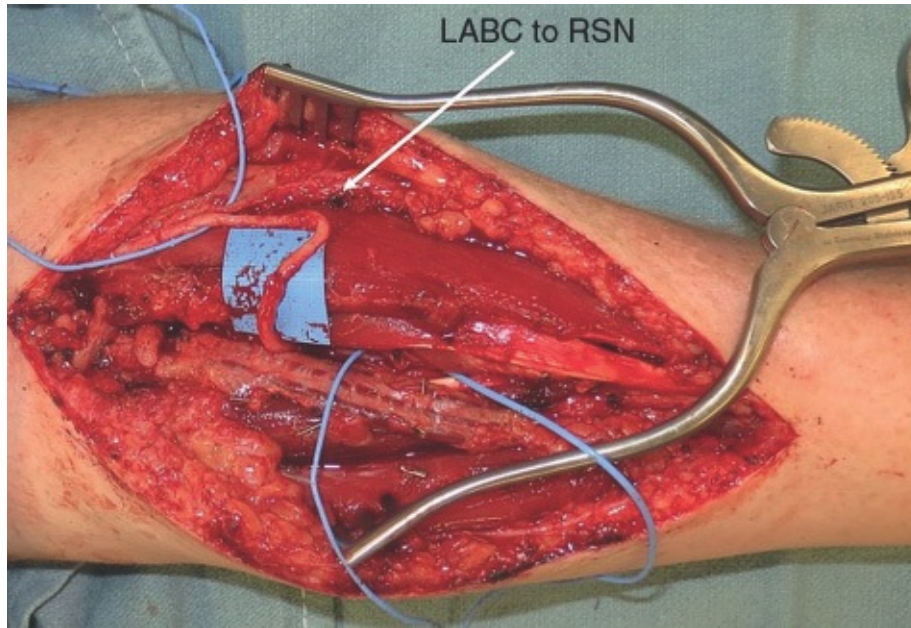
- Oppose the FCR (donor) and the PIN (recipient) to facilitate a tension-free repair (see **TECH FIG 2**).
- Perform end-to-end coaptation using a microscope and 9-0 nylon.
- May use two or three sutures followed by fibrin glue
 - This will minimize trauma and foreign body reaction.
- Perform complete wrist and elbow range of motion to confirm that no tension is present in any arm or wrist position.

■ Transfer of FDS to ECRB

- Oppose the FDS (donor) and the ECRB (recipient) to facilitate a tension-free repair (see **TECH FIG 2**).
- Perform end-to-end coaptation using a microscope and 9-0 nylon.
- May use two or three sutures followed by fibrin glue.
 - This will minimize trauma and foreign body reaction.
- Perform complete wrist and elbow range of motion to confirm that no tension is present in any position.

■ Transfer of LABC to RSN (Optional)

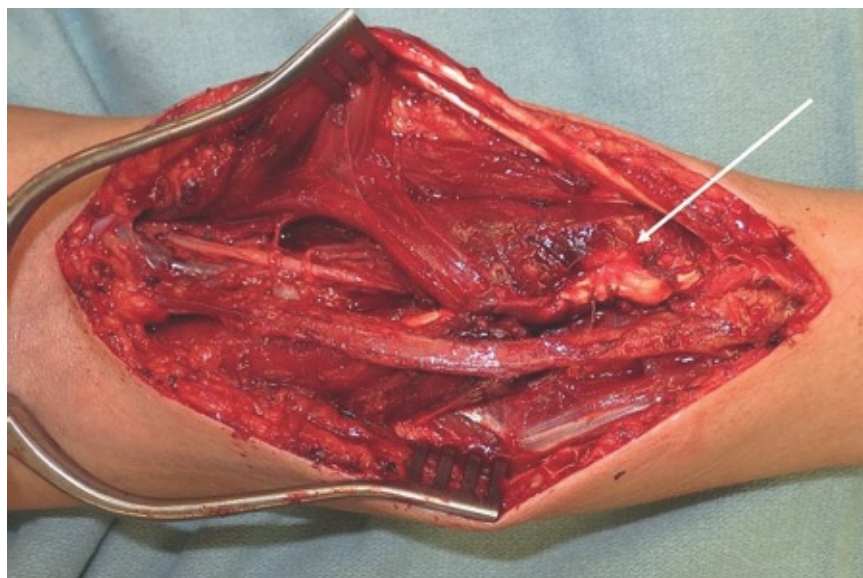
- Oppose the LABC (donor) and the RSN (recipient) to facilitate a tension-free repair (**TECH FIG 3**).
- Perform coaptation using a microscope and 9-0 nylon.
- May use two or three sutures followed by fibrin glue
 - This will minimize trauma and foreign body reaction.
- Perform complete wrist and elbow range of motion to confirm that no tension is present in any position.



TECH FIG 3 • Example of lateral antebrachial cutaneous nerve (LABC) to radial sensory nerve (RSN) transfer.

■ Tendon Transfer of PT to ECRB (Optional)

- The ECRB tendon is identified in the surgical field.
- The previously elevated distal PT insertion with periosteal strip is identified and dissected proximally.
- An end-to-side tendon transfer of the PT to ECRB is performed using three or four Pulvertaft weaves and secured with 3-0 braided, nonabsorbable suture (**TECH FIG 4**).



TECH FIG 4 • Example of pronator teres (PT) to extensor carpi radialis brevis (ECRB) tendon transfer (arrow).

PEARLS AND PITFALLS

Preservation of critical branches

- It is critical to preserve the pronator teres and anterior interosseous nerve branches during this operation.

Pronator teres step-lengthening

- This is critical to help with identifying the median nerve and its branches in the proximal forearm.

Decompression of involved nerve branches

- Decompression of involved nerves and branches facilitates axonal regeneration.

Nerve transection

- Remember that the donor nerve is always cut distal and the recipient nerve is always cut proximal.

POSTOPERATIVE CARE

- Immediately postoperatively, if no tendon transfer has been performed, a soft dressing is applied, allowing for free motion of the elbow, wrist, and fingers.

- If the PT to ECRB tendon transfer has been performed, a short-arm plaster splint should be applied to stabilize the wrist in an extended position.
- At 2 weeks postoperatively, this should be transitioned to a short-arm cast for an additional 2 weeks.
- If no tendon transfer has been performed, 2 weeks postoperatively, initiate early motor re-education, edema control, scar management, and gentle ROM.
- It is important to begin motor re-education before reinnervation.

OUTCOMES

- There are limited outcomes data for this procedure, but most case series report return of intrinsic function within 1 year of surgery.

COMPLICATIONS

- The most common complications are infection, bleeding, and lack of reinnervation of the radial-innervated musculature.

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Section IX: Tendon Conditions

37 Acute Repair of Flexor Tendon Injuries

CHAPTER

Jacques A. Machol IV, Neal Chen, and Kyle R. Eberlin

DEFINITION

- Flexor tendon repair has evolved substantially over time. Flexor tendon repair balances strong tendon healing against adhesion formation. There is a complex interplay between tendon repair technique and rehabilitation that dramatically affects the outcome of flexor tendon repair.
- Biomechanical strength of suture technique
 - The strength of most initial tendon repairs ranges between 30 and 150 N.¹
 - The repair may experience forces up to 50 N during rehabilitation.²
 - The strength of flexor tendon repair is related to the number of core strands crossing the repair site.
 - Strength of repair is related to suture caliber.
 - Locking sutures provide greater biomechanical strength than do grasping sutures.
 - Epitendinous sutures provide substantial strength to the tendon repair.
 - Venting of the A2 or A4 pulley can decrease friction in the flexor tendon system and improve clinical results.
 - Similarly, some surgeons elect to excise a slip of the flexor digitorum superficialis (FDS) tendon to reduce bulk and gliding resistance.
- Rehabilitation
 - During the first 1 to 3 weeks, up to 50% of initial repair strength is lost if a tendon is immobilized.

- Early motion yields superior tensile strengths compared to delayed motion or immobilization.
- Pyramidal rehabilitation protocols incorporating advancing force and excursion are also being used that are even more physiologically demanding than prior early active motion protocols.
 - Pyramidal protocols begin with the lowest stress force exercises and then progressively advance forces as needed in order to overcome adhesion formation.

ANATOMY

- The FDS muscle belly lies in the superficial anterior compartment of the forearm. It originates from the medial epicondyle of the humerus in the common flexor tendon and also has attachments on the oblique line of the radial head and the proximal ulna. This muscle belly is innervated by the median nerve.
- The FDS tendon to the small finger is congenitally absent in up to 7% of the population.³
- The FDS decussates at Camper chiasm. Here, it envelops the flexor digitorum profundus (FDP) and inserts with a 180-degree rotation.
- The FDP originates from the anteromedial surfaces of the ulna, the interosseous membrane, and the deep forearm fascia. It is located dorsal to the FDS.
 - The anterior interosseous nerve of the median nerve in most cases innervates the index and long fingers.
 - The ring and small finger FDPs are innervated by the ulnar nerve.
 - The long, ring, and small FDP tendons share a common muscle belly.
 - The FDP of the index finger is usually separate.
- The common muscle bellies of the long, ring, and small fingers are important clinically because of the quadriga phenomenon. If one of these tendons is shortened, the change in excursion may limit the ability of the other tendons to flex fully.
- The flexor tendons have limited blood supply. They are nourished by segmental, penetrating arteries via the vincular vasculature (**FIG 1A**).
- The digital nerve is volar to the digital artery in the finger.
- A complex pulley system in the distal palm and digits brings the tendons close to the bone, thus increasing the overall mechanical advantage (**FIG 1B**).

- The A5 and C3 pulley systems may require division in zone 1 injuries.
- Flexor tendon injuries are divided into five zones labeled from distal to proximal:
 - Zone 1: Insertion of the FDP to the insertion of the FDS. These are commonly referred to as “jersey fingers.” The Leddy-Packer classification is used for zone 1 FDP avulsion injuries:
 - Type 1: The tendon retracts into the palm; surgery is recommended within 7 to 10 days.
 - Type 2: The FDP is at the proximal interphalangeal (PIP) and held by the vinculum; surgery is recommended within 2 to 3 weeks.
 - Type 3: The FDP is located at the A4 pulley and held by the distal phalanx bone fragment; surgery within several weeks may be acceptable, but earlier repair is advocated.
 - It is possible to have a distal phalanx fracture with tendon avulsion off of the bone fragment. These are commonly referred to as Leddy-Packer 4 injuries.

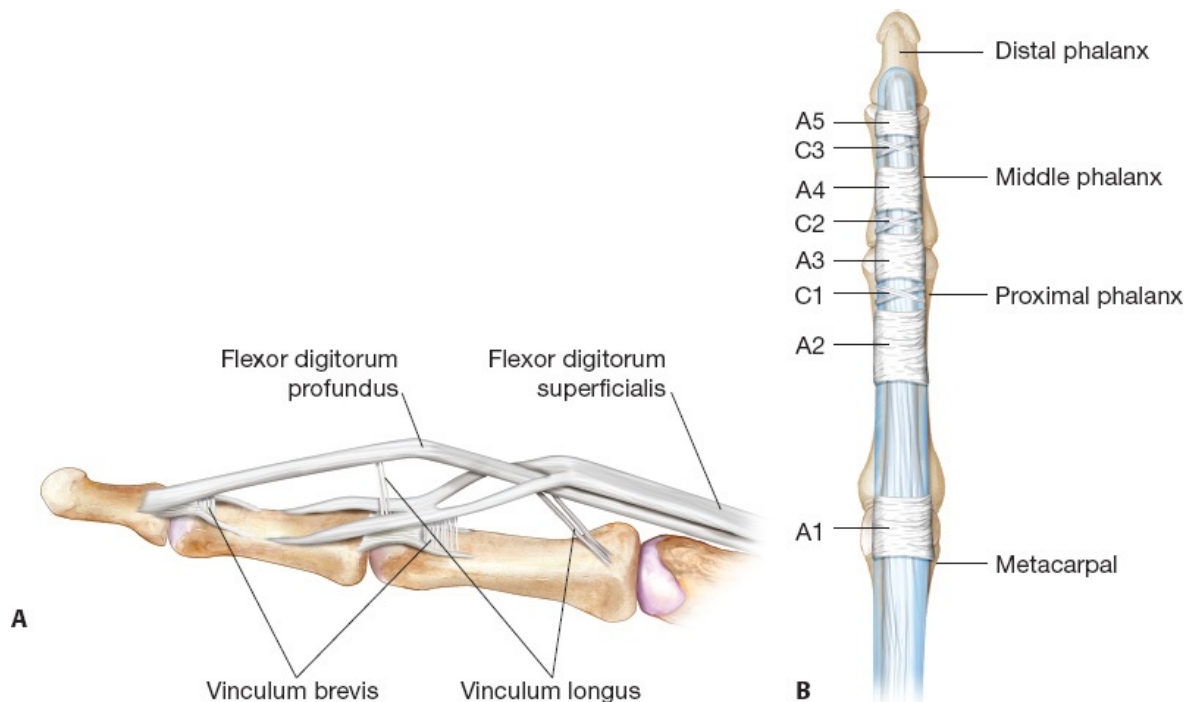


FIG 1 • A. Insertion of flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) with vinculum longus (VL) and vinculum brevis (VB). **B.** Flexor tendon

pulley systems. A indicates annular, and C indicates cruciate.

- Zone 2: FDS insertion to the distal palmar crease (A1 Pulley)
 - Much of the study of tendon repair has focused on zone 2 injuries, also termed “no man’s land.”
 - This area is particularly difficult to repair because of the complexity of the tendons, pulleys, and blood supply in this region.
- Zone 3: Distal palmar crease to the carpal tunnel
- Zone 4: Carpal tunnel
- Zone 5: Wrist to the forearm

PATHOGENESIS

- Zone 1 flexor tendon injuries often are caused by resistive flexion. The ring finger is slightly more prominent than other digits during midflexion. It is theorized this is why jersey fingers affect the ring finger more often than they do other digits.
- Flexor tendon injuries are typically caused by sharp lacerations but may also occur after crush injuries.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The digital cascade should be inspected. The index through small digits should gently point to the scaphoid tubercle.
- A passive tenodesis maneuver can be performed. All digits should flex with wrist extension. If a flexor tendon is injured, it will not reciprocally flex with wrist extension.
- FDP is tested by restricting the metacarpophalangeal (MCP) and PIP joints in extension and asking the patient to flex the digit at the distal interphalangeal (DIP) joint.
- FDS is examined by restricting the adjacent digit(s) in extension and asking the patient to flex the digit. This maneuver utilizes the quadriga effect to limit excursion of the FDP, thereby relying on the FDS to flex the digit at the PIP joint.
- It is important to recognize that incomplete injuries may be missed on clinical exam.
- Sensation of the ulnar and radial digital nerves of each digit should be

evaluated. Static two-point discrimination is beneficial in evaluating nerve transection.

- Vascularity of the digit can be evaluated by capillary refill. A digital Allen test can also be beneficial if a single digital vessel injury is suspected.

IMAGING

- Plain radiographs should be obtained to evaluate for underlying fracture or foreign body.
 - These may also be used to locate the distal end of FDP if there is a bony avulsion associated with a jersey finger.
- Ultrasound or MRI can be used if there is question regarding tendon integrity that is not apparent on clinical exam.
 - These studies are not routinely obtained in acute, penetrating trauma.

DIFFERENTIAL DIAGNOSIS

- Usually, the diagnosis is unambiguous based on history and clinical examination, but injuries may be heterogeneous.
- Tendon injuries are often accompanied by digital nerve or arterial injuries.

SURGICAL MANAGEMENT

- There are a large number of tendon repair techniques. We will describe those techniques we most commonly use: Tajima, modified Kessler, locking cruciate (Adelaide), and modified Becker (MGH suture).
 - The Tajima or modified Kessler is biomechanically weaker than the other two suture configurations; however, this suture construct is reasonable in zone 3 to 5 repairs where early motion is not as crucial. We use this suture in cases that may be time dependent, such as multiple digit replantations, to expedite the time expended for tendon repair.
 - The locking cruciate offers benefits of a single knot that is buried within the tendon.
 - The modified Becker is mechanically stronger than the locking cruciate but requires a larger exposure. One disadvantage is that knots are external to the tendon and may increase the bulk of the repair.
- We perform an epitendinous suture in our zone 2 repairs. With a modified Becker suture, some surgeons place half of the epitendinous suture first before inserting the core sutures.

Preoperative Planning

- Obtain a preoperative digital neurologic and vascular exam to evaluate for injury as these structures are often repaired during the same operative period.
- Wide-awake surgery (WALANT) is helpful to evaluate tendon repair and gliding intraoperatively.
- A pediatric feeding tube is helpful for tendon retrieval and passage through the intact proximal sheath when the tendon is retracted.
 - One trick is to place the feeding tube in a freezer to improve the stiffness of the catheter. There are also various funnels that can be used to help pass the tendon.

Positioning

- The patient is positioned supine with the arm abducted to 90 degrees on a padded hand table.
- A well-padded tourniquet, if used, should be placed on the biceps to avoid compressing the flexor tendon muscle bellies. Excess forearm pressure will affect resting tendon tension.

Approach

- The use of existing lacerations with extensions via Bruner-type incision or midaxial incision will provide adequate exposure for repair.
 - If skin viability/coverage is in question, a midaxial incision is preferable to avoid the acute angle at the tip of the flap that can cause tip flap necrosis and expose the underlying repair.
- It is important to get adequate visualization of the laceration. We commonly expose from the MP joint flexion crease to the DIP flexion crease for a transverse laceration. We find that a large exposure aids in performing an adequate tendon repair and generally does not hamper outcomes.
- Consider extending the incision more proximally, by including a separate carpal tunnel incision if there is concern for retraction into the palm (ie, Leddy-Packer type 1).
- One should preserve most of the pulley system in a way to prevent bowstringing.
 - Some authors will vent the A2 or 4 pulley systems by partially releasing the pulleys to facilitate gliding of repaired tendon and have reported no mechanical problems with this technique.

TECHNIQUES

■ Zone I Repair

Primary Suture

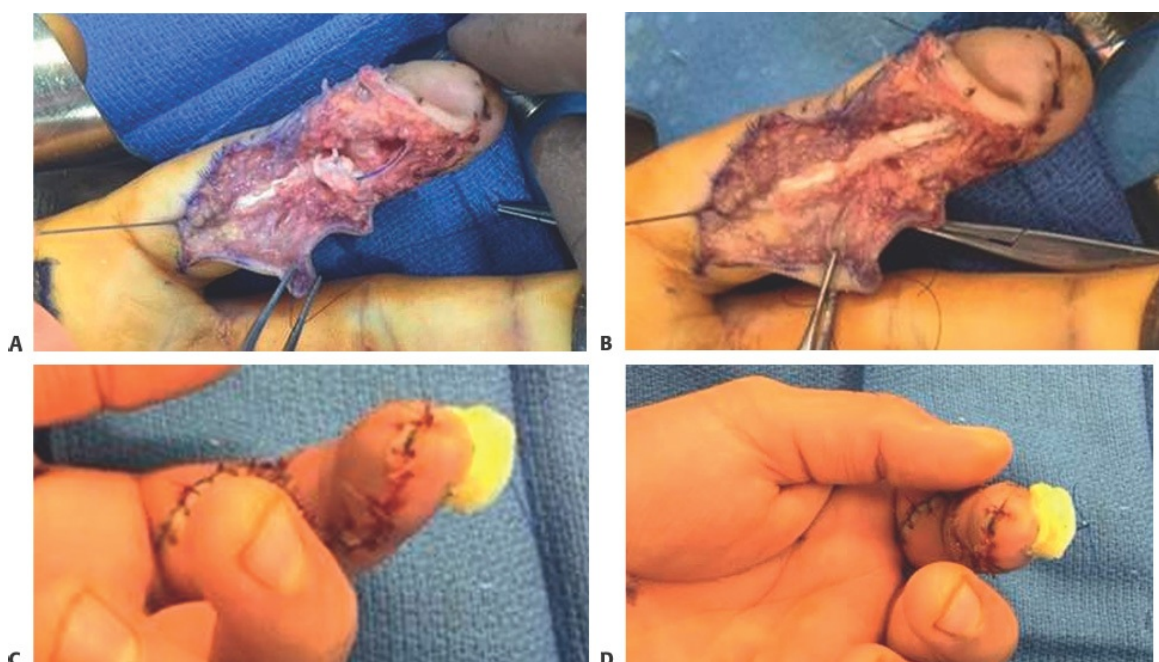
- There should be at least 1 cm of distal tendon stump to use this technique (**TECH FIG 1A**).
- The proximal FDP tendon may or may not be retracted.
- If retracted, it should be passed back through the pulley system. This may be completed using a tendon passer or pediatric feeding tube or via suture to pull through the pulley system.
- Sometimes, the pulley system is very tight, and it is helpful to use a funnel-type device to pull the tendon distally.
 - The funnel helps the tendon end enter the pulley system. We have found this particularly helpful to minimize fraying of the passed tendon, limiting trauma to the tendon and optimizing tendon gliding.
- Wrist and digit flexion will help tendon retrieval.
- A 25-gauge needle is used to maintain the location of the tendon by preventing retraction.
- After pulling the tendon into the repair site, the proximal tendon is skewered with the needle to the tendon sheath to stabilize the tendon (**TECH FIG 1B**).

Pull-Through Button

- The preparation of the proximal tendon is the same as previously described.
- Repair using a pull-through button is indicated if there is no distal stump or bone fragment for fixation.
 - The insertion site is prepared with a small curette to roughen a portion of the volar cortical bone to encourage tendon to bone healing.
 - A 3-0 nonabsorbable suture that can glide such as Prolene is placed at least 1 cm from the distal edge of the proximal tendon in a Bunnell weave fashion. Prolene is used because this suture will slide and can be pulled out readily during button removal.



TECH FIG 1 • Zone I repair: primary suture. **A.** Zone 1 flexor digitorum profundus laceration. **B.** Primary repair completed.



TECH FIG 2 • Zone I repair: pull-through button. **A.** Modified Kessler suture on tendon end (two Keith needles are used to pass the suture through the bone end, not shown). **B.** Suture passed through the distal phalanx. **C,D.** Suture tied over gauze dressing and button.

- Two Keith needles are then passed through the nail. There are two methods of passing the needles:
 - Some authors pass the needles through bone. They are passed using a drill

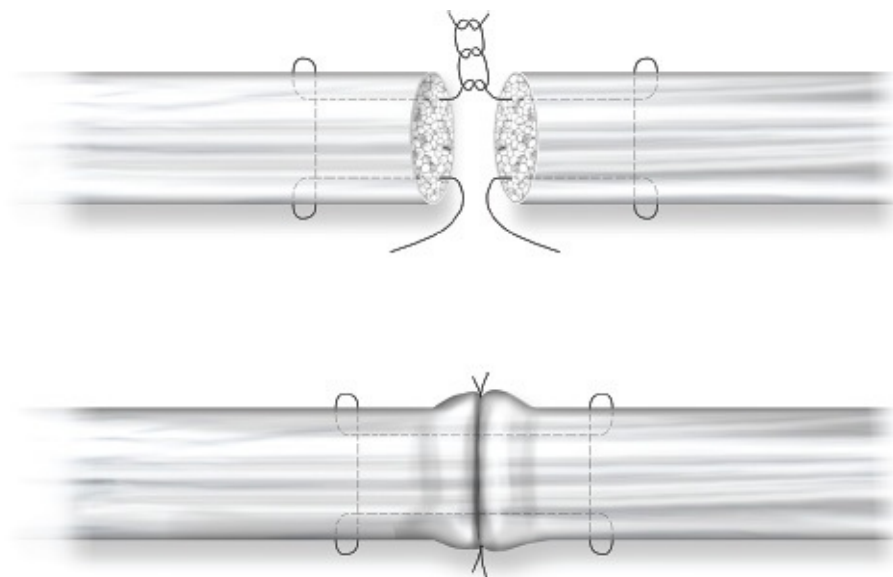
parallel to each other through the distal phalanx insertion site through the nail plate just distal to the lunula. It is important to pass the K-wires in a relatively acute angle relative to the phalanx (approximately 30 degrees). If they are passed too perpendicular to the nail and too distally, the DIP may assume an excessively flexed position (**TECH FIG 2A,B**).

- Other surgeons pass needles around the distal phalanx as an alternative to transosseous sutures. This is performed by pushing Keith needles along the edges of the bone through the nail. The trajectory of the needles should be aimed in a similar manner when passing through the bone as described above.
- The suture is then passed dorsally and tied over a nonadherent dressing and a tendon button after confirmation that the tendon is fully seating within the bone trough (**TECH FIG 2C,D**).
- Another option for repair is the use of bone anchors.
- If there is a large bone fragment on the tendon, this may be amendable to screw fixation into the distal phalanx.
- This repair can be augmented with a pull-through suture as well.

■ Zone II to V Repair

Tajima

- The Tajima modification of the Kessler uses two suture strands. If the proximal tendon is retracted into the palm, we will use a Tajima suture to draw the proximal tendon stump distally through the pulley system.
- The sutures are passed as they would for half of modified Kessler, but a separate suture is used on each side (**TECH FIG 3**).
- This technique is often applied when multiple tendons are injured. Sutures are passed into all of the injured tendons to allow tagging of proximal structures during exploration of the wound. Usually, once the bony structures are stabilized, the tendons are passed and then tied.



TECH FIG 3 • Tajima suture repair.

Modified Kessler

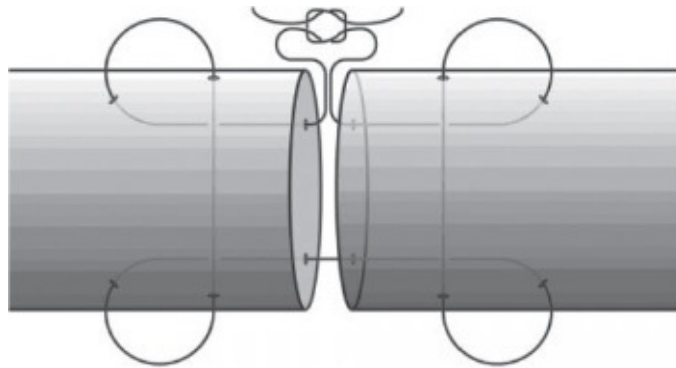
- The preparation of the zone 2 and 3 repairs may be complicated by the cruciate and pulley system blocking visualization, suturing, or passage. Generous windows should be made to allow the repaired site glide postoperatively.
- Align the proper orientation of the FDP and/or the FDS to prevent twisting and hold the proximal tendon in place with a 25-gauge needle.
- One or two slips of the FDS can be repaired at zone 2.
 - Some authors excise slips to maximize tendon gliding and minimize resistance. Some surgeons always repair the FDS with the rationale that if the FDP ruptures, the patient can preserve FDS function. Some excise the FDS to decrease tendon bulk in within the pulley system.
 - In our practice, we sometimes excise the ulnar slip of the FDS tendon depending on the tendon quality. We make this decision depending on the degree of tendon bulk and resistance after venting the pulleys.
 - The FDS is repaired using a horizontal mattress suture or a figure-of-8 suture using a 4-0 Ethibond or Tevdek suture.
- To start the modified Kessler technique, a suture is passed from the radial cut end of the tendon and exits out the volar surface 1 cm from the end.
- A transverse pass is then made from the radial side of the tendon transversely and out the ulnar side. This pass may be made closer to the cut

edge to lock the suture.

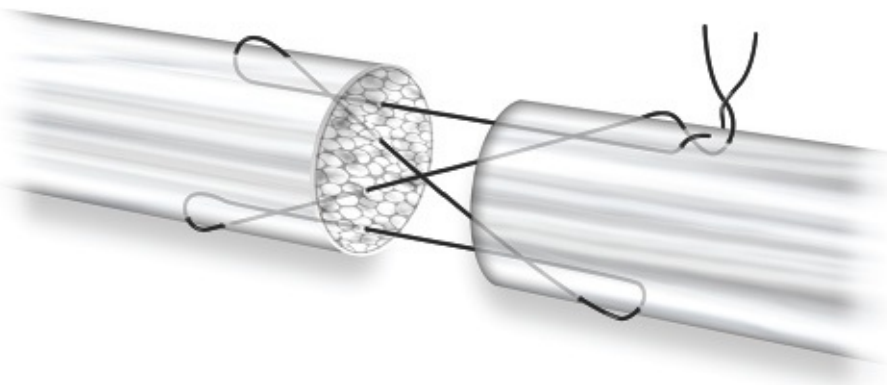
- Another loop is made passing the suture back into the volar aspect of the tendon and out the tendon end.
- The mirror image of the suture is passed on the other end and the knot is tied within the tendon ends (**TECH FIG 4**).
- A four-strand repair may be created with the addition of a second suture in the same pattern or with a horizontal mattress suture.

Locked Cruciate

- To begin the locked cruciate tendon suture, a 2-mm longitudinal slit is created 1 cm from the tendon edge and a suture is passed through this out the tendon end.
- The needle is then brought through the opposing tendon end and out 1 cm on the volar aspect.
- The suture is reinserted a few millimeters distal and lateral to the prior exit site and crossed through the tendon without locking.



TECH FIG 4 • Modified Kessler suture repair.

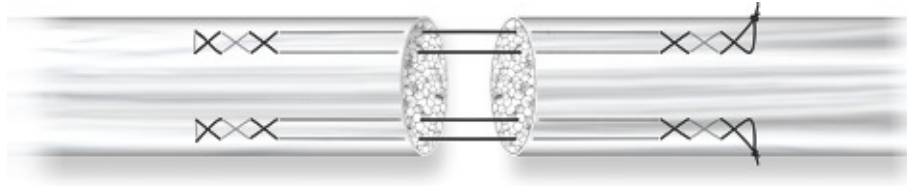


TECH FIG 5 • Locked cruciate suture repair.

- The suture is then reintroduced into the distal end and passed into other lateral edge across from the prior slit site.
- The needle is repassed retrograde a few millimeters distal to the insertion site and brought out the tendon end.
- This is passed into the opposing end again, looped back into the tendon a few millimeters distal, and crossed back into the distal tendon without locking.
- The needle exits the slit and the knot is tied within the tendon (**TECH FIG 5**).
- Slack should be removed from the suture and gapping approximated with each throw.

Modified Becker/Massachusetts General Hospital (MGH) Repair

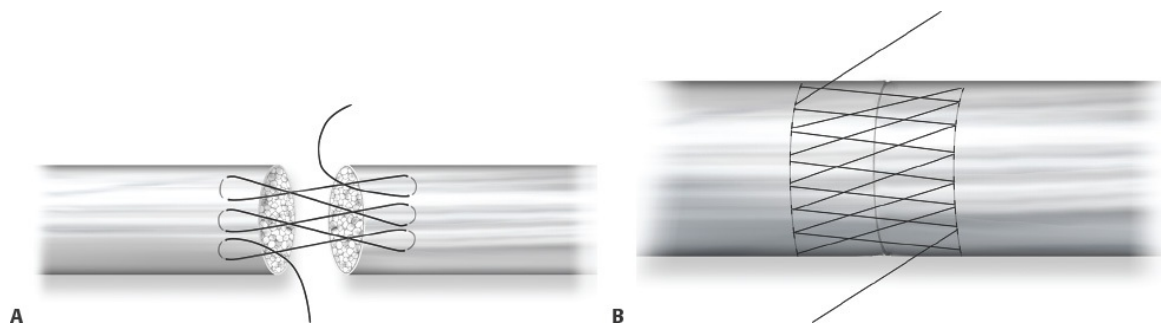
- This is our preferred core suture technique when possible.
- The suture is introduced from the volar, radial of the tendon 1 cm from the cut end.
- Two epitendinous crisscross sutures are placed on each tendon end, tightened snugly, and the knot is tied on the outside of the tendon.
- A second suture passed in the same fashion is completed on the ulnar side of the tendon creating a four-core suture repair (**TECH FIG 6**).
- This repair can be completed with a single-armed suture, but a double-armed suture will allow safe passes to prevent accidentally catching the suture with subsequent passes during placement of the crisscross epitendinous sutures.
- A 5-0 or 6-0 monofilament epitendinous suture is often started dorsally prior to core suture completion. This may be placed after the core suture repair as well.
- The use of an epitendinous suture increases repair strength up to 20% and may improve tendon gliding.



TECH FIG 6 • Modified Becker/Massachusetts General Hospital (MGH) suture repair.

■ Epitendinous Repair: Running, Running Locking, and Silfverskiold Suture

- Running and running locking sutures are typically done with a monofilament 5-0 or 6-0 suture.
 - The epitendon is grasped with the suture, and a knot is tied approximating the ends. This end may be left free to tie too after completion of the suture technique as well.
 - The suture is then passed from superficial to deep on one end and then out deep to superficial on the other with advancement of each throw.
 - Either the suture is tied to the tail of the first throw or a new knot is created.
 - The running locking is completed in the same fashion, but locking loops are used instead.
- The Silfverskiold suture is analogous to a horizontal cross-stitch suture (**TECH FIG 7**).
 - It is performed by placing an anchor stitch and then taking 1- to 2-mm bites perpendicular to the axis of the tendon approximately 1 cm from the repair site. Tendon passes are always taken toward the surgeon.
 - The following suture pass is taken on the other side of the repair site, and the starting point is advanced away from the surgeon.
 - About 10 passes are needed to circumferentially encompass the tendon.
 - The epitendinous suture is then tied to the anchor suture.



TECH FIG 7 • A,B. Epitendinous repair with Silfverskiöld sutures.

PEARLS AND PITFALLS

Technique

- Use a Tajima suture to retrieve retracted tendons if needed. In the cases of combined injury, the suture is placed during the exploration/approach, the bone is fixed, and then the suture is passed and tied.
- Use a pediatric feeding tube or funnel to help pass sutures through the proximal pulleys.
- The primary goal of zone 2 tendon repairs is to repair the tendon with four-core sutures and an epitendinous suture.
- Use an epitendinous suture to increase repair strength. Consider placing the dorsal epitendinous suture before the core repair.
- Avoid traumatic handling of the tendon to prevent epitendinous injury that may lead to adhesion formation.
- The A4 pulley may be vented if the A2 pulley is competent.

Therapy

- In children, we prefer immobilization in a cast rather than an early motion protocol.
- If the tendon repair is strong, begin early motion protocols.
- If the tendon repair is tenuous, a less aggressive motion protocol is preferred. Adhesions can be addressed with tenolysis later.

POSTOPERATIVE CARE

- Passive digital flexion-extension results in loads of around 3 N.⁴
- Active digital flexion-extension results in loads of about 30 N.⁴
- Tendon excursion during passive digital flexion-extension ranges from 3 to 8

mm in vivo.⁵

- Hook and straight fist result in greater loads than does composite fist.⁶
- Wrist motion results in greater flexor tendon excursion.
- A postoperative dorsal blocking splint with wrist and digit flexion is applied. This splint is removed at the first postoperative visit and a thermoplastic or like dorsal blocking splint is fashioned to initiate therapy.
- Earlier protocols consisted of immobilization for at least 3 weeks. This resulted in loss of digit motion due to tendon scarring; therefore, newer protocols were established to allow excursion and prevent tendon adhesions
- Kleinert, Duran, and active place-and-hold are commonly employed early motion regimens. There are many modifications of these protocols as well.
- If we have high confidence in the repair, we will begin early motion using the pyramid protocol described by Groth.⁷
- If the repair is tenuous, we will use a modified Duran protocol.
- Overall, the choice of protocol is surgeon and case dependent.

OUTCOMES

- Chesney et al. reviewed multiple rehabilitation regimens for zone II flexor tendon injuries. No significant difference existed between early active and early passive protocols (Duran- and Kleinert-type protocols), and all protocols resulted with high rates of acceptable range of motion. Duran protocols had the lowest rate of ruptures during rehab (2.3%).⁸
- Starr et al. performed a systematic review of early active and early passive protocols for all zones of flexor tendon injury. They found that early passive range of motion protocols had a statistically significantly decreased risk for tendon rupture but an increased risk for postoperative decreased range of motion when compared to early active motion protocols.⁹

COMPLICATIONS

- Adhesions are the most common complication.
- Tendon rupture may occur when loading during rehabilitation exceeds the strength of the repair and the healing tendon. It is sometimes not possible to distinguish between tendon rupture and adhesions if the proximal tendon stump scars to the FDS and the proximal phalanx.
- Quadriga occurs when the FDP is shortened. Because the FDP has a common muscle belly, once the finger with the shortened FDP has fully flexed, the other

fingers cannot flex any further.

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Repair of Multiple Flexor Tendon Injury at Wrist Zone V (Spaghetti Wrist)

38

CHAPTER

Jacques A. Machol IV, Neal Chen, and Kyle R. Eberlin

DEFINITION

- Volar wrist trauma with tendon, nerve, and arterial injuries is often referred to as a “spaghetti wrist.”
- Specific criteria for the definition of a “spaghetti wrist” vary in the literature, with some authors defining it as injury to at least three of the volar wrist structures including at least one nerve,^{1,2} with others defining this injury as inclusive of both median and ulnar nerve injuries at the level of the wrist.³
- Other authors have defined this injury as involving a minimum of 10 structures in the wrist.

ANATOMY

- The volar wrist structures include the radial and ulnar arteries, the median and ulnar nerves (along with the palmar cutaneous branch and the dorsal ulnar sensory branch), the flexor pollicis longus (FPL), the four flexor digitorum superficialis (FDS) tendons, the four flexor digitorum profundus (FDP) tendons, the palmaris longus (PL), the flexor carpi ulnaris (FCU), and the flexor carpi radialis (FCR) tendons. Any or all of these structures can be injured with a volar wrist laceration (**FIG 1**).
- The superficial nature of these structures and thin cutaneous coverage render them highly susceptible to penetrating injuries.
- At the wrist, the FDS tendons to the long finger (LF) and ring finger (RF) are volar to the FDS tendons to the index finger (IF) and small finger (SF).
- The FCU is volar to the ulnar artery and ulnar nerve. The ulnar artery is typically superficial (volar) to the ulnar nerve; it is therefore possible to injure

the FCU and ulnar artery while sparing the ulnar nerve.

- The palmar cutaneous nerve is often injured.
- Flexor tendon injuries in the spaghetti wrist are in zone V (see Flexor Tendon chapter for details)

PATHOGENESIS

- These injuries are often self-inflicted but also may result from other traumatic causes.⁴
- They often are the result of sharp lacerations but can also be caused by crush injuries.
- The mechanism of injury is most often sharp glass lacerations, followed by knife wounds and saw injuries.
- The median nerve and FDS tendons are the most commonly injured structures, because they are located superficially and centrally in the volar wrist.
- These injuries are more common in males.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A focused history and physical examination is performed with emphasis on the etiology and mechanism of injury, sensory and vascular examination, and examination of each individual tendon in the volar wrist.
- Self-inflicted spaghetti wrist injuries should ideally be identified prior to surgery. Psychiatry consultation is helpful for management.
- A thorough vascular examination should be performed including inspection for color and capillary refill, a Doppler exam with Allen test, and pulse oximetry of the digits.
- A formal nerve examination, including evaluation for light touch and two-point discrimination, intrinsic motor function, and palmar abduction, should be performed.
- The surgeon can glean much information about the status of tendon injuries simply by observing the digital cascade at rest, as the attitude of the digits can reflect the presence or absence of intact tendons.
- In these cases, tenodesis testing is not possible usually because the wrist cannot be flexed or extended because of the injury.

IMAGING

- Plain film radiographs are obtained to assess for fracture and foreign body.

SURGICAL MANAGEMENT

- Early definitive surgical management is recommended, particularly in cases of vascular or nerve injuries.
- Thorough debridement and removal of foreign material with copious irrigation is paramount.
- Identification and labeling of all injured structures is performed; a checklist is helpful to organize one's approach and ensure repair of all injured structures.
- It is important to label the proximal tendons, as the orientation is clear prior to dissection and may be lost with mobilization. The distal tendon ends are easily identified by manual traction intraoperatively.
- The deep structures including the FDP and FPL are repaired first, unless the hand is dysvascular in which case an arterial repair shunting is performed first (usually the radial artery).
- It is important to repair injured structures in a manner that facilitates microsurgical repair of the nerves and/or arteries.

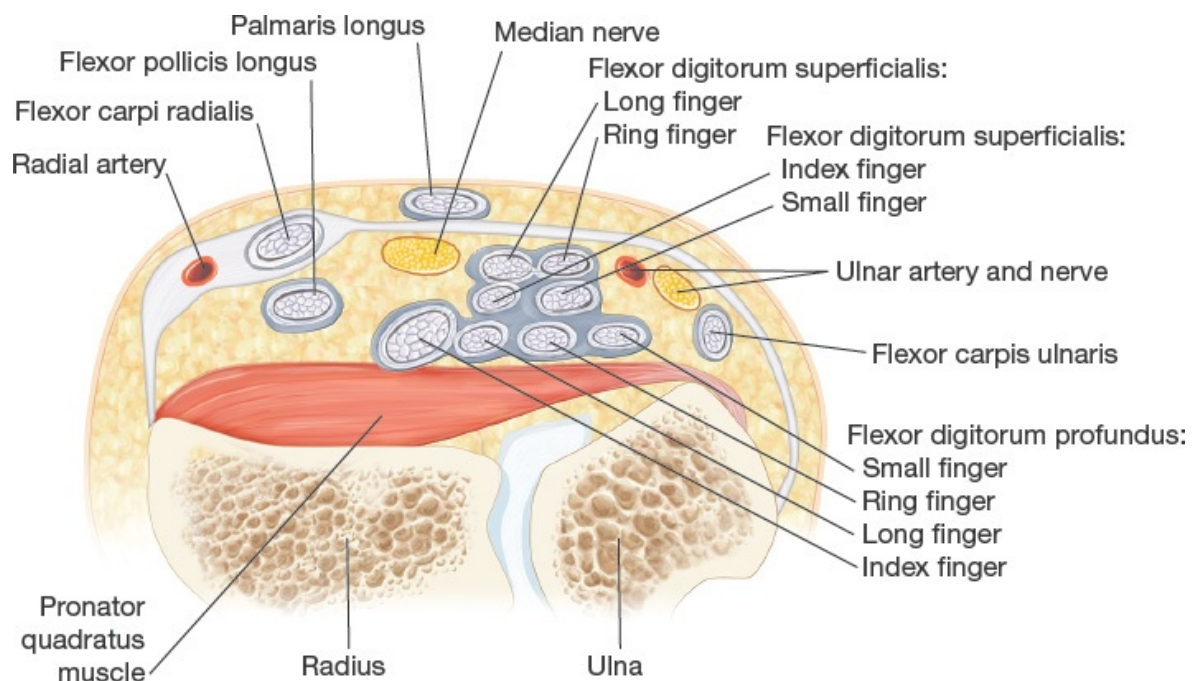


FIG 1 • Distal wrist axial slice anatomy. Flexor carpi radialis (FCR), palmaris longus (PL), flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), index finger (IF), long finger (LF), ring finger (RF), small finger (SF), and flexor carpi ulnaris (FCU).

- It is important to identify injured structures, repair deep structures, and then progress to more superficial structures.
- If microsurgical repair is anticipated, superficial structures such as the FCR and FCU are repaired last.

Preoperative Planning

- The aforementioned thorough preoperative examination formulates a concrete, definitive operative plan.
- The surgeon and patient should be prepared for vein and/or nerve grafts, depending on the time elapsed and mechanism of injury.

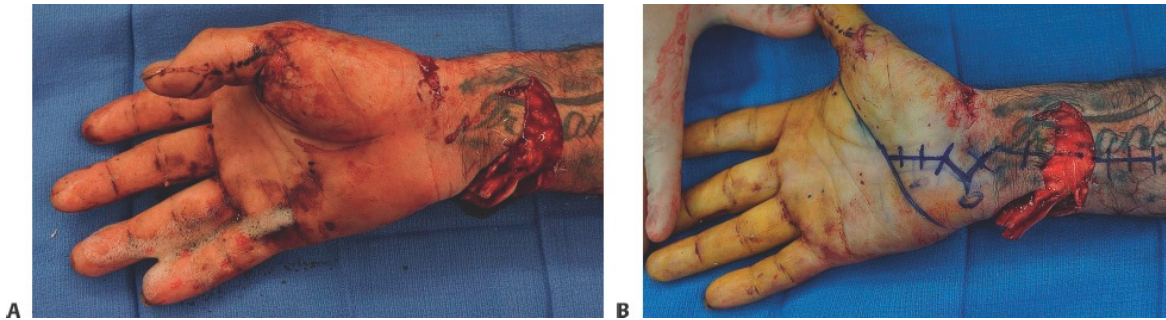
Positioning

- The patient is positioned supine with the arm abducted on a hand table; a tourniquet is used.
- The ipsilateral lower extremity is prepped sterilely for vein or nerve graft(s), if needed.
- The entire forearm to just above the elbow is prepped. This is particularly germane with distal lacerations near the wrist crease, where the distal tendon ends may retract into the carpal tunnel.
- Skin flaps can be retracted with either elastics/hooks or retraction sutures.

TECHNIQUES

■ Exposure

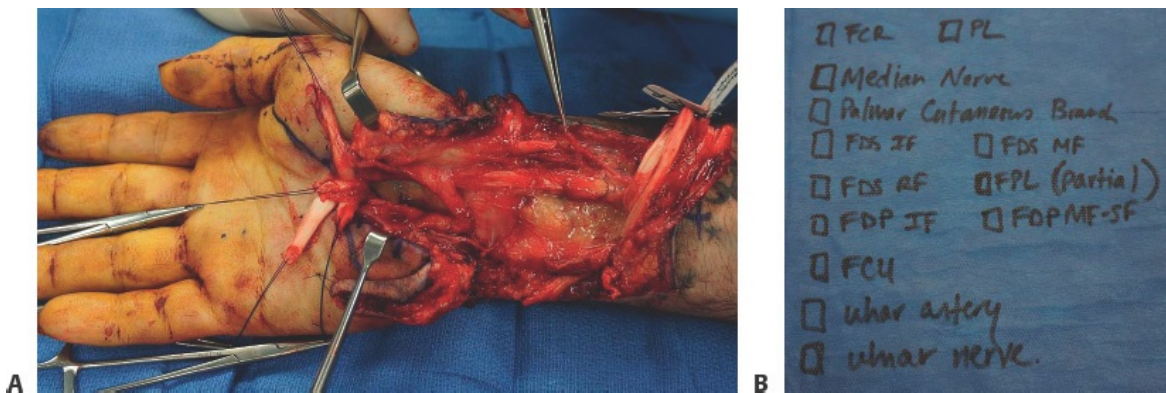
- The existing wound is extended proximally and distally to provide access to injured structures.
 - Do not try to limit incisions in these cases. Wide exposure is preferred (**TECH FIG 1**).
- Proximally, the incision is extended in linear, longitudinal fashion often in the central aspect of the volar forearm.
- Distally, an extended carpal tunnel incision may aid in mobilization of tendons for repair and is frequently performed to release of the transverse carpal ligament in anticipation of postoperative swelling.



TECH FIG 1 • **A.** Initial wound presentation with exposed injuries. **B.** Extension of the existing wound proximally and distally to provide access to injured structures.

■ Exploration and Tagging of the Structures

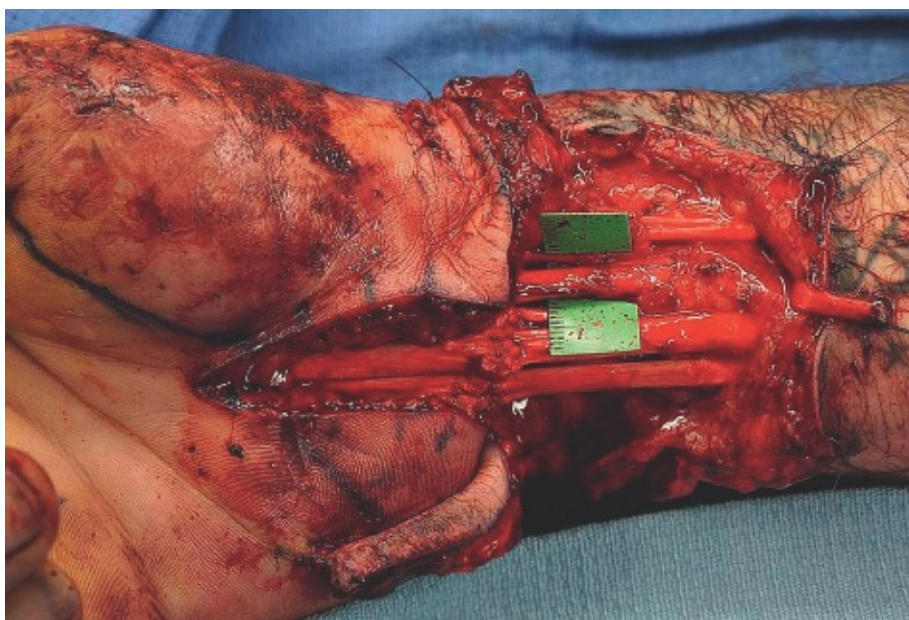
- The proximal tendons are exposed and tagged with one-half of the preferred suture technique and labeled (**TECH FIG 2A**). A four-core strand suture technique is commonly used.
- Arteries and nerve are tagged with a small monofilament suture with long tails.
- A checklist is used to ensure repair of all structures (**TECH FIG 2B**).



TECH FIG 2 • **A.** Tagging of the proximal structures to ensure proper anatomical repairs. **B.** Checklist ensuring repair of all structures.

■ Repair of Injured Structures

- Tendons are repaired first from deep to superficial, and often from radial to ulnar under tourniquet.
- The choice of tendon repair varies based on surgeon preference and experience but should entail at least four core strands.
 - We prefer a modified Becker, ie, MGH repair for flexor tendons in zone V. Epitendinous repair is not needed because gliding is not impeded in zone V and the surgeon needs to expedite the repairs because of the numerous structures injured.
- Microsurgical repair of the nerves and arteries is then performed.
- The tourniquet can be deflated to visualize arterial inflow and endoneurial bleeding during neurorrhaphy (**TECH FIG 3**).
- Meticulous nerve repair is critical; this should be performed by the most senior surgeon involved in the operation.
 - Care should be taken to avoid fascicular overlap during tension-free neurorrhaphy.
- If there is a single arterial injury, we tend to perform vascular repair even with a perfused hand.
 - We occlude the other major artery for 5 minutes at the time of reperfusion (for instance, the radial artery following ulnar artery repair) to allow for antegrade flow into the hand through the fresh vascular anastomosis.



TECH FIG 3 • Status post microsurgical repair.

PEARLS AND PITFALLS

Technique

- Careful preoperative examination helps surgical planning.
- Identification and tagging of proximal tendons will ensure correct repair of structures; a surgical checklist is helpful.
- Atraumatic tendon and tissue handling will facilitate gliding of tendons postoperatively.
- Meticulous epineurial repair following adequate nerve debridement will optimize chances of neural recovery; care should be taken to avoid fascicular overlap.
- Have the contralateral leg prepped if nerve grafts or vein grafts are anticipated.

Physical exam

- An Allen test and thorough nerve exam should be performed preoperatively.
- Inspection of the digits can often reveal the extent of tendon injuries.

Therapy

- Dedicated occupational/hand therapy is required postoperatively; this will depend on the strength of repair and the patient's motivation and compliance with postoperative instructions.
- Patients with self-inflicted lacerations may require a longer period of immobilization, sometimes involving casting.

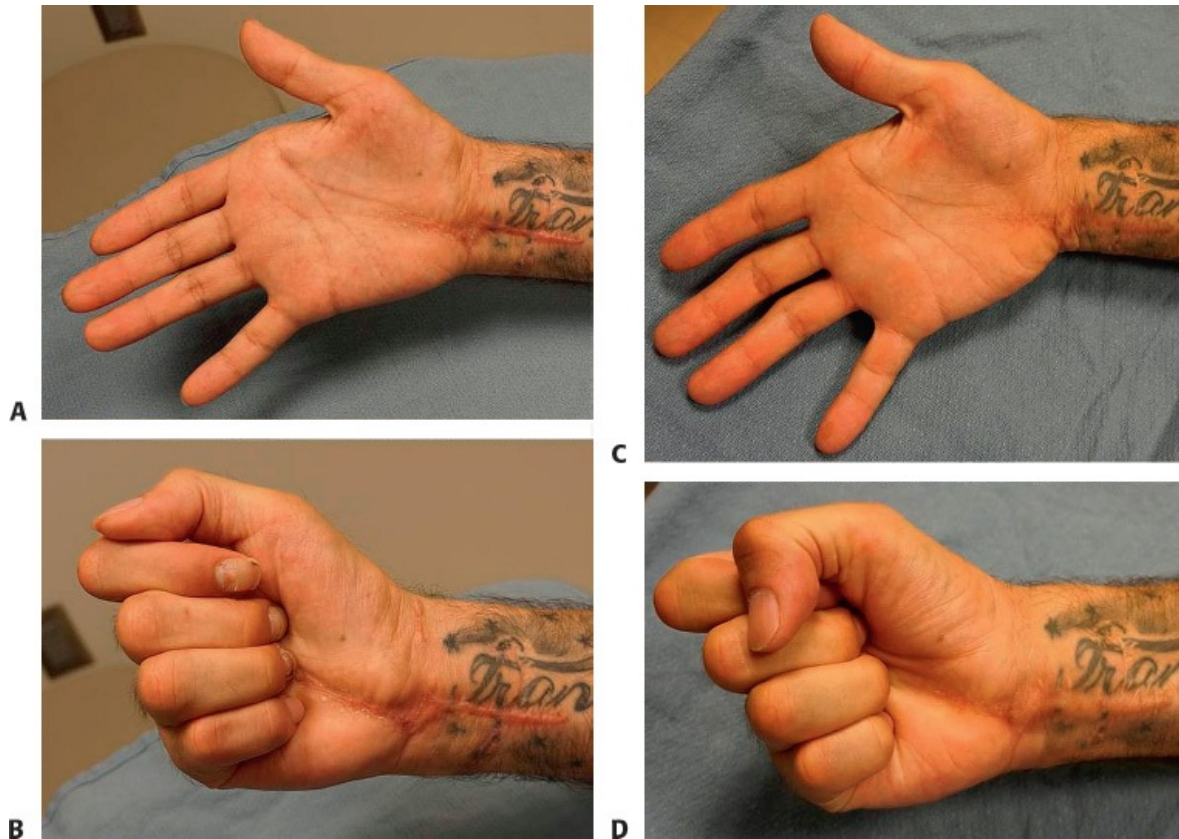


FIG 2 • Eight months (A,B) and 2 years (C,D) postoperatively.

POSTOPERATIVE CARE

- Patients are placed in a dorsal blocking “clam digger” splint with the wrist in 20 degrees of flexion, MP joints at 90 degrees of flexion, and PIP/DIP joints with mild flexion to off-load the tendon, nerve, and arterial repairs. The splint should extend to the fingertips.
- Strict elevation and non-weight bearing is emphasized, particularly for patients with self-inflicted lacerations.
- Continuous pulse oximetry is utilized for patients presenting with both radial and ulnar artery injuries or dysvascular hands; aspirin is utilized for 1 month postoperatively.
- The specific regimen of postoperative hand therapy is based on the quality of the repairs and the compliance of the patient; we prefer early active motion protocols for sophisticated patients who understand the nature of their injury and 3 to 4 weeks of immobilization for patients with self-inflicted injuries who

are unwilling or unable to follow strict postoperative instructions.

OUTCOMES

- Functional outcomes depend on the overall severity of injury and number of injured structures but are often predicated upon the degree of neural recovery (**FIG 2**).
- With sharp injuries, more than 50% of patients will recover protective sensation, but intrinsic dysfunction is common with ulnar nerve injuries.
- Digital range of motion and strength can be satisfactory, particularly with early active motion protocols in compliant patients.⁴
- Patients can be expected to have some degree of dysfunction compared to their premorbid state.

COMPLICATIONS

- Tendon adhesions and/or stiffness, greatest when patients are immobilized for extended periods of time postoperatively
- Tendon rupture, greatest when patients are not compliant with splinting or therapy instructions
- Infection and delayed wound healing, greatest with contaminated wounds
- Pain resulting from neuroma
- Clawing and intrinsic minus hand secondary to poor ulnar nerve recovery
- Arterial insufficiency or cold intolerance

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39 Staged Flexor Tendon Grafting and Pulley Reconstruction

CHAPTER

Richard Tosti, Jacques A. Machol IV, and Neal Chen

DEFINITION

- Flexor tendon reconstruction refers to the restoration of the flexor mechanism through the use of tendon grafts.
- Pulley reconstruction is the recreation of the flexor tendon sheath in order to prevent bowstringing and optimize strength.

ANATOMY

- Nine flexor tendons originate in the forearm. Flexor pollicis longus inserts at the base of the distal phalanx of the thumb. Four flexor digitorum superficialis (FDS) and four flexor digitorum profundus (FDP) tendons insert on the volar base of the middle and distal phalanges, respectively.
- The FDS tendons are superficial to the FDP in the hand, but as they enter the fibrous sheath, the FDS bifurcates into two slips, which are directed dorsally to their insertion.
- The flexor tendon sheath is a fibrous tunnel through which the flexor tendons glide. Composed of annular and cruciate pulleys, the sheath prevents bowstringing, reduces the flexor moment arm (imparting strength and efficient excursion), and provides nutrition (**FIG 1**). The thumb flexor sheath is composed of annular and oblique pulleys.
- The flexor sheath extends from the metacarpal head to the distal phalanx.

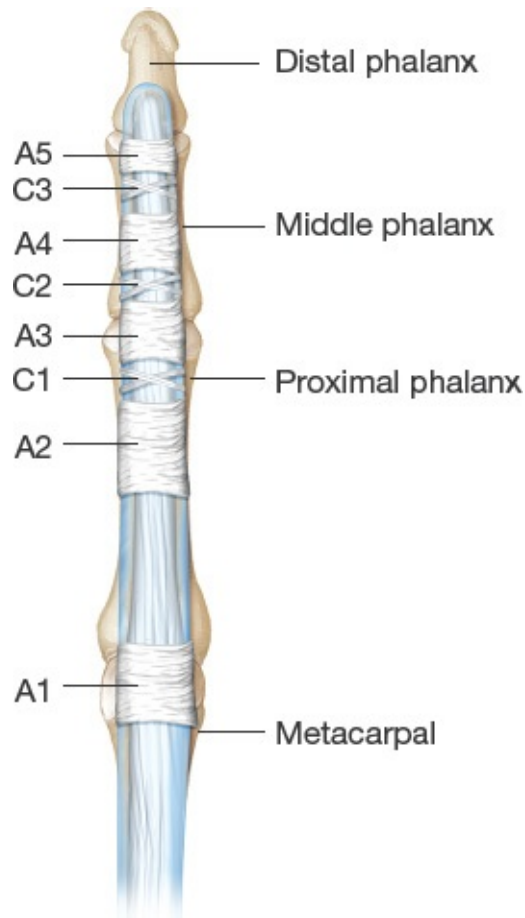


FIG 1 • Flexor tendon sheath of a finger consisting of annular and cruciate pulleys.

PATHOGENESIS

- Acute flexor tendon rupture occurs as a result of trauma, including laceration, avulsion, crush, or burn.
- Attritional ruptures may also occur from synovitis, Mannerfelt syndrome, prominent implants, bony prominences, infections, and neoplasms.

NATURAL HISTORY

- Following a rupture, the proximal end of the tendon retracts, leaving an empty space within the sheath.
- In as early as 3 to 6 weeks, irreversible contracture of the muscle tendon unit, degeneration, and scarring within the flexor sheath may occur. The tendon sheath volume will shrink without an intact tendon, which limits passage of tendons through the sheath after tendon repair.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients lose the ability to flex the finger at the proximal interphalangeal (PIP) joint or distal interphalangeal joint (DIP) when the FDS or FDP tendons are disrupted.
- Often the cascade of the hand is altered. The affected digit assumes a more extended posture.
- A skin injury overlies the approximate level of tendon injury
- “Tenodesis” effect of the hand is lost. When the wrist is passively extended, the affected finger does not flex.
- Active motion is lost. FDS rupture is detected by observing loss of PIP flexion in the affected digit while holding the adjacent digits in extension. Extending the adjacent digits isolates the FDS because the FDP tendon of the affected digit is placed at a mechanical disadvantage due to the common origin. FDP rupture is detected by stabilizing the PIP in extension and observing a lack of active flexion at the DIP joint.
- “Tenodesis” testing can also help detect flexor tendon injuries. When the wrist is extended, the digits should flex reciprocally if the flexor tendons are intact. If the flexor tendon is lacerated, there will be lack of reciprocal flexion in the injured digits.

IMAGING

- Flexor tendon rupture is usually diagnosed by history and physical exam.
- Radiographs may be helpful to evaluate for avulsion injuries or bony prominences causing attritional rupture.
- Computed tomography may also be useful in evaluating for carpal bone spurs in suspected attritional ruptures.
- Ultrasound or magnetic resonance imaging may be useful in determining the level of proximal tendon retraction.

DIFFERENTIAL DIAGNOSIS

- Adhesions. It is difficult to distinguish between adhesion and rupture clinically.
- Intra-articular injury
- Nerve injury
- Neuromuscular disorders

NONOPERATIVE MANAGEMENT

- Elderly, low-demand patients with comorbidities may not have an outcome worth the overall risk for multiple reconstructive procedures. Additionally, these patients may not be able to complete a rigorous postoperative protocol.
- Physical rehabilitation to maximize passive joint motion is critical prior to tendon reconstruction procedures.
- Although not considered “nonoperative,” alternative procedures to reconstruction include joint fusion or digit amputation, which could be considered for patients with injuries to multiple structures within the digit.
- Patients with an intact FDS may have reasonable function even if the FDP has been lacerated. In these situations, no reconstruction is reasonable. If the DIP is unstable, fusion is an option, but in many cases, this is not necessary.

SURGICAL MANAGEMENT

- Direct tendon repair should be performed when possible.
- Single stage tendon grafting can be performed for acute segmental tendon defects or delayed injuries without excessive retraction and good passive motion. An intact flexor tendon sheath is required.
- Two-stage flexor tendon reconstruction is indicated for failed direct repairs in zone II, severe injuries with concomitant injury to the adjacent bone or joint, chronic injuries with excessive scarring, or loss of flexor sheath.
 - Two-stage reconstruction was developed because joint contracture, flexor sheath volume/pulley insufficiency, and tendon length were problems. Two-stage reconstruction allows the surgeon to address these factors prior to addressing the tendon.
 - Prior to the first stage, wound healing, and joint contracture are addressed. The first stage allows for reconstitution of the flexor sheath and pulley reconstruction.
 - Once a gliding space is established, the second stage of the reconstruction can be performed with minimal scarring and inflammation.
- If the tendon is too short, patients will have problems with quadriga, ie, the tendon excursion for the injured finger would be shorter than the other digits. When the injured finger was fully flexed, the other fingers would not flex completely because of the common FDP muscle belly.
- If the tendon was too long, some patients developed a lumbrical plus finger. As the FDP contracts, the lumbricals tighten, resulting in paradoxical extension of the PIP joint through the lateral bands.
- Flexor tendon reconstruction, although not a perfect solution, is a method that

has more consistent results than these other techniques.

Preoperative Planning

- If autograft is planned for the procedure, one should ensure the presence and integrity of the tendon. Many options are possible, but the most common are palmaris longus, plantaris, and digital long toe extensors of the second, third, or fourth toes. Allograft tendon is also an option.
- Plan for a small-caliber graft (4–5 mm diameter).
- Plan for only one graft.
- Do not sacrifice FDS if it is found intact.
- Perform the repairs outside of the tendon sheath.
- Repair the proximal juncture to the FDP tendon to power the graft.

Positioning

- Position the patient supine on a hand table with a nonsterile upper arm tourniquet.

Approach

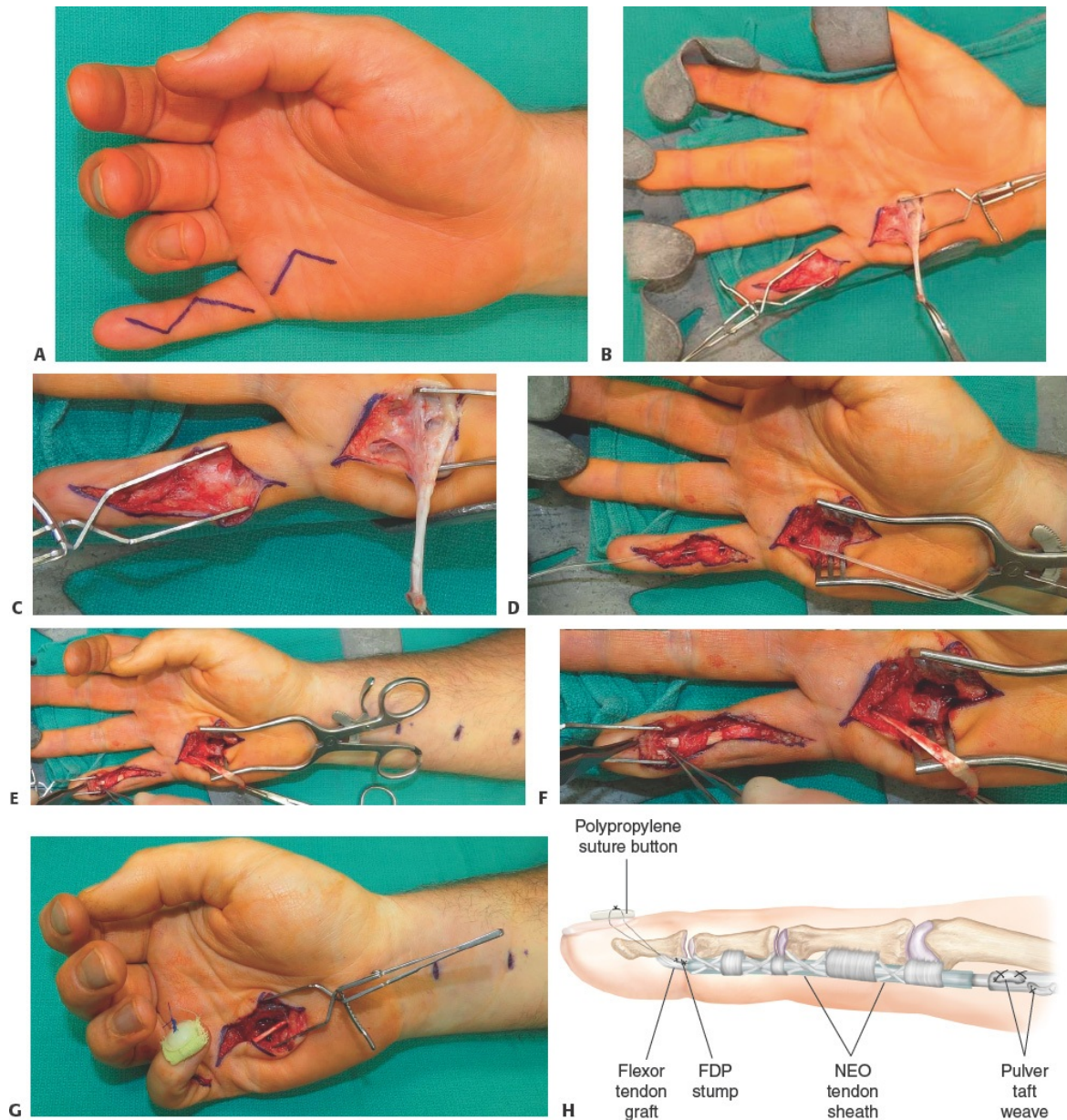
- A volar Bruner-style incision is planned along the length of the finger.
- A separate zigzag incision in the palm or distal forearm may be needed as well.

TECHNIQUES

■ Single-Stage Tendon Grafting

- The tendon sheath is approached through a volar Bruner incision (**TECH FIG 1A**) and must be examined for competency particularly for the A2 and A4 pulleys.
 - If an inadequate sheath is found, a staged reconstruction should be performed.
 - If single-stage reconstruction with tendon graft is planned, all the finger joints must have full supple motion and the skin over the tendon sheath must be soft so that the finger can move smoothly during therapy.
- The sheath should be preserved as much as possible.

- Leave FDS intact if it is not disrupted. The graft can be passed anatomically through the decussation.
- Often, both FDS and FDP are disrupted.
- The insertion of FDS can be left with a 1- to 2-cm tail to provide a gliding surface.
- The proximal FDS is transected under traction and allowed to retract (**TECH FIG 1B,C**).
- The FDP insertion is similarly left with a 1- to 2-cm stump. If no FDP stump is available, the graft can be inserted directly into the bone.
- The proximal FDP is often prepared in the palm if no scarring is present but can also be prepared in the distal forearm.
- When in the palm, the FDP is “freshened” with a blade just distal to the lumbrical origin. The proximal tendon graft is woven to the FDP at the level of the lumbrical muscle takeoff to assure that the proper tension can be set to avoid a lumbrical plus finger in which premature contraction of the lumbrical causes PIP joint extension when attempting finger flexion.



TECH FIG 1 • Single-stage flexor tendon reconstruction. **A.** Bruner incisions in the digit and palm. If needed, a forearm incision is marked for more proximal rod placement. **B,C.** The proximal tendon is excised. **D.** The tendon sheath is intact. **E,F.** The tendon graft is passed through the distal phalanx and tied over a button. **G.** The tendon suture is weaved to the profundus tendon proximally with fingers in slight flexion. **H.** Completed single-stage tendon

reconstruction.

- The lumbrical may be released if it is scarred.
- At this point, a moist gauze is placed over the wound, and the graft is harvested.
- The harvested graft may be first secured to the distal or proximal junction first, but we prefer to secure it first distally to facilitate setting tension.
- The graft is sutured. We prefer a smooth 2.0 Prolene or a 4.0 steel wire in a horizontal mattress configuration to facilitate easy pullout.
- The sutures are shuttled through the tendon sheath by using a tendon passer (**TECH FIG 1D**). The ends of the suture are brought distally and can be used to slide the tendon graft through the sheath.
- The distal end of the graft is woven once through the FDP stump with the tendon weaver (**TECH FIG 1E,F**).
- A Keith needle is placed into a wire driver and drill across the base of the distal phalanx.
- One suture end is threaded through the eyelet and passed dorsally through the nail plate either through or around the bone, taking care not to pierce the germinal matrix. The other suture is passed the same way.
- The sutures may be tied over a polypropylene button or over the nail plate.
- Alternatively, the graft can be secured with a small suture anchor in the distal phalanx; the anchor is placed in the FDP insertion and angled slightly proximally with care to avoid intra-articular penetration of the DIP joint.
- The graft is then sutured to the distal FDP stump at the distal weave.
- The wrist is positioned in neutral, and the graft is tensioned to place the finger in slight flexion and aligned with the natural cascade (**TECH FIG 1G**). Err on the side of overtensioning rather than undertensioning.
- The proximal end of the graft is then weaved through the proximal FDP tendon at the correct tension (**TECH FIG 1H**).
- We prefer three weaves, each 90 degrees to each other, which are secured with figure-of-8 sutures.

■ Two-Stage Flexor Tendon Reconstruction

Stage 1

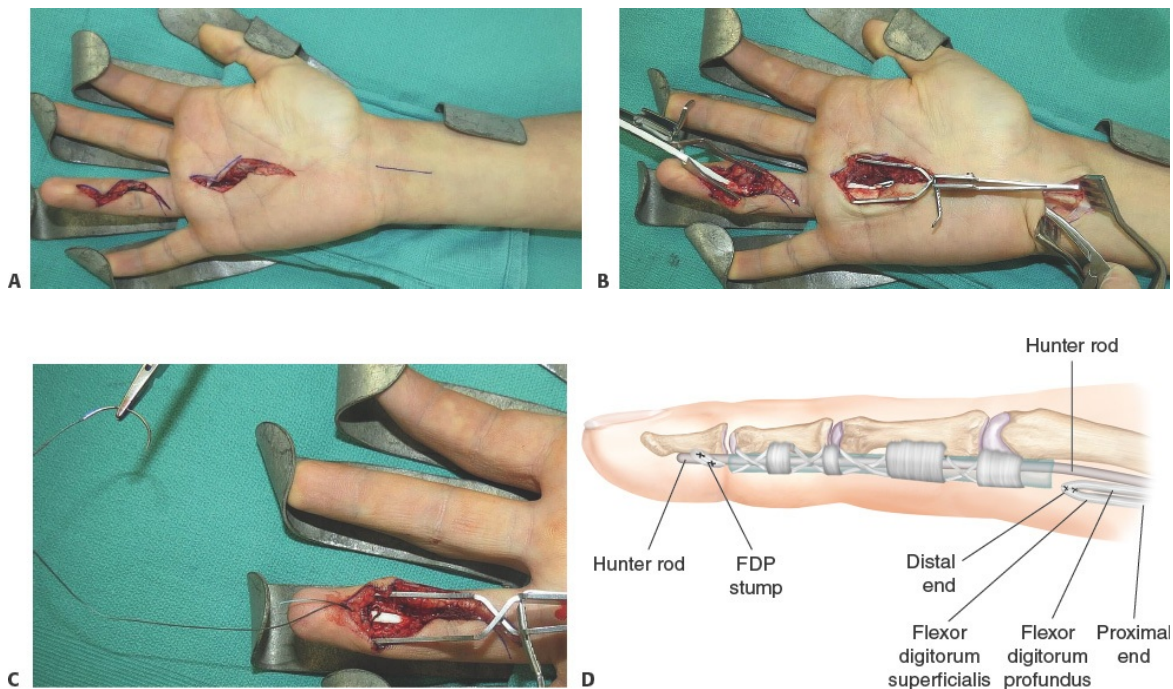
- Approach the finger with a volar Bruner incision (**TECH FIG 2A**).
- Assess the flexor sheath and preserve as much as possible.
- If the sheath is deficient, pulley reconstruction is indicated.
- A lacerated sheath may be repaired in this stage as long as it does not hinder the gliding of the rod.
- A stenotic sheath may require dilatation or partial release in order to pass the rod.
- Cut the FDS and FDP leaving a 1- to 2-cm stump at the insertion sites. The excised tendon can be used for pulley reconstruction and should be maintained on the field during the case.
- There are two approaches to rod placement, depending on the anticipated location of the tenorrhaphy. Some surgeons perform the tenorrhaphy in the palm, whereas others perform the tenorrhaphy at the level of the forearm.
 - If there is a large amount of scarring in the palm, forearm placement is preferred.
 - If a forearm tenorrhaphy is used, a palmaris longus tendon is usually too short and a plantaris tendon or other longer tendon may be needed at the secondary reconstruction.
- An incision can be made in the palm or in the distal forearm.
- Identify the FDS and FDP tendons by using a turn-key motion with an Allis clamp. This is performed by clamping around the tendon and then twisting the clamp so the tendon wraps around the tines. This allows the surgeon to apply a force in line with the tendon and helps avoid pulley rupture.
- The FDS is released and allowed to retract proximally in most cases, but may be retained as the motor for the second stage if the FDP is of poor quality.
- Shorten the FDP but tag it with a suture and sew it side to side to an adjacent FDP tendon to prevent retraction and allow easy identification in stage 2.
- Suture the silicone rod into the distal FDP stump. The size of the rod should fit snugly into the sheath. It is usually 4 to 6 mm.
- Guide the rod through the flexor sheath (**TECH FIG 2B–D**) and allow it to float freely through the carpal tunnel and into the forearm.
- You should observe the rod in the proximal forearm incision, and it should glide smoothly without buckling as the finger is taken through a range of motion.
- Alternatively, the silicone rod can be loosely tacked to the FDP at the level

of the palm if it has not retracted proximally.

- Over the course of 2 or 3 months, the gliding silicone rod creates a lubricated pseudosheath.¹

Stage 2

- Use the previous incisions to identify the silicone rod proximally and distally.
- Obtain the tendon graft. Be sure the length of the graft will be sufficient to span the length of the defect (**TECH FIG 3A,B**).

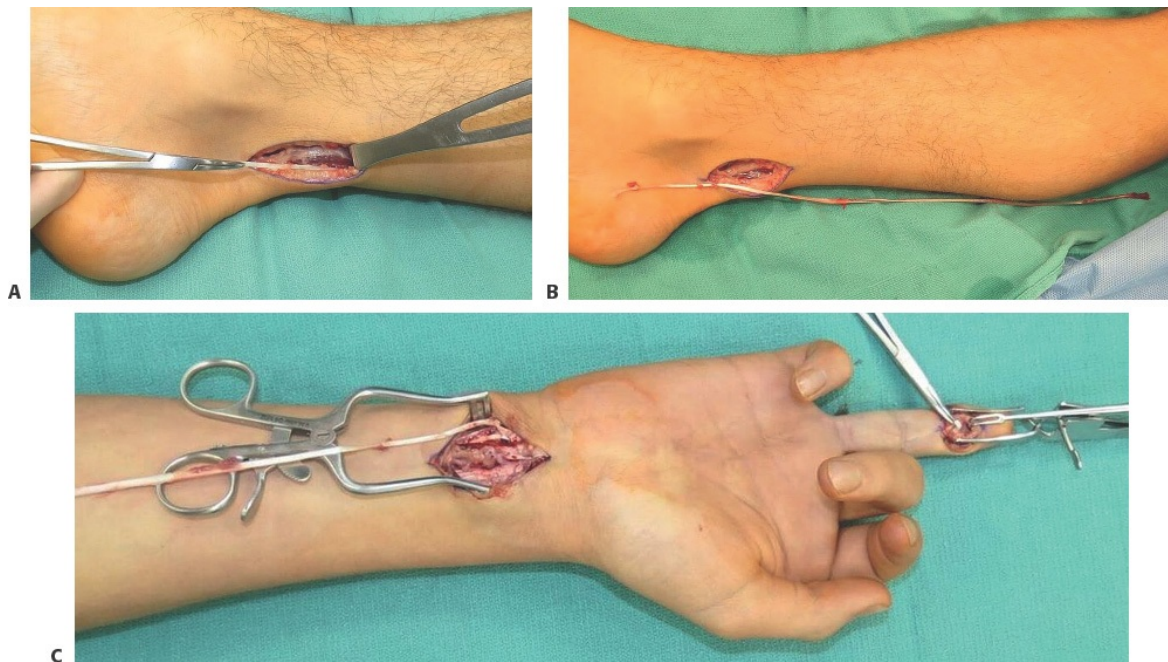


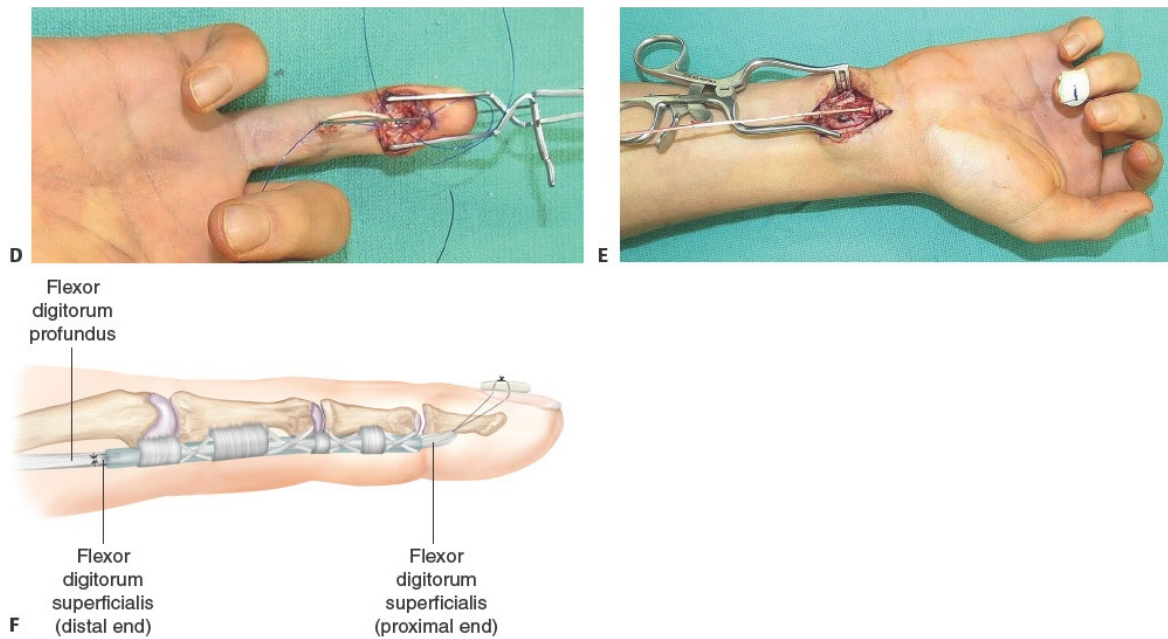
TECH FIG 2 • Stage 1 of two-stage flexor tendon reconstruction. **A.** Volar Bruner incision in the finger and palm. **B.** The Hunter rod placement in flexor sheath. **C.** Hunter rod sutured to the FDP stump. **D.** Completed stage 1 of two-stage tendon reconstruction.

- Identify the rod distally in the finger.
- Cut the sutures between the rod and the FDP stump and suture the distal end of the rod to the proximal end of the graft (**TECH FIG 3C**).
- Pull the rod through the proximal incision, which will shuttle the graft

through the sheath.

- Perform a tendon weave on the distal FDP stump as described above for single-stage grafting. If no stump is present, the graft can be inserted into the distal phalanx with transosseous sutures tied over a button or the nail plate or with a suture anchor (**TECH FIG 3D**).
- Estimate the tension of the graft to produce slight flexion aligned with the natural cascade (**TECH FIG 3E**).
- Err on the side of overtensioning rather than undertensioning.
- Perform a Pulvertaft weave on the proximal FDP using three orthogonal weaves (**TECH FIG 3F**).
- If the proximal FDP stump cannot be identified, a tenodesis to the adjacent FDP tendon can be performed.





TECH FIG 3 • Stage 2. **A,B.** The tendon graft is harvested. **C.** The sutures are cut between the rod and the FDP stump, and the distal end of the rod is sutured to the proximal end of the graft. **D.** A tendon weave is performed on the distal FDP stump. **E.** The tension of the graft is estimated to produce slight flexion aligned with the natural cascade. **F.** Completed stage 2 of two-stage tendon reconstruction.

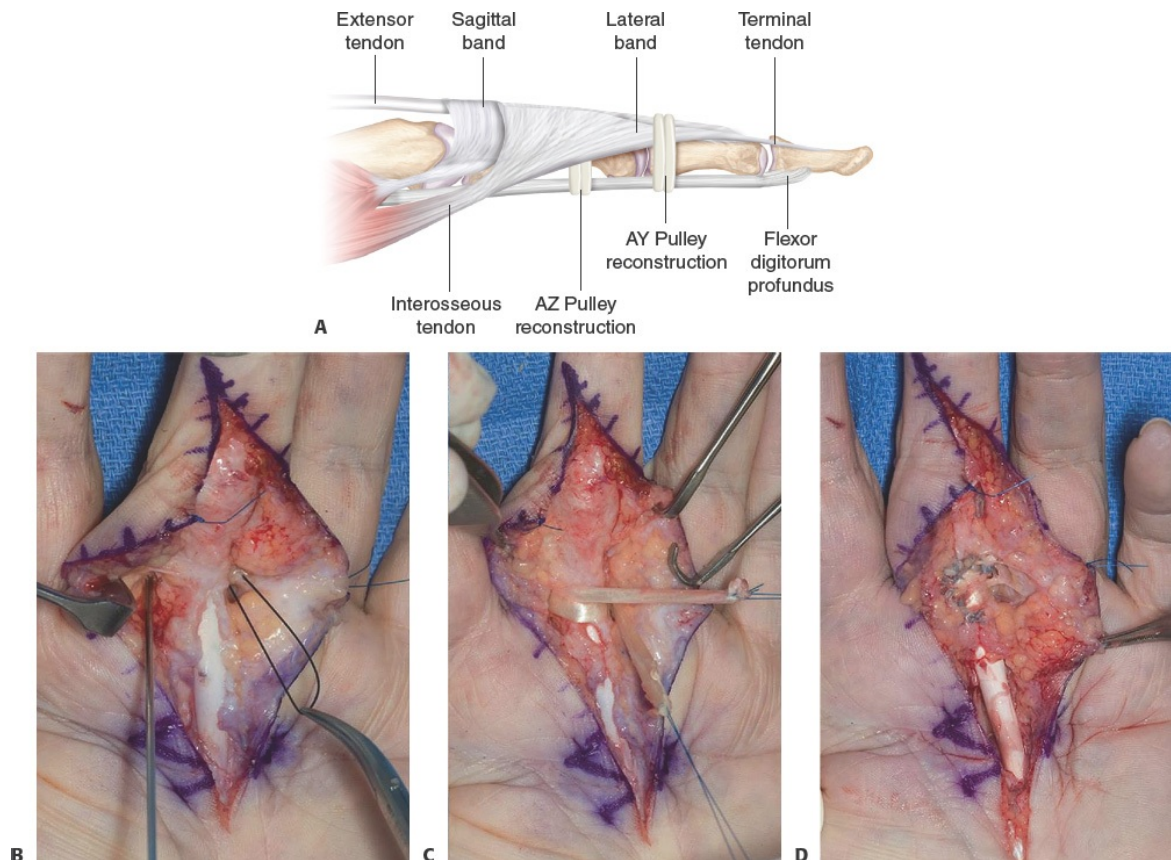
■ Paneva-Holevich Modification

- Described in 1969, this modification obviates the need for tendon graft harvest in stage 2.²
- In stage 1, the volar finger is approached and the silicone rod is secured to the distal FDP or the distal phalanx as described above.
 - The FDS and FDP tendons are both identified in the palm and transected at the level of the lumbrical origin proximal to the A1 pulley. Both distal ends are sutured to each other using a locking core suture technique. We prefer a Kessler stitch with a running epitendinous stitch.
 - The FDP-FDS “loop” will heal over 3 months.
- In stage 2, the finger is exposed again.

- The FDS tendon is transected as far proximal as possible. Pull the FDS-FDP loop out of the palm. The proximally cut FDS tendon now becomes the distal end of the graft.
 - Suture the distal end of the tendon graft to the silicone rod and shuttle the graft through the pseudosheath.
 - Tension the graft and secure it as described above.
-

■ Pulley Reconstruction

- Pulley reconstruction is performed at the first stage of the tendon reconstruction if the A2 and A4 pulleys are deficient (**TECH FIG 4A**).
- We prefer the tendon-wrapping method described by Bunnell.³
- Approximately 12 cm of graft may be required to encircle the phalanx twice. Oftentimes this can be obtained from excised flexor tendon.
- The A2 and A4 pulleys should be reconstructed.
- At the level of the proximal phalanx, the graft lies deep to the extensor mechanism and deep to the neurovascular bundle, so that the intrinsic tendons and the finger vascularity are not disrupted.
- Whipstitch one end of the graft with a 4.0 braided suture.
- Use a curved hemostat to dissect around the proximal phalanx deep to the extensor mechanism, and pass the suture into the clamp.
- Pass the graft around the mid shaft of the proximal phalanx twice and suture to itself using 3.0 nonabsorbable suture.
- At the level of the middle phalanx, the graft is passed superficial to the extensor mechanism but still deep to the neurovascular bundle. Encircle the middle phalanx twice and suture the graft to itself (**TECH FIG 4B–D**).
- An alternative method is to shoestring the graft through existing pulley edges. The residual pulley is often stiff enough to support the weave.



TECH FIG 4 • Pulley reconstruction using tendon autograft. **A.** A2 and A4 pulley location. **B.** The grafts are looped twice around the proximal phalanx. **C,D.** The graft is passed under the extensor mechanism for the A2 reconstruction and over the extensor mechanism for the A4 reconstruction.

PEARLS AND PITFALLS

Indications

- Single-stage grafting is indicated for a segmental gap in the tendon with an intact sheath.
- Two-stage grafting is indicated for a segmental tendon gap with excessive scarring, multistructure injury, failed tendon zone II repair, and/or a deficient sheath.
- Digits considered for reconstruction should have adequate

	vascularity and protective sensation. ■ Alternatives to tendon reconstruction include adjacent FDS to FDP tendon transfer, arthrodesis, and amputation.
Graft planning	■ Be sure the desired graft is anatomically present. ■ Plan for a graft with sufficient length. ■ If the graft needs to reach the palm, a palmaris graft may be sufficient. ■ If the graft needs to reach the forearm, a plantaris graft may be necessary. ■ If a graft is not present, an allograft gracilis or semitendinosus is an acceptable alternative. ■ The graft should be about 4–5 mm in width to pass through the sheath easily.
Preservation of intact structures	■ Do not sacrifice an intact FDS to pass a tendon graft. ■ Preserve as much of the native sheath as possible—not just A2 and A4.

POSTOPERATIVE CARE

Stage 1

- The major goal of stage 1 is to maintain passive range of motion
- 0 to 2 weeks: edema control, dorsal thermoplast splint (wrist neutral, MP joint 60 degrees of flexion, IP joints 0 degrees). Passive flexion and active/passive extension for all joints 6 times per day. If a pulley reconstruction was performed, a thermoplast circumferential pulley ring is worn for 6 weeks.
- 2 to 6 weeks: Remove splint. Buddy strap affected finger to adjacent finger. Continue active and passive exercises until stage 2 is performed (approximately 12 weeks).

Stage 2 (Modified Duran)

- 0 to 3 weeks: Edema control, dorsal thermoplast splint (wrist 20 degrees of flexion, MP joint 60 degrees of flexion, IP joints 0 degrees). Passive flexion and active/passive extension for all joints 6 times per day.
- 3 to 4 weeks: Add active range of motion (AROM), tendon gliding, and place hold exercises in the splint.
- 4 to 6 weeks: Exercises can be performed out of splint. Add blocking exercises to PIP and DIP. Add wrist tenodesis exercises. Add grasp, dexterity, and ADL

exercises.

- 6 to 8 weeks: Splint is only worn at night and in crowds. Volar pancake or IP joint extension splints may be added if necessary. Add light resistance exercises.
- 8 to 12 weeks: Discontinue splint. Add progressive resistance exercises and work simulation activities.

OUTCOMES

- Outcomes results are graded by a variety of measures including total active arc of motion (TAM), grip and pinch strength, and scoring systems by Schneider, Stark, and Strickland.⁴⁻⁶
- In general, results of primary repair are superior to reconstruction, and fingers with an intact FDS obtain better motion than do those without one.⁷ Other factors that portend a better prognosis are younger patient, less soft tissue scar, good preoperative mobility, and at least one intact sensory nerve.⁸
- Grafting through an intact FDS, Stark et al. reported “satisfactory” finger flexion in 20 of 25 patients, defined as a distance of the pulp to distal flexion crease within 3.2 cm and 20-degree active DIP flexion.⁵ Using similar criteria, McClinton et al. reported success in 87 of 100 patients with an average of 48 degrees of DIP flexion.⁹
- Two-stage grafting reported by Hunter and Salisbury resulted in pulp to crease flexion within 3.2 cm in 85% of the 69 cases.¹⁰
- TAM for two-stage grafting ranges from 186 to 206 degrees.^{7,11,12}

COMPLICATIONS

- Adhesion of the graft is the most common complication. A tenolysis may be required 3 to 6 months after stage 2 reconstruction.
- Bowstringing, tendon rupture, and infection are also not uncommon complications.
- A tight FDP graft may cause the “quadrigea effect,” whereby the adjacent digits experience a flexor lag as described earlier.
- A loose FDP graft may cause imbalance in the finger. A swan-neck deformity or a lumbrical plus finger may be the result. Lumbrical plus finger is diagnosed when “paradoxical extension” of the IP joints occurs when the patient attempts to make a fist; the lumbrical originates on the FDP and pulls the IP joints into extension when a retracted FDP contracts. Retensioning the graft or resection of the lumbrical origin may be required.

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CHAPTER Tenolysis of Flexor Tendons

Richard Tosti, Jacques A. Machol IV, and Neal Chen

DEFINITION

- Total active arc of motion in the fingers is approximately 260 degrees, which is the sum of each individual joint: metacarpophalangeal (MP) joint 85 degrees, proximal interphalangeal (PIP) 110 degrees, and distal interphalangeal (DIP) 65 degrees.
- Flexion contracture is a loss of passive extension. Extension contracture is a loss of passive flexion.
- Flexion lag is a loss of active flexion, but preserved passive flexion. Extension lag is a loss of active extension, but preserved passive extension.
- This chapter will primarily focus on loss of digital motion caused by adhesions of the flexor tendon.

ANATOMY

- The strength and versatility of the hand is dependent upon the balance and gliding of the long flexors and extensors and the intrinsic muscles.
- The extensor apparatus is composed of four lumbrical muscles, four dorsal interossei, three volar interossei, four extensor digitorum communis (EDC) tendons, the extensor indicis proprius (EIP), and the extensor digiti quinti (EDQ).
- The long extensors (EDC, EIP, EDQ) originate in the forearm and insert on the base of their respective proximal phalanx via the sagittal band attachments to the volar plate. The long extensors continue distally to insert on the base of the middle phalanx as the central slip but also give two “lateral slips” that join the intrinsic tendons to form the lateral bands, which insert on the base of the distal phalanx as the terminal tendon.

- The intrinsic muscles originate in the hand and insert on the extensor apparatus. The transverse fibers of the extensor hood link the intrinsic tendon and the proximal phalanx. The oblique fibers of the extensor hood link the intrinsic tendon and the middle phalanx. The tendons of the intrinsic muscles join the lateral slips of the long extensor to form the lateral bands, which insert as the terminal tendon.
- Important to note is the course of the intrinsic tendon relative to centers of rotation at the finger joints. At the MP joint, they course volar to the axis of rotation producing a flexion moment. At the PIP and DIP joints, they course dorsal to the axis of rotation producing an extension moment.¹
- Nine flexor tendons originate in the forearm. Flexor pollicis longus inserts at the base of the distal phalanx of the thumb. Four flexor digitorum superficialis (FDS) and four flexor digitorum profundus (FDP) tendons insert on the volar base of the middle and distal phalanges, respectively.
- The FDS tendons are superficial to the FDP in the hand, but as they enter the fibrous sheath, the FDS bifurcates into two slips, which are directed dorsally to their insertion.

PATHOGENESIS

- Traumatic or postsurgical stiffness usually begins with edema or hematoma.²
- The fluid distends the joints and surrounding structures, becoming a physical barrier to motion.
- The cellular response to injury initiates the inflammatory cascade.
- The inflammatory cascade leads to fibroblast accumulation and fibroblast proliferation into myofibroblasts.
- Reaction to foreign material such as metal plates stimulates adhesion formation as well.
- Persistent motion loss leads to soft tissue contracture.

NATURAL HISTORY

- Contracture or adhesions of dorsal structures generally limit passive flexion. These structures include the dorsal skin, extensor tendons, intrinsic tendons, dorsal capsule, and collateral ligaments.
- Contracture or adhesions of the flexor tendons generally limit active flexion.
- Contracture or adhesions of the volar structures limit passive extension. These structures include the volar skin, flexor tendons, and volar capsule.
- Contracture or adhesions of the extensor tendons limit active extension.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most common stiff posturing is MP joint extension and IP joint flexion. The MP joint is a cam shape, which holds the greatest fluid volume when in extension. Extension at the MP creates a relative tension on the flexor tendons that brings the IP joints into flexion.
- However, a variety of postures and motion limitations are seen (Table 1).

Table 1 Assessment of a Stiff Finger

Cause	Active Extension	Passive Extension	Active Flexion	Passive Flexion
Extensor tendon adhesion	–	+	–	+/-
Dorsal skin or capsular contracture	+	+	–	–
Flexor tendon adhesion	–	+/-	–	+
Volar skin or capsular contracture	–	–	+	+
Dorsal and volar combined ^a	–	–	–	–
Intrinsic contracture ^b	+	+	–	–

^aCombined pathology of dorsal and volar structures by adhesion and/or contracture.

^bTesting of PIP joint with the MP joint extended.

- Begin with assessment of passive and active range of motion (AROM).
- Passive motion greater than active motion suggests a barrier outside the joint (adhesion, rupture, denervation).
- Passive motion of the PIP joint that varies with the position of the MP joint suggests a barrier outside the joint (intrinsic or extrinsic tightness).
- Passive motion barriers may occur from pathology either within the joint or outside the joint.
- Passive motion barriers mask active motion (ability or disability); thus active joint motion can only be assessed after correction of passive motion barrier.

IMAGING

- Stiffness is usually diagnosed by history and physical exam.
- Radiographs may be helpful to rule out bone or joint malalignment as a cause.

DIFFERENTIAL DIAGNOSIS

- Tendon rupture
- Joint contracture

NONOPERATIVE MANAGEMENT

- Prior to any attempt at tenolysis, tissue homeostasis must be achieved. This includes a stable, supple soft tissue envelope, durable bony stability, and edema control.
- It is preferable to gain passive range of motion before a tenolysis procedure if possible.
- Daytime dynamic splints and nighttime static splints can help regain motion. Dynamic splints are typically not worn at night, as they may lose their position.
- Progressive static splints or serial casting can also be successful.

SURGICAL MANAGEMENT

- Surgery may be considered for disability resulting from stiffness if 6 months of nonsurgical management has failed to resolve symptoms.

Preoperative Planning

- Wide-awake surgery under local anesthesia has the advantage of assessing gains in active motion so that intraoperative modifications can be made.
- Hardware removal may be required but should only be performed after bony union has occurred.
- A flexion contracture may be caused by any combination of volar skin contracture, flexor tendon adhesion, or volar capsular contracture; these structures can be addressed by Z-plasty lengthening, flexor tenolysis, or joint release, respectively. Only after the flexion contracture is released can the integrity of the extensor mechanism be assessed.³
- An extension contracture may be caused by dorsal skin contracture, extensor tendon adhesion, or dorsal capsule; these structures can be addressed by Z-plasty lengthening, extensor tenolysis, or dorsal capsulotomy/collateral ligament release, respectively. Only after the extension contracture is released can the integrity of the flexor tendons be assessed.³

- A flexion lag is often caused by adhesions between the flexor tendon and surrounding bone, soft tissue, and skin. It may only be discovered after release of an extension contracture.
- An extension lag is often caused by adhesions between the extensor tendon and surrounding bone, soft tissue, and skin. It may only be discovered after release of a flexion contracture.

Positioning

- Position the patient supine with the arm on a hand table.
- A nonsterile tourniquet may be used proximally.

Approach

- Dorsal approach to the finger for extensor tenolysis is made through either a longitudinal incision centered over the PIP joint or a radially based curvilinear incision.
- For flexor tenolysis, a volar Bruner incision is the most common approach, although a longitudinal midaxial incision can be considered.
- In patients with a skin contracture, Z-plasty is often helpful.

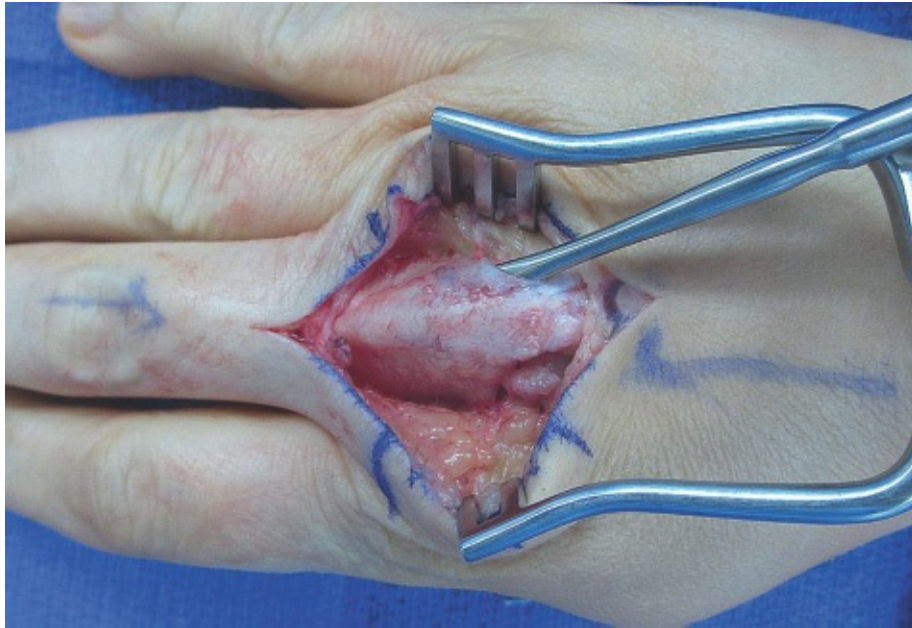
TECHNIQUES

■ Extensor Tenolysis With or Without Dorsal Capsular Release

- The extensor mechanism is exposed, and any adhesions to the skin are released.
- A Freer elevator can be used to free the extensor hood from the proximal phalanx. This is usually performed from proximally to distally or from laterally to centrally under the lateral bands.
- Caution is taken to avoid detaching the central slip.
- Adhesions to the middle phalanx can also be released from under the lateral bands/extensor hood.
- If there is a PIP joint contracture present, the collateral ligaments can be excised from underneath the lateral bands.
- Adhesions at the level of the metacarpal are approached in a similar manner

(**TECH FIG 1**).

- Hardware, if present, should be removed at the time of tenolysis.



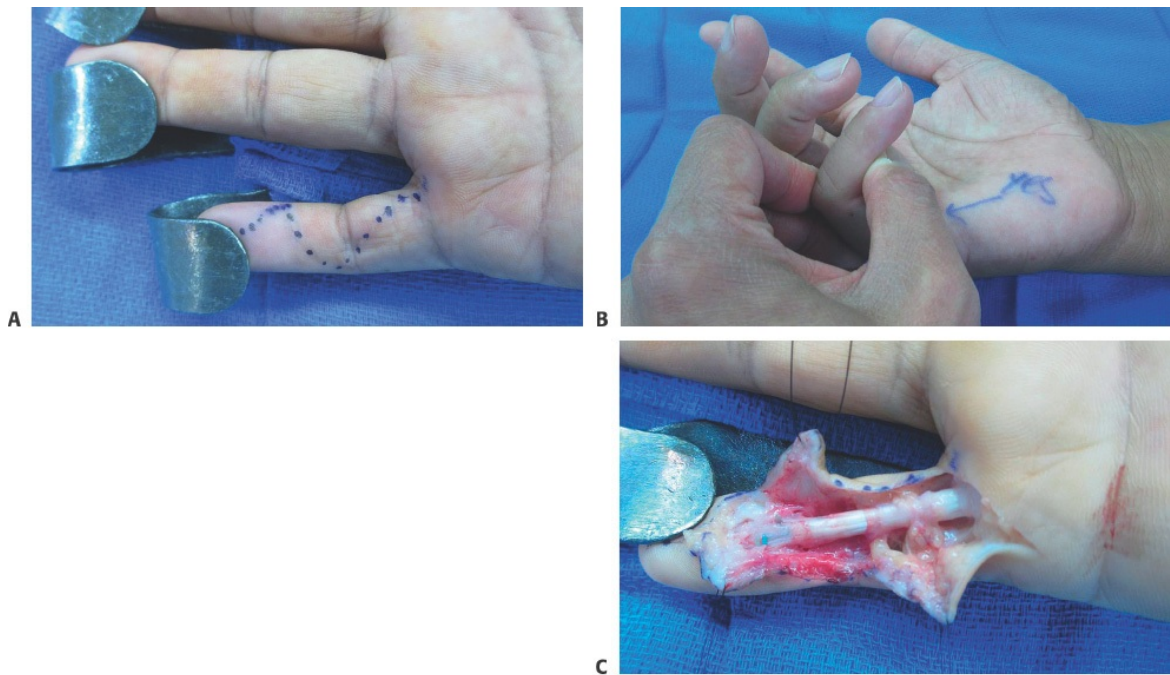
TECH FIG 1 • Extensor tendon adhesions after fixation of metacarpal fracture, dorsal approach showing adhesions of the extensor tendon to the skin and underlying plate.

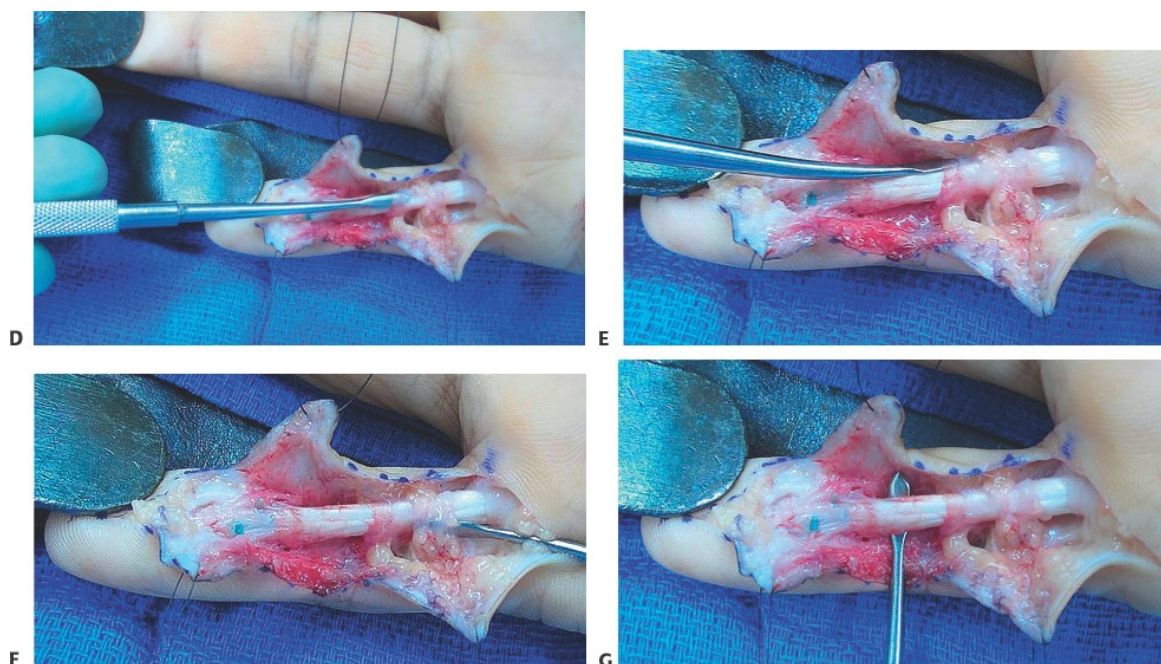
■ Flexor Tenolysis With or Without Volar Capsular Release

- Open the wound using the prior incisions and identify the neurovascular structures first to protect them (**TECH FIG 2A**).
- The A1 pulley is released and a window is opened over the cruciate and A3 pulleys.
- The A2 and A4 pulleys are preserved as much as possible. If necessary, pulleys may be partially “vented” by making a longitudinal incision along the radial or ulnar border of the sheath.
- The superficialis tendon and the profundus tendon are examined at the level of the A1 pulley using an Allis clamp “turnkey” maneuver (**TECH FIG 2B**).
- Tenolysis knives or a Freer elevator can be used to free adhesions around the

tendon. There are often deep adhesions to the bone and between the FDS and FDP (**TECH FIG 2C–G**).

- If a PIP joint contracture exists, the volar plate can be transversely incised and the checkrein ligaments released.⁴
- Rarely, FDS may be sacrificed if dense adhesions and a tight sheath are encountered.
- If contracture of the skin is causing the motion limitation, then preoperative planning should include the design of a longitudinal incision with Z-lengthening at the flexion creases.





TECH FIG 2 • A. Limited flexor tenolysis for adhesions after a pinning of a proximal phalanx fracture. **B.** Turnkey motion demonstrating return of extension. **C.** Both the FDS and FDP tendons were isolated. The A4 pulley was previously excised during the initial repair and was not competent. **D–G.** Tenolysis through traction with an Allis clamp was sufficient to disrupt the adhesions and restore motion.

■ Intrinsic Release

- There are two types of intrinsic release:
 - The intrinsics can be released at the extensor hood.
 - The intrinsics can be released proximally off of the metacarpal in the intrinsic slide procedure, typically for intrinsic contracture resulting from compartment syndrome.
- Distal release is indicated for a positive Bunnell intrinsic tightness test. The PIP joint will have less flexion when the MP joint is extended and more flexion when the MP joint is flexed.
- The extensor hood is approached through a single midline dorsal incision or a double midaxial incision.

- The oblique fibers are identified in the distal third of the proximal phalanx.
- A triangular wedge of the oblique fibers is excised.
- Avoid cutting into the transverse fibers, which attach the proximal phalanx to flex the MP joint.
- Proximal release is indicated in patients with severe intrinsic tightness, where the MP joint is also affected.¹
- Proximal release consists of cutting the intrinsics proximal to the MP joint. Another alternative is an intrinsic slide where the intrinsics are released from the metacarpal. These procedures are typically performed in more severe intrinsic contractures such as those secondary to compartment syndrome.

PEARLS AND PITFALLS

Indications

- Tenolysis will not improve a stiff finger that has joint incongruity or malalignment.
- Wounds, swelling, and inflammation should be resolved before surgery.
- Nonoperative measures should be continued as long as progress is being made.
- The patient must agree to a strict post-op rehab program before surgery is considered.

Incision

- For multiple MP joint extension contractures, avoid a single transverse incision, as this will gap during early rehab.
- Anticipate soft tissue contractures and be prepared to perform Z-plasty or advancement flaps for coverage.

Sequential release

- Begin with releasing the tendon adhesions from the bone and skin.
- Release the capsule and then ligaments if necessary.
- Be mindful that intrinsic tightness may coexist and warrant release.

Rehabilitation

- Begin rehab immediately after surgery.

POSTOPERATIVE CARE

- All protocols should begin 24 to 48 hours after surgery.
- The quality of the tendon should be noted intraoperatively.

- Thin, frayed, and poorly vascular tendons are at risk for rupture with an aggressive protocol.⁵

Flexor Tendon Rehabilitation

- Good-quality tendon
 - 0 to 2 weeks: Edema control, volar thermoplast splint (wrist neutral, MP and IP joints 0 degrees) to be worn at night and in between exercises. AROM, tendon gliding, and place-hold exercises to be performed hourly with 10 reps each
 - 2 to 4 weeks: Continue above. Add blocking exercises to PIP and DIP. Add grasp, dexterity, and ADL exercises. Add scar management.
 - 4 to 8 weeks: Continue above. Add sustained gripping and progressive resistance. May add dynamic extension splint if needed.
 - 8 to 12 weeks: Add heavy resistance exercises and work simulation activities.
- Poor-quality tendon
 - 0 to 2 weeks: Edema control, volar thermoplast splint to be worn at night and in between exercises. The splint is fabricated to place the joints in full extension for extensor lag and in resting position for extension contracture. Passive flexion performed hourly.
 - 2 to 4 weeks: Add AROM, tendon gliding, and place-hold exercises to be performed hourly with 10 reps each. The splint is gradually brought to allow MP joint at 0 degrees by 4 weeks. Add scar management.
 - 4 to 8 weeks: Add blocking exercises to PIP and DIP. Add grasp, dexterity, and ADL exercises.
 - 8 to 12 weeks: Add sustained gripping and progressive resistance. May add dynamic extension splint if needed.
 - 12 weeks: Add heavy resistance exercises and work simulation activities.

Extensor Tendon Rehabilitation

- Good-quality tendon
 - 0 to 2 weeks: Edema control, volar thermoplast splint to be worn at night and in between exercises. Fabricate the splint to place the finger joints in extension for extensor lag and in resting position for extension contracture. AROM, gliding, place-hold, and blocking exercises performed hourly.
 - 2 to 4 weeks: Add grasp, dexterity, and ADL exercises. Add scar management.

- 4 to 8 weeks: Add sustained gripping exercises. At 6 weeks, add progressive resistance. May add dynamic flexion splint if needed.
- 8 to 12 weeks: Add heavy resistance exercises and work simulation activities.
- Poor-quality tendon
 - 0 to 2 weeks: Edema control, volar thermoplast splint to be worn at night and in between exercises. Fabricate the splint to place the finger joints in extension for extensor lag and in resting position for extension contracture. Tenodesis exercise, gentle AROM, gliding, and place-hold performed hourly.
 - 2 to 4 weeks: Add AROM and blocking exercises. Add scar management.
 - 4 to 8 weeks: Add grasp, dexterity, and ADL exercises.
 - 8 to 12 weeks: Add sustained gripping exercises and progressive resistance. May add dynamic flexion splint if needed.
 - 12 weeks: Add heavy resistance exercises and work simulation activities.

OUTCOMES

- Weeks et al. evaluated 789 stiff MP and PIP joints in 212 patients at a mean 3.4 months after injury. Exercises and dynamic splinting alone were effective in 87% of patients. MP joint range of motion (ROM) improved 32 degrees on average, while PIP joint ROM improved 36 degrees on average. Surgery was required for the remaining 13%.⁶
- Hunter et al. reported on 61 digits with PIP joint contractures treated nonoperatively with exercises and static or dynamic splints. Preoperative motion at the PIP joint range of motion was 24 to 67 degrees, which improved to 8 to 98 degrees.⁵
- Breton et al. reported on 75 digits that underwent postinjury zone II flexor tendon tenolysis. They noted a preoperative total arc of motion of 128 degrees and a postoperative arc of 192 degrees at 3 months. Flexor tendon rupture occurred in seven cases.⁷
- Yamazaki et al. noted that the preoperative range of motion was the strongest predictor of postoperative range of motion in patients undergoing flexor tenolysis after phalangeal fracture.⁸
- Adjunctive treatments such as indwelling local anesthesia catheters and continuous passive motion (CPM) devices have been described; however, limited evidence justifies their routine use. Schwartz and Chafetz noted no difference in gains in total arc of motion with CPM.⁹

COMPLICATIONS

- Tendon rupture can occur if tenolysis performed before repair site is healed.
- Tendon disruption can occur if the tenolysis erroneously strips the insertion site.
- Recurrence can occur if the patient is not compliant with rehab or if the zone of injury is too great.

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41 Acute Repair of Extensor Tendon Injuries in Zones I to VI

CHAPTER

Michael Smith, Jacques A. Machol IV, and Neal Chen

DEFINITION

- The extensor apparatus of the hand is a delicate and complex system that works in synergy with the flexor system to facilitate gross and fine motor activity of the hand and digits.
- Extrinsic extensor function is provided to the digits by the extensor digitorum communis (EDC), extensor indicis proprius (EIP), and extensor digiti minimi (EDM). These muscles work in concert with the intrinsic muscles of the hand to provide extension of the proximal and distal interphalangeal (DIP) joints through the intrinsics' contributions to the extensor mechanism via the lateral bands.
- The extensor apparatus can be injured by blunt or sharp trauma, as well as by attrition from inflammatory conditions.

ANATOMY

- The extensor tendons can be divided into superficial and deep muscle groups.¹
- The superficial group includes the extensor carpi radialis longus (ECRL), the extensor carpi radialis brevis (ECRB), the EDC, the EDM, and the extensor carpi ulnaris (ECU).
- The deep group includes the extensor pollicis brevis (EPB), the extensor pollicis longus (EPL), and the EIP.
- The extensors are innervated by the posterior interosseous nerve (PIN) with the exception of the ECRB and ECRL, which are innervated by the radial nerve prior to the split into the PIN and the superficial radial nerve.²
- The ECRB may sometimes be innervated by the PIN after the radial nerve has

split.

- The extensor tendons travel through six separate dorsal compartments at the level of the wrist prior to entering the hand.
- The first dorsal compartment contains the abductor pollicis longus (APL) and the EPB tendons.
 - There is septation of this compartment in 20% to 60% of individuals, and it is common for the APL to have multiple tendon slips.³
- The second dorsal compartment contains the wrist extensors, the ECRB and ECRL.
 - The ECRB is located ulnarly in relation to the ECRL.
- The third dorsal compartment contains the EPL tendon and is just ulnar to Lister tubercle on the radius.
- The fourth dorsal compartment contains the EIP and EDC tendons. The PIN is also found within the base of this compartment.
 - The EIP can be identified at the level of the hand and wrist in that it:
 - Is ulnar to the index finger slip of the EDC
 - Has the distal most muscle belly
 - Is the deepest tendon proximal to the extensor retinaculum
 - Is not connected by juncturae tendinum
 - The EIP is absent in up to 1% of the population and can have multiple slips in up to 16% of the population.
- The fifth dorsal compartment contains the EDM and overlies the distal radioulnar joint (DRUJ).
 - The EDM is found ulnar to the EDC tendon to the small finger.
 - The EDC tendon to the small finger is often absent, and a double EDM tendon may occur in 80% to 90% of individuals.⁴
- The sixth dorsal compartment contains the ECU tendon.
- At the level of the hand, the tendons become flat and juncturae tendinum provides interconnections between the EDC tendons.
- At the level of the metacarpophalangeal (MCP) joint, the radial and ulnar sagittal bands form a sling around the extensor tendon and attach to the volar plate (**FIG 1A**).
- Distal to the MCP, the intrinsic muscles of the hand join the extensor tendons to form the extensor hood.

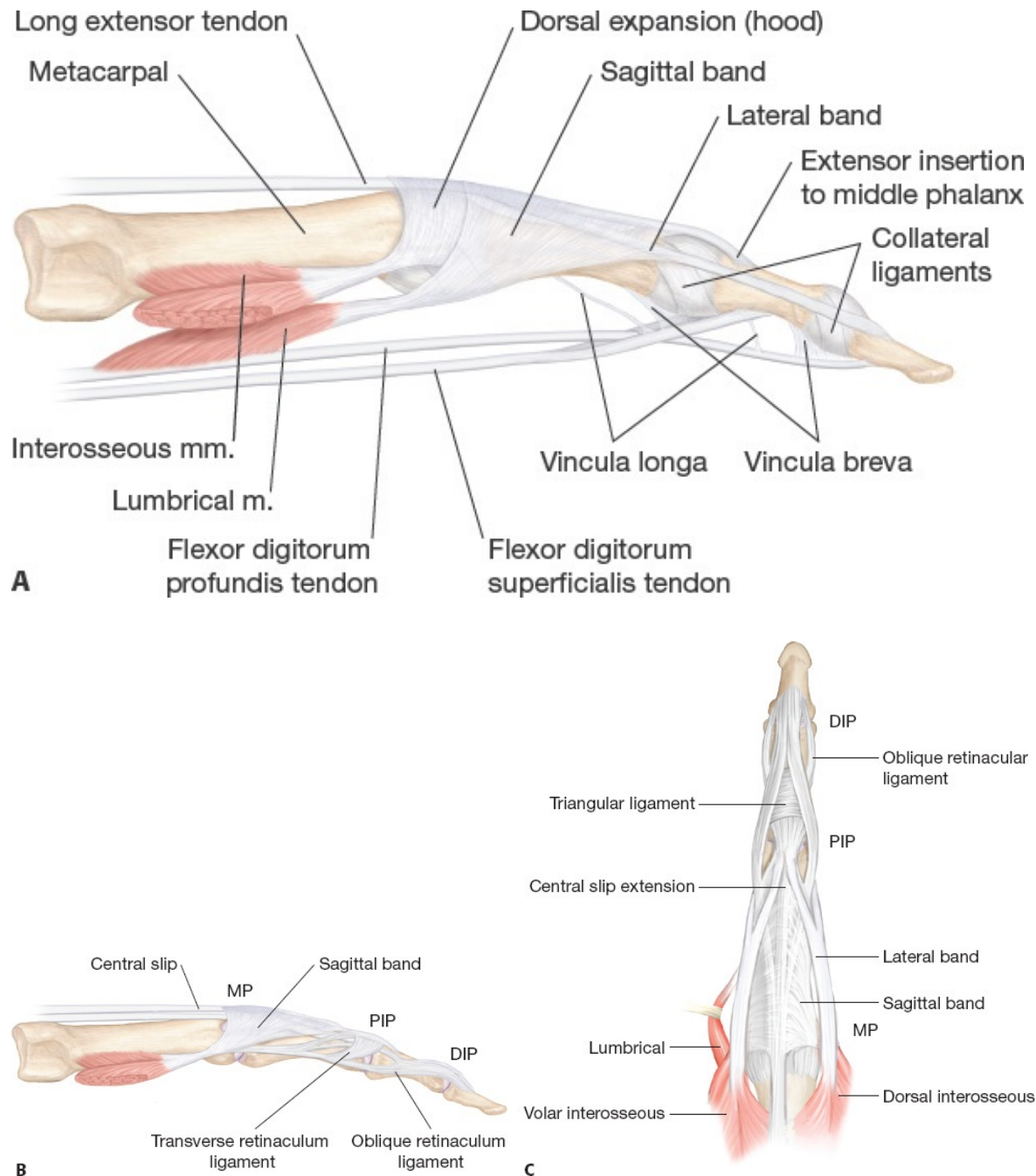


FIG 1 • A–C. Extensor apparatus at the digit.

- The central tendon trifurcates at the level of the proximal phalanx, with the radial and ulnar slips becoming the lateral bands and the central slip inserting into the base of the middle phalanx by providing proximal interphalangeal (PIP) joint extension.
- The interossei split into medial and lateral slips. The medial slip will insert

into the base of the proximal phalanx and functions to flex the MCP joint. The lateral slip will join with the lateral band of the common extensor tendon to form the conjoined lateral band. The radial and ulnar conjoined lateral bands will form the terminal tendon and insert onto the distal phalanx, extending the DIP joint (**FIG 1B,C**).

- The triangular ligament prevents the conjoined lateral bands from volar subluxation, and the transverse retinacular ligament prevents dorsal subluxation.¹
- By convention, the extensor tendons are divided into nine zones to assist in classification of extensor tendon injuries. Odd-numbered zones are located over joints, and even-numbered zones are located over the long bones (**FIG 2**):
 - Zone I includes the DIP.
 - Zone II is the middle phalanx.
 - Zone III is the PIP.
 - Zone IV is the proximal phalanx.
 - Zone V is overlying the MCP joint.
 - Zone VI is over the metacarpals.
 - Zone VII includes the carpus and extensor retinaculum.
 - Zone VIII involves the distal forearm, up to the musculotendinous junction of the tendons.
 - Zone IX involves the remaining part of the upper forearm.

PATHOGENESIS

- Extensor tendons can be disrupted in a number of ways.
- Disruption of the terminal tendon in zone I, resulting in a mallet finger, can occur either through an avulsion of the tendon from its insertion or a fracture of the base of the distal phalanx at the tendon insertion.
- The tendons can also be cut from a sharp laceration, and it is not uncommon to encounter tendon ruptures from attritional wear, from either inflammatory arthritis or other conditions such as prominent hardware.

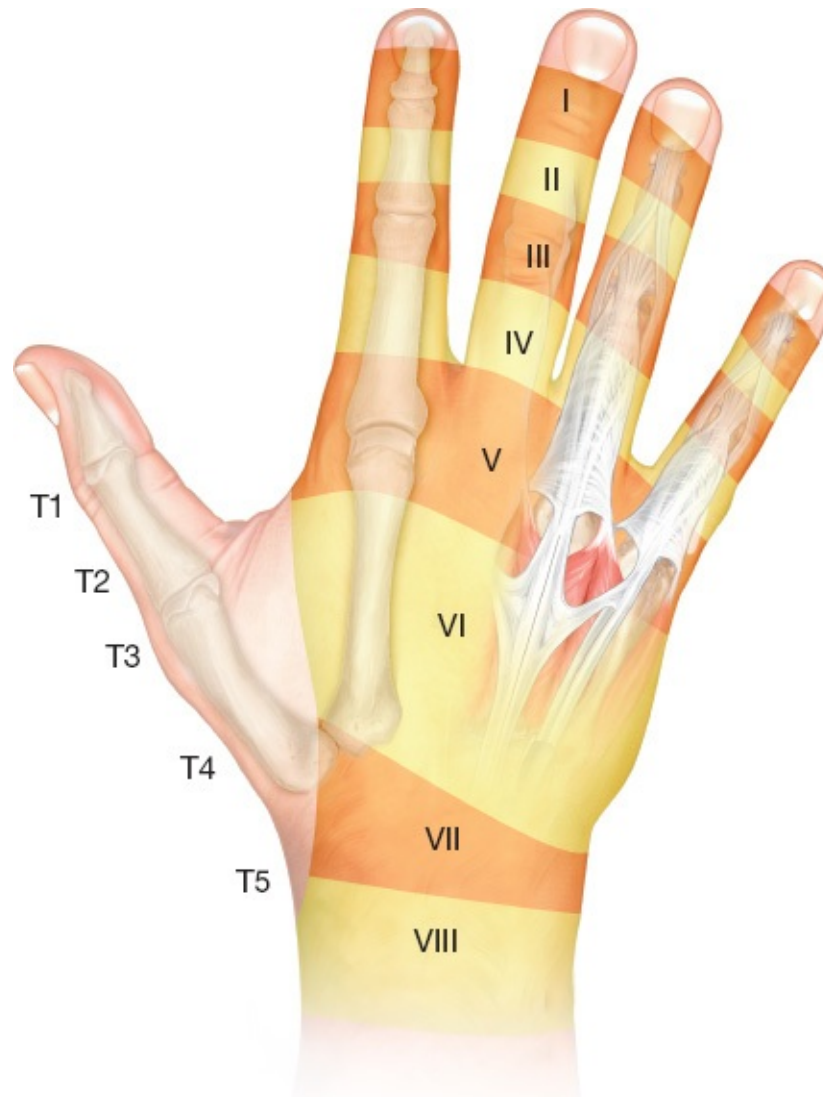


FIG 2 • Extensor tendon zones.

NATURAL HISTORY

- Often, there is an extensor deficit when the tendon is not repaired. In some cases, such as mallet fingers, the patient can still have a functional hand, even with the extensor tendon left unrepaired.
- In other cases, such as a sharp laceration of the EDC at zone VII, there will be residual impairment.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients will often present with a history of a recent trauma in the instance of extensor tendon laceration or mallet finger (**FIG 3**).

- Pain and a history of a pop are common with a mallet finger injury.
- Patients with attritional rupture, especially patients with inflammatory arthropathy who already have some functional deficits in their hand, may not realize that one of their extensor tendons has ruptured.
- Initial evaluation should include a thorough physical examination, testing all flexor and extensor tendons, in addition to the digital neurovascular bundles.
- Upon initial inspection, attention should be paid to the resting cascade of the digits. If this is disrupted, there is a high likelihood of tendon injury.
- Wounds should be closely inspected and a determination made of the cleanliness, sharpness, size, location, and potential for injury with the wound.
- The function of each extensor tendon should be tested both with and without resistance. Test each finger individually as the juncturae tendinum may mask an injury.
- To test the EIP and EDM, ask the patient to keep the middle and ring fingers flexed into the palm and extend the index and small fingers.
- If there is pain and swelling of the PIP joint, coupled with a mild PIP extension lag or weak PIP joint extension against resistance, one must consider a central slip injury.
- The Elson test, in which the DIP joint will become rigid with attempted extension of the PIP joint from a flexed position, will confirm an early central slip injury. The DIP becomes rigid because the finger extends through the intact lateral slips.
- Active and passive range of motion of all the joints in the hand and wrist should be tested and recorded.



FIG 3 • Clinical appearance of a mallet finger (zone 1 extensor tendon injury). (Courtesy of Philip Blazar, MD.)



FIG 4 • Radiographic appearance of a bony mallet

injury. (Courtesy of Philip Blazar, MD.)

IMAGING

- Radiographs of the hand or digit should be taken in orthogonal planes after an acute extensor tendon injury. This will identify any associated fractures, such as in a bony mallet injury (**FIG 4**), and can also identify any foreign bodies remaining in the extremity after a sharp injury.
- Ultrasound can be a useful adjunct in the setting of a chronic tendon injury to determine the position of the proximal and distal tendon ends if direct repair is being considered.
 - If 4 to 6 weeks have passed since injury, or if the nature of the rupture was secondary to attritional rupture, direct repair often is not possible because of shortening of the proximal tendon, and reconstruction or transfer should be considered.
- MRI can also aid in determining the position of the tendon ends; however, this is an expensive modality and can be time-consuming to obtain in some institutions.
 - In doubtful cases, ultrasound can make a precise determination of the tendon status.

DIFFERENTIAL DIAGNOSIS

- Extensor tendon laceration or disruption
- Adhesions of the extensor tendon system
- Fracture
- PIN palsy
- Radial nerve palsy

NONOPERATIVE MANAGEMENT

- Nonoperative management of extensor tendon disruption is usually considered for soft tissue mallet finger injuries and closed central slip avulsions.
- In closed soft tissue mallet finger injuries, good results can often be obtained with full-time DIP extension splinting.⁵ The duration of immobilization varies, but we usually use an extension splint for 8 weeks followed by 4 weeks of night splinting.
 - Patient compliance is the most important factor for achieving good outcome with extension splinting of soft tissue mallet injuries. However, patients

should be counseled that they will likely have a small extensor lag and dorsal prominence either with or without operative treatment.

- Surgical indications for soft tissue mallet injuries are debated but traditionally include open injuries or mallet fractures with volar subluxation or a fracture fragment larger than 30% to 50% of the articular surface.
- If there is a closed injury to the central slip, the injury can be treated with extension splinting of the PIP joint. One must ensure that the full passive PIP joint extension and DIP flexion can be achieved in the splint.
- Full-time extension splinting is continued for 6 weeks, followed by 6 weeks of nighttime splinting.
- Active flexion exercises of the DIP during this period of immobilization can help pull the lateral bands dorsally and prevent volar subluxation of the bands, which can result in a boutonniere deformity.
- If the tendon injury is incomplete, greater than 50% of the tendon is intact, and there is no extensor lag or weakness on physical exam, tendon injuries can be treated nonoperatively with 1 or 2 weeks of splinting.

SURGICAL MANAGEMENT

Preoperative Planning

- Prior to undertaking surgical repair of the extensor tendons, one must ensure that they have performed a complete physical examination of the hand and upper extremity. Other tendon injuries, nerve injuries, fractures, or concomitant conditions that will need to be addressed surgically should be identified preoperatively.
- Radiographs should be obtained to rule out fracture, foreign body, or other etiology of tendon injury such as inflammatory arthritis or prominent hardware.
- If the tendon disruption is chronic, a detailed preoperative plan should be developed to include the possibility of tendon reconstruction or transfer if the tendon cannot be repaired primarily.
- If necessary, pinning of the PIP joint is considered.
- Any additional equipment that may be required to complete and protect a strong repair should be communicated to the operating room staff in advance, including hardware and intraoperative fluoroscopy.

Positioning

- The positioning for the techniques listed below is the same.

- The patient is placed supine on the operating room table.
- A hand and upper extremity table extension is attached to the table.
- A nonsterile tourniquet is applied to the upper arm over padding.
- The arm is pronated to expose the dorsum of the hand.
- One or two OR towels are fluffed and placed in the palm of the hand to keep the fingers extended.

Approach

- There are a number of described surgical approaches to the dorsum of the DIP, PIP, and MCP joints as well as the hand, wrist, and forearm.⁶
- In general, a longitudinal incision is preferred to allow the surgeon to extend the incision distally or proximally should the need arise.
 - We prefer to make a gentle S incision over the DIP joint, a radially based curvilinear longitudinal incision across the PIP and MCP joints and a straight longitudinal incision over the metacarpals, wrist, and forearm.
- The incision should take into consideration possible future procedures.
- If there is a laceration, this is usually extended proximally and distally in a longitudinal manner to fully explore the wound and injured structures.
- Distal to the carpus, there is not much subcutaneous tissue between the skin and the tendon layer. The dissection is brought down sharply to the level of the tendons or extensor retinaculum with care taken to preserve dorsal veins if possible.
- Once the level of the tendon is encountered, full-thickness skin flaps are raised for full exposure of the tendon ends or extensor retinaculum.
 - If the extensor retinaculum is to be opened, we prefer to identify the EPL exiting distally and open the retinaculum in line with the third dorsal compartment to ensure the EPL tendon does not get inadvertently transected.

TECHNIQUES

■ Repair of Open Mallet Injury (Zone I Injury)

- If the terminal tendon has been sharply transected, it is possible to perform a primary repair that is then supplemented with Kirschner wire fixation of the DIP joint in extension.

- Often, the pre-existing laceration can be incorporated into the incision and should be extended distally and proximally.
- Careful sharp dissection of the skin off the terminal tendon is performed, preferably with a flexible scalpel (Beaver Mini-Blade No. 67, Beaver-Visitec Int.).
- Once the terminal tendon has been exposed, insert the K-wire in retrograde fashion under C-arm fluoroscopy to hold the joint in extension while the tendon repair is being performed.
- A determination is made if there is enough remaining terminal tendon in the insertion of the distal phalanx to facilitate direct repair.
 - If there is enough tendon remaining, a four-strand repair is then performed using a 4-0 nonabsorbable braided suture, usually in doubled horizontal mattress configuration if possible or a figure-eight configuration.
 - If there is not enough tendon remaining for a primary repair, the proximal tendon end can be brought back to the insertion site of the distal phalanx and secured over a pullout suture button.
 - Repair using one or two microsuture anchors has been described; however, the insertion of the terminal tendon is immediately adjacent to the origin of the germinal matrix and the risk of iatrogenic injury to the nail bed makes this our less preferred technique.
 - A simpler method of repair involves dermatotendodesis (**TECH FIG 1**). With this method, one or two 2-0 nylon sutures are placed through the skin and tendon ends and sutured in a horizontal mattress fashion. The sutures are left for 3 weeks and then removed. Full-time splinting is continued for a total of 6 weeks and nighttime splinting for an additional 6 weeks.
- Once the repair is completed, the wound is copiously irrigated and the skin is closed with interrupted suture.
- The joint is protected with an extension splint for the length of time the pin is in place.
- We pull the pin at 4 to 6 weeks and continue with nighttime splinting for an additional 6 weeks.
- Active and passive range of motion at the PIP and MCP joints is encouraged to prevent stiffness.



TECH FIG 1 • Example of dermatotenesis performed in the ring finger after a zone I extensor tendon injury. (Courtesy of Philip Blazar, MD.)

■ Closed Mallet Fracture Pinning

- Ideally, before a closed mallet fracture is brought to the operating room for surgical repair, one should attempt to obtain radiographs with the digit held in extension at the DIP joint to see if fracture reduces easily.
 - If seen acutely, oftentimes the fracture will reduce well with extension of the digit.
- At the beginning of the procedure, the C-arm is brought in and joint is visualized radiographically.
- The DIP joint is then flexed in an attempt to bring the dorsal fragment as far distal as possible.
- One 0.028- or 0.035-in. Kirschner wire (K-wire) is then placed just proximal and dorsal to the dorsal fragment and driven across the DIP joint into the middle phalanx.
- The distal phalanx is then extended, and the K-wire should hold the dorsal fragment in a stable position as the phalanx reduces back to the fragment.
- Once adequate reduction has been achieved, a second K-wire is inserted in a retrograde fashion from the tip of the distal phalanx across the DIP joint and

into the middle phalanx.

- The DIP joint is protected with an extension splint throughout the time the pins are in place.
- The pins are pulled in the office at 4 to 6 weeks and nighttime splinting continues for an additional 6 weeks.
- Active and passive range of motion at the PIP and MCP joints is encouraged to prevent stiffness.

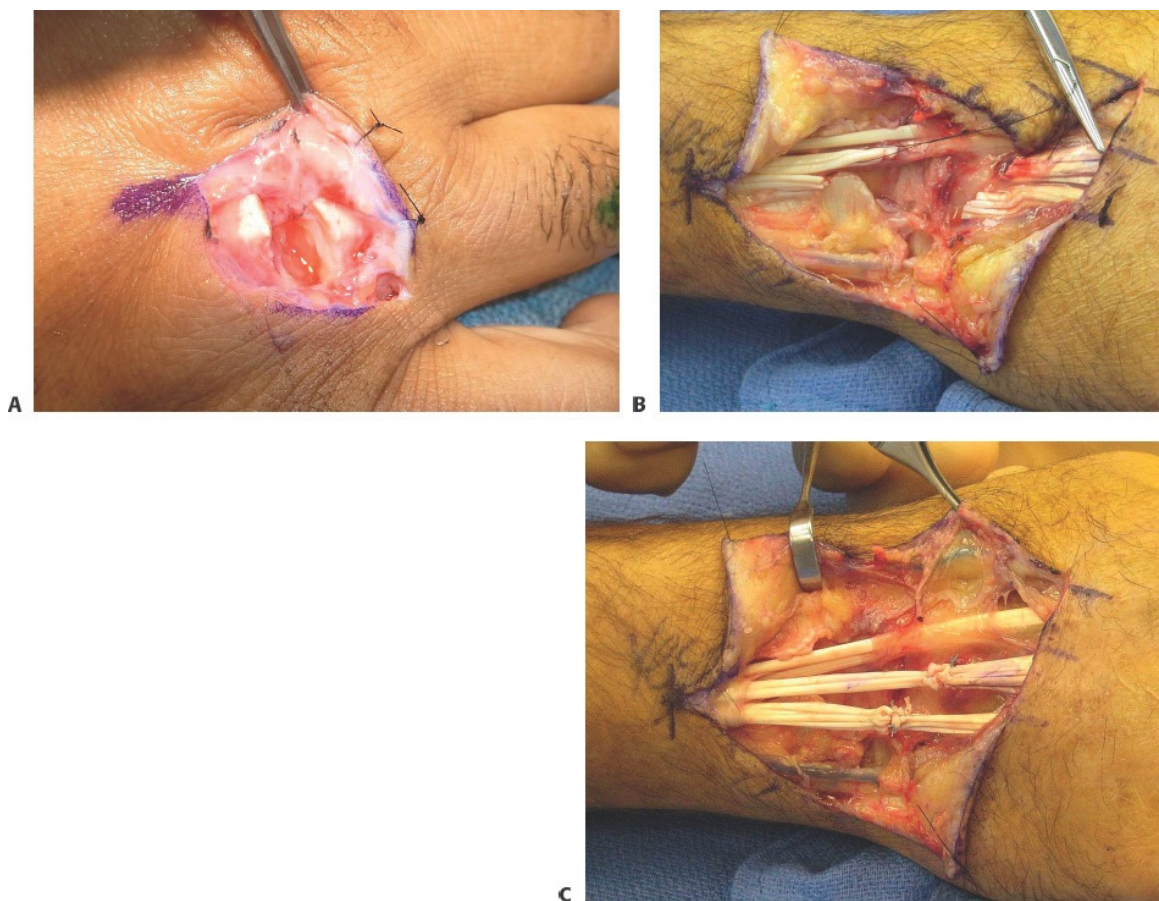
■ Zone III Central Slip Repair

- Zone III injuries overlie the PIP joint and involve the insertion of the central slip.
- If left untreated, the lateral bands will migrate volarly and a boutonniere deformity can develop (PIP joint flexion and DIP joint hyperextension).
- Central slip repair can be achieved by either primary repair in open lacerations or injuries or with suture anchors for avulsion injuries.
 - In 1999, Cluett et al.⁷ found similar biomechanical strengths for both suture anchor repair and primary repair.
- For lacerations, the laceration is extended proximally and distally to provide full exposure of the central slip and assess for any additional injury to the bone and PIP articular surface.
 - In closed, avulsion-type injuries, a dorsal curvilinear approach is utilized. This avoids making a longitudinal incision directly over the PIP joint.
- Skin flaps are raised sharply, taking advantage of the layer between the skin and the extensor apparatus.
- The injured central slip is identified and the tendon edges sharply debrided.
- The PIP joint is pinned in extension with a single 0.035-in. K-wire.
- If primary repair is to be performed, we prefer to perform the repair using a running, interlocking, horizontal mattress stitch popularized by Lee et al.⁸ using a 3-0 or 4-0 braided nonabsorbable suture.
- If suture anchor repair is to be performed, we prefer to place a single mini anchor into the central footprint of the middle phalanx. Care is taken to direct the suture anchor away from the base of the middle phalanx, so as not to penetrate the joint surface with the suture anchor.
- Postoperatively, active DIP motion is allowed. The pin is removed from the PIP joint at 3 weeks. At this point, begin gentle range of motion with hand

therapy and nighttime splinting as needed.

■ Zone V Extensor Tendon Repair

- Extensor tendon injury at the level of the MCP joint is the most common location for extensor tendon disruption (**TECH FIG 2A**).¹
- This zone is also where “fight bite” injuries often occur and special diligence must be made to ensure the MCP joint is thoroughly irrigated to prevent or treat an underlying septic arthritis of the MCP joint.
- There is a high incidence of partial tendon lacerations at this level. Extensor tendon lacerations involving more than 50% of the tendon should be repaired.
- Zone V injuries also must take into account the sagittal bands on the radial and ulnar sides of the MCP joint.
 - If the patient has an acute closed sagittal band rupture, it can often be treated with extension splinting of the MCP joint for 3 to 4 weeks with the PIP joint free.
- Extend the laceration both proximally and distally to ensure there is adequate exposure of the extensor tendon injury at this level and the MCP joint.
- Raise skin flaps with sharp dissection in the plane between the skin and the extensor apparatus.
- With open injuries, the MCP joint should always be explored and irrigated to prevent septic arthritis.
- Evaluate the sagittal band, and if it has been lacerated, perform a primary repair with a braided absorbable suture after the tendon has been repaired.
- At this level, the tendon is beginning to become thicker and may accommodate a core suture. If possible, we prefer to repair the tendon at this level with either a four-strand repair using 3-0 braided, nonabsorbable suture or the running, interlocking, horizontal mattress suture configuration described above (**TECH FIG 2B,C**).
- Postoperatively, there has recently been more emphasis on early, controlled mobilization of the repair.



TECH FIG 2 • A. Initial exploration of a zone V laceration with disruption of the extensor tendon to the ring finger. **B.** Zone VII extensor tendon laceration. **C.** Zone VII extensor tendon repair using core sutures. (Courtesy of Philip Blazar, MD.)

PEARLS AND PITFALLS

Counseling

- It is important to set realistic expectations with your patients for the treatment of mallet fingers. Long-term studies have shown that patients undergoing either surgical or nonoperative treatment will likely have some degree of mild extensor lag at the end of treatment.

Technique

- The dorsal skin can be thin and friable. Take extra care to handle the tissues delicately and develop full-thickness skin flaps.

Indications	■ In soft tissue mallet injuries, splinting is preferable to surgical repair as the skin is thin and sometimes can die after surgery. In addition, suture material can be prominent.
Suture anchors	■ If placing suture anchors into the distal phalanx for a zone I repair, be careful not to place the anchor into the germinal matrix.
Zone V injuries	■ Always explore the MCP joint in open injuries. Wound cultures should be obtained in “fight bite injuries.”

POSTOPERATIVE CARE

- Traditionally, extensor tendon repairs have been treated with initial immobilization for longer periods of time when compared with flexor tendon repairs.
- There is some evidence that for zone V and VI repairs, there are better short-term functional results with early mobilization protocols. There is some evidence of short-term superiority of early, controlled mobilization of extensor tendon repairs but no evidence of long-term superiority of early motion compared with immobilization⁹; plus, there is a higher risk of tendon repair rupture.^{10,11}
- For zone I, II, and III repairs, immobilization of the DIP and PIP joints respectively in extension for 6 weeks after repair is reasonable.
 - At that time, range of motion exercises can begin and nighttime splinting initiated for an additional 6 weeks.
 - Be sure to move the remaining joints of the finger to help prevent stiffness of the entire digit.
- For zone IV, V, and VI repairs, the MCP joints respectively are immobilized for about 4 weeks in extension, followed by gentle range of motion in conjunction with hand therapy. There is variation regarding immobilizing the PIP joints.

OUTCOMES

- Kalainov et al.¹² treated 21 patients with mallet fractures in which greater than one-third of the articular surface was involved with splinting in a 2005 retrospective study. They had good results in terms of pain and function, but their follow-up averaged only 2 years.
- Outcomes of surgical treatment for mallet injuries have been comparable across the various techniques. Most patients will have an extensor lag from 2 to

7 degrees and flexion ranged from 67 to 78 degrees.^{13–16}

- Pratt et al. reported on 27 patients who underwent zone III repairs and were treated with a postoperative protocol that consisted of static immobilization for 3 weeks and early controlled motion for an additional 3 weeks. Twenty-two of 27 patients had good results with mean PIP flexion of 94 degrees. Five fingers had extension lags of an average of 6 degrees.¹⁷
- Newport et al. reported on 101 digits that underwent extensor tendon repair and were treated postoperatively with static splinting.¹⁸ They found that patients with associated injuries (fracture, dislocation, flexor tendon injury) and distal repairs (zones I–IV) did worse than those without injuries and proximal repairs, with flexion loss being the most significant complication.

COMPLICATIONS

- Infection
- Tendon rupture
- Extensor lag
- Wound dehiscence
- Adhesions and stiffness
- Nail deformities

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Stabilization of Extensor Carpi Ulnaris Tendon Subluxation With Extensor Retinaculum

42

CHAPTER

Michael Smith, Jacques A. Machol IV, and Neal Chen

DEFINITION

- Symptomatic recurrent extensor carpi ulnaris (ECU) subluxation over the ulnar head with forearm rotation can be a cause of ulnar-sided wrist pain. Not all patients with subluxation of the ECU are symptomatic, and painless subluxation is not an absolute indication for surgery.
- Symptomatic ECU instability manifests in patients who play sports such as tennis, hockey, squash, golf, or baseball.
- It is suspected that snapping of the ECU over the ulnar head with resisted supination, flexion, and ulnar deviation is the mechanism that leads to symptoms.

ANATOMY

- The ECU tendon runs through the sixth dorsal compartment following an angular path across the ulnar head as it travels from its muscle origin on the lateral epicondyle to its insertion on the base of the fifth metacarpal.
- The ECU ulnarly deviates and extends the wrist. The ulnar deviation is counterbalanced by the radially deviating forces of the abductor pollicis longus, extensor carpi radialis longus, and the extensor carpi radialis.
- The ECU tendon lies just dorsal to the flexion/extension axis of the wrist; therefore, the tendon is at risk for subluxation volar to the flexion/extension axis with hypersupination of the forearm and flexion with ulnar deviation of the wrist.¹

- The ECU tendon is stabilized by the extensor retinaculum.
- The ECU tendon runs through a fibro-osseous tunnel at the level of the distal ulna called the ulnar groove.
 - The average ECU groove depth measures approximately 1.4 mm, and the radius of curvature is approximately 7.0 mm.²
- In addition, the ECU has its own subsheath, which consists of an overlying band of connective tissue measuring 1.5 to 2.5 cm in length that functions to keep the ECU tendon within the ulnar groove.
- There are transverse fibers of the medial wall of the ECU compartment that extend proximally and become confluent with the ECU epimysium. These fibers help prevent volar subluxation of the tendon during supination.^{2,3}
- The ECU subsheath stabilizes the ECU during forearm rotation, while the extensor retinaculum helps prevent bowstringing of the extensor tendons.
- The ECU subsheath also contributes to the dorsal portion of the triangular fibrocartilage complex.
- The distal subsheath contributes more to ECU stability than does the proximal half of the subsheath.⁴
- Wrist flexion and supination are positions of relative instability for the ECU subsheath.⁴

PATHOGENESIS

- Incompetence of the ECU subsheath, whether through attritional wear or acute traumatic injury, is thought to lead to ECU instability.
- Laxity in the ECU subsheath and painless snapping over the ulnar head may be a normal variant, especially in individuals that are ligamentously lax.
- It is proposed that traumatic wrist flexion, ulnar deviation, and supination can result in rupture of the ECU subsheath from its ulnar attachments and lead to the subluxation of the tendon out of the distal ulnar groove.¹
- Symptomatic patients may demonstrate a snap when the wrist is placed in the at-risk position of flexion, ulnar deviation, and supination.
- ECU instability injuries were classified by Inoue and Tamura and separated into three distinct types.
 - The ECU subsheath can have detachment along the ulnar border (type A), the radial border (type B), or a periosteal detachment with expansion of the sheath, creating a false pouch that allows subluxation of the tendon from the ulnar groove (type C).^{5,6}

NATURAL HISTORY

- If left untreated, chronic instability of the ECU tendon can exacerbate ECU tendinopathy as the tendon snaps over the ulnar prominence of the ulnar groove.
- Some authors have theorized that chronic dislocation of the ECU tendon may lead to distal radioulnar joint (DRUJ) instability and eventual degenerative changes at the DRUJ. This phenomenon is uncommon.
- There are some patients who have naturally lax ligaments and have a degree of subluxation of the ECU tendon without previous injury. Their ECU instability is often bilateral and asymptomatic and found incidentally on exam.
 - In general, we recommend observing these patients.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are often younger and participate in stick or racket sports such as tennis, golf, baseball, or hockey.
- Patients will complain of recurrent, painful snapping over the dorsoulnar wrist with wrist supination and pronation that limits their participation in sports, hobbies, or activities of daily living.
- There may be a history of a specific, acute injury.
- On physical exam, the ECU tendon can be palpated subluxating over the ulnar head with circumduction of the wrist.
 - Sometimes, supination and ulnar deviation against resistance are required to produce the snapping.
- If the ECU is irritated, it will often be most painful with full passive radial wrist flexion.
- Occasionally, the clinical exam is inconclusive if the patient is not able to voluntarily subluxate the ECU tendon.
- Painful subluxation of the ECU tendon is an important component of the physical examination, and the surgeon should be cautious if contemplating surgical treatment in the patient who does not have painful demonstrable ECU instability.
- Careful examination of the contralateral wrist should be done to ensure that the patient does not have asymptomatic subluxation of the ECU tendon as a natural variant and the patient's complaints do not have another etiology.
- Other etiologies for the patient's pain are ruled out, such as ulna impaction, ECU tendinosis, DRUJ instability, LT instability, or TFCC tears.

IMAGING

- Routine anteroposterior, lateral, and oblique radiographs of the wrist are obtained to rule out other pathologies that may be causing ulnar-sided discomfort such as fracture or DRUJ arthritis.
- It is important to note positive ulnar variance, as this can indicate ulnocarpal impaction.
- MRI is an option to evaluate for tendon subluxation; however, this is often a dynamic phenomenon that may not be visualized using a static MRI.
- Some authors suggest performing an MRI with both wrists positioned in pronation, neutral, and supination. This provides a comparison with the contralateral wrist to show the ECU tendon within the ulnar groove in all three positions. However, the usefulness of this imaging technique is debated.
- Other pathologies, such as TFCC tears, ECU tendonitis, or longitudinal tears, may be visualized with MRI, but the clinical significance of these findings needs to be considered thoughtfully.
- Dynamic ultrasound may demonstrate ECU subluxation out of the ulnar groove for patients in whom there was not definitive snapping or subluxation elicited during physical exam.⁷⁻⁹ The role of dynamic ultrasound is still in evolution.

DIFFERENTIAL DIAGNOSIS

- ECU tendonitis
- Triangular fibrocartilage complex tear
- Ulnocarpal impaction
- Carpal instability
- DRUJ instability
- DRUJ arthritis
- Ulnar nerve entrapment

NONOPERATIVE MANAGEMENT

- In acute injuries, 4 to 6 weeks of either a long-arm or Muenster cast immobilization is usually sufficient.
- Some authors recommend immobilizing in pronation and slight radial deviation, which allows the ECU subsheath to heal to the ulnar edge of the ulnar groove.¹
- After cast removal, a custom splint is applied and progressive return to activity

is begun in conjunction with occupational therapy.

- Full, unrestricted activity is usually achieved by 3 months if the patient is no longer painful.
- After treatment, some patients will have asymptomatic subluxation.

SURGICAL MANAGEMENT

- For patients in whom symptomatic instability of the ECU tendon persists after a period of immobilization and therapy, operative treatment is considered (**FIG 1**).
- If the ECU sheath is incompetent, a retinacular sling reconstruction should be elected. An ulnar groove deepening is performed only if the sheath is competent.
 - Some authors prefer sling reconstruction for all cases.

Preoperative Planning

- If a patient has an MRI present, it is useful to evaluate the anatomic details to understand if there is a type A, B, or C subluxation.

Positioning

- The patient should be positioned supine on the operating room table with the operative extremity on a hand or upper extremity table.
- Prior to draping the arm, perform an exam under anesthesia to recreate the ECU instability. It is important to note the position of instability preoperatively so one can confirm that the stabilization is effective once completed.
- A nonsterile tourniquet is placed on the upper arm to facilitate hemostasis.
- The arm is held in pronation to facilitate a dorsal approach to the ECU tendon.

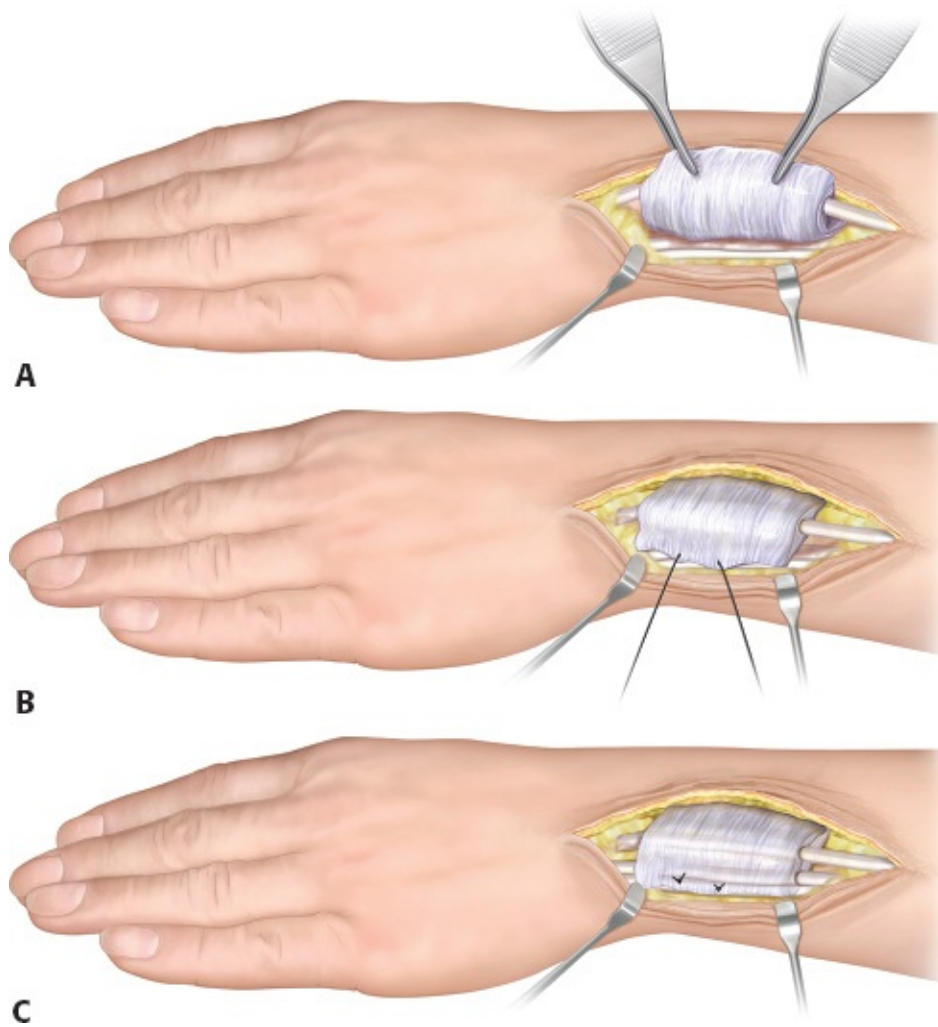


FIG 1 • Anatomic ECU tendon sheath reconstruction. **A.** Exposure of the 6th dorsal compartment and elevation of the extensor retinaculum. **B.** Imbrication of the extensor retinaculum and subsheath. **C.** Final fixation of the extensor retinaculum and subsheath after imbrications.

TECHNIQUES

■ Exposure

- The arm is exsanguinated and the tourniquet is inflated.

- A 5-cm longitudinal incision is made overlying the sixth dorsal compartment and ECU tendon (**TECH FIG 1**).
- After the skin is incised, blunt dissection is carried out through the subcutaneous fat to identify and protect the dorsal cutaneous branch of the ulnar nerve.
- The extensor retinaculum over the sixth compartment should be sharply incised in a longitudinal fashion on its ulnar-most border and the retinaculum carefully dissected off of the underlying ECU subsheath.



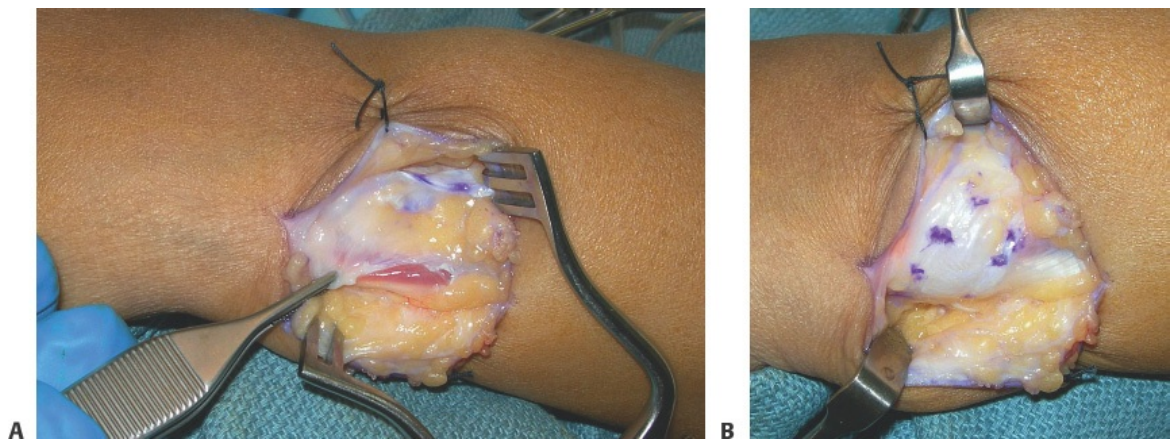
TECH FIG 1 • Marked incision for ECU retinacular sling reconstruction. (Courtesy of Philip Blazar, MD.)

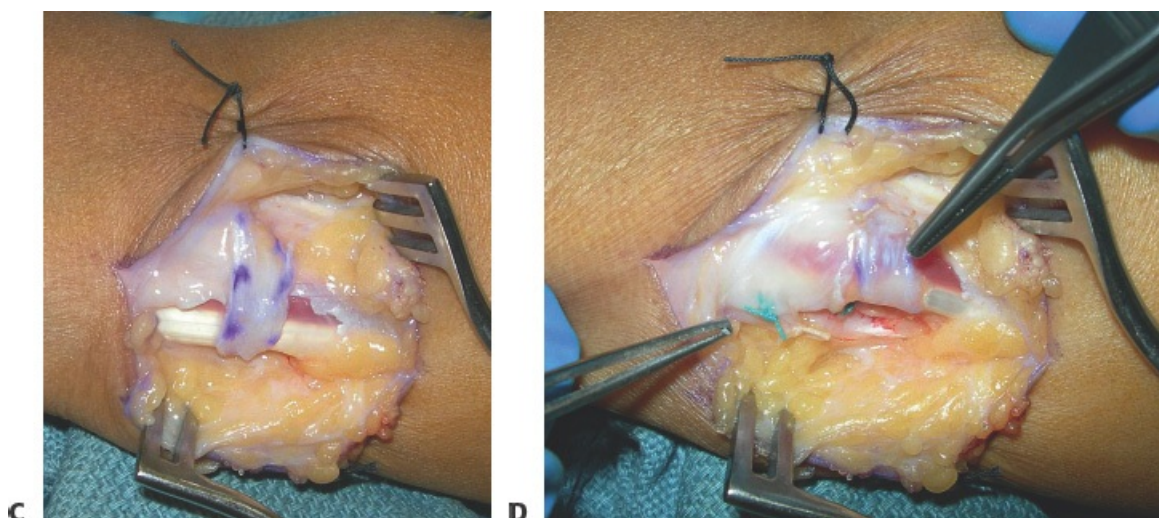
■ Retinacular Sling Reconstruction of the ECU Subsheat

- The extensor retinaculum is carefully dissected from its ulnar border to expose the ECU subsheath (**TECH FIG 2A**).
- Once the ECU subsheath is fully exposed, the type of pathology (type A, B, or C) of the subsheath is noted and the wrist is taken through a full arc of motion from pronation to supination to gauge the behavior of the tendon through wrist range of motion.
- At the level of the ECU subsheath, overlying the ulnar groove, a 3-cm

rectangular flap of retinaculum is developed starting at the second compartment; the base of which is the septum between the fifth and sixth dorsal compartments (**TECH FIG 2B**).

- This sling of retinaculum is then passed from radial to ulnar, volar to the ECU tendon, and folded back to the base of the flap (**TECH FIG 2C**).
- A trial stitch should be placed in order to assess the tightness of the sling in pronation, neutral, and supination in both wrist flexion and extension (**TECH FIG 2D**).
- The sling should not constrict the tendon, but it must still prevent subluxation of the ECU tendon about the ulnar head.
- The flap is sutured to itself using 3-0 nonabsorbable, braided suture.
- The remainder of the extensor retinaculum is anatomically repaired to ulnar border of the retinaculum using an absorbable suture.
- The tourniquet is let down, and hemostasis is confirmed.
- The wound is copiously irrigated, the dorsal incision is sutured, and the patient is placed into a sugar-tong splint with the wrist in mild pronation, extension, and radial deviation.





TECH FIG 2 • A. The extensor retinaculum flap is carefully dissected off the underlying ECU subsheath; this photograph also demonstrates a tear in the ECU subsheath. **B.** The extensor retinaculum rectangular flap is marked. **C.** The extensor retinaculum flap is laid over the ECU tendon in order to ensure adequate length. **D.** The extensor retinaculum flap is provisionally stitched, and stability is confirmed. (Courtesy of Philip Blazar, MD.)

■ Distal Ulnar Groove Deepening

- A dorsoulnar incision is made along the distal ulna starting 5 cm proximal to the wrist and ending 1 cm proximal to the joint (see **TECH FIG 1**).
- The dorsal sensory branch of the ulnar nerve is identified and protected.
- The extensor retinaculum is divided over the ulnar aspect of the sixth dorsal compartment, and care is taken to preserve flaps of retinaculum for later repair.
- The dissection is taken down sharply to the bone along the volar border of the ECU tendon subsheath.
- The ECU tendon within its subsheath is elevated dorsally by sharp subperiosteal dissection to the radial attachment of the subsheath.
 - The tendon subsheath is not routinely opened. However, if one suspects a longitudinal tear of the ECU tendon or other intratendinous pathology, the

subsheath can be opened at this point and the tendon pathology addressed.

- A power bur is then used to deepen the distal ulnar groove by 2 to 3 mm within the central groove. The groove is deepened until the ECU subsheath no longer subluxates with forearm rotation.
 - An alternative method is to perforate the cortex with a small drill or K-wire and then impact the cortex with a bone tamp so it sits deeper than the adjacent cortex.
- The ECU subsheath is reduced into the reconstructed groove, and two suture anchors are placed along the ulnar margin of the groove to maintain reduction.
 - The suture anchors are passed through the ulnar border of the ECU subsheath in a horizontal mattress pattern, and any redundant sheath is imbricated with the sutures.
- The sutures are tied, and the ECU tendon with its subsheath is secured to the distal ulna.
- The wound is copiously irrigated with normal saline.
- The tourniquet is let down, and hemostasis is obtained.
- The extensor retinaculum is repaired with an absorbable braided suture, and the subdermal and epidermal layers are then closed.
- A long-arm splint is applied with the elbow in 90 degrees of flexion and the wrist in neutral.

PEARLS AND PITFALLS

Approach

- Identify and protect the dorsal cutaneous branch of the ulnar nerve throughout the procedure.
- Inspect the ECU subsheath for injury or attenuation and determine if the subsheath can be repaired or will require reconstruction.

Ulnar groove deepening

- If the ulnar groove appears shallow, plan to perform an ulnar groove deepening.

Stability

- Be sure to check stability in extremes of ulnar deviation and supination with wrist flexion to ensure the ECU is stable before leaving the operating room.

Pitfalls

- Avoid injury to the dorsal cutaneous branch of the ulnar nerve with gentle retraction and protection throughout the procedure.
- Avoid overtightening the extensor retinaculum sling. The tendon should glide freely through the sling at the conclusion of the operation.
- Suture anchors placed into the deepened groove may inadvertently capture the ECU tendon.

Postoperative care

- Counsel patients that recovery can take 3–6 mo from the date of operation and they will need a period of immobilization and therapy after the operation.

POSTOPERATIVE CARE

- The wrist is initially immobilized in a sugar-tong or long-arm splint in the immediate postoperative period.
- At 2 weeks, the patient is converted to a Muenster-style orthoplast splint to prevent pronation and supination of the forearm but to allow elbow flexion and extension.
- At 6 weeks, occupational therapy is initiated beginning active and active assisted range of motion.
 - Passive range of motion and stretching are added progressively if needed.
 - The patient is advised to avoid forceful supination and flexion and heavy lifting during the rehabilitation period.
- Strengthening activities are initiated around 3 months postoperatively.

OUTCOMES

- A number of case reports and small case series have described the various techniques and outcomes for ECU tendon stabilization, but there is no level I evidence for surgical treatment of ECU instability.
 - Allende and Le Viet reported that 23 of 28 patients had good or excellent results at an average follow-up of 23 months after extensor retinaculum sling stabilization of the ECU tendon.⁶
 - MacLennan et al.⁹ reported improvements in DASH scores at 31 months after groove deepening.

COMPLICATIONS

- Injury to the dorsal cutaneous branch of the ulnar nerve
- Recurrent subluxation of the ECU tendon

- Infection
- Complex regional pain syndrome
- Decreased range of motion
- Decreased grip strength

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CHAPTER Trigger Finger Release

Donato Perretta, Jacques A. Machol IV, and Neal Chen

DEFINITION

- Trigger digit, also known as stenosis tenosynovitis or tenovaginitis (tendon sheath inflammation), is a pathology characterized by painful locking or clicking of the fingers or thumb as a result of impaired gliding of the flexor tendon at the level of the A1 pulley.

ANATOMY

- The proximal edge of the A1 pulley begins approximately at the level of the metacarpal heads of the fingers. This corresponds to the distal palmar crease.
 - For the index finger, this line can be extrapolated radially.
 - In the thumb, it is at the level of the proximal digital crease.

PATHOGENESIS

- Trigger digit is caused by a thickening of the flexor tendon sheath, specifically the A1 pulley.
- The pathological change in the A1 pulley has been described as fibrocartilaginous metaplasia.¹
- Over time, the flexor tendon can also undergo degenerative changes consistent with tendinosis.² The resulting imbalance in the size of the A1 pulley and the enclosed flexor tendons causes catching and locking.

NATURAL HISTORY

- The thumb is the most commonly involved digit.³
- Women are more commonly affected than are men.
- There are no long-term studies documenting the natural history of untreated

trigger finger.

- The condition may progress from tenderness at the A1 pulley to painless clicking to painful triggering of the finger that requires passive manual extension.
- Over time, flexion deformities may develop at the PIP joint due to persistent triggering.
- The condition is more common and progresses more often in patients with endocrinopathies and inflammatory arthritides.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- Tenderness over the A1 pulley
- Palpable nodule over the A1 pulley
- Painful popping or catching of the digit with flexion
- Inability to actively extend the PIP joint from a flexed position
- Flexion contracture of the PIP joint with long-standing trigger finger

IMAGING

- Imaging is not necessary.

DIFFERENTIAL DIAGNOSIS

- Locked MP joint. The collateral ligament can become entrapped over a metacarpal head osteophyte. This usually presents as inability to extend the digit fully after the collateral is locked.
- Early swan-neck deformity with snapping of lateral bands as they dislocate dorsally
- Subluxation of the extensor tendon after sagittal band rupture. In this situation, the finger can be passively extended and then can be actively maintained in extension. However, if the finger is flexed, the extensor tendon will subluxate and the finger cannot actively extend fully.

NONOPERATIVE MANAGEMENT

- Corticosteroid injection into or superficial to the A1 pulley is the first-line treatment. This is usually performed using a 25-gauge needle with 0.5 cc of 1% plain lidocaine and 5 mg of Kenalog. Injections can eliminate symptoms, but the duration of their effect is unpredictable.
- One study showed that after injection, 56% of the digits had a recurrence of symptoms within a year. Recurrence was associated with younger age,

insulin-dependent diabetes mellitus, involvement of multiple digits, and a history of other tendinopathies.

- Symptoms often recurred several months after the injection.⁴
- Taras et al. reported that extra-sheath injections may be more effective than those administered within the sheath.⁵
- Splinting the MCP joint of the affected digit in extension is another commonly used nonoperative measure. Colbourn et al.⁶ demonstrated short-term improvement in symptoms with a removable orthoplast splint in 28 patients.

SURGICAL MANAGEMENT

- Percutaneous A1 pulley release is a well-described treatment option that has been reported to be safe and effective.⁷ The A1 pulley is released under local anesthesia using a large-bore needle while the patient intentionally triggers the affected finger.
- Open A1 pulley release is our preferred treatment method in a patient with recurrent symptoms after two injections.
- Patients with rheumatoid hand deformity often develop tenosynovitis of the flexor tendons. In this group of patients, A1 pulley release is not recommended, as it can result in increased ulnar drift of the fingers. Instead, annular pulley-sparing tenosynovectomy and carpal tunnel release should be performed. The ulnar slip of the superficialis can be resected from the middle phalanx to reduce the bulk of tendon within the flexor sheath.⁸

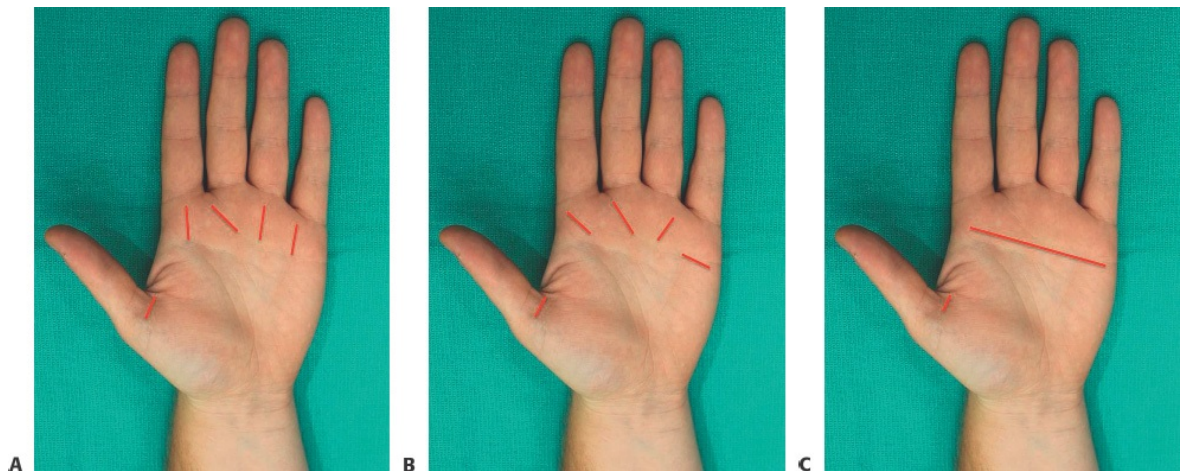


FIG 1 • Trigger finger incisions for single-digit surgery (A,B) and for multiple-digit surgery (C).

Positioning

- Supine with hand table
- The procedure may be performed with a brachial tourniquet with infiltration of local anesthetic into the surgical site.
- Intravenous sedation can be used as an adjunct.

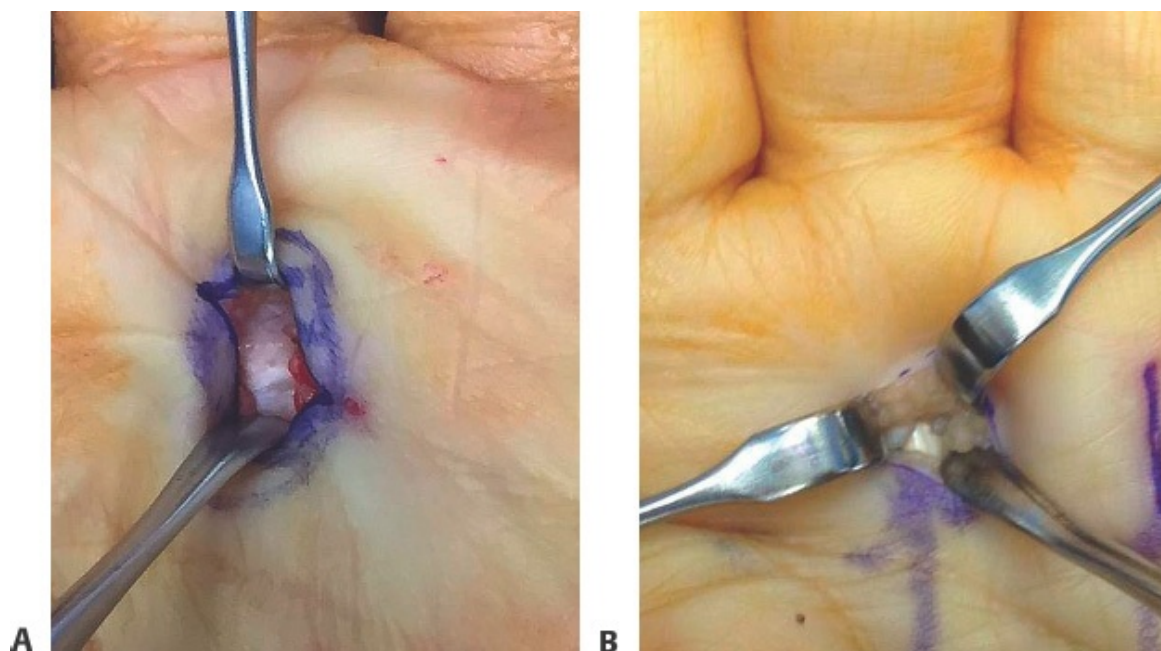
Approach

- If one digit is to be addressed, then a longitudinal or oblique incision is made over the A1 pulley (**FIG 1A,B**). The pulley lies over the metacarpal head.
- If adjacent digits are to be addressed, a transverse incision is used. Often, this is aligned within the distal palmar crease (**FIG 1C**).

TECHNIQUES

■ Open A1 Pulley Release

- After skin incision, blunt dissection is made down to the A1 pulley (**TECH FIG 1A**).
 - Retractors are placed on either side of the pulley to prevent damage to the neurovascular bundles.
- A no. 15 blade is used to incise the A1 pulley in line with the longitudinal axis of the finger in the center of the flexor tendon/pulley (**TECH FIG 1B**).
- Some surgeons describe an A0 pulley proximally or a proximal fascial band that may result in persistent triggering.
- One should be cautious not to release the A2 pulley distally.
- The patient is asked to actively flex the fingers down to the palm, and the presence of triggering is assessed. This can be done passively if the patient is unable to comply.
- If triggering continues once the entire A1 pulley has been released, excision of the ulnar slip of the FDS tendon is an option. This can be performed through a Bruner-type volar incision over the PIP joint.
- The skin is closed with 5-0 nylon interrupted sutures.



TECH FIG 1 • **A.** Identification of the A1 pulley. **B.** Flexor tendon is visible after A1 pulley release.

PEARLS AND PITFALLS

Incomplete release

- The entire A1 pulley should be divided under direct visualization.

Persistent triggering after complete A1 pulley release

- There is a band, which some call the A0 pulley, which lies proximal to the A1 pulley. This should be released if the finger still triggers after A1 pulley release.
- If triggering is still present after A1 pulley, one slip of the FDS tendon should be excised. Usually, the radial slip is preserved and the ulnar slip excised to help avoid ulnar drift of the digits.

Injury to neurovascular bundle

- Care must be made during exposure to protect the neurovascular bundle during A1 pulley release.

Bowstringing

- Release of the A2 tendon sheath distal to the A1 pulley may lead to tendon bowstringing.

POSTOPERATIVE CARE

- A sterile dressing is placed. It is removed on postoperative day 3, and digital motion is encouraged.
- Sutures are removed 10 days after surgery.
- No formal therapy is indicated.

OUTCOMES

- Outcomes are generally excellent.
- Recurrence rates after surgery have been reported at 3%.
- Rates of reoperation have been reported at 1% to 2.4%.³⁻⁵

COMPLICATIONS⁹

- Infection (superficial or deep)
- Digital nerve or artery injury
- Incomplete release
- Persistent swelling and pain
- Flexion contracture
- Tendon bowstringing

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44 First Dorsal Compartment (de Quervain) Release

CHAPTER

Donato Perretta, Jacques A. Machol IV, and Neal Chen

DEFINITION

- de Quervain syndrome is defined as tenosynovitis of the first dorsal compartment. The first extensor compartment contains the tendons of the extensor pollicis brevis (EPB) and abductor pollicis longus (APL).

ANATOMY

- The first dorsal compartment is the most radial extensor compartment at the level of the wrist and contains the tendons of the EPB and APL. The extensor retinaculum is the ceiling of the compartment.
- The APL may have multiple slips, and there may be separate subsheaths for both the APL and EPB.¹ The APL is more radial and volar, whereas the EPB is more ulnar and dorsal. The separate subsheath for the EPB may be missed if one does not look for it routinely.

PATHOGENESIS

- Although this is commonly described as tendonitis, histologic markers of inflammation are not present. The tendon sheath of the first compartment is thickened, and there is deposition of mucopolysaccharide, an indicator of myxoid degeneration.²
- The disease is also common in pregnancy and the postpartum interval. It often is self-limited and resolves with birth or the termination of breast-feeding.³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Tenderness at the radial styloid in the first compartment
- Positive Finkelstein test (radial wrist pain with ulnar deviation of the wrist while the thumb is held into the palm)

IMAGING

- Radiographs of the wrist are useful if the diagnosis is in doubt. They can help exclude other degenerative conditions about the wrist and thumb.

DIFFERENTIAL DIAGNOSIS

- Radiocarpal arthritis
- Intersection syndrome (pain and crepitus in the distal forearm at the intersection of the first and second dorsal compartments)
- Thumb basal joint arthritis
- Scaphoid or carpal fracture
- STT arthritis
- Injury or irritation of the superficial branch of the radial nerve

NONOPERATIVE MANAGEMENT

- A forearm-based thumb spica splint is usually the first-line treatment.
- Steroid injection into first dorsal compartment sheath is an effective treatment. Our preference is to use 0.5 cc of 1% lidocaine and 0.5 mg of dexamethasone.
 - About 80% of patients will experience symptomatic improvement after one injection, and half will remain symptom-free at 1 year.⁴
- Steroid injection may be more effective than splinting for breast-feeding mothers.³
 - Some pediatricians or obstetricians object to the use of steroid injections while breast-feeding, however, and this should be discussed with other caregivers. There is concern that trace amounts of steroid can enter the breast milk and that lactation can be affected after injection.⁵

SURGICAL MANAGEMENT

- First dorsal compartment release is indicated after failure of nonoperative management.
- Conservative measures such as splinting and injection should be attempted before surgical intervention.

Positioning

- Supine, with hand table, with brachial tourniquet. Local anesthetic infiltration is used.

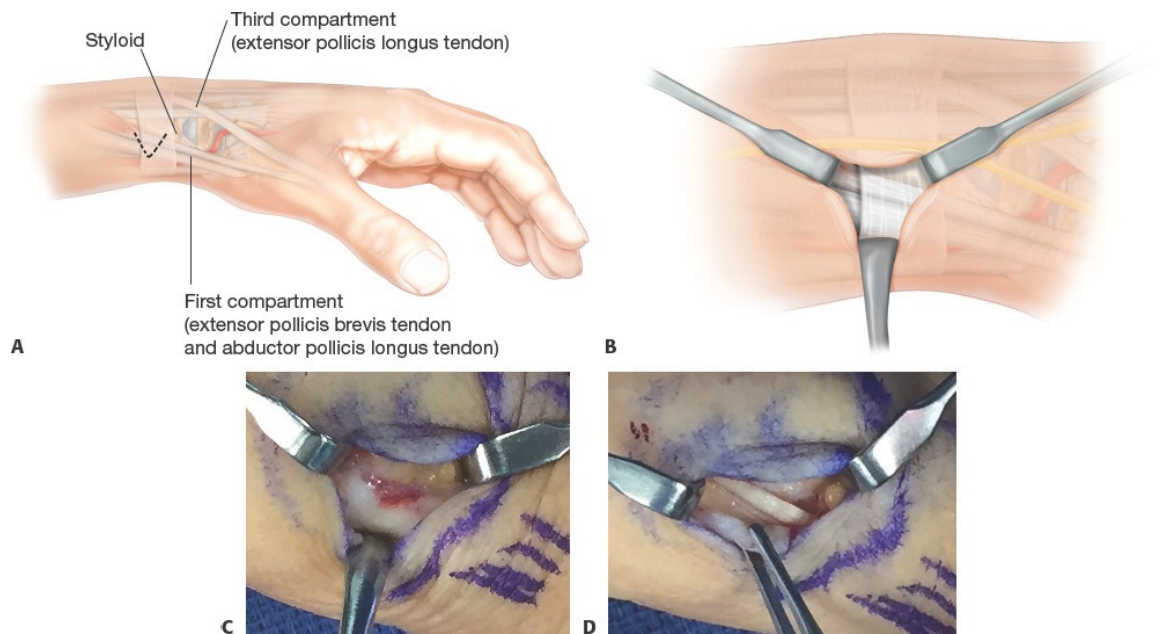
Approach

- Release of the compartment can be accomplished with a chevron, transverse, or longitudinal incision.

TECHNIQUES

■ First Dorsal Compartment Release

- A 2-cm incision is made 1 cm proximal to the distal extent of the radial styloid (**TECH FIG 1A**).
- The first dorsal compartment is exposed (**TECH FIG 1B,C**).
- Care is taken to avoid injuring the superficial branch of the radial nerve, which travels superficial to the extensor retinaculum.
- Injury to the radial sensory nerve can be minimized with retractors placed proximally and distally rather than dorsally/volarly.
- The first dorsal compartment is released longitudinally at the dorsal edge (**TECH FIG 1D**). This prevents volar subluxation of the tendons.
- The APL and EPB are wholly inspected to ensure that all subsheathes have been released.
 - Up to half of patients may have separate compartments for these tendons. It is theorized that these accessory compartments predispose to de Quervain's.⁶
- Interrupted buried 3-0 absorbable monofilament sutures are used for wound closure, and Steri-Strips are applied.
- A thumb spica plaster splint is applied for 7 to 10 days.



TECH FIG 1 • A. The chevron (*dashed lines*) is the preferred incision for release of the first dorsal compartment. **B.** Sheath of first dorsal compartment exposed. **C.** Once the skin is incised, care is taken to avoid the radial sensory nerve. The blood on the sheath is from the preoperative local anesthetic injection. **D.** First dorsal compartment tendons exposed. The sheath is released from the dorsal side to prevent volar subluxation of the tendons. The forceps are holding the sheath. The APL and EPB are visible, with the APL being the more volar structure.

PEARLS AND PITFALLS

Nerve injury

- Identify the superficial branch of the radial nerve. Aggressive retraction results in a problematic injury to the nerve and persistent pain.

Volar tendon

- Leave a cuff of tissue volarly when incising the sheath.

subluxation

Incomplete release

- Be sure to release both the EPB and APL as they often have separate subsheaths.

POSTOPERATIVE CARE

- The splint is removed in 7 to 10 days, and immediate at-home range-of-motion exercises are initiated. Typically, there is no need for formal therapy.

OUTCOMES

- A consecutive series of 94 patients found symptom resolution in 100% of patients.
- There were six perioperative complications, including one superficial wound infection, one delayed wound healing, and four transient lesions of the radial sensory nerve.⁷

COMPLICATIONS

- Infection
- Injury to superficial radial nerve
- Scar tenderness

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Section X: Flaps and Microsurgery

45 Flap Coverage of Fingertip Injuries

CHAPTER

Kate Elzinga and Kevin C. Chung

DEFINITION

- Fingertip injuries are defined as injuries that occur distal to the insertion of the flexor and extensor tendons of the finger.¹
- Fingertip injuries are the most common hand injuries; the fingertips are relatively unprotected compared to the rest of the hand.
- The fingertip plays an important role in fine motor skills, precise sensation, and hand aesthetics. Reconstruction of fingertip injuries can restore form and function for injured patients.
- The goals of fingertip reconstruction include the following:
 - Durable coverage
 - Preservation of sensation
 - Preservation of length
 - Maintenance of distal interphalangeal (DIP) joint function
 - Optimized appearance
 - Minimized donor-site morbidity
 - Permitting early return to work and recreational activities
 - Minimizing pain, in the short and long term
- Fingertip flaps are used to cover injuries with exposed bone and tendon. Local (V-Y advancement) and regional (thenar, cross-finger) flaps are useful options.
- Local flaps, such as the Atasoy-Kleinert V-Y advancement flap,² are the simplest flaps used for reconstruction; immobilization is not required and

donor-site morbidity is minimal.

- Regional flaps are employed when local flaps are not available because of the injury geometry (regional flaps are best used for volar oblique injuries) and size (local flaps can only be advanced 1 cm). Regional flaps require two-stage procedures and immobilization of the injured, and often adjacent, finger.

ANATOMY

- The volar fingertip is covered with glabrous skin. The epidermis is thick, and papillary ridges are prominent.
- The fingertip pulp is composed of fibrofatty tissue that is stabilized volarly by fibrous septa that run from the distal phalanx periosteum to the dermis and laterally by Grayson and Cleland ligaments.
- The proper digital nerve trifurcates distal to the DIP joint, sending branches to the nail bed, distal fingertip, and volar pulp. The proper digital artery also trifurcates at this level, sending two branches dorsally and one branch laterally.

PATHOGENESIS

- Trauma is the most common cause of fingertip injuries.³
- Common mechanisms of fingertip injuries include sharp injuries from a knife, power tool, or lawn mower and crush injuries from closing a door, a strike with a hammer, dropping a heavy object, becoming trapped in machinery, or sporting activities.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A careful patient history and physical examination help determine which flap options are suitable for a particular patient.
 - Some patients may prefer rapid return to their work and avocations and will refuse fingertip reconstruction, opting for fingertip amputation instead.
- A focused hand history must include age, sex, hand dominance, and occupation and recreational activities. The patients' goals are explored, including their need to return to work, their availability and willingness to undergo secondary procedures and hand therapy, and the importance of appearance.
 - Aesthetic outcome may be more important for females and patients from certain Asian cultures.
- Important considerations from the patient's past medical history include smoking, diabetes mellitus, peripheral vascular disease, connective tissue

disorders, arthritis, Dupuytren disease, and previous hand injuries.

- The presence of comorbidities may affect reconstruction options offered given their effect on flap vascularity and wound healing.
- Key injury factors to consider include the time of injury, mechanism of injury (sharp vs crush), contamination, and associated injuries.
- On physical examination, the defect size is measured. The level of the injury is assessed clinically and using radiographic imaging.
- Missing tissue (skin, pulp, bone, nail) and exposed structures are documented. The geometry of the injury is assessed and classified as volar oblique, transverse, or dorsal oblique (**FIG 1**).¹
- Tissue contamination is assessed, and any early signs of infection are noted.
- Surrounding tissues and digits are examined as potential donor sites.

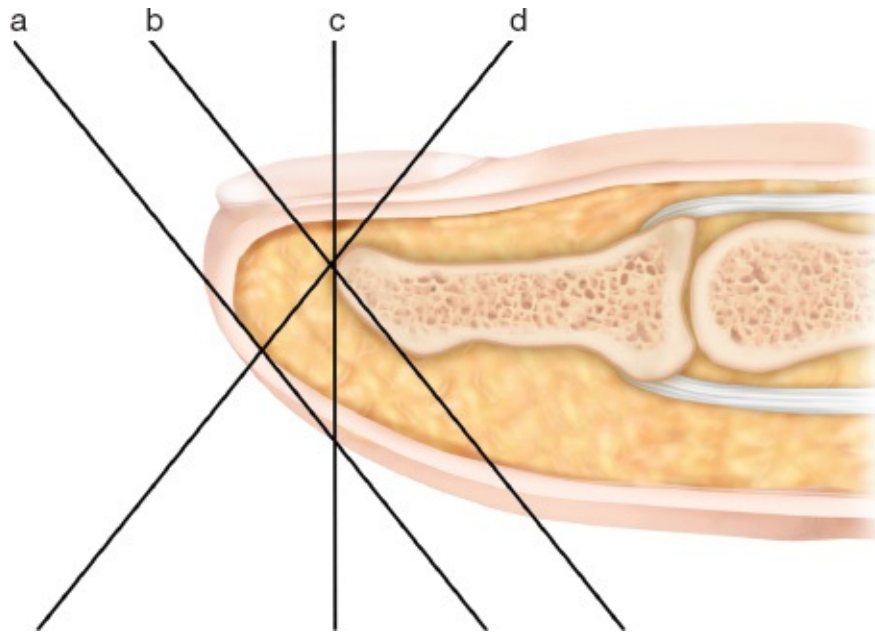


FIG 1 • The angle of amputation is assessed to aid in selection of an appropriate local or regional flap for fingertip coverage. Volar oblique injuries with no exposed bone (*a*) can heal by secondary intention. Volar oblique injuries with exposed bone (*b*) can be reconstructed with regional flaps (thenar flap, cross-finger flap). Transverse (*c*) and dorsal (*d*) oblique injuries with exposed bone can resurfaced with a volar

V-Y advancement flap.

- The integrity of the flexor digitorum profundus (FDP) and extensor digitorum communis (EDC) tendons is tested; it is important not to miss an associated jersey finger or mallet finger injury.

IMAGING

- Plain radiographs can identify fractures of the finger and the presence of a foreign body.
- Three radiographic views of the finger and amputated part should be obtained following a fingertip amputation.

NONOPERATIVE MANAGEMENT

- Small defects (less than 1 cm²) with no exposed bone can be treated nonoperatively.⁴
- Dressing changes are performed daily to maintain a clean moist wound bed as the wound heals by secondary intervention over several weeks.
- Outcomes are typically excellent in these cases as glabrous sensate skin heals over the exposed soft tissues.⁵
- Immobilization is not required and range-of-motion exercises are performed throughout.

SURGICAL MANAGEMENT

- Full-thickness skin grafts (FTSGs) can be considered for coverage of large soft tissue avulsion injuries without exposed bone or tendon.
- The glabrous skin of the hypothenar eminence is the preferred harvest site for volar skin defects. Palmar skin is an excellent donor site for structure and color matching of the fingertip skin; the resultant scar from the palm can be rather imperceptible.
- Skin grafting promotes faster wound coverage, but sensation, color, and durability are inferior to secondary healing.⁵

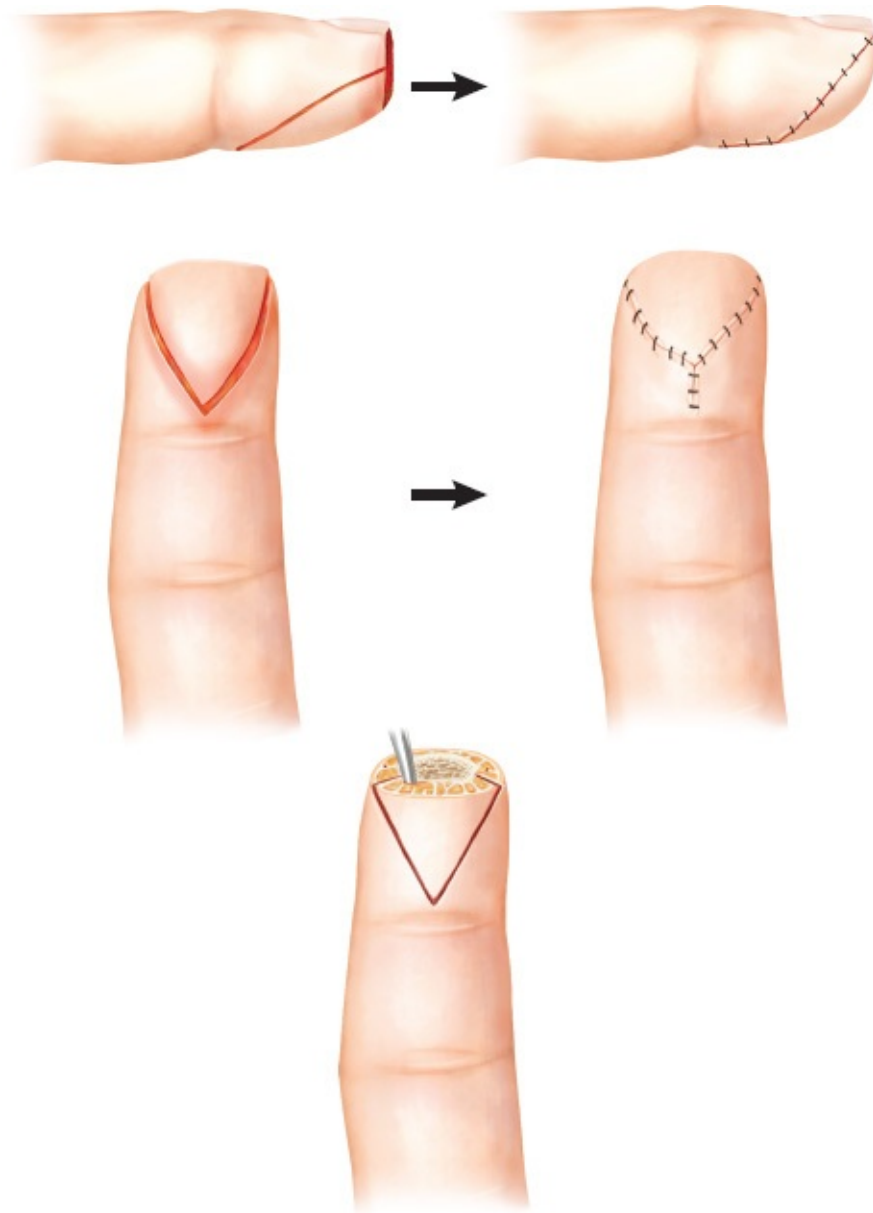


FIG 2 • Volar oblique fingertip defects can be closed with a V-Y flap. Distally, the fibrous septa are released from the undersurface of the flap to allow advancement of the flap distally into the defect, where it is sutured over the wound.

- Replacement of amputated tissue as a composite graft may be considered; outcomes are best for pediatric patients younger than 6 years of age within 5 hours of the amputation.⁶

- Fingertip flaps preserve finger length. Early coverage of exposed bone and tendon decreases the risk of osteomyelitis and tendon desiccation. Protecting the terminal phalanx with a flap preserves bone length that supports the overlying nail.
- The volar V-Y advancement flap (**FIG 2**) is well suited for transverse and dorsal oblique fingertip injuries.
 - The V-Y flap can cover defects of up to 2 cm² and can be advanced 1 cm.
- The thenar flap (**FIG 3**) and cross-finger flap (**FIG 4**) provide coverage for volar oblique injuries. The thenar flap provides improved sensory recovery and has a less conspicuous donor site compared with the cross-finger flap but requires greater finger flexion for inset, which can cause joint stiffness, particularly in elderly patients. However, the lack of donor-site morbidity and predictable outcomes makes the thenar flap our first choice, if possible, over the cross-finger flap.
 - The cross-finger flap can be used for defects up to 1.5 × 2.5 cm in size.
 - The thenar flap can be designed to cover the entire pulp with a width of up to 2 cm.

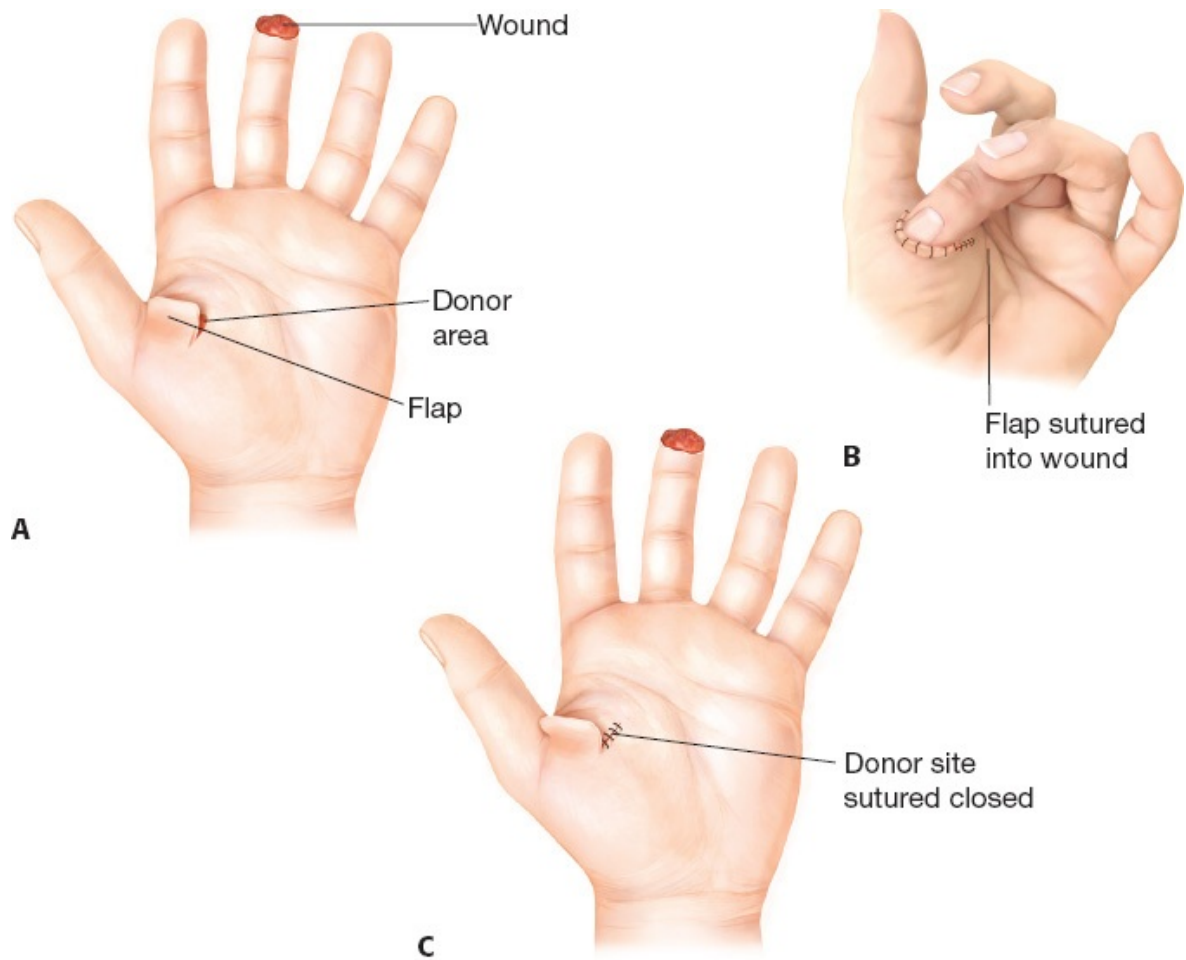


FIG 3 • A. Proximally based thenar flap is elevated from distal to proximal. **B.** Narrow donor sites may be closed primarily. **C.** This is done prior to flap inset to the fingertip defect to facilitate suture placement.

Preoperative Planning

- The risks and benefits of flap coverage for fingertip injuries are discussed with the patient during their initial assessment and reviewed again prior to their surgery.
- Fingertip and/or the removal of exposed bone followed by secondary intention healing are discussed as alternative treatment options.

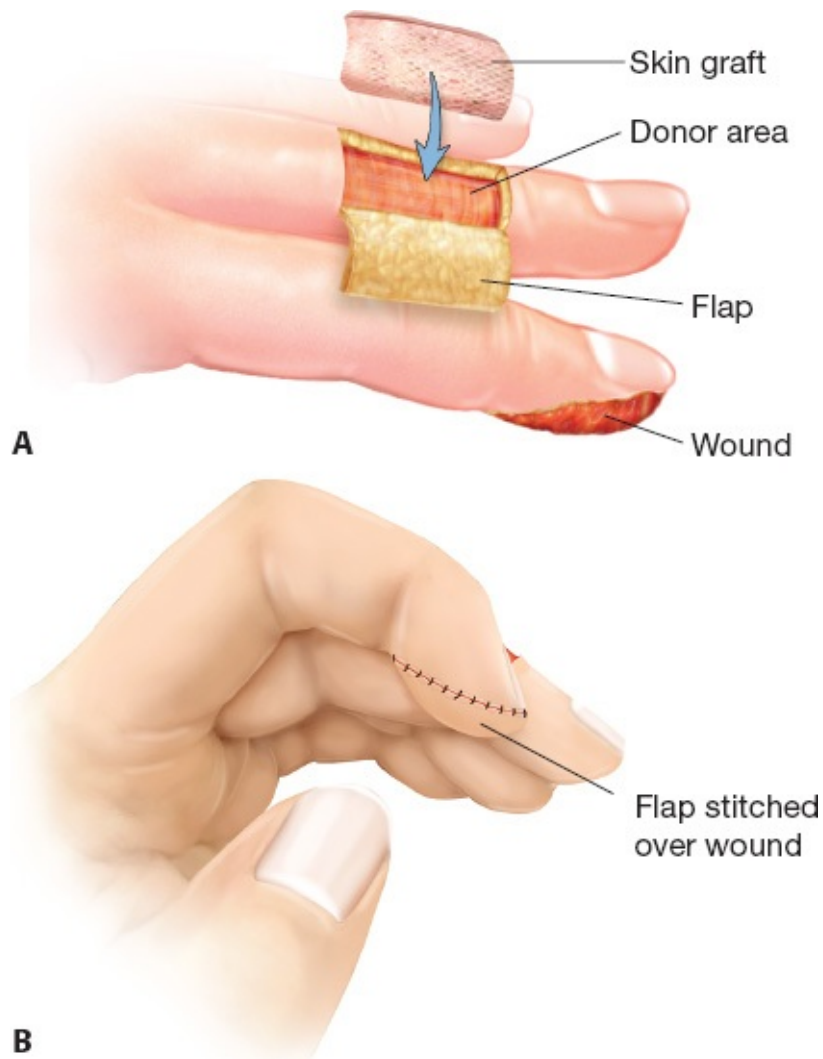


FIG 4 • A. The cross-finger flap is composed of skin and subcutaneous tissue from the dorsal middle phalanx of the adjacent finger. **B.** The flap donor site is closed with an FTSG.

- Benefits of flap coverage include preservation of finger length, provision of durable soft tissue coverage, and good aesthetic results.
- Drawbacks include the creation of a donor site, the possibility of flap failure, and the need for longer immobilization.
- Cross-finger and thenar flaps require the injured digit to be placed in flexion, which can lead to postoperative stiffness.
- These flaps are contraindicated in patients at high risk of joint contractures, eg, elderly patients with arthritis or Dupuytren disease.

- The thenar flap cannot be performed in patients without adequate passive metacarpophalangeal (MCP) and interphalangeal joint flexion.

Positioning

- The patient is positioned supine with the arm on a hand table.

Approach

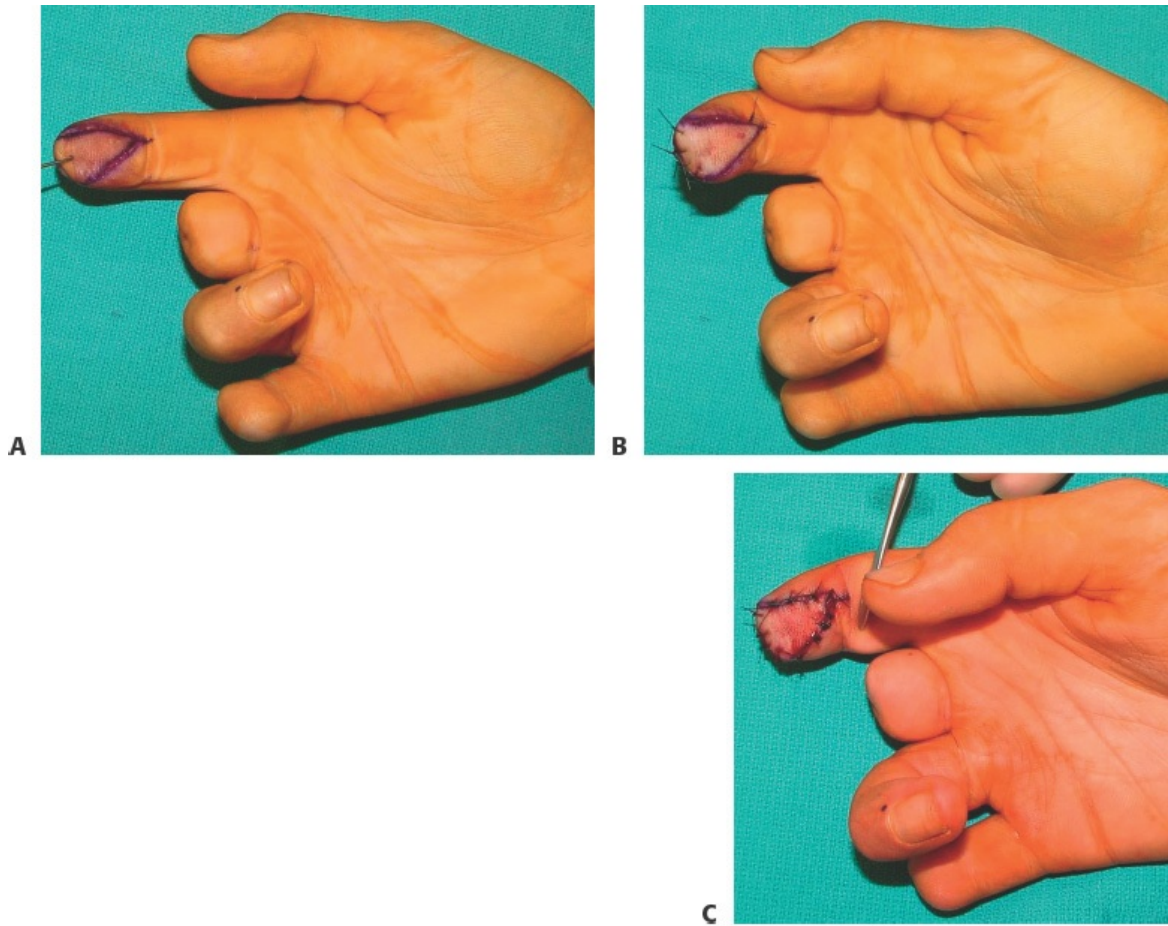
- Loupe magnification is helpful.
- Incisions are planned prior to inflation of the tourniquet.
- Exposed bone is smoothed out with a rongeur. Minimal shortening is performed.
- Soft tissues are debrided of all nonviable and contaminated tissue. A healthy wound bed is established prior to flap reconstruction.
- The sterile nail matrix should be shortened 2 mm proximal to the tip of the distal phalanx to prevent a hook-nail deformity.⁷ A hook-nail deformity can occur when there is a lack of distal support for the sterile matrix.
- The neurovascular bundles and FDP tendon insertion are protected throughout.

TECHNIQUES

■ V-Y Advancement Flap

- The flap width is marked to match the defect width distally; proximally, it is tapered as a V.
 - The proximal flap edge is traditionally located at volar midline of the distal interphalangeal (DIP) joint crease; proximal extensions have been described (see **FIG 2**).⁸
- The injured finger is exsanguinated, and a finger tourniquet is placed.
- The flap is incised; dissection is performed through the dermis. Once the subcutaneous tissues are exposed, no further deep dissection is required; this prevents injury to the bilateral neurovascular structures (**TECH FIG 1A**).
- Distally, the fibrous septa are divided from the distal phalanx periosteum to permit flap advancement.
- The central undersurface of the flap must not be undermined to maintain flap vascularity.

- The flap is inset into the defect and sutured into place with 4-0 nonabsorbable monofilament suture. The flap is secured to the surrounding intact skin and nail. Tension is avoided at the tip of the finger to lessen the risk of a hook-nail deformity.⁹
- The donor site is closed longitudinally in V-Y fashion (**TECH FIG 1B**). Alternatively, the donor site can be left open to heal secondarily, particularly if flap tension is a concern.⁹
- The tourniquet is released and flap vascularity is assessed (**TECH FIG 1C**). Alternating sutures may be released to lessen tension on the flap; these open areas are left to heal by secondary intention.
- Antibiotic-impregnated gauze is placed over all incisions and covered with sterile gauze. A soft finger dressing is applied.
 - A light dressing can be applied daily until the incisions are healed.
- The sutures are removed 2 weeks postoperatively.
- Range-of-motion (ROM) exercises may be started on postoperative day 2 to prevent finger stiffness.



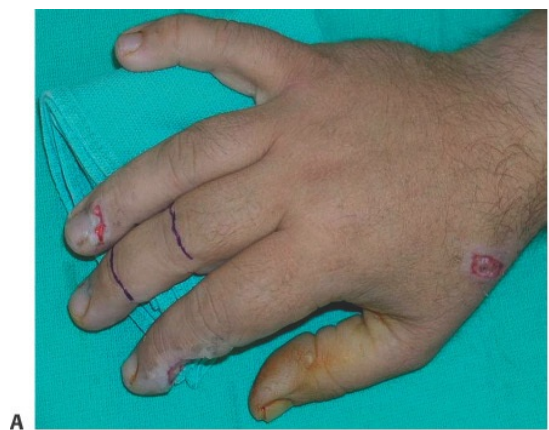
TECH FIG 1 • A. The V-Y advancement is designed with a distal width matching the width of the defect. Proximally, the flap is tapered to a V at the volar midline of the DIP joint crease. The dermis is incised, exposing the subcutaneous tissues below. **B.** The V-Y advancement flap is inset distally to the surrounding intact skin and nail. The donor site is closed proximally in a longitudinal V-Y fashion. **C.** The tourniquet is released, and the vascularity of the flap is assessed. Color, capillary refill, temperature, and turgor of the flap are examined.

■ Cross-Finger Flap

- A template of the defect is used to mark the flap dimensions on the dorsum

of the middle phalanx of the adjacent donor finger (**TECH FIG 2A**).

- The flap is pedicled on the side of the donor finger adjacent to the defect.
- The lateral extent of the flap can be marked as far as at the junction of the glabrous and nonglabrous skin for larger defects.
- The arm is exsanguinated and a tourniquet inflated.
- The flap is elevated sharply, just above the paratenon, beginning from the edge of the donor finger farthest from the injured finger (**TECH FIG 2B**). Cleland ligament is divided.
- The flap remains hinged to the side of the finger closest to the injured finger, along the midaxial line (**TECH FIG 2C**; see **FIG 4**).
- The injured finger is flexed, and the flap is secured to the flap using 4-0 nonabsorbable monofilament sutures (**TECH FIG 2D,E**).



TECH FIG 2 • A. The fingertip defect is marked on the dorsum of the middle phalanx of the adjacent donor finger using a template of the wound. The flap is hinged on the side of the donor finger closest to the defect. **B.** The flap is incised sharply and elevated in the loose areolar plane above the paratenon. **C.** The paratenon must be preserved to enable FTSG take at the flap donor site. **D,E.** Volar and oblique views, respectively, of a cross-finger flap from the middle finger after inset into the defect of the index finger. The patient also sustained an injury to the volar middle phalanx of the middle finger that was closed with an FTSG. **F,G.** A dressing change is performed 1 week postoperatively to assess the flap and flap donor site, respectively. The flap provides durable, padded soft tissue coverage for fingertip injuries.

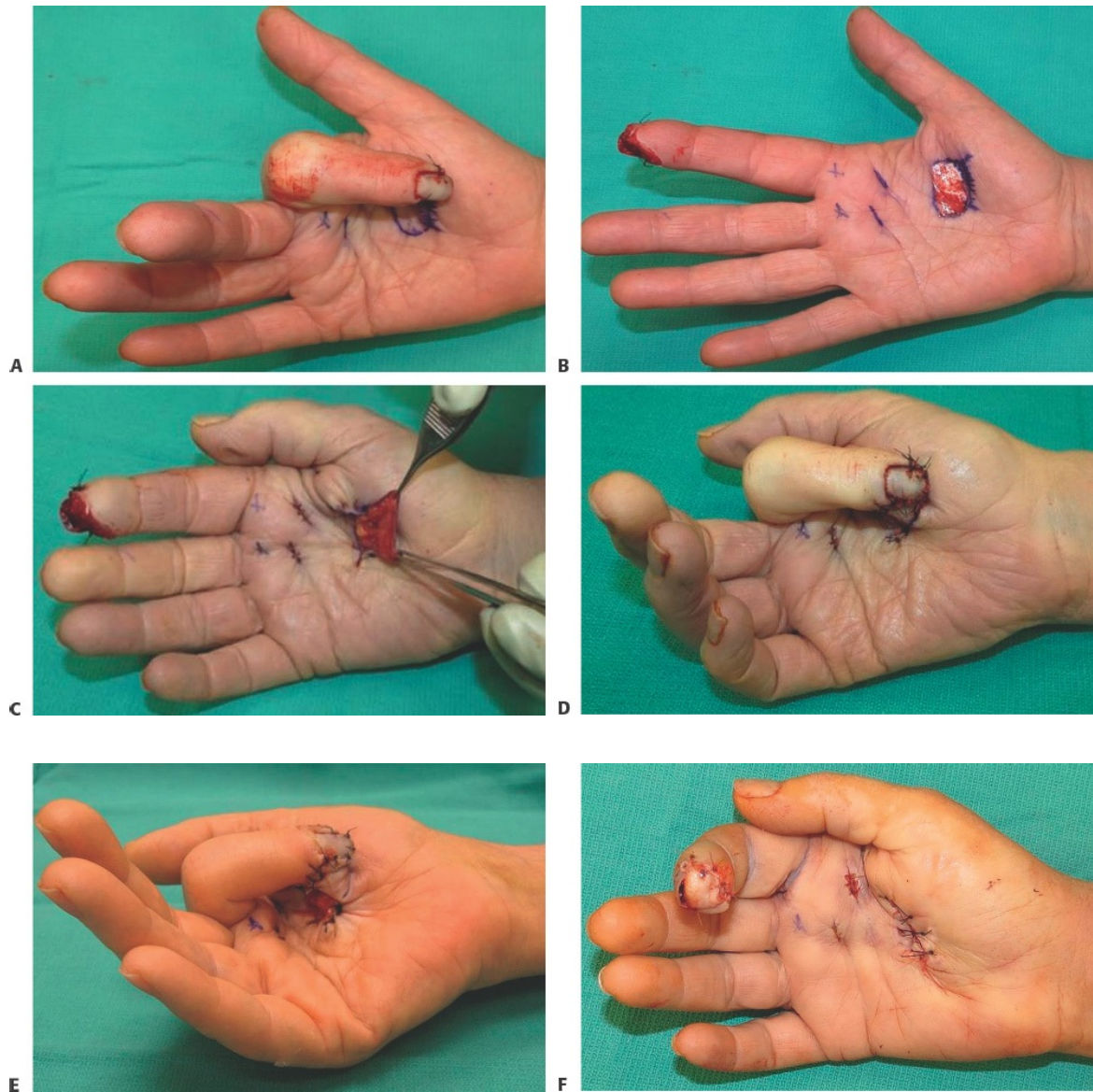
- A full-thickness skin graft (FTSG) is applied to the flap donor site. The FTSG can be inconspicuously harvested from the groin, medial proximal forearm, or nonglabrous hypothenar skin.
- Antibiotic-impregnated gauze is applied to the affected digit and FTSG donor site and covered with sterile gauze. A bolster dressing is applied over the skin graft. A splint is applied to the injured finger and its adjacent donor finger, immobilizing the interphalangeal joints; the metacarpophalangeal (MCP) joints may be left free.
- One week after the first surgery, a dressing change is performed (**TECH FIG 2F,G**). The bolster dressing is removed from the FTSG. A protective splint is reapplied.
- Two weeks after the first surgery, the flap is divided. Immobilization is not typically required after the second surgery, and ROM exercises are started.

■ Thenar Flap

- The injured digit is flexed into the palm (**TECH FIG 3A**). Maximal flexion

of the MCP and DIP joints is preferred while minimizing proximal interphalangeal (PIP) joint flexion to decrease postoperative PIP stiffness.

- The flap is marked over the ulnar aspect of the thenar eminence using a template of the defect size (**TECH FIG 3B**).
- Ulnar flap design is preferred on the thenar eminence to facilitate primary closure of the donor site; skin tension is decreased by adducting the thumb. Furthermore, designing the flap radially over the thenar eminence places the radial neurovascular bundle of the thumb at risk of injury.
- The flap width and length are designed 1.5 times wider and longer, respectively, than the defect length to permit tension-free inset with restoration of the normal rounded contour of the fingertip.
- The flap is proximally or distally based, depending on the geometry of the defect.
- The arm is exsanguinated and a tourniquet inflated.
- The skin and subcutaneous tissues of the flap are sharply incised. The flap is elevated from distal to proximal in the subcutaneous tissue plane, above the level of the palmar fascia, at a depth that matches the defect (**TECH FIG 3C**).
- Once the flap is elevated, the flap donor site is closed longitudinally with 4-0 nonabsorbable monofilament sutures. The thumb is adducted to facilitate primary closure of the donor site.



TECH FIG 3 • A. The flap is designed over the thenar eminence where the finger meets the palm when flexed. Maximal MCP and DIP joint flexion are preferred rather than PIP flexion to enable the finger to meet the palmar skin. Contractures of the PIP joint are more problematic postoperatively compared to those of the MCP and DIP joints. **B.** A template, cut out of foil, Telfa (shown here), or otherwise can be used to design the flap based on the defect size. **C.** The flap is elevated from distal to proximal in the

subcutaneous plane. The palmar fascia is not violated. The finger is flexed to bring the defect to the flap site. **D,E.** Volar and oblique views, respectively, of the flap inset to the intact skin around the defect and the nail. **F.** The thenar flap is divided at its proximal base. The proximal flap edge is inset to the proximal volar edge of the defect with sutures. The thenar donor-site skin is closed.

- An FTSG can be used if the flap donor site is too large for primary closure.
- Next, the injured finger is flexed and the flap is inset over the defect (see **FIG 3**).
- 4-0 nonabsorbable monofilament sutures are used to secure the flap to the defect; absorbable sutures are at increased risk of breakage and subsequent flap dehiscence.
- Multiple sutures are used to decrease the chance of accidental fingertip avulsion from the flap site (**TECH FIG 3D,E**).
- Antibiotic-impregnated gauze is placed over all incisions and covered with sterile gauze. A well-padded splint is applied dorsally over the injured finger to prevent accidental avulsion of the fingertip from the thenar eminence.
- Two weeks postoperatively, the flap is divided, and if needed, more skin is removed from the thenar area to cover the entire fingertip that is buried within the thenar pocket.
- The divided flap edge is sutured to the edge of the fingertip defect, and the thenar skin is closed with 4-0 sutures; absorbable or nonabsorbable sutures may be used at this stage (**TECH FIG 3F**).
- Immobilization is not typically required after the second surgery, and ROM exercises are started.

PEARLS AND PITFALLS

Physical findings

- Carefully assess the flexion and extension of the DIP for patients with a fingertip injury. Associated mallet injury is common.

Technique	■ Handle flaps atraumatically. The blood supply for fingertip flaps is random from small local vessels. ■ Cross-finger flap: The cross-finger flap can be used for resurfacing of fingertip defects of all fingers. A thumb defect is the most difficult to inset using a flap from the index finger because of the pronated position of the thumb relative to the other digits of the hand. Defects of the ring finger are best resurfaced with a flap from the middle finger, rather than the shorter small finger, for adequate inset. A fingertip defect of the small finger requires minimal flexion of the small finger for inset to a flap from the ring finger. ■ Thenar flap: The thenar flap can be used for all fingers; positioning is easiest for the index and middle fingers and most difficult for the small finger. ■ Obtain hemostasis and close the skin while the tourniquet is down to prevent a hematoma to optimize flap and graft survival. ■ Assess flap tension in the operating room with the hand at rest and with passive range of motion. If surgery is performed with local anesthesia only, active range of motion can also be assessed. Splint the hand accordingly; avoid immobilization of uninvolved joints that do not cause undue tension on the reconstruction when moved.
Postoperative	■ Perform second-stage flap division 2 wk after flap inset. Longer periods of immobilization lead to worsening joint stiffness.
Therapy	■ Patients can follow a home therapy program for fingertip desensitization.

POSTOPERATIVE CARE

- Fingertip sensitivity is the most common patient complaint following fingertip injury and reconstruction. Cold sensitivity can be particularly troublesome.
 - Time, reassurance, and hand therapy are beneficial.
 - Massage, desensitization exercises, and cortical retraining of the finger are useful techniques.
- Fingertip protectors can be worn early in the postoperative period when the fingertip is most sensitive. They can be weaned over time as symptoms improve.

OUTCOMES

- V-Y advancement flap

- Excellent contour of the fingertip can be achieved (**FIG 5**).
- Near-normal sensation is restored.
- Cross-finger flap
 - Good aesthetic outcomes are achieved following fingertip reconstruction (**FIG 6A,B**).
 - Sensory recovery improves with time; protective sensation is recovered, but tactile gnosis is not.¹⁰
 - Despite difficulty with cortical relearning and incomplete sensory recovery, particularly in adult patients, patient satisfaction remains high.¹¹
 - The donor site is aesthetically unappealing (**FIG 6C**), particularly for female patients, and the flap color match may be poor, especially in dark-skinned patients.
 - A thenar flap is favored for female and dark-skinned patients rather than a cross-finger flap.
- Thenar flap
 - Donor-site tenderness can be problematic; early hand therapy is recommended.
 - Sensory recovery in the injured finger is typically better compared to a cross-finger flap.¹²
 - Aesthetic outcome of the reconstructed fingertip is excellent, and the donor site is hidden in the palm (**FIG 7**).

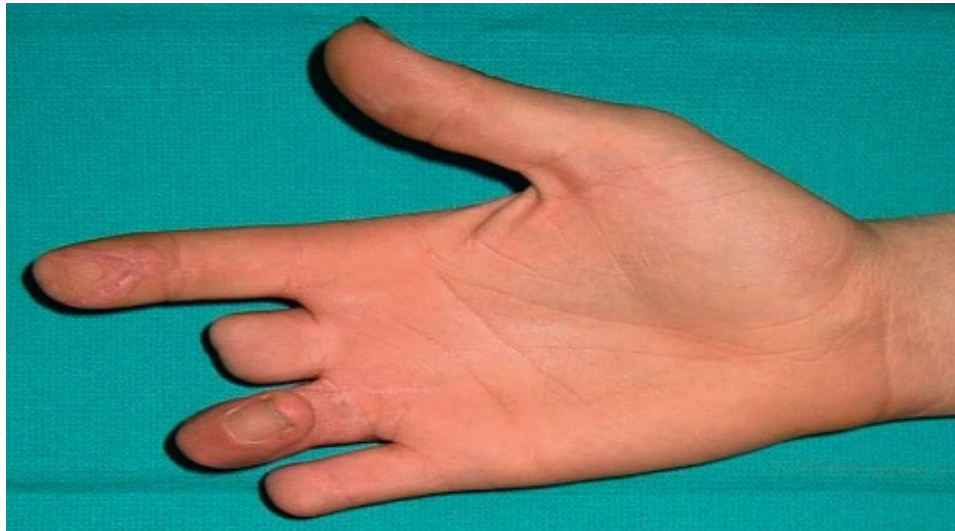


FIG 5 • The V-Y advancement flap of the index finger restores the contour of the fingertip with sensate,

durable soft tissue coverage. The donor site is inconspicuous. The incisions over the volar finger pulp can be sensitive; hand therapy may be required postoperatively.

COMPLICATIONS

- A shortened distal phalanx results in the loss of nail bed support. A hook-nail deformity can result. Excision of the sterile nail matrix 2 mm proximal to the shortened bone can help prevent this complication. The patient is taught to trim the nail frequently.
- If the nail remains troublesome, nail bed obliteration can be performed.
- A V-Y advancement flap creates additional incisions over the volar finger pulp. Hypertrophic and hypersensitive scarring can result.
- With regional flaps, stiffness can be marked postoperatively, particularly for older patients with arthritis and other comorbidities. Patients must be consulted preoperatively on the need for hand therapy following a two-stage flap reconstruction. For severe contractures, static progressive splinting can be used.



FIG 6 • The cross-finger flap provides excellent resurfacing for a fingertip injury, shown here volarly **(A)** and laterally **(B)** 4 months postoperatively. **C.** The appearance of the FTSG at the donor site, shown 4 months postoperatively, improves with time but remains noticeable over the dorsal middle phalanx of the donor finger. Aesthetic considerations must be discussed with the patient prior to use of this flap.



FIG 7 • The appearance of the reconstructed index fingertip and the thenar flap donor site 3 months postoperatively shows satisfactory healing.

- V-Y advancement and thenar flaps transfer glabrous skin to fingertip injuries; cross-finger flaps do not. Furthermore, cross-finger flaps may transfer hair-bearing skin to the volar skin pulp. Laser hair removal can be used once the flap is healed.

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46 Flap Coverage of Thumb Defects

CHAPTER

Kate Elzinga and Kevin C. Chung

DEFINITION

- The thumb accounts for over 40% of hand function.¹ Maintenance of length, ideally beyond the neck of the proximal phalanx, is critical for stable pinch and grasp.
- The goals of thumb reconstruction include maximizing length, stability, strength, mobility, sensation, durability of coverage, and appearance while minimizing donor-site morbidity.
- The function of the thumb is optimized following injury by restoring a sensate thumb pulp.²

ANATOMY

- The volar thumb is covered by thick, durable, highly innervated, glabrous skin.
- Dorsally, the nail provides protection for the distal phalanx and counterpressure for the pulp during pinch.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Following a thumb injury, important patient factors include age, sex, handedness, comorbidities, medications, allergies, occupation and avocations, and smoking status.
- Injury factors to consider include the time and mechanism of injury, the degree of tissue contamination and necrosis, and any previous hand injuries.
- The patients' goals are explored. Their desire for a rapid return to work and their level of compliance and motivation are considered when formulating a reconstructive plan.
- The thumb wound is examined, noting the level of the injury and tissue loss

(skin, soft tissue, neurovascular bundles, tendons, bone, nail). Exposed structures are evaluated and documented.

- The thumb's color, capillary refill, turgor, and temperature are assessed as part of the vascular exam. The digital nerves are assessed using light touch, two-point discrimination, or the ten test.³
- The function of the extensor pollicis longus and that of the flexor pollicis longus (FPL) are tested by asking the patient to actively flex and extend the interphalangeal (IP) joint of the thumb.
 - A digital block can be used for patient comfort to facilitate the examination following sensory testing of the thumb.
- Donor sites are examined locally and regionally for thumb reconstruction.

IMAGING

- Plain radiographs are performed for the thumb to assess for bony injury, level of amputation, and presence of a foreign body.

NONOPERATIVE MANAGEMENT

- Small defects, up to 1 cm² without exposed bone or tendon, heal well by secondary intention.
 - Ingrowth of glabrous skin results in durable, sensate coverage.
 - Moist, antibacterial dressings are applied daily.
 - Range-of-motion exercises are performed throughout to prevent stiffness.
 - Once healed, early use of the thumb is encouraged to help with desensitization of the fingertip and return of function.
- Elevation of the injured upper extremity and gentle compression decrease edema at the thumb defect site, which expedites wound healing.

SURGICAL MANAGEMENT

- Larger skin and subcutaneous tissue defects, over 1 cm² without exposed tendon or bone, can be covered with a full-thickness skin graft (FTSG).
 - Rapid healing occurs, but FTSGs are less durable and have poorer sensory recovery compared with healing by secondary intention.
- When tendon or bone is exposed, coverage with local and regional flaps is necessary.
- To restore sensate, durable coverage over an exposed distal phalanx, flap reconstruction with a local Moberg flap can provide coverage for defects of 1.5 cm in length or up to 2.5 cm in length if a transverse proximal releasing

incision is used (**FIG 1**).

- Larger defects can be covered with regional flaps such as the first dorsal metacarpal artery (FDMA) flap (**FIG 2**) or the reverse homodigital flap (**FIG 3**) based on the dorsal radial collateral artery.
- The FDMA flap can be harvested up to 6×3 cm in size.
- The reverse dorsoradial homodigital flap has been described from 2×2 cm up to 5×4 cm in size.⁴

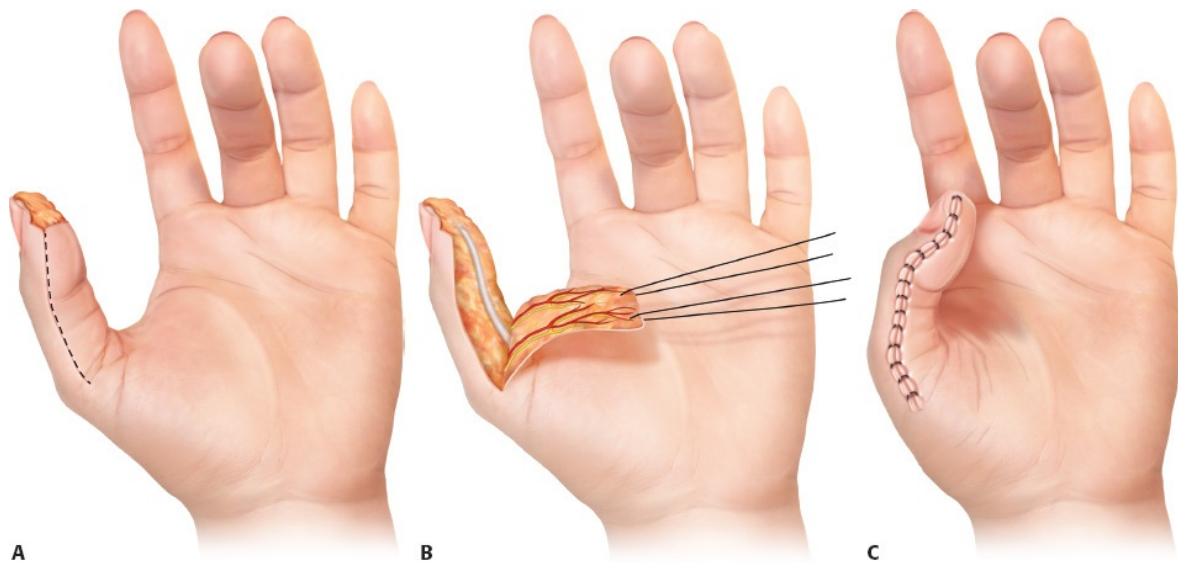


FIG 1 • The Moberg flap is designed over the volar thumb for coverage of distal thumb defects. **A–C.** Incisions are made at the midaxial line over the radial and ulnar digit up to the volar MCP joint crease. The radial and ulnar digital neurovascular bundles are elevated within the flap. The flap is elevated above the paratenon of the FPL and advanced distally. Flexion of the IP joint facilitates flap inset.

Approach

- The patient is positioned supine with the arm on a hand table.
- Loupe magnification facilitates flap dissection.
- The flap incisions are designed using a template of the defect prior to tourniquet inflation.
- A tourniquet is used for flap elevation to create a bloodless field that facilitates

exposure and decreases the risk of injury to the neurovascular structures supplying the flap.

- Following flap elevation, the tourniquet is released. Flap perfusion is assessed. Hemostasis is achieved prior to flap inset to prevent a hematoma that could result in flap compromise.

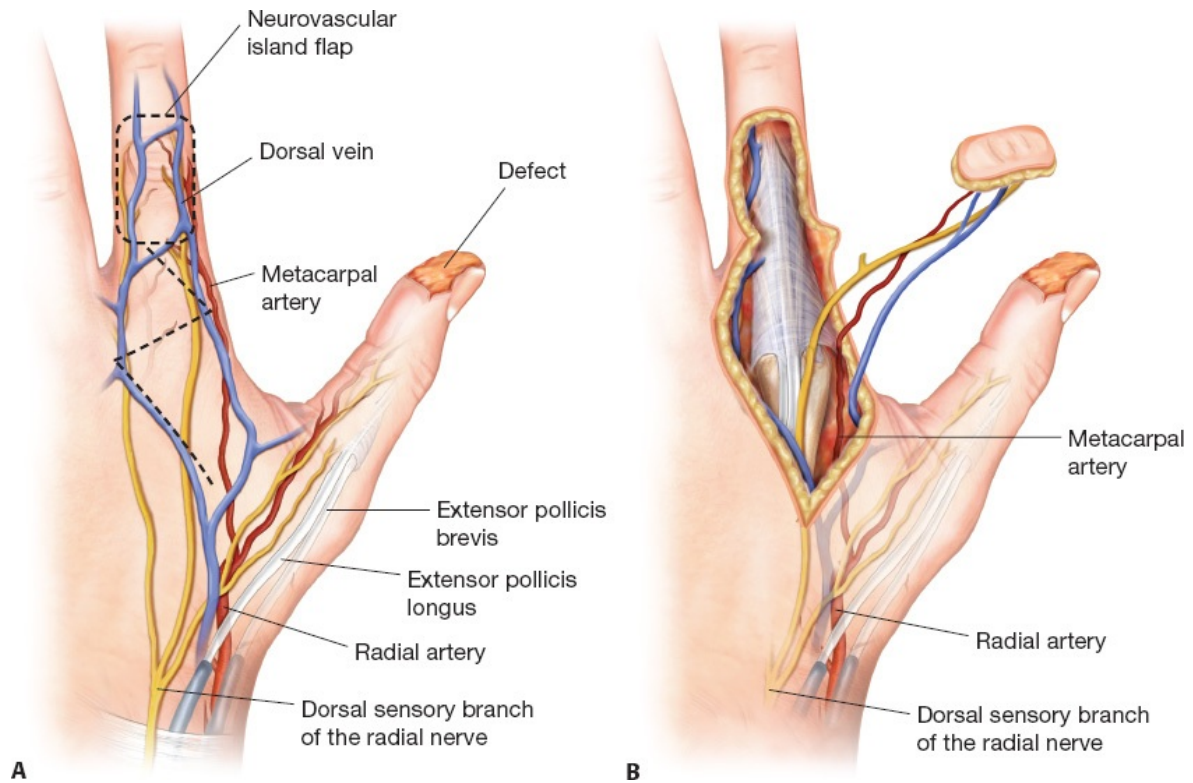


FIG 2 • The FDMA flap is elevated from the dorsal proximal phalanx of the index finger for coverage of thumb defects. **A,B.** The flap can be raised as an island flap, using a straight line, lazy S, or zigzag incision as shown here for elevation of the pedicle back to the flap pivot point, which is found just distal to the EPL tendon.

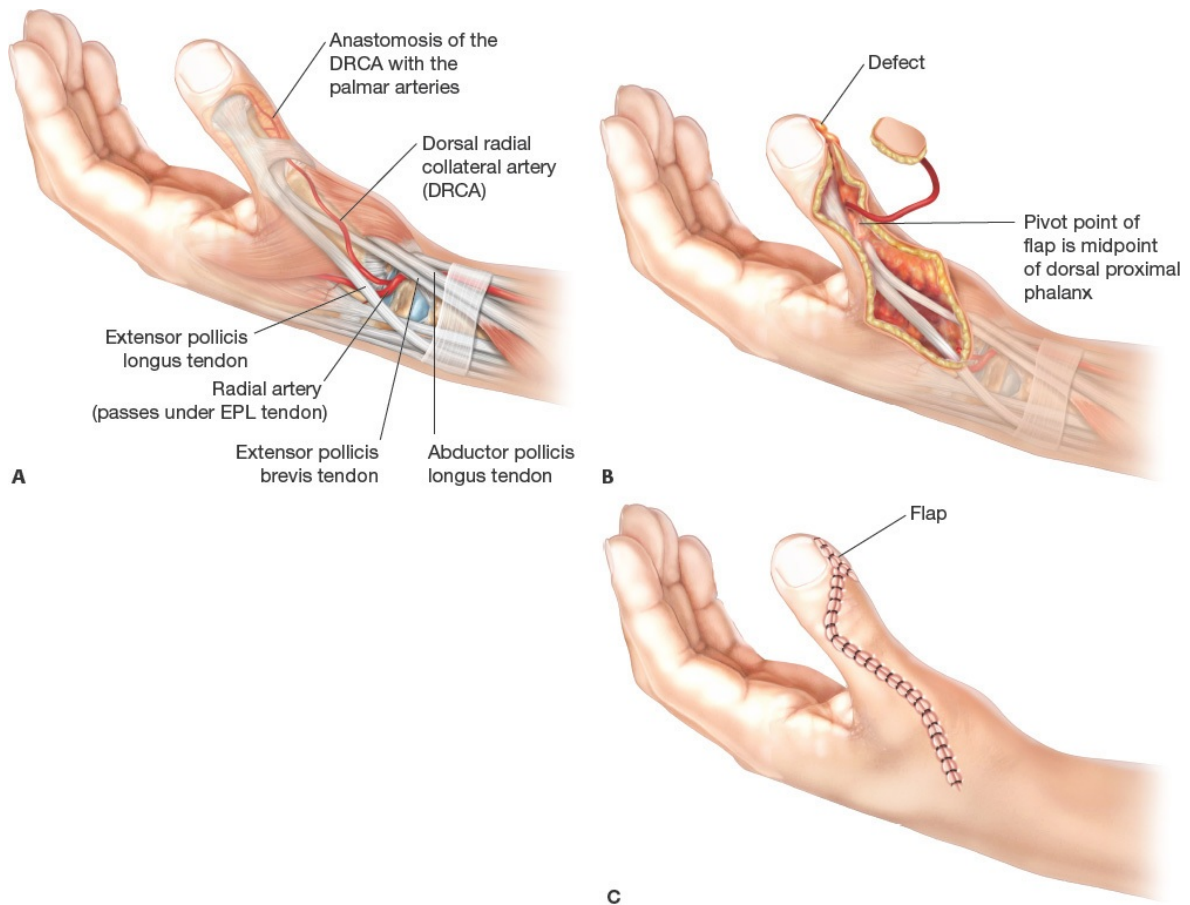


FIG 3 • A–C. The reverse dorsoradial homodigital flap is based on the anastomosis connection of the dorsal radial collateral artery and the palmar arteries of the thumb at the middle third of the thumb proximal phalanx. The flap is harvested as a distally based, reverse flap for coverage of distal thumb defects.

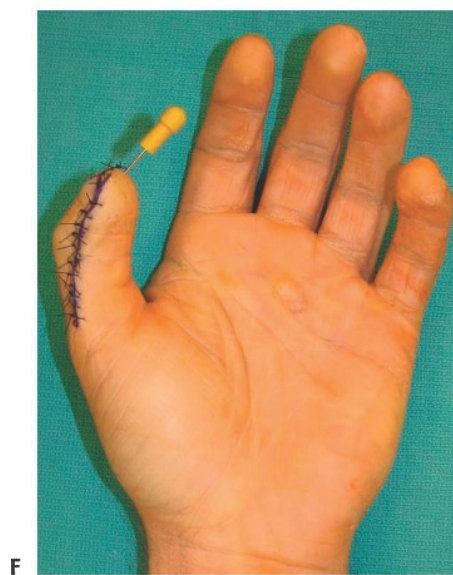
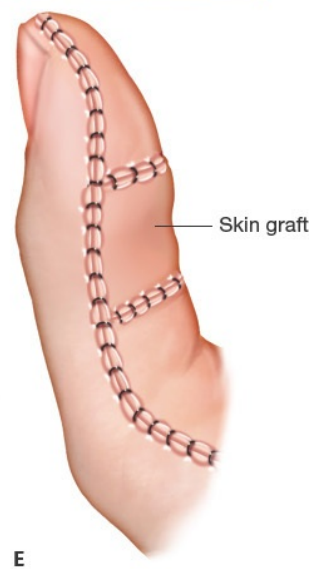
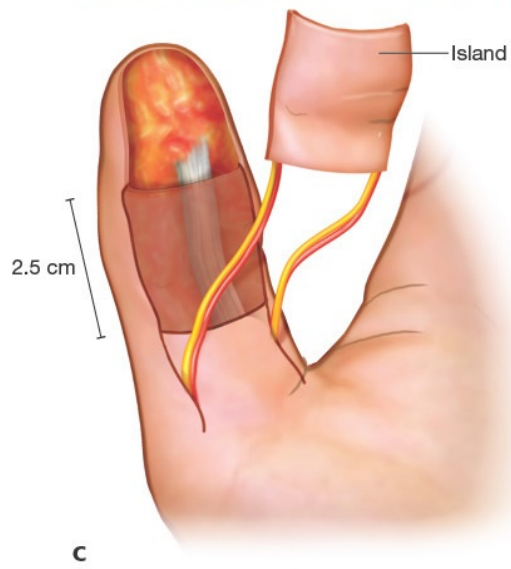
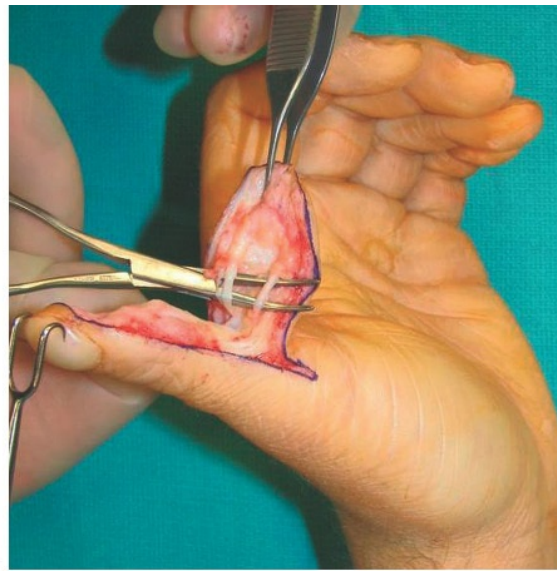
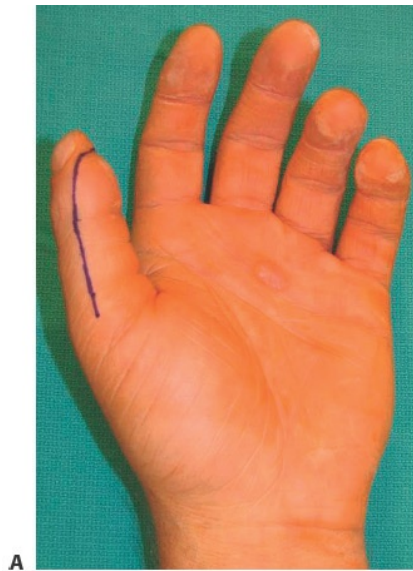
TECHNIQUES

■ Moberg Flap

- Incisions are designed over the midaxial lines of the ulnar and radial thumb, at the junction of the glabrous and nonglabrous skin (**TECH FIG 1A**; see **FIG 1**). Proximally, the flap is marked to the metacarpophalangeal (MCP) joint crease bilaterally. If further advance is necessary, the flap can be

extended proximal to the MCP, Burow triangles can be excised at the flap base bilaterally, or the flap can be advanced as a V-Y flap⁵ or as an island flap.⁶

- The ulnar and radial digital nerves and arteries are elevated within the flap, which maintains the blood supply to the flap as well as innervation (**TECH FIG 1B**). The dorsal blood supply of the thumb from the princeps pollicis artery permits safe flap elevation without compromising the thumb's perfusion.
- When used as an island flap, a transverse, proximal releasing incision is made over the proximal phalanx (PP), connecting the two midaxial incisions. The radial and ulnar neurovascular bundles are protected. This release is seldom necessary because the thumb interphalangeal (IP) joint can be flexed sufficiently for the flap to cover the tip of the distal phalanx.
- The flap is raised from distal to proximal, above the paratenon of the flexor pollicis longus (FPL). As dissection proceeds proximally, advancement of the flap can be tested until tension-free inset is achieved. At this point, proximal dissection ceases.
- The flap should not be advanced more than 2.5 cm to avoid traction on the neurovascular bundles. To achieve advancement of 2.5 cm, a transverse proximal releasing incision is required; the flap is then advanced as an island flap (**TECH FIG 1C,D**). Without a proximal releasing incision, the first dorsal metacarpal artery (FDMA) flap can be advanced 1.5 cm.
 - The donor site can be closed with a full-thickness skin graft (FTSG) (**TECH FIG 1E**).
- If needed, the thumb MCP and IP joints are flexed to facilitate flap inset over the distal thumb defect.
 - Rarely, a K-wire is used to maintain the flexed position of the IP joint (**TECH FIG 1F**).
 - For older patients with arthritis, limited flexion is recommended to prevent an IP joint flexion contracture.



TECH FIG 1 • A. Loss of soft tissue following a remote traumatic crush injury resulted in inadequate pulp coverage of the distal phalanx tuft and patient discomfort. A Moberg flap was designed to resurface the distal volar tip of the thumb. **B.** The ulnar and radial neurovascular bundles are elevated with the flap. The digital arteries and nerves provide perfusion and innervation to the flap. **C,D.** To permit advancement of a Moberg flap up to 2.5 cm distally, it is elevated as an island flap. A proximal transverse incision is used to connect the ulnar and radial midaxial incisions. **E.** The donor site is covered with an FTSG. **F.** A K-wire can be used to maintain IP joint flexion to facilitate flap inset to the distal thumb.

- The flap is inset using 4-0 nonabsorbable monofilament suture. The flap is secured to the intact skin surrounding the defect and to the nail.
- If used, the FTSG is secured with a bolster dressing. Antibacterial gauze is applied to the flap incisions followed by sterile gauze and a well-padded thumb spica splint.
- The splint can typically be discontinued 1 week postoperatively, and range-of-motion (ROM) exercises are started for the MCP joint. Two weeks postoperatively, if present, the K-wire can be removed and IP ROM is initiated.

■ First Dorsal Metacarpal Artery Flap (see FIG 2)

- Over the dorsal hand, distal to the anatomic snuffbox, the radial artery gives off three branches: the dorsal carpal arch (radial branch), the princeps pollicis (middle branch), and the FDMA (ulnar branch). After giving off the FDMA, the radial artery dives deep between the two heads of the first dorsal interosseous (DIO) and joins the deep palmar arch.
- The FDMA travels within or just above the fascia of the first DIO radial to the index finger metacarpal. A branch of the dorsal sensory branch of the

radial nerve travels with the FDMA.

- The FDMA flap provides innervated vascularized soft tissue coverage for large thumb or first web space defects (**TECH FIG 2A,B**).
- It is designed over the dorsal PP of the index finger. Typically, the flap is designed from the proximal interphalangeal joint to the MCP joint; proximal extensions are possible for coverage of larger defects (**TECH FIG 2C**).
- Ulnarly and radially, the flap extends to the midaxial lines of the index finger at the junction of the glabrous and nonglabrous skin.
- The pedicle is a proximal adipofascial extension of the flap that contains the FDMA, two dorsal veins, a branch of the dorsal sensory branch of the radial nerve, subcutaneous adipose tissue, and the fascia of the first DIO.
- Alternatively, the pedicle may be designed as a dermofascial flap extension with a 1-cm strip of overlying skin (**TECH FIG 2D**). In these cases, the skin donor-site defect from the pedicle harvest can be closed primarily.
- The pivot point of the flap is marked distal to the extensor pollicis longus at the junction of the metacarpal bases of the thumb and index finger. A handheld Doppler ultrasound (US) can be used to map the course of the FDMA from the dorsoradial index finger PP to the flap pivot point. The course of the FDMA is reliable; US mapping is optional.
- The flap is elevated above the paratenon of the extensor digitorum communis (EDC) and extensor indicis proprius (EIP). It is raised from distoulnar to proximoradial toward the pedicle that enters the flap base on the radial side of the index finger metacarpal.
- As the dissection approaches the proximoradial aspect of the flap and the first DIO is visualized proximal to the MCP joint, dissection must be continued deep to the fascia of the first DIO to prevent injury to the pedicle.
- When harvested as an island flap, a straight line, a lazy S, or a zigzag incision can be used from the flap base to the flap pivot point for pedicle exposure and elevation. The skin is incised and thin skin flaps are elevated radially and ulnarly in the subdermal plane. The pedicle is raised 1 cm in width. The subcutaneous fat and fascia are included to protect the FDMA and accompanying veins; the FDMA is not skeletonized.
- Our preferred approach is to harvest the flap with a dermofascial pedicle rather than as an island flap. A 1-cm skin bridge is incised. A wider adipofascial strip can be harvested below.

- Including the dermis helps protect the pedicle below during dissection and lessens the risk of pedicle kinking or compression during flap inset.
- The pedicle is raised with the flap from distal to proximal, just above the first DIO muscle (**TECH FIG 2E**).
- When harvested with skin overlying the pedicle, the flap is inset using a skin incision from the flap pivot point proximally to the thumb defect distally (**TECH FIG 2F**).
- When used as an island flap, the flap can be inset under a tunnel (**TECH FIG 2G**).
 - There is an increased risk of venous congestion of the flap when tunneled compared to inset using a skin bridge.
- Tension-free closure of the flap into the defect is performed using sutures (**TECH FIG 2H–J**).
- An FTSG is used to close the FDMA flap donor site (**TECH FIG 2K,L**). A bolster dressing is placed over the FTSG on the dorsal index finger PP.
- Antibacterial gauze and dry gauze are applied to the flap incisions.
- A well-padded splint is applied, taking care to avoid pressure on the flap or pedicle.
- The splint can typically be discontinued 1 week postoperatively, and ROM exercises are started as long as they do not cause undue tension on the flap.



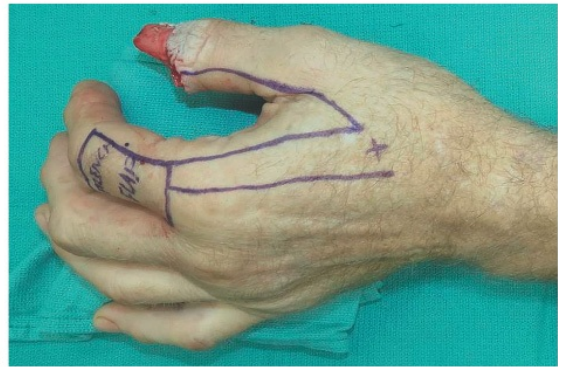
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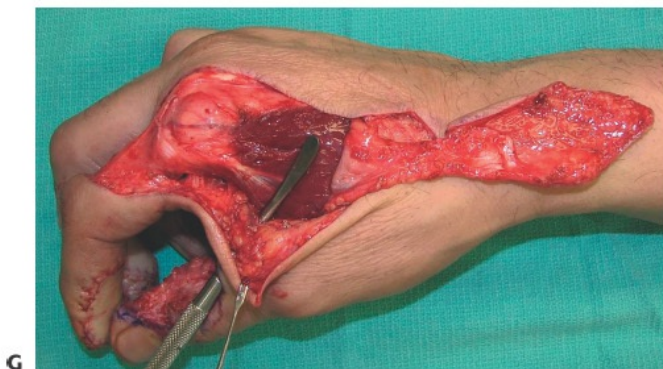
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E



F



TECH FIG 2 • A,B. A traumatic injury to the ulnar and volar thumb can be resurfaced using a FDMA flap. Prior to reconstruction, the wound should be free of infection and necrotic tissue. **C.** Most commonly, the FDMA flap is designed from the MCP proximally to the proximal interphalangeal joint distally over the dorsal index finger. Proximal extensions can be used as shown here for coverage of larger thumb defects. **D.** The FDMA flap can be raised with a dermofascial pedicle, as shown here, or with an adipofascial pedicle. The flap pivot point is marked here with an “X” at the junction of the first and second metacarpal bases, just distal to the EPL. An incision from the pivot point to the defect is marked for flap inset; alternately, the flap could be tunneled into the defect if an adipofascial pedicle was raised. **E.** The fascia of the first DIO is included with the pedicle to prevent injury to the FDMA and the draining veins of the flap. Here, the first DIO is shown radial to the flap pedicle, exposed but not violated. The paratenon is preserved over the extensor tendons of the index finger, shown ulnar to the flap pedicle. **F.** An incision is made from the flap pivot point to the thumb defect. The flap mobility is tested; tension-free inset is critical for flap survival. **G.** A different patient is shown here. In this case, the FDMA flap was raised with an adipofascial pedicle and tunneled into the defect. A wide tunnel is created to prevent pedicle compression and venous congestion. **H–J.** The FDMA flap and its dermofascial pedicle are inset using sutures. The nail had been avulsed; a splint was placed into the nail fold. The FDMA flap donor site was closed with an FTSG. **K,L.**

For this patient, the flap was tunneled into the defect over the volar-ulnar thumb and sutured into position. The flap donor site and additional superficial wounds over the distal radial index and middle fingers were closed with FTSGs.

■ Reverse Dorsoradial Homodigital Flap

- The reverse dorsoradial homodigital flap is harvested from the dorsoradial side of the thumb metacarpal (see **FIG 3**).
- Its arc of rotation permits coverage of distal volar and dorsal thumb defects and radial defects of the proximal and distal phalanx of the thumb.⁷ It is most commonly used for smaller defects over the dorsum of the thumb; the FDMA flap provides more tissue and is better suited for coverage of larger volar defects of the thumb.
- The flap pedicle is the dorsal radial collateral artery, which is a branch of the radial artery over the dorsoradial hand at the anatomic snuffbox. It passes under the extensor pollicis brevis (EPB) tendon as it travels from ulnar to radial. The pedicle is consistent in its course and caliber, traveling distally 1 cm radial to the midline of the dorsal thumb. It communicates with the palmar vessels at the middle third of the PP, permitting this flap to be used reliably as a reverse island flap.
- The course of the dorsal radial artery can be identified using a Doppler US. It runs from the snuffbox to the middle of the dorsoradial PP. The pivot point of the flap is over the middle of the dorsoradial PP.
- Using a template of the defect, the flap is designed over the dorsoradial thumb metacarpal, centered over the dorsal radial collateral artery.
- The skin island is incised, starting at its proximal edge. The dorsal radial collateral artery is identified, and the flap design is adjusted as needed to ensure it is over the pedicle.
 - The flap is raised above the paratenon of the extensor tendons. The incision over the distal flap is made through the dermis, but not deeper, to avoid transection of the pedicle below.
- The flap is elevated from proximal to distal. The dorsal radial collateral artery is divided just distal to where it passes under the EPB.

- A branch of the dorsal sensory branch of the radial nerve runs with the dorsal radial collateral artery. It is divided proximal to the flap to permit flap elevation. This sensory nerve branch can be coapted to the distal radial or ulnar digital nerve of the thumb; however, significant improvement in flap sensitivity has not been demonstrated.⁴
- A skin incision is made from the flap donor site to the defect to permit inset while minimizing the risk of pedicle compression and venous congestion that would occur if the flap were tunneled.
 - A lazy S or a zigzag incision is used.
 - Skin flaps are elevated subdermally radially and ulnarly from the flap donor site to the midpoint of the PP dorsally over the thumb.
- The pedicle is elevated with the surrounding subcutaneous tissue to ensure adequate venous outflow; all nearby venous skin branches are included in the flap elevation. The dorsal radial artery is not skeletonized.
- The flap is inset into the defect and sutured into place. The skin above the pedicle is loosely tackled together to prevent compression and left partially open to heal by secondary intention or covered with an FTSG.
- The flap donor site is closed primarily for flaps up to 4 cm in width. Larger donor sites are closed with an FTSG and covered with a bolster dressing.
- The flap incisions are covered with antibacterial gauze, sterile gauze, and a well-padded, hand-based thumb spica splint.
- The splint can be removed in one week and ROM exercises started.

PEARLS AND PITFALLS

Physical findings

- The anatomic course of the FDMA and dorsal radial collateral artery is consistent from the radial artery. Doppler US can be used as an adjunct during flap design, but it is not mandatory. Injuries to the dorsal radial hand and wrist preclude the use of these flaps as the flap pedicles may have been damaged. In these cases, an alternate flap should be used.

Technique

- The FDMA flap donor site leaves a visible donor site over the donor index finger. It can be harvested as an adipofascial flap to minimize the aesthetic morbidity of the donor site; however, the reconstruction of the thumb defect is compromised if the FDMA

flap requires an FTSG for coverage. A skin graft on the flap will be less durable and less sensate.

- Maintaining the paratenon over the tendons during flap harvest permits FTSG take at the donor site for an island Moberg flap, FDMA flap, and reverse dorsoradial homodigital flap. It also facilitates smooth tendon gliding for the FPL following a Moberg flap harvest, the EDC and EIP after a FDMA flap, and the EPL and EPB after a reverse dorsoradial homodigital flap.

Postoperative

- The most complete and natural sensation for the thumb pulp is regained using a Moberg flap. Over time, patients will adapt to the sensory input from the FDMA flap; however, cortical retraining is often incomplete and the patient continues to feel as though the dorsal index proximal phalanx is being touched rather than the pulp of the thumb. The homodigital island flap is not innervated. Sensation may be partially regained through the ingrowth of nearby cutaneous nerve fascicles.

Therapy

- Excessive IP joint flexion, particularly for over 2 weeks, can lead to a flexion contracture following an FDMA flap. Early ROM exercises are recommended, as long as flap viability is not compromised, to minimize IP joint stiffness.
- Hand therapy can help a patient regain ROM following a thumb injury. It can also help with desensitization of the reconstructed thumb and donor site.



FIG 4 • The FDMA flap provides excellent soft tissue coverage for thumb defects. The donor-site aesthetics improve with time. Here, the FDMA flap reconstruction is shown at 2 weeks (**A**) and 16 months (**B,C**) postoperatively.

POSTOPERATIVE CARE

- Nonabsorbable sutures are removed 2 weeks postoperatively.
- The dressings are changed and any FTSG bolster dressings are removed 5 days postoperatively.
- ROM exercises are started 5 to 7 days postoperatively.
- If there is any concern of flap tension, a thermoplastic splint can be used to protect the flap for an additional 1 to 2 weeks between ROM exercises and during sleep.

OUTCOMES

- The Moberg flap best restores sensation to thumb defects. The reverse dorsoradial homodigital flap is not innervated and offers the least complete sensory recovery, averaging 10-mm two-point discrimination.⁴
- The Moberg, FDMA, and homodigital flaps restore the thumb pulp contour well (**FIG 4**).
- The Moberg flap has the least donor site morbidity but can be used only for coverage of smaller thumb defects. The FDMA and homodigital flaps permit coverage of larger defects; the patient must be counseled preoperatively about the visible donor sites on the dorsal hand.

COMPLICATIONS

- Hair growth is rare over the dorsoradial thumb metacarpal. The Moberg and reverse dorsoradial homodigital flaps provide hairless coverage for thumb defects. In contrast, the FDMA flap typically contains hair. Laser hair removal can be used once the flap has healed if hair growth is problematic.

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47 Reverse Flow Radial Forearm Flap

CHAPTER

Kate Elzinga and Kevin C. Chung

DEFINITION

- The most commonly used regional flap for coverage of volar and dorsal hand and wrist wounds is the reverse radial forearm flap (RRFF). It is a reliable and versatile flap.
- The radial forearm flap can be used as an antegrade flap to cover defects of the elbow.
- The radial forearm flap can also be harvested as a free flap for distant defects.
- The RRFF can be designed up to 35×15 cm in size, harvesting up to two-thirds of the circumference of the forearm, from 4 cm distal to the antecubital fossa to the wrist crease.
- The RRFF's large size makes it suitable for coverage of nearly all wrist and hand wounds. However, the arc of rotation of the flap into the defect typically precludes harvesting the flap extending to the distal forearm.
- The flap can be pre-expanded to further increase its dimensions proximally in the forearm for adequate use as a reverse flap, although this is rarely necessary.¹

ANATOMY

- The RRFF is a Mathes and Nahai type B flap; it is supplied by septocutaneous perforators. Its pedicle is the radial artery and its two accompanying vena comitantes. The radial artery is divided proximally. Retrograde flow occurs from the ulnar artery through the deep palmar arch into the radial artery to provide arterial inflow to the flap.
- The radial artery originates from the brachial artery. It travels under the brachioradialis (BR) for most of its course. Distally, it is found in the interval

between the BR radially and the flexor carpi radialis (FCR) ulnarly. The radial artery perforators travel within the septum between the BR and FCR to supply the overlying fascia and skin (**FIG 1**).

- There are 6 to 10 septocutaneous perforators arising from the radial artery 2 cm proximal to the radial styloid.² A reverse radial artery perforator flap can be elevated on these perforators to preserve the radial artery for patients without an intact palmar arch.^{3,4}
- The cephalic vein can be harvested with the RRFF although it does not play a role in the venous drainage of reverse flaps. Venous outflow is through the avalvular oscillating veins.⁵ In cases of venous congestion, anastomosis of the cephalic vein within the flap will decompress the venous congestion.
- The RRFF is designed over the proximal and middle volar forearm.
- The RRFF can be harvested as a fasciocutaneous, adipofascial, or fascia-only flap. It may also be raised above the fascia; the subcutaneous tissue and dermis above the fascia are raised suprafascially.

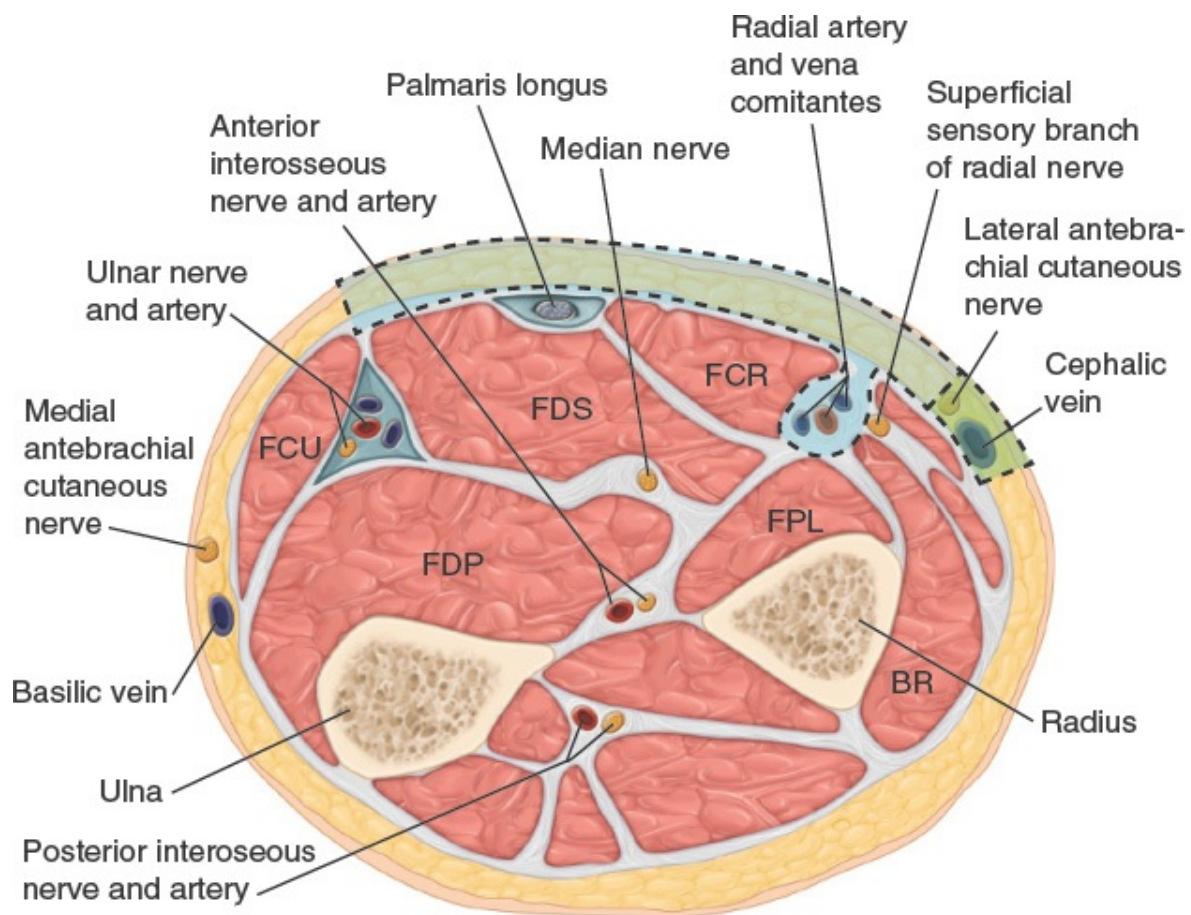


FIG 1 • The radial artery and its vena comitantes are found in the distal forearm within the intermuscular septum between the BR radially and the FCR ulnarly. The radial border of the RRFF can be centered over the radial artery as shown here. Alternatively, the flap can be designed with its radial margin over the radial artery. The LABC and cephalic vein are optional structures that can be included in the flap design.

- The lateral antebrachial cutaneous nerve (LABC) can be harvested with the flap and coapted to a sensory nerve at the defect site to innervate the flap.
- Alternatively, the LABC can be left in situ during flap harvest, preserving the sensation to the radial forearm.⁶
- The palmaris longus can be elevated with the flap for use as a vascularized tendon graft. For example, it can be used for an extensor tendon defect or to create a flexor pollicis longus during osteoplastic thumb reconstruction with an iliac crest bone graft and a RRFF.⁷ The BR can also be included as a vascularized tendon graft or part of the radius as a vascularized bone graft.⁸
- The pivot point for the RRFF is the radial styloid.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient is assessed for suitability for regional flap reconstruction following a wrist or hand injury.
- Important history includes the patient's age, handedness, and occupation and avocations.
- The patient's past medical history, medications, allergies, and social history are noted. In particular, risk factors for flap loss, poor wound healing, and additional postoperative complications are discussed.
- Comorbidities associated with poor wound healing include smoking, diabetes mellitus, end-stage renal disease, cardiac disease, peripheral vascular disease, vasculitis, malnutrition, immunosuppression, and hypercoagulable states.
- Details of previous trauma or surgeries to the forearm are gathered. History of any previous radial artery cannulation for invasive blood pressure monitoring is also important.

- If there is concern of damage to the radial artery or its perforators, angiography can be performed to evaluate the vascularity of the arm.
- The patient's defect is examined. The size of the wound is measured. Exposed structures, necrotic tissues, and any signs of infection are documented.
- Wounds with exposed tendon and bone are best covered using flaps. The radial forearm flap is a pedicled regional flap that can be safely performed in most patients. It alleviates the need for a two-stage flap reconstruction such as a groin flap or microvascular reconstruction with a free flap.
- The vascularity of the hand must be carefully assessed. If the radial artery is harvested for the RRFF, the patient must have an intact palmar arch with arterial inflow from the ulnar artery to prevent hand and finger ischemia.
- The modified Allen test is used to clinically assess the integrity of the palmar arch (**FIG 2**). The examiner compresses the patient's ulnar and radial arteries at the volar wrist and then instructs the patient to open and close the hand into a tight fist until the palm is blanched. The examiner then releases the ulnar artery and looks for arterial flow from the ulnar artery through the palmar arch to the radial side of the hand within 6 seconds. The test is repeated to assess the radial artery.
- The motor and sensory nerves of the hand and forearm are tested. Any pre-existing abnormalities are noted.

IMAGING

- Plain radiographs are performed for patients with traumatic wounds. Any fractures, foreign bodies, and abnormal joint intervals secondary to ligamentous injuries are noted.
- The authors do not routinely perform angiography prior to RRFF harvest. If the patient has sustained previous trauma to the forearm or has undergone previous surgery to the forearm, angiography can be used to evaluate the integrity of the vascular system of the arm and the patency of the radial artery, ulnar artery, and palmar arch.
- An ultrasound (US) can be performed to do a Doppler Allen test if the patient is unable to participate in a clinical Allen test or to confirm clinical findings.⁹ This is not necessary for most patients.

NONOPERATIVE MANAGEMENT

- Prior to flap coverage, the wound is debrided to ensure it is clean with no necrotic tissue.

- Antimicrobial dressings are used prior to RRFF coverage to minimize the bacterial load of the wound.

SURGICAL MANAGEMENT

- The size of the patient's wound and the presence of exposed bone and tendon help to guide the selection of an appropriate flap for reconstruction.
- Local flaps can be used for small defects.
- Regional flaps, such as the RRFF, are excellent options for moderate- to large-sized defects of the volar and dorsal hand and fingers.
- Free flaps are an alternative but require a longer operative time, a distant donor site, and microsurgical expertise.

Preoperative Planning

- The risks and benefits of flap reconstruction are discussed in detail with the patient.
- The benefits of the RRFF include a supple, durable, and thin flap for reconstruction. The color match is excellent for dorsal hand defects. In dark-skinned patients, the color match for volar defects may be poor.
- The risk of partial or complete flap loss is discussed.

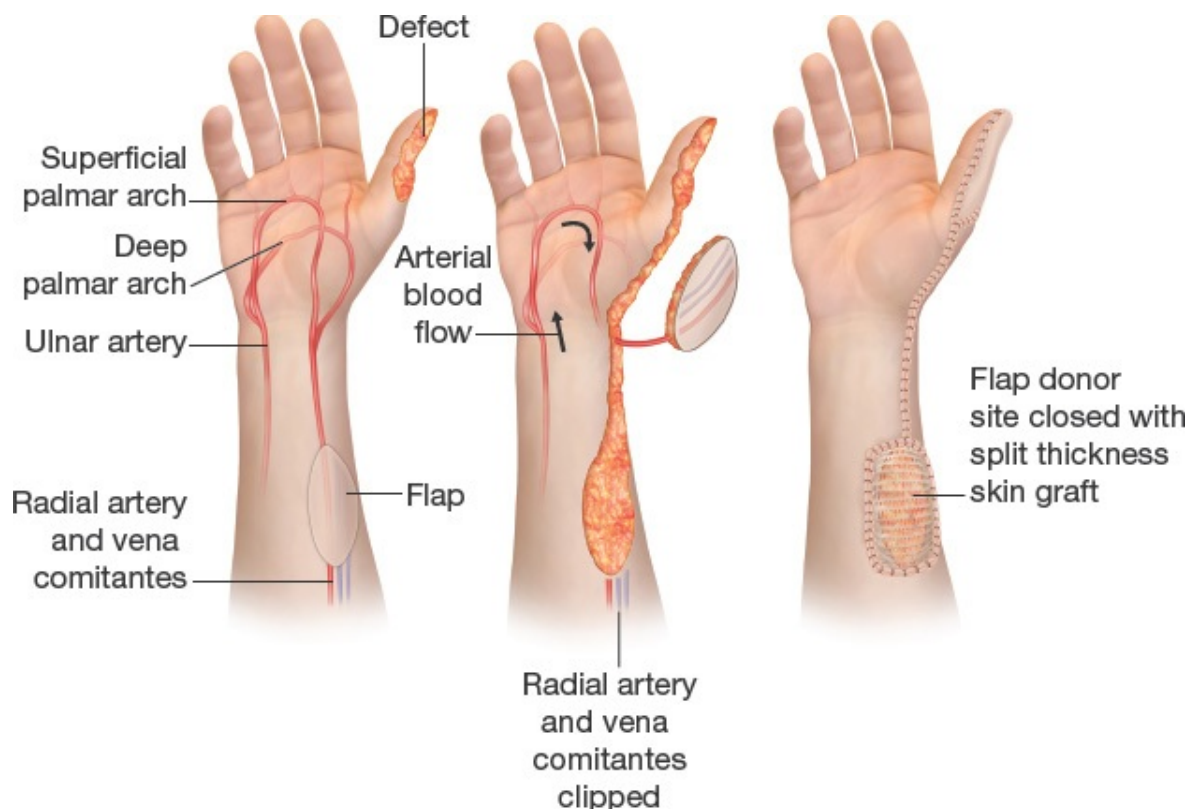


FIG 3 • The RRFF is harvested over the proximal and/or middle third of the forearm, depending on the required size and arc of rotation. For RRFFs harvested with a width over 6 cm, closure with an STSG is required.

- The patient is counseled about the donor-site defect of the RRFF. The donor site is visible over the proximal volar forearm.
- For flaps over 6 cm in width, a split-thickness skin graft (STSG) is typically used to close the donor site (**FIG 3**).
- The appearance of the STSG at the recipient site, the appearance of the STSG donor site (typically the anterior upper thigh), and the risk of the STSG failure are explained to the patient.
- If the LABC is harvested, the patient must be counseled about the sensory loss he or she will experience over the radial forearm postoperatively. This may improve with time due to collateral sprouting of adjacent nerves, but full sensory recovery is unlikely.
- The most feared complication of RRFF harvest is ischemia of the hand following division of the radial artery. If this occurs, a vein graft is typically used to restore the radial artery and thus the arterial inflow of the hand. The patient is counseled about this rare complication and the need for possible vein graft harvest, either the cephalic vein or the saphenous vein.

Positioning

- The patient is positioned supine with the arm supinated on a hand table for RRFF harvest.
- A tourniquet is applied over the upper arm.
 - After the flap incisions are designed, the tourniquet is inflated to permit safe flap elevation in a bloodless field.
 - Once the flap has been elevated with its pedicle, the tourniquet is deflated and the vascularity of the flap and the hand are assessed. Hemostasis is achieved prior to flap inset and donor-site closure to minimize the chance of hematoma and subsequent flap compromise.

Approach

- The flap is typically designed over the middle third of the volar forearm using a template of the wound to mark the flap dimensions. The arc of rotation of the

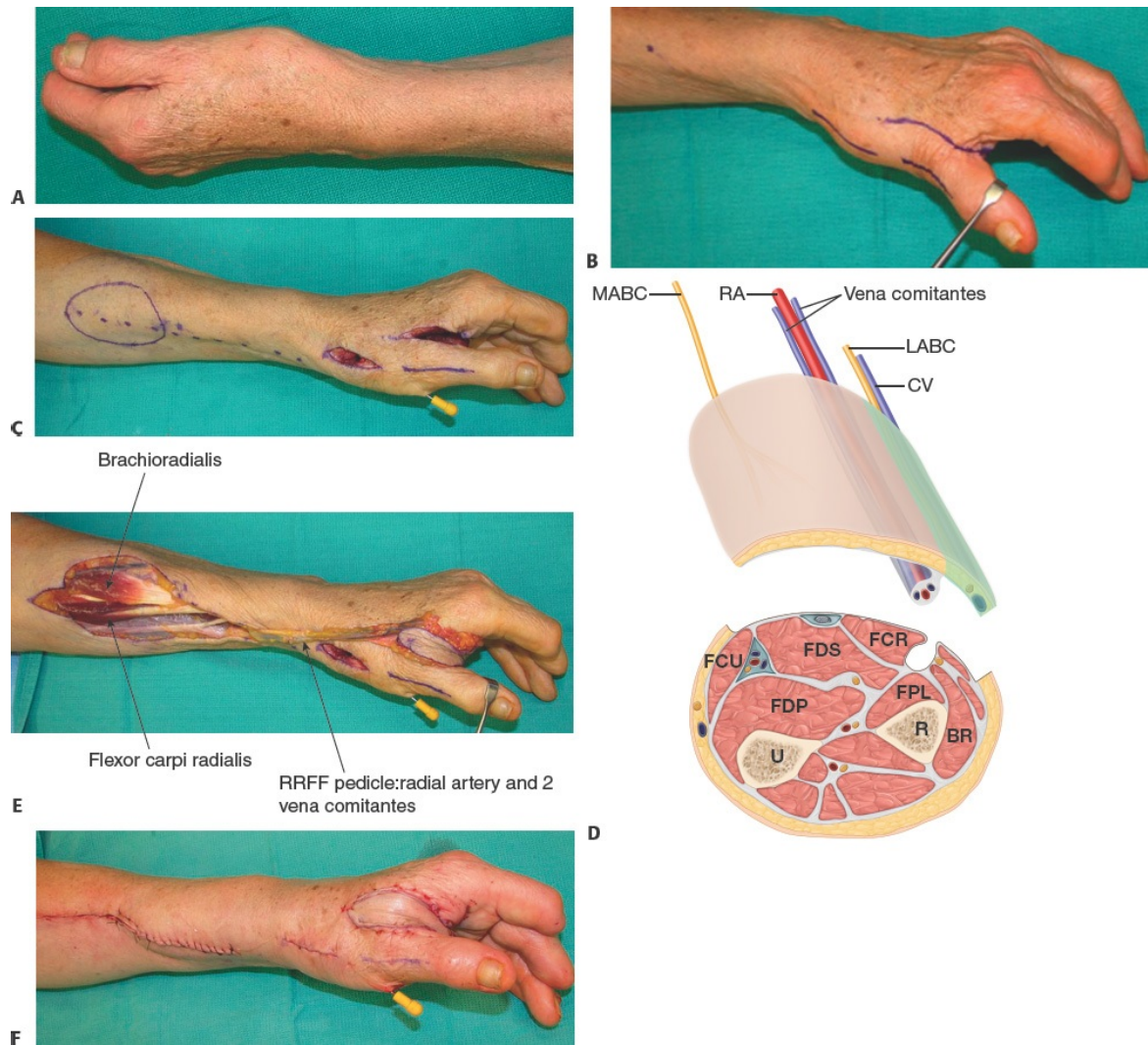
flap is tested to ensure the inset will be tension-free. If the flap must reach further distally, it can be designed over the proximal third of the forearm.

- Loupes are worn to facilitate flap elevation.

TECHNIQUES

■ Reverse Flow Radial Forearm Flap

- The flap can be designed with its radial margin over the radial artery or centered over the radial artery (**TECH FIG 1A–C**).
 - When centered over the radial artery, the flap is harvested around the radial border of the forearm that results in a more visible donor site.
- The radial artery can be palpated over the volar, radial wrist in the interval between the FCR and BR tendons, and then followed proximally using a Doppler US. The course of the radial artery is marked, starting from the volar, radial wrist to the middle of the antecubital fossa.
- An incision is designed from the distal margin of the flap skin paddle to the flap pivot point at the radial styloid. This permits elevation of the pedicle and rotation of the flap distally into the defect.
- When designed as a fasciocutaneous flap, the RRFF skin paddle is marked over the proximal and middle forearm. When used as an adipofascial or fascial flap, an incision is made over the radial proximal forearm centered over the radial artery. Thin skin flaps are lifted radially and ulnarly to expose the adipofascial tissue below.
- The RRFF is raised from ulnar to radial to the FCR and from radial to ulnar to the BR.
- The flap is elevated in either the suprafascial or the subfascial plane, depending on the tissues required for reconstruction of the defect. For both flap types, the fascia must be incised and harvested with the flap radially over the BR and ulnarly over the FCR to include the pedicle (**TECH FIG 1D**); the flap cannot be raised entirely in the suprafascial plane.



TECH FIG 1 • A. This patient presented with a first web space adduction contracture secondary to long-standing thumb carpometacarpal joint osteoarthritis. To alleviate the patient's basilar joint pain and to restore her first web space, a trapeziectomy was planned along with pinning of the first metacarpal in an abducted position and first web space contracture release with interposition of a RRFF. **B.** The surgical incisions are marked. A longitudinal incision was marked over the first web space, extending from the dorsal to the volar surface of the hand to permit the release of the contracted skin, subcutaneous tissues,

and adductor pollicis. The metacarpophalangeal joint of the thumb was marked as a reference point. The carpometacarpal joint of the thumb was marked proximally; this incision was used for the trapeziectomy. **C.** An RRFF was designed using a template of the first web space defect site. A 6 cm long × 4 cm wide flap was marked over the middle of the volar forearm, centered over the radial artery. The radial artery can be palpated distally between the FCR and BR and followed proximally using a Doppler US. Its course is marked by the dotted line. The radial styloid is the flap pivot point. **D.** The fascia must be raised over the BR radially and over the FCR ulnarly to ensure that the radial artery and its vena comitantes are raised with the flap. The LABC and cephalic vein can be included in the flap design if desired. **E.** Prior to tunneling the flap through a wide subcutaneous tunnel over the dorsoradial wrist to the first web space, the arc of rotation of the flap is tested to ensure the flap reaches the first web space defect without tension on it or its pedicle. Care is taken to avoid kinking and compression of the pedicle during inset. The tendons of the BR and the FCR are visible at the flap donor site. **F.** RRFFs less than 6 cm in width can be closed primarily, as shown here. Wider flap donor sites are closed with a STSG. In this case, the RRFF was tunneled distally into the first web space defect. Alternatively, a skin incision can be used to allow flap rotation distally. A percutaneous pin is placed to maintain thumb metacarpal abduction following first web space contracture release for 4 weeks.

- Perforators from the radial artery to the overlying fascia and skin are

identified in the lateral intermuscular septum between the BR and the FCR and are protected. To facilitate the identification of the lateral intermuscular septum, particularly in the proximal arm, the BR is retracted radially and the FCR is retracted ulnarly.

- The paratenon is preserved over all tendons during dissection; this permits STSG take when a wide flap is harvested. The superficial sensory branch of the radial nerve is protected throughout.
- The flap's proximal margin is incised. The radial artery and its vena comitantes are identified and ligated. Microclips or sutures can be used.
- If the LABC is harvested with the flap, it is divided at the proximal flap margin. If it is left in situ, it is identified and protected throughout the dissection as flap elevation continues.
- The dermis of the distal margin of the flap is incised sharply, taking care not to penetrate into the soft tissues below to prevent injury to the radial artery and vena comitantes.
- The skin incision is made from the distal flap margin to the flap pivot point. The flap is elevated from proximal to distal with its pedicle. The pedicle includes the radial artery and its vena comitantes as well as the cephalic vein and LABC when desired.
- When a fasciocutaneous flap is raised, the RRFF skin is secured to the underlying fascia using absorbable sutures to prevent shearing of the cutaneous perforators.
- Vascular branches from the radial artery to the flexor pollicis longus and to the radius are divided using microclips and bipolar cautery to permit pedicle elevation to proceed distally.
- The flap is inset into the defect site using sutures.
 - The flap can be inset through a wide tunnel (**TECH FIG 1E**) or using a skin incision from the flap pivot point at the radial styloid to the defect.
 - Care is taken to avoid kinking or compression of the pedicle and any flap tension.
- The RRFF donor site is closed primarily if the flap is adipofascial, fascial, or a narrow fasciocutaneous flap (**TECH FIG 1F**). Donor-site skin defects over 6 cm in width are closed with a STSG; a sheet STSG is preferred over a meshed STSG for improved appearance.
- The skin incision between the flap donor site to the radial styloid is closed primarily following pedicle dissection in this area.

- The flap vascularity is assessed after closure of all incisions. Color, capillary refill, temperature, and turgor are noted.

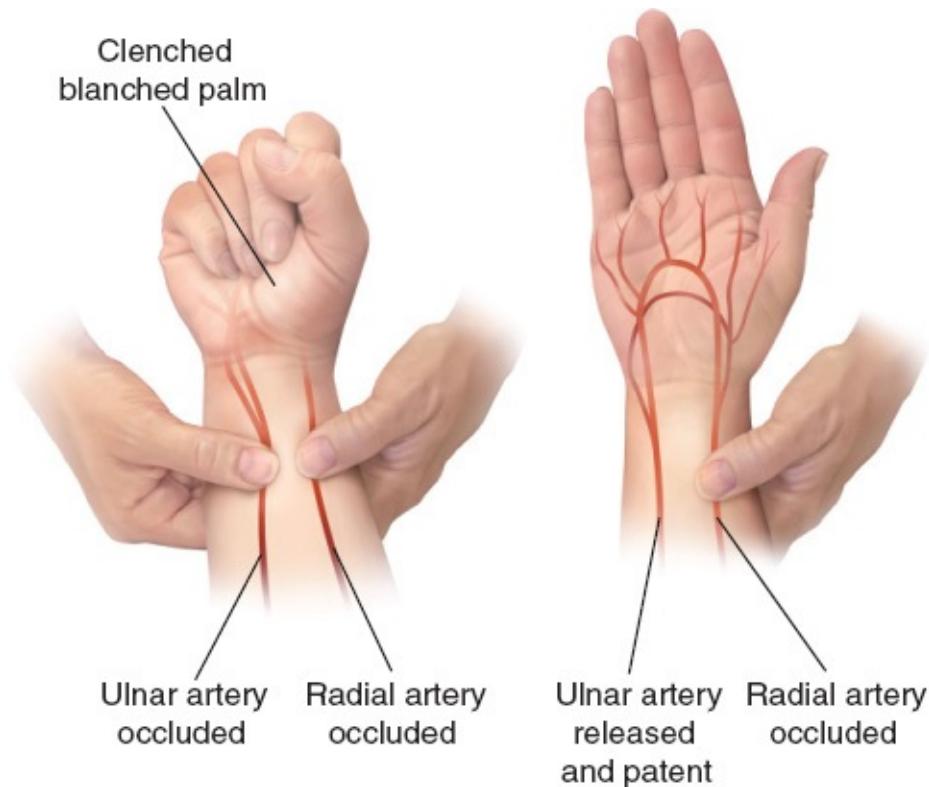


FIG 2 • The modified Allen test is used to confirm retrograde flow into the radial artery from the ulnar artery across the palmar arch prior to division of the radial artery for a RRFF. If the palmar arch is not patent, a reverse radial artery *perforator* flap or alternate flap should be used instead.

- The vascularity of the hand is confirmed, and arterial inflow to all digits is documented.
- Antibiotic-impregnated gauze is applied to all incisions and covered with sterile gauze. The skin paddle of the flap is left visible to facilitate postoperative flap checks.
- If used, the STSG is carefully padded to prevent shear and to optimize take.
- A well-padded forearm splint is applied.
- The arm is elevated postoperatively to minimize edema.

PEARLS AND PITFALLS

Physical findings	■ Previous trauma to the volar radial forearm precludes the use of the RRFF. In these cases, the small perforators to the overlying fascia and skin may have been injured.
Technique	■ For patients with recurrent or persistent carpal tunnel syndrome, an adipofascial RRFF can be used to wrap the median nerve. ¹⁰
Postoperative	■ No anticoagulation is used for pedicled flaps. Prophylactic low molecular weight heparin injections are given daily to prevent deep vein thrombosis until the patient is mobilizing well postoperatively. ■ A Doppler US can be used after flap inset to identify audible arterial and venous perforators to the skin paddle. The location of these perforators can be marked with a 6-0 polypropylene suture. This is not critical for pedicled flaps, but can be a helpful adjunct for postoperative monitoring.
Therapy	■ Scar massage and desensitization exercises can be started under the guidance of a hand therapist once the incisions are healed, approximately 3 weeks postoperatively.

POSTOPERATIVE CARE

- Flap checks are performed every 2 hours postoperatively. The flap and hand are assessed. If there is a lack of arterial inflow or venous outflow noted for the flap, the patient is taken back to the operating room urgently for flap exploration. A kink in the pedicle, hematoma, or compression from a tight closure can result in flap compromise.
- The patient is discharged home on postoperative day 3.
- The patient returns to the clinic on postoperative day 5 for a wound check and dressing change. If an STSG was used, its take over the donor site is assessed.
- Early range-of-motion (ROM) exercises are performed for all uninvolved joints of the upper extremity. If the flap crosses the wrist, gentle wrist ROM exercises are initiated on postoperative day 5 to 7 as long as no flap compromise occurs.
- For flaps crossing the wrist, a resting wrist splint is worn to maintain the wrist in neutral alignment to 20 degrees of extension for 2 weeks postoperatively.

The splint is removed multiple times during the day for ROM exercises during the 2nd postoperative week. After 2 weeks, the splint is weaned.

OUTCOMES

- The fasciocutaneous RRFF provides excellent resurfacing for palmar defects. Adipofascial or fascia-only RRFFs with STSG coverage provide a thin reconstruction for the thinner dorsal skin of the hand; these flaps are less durable but minimize donor-site morbidity compared to fasciocutaneous RRFFs.
- The RRFF can be harvested with the LABC. This is particularly helpful for thumb reconstruction. The LABC is coapted to a digital nerve of the thumb to innervate the flap. Static two-point discrimination has been reported as 11 mm for these patients.⁷ If the RRFF is used for wrist coverage, the LABC can be coapted to a branch of the superficial sensory branch of the radial nerve.⁵

COMPLICATIONS

- Flap loss is unusual with a pedicled RRFF.
- If the patient is bothered by the appearance of the RRFF donor site over the proximal arm following closure with an STSG, serial excision of the STSG can be performed.

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CHAPTER Ulnar Artery Perforator Flap

Kate Elzinga and Kevin C. Chung

DEFINITION

- The ulnar artery perforator flap was first described by Becker as a pedicled flap based on the dorsal branch of the ulnar artery (**FIG 1**).¹ The mobility of this flap is limited by its short pedicle.
- The ulnar artery perforator flap can also be designed based on the ascending branch of the dorsal branch of the ulnar artery, increasing its reach to distal hand defects (**FIG 2**).²
- The ulnar artery perforator flap is most commonly used as a pedicled flap. Alternatively, it can be harvested as a free flap.
- A major advantage of perforator flaps is the preservation of the major vessels of the forearm; the ulnar and radial arteries are not sacrificed.
- The ulnar artery perforator flap can be used for coverage of defects of the ulnar hand and wrist, both dorsal and volar, typically up to 10 × 5 cm in size.¹
 - Larger flaps, up to 20 × 9 cm, can be harvested, but venous congestion can result.³
 - Supercharging a larger flap by anastomosing a subcutaneous flap vein to a nearby vein of the dorsal hand can improve venous outflow.⁴
- The flap can be raised as a fasciocutaneous or adipofascial flap.

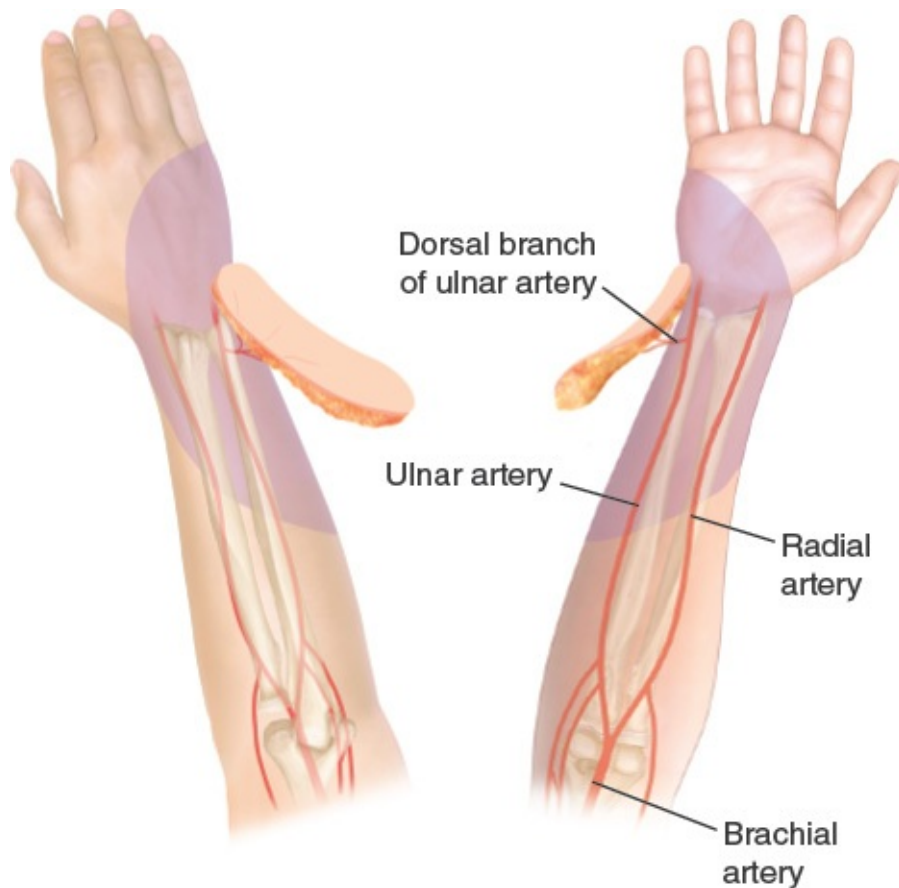


FIG 1 • The ulnar artery perforator flap is shown here based on the dorsal branch of the ulnar artery. It can be used for coverage of defects over the ulnar dorsal and volar wrist and hand (*shaded area*).

ANATOMY

- The hand is supplied by the radial and ulnar arteries that branch from the brachial artery over the antecubital fossa, 1 cm distal to the elbow joint. The ulnar artery travels distally beneath the flexor carpi ulnaris (FCU), volar to the flexor digitorum profundus. Perforators from the ulnar artery travel to the overlying fascia and skin between the FCU and the flexor digitorum superficialis. The superficial and deep palmar arches are located in the palm, formed by the radial and ulnar arteries.
- Sacrifice of the radial or ulnar artery for flap elevation risks hand ischemia if the patient does not have an intact palmar arch. Perforator flaps may be safely used in these cases.

- The ulnar artery gives off seven $\pm$ two perforators to the skin over the ulnar forearm with a diameter of 0.5 mm or greater.⁵
 - The pedicle length for propeller or free flaps based on these perforators is 3.3 mm on average, ranging from 2.5 to 4.0 mm.⁵
- About 69% of the perforators of the ulnar artery are musculocutaneous, traveling through the FCU or flexor digitorum superficialis to reach the skin.⁵
 - The remaining perforators are septocutaneous.
- The ulnar artery perforator flap can be designed as a propeller flap based on the dorsal branch of the ulnar artery. It can be harvested up to 15 cm in length, to the mid-forearm, depending on the location of the perforator.
- Greater pedicle length can be obtained when the flap is based on the ascending branch of the dorsal branch of the ulnar artery.

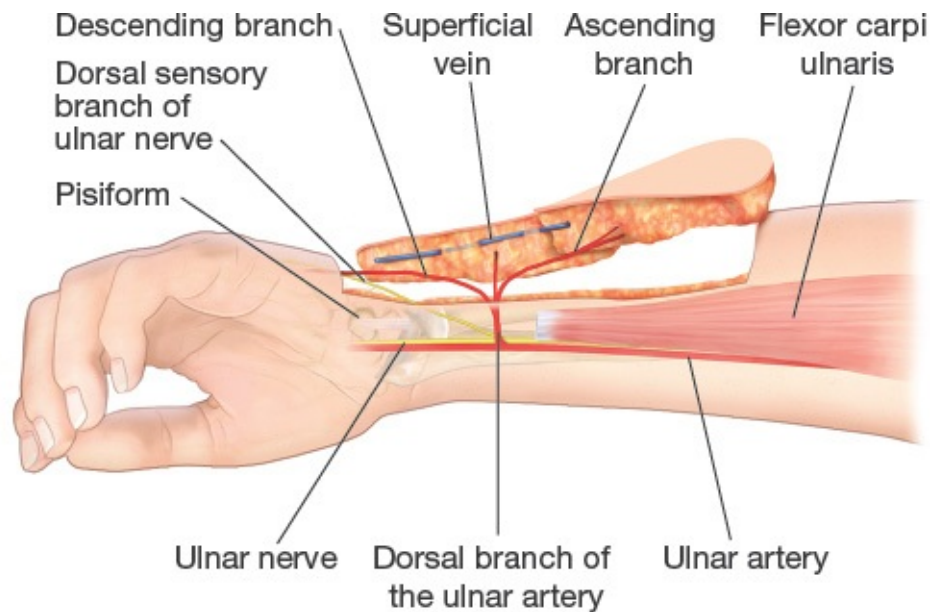


FIG 2 • The ulnar artery perforator flap has a longer pedicle and a greater arc of rotation when based on the ascending branch of the dorsal branch of the ulnar artery. The ascending branch travels proximally to the medial epicondyle. It supplies the overlying fascia and skin along its course.

- The dorsal branch of the ulnar artery arises from the ulnar artery 2 to 5 cm proximal to the pisiform.⁶

- Infrequently, in 2 of 26 cadaver dissections, the dorsal branch arises from the anterior interosseous artery rather than from the ulnar artery.⁷
- The dorsal branch of the ulnar artery has a diameter of 1.0 to 1.3 mm.² It travels from the volar distal forearm from radial to ulnar, under the FCU, to give off three branches:
 - The proximal branch enters the FCU 4 to 6 cm proximal to the pisiform.
 - The distal branch supplies the pisiform. It is called the pisiform artery.
 - The middle branch divides into an ascending and a descending branch over the dorsoulnar forearm to supply the forearm and hand, respectively. The ascending branch travels proximally to the medial epicondyle. The descending branch joins the dorsal carpal arch over the dorsal hand. An ulnar artery perforator flap can be designed based on the ascending branch of the dorsal branch of the ulnar artery and its two vena comitantes.²
- The ulnar artery perforator flap can be designed from the palmaris longus tendon volarly to the extensor digitorum communis tendon of the fourth finger dorsally.⁸
- The ulnar artery perforator flap is approximately 3 mm thick, providing thin soft tissue coverage.⁵
- The ulnar artery perforator flap is designed along the flap axis between the medial epicondyle and the pisiform (**FIG 3**). Proximally, the perforators are larger and more consistent and primary donor-site closure is easier.
 - When used as a free flap, the ulnar artery perforator flap is typically designed over the proximal forearm.
- The dorsal sensory branch of the ulnar nerve passes beneath the FCU 5 to 8 cm proximal to the pisiform to travel to the dorsal forearm. It is protected during dissection of the dorsal branch of the ulnar artery.
- Flaps widths up to 6 cm can be closed primarily over the ulnar forearm. Wider flaps require closure with a split-thickness skin graft (STSG).
- Bone defects of the small finger metacarpal can be reconstructed by harvesting vascularized cortical bone of the ulna with the ulnar artery perforator flap.⁹
 - Bone is harvested from the ulna 10 to 15 cm proximal to the pisiform between the FCU and extensor carpi ulnaris (**FIG 4**).

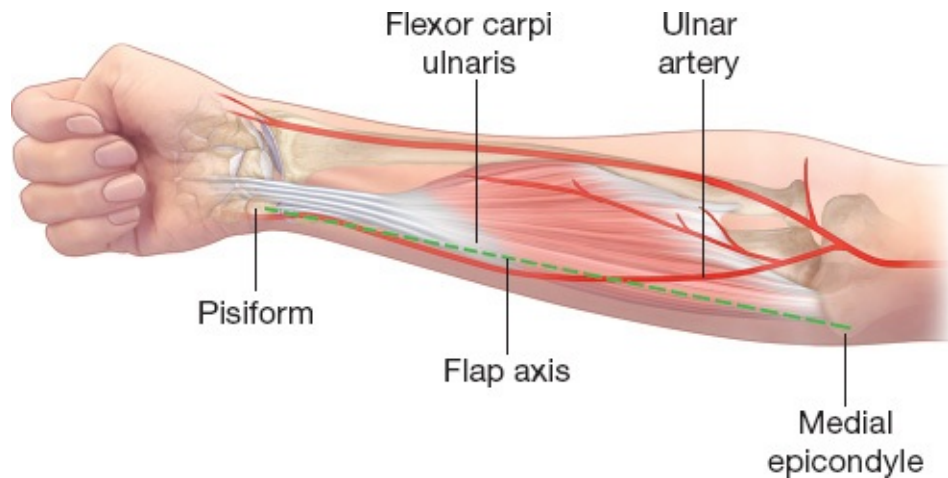


FIG 3 • To design an ulnar artery perforator flap, the medial epicondyle, pisiform, and FCU are marked. Next, the axis of the ulnar artery perforator flap is marked from the medial epicondyle to the pisiform. Ulnar artery perforators are identified along this line using a Doppler ultrasound. The flap is designed to include as many audible perforators as possible.

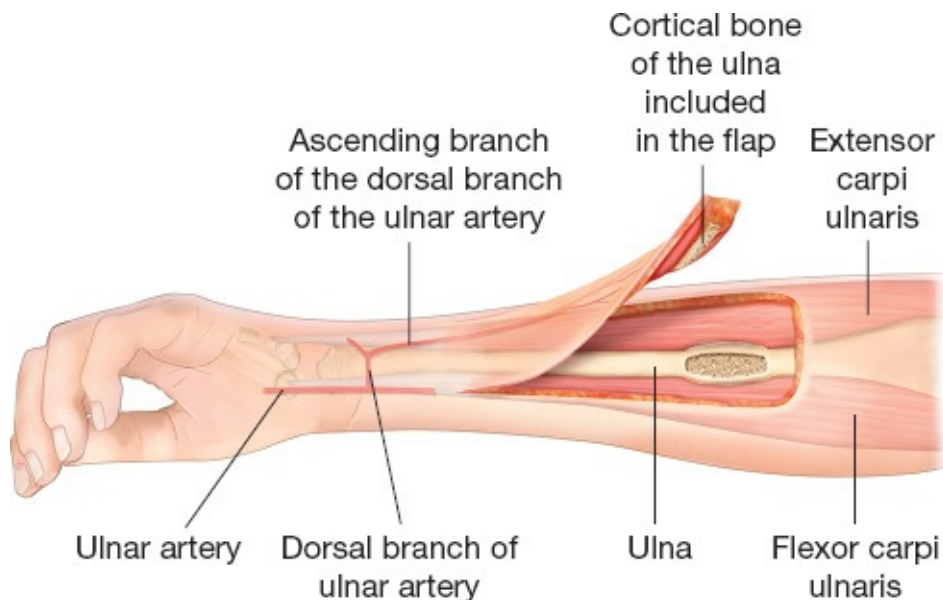


FIG 4 • The ulnar artery perforator flap can be used as an osteocutaneous flap for reconstruction of bone defects of the small finger metacarpal. Cortical bone of the ulna can be harvested in the flap 10 to 15 cm

proximal to the pisiform, between the flexor carpi ulnaris and the extensor carpi ulnaris. The flap is elevated on the ascending branch of the dorsal branch of the ulnar artery.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Important factors from the patient's history include the patient's age, sex, hand dominance, occupation and avocations, past medical history, medications, allergies, and social history.
- The timing and mechanism of the patient's injury are recorded. Traumatic injuries result from sharp, crush, and burn mechanisms. Oncologic defects result from sharp tissue resection.
- The patient's wound is explored, noting the size of the wound, contamination and tissue necrosis, and signs of infections.
 - Exposed structures are documented, in particular tendon and bone devoid of paratenon and periosteum; in these cases, flap coverage is required, graft take will not occur.
- Donor sites are assessed during wound reconstruction planning. Forearm local and regional flap donor sites are examined.
- Injuries to ulnar forearm preclude the use of the ulnar artery perforator flap. Ulna fractures often result in damage to the perforators, along with lacerations and crush injuries.

IMAGING

- Plain radiographs are used to assess for fractures, dislocations, and foreign bodies.
- Angiography is not typically performed unless there are specific concerns of the patency of the ulnar artery and its perforators.

NONOPERATIVE MANAGEMENT

- Prior to flap coverage, wound debridement is performed to prepare the wound bed for closure.
- Antibacterial dressings can be used prior to flap closure to decrease the wound's bacterial load.

SURGICAL MANAGEMENT

- The pedicled ulnar artery perforator flap is used for closure of ulnar wrist and hand defects.
- It has a smaller arc of rotation than does the radial artery forearm flap.
- It cannot reach the fingers.

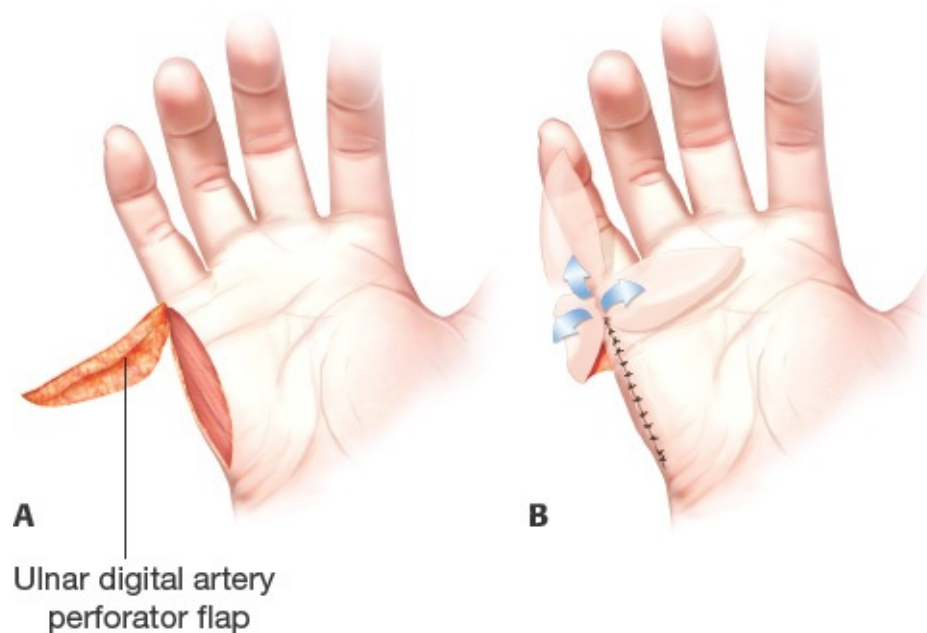


FIG 5 • A. An ulnar artery *digital* perforator flap can be raised over the ulnar hand. The largest perforators are found near the metacarpophalangeal joint. **B.** The flap can be rotated distally up to 180 degrees to cover defects of the small finger and volar and dorsal distal hand.

- The ulnar artery perforator flap can be raised as a free flap to cover a variety of defects, including finger injuries. Sizes of 3.5×2 cm to 24×4 cm have been reported.⁵
- To cover finger injuries, the flap's arterial pedicle can be anastomosed to the digital arteries and the vena comitantes can be anastomosed to superficial dorsal veins of the finger.
- The medial antebrachial cutaneous (MABC) nerve of the forearm can be harvested with the flap and coapted to a digital nerve for sensate flap reconstruction.

- For injuries of the small finger or distal dorsal or volar hand, an ulnar *digital* artery perforator flap can be elevated from the ulnar aspect of the hand and rotated distally as a propeller flap for closure (**FIG 5**).
- Three or four perforators arise over the palmar aspect of the hypothenar eminence over the abductor digiti minimi from the ulnar artery to supply this flap.¹⁰ The largest perforators are found near the metacarpophalangeal joint. The flap can be raised as a subfascial or suprafascial flap.

Preoperative Planning

- The patient is counseled about flap reconstruction using the ulnar artery perforator flap. Benefits include thin, supple soft tissue coverage. The flap is durable and reliable.
- Risks included partial or complete flap loss, wound dehiscence, sensitive scars, and a visible donor site over the ulnar volar forearm.
- To permit ulnar artery perforator flap elevation, the dorsal sensory branch of the ulnar nerve must be divided in some cases. The dorsal sensory branch of the ulnar nerve branches from the ulnar nerve 5 to 8 cm proximal to the pisiform.
- Patients are counseled about the risk of sensory loss over the dorsal ulnar hand if the nerve is divided during flap elevation.
- Primary nerve repair should be performed to aid sensory recovery and to prevent a painful neuroma.

Positioning

- The patient is positioned supine with the arm out on a hand table.
- A tourniquet is placed on the upper arm.

Approach

- Loupes facilitate safe elevation of the flap and pedicle.
 - The ulnar artery can be palpated over the volar ulnar wrist. Ulnar artery perforators can be identified using a Doppler ultrasound.
 - The flap design is marked to maximize inclusion of audible perforators.
 - Incisions are planned prior to inflation of the tourniquet. The tourniquet is inflated during flap elevation to permit bloodless dissection. Once the flap and its pedicle are raised, the tourniquet is deflated to assess the flap's vascularity. Hemostasis is achieved prior to flap inset and closure.
-

TECHNIQUES

■ Ulnar Artery Perforator Flap

- The medial epicondyle, pisiform, and flexor carpi ulnaris (FCU) are marked. The axis of the flap is marked from the medial epicondyle to the pisiform, ulnar to the FCU. The approximate position of the dorsal branch of the ulnar artery is marked 4 cm proximal to the pisiform, ulnar to the FCU.
- The ulnar artery is palpated over the distal volar forearm. It is followed proximally using a Doppler ultrasound to identify and mark perforators of the ulnar artery on the overlying skin. The largest and most constant perforators are found over the volar ulnar forearm, at the junction of the proximal and middle third of the forearm.⁵ Perforators are also consistently found at the junction of the middle and distal thirds of the forearm.
- A template of the defect is used to mark the flap dimensions.

Pedicled Flap

- The flap is designed over the junction of the proximal and middle thirds of the forearm, including as many perforators as possible from the ascending branch of the dorsal branch of the ulnar artery.
- The flap is incised proximally and elevated from proximal to distal in a subfascial plane. It can be raised as a fasciocutaneous or adipofascial flap.
- The skin between the flap and the pivot point is incised using a lazy S-shaped incision. Thin skins flaps are lifted radially and ulnarly exposing the subcutaneous tissue below containing the dorsal branch of the ulnar artery and its accompanying veins. The pedicle is raised with a 4-cm-wide strip of adipofascial tissue to prevent injury to the pedicle. The flap and pedicle are raised from proximal to distal until the dorsal branch of the ulnar artery is seen entering the undersurface of the pedicle. This marks the pivot point of the flap, 4 cm proximal to the pisiform.¹¹
- The flap is tunneled into the defect, or a skin bridge is incised between the flap pivot point and the defect for flap inset.
- The flap donor site is closed primarily for fasciocutaneous flaps with a width less than 6 cm or using a STSG if wider. The STSG is typically harvested from the ipsilateral anterior thigh.

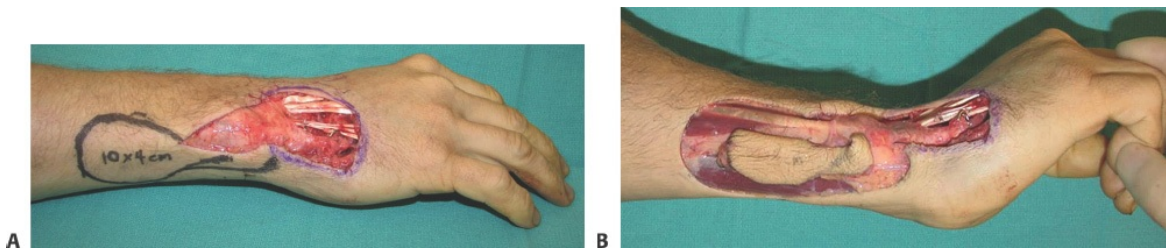
- Adipofascial flaps require coverage with a STSG after inset. Their donor sites can be closed primarily.
- Antibiotic-impregnated gauze and sterile dry gauze are placed over all incisions. The flap is left uncovered to facilitate.
- Postoperative flap monitoring. A well-padded splint is applied. Pressure on the flap is avoided.

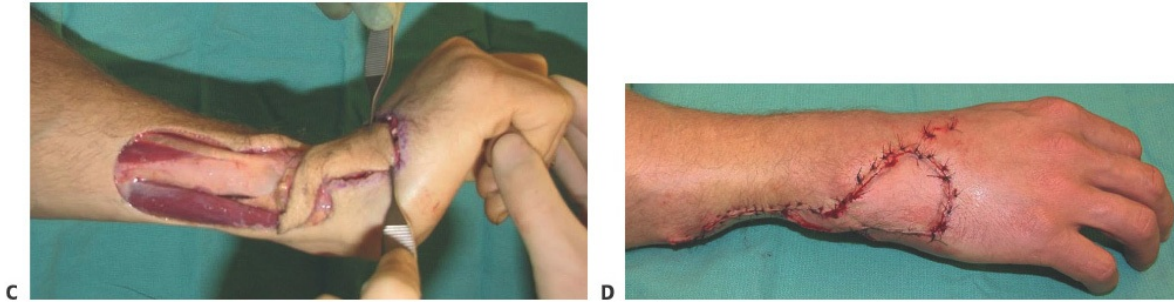
Propeller Flap

- When used as a distally based propeller flap for hand and wrist coverage, the flap is designed over one dominant perforator from the dorsal branch of the ulnar artery; including additional perforators can prevent adequate rotation of the flap.
 - The largest caliber perforator or the most optimally located perforator is used.
 - Distal perforators facilitate flap rotation distally and thus are often selected when multiple perforators are available.
 - All perforators are preserved during initial flap dissection. The desired perforator is selected. All additional perforators are clamped to ensure that flap vascularity will be maintained based on the main perforator prior their division.
- The width of the flap is designed to match that of the defect (**TECH FIG 1A**).
- The length of flap is designed so that the distance between the perforator and the distal edge of the defect matches the distance between the perforator and the proximal edge of the flap.
- The skin distal to the flap is incised to confirm the location of the ulnar artery and its perforators prior to elevation of the flap. The skin is incised radial to the FCU.
 - The FCU is retracted ulnarly, exposing the ulnar artery and nerve below.
 - The perforators of the ulnar artery are identified and followed to the overlying skin to confirm that the flap is properly centered over the perforators.
- The flap is elevated subfascially from ulnar to radial to the radial border of FCU.
- The radial aspect of the flap is then incised.
 - The flap is elevated in a subfascial plane from radial to ulnar to the ulnar aspect of FCU, where the dorsal branch of the ulnar artery is seen entering

the flap.

- The basilic vein is typically elevated with the flap. The basilic vein can be followed 2 or 3 cm proximal to the proximal flap edge and harvested to permit venous supercharging if poor venous outflow is noted after inset.⁴
- The MABC nerve can be elevated with the flap or left in situ. The ulnar artery and nerve must be protected.
- The main perforator is skeletonized as necessary to permit adequate rotation of the flap and to prevent pedicle kinking.¹²
- Additional perforators are clamped, and flap vascularity is assessed.
 - If perfusion is maintained, the additional perforators are divided.
 - If not, the additional perforators are maintained to ensure flap viability.
- The flap is inset into the defect. It can be rotated up to 180 degrees (**TECH FIG 1B,C**).
- If used as a sensory flap, the MABC is coapted to a sensory nerve located within or adjacent to the defect.
- The flap donor site is closed primarily for flaps up to 6 cm in width (**TECH FIG 1D**) or using a STSG if a wider flap is harvested.
- A drain can be placed under the flap or the donor site.
- Antibiotic-impregnated gauze is placed over all incisions and covered with sterile gauze. The flap is left uncovered to facilitate postoperative flap monitoring.
- A well-padded splint is applied to protect the flap and to decrease tension on the flap.
 - When the flap is used for coverage of palmar defects, the wrist is splinted in mild flexion to decrease flap tension.
 - When used for dorsal defects, the wrist is splinted in extension.





TECH FIG 1 • **A.** Following debridement of a traumatic wound, this patient had a 9 × 4 cm defect over the dorsal ulnar hand with exposed extensor tendons. An ulnar artery perforator flap was designed as a propeller flap for coverage. The width of the flap is designed to match the width of the defect. The length of the flap is marked so that when the flap is rotated 180 degrees around the perforator, the proximal edge of the flap will reach the distal edge of the defect. An umbilical tape, vessel loop, or surgical sponge can be used to visualize the arc of rotation of the proximal flap into the distal defect during flap marking. **B.** The ulnar artery perforator flap is elevated. **C.** The flap can be rotated up to 180 degrees into the distal defect. **D.** Here, the donor site was closed primarily. The flap width was 4 cm. Flaps widths up to 6 cm can generally be closed with sutures directly. Wider flaps require closure with an STSG.

PEARLS AND PITFALLS

Physical findings

- A modified Allen test is performed to assess the patency of the palmar arch. An intact palmar arch is not required for the ulnar artery perforator flap but provides valuable information about the arterial supply of the hand.

Technique

- During ulnar artery perforator flap elevation, the dorsal sensory branch of the ulnar nerve may require division. In these cases, the

	nerve should be repaired using 9-0 nylon suture or fibrin glue. ■ Dissection of the dorsal branch of the ulnar artery to its origin from the ulnar artery facilitates rotation of the flap up to 180 degrees.⁸
Postoperative	■ The patient is instructed to keep the hand elevated following flap coverage. This decreases flap edema, which lessens the risk of pedicle compression and venous congestion.
Therapy	■ The fingers, wrist, and forearm can be passively mobilized in the operating room to assess for flap tension with movement. Immediate range of motion exercises are performed for uninvolved joints that do not cause strain on the repair with motion.

POSTOPERATIVE CARE

- The patient is monitored in hospital for signs of flap compromise.
 - Poor arterial inflow or venous congestion should prompt removal of the dressings, flap assessment, and urgent return to the operating room to assess for pedicle compromise due to hematoma, kinking, or compression.
- The patient is discharged on postoperative day 3.
- The patient returns to clinic 1 week postoperatively for a dressing change.
- A thermoplastic splint can be worn for an additional week if range of motion causes tension on the flap.
- Range of motion exercises are started under the guidance of a hand therapist 1 week postoperatively and advanced weekly.

OUTCOMES

- The ulnar artery perforator flap provides thin, durable soft issue coverage in a single-stage operation (**FIG 6**).
- Compared to the radial forearm flap, the ulnar artery perforator flap donor site is less visible on the forearm and the skin paddle contains less hair.
- The ulnar artery perforator flap provides an excellent color match for dorsal wrist and hand defects.
 - In dark-skinned patients, the color is not as well matched for palmar defects.

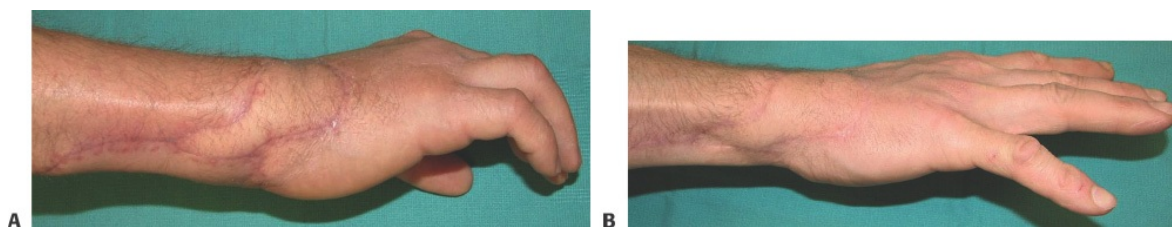


FIG 6 • The ulnar artery perforator flap at 1 **(A)** and 10 **(B)** months postoperatively. Supple, durable, thin soft tissue coverage is provided for defects of the hand. The donor site heals well with minimal morbidity.

COMPLICATIONS

- The MABC can be harvested with the flap to restore sensation at the defect site. The donor-site sensory deficit is minimal because of existing sensory overlap and subsequent sensory axon in-growth from neighboring nerves to the denervated skin.¹³
- The risk of venous congestion is lower for the ulnar artery perforator flap compared to reverse flow flaps, such as the reverse radial forearm flap or the reverse posterior interosseous flap. The ulnar artery perforator flap is a distally based island flap, not a reverse flow flap.
- Incisions over the ulnar forearm, wrist, and hand can be sensitive. Scar massage is recommended once the incisions are healed, starting approximately 3 weeks postoperatively.

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49 Posterior Interosseous Artery Flap

CHAPTER

Kate Elzinga and Kevin C. Chung

DEFINITION

- The posterior interosseous artery (PIA) flap is a perforator flap used for coverage of upper extremity defects. Its harvest avoids the sacrifice of a major artery, such as that of the radial artery during harvest of the radial artery flap.
 - It is available in patients without an intact palmar arterial arch.
- The PIA flap is typically used as a pedicled flap. It can also be harvested as a free flap.¹
- The PIA flap is most commonly used as a retrograde regional flap based on the anteroposterior interosseous artery system to cover defects of the first web space, dorsal wrist, dorsal and volar hand, and dorsal thumb up to the proximal interphalangeal joint.
 - The PIA flap can also be used as an antegrade flap for defects of the elbow, antecubital fossa, and proximal volar forearm.
- The dimensions of the PIA flap are designed based on the defect size.
 - One case series of 53 patients, from whom two-thirds of the circumference of the forearm skin was harvested, reported the use of PIA flaps from 5×2.5 cm to 21×10 cm in size.²
- The PIA flap provides a good color match for defects of the forearm, wrist, and hand, particularly dorsally.
 - In dark-skinned patients, resurfacing of the palmar skin with a PIA flap leads to a color mismatch.

ANATOMY

- The PIA flap is classified as a Mathes and Nahai type B flap; it is supplied by a septocutaneous perforator.

- Most commonly, the flap is harvested subfascially as a fasciocutaneous island flap.
- It can also be harvested with a skin bridge or as an adipofascial flap, which permits primary closure of the donor site; the subcutaneous tissue and fascia are harvested; the dermis is preserved at the donor site.³
- When used as an adipofascial flap, the flap is covered with a split-thickness skin graft (STSG) after inset.
- The flap pedicle is composed of the PIA and its two adjacent vena comitantes.
 - Proximally, the artery is 1.2 to 2.1 mm in diameter and the vena comitantes are 1.0 mm.
 - Over the middle third of the forearm, the PIA has its narrowest caliber, measuring 0.5 mm.
 - Distally, it measures 0.9 to 1.1 mm.⁴
- The PIA arises 4 cm from the lateral epicondyle from the common interosseous artery in 80% of cases and directly from the ulnar artery in 20% of cases.⁵
- The anterior interosseous artery (AIA) also arises from the common interosseous artery, or less commonly, directly from the ulnar artery. It runs along the volar surface of the interosseous membrane (IOM), deep to the flexor digitorum profundus and flexor pollicis longus.
- The PIA passes through the IOM from the volar forearm to the dorsal forearm 8 cm distal to the lateral epicondyle and 14.5 cm proximal to the ulnar styloid.⁵
 - In most cases, it gives origin to three fasciocutaneous perforators to the overlying skin in the proximal forearm and six to eight perforators in the distal forearm.⁴
 - The PIA runs with the posterior interosseous nerve (PIN) along the dorsal IOM to the hand in the septum between the extensor digiti minimi (EDM) and extensor carpi ulnaris (ECU).
- After passing under the supinator in the proximal forearm, the PIA runs over the abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, and extensor indicis proprius (**FIG 1**).
- Two centimeters proximal to the distal radioulnar joint (DRUJ), just proximal and radial to the head of the ulna, a branch of the PIA travels volarly through the IOM and anastomoses with the dorsal branch of the AIA.
 - This anastomotic connection is the basis for the retrograde PIA flap.
- The PIA continues distally and joins the dorsal carpal arch. The retrograde PIA

flap also receives some flow through this arch.

- The axis of the flap is marked from the lateral epicondyle of the elbow to the head of the ulna.⁵
- The flap design is centered on the septum between the EDM and ECU to maximize the number of perforators entering the flap from the PIA between the dorsal margins of the ulna and radius (**FIG 2**).
- The flap is typically designed up to 18 × 8 cm in size.
- A segment of the proximal third of the ulna, with a cuff of the extensor pollicis longus, can be included in the PIA flap for use as an osteocutaneous flap.⁶

PATIENT HISTORY AND PHYSICAL FINDINGS

- Important aspects of the patient history include age, sex, handedness, occupation and avocations, past medical history, medications, allergies, smoking and recreational drug use, and previous injury to the affected arm.
- The wound is evaluated for
 - Exposed and damaged structures—skin, tendons, neurovascular structures, bone
 - Health of remaining structures—tissue necrosis, contamination, signs of infection
 - Local and regional donor sites

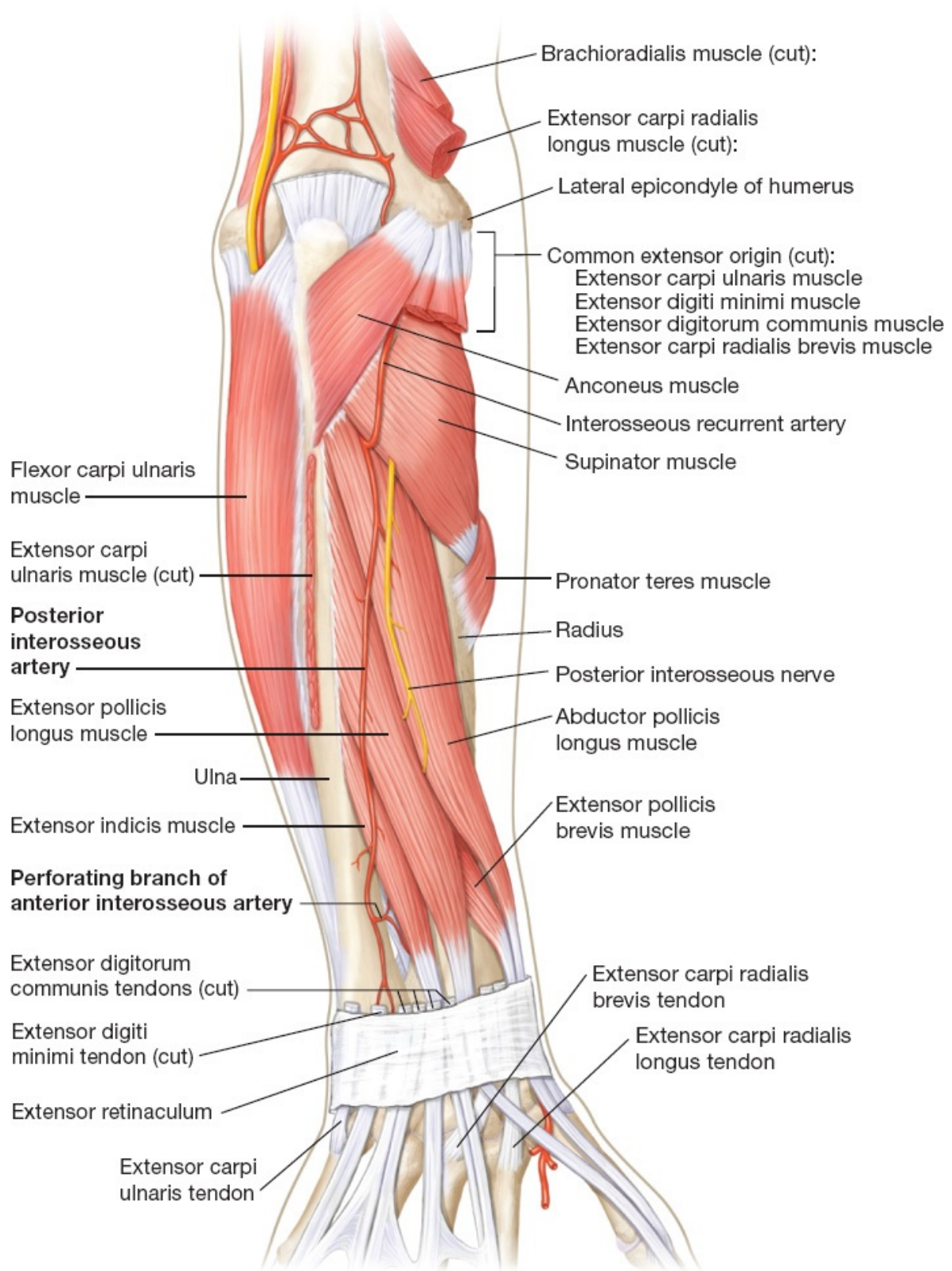


FIG 1 • The course of the posterior interosseous artery is shown in the dorsal forearm. It originates from the

common interosseous artery, or less commonly, from the ulnar artery directly. It passes under the supinator and then travels over the abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, and extensor indicis proprius. Two centimeter proximal to the DRUJ, a branch of the PIA travels volarly through the IOM to form an anastomosis with the dorsal branch of the AIA. The PIA continues distally to contribute to the dorsal carpal arch. The axis of the flap is marked from the lateral epicondyle to the head of the ulna to maximize the capture of PIA perforators into the flap.

- Radiographic imaging is used in conjunction with physical examination to determine the presence and extent of bone injuries.
- Skin and soft tissue defects can be adequately reconstructed using soft tissue flaps.
 - When the defect size is too large for local flap coverage, the PIA flap is a useful regional flap that can be performed. It alleviates the need for a microsurgical free flap from a distant donor site.
- Many tendon and bony defects can be reconstructed in the hand and then covered with a PIA flap during the same operation. This fasciocutaneous flap provides reliable, durable soft tissue coverage of exposed structures and a smooth gliding surface for underlying tendons.
- Skin laxity is assessed over the dorsal forearm using a pinch test.
 - Flaps larger than 4 to 6 cm in width typically require donor site closure with a skin graft.
 - If desired, the skin graft can be excised later using serial excision; the patient must be appropriately counseled prior to flap reconstruction regarding the expected appearance of the donor site given its visible location over the dorsal forearm.

IMAGING

- Radiographs are performed of the injured extremity to assess for fractures or foreign bodies.
- Angiography is not routinely performed prior to PIA flap reconstruction.

- If there is concern of the integrity of the PIA or AIA-PIA anastomotic arch, angiography can be considered to evaluate the vessels or a different flap can be selected.

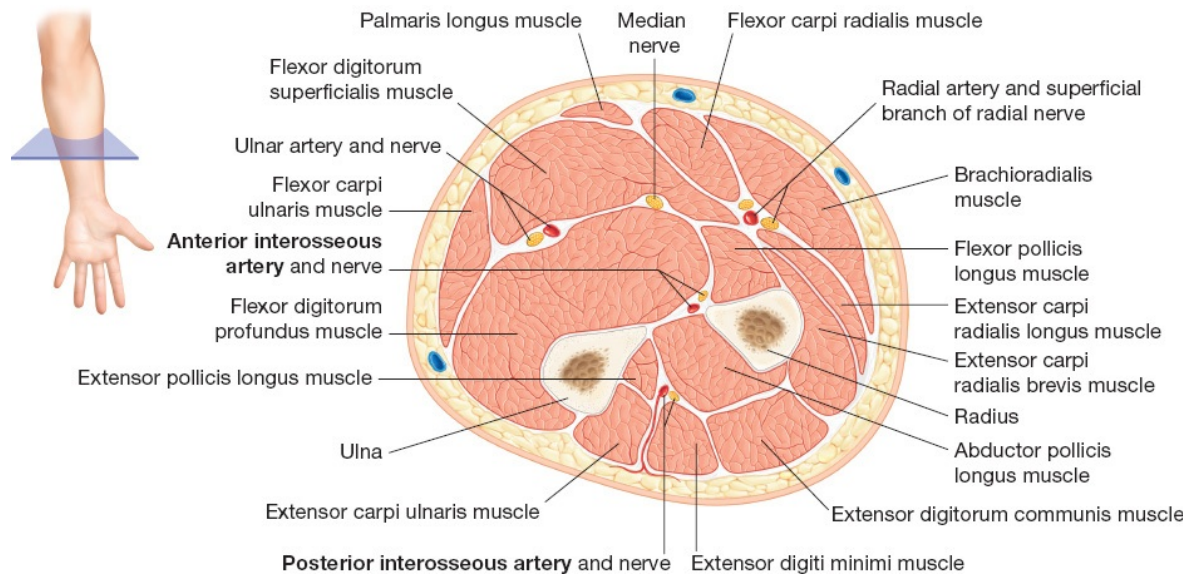


FIG 2 • The PIA perforators run in the interval between the EDM and ECU to supply the overlying skin. The AIA runs volar to the IOM in the forearm. Distally, 2 cm proximal to the DRUJ, the AIA gives off a dorsal branch that forms an anastomosis with the PIA.

NONOPERATIVE MANAGEMENT

- The wound must be adequately debrided and cleansed prior to flap reconstruction. Following traumatic injury, the wound is explored, injured structures are assessed, and necrotic tissue is debrided. Once the wound is clean and the tissues have demarcated, flap reconstruction can proceed.
- For the reconstruction of oncologic defects, final tumor pathology and negative margins are established prior to flap closure.
- Moist, antibacterial dressings can be used in the interim to minimize tissue desiccation and bacterial load.

SURGICAL MANAGEMENT

- Local flaps are limited to coverage of small defects of the upper extremity.
- Larger regional flaps, such as the PIA flap, provide coverage of forearm, wrist,

and hand defects without the need for free flap microsurgical reconstruction (**FIG 3**).

- Compared with free flaps, pedicled flaps require less general anesthesia time, avoid the need for flap harvest from an uninjured limb or the trunk, and are options when microsurgical equipment or expertise is unavailable.



FIG 3 • This patient underwent a ray resection of the thumb for treatment of squamous cell carcinoma. In-transit metastases were resected from the volar radial forearm. Following pathological confirmation of negative margins at both locations, a PIA flap was used for coverage of the exposed trapezium at the base of the radial hand wound. (Courtesy of Steven Haase, MD.)

Preoperative Planning

- The risks and benefits of flap reconstruction with a PIA flap are reviewed with the patient.
 - The benefits include provision of durable, supple soft tissue coverage, a donor site limited to the affected upper extremity, and a single-stage procedure.
 - The risks include partial or complete flap failure and injury to the PIN. The patient is counseled that the PIA flap has a visible donor site.
- When used as a retrograde flap, the PIA flap is insensate.
 - For antegrade or free PIA flaps, the posterior antebrachial cutaneous nerve of the forearm can be included for sensory restoration.
- Previous injury to the PIA flap donor site is a contraindication to its use.
 - The PIA perforators are small and thin-walled, so crush or shear injury to dorsal forearm makes flap harvest unreliable.
- Injury to the DRUJ and possible damage to the AIA-PIA anastomosis

precludes retrograde PIA flap use.

- Some authors have reported the absence of the AIA-PIA anastomosis or a hypoplastic or absent PIA in the middle third of the forearm. Penteado reported 5 such cases in 110 cadavers, Angrigiani reported 1 case in 80 patients, and Buchler reported 2 cases in 36 patients.⁷⁻⁹
- Anatomic dissections have confirmed the reliability of the AIA-PIA system and presence of the PIA throughout the dorsal forearm.^{5,7} Studies have noted that the PIA is more superficial and narrowest in caliber over the dorsal third of the forearm, measuring 0.5 mm.
- If there are doubts of the integrity of the PIA, the incision can be closed and another flap can be used.
- In rare cases, if the PIA is absent or hypoplastic, the AIA is dominant and an AIA perforator flap can be harvested instead.^{10,11}

Positioning

- The patient is positioned supine with the arm out on a hand table.
- A tourniquet is placed on the upper arm of the affected limb.
- If the PIA flap is harvested with a width over 4 to 6 cm, closure with a skin graft is typically required. Most commonly, the patient's ipsilateral thigh is used for STSG harvest.

Approach

- Loupes are worn for flap harvest and inset. An operating microscope is not routinely required; in rare cases, it may be employed if there is difficulty visualizing the vascular anatomy or concern of pedicle injury during flap harvest.
- The flap incisions are designed, most commonly as a longitudinal ellipse.
- The arm is then elevated and the tourniquet is inflated.
- Exsanguination with an Esmarch bandage is avoided to maintain visibility of the PIA and its perforators.

TECHNIQUES

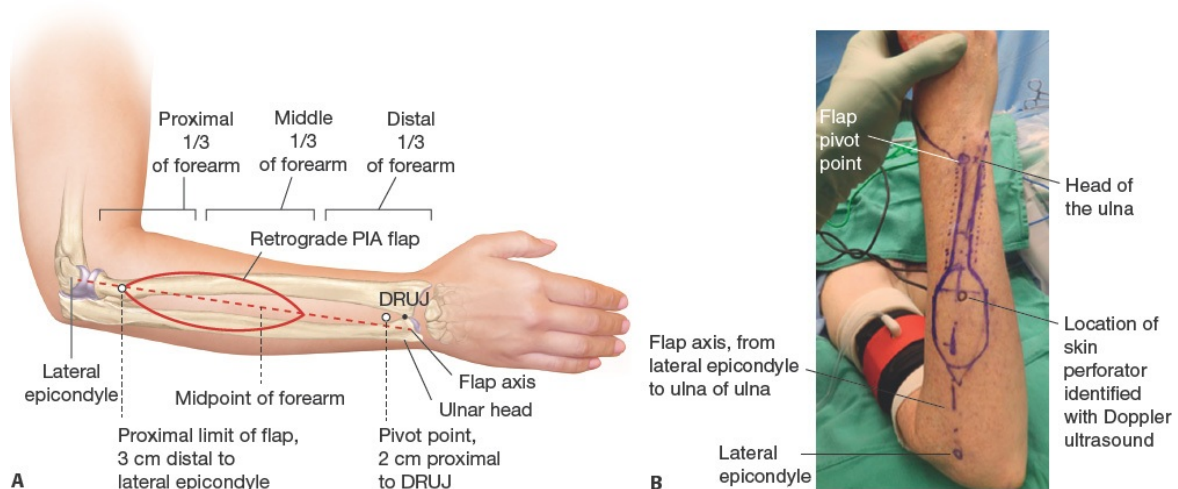
- The axis of the flap is marked with the forearm in full pronation from the lateral epicondyle to the ulnar head. This marks the course of the PIA.
- A Doppler ultrasound is used to identify perforators running along this axis

to the overlying skin. Typically, there is a large perforator found at the midpoint of the dorsal forearm, along the flap axis. The skin flap is designed to include this perforator and as many additional perforators as possible.

- To raise a fascia-only flap, the dorsal forearm fascia is exposed by incising the skin above the flap and elevating thin dermal flaps bilaterally.
- To raise a fasciocutaneous flap, the skin, subcutaneous tissue, and fascia are raised en bloc. Once elevated, it is recommended that the dermis is sutured to the underlying fascia using absorbable sutures to prevent shearing of the perforators to the skin.

■ Retrograde PIA Flap

- The pivot point of the flap is marked 2 cm proximal to the DRUJ, proximal to the edge of the extensor retinaculum, at the site of the AIA-PIA anastomosis (**TECH FIG 1A**).
- The rotation of the flap into the defect is tested using a sponge, umbilical tape, or vessel loop.
- The flap is typically designed at the junction of the proximal and middle thirds or over the middle third of the dorsal forearm to include the skin perforators arising distal to the supinator while permitting tension-free rotation into the distal defect of the wrist, hand, or first web space (**TECH FIG 1B**).
- The proximal flap limit is marked 3 cm distal to the lateral epicondyle. Proximally, there are no PIA perforators to the overlying skin.¹²



TECH FIG 1 • A. The axis of the PIA flap runs from the lateral epicondyle to the head of the ulna. The retrograde PIA flap is centered over the junction of the proximal and middle thirds of the forearm or over the middle third of the forearm based on the arc of rotation required to reach the defect. The flap pivot point is marked 2 cm proximal to the DRUJ. A large perforator is typically found near the midpoint of the dorsal forearm from the PIA to the overlying skin. The proximal flap limit is marked 3 cm distal to the lateral epicondyle. **B.** The flap axis is marked from the lateral epicondyle to the ulnar head with the forearm in full pronation. The pivot point is marked 2 cm proximal to the DRUJ. A Doppler ultrasound is used to mark skin perforators. The flap is designed as an ellipse over the proximal and middle thirds of the forearm to include audible skin perforators. The flap can be elevated as an island flap or with a skin bridge as shown here. The skin bridge overlies the pedicle and is elevated by incising a 1-cm strip of dermis (marked here in *solid lines*). An additional 0.75 cm of subcutaneous fat and fascia is included on either side of the dermis to protect the PIA and its vena comitantes (marked here with *dotted lines*). An incision is marked from the flap pivot point to the defect for inset of the flap (marked here with a *solid line* from the pivot point in a radial oblique direction to the thumb defect).

- A template of the defect is made using Telfa and used to mark the appropriate flap dimensions, up to 18 × 8 cm in size.
- The interval between the fifth and sixth extensor compartments can be palpated; the PIA is found in the septum between the EDM and ECU.
- The flap is centered over this interval.

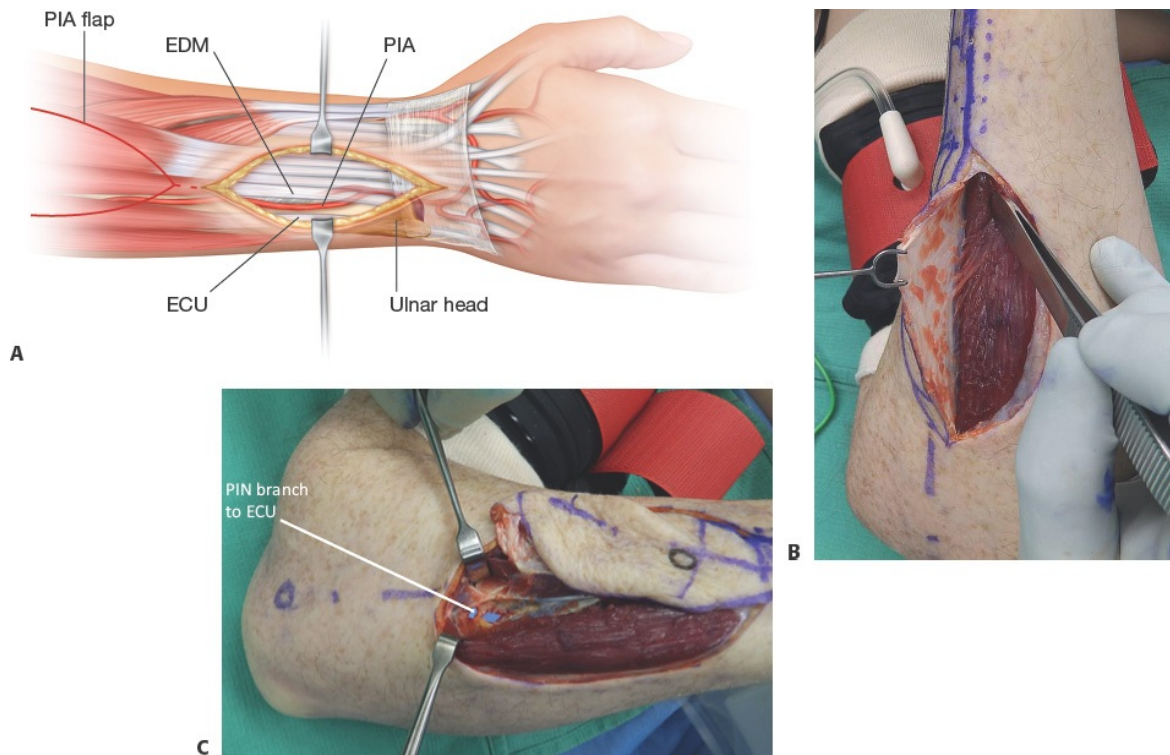
- The flap can be elevated as an island flap, or with a 1-cm skin bridge that can be closed primarily.
 - The skin bridge protects the pedicle, prevents kinking of the vessels on inset, and makes flap harvest safer.

Retrograde PIA Island Flap Harvest

- To raise the flap as an island flap, dissection is typically started distally by incising through the skin and subcutaneous tissue and identifying the PIA in the septum between the fifth and sixth extensor compartments (**TECH FIG 2A**).
 - The pedicle can be followed proximally to the distal edge of the flap. The flap markings are adjusted if needed to ensure that the flap is centered over the pedicle.
 - This is a most reliable way to ensure that the flap has been properly designed prior to elevation.
- The flap is raised subfascially from its ulnar border to the intermuscular septum (IMS) between the EDM and ECU (**TECH FIG 2B**).
- Next, elevation proceeds from the radial border of the flap, again toward the IMS between the EDM and ECU.
- Distal to the supinator, the PIN gives a branch to the ECU that crosses superficial to the PIA (**TECH FIG 2C**). The PIA is divided just distal to this nerve branch.
- Flap elevation proceeds from proximal to distal. The PIN runs with the PIA along the dorsal forearm and is protected throughout flap elevation.
- The pedicle is raised as a fascial strip between EDM and ECU containing the PIA and its vena comitantes.
- The PIA gives off multiple branches to the surrounding musculature; these are divided using microclips and bipolar cautery.

Retrograde PIA Flap Harvest With a Skin Bridge

- To raise a flap with a skin bridge, the flap is elevated first from its ulnar border in a subfascial plane toward the IMS between the EDM and ECU.
 - Gentle proximal traction on the muscle bellies confirms the anatomy; traction on the EDM will extend the small finger while traction on the ECU will extend the wrist.



TECH FIG 2 • A. To confirm the flap is properly centered over the PIA, dissection starts distally. The PIA is identified in the interval between the EDM and ECU over the dorsal wrist. The flap design is confirmed over the proximal-middle forearm to ensure the PIA will be centered within it and then the flap is elevated. **B.** The PIA flap is raised subfascially, here shown from ulnar to radial. Perforators can be seen entering the flap in the interval between the EDM and ECU from the PIA below. **C.** The PIN gives a motor branch to the ECU distal to the supinator (shown here on top of the blue background material). This branch crosses superficial to the PIA. It is protected. The PIA and its vena comitantes are divided just distal to this nerve branch and then the flap is elevated from proximal to distal for retrograde use.

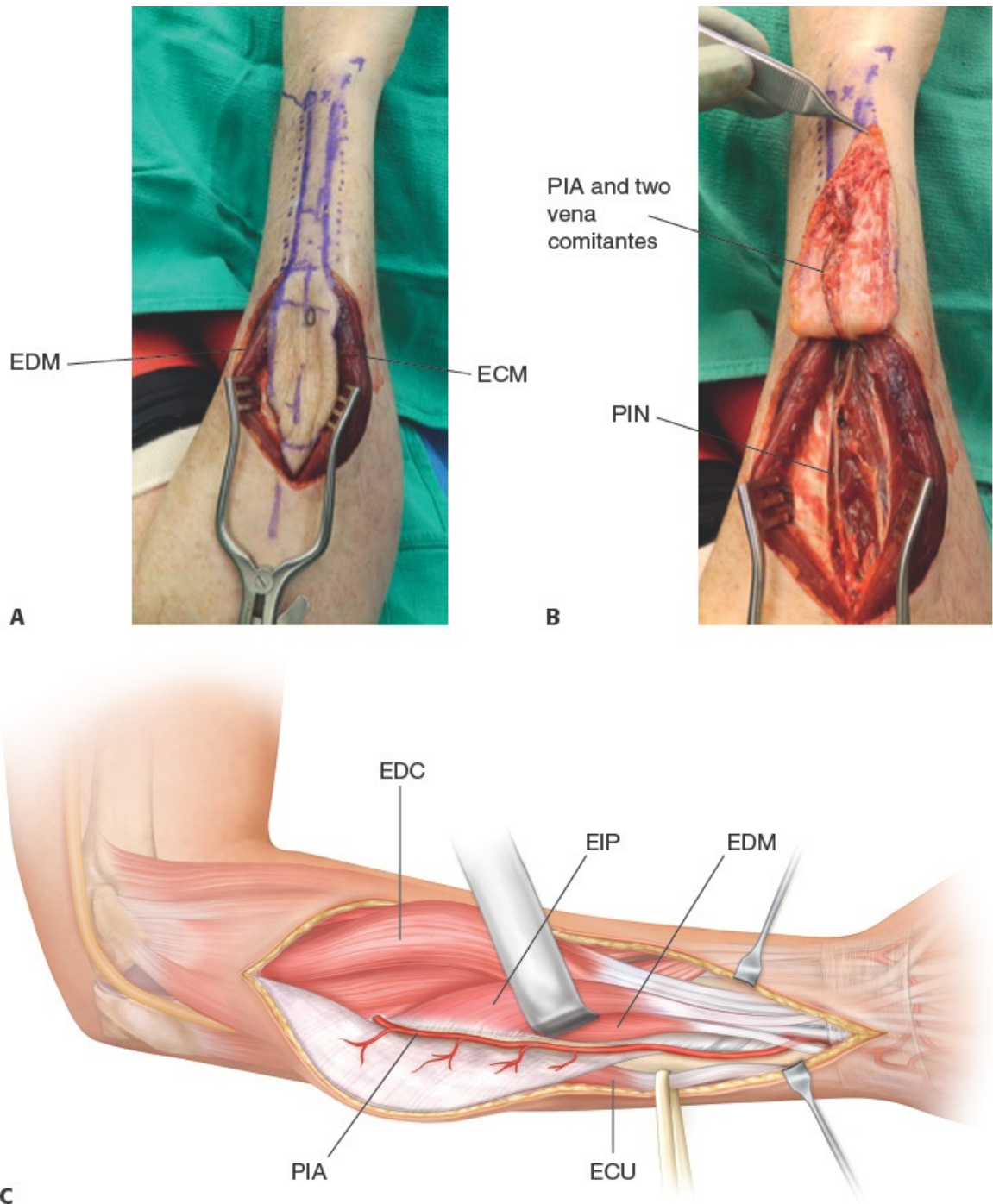
■ Next, the radial border of the flap is raised toward the IMS between the

EDM and ECU. The IMS between the extensor digitorum communis (EDC) and EDM will be encountered. The EDM is much smaller in size compared to the EDC that is found one interval radially. To elevate the flap subfascially above the EDC, the flap fascia is divided from the IMS between the EDC and EDM.

- Proximal retraction of the EDM radially and the ECU ulnarly with a self-retaining retractor facilitates exposure of the PIA (**TECH FIG 3A,B**).
- The skin bridge is incised from proximal to distal, a few centimeters at a time.
 - The pedicle location is confirmed sequentially.
 - The course of the skin bridge can be modified if needed to ensure the pedicle is maintained within it.
 - A 1-cm dermal bridge is used. An additional 0.75 cm cuff of subcutaneous fat and fascia is harvested on each side of the skin bridge to protect the pedicle.
 - Restricting the width of the dermis elevation to 1 cm facilitates primary closure of this area.
- Distally, the pedicle is closely associated with the periosteum of the ulna. Ulnar retraction of the ECU tendon exposes the PIA (**TECH FIG 3C**).

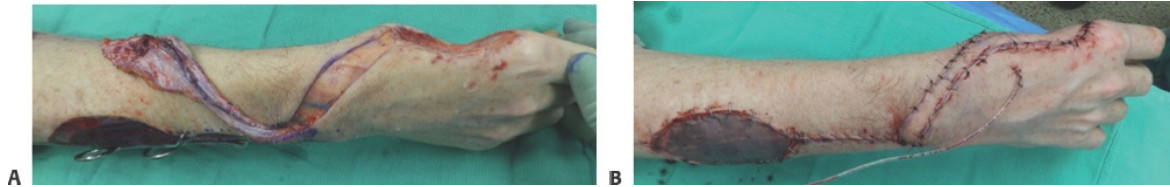
Retrograde PIA Flap Inset

- Once flap elevation has reached the pivot point, 2 cm proximal to the DRUJ, dissection stops.
- The tourniquet is deflated and flap color, capillary refill, temperature, and turgor are assessed.
 - Arterial bleeding is noted from the flap edges.



TECH FIG 3 • A. Radial retraction of the EDM and ulnar retraction of the ECU proximally facilitates exposure of the PIA and PIN in the septum between these muscles. **B.** The PIA and its vena comitantes are shown running centrally on the undersurface of the flap. The PIN is protected and left in situ between

the EDM and ECU. Branches of the PIA to the surrounding musculature are divided as the flap is elevated. **C.** The PIA is closely associated with the periosteum of the ulna distally. The ECU tendon is retracted ulnarly to facilitate elevation of the flap pedicle.



TECH FIG 4 • A. An incision is made from the flap pivot point to the thumb defect to permit inset of the flap. Dorsal veins and branches of the radial sensory nerve are protected. Alternatively, a wide subcutaneous tunnel could have been used to pass the flap into the defect. The flap is shown with its pedicle centered on the undersurface. The donor-site extensor musculature offers a well-vascularized wound bed for reliable STSG graft take. The skin bridge defect is shown here tacked closed with towel clips; primarily closure will be performed. **B.** The flap is inset without tension into the defect. Release of the dermis over the skin bridge at the flap pivot point facilitates flap rotation and skin inset. The donor site is closed with an STSG from the ipsilateral thigh. A small drain can be placed under the flap, away from the pedicle.

- The AIA-PIA anastomotic connection is reliable and does not need to be skeletonized to confirm its presence unless there are concerns with flap perfusion.
- The flap is rotated into the defect. It can be tunneled into the wound.

- To minimize the risk of pedicle compression and vascular compromise, we typically prefer to make an incision between the flap pivot point and the defect for inset (**TECH FIG 4A**). Skin flaps are elevated along this incision to achieve sufficient mobility to permit tension-free closure over the pedicle.
- Alternatively, the pedicle can be covered with a skin graft.
- For volar palm defects, the flap can be passed around the ulnar border of the hand or through the IOM using a wide tunnel.¹³
- The flap is inset into the defect and secured with sutures; it can be rotated up to 180 degrees.
 - The pedicle is carefully rotated at the pivot point to avoid kinking.
 - If a skin bridge has been used, release of the dermis at the pivot point can facilitate inset.
 - A small-caliber drain can be placed under the flap, away from the pedicle, if desired (**TECH FIG 4B**).
- Narrow flap donor sites are closed primarily.
 - For flap donors site over 4 to 6 cm in width, a split-thickness skin graft (STSG) is used for closure.
- Antibiotic-impregnated gauze is applied to the flap incisions and covered with sterile gauze.
 - The flap skin paddle is left exposed for monitoring in the postoperative period.
- Antibiotic-impregnated gauze is placed over the STSG at the flap donor site and covered with sterile gauze and an elastic bandage to apply gentle compression and to avoid shear of the STSG.
- The wrist and hand are immobilized with a well-padded splint.

■ Antegrade PIA Flap

- The axis of the flap is marked from the lateral epicondyle to the head of the ulna. The flap is designed at the junction of the middle and distal thirds of the dorsal forearm.
 - The distal edge of the flap is marked 4 cm proximal to the wrist to avoid injury to the dorsal sensory branch of the ulnar nerve.
- The radial aspect of the flap is incised.
- The flap is raised from radial to ulnar in the subfascial plane toward the IMS

between the EDM and ECU.

- The PIA and its perforators are visualized.
- The flap design is confirmed, ensuring the perforators enter the center of the flap, and then the ulnar incision is made.
 - The flap is raised to the IMS between the EDM and ECU in an ulnar to radial direction.
- Distal to the flap, the anastomotic branch of the PIA to the AIA is identified and ligated.
- The flap is elevated from distal to proximal, following the pedicle in the septum between the EDM and ECU.
 - The flap is typically raised as an island flap.
 - The dorsal sensory branch of the ulnar nerve and the PIN are protected at all times.
- The flap is inset into the defect; it can be rotated up to 180 degrees.
 - Care is taken to avoid pedicle kinking and compression as the flap is sutured.
- The flap donor site is closed primarily or with an STSG.
- The incisions are covered with antibiotic-impregnated gauze and dry sterile gauze.
 - The visibility of the flap skin paddle is necessary for flap monitoring.
- If used, the STSG is dressed with antibiotic-impregnated gauze and covered with sterile gauze and an elastic bandage.
- The elbow is immobilized with a well-padded splint, avoiding pressure on the flap and pedicle.

PEARLS AND PITFALLS

Physical findings

- The PIN must be protected throughout flap elevation. The PIA pedicle is dissected away from the PIN. If branches of the PIN cross superficial to the PIA and impede flap elevation, the flap can be converted to a free flap.
- The PIA flap offers a better skin color match than the radial forearm flap for defects of the dorsal hand and first web space.

Technique

- The vena comitantes of the PIA are small. To optimize the chances

	of flap survival, a cutaneous vein is raised with the flap to permit venous supercharging if venous congestion is noted after flap inset. ■ When harvesting a retrograde PIA flap, it is wise to harvest the PIA and its vena comitantes at least 1 cm proximal to the proximal flap edge. This also permits supercharging of the flap if there is poor arterial inflow through the PIA-AIA anastomosis or venous congestion. Conversion to a free flap is also possible. ■ Often the proximal and distal margins of the flap can be closed primarily. If the central flap width is over 4–6 cm, depending on the skin laxity, a skin graft may be required for closure. A sheet STSG is preferred rather than a meshed STSG for improved donor-site appearance.⁴ ■ For large defects, the PIA flap can be harvested simultaneously with an ipsilateral lateral arm flap.¹⁴ The two skin paddles are elevated together.
Postoperative care	■ Partial or complete flap necrosis is uncommon.^{5,12} However, the patient must be counseled preoperatively of the risk of flap necrosis and the need for a second flap.
Therapy	■ After flap inset, the elbow, wrist, and fingers are moved passively to evaluate the effect of joint range of motion on the flap. Tension-free inset is ideal; this permits early range of motion exercises starting 5 days postoperatively after the donor site graft has taken.

POSTOPERATIVE CARE

- Flap checks are performed every 2 hours for the first 24 hours postoperatively and then every 4 hours.
 - Tissue turgor, color, capillary refill, and temperature are monitored.
 - Any change in flap status, indicating possible arterial or venous insufficiency, should prompt a return to the operating room for flap assessment.
 - Compression by a hematoma or pedicle kinking is a common cause of flap insufficiency.
- The patient is typically discharged home on postoperative day 3.
- The patient returns to clinic on postoperative day 5 to assess the skin graft take and replace the dressings.
 - The splint is discontinued following this dressing change after confirming that the flap does not experience undue tension with elbow, wrist, and hand range of motion.
 - If there are concerns, the splint can be continued for an additional week.

OUTCOMES

- The PIA flap provides reliable soft tissue coverage for upper extremity defects.
- Along with the radial forearm flap, it is a valuable option for pedicled flap coverage of the wrist and hand.

COMPLICATIONS

- Most of the lymphatic drainage from the hand runs over the volar forearm. Compared with the radial forearm free flap, the PIA flap disrupts less lymphatic outflow that results in less edema postoperatively.
- PIN palsy is rare following PIA flap harvest. Motor functions of the muscles of the extensor compartment of the forearm are tested postoperatively to confirm PIN innervation.

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51 Pedicled and Free Groin Flap

CHAPTER

Mark Morris and Kevin C. Chung

DEFINITION

- A free flap requires the transfer of tissue from one body site to another, with anastomosis of arterial and venous systems to the recipient site using microsurgical techniques.
- A pedicled flap transposes tissue from a donor site to a recipient site while keeping the tissue partially attached to the donor site. The donor vascular pedicle is left intact to supply the flap. Pedicled flaps are reliable and do not require microsurgery.
- The groin flap was described in 1972 by McGregor and Jackson¹ for reconstruction of soft tissue defects of the hand. This was once a “workhorse” flap for hand reconstruction; however, with the introduction and advancement of microsurgery, it has fallen out of favor for many indications. Nevertheless, there are still many indications for its use.
- When a pedicled groin flap is used, patients must be counseled that they will require multiple operations (average 4.6 operations per patient), including flap division, debulking, and tissue rearrangement for contouring.²

ANATOMY

- The groin flap is based on the superficial circumflex iliac artery (SCIA).
 - The SCIA arises approximately 2 to 3 cm distal to the inguinal ligament, either directly from the femoral artery (70%) or from the superficial inferior epigastric artery (**FIG 1**).
 - The SCIA passes laterally from its origin and gives a deep branch at the medial border of the sartorius.
 - The superficial branch then pierces the fascia at the lateral border of the

sartorius and runs 2 to 3 cm distal and parallel to the inguinal ligament, toward the anterior superior iliac spine (ASIS). This superficial branch supplies the skin to be used for the flap.

- After reaching the ASIS, the superficial branch of the SCIA branches further and anastomoses with branches of the superior gluteal, deep circumflex iliac, and ascending lateral femoral circumflex arteries.
- The SCIA pedicle is generally between 0.8 and 1.8 mm in diameter.³

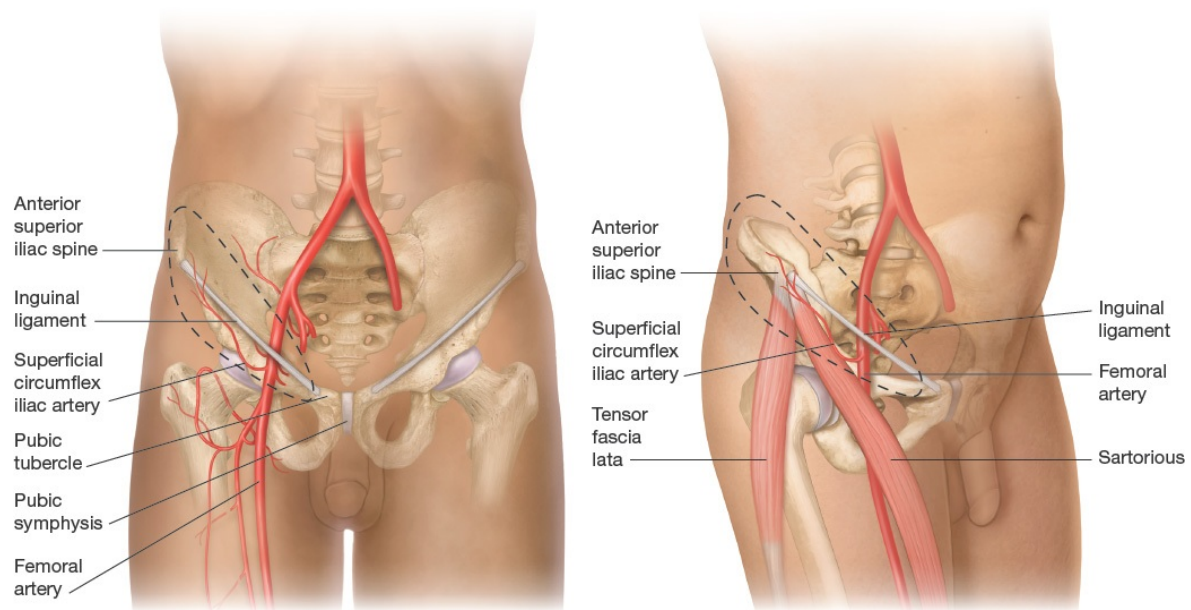


FIG 1 • Vascular and regional anatomy of the groin flap, which follows the axis of the superficial circumflex iliac artery.

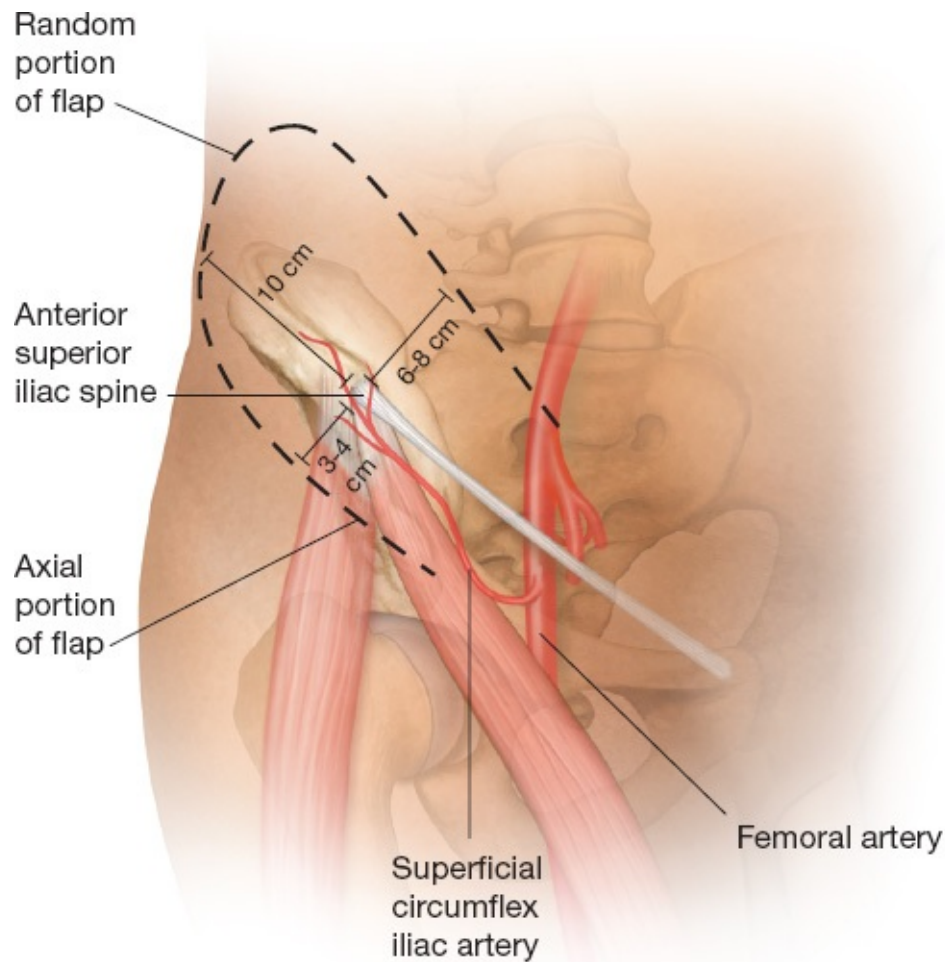


FIG 2 • Limits of the groin flap.

- Venous drainage of the flap is split between the superficial circumflex iliac vein and the venae comitantes of the SCIA. Both of these eventually drain into the femoral vein, either directly or via the saphenous vein.
- Flap size is limited to about 13×10 cm (**FIG 2**). The axis of the SCIA is marked by palpating the femoral pulse, marking the origin 2 to 3 cm distal to the inguinal ligament and then drawing a line to the ASIS. The flap will follow this axis.
- The medial boundary of the flap is about 3 to 4 cm lateral to the femoral artery (2–3 cm medial to the medial border of the sartorius).
- The maximum width of the flap that can be primarily closed in most patients is 10 cm. The flap should be positioned two-thirds superior to the vascular axis and one-third below the axis. This translates to up to 6 to 7 cm superior to

the axis and 3 to 4 cm inferior to the axis.

- The lateral portion of the flap should be designed with a 1:1 length-to-width ratio. This is because the portion of the flap lateral to the ASIS has a random pattern of vascularization. Therefore, because the width of the flap is limited to 10 cm, the lateral limit of the flap is then 10 cm lateral to the ASIS.
- Sensation to the lateral portion of the groin flap is supplied by the lateral cutaneous branches of the 12th thoracic subcostal nerve (**FIG 3**).⁴ This nerve can be harvested with the flap to provide sensation to the hand, but a sensate nerve is infrequently used.
- The 12th thoracic nerve pierces the internal and external oblique muscles and courses distally over the iliac crest, 5 cm posterior to the ASIS. Do not confuse the lateral femoral cutaneous nerve, which supplies sensation to the lateral thigh, for the 12th thoracic nerve.

Lateral cutaneous
branch of 12th
thoracic nerve

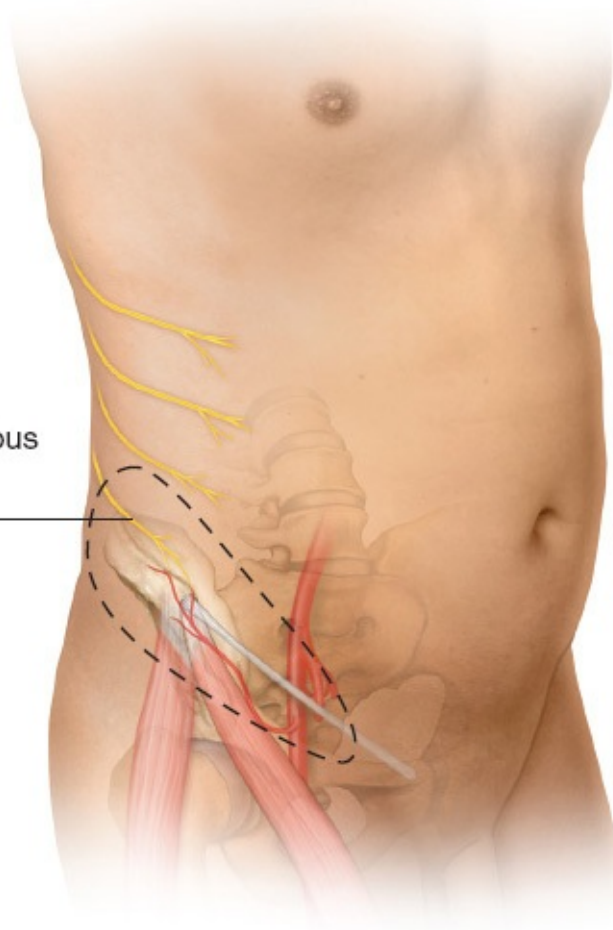


FIG 3 • The lateral cutaneous branch of the 12th thoracic nerve enters the graft opposite the vascular pedicle.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History must include the mechanism of injury.
 - Crush and blast injuries can lead to a much larger zone of injury than expected by initial examination (**FIG 4A,B**).
 - In the case of a crush injury, the physician must also assess the patient for signs of compartment syndrome.
- Contaminated wounds may require multiple irrigation and debridement procedures (**FIG 4C–E**).
- Medical and social history—such as diabetes mellitus, peripheral vascular disease, or smoking—does not contraindicate surgery but will affect the healing potential of the flap and must be discussed with the patient.
- Assess the vascular status of the remaining limb.
- Motor and sensory evaluation to assess damage to nerves, tendons, or muscles.

IMAGING

- Standard radiographs of the hand are done to evaluate for bony injury.

SURGICAL MANAGEMENT

- Free flaps are generally considered superior to the pedicled groin flap with today's microsurgical techniques. However, there are still many good indications for doing a pedicled groin flap:
 - Complex hand injuries in young children (less than 2 years). Microsurgery in infants is technically challenging because of the small size of the vessels.
 - In preparation for a toe-to-thumb transfer following thumb or finger loss. This preserves the recipient vessels for later microsurgery during transfer and also saves as much stump tissue as possible by providing coverage.

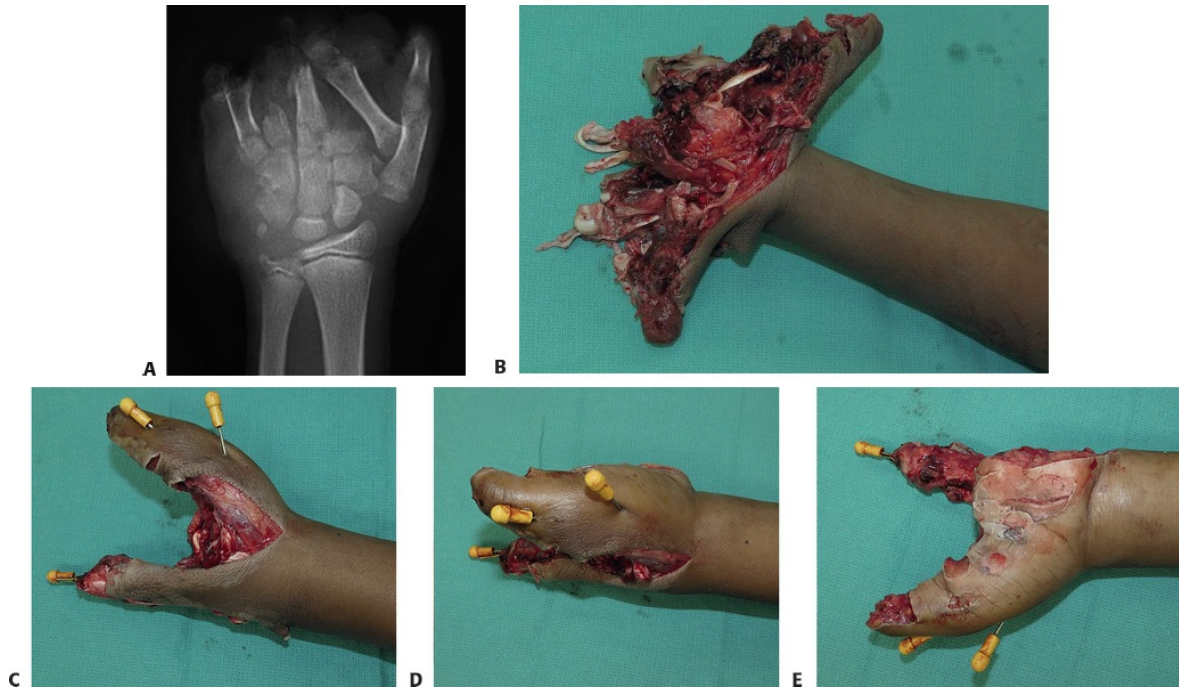


FIG 4 • A,B. Preoperative radiograph and clinical photograph, respectively, of a 12-year-old boy who sustained a bomb-blast injury to the left upper extremity. **C–E.** Images after left hand radical debridement, open reduction and internal fixation of the left thumb metacarpal using K-wires, and left index finger metacarpal transposition to the small finger and fixation with K-wires.

- Dorsal or palmar soft tissue defects involving multiple digits
- Degloving injury to all fingers
- Circumferential thumb soft tissue defect
- First stage of an osteoplastic thumb reconstruction
- High-voltage electrical burns with a hand surviving on collateral circulation. In some cases, a hand may survive based on collateral blood supply when both ulnar and radial arteries have thrombosed in the forearm. The extensive zone of injury affects available recipient vessels, and dissection of these vessels may inadvertently lead to hand necrosis.⁵
- Advantages to the pedicled groin flap are that it is thin and nearly hairless, it is reliable, flap elevation is quick, and the donor site can be closed primarily in

most cases.

- Disadvantages of the pedicled groin flap are that it is a mandatory two-stage operation, the patient's hand is connected to his or her groin for 3 to 4 weeks (which leads to stiffness in the shoulder, elbow, and wrist, especially in older patients), and there is a high risk of injury to the lateral femoral cutaneous nerve with subsequent loss of sensation in the lateral thigh or a painful neuroma.

Preoperative Planning

- The following is a rough guideline for skin requirements for reconstruction in an adult male:
 - Thumb (circumferential)
 - Distal to the metacarpophalangeal joint: 9×8 cm
 - Distal to the thenar crease: 13×12 cm
 - Palmar hand: 12×10 cm
 - Dorsal hand: 12×10 cm
 - Finger (circumferential): 7×10 cm
- Assess for any scars in the groin.
- Use a Doppler probe to confirm the location of the SCIA.

Positioning

- The patient is positioned supine on the operating table with a hand table in place.
- A bump is placed under the ipsilateral hip to better visualize the elevation of the random portion of the flap lateral to the ASIS.
- The operative extremity and ipsilateral groin are prepped and draped widely.
- A tourniquet is placed on the upper extremity.

Approach

- The wound must be thoroughly debrided back to healthy tissue.
- Keep in mind the above-mentioned limits of the flap when designing the groin flap.
- Bone fixation and nerve reconstruction can be performed at the same time as the groin flap; however, tendon reconstruction should be delayed until passive joint range of motion is re-established for rehabilitation purposes.
- The surgeon must decide on whether or not to attempt an innervated flap prior

to elevating the flap, as the lateral cutaneous branch of the 12th thoracic nerve will have to be harvested if this is desired.

TECHNIQUES

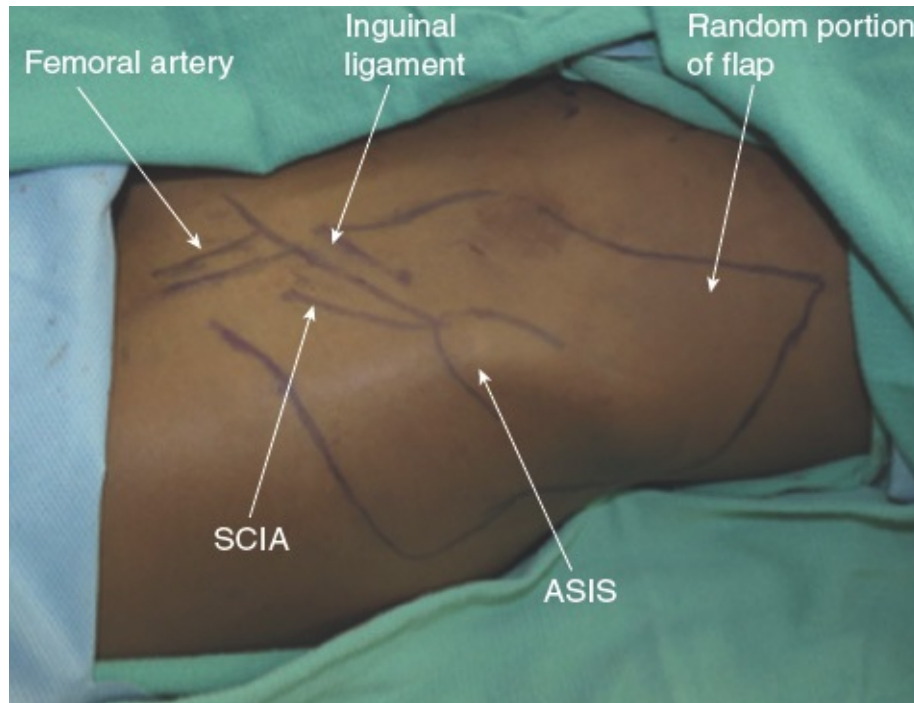
■ Pedicled Groin Flap

Flap Design

- Mark the inguinal ligament from the pubic tubercle to the anterior superior iliac spine (ASIS).
- Palpate the femoral pulse.
 - Mark the origin of the superficial circumflex iliac artery (SCIA) off of the femoral artery, 2 to 3 cm distal to the inguinal ligament (**TECH FIG 1**).
 - Draw another line perpendicular to the first line, 2 to 3 cm inferior to the inguinal ligament. This marks the axis of the SCIA. This can be confirmed with a Doppler probe.
- Make a template of the defect and transfer it to the groin within the limits of the graft discussed earlier.

Flap Harvest

- Elevate the flap starting at the superolateral margin.
 - The incision is taken down to the level of the external oblique aponeurosis. The flap is elevated in this plane from lateral to medial (**TECH FIG 2A**).
 - If an innervated flap is desired, the surgeon must identify the lateral cutaneous branch of the 12th thoracic nerve. This nerve pierces the internal and external oblique muscles and descends 5 cm posterior to the ASIS. Harvest the nerve at this time as it enters the lateral portion of the flap.
- Elevate the lateral and inferior margins of the flap.
 - The inferior portion of the flap is elevated superficial to the fascia lata.
- The random portion of the flap is elevated to the ASIS.
 - The lateral borders of the sartorius and fascia lata are identified inferior to the ASIS.



TECH FIG 1• Markings for a pedicled groin flap.

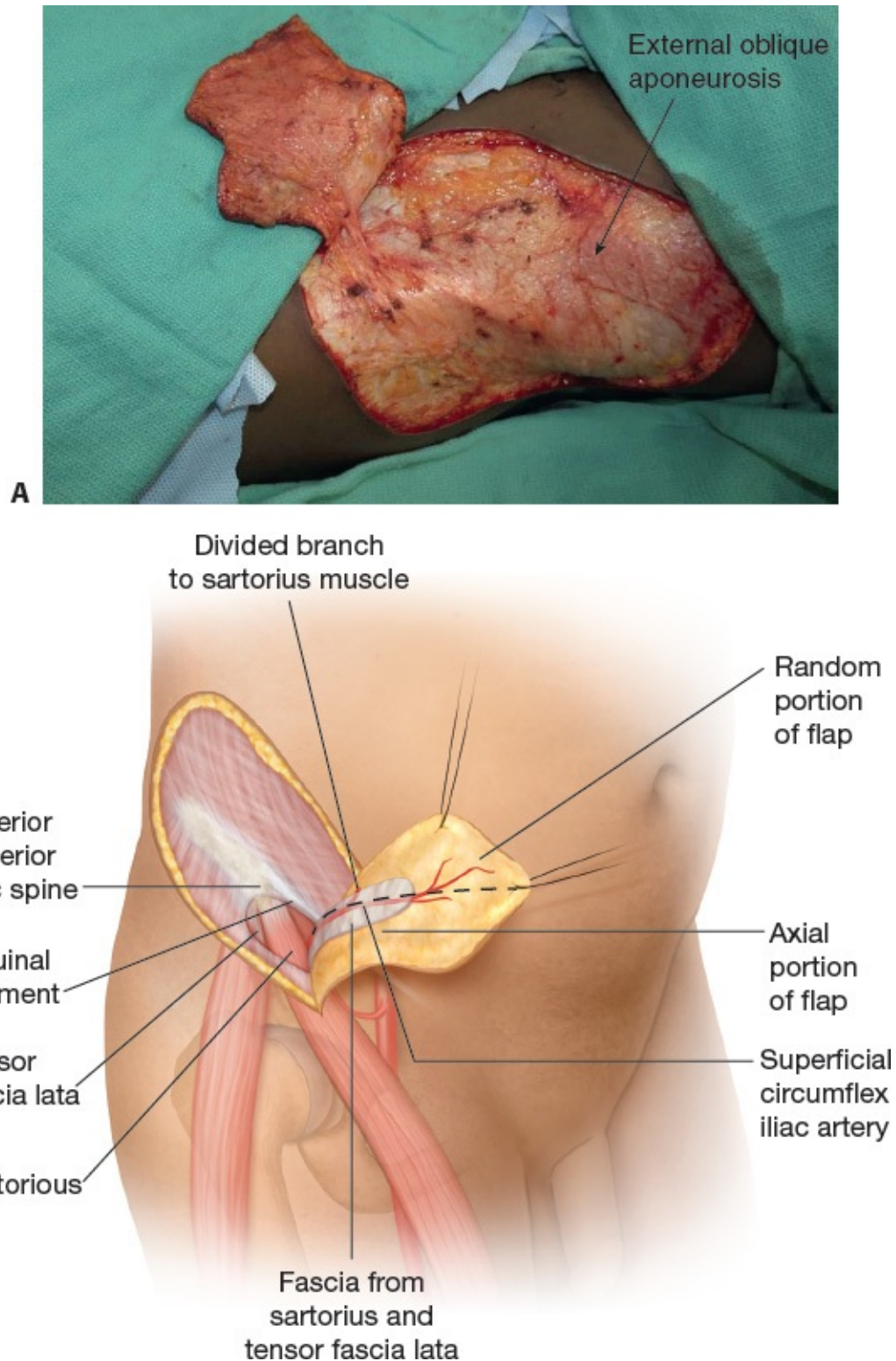
- Elevate the axial portion of the flap.
 - An incision is made longitudinally over the fascia lata and sartorius fascia. The flap is now elevated in this deeper plane to include this layer of sartorial fascia medial to the ASIS (**TECH FIG 2B**). This is critical because the SCIA is superficial to the fascia over the sartorius. Elevating the sartorial fascia protects the SCIA. This also prevents the fascia from tethering and kinking the vessel, which could cause flap necrosis. The SCIA does not need to be isolated for the pedicled flap.
 - Identify and ligate the deep branch of the SCIA. It will arise at the medial border of the sartorius. The deep branch is very short and should be ligated within the substance of the sartorius to avoid injury to the SCIA.
 - Identify and protect the lateral femoral cutaneous nerve as it arises beneath the inguinal ligament, near the medial border of the sartorius.
 - Divide any connections between the inguinal ligament and fascia lata.
 - The flap can be elevated 2 to 3 cm medial to the medial border of the sartorius.
- Close the flap donor site.
 - Close from medial to lateral in layers.
 - A drain is not usually required if adequate hemostasis was attained. The

closure is tight and should compress the bed sufficiently, so fluid collection under the flap is not a concern.

- Undermining skin flaps and hip flexion will assist with closure. The bump can also be removed from under the hip.

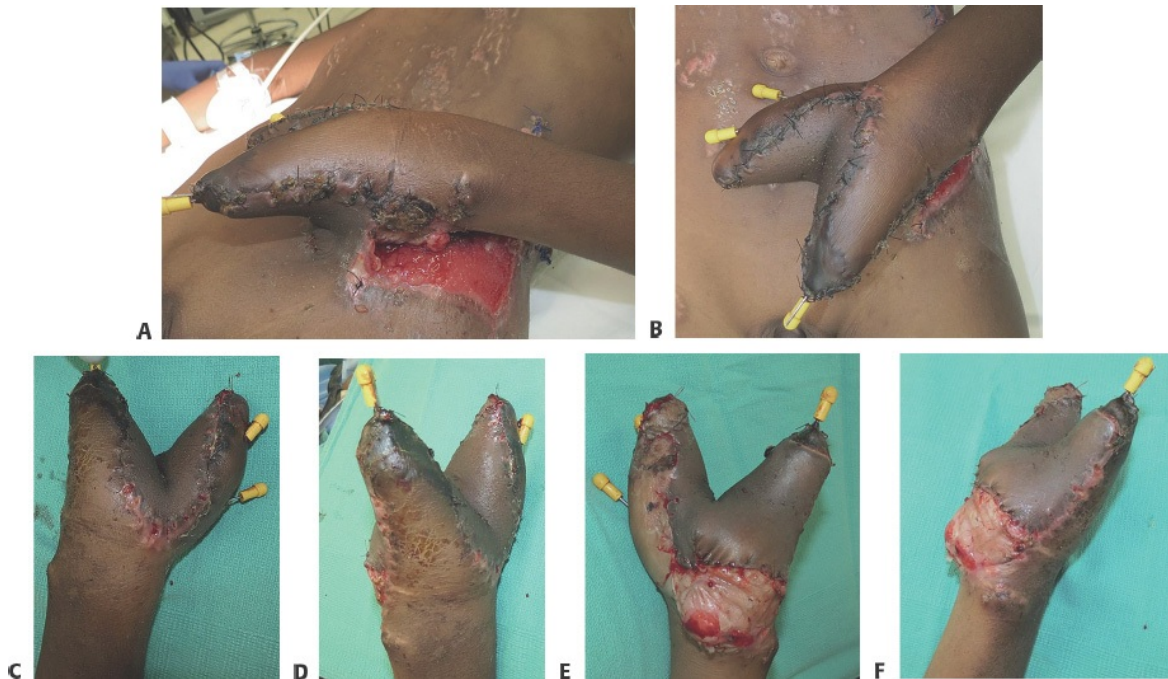
Flap Placement and Division

- Thin the flap to match the thickness of the recipient site.
 - The random portion of the flap lateral to the ASIS can be made thin safely because the flap relies on the subdermal plexus in this location.
 - Leaving excess fat increases vascular demands of the flap.
- The 12th thoracic nerve can now be repaired to an available digital nerve from the recipient hand if an innervated flap is planned.
- Inset the flap to the recipient site using 3-0 nylon interrupted sutures (**TECH FIG 3A,B**).
- Flap division generally occurs after 3 weeks (**TECH FIG 3C–F**).
- The surgeon can passively move the patient's shoulder, elbow, and hand while still under anesthesia after division.
 - This will break up adhesions and facilitate recovery of motion postoperatively.



TECH FIG 2• A. The flap is elevated from lateral to medial, superficial to the external oblique aponeurosis. **B.** The sartorius fascia is raised with the SCIA pedicle

as the flap is elevated from lateral to medial.



TECH FIG 3 • **A,B.** Images after the groin flap has been inset to the left hand. **C–F.** Postoperative images after flap division.

■ Free Groin Flap

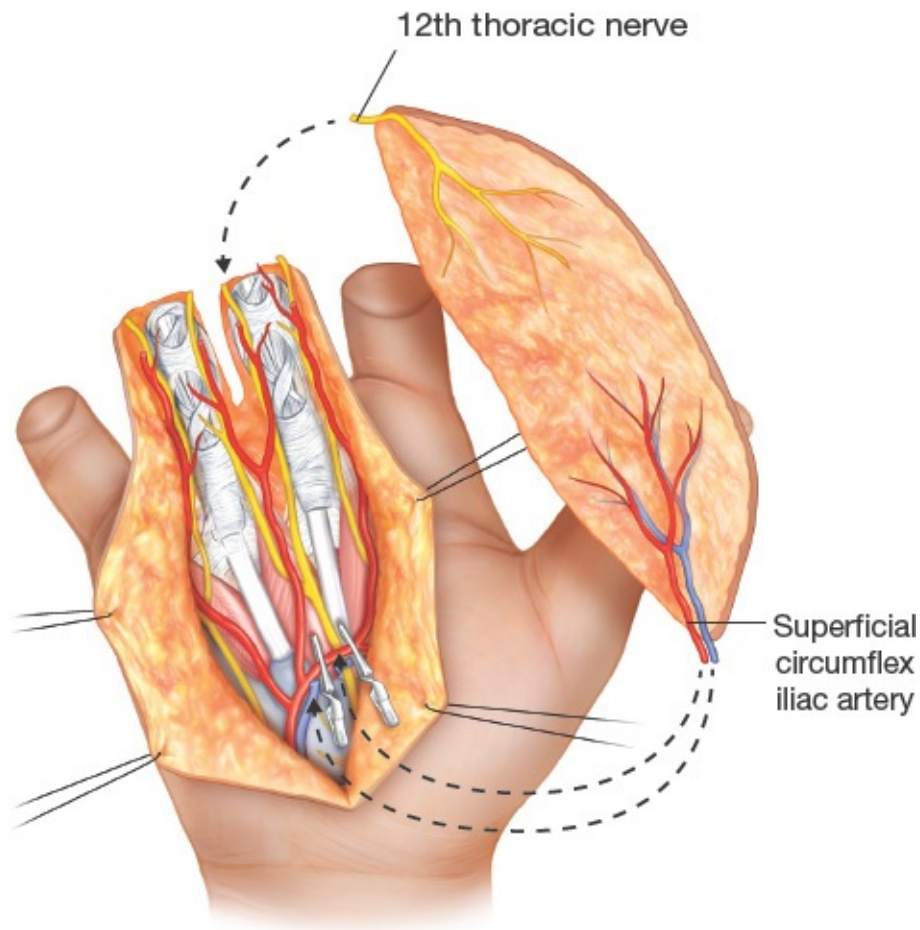
Flap Design

- Follow the same steps as for a pedicled flap to plan and elevate the free flap, except that the medial portion of the flap must also be elevated.
- The free flap can be harvested from the contralateral or ipsilateral groin.
- Free groin flap is seldom performed because of the short pedicle and variability of the pedicle origin.
- Identify and dissect out the SCIA and concomitant vein. Cutaneous veins may have to be used if there is no concomitant vein.
- Identify suitable arterial and venous sites of anastomosis in the hand, depending on the location of injury.

Flap Harvest

- Divide the vascular pedicle.

- Anastomose the SCIA to the appropriate vessels, depending on the location of the defect. An end-to-side anastomosis is recommended for the artery in order to not devascularize the recipient site. End-to-end anastomosis of veins is performed.
- The 12th thoracic nerve can now be repaired to an available nerve from the recipient hand if an innervated flap is planned (**TECH FIG 4**).
- Inset the flap to the recipient site using 3-0 nylon interrupted sutures.



TECH FIG 4• The SCIA and vein are anastomosed proximally, while a digital nerve or two can be repaired to a branch or branches of the 12th thoracic nerve.

Positioning	■ Place a bump under the ipsilateral hip to allow better visualization.
Technique	■ A full-thickness flap is raised. Thinning is done before inset. Leaving fat on the abdominal wall will make closure more difficult. ■ If the lateral femoral cutaneous nerve prohibits flap elevation, the surgeon can divide it to elevate the flap further and then repair the nerve. This nerve is usually not in the way when harvesting a pedicle flap because one does not need to skeletonize the pedicle medial to the sartorius fascia.
Postoperative care	■ The upper limb should be immobilized for 2 or 3 days, until the patient is comfortable with the position of the extremity and the flap. This is important to do prior to waking the patient up from anesthesia so the patient does not inadvertently reach for the endotracheal tube and damage the flap. ■ If the groin closure is very tight, patients may need to be immobilized with the hip in flexion. This can be done by placing pillows under the knee for a few days. ■ If there is marginal necrosis of the flap, wait for 2 to 3 days to let the necrosis demarcate as the initial postoperative swelling subsides. The patient should then return to the operating room for excision of necrotic portions and flap advancement and reinset. Waiting longer than 2 or 3 days risks further complications and failure of the flap. ■ The groin scar is closed under tension and will spread. Leave sutures in place until it is time for flap division, 3 to 4 weeks later.

POSTOPERATIVE CARE

- The open area near the pedicle is kept moist with bacitracin ointment twice daily and is covered with Xeroform gauze.
- Passive and active range of motion should start early under the supervision of a hand therapist.
- Compression bandages should be applied for bulky flaps.
- Surgery for thinning the flap should be delayed for at least 3 to 6 months.

OUTCOMES

- Arner and Moller⁶ retrospectively studied 44 pedicled groin flaps for coverage of hand and forearm soft tissue defects.

- Local complications (partial flap necrosis, infection, and seroma) occurred in 11 patients (25%).
- Defatting was subsequently required in 38 (86%) patients, and 4 patients (9%) required secondary revisions of donor sites.
- Goertz et al.² treated 85 patients with pedicled groin flaps and prospectively collected data on these patients. Forty-nine patients were later interviewed and examined, with mean follow-up of 9 years. Mean hospital stay was 29 days. Patients each required a mean of 4.6 operations (including thinning of the flap, deepening of the interdigital fold, stump, and flap revisions).
- One flap loss occurred.
- Of the 49 patients interviewed, 82% would undergo the procedure again.
- Mean Disabilities of the Arm, Shoulder, and Hand score was 23.
- The Vancouver Scar Scale showed close to normal height and vascularity of the flap (0.2 and 0.3, respectively), but pigmentation was slightly abnormal (0.8) and pliability was rated between “supple” and “yielding” (1.5).

COMPLICATIONS

- Flap necrosis
- Infection
- Shoulder and elbow stiffness
- Scarring

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52 Free Anterolateral Thigh Flap

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- The anterolateral thigh flap is a versatile free flap that is often harvested as a fasciocutaneous flap, supplied by the descending branch of the lateral femoral circumflex artery (LFCA).
- It can be harvested also as a cutaneous or musculocutaneous flap with the vastus lateralis, with the option of an innervated flap with inclusion of the lateral femoral cutaneous nerve (LFCN).

ANATOMY

- The LFCA arises from the profunda femoris artery and divides into three branches (ascending, transverse, descending) deep to the sartorius and rectus femoris muscles (**FIG 1**).
- The descending branch of the LFCA courses distally along the medial border of the vastus lateralis, supplying perforators of the anterolateral thigh.
- Perforators supplying the anterolateral thigh are either of the following:
 - Musculocutaneous, which pass through the vastus lateralis muscle
 - Septocutaneous, which travel along the septum between the vastus lateralis and rectus femoris
- The LFCN passes under the inguinal ligament and pierces the deep fascia to innervate the skin of the anterolateral thigh.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with a history of peripheral vascular disease, active nicotine use, or generally poor health are not candidates for free tissue transfer.
- Obese patients may have a very thick flap and require primary thinning or

secondary debulking procedures.

- Examine the donor site for scarring and obtain a thorough history to include previous injury or surgery to the thigh.
- We do not routinely obtain preoperative angiography.

SURGICAL MANAGEMENT

- Anterolateral thigh flap is indicated for large soft tissue defects, though it is versatile and can be used for smaller defects if needed.
- A two-team approach can be used to decrease surgical time.
- Flap vascular pedicle can be long (12 cm), allowing for anastomosis outside of zone of injury, if necessary.
- Flap dimensions are generally limited to 35 cm long and 15 cm wide on a single dominant perforator, though multiple perforators are preferred in large flaps.
- Limiting the width of the flap to 8 cm generally permits primary donor-site closure.

Preoperative Planning

- Preoperative Doppler exam is used to confirm the presence of a perforator.
- If one is not detectable, consider the contralateral thigh or a different type of flap.

Positioning

- Supine with a bump under the right hemipelvis, or lateral decubitus position
- Drape out the entire lower limb for leg manipulation.
- Ensure the anterior superior iliac spine (ASIS) and patella are included in the operative field.

Approach

- A suprafascial approach to flap harvest achieves a thinner flap design, though it is more technically challenging.
- Subfascial flap harvest is technically easier to identify the vascular anatomy but will result in a bulkier flap.

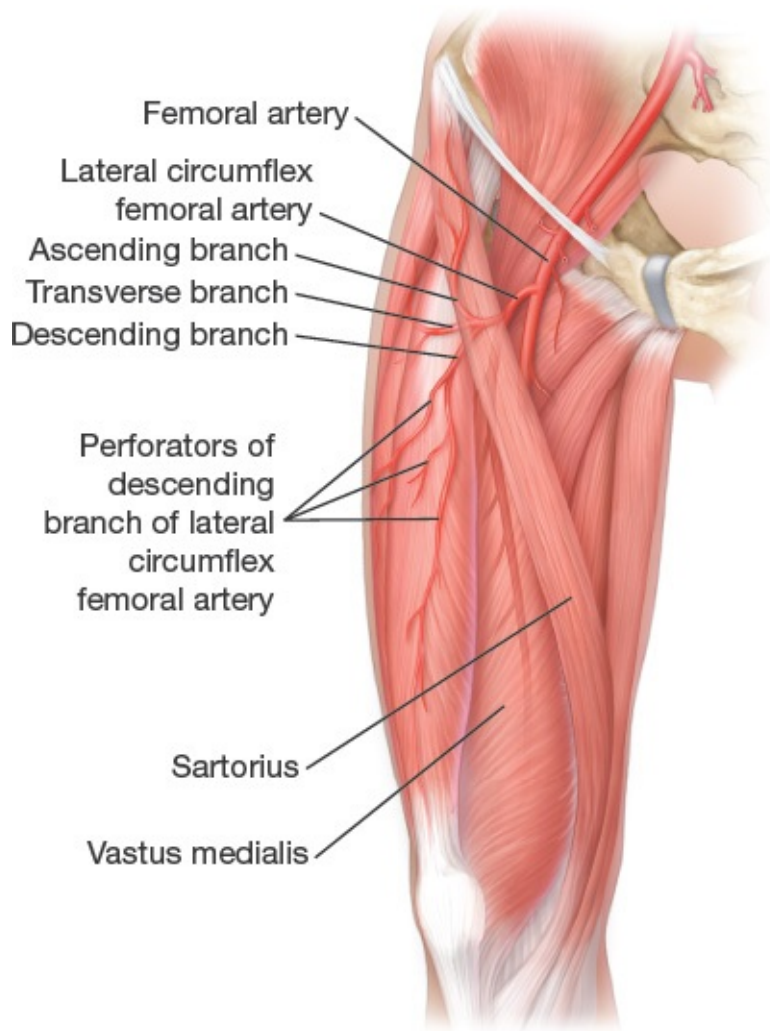


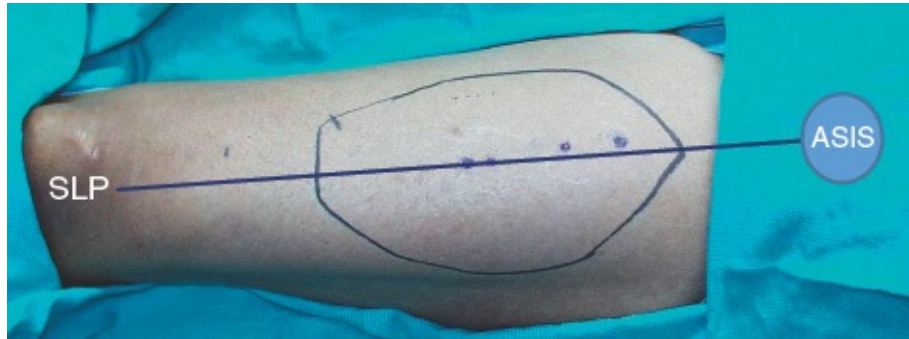
FIG 1 • Anterolateral thigh flap anatomy.

TECHNIQUES

■ Flap Design

- Draw a line from the anterosuperior iliac spine (ASIS) to the superolateral border of the patella. This represents the intermuscular septum between the rectus femoris and vastus lateralis muscles (**TECH FIG 1**).
- Use a portable Doppler device to identify the perforator around the midpoint of this line.
 - 80% of perforators are found within 3 cm of this point.¹

- Design the flap dimensions based on the recipient site defect.
 - We generally design the perforator to be centrally located in the flap.
- For large flaps, we attempt to incorporate multiple perforators.



TECH FIG 1 • Flap design and identification of perforator. A line from the anterosuperior iliac spine (ASIS) to the superolateral patella (SLP) represents the intermuscular septum between rectus femoris and vastus lateralis. Perforators are identified with a Doppler ultrasound probe.

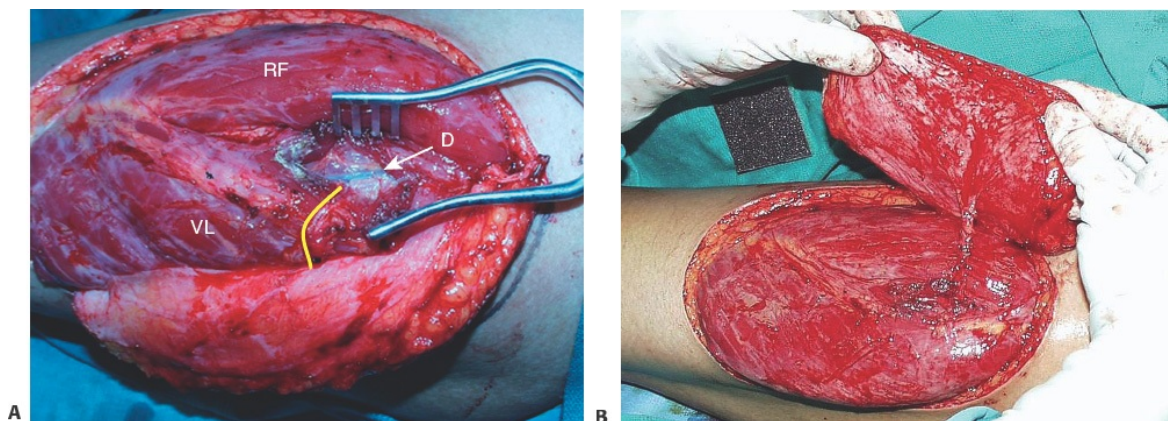
■ Flap Harvest

- Under loupe magnification, incise the medial margin of the designed flap.
- Suprafascial dissection
 - Deepen the medial incision to the deep fascia, and continue lateral dissection above the deep fascia.
 - Using tenotomy scissors, carefully separate the subcutaneous fat from underlying deep fascia. If possible, preserve cutaneous nerves overlying the fascia.
 - Continue dissection from medial to lateral and identify the marked perforator piercing through the fascia at the level of the intermuscular septum.
 - Incise the lateral margin of the flap and dissect from lateral to medial until the same perforator is visualized.
 - Leave a cuff of deep fascia around the perforator, and dissect retrograde toward its origin until adequate pedicle length and caliber is achieved.
- Septocutaneous perforators allow for uneventful dissection along the

intermuscular septum. However, the majority of the time perforators are musculocutaneous and pierce the muscle. To allow for safer dissection, the vastus lateralis is retracted laterally to visualize the descending LFCA, which can be dissected down to the perforator through the vastus lateralis muscle by separating the muscle fibers using scissors and bipolar cautery.

■ Subfascial dissection (**TECH FIG 2A**)

- Deepen the medial incision through the thigh fascia, exposing the rectus femoris muscle.
- Continue dissection laterally under the deep fascia until the intermuscular septum between rectus femoris and vastus lateralis is visualized.
- Retract the rectus femoris medially to visualize the descending branch of the lateral femoral circumflex artery (LFCA) and its perforating branches.
- The perforators may be musculocutaneous, traveling through the vastus lateralis, or septocutaneous, passing directly through the intermuscular septum.
- For septocutaneous vessels, dissection is performed from distal to proximal through the septum until adequate pedicle length and caliber is achieved. Leave a fascial cuff around the perforator (**TECH FIG 2B**).
- For musculocutaneous skin perforators, expose the point of exit from the muscle. Spread transversely over the vessel and divide the overlying muscle fibers. Ligate any intramuscular branches of the perforator, and continue retrograde dissection up to the descending LFCA until adequate pedicle length and caliber is achieved.
- If additional pedicle length is needed, continue retrograde dissection up the descending LFCA. During proximal dissection of the descending LFCA, take care to preserve the motor branches of the femoral nerve to the vastus lateralis.



TECH FIG 2 • A. Elevation of flap. Subfascial elevation allows for identification of the descending branch of the LCFA (D). Perforator is highlighted in yellow. RF, rectus femoris; VL, vastus lateralis. **B.** Completion of flap elevation. The perforator is dissected proximally, and the pedicle is dissected up the descending LFCA.

■ Flap Thinning

- If the flap is too bulky for the recipient site (hand/wrist), one can perform flap thinning at the time of harvest, as opposed to debulking at a later date. For beginners, we do not recommend primary flap thinning as inadvertent perforator injury can result in flap necrosis.
- Perform flap thinning after elevation but prior to transection of the vascular pedicle.
- Preserve a 3-cm radius cuff of full-thickness adipose tissue around the perforator.
- Thin the flap by removing the deep fat tissue, which is characterized by wide and flat lobules.
- Removing this deep layer of fat should result in flap thickness of 5 to 6 mm.

■ Donor-Site Closure

- Obtain adequate hemostasis of the donor site.
- Reapproximate vastus lateralis muscle edges in cases of intramuscular dissection.
- Primary closure is usually possible when the flap width is limited to 8 cm.
 - Place a suction drain to minimize risk of hematoma.
- If the donor-site width is more than 8 cm, the wound is unlikely to close primarily. Perform split-thickness skin grafting.

Flap dissection	■ Avoid unnecessary traction during flap elevation by dissecting around the perforator from the medial border and then lateral border, as opposed to elevating the entire flap from the medial border. ■ If the skin perforators are too small to safely perform an intramuscular dissection, consider the use of the operating microscope, or elevate the flap in a myocutaneous fashion by incorporating a cuff of muscle around the intramuscular pedicle. ■ Maintain the position of the flap during dissection. Traction on the perforator(s) from the weight of the flap may cause injury or vasospasm. ■ If there is concern for vasospasm, bathe perforators in topical lidocaine.
Flap thinning	■ Inexperienced surgeons should avoid aggressive one-stage flap thinning due to the risk of perforator injury and flap necrosis.
Hemostasis	■ Meticulous dissection during flap harvest is necessary particularly with musculocutaneous perforator dissection, as hasty division of muscular perforator branches will retract and be difficult to ligate.
Flap inset	■ Avoid twisting of the pedicle by preserving a cuff of fascia and allowing the pedicle to fall into its normal orientation before final inset.

POSTOPERATIVE CARE

- Avoid compressive bandages on the flap.
- Flaps are checked hourly with Doppler ultrasound for the first 48 hours postoperatively and then every 4 hours for the next 48 hours.
- The patient is kept hydrated with intravenous fluids and kept on thrombosis prophylaxis therapy (low molecular weight heparin) while hospitalized.
- Drain is removed once output is appropriate, typically less than 30 mL/d.
- If a skin graft was applied to the donor site, bed rest is instituted until the graft takes.
- Secondary debulking of the flap is delayed until 6 to 9 months postoperatively.

OUTCOMES

- Good results are reported with 96% overall survival rate of 672 flaps.²
- Donor-site morbidity is generally minimal. Anterolateral thigh numbness may result from sensory nerve division but can be avoided by careful preservation of suprafascial nerve branches.

COMPLICATIONS

- General complications related to free tissue transfer such as flap necrosis and hematoma are possible.
- Flap necrosis can occur from overaggressive flap thinning and perforator injury.

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53 Revascularization and CHAPTER Replantation of Digits

Mark Morris and Kevin C. Chung

DEFINITION

- Revascularization refers to the repair of injured structures and restoration of circulation to a digit that has been incompletely amputated. Restoration of vascularity to the incompletely severed digit is necessary to prevent necrosis.
- Replantation refers to the reattachment of a digit that has been completely amputated (**FIG 1**).
- Revision amputation refers to shortening a digit by debriding nonviable tissue and protruding bone in order to provide coverage of a digit that is not amenable to revascularization or replantation.

ANATOMY

- Each digit has a radial and ulnar proper digital artery. Each vessel is accompanied by a respective radial or ulnar proper digital nerve. Digital nerves are sensory only. In the digits, the artery is dorsal to the nerve (**FIG 2A**).
- There are three major palmar arches that arise from the digital arteries. The proximal, middle, and distal arches are located at the level of the C1 pulley, at the level of the C3 pulley, and just distal to the flexor digitorum profundus (FDP) insertion, respectively.
- Four palmar and four dorsal branches extend from each digital artery.
- The dorsal veins are larger than the palmar veins. Veins do not reliably travel with the arteries and nerves.
- Grayson ligament originates from the flexor tendon sheath and inserts on the skin. It lies palmar to the neurovascular bundle.
- Cleland ligament originates from the periosteum and inserts on the skin. It lies dorsal to the neurovascular bundle (**FIG 2B**).

- The flexor tendons travel within the flexor sheath. There is a series of five annular and three cruciform pulleys in which the flexor tendons pass through. The pulleys are discrete thickenings of the fibro-osseous sheath.
- Odd-numbered annular pulleys (A1, A3, A5) are located over the joints of the finger (metacarpophalangeal, proximal interphalangeal, and distal interphalangeal [DIP], respectively). Even-numbered annular pulleys (A2, A4) are located over the proximal and middle phalanges, respectively.
- The A2 and A4 pulleys are important in preventing bowstringing and should be preserved if possible.

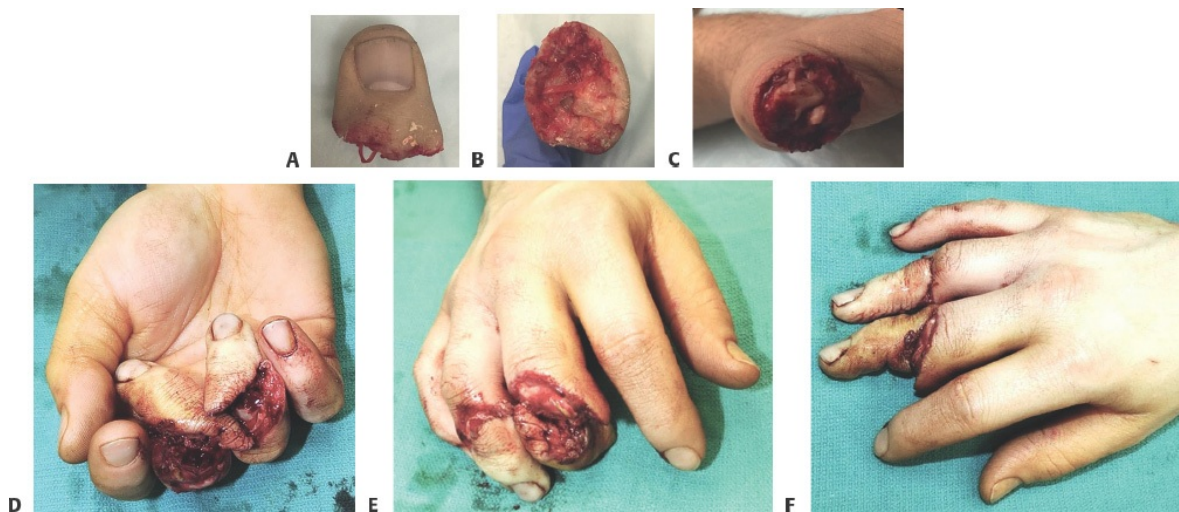


FIG 1 • A–C. Complete amputation of the thumb. This injury required replantation. **D–F.** Partially amputated long and ring fingers. This injury required revascularization.

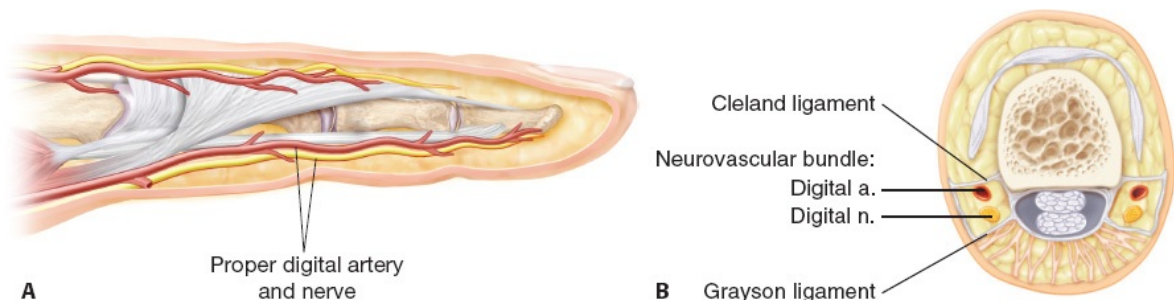


FIG 2 • A. Neurovascular anatomy of the digit. **B.** Axial cut of the digit, showing the relationship of Cleland and

Grayson ligaments to the neurovascular bundle. The digital nerve is palmar to the artery.

- The flexor digitorum superficialis (FDS) splits into two slips at Camper chiasm and inserts as two slips into the midportion of the middle phalanx.
- The FDP tendon passes between the two slips of FDS at Camper chiasm and inserts at the proximal base of the distal phalanx.
- The extensor digitorum communis (EDC) sends a tendon to each digit. The index finger also contains the extensor indicis proprius (EIP), and the small finger also contains the extensor digiti minimi (EDM). The EIP and EDM tendons are ulnar to their respective EDC tendon.

PATHOGENESIS

- Amputation can be caused by sharp or blunt dissection, crush injury, or avulsion injury.
- Sharp amputations have a narrow zone of injury and are thus better suited for replantation or revascularization (**FIG 3A**).
- Crush and avulsion injuries have a larger zone of injury, which may preclude replantation or revascularization (**FIG 3B**).



FIG 3 • A. Clean-cut amputation of the thumb. **B–D.** Crush-avulsion injury of the ring finger with a wide zone of injury secondary to the hand being caught in a gear mechanism, precluding successful replantation.

NATURAL HISTORY

- Mean survival rate after replantation is 86% reported by highly experienced surgeons and hospitals.¹
- Clean-cut amputations have a better survival rate (92%) than crush-cut (80%) or crush-avulsion injuries (75%).
- Mean two-point discrimination after replantation is 7 mm.
- Ninety-eight percent of patients are able to return to work after digit replantation.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history must include the mechanism and timing of injury. Crush injuries may preclude replantation depending on the degree of tissue damage.
- Ischemia time and method of transport must be evaluated. In general, warm ischemia time of less than 6 hours and cold ischemia time of less than 12 hours are desired for replantation.
- Delayed replantation has been shown to have success, however. In a study of delayed and suspended replantation of digits and hands, Woo et al.² studied 28 digital and 4 hand amputations that underwent delayed or suspended amputation (mean cold ischemic time 15 hours 48 minutes). In this series, 24 of 28 digits and all 4 hands survived (88% survival rate). Case reports exist with successful replantation after warm ischemia times of 42 hours and cold ischemia times of 94 hours.^{3,4}
- Transportation method of an amputated digit is important. The digit should not be placed directly on ice but should rather be wrapped in gauze moistened with normal saline or lactated Ringer's and placed into a plastic bag, which is then placed in an ice slush.
- A psychological and mental health history is important, as patients will require significant compliance with rehabilitation protocols.
- Medical history including diabetes mellitus, peripheral vascular disease, hypercoagulability, or smoking is not a contraindication to revascularization or replantation but will affect the healing potential of the digit(s) and must be discussed with the patient.
- The surgeon must examine the extremity to assess the number of digits injured, vascularity and sensation of partially amputated digits, wound contamination, and type of injury sustained.
- Several classifications exist for fingertip amputations. Two commonly used classifications are by Allen and Tamai.
 - Allen⁵ (**FIG 4A**)
 - Type I: Only the pulp of the finger is involved. No suitable vessel for anastomosis.
 - Type II: Pulp and nail loss. Preserves half of the nail bed. No dorsal vein available for anastomosis.
 - Type III: Partial loss of the distal phalanx in addition to pulp and nail loss. High incidence of hook-nail deformity if nail bed is not ablated.

- Type IV: Amputation proximal to nail fold. Dorsal vein usually available for anastomosis.
- Tamai⁶ (**FIG 4B**)
 - Zone 1: Fingertip to the base of the nail
 - Zone 2: Between the base of the nail and the DIP joint

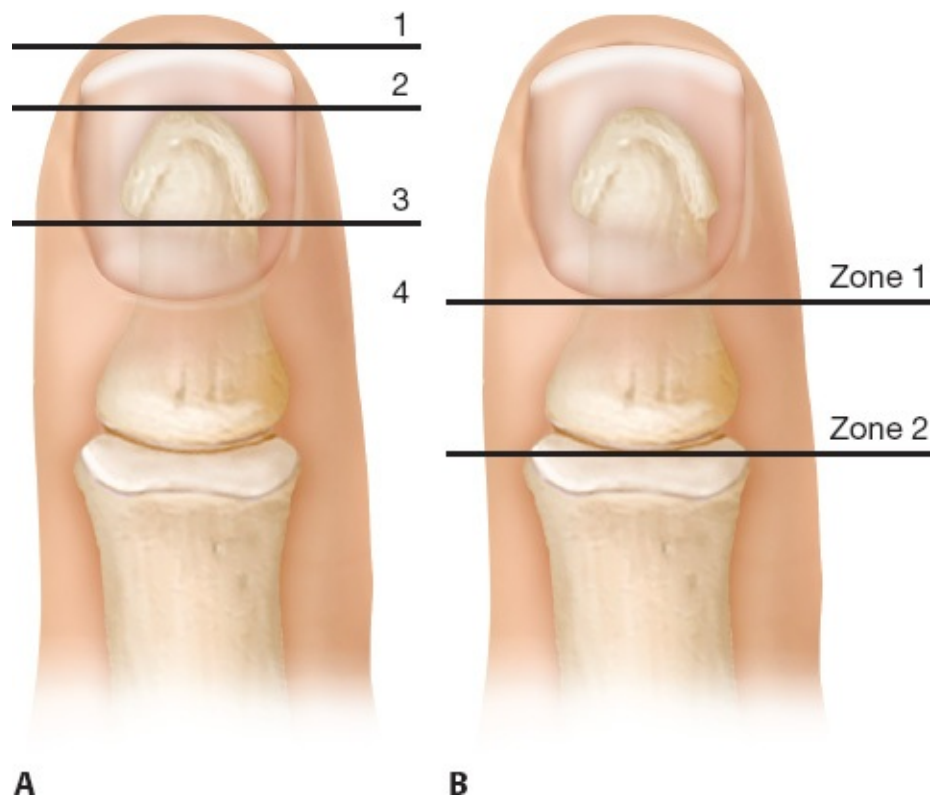


FIG 4 • Classification of fingertip amputations. **A.** Allen classification. **B.** Tamai classification.

- Red line sign—a red streak along the lateral border of a digit suggests hemorrhage from an avulsed branch of the digital artery after a traction injury.
- Ribbon sign—coiling of a digital artery at the amputation site. This also results from a traction injury (**FIG 5**). If replantation or revascularization is attempted, vein grafting will be required.

IMAGING

- Standard radiographs of the injured extremity and the amputated parts should be performed, in order to better understand the extent of injury and to plan fixation (**FIG 6**).

NONOPERATIVE MANAGEMENT

- There is no role for nonoperative management in digit amputations or dysvascular partial amputations.
- Occasionally, revision amputation can be performed in the emergency department, but this is often better done in the operating room with appropriate anesthesia, sterile conditions, lighting, and equipment.

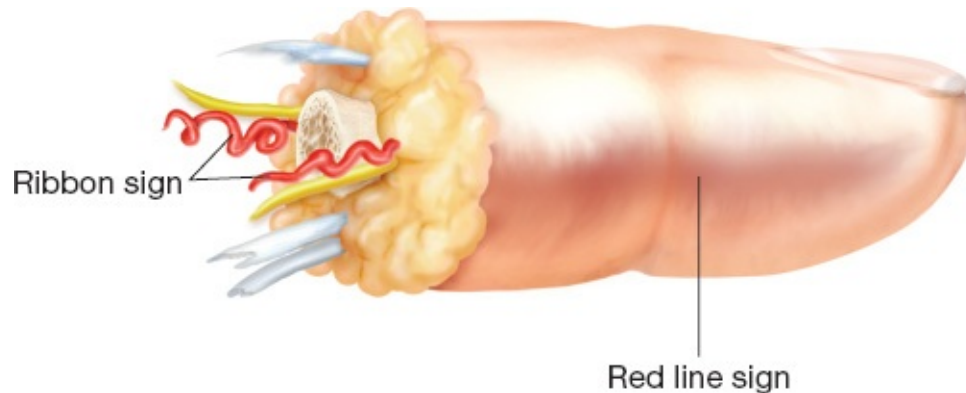


FIG 5 • The red line sign and ribbon sign are both signs of artery avulsion from a traction injury. If these signs are present, a vein graft should be attempted rather than direct repair, as the vessel walls have been injured.



FIG 6 • A,B. Radiographs of a patient who sustained a crush injury to the right hand, with multiple devascularized digits.

SURGICAL MANAGEMENT

- Patients undergoing revascularization or replantation should also be consented for possible revision amputation, as a final decision to revascularize or replant a digit will be made after all structures are carefully evaluated in the operating room.
- Indications for replantation:
 - Thumb
 - Multiple digits
 - Partial hand (through-palm amputation)
 - Through wrist or forearm
 - Almost any part in a child
 - Individual digit distal to the FDS tendon
- Contraindications to replantation:
 - Severely crushed or mangled digit
 - Multilevel amputation
 - Concomitant life-threatening injuries

- Severely atherosclerotic vessels
- Patients who are unable to comply with a postoperative rehabilitation program
- Prolonged warm ischemia time (relative; see discussion in history and physical section)
- Individual finger amputation in an adult at a level proximal to the FDS insertion (controversial; limited function in a replanted digit at this level may negatively affect overall hand function)
- The sequence of repair is as follows:
 - Debridement and identification of injured and intact structures. Place vascular clips on the arteries. This will help with later identification. In addition, if the tourniquet needs to be let down prior to arterial repair, the field will remain dry.
 - Bone shortening and/or fixation
 - Extensor tendon repair
 - Flexor tendon repair
 - Vein repair while still under tourniquet. This is a deviation from the classic teaching (arteries before veins), because many surgeons find it easier to repair veins in a bloodless field.
 - Arterial repair
 - Nerve repair
 - Skin closure/coverage

Preoperative Planning

- Antibiotics and tetanus prophylaxis are given as soon as possible upon presentation to the emergency department.
- Regional anesthesia provides increased peripheral vasodilation.
- Amputated digits are transported to the operating room, and initial preparation begins as soon as possible.
 - This can be done while the anesthesia team is evaluating the patient and inducing anesthesia.
 - The surgical team can use a back table to start dissecting the amputated part to identify all the parts that will be connected.

Positioning

- The patient is placed supine on the operating table.
- The operative extremity is placed on a hand table.

- A brachial tourniquet is applied.

Approach

- Debridement and careful identification of structures is the key first step.
 - Keep track of each structure as it is identified by writing a count sheet or having the circulating nurse do so.
 - Each structure is tagged with a suture or a clip for future identification.
- Duration of surgery is decreased by repairing “structure by structure” rather than “digit by digit.” Repair the same structure on each digit rather than completing all aspects of replantation on one digit at a time.
- A two-team approach can be used to save time. One team prepares the amputated digit(s) while the other team prepares the patient.
- Vein, artery, and nerve repairs are performed under the operating microscope. Microsurgical instruments are used.
- Never discard amputated parts until the surgery is over. Amputated parts are a useful source of autologous materials when needed such as nerve grafts, vascularized skin flap, tendons, bone, and vessels.

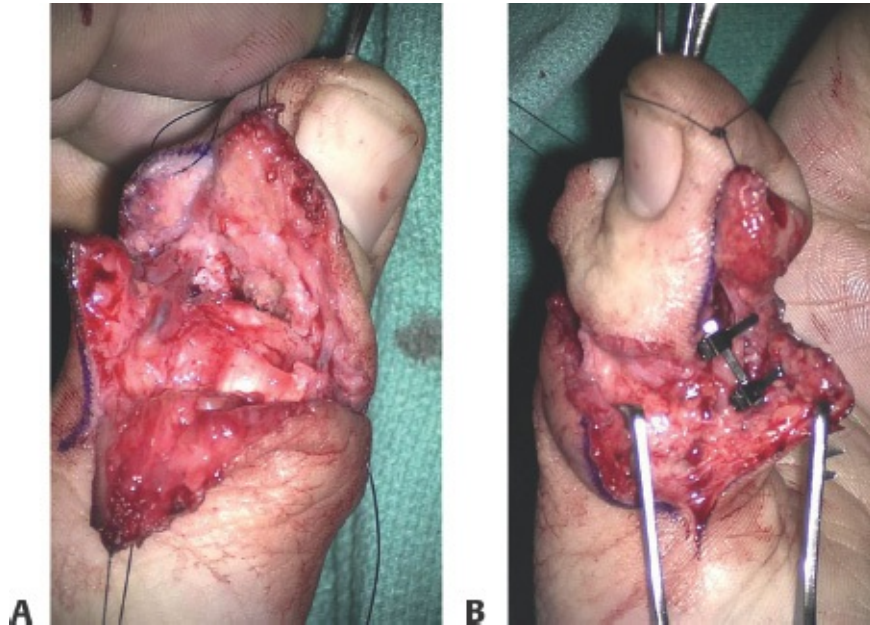
TECHNIQUES

■ Preparation of Amputated Digits and Stumps

- The amputated digits are brought to the operating room as soon as possible. One team will prepare the amputated digits while the other team prepares the patient.
- The parts are cleaned on a sterile prep table.
- Contaminated edges of the amputated digits and stumps are debrided, and arteries, nerves, and veins are identified.
 - Vascular clamps can be placed on arteries at this time for identification and later hemostasis.
- Midaxial incisions are made on the radial and ulnar sides of the digit to further expose neurovascular structures (**TECH FIG 1**).
- Flexor and extensor tendons are identified.
- Bone is shortened with a rongeur or a microsagittal saw to facilitate the vessel repair to obviate the use of vein graft and nerve graft. Bone should be

shortened if much tissue debridement was required. Shortening will facilitate tension-free anastomosis and skin closure.

- Amputated digits should be kept cool until they are ready to be replanted.

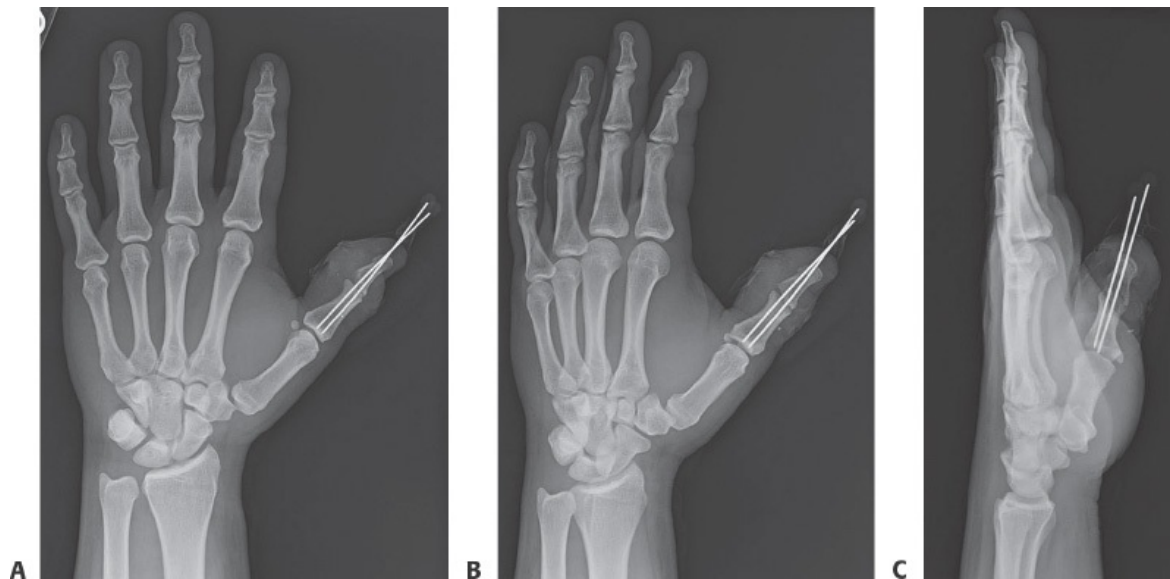


TECH FIG 1 • A,B. Midlateral incisions are made on either side of the amputation to assist in visualization, identification, and repair of neurovascular structures.

■ Bone Fixation

- Bone fixation can be accomplished using many different methods, including longitudinal K-wires, crossed K-wires, intraosseous wiring, tension band, intramedullary screws, and plate and screws.
 - Parallel longitudinal K-wires are fast and easy and have good success rates.
- In the amputated digit, two 0.045 K-wires are placed longitudinally into the bone in retrograde fashion.
 - The wire should exit the tip of the digit just palmar to the nail.
 - Advance the wire until just the tip is showing through the proximal end of the bone, ready to be advanced into the bone from the stump.
- Align the bones from the amputated part of the digit and its stump.
 - Take care to restore proper rotational alignment.
 - Advance the K-wires into the proximal bone and confirm location with

radiographs (**TECH FIG 2**).



TECH FIG 2 • A–C. Parallel K-wire fixation was used in this case of thumb replantation.

■ Tendon Repair

- Extensor tendons are repaired with two 4-0 nonabsorbable sutures in horizontal mattress fashion.
- In-depth discussion of flexor tendon repair can be found in a separate chapter in this text.
 - We typically use a looped 4-0 Supramid suture to complete a six-strand repair of flexor tendons, followed by a running epitendinous 6-0 Prolene suture.
 - Both flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) can be repaired; however, it is not necessary to repair the FDS if this will impede tendon gliding if the FDS is shredded and too traumatized.
 - If the amputation is distal to the FDS insertion, extensor and flexor tendon repair can be disregarded and the distal interphalangeal (DIP) joint can be fused.

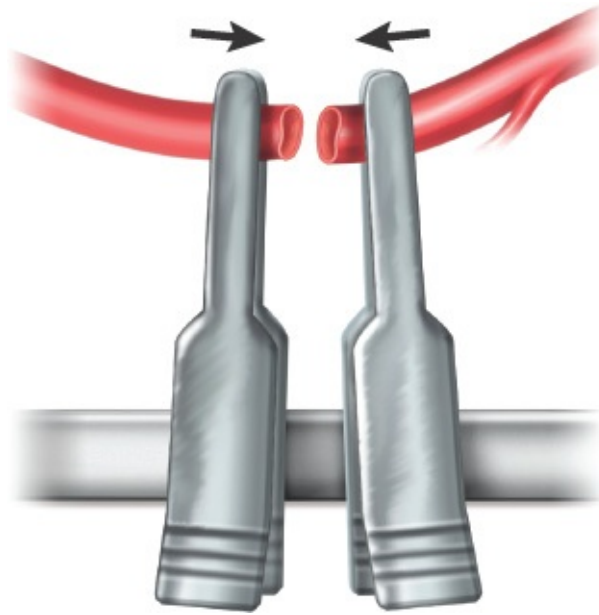
■ Vein Repair

- Ideally, two veins are repaired for each artery that is repaired.
 - Research has shown a significantly better survival rate after two venous anastomoses per digit compared with one. However, there was no difference in this study between none and one vein repaired.⁷
 - Another study also showed no difference in survival rates between distal digit replantations with and without venous anastomosis.⁸
 - We recommend venous repair whenever possible, despite the findings of the later study.
 - Venous repair prior to arterial repair allows for this most difficult task to be performed in a bloodless field and perhaps doing this critical procedure when the surgeon is still fresh, rather than at the end of the case when fatigue sets in.
 - Because the veins are thin, the surgeon needs to take minimal bites of the vessel wall to prevent folding in of the adventitia. Side branches can be clipped to lengthen the vein so that it can reach to the other end.
 - Irrigate the lumen of the vein with heparinized saline using a 30-gauge blunt-tipped needle to keep it open.
 - Fewer sutures are required for venous repair than arterial repair because of the low-pressure flow.
 - If vein grafts are required, appropriate-sized donor grafts (1–2 mm) can be harvested from the volar wrist.
-

■ Artery Repair

- Arteries have been previously clamped when structures were identified earlier. The tourniquet can be let down at this time. Vascular clamps will control bleeding.
- Both digital arteries should be repaired when possible, to maximize survival rates.
- Damaged ends of arteries are sharply debrided back to normal intima until one gets a robust spurt from the artery, which indicates suitable resection of the traumatized vessel.
- Vein grafts are used if there is any defect after debridement.
 - Vein grafts must be rotated 180 degrees with respect to flow, because of the valves that are present.
 - For proper size match, vein graft from the volar wrist is used.

- For vein grafting in the palm, vein graft from the forearm has suitable size match.
- Artery ends are approximated in a tension-free manner, but without redundancy of the vein graft. This can be done with vascular approximating clamps (**TECH FIG 3**).
- A microsurgical dilator is used to dilate the arterial lumen and assess blood flow by transiently releasing the vascular clamp on the stump side.
- If there is inadequate blood flow, evaluate for reversible causes such as vasospasm, cold, acidosis, hypotension/hypovolemia, or mechanical constriction.
- Vasospasm can be treated by irrigating with papaverine solution (diluted 1:20 with normal saline).
- Irrigate the lumen with heparinized saline using a 30-gauge blunt-tipped needle.
- We recommend the use of a background to help with visualization.
- A bolus of 5000 units of intravenous heparin is given prior to anastomosis. A heparin drip is then initiated at 1000 units per hour.
- Suture size depends on the size of the vessel being repaired. In general, 11-0 nylon suture is used in the distal digit, 10-0 nylon suture is used in the proximal digit, and 9-0 nylon suture can be used in the palm.
- Interrupted sutures are placed circumferentially, with care to avoid capturing the back wall with the needle.
- Each bite of the needle should be 1 to 2 times the thickness of the arterial wall.
- Leave one limb of each of the initial sutures long. The suture ends can be used later to manipulate the vessel in a minimally traumatic manner.
- Release the vascular clamps and observe for pulsations and a water-tight seal.



TECH FIG 3 • A vascular approximating clamp is used to bring the arterial ends together in a tension-free manner.

■ Nerve Repair

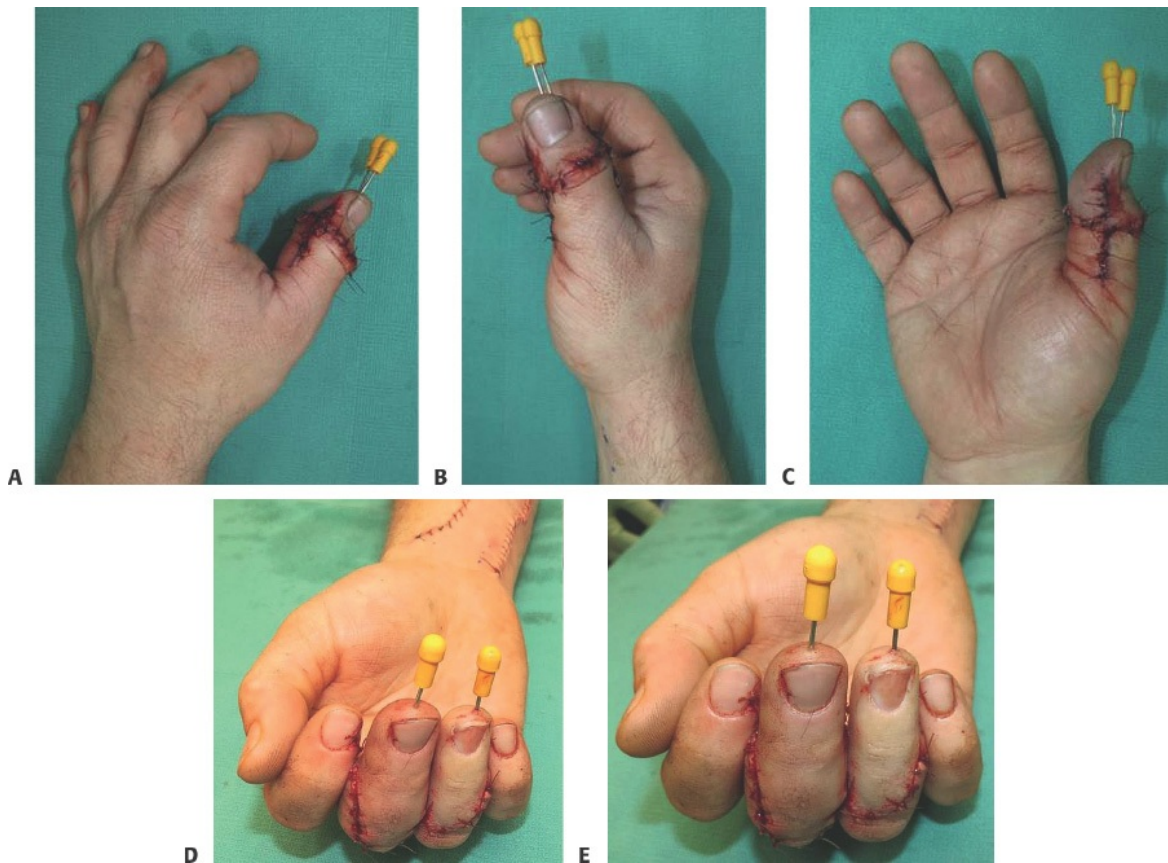
- The severed ends of the nerve are sharply cut using microsurgical scissors or a no. 11 blade against a wooden tongue depressor.
- Nerve ends are approximated in a tension-free manner.
 - If tension-free repair is not possible, primary nerve grafting is performed. The medial or lateral antebrachial cutaneous nerves can be harvested from the ipsilateral extremity.
 - Alternatively, other amputated digits that are not candidates for replantation can be used to provide nerve graft of appropriate caliber.
- Fascicles are aligned and epineural repair is performed using three or four 9-0 or 10-0 nylon sutures.

■ Closure

- Obtain hemostasis prior to skin closure. Hematoma will place pressure on vascular repairs and can result in failure of the replant.
- Interrupted 4-0 nylon sutures are used to close the skin (**TECH FIG 4**). Take

care to avoid constriction of underlying structures.

- Skin grafts or flaps are used as needed.



TECH FIG 4 • Same patient as in **FIG 1**. Postoperative images after thumb replantation (**A-C**) and long and ring finger revascularization (**D,E**).

PEARLS AND PITFALLS

Preparation

- Make a tally sheet for the structures that are injured in each digit as you debride and identify structures. This will help the case go smoother and will help with dictation postoperatively.
- Prioritize the functional goals of the patient for replantation. If multiple digits are amputated and some are not replantable, the salvageable digits should be placed in the most functional position—

	ie, if the thumb is not salvageable, replant a finger in the thumb's position.
Technique	■ Duration of surgery is decreased by repairing “structure by structure” rather than “digit by digit.” Repair the same structure on each digit rather than completing all aspects of replantation on one digit at a time. ■ All anastomoses should be tension-free. Bone shortening or vein grafting should be performed to accomplish this.
Treatment of venous congestion with leeches	■ If an inadequate number or quality of venous anastomoses are performed, venous congestion may occur in the digit. If this occurs, the nail can be removed and medical leeches (<i>Hirudo medicinalis</i>) can be placed postoperatively. They should be changed every few hours and continued for 7 days. ■ Patients should be treated with a third-generation cephalosporin while leeches are in use as prophylaxis against <i>Aeromonas hydrophila</i>, which is a symbiotic gram-negative rod in the leech gut.

POSTOPERATIVE CARE

- The postoperative dressing should not be circumferential or constricting.
 - Xeroform gauze is applied to the incisions.
 - A well-padded plaster splint is applied, with the tips of the digits exposed to monitor for vascular status.
 - Temperature probes or pulse oximeters can be applied to the fingertips for monitoring.
- The splint is changed after 1 or 2 days in case a blood cast forms. If there is excessive bleeding, the clotted blood on the dressings and splint will solidify and cause circumferential constriction.
- Color, warmth, and capillary refill are monitored by the surgeon and nursing staff.
- The patient's room should be kept above 72°F (22°C). We alternatively use a Bair hugger to cover the extremity and keep it warm.
- Bed rest is maintained for at least 2 or 3 days, or longer if the vascular status is tenuous.
- No caffeine, chocolate, or nicotine is permitted.
- A bolus of 50 mL Dextran 40 is given in the operating room, followed by a maintained rate of 20 mL/h while the patient is still hospitalized.
- The patient is maintained on low molecular weight heparin or unfractionated heparin for 5 days. Low molecular weight heparin has been reported to be as

effective as unfractionated heparin but with fewer adverse effects.⁹

- Aspirin 325 mg daily is started postoperatively and continued for 6 weeks.
- Anxiolytics can be provided to the patient so he or she does not unintentionally harm the repair secondary to anxiety.
- Thorazine 25 mg orally every 8 hours can be used as both an anxiolytic and a peripheral vasodilator.

OUTCOMES

- Sebastin and Chung¹ performed a systematic review of the outcomes of replantation of distal digital amputation (**FIG 7**). Thirty studies were included in the review.
- Mean survival rate after replantation was 86%.

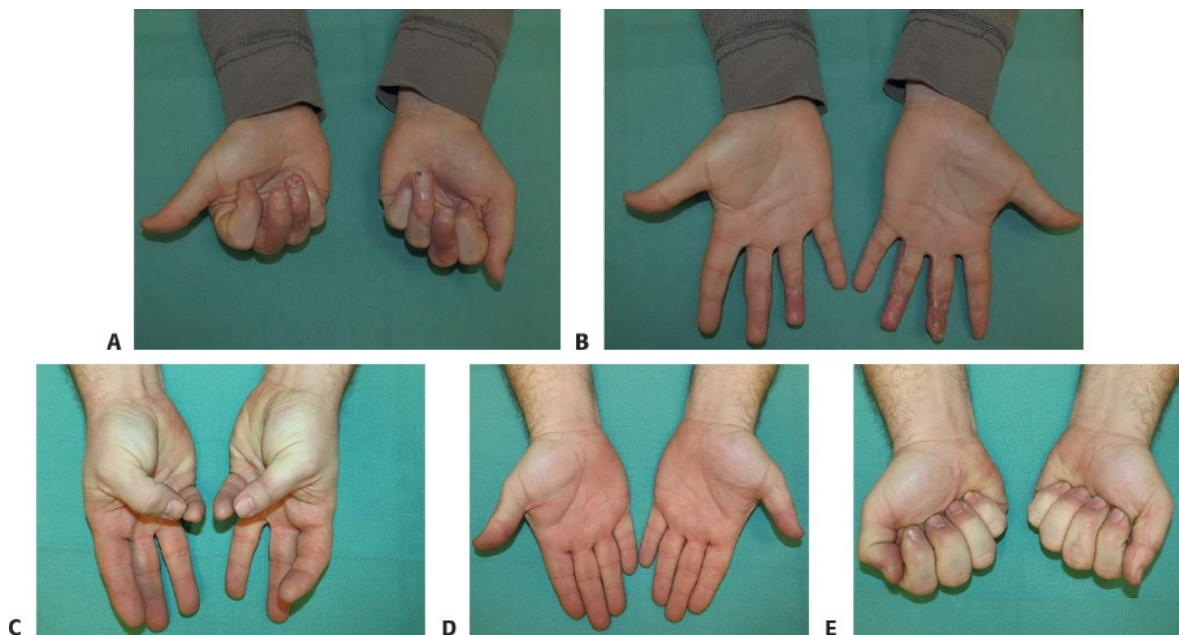


FIG 7 • **A,B.** Five months after bilateral long and ring finger revascularization. **C–E.** Ten months after left thumb replantation.

- There was no difference in survival of replanted digits based on Tamai classification of zone I or zone II.
- Clean-cut amputations had significantly better survival rates than crushed amputations (92% for clean-cut, 80% for crush-cut, and 75% for crush-avulsion).

- Repairing a vein improved survival in both zone I and II replantation (zone I with venous repair 92% survival vs 83% without repair. Zone II with venous repair 88% survival vs 78% without repair).
- Mean two-point discrimination after replantation was 7 mm.
- Ninety-eight percent of patients were able to return to work.
- Yu et al.¹⁰ performed a meta-analysis to investigate nonsurgical factors associated with survival rates of digital replantation.
- Ischemia time (over or under 12 hours) had no significant correlation with survival rate.
- Clean-cut injuries had better outcomes than crush and avulsion injuries.
- The thumb had a better chance of survival than did the small finger (OR 2.09), while there were no significant differences between other digits.
- The chance of survival was higher in digits that were transported cold when compared to those transported at room temperature (OR 4.89).

COMPLICATIONS

- Pulp atrophy (14%)
- Nail deformity (24%)
- Failure of replant (14%)
- Venous congestion
- Infection
- Cold intolerance—Almost all patients experience this. Cold intolerance is expected to improve over the first 2 years but may never resolve.
- Stiffness—Tenolysis should be delayed for at minimum 3 months postreplantation.
- Malunion
- Nonunion

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54 Digital Artery Sympathectomy

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- Raynaud disease (RD) is characterized by cold hypersensitivity and color changes to digits secondary to an exaggerated vasoconstrictive response to cold temperature, emotional stress, or trauma.
 - There is no underlying associated cause for these vasospastic events in RD.
- Raynaud phenomenon (RP) occurs in patients with a diagnosis of underlying collagen vascular disease such as scleroderma.

ANATOMY

- The superficial palmar arch is the continuation of the ulnar artery in the palm. The common digital arteries arise from this palmar arch (**FIG 1**).
- The common digital nerves course alongside the common digital arteries, supplying sympathetic fibers to the adventitial layer of the arteries.

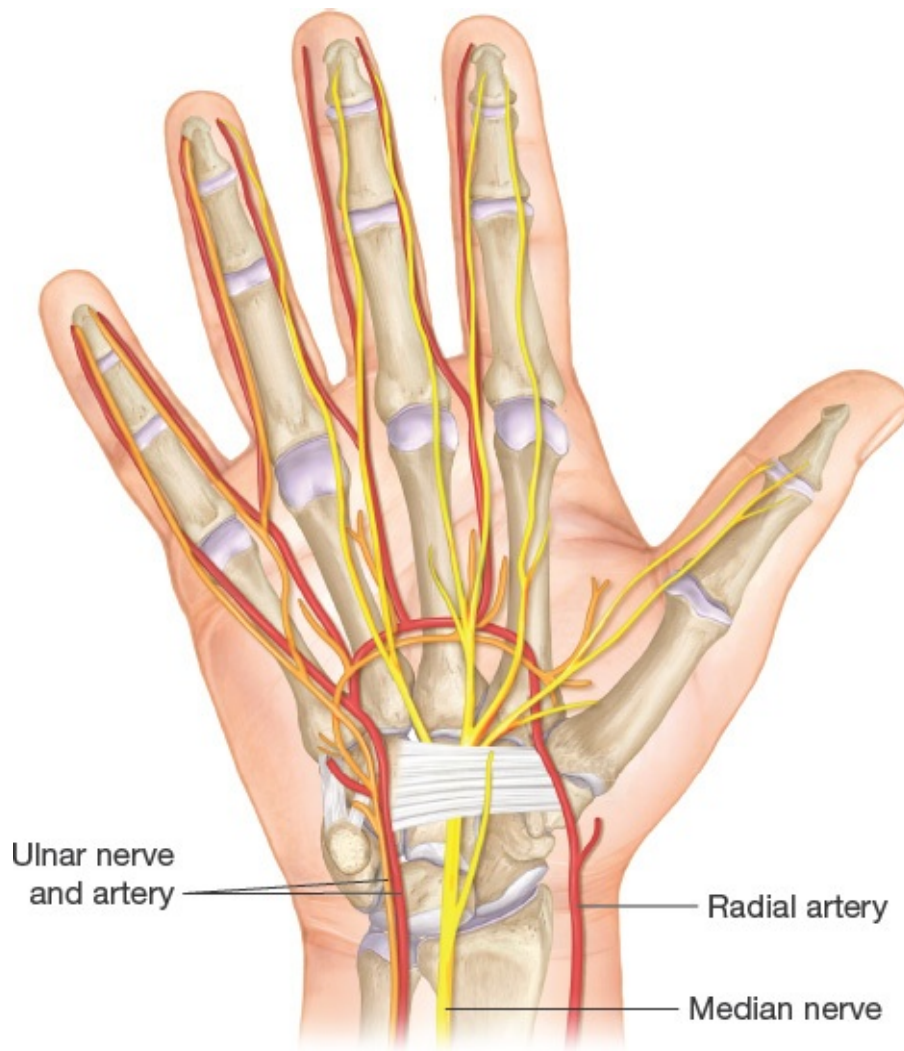


FIG 1 • Palmar neurovascular anatomy. The ulnar artery provides dominant flow to the superficial palmar arch (deep palmar arch not shown).

PATHOGENESIS

- The function of arterial smooth muscle is to constrict and decrease blood flow.
- Vasospastic disorders are characterized by reversible changes in flow, whereas occlusive disorders involve decreased flow unrelated to vasoconstriction.
- In occlusive disorders such as scleroderma, ischemia of the digit may result from inadequate collateral vessels or inadequate flow through collaterals secondary to vasospasm.

NATURAL HISTORY

- Natural history of the digital ischemia is largely dictated by the underlying cause.
- Patients with underlying mixed connective tissue disorder often have worsening digital symptoms/ischemia as their disease progresses. This can lead to trophic changes such as ulcers and gangrene.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients typically report a triphasic color change (white, blue, red) in both RD and RP.
- Obtain a thorough rheumatologic history. Patients with suspected primary RD may have unrecognized mixed connective tissue disorders.
- Frequency and severity of ischemic episodes, extent of cold sensitivity, numbness, pain
- Association of symptoms with emotional changes
- Active nicotine use is a contraindication to surgical intervention.
- Allen testing should be performed to assess patency of palmar arches.
- Note trophic changes such as ulcers and gangrene.
- Assess for laterality; focal unilateral symptoms may be concerning for embolic disease.

IMAGING

- Angiography provides excellent anatomic detail and structural information. Vasospastic contribution to ischemia can be enhanced by the use of intra-arterial vasodilators. If the patient fails medical management, we obtain this study as part of our preoperative evaluation.
- Noninvasive vascular studies
 - Digital brachial index (DBI) values assess total flow to the digit. DBI less than 0.7 indicates abnormal flow.
 - Doppler sonography
 - Digital plethysmography (pulse volume recordings) can differentiate vasospastic from vaso-occlusive disease, particularly with cold stress testing.

DIFFERENTIAL DIAGNOSIS

- Primary Raynaud disease
- Secondary Raynaud phenomenon
 - Rheumatic disease, eg, scleroderma, systemic lupus erythematosus
 - Hematologic disorder

- Atherosclerotic disease
- Embolic disease

NONOPERATIVE MANAGEMENT

- Lifestyle modification
 - Tobacco cessation
 - Avoidance of cold environment (gloves, warmer climate in winter)
- Biofeedback therapy
- Medical management¹
 - Calcium channel blocker such as nifedipine is a first-line treatment.
 - Phosphodiesterase-5 inhibitors (sildenafil, tadalafil, vardenafil), topical nitroglycerin, angiotensin-receptor antagonist (losartan), and selective serotonin reuptake inhibitors (fluoxetine) are other among second-line medications.
- There may be a role for botulinum toxin type A injection, but larger controlled trials are necessary to establish its effectiveness.²

SURGICAL MANAGEMENT

- Indications for digital sympathectomy include digital ischemic pain and/or trophic changes refractory to medical management. This commonly includes patients with autoimmune disorders such as scleroderma. Often, this is a surgery of last resort in patients with persistent and unrelenting ischemic pain.
- Patients with primary RD often respond to medical management. We rarely offer surgical sympathectomy to these patients.
- We do not offer this surgery to active smokers.
- Contraindication to sympathectomy includes severe primary atherosclerotic occlusive disease.
 - For the sympathectomy to produce increased flow to the digit, there must be a reversible vasospastic component to either the digital artery or its distal collaterals.

Preoperative Planning

- If preoperative studies demonstrate vasospastic disease with secondary occlusion of the radial/ulnar artery or palmar arch, we consider arterial reconstruction with vein grafting.

Positioning

- Supine with hand table and arm tourniquet

Approach

- For single-digit sympathectomy, we perform an extensile Bruner zigzag incision over the ray of the digit in the distal palm.
- In the setting of multiple-digit sympathectomies, we perform a transverse oblique incision at the palmar crease (**FIG 2**).

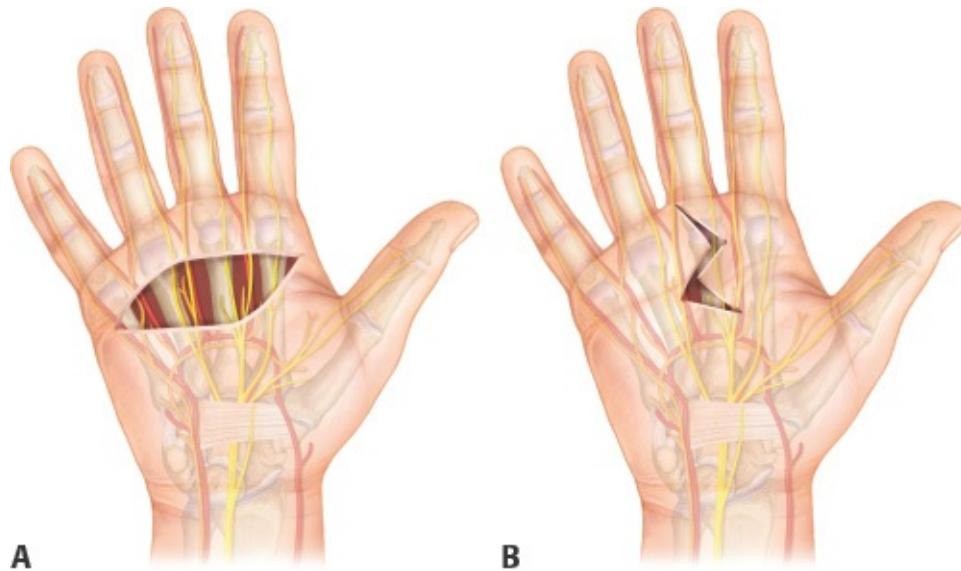


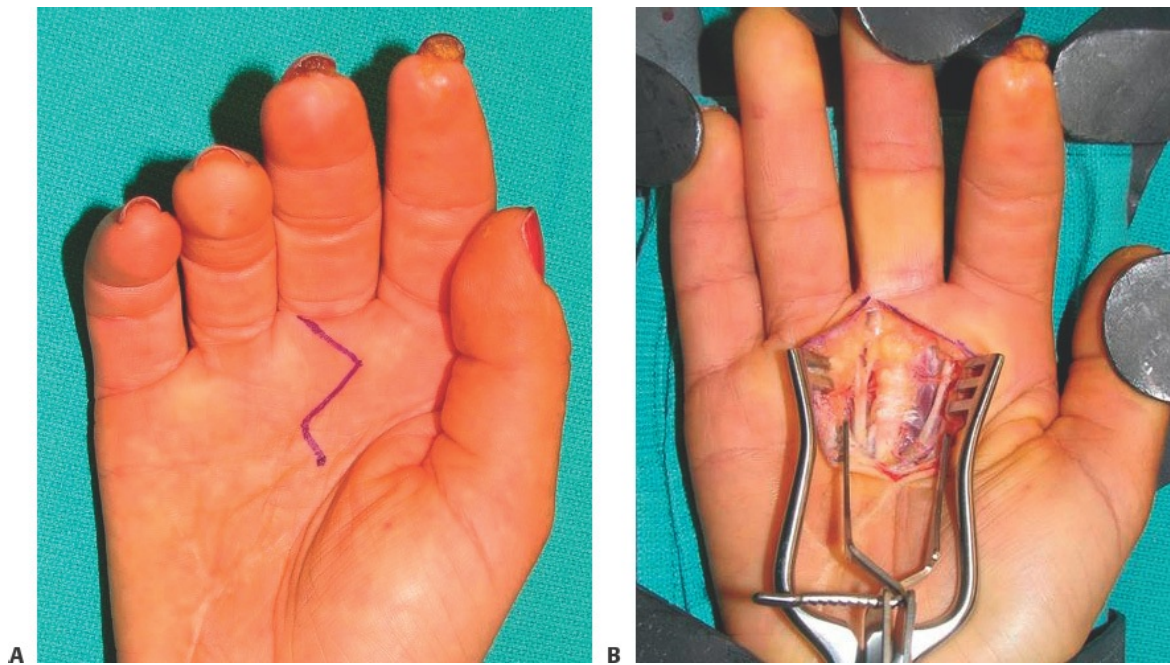
FIG 2 • Incision for multiple-digit artery sympathectomy (A) and single-digit sympathectomy (B).

TECHNIQUES

■ Exposure

- Under tourniquet control, perform a Bruner incision overlying the appropriate ray in the distal half of the palm (or transverse oblique incision for multiple-digit sympathectomies; **TECH FIG 1A**).
- Elevate full-thickness skin flaps and expose the superficial palmar arch proximally.
- Identify the origins of the common digital arteries supplying the radial and ulnar aspects of the appropriate finger.

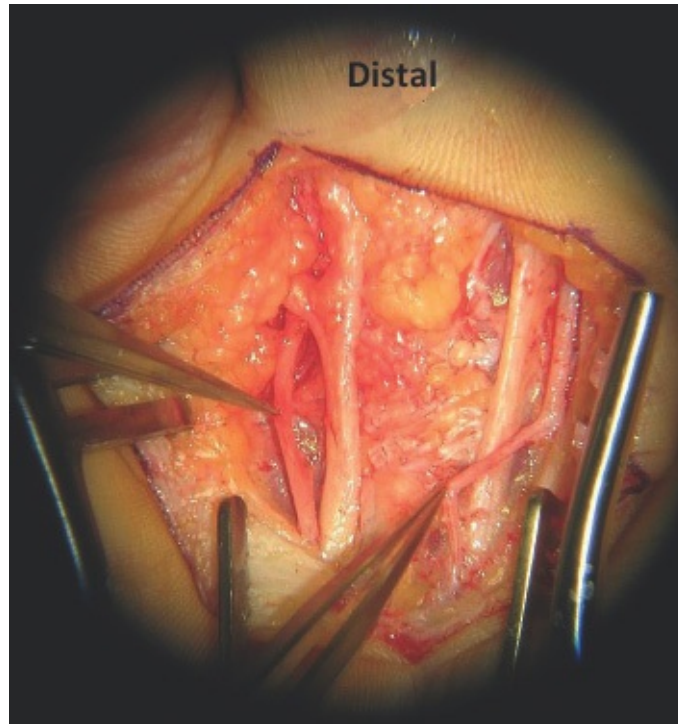
- Dissect the common digital arteries and nerves from proximal to distal, ensuring exposure of 2 to 3 cm of vessel length (**TECH FIG 1B**).



TECH FIG 1 • A. Brunner incision is marked. Trophic changes to the index and middle fingertips can be seen in this patient with scleroderma and persistent middle finger pain. **B.** Exposure of radial and ulnar digital neurovascular bundles to middle finger.

■ Sympathectomy

- Under microscope magnification, systematically strip the common digital artery adventitia for 2 to 3 cm.
- While doing this, any communicating sympathetic nerve branches from the digital nerve to the artery should be divided (**TECH FIG 2**).
- Take care to avoid injury to the digital artery. Small arterial branches should be tied off using microsurgical technique.
- Release the tourniquet and ensure hemostasis.
- Loosely close the wound.



TECH FIG 2 • Microscope view of neurovascular bundles after sympathectomy.

PEARLS AND PITFALLS

Technique

- Avoid iatrogenic arterial injury or vasospasm by minimizing trauma to the digital artery. Use microsurgical technique during adventitial stripping.

Arterial reconstruction

- When possible, consider arterial reconstruction if there is inadequate collateral circulation with proximal occlusion. Sympathectomy alone can be performed as a palliative salvage procedure if occlusive disease is nonreconstructible.

POSTOPERATIVE CARE

- Patient is placed in a volar forearm-based splint postoperatively.
- At the first 2-week postoperative visit, sutures are removed and range of motion is encouraged.

OUTCOMES

- Reported outcomes on ulcer healing and pain improvement are heterogeneous due to small case volume and lack of controlled studies.³
- In general, better outcomes in terms of ulcer healing are noted in patients who have underlying autoimmune disease as compared to severe atherosclerotic disease.⁴
- Twenty-eight of forty-two digits in patients with autoimmune disease had complete ulcer healing or decrease in number of ulcers. Two of seventeen digits had healing in the atherosclerotic group.
- At a minimum of 23 months of follow-up, 26% (11 of 42) of digits in the autoimmune disease group ultimately required amputation, whereas 59% (10 of 17) in the atherosclerotic group ultimately required amputation.

COMPLICATIONS

- Persistent ischemic pain
- Persistent wound/ulcers necessitating amputation
- Iatrogenic arterial injury/thrombosis

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Ulnar Artery to Superficial Arch Bypass With a Vein Graft for Ulnar Artery Thrombosis

55

CHAPTER

Mark Morris and Kevin C. Chung

DEFINITION

- Hypothenar hammer syndrome refers to post-traumatic digital ischemia secondary to thrombosis of the ulnar artery.
- The ulnar artery at Guyon canal and the proximal superficial arch are the most common sites of occlusion.
- “Critical” vascular injuries result in tissue death without intervention.
- “Noncritical” vascular injuries occur when an artery is damaged, but collateral circulation is adequate and prevents tissue necrosis.
- A “complete” superficial or deep palmar arch is defined as having a significant connection to a branch from another independent arterial limb such that it provides branches to all digits. The superficial arch is complete in 78.5% of extremities, and the deep arch is complete in 98.5% of extremities.¹

ANATOMY

- The major blood supply to the hand is from the superficial palmar arch, which is a continuation of the ulnar artery, and the deep palmar arch, which is a continuation of the radial artery (**FIG 1**).
- A median artery may also be present.
- The radial artery bifurcates into dorsal and volar branches at the level of the radial styloid. The dorsal branch traverses the floor of the snuffbox and passes through the first dorsal interosseous muscle, diving volar and becoming the primary contributor to the deep palmar arch. The volar branch contributes to

the superficial arch.

- The ulnar artery bifurcates into deep and superficial branches at the level of the wrist. The deep branch anastomoses with the deep palmar arch, whereas the superficial branch terminates as the superficial palmar arch.
- The radial artery and deep palmar arch provide the dominant blood flow to three or more digits in 57% of normal extremities, whereas the ulnar artery and superficial arch provide dominant flow to three or more digits in 21.5%, and there is equal contribution from radial and ulnar arteries in 21.5% of extremities.²
- Deep palmar arch runs deep to the flexor tendons at the level of the base of the metacarpals, 1 cm proximal to the superficial arch.
- Superficial palmar arch is located at Kaplan line (line drawn across the palm from the first web space parallel to the proximal palmar crease toward the hook of the hamate), 1 cm distal to the deep palmar arch.
- The deep and superficial arches provide common digital arteries to the second, third, and fourth web spaces at the mid-metacarpal level. These then divide into proper digital arteries at the level of the MCP joint.
- A less significant dorsal circulation also exists, receiving contributions from dorsal carpal branches of the radial and ulnar arteries.

PATHOGENESIS

- A single or more likely repetitive impact to the hypothenar eminence leads to ulnar artery thrombosis or aneurysm (**FIG 2**).
- Ulnar artery thrombosis has been reported in patients participating in baseball, golf, weight lifting, karate, mountain biking, volleyball, and overenthusiastic clapping by fans. At-risk occupations are those requiring vibrating tools such as carpentry, construction, machine operators, and mechanics.
- The hook of the hamate acts as an anvil against which the ulnar artery is crushed.

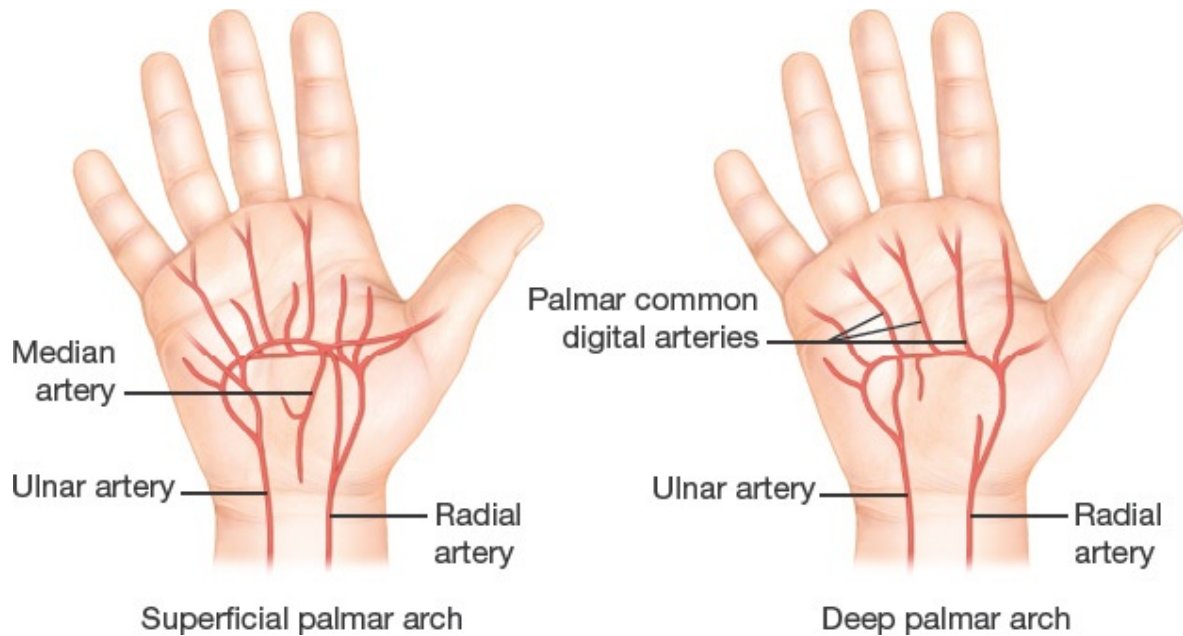


FIG 1 • Vascular anatomy of the hand. The superficial palmar arch is supplied by the ulnar artery. The deep palmar arch is supplied by the radial artery.

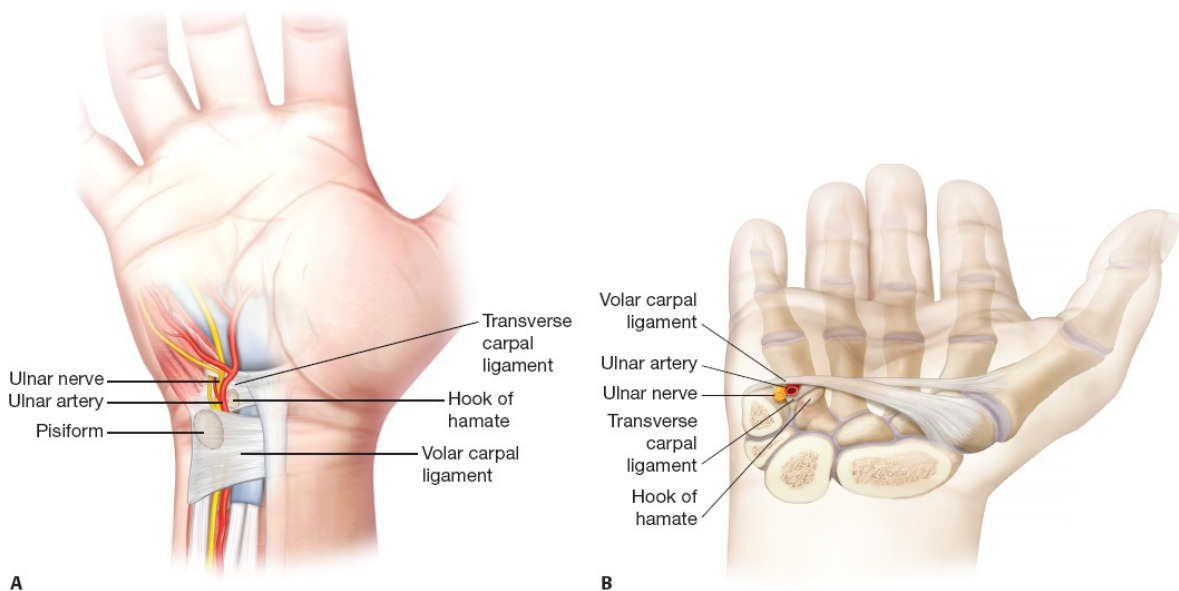


FIG 2 • The ulnar artery travels in Guyon canal with the ulnar nerve. **A,B.** The floor of the canal is made by the transverse carpal ligament, and the roof is made by the volar carpal ligament. The close proximity of the artery leaves it susceptible to impact into the hook of the

hamate.

- Repetitive trauma can lead to direct intimal damage, which leads to thrombosis, or periadventitial thickening of the artery that constricts the vessel and obstructs flow.
- Disruption of the internal elastic lamina of the artery leads to aneurysm, which predisposes to mural thrombosis, complete occlusion, and distal thrombotic emboli (**FIG 3**).
- Arterial occlusion or distal emboli can lead to ulceration, gangrene, and necrosis of digits.

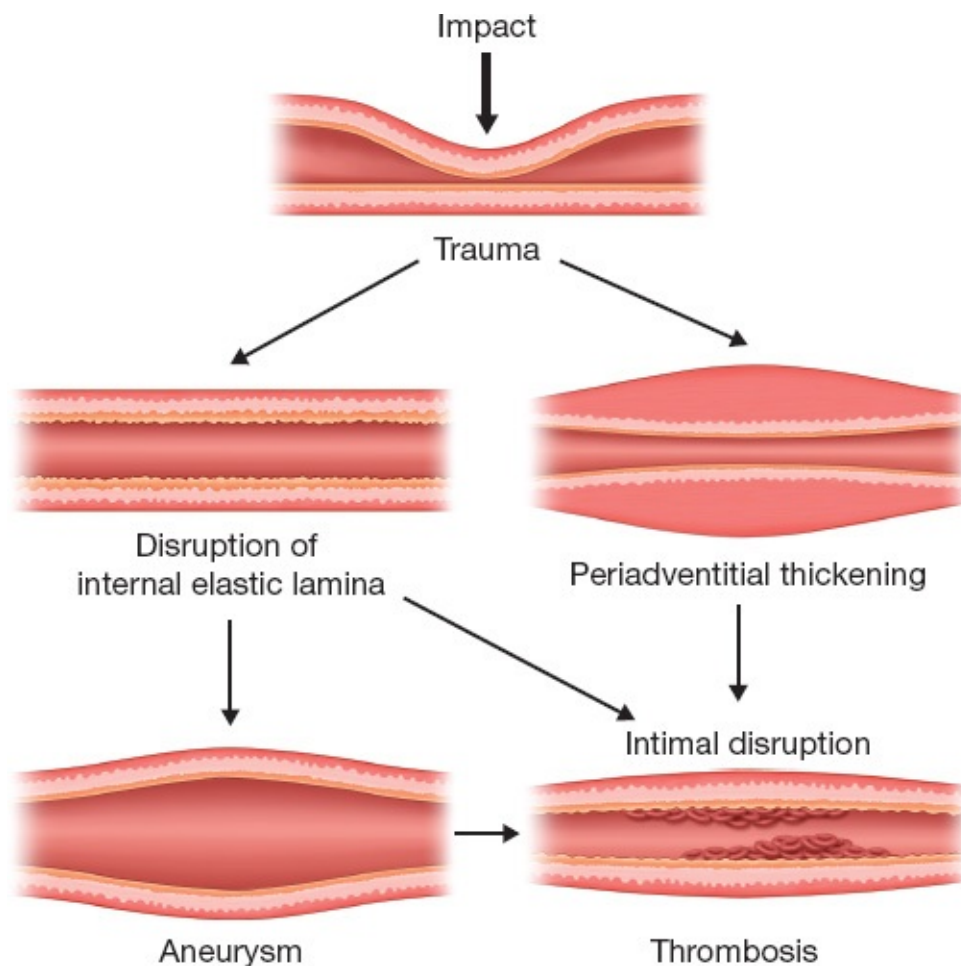


FIG 3 • Repetitive impact to the ulnar artery leads to either periadventitial thickening or disruption of internal elastic lamina. Both conditions leave the artery prone to thrombosis.

NATURAL HISTORY

- Depending on the severity of occlusion and quality of flow from the deep arch, the natural history will vary.
- The long, ring, and small fingers may develop cyanosis, pallor, splinter hemorrhages, ulcerations, atrophy of distal finger pads, or even necrosis of digits.
- Most patients will develop cold intolerance.
- Most patients will have persistent symptoms even after revascularization, although with decreased frequency and severity.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with post-traumatic ulnar artery thrombosis are predominantly male and present with unilateral hand and digit ischemia.
- The dominant hand is most commonly affected, although bilateral cases have been reported.
- History of interest includes vascular disease, smoking, manual labor, use of palm as a hammer, use of vibrating tools.
- Symptoms include pain, numbness or tingling, cold intolerance, and weakness in the ulnar nerve distribution.
- Signs on physical exam include pallor, cyanosis/mottling, a palpable hypothenar mass (if an aneurysm is present), atrophy of distal finger pads, splinter hemorrhages, ulcerations, and gangrene of the long, ring, and small fingers (**FIG 4**).
- Ischemic problems of the thumb have never been described with post-traumatic ulnar artery thrombosis. If present, a different diagnosis should be considered.
- Radial and ulnar pulses are palpated and examined by Doppler probe if not palpable.
- Doppler can also be used to assess the palmar arch and radial and ulnar digital arteries to each finger.

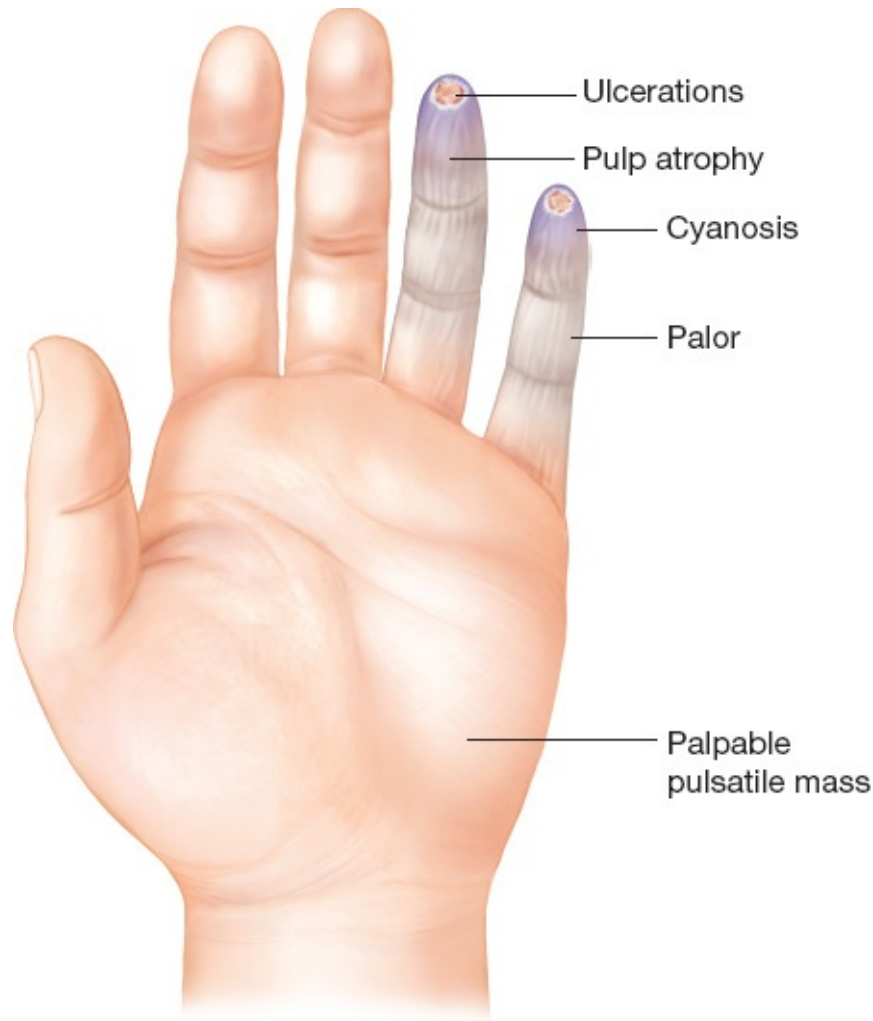


FIG 4 • Signs of ulnar artery thrombosis—pulp atrophy, ulcerations, cyanosis, pallor, palpable pulsatile mass in the hypothenar eminence. The thumb should appear normal. The number of affected digits will vary depending on perfusion from the radial artery and deep arch.

- A modified Allen test should be performed to assess blood flow to the hand from the radial and ulnar arteries independently (**FIG 5**):
 - One hand is examined at a time.
 - The patient is asked to clench the fist tightly for one minute.
 - Pressure is applied over the radial and ulnar arteries so as to occlude both.

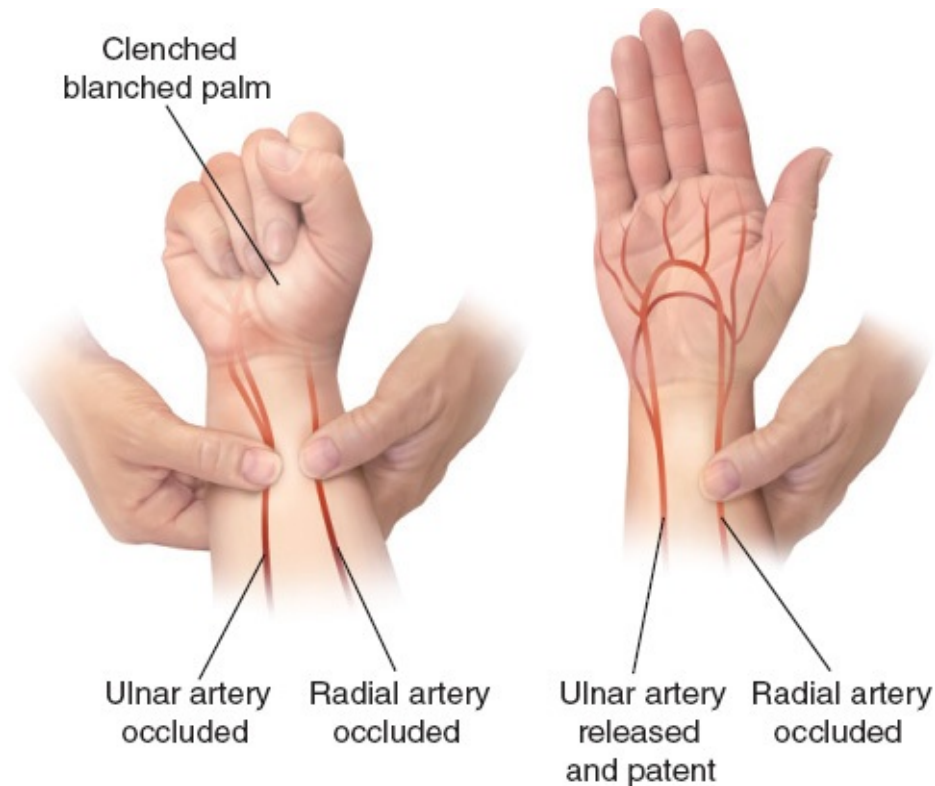


FIG 5 • Allen test in a patient with ulnar artery thrombosis. The examiner occludes both the ulnar and radial arteries and the hand is white as a result of a lack of perfusion. When pressure is released from the ulnar artery, the hand remains white because of an occluded ulnar artery.

- The patient opens the fingers. Pallor should be observed at this time.
- Pressure is released from the ulnar artery, and color should return if ulnar artery supply to the hand is sufficient. Pallor will remain if there is insufficient ulnar flow. The radial artery is then released and color should return to the entire hand if the deep arch is complete.
- The test is repeated, but with pressure being released from the radial artery first.
- Several questionnaires exist to assess symptoms and disability related to ischemia of the hand:
 - The Levine-Katz questionnaire assesses pain, symptoms of dysesthesia, and hand function.³

- The McCabe Cold Sensitivity Test assesses cold sensitivity and associated symptoms.⁴
- The Cold Intolerance Symptom Severity questionnaire adds questions and assessments that are not addressed by the McCabe test.⁵

IMAGING

- Noninvasive studies are done first.
 - Standard PA, lateral, and oblique radiography of the hand are performed to evaluate bony architecture as well as vascular calcifications.
 - Pulse volume recording measures the volume of arterial blood flow. Inadequate flow to the hand and digits can be detected by comparing proximal and distal blood flow. The severity and general location of occlusive disease can be determined by pulse volume recording.
 - Digital brachial index (DBI) compares digital blood pressure to contralateral brachial blood pressure in order to quantify perfusion to the hand and digits. The normal range for DBI is 0.75 to 0.97. Values equal or less than 0.7 signify inadequate perfusion.
 - Doppler or vascular duplex ultrasound can be used to evaluate flow. This provides audible and color-coded visual information about flow. Duplex can provide information about flow abnormalities, structural abnormalities of vessels, presence of thrombus, and aneurysm. The weakness of this study is the lack of standardization and operator-dependent nature of the study.
- Invasive tests can be performed if noninvasive tests are abnormal.
 - Computed tomographic angiography (CTA) and magnetic resonance angiography (MRA) are minimally invasive tests that require venous access for the administration of contrast dye. Both hands can be evaluated simultaneously for comparative assessment. Anatomic details provided by both tests are similar, but both have advantages and disadvantages. MRA contrast is less nephrotoxic than CTA contrast. MRA is susceptible to motion artifact and cannot be used in patients with certain metallic implants or claustrophobia. MRA is significantly more expensive than CTA, although both are cheaper than conventional angiography.
 - Conventional angiography/arteriography is the standard for evaluation of ulnar artery thrombosis (**FIG 6**). Angiography shows the surgeon the features of ulnar artery thrombosis including a corkscrew appearance of the ulnar artery, alternation of stenosis and dilation, aneurysm formation, occlusion of the ulnar artery at the hook of the hamate, or occlusion of the superficial

palmar arch or digital arteries with a normal proximal ulnar artery. Conventional angiography requires arterial access and contrast dye administration and has risks of bleeding, hematoma, thrombosis, pseudoaneurysm, allergic reaction, renal toxicity, and a four-fold higher dose of radiation than CTA. Conventional angiography is contraindicated in patients with renal insufficiency.



FIG 6 • Arteriogram demonstrating absent flow from the ulnar artery into the hand.

DIFFERENTIAL DIAGNOSIS

- Hypothenar hammer syndrome (post-traumatic ulnar artery thrombosis)
- Raynaud disease
- Malignancy, vascular tumors

- Pseudoaneurysm
- Trauma, iatrogenic injury
- Buerger disease
- Arteritis
- Peripheral vascular disease (atherosclerosis)
- Connective tissue disorders (scleroderma, systemic lupus erythematosus)

NONOPERATIVE MANAGEMENT

- Nonoperative treatment can be considered for patients without impending digital loss.
- Smoking cessation
- Medications can be used to decrease sympathetic tone and vasospasm—calcium channel blockers, α -blockers, β -blockers, steroids, prostaglandins, and prostacyclin have been described.
- Antiplatelet or anticoagulant agents can be used in patients with thrombosis and embolic disease.
- Intra-arterial thrombolytics can be percutaneously directed to the site of ulnar artery thrombosis. Success of this procedure is limited, with a high complication rate.
- Digital sympathectomy with botulinum toxin A can be performed, with low morbidity.

SURGICAL MANAGEMENT

- Surgical intervention is indicated in patients who have failed medical management or those with impending digital necrosis.
- Surgical options include open sympathectomy, exploration and ligation of the diseased segment of artery, exploration and primary repair of the ulnar artery, or exploration and revascularization by arterial bypass.

Preoperative Planning

- Preoperative imaging (eg, CTA, MRA, angiogram) is reviewed to determine the site of bypass.
- Donor vessels are identified and marked.
- Venous or arterial grafts can be used.
 - Vein interpositional grafts must be reversed because of the presence of valves.
 - Veins are typically more expendable than arteries and provide longer grafts.

- Arterial grafts are easier to match in size. They are less flimsy and do not need to be reversed.
- Table 1 covers donor grafts available for ulnar artery bypass.
- An operating microscope and microsurgical instruments are used for microvascular anastomosis.

Table 1 Donor Grafts for Ulnar Artery Bypass

Graft	Length (cm)	Comments
Vein		
Greater saphenous	50–85	Found superficially, easier dissection, but decreased long-term patency rates compared to arterial grafts. Greater saphenous and basilic have poor size match to the ulnar artery at the wrist.
Lesser saphenous	35–60	
Forearm	14–20	
Basilic/cephalic	15–30	
Dorsum of foot	5–8	
Artery		
Subscapular	2–4	Short pedicle length
Superficial inferior epigastric	6–10	Abdominal bulge
Deep inferior epigastric	10–12	Abdominal bulge
Thoracodorsal	11–14	Dissection in axilla
Lateral circumflex femoral	10–18	Deep, variable anatomy

Positioning

- The patient is placed supine on the operating table with a hand table for the operative extremity.
- A brachial tourniquet is placed.
- Depending on the graft to be used, another extremity (usually a lower extremity) may need to be prepped and another tourniquet placed.

Approach

- The affected segment of artery will be excised. The surgeon must first obtain

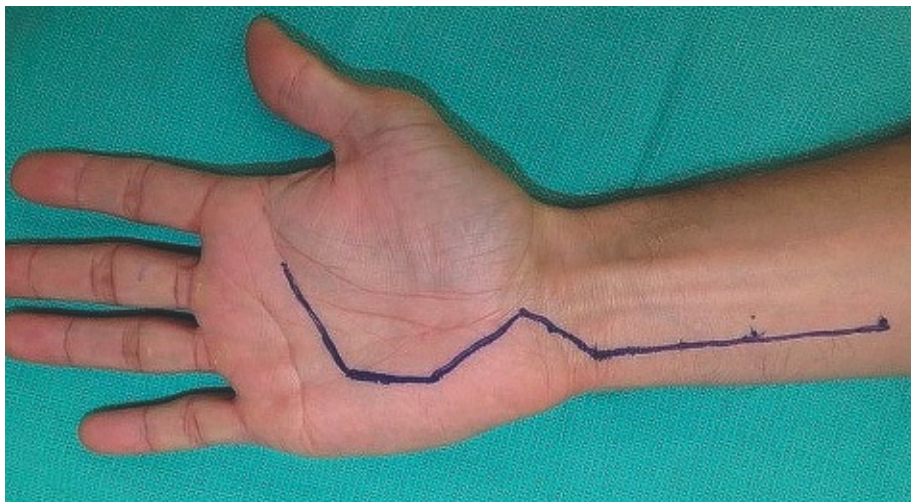
proximal and distal control of the ulnar artery and superficial arch.

- Palmar arches are exposed via zigzag incisions extending proximally from the phalanges or through an inverted J-shaped incision in the palm. The ulnar artery is exposed using a zigzag incision more proximally in the palm. The wrist crease is crossed in an oblique fashion.

TECHNIQUES

■ Approach

- An incision is made that parallels the thenar crease, zigzags in the palm, and extends proximally into the forearm between the flexor carpi ulnaris and palmaris longus (**TECH FIG 1**).
 - Alternatively, two separate incisions can be made and the graft is tunneled under the skin, depending on the location of ulnar artery to be resected.
- The ulnar artery and nerve are identified 3 to 5 cm proximal to the wrist crease, and vessel loops are placed around each structure.
 - The artery is radial to the nerve at the wrist. The ulnar artery enters the hand through the Guyon canal. It runs deep to the volar carpal ligament and superficial to the transverse carpal ligament.

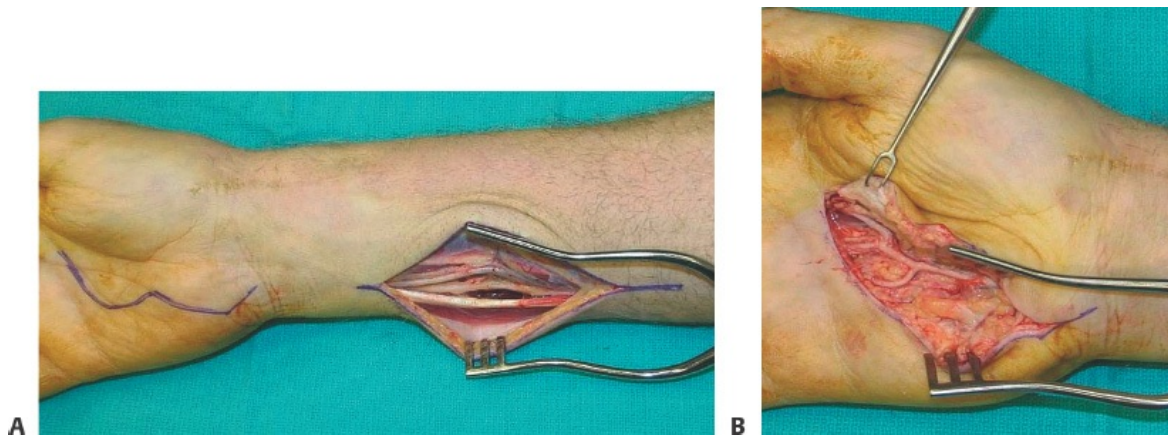


TECH FIG 1 • Planned incision to access the ulnar artery and superficial palmar arch. The wrist crease is crossed with an oblique incision. A zigzag incision is

made in the palm. If the entire superficial arch needs to be accessed, continue the incision along the proximal palmar crease. The extent of the forearm incision depends on the length of bypass required.

■ Dissection of the Ulnar Artery

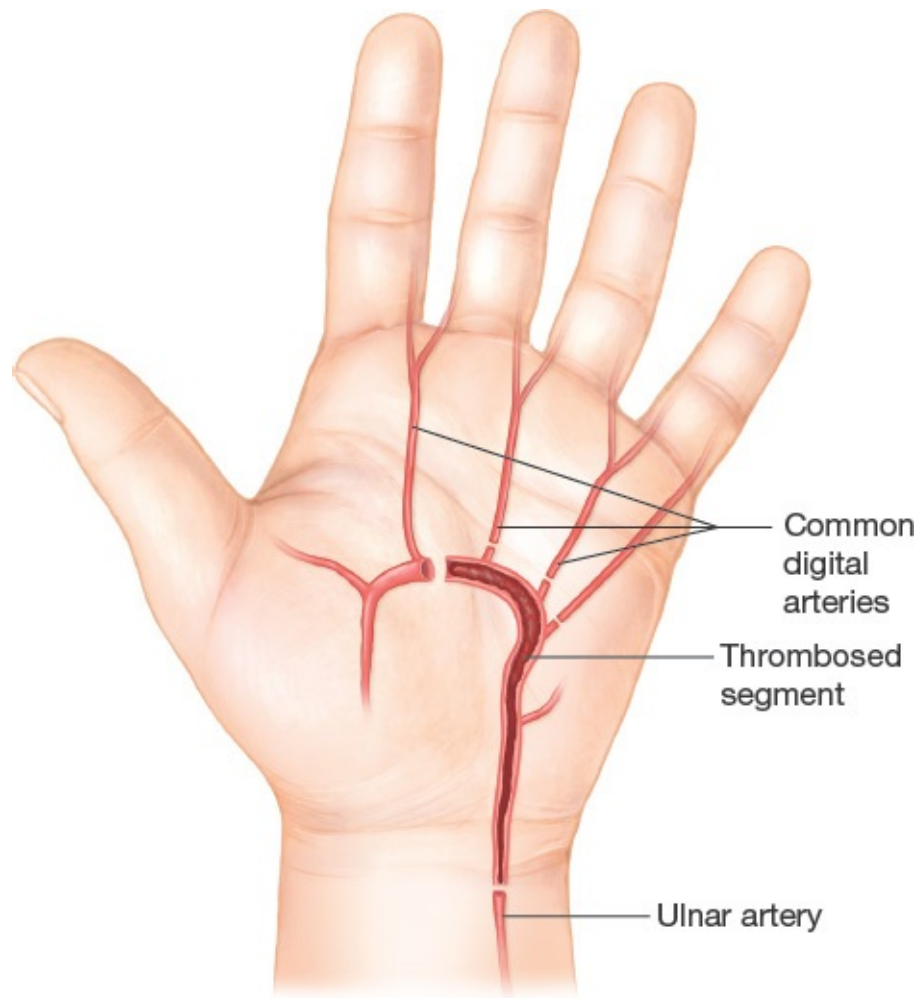
- Dissect from proximal to distal, following the ulnar artery. First identify the patent portion of the ulnar artery proximal to the wrist crease (**TECH FIG 2A**).
- Identify the arterial branch or branches that accompany the deep motor branch of the ulnar nerve. Identify the origin of the proper digital artery to the small finger and the origins of the common digital arteries from the superficial arch.
- Mobilize the ulnar artery and superficial arch (**TECH FIG 2B**). Spread the artery away from surrounding tissue and venae comitantes using scissors. Venae comitantes are cauterized with bipolar electrocautery.



TECH FIG 2 • A. The ulnar artery is exposed in the forearm. **B.** The superficial palmar arch is exposed in the hand.

■ Resection of Affected Segment of Ulnar Artery and Superficial Arch

- All abnormal segments are resected to normal vessel.
- Once all damaged vessels are resected, distal outflow can be assessed by transiently deflating the tourniquet and observing backflow (**TECH FIG 3**).
- Measure the size of the defect.



TECH FIG 3 • The thrombosed section of ulnar artery and superficial arch is resected back to normal artery. Measure the segment that is resected in preparation for vein harvest.

■ Harvesting of Vein Graft

- Select the appropriate donor graft depending on the length and diameter needed (see Table 1).

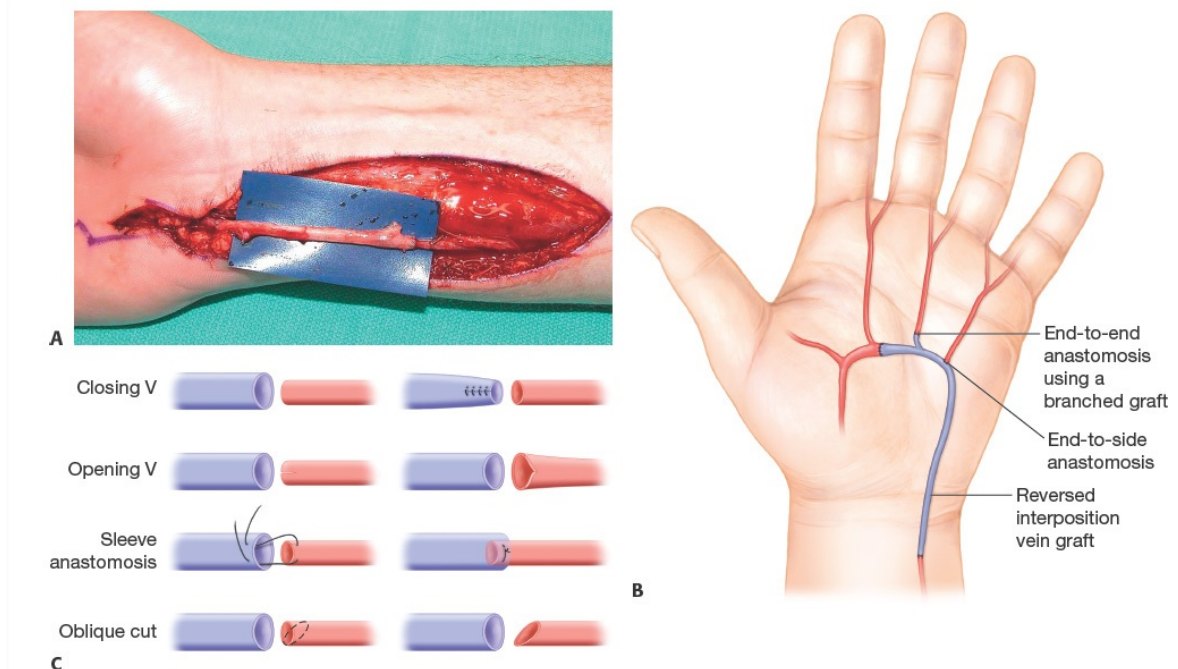
- A vein graft is harvested through a longitudinal incision under tourniquet.
- Adequate length is mobilized (harvest 10%–30% longer than estimated to perform the bypass).
- Draw an axial line down the length of the vein to be harvested while it is still in situ. This will help the surgeon prevent inadvertent twisting of the graft during the anastomosis.
- Occasionally, branches are desired for anastomosis. All other branches are ligated or coagulated with bipolar electrocautery.
- Harvest the graft (**TECH FIG 4**).
- Reverse the vein graft and prepare for anastomosis.
- The vein is distended with heparinized saline, and veins are dilated.



TECH FIG 4 • The vein graft is harvested and reversed. A saphenous vein graft is pictured here.

■ Microvascular Anastomoses

- The proximal anastomosis is done first. End-to-side or end-to-end anastomosis of the graft to the ulnar artery stump is performed (**TECH FIG 5A**).
- End-to-end or end-to-side anastomoses are performed to the superficial arch or the common digital arteries, as indicated by the amount of resected artery (**TECH FIG 5B**).
- Size discrepancy is managed by making a closing V in the vein graft, an opening V in the artery, a sleeve anastomosis, or a 30-degree oblique cut in the artery (**TECH FIG 5C**).
- If multiple anastomoses are required, end-to-end and end-to-side repairs can be performed serially.
- Intravenous heparin 2000 units is given prior to tourniquet release. Dextran 40 is started at 20 mL/h in the operating room and continued postoperatively.



TECH FIG 5 • A. The vein graft is anastomosed into place. **B.** A branched graft is used in order to perform an end-to-end anastomosis to one common digital artery and end-to-side anastomoses to the remaining common digital arteries. **C.** Several methods of addressing an oversized vein graft are shown.

■ Assessing Flow and Closure

- Vascular clamps are released (or the tourniquet is deflated if this has not been done previously) after all anastomoses have been completed.
- Compress the radial artery manually for a few minutes to maximize flow across the anastomoses.
- Any leaks are repaired.
- A Doppler probe is used to assess distal arterial flow.
- Hemostasis is achieved.
- The wrist incision and vein donor sites are closed using 4-0 nylon sutures.
- Splint is placed to immobilize the operative site, with care to avoid any pressure on the underlying anastomosis.

PEARLS AND PITFALLS

Preoperative planning	■ Adequate arterial inflow and distal runoff is essential.
Technique	■ Resecting to normal intima is critical to success. ■ Use an extensile incision. ■ Close over a drain if indicated.
Vein grafting	■ A vein graft with a larger diameter than the artery does not usually pose a problem, but a vein graft that is significantly smaller than the artery leads to higher rates of thrombosis. ■ Anastomoses must be performed in a tension-free manner. ■ Set the tension to prevent kinking. ■ Avoid rotation of the graft. ■ For the proximal anastomosis, end-to-end anastomosis is easier, but end-to-side anastomosis will help to maintain any remaining circulation to the hand from the ulnar artery.
Postoperative expectations	■ Cold sensitivity is expected. ■ Recurrent thrombosis is possible and has been reported up to 10 years postoperatively.

POSTOPERATIVE CARE

- The operative extremity is splinted from fingertips to elbow, with care to avoid pressure on the anastomosis.
- No nicotine, caffeine, or chocolate
- The patient's room is kept warm, or alternatively, we use a Bair Hugger over the operative extremity. The room should also remain quiet and free of unnecessary stimuli.
- Dextran 40 is continued at 20 mL/h for 2 to 5 days.
- The patient is given aspirin 81 mg daily for 3 months.
- Anxiolytics can be used to protect the patient from damaging the repair inadvertently.
- Sutures are removed at 10 to 14 days postoperative.
- The patient is kept off of work for at least 4 to 6 weeks, or potentially longer depending on the nature of his or her occupation.
- The patient is forever forbidden from using the hand as a hammer.

OUTCOMES

- Most patients have continued symptoms, but with decreased frequency and severity.
- In a series of 47 patients, Marie et al.⁶ found that digital necrosis healed, and there was no recurrence of hypothenar hammer syndrome after surgical intervention.
 - Recurrence of hypothenar hammer syndrome was 27.7% after medical management. Of the patients in this study, 69.2% continued to smoke.
- Long-term patency rates of arterial grafts are higher than venous grafts. Venous graft patency ranges from 77% to 88%.⁷
- Chloros et al.⁸ studied 13 patients who underwent reverse interpositional vein grafting for post-traumatic ulnar artery thrombosis with a minimum of 2-year follow-up.
 - Ten of 13 grafts (77%) were patent at final follow-up.
 - Patients with patent grafts all significantly improved on the Levine symptom scale, McGill visual analog pain scale, McCabe cold sensitivity severity scale, and isolated cold stress testing.
 - Patients with nonpatent grafts were more likely to complain of pain, numbness, and cold sensitivity.

COMPLICATIONS

- Persistent cold intolerance
- Thrombosis of the graft
- Donor site complications (neuroma)
- Wound healing complications
- Hand stiffness

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56 Second Toe to Thumb Transfer

CHAPTER

John R. Lien and Kevin C. Chung

DEFINITION

- The thumb is critical for hand function.
- Toe to thumb transfer is a composite tissue microsurgical reconstructive option for patients with loss of significant thumb length.

ANATOMY

- Great toe
 - Wider pulp and nail plate than native thumb and lesser toes; “thumblike” appearance
 - Significant aesthetic and functional morbidity at donor site; difficulty with push-off during gait
- Second toe
 - Pulp is bulbous and more rectangular in appearance than the native thumb or fingers.
 - Interphalangeal joints tend to claw.
 - Superior cosmetic and functional results on donor foot
- Arterial anatomy of the foot
 - The anterior tibial artery becomes the dorsalis pedis artery (DPA) distal to the ankle extensor retinaculum. The DPA courses along the dorsal foot lateral to the extensor hallucis longus tendon.
 - At the first intermetatarsal space, the DPA terminally divides into the first dorsal metatarsal artery (FDMA) and the deep plantar artery. The deep plantar artery communicates with the deep plantar arch of the foot, connecting the dorsal and plantar arches (**FIG 1**).
 - The FDMA generally travels deep to the extensor hallucis brevis tendon and

usually dorsal to the first dorsal interosseous muscle. It then communicates (through the distal communicating artery) with the first plantar metatarsal artery (FPMA) distal to the deep intermetatarsal ligament. The FDMA also terminally branches into the lateral dorsal digital artery of the great toe and medial dorsal digital artery of the second toe, which are of small caliber and clinically insignificant¹ (see **FIG 1**).

- **FIG 2** shows variants of FDMA anatomy in relation to the first dorsal interosseous muscle, as well as a variant unfavorable for vascular anastomosis.
- The plantar digital arteries are the effective blood source to the great and second toes. Their origin is the distal communicating artery connecting the FDMA and FPDA distally (**FIG 3**).
- Venous anatomy of foot
 - The superficial dorsal venous system is utilized for venous anastomosis.
 - The dorsal veins of the toes join the dorsal venous arch in the forefoot, which supplies the greater and lesser saphenous veins.
- Sensory nerve anatomy of foot
 - The superficial peroneal nerve innervates the dorsal foot while the deep peroneal nerve innervates the first dorsal web space.
 - Branches from the posterior tibial nerve innervate the plantar foot and toe pulps. Coaptation of plantar digital nerves are important for pulp sensation.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Advanced age is not a contraindication to surgery, but the patient must be in generally good health to tolerate a prolonged surgery.
- Active nicotine use and a history of atherosclerotic disease are contraindications to toe transfer.
- Assess whether there is adequate, supple skin coverage. If not, consider a staged procedure (groin flap) to increase pliable tissue at the recipient site. Harvesting too much soft tissue from the foot will lead to foot deformity and marked donor-site morbidity.

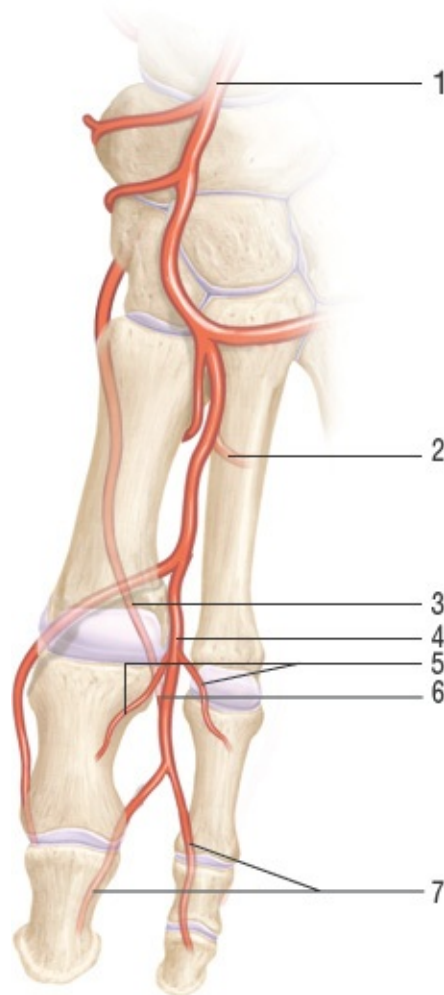


FIG 1 • Dorsal foot arterial anatomy: (1) dorsalis pedis artery (DPA), (2) deep plantar artery, (3) first plantar metatarsal artery (FPMA), (4) first dorsal metatarsal artery (FDMA), (5) dorsal digital arteries, (6) distal communicating branch (intersection of the FDMA and FPMA), (7) plantar digital arteries.

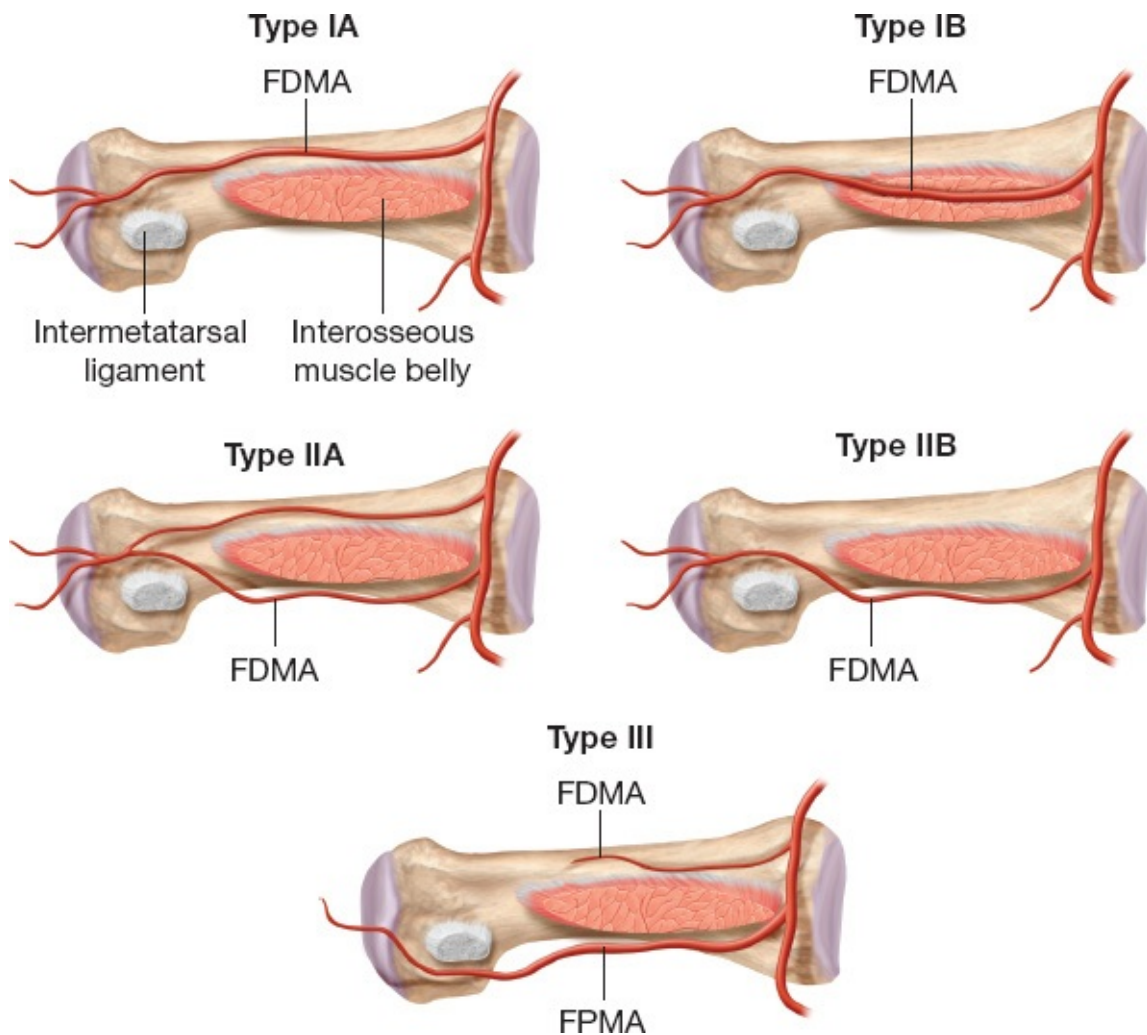


FIG 2 • Variants of first dorsal metatarsal artery (FDMA) anatomy. In type I, the FDMA passes superficial (IA) or within (IB) the interosseous muscle belly. In type II, the FDMA passes at the deep aspect of the interosseous muscle belly but superficial to the intermetatarsal ligament. Type IIA includes a fine accessory branch superficial to the interosseous muscle, whereas IIB does not have an accessory branch. In type III, the FDMA is miniscule or absent with plantar-dominant (FPMA) flow.

- The level of thumb amputation will dictate harvest length.
- Assess the donor foot (contralateral foot for second toe transfer) to ensure no

prior trauma or surgery that would alter vascular anatomy to the second toe. Doppler ultrasound examination can be used to confirm presence of DPA and FDMA.

IMAGING

- Review preoperative radiographs of the recipient site to prepare for bone fixation and length requirement of donor toe (**FIG 4**).
- We do not routinely obtain preoperative angiography of the foot, but this is an option if there is concern for altered vascular anatomy on physical and Doppler exam.

SURGICAL MANAGEMENT

- Toe to thumb transfer is generally performed after the acute traumatic injury has healed and adequate soft tissue coverage is obtained.
- Ensure adequate soft tissue coverage and pliability prior to transfer.
- Amputations through the thumb metacarpal (with preserved carpometacarpal joint) or proximal half of the proximal phalanx are good candidates for toe transfer. We prefer the second toe transfer to minimize donor-site morbidity. Other options for toe transfer include great toe and trimmed great toe. Alternatives to toe transfer include metacarpal bone lengthening and on-top plasty. Osteoplastic reconstruction of the thumb using iliac crest bone graft and groin flap is of historical significance only.

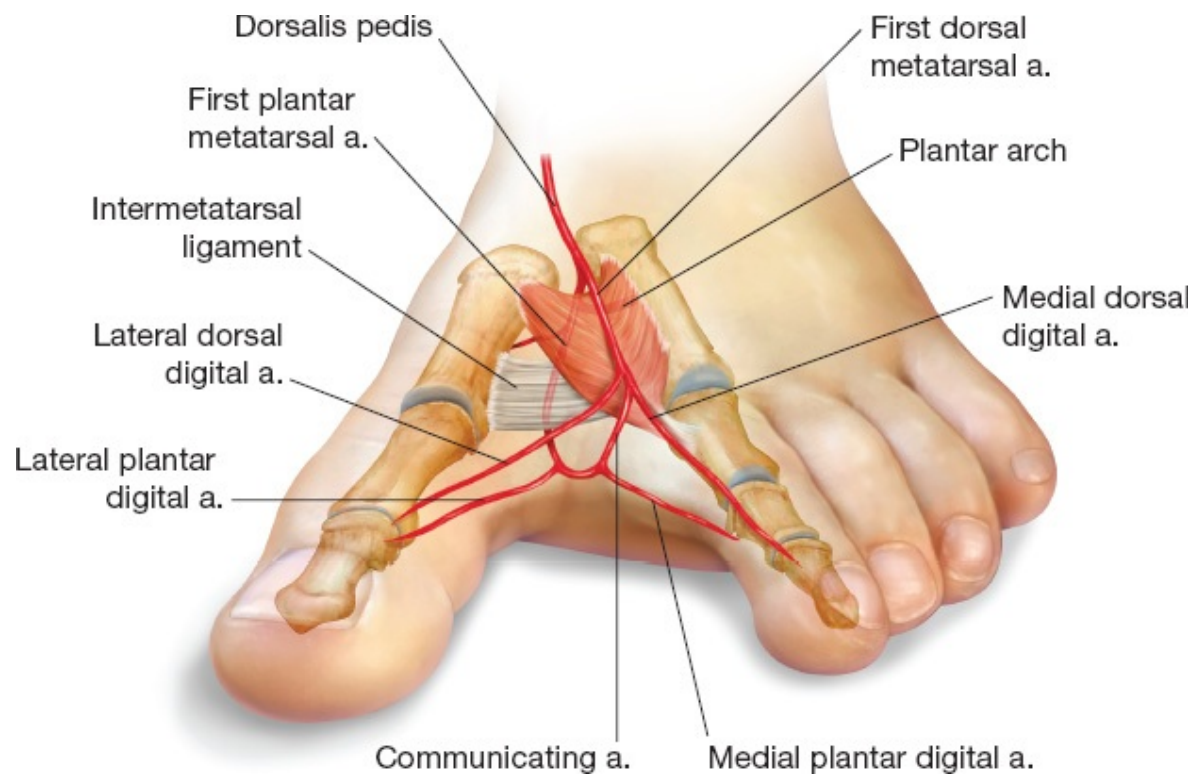


FIG 3 • First web space arterial anatomy.

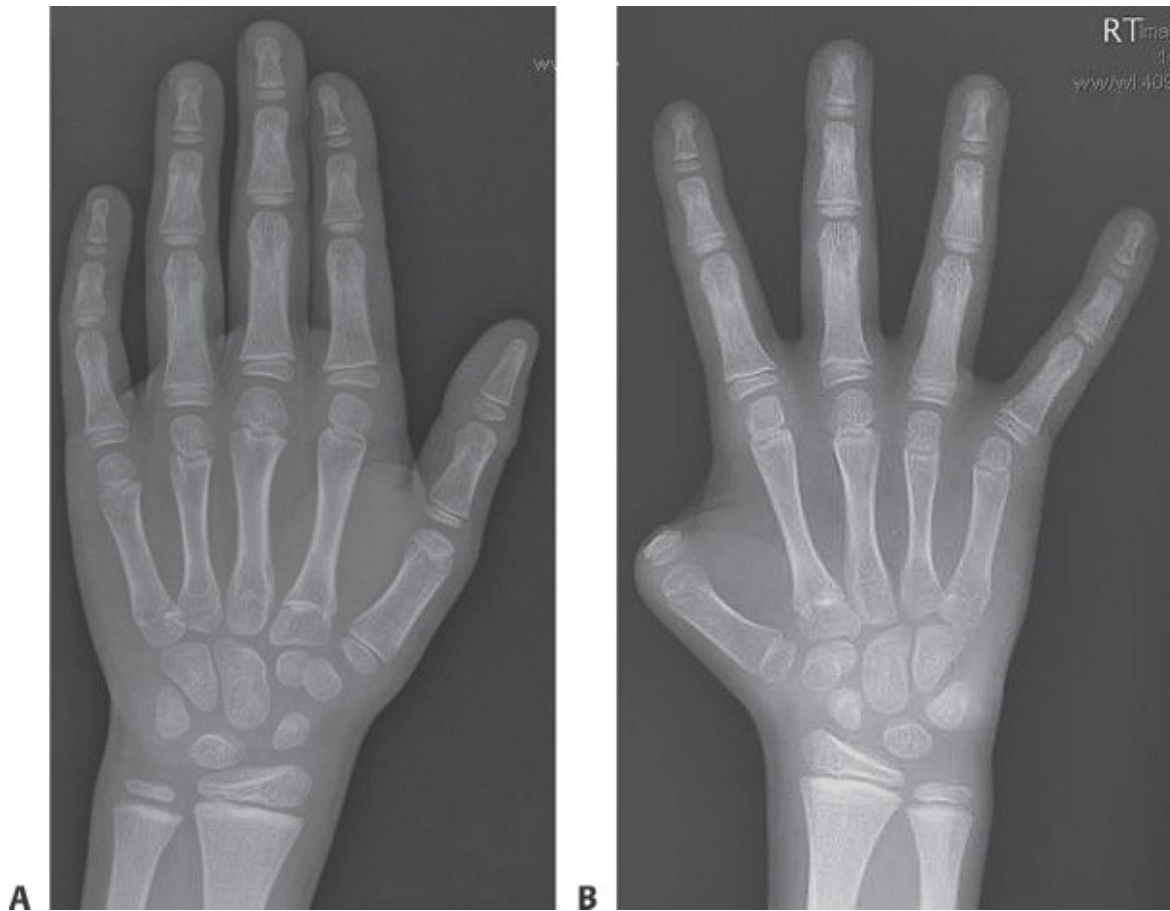


FIG 4 • Preoperative radiograph of recipient hand. Amputation level is at the proximal phalanx base. Contralateral radiographs help estimate defect length.

- Amputations at the distal proximal phalanx or distal phalanx often retain enough length for thumb function. Web space deepening may be performed as needed.
- Amputations through the base of the metacarpal or through the carpometacarpal joint require index finger pollicization to recreate a basilar thumb joint.

Preoperative Planning

- The contralateral toe vascular pedicle is in a better position for radial artery anastomosis at the snuffbox.
- The length of the transferred toe should be based on the length of the contralateral uninjured thumb (see **FIG 4**).
- A two-team approach is preferable to minimize operative time. One team

prepares the recipient site while the other harvests the contralateral toe.

- Good communication between teams is necessary to harvest tendons, nerves, and vessels of adequate length and caliber for primary repair.

Positioning

- Supine
- General anesthesia
- Thigh and arm tourniquets
- The recipient upper extremity and contralateral donor lower extremity are prepped.

Approach

- For second toe transfer as well as great toe transfer, the FDMA is the preferred arterial supply.
- However, one may need to alter the approach and harvest the FPMA if it is dominant (about 20% of cases).

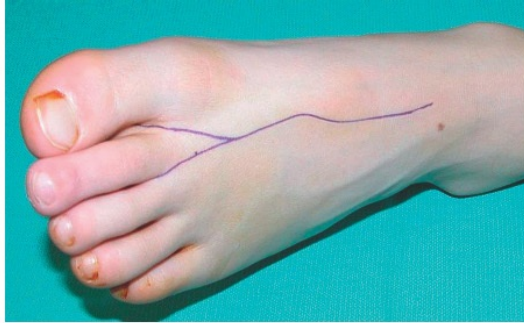
TECHNIQUES

■ Foot Exposure and Second Toe Harvest

- Identify and mark the DPA and FDMA using Doppler ultrasound probe.
- Identify the course of the dorsal forefoot veins to the greater saphenous vein on the dorsomedial foot.
- Design dorsal and plantar curvilinear incisions on the dorsal and plantar foot (**TECH FIG 1A,B**).
 - Avoid incision over the thick plantar skin overlying the weight-bearing first metatarsal head.
- Gravity exsanguinate the limb and inflate the tourniquet.
- Perform an incision over the first web space and identify the vascular pattern of the FDMA using retrograde dissection (**TECH FIG 1C**). Be sure to visualize the proper palmar digital artery to the second toe.
 - A dorsal-dominant system is present in most cases. In this case, continue proximal dissection along the FDMA and DPA after ligating the communicating branch to the proximal FPMA. If necessary, perform

intramuscular dissection through the first dorsal interosseous muscle. If planning an osteotomy of the second metacarpal shaft to restore length of significant metacarpal thumb defects, preserve the vascular connections between the FDMA and second metatarsal. This is performed by preserving the interposed interosseous muscle.

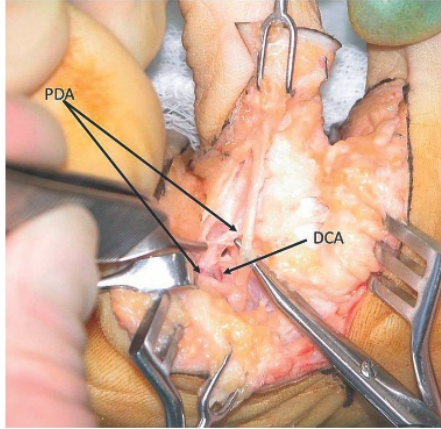
- If the patient has a plantar-dominant system, divide the deep intermetatarsal ligament and dissect the FPMA proximally. We often do dissect out the more inaccessible FPMA in case the dorsal circulation is insufficient to perfuse the toe, which may require anastomosis of the FPMA.
- Extend the dorsal incision proximally and identify the dorsal vein to the second toe, and extensor digitorum longus. The extensor digitorum brevis is divided (**TECH FIG 1D,E**).
- Perform the plantar curvilinear incision and identify the flexor digitorum profundus tendon and both plantar digital nerves (**TECH FIG 1F**).
- Perform the osteotomy at the planned level with a microsagittal saw while protecting identified structures.
- Alternatively, a metatarsophalangeal disarticulation is an option depending on length needs. Detach the collateral ligaments and volar plate from the metatarsal head.



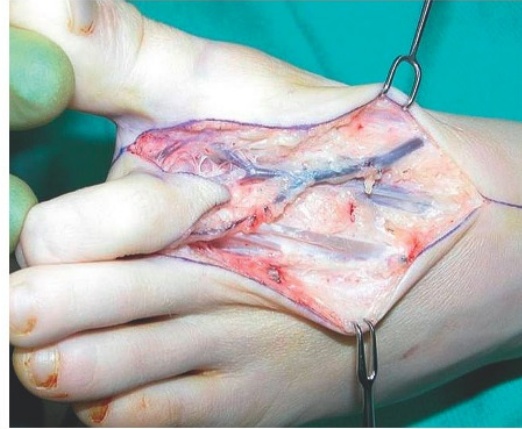
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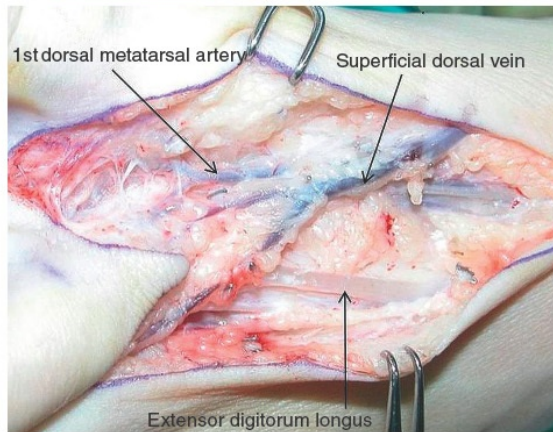
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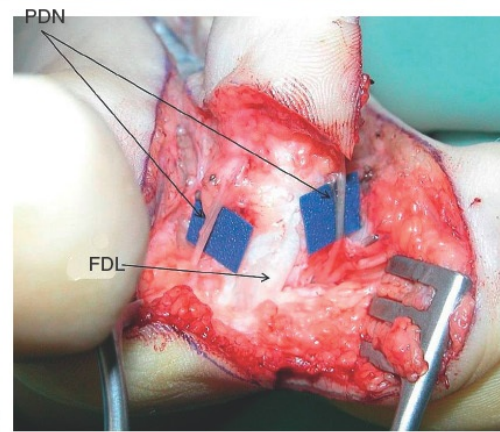
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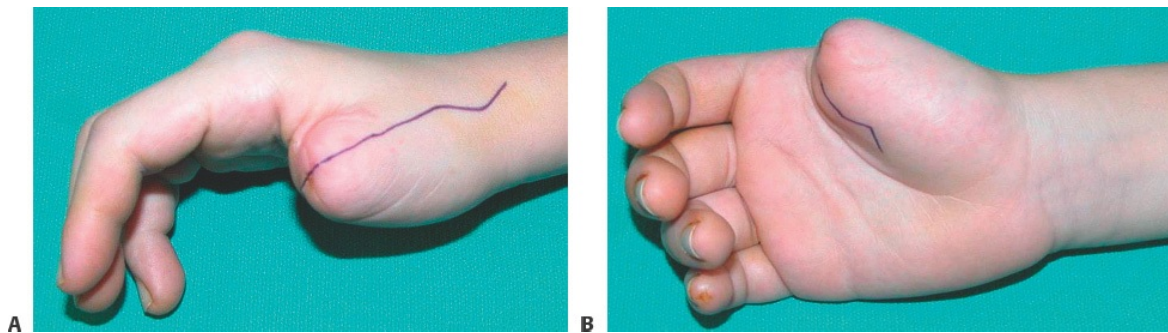


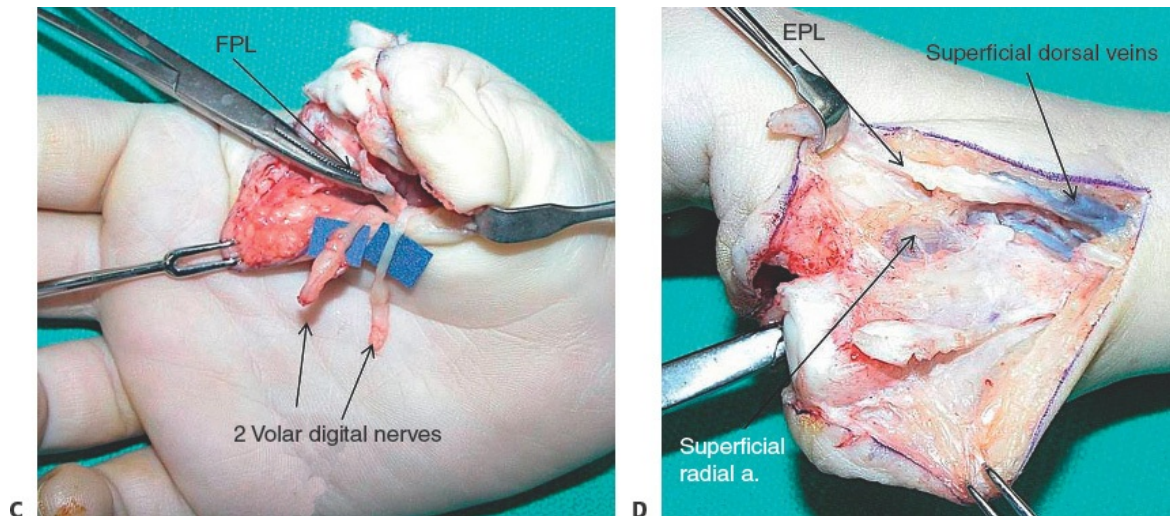
TECH FIG 1 • A,B. Donor foot incisions. Dorsal and plantar curvilinear incisions avoid the weight-bearing plantar first metatarsal head. **C.** First web space dissection. Note the palmar digital arteries (PDA) and the distal communicating artery (DCA) to the FPMA. The forceps is overlying the FDMA. **D,E.** Dorsal exposure of second toe. **F.** Plantar foot dissection. Note the plantar digital nerves (PDN) and flexor digitorum longus (FDL). **G,H.** Completion of second toe harvest. In this case, a metatarsophalangeal disarticulation was performed. Note the metatarsal head (MT) in the wound. **I,J.** Donor foot closure. Note preservation of the longitudinal and transverse arches of the foot.

- Determine the proper length of appropriate structures in the toe. Divide the nerves and tendons, taking care to tag the nerves with fine suture (6-0 Prolene) for easy identification. Leave the vessels intact.
- Deflate the tourniquet and check perfusion of the toe. It may take 5 minutes of warming the toe before adequate perfusion is seen.
- Once adequate perfusion is appreciated and the recipient site is ready, detach the dorsalis pedis artery and dorsal vein (**TECH FIG 1G,H**).
- Use nonabsorbable suture to repair the deep intermetatarsal ligament if transected.
- Obtain hemostasis and then close the wound primarily (**TECH FIG 1I,J**).

■ Recipient Site Preparation

- Create an incision at the thumb amputation stump and extend it proximally with a dorsal zigzag incision toward the anatomical snuffbox (**TECH FIG 2A,B**).
 - If previous soft tissue transfer was performed, elevate the margin of the tissue flap dorsally.
- Identify the radial artery at the snuffbox, cephalic vein, and dorsal branch of superficial radial nerve (**TECH FIG 2C,D**).
- Identify the residual extensor pollicis longus (EPL) tendon and perform a tenolysis to ensure free gliding. If the EPL is not salvageable, transfer the extensor indicis proprius (EIP) tendon.
- Extend the incision on the palmar residual thumb to identify the digital nerves of the thumb and flexor pollicis longus (FPL) tendon. A counterincision may be necessary at the carpal tunnel to retrieve the FPL tendon.
- Debride the residual metacarpal or proximal phalangeal bone of any fibrous scar or articular remnants. Preserve thenar muscle attachments to the metacarpal.





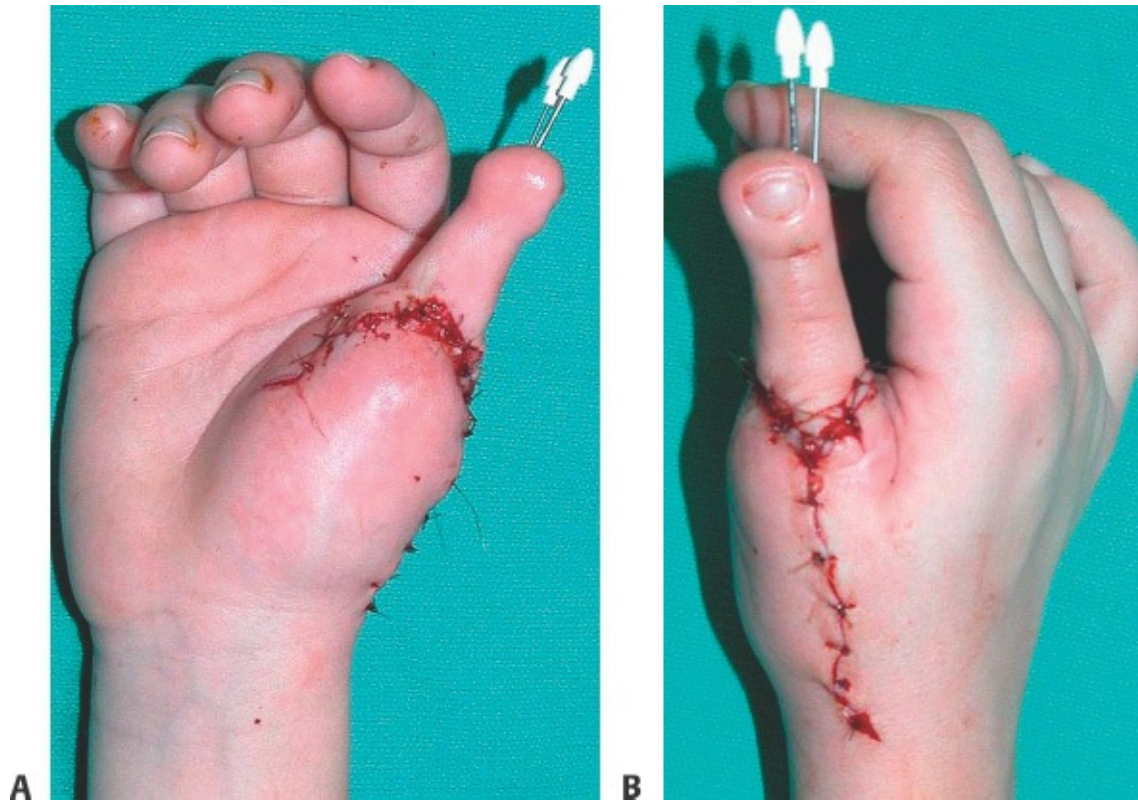
TECH FIG 2 • A,B. Dorsal and palmar thumb incisions. The dorsal incision must extend proximally to the anatomical snuffbox to allow for arterial anastomosis to the radial artery. **C,D.** Recipient site preparation. FPL, flexor pollicis longus; EPL, extensor pollicis longus.

■ Transfer of Second Toe

- Kirschner wire, 90-90 intraosseous wiring, and rigid plate fixation are options for bone fixation.
 - We prefer two longitudinal Kirschner wires for ease of fixation and less soft tissue dissection inherent with plate fixation.
- However, using plate fixation does have the advantage of initiating more aggressive tendon gliding exercises.
- After bone fixation, the flexor digitorum profundus tendon of the toe is transferred to the FPL tendon using four- or six-core strand repair technique.
- The extensor digitorum longus is weaved to the EPL or EIP tendon using Pulvertaft technique. Tension this weave tightly.
- Using microsurgical technique, the radial and ulnar digital arteries are coapted as distally as possible to promote early sensory recovery.
- Repair any branches of the superficial radial nerve to the superficial and deep peroneal nerves dorsally.
- The arterial anastomosis is performed in an end-to-side fashion to the radial

artery at the snuffbox. The venous anastomosis is then performed to a dorsal hand vein, feeding into the cephalic vein.

- The transferred toe is warmed, and perfusion is assessed.
- The wounds are then closed loosely to avoid compression of the dorsal anastomoses (**TECH FIG 3**).



TECH FIG 3 • A,B. Thumb closure.

PEARLS AND PITFALLS

Preoperative evaluation

- Ensure adequate soft tissue coverage and pliability prior to transfer. Otherwise, wound closure will be difficult and cause potential compression of the vascular anastomosis.

FDMA dissection

- Retrograde dissection of the first web space facilitates efficient identification of the variations in FDMA anatomy. Identify the FDMA, the distal communicating artery to the FPMA, and the

	medial and lateral plantar digital arteries to the great and second toe, respectively.
FPMA dominant pedicle harvest	■ If there is only one sizeable vessel that is plantar to the deep intermetatarsal ligament, the toe pedicle should be harvested based on the FPMA through the plantar incision. The dissection is challenging proximal to the metatarsal neck, and for this reason, we avoid more proximal dissection and use an interpositional vein graft to augment our arterial pedicle length.
Claw deformity of the transferred toe	■ The lesser toes tend to form claw deformities at the interphalangeal joint. If this causes a functional problem for the patient in subsequent follow-up, consider interphalangeal joint arthrodesis.

POSTOPERATIVE CARE

- The hand is placed in a well-padded volar forearm-based thumb spica splint with dorsal window and elevated at heart level in a warm room.
- Transferred digit skin color, capillary refill, and Doppler ultrasound checks are performed hourly for the first 48 hours.
- Oral aspirin is administered daily for 2 weeks.
- Prophylactic heparin or low molecular weight heparin anticoagulation per inpatient hospital protocol is performed.
- Patient is kept non-weight bearing to the donor foot for two weeks until sutures are removed.
- At 4 to 6 weeks postoperatively, we remove the Kirschner wires and begin tendon motion protocol.

OUTCOMES

- Toe to hand transfer is a safe procedure, with approximately 95% success rate in experienced centers (**FIG 5**).



FIG 5 • Successful toe transfer at 6-year postoperative visit. **A.** Radiographs demonstrate preservation of metacarpophalangeal joint articulation. **B.** Donor site with mild hypertrophic scar but overall good aesthetic appearance. **C,D.** Clinical photographs of hand.

- Toe transfer patients have superior outcomes in overall hand function, activities of daily living, work performance, aesthetics, and satisfaction compared to patients with thumb MCP level amputations without reconstruction.²
- Average static two-point discrimination is approximately 8 mm at long-term follow-up.³
- Average digit mobility was 33 degrees of flexion with extensor lag of 34.5

degrees at long-term follow-up for second toe to long finger transfer.³

COMPLICATIONS

- Arterial vasospasm is a potential complication and may occur within the first three days postoperatively.
 - If spasm occurs, consider loosening the dorsal sutures, placing the hand in a more dependent position, and use a warming lamp or warming blanket.
 - Papaverine or lidocaine can be injected.
 - Regional nerve block with a continuous flow catheter can be attempted.
 - If there is no improvement, return to the operative room and explore the anastomosis for thrombosis or compressive hematoma.
- If there is development of significant vascular congestion, loosen dorsal sutures and any potentially compressive dressings.
 - Consider venous exploration if there is no clinical improvement.

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Section XI: Dupuytren Disease

57

CHAPTER Dupuytren Contracture

John R. Lien and Kevin C. Chung

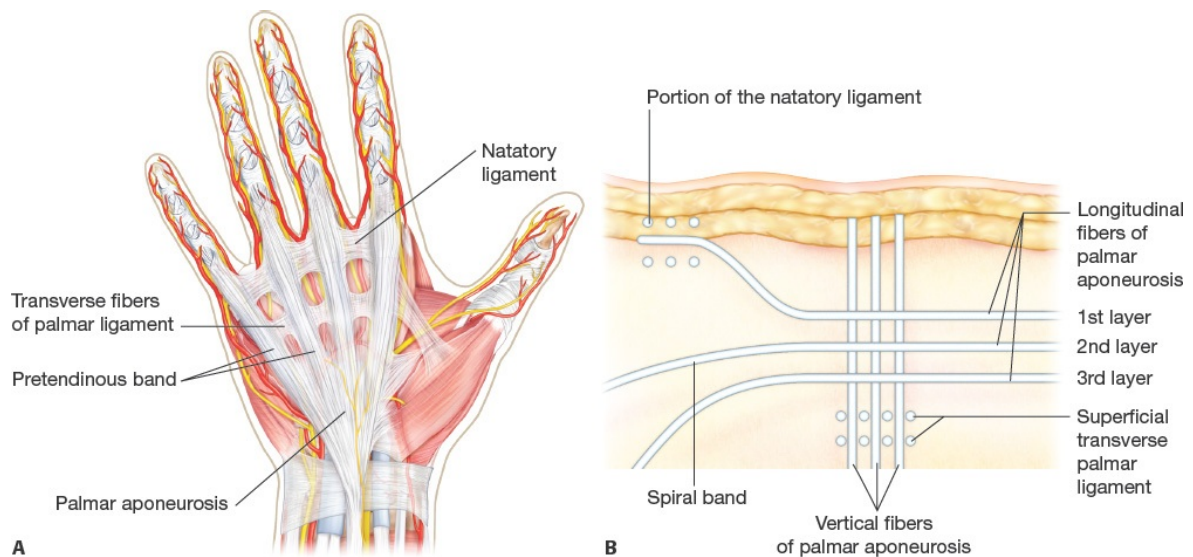
DEFINITION

- Dupuytren disease is a benign fibroproliferative disorder affecting the palmar and digital fascia of the hand.
- Dupuytren disease can result in progressive contracture of the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints.

ANATOMY

- The palmar fascia consists of thenar, hypothenar, and central palmar aponeuroses.
- The palmar aponeurosis (PA) is usually involved with Dupuytren disease.
 - It is triangular with a proximal apex confluent with the palmaris longus tendon.
- The PA is a three-dimensional structure consisting of longitudinal, transverse, and vertical fibers (**FIG 1A**).
 - Longitudinal fibers fan out as pretendinous bands that bifurcate and divide into three layers extending to the distal palm (**FIG 1B**).
 - The first layer inserts into the dermis of the distal palm.
 - The second layer continues toward the digit as the spiral band, which lies deep to the natatory ligament and neurovascular bundle at the level of the palmodigital crease.
 - The third, deepest layer passes vertically toward the flexor tendon sheath.
 - Transverse fibers form the natatory ligament in the distal palm and the superficial transverse palmar ligament more proximally.

- Vertical fibers form the septa of Legueu and Juvara, which lie deep to the palmar fascia (**FIG 1C**). These eight septa form seven fibro-osseous compartments separating the flexor tendons from the lumbricals and neurovascular bundles. Superficial vertical bands of Grapow insert into the dermis of the palmar skin.
- Digital fascia
 - Grayson ligament is palmar to the neurovascular bundle.
 - Cleland ligament is dorsal to the neurovascular bundle.
 - The lateral digital sheet receives contributions from the natatory ligament and spiral band (**FIG 2**).
- PIP joint
 - The proximal attachment of the volar plate tapers into separate radial and ulnar bands, termed the checkrein ligaments (**FIG 3**).
 - The accessory collateral ligament arises from the head of the proximal phalanx and inserts on the volar plate.
 - The accessory collateral ligaments become lax in flexion and taut in extension.



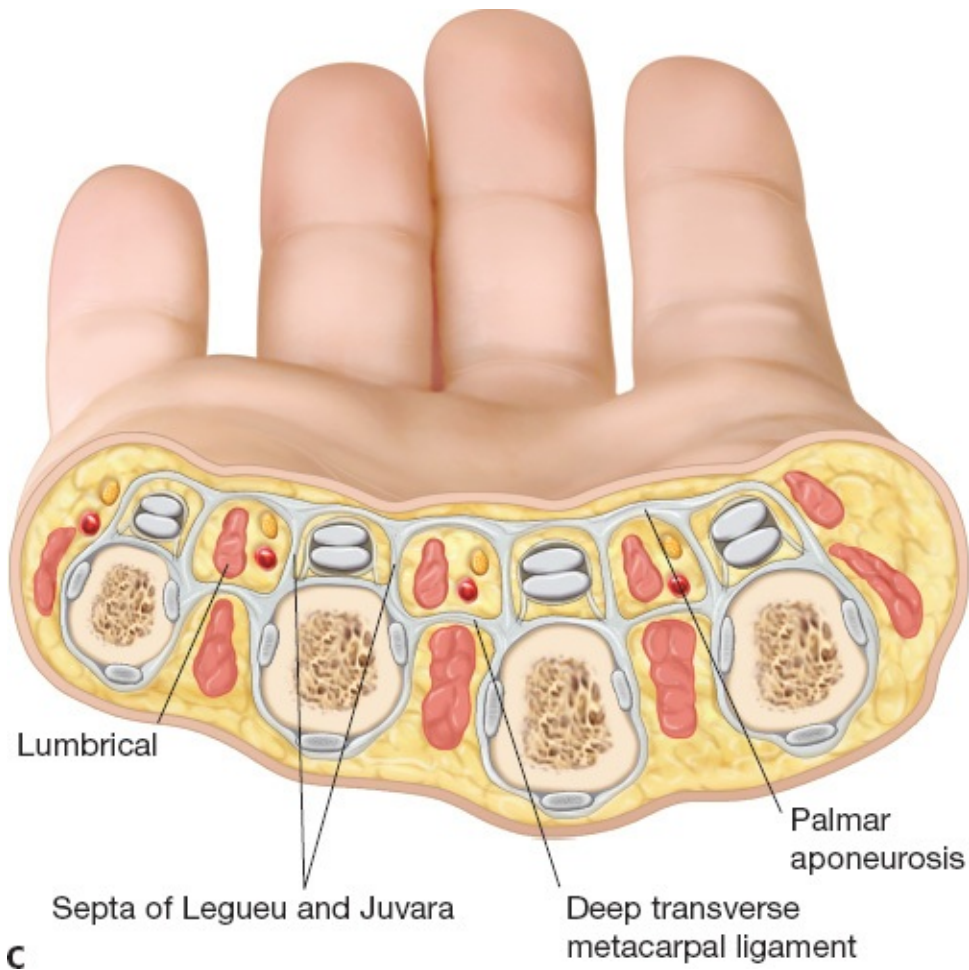


FIG 1 • A. Anatomy of the palmar aponeurosis. **B.** Sagittal anatomy of the palmar aponeurosis. **C.** Septa of Legueu and Juvara are formed from the vertical deep extensions of the palmar aponeurosis.

PATHOGENESIS

- Nodules are often the first sign of Dupuytren disease. They are found superficially in the palm or finger, adherent to the dermis and underlying fascia.
- Normal fascial bands become pathologic cords.
- The pretendinous cord develops from the pretendinous band.
 - Cords are pathologic structures, whereas bands are normal structures.
 - Isolated pretendinous cords can result in MCP joint contracture.
- The spiral cord is composed of pathologic pretendinous band, spiral band,

lateral digital sheet, and Grayson ligament.

- The spiral course of this cord around the neurovascular bundle causes proximal, superficial, and central displacement of the bundle as it contracts (**FIG 4**).
- Spiral cords can cause MCP and PIP joint contracture.

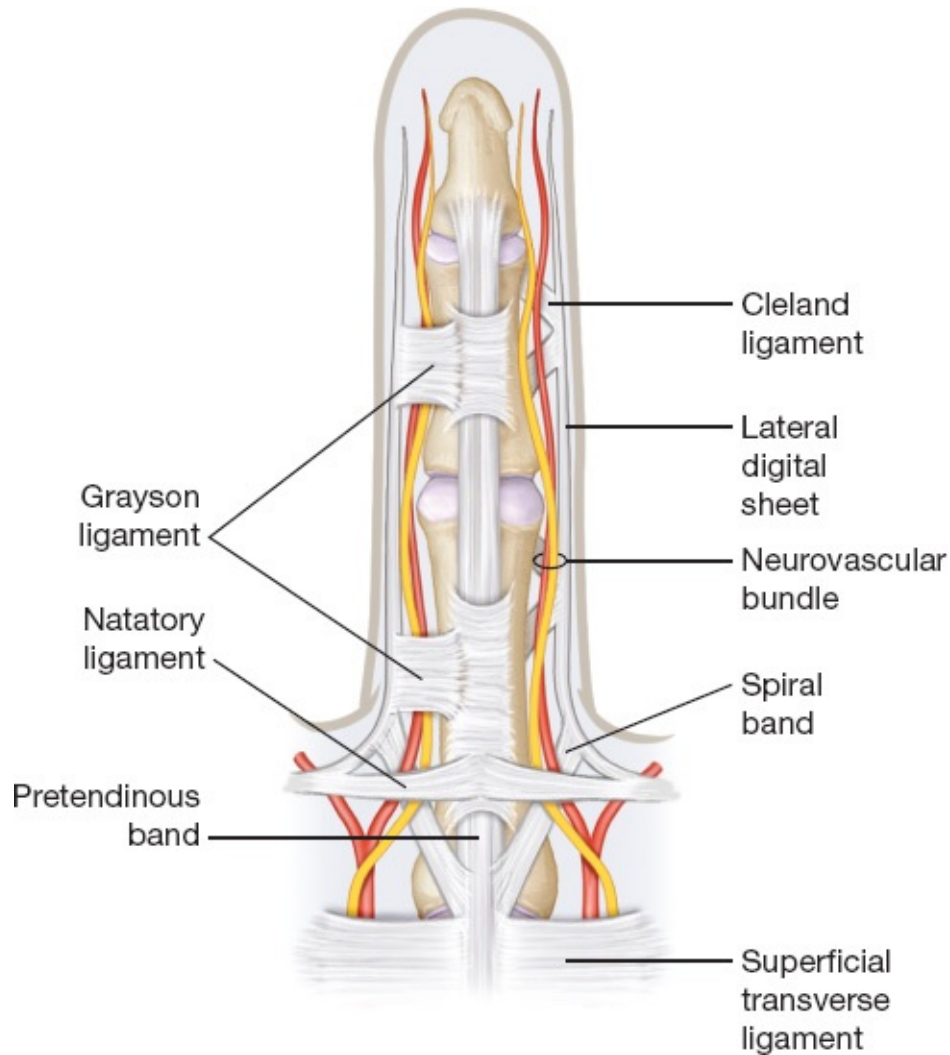


FIG 2 • Digital fascia. Note the contributions of the natatory ligament and spiral band to the lateral digital sheet.

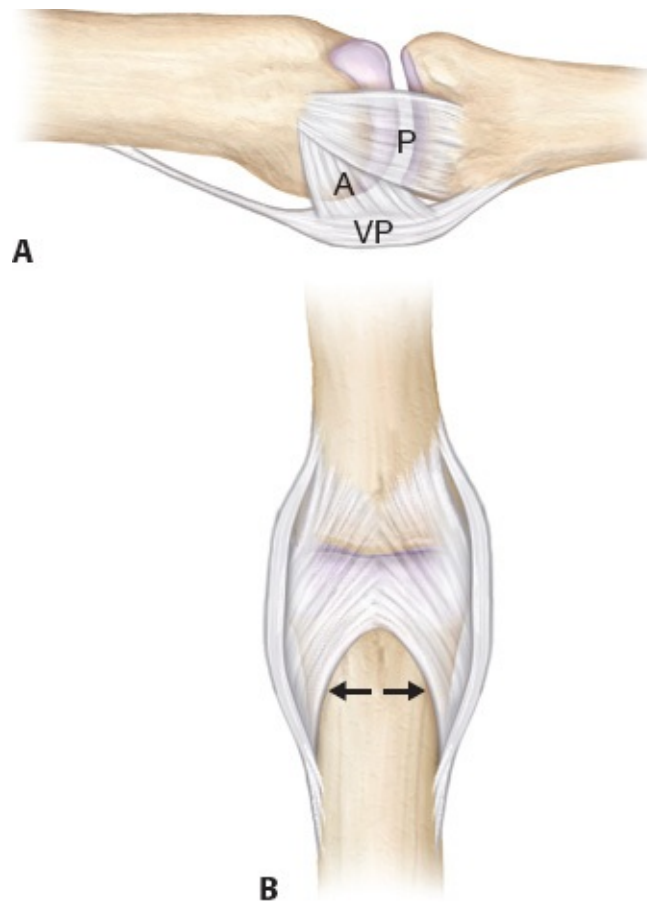


FIG 3 • Lateral (**A**) and volar (**B**) representations of the soft tissue support at the PIP joint. *Arrows* indicate the radial and ulnar checkrein ligaments. A, accessory collateral ligament; P, proper collateral ligament; VP, volar plate.

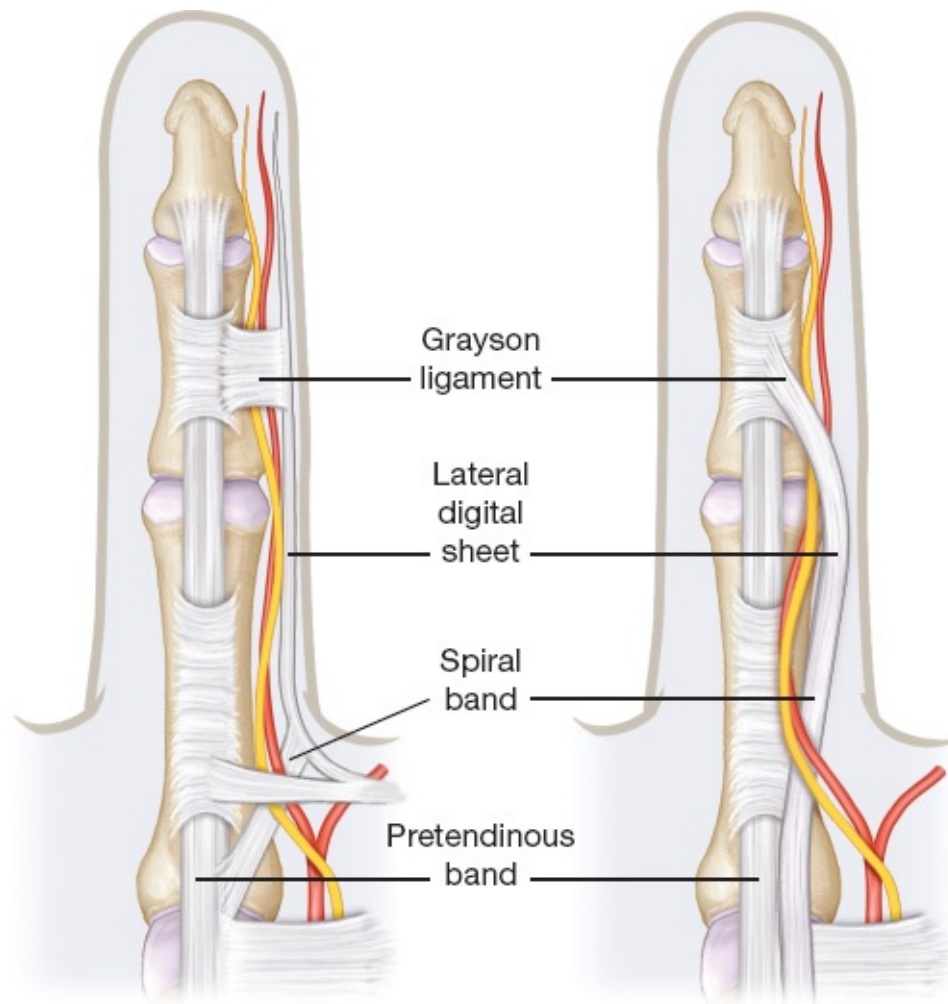


FIG 4 • In contrast to normal spiral cord anatomy (*left*), pathologic spiral cord anatomy (*right*) can displace the neurovascular bundle.

- The natatory cord can cause web space contracture.
- The central cord is a distal extension of the pretendinous cord in the palm but does not cause neurovascular bundle displacement.
- The lateral cord is diseased lateral digital sheet and can cause PIP joint contracture.
- The abductor digiti minimi cord runs from the abductor digiti minimi fascia to the base of the middle phalanx and can displace the neurovascular bundle toward the midline.
- The retrovascular cord causes flexion contracture of the distal interphalangeal joint.

NATURAL HISTORY

- Early presentation of Dupuytren disease causes isolated nodules and skin pitting.
- With progression of disease, pathologic cords will form.
- As cords contract, the MCP and PIP joints may be drawn into flexion.
- Fixed PIP joint contractures may develop over time.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with Dupuytren disease are commonly older men with northern European ancestry but can present in all ethnic groups and both genders.
- Dupuytren diathesis describes a predisposition toward aggressive disease and increased recurrence after surgical treatment. Five factors¹:
 - Male gender
 - Age of onset younger than 50 years
 - Family history with one or more affected siblings/parents
 - Ectopic lesions in the dorsal hand (Garrod pads)
 - Bilateral disease
- Palpate for thick, diffuse disease in the palm and finger, compared to discrete well-defined cords.
- Document the degree of MCP and PIP joint contracture.
 - If the cord spans the MCP and PIP joints, assess for fixed PIP contracture by testing passive PIP extension with the MP joint in maximal flexion.
- Examine for web space contracture.
- Carefully document the sensory examination, particularly if the patient has had previous surgery.

IMAGING

- Radiographs are obtained if there is a significant PIP joint flexion contracture.
 - Assess for articular congruency or arthritic change.

NONOPERATIVE MANAGEMENT

- Observation is appropriate for mild disease without compromise of function and minimal contracture.
- Percutaneous needle aponeurotomy (PNA) is mechanical division of a Dupuytren cord with the bevel of a hypodermic needle.
- Collagenase *Clostridium histolyticum* (CCH; Xiaflex, Auxilium

Pharmaceuticals, Inc., Malvern, PA) is an enzyme used for nonsurgical chemical division of Dupuytren cords. CCH therapy received Food and Drug Administration approval in 2010.²

- Consider CCH and PNA as a minimally invasive option for patients with discrete cords who meet indications for surgery. Patients may:
 - Wish to avoid the recovery associated with surgery
 - Have significant medical comorbidities precluding surgery
- We offer these minimally invasive options to patients with discrete palpable cords.

SURGICAL MANAGEMENT

- Limited fasciectomy excises diseased palmar and digital fascia. This is the most widely used surgical technique for Dupuytren contracture.
 - We prefer limited fasciectomy for patients with diffuse disease and severe PIP joint contractures or those who have failed PNA and/or CCH therapy.
- Indications for limited fasciectomy include the following:
 - Palpable disease with flexion contracture of the MCP joint greater than 30 degrees
 - Palpable disease with flexion contracture of the PIP joint greater than 15 degrees
- The “surgical techniques” discussed in this chapter include minimally invasive techniques discussed in nonoperative management (CCH and PNA).

Preoperative Planning

- Long-standing PIP joint contractures may persist after cord division or excision.
 - Consider PIP joint capsulotomy and checkrein release if residual contracture is present.
 - Review hand radiographs if the patient has significant contractures of the PIP joint. Consider arthrodesis in the setting of severe contracture or articular degeneration.

Positioning

- PNA
 - This procedure can be performed in an office procedure room or in the operating room.
 - Explain the procedure to the patient so that he/she will be prepared to

participate.

- Supine positioning with a hand table or padded Mayo stand.
- CCH
 - The patient is positioned sitting upright with the affected hand on the examination table.
 - Alternatively, position the patient supine with the hand on a Mayo stand.
- Limited fasciectomy
 - Upper arm tourniquet
 - Regional or general anesthesia
 - Supine positioning with a hand table

Approach

- PNA
 - The importance of reporting paresthesias or numbness to the fingertips is reviewed with the patient. Establish a baseline “normal sensation” to light touch of the radial and ulnar finger pulp.
 - Have the patient demonstrate short arc motion of the PIP and DIP joints; this will be useful to rule out intratendinous needle placement.
 - Cords are approached from distal to proximal for nerve monitoring.
 - Anesthetic is injected intradermally to avoid digital nerve anesthesia.
- CCH
 - Initial on-label use involved the injection of one cord at a time, and finger extension manipulation was recommended post injection day one. Recent studies broadened this approach.
 - Coleman et al.³ concluded that two affected joint contractures can be effectively and safely treated with concurrent injections. The incidence of multiple adverse events was higher, but the incidence of severe adverse events was not greater than single cord injection.
 - Compared to 1-day postinjection manipulation, 7-day postinjection manipulation had no significant differences in correction, pain, or skin tears.⁴ This suggests manipulation can be scheduled within the first 7 days after injection.
- Limited fasciectomy
 - Surgical incisions are variable and depend on the location of the cord (**FIG 5**).
 - Hand: For extensive palmar disease, make a transverse incision at the distal

palmar crease.



FIG 5 • Skin incisions for palmar fasciectomy.

- If there is significant MCP contracture, the distal palmar crease is left open to heal by secondary intention.
- Consider PIP joint volar capsulotomy if there is residual joint contracture after fasciectomy.

TECHNIQUES

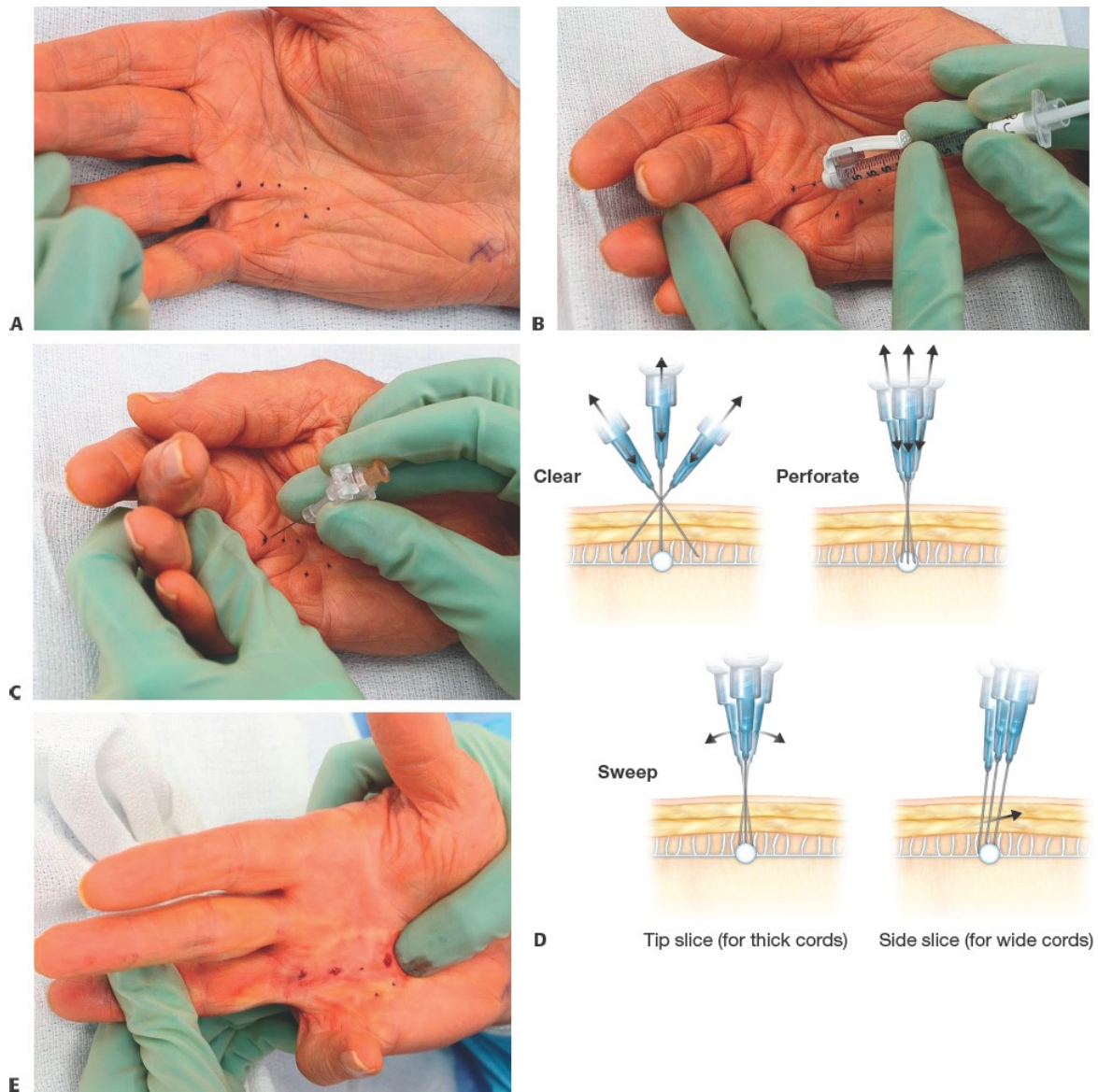
■ Percutaneous Needle Aponeurotomy

- Prepare the hand with antiseptic solution.
- Plan and mark fasciotomy portals in areas with supple skin overlying a discrete linear cord (**TECH FIG 1A**). The cord should change from soft to

firm with joint extension.

- Portals are placed directly over the cord or along each side of the cord if it is broad.
- Space portals out at least 5 mm.
- Avoid portals over nodules.
- Avoid portals in skin creases because of:
 - Risk of skin tears
 - Proximity to flexor tendons
- Use a small probe to evaluate portals near skin dimples. To avoid entering a pit, avoid making the portal too close to the dimple sinus.
- Use a 30-gauge needle and inject 0.05 to 0.10 mL of anesthetic at the most distal portal site (**TECH FIG 1B**).
 - Penetrate into the dermis and then inject as the needle is withdrawn.
 - Do not inject subcutaneously.
- Place a 5/8-in. 25-gauge needle into the portal, with the needle bevel perpendicular to the cord fibers (**TECH FIG 1C**).
 - Nerve assessment: Ask the patient if he or she feels pain, paresthesia, or electric shocks along the finger. Reassess sensation to light touch along the side of the digit.
 - Tendon assessment: Have the patient slightly flex and extend the PIP and DIP joints. The needle should be withdrawn more superficial if there is needle bowing with flexor tendon excursion.
 - Repeatedly check nerve and tendon proximity to ensure the safety of the current portal.⁵
 - If the fingertip is numb, remove needle from current portal and move to a proximal portal.
 - If it is not, and the finger AROM does not catch the needle, continue with the current portal.
 - However, if the fingertip is not numb and the finger AROM *does* catch the needle, remove needle from current portal and move to a proximal portal.
- Hold tension on the cord by pulling adjacent skin or nodules.
 - Tension allows the needle to cut and moves the cord away from underlying structures.
- The cutting edge of the needle is used as a scalpel to divide the cord fibers deep to the dermis. Three maneuvers are performed (**TECH FIG 1D**)⁵:

- Clear: Use a side-to-side motion to clear a plane between the dermis and cord.
- Perforate.
 - Orient the needle vertically with the bevel transverse, and perforate the needle through the cord.
 - Pull the needle back superficial to the cord but still deep to dermis.
 - Using this up-and-down motion, move the needle radially and ulnarly to make multiple perforations at the level of the portal along the width of the cord.
 - Tactile feedback is important during this procedure, as one should feel a crackly or grating sensation as the bevel cuts the fascia.



TECH FIG 1 • Percutaneous needle aponeurotomy. **A.** Cords and portals. **B.** Start distally with portal anesthetic injection. **C.** Insertion of 25-gauge needle with bevel perpendicular to cord. Left thumb is used to hold tension on the cord without extending the digit. **D.** Needle maneuvers. **E.** Ring finger manipulation to rupture cord.

■ Sweep

- Once the cord is defined and perforated, use the needle bevel to

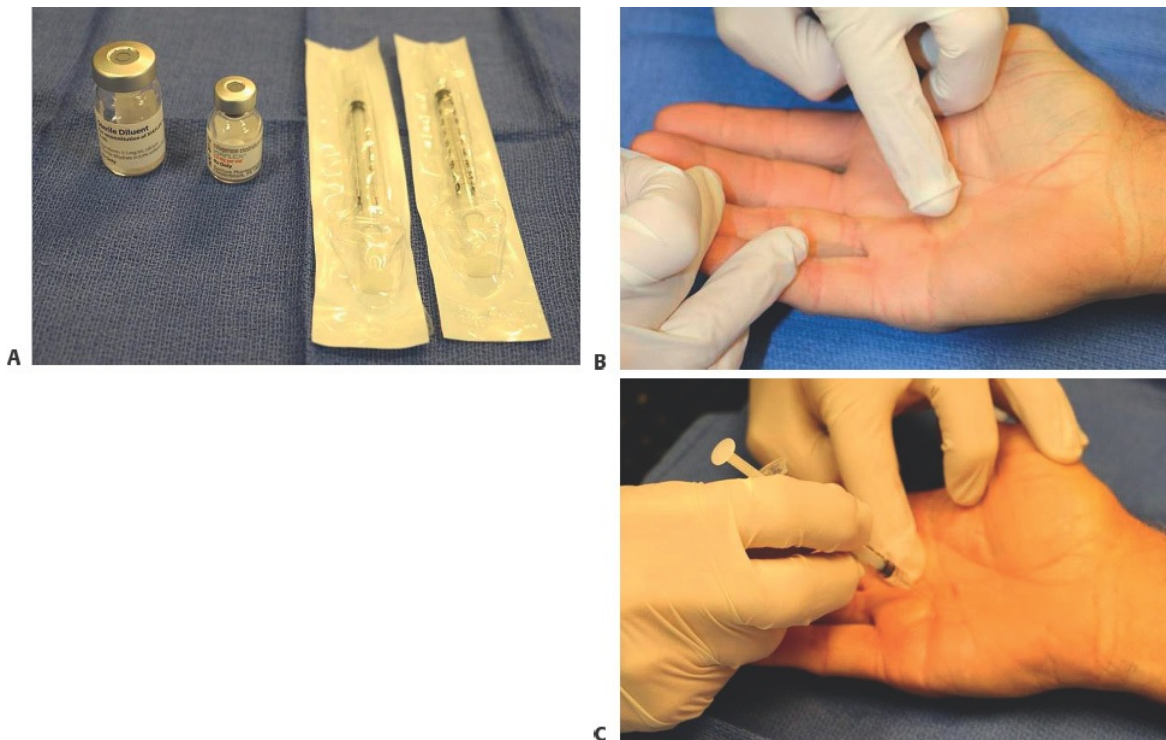
- transversely sweep across the width of the cord, from superficial to deep.
- Tactile feedback should include a scraping sensation with the needle.
 - Avoid being overaggressive to avoid neurovascular or tendon injury deep to the cord.
 - Rupture can be achieved without complete needle transection of the cord.
- If the patient reports shooting or electric pain along the finger at any time, reposition the needle to avoid nerve injury.
 - Move from distal to proximal portals and repeat the anesthetic injection and needle process.
 - Passively stretch after each portal release to attempt to rupture the cord (**TECH FIG 1D**).
 - If a portal looks concerning for skin tear, avoid manipulation until more proximal portals are established.
 - When the cord ruptures, an audible “pop” may be heard.
 - Reassess for residual flexion contracture.
 - If there is still palpable cord proximally, reassess for more portal placement and further fasciotomy.
 - Remember to monitor the nerve and tendon.
 - Once the procedure is complete, apply a Band-Aid on the portal sites. If a skin tear occurs, apply a soft bandage.
-

■ Collagenase Therapy⁶

- Before use, allow the vial containing the powder form of collagenase and the vial containing the diluent for reconstitution to stand at room temperature for 15 to 60 minutes. Remove the flip-off caps and clean the surface of the vials with alcohol (**TECH FIG 2A**).
- Using a 1-mL syringe with a 27-gauge 0.5-in. needle, withdraw the appropriate volume of diluent from the diluent vial (see package insert):
 - 0.39 mL for cords affecting the MCP joint
 - 0.31 mL for cords affecting the PIP joint
- Inject the diluent slowly into the sides of the vial containing the powder form of Xiaflex.
- Slowly swirl the vial to ensure the powder is in solution. The reconstituted solution should be clear.

- Using a new 1-mL syringe with a 27-gauge 0.5-in. needle, withdraw the appropriate volume of reconstituted solution (containing 0.58 mg of Xiaflex):
 - 0.25 mL for cords affecting the MCP joint
 - 0.20 mL for cords affecting the PIP joint
- Do not inject local anesthetic as the tumescence may interfere with proper placement of the Xiaflex injection.
- Confirm the cord to be injected. The ideal site should be where the cord is maximally separated from the underlying flexor tendon and where the skin is not intimately adhered to the cord (**TECH FIG 2B**).
- Clean the injection site with an antiseptic.
- With the nondominant hand, secure the patient's hand and apply tension to the cord.
- With the dominant hand, place the needle into the cord, taking care to keep the needle within the cord.
 - If there is concern that the needle is in the flexor tendon, passively move the distal interphalangeal joint to assess for tension on the needle.
 - Reposition the needle as necessary.
- Once you are satisfied with needle placement, inject one-third of the dose into the cord (**TECH FIG 2C**).
- Next, withdraw the needle and reposition it slightly more distally in the cord (2–3 mm) and inject another one-third of the dose.
- Finally, withdraw the needle and position it in the cord proximal to the initial site of injection (2–3 mm) and inject the remaining dose into the cord.
- When administering two concurrent injections, use separate vials and syringes for each cord.
 - For multiple digit injections, begin with the more ulnar digit.
 - For multiple cords in one digit, begin injections in the proximal cord and move to the more distal cord (move from the MCP joint to the PIP joint).
- Place the treated hand in a soft bulky dressing.
- Patient should follow up 1 to 7 days post injection.
- Assess the cord for autorupture.
- Assess the involved joint range of motion.
- Apply local anesthetic to the area of manipulation.
- For MCP joint cords, apply extension force to the MCP joint while the wrist is held in a flexed position.

- For PIP joint cords, perform the finger extension maneuver with the MCP joint in a flexed position.
- Hold moderate extension pressure for 10 to 20 seconds.
- If the cord is not disrupted, second and third manipulation attempts are performed at 5- to 10-minute intervals.
- If the cord does not disrupt after three attempts, additional collagenase injections and manipulation are performed after 4 weeks.



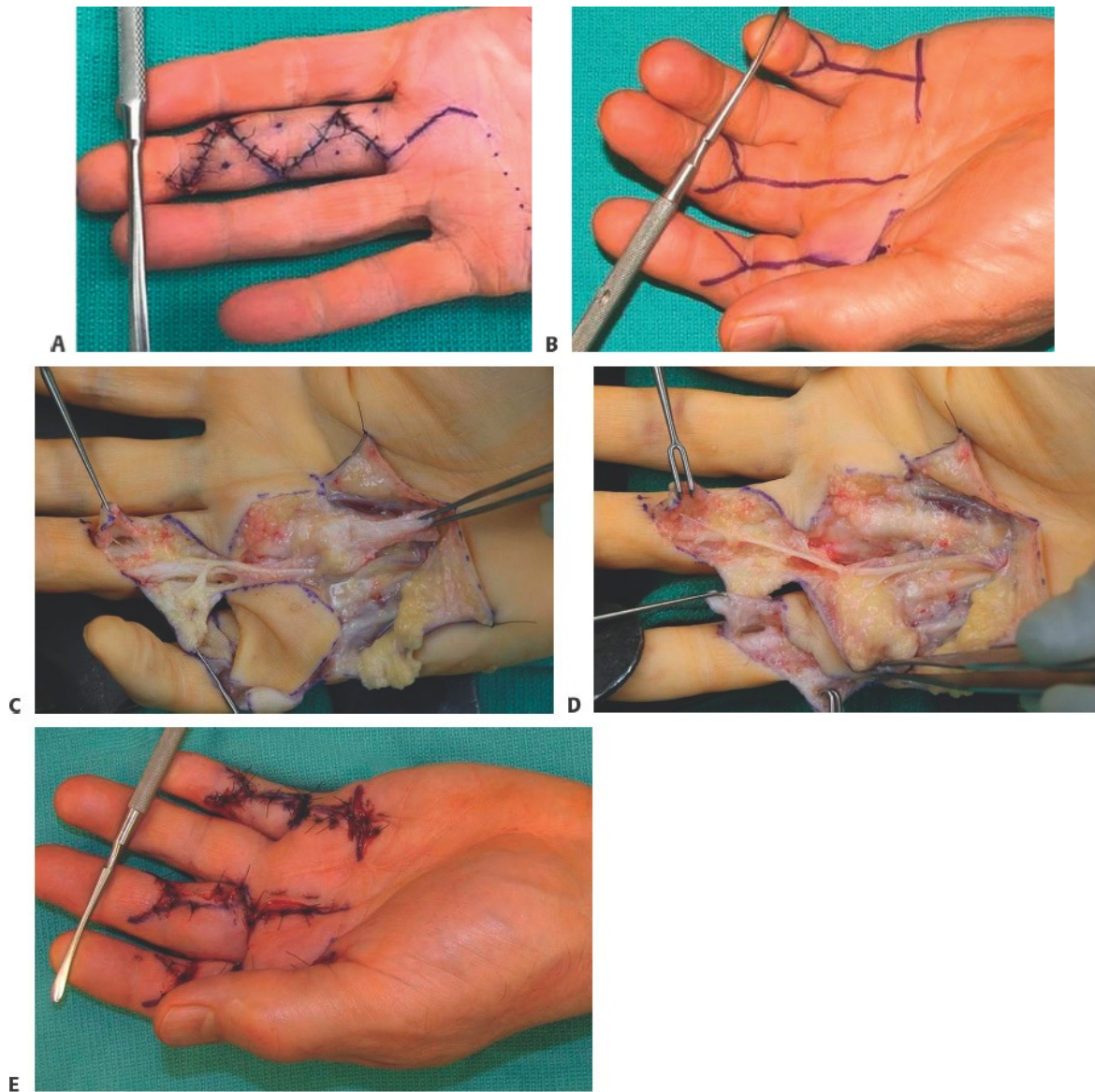
TECH FIG 2 • Collagenase therapy. **A.** Powder, diluent, and needles for reconstitution and injection. **B.** Palpation of a pretendinous ring finger cord. **C.** Collagenase injection. Note multiple sites of injection along the cord.

■ Limited Fasciectomy

- If there is widespread disease in the palm, make a transverse incision in the distal palmar crease to allow access (see **FIG 5**).
- Make an oblique longitudinal incision proximally toward the apex of the

palmar aponeurosis.

- Make an incision from the distal palmar crease to the palmodigital crease.
 - This incision can be extended distally in the digit if there is digital involvement.
- If there is digital extension of disease, we prefer to extend the incision using modified Bruner incisions or a longitudinal midline incision with V-shaped extension (**TECH FIG 3A,B**).
- Raise skin flaps off the diseased fascia, taking care not to buttonhole through the dermis.
- Identify the neurovascular bundles proximally.
- Release the pretendinous cord proximally (**TECH FIG 3C**).
 - The MCP joint should extend, allowing better access and visualization distally.
- In the digit, raise full-thickness skin flaps and identify the neurovascular bundle proximally.
- Carefully dissect the neurovascular bundle from the cord from proximal to distal.
 - If the pretendinous cord extends into a spiral cord, the neurovascular bundle will be displaced proximal, toward the midline of the ray, and superficial. The cord will spiral deep and from central to lateral to the neurovascular bundle as it extends into the lateral digital sheet (**TECH FIG 3C**; see **FIG 4**).
- Once the neurovascular structures are identified and protected along the involved cord (**TECH FIG 3D**), separate and excise the diseased cord from the surrounding tissue.
- Reassess for residual joint contracture.
 - If there is a persistent PIP joint contracture after fasciectomy, consider volar capsulotomy.
- After fasciectomy and any other concurrent procedures, release the tourniquet.
 - Hemostasis is critical to prevent hematoma formation.
- If a longitudinal incision is made, make a Z-plasty at the flexion creases to prevent scar contracture (**TECH FIG 3E**).



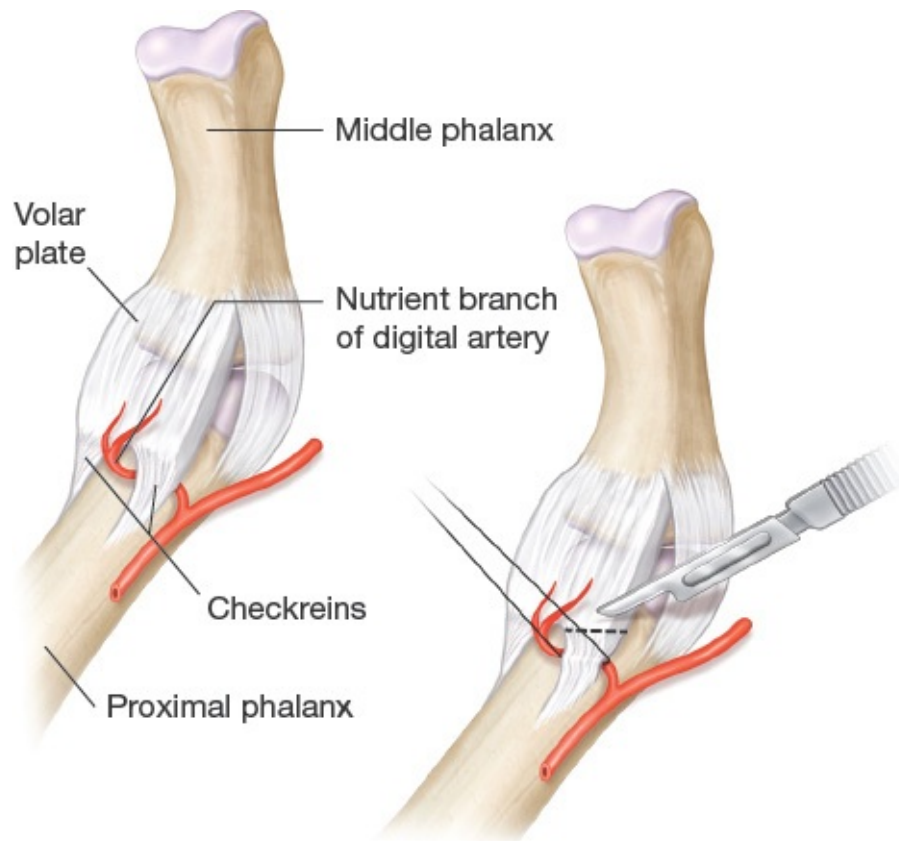
TECH FIG 3 • Limited fasciectomy. Preferred digital incisions: modified Bruner incision **(A)** and longitudinal incision with V-Y advancement distally **(B)**. **C**. Release of pretendinous cord proximally. Note course of ulnar spiral cord (*blue*, dorsal to nerve) and digital nerve (*yellow*, superficial). **D**. After excision of spiral cord. **E**. Closure of incision after Z-plasty across flexion creases.

■ Close the skin loosely.

- Leave the transverse palm incision open to heal with secondary intention if there is significant tension with MCP joint extension.
 - The open palm technique will also decrease the risk of hematoma formation.
 - Apply a volar forearm-based extension splint.
 - If digital perfusion is compromised in full extension, allow the digit to remain slightly flexed. This can occur after correction of severe contractures.
-

■ PIP Joint Volar Capsulotomy

- If there is persistent PIP joint flexion contracture after fasciectomy, consider volar plate release.
- Identify and release the A3 pulley.
- Retract the flexor tendons with a Ragnell retractor.
- Identify the proximal volar plate, and release the checkrein ligaments (**TECH FIG 4**).
- If necessary, release the accessory collateral ligaments, which course from the condyle to the lateral edge of the volar plate.
- Gentle passive extension of the PIP joint should be achieved after sufficient release.
 - Reassess the vascularity of the digit with the joint fully extended. Splint in as much flexion as necessary to preserve perfusion to the digit.



TECH FIG 4 • Checkrein ligament release.

PEARLS AND PITFALLS

Indications

- Consider PNA or CCH in patients with discrete cords who will accept a higher recurrence rate in order to avoid surgery.
- Diffuse, matted disease without a defined cord is better suited for surgical fasciectomy.

PNA portal placement

- Avoid portals over flexion creases, nodules, and matted skin.

PNA nerve monitoring

- Use anesthetic sparingly to avoid nerve blockade. A sensate nerve with a cooperative patient will help avoid digital nerve injury.

PNA technique

- Do not pull on the fingertips to gain tension on the cord. This will place the flexor tendons under tension, increasing risk of

	tendon injury during needling. ■ Replace needles regularly, as a dull bevel impairs tactile feedback and will not cut cord fibers.
CCH injection technique	■ Avoid injection into the flexor tendon; injection should be superficial within the involved cord. ■ Slight resistance to injection is normal.
PNA and CCH finger extension technique	■ Isolate and extend each involved joint individually to minimize risk of skin tears. ■ Hold other joints in a flexed position to minimize skin tension.
Limited fasciectomy	■ Neurovascular bundles can be displaced to the midline by spiral cords. ■ Take care to dissect the nerve from proximal to distal prior to excision of diseased tissue. ■ Meticulous hemostasis and loose wound closure (or open palm technique) minimizes hematoma formation. ■ Hematoma formation can cause painful swelling and skin flap ischemia.

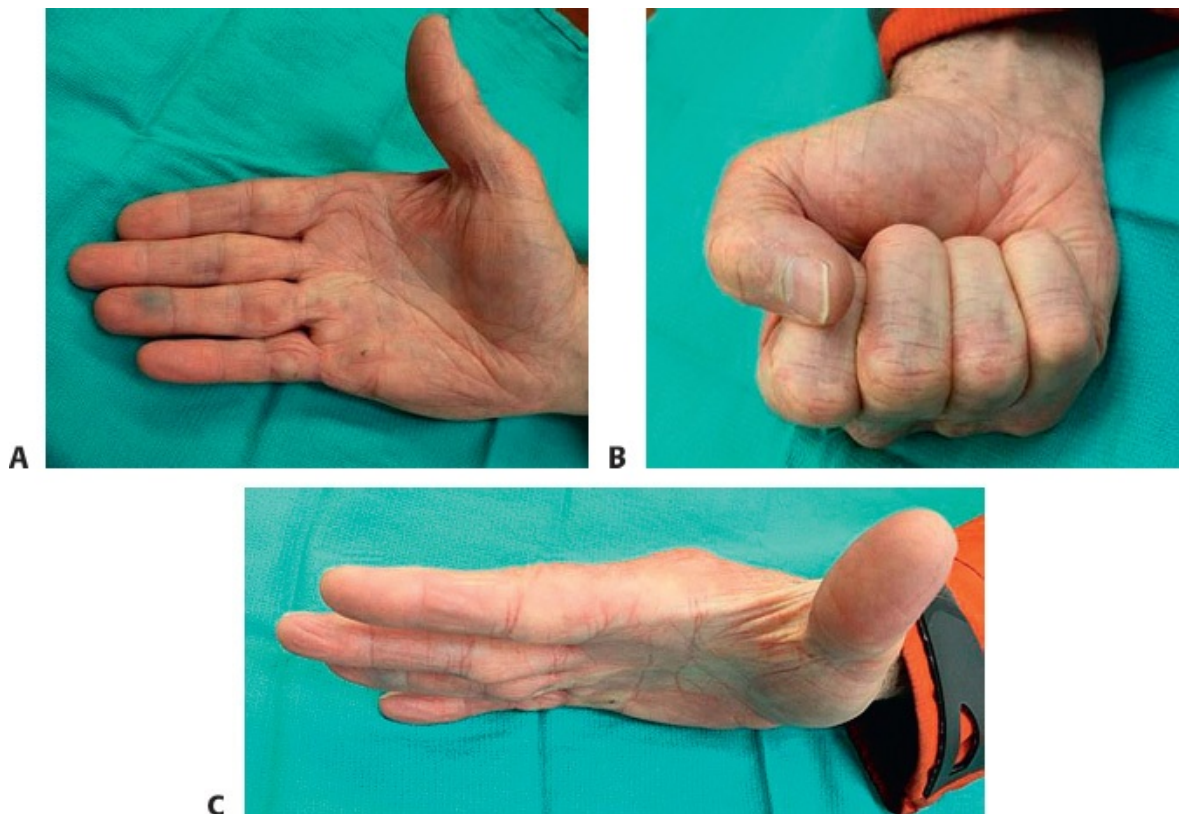


FIG 6 • A–C. Two-week postoperative visit after

percutaneous needle aponeurotomy of ring and small fingers, showing full active range of motion.

POSTOPERATIVE CARE

- PNA and CCH
 - Immediate active digital flexion and extension is encouraged (**FIG 6**).
 - No formal therapy is prescribed.
 - Skin tears are managed with local wound care.
 - Patients perform activities as tolerated.
- Limited fasciectomy
 - Remove the splint one week postoperatively.
 - Begin range of motion exercises.
 - For open palm wounds, local wound care with nonadherent gauze is initiated after splint removal.
 - For contractures involving the PIP joint, night extension splints are worn for 6 months postoperatively.

OUTCOMES

- PNA has a high rate of immediate contracture correction (less than 5-degree residual contracture).⁷
 - 98% success of MCP joint correction
 - 67% success of PIP joint correction
- PNA contracture recurrence rate is higher and occurs sooner compared to open fasciectomy.⁸
- With CCH, the overall rate of clinical success (residual contracture 0–5 degrees) ranges from 44% to 64%.^{2,9,10}
 - Higher success is reported for treatment of MCP contractures (65%–77%) compared to PIP contractures (28%–40%).
- CCH disease recurrence (20 degree or greater increase of joint contracture in the presence of a palpable cord) after 5 years is reported at 39% for MCP joints and 66% for PIP joints.¹¹
 - 16% of recurrent contractures underwent additional procedures, most commonly fasciectomy or repeated CCH therapy.
- 94% of MCP and 47% of PIP joints achieved clinical success with limited fasciectomy, with deformity correction to within 0 to 5 degrees of full extension.⁸

- 6 months postoperatively after limited fasciectomy, 73% of patients are satisfied with their hand function.¹²
- Volar capsulotomy is controversial, as combined volar capsulotomy and fasciectomy does not have better results than fasciectomy alone.¹³
- Recurrence rates vary due to inconsistent definitions, but a recent study demonstrates a 20.9% recurrence rate (defined as worsening of total passive extension deficit of 30 degrees or more in a ray) at 5 years postoperatively after limited fasciectomy, which is significantly lower than recurrence after PNA (85%).⁸

COMPLICATIONS

- PNA: Overall complication rate is low.⁷
 - 3.4% skin tear
 - 1.2% transient neuropraxia
 - 0.1% nerve laceration
- CCH¹⁴:
 - Skin tear
 - Peripheral edema
 - Contusion
 - Drug ineffective
 - Injection-site hematoma
 - Lymphadenopathy
 - Pain in extremity
 - Blood blister
 - Injection-site pain
 - Tenderness
 - Localized rash/pruritus
 - Flexor pulley injury
 - Flexor tendon rupture can occur with injection into the flexor tendon; care must be taken when treating the small finger.
- Limited fasciectomy
 - Hematoma
 - Infection
 - Skin flap necrosis
 - Postoperative stiffness
 - Subjective paresthesias
 - Digital nerve injury

- Digital ischemia
- Tendon injury

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Section XII: Spastic Conditions

58 Elbow Extension Procedures

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- The impairment suffered by patients with spastic conditions can be quite debilitating, robbing them of their ability to perform basic activities of daily living and independence.
- Depending on the level of spinal cord injury, the deficits, and, in turn, the options for reconstruction, can vary. Spinal segments C5 through T1 innervate the upper extremity.
- The International Classification for Surgery of the Hand in Tetraplegia (ICT)¹ is a useful way to group tetraplegic patients based on functioning muscles with strength of grade 4 or higher to determine the potential donors for tendon transfer:
 - Group 1: Brachioradialis (BR)
 - Group 2: Extensor carpi radialis longus (ECRL)
 - Group 3: Extensor carpi radialis brevis (ECRB)
 - Group 4: Pronator teres (PT)
 - Group 5: Flexor carpi radialis (FCR)
 - Group 6: Extensor digitorum communis (EDC) and finger extensors
 - Group 7: Extensor pollicis longus (EPL) and thumb extensors
 - Group 8: Finger flexors
 - Group 9: All except intrinsic muscles
- With spinal cord injury at the C5/C6 level, patients will maintain shoulder

function through an innervated deltoid muscle and maintain elbow flexion through innervated biceps and brachialis muscles.

- The role of the shoulder and elbow is to move the hands in a functional “workspace.” The forearm and wrist then position the hand in preparation for specific tasks of daily living.
- In spinal cord injury, a spastic elbow flexion contracture may develop from spasticity of the elbow flexors and an absence of elbow extension. The patient becomes entirely dependent on the weight of the forearm for stability, limiting the effective “workspace.” The ability to extend the hand an additional 12 in. from the body will provide an additional 800% of workspace.²
- An elbow extension deficit severely interferes with performing activities of daily living and with wheelchair propulsion. Active elbow extension gives the patient the ability to transfer and to provide pressure relief, reducing the risk of developing ischial or sacral pressure ulcers.
- In cases of cerebral palsy, stroke, or traumatic injury, an elbow extension deficit may also result from a fixed elbow flexion contracture from biceps, brachialis, or brachioradialis muscle contracture.
- The first priority in patients with spasticity and/or tetraplegia is to improve elbow extension. The outcome of any other reconstruction for improvement of wrist or hand function will be entirely dependent on the patient having a usable workspace to perform new functions.

ANATOMY

- The deltoid originates from the scapula and inserts on the lateral shaft of the humerus.
 - The axillary nerve and the posterior circumflex humeral artery supply the deltoid posteriorly after passing through the quadrangular space (**FIG 1**).
 - The average fiber length is nearly twice that of the triceps muscle giving it a large amount of excursion and a good potential donor for transfer.
- The biceps originates from the coracoid process and the supraglenoid tubercle inserting on the radial tuberosity and the bicipital aponeurosis.
 - It is innervated by the musculocutaneous nerve that travels between the biceps and the brachialis.
 - The boundaries of the cubital fossa are the pronator teres medially and the brachioradialis laterally. The brachial artery and the median nerve are medial to the biceps brachii tendon. Lateral to it is the lateral cutaneous nerve of the forearm (**FIG 2**).

- The biceps muscle has a large physiologic cross-sectional area and long fibers empowering it to exert large amplitudes of force.
- Transfer requires the biceps tendon to curve around the humerus either laterally across the radial nerve or medially across the ulnar nerve.
- The triceps originates from the infraglenoid tubercle of the scapula and the posterior superior humerus.
 - It has three heads that converge to form the central tendon of the triceps inserting on the posterior olecranon (**FIG 3**).
 - The radial nerve passes through the triangular space and travels posterior to the lateral head of the triceps from a medial to lateral direction in the radial groove of the humerus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Factors that influence functional ability must be considered during the examination:
 - Whether the injury is neurologically complete
 - Cognitive impairment from brain injury
 - Age of the patient
 - Concomitant upper extremity injuries
 - Presence of uncontrolled spasticity
 - Contractures limiting mobility
 - Patient depression

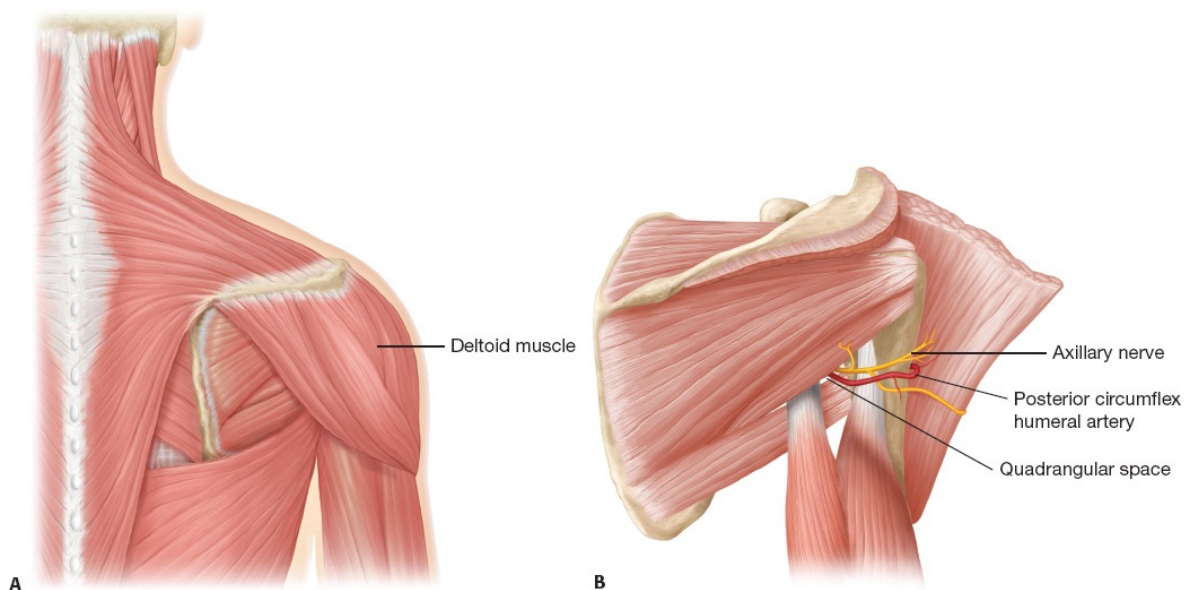


FIG 1 • A. Posterior view of the deltoid. It originates

from the scapula and inserts on the anterolateral humerus to abduct the arm. **B.** It is supplied by the axillary nerve and the posterior circumflex humeral artery emerging from the quadrangular space.

- Patients with motor levels of C5 or higher ($ICT \geq 1$) will have deltoid, biceps, and brachialis function.
- The exam should include an accurate assessment of the range of motion of the elbow, including the strength of the deltoid and biceps muscles. Supple joints and a Medical Research Council (MRC) grade of 4 or higher are a prerequisite for tendon transfer.
- To test the posterior deltoid, the examiner places one palm on the patient's posterior humerus with the patient's arm in 90 degrees of abduction and the elbow in flexion. The patient is asked to push as hard as possible against the examiner's palm while the examiner places the other hand against the posterior half of the deltoid assessing its tension and mass.

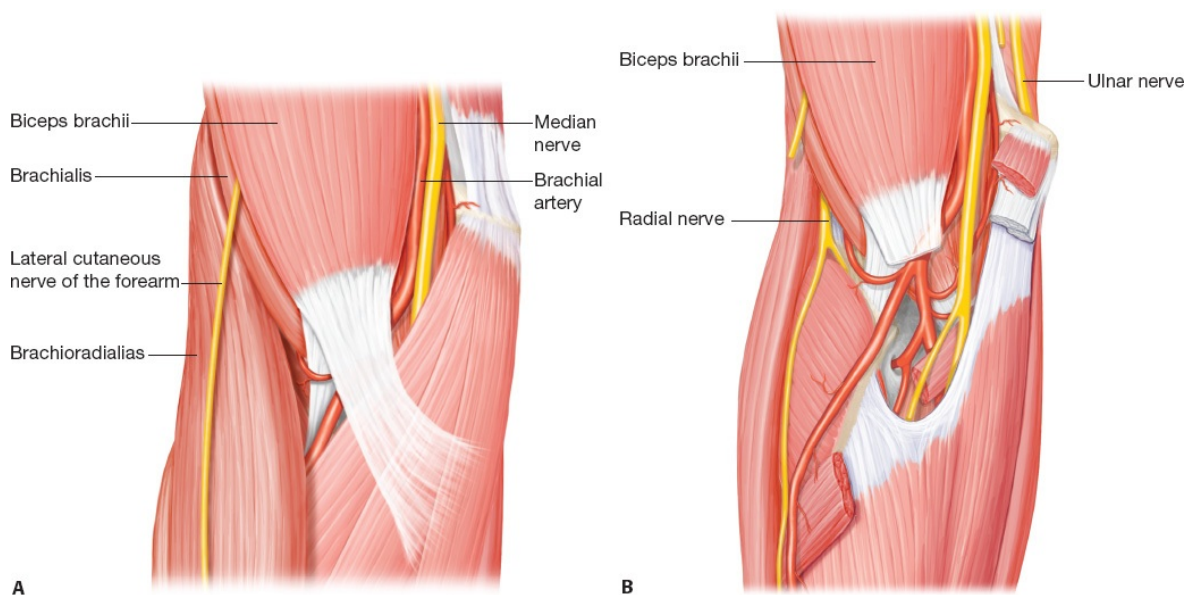


FIG 2 • Biceps anatomy. A. The brachioradialis and the pronator teres form the respective lateral and medial boundaries of the cubital fossa. Note the relationship of the biceps with the median nerve and brachial artery. **B.** Transfer of the biceps tendon can be done laterally

crossing the radial nerve or medially crossing the ulnar nerve. Medial transfer is more often performed, particularly if the patient does not have ulnar nerve function.

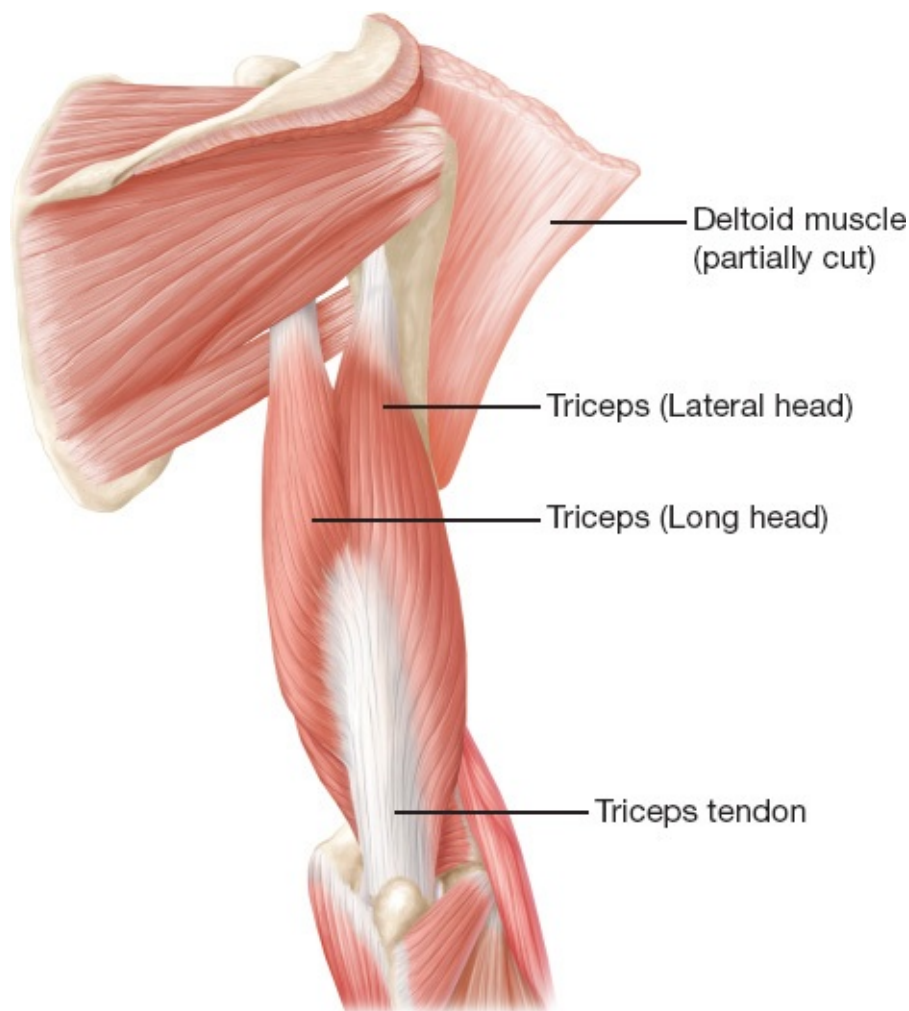


FIG 3 • Triceps anatomy. The triceps tendon is identified and used for the deltoid and biceps transfers.

- If the examiner can easily push the patient's arm out of this position, the posterior deltoid likely does not have sufficient strength for transfer.²
- The role of the biceps muscle is to flex the elbow and supinate the forearm. Therefore, prior to consideration of the biceps as a donor muscle, examination of the supinator and brachialis muscles are imperative to ensure adequate

postoperative flexion and supination.

- Forearm supination without resistance activates the supinator, which can be palpated along the proximal radius. Similarly, elbow flexion without resistance will activate the brachialis, and it is palpable along the anterior humerus.
- If the exam is equivocal, the biceps may be paralyzed with injection of local anesthetic around the musculocutaneous nerve, facilitating an independent evaluation of the supinator and brachialis.³
- The patient's overall psychosocial and mental state must be evaluated.
 - This includes consideration of the patient's social support network and personal motivation for improvement of function.
 - There will be a long period of postoperative rehabilitation, and without long-term cooperation from the patient and adequate assistance, a successful outcome is unlikely.

IMAGING

- Plain radiography can identify the presence of heterotopic ossification, a potential cause of joint contracture that must be ruled out or treated before any tendon lengthening or transfer.
- If, despite clinical examination, the examiner is still uncertain of whether a muscle is under volitional control, electromyography focusing on the muscle of interest can help identify spastic and flaccid muscles and determine phasic activity.

NONOPERATIVE MANAGEMENT

- Attempts to control the position of the elbow can be done with serial splinting or casting. Phenol motor blocks have been used to alleviate spasticity.
- Patients who are many years from their injury may be well adapted to their deficits. For example, some will learn to substitute the biceps to propel themselves in a wheelchair and do not wish any surgical intervention.
- It is important to thoroughly question each individual patient to determine what the postoperative goal is and whether surgery can realistically attain that goal.

SURGICAL MANAGEMENT

- The primary goal of surgical intervention in spasticity is to achieve, maintain, or maximize the patient's physical independence. Any treatment that can improve a level of function will have a dramatic effect on the patient's

independence.

- The goals of reconstructing elbow extension are to provide improvement in the following activities⁴:
 - Reaching for an object above shoulder level
 - Driving
 - Handwriting
 - Wheelchair propulsion
 - Pressure relief when seated
 - Using the hand while supine
- In patients with multiple levels of deficits, the reconstitution of active elbow extension should be performed first. It not only will stabilize the elbow and facilitate the transfer of other muscles in the future, such as the brachioradialis, but also gives the patient confidence in the rest of his or her treatment.⁵
- The following principles of tendon transfers apply in reconstruction of spastic conditions:
 - Supple joints with a functional arc of motion
 - Sufficient strength of donor muscle for its new function
 - Although an MRC ≥ 4 is recommended, a muscle will lose one grade of strength after transfer, and therefore, an MRC of 5 is preferable.
 - Comparable force of contraction and excursion between the donor muscle and the muscle to be replaced
 - Synergy—motions that are synchronized during functional activity (finger flexion with wrist extension)
 - Transfer should occur across a healthy bed of tissue with minimal inflammation or scarring
 - Stabilization of a joint whenever a transfer spans multiple joints
 - Straight line of pull for the transfer whenever possible
 - Minimal morbidity from loss of the donor muscle
- Elbow extension can be restored with a posterior deltoid or biceps transfer to the triceps. In cases of contracture as a result of spasticity, tendon lengthening is another treatment option.
- Deltoid to triceps transfer
 - The deltoid transfer uses the posterior half of the deltoid muscle. There is minimal to no functional loss of the donor muscle, as arm abduction is preserved postoperatively.
 - The deltoid and the triceps are synergistic muscles. Reaching for an object

overhead involves abduction of the arm (deltoid) and extension of the elbow (triceps).

- One significant disadvantage of the posterior deltoid muscle is that it does not have sufficient length to be directly inserted into the triceps tendon. Therefore, the gap must be bridged with a free tendon graft.
- The deltoid transfer is also prone to stretching, particularly at the proximal suture repair between the deltoid and the tendon graft. The tendon elongation most commonly occurs during the first 4 to 6 weeks after surgery but has been found to occur months after surgery. Tendon elongation will result in a loss of strength and excursion for elbow extension. Thus, a strict and rigorous postoperative rehabilitation program is essential to optimize results.⁶
- Absolute contraindications include a fixed elbow contracture or inadequate posterior deltoid strength on clinical examination.
- Biceps to triceps transfer
 - A biceps to triceps transfer can be considered in cases where there is less than grade 4 strength of the posterior deltoid but biceps with strength of 4 or greater.
 - Patients with elbow contracture less than 20 degrees may benefit from biceps transfer over a deltoid transfer, because biceps lengthening would likely be necessary to correct the elbow contracture.
 - Although there is a postoperative reduction in elbow flexion power of up to 47% after biceps transfer, patients report that the significant functional improvement with added elbow extension far outweighs the decrease in flexion strength.^{7,8} Again, it is important to confirm that the patient has active supinator and brachialis muscles to minimize the elbow flexion deficits after biceps transfer.
 - Advantages of the biceps transfer over the deltoid transfer include a shorter operation, ability to use a tourniquet for a portion of the operation, avoiding the need for a tendon interposition graft, and the need to heal only one tendon junction to permit earlier mobilization.
 - Biceps transfer is not without its disadvantages. The transfer requires routing the biceps tendon around the humerus resulting in a drop in power across the transfer.
 - Furthermore, the biceps and triceps are antagonist muscles. Normally, with triceps contraction and elbow extension, the biceps muscle relaxes. However, after biceps to triceps transfer, biceps contraction is necessary to activate elbow extension. The patient will require a longer period of rehabilitation to

train the biceps to function as an elbow extensor.

- Tendon lengthening procedures for contracture
 - Patients with volitional control of the elbow and hand and with more than 40 degrees of contracture are candidates. Additionally, those without volitional control and more than 100 degrees of contracture would also benefit for help with personal hygiene.
 - Patients recovering from strokes are typically older with weaker muscles, resulting in poor recovery of motor function regardless of the surgical procedure. Stroke patients with contractures will likely have some benefit in correction of the contracture, but less likely to have a significant improvement in function.
 - For biceps or brachialis lengthening procedures, a fractional lengthening can be performed for mild contractures, whereas a Z-lengthening (step cut) is indicated for more severe contractures.

Preoperative Planning

- A local nerve block is a useful preoperative tool differentiating muscle spasticity from muscle contracture. In the case of contractures, movement will not improve with neuromuscular blockade.
- The underlying cause of the spasticity will guide preoperative preparation.
 - Cerebral palsy
 - Voluntary hand use, sensibility, intelligence quotient, and presence of athetosis must be measured. An uncooperative patient with limited preoperative function is unlikely to have significant postoperative functional improvement.
 - The examiner must confirm the cause of contracture: joint contracture, muscle contracture, or muscle spasticity. Unlike muscle or joint contractures, muscle spasticity presents with full range of motion of the affected joint. The contractures should be treated with either therapy or surgery before a tendon transfer.
 - Older patients may have learned to compensate for their disability, and reconstruction in those cases must be considered carefully.
- Stroke
 - Patients often present with hemiplegia of the upper extremity and less spasticity than younger patients.
 - Surgery should be delayed until there is maximal neurologic recovery,

typically around 12 to 18 months.

■ Traumatic brain injury

- On average, patients are younger than stroke patients and will present with a greater degree of spasticity.
- Trauma patients may also have concomitant injuries, heterotopic ossification, deformities from other fractures, and possible quadriplegic involvement that can complicate postoperative functional improvement. Each patient must be considered individually.
- Similar to cerebral palsy, patient cognition and cooperation is variable and must be carefully assessed preoperatively to predict likelihood of patient cooperation and a successful postoperative outcome.

- If the patient has had a contracture treated preoperatively, it is important to repeat examination of the range of motion on the day of surgery to confirm there is no contracture recurrence.

Positioning

- The patient is placed in a lateral decubitus position for the deltoid to triceps transfer.
- Alternatively, the patient can be supine with a surgical “bump” placed beneath the torso to elevate the shoulder anteriorly.
- The supine position is appropriate for the biceps to triceps transfer and the biceps/brachialis lengthening.
- A high proximal tourniquet can be applied for the biceps and brachialis lengthening, as well as for a portion of the biceps to triceps transfer.

Approach

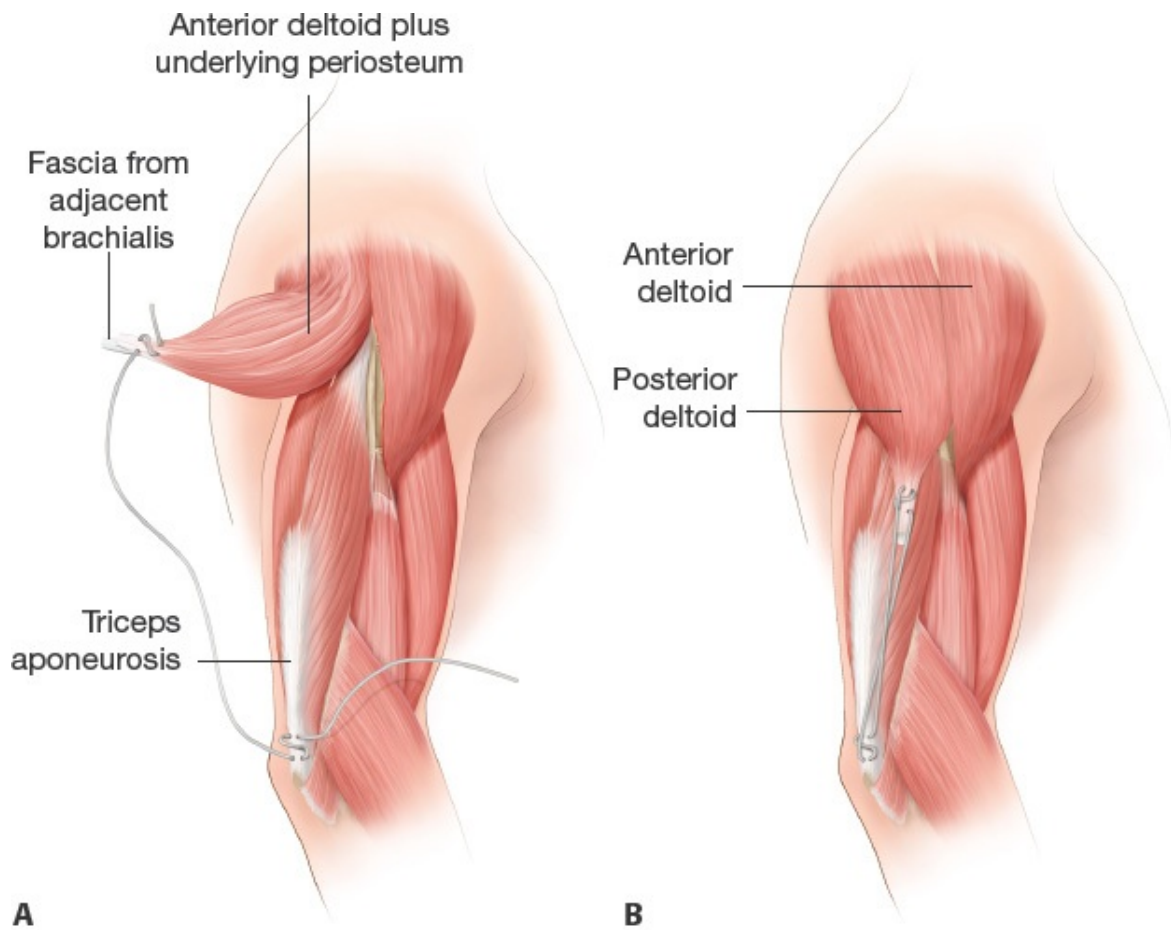
- A variety of tendon grafts can be used for the deltoid to triceps transfer, including toe extensors, tensor fascia lata, tibialis anterior, extensor carpi ulnaris, or the central third of the triceps tendon.
- The deltoid to triceps incision can be made as two separate incisions, one overlying the posterior deltoid and one over the triceps, or it can be made as one continuous incision.
- The biceps to triceps transfer can be performed by tunneling the biceps tendon either laterally or medially, though medially is the preferred method to avoid compression of the radial nerve.^{8,9}

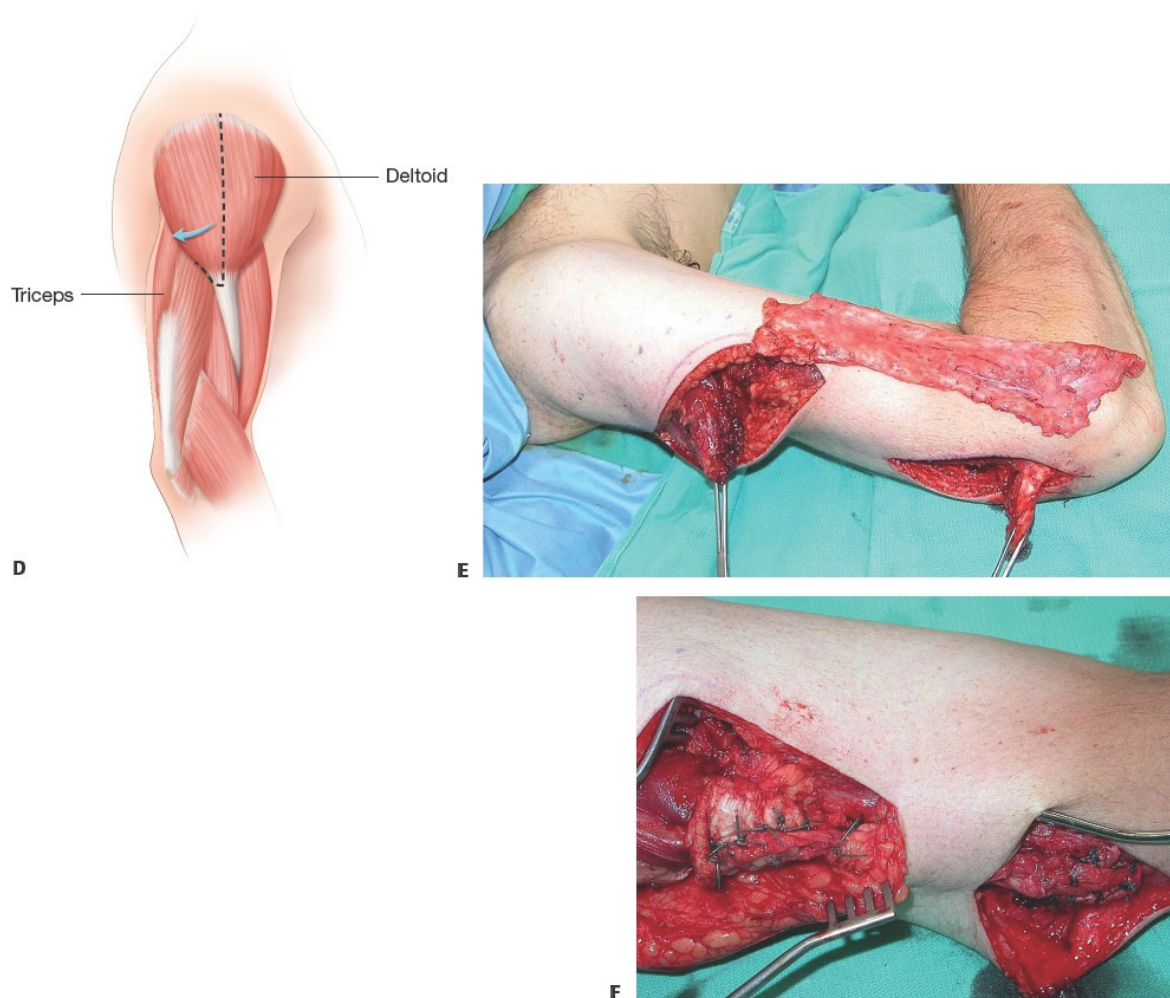
TECHNIQUES

■ Posterior Deltoid to Triceps Transfer

- To reach the triceps, the posterior deltoid must be lengthened with a free tendon graft harvested from the surgeon's preferred donor site. A free tensor fascia lata graft has sufficient length and strength and leaves minimal donor-site morbidity (**TECH FIG 1A,B**).
- Make an S-shaped incision from the posterior tip of the acromion to the deltoid insertion on the humerus (**TECH FIG 1C**).
- Dissect along the posterior edge of the deltoid from proximal to distal. Identify the tendinous band marking the separation between the middle and posterior parts of the deltoid.
- Sharply dissect the posterior muscle fibers from their insertion on the humerus. This measures an area of approximately 1×6 cm (**TECH FIG 1D**). Include the periosteum and a small rectangular strip of fascia to include tissue with sufficient strength to hold suture for the tendon repair and to provide as much length as possible.
 - Take care to avoid dissection too far distal. The radial nerve emerges several centimeters distal to the deltoid insertion and can be injured with overzealous dissection.
- Completely separate the posterior deltoid muscle fibers from the remainder of the muscle, providing approximately 3 cm of excursion (**TECH FIG 1E**).
 - Avoid injury to the axillary nerve and the posterior circumflex pedicle, located approximately 10 cm proximal to the insertion on the humerus.
- To expose the triceps tendon and fascia, make a separate lazy-S incision along the distal third of the humerus lateral to the olecranon process (see **TECH FIG 1A,B**).
- Create a subcutaneous tunnel connecting the proximal and distal incisions (see **TECH FIG 1E**).
- First, interweave the graft proximally to the deltoid. Then, secure the tendon graft to the triceps tendon under moderate tension with the elbow fully extended and the shoulder slightly abducted. Secure the repair with two double rows of 4-0 nonabsorbable, running suture (**TECH FIG 1F**).
- Ensure adequate hemostasis and close the incisions primarily.

- Apply a splint with the elbow in 5 to 10 degrees of flexion.



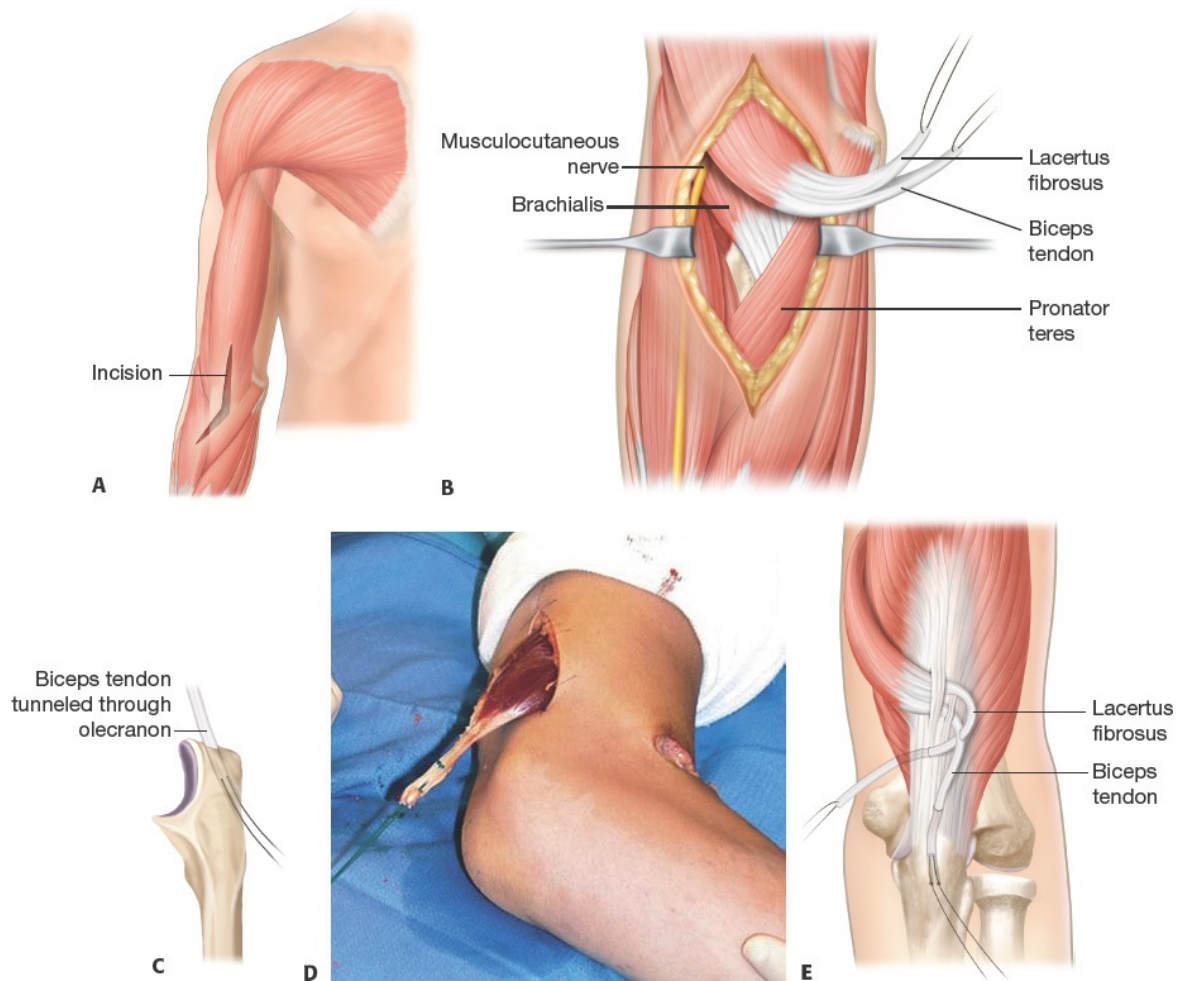


TECH FIG 1 • A,B. The gap between the deltoid tendon and the triceps tendon must be bridged with a tendon graft. **C.** The deltoid is palpated and marked out with a dashed line. The incision is a lazy-S, spanning from the proximal extent of the muscle to near its insertion. The triceps incision is similarly S-shaped and is placed lateral to the lateral epicondyle to avoid potential pressure necrosis. **D.** The posterior deltoid is freed from its attachments to the humerus and will be transferred posteriorly toward the triceps tendon. **E.** The posterior deltoid (held by left clamp) after dissection has an approximate 3-cm excursion. The triceps tendon (held in right clamp) is prepared for

the transfer. The free tensor fascia lata graft has sufficient length and strength for transfer. **F.** Suture repair of the tendon graft to the deltoid proximally (*left*) and the triceps distally (*right*).

■ Biceps to Triceps Transfer

- Make an anterior longitudinal incision over the medial biceps muscle belly. Extend the incision obliquely across the antecubital fossa (**TECH FIG 2A**).
- Dissect and expose the biceps muscle. Identify and protect the musculocutaneous nerve.
- Divide the lacertus fibrosus while avoiding injury to the brachial artery and the median nerve lying deep to it. If the lacertus fibrosus has a substantial antebrachial fascia, preserve to use as an additional tail for subsequent tendon weaving (**TECH FIG 2B**).
- Identify the biceps tendon and trace it distally to its insertion on the radial tuberosity. To identify the radial tuberosity, flex the elbow and supinate the forearm.
- Detach the biceps tendon from its insertion as far distally as possible. Avoid injury to the recurrent radial vessels, as they are the main blood supply to the brachioradialis and the extensor carpi radialis, which may be donor muscles for potential future transfers.
- Place a braided, nonabsorbable suture through the substance of the biceps tendon.
- Make a second incision overlying the distal triceps aponeurosis. Ensure that the incision is lateral to the olecranon to avoid pressure ulceration and a narrow medial skin bridge.
- After exposing the triceps tendon, split it over the tip of the olecranon. Drill a unicortical hole into the medullary canal from the olecranon tip. This hole can be sequentially drilled to an appropriate size to receive the biceps tendon (**TECH FIG 2C**).
- From the posterior incision, create a generous subcutaneous tunnel medial to the humerus and deep to the ulnar nerve, traveling toward the anterior incision. The medial intermuscular septum may need to be resected to create the tunnel.



TECH FIG 2 • **A.** Anterior incision for exposure of the biceps. **B.** Elevation of the biceps tendon and the lacertus fibrosus. If the lacertus fibrosus is of substantial thickness, it can be preserved and used for the tendon weave. **C.** The biceps tendon is brought from the medial incision to the lateral incision through a subcutaneous tunnel. Sufficient proximal dissection of the biceps is necessary. **D.** The biceps tendon is brought through a slit in the triceps (posterior view). A unicortical hole is drilled in the proximal olecranon large enough to fit the biceps tendon. Two smaller distal holes are drilled in continuity with the proximal hole large enough to pass through a Keith needle with each end of the suture holding the biceps tendon. The

two ends of the suture are secured and tied over the olecranon.

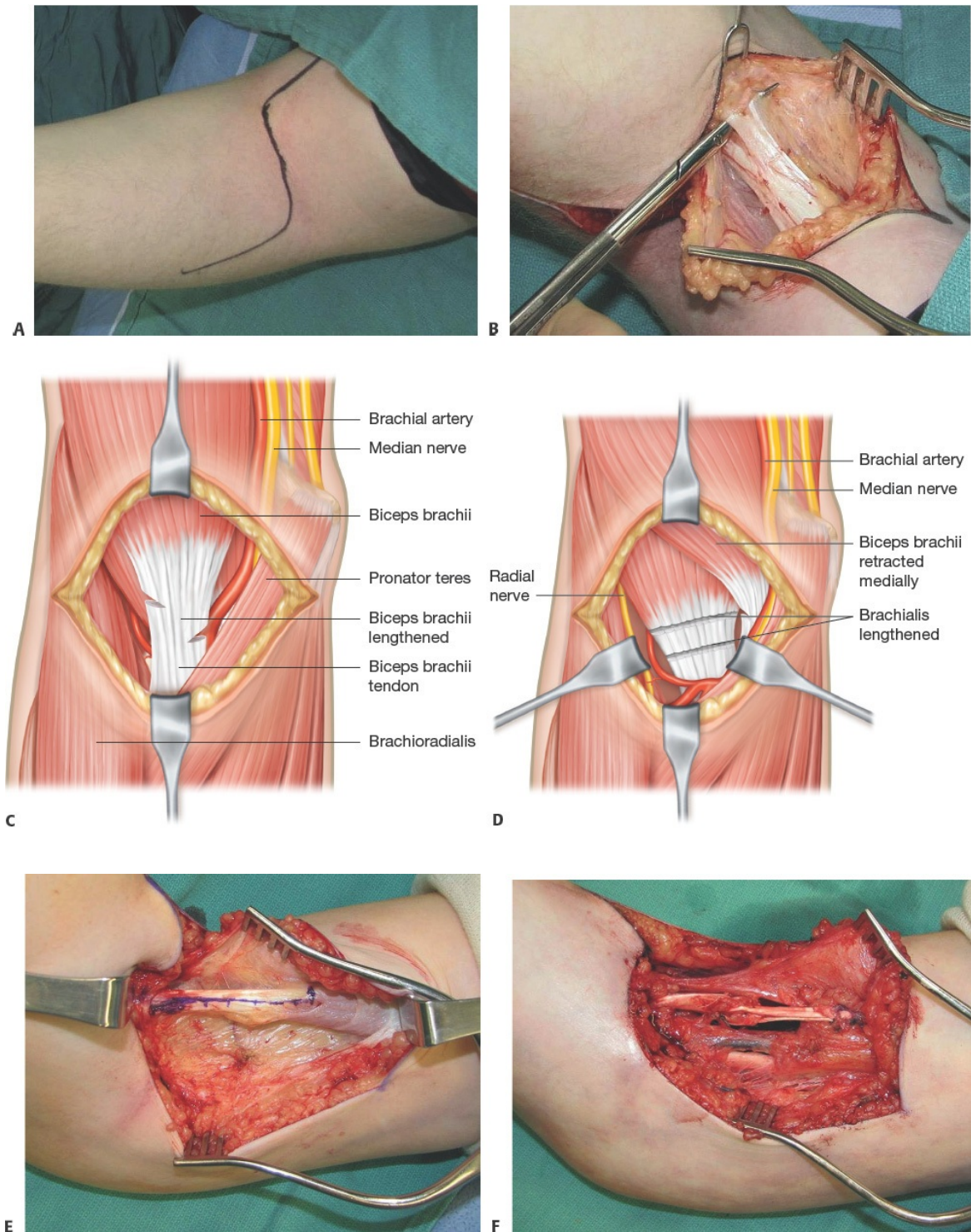
- Free the biceps muscle as far proximally as possible to provide the straightest line of pull possible toward the olecranon. The tourniquet must be removed for this portion to permit adequate proximal exposure. Avoid injury to the vascular pedicle to the biceps, which enters the deep surface of the proximal third of the muscle. Proximal dissection should stop once the distal motor branches of the musculocutaneous nerve entering the biceps are identified.¹⁰
- Transfer the biceps tendon from the anterior incision medially toward the posterior incision (**TECH FIG 2D**).
- Pull the biceps tendon through the slit in the triceps tendon and secure with a Pulvertaft weave with a braided nonabsorbable suture. The tail of the biceps tendon should remain free to be brought through the olecranon.
- Drill two small holes through the opposite cortex of the olecranon to permit passage of a Keith needle. Secure a suture in the tail of the biceps and bring each end of the suture through each of the distal olecranon holes with a Keith needle. With the elbow in full extension, tie the two ends of the suture together over bone (**TECH FIG 2E**).⁹
- Place additional braided nonabsorbable sutures between the biceps and triceps tendon to further secure the transfer. If a tail of lacertus fibrosus was preserved, it can be secured at this time, either to the biceps tendon or to the triceps tendon.
- Set the tension maximally with the elbow held in full extension, such that the elbow cannot be passively flexed beyond 30 degrees when the arm is abducted about 30 to 40 degrees.⁸
- Achieve hemostasis, and close all skin incisions primarily. A suction drain can be placed at the surgeon's discretion.
- Place a splint holding the arm in 10 degrees of elbow flexion and the wrist in 30 degrees of extension. The shoulder is not immobilized.

■ Biceps and Brachialis Lengthening

- Make a 15-cm S-shaped incision across the antecubital fossa beginning laterally above the elbow and curving distally in an anteromedial direction

(**TECH FIG 3A**).

- Dissect from medial to lateral, exposing the lacertus fibrosus, biceps brachii tendon, median nerve, brachial artery, and the lateral antebrachial cutaneous nerve (see **FIG 2**).
- Identify the bicipital aponeurosis medial to the biceps brachii tendon, and resect it completely (**TECH FIG 3B**).
- Identify the lateral antebrachial cutaneous nerve between the biceps and brachialis lateral to the biceps tendon and retract it laterally. Expose the biceps completely and dissect distal to its insertion.
- For a fractional lengthening, make two cuts in a slightly oblique direction, spaced approximately 1 to 2 cm apart. One cut is made on the lateral side of the tendon, and the other is made on the medial side. The cuts should be no more than halfway through the tendinous portion of the musculotendinous junction, leaving the muscle fibers intact (**TECH FIG 3C**). Gently extend the elbow facilitating separation of the tenotomy sites, keeping the muscle in continuity.
- After release of the biceps, the brachialis can be visualized. Similarly, perform a fractional lengthening. Again, if two releasing incisions, space them approximately 1 to 2 cm apart and perform the proximal incision first. If the distal incision is made first, proximal migration of the brachialis will make it challenging to make the second incision (**TECH FIG 3D**).
- To perform a Z-lengthening of the biceps, make a transverse cut halfway through the tendon on the proximal side. Make a second distal transverse cut halfway through the opposite side of the tendon. The two cuts are connected longitudinally completely releasing the tendon with each end representing half the Z limbs (**TECH FIG 3E**).



TECH FIG 3 • **A.** Incision for biceps and brachialis lengthening. An S-shaped incision starts on the lateral arm and crosses the cubital fossa transversely to the medial forearm. **B.** Exposure of the bicipital

aponeurosis. **C.** Fractional lengthening of the biceps tendon. **D.** Fractional lengthening of the brachialis. **E.** Markings for Z-lengthening of the biceps tendon. **F.** Repair of the two ends of the biceps following Z-tenotomy and lengthening of the biceps.

- The elbow is extended to 30 degrees of flexion lengthening the tendon to the appropriate length. The two ends are sutured together where they remain overlapping using a Pulvertaft weave with 3-0 braided, nonabsorbable sutures (**TECH FIG 3F**).
- Be certain to perform the Z-lengthening over as much of the tendon length as possible to maximize the amount of tendon available for reattachment.
- If adequate lengthening of the brachialis cannot be obtained with fractional lengthening or Z-lengthening, the muscle can be completely transected.
- If preoperative evaluation revealed a spastic brachioradialis, it can be assessed for partial or complete release at this time. Dissect between the brachialis and brachioradialis to identify the origin of the brachioradialis. Perform the release (partial or complete) at the origin, permitting the muscle to slide distally. Be certain to identify and protect the radial nerve before performing a brachioradialis release.
- Release the tourniquet, achieve hemostasis, and close the wound primarily.
- Place the arm in a splint with the elbow at 30 degrees of flexion.

PEARLS AND PITFALLS

Incision

- Avoid making incisions directly over the olecranon to prevent pressure ulceration.
- Make a longitudinal incision on the lateral elbow for patients with contractures greater than 100 degrees facilitating skin closure with multiple Z-plasties if necessary.

Deltoid to triceps transfer

- A tendinous band in the intermediate part of the deltoid can be used to help demarcate the separation between the middle and posterior portions of the deltoid.
- Include the periosteum when dissecting the deltoid insertion from

	the humerus to better hold sutures for repair. ■ The axillary nerve is approximately 10 cm proximal to the humeral insertion of the deltoid and must be avoided.
Biceps to triceps transfer	■ Identify and protect the lateral cutaneous nerve of the forearm. ■ If using a tourniquet, release will be necessary to achieve adequate proximal dissection of the biceps. ■ Create a generous subcutaneous tunnel to avoid any compression or loss of strength of the transferred biceps tendon. ■ If the lacertus fibrosus has substantial fascia, it can be preserved and used as a second tail to further strengthen tendon weaving. ■ Medial routing of the biceps tendon avoids the potential for radial nerve palsy. ■ Avoid injury to the recurrent radial vessels so that the blood supply to potential donor muscles for future transfers is not compromised.
Biceps and brachialis lengthening	■ Perform a fractional lengthening in cases of mild contractures and a Z-lengthening for more severe contractures. ■ When performing a double incision release of the brachialis, perform the proximal incision first. ■ Avoid placing the elbow in full extension in patients with volitional control, as this may result in postoperative problems with elbow flexion.

POSTOPERATIVE CARE

- Deltoid and the biceps to triceps transfer
 - Immobilization is continued for 4 weeks. The patient is then placed in an active exercise program gradually increasing elbow flexion at a rate of 15 to 20 degrees per week with a daytime dial-hinge brace and a nighttime splint in full extension.
 - Occupational therapy is used to train biceps activation for elbow extension and to incorporate functional activities of daily living.⁸
 - The dial-hinge brace is continued until the patient is at 90 degrees of elbow flexion. The nighttime splint is used for 12 weeks, after which strengthening can begin.
- Biceps and brachialis lengthening
 - The wound is inspected and sutures removed in 10 to 14 days.
 - If a fractional lengthening was performed, the patient can begin mobilization immediately.

- For biceps Z-lengthening, the elbow is splinted in 30 degrees of flexion for 4 weeks to protect the tendon repair. Active and passive range of motion can then begin with nighttime splints worn for an additional 3 weeks for protection.

OUTCOMES

- The biceps comprises one of the two strong elbow flexors. Therefore, transfer does result in an approximate 47% reduction of preoperative strength.^{4,8}
- The biceps is an antagonist to the triceps, leading to a longer rehabilitation period to learn to activate it as an elbow extensor. This learning curve can vary from 2 to 6 months.^{4,8}
- Patients typically regain full or near full elbow extension against gravity with both tendon transfer techniques.^{2,3} In cases where patients do not, myofeedback with electrical stimulation can be used with good success.⁴
- On average, fractional lengthening of the biceps leads to a 10- to 30-degree improvement in flexion contracture with minimal loss of flexion power.
- For patients with a Z-lengthening procedure, there is on average a 45- to 60-degree improvement of elbow flexion contracture albeit with a loss of flexion power.

COMPLICATIONS

- Wound breakdown, infection, iatrogenic nerve injury, or inappropriate tensioning of a tendon transfer are all uncommon but possible surgical complications.
- For tendon transfers, tendon rupture or stretching of the repair can occur postoperatively leading to ineffective elbow extension. This can best be avoided with a strict postoperative immobilization and rehabilitation regimen.
- Tendon pullout from the olecranon is another potential complication that can best be prevented with a secure fixation.
- Though rare, compartment syndrome is a potential complication and can easily be missed in a patient with lack of preoperative sensation.³

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CHAPTER Wrist Extension Procedures

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Patients with tetraplegia may have difficulty with wrist extension, constantly assuming a partially flexed posture.
- A flexed wrist position diminishes the tenodesis effect on the digital flexors, leading to a weakened grip, difficulty with hygiene, and obstructed visual feedback when grabbing objects.
- After elbow extension, the second priority in reconstruction for tetraplegia or spinal cord injury is the restoration of wrist extension. Augmentation of wrist extension can indirectly enable passive thumb and finger flexion by improving pinch and grasp. This tenodesis effect is valuable in patients who do not have enough donor muscles to reconstruct active grasp and pinch.
- Those patients with an International Classification for Surgery of the Hand in Tetraplegia (ICT) score of 1 have an active brachioradialis that can be used for tendon transfer to augment wrist extension (see Table 1 from Elbow Extension chapter).

ANATOMY

- Tetraplegic patients with an active brachioradialis typically have an innervated biceps and brachialis muscle. Therefore, there is minimal donor-site morbidity on elbow flexion with its use for tendon transfer, making it a versatile workhorse muscle in tetraplegia reconstruction.
- The brachioradialis originates from the lateral supracondylar ridge of the humerus and the lateral intermuscular septum and inserts on the lateral base of the radial styloid beneath the tendons of the abductor pollicis longus and extensor pollicis brevis.

- It is innervated by a branch from the radial nerve entering the deep portion of the muscle, proximal to the elbow.
- The superficial branch of the radial nerve (radial sensory nerve) runs deep and medial to the brachioradialis between it and the supinator muscle. In the mid to distal forearm, the radial artery can be found between the brachioradialis and the flexor carpi radialis tendon (**FIG 1**).
- The brachioradialis is a long muscle with good excursion and a large circumference, giving it a high force of contraction.¹ Its tendon is bound with fascial coverings and does not glide freely past the mid-forearm (**FIG 2**).
- Releasing the tendon fascial attachments and freeing the muscle belly from the surrounding muscle significantly increases its excursion.²
- The extensor carpi radialis brevis (ECRB) attaches to the long finger metacarpal and is a more efficient wrist extensor than the extensor carpi radialis longus (ECRL), whose tendon attaches to the radial side of the second metacarpal, resulting in both extension and radial deviation of the wrist (**FIG 3**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- As for all patients with spastic conditions considering surgical reconstruction, there are a variety of anatomic, functional, and psychosocial factors that must be examined (see Elbow Extension chapter).
- The strength of the brachioradialis must have a Medical Research Council grade 4 or higher. To test the brachioradialis, position the patient's elbow in a midprone position and have the patient flex against resistance contracting the brachioradialis. Palpate and attempt to move the belly of the muscle. If the muscle is tight, the brachioradialis has adequate strength for transfer (**FIG 4**).

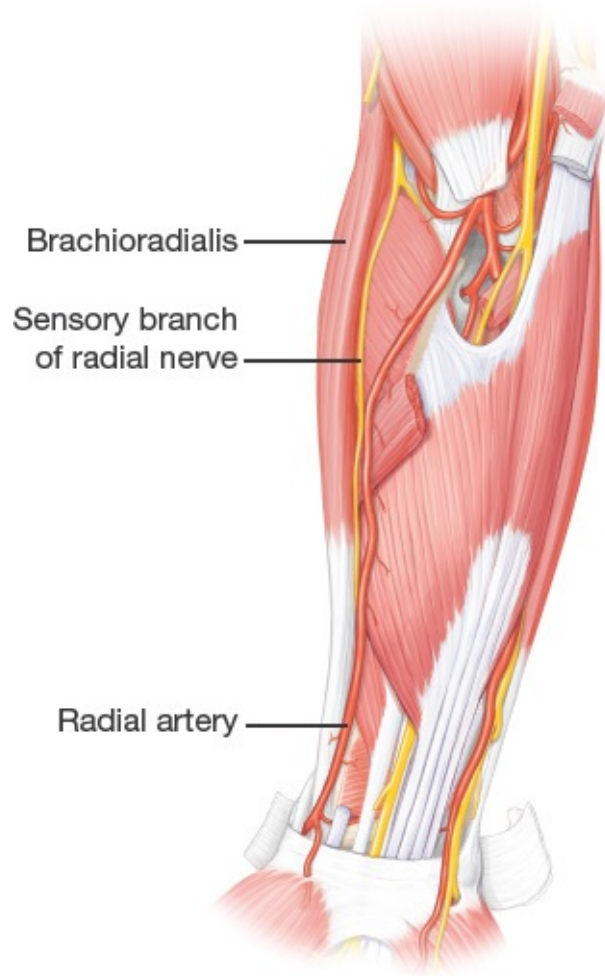


FIG 1 • Relevant volar anatomy. Note the relationship of the brachioradialis with the sensory branch of the radial nerve and the radial artery.

- Examination also includes the wrist and metacarpophalangeal joints to ensure a full passive range of motion with good passive tenodesis of the fingers with wrist flexion and extension.³

IMAGING

- Electromyography can confirm volitional activity of the brachioradialis if the exam is equivocal. It will identify whether the muscle is spastic or flaccid and will determine its phasic activity.

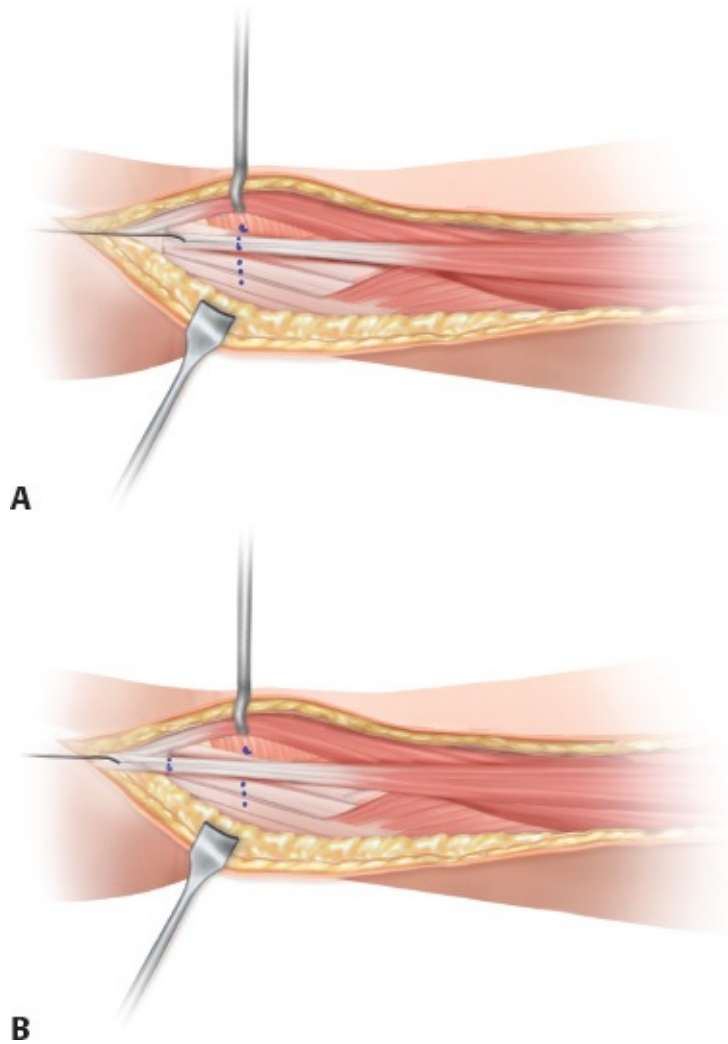


FIG 2 • Excursion from dissection of the brachioradialis. **A.** A mark is placed on the distal tendon of the brachioradialis and extended to the surrounding tissue as a reference point. **B.** After ligation of the distal tendon and freeing the tendon and muscle attachments, there is approximately 3 cm of advancement beyond the reference point.

SURGICAL MANAGEMENT

- The goal of surgery is to improve pinch and grasp by taking advantage of the tenodesis effect. Wrist extension effectively lengthens the palmar surface of the wrist by increasing tension on the digital flexors and reducing tension on the digital extensors. This results in bringing the thumb and fingers into passive

flexion⁴ (**FIG 5**).

- With restoration or augmentation of active wrist extension, the patient can grasp light objects and pinch to hold and write with a pencil.
- Prerequisites include an active brachioradialis muscle and full range of motion of the wrist and MCP joints.
- The transfer can be performed with a number of other procedures as described by Moberg to maximize lateral pinch tenodesis⁵:
 - Resection of the thumb annular ligament to release the flexor pollicis longus (FPL) tendon over the metacarpophalangeal joint, increasing its mechanical advantage
 - Stabilization of the thumb interphalangeal joint with a buried Kirschner wire to prevent interphalangeal flexion with pinch (Froment sign)
 - Tenodesis of the FPL by attaching it to the volar radius
- It is best to delay tendon transfer for at least 1 year following injury to facilitate maximal recovery prior to surgical reconstruction.⁶

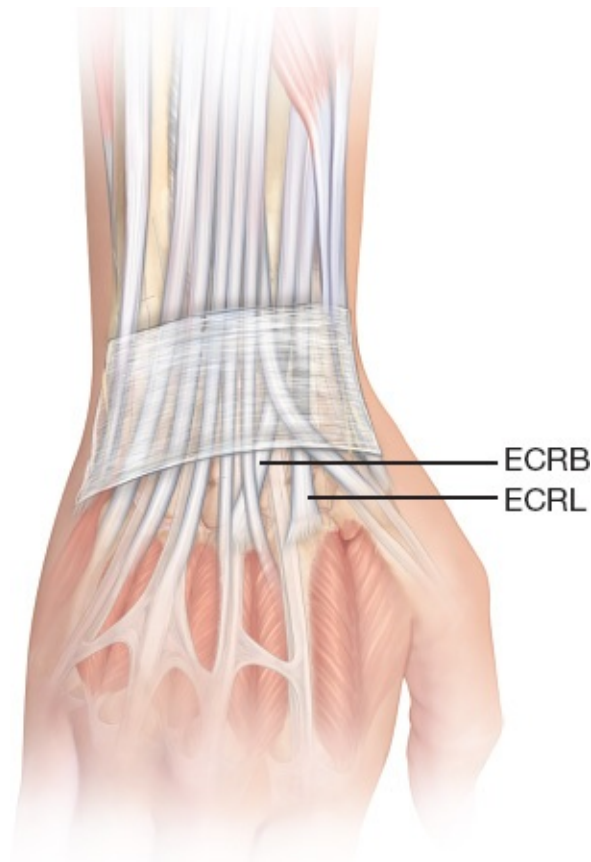


FIG 3 • Dorsal forearm anatomy. Note the location of

the extensor carpi radialis longus (ECRL) and the extensor carpi radialis brevis (ECRB).

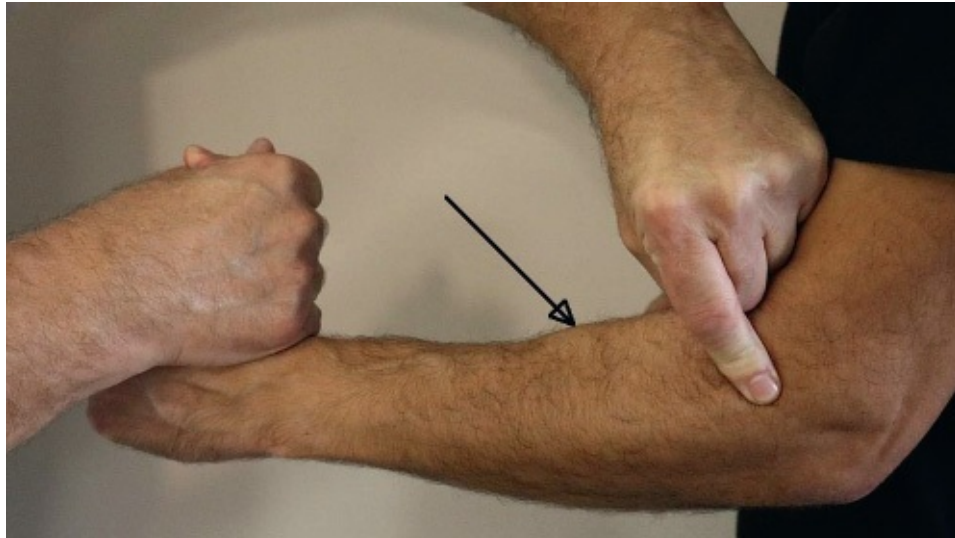


FIG 4 • To examine the brachioradialis, place the patient's forearm in neutral position and ask the patient to flex the elbow against resistance. The prominence of the muscle belly is evident along the proximal radial forearm (*arrow*). Difficulty to displace the muscle with the examiner's hand confirms adequate strength for transfer.



FIG 5 • Active wrist extension results in finger flexion and automatic pinch via the tenodesis effect.

Preoperative Planning

- The patient's underlying cause of spasticity and the current psychosocial state must be carefully assessed before proceeding with surgical reconstruction (see Elbow Extension chapter).
- Any preoperative contractures must be diagnosed and treated with tendon transfer. A local nerve block can differentiate spasticity from contractures. Paralysis of the muscle will have no effect on contractures but will improve range of motion with spasticity.
- Contractures can be treated with occupational therapy, progressive splinting, or surgery depending on the severity.
- On the day of surgery, full range of motion must be confirmed before proceeding with a tendon transfer, particularly in patients who were treated for preoperative contractures.

Positioning

- The patient is positioned in the supine position with the arm extended on an armboard. A nonsterile upper arm tourniquet is applied to provide a bloodless operative field.

Approach

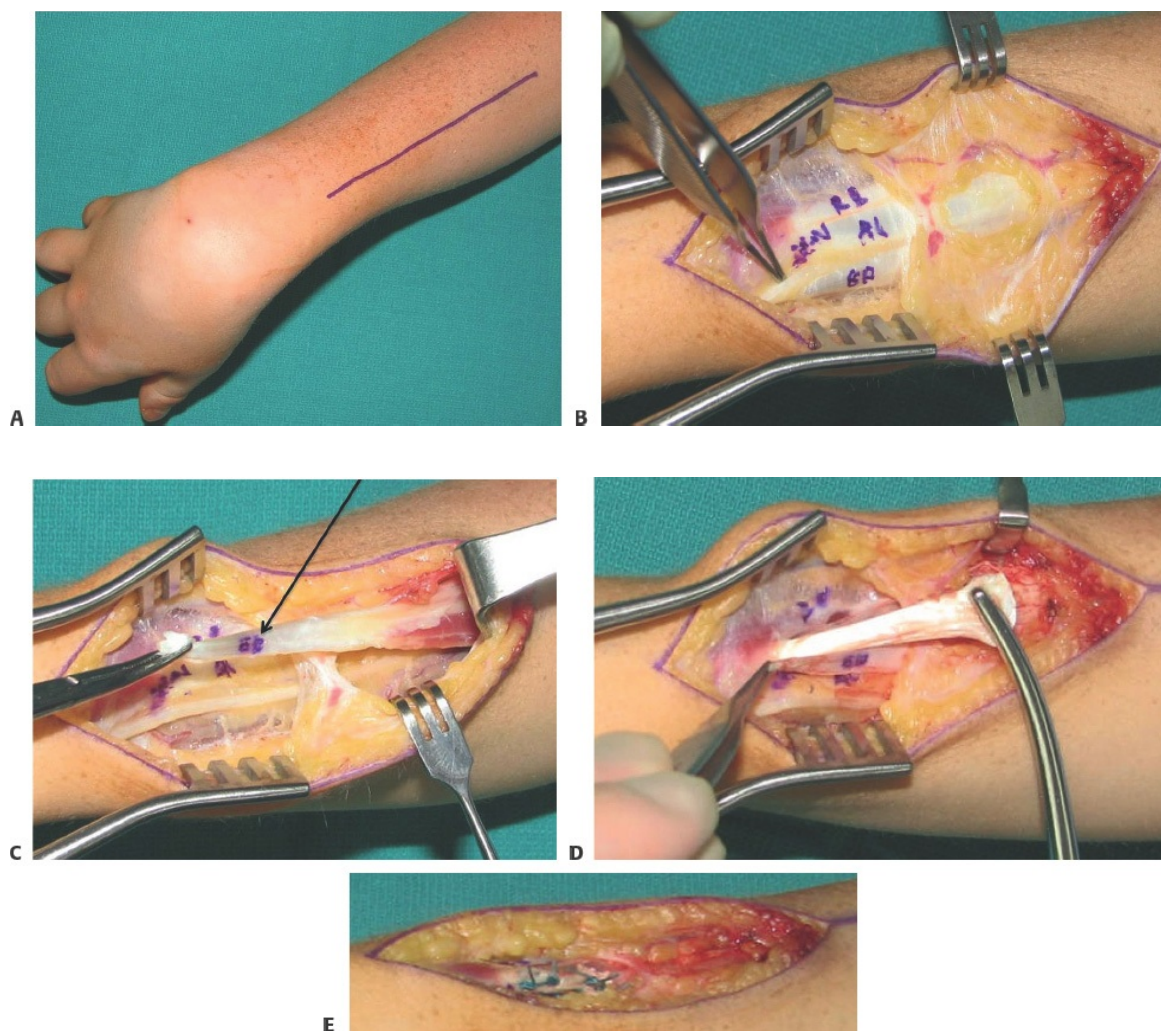
- The brachioradialis can be transferred to the ECRB or to both the ECRB and ECRL. Transfer to the ECRL alone is not advised, as this can lead to more radial deviation than wrist extension.^{3,6}

TECHNIQUES

■ Brachioradialis to Extensor Carpi Radialis Brevis Tendon Transfer

- Make a longitudinal dorsoradial incision from the midforearm to the wrist (**TECH FIG 1A**).
- Identify the brachioradialis, ECRL, and ECRB tendons (**TECH FIG 1B**).

- Longitudinally incise the paratenon of the brachioradialis. Sharply divide the terminal tendon as distal as possible under the abductor pollicis longus and the extensor pollicis brevis.
- Dissect along the deep aspect of the brachioradialis freeing it from its fascial connections proximally to the midforearm (**TECH FIG 1C**).
 - Take care to identify and protect the superficial branch of the radial nerve and the radial vessels during the dissection.
- Continue proximal dissection until an approximate 3 cm of excursion is obtained. If necessary, dissection can continue proximally to just distal to the elbow crease. The radial recurrent vessels traveling transversely on the deep aspect of the muscle mark the extent of the proximal dissection.
- Dissect the ECRB tendon proximally and sharply divide it at the level of the mid-forearm (**TECH FIG 1D**).
- Avoiding compression of the radial sensory nerve, transfer the brachioradialis dorsally toward the ECRB superficial to the ECRL.
- In an end-to-end fashion, perform a Pulvertaft weave between the brachioradialis and the ECRB using multiple 2-0 nonabsorbable braided sutures.
- Place the elbow in 90 degrees of flexion, the forearm in neutral, and the wrist in 45 degrees of extension prior to suturing the tendons.⁷ Do not pull up on the tendons when placing the first suture to avoid a lax repair once the tendon falls back to its natural position.
- Set the tension on the brachioradialis so that the normal resting length is re-established. To estimate this, passively stretch the muscle to its initial length relative to the radius. Place a mark on the brachioradialis tendon at its most proximal intersection with the ECRB tendon. Confirm that the mark remains in the same location after placement of all the sutures between the brachioradialis and ECRB.⁴
- The tension should be set such that the wrist is in a neutral to slightly extended position but passive flexion is still possible (**TECH FIG 1E**).
- Release the tourniquet, achieve hemostasis, and close the incision primarily.
- Place a splint holding the elbow in 90 degrees of flexion, the forearm in neutral rotation, and the wrist in 45 degrees of extension.



TECH FIG 1 • A. A longitudinal dorsoradial incision will provide exposure to the brachioradialis and the ECRB. The incision can be extended proximally, if necessary, for additional exposure of the brachioradialis. **B.** The brachioradialis, extensor carpi radialis longus, and extensor carpi radialis brevis in situ prior to dissection. **C.** After division of its distal tendon, dissection of the brachioradialis (*arrow*) proceeds proximally until there is approximately 3 cm of excursion. **D.** The ECRB is identified, and its tendon is incised proximally, permitting enough length for the transfer of the brachioradialis. **E.** The Pulvertaft weave completes the transfer. The weave is set with the elbow in 90

degrees of flexion, the forearm in neutral position, and the wrist in 45 degrees of extension. It is important to confirm that passive flexion of the wrist is possible at the completion of the transfer.

PEARLS AND PITFALLS

Tension

- Elbow extension causes a tenodesis effect on the brachioradialis. The tension should be set with the elbow flexed in 90 degrees to eliminate this effect.
- Postoperatively, the elbow should be immobilized in 90 degrees of flexion to minimize tension during tendon healing.

Neurovascular structures

- Identify and protect the radial sensory nerve before commencing dissection and before dividing the brachioradialis tendon.
- Do not injure the radial recurrent vessels when dissecting the BR proximally. They can be found on the deep surface of the muscle just distal to the elbow flexion crease signaling the extent of proximal dissection.
- The neurovascular supply to the brachioradialis should not be at risk because it enters the muscle proximal to the elbow.

Tendon transfer

- Free the brachioradialis until a 3-cm excursion is obtained.
- Tension on the brachioradialis should be set to re-establish normal resting length.

POSTOPERATIVE CARE

- After 4 weeks of immobilization, the patient can begin passive range of motion exercises with occupational therapy. The patient remains in a dorsal splint holding the wrist in 45 degrees of extension.
- Active range of motion exercises and strength training can begin 6 weeks after surgery. For 12 weeks, the patient remains in a protective splint removing it only to participate in therapy.

OUTCOMES

- The strength of wrist extension improves in almost all patients undergoing brachioradialis transfer without compromising strength in elbow flexion.^{3,6}
- The greater the preoperative strength of the brachioradialis and wrist extensors, the better the postoperative result.⁶

COMPLICATIONS

- Failures from tendon ruptures or adhesions are rare but can occur. Tenolysis should be delayed until 9 to 12 months after surgery.

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60 Finger Extension Procedures

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Patients with spastic conditions may develop a finger flexion deformity resulting in difficulty with passive finger extension, even with the wrist in full flexion.
- The deformity can be quite severe with fingers clasped into the palm resulting in skin maceration and breakdown from the digging of fingernails into palmar skin.
- This also results in problems for the patient with activities of daily living and personal hygiene.

ANATOMY

- The flexor digitorum superficialis (FDS) and the flexor digitorum profundus (FDP) are most often involved in flexion deformities.
- The surgeon must be familiar with the volar forearm muscle anatomy, including the location of critical neurovascular structures such as the median nerve, ulnar nerve, radial artery, and ulnar artery.
- The FDS originates from the medial epicondyle, the coronoid process of the ulna, and the anterior oblique line of the radial head before splitting into four bellies at the junction between the middle and distal thirds of the radius. It has a humeroulnar head and a radial head, with the median nerve and ulnar artery traveling between them.
- Each muscle belly contributes a tendon that passes through the carpal tunnel and inserts on the middle phalanx of the corresponding digit (**FIG 1**).
- The tendons of the middle and ring finger travel volar to the tendons of the index and small finger through the carpal tunnel.

- The FDP originates from the proximal ulna and the interosseous membrane and sends tendons through the carpal tunnel to insert on the distal phalanges of the medial four digits.
- The extensor digitorum communis (EDC) origin is on the lateral epicondyle as a single muscle eventually splitting into separate muscle bellies to insert on the extensor expansions of the corresponding digits.

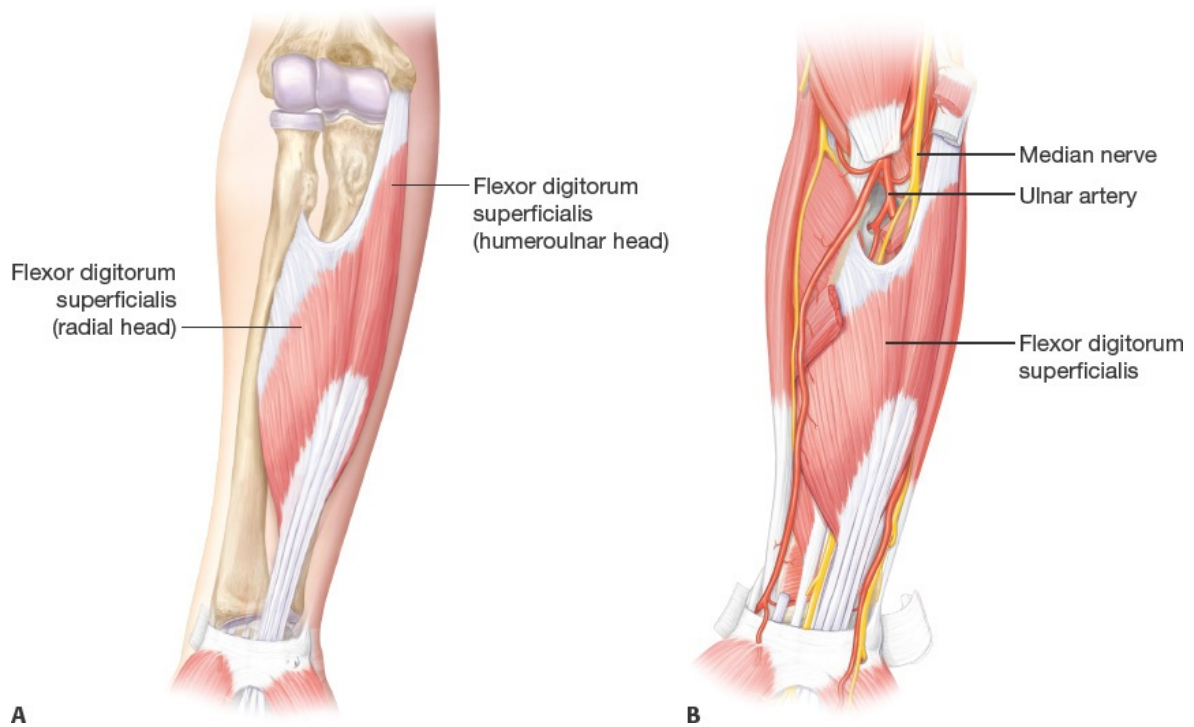


FIG 1 • Volar forearm anatomy. **A.** The flexor digitorum superficialis has a humeroulnar and a radial origin with insertion on the proximal phalanges of the medial four digits. **B.** The median nerve and ulnar artery travel between the two heads.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The exam must involve a full examination of all flexor muscles of the wrist, hand, and fingers.
- The patient typically presents with the fingers flexed into the palm. A thumb-in-palm deformity is also frequently present (**FIG 2**).



FIG 2 • Common clinical appearance of finger flexion deformity with flexed digits and a thumb in palm deformity.

- Any degree of active finger flexion or extension must be ascertained. The examiner can test active flexion by placing a finger in the patient's palm and asking the patient to grasp. Any increase in pressure indicates some degree of muscle control.
- Active extension can be tested by eliminating flexor tone with an anesthetic block of the median nerve in the antecubital space and the ulnar nerve in the cubital tunnel.
- Patients who have marked flexion of the proximal interphalangeal joints without flexion of the distal interphalangeal joints (DIP) likely have involvement of the FDS. On the other hand, flexion of the DIP suggests FDP involvement.
- To best differentiate between FDS and FDP involvement, examine the patient with the wrist flexed.
- It is imperative to examine the remainder of the hand for any other fixed contractures that could lead to a suboptimal postoperative outcome with a tendon transfer or fractional lengthening.

IMAGING

- Electromyography (EMG) may be helpful to evaluate which muscles are under volitional control prior to transfer.

SURGICAL MANAGEMENT

- Finger extension can be established with a tendon transfer or a fractional lengthening.
- The advantages of an FDS to EDC tendon transfer include a straight line of pull, sufficient power, and adequate excursion.¹
- Fractional lengthening is best performed for functional hands where the fingers cannot be actively extended with the wrist in a neutral position but can be extended when the wrist is flexed.
- The maximum length of excursion that can be gained from fractional lengthening is 2.5 cm. If a greater degree of lengthening is necessary, a transfer may be more appropriate.²

Preoperative Planning

- In cases of spasticity as a result of neurologic injury, it is important to delay surgery until there is a plateau in neurologic recovery, as the degree of spasticity can change with recovery.
 - This period of recovery can range from 6 to 18 months.
- For flexor lengthening, the amount of preoperative active extension is measured and noted, as this will be used to measure the amount of lengthening required intraoperatively.

Positioning

- Position the patient supine with the arm on an armboard. A nonsterile tourniquet can be applied to the upper arm to provide a relatively bloodless field during the procedure.

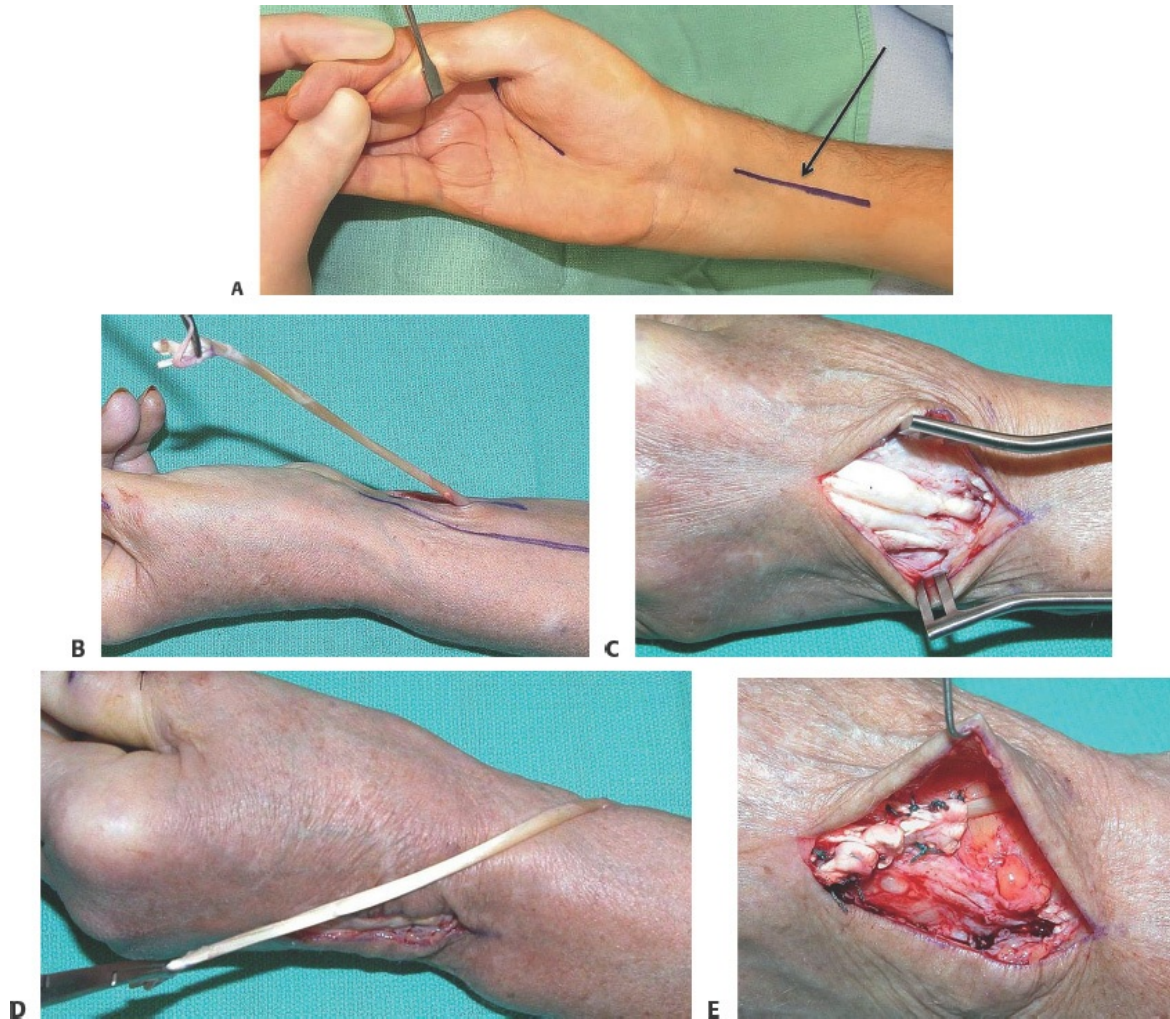
Approach

- The superficialis tendon can be routed through a radial or ulnar subcutaneous route or through the interosseous membrane.
- Either the superficialis tendon to the ring or the long finger can be used for transfer to the EDC.
- A longitudinal volar incision in the distal third of the forearm is typically used for fractional lengthening of the flexor tendons.

TECHNIQUES

■ Flexor Digitorum Superficialis to Extensor Digitorum Communis Tendon Transfer

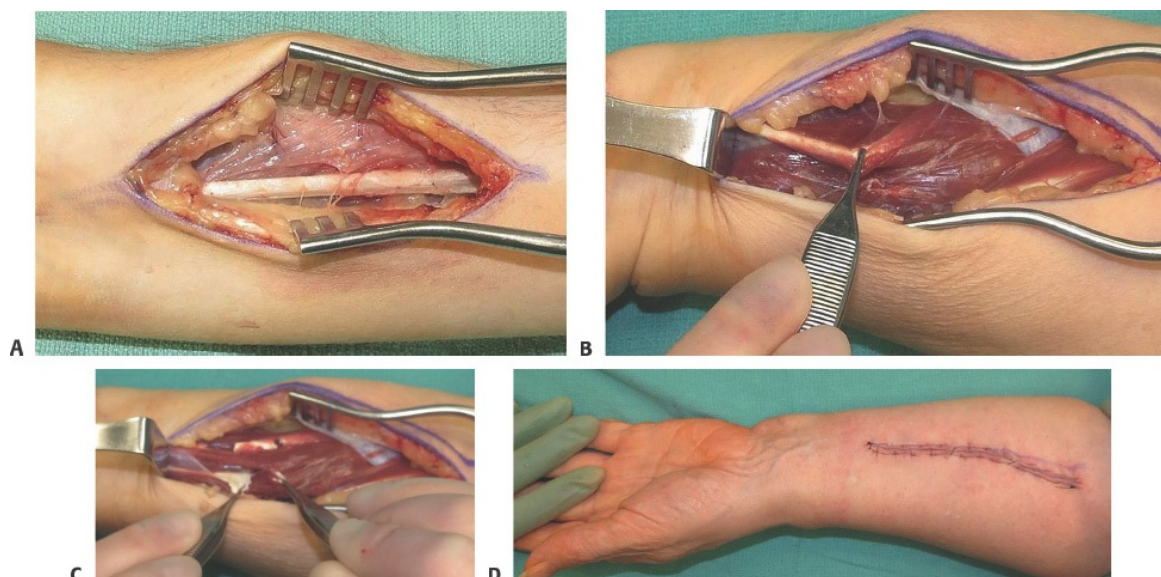
- Make an approximate 5-cm longitudinal incision along the border of the volar mid-forearm (**TECH FIG 1A**).
 - Dissect through the subcutaneous tissue to visualize the pronator quadratus and the interosseous membrane.
- Make a transverse incision at the base of the long or ring finger. Carry out dissection through the palm and identify the interval in the flexor sheath between the A1 pulley and the A2 pulley.
 - While protecting the flexor digitorum profundus (FDP) tendon, sharply divide the flexor digitorum superficialis (FDS) proximal to Camper chiasm, which should be adequate length for transfer to the extensor digitorum communis (EDC).
 - Deliver the FDS through the forearm wound with the wrist flexed (**TECH FIG 1B**).
- Make a longitudinal incision along the dorsal hand to identify the EDC tendons (**TECH FIG 1C**).
- Create a radial-based subcutaneous tunnel from the volar incision to the dorsal incision. Avoid injury to the radial neurovascular structures. Transfer the FDS tendon through this tunnel from a volar to dorsal direction (**TECH FIG 1D**).
- Perform a Pulvertaft weave with the FDS tendon to the EDC tendons in an end-to-end fashion distal to the extensor retinaculum (**TECH FIG 1E**). Set the tension with the wrist in 30 degrees of extension while the assistant clenches the fingers and the thumb into a fist to ensure that the repair is not too tight. Range the wrist from 30 degrees flexion to 30 degrees of extension and observe the finger cascade to confirm an appropriate tenodesis effect. The fingers should passively extend with wrist flexion and passively flex with wrist extension. If this does not occur, the tension of the repair may need to be adjusted.
- Release the tourniquet and achieve hemostasis. Close all the wounds primarily.
- Apply a splint with the wrist and digits in extension to the level of the proximal interphalangeal joints.



TECH FIG 1 • **A.** Volar mid-forearm incision (*arrow*) to approach the flexor tendons both for the FDS to EDC transfer and for flexor lengthening. **B.** FDS tendon divided distally and delivered through proximal forearm wound. **C.** Dorsal incision with exposure of the extensor digitorum communis tendons. **D.** Transfer of the FDS tendon from a volar to dorsal direction around the radial side of the wrist. **E.** Pulvertaft weave of FDS to EDC in an end-to-end fashion.

■ Step-Cut Fractional Lengthening of Flexor Tendons

- Make an approximate 5-cm longitudinal volar incision in the mid-distal forearm overlying the musculotendinous junctions of the flexor muscles.
- Carry out subcutaneous dissection to visualize the tendinous portions of the flexor muscles (**TECH FIG 2A**).
- Identify the musculotendinous junction (**TECH FIG 2B**).
- Measure the amount of lengthening necessary by placing the wrist and digits in the position of maximum active extension determined preoperatively. From this position, passively extend the fingers and measure the amount of tendon excursion. The tendons will need to be lengthened by a value half of that measured.
- Obliquely divide each of the FDS tendons at the musculotendinous junction without injuring the muscle fibers (**TECH FIG 2C**). The vascularity and support of the muscle will be necessary for postoperative tendon healing.
- Passively extend each digit just short of the desired length and observe as the tendon and muscle fibers slide distally creating a 2- to 3-cm gap.
- If the procedure is also being performed for wrist flexion, first divide the flexor carpi radialis and flexor carpi ulnaris myotendinous junctions before the finger flexors.
- Determine if FDP lengthening is necessary by examining the amount of extension attained after FDS lengthening.
 - If FDP lengthening is required, dissect the FDP tendons.
 - During the dissection, carefully ligate small ulnar artery perforators with bipolar cautery to prevent postoperative bleeding.
 - Divide the FDP tendons at the musculotendinous junction as described above.
- The flexor pollicis longus tendon can also be lengthened if necessary.
- If, after dividing all the FDS and FDP tendons, there is still inadequate lengthening, a second recession can then be made.
- Deflate the tourniquet and achieve hemostasis. Close the incision primarily (**TECH FIG 2D**).
- Provided there is no excess tension on the neurovascular structures, splint the patient with the wrist in neutral position and permitting mobilization of the fingers.



TECH FIG 2 • **A.** Volar incision with visualization of the FDS tendon. **B.** The musculotendinous junction is identified and will be the location of the lengthening. **C.** Recessions made in the FDS and FDP. Note the lengthening of the tendon between the two forceps. **D.** Wound closure with the fingers in extension. Care is taken to appreciate any tension on neurovascular structures before closing the wound and splinting the fingers in extension.

PEARLS AND PITFALLS

Flexor digitorum superficialis to extensor digitorum communis transfer

- Confirm that the extensor retinaculum does not impinge on the conjoined tendons. It can be incised if necessary.
- Perform a Pulvertaft weave and confirm that appropriate tension has been set by observing the finger cascade with tenodesis of the wrist. Wrist extension should result in passive finger flexion. Similarly wrist flexion should result in passive finger extension.

Flexor lengthening

- Be certain to identify the median nerve prior to dividing any of the flexor tendons.

- Incise the flexor tendons within the muscle to provide adequate lengthening. Do not cut the tendons too distally.
- Do not incise the muscle belly when dividing the tendons.
- Re-examine the neurovascular structures prior to postoperative positioning to ensure there is no excess tension with the wrist in neutral position. If there is tension, position the wrist as close to neutral as possible.
- Do not fully extend the digits intraoperatively to prevent overcorrection and excess weakening of the flexor tendons, which can lead to a swan-neck deformity.

POSTOPERATIVE CARE

- After the FDS to EDC transfer, the postoperative splint is maintained for 4 weeks. At that point, the splint can be removed for therapy but is to otherwise be worn for another 2 weeks.
 - At 6 weeks, the patient will no longer need external support.
- After flexor tendon lengthening, active and active-assisted exercises begin on the first postoperative day. The immediate active motion permits the flexor tendons to continue to lengthen as necessary given each individual patient's tone and control.
- Passive extension can begin after 4 weeks, and the patient wears a custom orthotic to maintain passive extension for an additional month.
 - The patient can then transition to a nighttime orthotic for an additional 3 months.

OUTCOMES

- After the FDS to EDC transfer, almost all patients have an improvement in function with the majority being excellent to good.¹
- With flexor lengthening, improvement in function can be observed in up to 90% of patients.²

COMPLICATIONS

- With FDS to EDC transfer, patients may rarely develop postoperative extension contractures of the metacarpophalangeal joints necessitating a joint capsulectomy with extensor tenolysis.¹ Other possible complications include setting the tension too loosely or pulling out the tendon weave.
- Transfer of the FDS tendon can lead to proximal interphalangeal joint flexion contracture or hyperextension deformity. This can best be avoided by diving

the FDS tendon proximal to the decussation, and not at the level of its insertion, to prevent disruption of the blood supply to the profundus tendon.^{3,4}

- In flexor lengthening, it is possible to overlengthen the flexor tendons, leading to a loss of grip strength and a decrease in function.² Similarly, an inadequate lengthening can result in persistent postoperative flexion deformity.

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61 Lateral Key Pinch Reconstruction

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Lateral key pinch is necessary to secure small objects for many activities of daily living including writing, feeding, drinking, and self-catheterization.
- The act of pinching involves four phases:
 - Object acquisition
 - Pinch/grasp
 - Holding/manipulation
 - Object release
- Patients with C5-C6 tetraplegia most often present with an International Classification for Surgery of the Hand in Tetraplegia (ICT) of 1 or higher. The only muscle available for transfer is the brachioradialis, which is typically used for wrist extension. Therefore, these patients are entirely dependent on tenodesis for passive lateral pinch, resulting in a weak pinch that often stretches with time.
- Patients with an ICT of 2 or more have active wrist extension and are candidates for augmentation of lateral pinch with a brachioradialis (BR) to flexor pollicis longus (FPL) transfer.
 - Those with ICT of 4 or higher are candidates for pronator teres (PT) transfer to the FPL, freeing up the BR for additional tendon transfers.

ANATOMY

- The surgeon must be familiar with the forearm anatomy, including the brachioradialis and its local neurovascular structures (**FIG 1**).
- Two-thirds of the pronator teres (PT) originates from the medial epicondyle inferior and lateral to the flexor carpi ulnaris. One-third originates from the

anterior proximal ulna. The PT has very little free tendon distal to its muscle belly, measuring approximately 1 cm and often blending with the periosteum.¹

- The FPL origin is the volar surface of the radius adjacent to the interosseous membrane, and it inserts on the base of the distal phalanx of the thumb. It runs in the same plane as the flexor digitorum profundus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The exam should include a complete motor and sensory assessment of the extremity. Patients with inadequate sensation are less likely to use the reconstruction, leading to suboptimal outcomes.
- The patient's ability to perform baseline lateral pinch should be assessed, with the wrist in 30 degrees of flexion, neutral position, and 30 degrees of extension.
- The brachioradialis or the pronator teres must be confirmed to have a MRC grade 4 or higher prior to transfer.
- The strength of the brachioradialis must have a Medical Research Council grade 4 or higher. To test the brachioradialis, position the patient's elbow in a midprone position and have the patient flex against resistance contracting the brachioradialis. Palpate and attempt to move the belly of the muscle. If the muscle is tight, the brachioradialis has adequate strength for transfer (**FIG 2**).
- The pronator teres can be palpated on the lateral forearm distal to the antecubital fossa with resisted pronation.
- The index finger strength should be evaluated to ensure stability to serve as a post for the reconstructed thumb.

IMAGING

- If the examination is equivocal, electromyography (EMG) may be used to confirm or verify that the brachioradialis or pronator teres is under volitional control prior to transfer.

SURGICAL MANAGEMENT

- The goal of surgery is to establish a strong key pinch between the pulp of the thumb and the radial side of the index finger, independent of wrist extension.

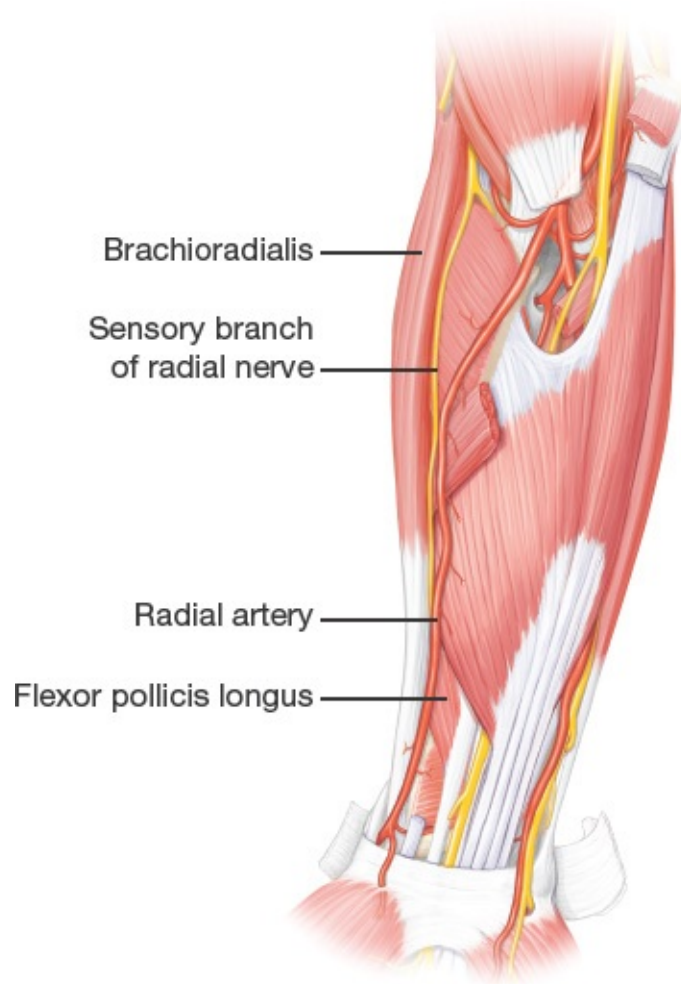


FIG 1 • Relevant volar anatomy. Note the relationship of the brachioradialis with the sensory branch of the radial nerve and the radial artery.

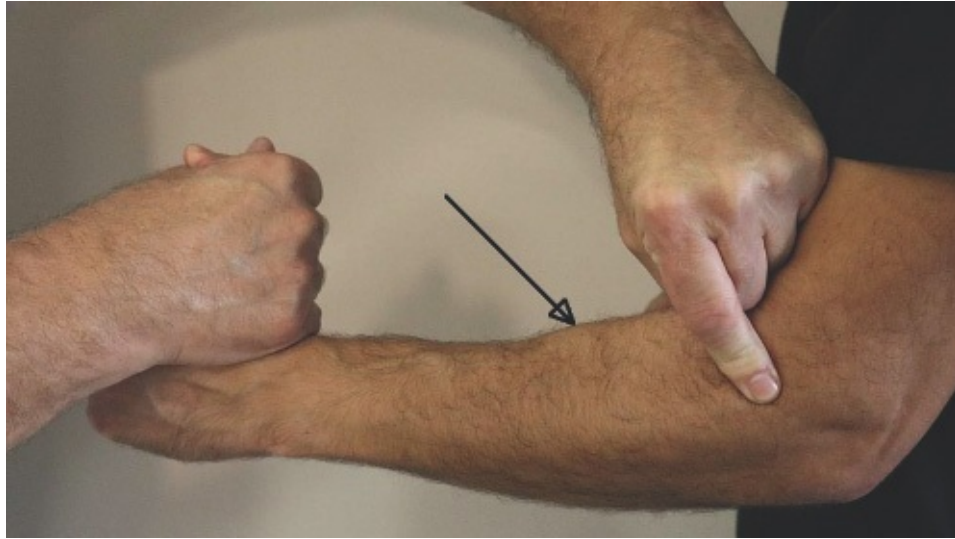


FIG 2 • To examine the brachioradialis, place the patient's forearm in neutral position and ask the patient to flex the elbow against resistance. The prominence of the muscle belly is evident along the proximal radial forearm (*arrow*). Difficulty to displace the muscle with the examiner's hand confirms adequate strength for transfer.

- Prerequisites to surgery include² the following:
 - Stability in a wheelchair. The patient must be able to sit for extended periods of time to use the reconstruction for meaningful tasks.
 - Control of the elbow. Control of the arm and hand position in space is imperative for key pinch.
 - Ability to pronate the arm. With pronation, gravity will enable wrist flexion to releasing the pinch.
 - Sufficient power in wrist extension to augment the power of the pinch
 - Normal passive range of motion of the thumb carpometacarpal (CMC) joint
 - Stability of the index finger to serve as a post against which the thumb can push during pinch
- Patients should have intact two-point discrimination of less than 1.5 cm at the thumb and index finger.³
- Patients with active wrist extensors and the ability to passively or actively flex the fingers are the ideal candidates for active key pinch reconstruction.

- In patients with tetraplegia, activation of the FPL alone will often interfere with the normal balance of the thumb. This will lead to unpredictable thumb positioning and instability. To help circumvent this problem, the following procedures can accompany the tendon transfer to the FPL:
 - Preposition the thumb ray through a fusion at the CMC joint. This helps to stabilize the normally complex movements of the CMC saddle joint.
 - Stabilize the interphalangeal (IP) joint of the thumb to prevent IP joint hyperflexion from unopposed FPL flexion across the IP joint (Froment sign).
 - Tenodesis of the extensor pollicis longus (EPL) extending the IP joint of the thumb with wrist flexion to aid in release of the pinch
- In cases of spinal cord injury, it is important to delay the surgical intervention until the patient's recovery has plateaued, typically 12 to 18 months.

Preoperative Planning

- The patient's underlying cause of spasticity and the current psychosocial state must be carefully assessed before proceeding with surgical reconstruction (see chapter on Elbow Extension Procedures).
- Any contractures preventing passive range of motion must be treated prior to tendon transfer. On the day of surgery, the range of motion must be assessed to rule out recurrence of the contracture.

Positioning

- Position the patient supine with the arm extended on an armboard.
- An upper arm tourniquet can provide a relatively bloodless field during the procedure.

Approach

- The brachioradialis or the pronator teres can be utilized for transfer to the FPL depending on the number of active muscles available with an MRC score of 4 or higher.

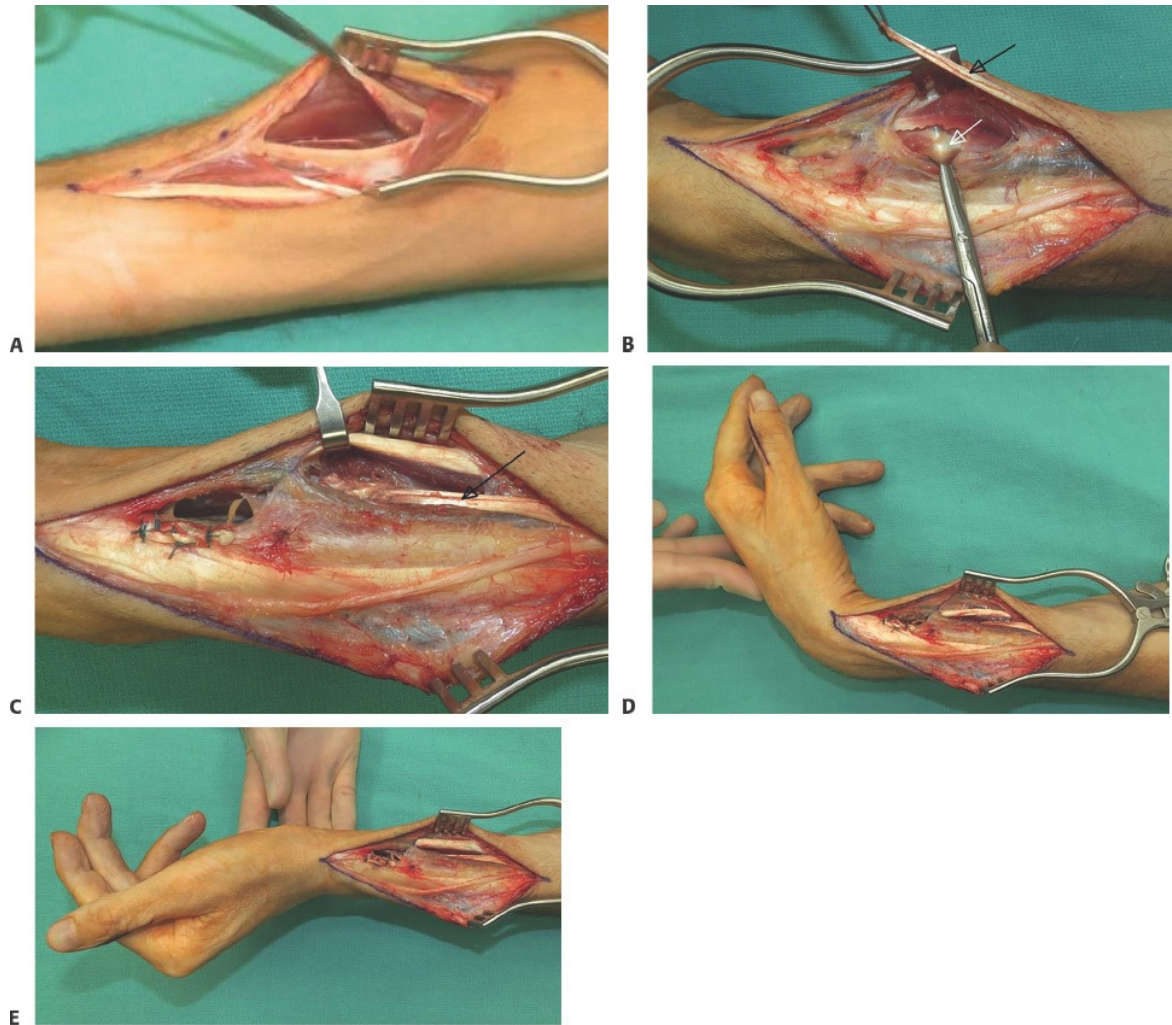
TECHNIQUES

■ Brachioradialis/Pronator Teres to Flexor Pollicis

Longus Transfer

- Make an 8- to 10-cm longitudinal incision on the dorsoradial wrist beginning at the radial styloid and extending proximally.
- If the brachioradialis will be used for transfer, begin subcutaneous dissection and identify the tendon of the brachioradialis, the superficial branch of the radial nerve, and the radial artery. Protect the neurovascular structures, longitudinally incise the paratenon, and dissect the brachioradialis.
- Sharply divide the terminal tendon as distal as possible under the abductor pollicis longus and the extensor pollicis brevis.
- Dissect along the deep aspect of the muscle by freeing it from its fascial and muscle connections proximally toward the elbow. As dissection proceeds proximally from the tendon insertion, the radial artery and the dorsal sensory branch of the radial nerve become more prominent. Ligate the small perforating vessels entering the muscle belly.
- Continue proximal dissection until the radial recurrent vessels are identified. The vessels will be traveling transversely on the deep aspect of the muscle just distal to the elbow flexion crease.
 - This marks the extent of the proximal dissection.
- An approximate 3 cm of excursion will be obtained if the muscle is completely freed.
- If the pronator teres is to be used for transfer, identify and incise it at its insertion on the radius. Similar to the brachioradialis, elevate the PT from the radial periosteum proximally for 4 to 5 cm (**TECH FIG 1A**).
- Identify the FPL tendon deep to the flexor carpi radialis (FCR) and radial to the flexor digitorum profundus. Take care to identify and protect the radial artery. Divide the FPL 1 cm proximal to the proximal edge of the pronator quadratus (**TECH FIG 1B**).
- Tunnel the brachioradialis under the radial neurovascular bundle so that it can reach the FPL. Suture the BR or the PT tendon to the FPL with 2-0 nonabsorbable braided sutures with a Pulvertaft weave (**TECH FIG 1C**).
- Set the tension so that passive wrist flexion causes thumb abduction and extension and so that wrist extension flexes the thumb metacarpophalangeal joint, positioning the pulp of the thumb against the radial side of the middle phalanx of the index finger (**TECH FIG 1D,E**).
- Release the tourniquet and achieve hemostasis. Close the incisions primarily.

- Place a long-arm splint with the elbow in midprone position and 90 degrees of flexion, the wrist in 10 to 20 degrees of flexion, and the thumb in abduction.



TECH FIG 1 • A. Dissection of the pronator teres muscle. An approximate 4 to 5 cm of elevation off the periosteum of the radius is necessary. **B.** The FPL (*white arrow*) is identified and ligated proximal to the pronator quadratus for transfer. The *black arrow* indicates the brachioradialis. **C.** The brachioradialis (*black arrow*) is tunneled deep to the radial neurovascular bundle and sutured to the FPL with a Pulvertaft weave. **D,E.** The tension is set so that

passive wrist flexion causes thumb abduction and wrist extension positions the pulp of the thumb against the radial side of the middle phalanx of the index finger, effectively creating a pinch.

PEARLS AND PITFALLS

Patient selection

- Confirm that there is adequate index finger strength and stability to serve as a post for the thumb.
- Sensation is important for useful pinch function.

Surgical procedure

- Identify and protect the radial sensory nerve before dividing the brachioradialis tendon.
- Do not injure the radial recurrent vessels when dissecting the BR proximally. They can be found on the deep surface of the muscle just distal to the elbow flexion crease signaling the extent of proximal dissection.
- The neurovascular supply to the brachioradialis should not be at risk because it enters the muscle proximal to the elbow.
- Free the brachioradialis proximally to the level of the elbow (without injuring the vascular pedicle) to provide adequate excursion.
- Pass the brachioradialis deep (dorsal) to the radial artery before performing the tendon repair.
- Elevate the pronator teres off the radial periosteum for approximately 4–5 cm.
- Other procedures such as IP joint stabilization, CMC fusion, or EPL tenodesis may be necessary depending on the individual.

POSTOPERATIVE CARE

- The patient remains immobilized in a splint for 6 weeks followed by mobilization with occupational therapy.

OUTCOMES

- Patients can achieve an average postoperative key pinch strength of 2 kg, facilitating many activities of daily living including hygiene, grooming, mobility, and writing.³ The longevity of the reconstruction is excellent with a

minimal decrease in strength over time.⁴

COMPLICATIONS

- Tendon adhesions are a potential complication particularly if additional tendon transfers are being performed during the procedure.⁵
- Brachioradialis transfer to the FPL can result in hyperflexion of the interphalangeal joint resulting in a pinch posture between the dorsal distal thumb phalanx and the volar index middle phalanx.⁶ This can be addressed with stabilization of the IP joint.

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62 Grasp Improvement Procedures

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- The primary purpose of the hand is for gripping, feeling, and engaging in human contact. The capacity to pinch and grasp is key to productive gripping.
- With the ability to grasp objects in the palm, an individual can handle larger objects than would otherwise be possible with pinch alone. Manipulating cans, bottles, or a telephone becomes a reality, significantly expanding an individual's breadth and capacity to perform activities of daily living.
- Patients with a midlevel tetraplegia or International Classification for Surgery of the Hand in Tetraplegia (ICT) scores of 3 or higher have sufficient donor muscles for active grasp reconstruction (see chapter on Elbow Extension Procedures). The extensor carpi radialis longus (ECRL) can be used for tendon transfer while preserving the extensor carpi radialis brevis (ECRB) for active wrist extension.
- The ECRL is a good potential donor for active finger flexion because it is synergistic with the finger flexors. Normally, finger flexion is paired with wrist extension, making postoperative rehabilitation much easier for the patient.
- Additionally, patients with spasticity may present with fixed finger flexion deformities.
- A fixed flexion deformity of the flexor digitorum superficialis (FDS) and the flexor digitorum profundus (FDP) can lead to difficulty with personal skin care and hand hygiene.
 - An FDS to FDP (superficialis to profundus, STP) transfer can alleviate such contractures.
- Performing grasp is also challenging in patients with an intrinsic minus hand position: metacarpophalangeal (MCP) hyperextension and interphalangeal (IP)

flexion.

- A Zancolli lasso procedure using the FDS tendons can provide hand intrinsic balancing in patients with an intrinsic minus deformity via a dynamic tenodesis effect.

ANATOMY

- The surgeon must be familiar with the anatomy of the finger flexors including both the FDS and the FDP (see Finger Extension chapter).
- The ECRL originates from the distal supracondylar ridge and inserts on the base of the index metacarpal. It serves to extend and radially deviate the wrist.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The entire upper extremity must be examined for both motor and sensory function including range of motion. The evaluation must also incorporate the resting position of the hand, as this will guide the surgical approach. Patients with a contracture and flexion posture of the fingers will benefit from an STP transfer, whereas those with clawing may require a lasso procedure.
- In patients with tetraplegia, the ICT score must be determined. Both the ECRL and the ECRB must be active with sufficient wrist extension if the ECRL is to be used as a donor muscle for active grasp reconstruction.
- To test the ECRB and ECRL, the patient attempts wrist extension against resistance. A palpable groove, or V sign, forms between the two proximal muscle bellies if both have an MRC grade of 5 (**FIG 1**).¹
- For patients presenting with a contracture, it is important to specifically evaluate the contribution of the FDS and FDP muscles to the contracture. Examine finger extension both with the wrist in maximum flexion and in maximum extension.
 - In cases of FDS and FDP contracture, finger flexion deformity will be worse on examination with the wrist in maximum extension as compared to maximum flexion. This occurs because wrist extension tightens the flexor tendons exacerbating the deformity.
- The MCP, proximal IP, and distal IP joints should be examined to rule out joint contracture and intrinsic tightness.
 - An ulnar nerve lidocaine block during examination can help better determine the presence of intrinsic spasticity or contracture.² Spasticity will improve after a nerve block whereas a contracture will not.



FIG 1 • Test to confirm active use of the ECRL and ECRB. A V sign forms between the two muscle bellies of the wrist extensors with resisted wrist extension.

IMAGING

- If despite clinical examination, the examiner is still uncertain of whether a muscle is under volitional control, electromyography focusing on the muscle of interest helps identify spastic and flaccid muscles and determine phasic activity.

NONOPERATIVE MANAGEMENT

- Modest attempts to control the position of the hand in contracture or spasticity can be performed with serial splinting or casting.
- Phenol motor blocks may alleviate spasticity to a degree.

SURGICAL MANAGEMENT

- ECRL to FDP transfer
 - For an effective grasp, the fingers must first be able to extend to wrap around an object and then flex to grab it.
 - Unlike lateral pinch where tenodesis of the EPL can be used to extend the thumb in preparation for pinch, for grasp, and for release, the reconstruction cannot rely solely on finger tenodesis for finger extension. The presence of active finger flexion without active finger extensors will create a tendon imbalance, leading to flexion contractures.
 - Finger extension and finger flexion reconstructions have competing postoperative rehabilitation protocols. Historically, a two-staged reconstruction has been described. The ECRL to FDP transfer is typically the

second stage, whereas the extensor reconstruction is the first stage (see Finger Extension chapter). However, both stages are more frequently performed simultaneously, particularly in a more frail and elderly patient who may not tolerate multiple operations with multiple periods of immobilization.

- Before active grasp reconstruction, the priority is to first ensure the patient has active elbow and wrist extension. Therefore, only patients with ICT grade 3 or higher have sufficient donor muscles for reconstruction.
- ECRL to FDP transfer is indicated in patients who require active finger flexion and have good active wrist extension with supple wrist and PIP joints.
- Wrist extension occurs synergistically with finger flexion, making the ECRL an ideal motor for transfer to the FDP. Postoperative learning and rehabilitation is simpler than with other nonsynergistic transfers. Additionally, active wrist extension will shorten the flexors via tenodesis. The ECRL to FDP transfer takes advantage of this biomechanical principle by enhancing FDP flexion with wrist extension and providing an additional 2 cm of tendon excursion.³

■ STP transfer

- The STP transfer is indicated in patients with severe spasticity or in patients with an established contracture of the forearm musculotendinous units, resulting in fixed finger flexion contracture.⁴
- The patient typically has no functional use of the fingers and often suffers from hygiene problems with skin maceration and nonhealing palmar wounds.
- The goal of the procedure is to position the hand in a more functional posture, facilitating hygiene and personal care, without leaving the patient with flaccid fingers.
- The procedure alleviates contracture by transecting the finger flexors but still maintains wrist balance by transferring the FDS to the FDP tendons (**FIG 2**). The STP transfer can be performed with concomitant lengthening of wrist and thumb flexors when necessary, to achieve a position of balance between the wrist and digits.⁴

■ Zancolli lasso procedure

- The Zancolli lasso procedure is indicated in patients with clawing or an intrinsic minus deformity of the digits.
- As originally described by Zancolli, the lasso procedure results in a dynamic passive tenodesis causing MP flexion with active wrist extension. This augments grasp by initiating the first stage of grasping: MP flexion.
- Patients with a concurrent PIP flexion deformity from FDS spasticity further

benefit from the lasso procedure by releasing the FDS as the spastic deforming force and transferring it into an MP flexor.

- The lasso procedure can also be performed prophylactically to prevent MP joint hyperextension and clawing with finger extension.
- Taking advantage of the tenodesis effect, the lasso procedure is also effective in patients with a paralyzed FDS.

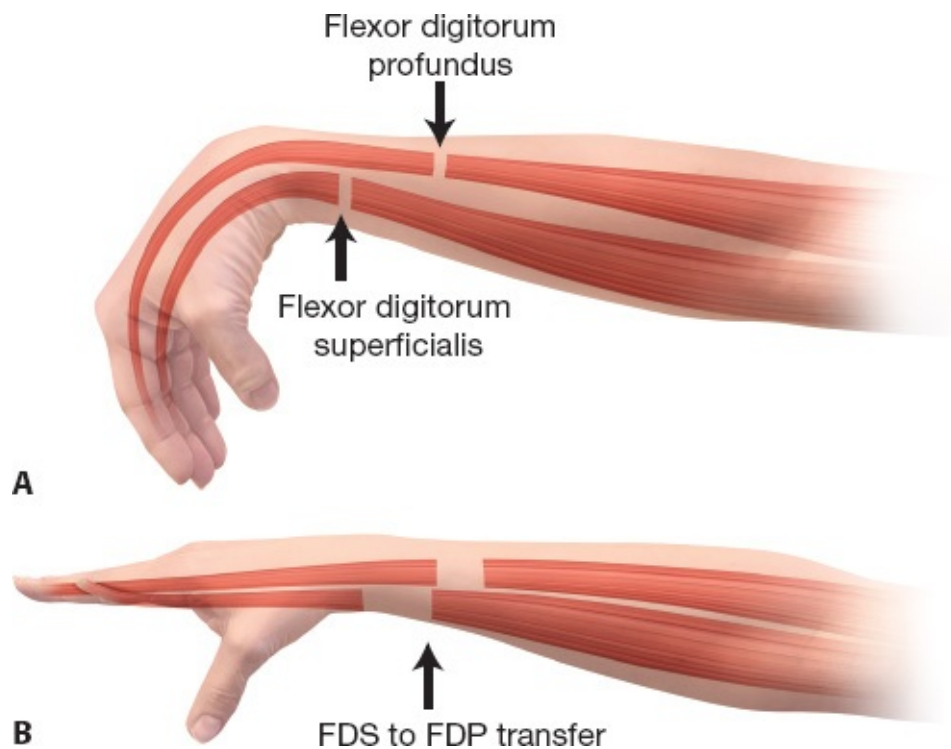


FIG 2 • FDS to FDP transfer. **A.** Finger flexion deformity involving both the FDS and FDP muscles. A transection is made in the proximal FDP and the distal FDS. **B.** The wrist is extended and the proximal end of the FDS is transferred to the distal end of the FDP to re-establish wrist balance and permit finger flexion.

Preoperative Planning

- It is imperative to confirm that the patient is not entirely dependent on the ECRL for wrist extension prior to its use for transfer. The V sign confirming the presence of a strong ECRL and ECRB on physical exam is very reliable, but if there is any doubt, the surgeon should leave the ECRL intact (see **FIG 1**).

- Prior to an STP transfer, confirm that the MCP and IP joints are supple. If joint contracture is present, the transfer alone will do little to improve the flexion deformity. The patient may need additional procedures such as closed manipulation, capsulotomies, or joint fusions.
- Following an STP transfer, the patient will continue to have limited finger motion. The purpose of the operation is to improve finger position for better hygiene, not function. This should be clearly discussed with the patient and caregivers before surgery.
- If an anterior elbow release is also planned, perform the release prior to the FDS tendon transfer. This will facilitate positioning the forearm, simplifying exposure and visualization for STP transfer.

Positioning

- The patient is placed in the supine position with the arm extended on an arm board. A nonsterile upper arm tourniquet is applied to provide a bloodless operative field. General anesthesia can help provide maximum muscle relaxation.

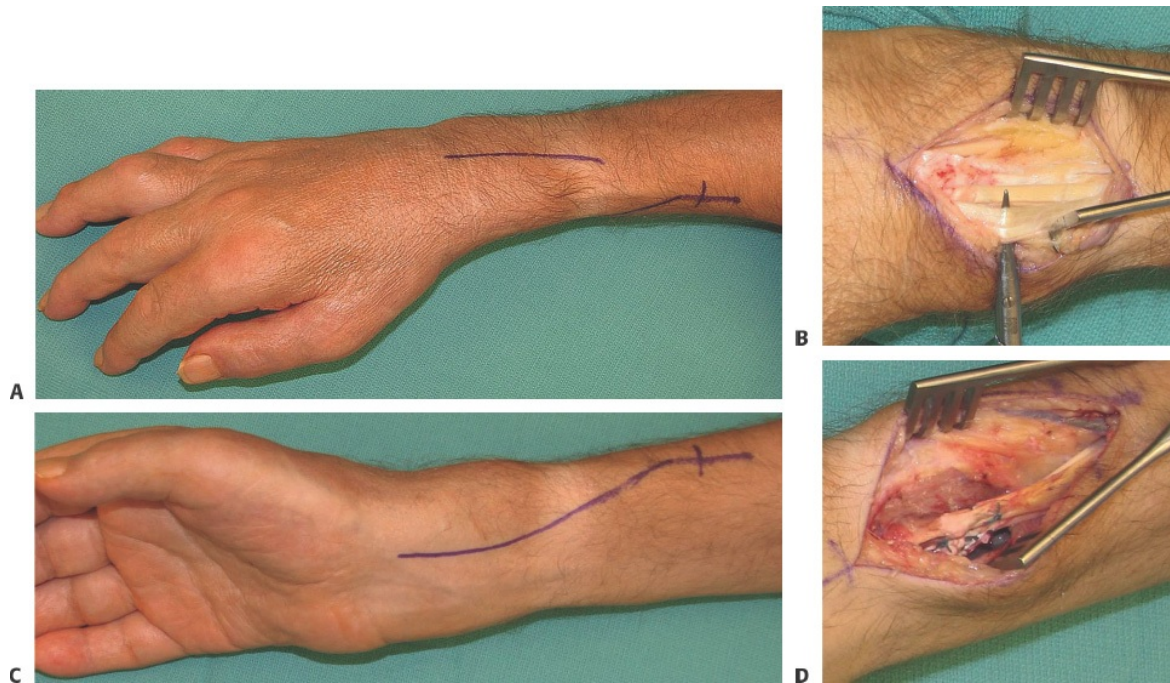
Approach

- Various approaches are possible, and multiple incisions are often required.
- The ECRL can be transferred to the FDP around the radial border of the radius or through the interosseous membrane. An advantage of transfer around the radius is that the line of pull provides secondary forearm supination.
- The Zancolli lasso is an intrinsic reconstruction that is an adjunct to the extrinsic tendon reconstruction. It can be performed during either of the two stages of hand reconstruction (extensor or flexor stage).
- For the Zancolli lasso procedure, a single transverse incision or separate zigzag incisions can be made across the MP flexion creases. The lasso can be performed with the FDS of each individual finger used as a lasso or splitting the slips of the FDS of the middle and ring finger to lasso around the index/middle and the ring/small fingers, respectively. Another technique involves taking only the middle finger FDS tendon and splitting it into four slips to be used for all the fingers.⁵

TECHNIQUES

■ Extensor Carpi Radialis Longus to Flexor Digitorum Profundus Transfer for Active Finger Flexion

- Make an 8- to 10-cm longitudinal dorsal incision (**TECH FIG 1A**).
- Identify the extensor carpi radialis longus (ECRL) and the extensor carpi radialis brevis tendons (ECRB). Identify and protect the superficial radial nerve (**TECH FIG 1B**).
- Sharply transect the ECRL tendon as distal as possible at the level of its insertion on the index metacarpal and deliver it proximal to the extensor retinaculum.
- Dissect the ECRL as far proximal as possible to maximize its excursion and to provide a straight line of pull for its new insertion.
- Make a volar incision to identify the FDP tendons at its musculotendinous junctions at the wrist crease (**TECH FIG 1C**).
- Pass the ECRL tendon under the radial vessels into the volar forearm and perform a Pulvertaft weave in an end-to-end fashion to the flexor digitorum profundus tendons with 2-0 nonabsorbable braided sutures (**TECH FIG 1D**).
 - Be certain to include the FDP tendon to the index finger. It often is separate from the remaining digital profundus tendons and can easily be missed in the transfer.⁶
- Set the tension with the wrist in maximal tension. The fingertips should touch the palm with the wrist in full passive extension after tendon transfer.⁷
- If a Zancolli lasso procedure is also part of the reconstruction plan, perform it before ECRL transfer (either as a first-stage procedure or just before the ECRL transfer). The tension can be better gauged in this manner.
 - After the lasso procedure is complete, set the ECRL tension with the finger MP joints at 0 degrees when the wrist is at neutral. With the wrist in extension, the MP joints should flex 30 to 40 degrees.
- Release the tourniquet and achieve hemostasis. Close the incisions primarily.



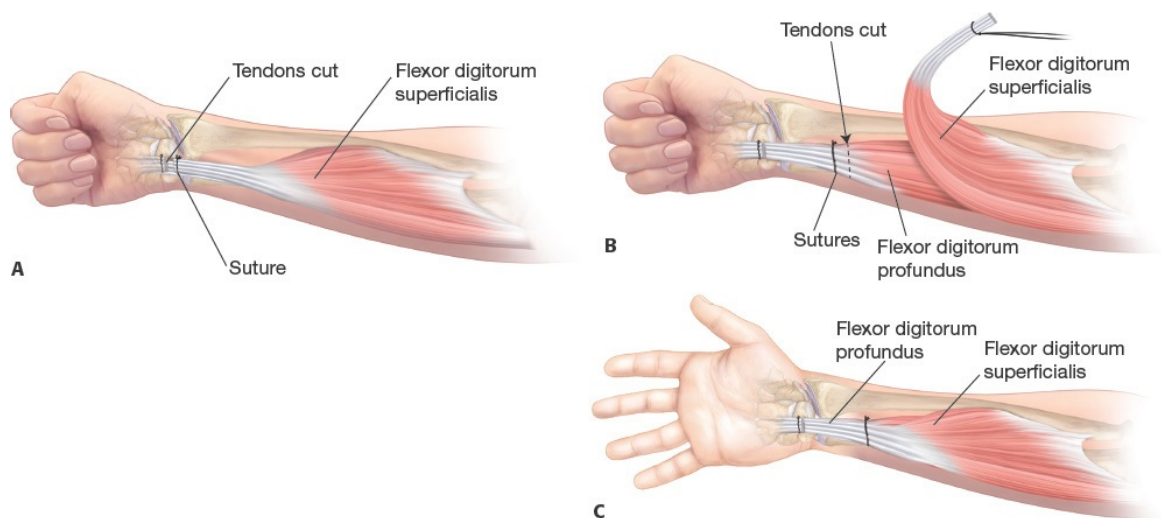
TECH FIG 1 • **A.** Dorsal incision for exposure of the extensor tendons. **B.** Identification of the ECRL tendon. **C.** Volar incision for exposure of the FDP tendons. **D.** Transfer of the ECRL tendon in the volar direction and completion of a Pulvertaft weave with the FDP tendons. Left, distal; right, proximal.

■ Flexor Digitorum Superficialis to Flexor Digitorum Profundus Transfer (Superficialis to Profundus Transfer)

- Identify the FDS and FDP tendons through a volar forearm incision (see **TECH FIG 1C**). Take care to avoid injury to the median nerve and the ulnar neurovascular bundle.
- Identify the palmaris longus, and perform a tenotomy proximally.
- Flex the wrist and identify the tendons of the FDS to the index, long, ring, and small fingers. Proximal to the transverse carpal ligament, suture all the FDS tendons together with a running, locking, nonabsorbable suture creating a single tendon unit.
- Sharply transect the FDS tendons at the level of the wrist distal to the suture

line (**TECH FIG 2A**).

- Retract the FDS tendon unit proximally exposing the FDP tendons. In a similar fashion, create a single tendon unit across the most proximal convergence of the FDP tendons to the index, long, ring, and small fingers. This location is approximately 10 cm proximal to the wrist crease. Sharply transect the FDP tendons proximal to the suture line (**TECH FIG 2B**).
- Extend the wrist and fingers, and note that the distal ends of the cut FDP tendons migrate distally.
- Suture the proximal FDS tendon unit to the distal FDP tendon unit with a nonabsorbable braided suture. Set the tension with an assistant holding the wrist and the fingers in maximum extension (**TECH FIG 2C**).
- Confirm that there is corrected finger extension and presence of the normal finger cascade.
- Release the tourniquet and achieve hemostasis. Close the wound primarily.
- Place a postoperative splint with the wrist in 20 degrees of extension and fingers in 20 degrees of flexion at the metacarpophalangeal and interphalangeal joints.



TECH FIG 2 • A. The tendons of the FDS are sutured together at the level of the wrist creating a single tendon unit. The tendons are ligated distal to the suture line. **B.** The sutured FDS unit is retracted proximally, and the FDP is identified. Approximately 10 cm proximal to the wrist crease, the FDP tendons are

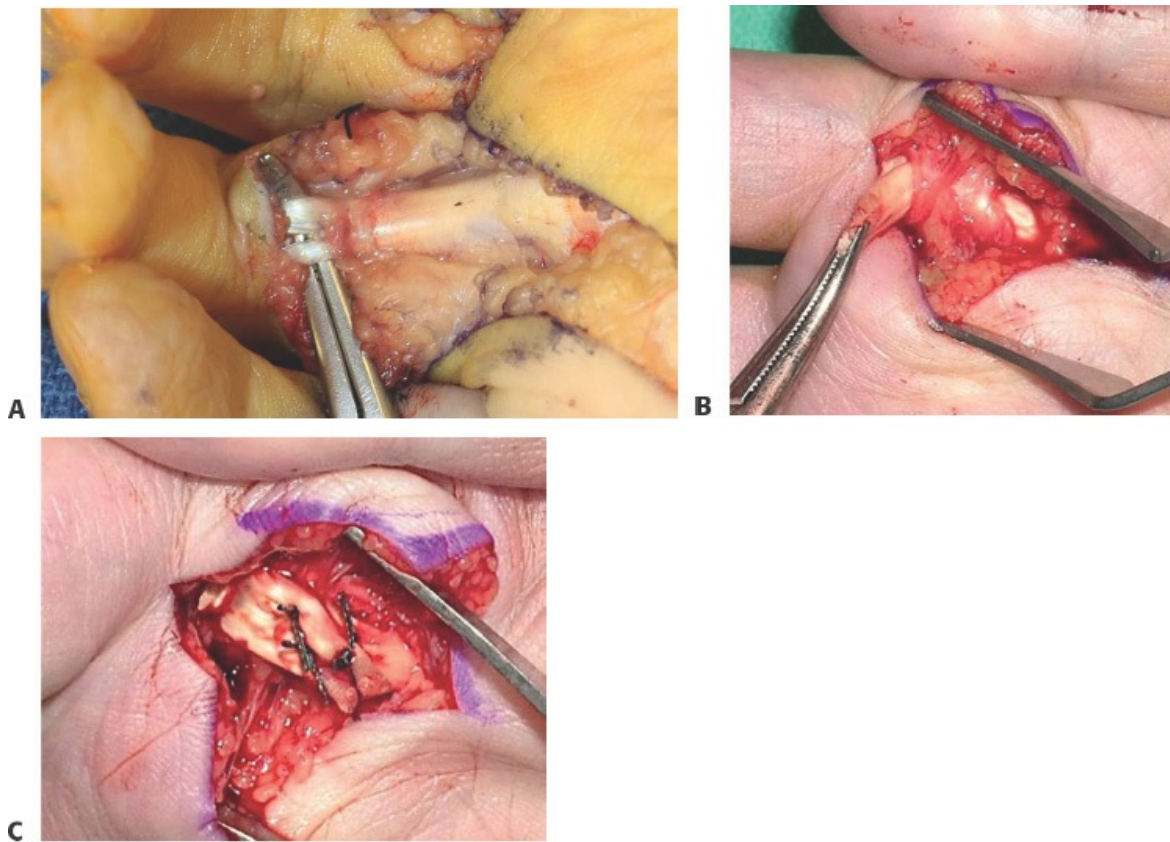
sutured together. The tendons are ligated proximal to the suture line. **C.** The hand is extended and the distal end of the FDP unit will migrate distally. The proximal end of the FDS is sutured to the distal end of the FDP.

■ Zancolli Lasso Procedure

- Make zigzag incisions on the palm and proximal digits to expose the flexor tendon sheaths from the middle of the metacarpal to the middle of the proximal phalanx. Take care to avoid injury to the neurovascular bundles.
- Identify the proximal and distal limits of the A1 pulley.
- Using a forceps, apply tension to the A1 pulley, simulating transfer, to determine whether the MP joint will be pulled into flexion.
 - If the MP joint cannot be pulled into flexion, include a portion of the A2 pulley in the transfer.
- Open the tendon sheath distal to the A1 pulley with an L-shaped incision.
- Flex the finger and identify the two slips of the FDS (**TECH FIG 3A**). Place a suture in the FDS to minimize proximal retraction with ligation.
- Divide both slips of the FDS tendon as far distally as possible. Use the suture in the FDS to help minimize handling of the FDP tendon and potential postoperative adhesions.
- Pull the FDS slips through the opening in the pulley sheath. Ensure that both slips of the FDS are free from all surrounding attachments, including the synovial sheath and vincula (**TECH FIG 3B**).
- Repeat the same procedure for each finger.
- Loop the FDS tendons back over the pulley sheath in a palmar and proximal direction. Suture the FDS tendon to itself using a 4-0 nonabsorbable suture in an interweave fashion (**TECH FIG 3C**).
- After inserting the first suture, confirm that there is appropriate tension by observing the MP motion to passive tenodesis.
 - When the wrist is extended, the MP joints should flex with a uniform cascade.
 - When the wrist is flexed, the MP joints should extend fully without hyperextending.
- Adjust the tension as necessary. Typically, the tension is increased gradually

from the index to small fingers to restore a physiologic cascade.³

- Confirm that the position of the index finger's MP joint will continue to permit key pinch with the thumb.
- Release the tourniquet and achieve hemostasis. Close the wounds primarily.
- Place the patient in postoperative immobilization with the wrist in 20 to 30 degrees of flexion, MP joints at 60 to 70 degrees of flexion, with the PIP and DIP joints free for 4 weeks.



TECH FIG 3 • A. The two slips of the FDS tendon are identified distal to the A1 pulley. The slips are ligated as distal as possible. **B.** The FDS tendon is pulled through the opening in the flexor sheath after ensuring that it is not tethered by the synovial sheath or vincula. **C.** The FDS tendon is looped around the A1 pulley in a palmar and proximal direction. It is sutured to itself forming a lasso around the A1 pulley.

PEARLS AND PITFALLS

General	■ Release the tourniquet and check for hemostasis prior to wound closure for the STP transfer. There are multiple perforators from the ulnar artery to the FDP that can easily be missed. ■ The median nerve can easily be mistaken for a flexor tendon under tourniquet control. A gentle exsanguination will preserve the longitudinal neural blood supply, making it easier to correctly identify and protect the nerve.
ECRL to FDP transfer	■ Patients must have strong wrist extension and not be solely dependent on the ECRL for wrist extension. ■ Identify the tendons of both the ECRL and the ECRB prior to transection to avoid injury to the ECRB. ■ Be certain to identify and include the FDP tendon to the index finger.
FDS to FDP transfer	■ Before closure, confirm that there is no excess tension on the neurovascular structures. This can limit the length of contracture release. ■ Create a single tendon unit of the FDS and FDP prior to transection to maintain the normal finger cascade. ■ Excursion of the median nerve may be a limiting factor for the amount of contracture release that can safely be attained.
Zancolli lasso procedure	■ If the small finger FDS is vestigial, the ulnar slip of the ring finger FDS can be used for the lasso.

POSTOPERATIVE CARE

- Following the ECRL to FDP transfer, the patient remains immobilized for 4 weeks until the tendon junctures have healed.
 - At that point, the patient begins mobilization and training with occupational therapy.
- After the STP transfer, the wound is examined at 10 days and sutures are removed.
 - The patient remains immobilized for another 4 weeks. Active finger flexion and extension can then begin, but the patient is to remain in a splint when not undergoing hand therapy or bathing.

- After 4 weeks, the patient can transition to a nighttime splint for 3 to 6 more months.
- After the Zancolli lasso procedure, patients begin immediate daily therapy with passive range of motion of the IP joints.
- After 4 weeks, convert the patient to a nighttime resting splint in the same position and active range of motion can be initiated.

OUTCOMES

- The ECRL to FDP transfer typically has good results in establishing active finger flexion.
- Following STP transfer, the majority of patients have an open position of the hand and wrist with resolution of palmar hygiene problems.^{2,4}
- Most patients have good to excellent results following the Zancolli lasso procedure with a significant improvement in grip strength.⁸

COMPLICATIONS

- In addition to typical surgical complications, rupture of the tendon repairs is a potential complication. This should be suspected if there is a sudden loss or drop of function during rehabilitation.
 - There should be a low threshold to return to the operating theater for exploration and the surgeon should be prepared to repair or revise the transfer with a tendon graft if necessary.
- If wrist extension is not properly assessed preoperatively and it is not properly established that the patient is dependent on the ECRL for wrist extension, its transfer can lead to postoperative difficulty with wrist extension.
- Following STP transfer, the risk of superficial wound infections is elevated, particularly in patients with macerated palmar skin at time of surgery.²
 - In patients with intrinsic hypertonicity, a swan-neck deformity can result if the intrinsic spasticity is not also addressed.
- FDP adhesions in the metacarpophalangeal area are common in the Zancolli lasso procedure, occasionally requiring tenolysis.

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Section XIII: Congenital Hand Disorders

63 Release of Finger Syndactyly Using Dorsal Rectangular Flap

CHAPTER

Amir H. Taghinia

DEFINITION

- Syndactyly is fusion of adjacent digits (Gr. *syn* with or together + *dactylos* finger).
- Syndactyly can be congenital or acquired. This discussion focuses on congenital syndactyly.

ANATOMY

- Syndactyly can involve skin, nail, bone, nerves, vessels, and tendons.
 - It can be simple, involving only skin, or complex, involving bone and other tissues. It can also be complicated, wherein the delineation of structures belonging to different digits is difficult to differentiate (**FIG 1A**).
 - It can be complete (involving the entire finger) or incomplete (partial involvement).
 - It can also be wide or narrow (**FIG 1B**). Most authors do not discuss this issue, but it bears greatly on the operative plan for release.
- The normal interdigital web space has an hourglass appearance. It begins dorsally distal to the metacarpophalangeal joint and takes a 45-degree palmar angle. The web meets the palmar skin halfway between the metacarpal head and the proximal interphalangeal (PIP) joint (**FIG 2**).

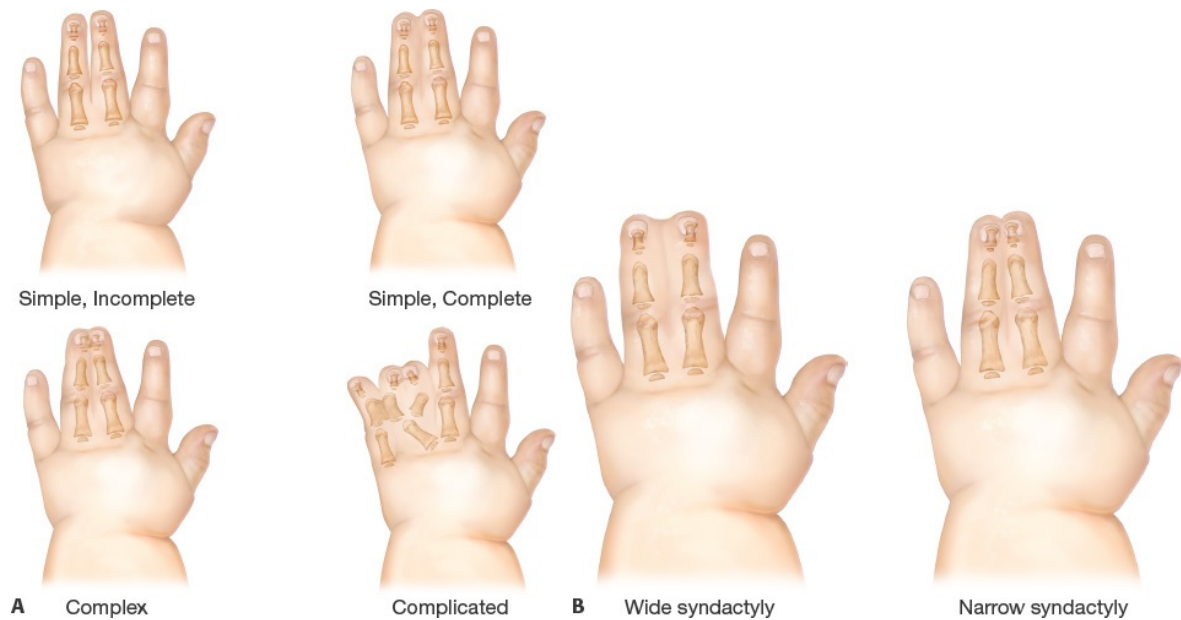


FIG 1 • A. Four types of syndactyly are shown. **B.** Syndactyly can be wide or narrow. Wide cases provide more skin for closure and allow easier interdigitation of flaps.

PATHOGENESIS AND NATURAL HISTORY

- The exact etiology of syndactyly has not been elucidated. It is considered to be a malformation, based on the Oberg, Manske, and Tonkin classification, likely due to failure of apoptosis.¹
- Syndactyly occurs in 1 out of 2000 to 3000 births. The natural history of untreated syndactyly is dependent on the degree of involvement.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are usually seen in infancy. The diagnosis is clear, but the involvement of deeper structures can be difficult to ascertain via physical examination alone.
- The surgeon should examine and record the web spaces involved, degree of involvement, deviation or angulation, nail involvement, and any deficits in range of motion. In most simple cases, range of motion is normal.
- The surgeon should elicit family history and determine if there are any associated medical conditions (syndromes).

IMAGING

- Plain radiographs are the study of choice, although they are rarely needed for simple syndactyly.

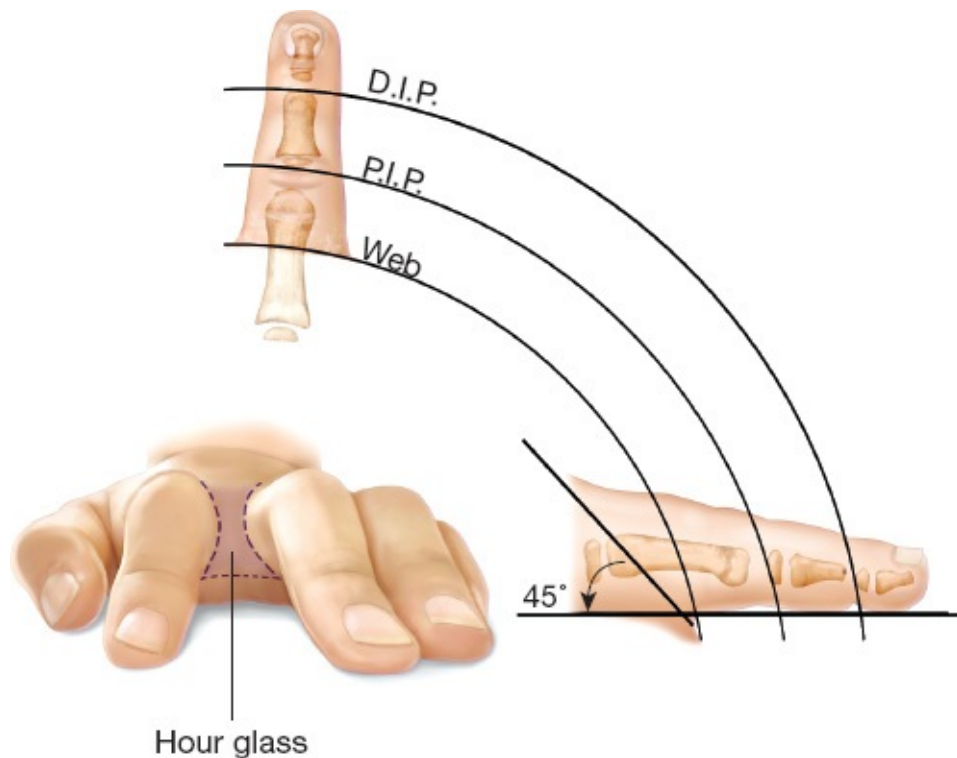


FIG 2 • The normal web space has an hourglass appearance with a 45-degree inclination. It meets the palmar skin halfway between the MP and PIP joints.

- Plain radiographs help delineate the degree of bone involvement and guide timing and technique of surgical release in complex and complicated cases (**FIG 3**).
- A few experts have advocated CT angiography to understand the vasculature when considering simultaneous release of neighboring web spaces,² but this is not routinely done.
- Even if simultaneous releases of adjacent digits are planned, the surgeon can make intraoperative judgment by dissecting the neurovascular bundles to preserve at least one artery to each digit.

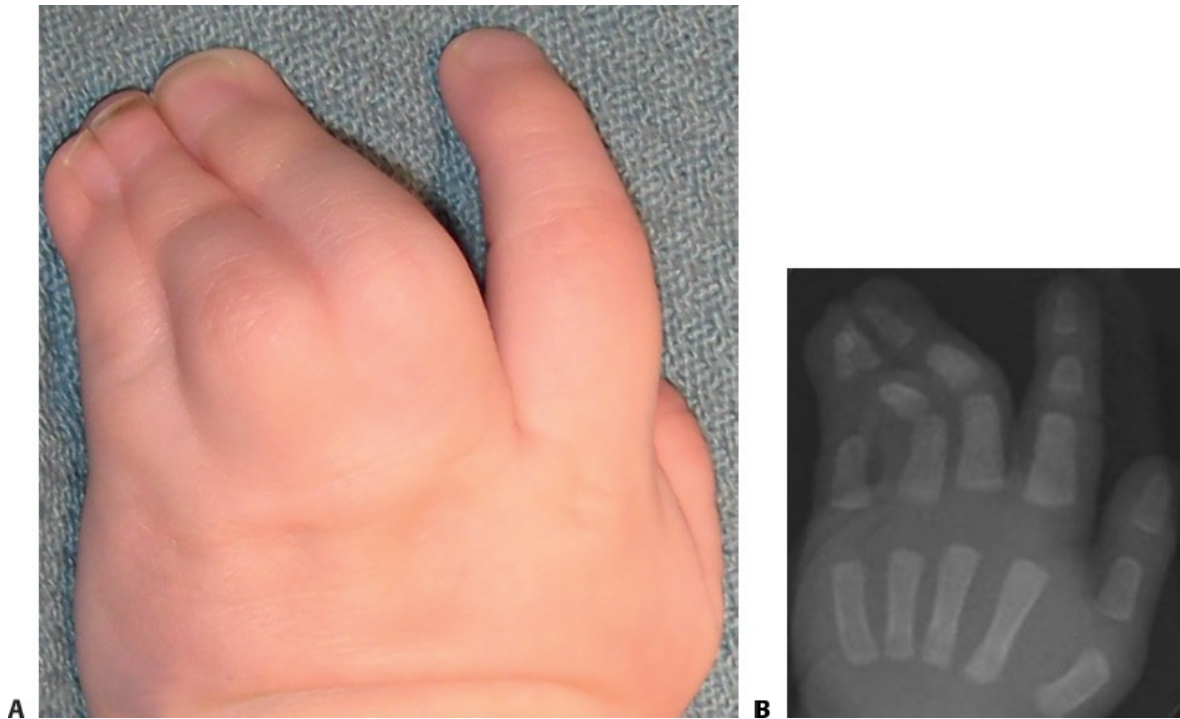


FIG 3 • Complex third and fourth web space syndactyly. Distal phalangeal coalition causes flexion and ulnar deviation of the longer digits.

SURGICAL MANAGEMENT

- The principles of syndactyly release are dorsal flap for commissure reconstruction, volar zigzag incisions to avoid contractures across flexion creases, and use of skin grafts as needed for coverage of open wounds.
- The author plans timing of syndactyly release based on the degree of involvement.
 - Patients with distal phalangeal coalition, especially between the small and ring fingers (with or without involvement of the middle finger), can develop significant deviation and flexion contractures of the longer fingers as the distal phalanges cause tethering (see **FIG 3**). Early intervention can help relieve this problem and allow improved directional growth.
- Simple syndactyly releases can be performed between 1 and 2 years of age. To relieve tethering and deviation, earlier release around 9 months is advocated. The decision to operate early has to be carefully weighed against possible long-term consequences of general anesthesia early on in childhood.
- The decision to use skin grafts, whether they should be split or full thickness,

and the places from which to harvest them have been hotly debated in the literature.^{3,4} A number of surgeons have presented different techniques for release without use of skin grafts.

- The author prefers to use of full-thickness skin grafts in most syndactyly release procedures. Syndactyly is a problem of missing skin. Skin grafting provides the best possible release and widest web space.
- The author takes full-thickness grafts from the lower abdomen (not the groin). This area provides ample skin for subsequent releases if there is multiple web involvement and heals nicely.
- Bilateral syndactyly release procedures are performed routinely in infants and toddlers.
- Neighboring web space releases are not performed simultaneously; they are staged about 6 to 9 months apart.
- Vascular insufficiency concerns alone do not inform this practice; rather, skin deficit on both sides of a finger makes closure more difficult.

Preoperative Planning

- Review radiographs again.
- Discuss risks, benefits, and expectations again with parents on the day of surgery. Specifically outline the risks of dense scarring, flap or graft loss (partial or complete), future web creep, and hyperpigmentation of skin grafts (especially in those with Fitzpatrick skin type IV and above).



FIG 4 • Draping of lower abdominal donor site for skin graft.

Positioning

- The patient is positioned supine with the arm out on a small hand table.
- The lower abdominal area for the skin graft is squared off with Steri-Drapes (**FIG 4**).

Approach

- Incisions are planned carefully prior to use of the tourniquet. The majority of the “case” is incision planning. The markings dictate where flaps will transpose and where skin grafting is needed.

- In cases where skin is deficient and dorsal and palmar flaps will not interdigitate, the author plans a dorsal straight-line release (**FIG 5**) and zigzag volar incisions (if flexion creases are present) as outlined above. This approach creates more open wounds to skin graft.
- Dorsal and volar incisions are made for every syndactyly release. Conjoined bones and neurovascular bundles are best approached dorsally.



FIG 5 • When the syndactyly is very narrow (usually due to bone fusion) and/or multiple adjacent web spaces are

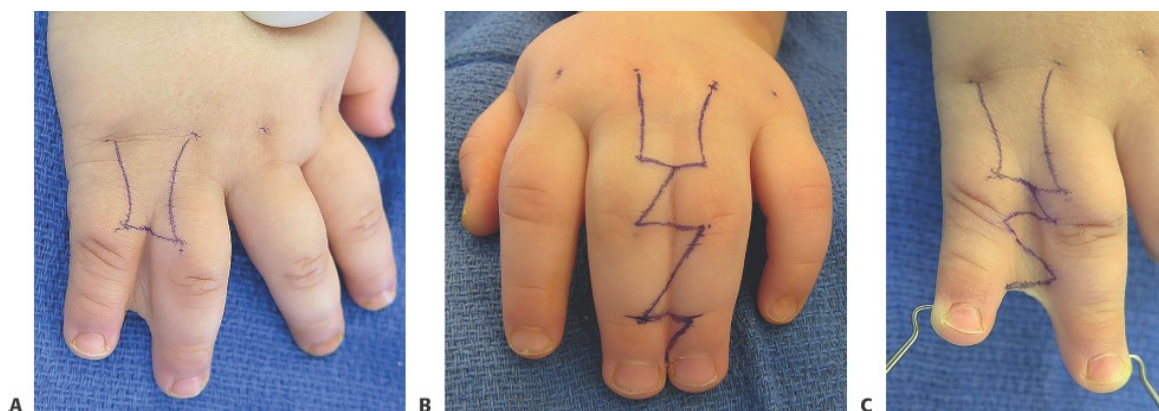
involved—such as in this patient with type I Apert syndrome—there is not enough skin to allow the dorsal and volar triangular flaps to interdigitate. Accordingly, a straight-line dorsal release is planned. In the case shown, adjacent rectangular commissure flaps (for both third and fourth web spaces) would remove too much skin from the nonborder digits; accordingly, triangular flaps were planned.

TECHNIQUES

■ Dorsal Rectangular (Hourglass) Flap for Syndactyly Release

Dorsal Markings

- Mark the metacarpal head pit for each neighboring digit. Draw an hourglass-shaped flap with the distal straight-lined, transverse incision located two-thirds to three-fourths of the distance between the metacarpal head and proximal interphalangeal joint (**TECH FIG 1A**).
- The palmar border of the normal web space lies about halfway between these two anatomic landmarks (see **FIG 2**).
 - Planning the flap's distal extent beyond the halfway point allows it to rotate about its axis proximally (at the metacarpal heads) and reach just proximal to the ideal location of the web space.
- Mark the extension creases with transverse or slightly oblique lines.
 - In complete and near-complete syndactyly cases, draw these lines from (just shy of) the midpoint of one finger to the other (**TECH FIG 1B**). In incomplete cases, these lines can be shorter (**TECH FIG 1C**).
 - Connect the lines via oblique lines that create the least acute angle to allow for optimal blood flow to the flap. The reason for longer flaps in narrower cases is not additional skin (the amount of skin remains fixed) but greater flexibility in maneuvering the flaps.



TECH FIG 1 • Dorsal hourglass commissural flap markings **(A)** with extensions for complete syndactyly **(B)** and incomplete syndactyly **(C)**.

Volar Markings

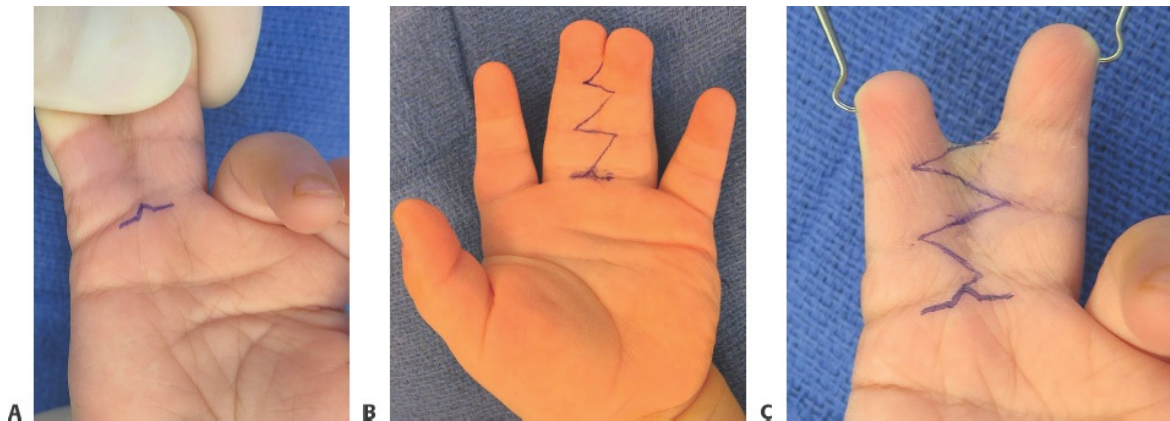
- Draw a transverse line 2 to 3 mm proximal to the mid-proximal phalanx flexion crease (**TECH FIG 2A**).
 - A small triangular dart in the middle of this line helps to break up the web scar.
- Mark the flexion creases similarly to the extension creases on the dorsum.
 - Similar to the dorsal markings, the extension of these transverse lines is dictated by the degree of involvement. These are then connected via oblique lines similar to the dorsal oblique markings (**TECH FIG 2B, C**).
 - Ensure that the dorsal and volar flaps are designed such that they will interdigitate once raised.

Flap Creation

- Exsanguinate the upper extremity.
 - In infants and toddlers, an Esmarch bandage is used as a tourniquet because it is more effective at providing a bloodless field in small arms (**TECH FIG 3**). The technique is controversial, as the pressure is not known; however, with experience, the surgeon can perform it predictably and safely in cases of short duration.
 - In older children, a standard pneumatic tourniquet is used.
- Raise the dorsal flap in the subcutaneous plane leaving 2 to 3 mm of fat on the flap (**TECH FIG 4A**).
- Raise the remaining dorsal and volar flaps. Raise the dorsal flaps on the

extensor mechanism. Raise the volar flaps subcutaneously.

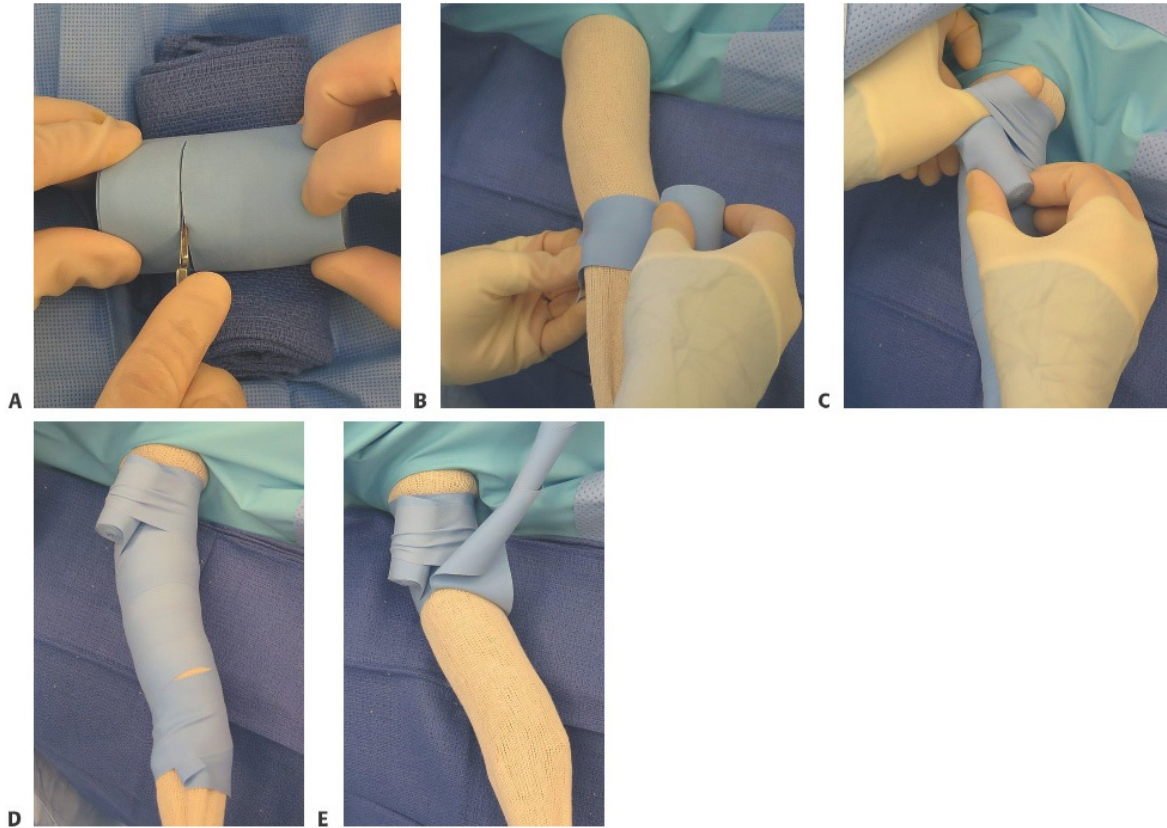
- Approach the web space with fine scissors and forceps. Spreading helps define the neurovascular structures (**TECH FIG 4B**).
 - Any interdigital bands/fascia should be excised.
 - Defat the fingers as needed, protecting the neurovascular bundles, to allow for the dorsal and palmar flaps to transpose.
- Split the dorsal flap down the midline to allow inset (**TECH FIG 4C**). The dorsal flap insets into the dart on the volar side (**TECH FIG 4D**).
 - By design, two volar flaps on either side of the web are created (see **TECH FIG 4D**), which are sutured to either edge of the dorsal flap thereby dividing the web scar even more.
- Mobilize, trim, and appropriately inset the dorsal and palmar flaps.



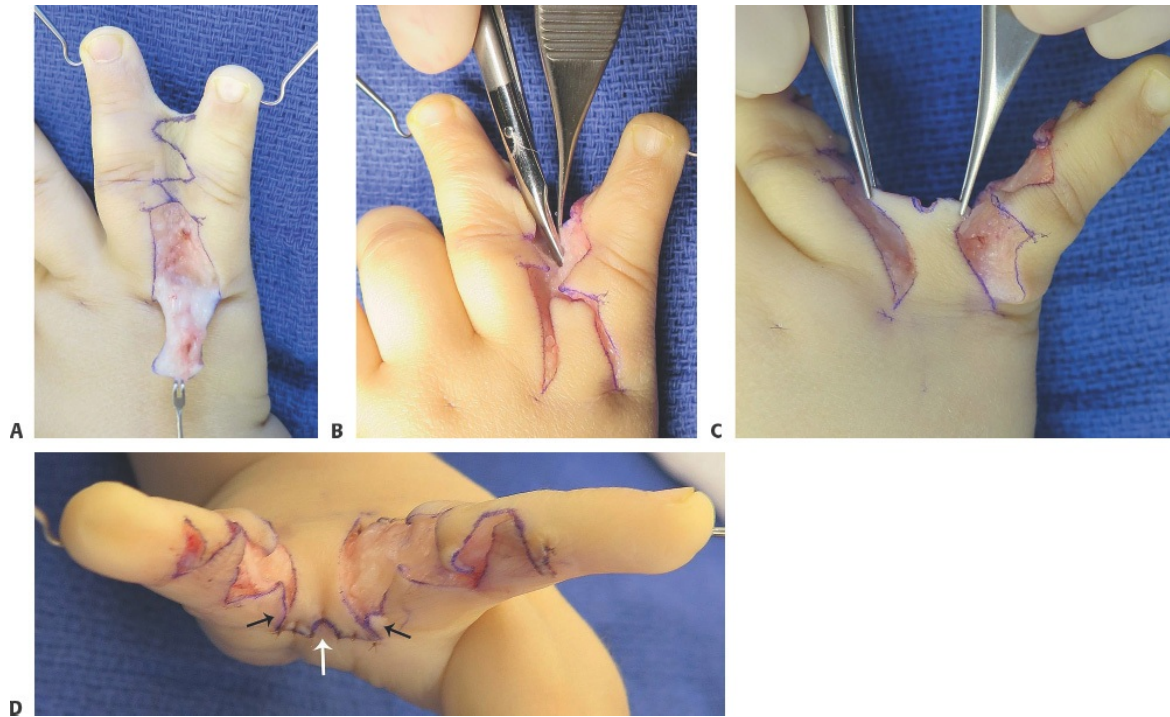
TECH FIG 2 • Volar markings with small dart to break up web scar (**A**) and for complete syndactyly (**B**) and incomplete syndactyly (**C**).

Grafting

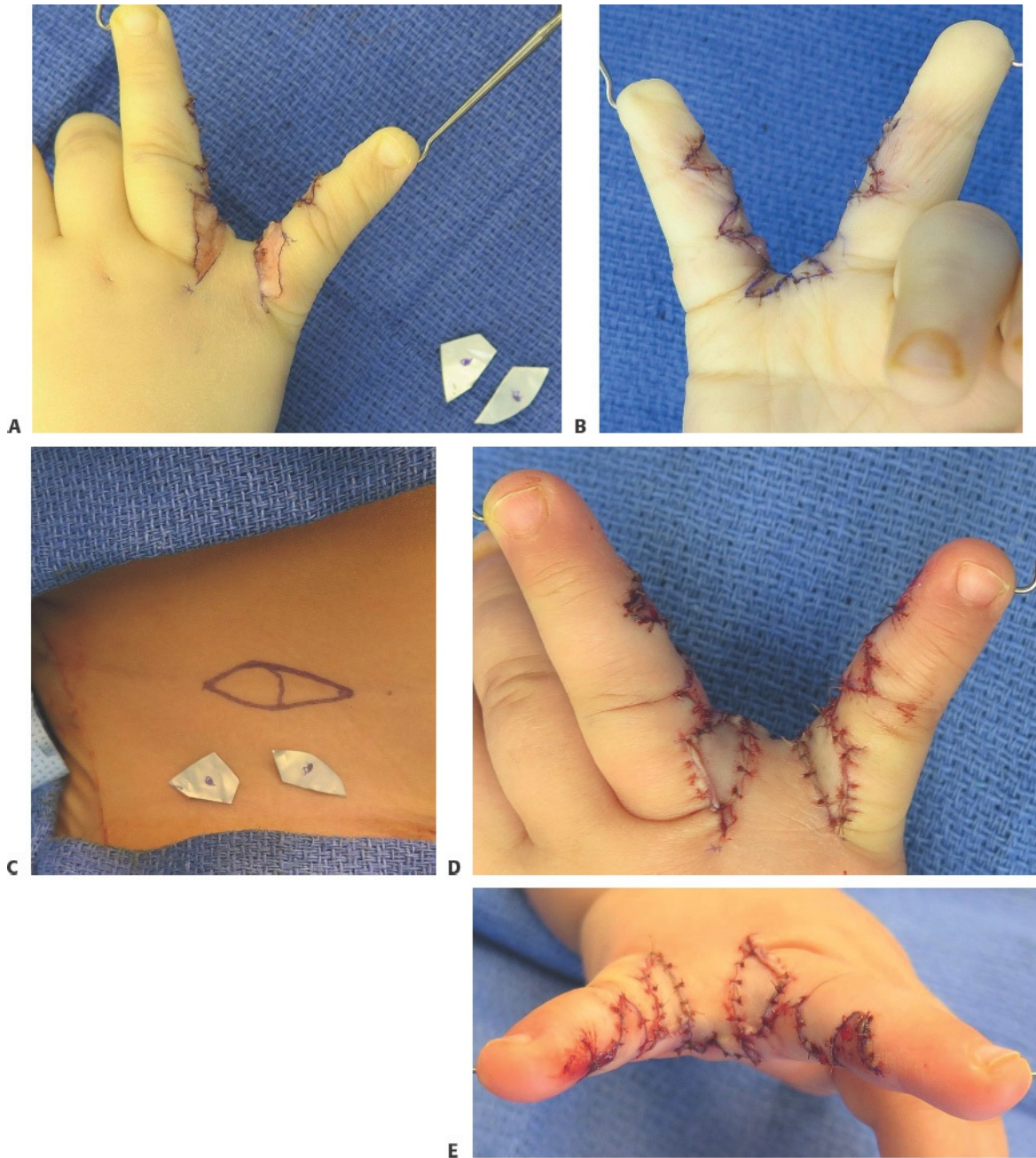
- Use suture foil to create templates of the resultant defects for skin grafting (**TECH FIG 5A, B**).
- Release the tourniquet and obtain hemostasis. The author uses the bipolar electrocautery for bleeding in the skin graft bed only.



TECH FIG 3 • Technique of applying Esmarch bandage as tourniquet. In small children, the standard 3-in. Esmarch bandage is too wide. **A.** It is trimmed to about 2 in. long by using a no. 10 blade. It is then rolled out, and about one-third of its length is cut off and discarded to decrease its bulk (not shown). It is then wrapped around the extremity (**B**) and secured at the upper arm (**C–E**). Tightness is gauged by using the thumb (**C**).



TECH FIG 4 • A. Dorsal flap raised in the subcutaneous plane. **B.** Spreading to divide soft tissue in the web with fine instruments. Dorsal flap split (**C**) and inset (**D**). The dorsal flap insets into the previously created volar dart (*white arrow*). The two volar flaps on either side of the web (*black arrows*) are sutured to either edge of the dorsal flap thereby breaking up the web scar.



TECH FIG 5 • A. With the dorsal flap and digital flaps fully inset, the dorsal view shows the remaining skin defects and foil templates. **B.** Palmar view. **C.** Foil templates outline a lenticular excision centered on a lower abdominal skin crease. Dorsal (**D**) and web space (**E**) views after inset of skin grafts.

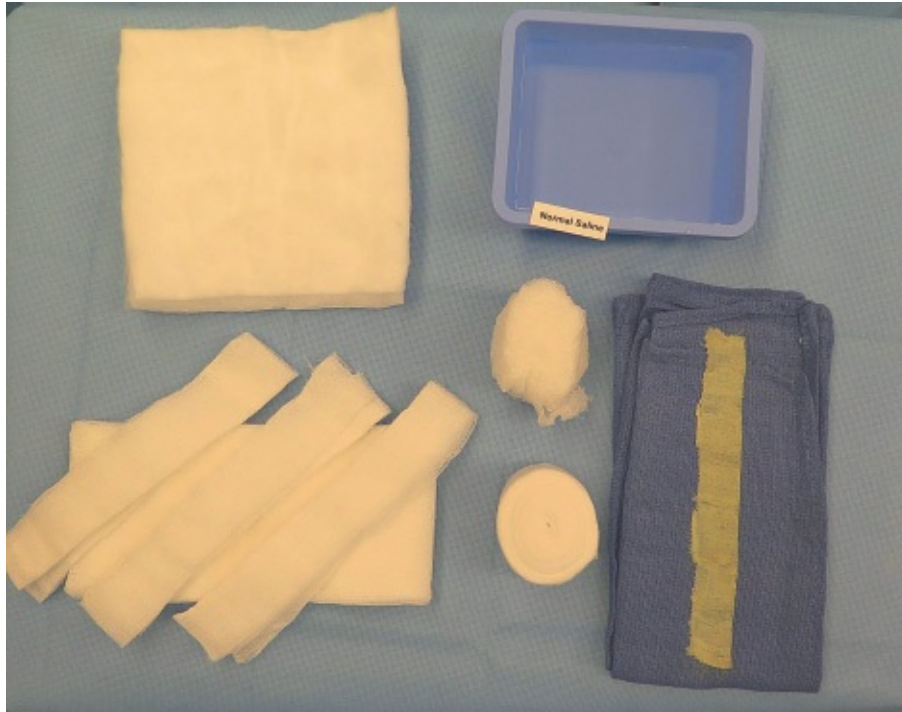
- Skin edge bleeders usually stop when the skin grafts are applied.
- Mark a transverse crease in the lower abdomen for skin graft harvest. Avoid areas near the midline to prevent subsequent hair growth. A crease just below the anterior superior iliac spine provides ample skin, is well hidden, and heals beautifully.
 - Transpose the foil templates to this area and mark out a lenticular excision (**TECH FIG 5C**).
- With assistants holding traction, harvest a thin full-thickness skin graft. With enough traction, one can use the blade alone to harvest a graft that requires no defatting.
- Apply the skin grafts (**TECH FIG 5D,E**). The author uses 6-0 chromic sutures.
 - The grafts have elasticity in multiple dimensions, so the surgeon must take care to apply them under appropriate tension and disallow pleating and redundancy of the graft.
 - Running horizontal mattress sutures provide the best appearance on the dorsum.

Dressing and Immobilization

- Dressings and immobilization are critical to predictable healing (**TECH FIG 6**).
- Antibiotic-impregnated gauze is applied to incisions and grafts. Gauze wrap and cotton packing are used in the web space help to provide compression on the grafts.
- The limb is immobilized in a well-padded long-arm mitten cast for 3 weeks.
 - Slip on a long 2-in. stockinette and apply the padding high up to the shoulder with the elbow at 90 degrees.
 - Apply the cast with the fingers buried but the thumb exposed.
- Infants between 9 and 15 months of age, especially those with significant subcutaneous fat, are notorious for slipping out of their casts. One can minimize this by taking several steps:
 - Extend the cast high up to the shoulder (but avoid compressing the vessels in the axilla).
 - Apply skin adhesive (such as Benzoin or Mastisol) to the arm and forearm prior to placing the stockinette.
 - Mold the cast to create a well-defined 90-degree angle on the posterior aspect of the elbow as the arm meets the forearm. Additionally, mold the

cast to the contour of the underlying skeleton with a supracondylar and proximal forearm “squeeze.”

- Finally, leave the thumb out and instruct parents to call if the thumb slips into the cast.



TECH FIG 6 • Dressing supplies needed include antibiotic-impregnated gauze (in yellow), 4 × 8 gauze sponges cut longitudinally into thirds for wrapping the digits, cotton for compression in the web, and cling and Webril wraps.

PEARLS AND PITFALLS

Surgical management

- Syndactyly can be narrow or wide. This bears on surgical planning because wide syndactyly has more skin for transposition. It is important to ascertain how much skin is available in the web preoperatively.

Exsanguination

- Regular pneumatic tourniquets are not effective in small

and tourniquet	children—the Esmarch bandage works better. The surgeon must be careful not to make the tourniquet too tight.
Release	■ The most proximal extent of release is the bifurcation of the arteries. A distal nerve bifurcation can be teased apart with gentle intraneural dissection and splitting of the fascicles. Occasionally, one will encounter an arterial bifurcation that is too distal. In these instances, the smaller branch can usually be sacrificed depending on the blood supply to the other side of the digit. One can place a microvascular clamp, release the tourniquet, and assess vascularity before dividing any branches.
Postoperative	■ Adequate compression and immobilization is critical to successful skin graft take and predictable healing. Children between 9 and 12 months of age occasionally will slip out of long-arm casts; these should be reapplied promptly.

POSTOPERATIVE CARE

- Immobilize the arm for 3 weeks as noted previously. If the cast falls off, it should be replaced.
- Remove the cast in the office and assess healing of skin grafts. Sutures, old clots, and debris can be removed from the wounds at this time.
- Occupational therapy to make nighttime volar resting thermoplast splints with web space conformers at this time. The conformers put pressure on the scars and allow them to soften and settle more quickly. These should be worn for about a month after the cast is removed.

OUTCOMES

- Functional outcomes after syndactyly release depend mostly on the preoperative status of the digits and the hand.
- In simple cases where the joints are not involved, full range of motion of the involved digits should be expected postoperatively (**FIG 6**).
- In complex cases, reconstruction is difficult and common postsurgical functional issues include rotational and angular deformity and nail deformity.⁵

COMPLICATIONS

- Web creep (loss of initial depth of the web space) can occur over time, with incidence ranging from 2% to 24% (**FIG 7**).⁴
- Web scars are best corrected right before the child starts school, around 5 or 6 years of age, after a significant growth spurt has occurred and the scars have

had ample time to soften.

- Most webs scars respond well to Z-plasty, but occasionally, skin grafting may be necessary.
- Skin graft loss or flap loss, partial or complete
- Vascular compromise—especially in complex and complicated cases
- Nail deformity
- Rotational and angular deformities
- Dense scars



FIG 6 • Long-term postoperative dorsal (**A**) and web space (**B**) views of the patient with complete third web space syndactyly in TECH FIGS 1B and 2B. Patient has a pliable web space with no limitations in range of motion or function. Three-month postoperative dorsal

(C) and web space (D) views of the patient with incomplete fourth web space syndactyly in TECH FIGS 1A and 2A. Early healing with good maintenance of web and normal function.

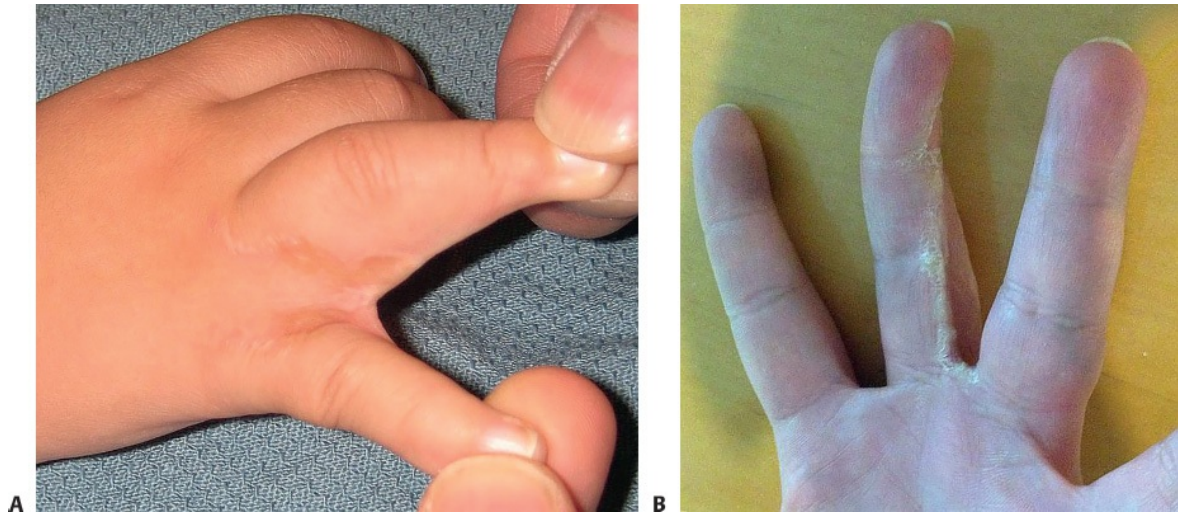


FIG 7 • Web space scar after syndactyly release. **A.** Three years after syndactyly release, this child has a scar that tethers the web space and prevents full extension of the ring finger. **B.** Twenty years after syndactyly release, this adult patient has a web scar that is bothersome but does not interfere with function. Note desquamation of scarred skin.

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64 Hypoplastic Thumb Reconstruction

CHAPTER

Amir H. Taghinia

DEFINITION

- A thumb is considered hypoplastic if any of its osseous, musculotendinous, or articular components is deficient or missing or if the web space that it forms with the index finger is shallow.

ANATOMY

- The normal thumb is broad with osseous and articular structures that allow ample movement in multiple planes. Its intrinsic muscles provide a short moment arm, powering the motion enabled by the ossearticular column. The normal first web space has a gentle curve spanning from the thumb metacarpophalangeal (MP) joint to the index finger MP joint.
- The modified Blauth classification system¹ provides a surgically useful basis for categorizing thumb hypoplasia.
 - Type I thumbs have minimal shortening and narrowing. No surgical intervention is needed.
 - Type II thumbs have narrowing of the first web space, hypoplastic intrinsic thenar muscles, and laxity of the MP joint. Reconstruction is recommended.
 - Type IIIA thumbs have features seen in type II thumbs, but they also have extrinsic tendon anomalies and a hypoplastic metacarpal. Reconstruction is recommended.
 - Type IIIB thumbs have features seen in type IIIA thumbs, but they also have an absent proximal metacarpal and instability of the carpometacarpal (CMC) joint. Pollicization is the treatment of choice.
 - Type IV (*pouce flottant*, floating thumb) and V (*aplasia*, complete absence) thumbs are also best treated with pollicization—these thumbs are discussed

in the chapter on Index Finger Pollicization.

- Specific anatomic deficiencies in types II and III thumbs include the following^{1–3}:
 - Laxity of the MP joint ulnar collateral ligament (UCL). The radial collateral ligament (RCL) may also be lax, as may the entire joint capsule (global laxity).
 - Hypoplasia or absence of the thenar muscles manifested as poor opposition
 - The flexor pollicis longus (FPL) tendon may be eccentrically attached to the distal phalanx. But it also may be absent, may follow an abnormal path (usually radially transposed), may have a very distal muscle belly, or may anomalously attach to the proximal phalanx.
 - The extensor pollicis longus (EPL) tendon may also be eccentrically attached to the distal phalanx. It may also be absent or follow an abnormal, more radial path.
 - Abnormal radial interconnections between the EPL and FPL lead to a characteristic radial deviation of the thumb termed pollex abductus. These connections are usually present at the MP joint and prevent active interphalangeal (IP) joint motion.
- The distinction between type II and IIIA may not bear strongly on the choice of surgical intervention, as there can be some overlap. If the thumb requires web space deepening, collateral ligament reconstruction, and opponensplasty, then there is usually some degree of extrinsic tendon abnormality present.² The surgeon should focus on treating the individual deficiencies that are present in a given thumb.

PATHOGENESIS

- Thumb hypoplasia occurs as a result of multiple potential factors—including genetic (associated syndromes), environmental, teratogenic (thalidomide), and idiopathic causes.
- It is considered to be a malformation, based on the Oberg, Manske, and Tonkin classification of 2010.⁴

NATURAL HISTORY

- Thumb hypoplasia occurs in 1 out of 100 000 live births. A large number of patients with thumb hypoplasia will have associated conditions such as cardiac or hematologic anomalies.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with type I to IIIA can present anytime in life. In milder cases, the differences can be so subtle that parents do not notice a mild deficiency (in function or appearance) until much later in life, especially if the nondominant side or both sides are involved.
- Physical findings:
 - Intrinsic thenar muscle hypoplasia (**FIG 1A**). This finding is usually evident early, especially if there is a comparative normal contralateral side. Patients lack strong opposition.
 - MP joint instability (**FIG 1B,C**). The stability of this joint is difficult to assess in an infant because of global joint laxity. However, as the child grows, the laxity becomes more evident on examination. Patients sometimes use a “metacarpal grasp”—when an object is held between the fingers and the thumb metacarpal head, thus avoiding the distal thumb.

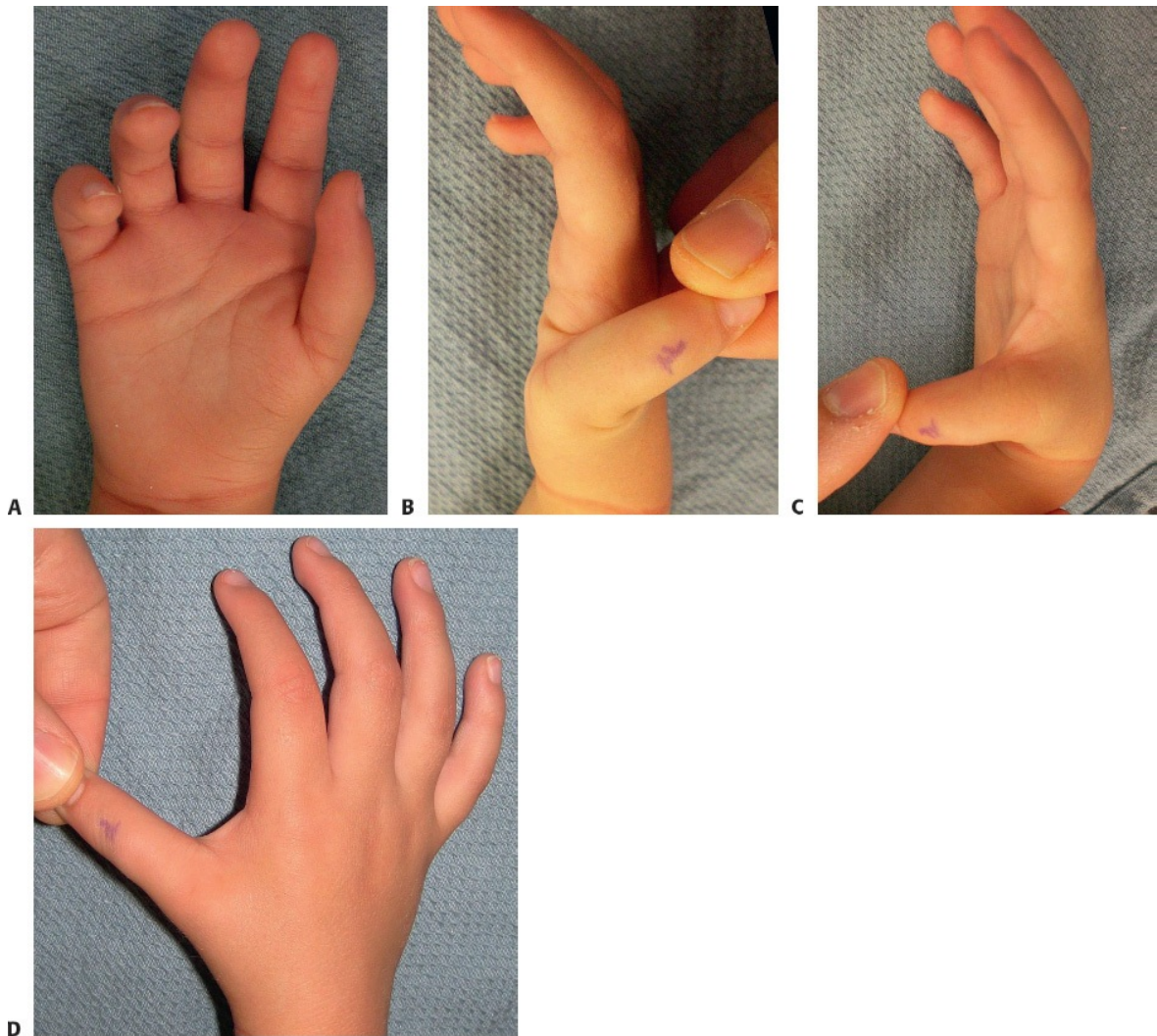


FIG 1 • A. Palmar view of hand with thumb hypoplasia. The thumb is short with flattening of the thenar eminence and lack of flexion or extension creases at the IP joint. The RCL **(B)** and UCL **(C)** are lax, allowing significant deviation of the joint. **D.** The first web space is shallow; radially deviating the thumb any more to widen the web space would result in deviation at the MP joint rather than splaying of the metacarpals.

- Shallow web space (**FIG 1D**). This finding is also evident early, though the degree of involvement is assessed subjectively. An incompetent UCL can sometimes mask a shallow web space. It is best to assess the web space by the angle achieved between the index and thumb metacarpals.
- Extrinsic muscle abnormalities. These include abnormal size, length, strength, and insertion of the thumb flexor and extensors. These anomalies are typically manifested as joint deviations (MP joint) and/or lack of flexion or extension creases (IP joint).
- The functional ability of the CMC joint is often not obvious on the infant's plain film radiograph. Functional differentiation can be made by allowing the child to grow and watching the toddler at play. If the thumb is bypassed in favor of the index finger, the joint is likely nonfunctional.
- The hand surgeon should be aware of the conditions associated with thumb hypoplasia (eg, VACTERL, Fanconi anemia, and Holt-Oram syndrome) and have a low threshold to refer if suspicions arise.
- In particular, Fanconi anemia is a fatal disease that occurs mainly in those with thumb hypoplasia and is easily diagnosed with a simple blood test.

IMAGING

- Plain radiographs (**FIG 2**) help to determine the status of the metacarpal, CMC joint, any abnormalities of the index finger, and the status of the distal radius and ulna (presence of radial longitudinal deficiency).

NONOPERATIVE MANAGEMENT

- Most patients with Blauth type I thumb hypoplasia do not need surgical intervention.

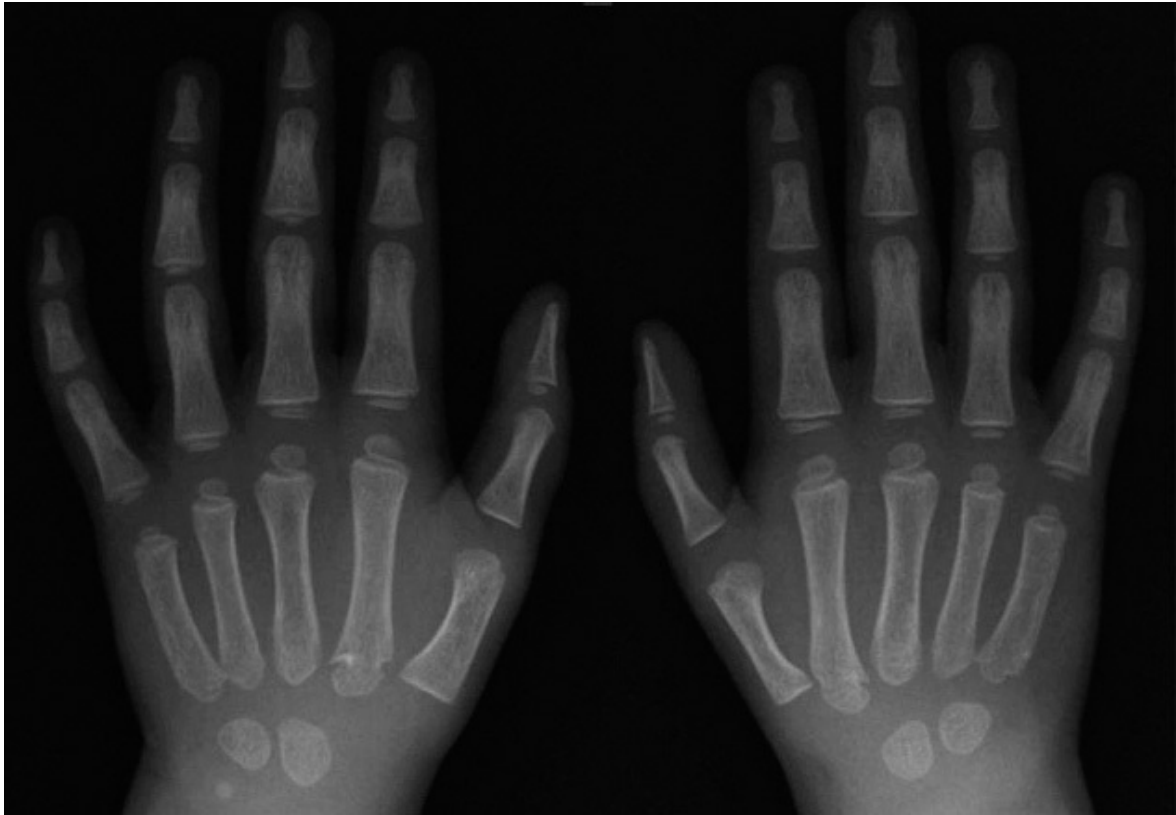


FIG 2 • Plain radiographs of both hands demonstrate a comparatively shorter right thumb with thinner first metacarpal.

SURGICAL MANAGEMENT

- The author performs hypoplastic thumb reconstruction around 2.5 to 3 years of age, particularly if MP joint ligament reconstruction is needed. The metacarpal head should be big enough to allow creation of a tunnel without fracturing. Key procedures are outlined below.
- Opponensplasty
 - In congenital cases, opponensplasty is done using the flexor digitorum superficialis (FDS) tendon to the ring finger or the abductor digiti minimi (ADM).
 - The FDS is advantageous because it provides simultaneous opponensplasty *and* ligament reconstruction.
 - The ADM is used in patients who have had previous pollicization procedures (and have weak opposition) or those with thumb hypoplasia who do not need ligament reconstruction.

■ MP joint ligament reconstruction

- This procedure is done with tightening of the existing capsular tissues or extrinsic reconstruction with either the FDS to the ring finger (in cases that need simultaneous opponensplasty) or the palmaris longus tendon. In cases of global laxity, chondrodesis or epiphyseal arthrodesis is advocated, though both of these procedures have significant downsides.
- The author errs toward stability. Thus, for most cases, both UCL and RCL are reconstructed using a tendon graft. The tendon is split, and one-half is routed through a tunnel made in the metacarpal head to reconstruct the UCL. The tendon is then passed underneath the adductor aponeurosis and routed from dorsal to palmar through a tunnel in the periosteum in the proximal phalanx. It is then passed under the aponeurosis once again before being sutured back to itself at the metacarpal head. The RCL is reconstructed on the radial side using a similar method.
- Web space deepening.
 - This procedure is best done with a four-flap Z-plasty.
 - Multiple other procedures have been proposed, but the Z-plasty remains the workhorse for this condition.
- Other adjunct procedures include correction of MP and IP joint deviation by division of the tendinous attachments of the flexor to the extensor (pollex abductus), division of the musculus lumbricalis pollicis, step-lengthening of the extrinsic flexor tendon, and detachment and reinsertion of the EPL and/or FPL tendon.
 - Pin fixation is advocated after these procedures.
- Depending on the degree of involvement and interventions planned, it is important to establish a logical sequence for performing these procedures. For example, performing the web space release first releases the investing tight fascia of the intrinsic muscles, thus allowing better palmar abduction prior to opponensplasty.

Preoperative Planning

- Discuss risks, benefits, and expectations with parents on the day of surgery.

Positioning and Approach

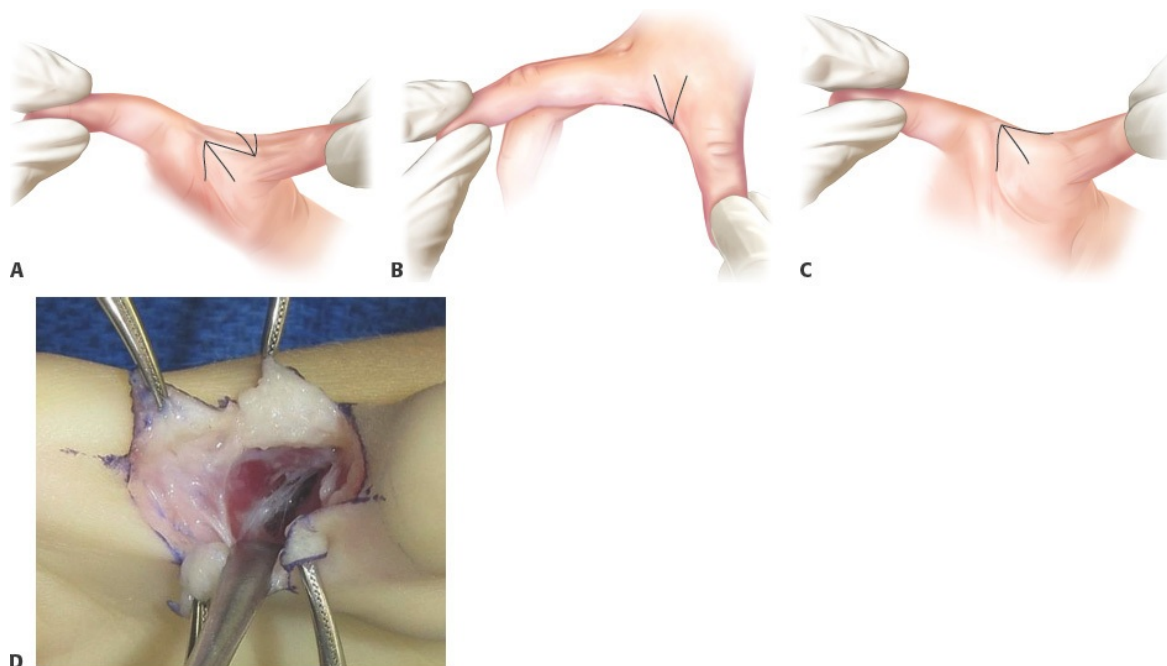
- The patient is positioned supine with the arm out on a small hand table.
- Incisions are planned carefully prior to use of the tourniquet.
- Plan all incisions before exsanguinating the upper extremity.

- In toddlers, an Esmarch bandage is used as a tourniquet as it provides better hemostasis. In older children, a pneumatic tourniquet works best.

TECHNIQUES

■ Four-Flap Z-Plasty for First Web Space

- Splay the web with the help of an assistant and draw a transverse line across the tightest area of the web. On the thumb side, draw a perpendicular line dorsally. On the index finger side, draw a perpendicular line palmarly. Bisect these 90-degree angles with two additional lines at 45 degrees.
 - The five lines that are drawn should be the same length (**TECH FIG 1A–C**).
- Incise the limbs and raise the flaps with a few millimeters of fat to preserve the blood supply.
- Spread in the web space, and define and protect the neurovascular structures. Bluntly dissect the muscles and sharply divide their investing fascia to widen the distance between the index and thumb metacarpals (**TECH FIG 1D**).
 - Releasing the fascia of the adductor pollicis and first dorsal interosseous muscle is critical to obtaining a wide web space.
- If designed correctly, the flaps should transpose into their new respective positions.
- If performing a ligament reconstruction, extend the ulnar skin incision to fully expose the MP joint.



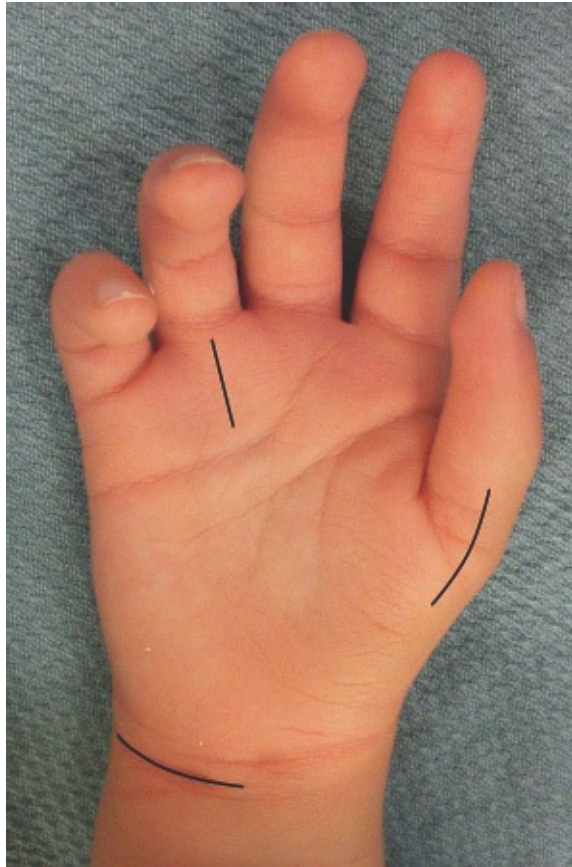
TECH FIG 1 • A–C. Designing the four-flap Z-plasty. The dorsal incision perpendicular to the web should be next to the thumb; the alternative approach would place the incision on the volar thumb and cause a flexion contracture. **D.** The investing fasciae of the adductor pollicis and first dorsal interosseous are seen in the first web space. These should be sharply divided or excised to allow optimal widening of the web.

■ Opponensplasty and Ligament Reconstruction Using FDS

Markings

- Design a radial mid-lateral incision on the thumb MP joint, just dorsal to where the glabrous skin meets the nonglabrous skin.
- Design a transverse incision over the distal wrist flexion crease; this incision should be long enough to gain access to the flexor carpi ulnaris (FCU) tendon ulnarly and the ring finger flexor digitorum superficialis (FDS) tendon radially.

- Finally, design a longitudinal A1 pulley incision in the distal palm over the ring finger ray (**TECH FIG 2**).



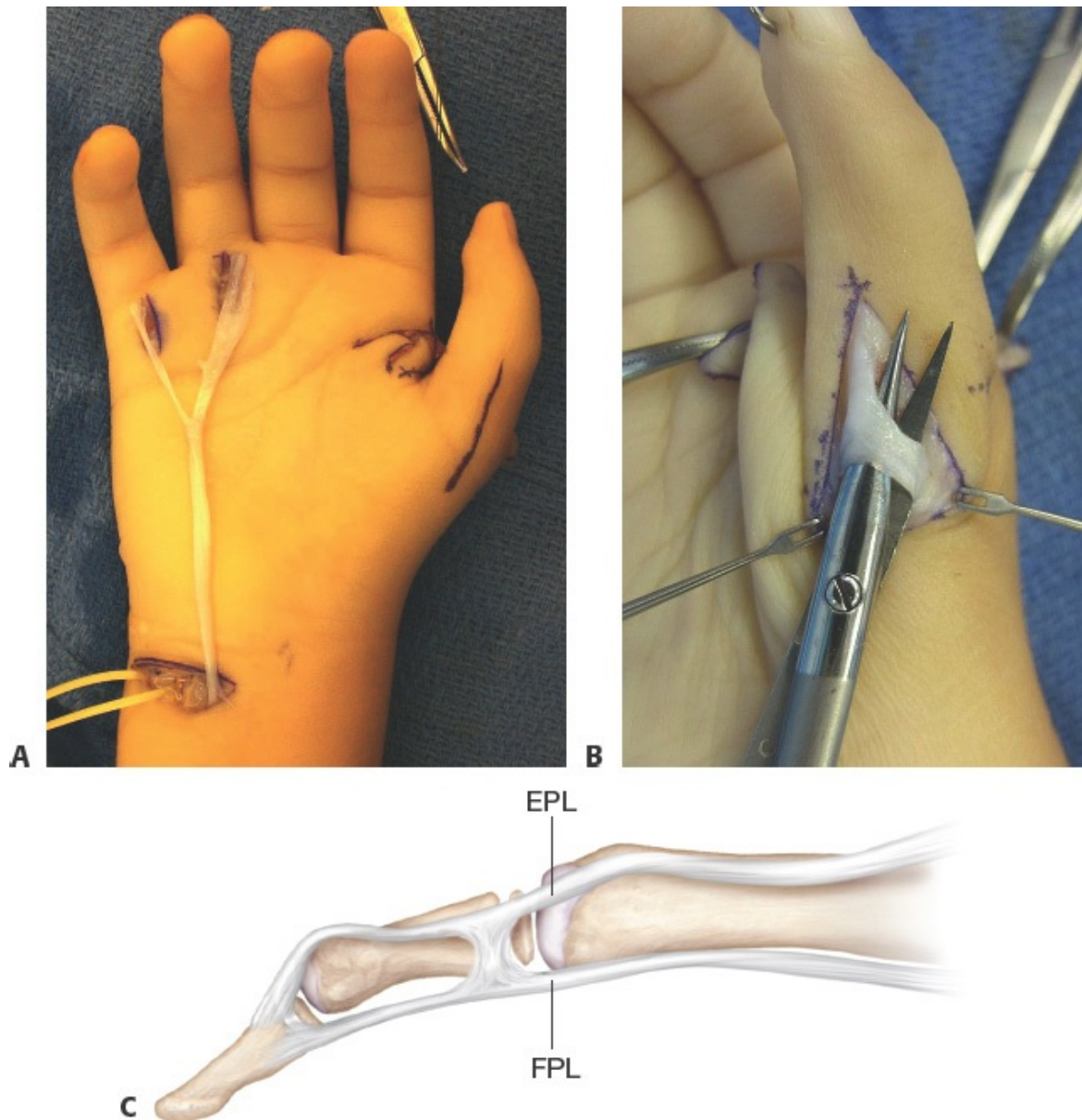
TECH FIG 2 • Design of the incisions, palmar view.

Exposure and Tendon Harvest

- Incise the wrist crease incision. Find and isolate the FCU tendon while identifying and protecting the ulnar artery and nerve.
- Find and isolate the FDS tendon to the ring digit at the wrist. It is usually the most palmar and ulnar flexor tendon.
 - Retract the tendon and confirm that it flexes the ring proximal interphalangeal (PIP) joint. Free its distal attachments.
- Incise the A1 pulley incision over the ring finger, spread down to the tendon sheath, and sharply divide the A1 pulley. Using a small retractor, pull the FDS up into the wound with the finger in maximal flexion.
- Obtain maximal exposure in the wound, and free the FDS from the FDP in both directions. Incise the two limbs of the FDS as distally as possible,

leaving its insertion intact.

- Occasionally, the FDS tendons of the ring and little digits are joined proximally. If pulling on the ring FDS causes flexion of the little digit PIP joint, a separate incision to release the little finger FDS may be necessary (**TECH FIG 3A**).
- Deliver the FDS into the wrist wound, and wrap with moist gauze so it does not desiccate.
- Incise the radial thumb incision and dissect to the extensor mechanism.
- If present, release the pollex abductus and free the extensor from the flexor (**TECH FIG 3B,C**).
 - It is crucial to divide these attachments, as they will otherwise act as a deforming force, stressing the MP ulnar collateral ligament (UCL) reconstruction.
 - Once released, pull the extensor and flexor proximally to ensure that the MP joint does not deviate radially.
- Correct any extrinsic tendon abnormalities. Depending on the anatomy, options include realignment of tendons with pulleys, step-lengthening, and/or reinsertion of eccentrically attached tendons. (None were performed in the example case.)



TECH FIG 3 • A. The first web space has been released and the FDS tendon has been isolated and delivered through the wrist wound. The fourth and fifth digit FDS tendons were joined up to the mid-palm, so a separate A1 pulley incision was needed on the fifth ray. **B.** Pollex abductus is radial deviation of the thumb caused by attachments of the extensor pollicis longus (EPL) tendon to the flexor pollicis longus (FPL) tendon present at the MP joint level. **C.** Extrinsic tendons can

be radially transposed and attached to each other via tendinous bands. In addition, the extrinsic tendons can have eccentrically placed insertions (radially) on the distal phalanx.

Tunnel Creation

- Retract the extensor dorsally and identify the metacarpal head on the radial side without entering the joint.
- Define the metacarpal head in the ulnar incision as well. Create a tunnel underneath the adductor aponeurosis in the proximal to distal direction. The tendon will be routed underneath the aponeurosis.
- To create the tunnel in the metacarpal head, incise the periosteum over the metacarpal head and strip off a small area. Clearly define the dorsal and palmar aspects of the metacarpal head and mark a spot exactly in the middle.



TECH FIG 4 • Multiple drill holes using a K-wire through the metacarpal head allow for creation of an elliptical tunnel through which the tendon can be

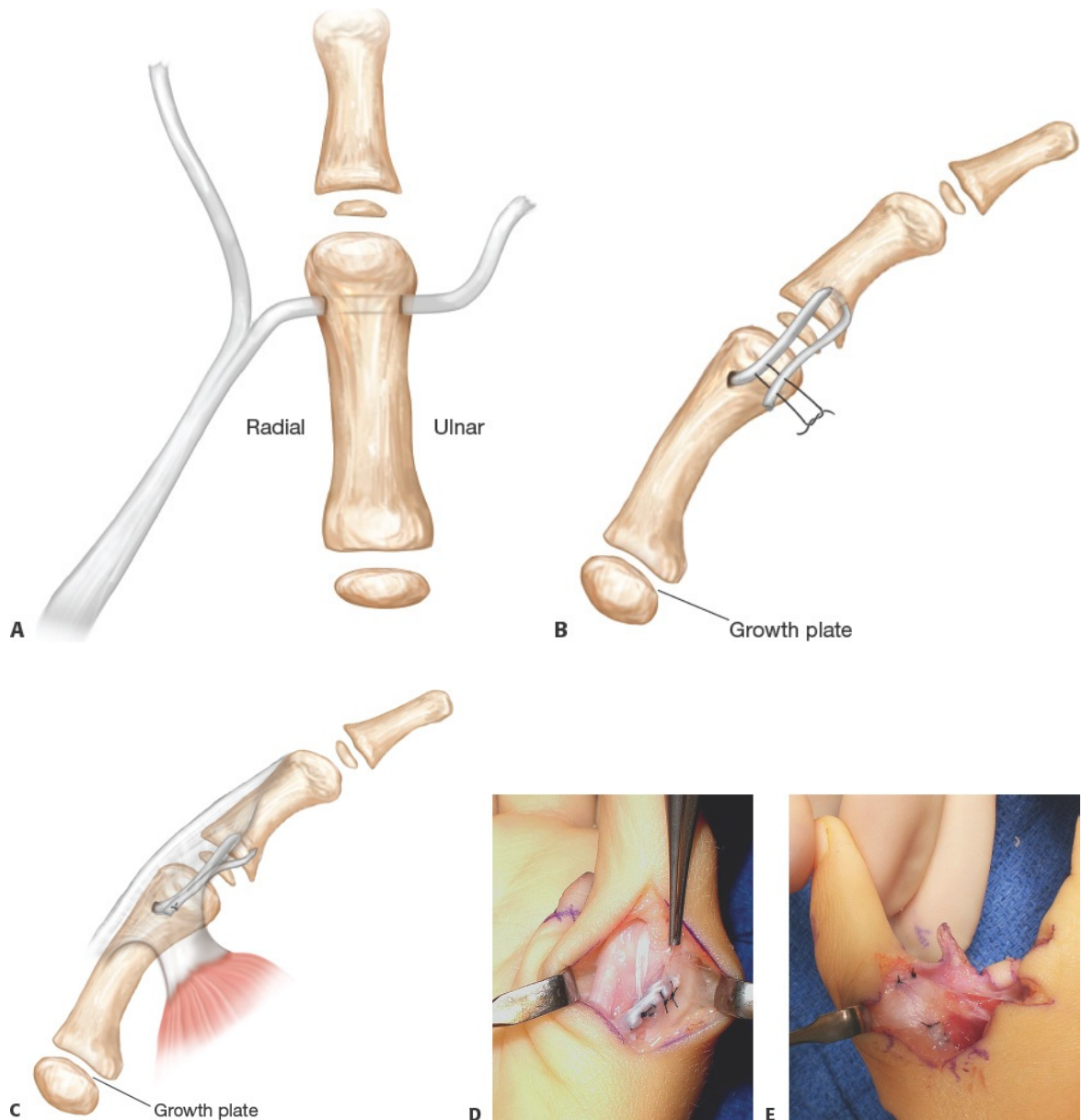
passed for ligament reconstruction.

- Make one wide tunnel by drilling multiple holes side by side using a 0.035-in. Kirschner wire (**TECH FIG 4**), then drilling in between these holes.
 - The tunnel may also be created with a single pass of a drill, appropriately selected for size.
- Ensure that the tunnel is generous and visibly larger than the tendon. Pulling the tendon through a small tunnel causes it to fray.
- The thumb metacarpal's physis is located proximally, in contrast to the physes for the finger metacarpals, which are located distally. Therefore, there are no concerns about growth arrest when this bone tunnel is created.
- Create two vertical (dorsal to palmar) tunnels in the periosteum on the radial and ulnar aspects of the proximal phalanx just distal to the physis. These tunnels should be centered volarly to best mimic the normal collateral ligaments.
 - The author does not bore vertical bone tunnels in proximal phalanges of small children. This technique is technically difficult, threatens the physis, and has not been found to be necessary.

Passing the Tendon

- Create a subcutaneous tunnel from the distal wrist incision to the radial thumb incision.
 - Loop the FDS tendon around the FCU tendon and pass it through the tunnel into the radial thumb wound.
- Pass one limb of the distal FDS through the metacarpal head tunnel from radial to ulnar (**TECH FIG 5A**).
 - Split the FDS proximally and keep pulling the tendon limb through until palmar abduction reaches about 70 degrees.
 - Suture the tendon to the periosteum on the radial and ulnar sides of the metacarpal head to secure the opponensplasty.
- On the ulnar side, pass the tendon under the aponeurosis, then dorsal to palmar through the periosteal tunnel, and then under the aponeurosis again (**TECH FIG 5B**) and suture it to the tendon itself at the metacarpal head (**TECH FIG 5C**).
- Repeat this procedure on the radial side; there is more tendon length on this side and there is no aponeurosis in the way.

- Trim any excess tendon and place additional securing sutures if necessary (**TECH FIG 5D,E**).
- Test the integrity of the ligament reconstruction to assure there is no laxity. Usually, pins are not necessary.

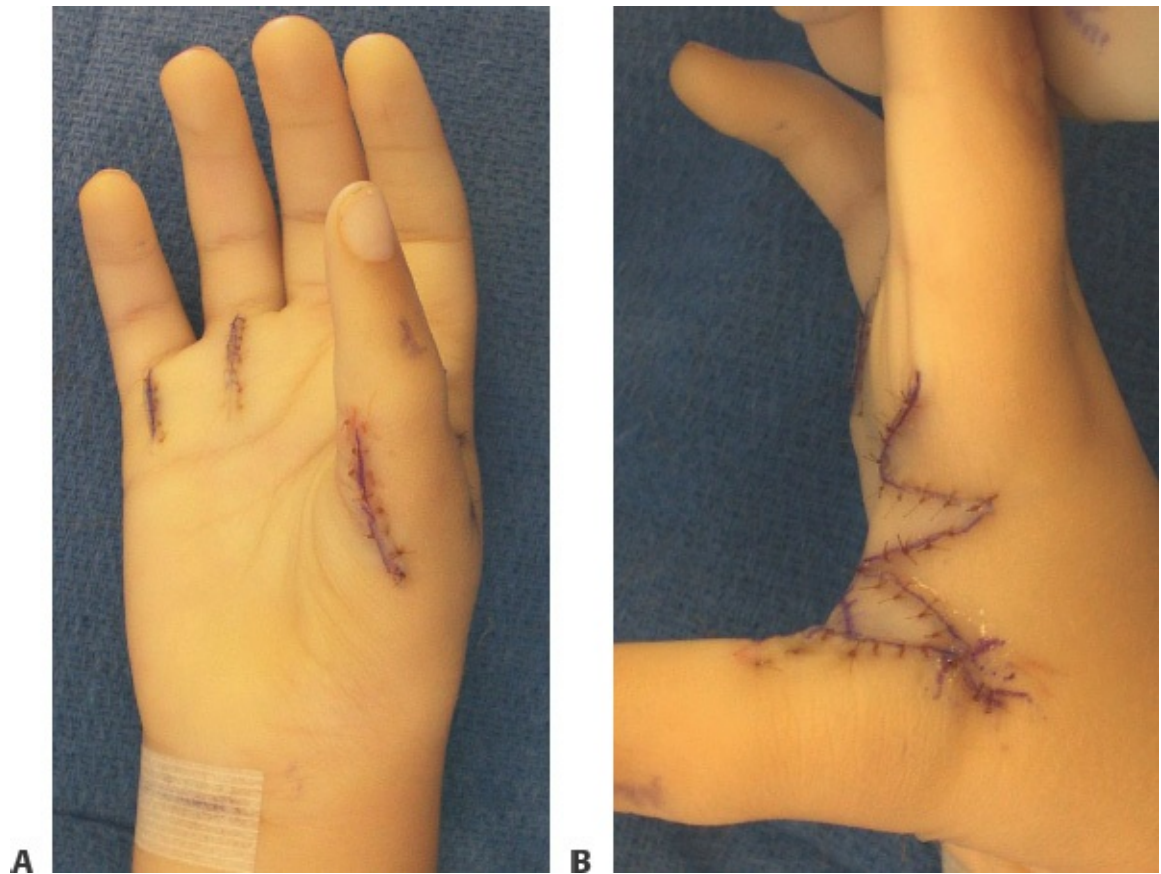


TECH FIG 5 • A. The FDS limbs are separated, and one is passed through the bone tunnel to create the UCL, while the other creates the RCL. **B.** The UCL is reconstructed in the shape of a triangle. The tendon is

passed superior to inferior in the periosteal tunnel and sutured back to itself. **C.** The UCL reconstruction is done under the adductor aponeurosis. **D.** RCL reconstruction is demonstrated. **E.** UCL reconstruction performed under the adductor aponeurosis.

Completion

- Close the wrist wound using several deep dermal 4-0 Monocryl sutures followed by a running 5-0 Monocryl intracuticular suture. Close the palm and radial thumb wounds with interrupted simple or horizontal mattress 6-0 chromic gut sutures.
- Transpose the Z-plasty flaps, and close the web space wounds using simple interrupted 6-0 chromic gut sutures (**TECH FIG 6**).
- Place antibiotic-impregnated petroleum gauze (Xeroform) on the wounds and apply compression gauze.
- Deflate (or remove) the tourniquet and assess perfusion.
- Apply dressings and a well-padded long-arm cast for 3 to 4 weeks.



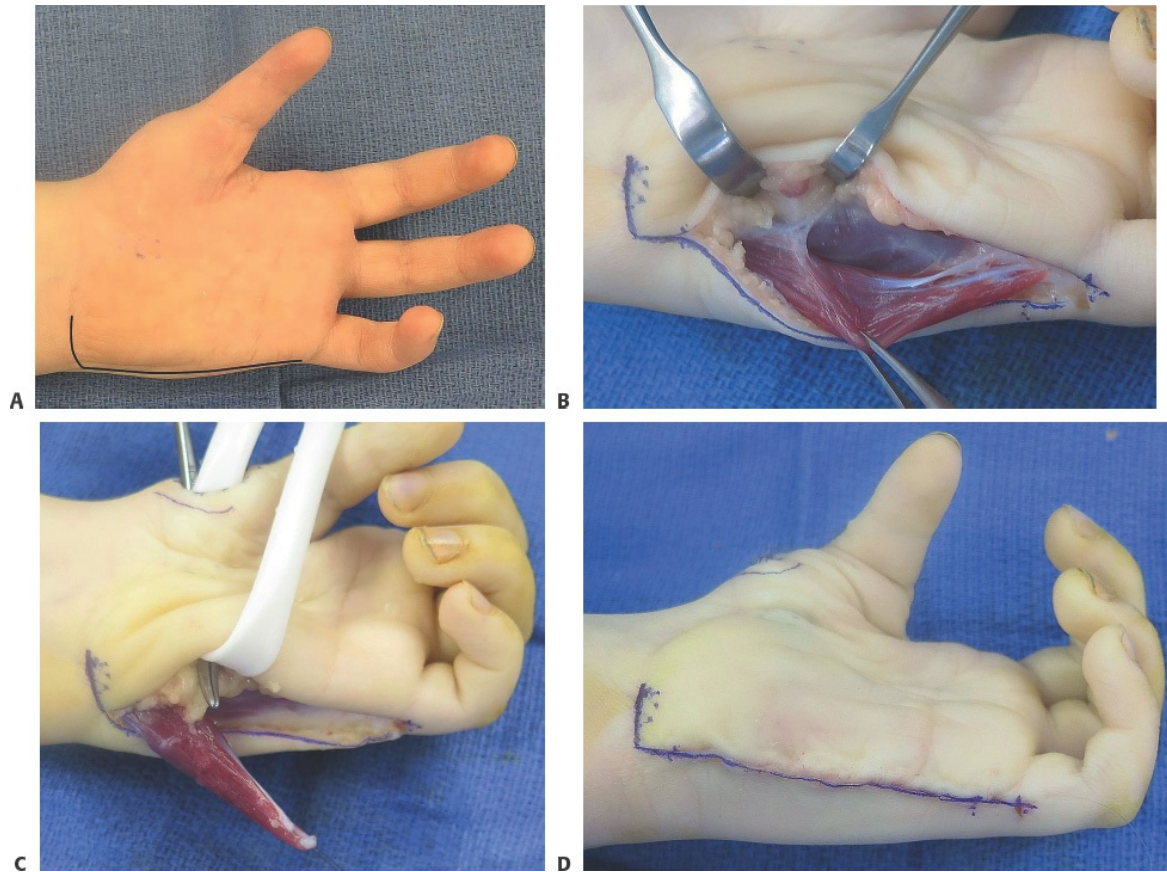
TECH FIG 6 • Immediate postoperative palmar view shows good opposition (**A**) and a wide web space after four-flap Z-plasty (**B**).

■ Opponensplasty With Abductor Digiti Minimi (Huber)

- Design an L-shaped incision on the ulnar side of the hand (**TECH FIG 7A**).
 - The long limb of the incision should be a high mid-lateral ulnar incision extending from just distal to the fifth digit MP joint to the pisiform.
 - The short limb is a transverse volar incision on the distal wrist crease just proximal to the pisiform. This second incision helps to free the proximal origin of the abductor digiti minimi (ADM) muscle *if needed* for additional mobilization of the muscle. Note: The transfer can also be raised as a myocutaneous flap thus avoiding tunneling and adding more bulk to the thenar area.⁵
- Incise the mid-lateral ulnar marking and dissect down to the ADM muscle.

Isolate and protect any branches of the dorsal sensory ulnar nerve.

- Incise the fascia and dissect the muscle free (**TECH FIG 7B**), following it distally until its insertion is encountered on the fifth digit proximal phalanx.
- Disinsert the muscle, leaving a long cuff of periosteum attached to the muscle to facilitate subsequent reinsertion.
- Dissect the muscle proximally and identify and protect its neurovascular bundle. If additional length is needed on the muscle, the short limb of the L-incision can be made and the origin mobilized off the pisiform and flexor carpi ulnaris. The author does not transfer the origin.
- Make a high mid-axial incision on the radial aspect of the thumb MP joint and dissect down to the distal metacarpal.
- Create a generous subcutaneous tunnel between the thumb MP joint and the proximal aspect of the ulnar wound (**TECH FIG 7C**). Tunnel the muscle through.
- There are multiple sites where the muscle can now be attached: the extensor hood, the proximal aspect of the proximal phalanx, or the distal aspect of the metacarpal.
 - The author typically attaches the muscle to periosteum near the metacarpal head. This insertion site gives the most direct pull without taxing the MP joint UCL. It also avoids radial pull on the extensor mechanism, which may disrupt the learned prehensile patterns in postpollicization cases or translate the (already radially displaced) extensor tendon in hypoplastic cases.
- Attach the muscle and secure with several sutures to obtain maximal palmar abduction under moderate tension. Ensure that the pedicle is not kinked.
- Close the wounds with absorbable sutures (**TECH FIG 7D**). The ulnar incision is closed with a running intradermal suture.
- Place antibiotic-impregnated petroleum gauze (Xeroform) on the wounds and apply compression gauze.
- Deflate (or remove) the tourniquet and assess perfusion.
- Apply a well-padded long-arm cast for 3 weeks.



TECH FIG 7 • A. A 6-year-old boy who underwent left index finger pollicization for type IV thumb hypoplasia presented with weakness of palmar abduction and opposition. A high midlateral ulnar incision is planned with a transverse extension at the distal wrist crease, just proximal to the pisiform. **B.** The ADM muscle is seen as the most ulnar/palmar structure deep to the skin. **C.** The ADM muscle has been mobilized. A generous tunnel housing a Penrose drain connects the ulnar incision to the mid-lateral incision on the radial aspect of the neothumb “MP joint.” **D.** The muscle has been tunneled and inset in maximal palmar abduction/opposition. The wounds have been closed.

PEARLS AND PITFALLS

Anatomy

- There are numerous variations of extrinsic and intrinsic muscle/tendon anatomy, including a lumbrical emanating from the flexor (so-called musculus lumbricalis pollicis), flexor that inserts partially on the proximal phalanx, joined flexor and extensor proximally, eccentric insertions, and various degrees of attachment of the FPL to the EPL. Not all of these abnormalities need to be surgically repaired.

Technique

- Radial deviation at the MP and IP joints can be improved by releasing the pollex abductor with or without step-lengthening of the flexor tendon and reinsertion of the EPL and/or FPL into a more ulnar position on the distal phalanx. Pin fixation may be necessary after this procedure to keep the joints straight.

Surgical management

- Although many parents ask the surgeon to restore active IP joint motion, this is possible only in a small subset of patients who have preoperative passive but not active IP joint motion.
- On occasion, the MP joint laxity is so severe (global) that one should consider MP joint chondrodesis or epiphyseal arthrodesis. Chondrodesis does not heal predictably, and epiphyseal arthrodesis is only possible if there is enough epiphysis to allow fusion. Both techniques shorten the thumb and stress the CMC joint.

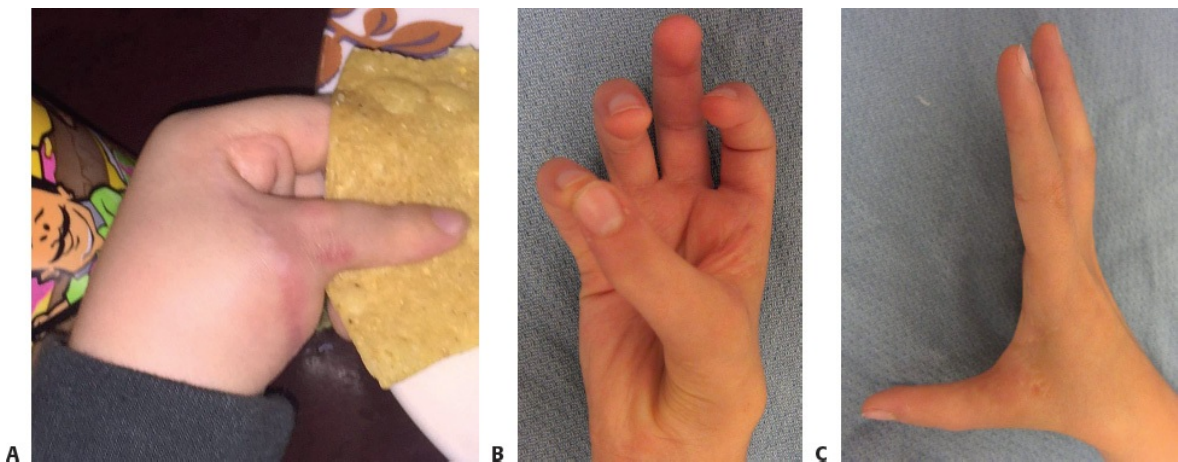


FIG 3 • **A.** Two months postoperatively, the patient was using the opposition transfer for grasping food. Three years postoperatively, he demonstrates a stable MP joint with strong opposition (**B**) and a wide first web

space (C).

POSTOPERATIVE CARE

- Remove the cast after 3 or 4 weeks of immobilization.
- Fashion a thumb spica thermoplast splint that can be worn for 2 or 3 weeks at night for protection.
- Start range of motion exercises with hand therapy.

OUTCOMES

- Functional outcomes for hypoplastic thumb reconstruction are satisfactory if the anatomic abnormalities are appropriately treated (**FIG 3**).
 - There is a lack of good long-term data on functional outcomes, especially data that have been controlled for severity of involvement.
- The reconstructed thumb remains smaller and less powerful than the normal thumb.

COMPLICATIONS

- Immediate complications are rare. Long-term functional concerns relate to the degree of hypoplasia, correct preoperative diagnosis, and appropriate treatment.
- Persistent lack of active IP joint motion can be seen despite adequate release of the tendon adhesions.
- Inadequate release of pollex abductor attachments can cause a deforming radial force and weaken the MP joint UCL repair in the long term.
- If the collateral ligament is reconstructed dorsal to the axis of rotation, hyperextension of the MP joint may result. Ensure that the vertical tunnel on the proximal phalanx is centered volarly.

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65 Reconstruction of Radial Polydactyly

CHAPTER

Amir H. Taghinia

DEFINITION

- Polydactyly refers to the presence of extra digits. Most surgeons prefer this term to duplication, as the latter implies that the partners are exactly identical, which is the exception rather than the rule.
- Radial polydactyly is the presence of extra digits involving the thumb ray. This terminology is preferable to preaxial polydactyly because the term preaxial encompasses the thumb through ring rays.

ANATOMY

- Radial polydactyly is most commonly classified using the Iowa classification system.¹ The system divides polydactyly based on longitudinal level of bone and/or joint arborization but does not account for soft tissue differences (**FIG 1**).
- Not considering small soft tissue-only (nubbin) polydactyly cases, type IV is the most common radial polydactyly (approximately 45% of cases) and type II is the second most common (approximately 20% of cases).
- Type VII radial polydactyly, which has a triphalangeal component, is further subdivided into six types.
- The Iowa classification does not include soft tissue differences and certain types of radial polydactyly. Accordingly, additional classification systems have been proposed.
- The Rotterdam system gives broader classification possibilities (including triplicate thumb) but introduces more complexity.²
- Although the thumb partners may be nearly identical, the ulnar partner is usually the more dominant one; it is larger and better developed and has greater

range of motion and strength.

- Nevertheless, both partners may exhibit findings of thumb hypoplasia, including smaller stature, poorly developed joints and tendons with lack of flexion or extension creases, joint deviations, eccentrically inserting extrinsic tendons, and abnormal or deficient intrinsic muscles.

PATHOGENESIS

- The exact etiology of radial polydactyly remains unknown. The literature suggests an imbalance between the apical ectodermal ridge (AER) and the underlying mesoderm as one cause.
- Based on the Oberg, Manske, and Tonkin classification,³ polydactyly is considered to be a malformation with abnormal formation/differentiation of the hand plate in the radioulnar axis.

NATURAL HISTORY

- Radial polydactyly occurs more commonly in those with Caucasian and Asian descent, with an incidence of 1 in every 3000 live births.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are usually seen in infancy.
- Radial polydactyly may run in families.
- Associated conditions may occur, even Fanconi anemia, a rare condition that can be fatal if not diagnosed early.
- Examine the thumbs for flexion and extension creases, passive and active range of motion, joint stability, and strength.
- During late infancy, the child usually starts to use the more dominant thumb. It is worthwhile to see the child at play to better understand the developing prehensile patterns.

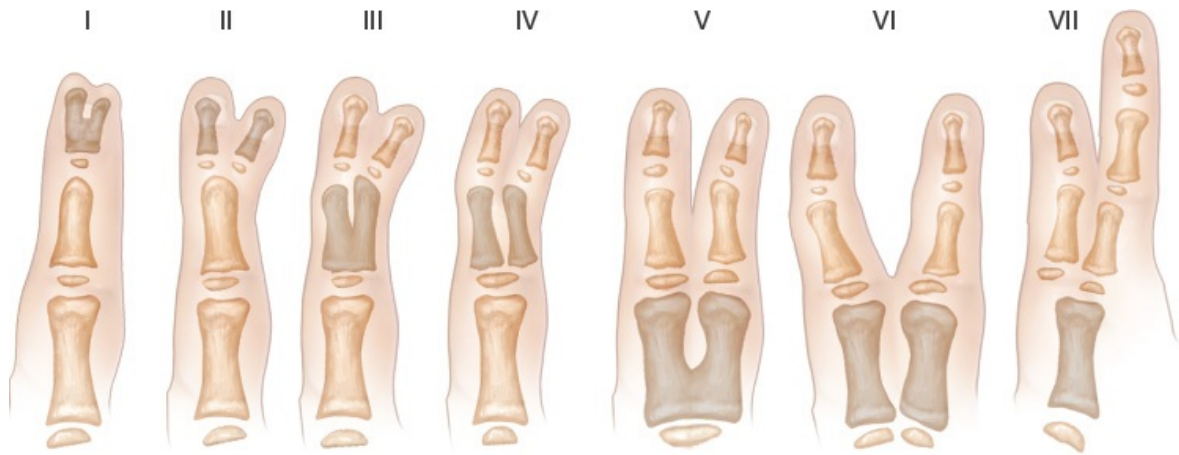


FIG 1 • Iowa classification of radial polydactyly. The distinctions are based on increasing levels of proximal divergence. The radial partner tends to be smaller and less developed.

IMAGING

- Plain radiographs are the study of choice and should be obtained for most polydactyly cases involving bone.
- Radiography resolves all uncertainty about the level and involvement of a polydactyly that may not be clear on physical examination.

SURGICAL MANAGEMENT

- Small pedunculated (“nubbin”) polydactyly is treated in the office before a month of age. Young infants are not strong enough to resist small procedures, and they can be soothed easily with a pacifier or sugar water.
- Suture ligation can leave a small bump, so two alternatives are preferred, both using local anesthesia in the clinic treatment room: excision and suture closure or clipping at base with a hemoclip and excision. Both options are offered to the parents in this early age.
- The advantage of the clipping is that it is quick, but the clip can stay several weeks and cause local skin irritation, and there is a small risk of ingestion (especially on the radial side) if not covered with a dressing at all times.
- The excision and closure option takes more time but with likely fewer potential complications.
- For older infants or those in whom the polydactyly has a wide base, the author prefers excision in the operating room under general anesthesia at about 9 to 12

months of age.

- General anesthesia is also required in cases with more extensive involvement. No clear consensus exists regarding timing of repair. The risk of anesthesia in a small child should be weighed against early repair that takes advantage of brain plasticity. Other medical comorbidities should be taken into account.
- Small object grasp in the infant starts around 9 months of age; accordingly, the author prefers to correct polydactyly between 9 months and 1.5 years of age.
 - For very complex cases, it is worthwhile to delay repair until the structures are large enough to conduct a more technically precise operation. An example is a small trapezoidal or delta phalanx that requires a closing wedge osteotomy (eg, triphalangeal thumb).

Surgical Options

- There are three methods for repair of radial polydactyly: resection and reconstruction, the sharing technique, and acral transposition (“on-top plasty”).
 - The surgeon should not apply one technique to one type of polydactyly based purely on algorithm.
 - Instead, a careful analysis of the clinical and radiographic findings, as well as expected functional outcome and patient factors, should dictate the choice of reconstruction.
- The main principles for repair are ablation of nonfunctional structures, creation of the best functional and aesthetic single digit from parts of both partners, and preservation of length, stability, and a wide first web space.

Resection and Reconstruction

- Resection and reconstruction involves resecting the more hypoplastic partner and augmenting the better developed one (see Technique section).
- This technique is indicated when the dominant partner alone is sufficient to be a thumb with good appearance and function.
- It is the easiest and the most favored approach. It can be applied to all types of polydactyly and is the most common operation for types IV to VI.
- The main sequence of this procedure is as follows:
 - Disarticulation of the discarded partner but preservation of a ligamentoperiosteal flap and (if present) muscle insertion
 - Shaving of redundant proximal articulation
 - Osteotomies to correct angulation, if needed

- Reattachment of the ligamentoperiosteal flap and muscle insertions
- Rebalancing of eccentrically aligned extensor and flexor tendons, if needed

Sharing Technique

- The sharing technique uses parts from both partners to create a single digit. The most common expression of this technique is the Bilhaut operation, which removes central tissues and combines two digits into one.
- The procedure is indicated for nearly symmetrical but hypoplastic partners when removal of one partner only would leave a small thumb.
- The original Bilhaut technique removed equal parts from symmetrical partners but resulted in unsatisfactory outcomes including nail ridging, growth disturbance, and stiffness.
- The modified Bilhaut technique proposed by Baek⁴ shows more promising results. It removes extra-articular unequal parts from symmetrical partners, thus avoiding articular reconstruction and creating a well-contoured distal phalanx for the nail.
- The technique is typically performed for types II and III thumbs when the two partners are small but nearly equal in size.
- It can also be applied to type IV thumbs, but because the phalanges are usually asymmetrical, articular step-offs and bony misalignment are more likely to occur, resulting in less satisfactory outcomes.⁵
- Dorsal and volar incisions are made, the central soft tissue is excised, and the phalangeal components are identified. The dominant phalanx's articular surface is preserved. Similarly shaped extra-articular osteotomies are performed in each phalanx such that the defect in the dominant distal phalanx will be matched by a small nonarticular, soft tissue-bearing bone segment of the nondominant distal phalanx (**FIG 2**). The phalanges are then opposed and secured with Kirschner wires or sutures.

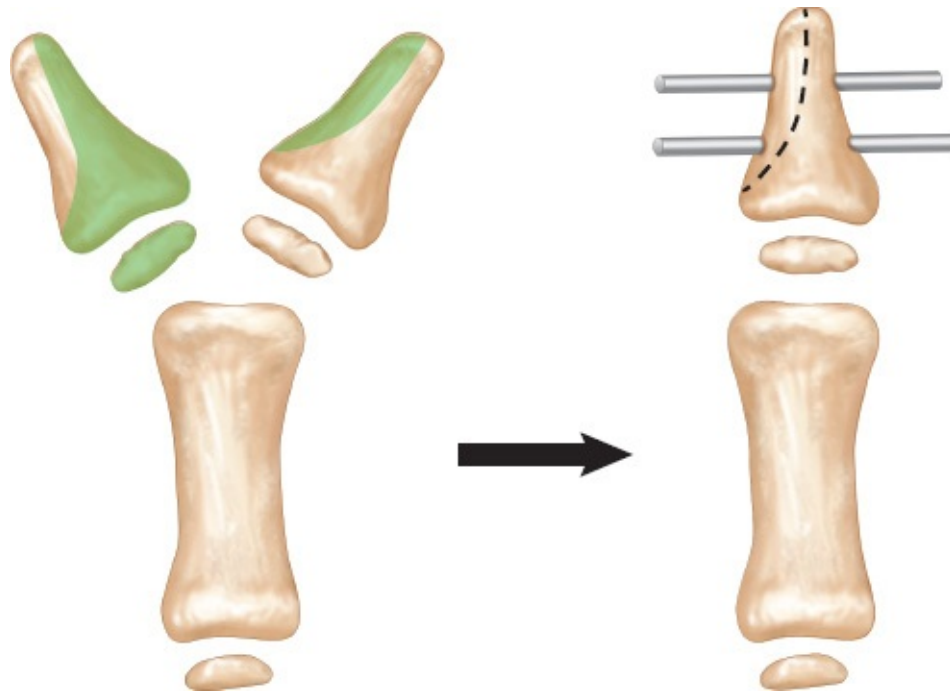


FIG 2 • In the modified Bilhaut operation for type II radial polydactyly, an extra-articular portion of each distal phalanx is shared to reconstruct one distal phalanx. Typically, a greater portion of the more dominant partner is preserved. Kirschner wires (shown) or sutures provide fixation for the osteotomy.

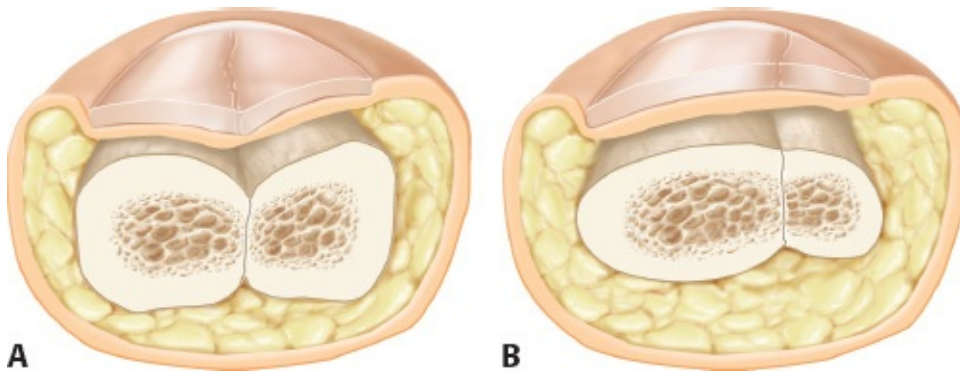


FIG 3 • In the original Bilhaut operation, half of each distal phalanx was used to reconstruct the thumb. **A.** The contour was suboptimal, leading to a groove in the nail. **B.** In the modified Bilhaut technique, slight volar axial rotation of the distal phalanges prior to fixation

ensures a smoother nail contour.

- Slight volar axial rotation of the distal phalanges prior to fixation will ensure a smoother nail contour without a groove, avoiding the so-called seagull deformity (**FIG 3**).
- The nail bed and skin are then repaired using fine sutures.

Acral Transposition

- On-top plasty is performed when one digit has better proximal components and the other has better distal components.
- This reconstruction is more common for cases with metacarpal or carpometacarpal arborization such as in types V to VII radial polydactyly.
- The procedure involves moving the better distal component of one partner onto the better proximal component of the other.
- The better distal component is isolated as a neurovascular island flap, and an osteotomy is performed at the desired level of transfer. The lesser distal component is excised and an osteotomy of the better proximal component is done at the desired level of transfer (**FIG 4**).
- The transfer is then performed and fixed with pins or interosseous wires. The intrinsic muscles are rebalanced and the skin is closed.
- Joint and bone deviations should be corrected (to the greatest extent possible) in the first operation with osteotomies and tendon rebalancing as needed. Subsequent repairs may be needed with growth.⁶
- In more proximal cases (eg, type V and VI), the surgeon should carefully consider the first web space. Because the ulnar partner is the one that is most commonly preserved and it is usually ulnarly deviated, the surgeon should perform maneuvers necessary to make sure that the first web space will be sufficiently wide.

Preoperative Planning

- Discuss risks, benefits, and expectations with parents on the day of surgery.
- Specifically outline the risks of scarring, joint deviations, stiffness, and bulges.

Positioning

- The patient is positioned supine with the arm out on a small hand table.

Approach

- Incisions are planned carefully prior to use of the tourniquet. The author prefers mid-lateral incisions to dorsal incisions, since they produce the best appearance.
- In infants and toddlers, an Esmarch bandage is used as a tourniquet.

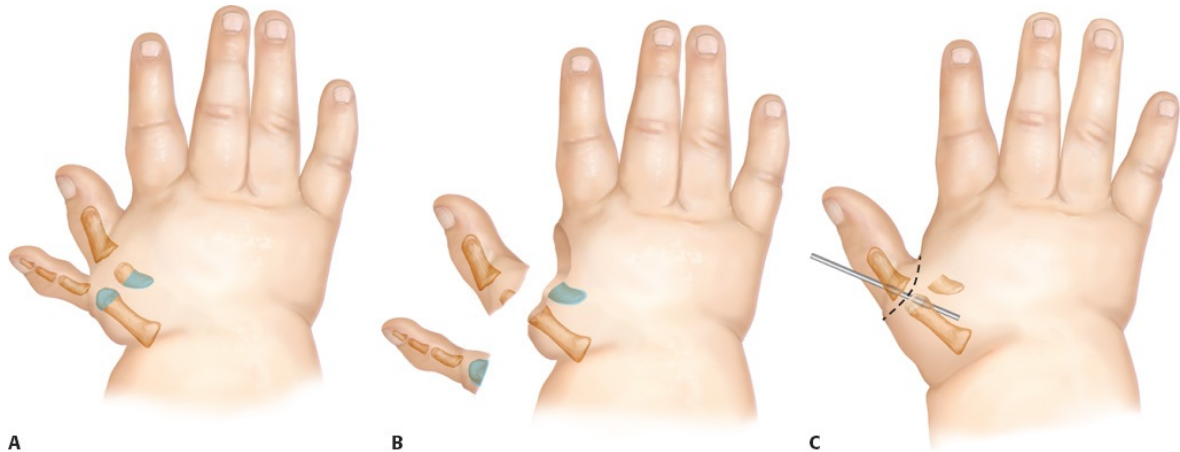


FIG 4 • Acral transposition (“on-top plasty”) is usually indicated in more proximal radial polydactyly where one partner is dominant distally and the other is dominant proximally. **A.** In this case, the dominant ulnar distal partner will be transferred to the dominant proximal radial partner. Osteotomy sites are indicated in blue highlighting. The shaded portion of the ulnar partner’s metacarpal will be discarded. The skin incisions are planned such that plenty of skin is preserved on the hand from the radial partner. The goal is to dissect the ulnar partner as a vascularized island flap and translate it into the soft tissue sleeve of the radial partner. The wound where the ulnar partner resided will then be closed linearly, thus constructing a wide first web space. **B.** During the operation, the distal radial partner is discarded while any intrinsic muscles that attach to it are preserved for subsequent attachment onto the transferred partner. **C.** After the ulnar partner is isolated as a vascularized island flap, osteotomy is performed,

and it is transferred onto its new position and secured with interosseous wires or Kirschner wires. The intrinsic muscles are reattached, and the skin is closed, resulting in an improved web space.

TECHNIQUES

■ Reconstruction of Type IV Radial Polydactyly

Markings and Exposure

- The case of a 9-month-old boy with type IV polydactyly is presented with step-by-step surgical treatment (**TECH FIG 1A–C**).
- Draw the markings for a mid-lateral closure. Leave excess skin on the preserved partner and trim the skin later to create a custom closure (**TECH FIG 1D,E**).
 - The closure takes extra time but improves appearance.
- Once the tourniquet is applied, incise the dorsal markings and dissect sharply to the extensor tendon (**TECH FIG 1F**).
- Develop a plane above the extensor mechanism to just beyond the metacarpophalangeal (MP) joint (**TECH FIG 1G**).
- Incise the extensor tendon distal to its bifurcation and dissect under the extensor above the MP joint capsule.
- Incise the palmar markings; dissect and divide the neurovascular bundle (**TECH FIG 1H**).
- Dissect a plane over the flexor mechanism and the intrinsic abductor of the thumb (**TECH FIG 1I**). The abductor usually inserts on the radial and volar aspects of the proximal phalanx, but the anatomy is quite variable.

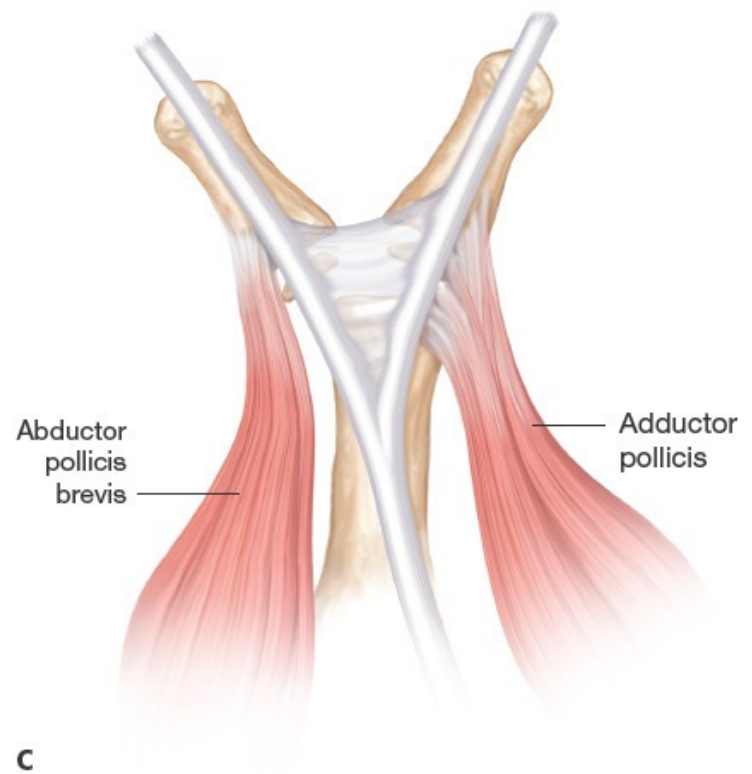
Flap Creation

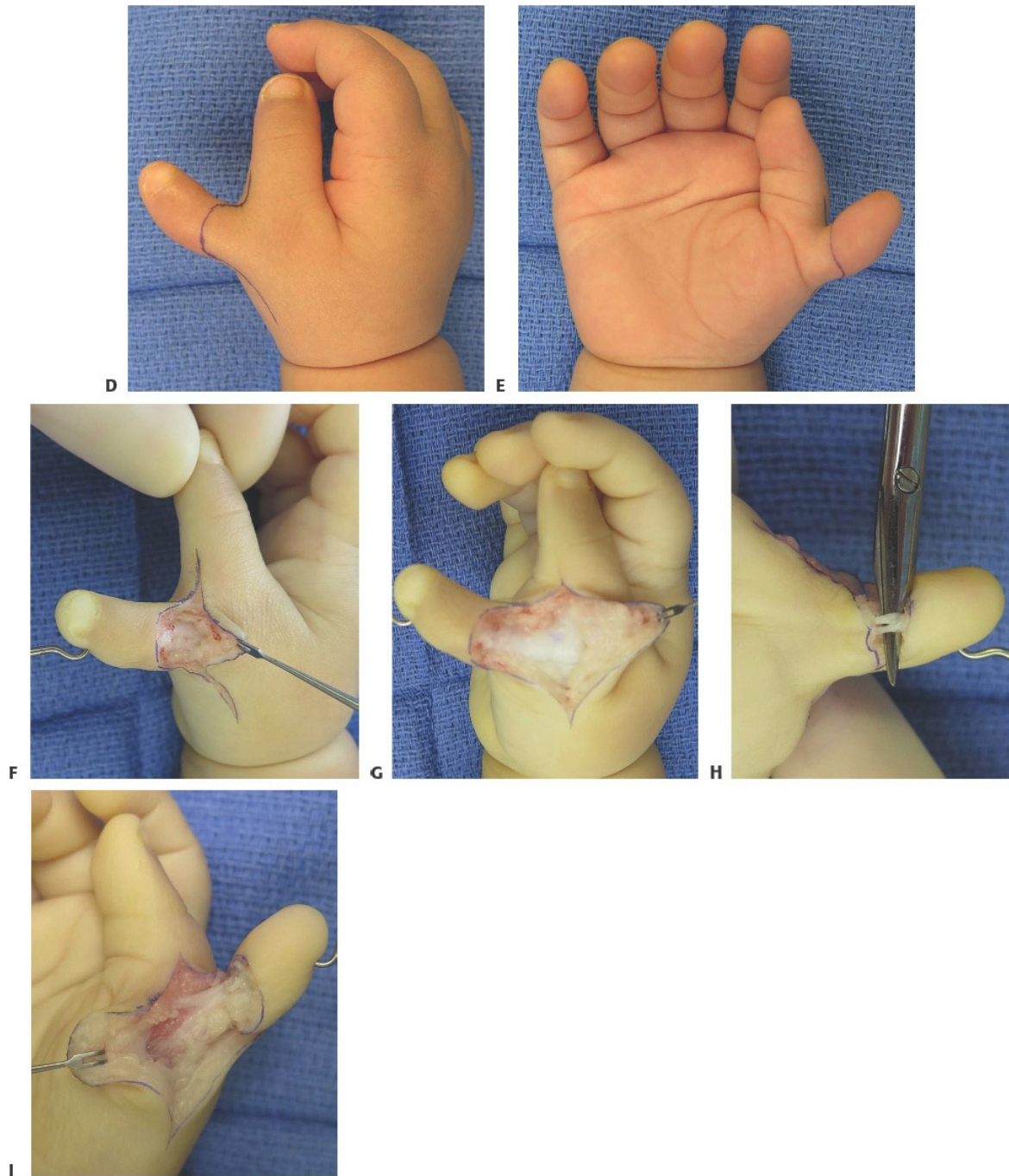
- Design a proximally based periosteal flap on the radial aspect of the proximal phalanx (**TECH FIG 2A**).
- Incise the markings and elevate this flap with the radial partner's MP joint radial collateral ligament and the abductor muscle (**TECH FIG 2B**).
 - This flap will be used for subsequent reconstruction of the retained partner.

- Isolate and divide the extrinsic flexor tendon (**TECH FIG 2C**).

Disarticulation, Osteotomy, and Fixation

- Disarticulate at the MP joint. A bifid metacarpal head will now be visible (**TECH FIG 3A**).
- Cut the metacarpal head that articulated with the discarded partner (see **TECH FIG 2B**).





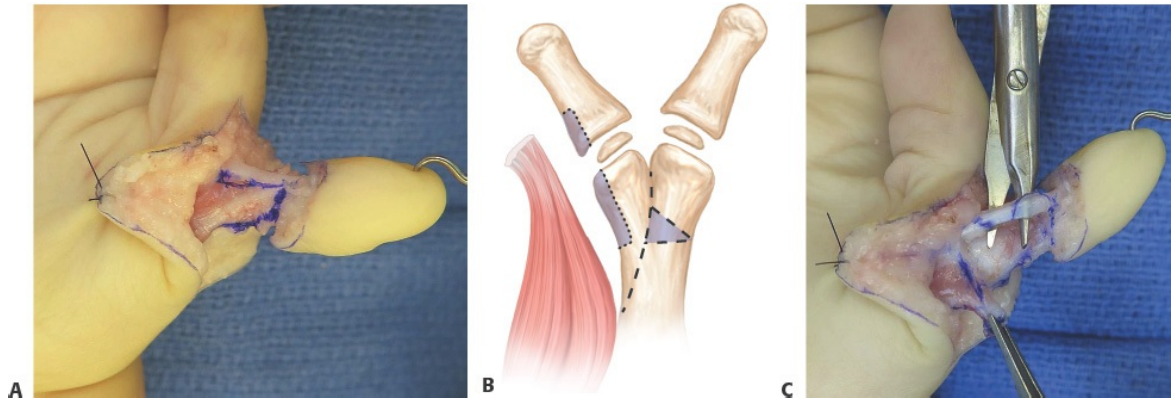
TECH FIG 1 • Type IV radial polydactyly in a 9-month-old boy. **A,B.** Anteroposterior clinical and radiographic views demonstrate a smaller, less developed radial partner. The ulnar partner is inline (parallel) to the metacarpal, and so an osteotomy of the metacarpal will not be needed. **C.** Simplified anatomy of radial

polydactyly. The abductor pollicis brevis muscle can have variable, and potentially multiple, insertion sites, such as onto the extensor, the bone, and the flexor tendon. If on-top plasty is planned, the insertion of the adductor pollicis should be considered. **D,E.** Dorsal and palmar views of the operative markings for planned excision of radial partner. A mid-lateral closure is planned. Excess skin is left on the retained partner for subsequent closure. **F.** The dorsal skin incision has been incised, the dorsal veins are cauterized, and a plane is developed over the extensor mechanism. **G.** The dorsal skin flap is elevated proximal to the MP joint. **H.** The volar incision is made, and the neurovascular bundle to the radial partner has been identified. **I.** The volar skin flap is elevated to expose the flexor tendon and the intrinsic abductor musculature.

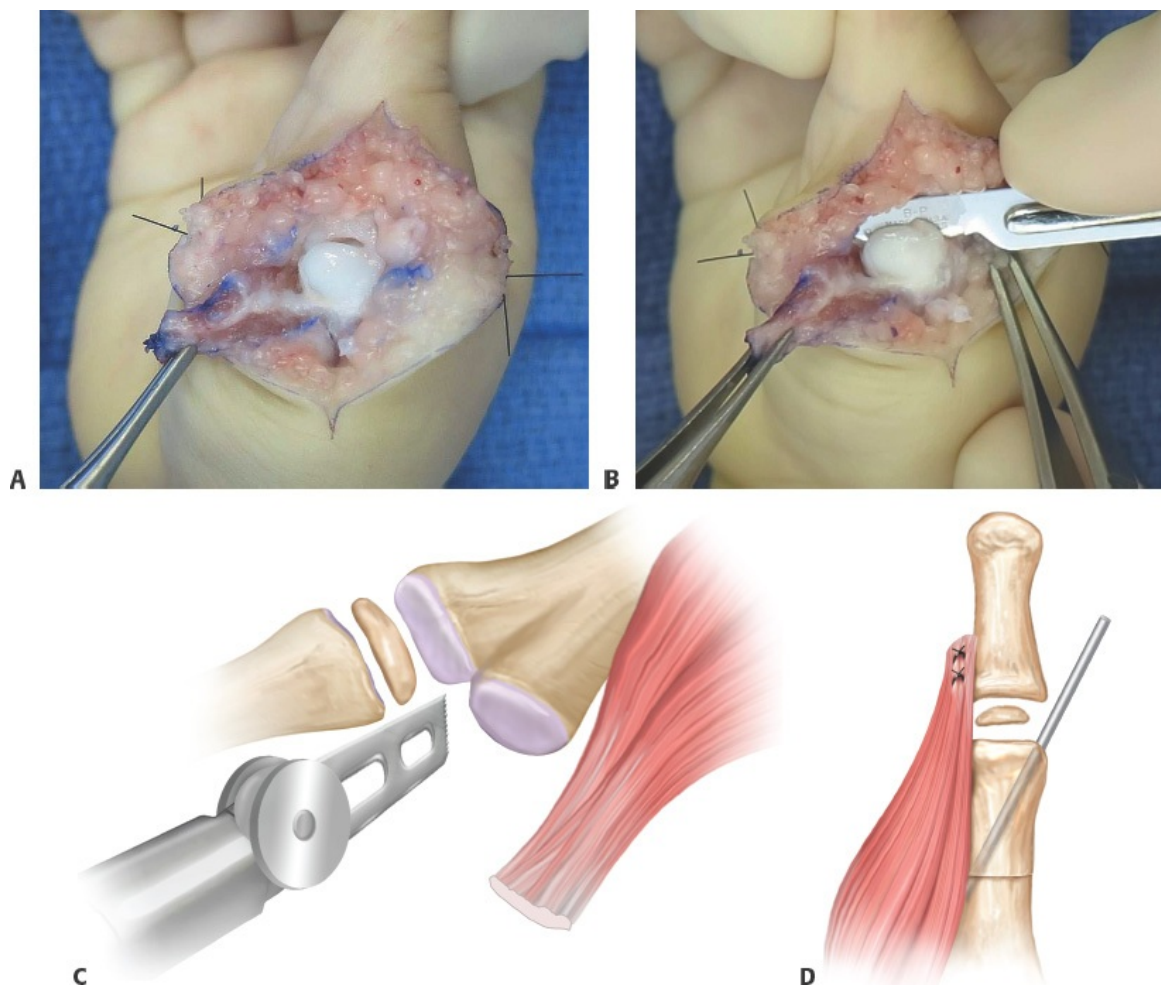
- If only cartilage is involved (in minor cases), a knife will be sufficient to complete this task (**TECH FIG 3B**).
- In most cases, however, a retrograde osteotomy with a saw or a fine bone cutter is needed (**TECH FIG 3C**).
- Assess the need for closing wedge metacarpal osteotomy. When MP joint ulnar angulation of the retained partner is prominent, a closing wedge osteotomy is needed (**TECH FIG 3D**).
- Pin fixation is necessary after osteotomy (**TECH FIG 4**). Insert a retrograde 0.028 in. Kirschner wire from the ulnar side.

Tendon Correction in Type IV Polydactyly

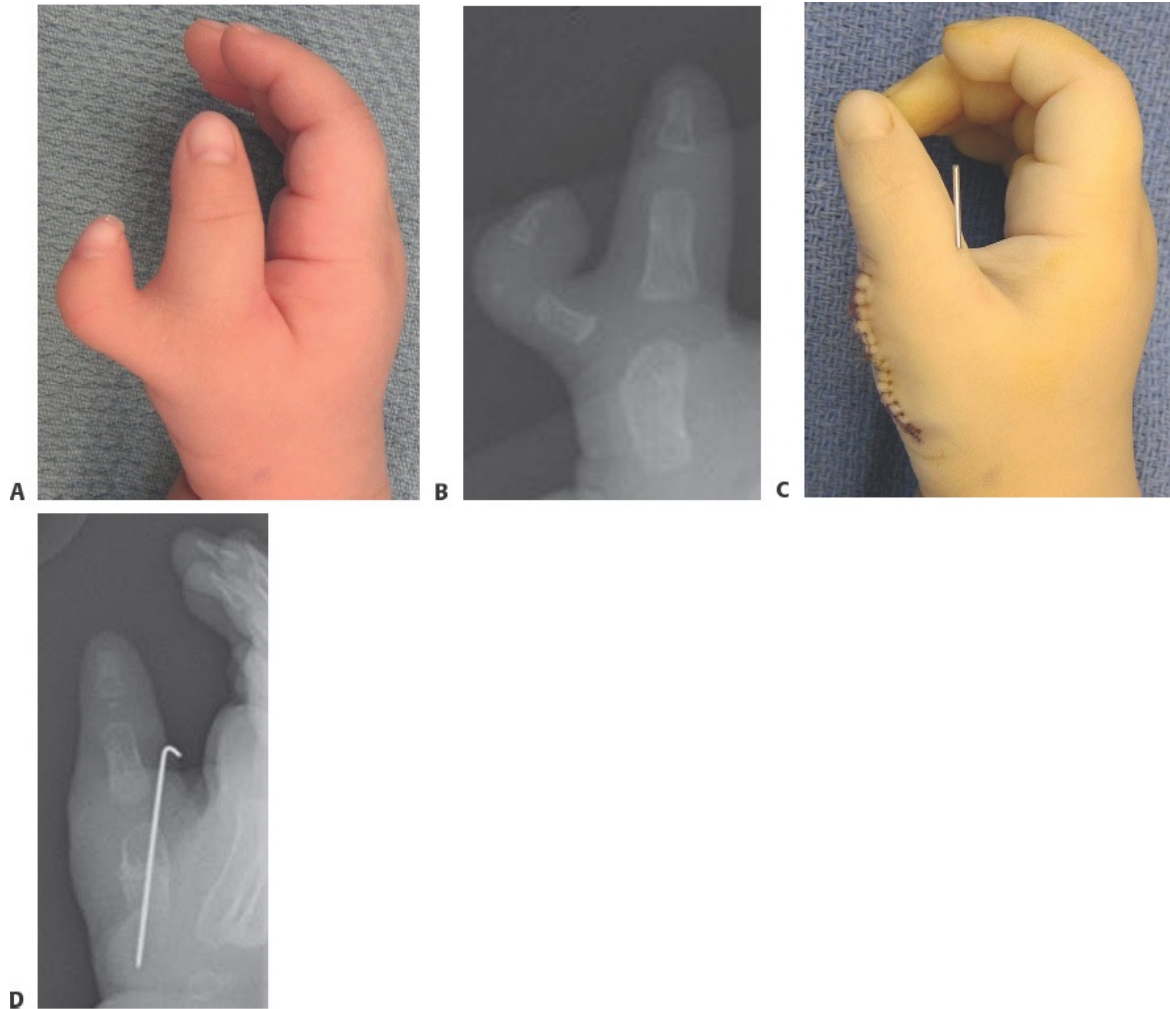
- In divergent-convergent (rhomboid) type IV polydactyly, the extensor and flexor tendons can have eccentric insertions onto the distal phalanges (**TECH FIG 5**).



TECH FIG 2 • A. A proximally based periosteal flap is designed. The flap will include the radial collateral ligament and the abductor muscle insertion. Note that the muscle is inserting onto the bone (periosteum) and the flexor tendon. **B.** Technical maneuvers necessary for reconstruction of type IV radial polydactyly. The periosteal/muscle flap has been lifted, the dotted area showing the previous area of flap adherence. It is ideal to leave a long periosteal cuff on the flap to make subsequent repair easier. The radial head of the bifid metacarpal is cut, and a closing wedge osteotomy is performed if there is deviation of the ulnar partner. **C.** The flexor tendon is isolated. Note the periosteal/muscle flap reflected proximally and held with forceps.



TECH FIG 3 • **A.** The radial partner has been disarticulated at the MP joint, and the bifid metacarpal head is noted. **B.** In minor cases, such as this one, the radial head of the metacarpal is mostly cartilaginous and can be excised using a blade. **C.** In most cases, the radial head of the metacarpal has an osseous component and a retrograde osteotomy with a saw is needed. **D.** Illustration demonstrates result after closing wedge osteotomy (secured with a pin) and reattachment of the periosteal/muscle flap.



TECH FIG 4 • A,B. A different patient is demonstrated with type IV radial polydactyly and more significant ulnar angulation of the ulnar partner at the MP joint. Improvement in angulation is noted after closing wedge osteotomy and pin fixation intraoperatively **(C)** and 3.5 weeks postoperatively **(D)**.



TECH FIG 5 • In rhomboid type IV polydactyly, the extrinsic tendons can attach eccentrically on the distal phalanges, thus exaggerating the deviation. If these abnormal insertions are not addressed, deviation can recur with growth.

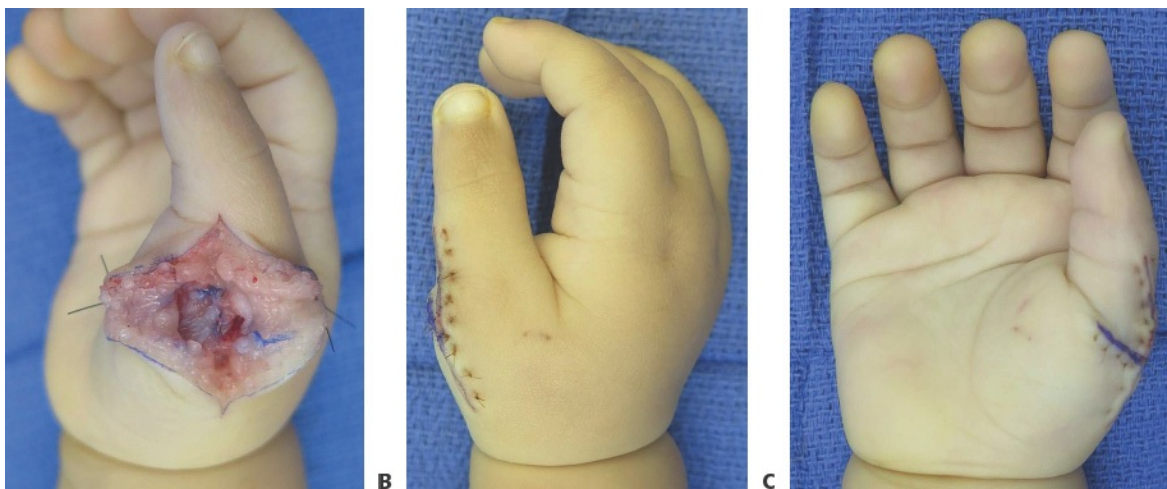
- If left alone, these abnormal tendons can contribute to long-term misalignment and deviation of the thumb.
- They should be detached and reattached at the proper location on the distal phalanx.

Reattachment and Closure

- Reattach using sutures the flap of periosteum, collateral ligament, and muscle to the radial aspect of the retained proximal phalanx (**TECH FIG 6A**).
- After removal of the radial metacarpal head, the radial aspect of the

remaining metacarpal is bare and not attached to the collateral ligament; however, the collateral ligament heals well to the metacarpal.

- Additional reinforcing sutures to the metacarpal may be necessary.
- There will be excess skin in multiple dimensions. In most cases, the excess skin can be trimmed and “cheated in” and a mid-lateral closure completed.
- If there is abundant excess, a better approach is to make a separate palmar incision along the MP joint flexion crease to excise skin in an orthogonal dimension (**TECH FIG 6B,C**).
- Apply a soft dressing and a long-arm cast for 3 to 4 weeks.



TECH FIG 6 • **A.** The periosteal, collateral ligament, and muscle flap have been reattached to the proximal phalanx with additional reinforcing sutures onto the radial aspect of the metacarpal. **B.** Final appearance after closure. **C.** Note that the “dog ear” has been ablated via a separate incision in the volar MP joint flexion crease.

PEARLS AND PITFALLS

Surgical management

- It is the author’s opinion that, when possible and especially in more proximal polydactyly cases, resection and reconstruction give a

better aesthetic outcome than does the Bilhaut “sharing” technique. The downside is that the thumb is usually smaller.

- The surgeon should have a well-defined stepwise approach for each case.

Technique

- When developing muscle and/or collateral ligament flaps, leave a long periosteal sleeve to allow easier subsequent reattachment.
- In polydactyly cases that have multiple levels of joint deviation (eg, rhomboid type IV), multiple simultaneous osteotomies should be undertaken.

POSTOPERATIVE CARE

- Immobilize the extremity with a long-arm cast with the elbow at 90 degrees of flexion for 3 or 4 weeks. The author immobilizes longer in those patients who have undergone osteotomies.
- Remove the cast (and pins) and refer to hand therapy for fabrication of a thermoplast thumb spica splint.
- Start range-of-motion exercises.
- Wear the splint for 2 or 3 weeks at night.
- See patients once every 1 to 2 years to assess function, growth, and joint deviation.

OUTCOMES

- Although multiple different outcome scoring systems have been proposed, reliability appears highest for the scoring system proposed by the Japanese Society for Surgery of the Hand.⁷
- The results after polydactyly repair are generally satisfactory but depend greatly on the initial deformity.
 - Results of type III, V, and VI repairs are less satisfactory.
- The affected side is weaker than the normal side and revisions are common, but patients have favorable scores on objective outcome measures.⁶
- Long-term unfavorable outcomes after repair include deviations and angulations (with associated pain), bony prominences, stiffness, and nail deformity. Deviations maybe the result of trapezoidal or delta phalanges, canted or unstable joints, or asymmetrical growth and can occur long term despite an adequate initial repair.
- The Bilhaut procedure has had unfavorable results including stiffness and nail deformity. Many prefer resection and reconstruction to this technique,⁵

although the aforementioned modification of the Bilhaut technique for more distal polydactyly cases⁴ has shown promising results and gained support.

COMPLICATIONS

- Immediate complications are rare and include bleeding, infection, and wound dehiscence.
- Wound dehiscence is almost always due to inadequate immobilization and can be prevented with a long-arm cast.

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66 Index Finger Pollicization for Hypoplastic Thumb

CHAPTER

Amir H. Taghinia, Brian I. Labow, and Joseph Upton

DEFINITION

- The thumb is the functional keystone of the hand. The basic hand unit has three main elements: a thumb, a web space, and a prehensile post. Severe hypoplasia or aplasia of the thumb leads to significant functional impairment.
- Index finger pollicization is the procedure of transposing the index finger into the position of the thumb. It is the quintessential operation of hand surgery, incorporating key principles and requiring meticulous technique and execution.
- The methods outlined herein include further refinements¹ to the techniques initially proposed, developed, and refined by D. Buck-Gramcko² and J. W. Littler.³

ANATOMY

- The normal thumb is perfectly adapted for pinch and grasp. It is broad with osseous and articular structures that move in multiple planes. Its intrinsic muscles provide a short moment arm, powering the movement enabled by the osseoarticular column.
- The normal first web space has a gentle curve spanning from the thumb metacarpophalangeal (MP) joint to the index finger MP joint.
- A thumb is considered hypoplastic if any of its osseous, musculotendinous, or articular components is deficient or if the web space that it forms with the index finger is shallow.
- The modified Blauth⁴ classification system provides a surgically useful basis for categorizing thumb hypoplasia. Most surgeons agree that Blauth types I, II, and IIIA thumbs can be reconstructed, whereas Blauth types IIIB, IV (*pouce flottant*), and V (aplasia) hypoplastic thumbs require index finger pollicization.

- The differentiating factor between Blauth type IIIA and IIIB thumbs is the presence (IIIA) or absence (IIIB) of a functional carpometacarpal (CMC) joint.
- The preoperative state of the index finger is the greatest determinant of long-term postoperative function after pollicization.^{1,5} Patients with normal index fingers will have the best function. Abnormal index fingers are typically seen in patients with radial longitudinal deficiency. Abnormalities include stiffness, joint hypoplasia, incomplete intrinsic muscles and/or extrinsic tendons, and hypoplastic or anomalous vessels and nerves.

PATHOGENESIS AND NATURAL HISTORY

- Thumb hypoplasia occurs as a result of multiple potential factors, including genetic (associated syndromes), environmental, teratogenic (thalidomide), and idiopathic causes.
- It is considered to be a malformation, based on the Oberg, Manske, and Tonkin classification of 2010.⁶
- Thumb hypoplasia occurs in 1 out of 100 000 live births.
- A large number of patients with thumb hypoplasia have associated conditions such as cardiac or hematologic anomalies.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are usually seen in infancy. In severe cases such as type IV or type V, the diagnosis is clear. Nevertheless, the difference between type IIIA and IIIB can be difficult to ascertain in a newborn. The integrity of the CMC joint is sometimes not obvious on plain film radiographs. Functional differentiation can be made by allowing the child to grow and watching the toddler at play—if the thumb is not used, the joint is likely nonfunctional.
- Indeed, most children with severe thumb hypoplasia will scissor pinch using the index and middle fingers in lieu of the nonfunctional thumb. With time, the web space between the index and middle fingers widens and the index finger starts to pronate. These patients are ideal candidates for pollicization.
- The hand surgeon should be aware of the conditions associated with thumb hypoplasia, and have a low threshold to refer if suspicions arise.
 - In particular, roughly 50% of patients with Fanconi anemia (an inherited defect in DNA repair leading to bone marrow failure and premature malignancy) manifest thumb hypoplasia, along with a variety of other anomalies. The diagnosis of Fanconi anemia can be made via a blood test early in life.

- Other associated conditions include Holt-Oram syndrome, VACTERL association, radial longitudinal deficiency, and thrombocytopenia-absent radius (TAR).

IMAGING

- Plain radiographs help to determine the status of the CMC joint, any abnormalities of the index finger, and the status of the distal radius and ulna (presence of radial longitudinal deficiency).
- The authors do not routinely perform angiography.

DIFFERENTIAL DIAGNOSIS

- Differentiate type IIIA and IIIB thumbs by functional assessment of the child.

SURGICAL MANAGEMENT

- The authors perform index finger pollicization in toddlers around 2 years of age, but the timing is more dependent on size, weight, and other medical comorbidities that may delay intervention.
- The procedure is technically easier if performed in a toddler, rather than an infant.
- Manske⁵ has shown that pollicization can be functional and effective even if performed later in childhood.
- The main objective of the operation is to shorten and reposition the index finger into a recessed, pronated, and palmarly abducted position, as well as to simultaneously create a well-contoured web space.
- The main steps of the procedure are as follows:
 - Make incisions in a modified Y to V fashion that will allow the index finger to be recessed and rotated.
 - Isolate the index finger as a neurovascular island.
 - Disinsert and isolate the intrinsic muscles of the index finger.
 - Excise the metacarpal, ablate the metacarpal growth plate, and secure the metacarpal head in a hyperextended position into the cut metacarpal base.
 - Rebalance the extensor tendons.
 - Rebalance the intrinsic muscles.
 - Adjust skin flaps to create an aesthetically pleasing outcome.
- Almost always, there is sufficient skin to transpose the index finger and close all the wounds without needing skin grafts.
- Any open wounds or flaps under tension are the result of poor incision

planning or execution.

- Simultaneous bilateral index finger pollicization is not performed.

Preoperative Planning

- Again discuss risks, benefits, and expectations with parents on the day of surgery.
 - Specifically outline the risks of flap loss (partial or complete), ischemia of the digit, poor positioning, and suboptimal function and the potential need for revisional or adjunct procedures later in childhood.
- The surgeon needs fine surgical instruments and vessel loops for tagging and dissection of important structures.

Positioning

- The patient is positioned supine with the arm out on a small hand table.

Approach

- Incisions are planned carefully prior to use of the tourniquet. Dorsal and palmar approaches are needed.

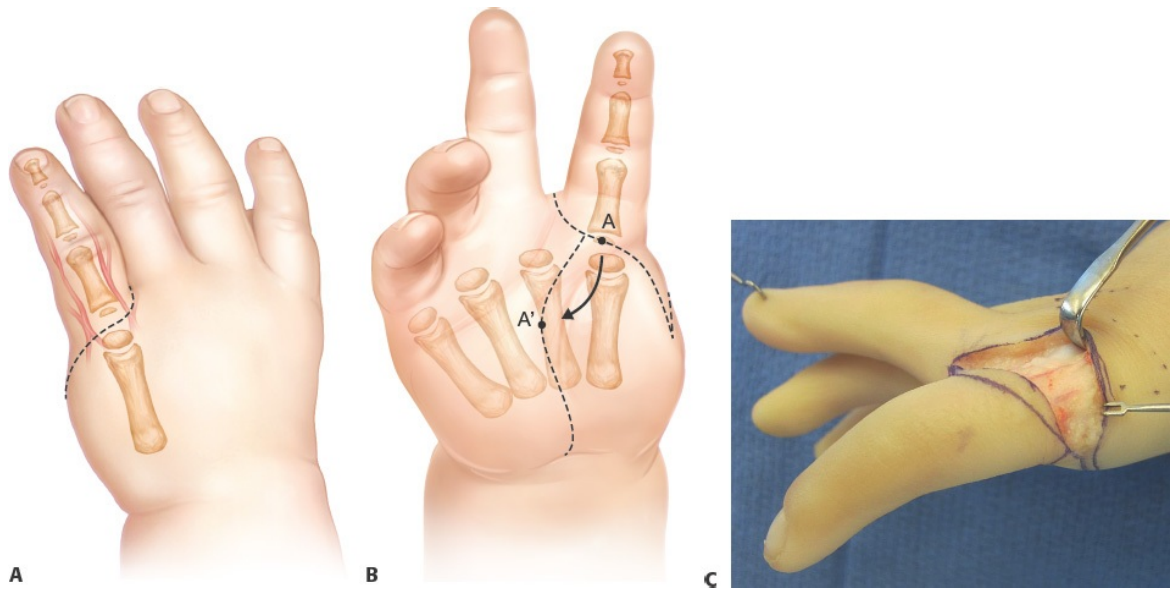
TECHNIQUES

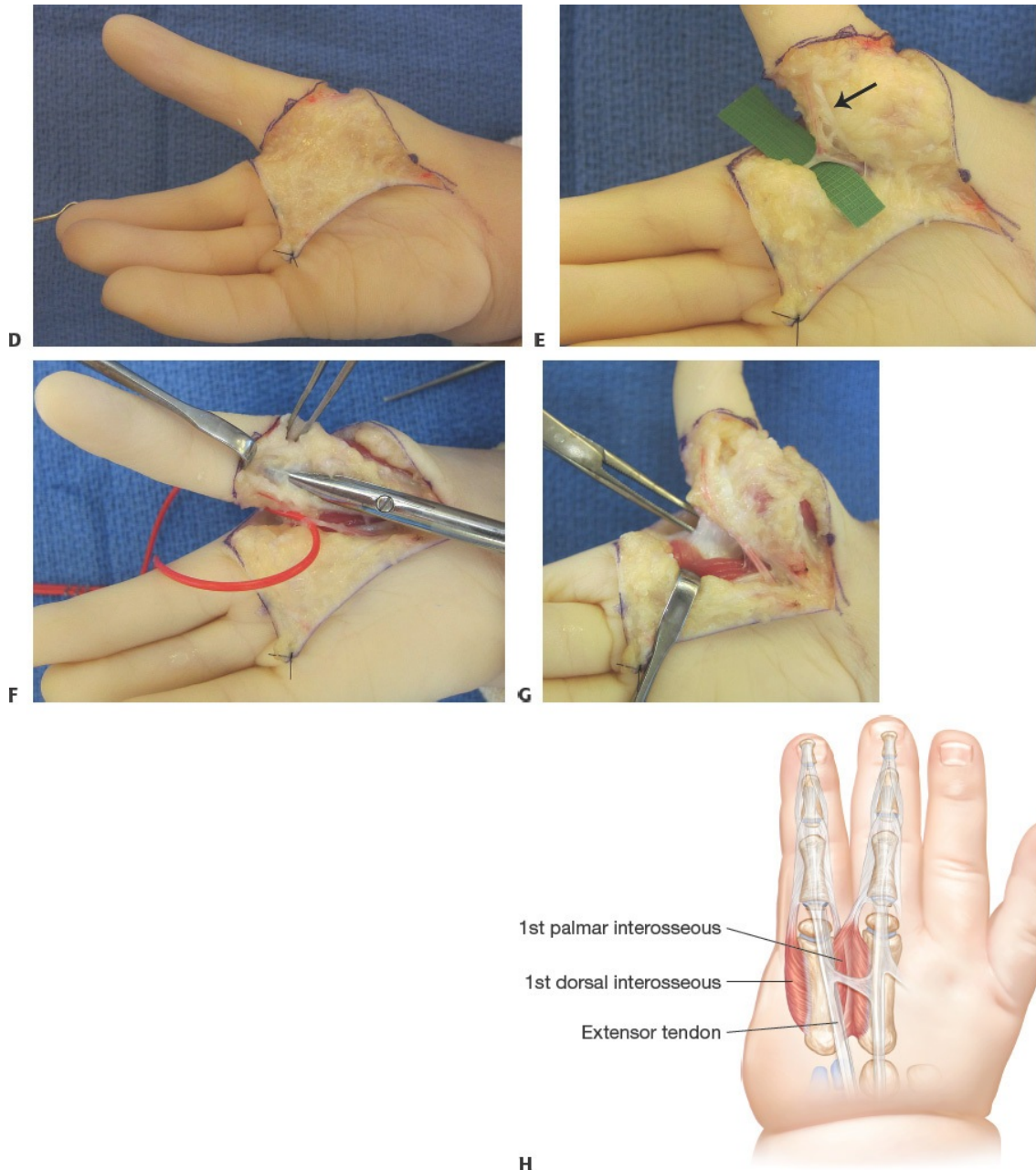
■ Index Finger Pollicization

Markings and Dissection

- Place two small round marks, one at the base of the index finger and the other at the position where the new thumb base will be placed. Mark a racquet-shaped incision around the base of the index finger. Extend these markings onto the proposed new thenar flexion crease; this will be the recession incision.
 - The markings for the incisions should be planned so they extend through the round marks (**TECH FIG 1A, B**).
 - The back-cut incision is not made until the ray has been transposed.
- Exsanguinate the upper extremity and inflate a tourniquet in the upper arm.
- Incise transversely on the dorsum of the index finger (**TECH FIG 1C**). (Note that the patient shown in the clinical photographs has radial

longitudinal deficiency and a stiff index finger.)





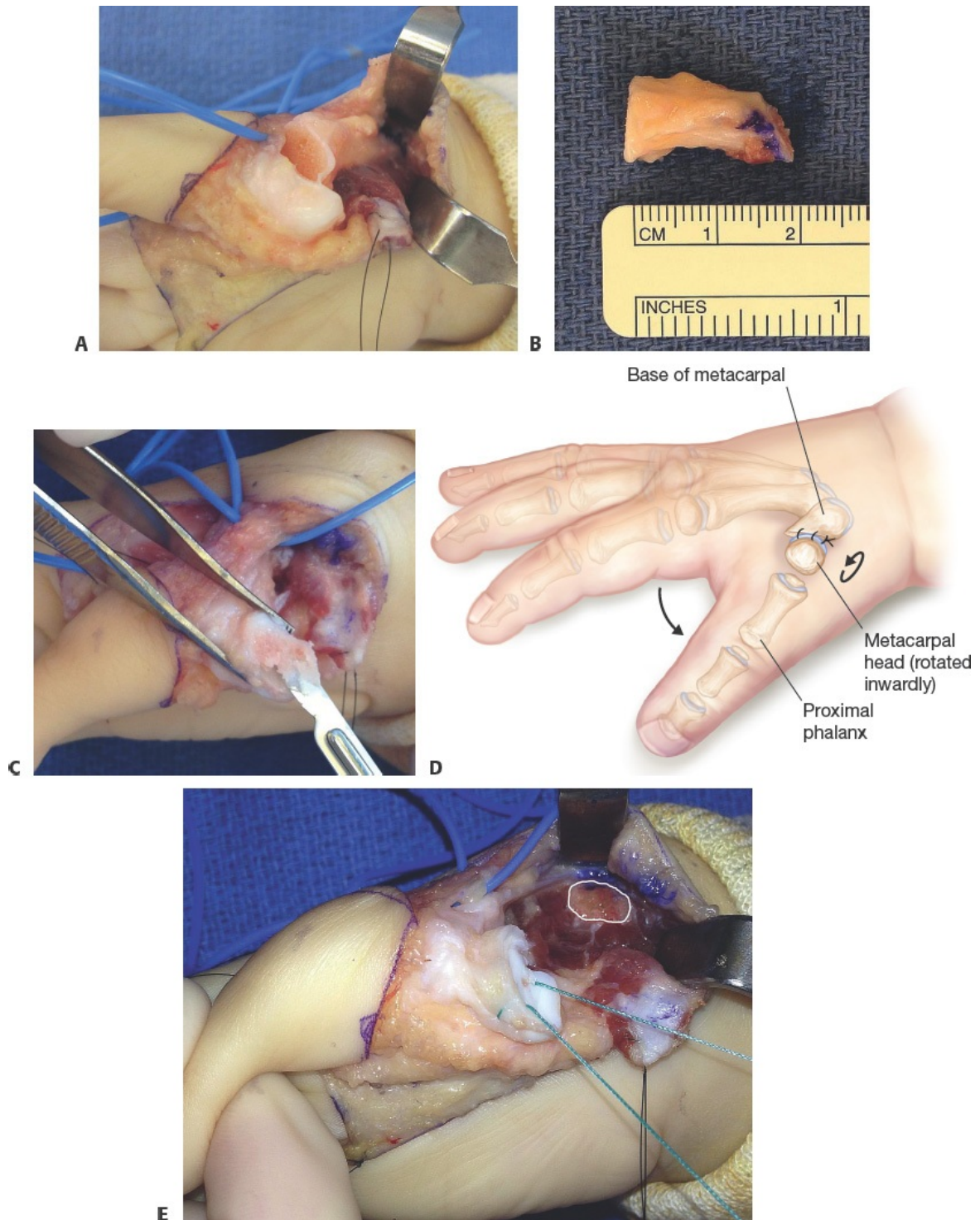
TECH FIG 1 • A,B. Dorsal and palmar markings. A racquet-shaped incision is planned around the index finger. The index finger will be recessed into the proposed thenar flexion crease incision. **C.** Dorsal incision is made, and veins are identified and dissected. One sizeable vein should be present on either side of the extensor tendon. **D.** The palmar incision is made and a flap raised on the palmar

fascia. The flap is reflected and tacked back for the remainder of the case. **E.** The ulnar contribution of the common digital artery to the index-middle web is isolated (on the green background). The ulnar digital nerve of the index finger is visualized (*arrow*). **F.** The A1 pulley is exposed and ready to be divided. The scissor tip is underneath the pulley. **G.** The fine-tipped clamp is underneath the intermetacarpal ligament. The retractor is pulling the lumbrical muscle to the middle finger. The artery and nerve are free with the index finger. **H.** First dorsal and volar interosseous muscles. These muscles will be rebalanced to mimic the intrinsic muscles of the new thumb.

- Upward traction on the skin will reveal the longitudinally oriented veins on either side of the extensor tendon at the MP joint level. These veins run in the plane between the superficial (small globular) fat and the deep (large lobular) fat.
 - Dissect these veins proximally beyond the mid-dorsum of the hand.
 - Place blue vessel loops around these veins to help with dissection and subsequent identification.
- Incise the remaining volar markings and raise a volar skin flap just above the palmar fascia up to the middle finger (**TECH FIG 1D**).
- Identify and dissect the neurovascular bundle in the index-middle web, and isolate the middle finger contribution of the common digital artery (**TECH FIG 1E**). Ligate this branch.
- Separate the nerves. Intraneural loops may be present and should be carefully dissected.
- Divide the A1 pulley (**TECH FIG 1F**).
- Isolate the intermetacarpal ligament and divide it sharply (**TECH FIG 1G**).
- Dissect and isolate the intrinsic muscles of the index finger—the first dorsal interosseous and the first volar interosseous (**TECH FIG 1H**).
 - The first dorsal interosseous may have two heads; each should be isolated. A small lumbrical may also be present.
- Dissect and isolate the extensor tendons.

Metacarpal Preparation and Osteosynthesis

- Incise and strip the periosteum off the diaphysis of the metacarpal.
- Cut the metacarpal head at the level of the growth plate (**TECH FIG 2A**). This can usually be done with a blade.
- Cut the metacarpal base in a volar oblique fashion using a saw. The angle of this cut determines the degree of palmar abduction of the neothumb. Ideal is about 60 degrees of palmar abduction.
- Measure the length of the removed metacarpal (**TECH FIG 2B**). This measurement approximates the length of extensor to shorten.
- Ablate the growth plate using a blade (**TECH FIG 2C**). Avoid injuring the collateral ligaments.
- Affix the metacarpal head to the metacarpal base (**TECH FIG 2D**).



TECH FIG 2 • A. The metacarpal head is divided. The metacarpal has been stripped of its periosteum. The first dorsal interosseous muscle is seen retracted with a black suture at its insertion. A volar oblique

osteotomy is planned at the base of the metacarpal (*purple* markings). **B.** The removed metacarpal. Figure left is distal; figure top is dorsal. The length of the excised bone approximates the shortening of the extensor tendons. **C.** Use a blade to ablate the metacarpal physis. **D.** The metacarpal head should be placed at its base with the joint in hyperextension. The angle of the base osteotomy determines the degree of palmar abduction. **E.** Suture osteosynthesis gives more control for accurate positioning of the metacarpal head. The base is outlined in white.

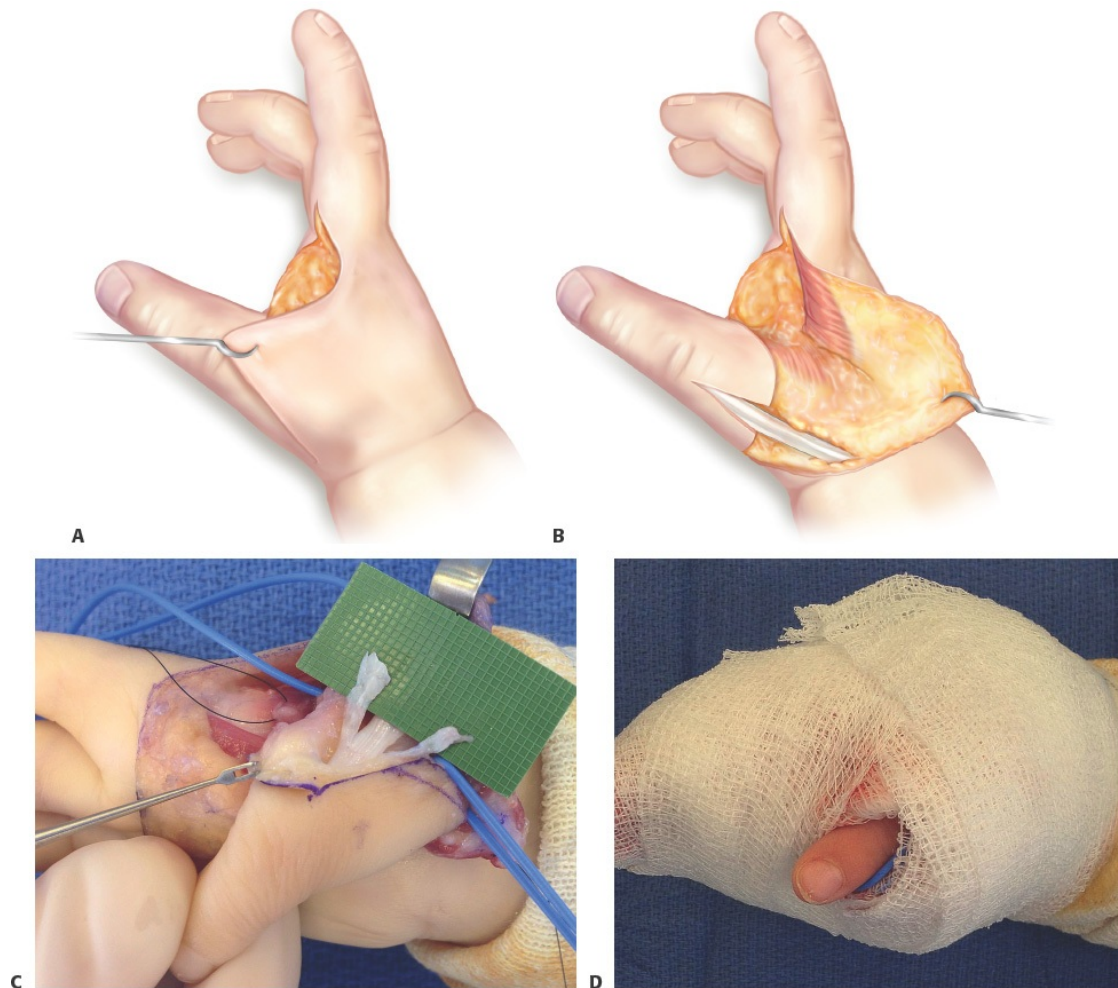
- The metacarpal head should be pronated and flexed so its cut surface aligns with the cut surface of the base. The MP joint should be hyperextended.
- If placed in a neutral or flexed position, the MP joint will hyperextend naturally with time. Placing it initially in hyperextension prevents this problem.
- Place a braided nonabsorbable, double-armed suture (3-0 Ethibond) in a mattress fashion into the metacarpal head (**TECH FIG 2E**). Insert the needles from inside the cut surface of the metacarpal base dorsally and tie. Additional sutures to the nearby soft tissues help to secure the fixation. Wires are not needed.

Dorsal Flap Placement

- Make the back-cut incision. Advance the dorsal hand skin flap and assess a position on the digit where the dorsal flap will inset (**TECH FIG 3A**).
- Design a straight, longitudinal incision on the dorsum of the transposed digit. The incision typically stops just proximal to the PIP joint. Incise the skin and spread down to the extensor tendon to separate the veins and subcutaneous tissue (**TECH FIG 3B**).
- Dissect the lateral bands from the extensor mechanism for subsequent attachment to the intrinsic muscles on each side of the new thumb (**TECH FIG 3C**).
- Release the tourniquet and watch for vascularity of the fingertip (**TECH FIG 3D**).

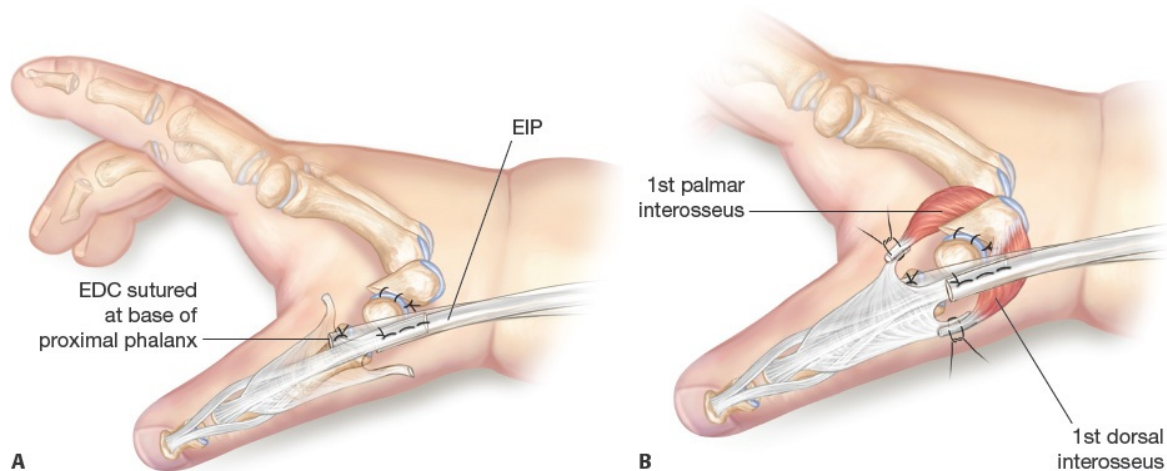
Tendon Repair

- Rebalance the extensor tendons. Dissect and separate the extensor indicis proprius (EIP) from the extensor digitorum communis (EDC). On occasion, the interval between these two tendons can be difficult to ascertain.



TECH FIG 3 • A. Once the osteosynthesis is complete, the dorsal flap is advanced and the location of the cut back incision on the index finger is determined. **B.** An incision is then made, and the veins and subcutaneous structures are separated. **C.** The lateral bands on either side of the extensor are delineated. **D.** Releasing the tourniquet allows one to assess vascularity of the digit. Furthermore, any

bleeding sites can be addressed at this time.

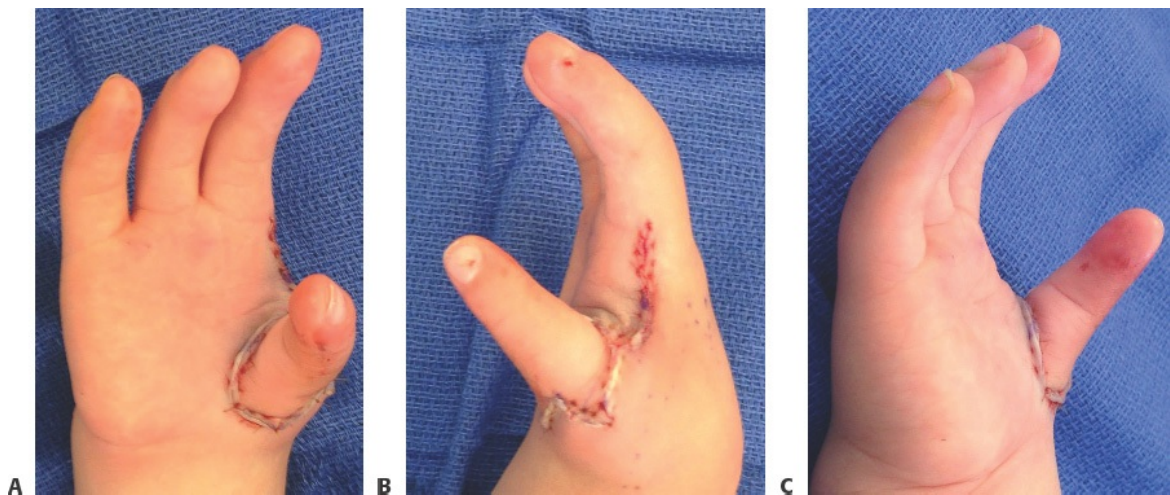


TECH FIG 4 • A. The EIP is shortened and secured with a side-to-side tenorrhaphy. The EDC is shortened and attached to the ulnar base of the proximal phalanx. **B.** The first dorsal interosseous and volar interosseous are sutured to the lateral bands. If the first dorsal interosseous has two heads, one head can be directly attached to the periosteum on the radial side of the middle phalanx.

- Shorten the EIP by approximately the length of bone removed. Side-to-side tenorrhaphy works well (**TECH FIG 4A**). The digit should hold an extended posture. The EIP becomes the new extensor pollicis longus.
- Disconnect the EDC, shorten it, and reattach it to the ulnar base of the index finger proximal phalanx (see **TECH FIG 4A**). Attaching it to the ulnar base of the proximal phalanx enhances pronation. The EDC becomes the new abductor pollicis longus.
- Reattach the first dorsal interosseous to the radial lateral band and the first volar interosseous to the ulnar lateral band (**TECH FIG 4B**). The first dorsal interosseous will mimic the abductor pollicis brevis, and the first volar interosseous will mimic the adductor pollicis muscle.
- If the first dorsal interosseous has two heads, one head can be attached to the periosteum of the radial middle phalanx. The digit should hold an extended posture but be easily flexed down with gentle finger pressure.

Completion

- Inset the proximal neothumb skin flap into the proximal corner of the thenar crease incision.
- Close the web space with 6-0 chromic sutures.
- Inset the remaining skin flaps and close (**TECH FIG 5**).
- Apply antibiotic-impregnated gauze to all incisions and cover with sterile gauze.
- Wrap loosely and apply a well-padded long-arm cast. Keep the tip of the neothumb exposed for vascular checks postoperatively.



TECH FIG 5 • A–C. The final outcome after inseting of the skin and closure of the web space. (As mentioned previously, this patient had radial longitudinal deficiency.)

PEARLS AND PITFALLS

Physical findings

- It may be difficult to differentiate between type IIIA and IIIB thumbs in an infant. Allow the child to grow. With time, the functional differentiation becomes more apparent.

Technique

- The more common, and more difficult, vascular problem that occurs is venous insufficiency. Be most cautious with the veins

	during the initial dissection. Although it may oppose common practice, using a blade (instead of scissors) to sharply lift the dorsal skin flap off the veins works well at avoiding venous injury. ■ Neural loops around the arteries can be difficult to separate especially in smaller children. Do not hesitate to employ a microscope or microinstruments for this purpose. ■ Obtain careful hemostasis and close the skin while the tourniquet is down so hematoma is avoided.
Postoperative	■ Because the flexor tendon is not routinely shortened, it takes up to 6 months for digit to start actively flexing.
Therapy	■ Early on, a few children will avoid use of the new thumb and instead start pinching with the middle and ring fingers. To discourage this behavior, consider buddy taping the middle and ring fingers together.

POSTOPERATIVE CARE

- Remove the cast after 3 to 4 weeks of immobilization.
- Fashion a thumb spica thermoplast splint that can be worn for 2 to 3 weeks at night for protection.
- Start range-of-motion exercises with hand therapy.

OUTCOMES

- Functional outcomes of pollicization depend mostly on the preoperative status of the index finger. Those patients with normal index fingers will have the best results, whereas those with stiff or abnormal index finger (eg, radial longitudinal deficiency) will have suboptimal results.^{1,5}
- The new thumb is a suboptimal replica of a normal thumb. It lacks the broadness, strength, and osteoarticular integrity of a normal thumb. Under the best of circumstances, one can expect about 50% pinch strength as compared to an unaffected contralateral side.

COMPLICATIONS

- Positional problems include the new thumb being too long or not adequately pronated and/or abducted. Both of these complications make the thumb appear like a shortened finger, the former because it is too long and the latter because it is in the same plane as the fingers.
- Inadequate web space is mainly a problem of poor incision planning or excessively thinned/ischemic flaps.

- Hematoma is most commonly seen on the dorsum where it can cause ischemia of the dorsal skin (via pressure and direct toxicity) or of the new thumb (via pressure on the draining veins).
- Vascular insufficiency is a dreaded complication and can be arterial or venous in origin. Fortunately, these complications are rare.
 - Arterial insufficiency is less commonly due to kinking and compression and more commonly due to direct injury. Once the injury is recognized, it should be promptly repaired using the operating microscope.
 - Venous insufficiency can be due to direct injury, kinking, or compression. Ensure that veins are adequately dissected proximally, that they lie tension-free without kinking, and that there is no hematoma or site of compression.
- Opposition weakness is commonly seen in the long term. Opponensplasty with abductor digiti minimi transfer (Huber) can provide additional power. If needed, this procedure is performed several years after the pollicization.

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67 Second Toe-to-Thumb Transfer for Hypoplastic Thumb

CHAPTER

Amir H. Taghinia, Brian I. Labow, and Joseph Upton

DEFINITION

- Toe-to-thumb transfer for congenital conditions is usually indicated in cases in which the carpometacarpal joint and (at least) the proximal part of the metacarpal are intact and functional but the remainder of the thumb is absent or diseased.¹
- Either the great toe or the second toe is typically used for thumb reconstruction. Although the modified great toe looks more like a thumb, the length of first metatarsal that can be harvested without functional loss in the foot is quite limited.
- In congenital patients,² toe-to-thumb transfer is most commonly performed for amniotic constriction bands, symbrachydactyly (atypical cleft hand), transverse failure of formation, (typical) cleft hand, and highly select cases of type IIIB thumb hypoplasia.
- The congenital conditions in which the thumb is diseased include macrodactyly and vascular anomalies.

ANATOMY

- The second toe is smaller than the normal thumb. It has a lower width to pulp depth ratio, thus appearing more clubbed and bulbous. It has three phalanges and a metatarsophalangeal joint, which, in the foot, functions as a hyperextension joint rather than a flexion joint as in the thumb.
- The arterial anatomy of the second toe can be variable. The dorsalis pedis artery is the main proximal blood supply. It gives rise to the first dorsal metatarsal artery (FDMA) and the first plantar metatarsal artery (FPMA) via

anastomosis with the medial plantar artery, a branch of the posterior tibial arterial system of the foot.

- There are three common branching patterns (**FIG 1**)³:
 - The FDMA lies superficial to the first dorsal interosseous muscle.
 - The FDMA lies within or deep to the first dorsal interosseous muscle.
 - The FDMA is diminutive or absent.
- The more plantar the dominant system, the more difficult is the dissection.
- The venous anatomy provides abundant large veins. Venous branches of the second toe reside in the dorsal subcutaneous plane; a vein on either side of the toe drains to the lesser saphenous (lateral) or great saphenous (medial) veins.
- The second toe has two extensor tendons—extensor digitorum longus and brevis—and two flexor tendons—flexor digitorum longus and brevis. The extensors approach the second ray in an oblique fashion, from lateral to medial. Two plantar digital nerves travel below the transverse metatarsal ligament and arrive on either side of the toe to provide sensation to the pulp.
- Unlike the first ray of the foot where the metatarsal is crucial for gait, the second ray's metatarsal is expendable and its entire length may be harvested if needed. The goal should be to construct a new thumb of normal length. In full adduction, a normal thumb extends to the proximal interphalangeal (PIP) joint of the adjacent index finger.
- In congenital conditions where the foot is also affected, the surgeon may carefully consider harvesting an anatomically abnormal toe. Investigation of arterial anatomy under these special circumstances is, at a minimum, important to avoid vascular compromise of the toe transfer—or worse, the other toes.
- In cases of amniotic constriction bands, the proximal anatomy of the hand is usually normal. However, in other conditions such as symbrachydactyly or transverse failure, the anatomy of the hand may not be normal.



FIG 1 • Variations in arterial anatomy of the first web

space of the foot. As it reaches the base of the first and second metatarsals, the dorsalis pedis artery can continue on dorsally as the first dorsal metatarsal artery (FDMA) and send a plantar branch, the first plantar metatarsal artery (FPMA). **A.** The FDMA may be the dominant blood supply to the second toe and may lie superficially to the first dorsal interosseous. **B.** Alternatively, the FDMA may lie within or deep to the first dorsal interosseous. **C.** Last, the FDMA may be diminutive or completely absent.

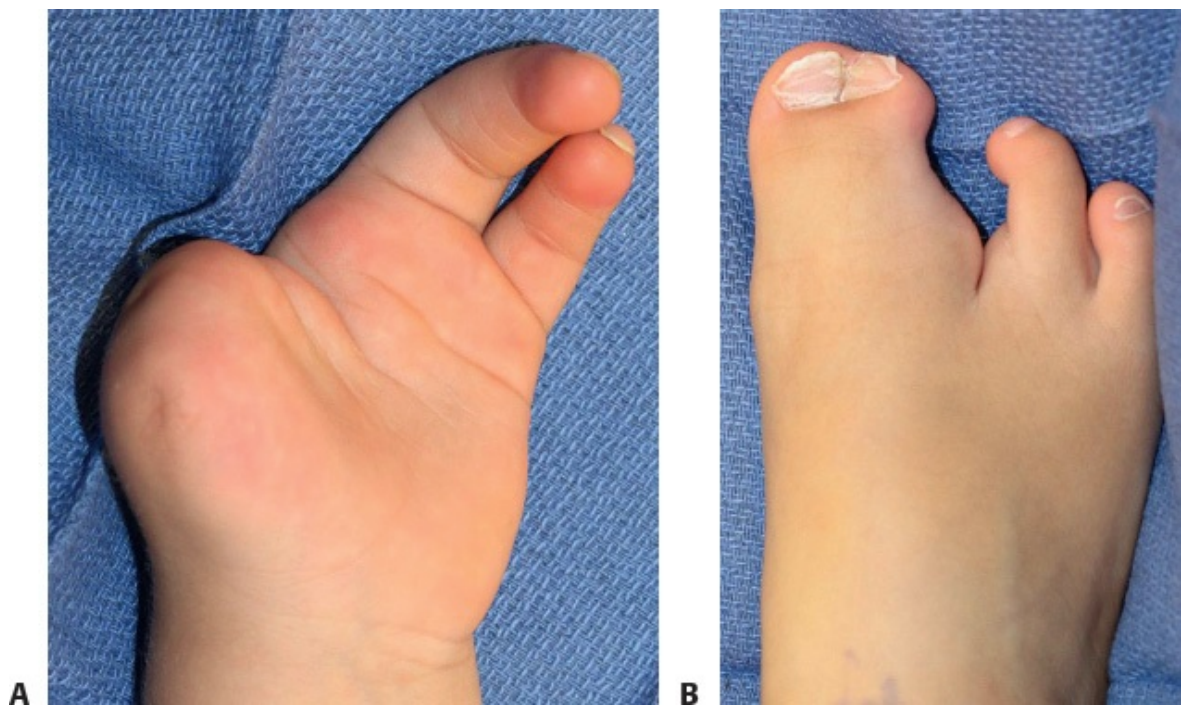


FIG 2 • This 3-year-old patient with typical cleft hand/cleft foot syndrome (the example case throughout) has two ulnar fingers but no thumb (**A**), as well as webbed great and second toes (**B**).

- Variations in anatomy tend to be the rule and include deficient or missing tendons, nerves, muscles, and arteries. These variations may only become evident during the operation, and so the surgeon should be prepared with

multiple contingency plans. Angiography is used more liberally in these patients.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A full history and physical examination should be obtained to define and document deficient anatomy, assess current functional use, ascertain associated conditions, and set goals for reconstruction.
- Physical examination of the hand (**FIG 2A**)
 - The skin is inspected for suppleness, turgor, and pliability.
 - The soft tissue around the thumb is inspected for presence of intrinsic muscles.
 - Dimples in the skin may indicate underlying tendons.
 - Pulse examination and an Allen test are necessary to assess the blood supply to the hand and presence of palmar arch.
- Physical examination of the foot (**FIG 2B**)
 - General appearance of the foot and/or toe may indicate presence of any anatomic abnormalities. In amniotic constriction bands, the toes may also be affected.
 - Pulses are examined. A pencil Doppler probe can be used to ascertain the presence of an FDMA by tracing its course on the dorsum of the foot.

IMAGING

- Plain radiographs of the hand and foot are required (**FIG 3**).
- Routine angiography is debatable; nevertheless, it is the authors' practice to obtain angiography of the hand and foot on most patients (**FIG 4**).
 - Angiography helps to create a road map and a plan for the operation. Questions such as the need for vein grafting (foot), end-to-side vs end-to-end anastomoses (hand), and residual vascularity of the foot after flap harvest can be answered preoperatively. This planning is essential in cases where a team approach with multiple surgeons is undertaken. Certainly for patients with abnormal foot anatomy (**FIG 5**), angiography helps with preoperative planning to ensure a viable flap.

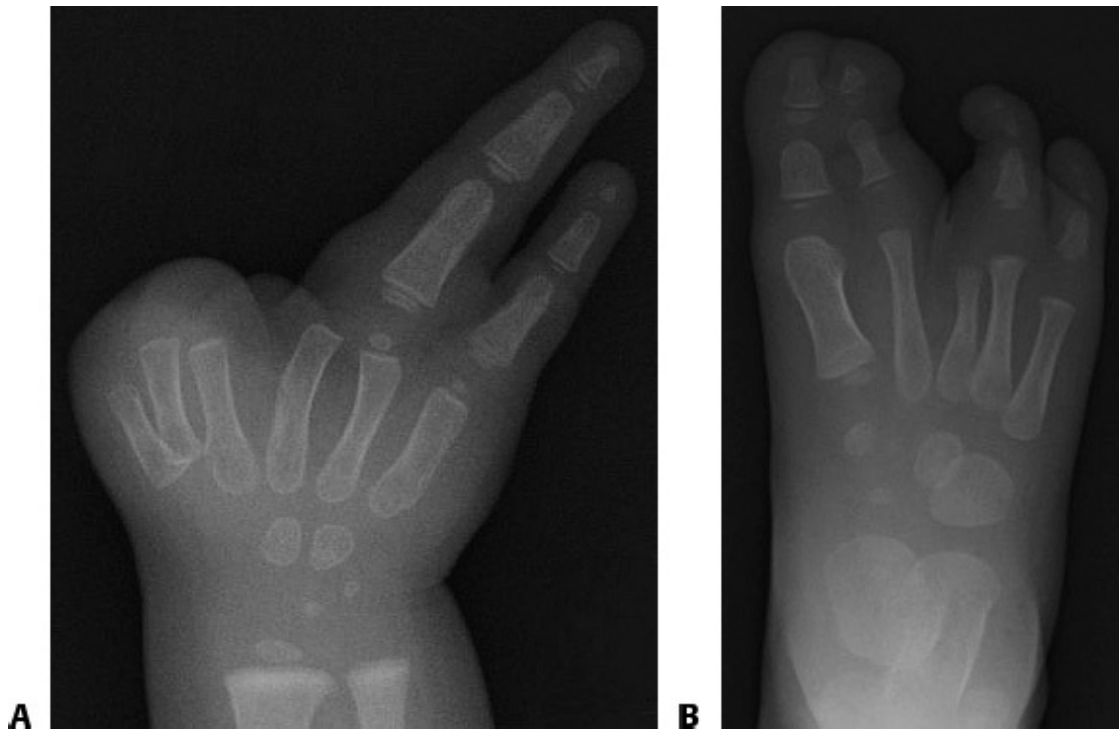


FIG 3 • Radiography of the example case shows three metacarpals on the radial side of the hand (**A**) and separate skeletal structures in the foot despite webbing of the great and second toes (**B**). Note that there are only two phalanges in the second toe. The epiphysis of the second metatarsal is not present in this early radiograph, but it is distally located in subsequent films (see **TECH FIG 7A**), indicating that this is indeed a phylogenetic second toe rather than a preaxial synpolydactyly.

SURGICAL MANAGEMENT

- The time to perform the toe transfer should not be an arbitrary age but rather tailored to the individual child.
- Although it is important to perform the transfer as early as possible to take advantage of brain plasticity and enhanced nerve regeneration, the child has to be of appropriate size to allow a technically feasible operation.

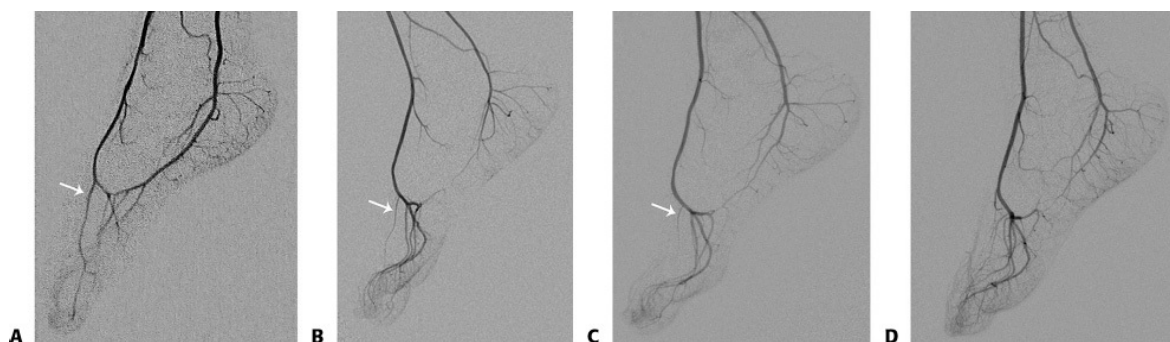


FIG 4 • Angiographic variation in arterial anatomy of the foot (FDMA indicated by *white arrow*). The variations outlined in **FIG 1** are seen in the angiograms, with a large, dominant FDMA (**A**); a thinner, intramuscular FDMA (**B**); a diminutive FDMA (**C**); and no FDMA (**D**). The plantar system is dominant in **B** to **D**.

- Specifically, the vessels tend to be too small for a predictable operation in most children under the age of 2.
- The decision-making process for the parents (and the child) often requires substantial discussion. The sacrifice of part of a foot for improved function of the hand can be a difficult decision, especially when there is a small risk that the toe may not survive or that the function may not be optimal.
- Thorough preparation of the parents for this process, including an honest explanation of the risks and expected outcomes, is a crucial preoperative step.
- Radiographs, preoperative and postoperative photographs, molds, and movies of other patients can help with the decision-making.
- Jones advocates arranging for parents to meet the families of previous patients with toe transfers.¹
- Multiple toe transfers are possible and can be performed reliably. Reconstruction of a thumb and finger(s) usually requires separate toes from both feet.
- In contrast, multiple toes from the same foot can be used to reconstruct fingers.
- Preparation of the hand recipient site with the addition of skin and soft tissue as a first-stage procedure is rarely needed in congenital cases.
- However, in cases in which there is a paucity of soft tissue and skin (eg, where the base of the thumb is very short), transfer of skin via pedicled (eg,

groin or lower abdomen) or free (eg, anterolateral thigh) should be considered at least 6 to 9 months before definitive toe transfer.

- Skin grafting is often necessary and is much better tolerated on the hand than on the foot.

Preoperative Planning

- Simultaneous dissection of the donor toe and the recipient site requires two surgical teams. This approach minimizes time of surgery and anesthesia and ensures that the critical portions of the operation take place during times when operating room staffing is optimal.
- A careful analysis of deficient length is critical to ensure optimal function in the future. Plan the length of the thumb needed and the appropriate length of the second ray to harvest to achieve this length.
- The surgeon will need fine instruments for toe and hand dissections, loupe magnification, microsurgical instruments, a microscope, a handheld Doppler probe, and an adhesive-backed, disposable finger pulse oximetry monitor for postoperative monitoring of the toe transfer. In addition, automatic clip appliers and vascular loops greatly enhance the dissection.

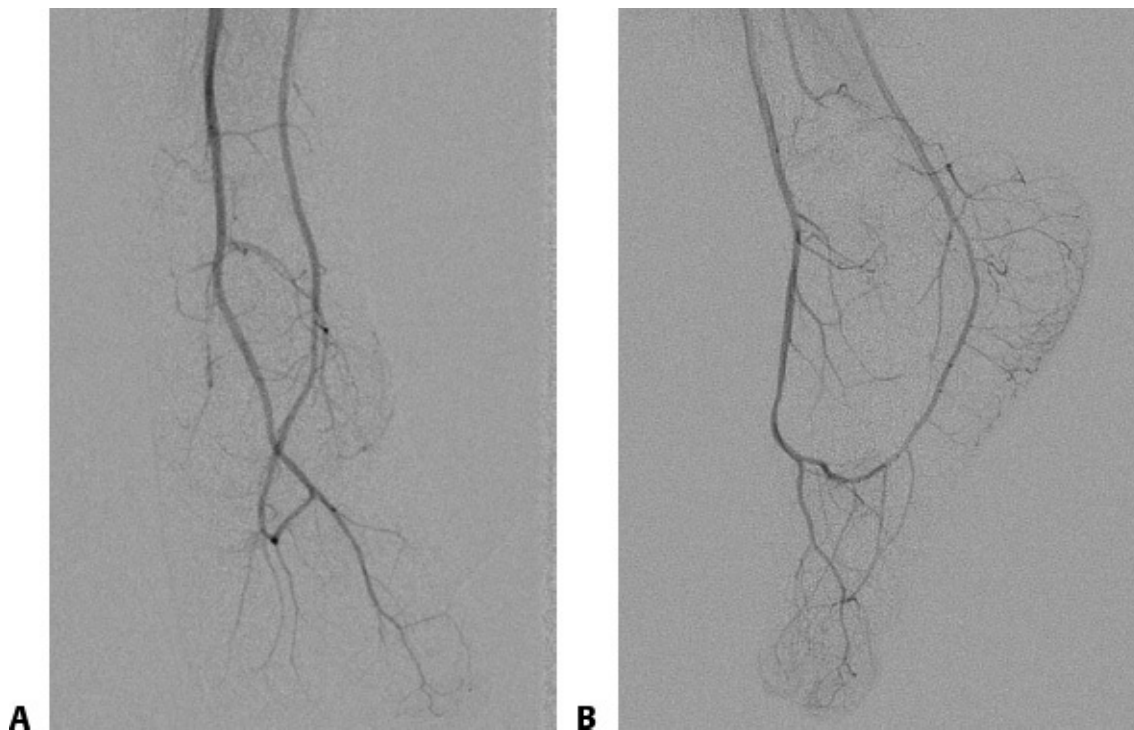


FIG 5 • Angiography of the foot of example case reveals

an FDMA deep to the first dorsal interosseous supplying a single diminutive common dorsal and a single large common plantar artery. The dominant (plantar) vessel to the tibial, webbed toes lies in the web space and extends distally to the tips, sending branches along the way to both toes **(A)** anteroposterior view, **(B)** lateral view. The entire vessel was harvested with the second toe.

Positioning

- The patient is positioned supine with the arm out on a small hand table. A small gel roll under the ipsilateral hip can help orient the foot into a more pronated position for dissecting the toe. The lower abdominal area for the skin graft is squared off with Steri-Drapes.
- Incisions are planned carefully prior to use of the tourniquet.

TECHNIQUES

■ Second Toe Flap

Markings and Incision

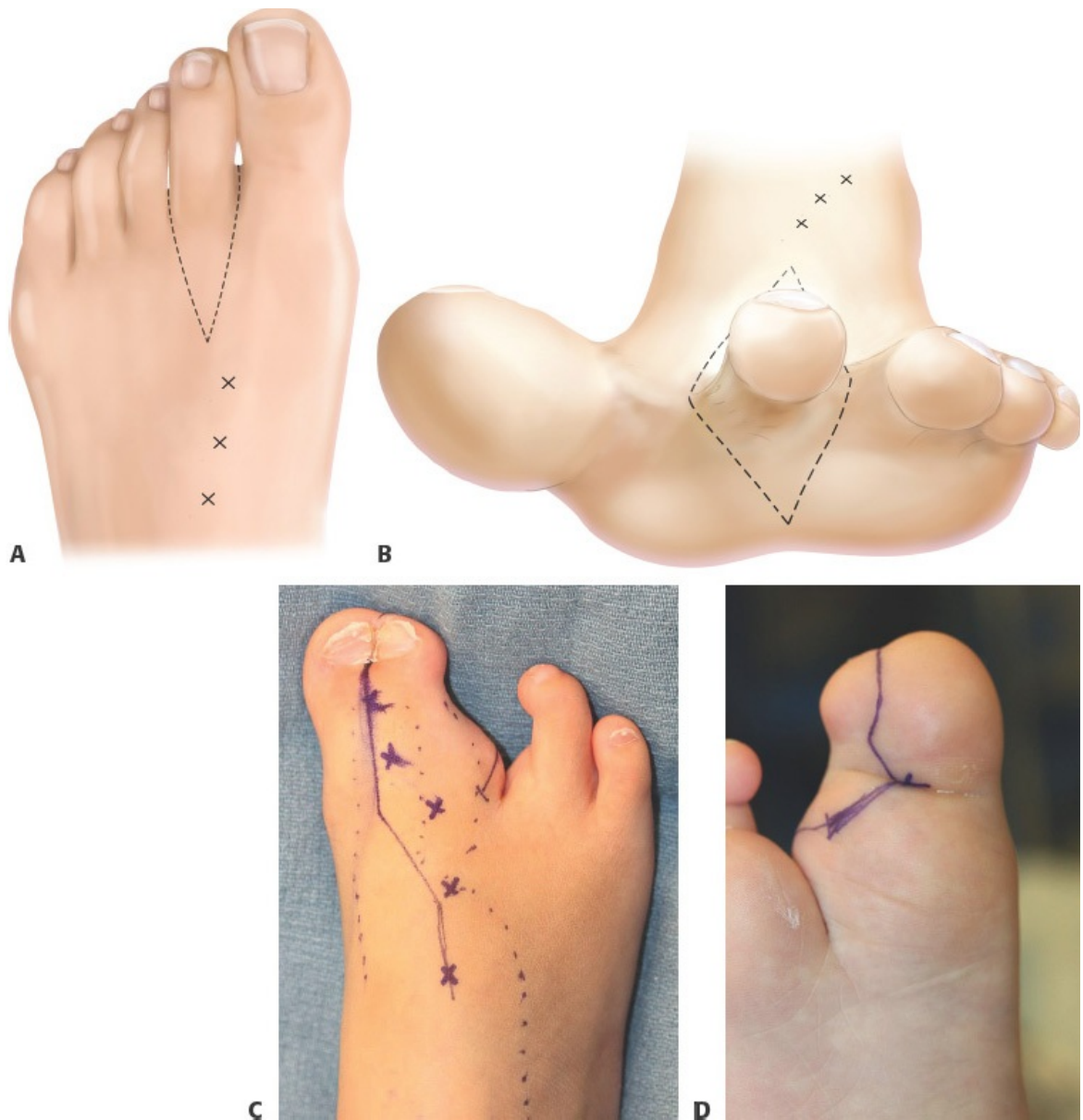
- Identify and mark the path of the dorsalis pedis and FDMA, if present, using a handheld Doppler probe.
- Squeeze the ankle and milk the soft tissue distally to allow the dorsal foot veins to engorge. Mark these veins.
- Draw a wedge-shaped incision around the second toe (**TECH FIG 1A,B**).
 - In the case of abnormal foot anatomy, the incisions will need to be modified (**TECH FIG 1C,D**).
- Exsanguinate the extremity and inflate a mid-thigh tourniquet.
- Incise the dorsal markings and extend the incision along the path of the FDMA.

Soft Tissue Dissection

- Identify, dissect, and follow the superficial veins to the large dominant veins.

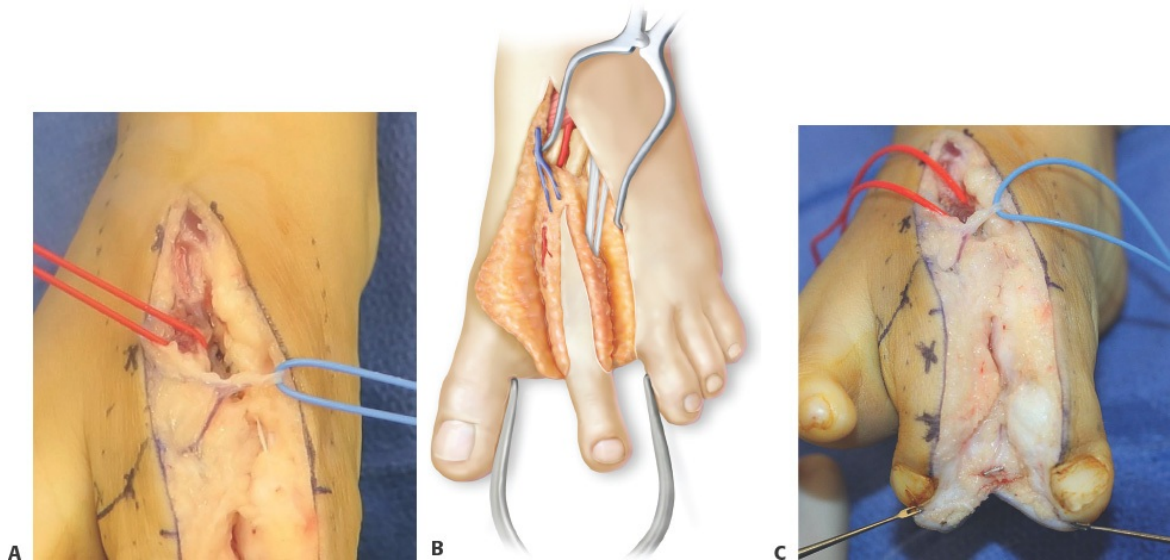
Clip and divide all tributaries. Place blue vessel loops around the dominant veins and free them proximally.

- Identify and tag any dorsal sensory branches of the superficial peroneal nerve coursing to the second toe.
- Identify and dissect the extensor digitorum communis (EDC) tendon until enough length is achieved; transect it.
- Identify the short extensor tendon, which has a distal muscle belly and a thin tendon. Divide the tendon.
- Dissect proximal to the first and second metatarsal bases and identify the vascular pedicle. Place loops around the dorsalis pedis artery and its venae comitantes (**TECH FIG 2A**).
 - Usually, two comitant veins are present, but only one is suitable for microvascular anastomosis.
- Trace the pedicle distally to the FDMA, if present. The FDMA may lie dorsal to the first dorsal interosseous, may lie within or deep to the first dorsal interosseous, or may be absent (see **FIG 1**).
- Incise the first and second web space and plantar markings and dissect the soft tissues.
- Splay the great and third toes with a Gelpi retractor. This maneuver provides ample retraction and allows great visualization of the web space (**TECH FIG 2B**).
- Identify the neurovascular bundle on the fibular side of the great toe and the tibial side of the second toe in the first web space. Clip and divide the fibular digital artery to the great toe and sweep the vessels in the fibular direction (**TECH FIG 2C**). Similarly, clip and divide the tibial digital artery to the third toe, if present.



TECH FIG 1 • A,B. Typical incision placement for second toe flap on a normal foot. The Xs mark location of audible Doppler pulses. Minimal skin is taken with the toe to allow tension-free linear closure of the foot. **C,D.** Modified incision planning for abnormal foot anatomy seen in the example case. Straight-line dorsal and plantar incisions were planned distally, with a racquet-type diversion proximally on the plantar surface. The Xs mark the path of the (deep)

FDMA and (diminutive) dorsal common digital artery.

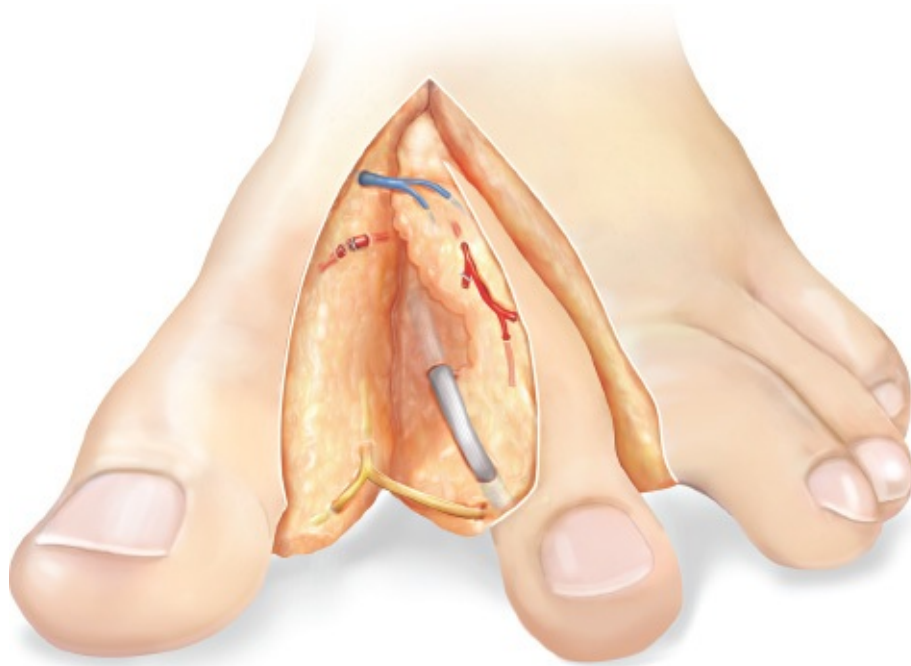


TECH FIG 2 • A. A dorsal superficial vein (*blue loop*) and the dorsalis pedis and its venae comitantes (*red loop*) have been identified and tagged. The muscle next to the artery, the extensor hallucis brevis, has been divided to expose the underlying vessels. **B.** Typical second toe dissection, dorsal view. Gelpi retractors help with exposure. A dorsal dominant arterial system is shown. The extensors to the second toe take an oblique course medially. The extensor hallucis brevis muscle (next to the artery) has been divided. **C.** The first web space has been exposed. The dominant, plantar common digital artery is shown with a clip on the great toe branch that has been divided. The entire common digital artery was kept with the second toe.

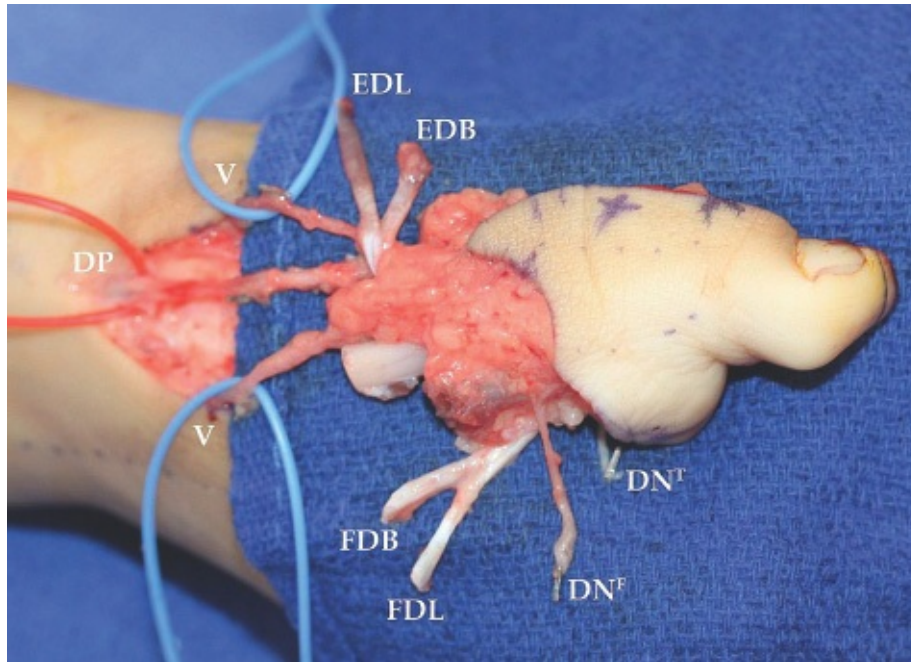
- Follow the artery proximal. The FDMA may have a communicating branch to the FPMA that passes anterior to the intermetatarsal ligament (see **FIG 1**).
- Isolate and divide the intermetatarsal ligament.

Artery and Nerve Dissection

- At this point, the plantar and dorsal systems are outlined and the dominance of the arterial system should be clear, even if an angiogram was not obtained.
- Select the dominant arterial system, and divide communicating branches as needed. The first dorsal interosseous may need to be divided; there are many small branches from the main pedicle to the bone and the muscle in this area.
- If the dominant system is plantar, the surgeon can avoid performing the tedious plantar dissection by using a vein graft to bridge the gap. The authors' practice, however, is to perform the full plantar dissection and avoid vein grafting.
 - Early osteotomy and elevation of the second metatarsal will help with exposure if the system is plantar dominant.
- Trace the artery all the way to the dorsalis pedis system. There is a hub of multiple arterial and venous branches at the base of the first and second metatarsals. Substantial additional length on the pedicle can be obtained if these branches are divided, and the dorsalis pedis system proper is used as the feeding vessel to the toe.
- Dissect the fibular and tibial digital nerves of the second toe to the common digital nerves in the respective proximal web spaces. These nerves are short and additional length is always necessary (**TECH FIG 3**).
 - Use microinstruments to gently tease the nerves to the second toe from the common digital nerve on both sides. Perform the intraneural dissection as far proximal as needed.
- Transect the digital nerves and mark them with either small clips or sutures.
- Identify the flexor digitorum longus and brevis tendons (see **TECH FIG 3**); dissect and divide these as far proximally as possible.



TECH FIG 3 • Typical second toe dissection, web space view. A dorsal dominant system is shown with the dorsal digital branch to the great toe clipped and divided. The proper digital nerves usually require intraneural dissection to obtain adequate length. The flexor system to the second toe should be divided as far proximal as possible.



TECH FIG 4 • The second toe has been fully dissected and remains attached to the foot via its blood supply, the dorsalis pedis (DP) and two superficial veins (V). The extensor digitorum longus (EDL) and brevis (EDB), the flexor digitorum longus (FDL) and brevis, and the tibial (DN^T) and fibular (DN^F) are outlined. The FDMA was deep to the first DI in this case.

Metatarsal Osteotomy and Flap Placement

- Incise the periosteum over the second metatarsal, retract the vessels and tendons dorsally, and cut the metatarsal at the preplanned location.
 - Even though there is temptation to leave redundant bone length on the flap, trimming the bone when the flap is free and all the structures are loose is tedious and can be dangerous. It is best to get the ballpark length right the first time and make only small adjustments during the transfer.
- Isolate the flap as a vascularized island (**TECH FIG 4**) and release the tourniquet.
 - Apply papaverine to the vessels and warm saline-soaked sponges to the wounds.
 - Assess the perfusion to the flap. If a difficult plantar system is encountered,

the dissection may require a second, albeit shorter, tourniquet run.

Closure

- Close the foot wound by suturing the intermetacarpal ligaments attached to the first and third metatarsals, thus closing the gap in the first web space.
- Close the skin wound using absorbable sutures.
- A skin graft may be used if needed, but it is imperative to avoid skin grafts on the plantar surface. A thin drain may be used for a few days (**TECH FIG 5**).
- Apply a well-padded leg cast.

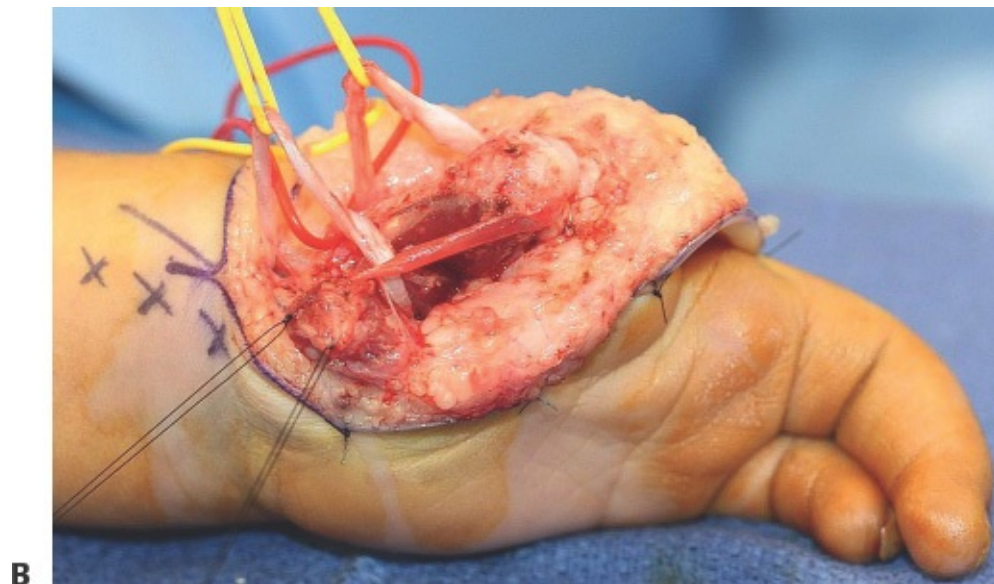


TECH FIG 5 • Foot closure is complete. The fibular side of the great toe has been covered with a full-thickness skin graft.

■ Preparation of the Hand for Toe Transfer

- The steps for the hand are dependent on the given anatomy.
- Placement of the incisions is likely to differ for each case (**TECH FIG 6A**).
 - If the incisions for inset are distant from appropriate vessels (most cases), a separate dorsal/radial transverse wrist incision provides ample access to large dorsal veins and the dorsal branch of the radial artery in the anatomic snuffbox.
- Exsanguinate the arm and inflate a tourniquet.

- Make the incisions and raise flaps.
- Identify and tag two large dorsal veins and the dorsal branch of the radial artery. The authors prefer to use at least two veins for microanastomosis.
- Dissect, isolate, and tag the intrinsic muscles of the proposed new thumb.
- Identify the extrinsic extensor and flexor tendons. Multiple tendons may be present, in which case the best flexor and extensor should be chosen (**TECH FIG 6B**).
- Dissect, isolate, and tag the digital nerves.
- Prepare the bone for osteosynthesis. Options include Kirschner wires, 90-90 interosseous wiring, or plate and screws for fixation.



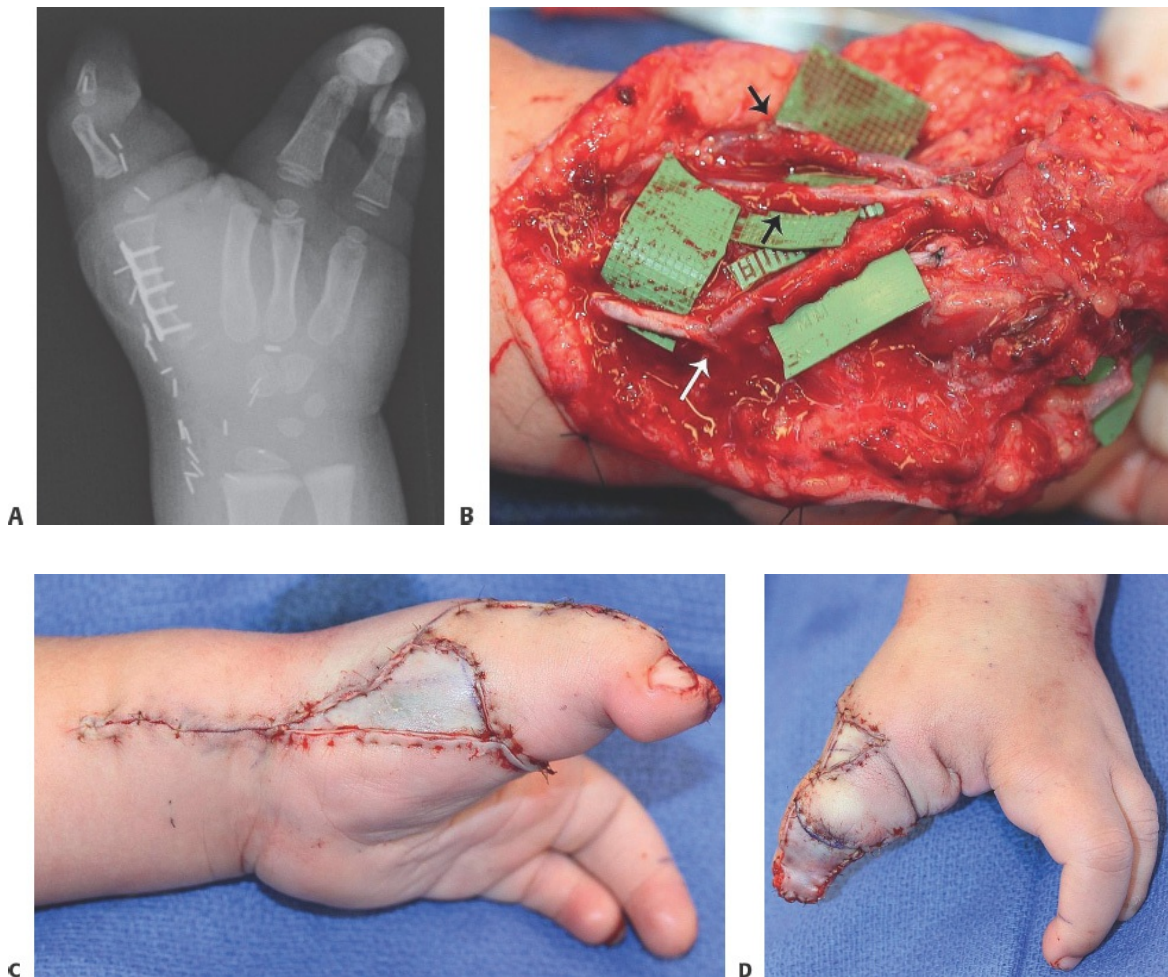
TECH FIG 6 • A. Markings for hand dissection. An ulnarly based skin flap is planned to partially cover the tibial portion of the second toe flap. A volar wrist incision exposes the radial artery. A dorsal transverse wrist incision exposes large dorsal veins. **B.** Recipient hand has been prepared. Of the three radial metacarpals, the middle one has been preserved for osteosynthesis while the other two adjacent ones have been removed. Long extensor and flexor tendons are retracted (*yellow loops*). The intrinsic muscles of the thumb base are reflected (*black sutures*).

■ Transfer of Toe to Hand

- Assess the length of the toe on the new thumb, and adjust the size by cutting the bone with a saw.
 - The fully adducted, normal thumb tip extends to the level of the index finger PIP joint.
- Perform the osteosynthesis of choice (**TECH FIG 7A**).
- The positioning of the thumb is critical for function. The CMC joint and the proximal metacarpal are already set; however, the surgeon does have control over the degree of pronation and radial/ulnar angulation of the new thumb. Ensure that the new thumb rests in an appropriate position of function.
- Gauge the tension on the flexor and extensor tendons. Balance these so that the toe rests in near full MP joint extension and minimal flexion of the toe PIP and DIP joints. Repair the extensor tendon and then the flexor tendon using side-to-side tenorrhaphies.
- Perform the arterial and venous anastomoses using an operating microscope and microinstruments. Ideally, an end-to-side arterial anastomosis is performed to the radial artery to avoid compromise of the palmar arch (**TECH FIG 7B**).
- Perform the neurorrhaphies using the microscope; these repairs can be augmented by wrapping with neural conduit and/or topical tissue sealant.
- Close the skin. Avoid pressure on the vessels. Use full-thickness skin grafts

from the lower abdomen to close any remaining open wounds (**TECH FIG 7C,D**).

- Apply a bulky protective dressing and a stable sugar-tong splint with the elbow at 90 degrees with just enough of the toe exposed for monitoring.
- Wrap a pulse oximeter–adhesive probe around the toe for continuous monitoring.



TECH FIG 7 • A. Osteosynthesis is complete. Of the three radial metacarpals, the middle metacarpal forms the base of the thumb; the other two adjacent metacarpals have been removed. Plate and screws provide rigid fixation. **B.** The vascular anastomoses in the example patient demonstrate an end-to-side arterial anastomosis to the radial artery (*white arrow*)

and two separate end-to-end venous anastomoses (*black arrows*). **C,D.** Radial and ulnar views, respectively, of the example case after skin closure. The ulnar-based flap has been trimmed and inset. The open wounds have been covered with full-thickness skin grafts from the lower abdomen.

PEARLS AND PITFALLS

Surgical management

- Have low threshold to obtain angiogram in cases where the foot anatomy may not be normal, eg, congenital cleft.

Technique

- Exposure of a plantar-dominant system is made easier by performing the metatarsal osteotomy early on.
- Meticulous closure and protection of the donor site helps to avoid wound-related problems that can take weeks to heal. Skin grafts are much better tolerated on the hand than the foot.
- Once the toe is disconnected from the foot, a lot of preparation work is needed prior to performing the vascular anastomosis. Ensure that as much of this preparation as possible is performed prior to introducing ischemia. Do not rush through this part, as the osteosynthesis and balancing of tendons are critical for future function.
- Although some surgeons prefer to avoid skin grafting directly over vessels, sometimes this practice is unavoidable after toe transfer. The authors have performed this practice many times without any untoward consequences.

Postoperative monitoring

- There are multiple options for postoperative monitoring: these include clinical assessment of capillary refill and warmth as well as handheld or implantable Doppler probe assessment of pulses. The authors prefer using a continuous pulse oximeter as a monitor as its use is simple and its monitoring of vascularity is reliable.

POSTOPERATIVE CARE

- Admit the patient to a high-level care unit and monitor the toe once per hour, assessing capillary refill, turgor, and warmth.

- A small opening can be left in the dressing where a site distal to the anastomosis can be monitored with a handheld Doppler.
- A continuous pulse oximeter is cheap, accurate, widely available, and highly reliable. Pulse wave changes are indicative of arterial compromise, whereas saturation changes may signal venous compromise.⁴
- Adequate pain control is important postoperatively. Regional anesthesia with indwelling catheters can provide both pain control and sympathetic block, which may help with perfusion.
- The authors use aspirin for 30 days routinely to avoid unwanted platelet aggregation.
 - No other anticoagulants are used unless there are problems with the anastomosis or abnormal clotting early on.
- After several days, the dressings and splint are removed and a well-padded cast is applied. The patient can then be discharged.
- No weight bearing should be undertaken with the lower extremity for 3 weeks.
- The casts are removed after 3 to 4 weeks; weight bearing, hand therapy, and range-of-motion exercises commence at this time.

OUTCOMES

- Outcomes after toe transfer for congenital absence of the thumb are very good.
 - Patients with amniotic constriction bands and a stable CMC joint with solid metacarpal base tend to have the best outcomes because the proximal structures are normal and present.
 - Those with congenital absence do not have as good outcomes because structures may be abnormal or absent proximally.
- In large series of toe transfers,^{1,5-8} most investigators have found that mobility and sensation are satisfactory and function and appearance show significant improvement.
 - The toe does grow, though not to the same extent as a normal thumb.
 - Most parents and patients are very satisfied with function and appearance.

COMPLICATIONS

- Vascular compromise can be due to arterial or venous problems. In most series, about 5% to 10% of patients require take-back for vascular compromise, but most of these toes are salvaged with prompt return to the operating room.
 - The main steps to minimize vascular compromise are in the setup prior to performing the anastomoses.

- These include atraumatic dissection, appropriate pedicle length, avoiding vein grafts (if possible), and minimizing sharp turns, kinks, and external pressure from tightly closed wounds.
- Wound complications can occur, especially on the foot. Meticulous technique in harvesting, tension-free skin closure, and adequate postoperative immobilization can minimize these issues.
- Long-term functional problems can include poor growth, flexor/extensor imbalance, inappropriate length, problematic positioning, and poor sensory or motor return. Tendon transfers, osteotomies, and other operations can alleviate some of these problems, but they can be challenging to perform.

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68 Reconstruction of Amniotic Constriction Bands

CHAPTER

Amir H. Taghinia

DEFINITION

- Amniotic constriction band (ACB) refers to the clinical manifestation of an unknown insult that results in predictable phenotypic patterns including bands around limbs and digits, oligodactyly, acrosyndactyly, lymphedema, and other conditions.
- The etiology, terminology, and nosology of this condition have been debated in the literature for years, resulting in no less than 34 different names for this condition.¹ As some others do,^{1,2} the author prefers *amniotic constriction band*, as this terminology conveys the most accurate description and most widely accepted etiology.

ANATOMY

- Extremity anatomy can be quite variable, and in fact, no two cases are the same.
 - The bands may be circumferential (rings) or incomplete, and the anatomic presentation may include amputation, hypoplasia, nail deformities, joint deviations, stiffness, and coalescence of the digits termed *acrosyndactyly*.
 - Usually, the anatomy proximal to the constriction band is normal.
- Patterson³ classified the extremity findings:
 - Type 1—mild digital groove with normal distal extremity
 - Type 2—deeper ring with distal deformity, including atrophy or lymphedema
 - Type 3—syndactyly with fusion of the distal parts, termed *acrosyndactyly* or *fenestrated syndactyly*
 - Type 4—amputation distal to the constriction band
- Syndactyly in this condition is different from developmental syndactyly, which

is caused by failure of apoptosis and is always present proximally. In typical syndactyly, the involvement proceeds proximal to distal and the digits are normal length, whereas the opposite is true in ACB.

- Constriction bands can affect underlying muscles, tendons, nerves, and vessels.
- Urgent release is indicated in cases of ischemia or severe (or worsening) lymphedema.

PATHOGENESIS

- The cause of this condition is unknown, and potential etiologies are still debated. Three main theories have been proposed²:
 - The intrinsic theory implicates a germline developmental abnormality. It helps to explain the craniofacial, body wall, and internal organ anomalies seen but fails to sufficiently explain the patterns of limb findings.
 - The vascular theory advocates that a traumatic insult may disrupt development by disrupting blood flow, with the timing during gestation determining the anomaly.
 - The extrinsic theory best explains the limb manifestations. It maintains that a rupture of the amniotic sac creates mesodermal bands of tissue that entangle limbs and cause the characteristic findings.

NATURAL HISTORY

- ACB occurs in 1200 to 15 000 live births.
- It is more common in females and is likely to occur more frequently in African Americans as compared to Caucasians.
- It is not considered a familial condition.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Newborns who need relatively urgent care can present with either progressive limb ischemia or lymphedema due to a tight band. Ischemia is a surgical emergency, and the band should be treated quickly to avoid limb loss. Worsening lymphedema should also be treated quickly because it can go on to cause ischemia if treatment is delayed.
- Infants who present electively should be evaluated for limb involvement. Digits and limbs involved, depth, presence of syndactyly, stiffness, joint deviation, and distal manifestations should be documented (**FIG 1**).
- Other potentially associated conditions should also be noted, especially those

that impact the general health of the child and may influence anesthetic safety.

IMAGING

- Plain radiographs are the study of choice, though they are not needed in mild cases where the distal limb is normal (**FIG 2**).
- For complex syndactyly cases, plain radiographs with multiple views are critical for surgical planning of separation.
- Other imaging modalities may be needed if nerve, vessel, tendon, or muscle compression is suspected.

DIFFERENTIAL DIAGNOSIS

- Differential diagnosis includes symbrachydactyly, cleft hand, and transverse deficiency.
- Another condition that can mimic ACB is ectrodactyly, ectodermal dysplasia, and cleft lip and palate (ECC) syndrome.



FIG 1 • A 9-month-old girl (the example case throughout) with multilimb ACB. **A,B.** Dorsal and palmar views of her left hand demonstrate “overlapping” fenestrated syndactyly. **C.** The middle finger deviates ulnarly, lying palmar to the ring and small fingers, which are short and tightly adherent. There are fenestrations (tracts/pits) located proximally in the third and fourth web spaces. **D,E.** Dorsal and palmar views of her right

hand demonstrate distal fenestrated syndactyly. **F,G.** Medial and lateral views of her left lower extremity show significant involvement. The leg has two adjacent deep bands, and there are multiple bands around the toes.

NONOPERATIVE MANAGEMENT

- Minor bands may not need operative intervention. This determination is subjective and based on the experience of the surgeon.
- As the infant grows and becomes more ambulatory, the subcutaneous fat that accentuates the band gets absorbed and most minor bands improve significantly in appearance.

SURGICAL MANAGEMENT

- Urgent intervention is needed in cases of vascular compromise or worsening lymphedema soon after birth. For other cases, usual time of surgery is around late infancy or early childhood. In treating bands, the surgeon should take advantage of extra subcutaneous tissue and elastic skin in the young child.
- The treatment of this condition includes repair of the band and the fenestrated syndactyly. The main goals of treatment are to improve appearance and function.
- Multiple approaches have been advocated for repair of the band. These include a variety of rearrangement schemes of skin and subcutaneous tissue. Many of these options are effective at releasing the band.
- The author advocates the adipofascial advancement technique first proposed by Upton.⁴ The band is excised and skin flaps are elevated; extra fat is removed, and adipofascial flaps are elevated and closed as a separate, distinct layer underneath the skin.



FIG 2 • Plain film radiographs of the example case demonstrate ulnar deviation of the middle finger of the left hand **(A)** and foreshortened digits on the right hand **(B)**.

- Similar to others,⁵ the author prefers to avoid Z-plasties, especially in narrow bands where excellent contour can be obtained with flap advancement and linear closure. In cases where the band is wide and adequate contour cannot be obtained (see Technique section), Z-plasties can be placed on the lateral and medial aspects of the limb/digit.⁴
- In most cases, it is safe to repair circumferential bands in one stage, especially if the band is not too deep.
- In general, however, the deeper and more distal the band, the less safe it is to perform a circumferential repair. Circumferentially releasing deep bands in the digits may predispose to venous insufficiency as dermal drainage may become impaired.
- Another indication to perform staged repair is when two bands are in close proximity.
- In most cases of fenestrated syndactyly, there are no flexion or extension creases in the area of the syndactyly. As such, there is little need to do zigzag incisions.
- The author releases most cases using straight-line incisions and covers the wounds with full-thickness skin grafts.

- If bands are released at the same operation, one can consider using discarded skin from the bands for skin grafting. However, this skin tends to be somewhat thicker, and it does not take as well as thinner grafts from the lower abdomen.

Preoperative Planning

- Review radiographs again.
- In cases of deep bands that seem fixed to the underlying bone, one should consider assessing distal blood flow with a Doppler probe. An Allen test is important in cases of deep distal forearm bands.

Positioning

- The patient is positioned supine with the arm out on a small hand table.
- The lower abdominal area is squared-off with Steri-Drapes for skin grafts, if needed for treating fenestrated syndactyly.
- Incisions are planned carefully before the tourniquet is applied.

TECHNIQUES

■ Adipofascial Advancement

Markings and Flap Creation

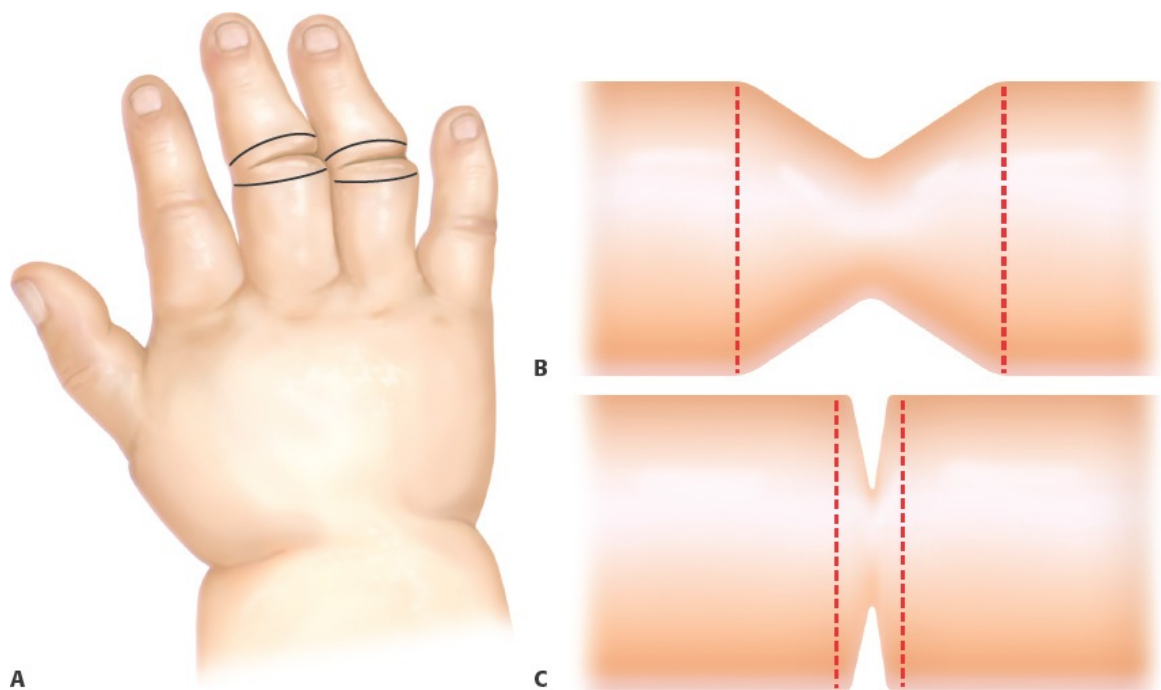
- The markings dictate where flaps will advance. Push the edges of the band together and mark the area of skin excision (**TECH FIG 1A**).
- The operation is easier and results are better when there is ample subcutaneous tissue and when the band is narrow rather than wide (**TECH FIG 1B,C**).
- Make the skin incisions and remove the intervening skin but leave all of the subcutaneous fat. Any tendon adhesions or nerve or vessel compression can be relieved at this point.
- Elevate skin flaps proximally and distally.
- Elevate adipofascial flaps in the areolar plane just above the extensor mechanism or fascial plane.
- Excise and discard any excess fat.

Advancing Flaps and Creating Z-Plasties

- Suture the adipofascial flaps together. Use a horizontal mattress technique so as to evert the edges and create additional tissue redundancy under the skin incision (**TECH FIG 2**).
- Plan and create Z-plasties to gain additional circumference for the closure (**TECH FIG 3**).
 - Plan these so the transverse limb falls in the midlateral aspect of the limb or digit.

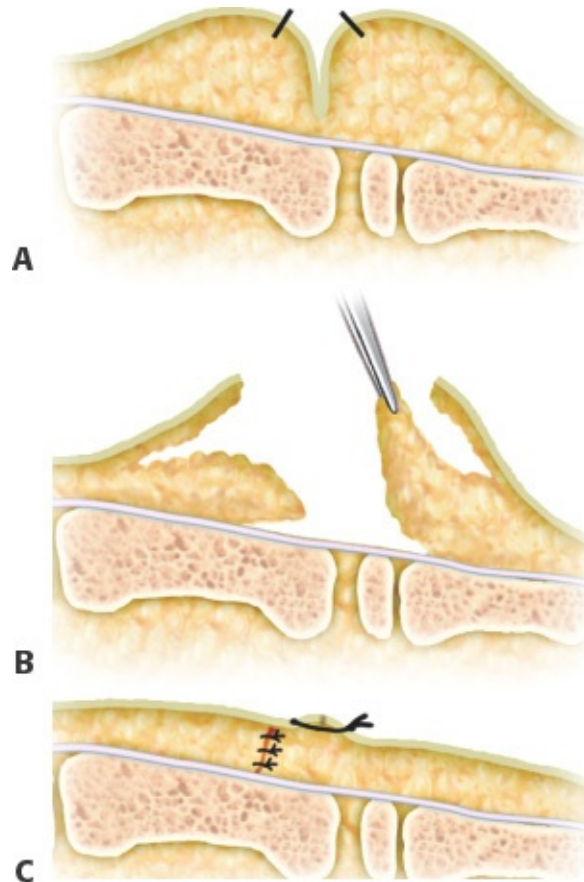
Closure

- Close the skin with everting horizontal mattress 6-0 chromic gut sutures for the digits (**TECH FIG 4A–D**).
- More proximal limb bands are repaired using deep dermal and running intradermal absorbable sutures (4-0 and 5-0 Monocryl) (**TECH FIG 4E**).
- Immobilize with a long extremity cast for 3 weeks.

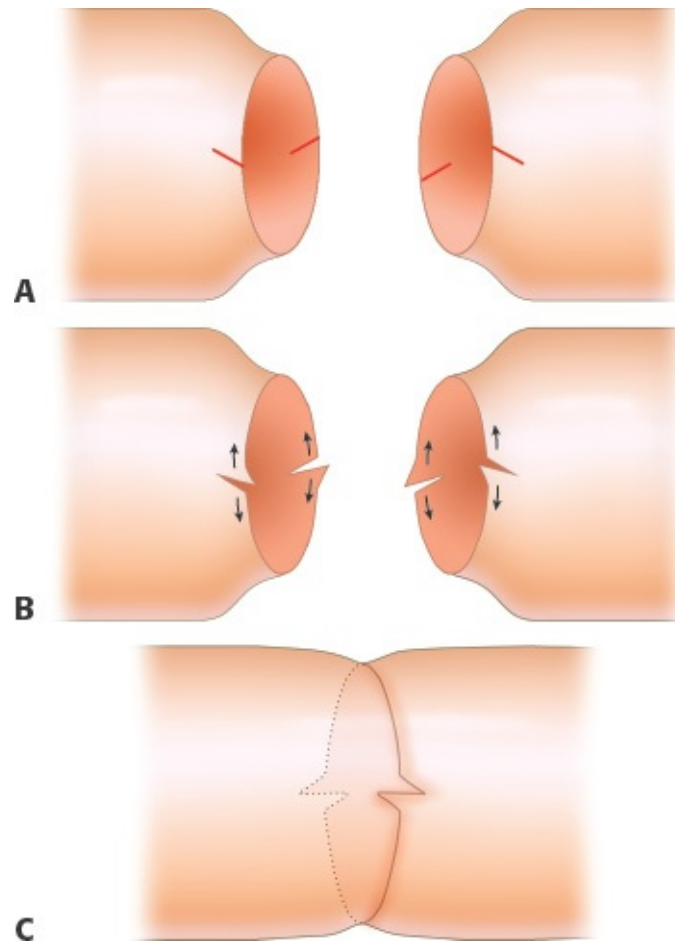


TECH FIG 1 • A. Incision planning for bands. The surgeon can push the edges together and draw one line where the edges meet. When the edges are allowed to retract, two lines result where the incisions should be made. **B,C.** Narrow vs wide bands. To

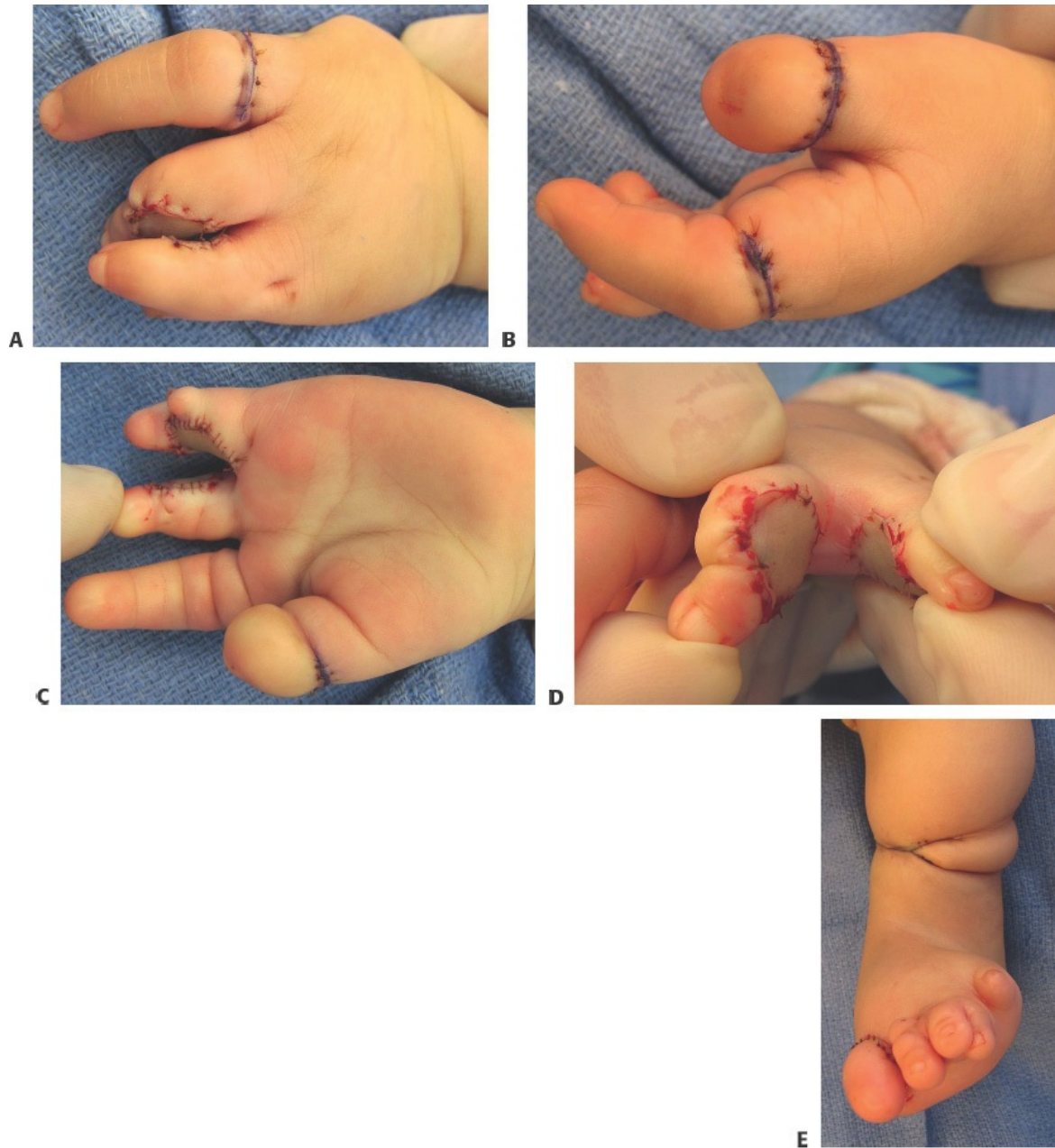
achieve normal contour, wide bands **(B)** require a larger section of the band to be removed (*dashed lines*) as compared to narrow bands **(C)**.



TECH FIG 2 • Technique of adipofascial flap and skin advancement for correction of bands. The band is excised **(A)** and separate skin and adipofascial flaps are raised **(B)**. Unnecessary fat is excised and the adipofascial flaps are advanced and closed. **C**. The skin is closed as a separate layer away from the adipofascial flap closure line.



TECH FIG 3 • Theoretical basis of using Z-plasties for treatment of amniotic constriction bands. Z-plasties performed at the edge increase the circumference of the band. **A**. This is useful in wide bands where the entire band cannot be excised but unnecessary for narrow bands. Z-plasties are performed (only two are shown in **B**, but multiple can be performed), lengthening the circumference and allowing improved contour (**C**).



TECH FIG 4 • Immediate postoperative clinical images of the example case showing dorsal **(A)**, radial **(B)**, palmar **(C)**, and web space **(D)** views after correction of thumb and index finger constriction bands and release of third web space fenestrated syndactyly and coverage with full-thickness skin grafts. **E.** Anterior view after repair of medial leg band. These were two adjacent deep bands, and thus a staged approach

was undertaken. The medial bands were treated in one stage by removing the intervening skin between the two bands. The lateral bands were treated in a second stage, preserving the intervening skin, because the band was wider on the lateral aspect.

■ Release of Fenestrated Syndactyly

- Release the fenestrated syndactyly using straight-line longitudinal incisions. In most cases, there are no functional joints in the area where the fingers are joined.
 - Accordingly, the surgeon should not worry about flexion contractures due to straight-line incisions.
- In cases where the syndactyly is distal, the resulting wounds can be closed or skin grafted (**TECH FIG 5**).
- In more proximal cases, the fenestration can be a narrow tract that communicates dorsal and palmar pits (see **FIG 1A,B**). Place a lacrimal probe into this tract.
- Release the syndactyly up to this tract. This degree of release is sufficient in most cases; however, if the tract is too distal, additional release can be performed with standard commissure flaps and full-thickness skin grafts.
- Apply skin grafts to the open wounds (see **TECH FIG 4C,D**).
- Apply a standard syndactyly release dressing with antibiotic-impregnated gauze, moist cotton, and gauze wrap.
- Immobilize with a well-padded long extremity cast.



TECH FIG 5 • Postoperative image after release of fenestrated syndactyly of the right hand. The wounds were small and could be closed primarily.

PEARLS AND PITFALLS

Surgical management

- The older infant or younger toddler is an ideal candidate for repair because there is ample subcutaneous fat and highly elastic skin.
- Mild, shallow bands can be treated conservatively and usually improve with observation as the child grows.
- If releasing the band is done to improve appearance (as in most cases), by performing the operation, the surgeon and patient are choosing to trade one appearance for a better one. This issue should be kept in mind, as sacrifices in technique and approach may be necessary to maximize overall appearance. For example, it may be worthwhile to accept a small bit of contour depression to avoid multiple zigzag incisions in a conspicuous area.

Technique

- In treating bands, the primary focus should be to improve contour. Overall appearance is much more influenced by contour than by scar.
- Be meticulous about hemostasis as hematoma under advanced skin

flaps can cause ischemia and tissue loss.

- The proximal tract in fenestrated syndactyly may be located too distally—in these cases, plan a standard syndactyly release using commissure flaps and skin grafts. Make sure to excise the epithelial tract.

POSTOPERATIVE CARE

- Remove the cast in 3 weeks.
- Start range of motion exercises
- In cases of syndactyly release, refer the patient to hand therapy for fabrication of splint and web space pressure conformer to be used at night for about 1 month.

OUTCOMES

- Functional outcomes after treatment of this condition are fully dependent on the preoperative degree of involvement. Function is much more likely to be determined by the presence of any congenital amputations as compared to minor bands or syndactyly.
 - Because each patient is different, comparative functional outcomes are difficult to standardize.
- Aesthetic outcomes are dependent on the preoperative status of the bands and the technical execution of the repair (**FIG 3**).
- Unfavorable outcomes include contour depression, significant scarring, and contractures.

COMPLICATIONS

- In repair of bands, complications include flap ischemia or distal limb ischemia. Flap ischemia occurs as a result of overzealous undermining, too much tension, or hematoma. Venous insufficiency can occur when deep circumferential digital bands are treated in one stage.

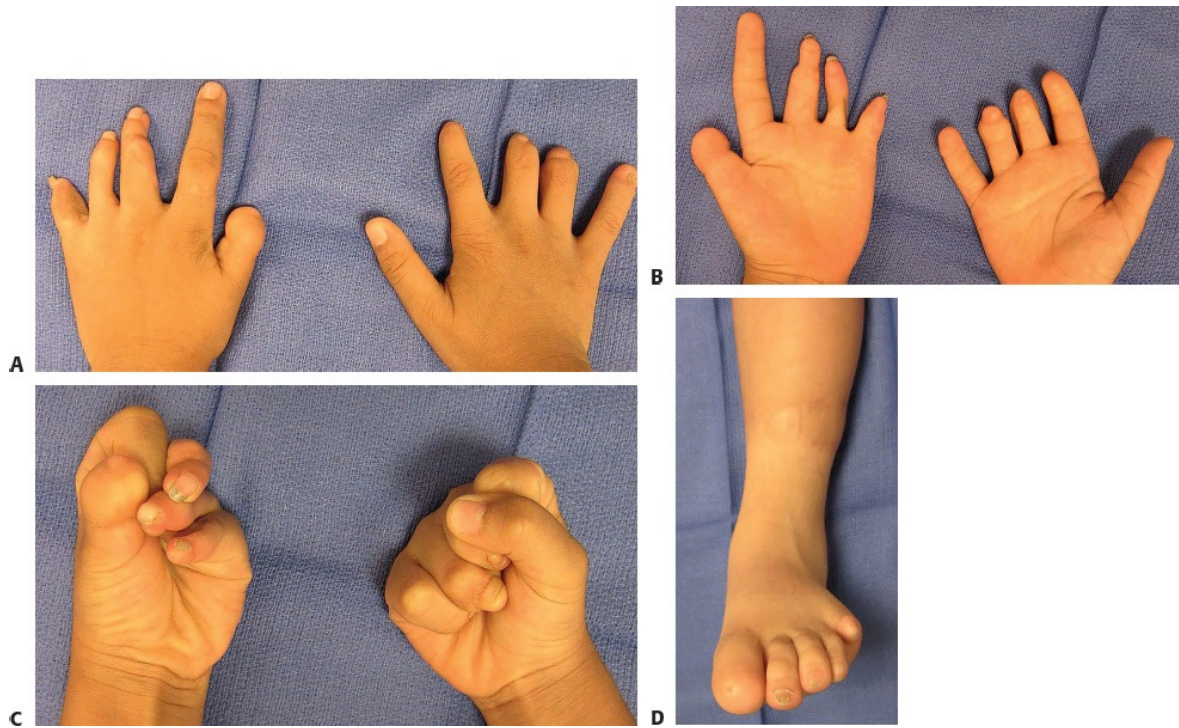


FIG 3 • Long-term postoperative photographs of the example case. **A,B.** Dorsal and palmar view of the hands. **C.** The digits of the left hand are short and stiff, as shown in the clenched fist view. **D.** The leg shows significant improvement in contour of the leg (note one medial scar and two lateral scar; see **TECH FIG 4E**) and toes after two-stage correction. The patient is fully ambulatory.

- Typical complications after syndactyly repair can be seen. These include flap ischemia, skin graft loss, and web creep. Careful planning and meticulous execution can avoid these complications.

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69 Centralization for Radial Longitudinal Deficiency

CHAPTER

Amir H. Taghinia, Brian I. Labow, and Joseph Upton

DEFINITION

- Radial longitudinal deficiency (RLD) is a congenital condition characterized by hypoplasia of the radial side of the hand, wrist, and forearm. The bony, articular, and soft tissue structures can be affected in various degrees.
- RLD encompasses a spectrum of conditions ranging from minimally affected radius and normal hand to complete absence of radius and thumb. In some instances, other digits on the affected limb can also be involved—most significantly the index finger, which can be hypoplastic.
- The degree of severity lessens with progression from the radial to ulnar side of the hand.

ANATOMY

- The radius can be mildly foreshortened, significantly hypoplastic, or completely absent. In the most severe cases, the radius, radial carpal bones (scaphoid and trapezium), and thumb are absent. Elbow and (to a lesser extent) shoulder abnormalities can also be present.
- The most common manifestation is an absent radius or a small proximal remnant. In these cases, a tough fibrous anlage is present that connects the proximal radius to the carpal region and distal ulna (**FIG 1**).
- The ulna may be bowed, and its distal end is widened.
- The absence or hypoplasia of the radial structures is accompanied by radial deviation and radial-palmar displacement of the wrist. This positioning weakens flexion power of digits and wrist.
- When the thumb is severely affected, the index finger is usually stiff and hypoplastic. This is clear on physical examination as the finger is usually

thinner, slightly flexed with poorly developed flexion and extension creases.

- The ulnar digits and ulnar muscles tend to be normal, so children manipulate objects with their ulnar digits.
- The flexor carpi radialis and extensor carpi radialis brevis and longus may not be distinctly present. They are usually joined together to form a single set of muscles dubbed “dorsoradial muscle mass.” These radial extensors of the wrist may be poorly developed or nonfunctional. In contrast, the ulnar-sided flexors and extensors are usually present and functional (see **FIG 1**).
- The radial nerve usually ends proximally around the elbow. The median nerve is radially and dorsally displaced, lying superficially on the radial aspect of the wrist.
 - During surgical exposure, the median nerve is superficial over the radial incision and is often mistaken for a tendon. One must recognize and protect this cordlike structure, the median nerve, during surgery. In addition to providing sensation to the radial palm, this nerve also supplies sensation to the usual areas of radial nerve distribution. For this reason, it is often dubbed the “radian” nerve.
 - The radial artery is absent or hypoplastic, but a median artery is present instead.
- RLD is classified based on the degree of involvement. The original Bayne and Klug classification remains widely accepted (**FIG 2**), though a few modifications have been introduced. Types III and IV are the most common.
 - Type I—Minimal radial shortening of 2 mm as compared to ulna. The elbow is normal and the thumb is present, though possibly hypoplastic.
 - Type II—Radius is hypoplastic (“radius in miniature”), wrist is deviated, ulna is bowed, and thumb and radial carpal bones are absent.
 - Type III—The radius is partially absent, usually the distal two-thirds. The thumb and radial carpus are severely affected. A fibrous anlage is associated with flexion and pronation of the wrist.
 - Type IV—The radius is absent and the wrist is severely deviated—sometimes beyond 90 degrees. The thumb is usually absent. Often a small remnant of proximal radius will ossify during the adolescent growth spurt.



FIG 1 • Wrist and forearm anatomy in radial longitudinal deficiency (type III is shown). The fibrous anlage, a remnant of the radius, tethers the wrist radially. The radial wrist extensors and flexors fuse into a “dorsoradial muscle mass.” The radial carpal bones are absent as is the thumb.

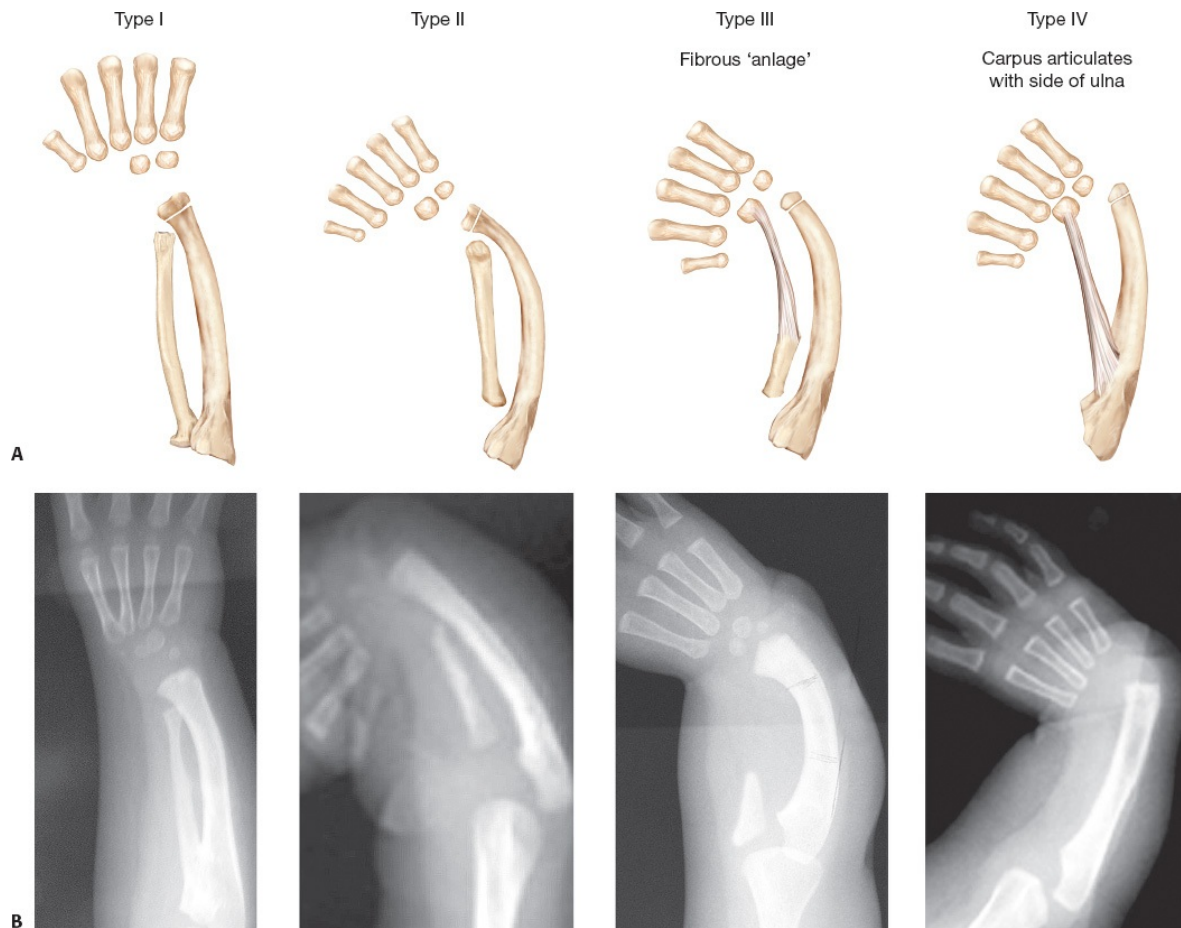


FIG 2 • Bayne and Klug classification of RLD. **A.** Radial deviation and palmar subluxation are worse with increasing hypoplasia of the radius. **B.** Representative radiographs of RLD types I to IV.

- Modifications to the original classification system includes introduction of three additional types:
 - Type N—Thumb hypoplasia with normal radius
 - Type 0—Absent or hypoplastic carpal bones with normal radius
 - Type V—Humeral abnormalities

PATHOGENESIS

- RLD occurs in 1 in 30 000 to 1 in 100 000 live births. Bilateral and unilateral cases occur in equal frequency.
- The cause of RLD is unknown. Environmental and genetic factors are likely responsible for developmental anomalies in the apical ectodermal ridge (AER)

between the 4th and 7th weeks of gestation. Animal models with radial deficiencies can be created by ablation of the radial section of the AER.

- RLD is considered to be a malformation, based on the Oberg, Manske, and Tonkin classification of 2010.¹

NATURAL HISTORY

- If untreated, radial deviation usually worsens and the wrist develops stiffness.
- Radial deviation usually recurs to some extent even after surgical correction unless the ulnocarpal joint has been fused.
- Although the forearm does grow, it usually grows slower than the normal forearm and ends up about 60% of normal length.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The infant's shoulder, elbow, and wrist should be examined.
- The degree of wrist deviation and the capacity for passive correction should be noted and recorded.
- The status of the thumb and the radial fingers should be noted, especially in terms of intrinsic muscle development, passive motion of the joints, flexion and extension creases, and the presence of contractures.
- RLD is frequently associated with other conditions (70%–90%) and the likelihood increases with severity.² Bilateral involvement increases the likelihood of associated conditions by over 30%.
 - Although a long list of possible conditions can occur with RLD, the most common are the VACTERL association, Holt-Oram syndrome, craniofacial microsomia, and Fanconi anemia.

IMAGING

- Plain radiographs delineate the degree of involvement and help with classification.
- The hand-forearm angle (HFA) and the hand-forearm position (HFP) should be measured on the anteroposterior radiograph (**FIG 3**).
 - HFA is the angle between the longitudinal axes of the long finger and the distal ulna.
 - HFP is the shortest distance between a line drawn through the longitudinal axis of the distal ulna and the proximal pole of the fifth metacarpal.
- These measures can be followed over time and growth to assess long-term success of surgical correction vs nonoperative treatment.

DIFFERENTIAL DIAGNOSIS

- Thrombocytopenia-absent radius (TAR) syndrome is a genotypically distinct entity, although the treatment is similar.
- Patients have hypomegakaryocytic thrombopenia with a completely absent radius. In contrast to RLD with absent radius (type IV), patients with TAR have thumbs.
- TAR is an autosomal-recessive condition linked to a defect in chromosome 1q21.1.
- Clinical findings include bruising, hemorrhage, and cardiac and renal anomalies.
- The thumb is biphalangal and contains varying degrees of skeletal and thenar muscle hypoplasia.

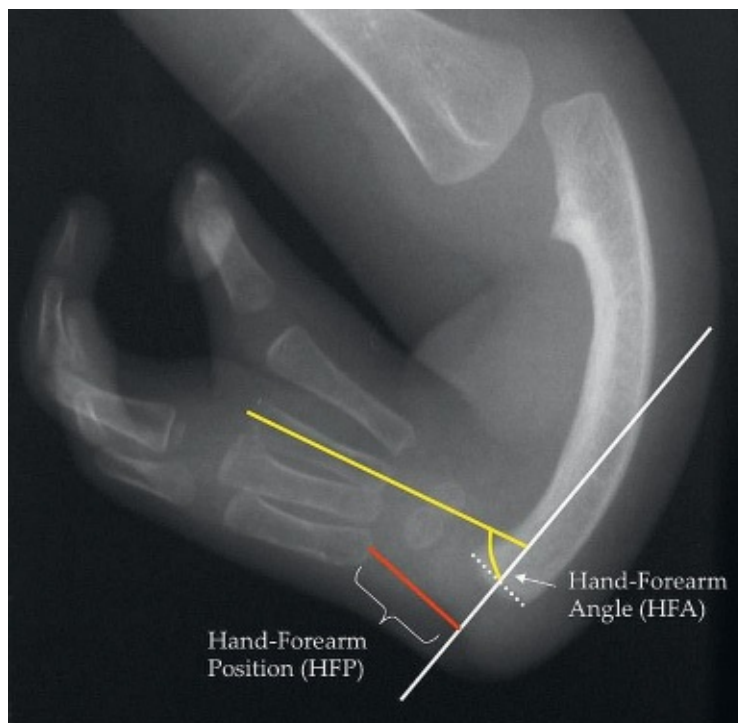


FIG 3 • Measuring hand-forearm angle (HFA) and hand-forearm position (HFP) on the plain radiograph.

NONOPERATIVE MANAGEMENT

- For most patients, nonoperative management with splinting and stretching is instituted early in infancy.

- This type of treatment maybe a long-term solution for those with mild RLD (types 0, I, and II) or a short-term “bridge” solution in preparation for subsequent surgery (types III and IV).
- The family performs stretching about 8 to 10 times per day by applying longitudinal traction and ulnar deviation.
 - A form-fitting radial gutter splint is then used to keep the wrist in the corrected position.
- Early on, as the family strives for a neutral wrist, the splint will need to be worn at all times and will need frequent revisions. Once the wrist is passively correctable to neutral, the splint can be weaned to night use only.
- Splinting is also a critical postoperative adjunct to keep the wrist in neutral; as the natural history of this condition is progressive radial deviation of the wrist with growth.
- Treatment may not be indicated at all in the following:
 - Adults who have adapted well
 - Patients who cannot tolerate stretching and splinting (eg, develop hygiene problems such as rash)
 - Patients in whom operative treatment poses unnecessary medical risk
 - Patients whose function will worsen with a straight wrist (eg, patients with stiff elbows who may be unable to wipe or feed themselves with the hand).

SURGICAL MANAGEMENT

- Types 0, I, and II RLD are usually treated with stretching and splinting. In rare instances where these measures are ineffective, surgical management can include tendon transfers and/or distraction lengthening.
- Types III and IV RLD can be treated with stretching and splinting first, as a “bridge” intervention, to bring the wrist into neutral prior to formal repair. However, this intervention alone is usually not sufficient to allow the carpus to translate beyond the distal ulna.
- In most cases, preoperative soft tissue distraction is necessary to achieve satisfactory positioning.² This procedure involves application of a (usually) uniplanar distractor without an osteotomy. Once slow distraction (1 mm/d) moves the carpus beyond the distal ulna, formal centralization or radialization can be performed (**FIG 4**).
- In early reports, centralization involved resection of the distal ulna, but this led to early growth arrest. Thereafter, carpal resection was introduced (carving a notch in the carpus to accommodate the distal ulna), which helped with

alignment and avoided growth arrest, but led to stiffness and recurrence.

- To remedy these issues, Buck-Gramcko introduced radialization, which involves:
 - Stabilization of the radial carpal column onto the distal ulna without carpal resection.
 - Transfer of the dorsoradial muscle mass ulnarly to counteract the deforming forces and provide long-lasting correction.
- There is debate about what constitutes centralization vs radialization.
 - Traditionally, centralization involves carving of a carpal notch for insertion of the ulnar head and alignment of the base of the third metacarpal with the central carpus and the distal ulna (**FIG 5A**).
 - In contrast, radialization involves alignment of the second metacarpal with the radial carpus without carpal resection (**FIG 5B**).
- There continues to be disagreement about which of these options is best. Some argue that stabilization of the wrist (radialization) without a carpal notch does not provide a stable equilibrium, whereas others prefer to preserve motion and avoid shortening.
- Nevertheless, most surgeons agree that for the operation to be effective:
 - The fibrous anlage and dense soft tissues should be released or excised.

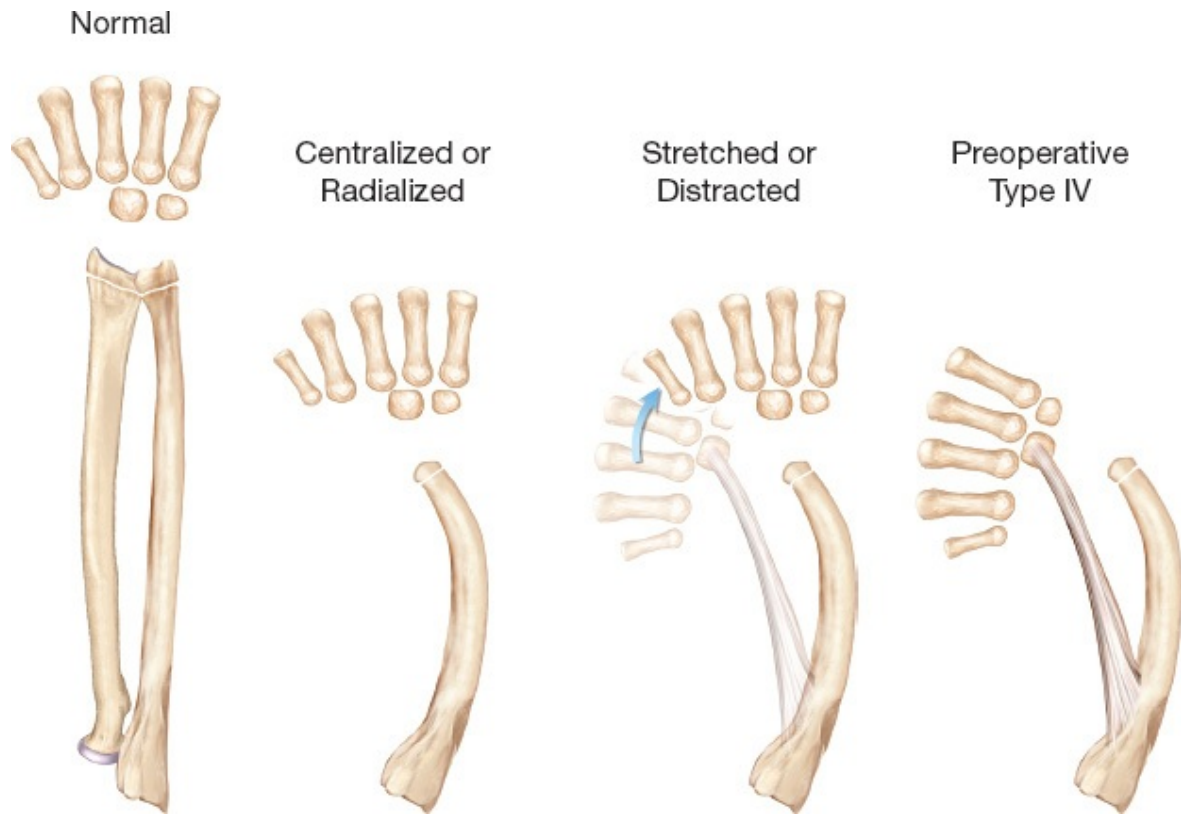


FIG 4 • The process of soft tissue distraction is demonstrated. The deficient forearm reaches about 60% of the length of a normal one.

- The dorsoradial muscle mass should be transferred to the ulnar wrist.
- Alignment should be maintained with a pin that is kept in for several months, if not longer.
- Microvascular free toe joint transfer involves transfer of vascularized osseous structural support to stabilize the radial column of the wrist. Soft tissue distraction is usually necessary to align the wrist and create a “space” into which the toe will be placed. The metatarsal and proximal phalanx of the second toe are transferred with their growth centers and attached to the distal ulna.
- Although technically demanding, the operation provides the advantage of avoiding injury to the distal ulnar physis and preservation of wrist motion.
- The time to perform corrective surgery is about 1 year of age, barring small patient size and/or associated comorbidities.

Preoperative Planning

- Review risks, benefits, and expectations with parents on the day of surgery. Specifically outline the risks of possible wrist stiffness, poor growth, and persistent or recurrent deviation.
- The long-term outcomes and natural history of this condition should be discussed well before the operative date.
- Fluoroscopy, drills, and pins will be required for the procedure.

Positioning and Approach

- The patient is positioned supine with the arm out on a small hand table.
- Incisions are planned carefully prior to use of the tourniquet.
- A transverse dorsoulnar approach is usually undertaken. There is usually no need to extend incisions along the entire dorsal forearm.

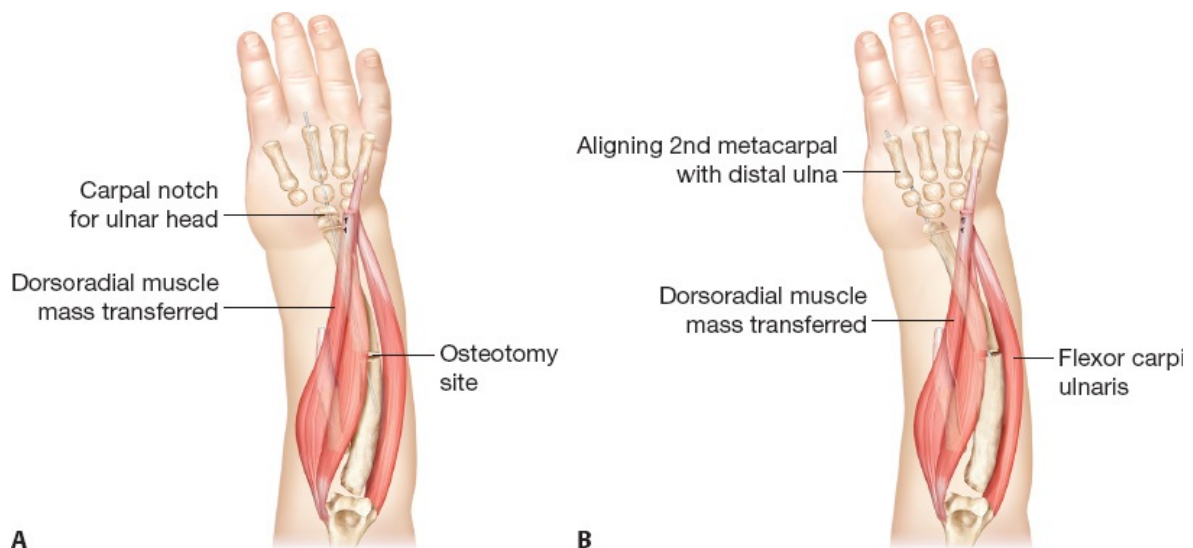


FIG 5 • Centralization vs radialization. A. For centralization, a transverse distal wrist incision is made, the “radian” nerve identified, and the tight radial fibrous anlage released. All tethering soft tissues must be release. A small notch is carved into the carpus to allow introduction of the ulnar head. The wrist is reduced and stabilized with a pin aligning the third metacarpal with the ulnar head. The ECU is advanced. The dorsoradial muscle mass is transferred to the ulnar wrist extensors.

A corrective osteotomy of the ulna may be necessary if the bowing is significant. Excess skin on the ulnar side of the wrist is excised. **B.** In radialization, the maneuvers are similar to those for centralization except that the carpal bones are not excised. Instead, the carpus is stabilized over the distal ulna and held there with a pin. The hand is more ulnarly deviated to provide a better moment arm for the musculature to keep the wrist in the proper posture. The pin aligns the second metacarpal with the distal ulna.

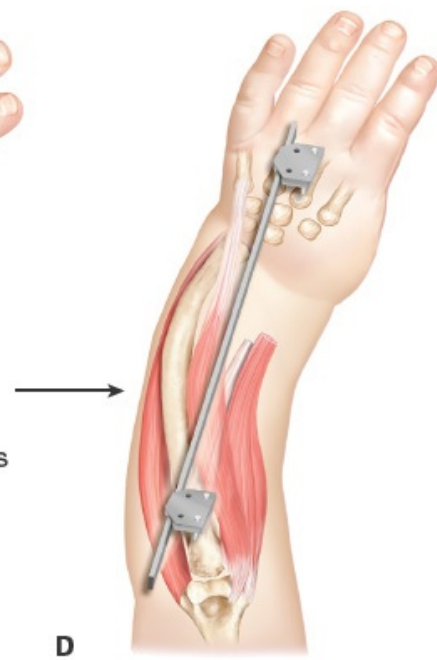
TECHNIQUES

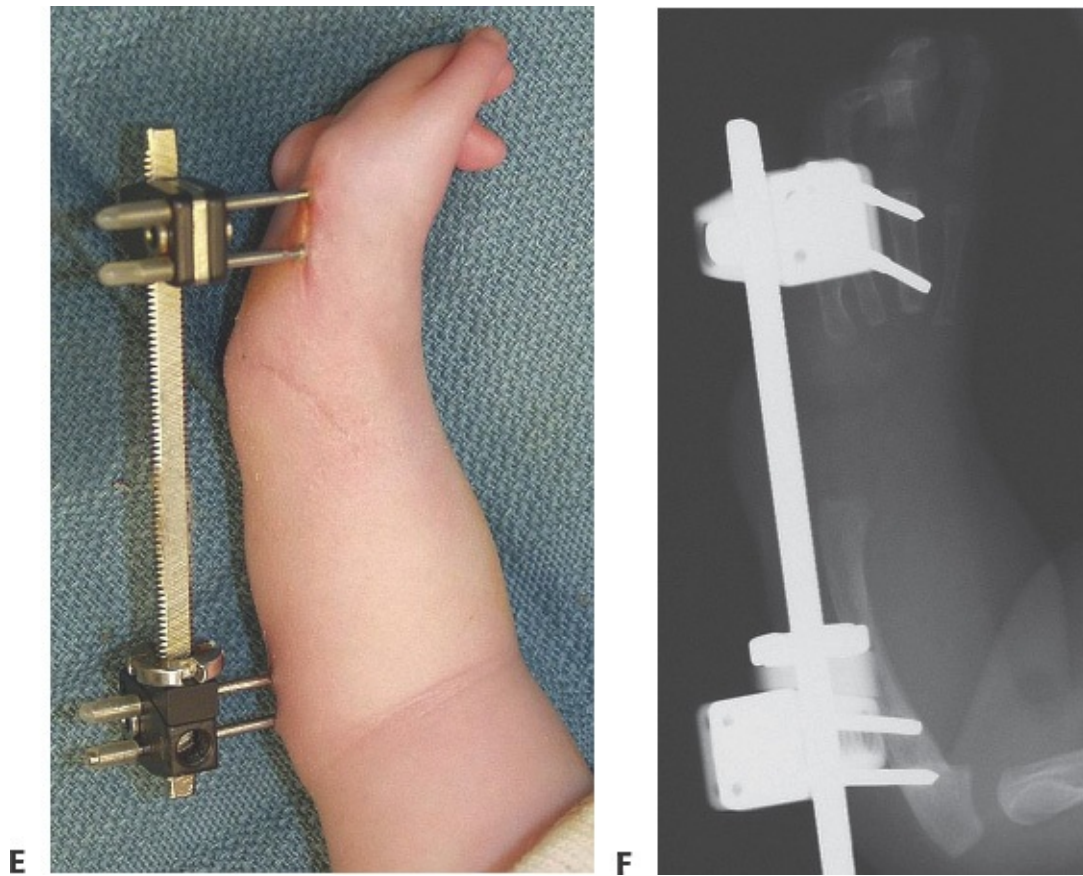
■ Preoperative Soft Tissue Distraction

- Consult manufacturer instructions for application of distractor of choice.
 - The authors prefer a uniplanar distractor as it is easy to apply and manage and effective at achieving the desired result.
- If the wrist is not passively correctable to 50 to 60 degrees of radial deviation (**TECH FIG 1A,B**), a concomitant releasing procedure may be necessary to obtain adequate alignment for placement of the distractor.
 - In this case, plan a transverse incision dorsally on the ulnocarpal joint for exposure of the radial fibrous anlage and tethered soft tissues.
- Plan small longitudinal incisions over the third metacarpal and the proximal ulna. Plan the length of these incisions based on the length of the distractor clamp that will house the pins. Assemble the apparatus and obtain all needed parts before the tourniquet is inflated.
- Exsanguinate the upper extremity.
- If performing a release, make the dorsal wrist incision and expose the fibrous anlage from the dorsal approach (**TECH FIG 1C**).
 - Take care to avoid injury to the “radian” nerve and the extensor tendons.
 - Release the tough radial soft tissues (**TECH FIG 1D**).
- Incise over the third metacarpal and the proximal ulna. Spread the soft tissues; retract and protect any longitudinally running vital structures (tendon,

muscle) until down to bone.

- Insert one pin into the metacarpal and another into the ulna.
- Arrange the distractor clamps onto the pins and tighten slightly. Apply the lengthening bar while manually distracting the wrist; secure the clamps onto the bar.
- Insert another pin into the metacarpal and one more into the ulna, each into the second seat of the respective distractor clamp.
- Loosen the clamps from the bar. Distract the soft tissues as much as possible and secure the clamps back onto the bar tightly.





TECH FIG 1 • Preoperative clinical (**A**) and radiographic (**B**) images of 6-month-old girl with type IV RLD. **C**. If the wrist is tight and significantly radially deviated, the fibrous anlage and tough tethering tissues should be released prior to placing the distractor. **D**. Releasing these structures allows proper alignment of the distractor and makes the process of distraction smoother. **E,F**. After soft tissue distraction and immediately prior to centralization, the deviation and subluxation of the wrist has been corrected.

- Close all the wounds and apply a soft dressing.
- The family can start distraction at 1 mm/d in about 3 to 4 days.
- Instruct the family on how to perform pin-site care to avoid infection. Provide written instructions and a timetable or turning the screw, and mark the distance between the pins so they can see the progress (and avoid

turning the wrong way).

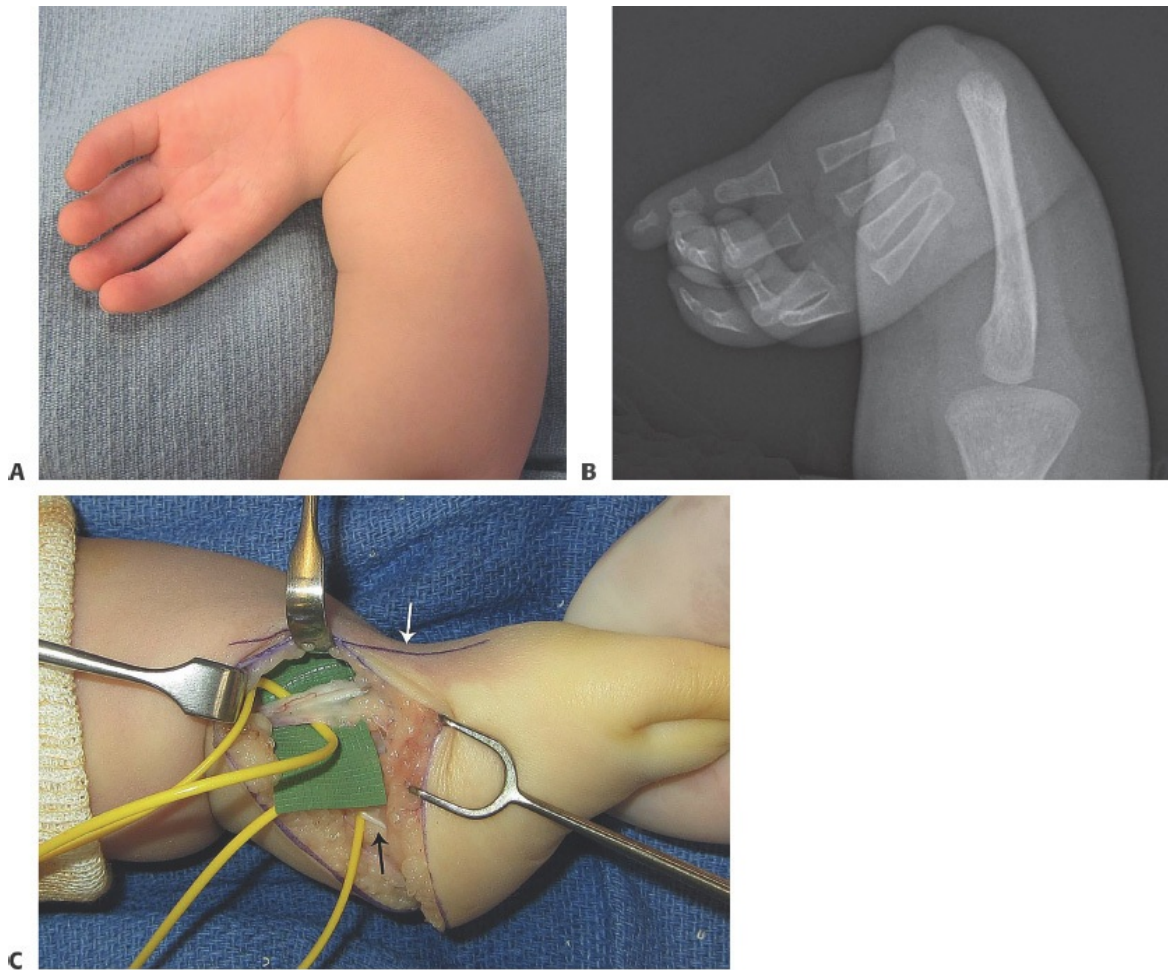
- It helps if they send weekly pictures via e-mail so the surgeon can monitor the progress.
- Once the carpus has translated beyond the distal ulna, leave the distractor on without distracting for another several weeks.
- At that point, the patient will be ready for formal centralization or radialization (**TECH FIG 1E,F**).

■ Centralization or Radialization

- If preoperative distraction has been performed, the distractor can be removed at the time of the centralization or radialization procedure.
- A transverse dorsoulnar incision is planned over the ulnocarpal joint. Extra skin should be reserved until the end where the exact amount can be carefully assessed prior to removal.
- The authors do not routinely employ local Z-plasty or transposition flaps. The use of preoperative soft tissue distraction has virtually eliminated any problems with skin deficiency.
- Exsanguinate the extremity.
- Incise the skin; identify and protect any veins that can be saved. Identify the fibrous anlage, the radial nerve, the dorsoradial muscle mass, the extensor tendons to the digits, and the extensor carpi ulnaris tendon.
- The radial nerve is usually radiodorsally translated and located just under the skin on the radial aspect of the wrist (**TECH FIG 2A–C**).
- Release the fibrous anlage and the dorsoradial muscle mass. Release any other tight investing fascia.
- Release the extensor carpi ulnaris from its attachment on the fifth digit metacarpal. This tendon will be advanced to provide more ulnar pull.
- Incise the wrist capsule transversely.
- If performing traditional centralization, carve a small notch into the carpus to accommodate the distal ulna. Otherwise, no carpal resection is needed.
 - Align the third metacarpal (centralization; see **FIG 5A**) or second metacarpal (radialization; see **FIG 5B**) with the distal ulna.
 - A 0.062-in. Kirschner wire can now be passed antegrade through the wrist entering the base of the chosen metacarpal. The authors prefer to insert the pin obliquely to avoid the metacarpophalangeal joint. Thus, the

pin would come out of either the first (if second metacarpal) or second (if third metacarpal) web space.

- Insert the distal ulna into the carpal slot (centralization) or stabilize the carpus over the distal ulna (radialization). Drive the K-wire down the ulna in retrograde fashion.
- If necessary, perform an opening wedge ulnar osteotomy to correct any bowing of the ulna and drive the pin further proximally to secure this osteotomy.
- Close the wrist capsule securely.
- Advance the extensor carpi ulnaris and reattach to the base of the fifth digit metacarpal. Transfer the dorsoradial muscle mass to the extensor carpi ulnaris tendon to provide additional ulnar moment arm to the wrist.
- Excise any redundant skin and close using absorbable sutures. Apply antibiotic-impregnated gauze to all incisions and cover with sterile gauze. Wrap loosely.
- Apply a long-arm cast.



TECH FIG 2 • Preoperative clinical (**A**) and radiographic (**B**) images of an 8-month-old boy with type IV RLD showing significant deviation. His family declined preoperative soft tissue distraction but did perform stretching and splinting such that the wrist could be passively corrected to 20 degrees of radial deviation. The “radian” nerve is the most superficial structure on the radial side of the wrist. **C**. It is demonstrated here under the green background. A smaller dorsal sensory branch (sensory radial nerve equivalent) is looped and visible dorsally (*black arrow*). The expected path of the nerve was marked on the skin preoperatively (*white arrow*).

PEARLS AND PITFALLS

Technique

- The pins may be left in for a long time; in fact, some surgeons leave the pins in for a year or longer. Although this may increase stability, it decreases range of motion and can result in physeal injury and hardware failure.
- The “radian” nerve is the most superficial structure on the radial side of the wrist; the surgeon should be cautious to avoid injury while dissecting in this area.

Postoperative

- Cast immobilization time should be limited, only to allow the soft tissues to heal. These children have short forearms and can easily escape from their casts.

Therapy

- It is critical to instruct the parents to move the fingers passively during preoperative soft tissue distraction. This action prevents stiffness and contractures.

POSTOPERATIVE CARE

- Remove the cast after 2 or 3 weeks and apply a thermoplast splint. Range-of-motion exercises of the digits can be started at this time.
- Leave the pin in for 8 to 10 weeks.

OUTCOMES

- Long-term outcomes for the two cases depicted are shown in **FIG 6**.
- The main unfavorable outcome seen after centralization or radialization is recurrence of the deviation. The recurrence appears to be related to the preoperative degree of deviation and amount of correction achieved postoperatively.²
- Rigorous compliance with night splinting may decrease the risk of recurrence (**FIG 7**).
- Despite the leveling and realignment of skeletal support from the remaining carpus and hand, the muscular imbalance across the wrist remains the primary cause for recurrent deviation.
- Despite the risk of recurrence, Kotwal et al.³ showed that surgical treatment of RLD is sensible. He compared patients who had undergone surgery to those who had not, showing that surgical treatment of RLD improves appearance and

function, and leads to better performance in daily activities.

- Although the focal point of treatment is correction of the radial deviation, the importance of this concern has been questioned. Recent studies have shown that wrist and digit range of motion as well as grip strength and forearm length may be better than wrist angulation in predicting functional outcomes in RLD.⁴
- Hence, it may be worthwhile to avoid carpal resection, thereby sacrificing some loss in position of the wrist in favor of better motion.

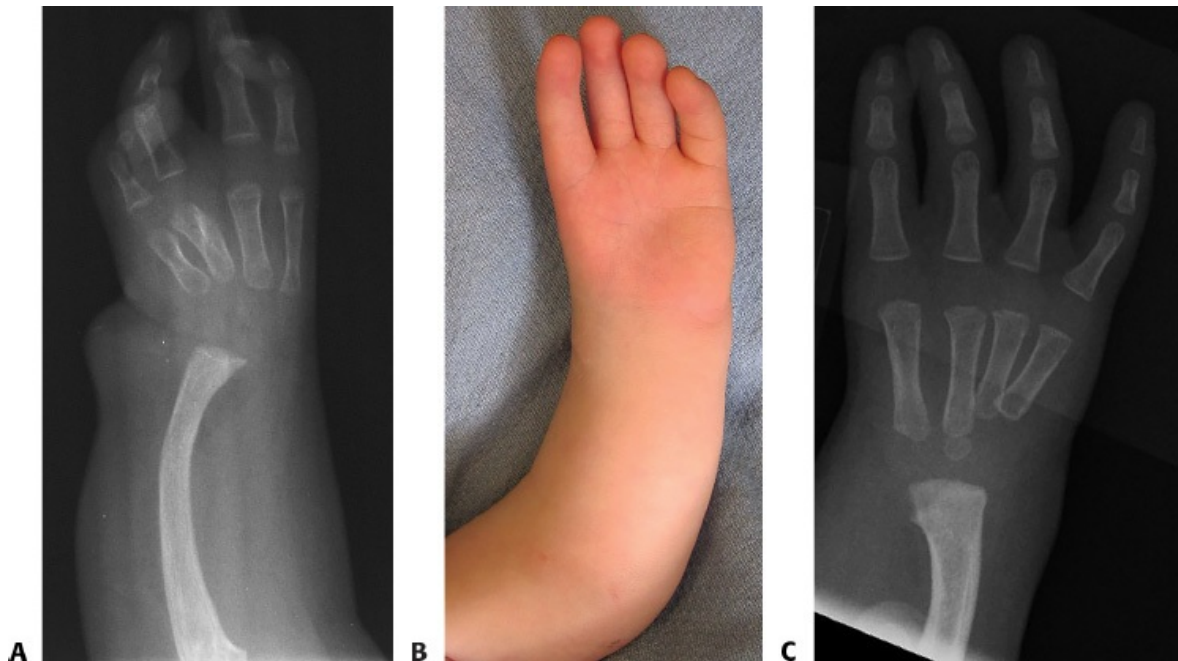


FIG 6 • A. The case in **TECH FIG 1** year after radialization. **B,C.** Long-term postoperative images after centralization for the case in **TECH FIG 2**. A carpal notch was required to adequately reduce the wrist.

COMPLICATIONS

- Infections during soft tissue distraction are frequent and range from minor pin-tract infections to cellulitis and, rarely, deep bone infection. These problems are avoided with good pin-site care and close follow-up.
- Other complications with the distraction include inadequate distraction by the parents, device malfunction or malalignment requiring repair, and stiffness and/or contracture of the digits. These problems can be avoided with good parent education and support as well as passive range-of-motion exercises.

- Complications of centralization or radialization include wound infections and hardware problems. Because the pin has to be in place for many weeks, it may migrate, dislodge, or break.
- One of the most concerning complications is early growth arrest of the distal ulna, since it will cause additional shortening of an already short forearm.
- This issue can be avoided by earlier removal of the pin and minimal manipulation of the distal ulna during the corrective operation.
- Physeal damage may also occur with rapid, aggressive distraction in young children.

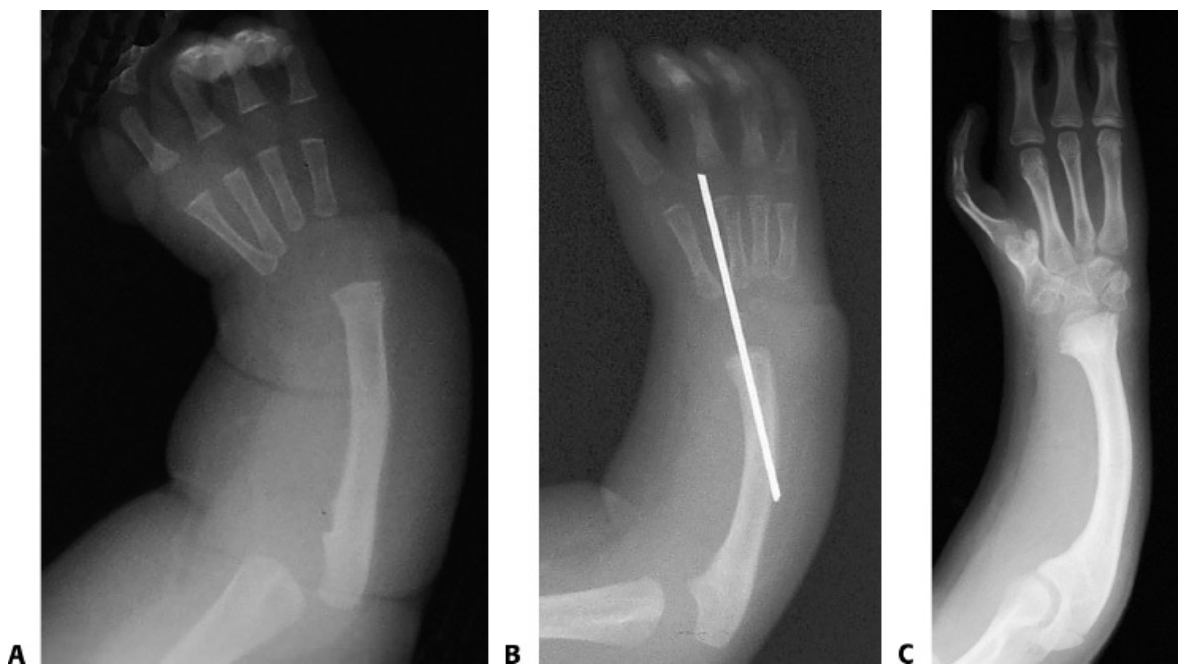


FIG 7 • Long-term result after centralization. **A.** Initial radiograph showing type IV RLD. After centralization and 12 weeks of pin fixation **(B)** and 14 years later **(C)**. At long-term follow-up, the wrist maintained adequate alignment. This child was compliant with nightly splint use. Note the index finger has been pollicized.

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70 Excision of Vascular Malformation of the Hand

CHAPTER

Amir H. Taghinia

DEFINITION

- Vascular anomalies fall into two main categories: tumors and malformations. Tumors, such as hemangiomas, exhibit cellular hyperplasia. In contrast, malformations represent a localized defect in vascular morphogenesis.
- Vascular malformations can be broadly classified into slow-flow and fast-flow lesions.
 - Slow-flow lesions include capillary, lymphatic (LM), and venous (VM) malformations or mixed lesions.
 - Fast-flow lesions include arteriovenous malformations (AVM).

ANATOMY

- Vascular anomalies can occur anywhere in the hand and upper extremity, and can involve all components of soft tissue, bone, and joint. When present, they can alter or distort the normal anatomy.

PATHOGENESIS

- The exact etiology of vascular anomalies is the subject of intense scientific investigation.
- Somatic activating mutations in the phosphatidylinositol-3-kinase (PIK3CA)/mammalian target of rapamycin (mTOR) pathway appear to underlie a number of overgrowth phenotypes with vascular anomalies.¹

NATURAL HISTORY

- Hemangiomas have a biphasic growth phase with proliferation early in life and subsequent involution.
- Malformations have a propensity to slowly expand throughout life.

PATIENT HISTORY AND PHYSICAL FINDINGS

- With a few exceptions, hemangiomas are usually absent at birth or present as a small stain.
- Patients present with a growing, vascular, high-flow lesion in early infancy.
- These lesions have a deep red appearance and strong Doppler signals throughout.
- Vascular malformations can present any time in life. Although they are likely present at birth, they may be clinically silent for years. They usually present with a combination of discoloration, disproportionate growth, swelling, and pain (**FIG 1**).

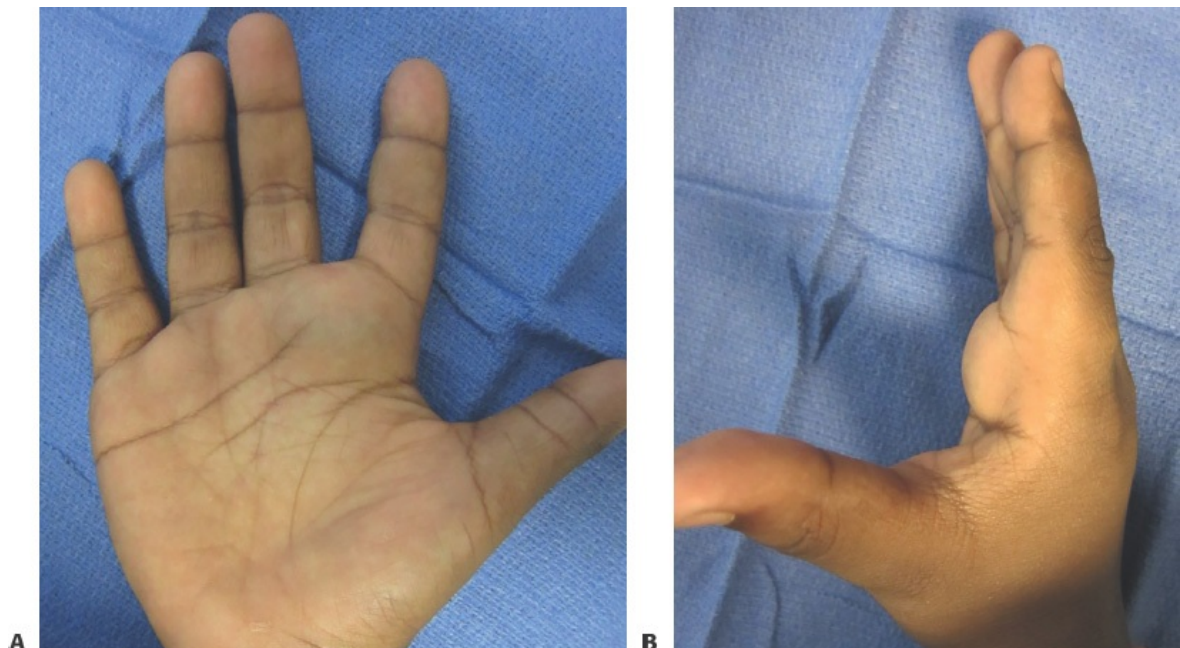


FIG 1 • **A,B.** AP and lateral views of a growing, painful mass on the palm of a 7-year-old boy (the example case throughout).

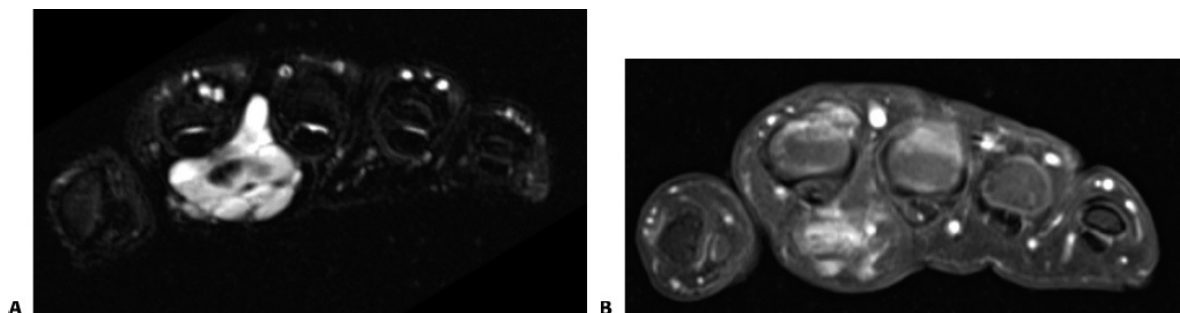


FIG 2 • T2-weighted (A) and T1-weighted postgadolinium (B) MRI images of the lesion.

- LMs may also develop drainage or infections, and AVMs can develop paradoxical ischemia and ulceration.
- Most vascular malformations can be correctly diagnosed by physical examination. A multidisciplinary approach to diagnosis and treatment gives the best outcomes.

IMAGING

- Ultrasonography is the best initial radiological examination for these lesions. It can be done in the clinic room during the first multidisciplinary visit. The type and extent of the lesion can be determined quickly and easily.
- For surgical planning purposes, however, more extensive imaging is usually required. An MRI is the best soft tissue imaging tool for these lesions (**FIG 2**). Angiography is helpful for high flow AVMs.

DIFFERENTIAL DIAGNOSIS

- The myriad of multiple overlapping conditions that include vascular malformations can be confusing. Although these lesions can be solitary, the presence of associated conditions is often the rule rather than the exception. For an extensive list of associated conditions, the reader is referred to other readings.²
- Differential diagnosis includes overgrowth conditions, malignancies, and a variety of other benign conditions. When in doubt, biopsy is recommended.

NONOPERATIVE MANAGEMENT

- Hemangiomas are often treated conservatively with no intervention or with medical therapy including steroids and beta-blockers. Surgery has a minimal role in the treatment of these lesions.
- Most malformations are amenable to interventional radiological treatments, which involve sclerotherapy and embolization. Certain lesions cannot be treated this way—notably, microcystic lymphatic malformations—and thus require surgery.
- In the hand and upper extremity, the authors advocate against sclerotherapy of lesions close to neurovascular structures unless surgical resection is deemed to be too morbid. Sclerotherapy around major upper extremity nerves can cause

numbness, motor deficit, and chronic pain.

SURGICAL MANAGEMENT

- The indications for surgical intervention are pain, functional compromise (impending or extant), rapid or persistent growth, ischemia, and ulceration in lesions that are not suitable for treatment by interventional radiologists.
- A few key principles are outlined here²:
 - Plan extensively. Outline the extent of the resection and abide by it.
 - Place incisions thoughtfully. Often multiple debulking procedures may be necessary.
 - Use magnification.
 - Approach the lesion from known to unknown.
 - Avoid vascular compromise. When a critical arterial segment to an extremity is removed, it should be reconstructed.
 - Avoid intraneural dissection. Dissection within nerves often leaves neuromas-in-continuity with disruption of distal sensory or motor function.
 - Avoid partial dissections. Removal of an entire involved area is preferred as it avoids future challenging dissection in a scarred bed.
 - Replace abnormal or ischemic skin; use flaps or skin grafts.
 - Use drains liberally.
 - Amputate if needed. Ischemic, nonfunctional, painful, and parasitic digits or limbs should be removed.
 - Follow patients long term.
- The purpose of surgery should be clearly outlined. In large or complex cases, the goal of surgery is relief of pain and improvement of function. With the exception of small lesions, total eradication of most lesions is impossible. These lesions are not malignant, and so a wide excisional approach that sacrifices normal functioning structures is ill advised.

Preoperative Planning

- Again discuss risks, benefits, and expectations with parents and patient on the day of surgery.

Positioning and Approach

- The patient is positioned supine with the arm out on a hand table.
- Incisions are planned carefully prior to use of the tourniquet.
- In infants and toddlers, an Esmarch bandage is used as a tourniquet because it

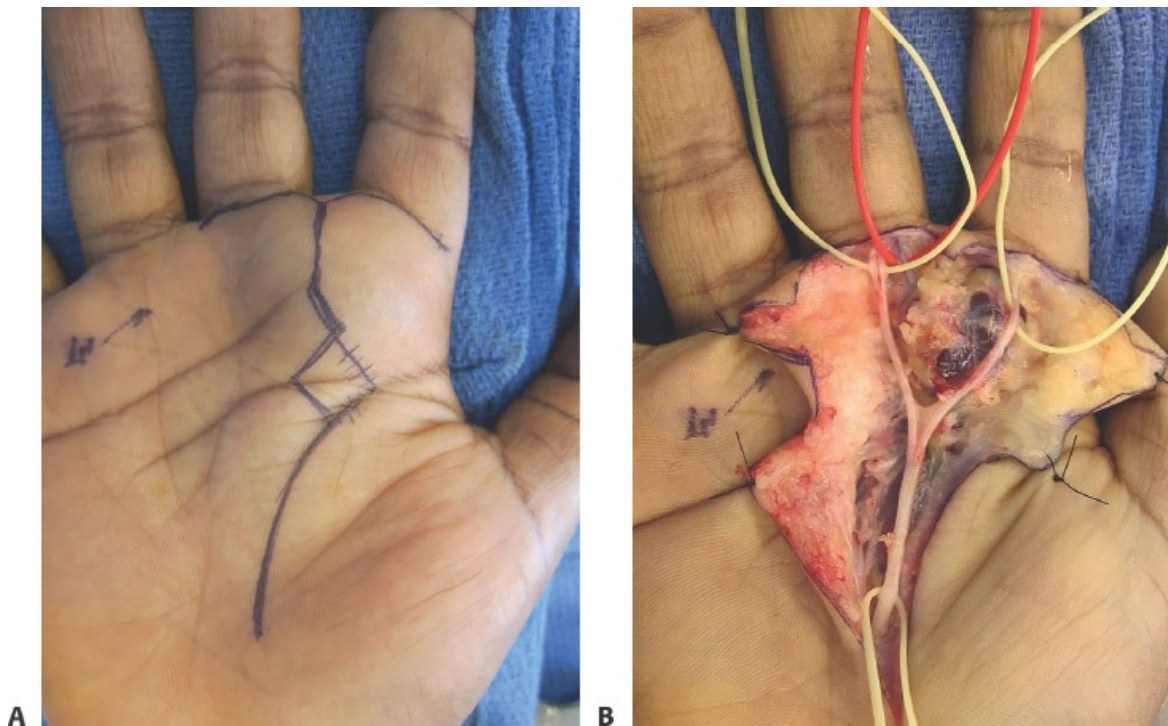
is more effective at providing a bloodless field in small arms. In older children, a standard pneumatic tourniquet is used.

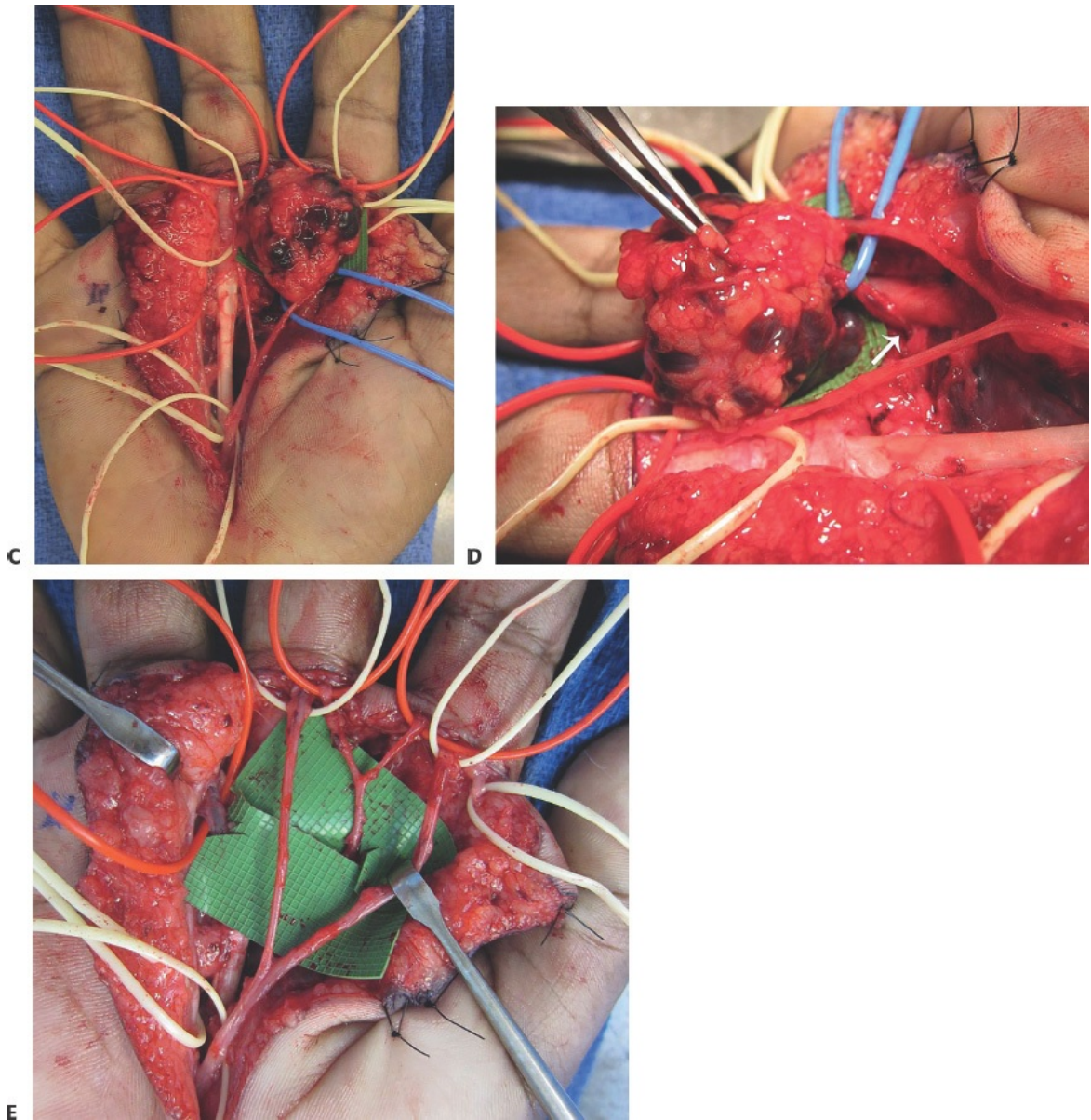
TECHNIQUES

■ Excision of Palmar Venous Malformation

- Mark a palmar incision that incorporates the thenar flexion crease (**TECH FIG 1A**).
 - Exposure will be needed beyond the area of malformation to fully expose all the vital neurovascular structures—away from the lesion.
 - Design the incision so that distal or proximal extension of the wounds will be possible.
- Raise skin flaps over the palmar fascia.
- Venous malformations tend to become much smaller when the limb is exsanguinated and the tourniquet is inflated.
- Incise the palmar fascia sharply and explore to find the nerves and vessels proximal to the lesion.
- Isolate the arteries and nerves with vessel loops (**TECH FIG 1B**). Dissect these structures off the venous malformation.
 - For lesions of the palm, it is easier to dissect the ulnar and radial aspects of the lesion first. This way, any vital longitudinal structures that traverse the lesion can be identified, protected, and dissected more easily.
- Use vessel loops not only for identification but also to place traction on vital structures so they can be dissected along their native paths.
- Venous malformations of the digits and distal palm will often arise from the venae comitantes of the digital arteries and thus run along the arteries. Isolate the venous malformation completely with the arteries that traverse it on either side (**TECH FIG 1C,D**).
- Avoid sacrificing arteries. Dissection of the venous malformation off the digital arteries is possible and should be attempted.
 - Perform the dissection with magnification using an operating microscope and micro instruments (**TECH FIG 1E**).
 - Use an ultrafine bipolar forceps (on a low setting) to cauterize all of the branches of the arteries that feed the venous malformation.

- Release the tourniquet and obtain hemostasis.
 - To avoid bleeding postoperatively, the best strategy is to remove all the venous malformation.
 - If subtotal excision is too difficult, the second best strategy is to prophylactically (ie, during the excision procedure) tie or clip the entire portion of the venous malformation that will be left behind.
 - The least favorable (though not always avoidable) strategy is to sharply remove some of the venous malformation and leave some behind with channels wide open. These will bleed a lot and are very hard to control with the tourniquet down. Bleeding should be controlled with a combination of prolonged direct pressure, tissue sealants, and local clotting enhancers.
- Use drains liberally. The author prefers the TLS drain system for digital and palmar lesions. The suction tube can be changed once it is one-third full or every 4 hours.
- A soft gauze dressing is applied followed by a well-padded cast. The cast is bivalved if there is any concern about postoperative bleeding or swelling.





TECH FIG 1 • A. Incision markings. The proximal incision extends into the thenar flexion crease. This incision is made proximal to the lesion to identify the digital nerves and branches of the superficial palmar arch. A Y-type pattern at the distal extension in the web is versatile as this incision can be extended into the digits via midlateral or oblique incisions while keeping the flaps wide-based for optimal vascularity. **B.** The common digital nerve to the second web space

and its branches have been mobilized (*yellow loops*). Proximal incision extension was made to find the superficial palmar arch, which was absent in this patient. The venous malformation is decompressed under tourniquet control. **C.** The venous malformation has been completely mobilized—the green background sits underneath it. The ulnar digital artery to the index finger and the radial digital artery to the middle finger have been identified and looped. These vessels emerge from the malformation. The *blue loop* is around the common digital artery to the second web space. **D.** The common digital artery (*arrow*) can be seen emerging from (the deep arch) underneath the flexor tendon to the index finger and piercing the venous malformation. **E.** The venous malformation can be safely dissected away from the common and proper digital arteries using the operating microscope and microinstruments. The vessels are shown after the lesion has been removed.

PEARLS AND PITFALLS

Diagnosis

- A multidisciplinary approach is the best way to take care of these patients, especially in more complicated cases.

Nonoperative management

- Avoid sclerotherapy of palmar venous malformations.

Technique

- Keep meticulous hemostasis during the case. Once important structures become bloodstained, they can be much more difficult to identify and dissect.

Technique

- Use fine instruments, especially in children who have smaller vital structures in the hand than do adults.

POSTOPERATIVE CARE

- For VMs, the drain can be removed within 24 hours, once the threat of bleeding has faded. For LMs, the drain should be in until drainage has abated significantly. If the fluid collects in the wound, it can coalesce into firm scar and added bulk.
- Immobilize with a cast or a splint for 2 to 3 weeks.
- Discontinue immobilization and start hand therapy.

OUTCOMES

- Outcomes are variable and highly dependent on the initial degree of involvement. In patients with joint and or tendon/muscle contractures, surgery may result in limited improvement.
- For patients with painful VMs, removal usually results in significant improvement in symptoms.³

COMPLICATIONS

- The most common complications are bleeding and skin flap compromise.
 - Bleeding and hematoma can be avoided with meticulous hemostasis and liberal use of drains and hemostatic agents.
 - Skin flap compromise may be caused by inherent disease (vascular steal) or attributed to poor planning and execution. Ischemic flaps should be debrided and replaced with healthy flaps or skin grafts.
- Recurrence and persistent growth are common problems, especially in extensive lesions.
- Distal ischemia is a dreaded complication, especially after treatment of AVMs when the arterial feeders have to be divided.
 - In these cases, it is wise to have a backup plan to bypass with vein grafts if needed.

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Section XIV: Tumors

71 Lumps and Bumps of the Hand and Wrist

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Ganglion cysts
 - Ganglion cysts are the most common soft tissue tumor of the hand.
 - Though not a true cyst because the lack of an epithelial lining, ganglion cysts are mucin-filled lesions with collagen-lined walls, usually attached to an underlying joint capsule, tendon, or tendon sheath.¹
 - Ganglion cysts are a frequent cause of hand and wrist pain. Sixty to seventy percent of ganglion cysts appear in the dorsal wrist, whereas 18% to 20% of ganglions can be found in the volar wrist.¹
- Mucous cysts
 - Mucous cysts are primarily found in the dorsal distal interphalangeal (DIP) joint and have been referred to as mucous cysts of the finger, mucoid cysts, mucinous pseudocyst, myxomatous cutaneous cyst, synovial cyst, periarticular fibroma, periungual ganglion, epidermal cyst, nail cyst, dorsal cyst, digital myxoid cyst, and cutaneous myxoid cyst.²
 - The lesions may be associated with osteoarthritis of the joint (degenerative mucous cyst).
- Giant cell tumors
 - Giant cell tumors are benign, slow-growing tumors of the tendon sheath, and have also been referred to as fibrous xanthoma, pigmented villonodular tenosynovitis, or localized nodular synovitis.
 - After ganglion cysts, giant cell tumors are the second most common tumor of

the hand.

ANATOMY

■ Ganglion cysts

- Ganglion cysts consist of a solitary or multilobulated cyst sac filled with a clear jellylike mucinous fluid. They are composed of hyaluronic acid, glucosamine, albumin, and globulin.¹
- The lesion originates from an underlying joint or tendon sheath and maintains communication to the cyst sac via a tortuous stalk (**FIG 1**).
- Dorsal ganglion cysts typically originate at the scapholunate ligament, whereas volar ganglion cysts often originate from the radiocarpal or scaphotrapeziotrapezoidal joint, flexor carpi radialis tendon, or A1 pulley.³
- Volar wrist ganglions may be intertwined with branches of the radial artery, complicating surgical dissection.

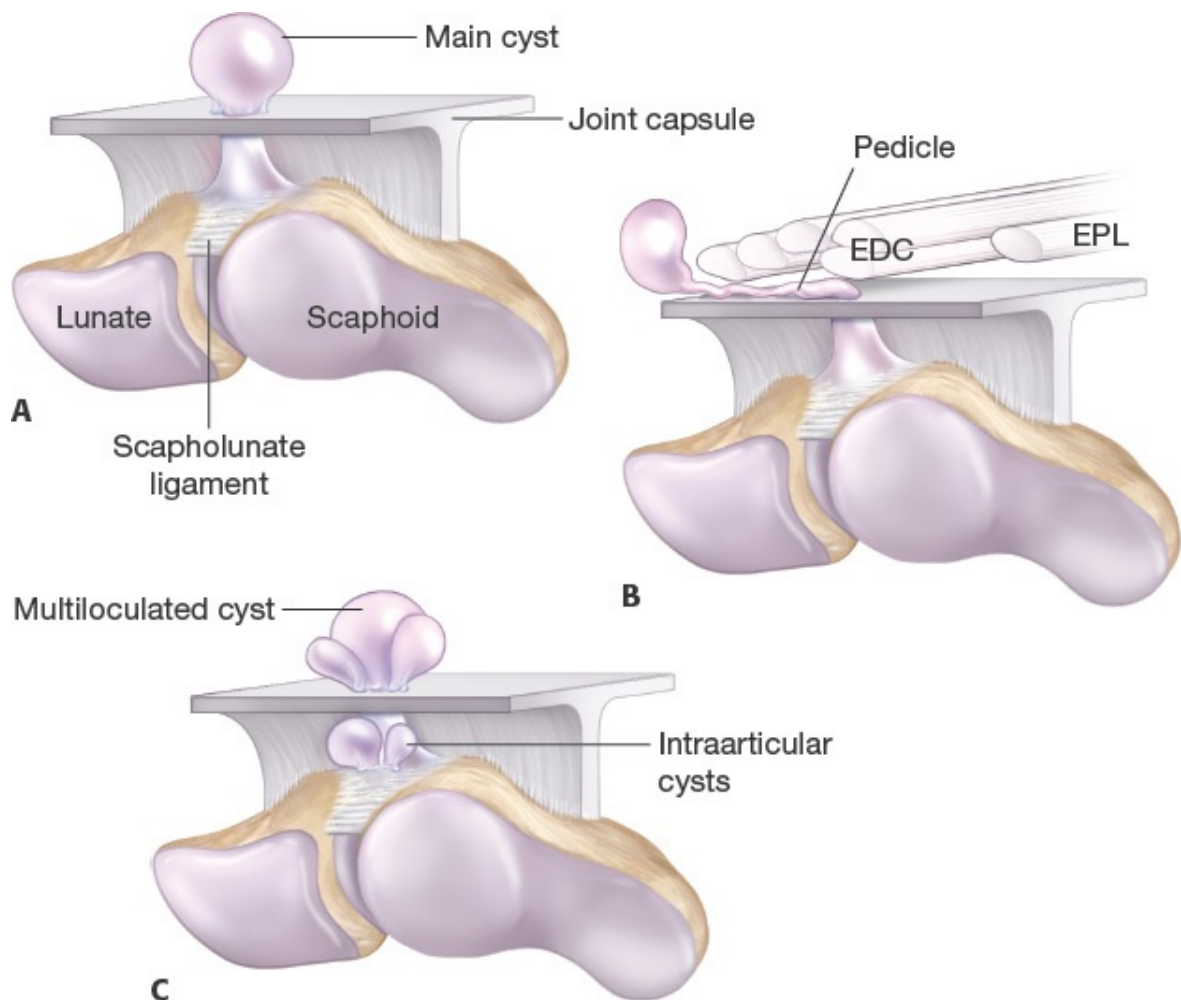


FIG 1 • A. Communication of a dorsal ganglion through the joint capsule to the underlying scapholunate ligament. **B.** In cases where the ganglion cyst is not directly overlying the scapholunate ligament, it is still connected via a long pedicle. **C.** A multicystic ganglion with intra-articular cysts.

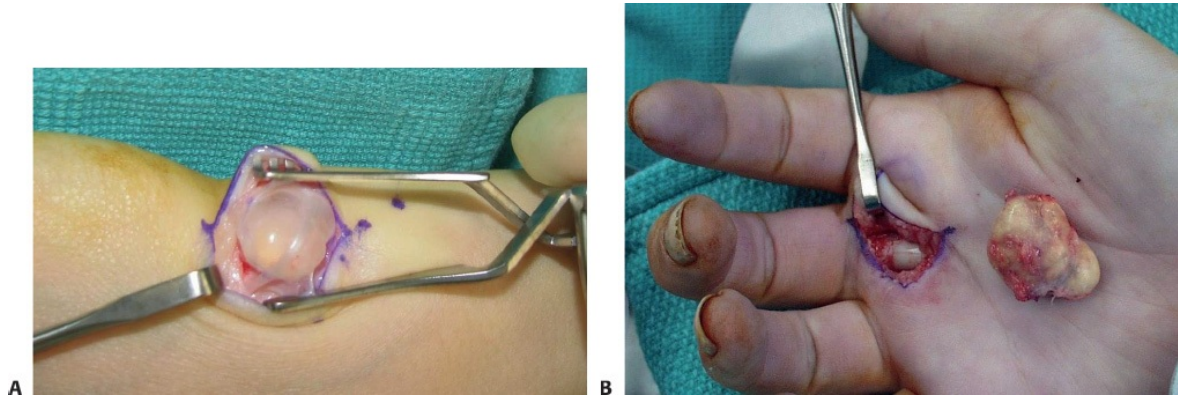


FIG 2 • A. Volar ganglion cyst in situ. **B.** Giant cell tumor of the tendon sheath removed from the volar surface of the long finger.

- Grossly, the lesions are smooth, well circumscribed, white, and translucent (**FIG 2A**).
- Microscopically, the cysts have dense fibrous connective tissue without any true cellular lining. The outer surface is irregular and fibrillated, composed of disorganized collagen fibers.⁴
- Mucous cysts
 - Mucous cysts typically originate at the DIP joint with its stalk passing between the extensor insertion and the collateral ligament.
 - The microscopic appearance is similar to ganglion cysts.
- Giant cell tumors
 - Giant cell tumors are yellow- to brown-colored rubbery lesions that may present with joint involvement or bone erosion (**FIG 2B**).
 - The tumors are typically found on the volar surfaces of the radial three digits of the hand, though dorsal involvement is also common.⁵
 - A type I tumor is a single round or multilobulated tumor entirely surrounded

by one pseudocapsule. Type II tumors consist of two or more distinct tumors not joined or surrounded by a pseudocapsule.⁶

- Histologically, giant cell tumors contain multinucleated giant cells, histiocytes, and hemosiderin deposits.

PATHOGENESIS

- There are multiple theories for the cause of ganglions and mucous cysts. It had been thought that synovial herniation resulted in mucoid degeneration. However, the lack of a cellular lining argues against this theory.
- Another theory is that a stress-induced stretching of capsular and ligamentous joint structures stimulates increased mucin production. The mucin collects in the form of capsular ducts and lakes that eventually coalesce into a main cyst.⁷
- The pathogenesis of giant cell tumors is not completely understood. The most widely accepted hypothesis is that of an inflammatory process leading to a reactive or regenerative hyperplasia.⁸

NATURAL HISTORY

- Ganglion cysts
 - Ganglion cysts typically arise spontaneously and are most frequently found in women between the second and fourth decades of life.
 - Though a history of trauma is rare, local injury may make the patient aware of the presence of the tumor.
 - The size of ganglion cysts may fluctuate with use of the extremity, enlarging with increased activity and shrinking with rest.
 - Ganglion cysts may rupture or disappear without treatment. However, there is no known marker to reliably predict which cysts will resolve spontaneously and which will persist.
 - Spontaneous resolution is more commonly seen in the pediatric population.⁹
- Mucous cysts
 - Mucous cysts primarily occur between the fifth and seventh decades in the DIP joint of the index and long fingers.
 - The lesions are typically associated with osteoarthritis of the joint.
 - An open or draining cyst can become infected leading to septic arthritis of the underlying DIP joint.¹
- Giant cell tumors
 - A giant cell tumor begins as a single nodule but may become multinodular as it enlarges over time.

- Malignant transformation has not been reported.¹⁰

PATIENT HISTORY AND PHYSICAL FINDINGS

- Ganglion cysts
 - Patients often present with an asymptomatic 1- to 2-cm well-circumscribed, slightly mobile, fluid-filled mass.
 - Patients typically report that the mass has been present for months to years with fluctuations in size.
 - Dorsal wrist ganglions most often present with the mass overlying the dorsal scapholunate interval (**FIG 3A**).
 - Volar wrist ganglions commonly appear with a mass between the extensor tendons and the flexor carpi radialis (**FIG 3B**).
 - Volar retinacular cysts involve the tendon sheath overlying the A1 or A2 pulleys and may appear fluctuant or firm with palpation. Though typically asymptomatic, patients may complain of discomfort with forceful grip. Although on examination these lesions may be slightly mobile, they do not typically glide with tendon movement.
 - Patients often seek medical attention for ganglion cysts due to aesthetic concerns.
 - Pain or sensory symptoms secondary to ulnar or median nerve compression can occur. The pain is typically a dull ache and is most pronounced with active hand use.
 - Weakness of grip may be a complaint, particularly with dorsal wrist ganglions.

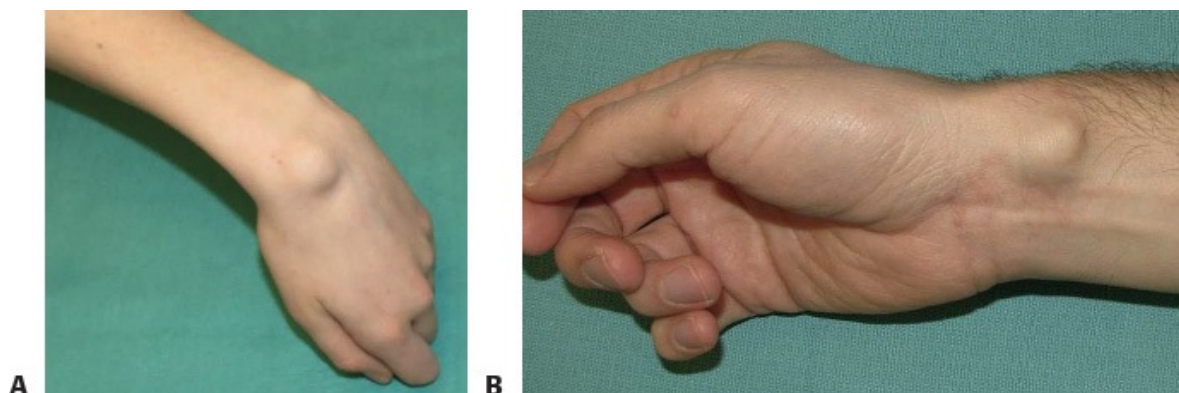


FIG 3 • **A.** Clinical appearance of dorsal ganglion cyst.
B. Clinical appearance of volar ganglion cyst.

- The fluid within ganglion cysts will transilluminate light, whereas other solid lesions will not.
- Frequently, there is no history of antecedent trauma. However, if there is a dorsal ganglion in the presence of trauma, the exam should include a complete evaluation of carpal stability.
- Mucous cysts
 - Mucous cysts are commonly found over the DIP joint of the long or ring finger as a painless mass lateral to midline on either the dorsal radial or ulnar side of the joint with extension into the eponychial fold.
 - Mucous cysts may make the overlying dermis thin, causing rupture of the skin and drainage.
 - Longitudinal nail grooving or Heberden nodes with DIP joint osteoarthritis can be present in mucous cysts.
- Giant cell tumor
 - Giant cell tumors present as a painless, firm, nodular, nontender, slow-growing subcutaneous nodule.
 - Patients may present with sensory deficits secondary to nerve compression.
 - It typically presents in females in the fourth to sixth decade and is often found on the volar surfaces of the hand, though dorsal involvement is not infrequent. Most often, it is found in the radial three digits and the DIP joint.
 - The lesion is firmer than a ganglion cyst and will not transilluminate light.

IMAGING

- Radiographs are required if the patient complains of pain or there is a history of trauma.
- Plain films are useful in identifying intraosseous ganglion cysts.
- An arthrogram can demonstrate communication between the cyst and the joint space.
- MRI is used to identify an occult ganglion cyst or to localize the site of origin for preoperative planning.
- Mucous cysts often have radiographic osteoarthritic changes in the joint with Heberden nodes
- On plain radiographs, giant cell tumors may demonstrate erosion of bone secondary to mass effect. Although bony erosion may indicate a higher risk of recurrence, bony indentation does not.⁶
- Ultrasonography can aid in detecting giant cell tumor satellite lesions.¹¹

DIFFERENTIAL DIAGNOSIS

- Ganglion and mucous cysts
 - Lipoma
 - Synovial cyst
 - Epidermal inclusion cyst or sebaceous cyst
 - Giant cell tumor of tendon sheath
- Giant cell tumor
 - Tendon sheath fibroma
 - Synovial hemangioma
 - Tophaceous gout
 - Periosteal chondroma

NONOPERATIVE MANAGEMENT

- Ganglion cysts can be treated nonsurgically with rest, splinting, oral analgesics, or aspiration. The injection of lidocaine, hyaluronidase, or steroids can also be employed during aspiration.
- Aspiration treatments yield recurrence rates as high as 59%.¹²
- Volar retinacular cysts that are not associated with a stenosing tenosynovitis have a better response to aspiration/injection, and surgical excision can often be avoided.
- Traumatic rupture with a book (ie, Bible) is only of historical significance.
- Aspiration of nondraining mucous cysts may be performed, but repeat aspiration is not advised to avoid joint infection.
- There is no role for nonoperative management for giant cell tumors.

SURGICAL MANAGEMENT

- For ganglion and mucous cysts, excision is indicated for symptomatic patients and for those who have failed conservative measures.
- Draining mucous cysts should be excised because of the risk of infection, which can ultimately lead to septic arthritis.
- Surgery is indicated for giant cell tumors for appearance, loss of function, or neuropathy.
 - A marginal excision with identification and excision of satellite lesions is necessary.

Preoperative Planning

- Appropriate preoperative imaging should be performed to identify the extent of the lesion, presence of any satellite lesions, or involvement of any vital structures.
- In cases of volar wrist ganglions, an intact palmar arch must be confirmed with a preoperative Allen test.
- Patients with giant cell tumors must be informed of the high recurrence rates.

Positioning

- The patient is positioned supine on the operating table, and the extremity is positioned on a hand table.
- The extremity is prepped and draped circumferentially.
- The appropriate anesthesia is administered (general, regional block, digital block) and an appropriate tourniquet is applied (upper arm or digit).
- The location of the lesion dictates the technique and the approach chosen.

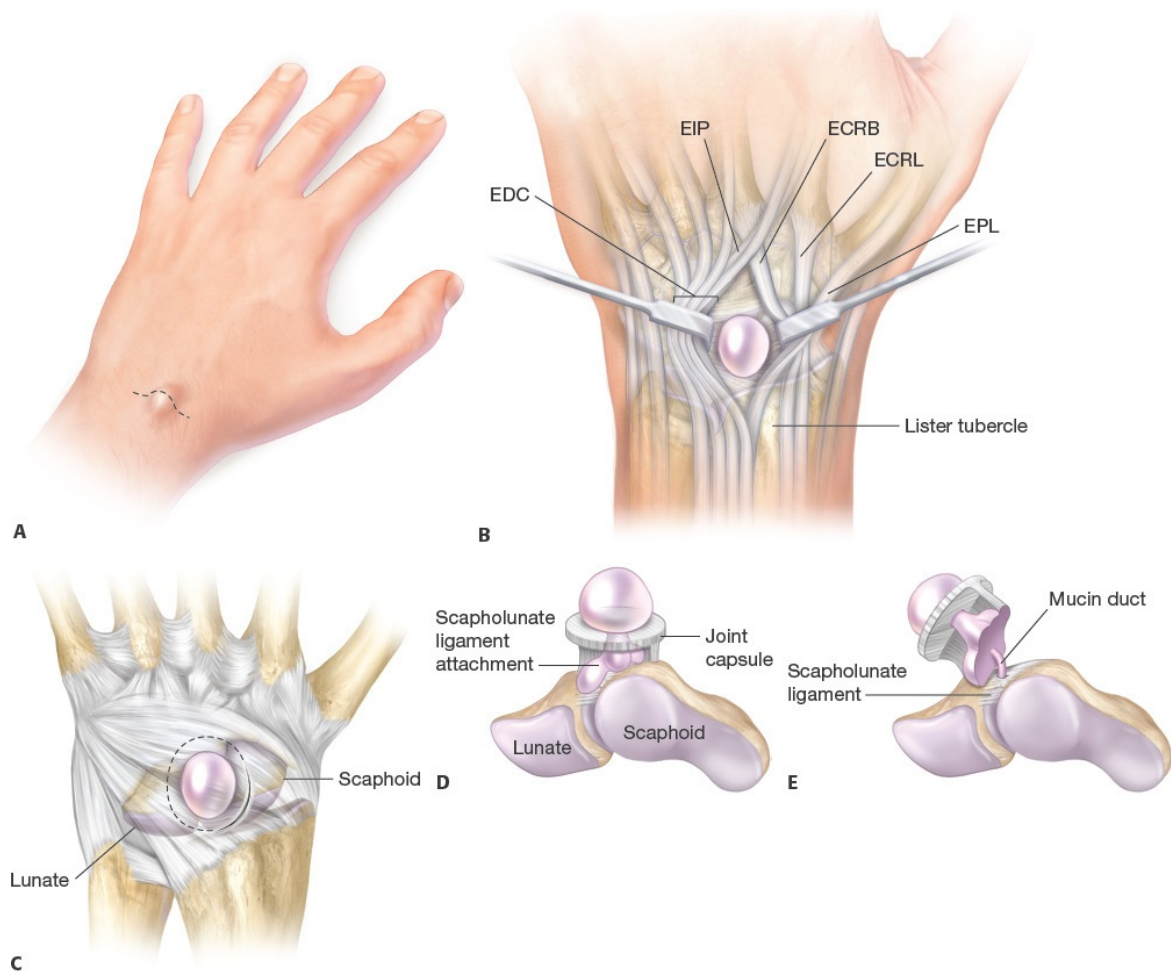
TECHNIQUES

■ Dorsal Wrist Ganglion

- Exsanguinate the extremity and apply an upper arm tourniquet.
- Make a 2-cm transverse incision centered over the dome of the ganglion (**TECH FIG 1A**).
- Dissect the subcutaneous tissues, taking care to identify and protect the dorsal radial and ulnar sensory nerve branches.
- Identify the extensor pollicis longus (EPL) and extensor digitorum communis (EDC) tendons and retract them. Use a self-retaining retractor for exposure. The ganglion is typically in the interval between the third and fourth extensor compartments (**TECH FIG 1B**).
- Free the cyst circumferentially using blunt dissection. If possible, avoid rupturing the capsule, so that it is easier to trace the ganglion to the stalk, which is attached to the dorsal retinaculum (**TECH FIG 1C,D**).
- Identify the stalk connecting the main cyst to the joint. It usually can be found on the dorsal aspect of the scapholunate interosseous membrane just proximal to the dorsal scapholunate ligament.
- Tangentially excise the ganglion with the capsular attachments, without

disrupting the scapholunate ligament. A mucin-filled duct piercing the fibers of the scapholunate ligament connecting the joint with the cyst can be identified (**TECH FIG 1E**). One should not cut into the scapholunate ligament.

- If the ganglion is large, it should first be decompressed. With a no. 15 blade, excise the base of the stalk with a rim of the dorsal wrist capsule.
- To minimize recurrence, cauterize the site of origin of the cyst and the edge of the wrist capsule with bipolar cautery.
- Release the tourniquet, confirm hemostasis, and close the wound in multiple layers. The skin is closed with a nonabsorbable monofilament suture.
- Capsular closure should be avoided to prevent joint stiffness. Place the wrist in slight flexion postoperatively.
- Place the hand in a bulky dressing with a neutral palmar splint. Remove the dressing and sutures in 7 to 10 days.



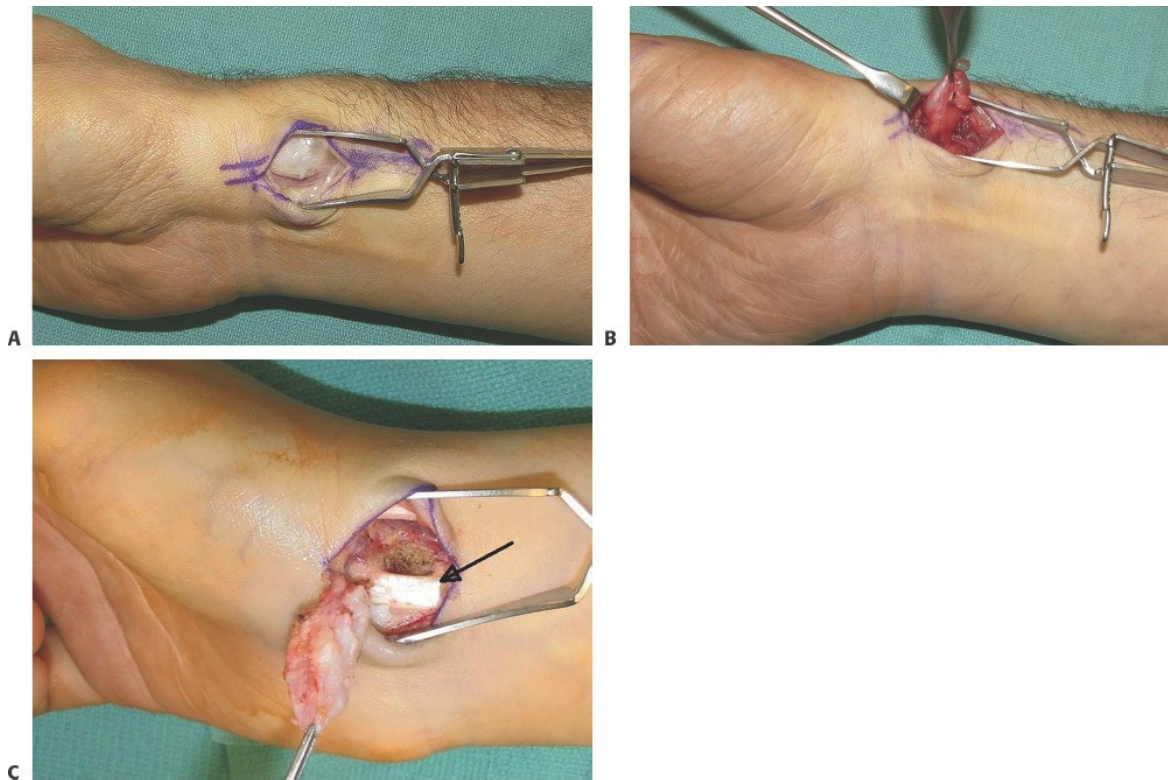
TECH FIG 1 • A. Typical transverse incision made over the scapholunate ligament. **B.** The dorsal ganglion cyst is most frequently found between the extensor pollicis longus (EPL) and extensor digitorum communis (EDC) tendons. **C.** The incision into the capsule begins on the radial surface of the cyst and continues circumferentially. **D.** A circumferential rim of capsule is taken with the cyst and continued in the volar direction. **E.** The typical relation of the mucin duct with the scapholunate ligament. It is important to include this in the resection to minimize future recurrence.

■ Volar Wrist Ganglion

- Perform a preoperative Allen test to evaluate for radial dominant circulation.
- Make an incision centered over the cyst. This incision is most commonly in the interval between the first extensor compartment and the flexor carpi radialis (FCR) tendon (**TECH FIG 2A**).
- Create skin flaps and place a self-retaining retractor for exposure. Incise the underlying forearm fascia longitudinally.
- While taking care to protect the branches of the lateral antebrachial cutaneous nerve and the radial artery, identify the capsule and trace the pedicle to the volar joint capsule (often the radiocarpal or the scaphotrapezial ligament) (**TECH FIG 2B**).
- If extension into the carpal canal is necessary, avoid injury to the palmar cutaneous branch of the median nerve by not straying ulnar to the FCR tendon.
- In a fashion similar to the dorsal wrist ganglion, open the joint and excise all the capsular attachments along with the cyst (**TECH FIG 2C**).
- If the cyst is adherent to the radial artery, a small cuff may be left behind to avoid arterial injury. It is particularly important to avoid dissecting the ganglion away from the radial artery because a shared wall may be indistinct and injuring the radial artery is likely. Therefore, one should decompress the

ganglion and leave the cyst wall attached to the artery. Then trace the ganglion to the wrist joint for resection and cauterization of the stalk.

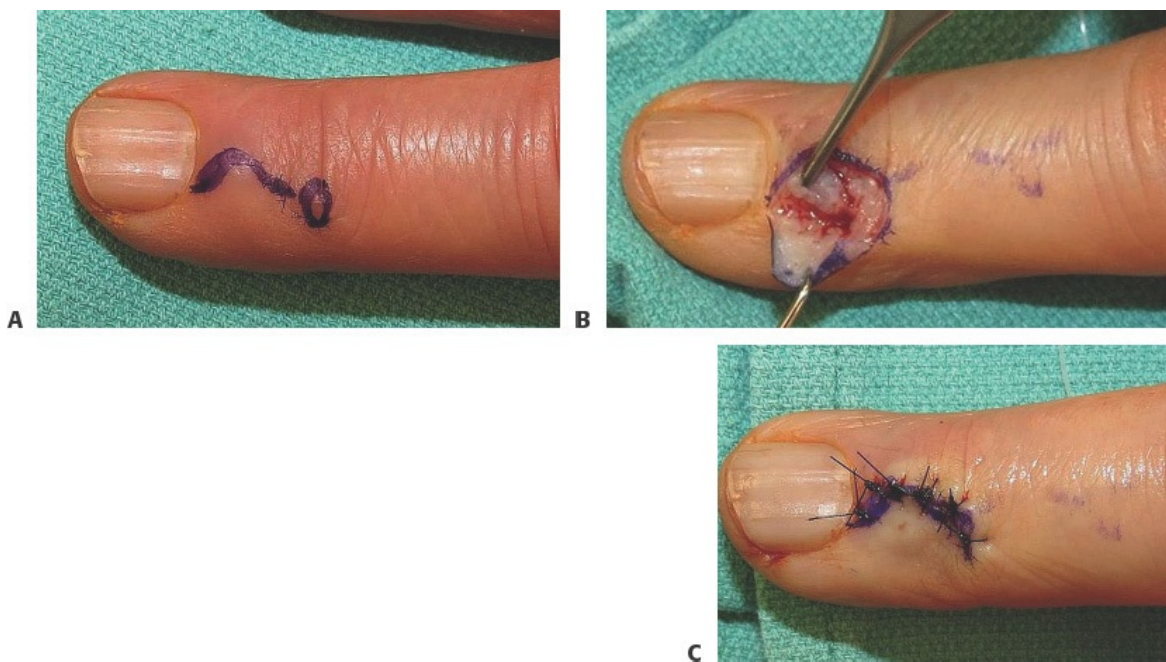
- After excision of the cyst, digitally compress the surrounding tissue to rule out additional mucin-filled pockets requiring excision.
- Release the tourniquet, obtain hemostasis, and close the wound with a nonabsorbable monofilament suture. Avoid capsular closure.
- Place a bulky dressing. Remove sutures approximately 7 to 10 days after surgery.



TECH FIG 2 • A. A longitudinal incision spanning from the proximal portion of the cyst to its distal extent. If additional distal exposure is necessary, the incision may be carried out into the carpal tunnel. **B.** Identification of the cyst pedicle toward the volar joint capsule. **C.** Excision of ganglion with all the capsular attachments. (Arrow indicates the FCR tendon.)

■ Mucous Cyst

- Apply a finger tourniquet after obtaining digital block anesthesia.
- If the overlying skin is of good quality, make a gentle curving transverse incision centered over the DIP joint.
- If there is involved overlying skin, make a longitudinal elliptical incision including the overlying skin to be excised (**TECH FIG 3A**).
- Mobilize the cyst and trace it to the joint capsule, excising it with the capsule and any involved skin (**TECH FIG 3B**).
- Often, it will be necessary to excise all the soft tissue between the collateral ligament and the extensor tendon, leaving the DIP joint exposed.
- It is imperative to avoid injury to the germinal nail matrix, the insertion of the extensor tendon, and the collateral ligament.

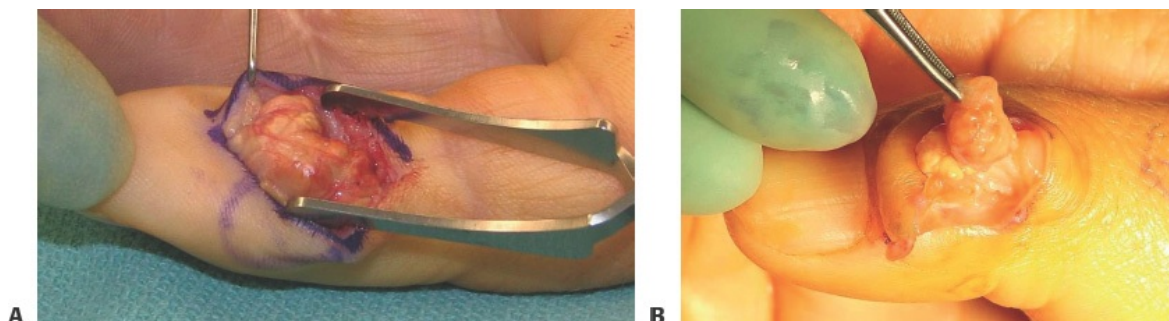


TECH FIG 3 • **A.** An elliptical incision is used to include the overlying skin when it is involved with the mucous cyst. **B.** The cyst is identified and traced down to the joint capsule. **C.** Closure of defect with nonabsorbable monofilament suture. Sutures are typically removed 7 to 10 days after surgery.

- With the extensor tendon retracted dorsally, explore the opposite side and excise any occult cysts or thickened synovial tissue.
 - Excise osteophytes and hypertrophic synovial tissue with a rongeur to minimize recurrence.
 - Release tourniquet and achieve hemostasis.
 - Close the defect primarily with nonabsorbable monofilament suture (**TECH FIG 3C**).
 - If the skin defect is excessive, a long rotational flap or full-thickness skin graft may be necessary. No excess tension should be placed on the closure.
 - Place the distal joint in a splint, and remove sutures in 7 to 10 days.
-

■ Giant Cell Tumor

- Perform initial exposure using an appropriate incision based on the anatomic location of the mass, and isolate the neurovascular bundle proximal and distal to the mass.
 - After identifying the pseudocapsule, use a Freer elevator to bluntly dissect the surrounding tissue from the lesion (**TECH FIG 4A**).
 - Excise the tumor in total with a margin of normal tissue. If necessary, a portion of the tendon sheath may be excised and the area cauterized with bipolar electrocautery.¹
 - Meticulously examine the local area and excise any satellite lesions to minimize recurrence (**TECH FIG 4B**).
 - If there is joint involvement, perform a capsulotomy and inspect the joint, debriding any pigmented soft tissue. If there is bony erosion, local curettage is necessary. If joint involvement is extensive, arthrodesis may be necessary to ensure complete excision.
 - If the extensor tendon is involved, a portion may need to be excised. In rare cases, a tendon reconstruction can be performed if necessary.
 - Close primarily and place hand in a bulky dressing.
-



TECH FIG 4 • A. The giant cell tumor is dissected with a margin of normal tissue after identifying the neurovascular bundle proximal and distal to the mass. **B.** The local area must be closely inspected to identify and excise any satellite lesions. Failure to do so will inevitably lead to a high likelihood of recurrence.

PEARLS AND PITFALLS

Ganglion cyst

- Adequate excision requires removal of a small cuff of the joint capsule.
- Do not cut into the scapholunate ligament to avoid inadvertent injury.
- Cauterize the edge of the capsule before releasing the tourniquet. It will be very difficult to adequately cauterize it subsequently.
- Do not repair the capsule to avoid joint stiffness.
- Always identify the deep and superficial branches of the radial artery when excising volar wrist ganglion cysts. It may be adherent to the artery.

Mucous cyst

- Adequate excision requires debridement of joint osteophytes and any occult cysts.
- Great care must be taken to avoid nail bed injury even if a small amount of cyst must be left behind.
- Avoid injury to extensor tendon or collateral ligament to prevent postoperative extensor lag or DIP joint instability.
- Evaluate both sides of the extensor tendon and the entire DIP joint to rule out occult cysts.
- Do not close skin flaps under excess tension.

Giant cell tumors

- Satellite lesions must be identified and excised to lower the likelihood of recurrence.
- Perform capsulotomy if there is joint involvement to adequately resect

all involved tissue.

- Take care to identify and protect the neurovascular bundles because the lesion can displace or envelop the neurovascular structures

POSTOPERATIVE CARE

- For ganglion and mucous cyst excisions, the hand is placed in a neutral wrist splint. Early hand elevation and early finger motion are encouraged. The splint and sutures are removed at 7 to 10 days postoperatively, and range-of-motion exercises begin at this time.
- After excision of a giant cell tumor, range-of-motion exercises should be started immediately. Sutures can be removed after 7 to 10 days.

OUTCOMES

- Ganglion cysts: The recurrence rates following open surgical excision is 21%.¹²
- Mucous cysts: Recurrence rates are as low as 2% with complete osteophyte excision at the time of surgery.²
- Giant cell tumors: Recurrence rates range from 5% to 50%.¹
 - Factors predictive of high recurrence include incomplete excision, bony invasion, type II tumors, cellularity and mitotic activity on histology, and absence of nm23 gene expression on immunohistochemistry.^{6,10}

COMPLICATIONS

- Ganglion cysts: The most common complications include wound complications (painful or hypertrophic scar, infection, neurapraxia) or early recurrence.
 - Recurrence is secondary to incomplete excision or a missed occult cyst.
 - Pain may persist postoperatively despite complete resection.
 - Stiffness can occur as a result of capsular closure or delayed postoperative movement.
- Mucous cysts: Excisions can result in extensor lag, joint stiffness, DIP joint deformity, nail plate deformity, pain, or infection.
- Giant cell tumors: In addition to recurrence, postoperative complications may include transient numbness or infection.

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CHAPTER Excision of Glomus Tumors

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Glomus tumors are benign hamartomas of the glomus body typically found in the reticular layer of the dermis in the distal phalanx or the subungual region.
- Glomus tumors account for 1% to 5% of all hand tumors.¹

ANATOMY

- The glomus body normally regulates blood flow in the reticular dermis in response to local temperature changes, functioning as an arteriovenous shunt.
- Glomus bodies are found throughout the body but are most numerous in the fingertips and the nail bed.
- Subungual involvement is found in 25% to 65% of cases, typically seen as discoloration or deformation of the nail plate.²
- Histologically, glomus cells, smooth muscles, blood vessels, and nonmyelinated nerve fibers are found within the glomus tumor. There are three distinct histologic types that can occur with the possibility of having multiple histologic tumors simultaneously.³
 - Type I: mucoid hyaline type
 - Type II: solid type (classic glomus tumor)
 - Type III: angiomatous type
- The solitary glomus tumor is a well-encapsulated lesion with numerous small lumina, most commonly found in the subungual region.
 - Multiple tumors, on the other hand, are not encapsulated and rarely subungual.

PATHOGENESIS AND NATURAL HISTORY

- Glomus tumors occur as a result of hyperplasia of the neuromyoarterial glomus body.³
- They can be solitary or multiple. Solitary tumors often present with chronic extremity pain, frequently leading to initial misdiagnosis and inappropriate treatment.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- Glomus tumors typically present in women 30 to 50 years old.
- Solitary glomus tumors have been associated with a classic triad of paroxysmal pain, pinpoint tenderness, and cold intolerance. The lesions can present with nail plate ridges, a pulp nodule, and/or bluish discoloration of the nail bed.⁴
- Often patients present with years of pain before definitive diagnosis. The tumor is often misdiagnosed because of its rarity, lack of the triad symptoms in the early course of the tumor, and several differential diagnoses.^{1,5}
- Multiple glomus tumors tend to present earlier in life than solitary glomus tumors, and are usually asymptomatic.
- Diagnostic tests include the following:
 - Love's pin test—severe pain reproduced with direct pressure
 - Hildreth's test—relief of pain with tourniquet application followed by subsequent return of pain with tourniquet release
 - Cold sensitivity test—immersion in an ice bath or application of a refrigerant spray elicits pain.

IMAGING

- If there is doubt about the diagnosis or the specific location of the tumor, MRI is helpful in identifying glomus tumors as small as 2 mm in the fingertip.
 - There will be high signal intensity on T2 images with strong enhancement following gadolinium infusion on T1 images.
 - The appearance of a high signal central dot surrounded by a zone of less signal intensity is characteristic^{3,5,6} (**FIG 1**).
- In long-standing glomus tumors, a plain x-ray may show pressure atrophy of the distal phalanx.¹
- Doppler ultrasonography can identify low signals within a hypoechogenic mass as small as 2 mm.⁶

DIFFERENTIAL DIAGNOSIS

- Leiomyoma
- Eccrine spiradenoma
- Cavernous hemangioma
- Sarcoma
- Neuroma
- Chronic paronychia
- Calcinosis
- Ganglion/mucous cyst
- Epithelial inclusion cyst

NONOPERATIVE MANAGEMENT

- Although excision is the only known cure for glomus tumors, nonsurgical treatment with prostaglandin inhibition, sclerotherapy, laser, or radiation have been described with mixed results.^{5,6}

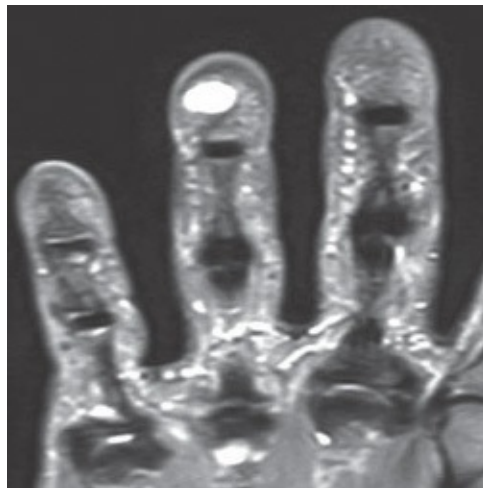


FIG 1 • MRI of glomus tumor of the ring finger. Note the high signal intensity of the tumor.

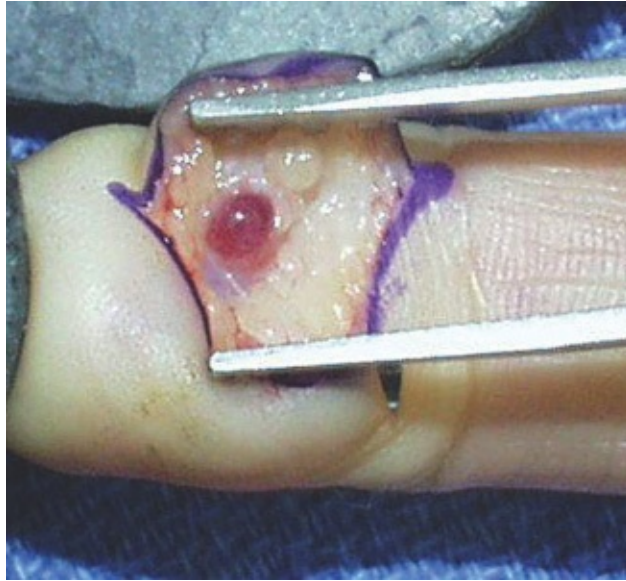


FIG 3 • A. The tumor is palpated and marked for excision. This corresponds to the area of most tenderness on examination. **B.** The volar digital glomus tumor was resected through a zigzag incision.

SURGICAL MANAGEMENT

- A bloodless field is necessary during excision to delineate the tumor from surrounding tissues. Poor visualization increases the likelihood of inadequate resection and future recurrence (**FIG 2**).
- Subungual tumors require elevation of the nail plate and excision of the mass from the nail bed, followed by nail bed repair.
- If no gross tumor is found at exploration, remove a wedge of tissue from the area of maximum patient discomfort.⁵
- If the tumors have invaded the underlying bone, perform a partial bone excision or curettage.¹

Preoperative Planning

- Preoperative imaging, if necessary, should be performed to identify the extent of the lesion and the involvement of any local vital structures.

Positioning

- The patient is positioned supine on the operating table, and the extremity is placed on a hand table.

- The extremity is prepped and draped circumferentially.
- The appropriate anesthesia is administered (general, regional block, digital block), and a tourniquet is applied (upper arm or digit). Typically, a digital nerve block is sufficient.



FIG 2 • A clean bloodless field permits easy visualization of the glomus tumor and the surrounding normal tissue.

Approach

- The location of the lesion dictates the approach. Subungual tumors are excised through either a transungual or a midaxial incision.
- Although the transungual approach provides the best visualization, it can lead to nail bed injury and postoperative nail deformity leading to an unsatisfactory cosmetic result. Careful excision and precise placement of sutures to repair the nail bed are essential.
- The midaxial incision does not risk injury to the nail bed, but a flap needs to be developed under the periosteum, making the approach more challenging. Also, there is a risk of digital nerve injury.
- Mark the specific location of the tumor based on palpation or the area of most tenderness (**FIG 3A**).
- Volar digital tumors are resected with a zigzag incision (**FIG 3B**).

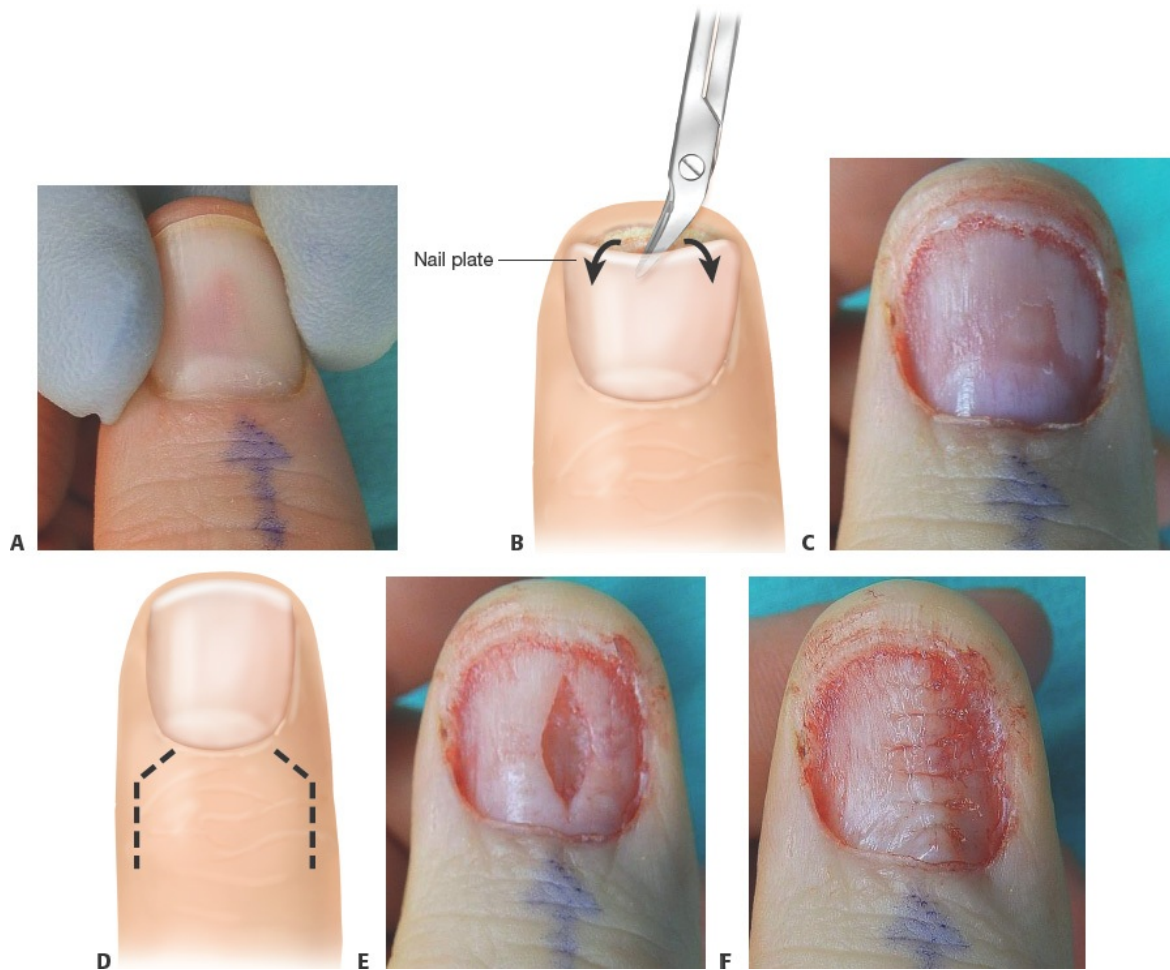
TECHNIQUES

■ Transungual Approach

- Identify the area of most tenderness or discomfort. This is particularly important in lesions that are not grossly evident on examination (**TECH FIG 1A**).
- Inject digital anesthesia and apply a tourniquet. Limit exsanguination to elevation of the extremity because the tumors lose color in a bloodless field, making it more difficult to distinguish tumor from normal surrounding

tissue.⁵

- Elevate the nail plate (**TECH FIG 1B**).
- Fold the nail over or remove it completely for adequate exposure if necessary (**TECH FIG 1C**).
- If additional exposure is necessary, make incisions over corners of the nail fold in an oblique angle to avoid contracture (**TECH FIG 1D**).
 - With a no. 15 blade, make a longitudinal incision into the nail matrix directly over the tumor. Dissect the tumor from the surrounding nail matrix.³
 - Free the lesion circumferentially to the level of the phalanx and excise it completely by leaving a defect in the nail bed (**TECH FIG 1E**).
- Curette the portion of the phalanx involved with the lesion.
- Close the nail bed defect with 6-0 plain gut suture meticulously by reapproximating the edges of the incision to minimize nail deformity (**TECH FIG 1F**).
- Replace the nail into the eponychial fold to act as a protective stent for the nail bed.
- Close the corner incisions primarily.
- Place a bulky dressing.



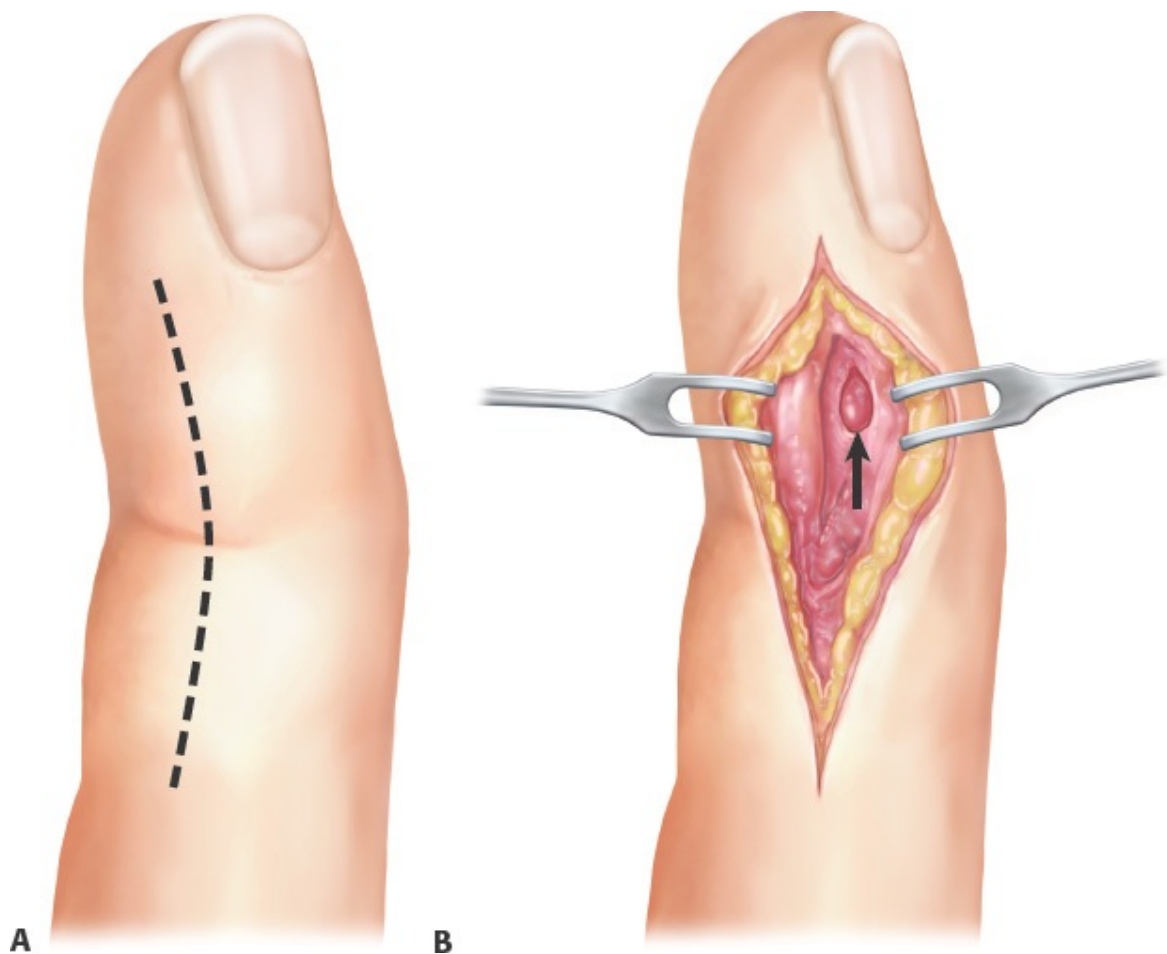
TECH FIG 1 • **A.** When the subungual glomus tumor cannot be palpated on examination, the area of most tenderness or discomfort is identified and marked. **B.** Elevation of the nail plate for exposure of a subungual glomus tumor. **C.** The nail is removed for exposure of the nail matrix. **D.** Incisions along the corners of the nail fold can provide additional proximal exposure if needed. **E.** The tumor is removed from a longitudinal incision in the nail matrix. **F.** Repair of the nail matrix is typically done with a 6-0 absorbable suture.

■ Lateral Approach

- This approach is more suitable for more proximal subungual lesions to avoid

violating the nail matrix.

- Make a longitudinal midaxial incision dorsal to the digital neurovascular bundle and volar to the lateral nail germinal matrix on the side of the digit closest to the lesion (**TECH FIG 2A**).
- Dissect sharply to the level of the distal phalanx.
- Create a composite dorsal subperiosteal flap with a sharp elevator. The flap consists of skin, nail, germinal tissue, and the nail plate as a unit⁷ (**TECH FIG 2B**).
- Identify the lesion and excise it or remove it with a curette. Inspect for any additional lesions to excise.
- Replace the flap and close the incision primarily with an interrupted permanent suture.
- Place a bulky dressing.



TECH FIG 2 • **A.** Incision for the lateral approach. **B.**

Exposure is obtained by raising a dorsal subperiosteal flap exposing the glomus tumor (*arrow*).

PEARLS AND PITFALLS

Approach	■ Transungual approach will give the widest view of the tumor. ■ The lateral approach has less incidence of nail deformity.
Outcomes	■ Early postoperative recurrence of symptoms is typically from an incomplete resection. ■ A delayed recurrence is likely the development of a new tumor.

POSTOPERATIVE CARE

- The patient remains in the bulky dressing for 1 to 2 weeks.
- Sutures are removed at 10 to 14 postoperative days.
- Early range of motion and return to normal activity is encouraged.

OUTCOMES

- Recurrence rates range from 15% to 24%.⁷
- Early recurrence is typically from an incomplete excision, whereas late recurrence is likely from the formation of a new tumor.

COMPLICATIONS

- A nail bed deformity is described in 3.3% to 10% of cases with transungual excision.⁷
- There is always a risk of digital nerve injury with the lateral subperiosteal approach.

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73 Excision of Hemangioma of the Hand

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Hemangiomas are the most common benign tumor of infancy, with approximately 15% found on the upper extremities.^{1,2}
- The lesion is a vascular tumor consisting of plump endothelial cells with a rapid turnover and a three-phase growth cycle³:
 - Rapid cell proliferation and growth
 - Slow growth and maturation
 - Involution

ANATOMY

- Histologically, there are two types of infantile hemangiomas.
 - The capillary type is nonvascular with a spongy appearance.
 - The cavernous type has plump endothelial cells and many mast cells lining large vessels with small lumina.^{1,2}
- During the proliferative phase, the lumina widen and the endothelium flattens. As the hemangioma enters the involution phase, there is increased mast cell infiltration and progressive fibrosis of the mass.¹
- Infantile hemangiomas will stain positive for GLUT-1 in all phases, differentiating them from other hemangiomas.²

PATHOGENESIS

- Hemangiomas occur as a result of endothelial cell proliferation.
- Congenital hemangiomas are caused by a failure of proper differentiation of vascular channels during embryonic development.
- Studies have shown that children with hemangiomas have increased estrogen

levels that resolve after treatment. That, along with a female predominance, suggests a hormonal association.^{1,3}

NATURAL HISTORY

- Although only 30% of hemangiomas are visible at birth, 70% to 90% are apparent by 4 weeks of age.
- The rapid cell proliferation phase outpaces the growth of the child, whereas the slow growth phase is more proportional to the child's growth.¹
- About 50% will involute by age 5 and 90% involute by age 9 years.²
- Thirty percent of hemangiomas ulcerate with superficial bleeding.³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Hemangiomas of the hand are found most commonly on the palm because it is the richest vascular area of the hand.⁴
- Superficial hemangiomas appear as a raised red papule, nodule, or plaque (**FIG 1A,B**). Deeper hemangiomas have a bluish hue (**FIG 1C**).
- An area of pallor with telangiectasias may be a precursor lesion identifiable at birth.²
- Children with a propensity to suck their fingers may present with ulcerations and paronychia.
- Other clinical findings may include pain, infection, bleeding, or congestive heart failure in very large lesions. Pain is most notable when the extremity is held in a dependent position secondary to venous engorgement.
- Platelet trapping within the hemangioma can lead to gross thrombocytopenia and consumptive coagulopathy, known as Kasabach-Merritt syndrome.
- Upper extremity growth and function is typically unaffected with hemangiomas.

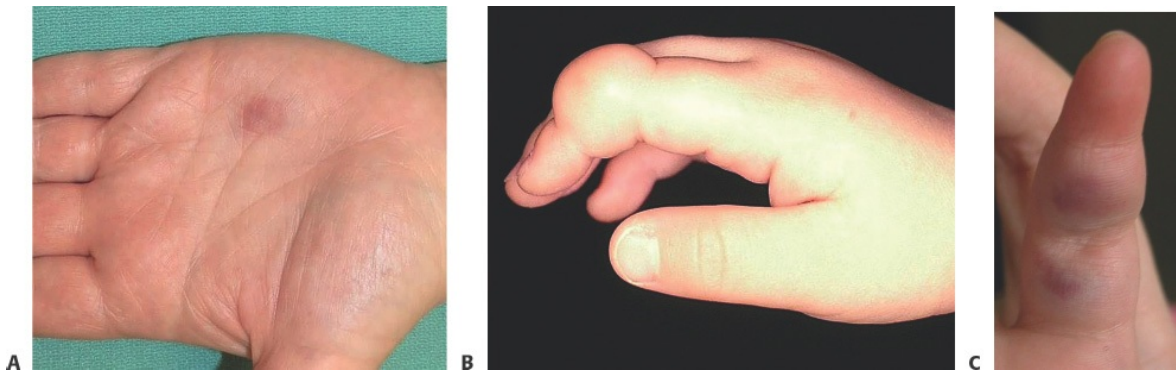


FIG 1 • A,B. Superficial hemangiomas typically appear as a raised red-colored papule. **C.** Deeper hemangiomas typically have a bluish hue.

IMAGING

- Plain radiographs rarely show small, smooth, round calcifications, termed phleboliths, but otherwise are of limited value.^{4,5}
- Hemangiomas appear as a well-circumscribed mass on MRI with gadolinium enhancement.
 - The T1 signal is low and the T2 signal is high with an appearance of heterogeneity due to the variable feeding and draining vessels.¹
- Ultrasound is also a valuable preoperative tool to determine the depth of the lesion.
- Angiograms will show a well-circumscribed lesion with a blush, as well as tributary feeding and draining vessels. It can be used for diagnosis and treatment if embolization is planned.

DIFFERENTIAL DIAGNOSIS

- Arteriovenous or lymphatic malformation
- Glomus tumor
- Angiosarcoma
- Hemangioendothelioma
- Pyogenic granuloma

NONOPERATIVE MANAGEMENT

- In the absence of systemic hematologic symptoms (thrombocytopenia), the initial treatment for hemangiomas is observation.
- Other modalities including steroids, propranolol, vincristine, laser ablation, and treatment with interferon alpha have been described.
- Propranolol is thought to increase apoptosis of endothelial cells and induce adipogenesis of hemangioma stem cells.²

SURGICAL MANAGEMENT

- Surgery is rarely indicated except for cases of mass effect, uncontrollable bleeding, or lesions refractory to conservative measures.
- Presence of a pseudocapsule during the proliferative phase simplifies excision

as compared to surgery during the maturation or involution phases when the margins are more difficult to define.³

Preoperative Planning

- Appropriate radiographic studies should be performed to identify the extent of the lesion and involvement of any vital structures.
- Complete knowledge of the vascular anatomy is crucial, including assessment of the superficial palmar arch with an Allen test.

Positioning

- The patient is positioned supine on the operating table, and the extremity is positioned on a hand table.
- The extremity is prepped and draped circumferentially.
- Anesthesia is administered and a tourniquet is applied.

Approach

- The location of the lesion dictates the approach to provide adequate visualization for excision.
- Digital lesions are best approached with mid-axial or zigzag incisions, taking care to avoid crossing the flexion creases.
- Similarly, palmar lesions are best excised with zigzag incisions by avoiding placement of the incision at 90-degree angles to flexion creases.

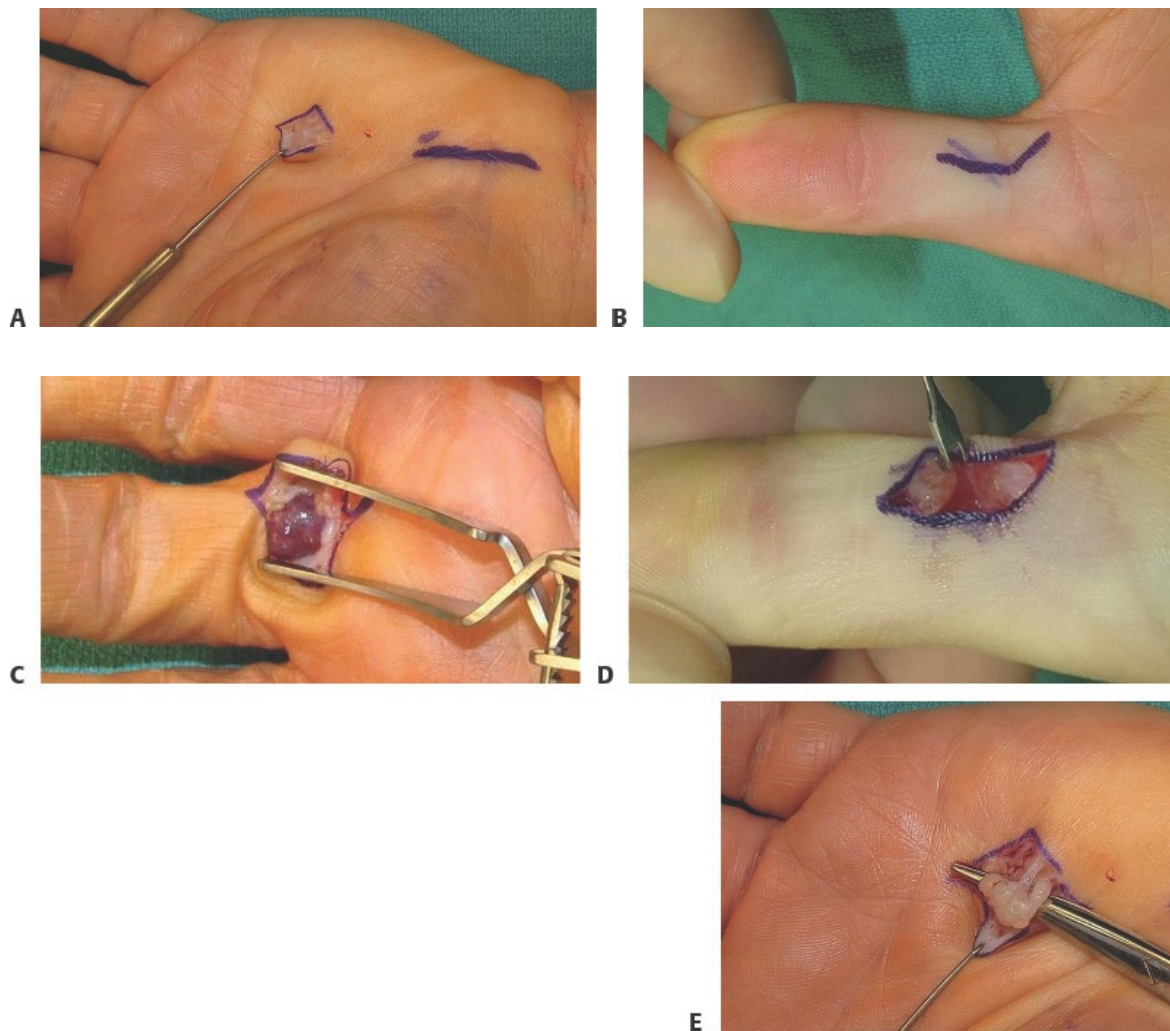
TECHNIQUES

■ Incision and Dissection

- Apply a tourniquet without exsanguinating the extremity so that the entire tumor mass can be better identified for excision.⁴
- Make an incision to provide adequate access for excision of the hemangioma (**TECH FIG 1A,B**).
 - If ulceration is present, use an elliptical incision to excise the affected skin.
 - Take care to incise only to the depth of the dermis, avoiding the subdermal layer with any potential dilated plexuses.
- Identify the dilated subdermal vessels and ligate with suture or, if small

enough, with electrocoagulation.

- Circumferentially dissect the tumor (**TECH FIG 1C,D**).
 - Between the surrounding fat will be septal structures with capillary networks that must be identified and coagulated with bipolar cautery.
 - Any reddish or purple fat particles within the tumor should not be disturbed to avoid significant bleeding.⁶
- Carefully dissect through the subcutaneous tissue to identify and ligate the proximal and distal tributary vessels (**TECH FIG 1E**).

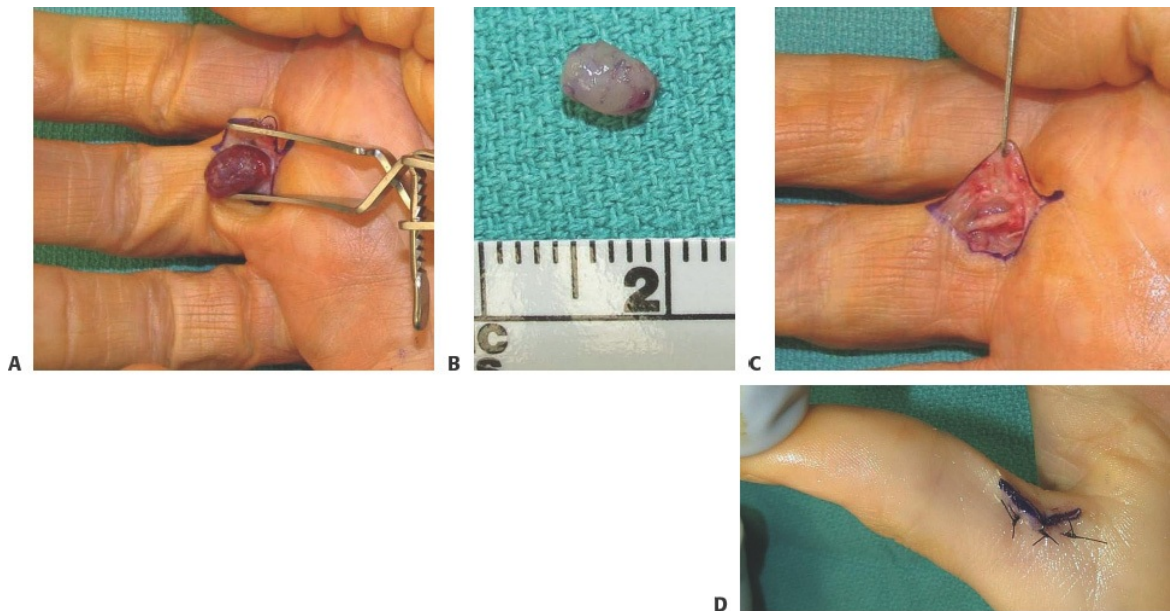


TECH FIG 1 • **A.** Hemangioma of the palm of the hand. Note the zigzag incision for exposure. **B.** Hemangioma of the volar thumb. The incision provides adequate exposure and does not cross the

flexion creases avoiding the risk of scar contracture. **C,D.** Identification and circumferential dissection of the tumor. Take care to avoid injury to the tributary vessels prior to ligation. **E.** The tributary vessels feeding and draining the hemangioma should be ligated as far from the tumor as possible.

■ Excision

- Identify all local neurovascular structures to confirm that the tumor is not wrapped around a nerve or vessel.
- Occasionally, the tumor may arise from vessels within striated muscle. Perform careful dissection and take a small cuff of muscle if necessary.⁴
- Excise the hemangioma and confirm that the resection is complete with margins (**TECH FIG 2A,B**).
- Inspect to confirm there is no injury to surrounding neurovascular structures (**TECH FIG 2C**).
- Release the tourniquet and obtain hemostasis.
- Perform primary closure if possible (**TECH FIG 2D**). If skin is excised due to dermal involvement and primary skin closure is not possible, the resultant defect may be closed with a skin graft or local flap.



TECH FIG 2 • A. Excision of the specimen. **B.** Resected specimen. Hemangiomas can vary in size from millimeters to multiple centimeters in size. **C.** Inspection reveals that the digital neurovascular bundle remains intact. **D.** Primary closure following excision of a thumb hemangioma.

PEARLS AND PITFALLS

Management ■ Most lesions can be managed with observation.

Operative ■ Surgical excision is easiest in the proliferative phase because of the presence of a pseudocapsule making it easier to identify tumor margins.
■ Apply the tourniquet without exsanguination.
■ Ligate the tributary vessels as far as possible from the lesion.
■ The lesion may be encasing a neurovascular structure. Meticulous dissection is crucial.

POSTOPERATIVE CARE

- A bulky dressing is applied for approximately 1 week and sutures are removed at 10 to 14 days after surgery.
- If a skin graft or flap is required, the appropriate dressing and wound care should be performed.

OUTCOMES

- Diffuse lesions have higher recurrence rates.
- Amputation may be necessary if there are multiple recurrences despite repeated excisions.
- Deep cavernous hemangiomas are the only type found to recur due to its intramuscular location, high vascularity, and proximity to neurovascular structures.⁵
- Most recurrences manifest by 2 years but can appear as long as 6 years after the primary excision.⁷

COMPLICATIONS

- Although rare, the most common complications are wound related (infection, dehiscence, contracture).
- Postoperative hematoma or bleed can best be avoided with meticulous hemostasis.

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74 Excision of Metacarpal Enchondroma

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Enchondromas are benign, intramedullary, cartilaginous lesions that are the most common primary bone tumors of the hand.

ANATOMY

- Enchondromas are typically white to blue-gray solitary lesions found in the diaphysis of tubular hand bones with varying degrees of calcification.
- The lesions are most often found in medullary cavities of the metacarpals and the phalanges.

PATHOGENESIS AND NATURAL HISTORY

- Enchondromas are thought to arise from displaced chondrocytes left behind in the metaphysis and diaphysis as the epiphysis moves through the process of enchondral growth.¹
- Typically, they are found incidentally, but they can occasionally present with pathologic fractures.
- Although incidental enchondromas can be observed, those presenting with a fracture or radiographically at risk for a fracture can be treated surgically with a low likelihood for recurrence.²
- Rarely, an enchondroma may transform to chondrosarcoma.
- Malignant transformation is more likely in patients with enchondromatosis. However, malignancy occurs more often in the long bones rather than in the hand.³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Enchondromas are typically asymptomatic and found incidentally.
- Bony deformities can be present with pathologic fractures.
- Patients may complain of painful swelling if bone distension is present.
- Multiple enchondromas are found in patients with Ollier disease (multiple enchondromatosis) and Maffucci syndrome (multiple enchondromatosis with multiple soft tissue hemangiomas).

IMAGING

- An appearance of a well-defined lobulated lytic lesion in the diaphysis or metadiaphysis on plains films is characteristic (**FIG 1**).
- There may be calcifications or endosteal scalloping.²
- Findings concerning for malignant degeneration include progressive cortical bone destruction, replacement of the mineralized portion by a nonmineralized component, bone proliferation, or a soft tissue mass.²



FIG 1 • Radiograph of fifth metacarpal enchondroma presenting with pathologic fracture (*arrow*).

DIFFERENTIAL DIAGNOSIS

- Chondrosarcoma
- Chondroblastoma
- Unicameral bone cyst
- Giant cell tumor of bone
- Chondromyxoid fibroma
- Fibrous dysplasia
- Bone infarct

NONOPERATIVE MANAGEMENT

- Incidental enchondromas can be observed if radiographic assessment suggests a benign, nonaggressive lesion.
- It is imperative to determine the risk of pathologic fracture, given the patient's activity level. Any concern for the possibility of pathologic fracture should prompt excision.
- The patient must be made aware of the rare but present risk of malignant degeneration with observation.
- Routine follow-up radiographs should be performed for at least a 2-year period to confirm stability of the lesion.²
- There should be a low threshold to re-evaluate a patient should symptoms develop.

SURGICAL MANAGEMENT

- Enchondromas that present with a pathologic fracture should be treated after a period of immobilization to allow fracture healing.
- If the fracture requires acute treatment with an open approach, immediate treatment of the enchondroma should be considered.⁴
- The first step in surgical management is an open biopsy with frozen section analysis to confirm the presence of cartilage tissue and rule out chondrosarcoma. If there is a concern for malignancy, the wound should be closed and further treatment deferred until permanent section analysis is performed.²
- The bony defect can be filled with bone autograft, bone allograft, a bone substitute such as calcium-based cement, or left unfilled with relatively comparable results.⁴⁻⁷

Preoperative Planning

- Radiographic imaging will reveal the location and extent of the lesion.

Positioning

- The patient is positioned supine on the operating table, and the extremity is positioned on a hand table.
- The extremity is prepped and draped circumferentially.
- The appropriate anesthesia is administered (general, regional block, digital block), and a tourniquet is applied.

Approach

- Metacarpal lesions are best approached through a dorsal incision.
- A longitudinal incision is preferable to facilitate future limb-sparing surgery if malignancy is identified on pathology.

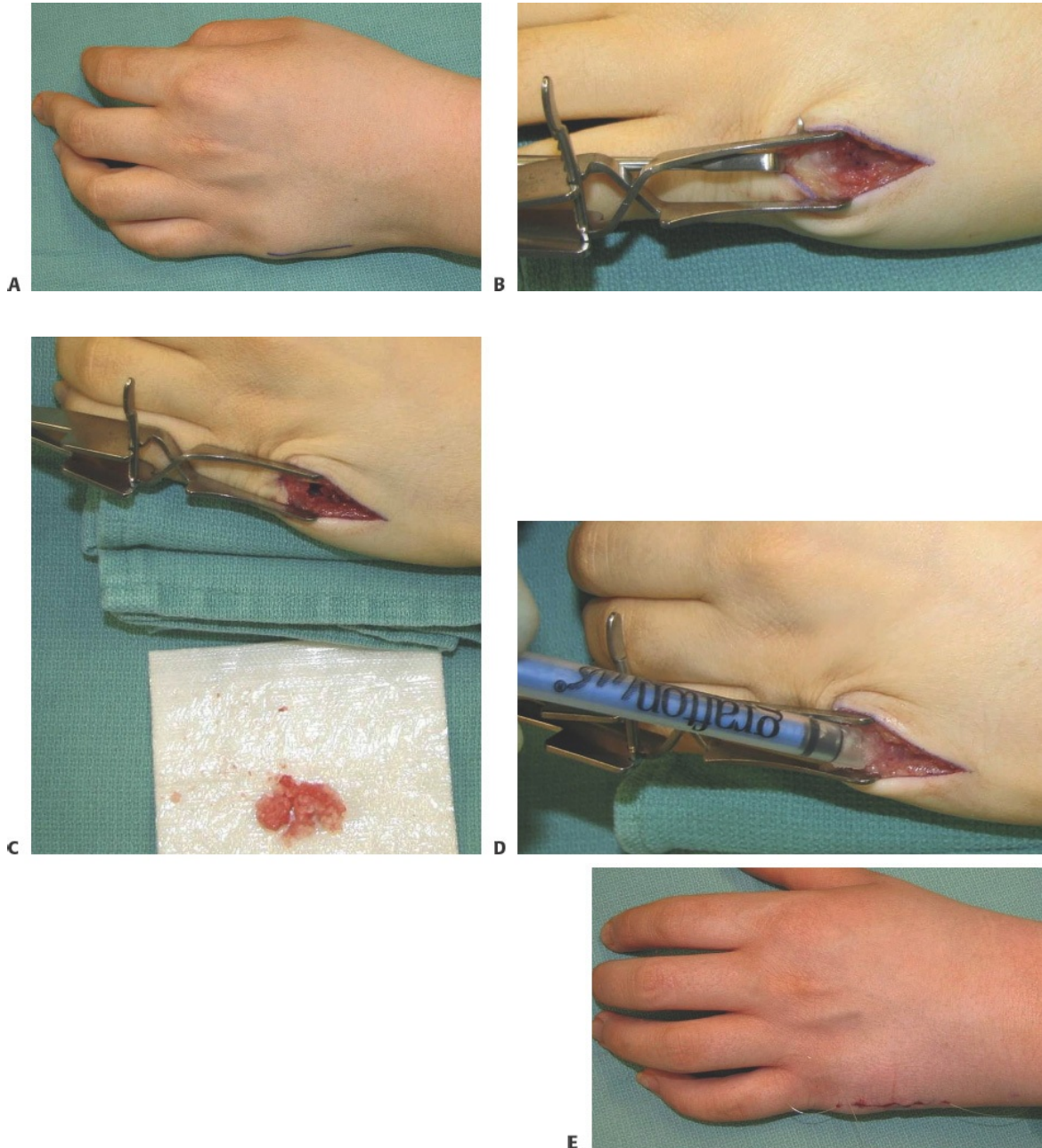
TECHNIQUES

■ Enchondroma Excision and Bone Grafting

- Make a dorsal longitudinal incision overlying the involved metacarpal (**TECH FIG 1A**).
- Reflect the periosteum and identify the metacarpal bone (**TECH FIG 1B**).
- Create a cortical bone window with the use of a blade, rongeur, curette, or drill.
- Send a sample to pathology for frozen section to confirm the diagnosis of a benign enchondroma.
 - If there is any question of a malignancy, definitive treatment must be deferred until a final diagnosis is made on permanent pathologic analysis.
- Once diagnosis of enchondroma is confirmed, enlarge the bone window and curette the lesion (**TECH FIG 1C**).
 - It is imperative that there is adequate exposure to confirm complete excision.
- Pack the resultant cavity with preferred bone grafting material (autograft, allograft, or synthetic bone substitute; **TECH FIG 1D**).
- Confirm complete excision and adequate grafting with intraoperative

radiographs.

- Close the incision primarily (**TECH FIG 1E**).
- Apply a bulky dressing and a protective splint.



TECH FIG 1 • **A.** Dorsal longitudinal incision for a fifth metacarpal enchondroma. **B.** Soft tissue dissection reveals the periosteum of the metacarpal. **C.** An appropriately sized bone window will give access to

curettage the enchondroma specimen, which has been removed in this photo. **D.** Placement of allograft in the bone defect. **E.** Primary closure of incision.

PEARLS AND PITFALLS

Presentation	■ In cases of pathologic fracture, allow healing of the fracture site before definitive treatment because fixation of the fracture can be difficult in the thin bone surrounding the tumor. ■ If found incidentally, the lesion can be observed if no malignant features are present.
Diagnosis	■ Plain films will show characteristic features. ■ Malignancy must be ruled out before proceeding with definitive excision. Consult a pathologist in advance.
Operative	■ Make the “bone window” approximately 2/3 the size of the lesion for adequate visualization of the lesion and the cavity. ■ Confirm complete excision with imaging before leaving the operating theater.

POSTOPERATIVE CARE

- Continue protective splinting for 6 weeks after surgery but begin range-of-motion exercise at 7 to 10 days after surgery with supervised therapy.
- Obtain surveillance radiographs at 6 months, 1 year, 2 year, and subsequently if symptoms develop.

OUTCOMES

- Recurrence after curettage is between 2% and 15%.^{2,7}
- A malignant process must be considered and ruled out in all cases of recurrences, prompting a thorough review of the radiographs and histology.

COMPLICATIONS

- Enchondromas may lead to extensor tendon adhesions, nonunions, metacarpal shortening, decreased range of motion, or postoperative fracture.
- Complication rates are higher with excision of recurrent lesions.⁷

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75 Excision of Peripheral Nerve Schwannoma

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Schwannomas, also termed neurilemmomas are the most common benign nerve tumors of the hand.
- The lesions are peripheral nerve sheath tumors arising from Schwann cells within the endoneurial layer.
- Schwannomas do not result in neural dysfunction. As a result, if it is not considered in the differential for an upper extremity mass, inadvertent nerve injury may result during excision.

ANATOMY

- Schwannomas grow eccentrically from the nerve sheath and are well encapsulated. As a result, nerve fasciculi cannot enter the lesions.
- The tumors are typically found on the volar surface of the forearm or the hand and are usually less than 2.5 cm in diameter.¹
- On histology, there are interlacing fascicles of spindle cells with large oval nuclei in a palisade appearance, referred to as Antoni type A. Areas that are less well defined with fewer cells and less extracellular ground substance are termed Antoni type B.^{1,2}

PATHOGENESIS

- Schwannomas are a result of a benign proliferation of differentiated Schwann cells of a single nerve funiculus that surround the nerve.³
- Malignant transformation is rare.⁴
- Neurofibromas also arise from Schwann cells but can easily be differentiated from schwannomas due to growth within the substance of the nerve, making

enucleation impossible.

NATURAL HISTORY

- Schwannomas are quite rare and have a variable presentation, frequently leading to an incorrect clinical diagnosis.
- Multiple schwannomas of the large peripheral nerve trunks may be found in patients with neurofibromatosis type 1 (von Recklinghausen disease).
- Patients with neurofibromatosis type 2 develop bilateral acoustic schwannomas.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Schwannoma typically presents in the middle decades of life as a well-circumscribed, firm, painless, slow growing tumor. It is rarely associated with a neurologic deficit.
- Typically, schwannoma is a mass that appears in line with the nerve trunk. Therefore, it is mobile in the transverse direction but not in the longitudinal plane.²
- Although schwannomas are usually solitary, they have been found to occur as multiple lesions. These tumors usually have no mass effect or ischemic effect of the involved nerve.⁵
- On exam, it can appear to have a cystic consistency often being misdiagnosed as a ganglion.^{3,5}
- Intraoperatively, the tumor can easily be shelled out, distinguishing it from other nerve tumors (**FIG 1A**).
- Schwannomas appear within the digital nerve approximately half the time. However, it is uncommon to find one distal to the proximal interphalangeal joint of the fingers or distal to the interphalangeal joint of the thumb (**FIG 1B**).³

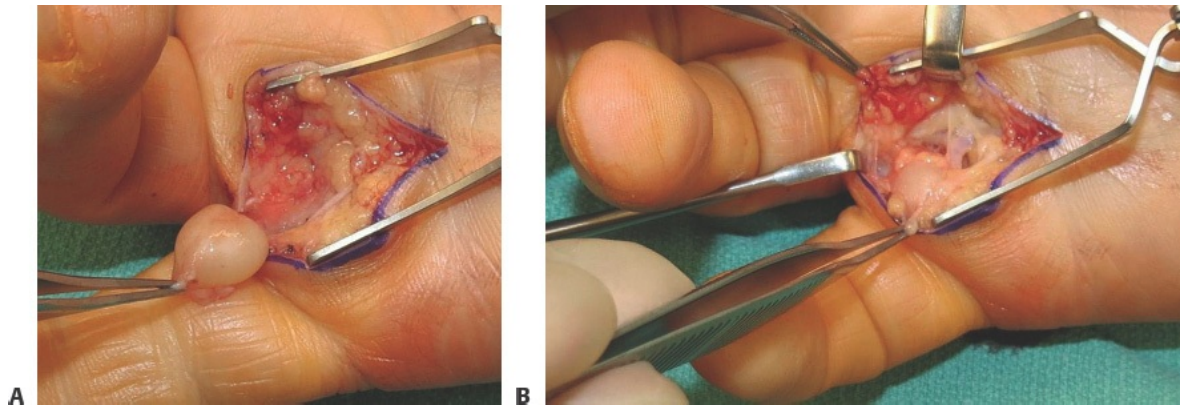


FIG 1 • A. Schwannomas are well-circumscribed tumors that can easily be enucleated from the involved nerve. **B.** Approximately half of schwannomas are found within digital nerves.

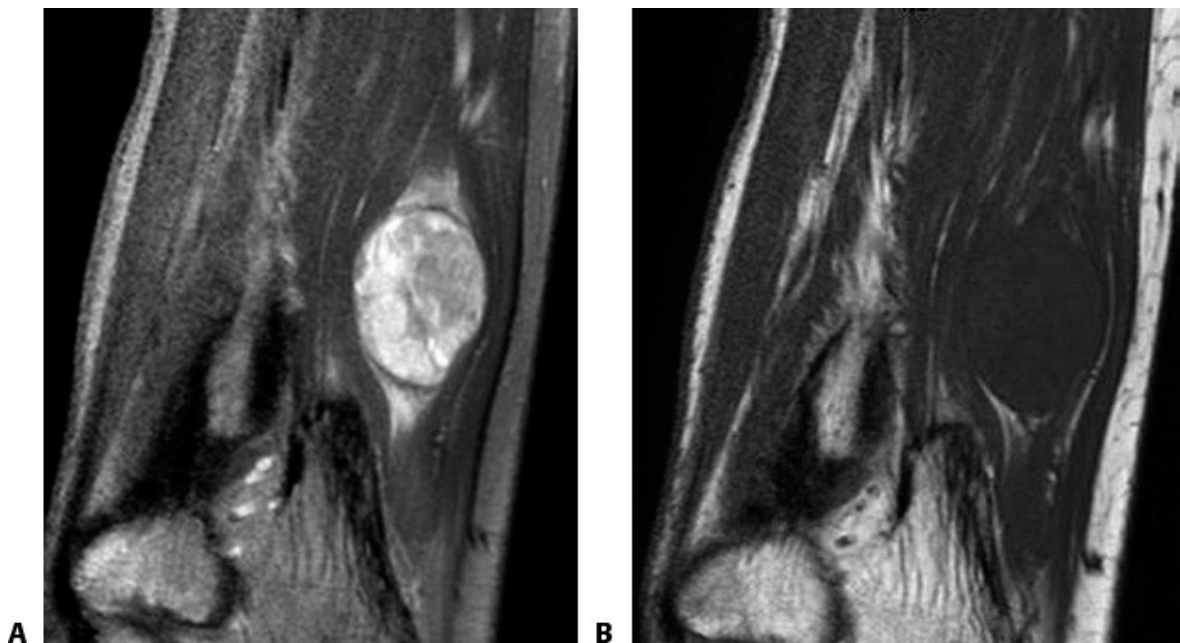


FIG 2 • MR images of an ulnar nerve schwannoma. **A.** T2-weighted image with bright appearance of the schwannoma. **B.** T1-weighted image has an intermediate signal intensity due to the presence of fat within the tumor.

IMAGING

- MRI is the standard to localize the tumor and delineate the surrounding anatomy for surgical planning.
- The lesion appears bright on T2-weighted images though the presence of adipose tissue within the lesion will give an intermediate signal intensity on T1-weighted images (**FIG 2**).
- The similar appearance on MRI makes it difficult to distinguish between a schwannoma, neurofibroma, and a malignant nerve sheath tumor.
- High-frequency ultrasound will show schwannomas as masses of low echogenicity with distal enhancement.²

DIFFERENTIAL DIAGNOSIS

- Ganglion cyst
- Neurofibroma
- Giant cell tumor
- Lipoma
- Epidermal inclusion cyst

NONOPERATIVE MANAGEMENT

- For asymptomatic schwannomas, observation is acceptable.
- Any malignant features on MRI imaging should prompt a discussion with the patient for surgical excision.

SURGICAL MANAGEMENT

- Surgery is indicated for definitive diagnosis, for symptom control, or to exclude malignancy.
- An excisional biopsy is performed by enucleation of the tumor following an intraneural dissection.
- Schwannomas are noninfiltrative and can be freed from adjacent fascicles without injury.³
- If the tumor is adherent to the surrounding tissue or is not well encapsulated, the diagnosis should be questioned.
 - An incisional biopsy should be performed with definitive treatment delayed until after a permanent pathologic examination.¹

Preoperative Planning

- Preoperative imaging, typically MRI, can be used to identify the extent of the lesion and its proximity to other vital structures.

- The possibility of postoperative neurologic deficit, though uncommon, must be discussed with the patient.

Positioning

- The patient is positioned supine on the operating table, and the extremity is positioned on a hand table.
- The extremity is prepped and draped circumferentially.
- The appropriate anesthesia is administered (general, regional block, digital block) and a tourniquet is applied.

Approach

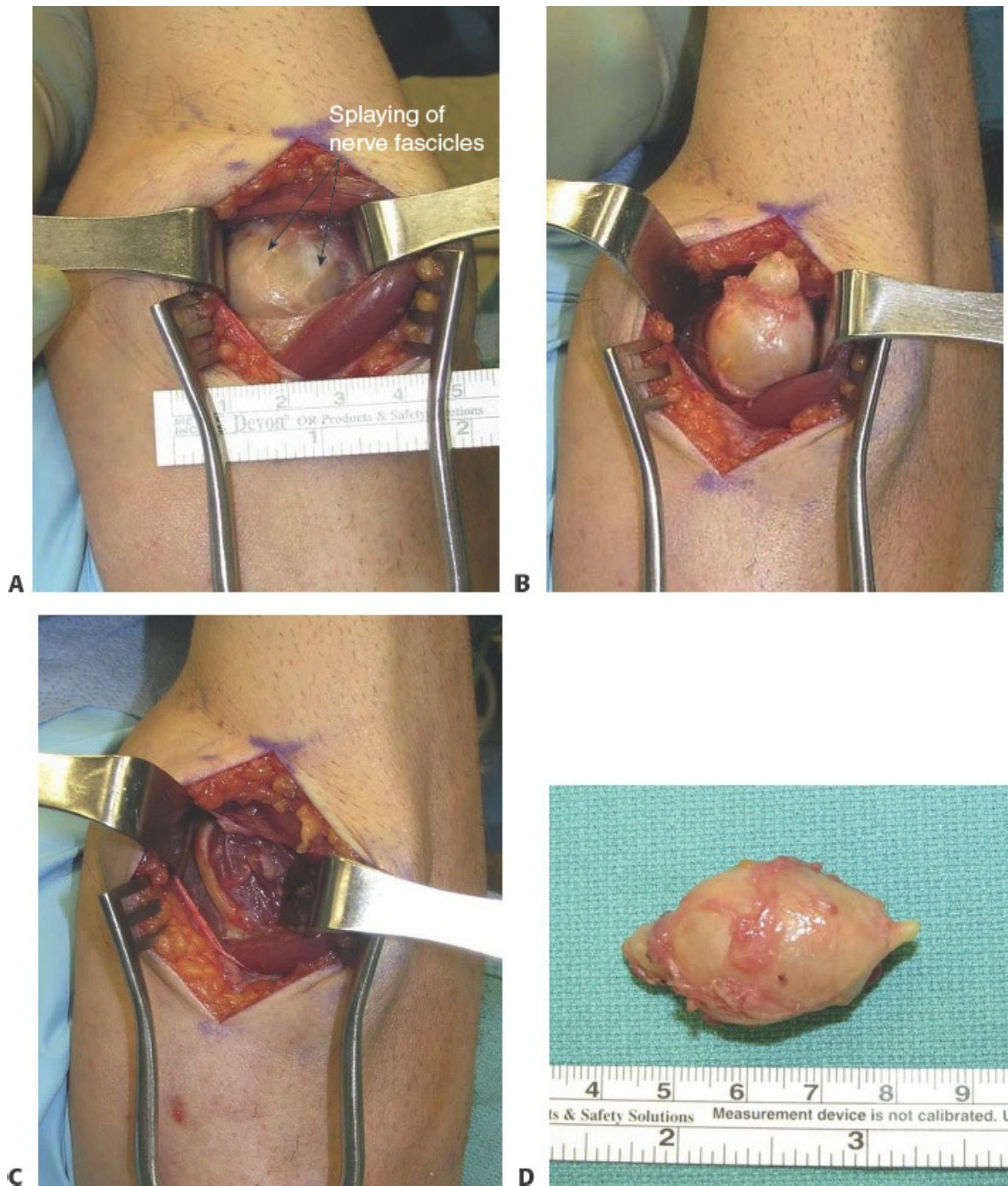
- The location of the lesion dictates the technique and the approach chosen.
 - Palmar lesions are best approached with a zigzag incision.
 - A midaxial approach is most effective for digital nerve lesions for best visualization and protection of the adjacent digital vessel.
 - Median nerve lesions should be excised with an open carpal tunnel incision.

TECHNIQUES

■ Schwannoma Enucleation

- Expose the involved nerve and its nerve fascicles proximal and distal to the tumor. Fascicles will be seen draping over the mass and may have a multilobulated or pedicled appearance.
- Completely inspect the nerve to determine the location where there is a splaying of fascicles that would be the best resection plane (**TECH FIG 1A**).
- Incise the nerve sheath longitudinally, taking care to avoid injury to the fascicles and vessels running within the epineurium.
- Carefully peel away the fascicles from the tumor circumferentially until the tumor can be shelled out from the nerve (**TECH FIG 1B**).
- Following resection, inspect the nerve to confirm fascicular continuity (**TECH FIG 1C**).
- In cases of digital nerve, an operating microscope is needed to preserve axons.
 - Identify normal nerve fibers proximally.

- Trace axon bundles distally and carefully dissect them free from the mass.
- The specimen should have no nerve fascicles within it (**TECH FIG 1D**).
- Close the incision with interrupted 4-0 nylon sutures and place a bulky dressing.



TECH FIG 1 • Schwannoma of the ulnar nerve. **A.**

Splicing of the nerve fascicles around the lesion. A clean plane exists between the mass and the fascicles. **B.** The mass is shelled out carefully between the spliced fascicles. **C.** Following resection of the schwannoma, all nerve fascicles remain intact. **D.** Schwannoma specimen.

PEARLS AND PITFALLS

Indications	■ Diagnosis—exclude malignancy ■ Symptom control
Diagnosis	■ Misdiagnosis is common—often confused with a ganglion. ■ MRI is the best imaging modality.
Surgical approach	■ Loupe magnification or an operative microscope will facilitate microdissection to minimize axonal injury. ■ If the mass is adherent to the nerve, question the preoperative diagnosis and consider malignancy.

POSTOPERATIVE CARE

- A bulky dressing is typically adequate. Early hand elevation and early finger motion are encouraged.
- The sutures are removed at approximately 10 days and range-of-motion exercises begin at this time.

OUTCOMES

- Recurrence is very rare.
- Transient paresthesias are common, but long-term nerve dysfunction is very uncommon.

COMPLICATIONS

- Incidence of postoperative neurologic deficit is 4%.⁴
- Inadvertent nerve resection can occur if the diagnosis is not considered preoperatively.

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76 Excision of Malignant Skin Tumors

CHAPTER

Paymon Rahgozar and Kevin C. Chung

DEFINITION

- Basal cell carcinoma (BCC), the second most common cutaneous malignancy of the hand, arises from the basal layer of the epithelium or from the external root sheath of the hair follicle.
- Squamous cell carcinoma (SCC) is the most common malignant cutaneous tumor of the hand.
- Melanomas are aggressive tumors of the epidermis that account for 3% of all hand tumors.
- Both SCC and melanoma can invade locally, involve regional lymph nodes, or metastasize to distant sites.

ANATOMY

- BCCs most often occur in sites with higher concentrations of pilosebaceous follicles.
 - Up to 87% of the tumors appear on the dorsum of the hand between the wrist crease and the metacarpal heads.¹
- SCC derives from the epidermal keratinocyte cell layer but can also develop in the nail matrix.
 - Although dorsal hand involvement is common for SCC, the tumors can also be found on the nails, fingers, interdigital skin, or dorsal wrist with relative frequency.^{1,2}
- Melanoma is from a neural crest origin developing from the dendritic cell within the epidermis. The melanocytes can migrate to both cutaneous and noncutaneous locations, such as the nail matrix.
 - Subtypes include superficial spreading (most common), nodular (most

aggressive), lentigo maligna, acral lentiginous, and amelanotic melanoma.

- Skin tumors found in the palm are most commonly the acral lentiginous subtype.^{1,3}

PATHOGENESIS

- Malignant tumors of the hand are rare, often leading to a delay in diagnosis and treatment.
- Risk factors for malignant skin tumors are similar and include sun/ultraviolet exposure, fair skin, male gender, or advancing age.
- Although basal cell cancer is the most common cutaneous malignancy, only 2% to 3% of all BCC appear in the upper extremities.² Therefore, in the hand, squamous cell cancer is the most common cutaneous malignancy.
- A history of severe burns, chronic ulcers, or immune compromise can lead to SCC.
- Those with a personal history of skin cancer, family history of melanoma, history of a changing mole, or exposure to coal tar, arsenic compounds, or radiation have an increased risk of melanoma.

NATURAL HISTORY

- Basal cell carcinoma
 - In comparison to SCC or melanoma, BCC does not arise from malignant changes of pre-existing structures. It originates from the basal layer of the epithelium or the root sheath of a hair follicle.²
 - High-risk lesions include the superficial, micronodular, morpheaform, and infiltrative subtypes.³ Nodular BCC is the most common low-risk subtype.
 - The metastatic rates in BCC are as low as 0.1%, presumably because the reticular dermis functions as a relative barrier to its spread.^{2,4}
- Squamous cell carcinoma
 - Seventy-five percent of skin cancers that appear in the hand are SCC with a male-to-female ratio of 4:1.⁵
 - SCCs originate from the spindle cell layer of the epithelium.² The tumor will typically begin as a nodule and will progress to develop areas of necrosis.
 - High-risk lesions are those with a diameter greater than 2 cm, vertical depth greater than 4 mm, rapid growth, perineural invasion, or presence of poorly differentiated cells.^{4,5}
 - The risk of metastases involving the extremities is 2% to 5%.⁶
- Melanoma

- The incidence of melanoma is increasing at a rapid rate, nearly doubling every 8 to 10 years.^{3,6}
- The lifetime probability of developing melanoma is 1 in 49 for males and 1 in 73 for females.
- Prognosis is dependent on the vertical thickness (Breslow classification) or the anatomic level of invasion (Clark classification).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Basal cell carcinoma
 - BCCs are characteristically found in middle-aged and elderly light-skinned individuals who report a history of multiple skin malignancies.
 - The typical appearance is that of a raised maculopapular lesion in the setting of skin atrophy, skin discoloration, and telangiectasias, with raised pearly borders and eventual ulceration (**FIG 1A**).
- Squamous cell carcinoma
 - SCC may appear as a slow-growing, verrucous, exophytic lesion or as a rapid-growing, nodular, indurated lesion with raised borders and early ulceration (**FIG 1B**).
 - The slow-growing variety has a higher propensity to metastasize.

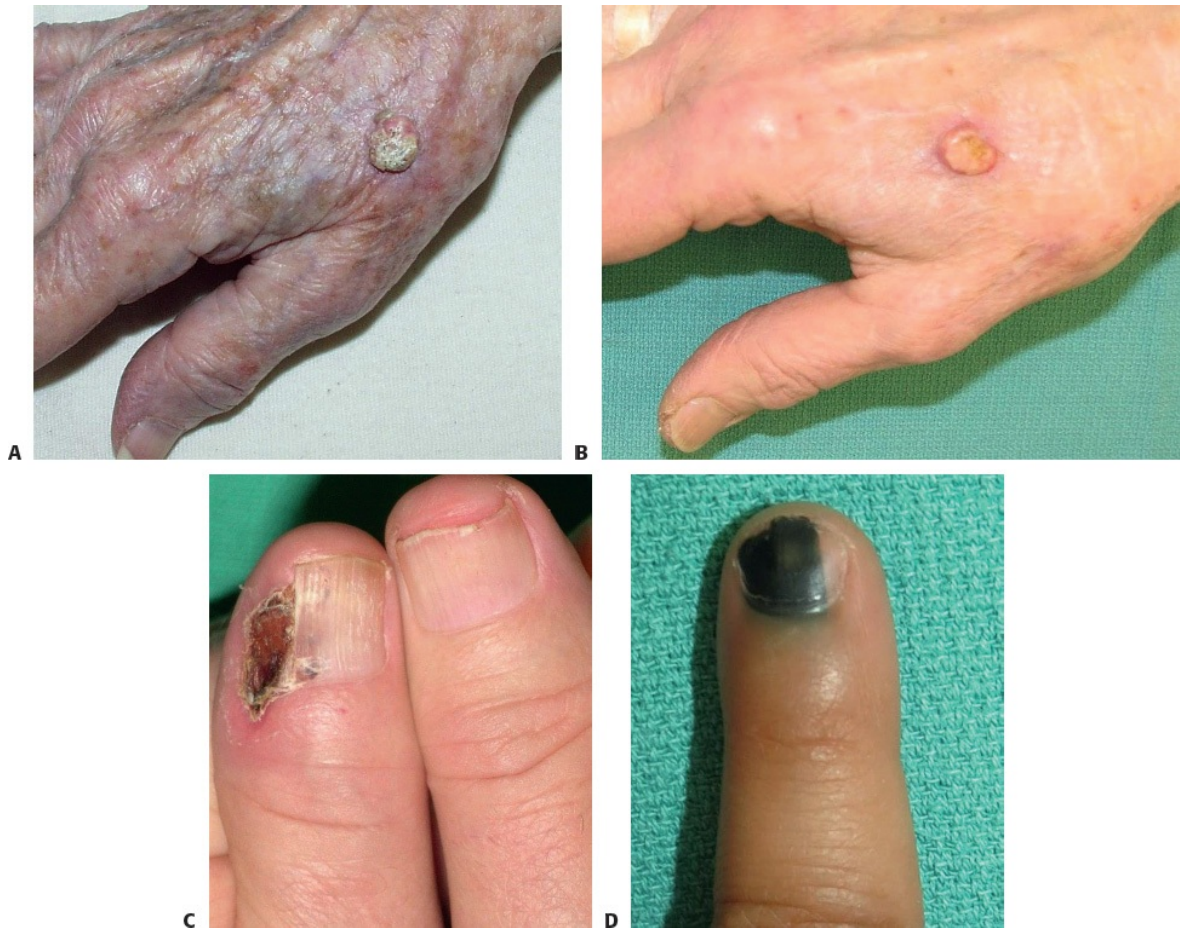


FIG 1 • A. Basal cell carcinoma on the dorsum of the hand. Note the raised pearly borders. **B.** Squamous cell carcinoma of the dorsum of the hand with ulceration. **C.** Squamous cell carcinoma with nail involvement. Often, this is misdiagnosed as a chronic paronychia or other benign pathology. **D.** Subungual melanoma with a Hutchinson sign, extension of pigment from the nail bed to the proximal nail fold.

- With time, most untreated SCCs will eventually become an inflamed, indurated lesion with central ulceration.
- The frequency of lesions on the dorsum of the hand is consistent with its association with sun exposure.
- It can be distinguished from basal cell cancer by the lack of a well-defined edge when placing stretch on the tumor with two hands.⁵

- Involvement of the nail unit presents as a chronic ulcer and is often misdiagnosed as a chronic paronychia, pyogenic granuloma, or verruca vulgaris⁵ (**FIG 1C**).
- Similar to melanoma, regional lymph nodes should be evaluated to evaluate for lymphadenopathy.
- Melanoma
 - Evaluation involves the ABCs (asymmetry, borders, color) with regard to a changing mole.
 - Critical findings include asymmetry, irregularity, diameter greater than 6 mm, or presence of satellite lesions.
 - Regional lymph nodes must be examined to evaluate for metastasis.
 - Subungual melanoma may present with a Hutchinson sign (extension of brown/black pigment from the nail bed onto the cuticle or nail fold) (**FIG 1D**). It can also appear as a pigmented streak of the nail bed that is wider than 3 mm.

IMAGING

- Plain films can reveal bony involvement, particularly with nail bed involvement.
- Other imaging studies are typically performed to rule out distant disease (CT, PET, MRI).

DIFFERENTIAL DIAGNOSIS

- Hemangioma
- Dermatofibroma
- Blue nevus
- Seborrheic keratosis
- Kaposi sarcoma
- Metastasis
- Subungual lesions: chronic paronychia, pyogenic granuloma, onychomycosis, glomus tumor, hematoma

NONOPERATIVE MANAGEMENT

- Basal cell carcinoma
 - Small or superficial lesions can be considered for treatment with electrodesiccation and curettage, cryotherapy, radiotherapy, or CO₂ laser.
 - Nonoperative management is contraindicated in morpheaform or sclerosing

subtypes.

- Squamous cell carcinoma
 - Small, low-risk, or in situ squamous cell lesions can be managed conservatively in patients who are high-risk operative candidates with electrodesiccation and curettage, cryosurgery, or 5-FU.
 - Radiation therapy may also be used to treat inoperable lesions or recurrences.
- Melanoma
 - There is no role for nonoperative management in melanoma.

SURGICAL MANAGEMENT

- Basal cell carcinoma
 - Small (no more than 2 cm) BCCs should be resected with at least 4-mm margins.
 - Large (over 2 cm) BCCs or those with high-grade features require a 6-mm margin or the use of Mohs micrographic surgery to maximize preservation of uninvolved tissue.
 - Mohs micrographic surgery should be applied in the setting of tumors with aggressive malignant features and for morpheaform or sclerosing subtypes.²
- Squamous cell carcinoma
 - Because of the more aggressive nature of SCC, a wider margin of resection is typically necessary as compared to BCC.
 - A 3- to 10-mm margin of disease-free tissue should be maintained.
 - Mohs micrographic excision results in the highest cure rate and the best preservation of uninvolved tissue. It should be performed for high-risk lesions.
 - If the nail matrix is involved, amputation at the DIP joint is necessary.
- Melanoma
 - The depth of the lesion (Breslow thickness) dictates margin of resection:
 - In situ tumors: 0.5-cm margin
 - Less than 1 mm deep: 1-cm margin
 - 1 to 4 mm deep: 2-cm margin
 - More than 4 mm deep: 2- to 3-cm margin
 - For melanomas deeper than 0.76 mm, treatment includes intraoperative lymph node mapping with sentinel lymph node biopsy, followed by completion of lymphadenectomy if positive.
 - For nail matrix melanomas, the digit should be amputated proximal to the

DIP joint.

- In proximal digital melanomas with perineural invasion or bone involvement, a complete digital amputation or ray amputation is typically necessary.
- Large excision reconstruction can involve primary closure, skin graft, locoregional flap, or free flap (**FIGS 2** and **3C**).

Preoperative Planning

- Preoperative imaging, if necessary, should be performed to identify the extent of the lesion and the involvement of any vital structures.
- In cases of malignancy, the extremity should not be exsanguinated with the use of an Esmarch bandage to avoid a theoretical risk of seeding malignant cells.

Positioning

- The patient is positioned supine on the operating table, and the extremity is positioned on a hand table.
- The extremity is prepped and draped circumferentially, including the axilla if sentinel lymph node biopsy is planned.
- The appropriate anesthesia is administered (general, regional block, digital block), and an appropriate tourniquet is applied (upper arm or digit).

Approach

- The location of the lesion dictates the technique and the approach chosen.
- Wide local excision involves excision of the lesion with a predetermined perimeter of normal tissue (**FIG 3A**).
 - It is important to mark the specimen to orient the pathologist (**FIG 3B**).
 - If any margins are positive, the pathology will dictate the location for repeat excision.
- To facilitate primary closure, if the anatomy and the size of the lesion permit, the excision should be an ellipse.
- The incision for a biopsy should be designed longitudinally so that the biopsy site can be resected at the time of definitive treatment.
- Mohs micrographic surgery has good results for BCC and SCC. A Mohs-trained surgeon can excise the lesion and perform immediate pathologic analysis for critical areas where tissue preservation is important.

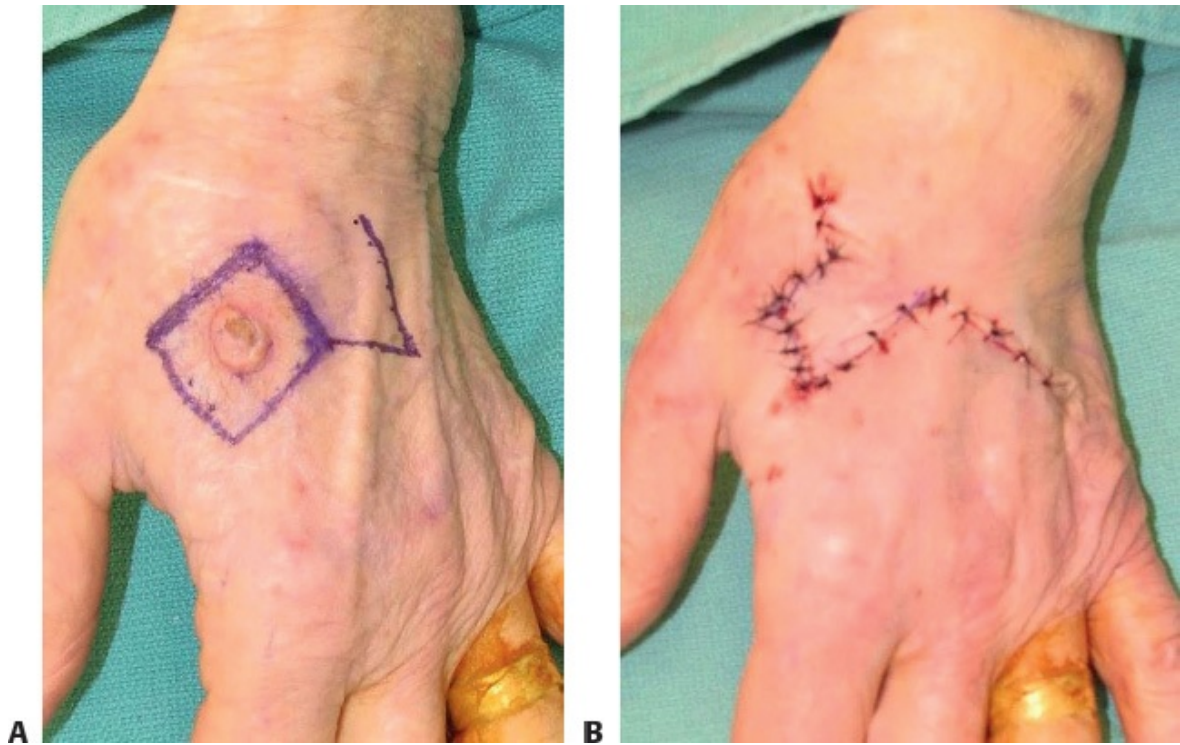


FIG 2 • SCC excision requiring a local flap for closure. **A.** Preoperative markings for a rhomboid flap for reconstruction. **B.** Closure after advancement of the flap.



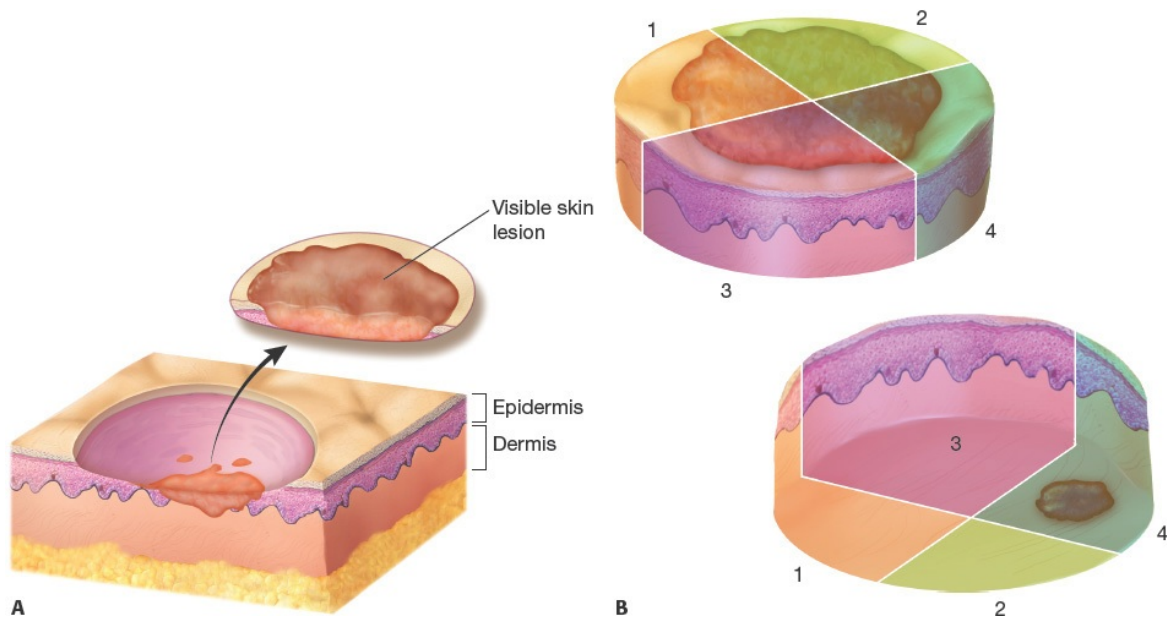
FIG 3 • Wide local excision of a SCC. **A.** The inner circle represents the boundaries of the lesion and the outer circle is the excision of a margin of normal tissue. **B.** The specimen is marked with sutures for pathologic orientation. **C.** Closure of dorsal hand defect with a split-thickness skin graft.

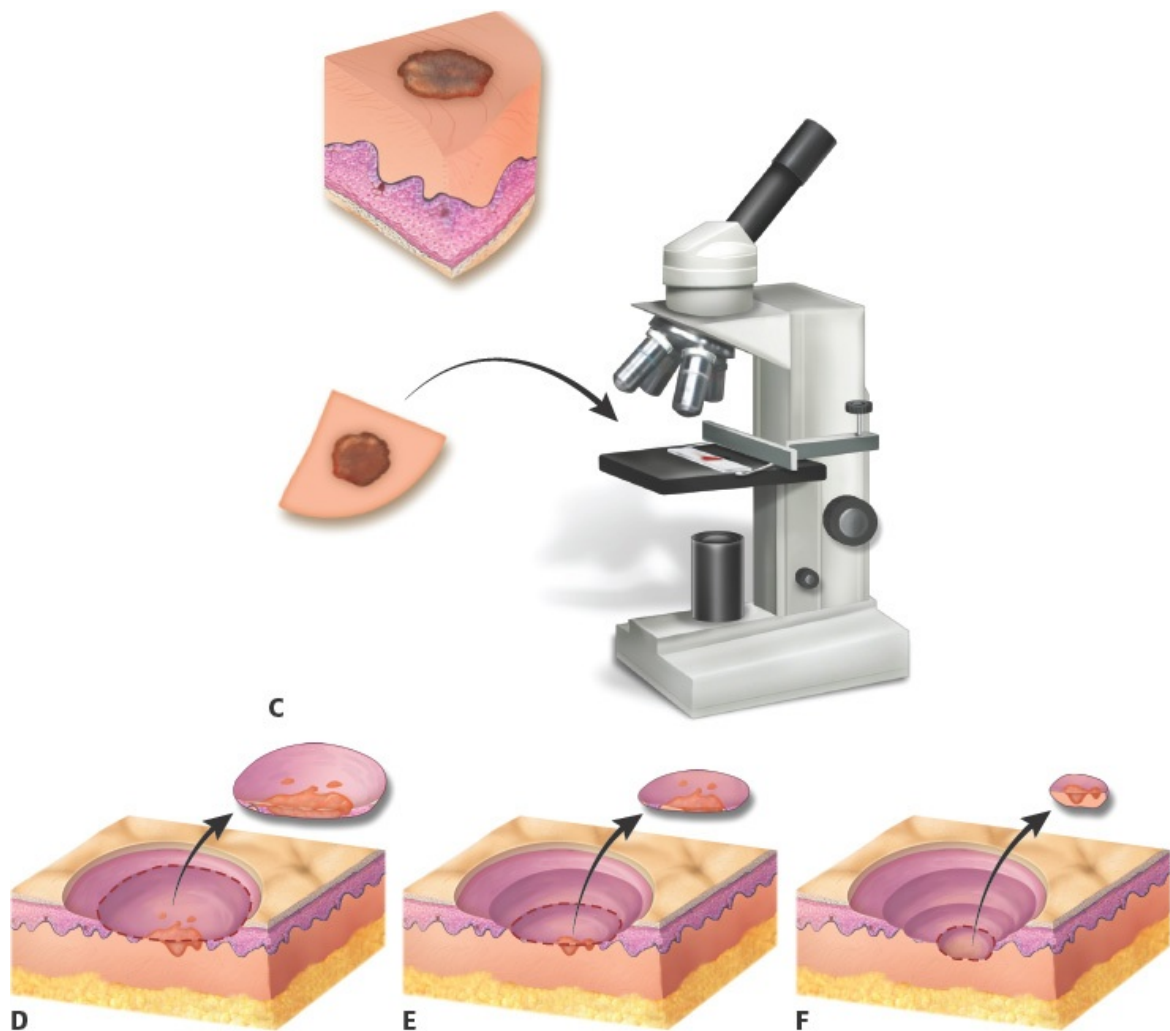
TECHNIQUES

■ Mohs Micrographic Surgery

- Remove all evidence of gross tumor.
- Excise a thin 2- to 3-mm margin with the tissue (**TECH FIG 1A**). Bevel the peripheral skin edge such that it is in the same horizontal plane as the deep margin.

- Using a color-coded three-dimensional orientation, map the tissue for reference (**TECH FIG 1B**).
- Examine the deep and peripheral margin by frozen section analysis to determine the precise anatomic location of any residual tumor (**TECH FIG 1C**).
- Re-excise any residual tumor and repeat pathologic evaluation until margins are negative (**TECH FIG 1D-F**).





TECH FIG 1 • Mohs micrographic surgery. **A.** Gross tumor with a thin margin is excised. **B.** The sample is divided and mapped with color to help pinpoint any areas of residual tumor with frozen section analysis. **C.** Microscopic evaluation reveals that there is residual tumor in segment 4. **D–F.** The process is repeated, focusing on re-excision of the involved quadrant until all clear margins are obtained.

Incision	■ Be certain of diagnosis before committing to a transverse incision for resection. This will make a limb-sparing incision more challenging for definitive resection if the lesion is malignant.
Basal cell carcinoma	■ Telangiectasias with raised pearly borders are characteristic.
Melanoma	■ Always consider amelanotic melanoma as part of the differential of a nonpigmented skin lesion. ■ Before committing to a definitive reconstruction, perform temporary coverage until the final pathology confirms negative margins. ■ Sentinel lymph node biopsy is often part of the management algorithm.
Squamous cell carcinoma	■ Biopsy tissue in a chronic or nonhealing skin or nail matrix lesion
Mohs micrographic surgery	■ Very low recurrence rates for BCC and SCC

POSTOPERATIVE CARE

- The hand is placed in a bulky dressing from the proximal forearm to the MP joints. Early hand elevation and early finger motion are encouraged.
- The splint and sutures are removed at 1 week, and range-of-motion exercises begin at this time.
- In cases of melanoma, the patient should follow up at regular 3-month intervals for 2 years, 6-month intervals for the following 2 years, and annually thereafter.

OUTCOMES

- Basal cell carcinoma
 - Cure rates for primary BCC treated with Mohs surgery have been reported as high as 99%.²
 - Recurrence rates are higher for lesions with increasing size or for those with more aggressive clinical subtypes.
- Squamous cell carcinoma
 - The risk of metastasis and recurrence is higher on the upper extremity than

SCC at other locations on the body.

- Excision with Mohs micrographic surgery has recurrence rates as low as 2.4%. However, periungual lesions have comparatively higher recurrence rates.⁴
- The histologic risk factors associated with recurrence include degree of cellular differentiation, depth of tumor invasion, and presence of perineural invasion.²
- Melanoma
 - Prognosis is dependent on depth of tumor invasion, presence of nodal disease, and presence of metastatic disease.
 - The approximate 5-year survival rate for a melanoma less than 0.76 mm thick is 98%. Survival drops to 30% with nodal involvement and less than 10% if there are metastases.⁶

COMPLICATIONS

- Incomplete resection on final pathology warrants re-excision.
- With lymphadenectomy, there is a risk of hematoma, seroma, lymphocele, or lymphedema. Although the risk is also present with sentinel lymph node biopsies, it is much less commonly encountered.

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Kevin C. Chung, MD, MS

EDITOR-IN-CHIEF

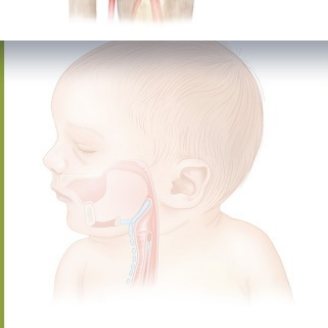
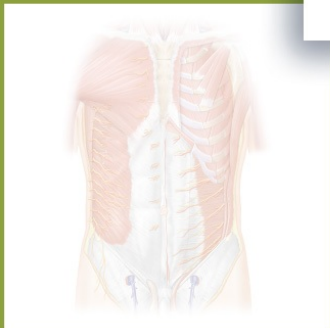
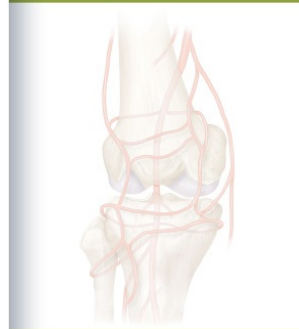
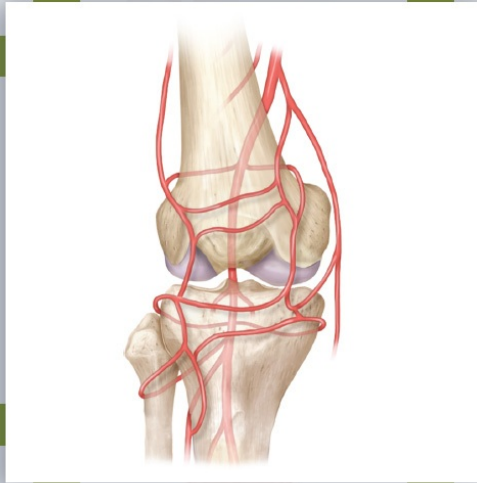
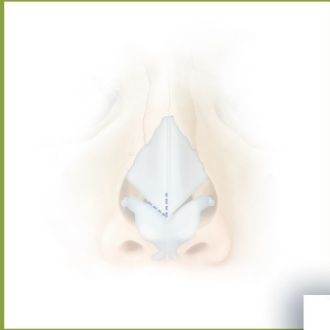
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PART 7

Lower Limb Reconstruction and Amputation



Section I: Anesthesia and Emergency Procedures

1 **Femoral and Adductor Canal Blocks**

CHAPTER

Sarah Madison and Jean-Louis Horn

DEFINITION

- A peripheral nerve block is an analgesic technique in which local anesthetics are injected percutaneously in proximity to a sensory nerve.
- The location of the injection determines the distribution of analgesia.
- Femoral nerve block may be used for postoperative analgesia for procedures on the anterior thigh, knee, medial leg, or medial ankle.
- Adductor canal block may be used for postoperative analgesia for procedures on the knee or medial leg.
- A continuous infusion of local anesthetic via a perineural catheter can provide analgesia for several days after surgery.
- Nerve blocks are often part of a multimodal regimen that also includes systemic medications.
- Nerve blocks can reduce pain and opioid consumption and enhance satisfaction and recovery.¹
- Depending on the location and extent of surgery, nerve blocks may be used for surgical anesthesia.

ANATOMY

- The femoral nerve arises from the lumbar plexus and is formed by the ventral rami of L2-L4.
- In the area of the femoral triangle, the femoral nerve lies deep to the fascia

iliaca, lateral to the femoral artery, and superficial to the iliacus muscle.

- The femoral nerve divides into anterior and posterior divisions and descends as the saphenous nerve to the medial leg.
- The posterior branch provides motor innervation to the quadriceps muscles as well as sensory articular branches to the knee joint.
- The saphenous nerve, obturator nerve (posterior division), and the nerve to the vastus medialis lie within the adductor canal.
- The adductor canal is bounded by the sartorius and the vasto-adductor membrane medially, the vastus medialis anteriorly, and adductor longus and magnus muscles posteriorly.
- The adductor canal also contains the femoral artery and vein.
- The saphenous nerve and the nerve to the vastus medialis supply sensory branches to the knee.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- A preoperative history and physical must be performed prior to any anesthetic technique.
- A thorough history and physical exam will include anesthetic history, exercise tolerance, cardiopulmonary examination, and airway examination.
- Any pre-existing neuropathies in the distribution of the block should be defined and documented.
- Any local infections, masses, previous surgeries, or other irregularities at the site of injection should be identified.

IMAGING

- Ultrasound imaging confers efficiency and increases the success rate of most peripheral nerve blocks.
- Using a high-frequency linear transducer, scan in a transverse orientation at the level of the inguinal crease. The femoral artery and femoral nerve should be easily identified in cross-section (**FIG 1**).
- The adductor canal block is often performed in a location that is proximal to the true adductor canal, near the point at which the sartorius muscle covers the femoral vessels. The nerve can be visualized next to the femoral artery, just deep to the sartorius muscle (**FIG 2**).

NONOPERATIVE MANAGEMENT

- The balance of risks and benefits must be considered before any nerve block.

Sometimes, it is more appropriate to only employ systemic medications for pain control.

- Opioids and nonopioid adjuvant medications may be used when medically appropriate, with or without a nerve block.

SURGICAL MANAGEMENT

- Femoral nerve block is indicated for postoperative analgesia of the anterior thigh, knee, medial leg, or medial ankle, or for surgical anesthesia of the anterior thigh.
- When combined with a sciatic block, it can be used for surgical anesthesia of the foot/ankle.
- Local anesthetics will affect both motor and sensory nerves. Blocking the femoral nerve at the level of the inguinal crease results in quadriceps weakness.
- Adductor canal block is indicated for postoperative analgesia of the knee, medial leg, or medial ankle.
- It can be used as a surgical anesthetic in conjunction with a sciatic block for procedures on the foot/ankle.



FIG 1 • Ultrasound image of femoral nerve block. FN, femoral nerve; A, femoral artery.

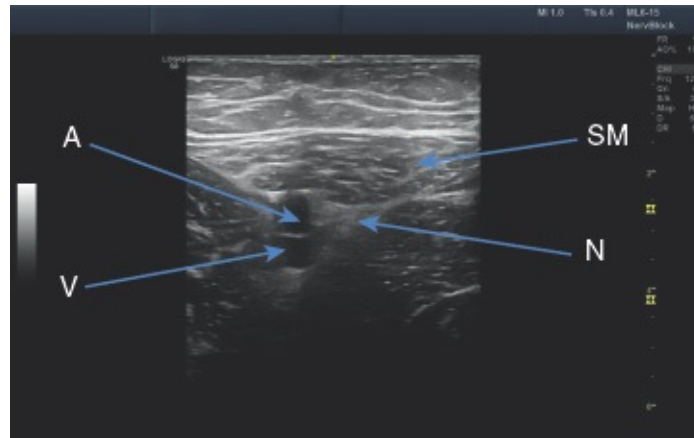


FIG 2 • Ultrasound image of adductor canal block. SN, saphenous nerve; SM, sartorius muscle; A, femoral artery; V, femoral vein.

- A nerve block in the adductor canal is less likely to cause quadriceps weakness than a femoral nerve block; however, local anesthetic may spread proximally and affect motor nerves.
- The nerve to the vastus medialis is reliably anesthetized with an adductor canal block, but the overall effect on quadriceps function is minimal.³

Preoperative Planning

- Surgical site, extent of incision, anticipated degree of pain, and any pre-existing conditions that increase risk of complications should be considered before offering the patient a nerve block.
- Postoperative ambulatory status should be determined to optimize dosing.
- Crutch training, if appropriate, should take place prior to surgery.
- Inpatients should be labeled as a “fall risk” and should not get out of bed without assistance.
- Femoral nerve blocks for outpatients should be carefully considered and only performed with close follow-up and an otherwise low risk of falls.
- The use of crutches and a knee immobilizer may attenuate fall risk with ambulation after a femoral nerve block.

Positioning

- The patient should be positioned supine with the operative leg slightly externally rotated.

- The bed should be flat with hips extended.
- The patient's ipsilateral hand may be kept out of the sterile field by lightly taping it to the chest.
- The operator should stand on the side to be blocked, with the ultrasound machine on the other side of the patient.

Approach

- With the use of ultrasound, the nerve may be approached either in-plane (needle parallel to transducer surface) or out-of-plane (needle perpendicular to transducer surface) with the ultrasound probe placed in a transverse orientation.
- When a nerve stimulator technique is used, the needle approach is generally *with* the long axis of the nerve, at a 45-degree angle to the skin.

TECHNIQUES

■ Femoral Block: Ultrasound-Guided Technique

- Position the patient as described above, with ASA (American Society of Anesthesiologists) standard monitors and supplemental oxygen applied.
- IV sedation, usually with fentanyl and midazolam, may be titrated to patient comfort.
- Using a high-frequency linear transducer, scan at the level of the inguinal crease in a transverse orientation to visualize the femoral artery and nerve in cross-section.
 - The best image may be obtained in a location proximal to the bifurcation of the femoral artery where the neurovascular bundle is closest to the skin.
 - Identify the fascia lata, fascia iliaca, femoral nerve, and iliacus muscle.
 - Slowly tilt the ultrasound transducer to optimize nerve imaging.
- Estimate the depth of the nerve in the ultrasound image.
- After sterile skin preparation, place a skin wheal just lateral to the ultrasound probe.
 - The depth of the nerve should guide the insertion site; start closer to the probe for more superficial targets, and farther away if the target is deeper.
- Insert the block needle in the plane of the ultrasound image, visualizing the tip of the needle in real-time as the target is approached (**TECH FIG 1**).

- The needle should pass through the fascia iliaca just lateral to the nerve.
- Tactile feedback through the needle may include a “pop” as the needle traverses fascial layers.



TECH FIG 1 • Positioning and approach for ultrasound-guided in-plane femoral nerve block.

- Take care to avoid the lateral edge of the nerve. The patient may experience a paresthesia if the nerve is contacted directly.
- The lateral circumflex femoral artery or one of its branches may be in the needle path or pass through the nerve, and should be avoided.
- After careful aspiration, inject a small amount of local anesthetic.
- Local anesthetic spread should appear as hypoechoic fluid filling the space deep to fascia iliaca and surrounding the nerve.
- The needle may be advanced closer to the nerve as a local anesthetic pocket is formed (hydrodissection); this reduces the risk of needle-nerve contact.
- When the needle is positioned in close proximity to the nerve, and local anesthetic spread is confirmed around the nerve, an additional 10 to 15 mL of local anesthetic can be injected.
- Local anesthetic selection and volume of injection depend on the goals of the block.
 - For a surgical block, use 20 to 30 mL of 1.5% mepivacaine, 2% lidocaine, 0.5% bupivacaine, or 0.5% ropivacaine.
 - For an analgesic block, use 15 to 20 mL of 0.25% bupivacaine or 0.25% ropivacaine.

- A catheter may be placed for continuous local anesthetic infusion.
 - Use 0.2% ropivacaine or 0.125% of bupivacaine at 4 to 6 mL/h for continuous infusion, with a patient-controlled bolus of 2 to 4 mL every 30 minutes.
 - Infusions are generally continued for 2 to 3 days following surgery.
-

■ Femoral Block: Nerve Stimulator Technique

- Following patient positioning and preparation described above, identify and mark the inguinal crease.
- Standing near the patient's hip and facing the head, palpate the femoral pulse along the crease.
- After sterile prep, place a local anesthetic skin wheal 2 cm lateral to the femoral artery pulse.
- Insert a stimulating block needle at a 45 to 60 degree angle to the skin in a cephalad direction (**TECH FIG 2**).
 - A quadriceps twitch ("patellar snap") should be elicited at a current of 0.2 to 0.5 mA. Redirect the needle until the appropriate stimulation is observed.
 - Sartorius contraction indicates a needle placement on the anterior division of the femoral nerve. Further advancement of the needle toward the posterior division of the nerve will usually solve this.
 - Aspiration of blood indicates intravascular placement. Reposition the needle.
 - Muscle contraction at a current of greater than 0.5 mA usually indicates inadequate needle-nerve proximity and may result in an incomplete or failed block.



TECH FIG 2 • Positioning and approach for stimulator-guided femoral nerve block.

- Muscle contraction at a current of less than 0.2 mA may indicate intraneural needle placement. Withdraw the needle slightly before injecting, carefully noting injection pressure.
- Avoid high-pressure injection (greater than 15 psi), indicative of an intraneural needle placement.
- Once an acceptable motor response is elicited, inject local anesthetic as above. The motor response should terminate with injection (Raj test).

■ Adductor Canal Block: Ultrasound-Guided Technique

- Position and prepare the patient as for a femoral block. Externally rotating the leg may facilitate access to the adductor canal.
- Place a high-frequency linear transducer in a transverse orientation over the medial thigh at the midpoint between ASIS and the superior pole of the patella.
 - Identify the sartorius, vastus medialis, and adductor longus muscles.
 - The femoral artery and vein lie within the adductor canal.
 - The saphenous nerve may be visualized just lateral to the artery, beneath the sartorius muscle and the vasto-adductor membrane.
- Estimate the depth of the nerve in the ultrasound image.
- After sterile skin preparation, place a skin wheal just lateral to the ultrasound probe.

- The depth of the nerve should guide the insertion site.
- Insert the block needle in the plane of the ultrasound image, visualizing the tip of the needle in real-time as the target is approached (**TECH FIG 3**).
- Traverse the sartorius muscle to position the needle tip just lateral to the femoral artery.
- A “pop” may be felt as the needle passes through fascial layers.



TECH FIG 3 • Positioning and approach for ultrasound-guided adductor canal block.

- Take care to avoid the femoral vein, which often lies deep and lateral to the artery, and may not be visible when pressure is applied to the ultrasound transducer.
- After careful aspiration, inject a small amount of local anesthetic.
 - Observe local anesthetic spread in the ultrasound image. This should appear as hypoechoic fluid filling the space deep to sartorius and lateral to femoral artery.
 - Ensure that local anesthetic is not tracking back along the sartorius muscle, but rather staying contained in the adductor canal while partially surrounding the femoral artery.
 - The needle should be advanced beyond the subsartorial fascia.
 - When the needle is positioned in close proximity to the nerve, and local anesthetic spread is confirmed around the nerve, an additional 10 to 15 mL of local anesthetic can be injected.
- The adductor canal block can be used as an analgesic block or as a surgical block in combination with sciatic block for surgery below the knee.

- For a surgical block, use 15 to 20 mL of 1.5% mepivacaine, 2% lidocaine, 0.5% bupivacaine, or 0.5% ropivacaine.
- For an analgesic block, use 10 to 15 mL of 0.25% bupivacaine or 0.25% ropivacaine.
- A catheter may be placed for continuous local anesthetic infusion.
 - Use 0.2% ropivacaine or 0.125% bupivacaine at 4 to 6 mL/h for continuous infusion, with a patient-controlled bolus of 2 to 4 mL every 30 minutes.
 - Infusions are generally continued for 2 to 3 days following surgery.

PEARLS AND PITFALLS

Positioning	■ In obese patients, retracting and taping the abdominal pannus helps optimize ultrasound imaging.
Sterility	■ For catheter placement, nerve blocks should be performed under strict sterile conditions.
Paresthesias	■ Avoid needle-to-nerve contact if possible. Use hydrodissection to achieve proper needle placement.
Vascular puncture	■ The femoral and adductor canal blocks involve needle placement in close proximity to vascular structures. To avoid vascular puncture, always visualize the needle tip in the ultrasound image while advancing.
Local anesthetic toxicity	■ Even with acceptable needle visualization, vascular puncture can occur. Always aspirate before injection, inject slowly, and visualize local anesthetic spread in the ultrasound image. Epinephrine may be used at a low concentration (1:400 000) as a vascular marker. Do not exceed the maximum safe dose of local anesthetics.
Catheter placement	■ Once a catheter is placed, its position should be confirmed with ultrasound imaging. Inject a small volume of local anesthetic through the catheter to ensure appropriate spread around the nerve.
Dressing	■ Catheters should be secured with a clear occlusive dressing. An anchoring device may be used as well and should be secured away from the surgical field or tourniquet site.
Block assessment	■ Quadriceps weakness is an early sign of successful femoral nerve block. Femoral and adductor canal nerve blocks are reliably assessed with testing the skin over the medial malleolus.

POSTOPERATIVE CARE

- Following a nerve block procedure, patients should be monitored for at least 30 minutes for any signs of local anesthetic toxicity.
- Patients should be contacted every day until the block wears off or the catheter is removed.
- Leakage from the catheter site is normal and expected but can be minimized with the application of surgical glue at the insertion site.
- Patients should be educated on expected weakness and fall risk.
 - Crutches and a knee immobilizer should be provided when appropriate.
 - Careful consideration should be given to using continuous femoral blocks for outpatients.
- Patients should be encouraged to use their systemic analgesics as needed.
 - Perioperative use of multimodal analgesia may include acetaminophen, NSAIDs, and/or gabapentinoids around the clock to improve pain management and decrease opioid usage.
 - Systemic analgesics should be initiated prior to the block wearing off.
- Dressings should be left alone until the catheter is removed.
 - Dressing changes are not necessary and may increase the risk of infection or catheter dislodgement.

OUTCOMES

- Peripheral nerve blocks provide better pain control than traditional medications; they reduce opioid consumption and its associated side effects.
- Patient satisfaction is higher when peripheral nerve blocks are used for perioperative pain control.
- Pain management strategies that include a peripheral nerve block may reduce the systemic inflammatory response and reduce persistent pain that is associated with surgery.⁴

COMPLICATIONS

- Peripheral nerve blocks have a low complication rate.
- Short-term complications may include prolonged numbness, weakness, or paresthesias.
- Long-term numbness, weakness, or paresthesias are rare.
 - In a multicenter, international clinical registry of regional anesthetics, the all-cause 60-day rate of neurological sequelae is 8.3/10 000.⁵

- Local anesthetic systemic toxicity (LAST) is a rare but potentially deadly complication.
- A LAST protocol should be in place in institutions where nerve blocks are performed.
 - LAST checklist and resuscitation guidelines should be posted in the block area (https://www.asra.com/content/documents/asra_last_checklist.2011.pdf).
 - Resuscitation medications (including Intralipid) and equipment should be available in the block area.
 - Access to cardiopulmonary bypass should be available in case of refractory cardiovascular collapse.

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CHAPTER Popliteal Nerve Blocks

Ming Zhuo-Stine and Sarah J. Madison

DEFINITION

- The popliteal nerve block targets the sciatic nerve in the popliteal fossa proximal to its bifurcation into the common peroneal and tibial nerves.
- It is a commonly used block for surgeries involving the lower leg, ankle, and foot.
- The nerve block can provide surgical anesthesia or postoperative analgesia. The duration of the block varies based on the choice of local anesthetic and the choice of single injection versus continuous catheter technique. For painful surgeries, the continuous catheter technique can provide several days of excellent postoperative pain control.¹
- The popliteal nerve block spares the medial aspect of the lower leg, an area that is innervated by the saphenous nerve. A femoral or saphenous nerve block must be performed in conjunction with a popliteal block for full sensory blockade of the lower leg (**FIG 1**).

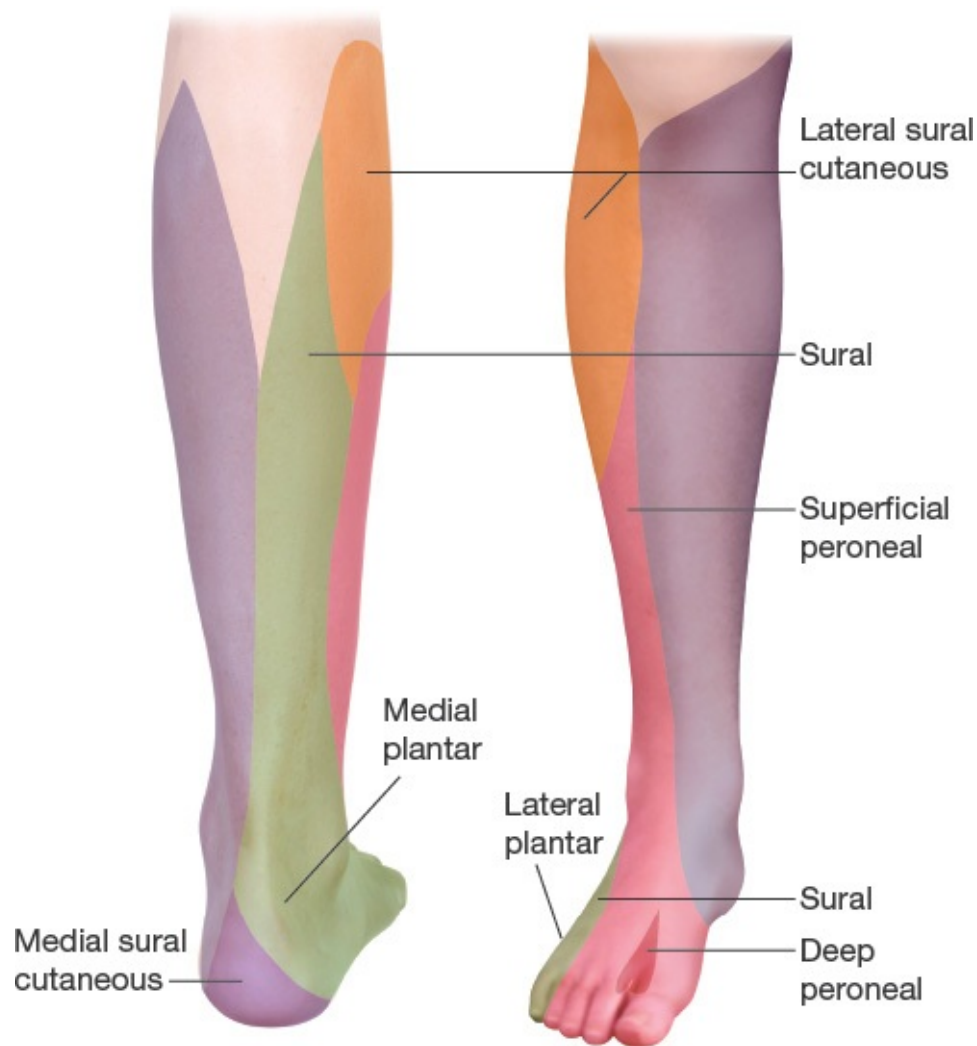


FIG 1 • Sensory distribution of the leg.

ANATOMY

- The sciatic nerve consists of two distinct nerves, the tibial and common peroneal nerves, which provide motor and sensory innervation to the majority of the lower leg. The two nerves have their own epineurium and are encased in an additional layer of connective tissue.^{2,3}
- Within the popliteal fossa, the branches of the sciatic nerve usually lie lateral and posterior to the popliteal vessels. More proximally, the nerve can be found between the biceps femoris, and semitendinosus and semimembranosus tendons.
- 2 to 10 cm proximal to the popliteal fossa crease, the sciatic nerve bifurcates into the tibial and common peroneal nerves. The common peroneal nerve then

travels laterally around the head and neck of the fibula, whereas the large tibial nerve continues caudally with the popliteal vessels.

- The popliteal nerve block is often performed proximal to the point of bifurcation or at the point of bifurcation, with injection of local anesthetic in or around the common connective tissue sheath described by some as the “paraneural sheath.”^{4,5}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Assess patient’s pain history and proposed surgery to determine if a popliteal nerve block is appropriate for the procedure.
- Examine patient for preexisting neuropathy and weakness.
- Assess for contraindications or increased risk of complications with regional anesthesia:
 - Patient refusal
 - Allergy to local anesthetic
 - Infection at site of nerve block or systemic infection
 - Coagulopathy
 - Preexisting neuropathy
 - Increased risk of compartment syndrome
- The patient’s surgeon and primary anesthesia team should agree with placement of block.
- Determine if a single injection nerve block or perineural catheter is indicated depending on the requirements for surgical anesthesia and postoperative analgesia. If a prolonged block is preferred for outpatient surgery, ensure that the patient will be able to care for an insensate limb at home and can be contacted for follow-up.
- Prior to starting the nerve block, ensure that the patient will be able to proceed with surgery and anesthesia (consents completed, appropriately NPO, etc.).

SURGICAL MANAGEMENT

Preoperative Planning

- Patient preparation:
 - Surgical and anesthesia consents signed
 - Monitors—blood pressure cuff, ECG, pulse oximeter, capnography
 - Supplemental oxygen via nasal cannula or facemask
 - Pillows, blankets, or tables to aid positioning

- Skin marker to mark the site laterality and surface landmarks
- Sedation to optimize patient comfort—typically midazolam and fentanyl
- Rescue drugs and emergency airway equipment available
- Supplies for single injection technique:
 - Antiseptic skin disinfectant
 - Sterile gloves, mask, hat
 - Sterile drapes or towels
 - 50- to 100-mm 20- to 22-gauge short-bevel insulated stimulating needle
 - Small syringe and small gauge needle with lidocaine for skin infiltration
 - 30 mL local anesthetic of choice
 - Nerve stimulator and/or ultrasound machine with high-frequency linear probe, sterile ultrasound probe cover, and ultrasound gel
- Supplies for continuous catheter technique:
 - Antiseptic skin disinfectant
 - Sterile gloves, gown, mask, hat
 - Ultrasound machine with high-frequency linear probe or nerve stimulator
 - 30 mL local anesthetic of choice
 - Sterile regional anesthesia tray:
 - Drapes or towels
 - Gauze
 - A 100-mm block needle, often a 17- or 18-gauge Tuohy needle
 - A flexible nerve block catheter with connector (may use stimulating catheter with nerve stimulator technique)
 - 10- to 20-mL syringe
 - Local anesthetic or saline for injection through needle
 - Extension tubing
 - Small syringe and small gauge needle with lidocaine for skin infiltration
 - Surgical skin glue
 - Transparent dressing
 - Catheter stabilization device
 - Ultrasound probe cover with ultrasound gel

Approach

- Ultrasound-Guidance Versus Nerve Stimulation
 - Nerve localization can be achieved using peripheral nerve stimulators and/or

ultrasound guidance.

- Over the past decade, ultrasound-guided nerve blocks have rapidly gained popularity because they provide several advantages compared to the nerve stimulator technique. The use of ultrasound provides direct, real-time visualization of target nerves, needle advancement, and spread of local anesthetic in the desired location.⁶ With continuous catheter techniques, the precise location of the catheter tip can be visualized. Blood vessels and smaller peripheral nerves can be identified and avoided. Research suggests that ultrasound guidance provides an improvement in time required to perform the block, block onset, and block success.^{7–10}
- For the popliteal sciatic block, ultrasound allows visualization of the precise point where the sciatic nerve bifurcates, which is variable between patients. Identifying this location is helpful in blocking both components of the sciatic nerve.
- For these reasons, although this chapter briefly covers nerve stimulator approaches, the focus will be on ultrasound-guided techniques, which have become routinely used in regional anesthesia.
- Ultrasound in-plane versus out-of-plane needle insertion approaches
 - With the in-plane approach, the needle is inserted at the side of the transducer, in line with the ultrasound beam (**FIG 2**). Because the needle is within the plane of imaging, the entire needle shaft and tip should be seen as echogenic line. In-plane approach is often used due to superior visualization of the entire needle as it is advanced toward the target.
 - With the out-of-plane approach, the needle is introduced perpendicular to the transducer (**FIG 3**). The needle crosses the plane of the ultrasound beam such that the needle shaft and tip are seen as an echogenic dot on ultrasound. Needle tip localization is more difficult with this approach. Techniques to help locate the needle tip include looking for tissue displacement, scanning for the needle tip, and injection of fluid to separate tissue planes (hydrodissection). One advantage of using the out-of-plane approach is that the needle traverses only skin and adipose tissue, avoiding muscle.
- Approaches related to patient positioning
 - A wide range of positions can be used during popliteal sciatic nerve blockade. Each is discussed and illustrated in further detail in the following section.
 - Choice of positioning is typically dictated by a combination of patient comfort, patient mobility, operator ergonomics, and the operator's personal

preference. Body habitus, pain, or the presence of external fixation devices may limit the ability of the patient to assume a lateral or prone position.

- Patients may be positioned supine or prone for nerve stimulator techniques.
- Patients may be positioned supine, lateral, or prone for ultrasound-guided nerve blocks. Regardless of the position, the ultrasound image is identical. If the out-of-plane needle insertion approach is desired, prone or lateral positioning provides better access.



FIG 2 • In-plane approach to popliteal sciatic nerve block.

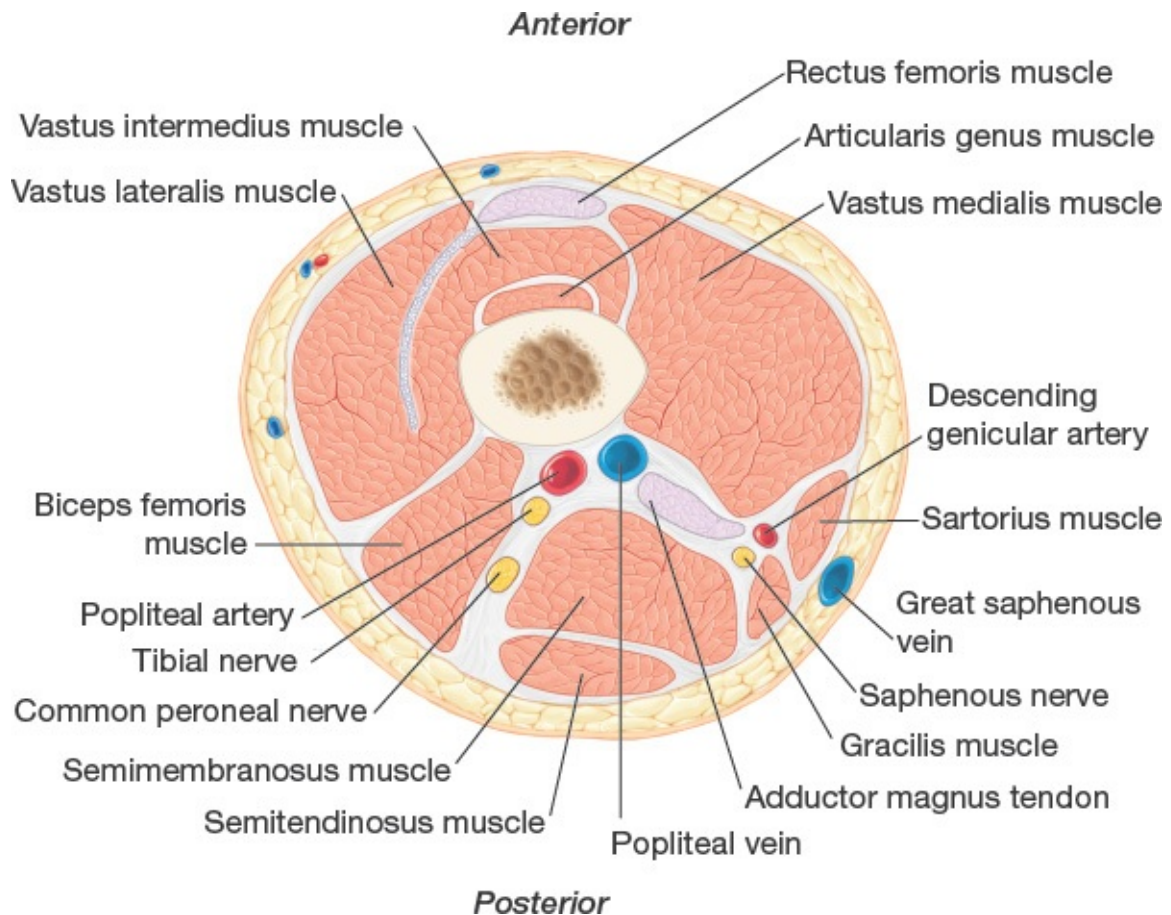


FIG 3 • Out-of-plane approach to popliteal sciatic nerve block.

TECHNIQUES

■ Nerve Stimulator, Lateral Approach

- The patient is positioned supine with leg slightly elevated to visualize foot movement. This is best achieved by placing the leg on a small stack of blankets such that the foot and heel protrude beyond the blankets.
- Main landmarks are the popliteal fossa crease and the muscular groove between the biceps femoris and vastus lateralis muscles. The site of needle insertion is within the muscular groove, about 7 to 8 cm cephalad to the popliteal crease; the muscular groove may be accentuated by having the patient lift their leg off of the plane of the table. Use a skin marker to denote landmarks.
- Prepare the skin with an antiseptic solution and infiltrate the proposed needle insertion point with local anesthetic via a small gauge needle. Connect the peripheral nerve stimulator to a 100-mm 20- to 22-gauge short-bevel insulated stimulating needle. Using sterile technique, insert the needle perpendicular to the skin and advance in a horizontal plane between the vastus lateralis and biceps femoris muscles until femur is contacted; bony contact provides a reference point for nerve localization. The sciatic nerve is typically 1 to 2 cm beyond the skin-to-femur distance and located posterior to the femur (**TECH FIG 1**).
- With the nerve stimulator set to 1.5 mA, withdraw needle almost to the skin and redirect at a 30-degree angle posteriorly until foot twitch is seen, typically at a depth of 5 to 7 cm. Stimulation of the common peroneal nerve causes dorsiflexion and foot eversion. Stimulation of the tibial nerve, which is more medial, results in plantar flexion and foot inversion. Tibial stimulation is preferred because it may result in a higher rate of complete sciatic nerve block.¹¹ Local twitches of the biceps femoris muscle or vastus lateralis muscle indicates that the needle is located too superficial or anterior, respectively.
- If a motor response is not elicited, withdraw needle to skin and redirect 5 to 10 degrees more posterior.
- Once sciatic nerve stimulation is obtained, make small needle adjustments until twitches are obtained at 0.3 to 0.5 mA.
- Check for intravascular placement with gentle aspiration and then slowly inject 30 to 40 mL of local anesthetic.



TECH FIG 1 • Cross-sectional anatomy of the distal thigh (right leg 8 cm above knee).

■ Nerve Stimulator, Posterior Approach

- Position the patient prone with the leg to be blocked protruding from the end of the bed or slightly elevated on a blanket to allow for visualization of foot movement.
- Primary landmarks are the popliteal fossa crease, tendon of the biceps femoris laterally, and tendons of the semitendinosus and semimembranosus muscles medially. Knee flexion against resistance can help accentuate the tendons and identify the knee crease. The needle insertion point is about 7 cm above the popliteal fossa crease 1 cm lateral and 1 cm caudal to the apex of the popliteal fossa. Use a skin marker to denote landmarks (**TECH FIG 2**).
- Prepare the skin with an antiseptic solution and infiltrate the proposed needle insertion point with local anesthetic via a small-gauge needle. Connect the

peripheral nerve stimulator set at 1.5 mA to a 50-mm 20- to 22-gauge short-bevel insulated stimulating needle.

- Using sterile technique, insert the needle 45 to 60 degrees to the skin, then advance the needle until foot twitches are obtained. Typical depth is 3 to 5 cm from the skin. Stimulation of the common peroneal nerve causes dorsiflexion and foot eversion. Stimulation of the tibial nerve, which is more medial, results in plantar flexion and foot inversion. Tibial stimulation is preferred because it may result in a higher rate of complete sciatic nerve block.¹¹
- If a motor response is not elicited, withdraw the needle to the skin and redirect 5 to 15 degrees laterally. If there is continued difficulty localizing the sciatic nerve, withdraw needle to skin and reinsert 1 cm laterally in incremental steps.
- Once sciatic nerve stimulation is obtained, make small adjustments to the needle position to obtain foot twitches at 0.3 to 0.5 mA.
- Check for intravascular placement with gentle aspiration, and then slowly inject 30 to 40 mL of local anesthetic.



TECH FIG 2 • Positioning and landmarks for stimulator-guided popliteal block.

■ Nerve Stimulator, Continuous Catheter Technique

- Use the same procedure as for single injection nerve stimulator technique described above, but with a larger insulated stimulating Tuohy needle to allow for passage of a catheter. An in situ catheter allows for continued

dosing of local anesthetic to provide prolonged anesthesia and analgesia. Either a stimulating or nonstimulating catheter can be used:

■ Nonstimulating catheter:

- After localizing the sciatic nerve with motor response at 0.3 to 0.5 mA, inject local anesthetic to open up space for the catheter.
- Insert a catheter through the Tuohy needle and advance 3 cm past the tip of the needle. If catheter insertion is difficult, slight adjustment of the needle or direction may facilitate catheter advancement.
- Carefully withdraw needle while simultaneously advancing the catheter. Aspirate the catheter to check for inadvertent intravascular placement and secure using a catheter stabilization device and clear dressing.

■ Stimulating catheter:

- Localize the sciatic nerve with a motor response around 0.5 mA. Do not inject local anesthetic or saline through the needle or the motor response will be lost. D5W can be used if necessary.
- Insert a stimulating catheter with the nerve stimulator now attached to the catheter. Advance the catheter 3 to 5 cm past the needle tip while maintaining a motor response. If motor response is lost, withdraw and readvance the catheter. If catheter insertion is difficult, withdraw the catheter and adjust the needle slightly to facilitate catheter advancement.
- Once the catheter is in a satisfactory position, the needle can then be carefully withdrawn while advancing the catheter simultaneously. Feed additional catheter under the skin to minimize premature dislodgment. Aspirate the catheter to check for inadvertent intravascular placement and secure.

■ Ultrasound-Guided, In-Plane Needle Insertion Approach

- Of the various approaches described, this is the most commonly used approach due to ease of needle and target visualization.
- Positioning—Patients may be positioned supine, lateral decubitus, or prone (**TECH FIG 3**). Regardless of the position selected, ultrasound imaging and needling are similar. Thus, patient positioning is determined by a combination of patient comfort, patient mobility, and operator ergonomics and preference.

■ Supine position

- Position the patient supine with the operative leg elevated using blankets, pillows, or a table to accommodate an ultrasound probe beneath the thigh.
- The operator is positioned on the side to be blocked with the ultrasound screen on the opposite side of the patient.

■ Lateral decubitus position

- Position patient lateral with the procedural leg on top, knee extended. The dependent leg can be bent at the knee to enhance stability.
- Operators may choose to stand in front of the patient, facing the anterior thigh with the ultrasound probe directed toward themselves or stand behind the patient, facing the posterior aspect of the thigh, pointing the probe away from themselves.

■ Prone position

- Position the patient prone with the operative leg slightly abducted. A blanket folded under the lower leg may help relax the hamstring tendons to facilitate ultrasound transducer placement.
- The operator is positioned on the side to be blocked with the ultrasound screen on the opposite side of the patient.

■ Imaging

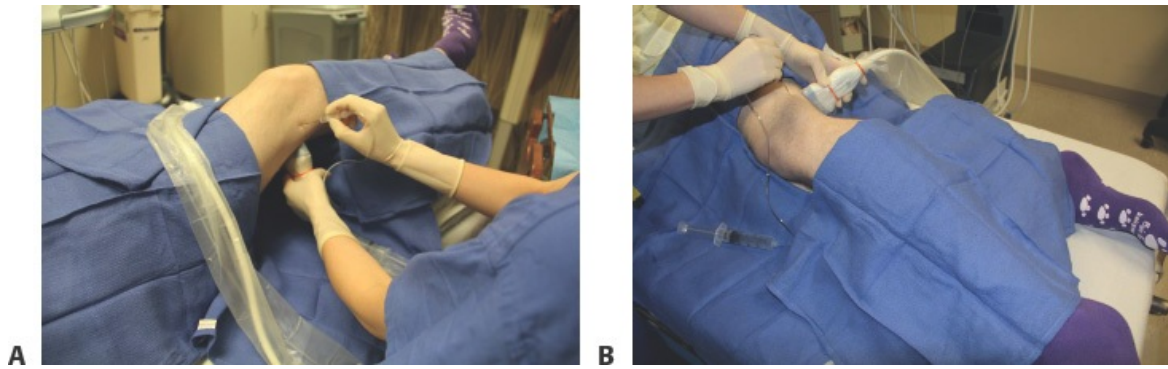
- Disinfect the skin with an antiseptic solution, drape the procedural area, and cover the ultrasound probe with a sterile ultrasound sheath and gel.
- Place the transducer in a transverse orientation in the popliteal fossa to obtain a short-axis view of the nerves.
- Perform a systematic survey of the surrounding structures. Identify the femur. The pulsatile popliteal artery and the accompanying vein are located posterior to the femur. The sciatic nerve appears as a hyperechoic oval structure with a honeycomb pattern that is posterior and lateral to the artery, medial to the biceps femoris muscle, and lateral to the semitendinosus and semimembranosus muscles.
- Optimize the ultrasound image by adjusting variables especially frequency, gain, depth, and focal zones. Tilting the ultrasound transducer to direct the beam caudally may enhance the visualization of the nerve by bringing the ultrasound plane more perpendicular to the nerve.
- Scan proximally and distally along the sciatic nerve to identify the bifurcation point of the common peroneal and tibial nerves. This division usually occurs 2 to 7 cm proximal to the popliteal crease and at a depth of 2

to 4 cm.

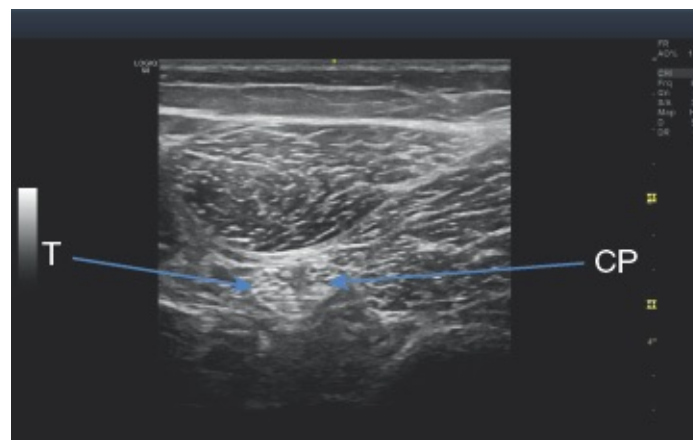
- Choose a location just proximal to the bifurcation, where the peroneal and tibial nerves are still enclosed in a common connective tissue sheath (**TECH FIG 4**).

■ Needling

- Determine the optimal needle path. Identify small vessels that should be avoided. The needle insertion point will be near the lateral aspect of the transducer.
 - Choose an insertion point lateral to the transducer. The needle will traverse the biceps femoris muscle.
 - Choose an insertion point close to the transducer to decrease the amount of muscle tissue along the needle path.
- Infiltrate the skin with local anesthetic at the insertion site. Use a 20- to 22-gauge 100-mm block needle. Flush the tubing and syringe to remove air since air will obscure the ultrasound image.
- Introduce the block needle in the same plane as the ultrasound beam with the bevel of the needle facing the probe. The needle shaft and tip should always be visualized during needle advancement.
- Carefully advance needle under direct visualization toward the nerve sheath, taking care to bring the needle close to the edge of the nerve, to avoid puncturing the nerve.
- Aspirate, then inject 1 to 2 mL of local anesthetic. Never inject or advance needle if patient complains of pain or if high pressure (greater than 15 psi) is met on injection or if the nerve is swelling. These signs dictate an immediate repositioning of the needle tip.
- If in the correct location, the hypoechoic fluid should surround the nerve completely.
- If fluid spread is not ideal, reposition needle to achieve adequate circumferential spread with a total of 20 to 30 cc local anesthetic.



TECH FIG 3 • Supine, lateral decubitus (**A**), and prone positioning (**B**) for in-plane ultrasound-guided popliteal block.



TECH FIG 4 • Ultrasound image of the sciatic nerve at its bifurcation. T, tibial nerve; CP, common peroneal nerve.

■ Ultrasound-Guided, Out-of-Plane Needle Insertion Approach

- Needle localization is more difficult with an out-of-plane approach in comparison to an in-plane approach. Because the needle crosses the plane of the ultrasound beam, the needle shaft and tip are seen only as an echogenic dot. The advantage is that the needle traverses only skin and adipose tissue, avoiding muscle.
- Positioning—Patients may be positioned lateral decubitus or prone for out-

of-plane needling. Regardless of the position selected, ultrasound imaging and needling are identical. Choose the best position based on patient comfort and operator preference.

■ Imaging

- Disinfect and prepare the site as described above.
- Place the transducer in the transverse orientation in the popliteal fossa to obtain a short-axis view of the sciatic nerve.
- Follow the same steps for imaging as with the in-plane ultrasound approach.

■ Needling

- Align the sciatic nerve in the center of the ultrasound screen and place a wheal of local anesthetic in the center of the probe, close to the probe.
- Insert a block needle through the skin wheal directed approximately 60 to 80 degrees cephalad. Aim to place the needle tip to the side of the nerve to avoid nerve trauma.
- As the needle crosses the plane of the ultrasound beam, it will appear in cross-section as an echogenic dot. Because both the needle shaft and tip have a similar appearance, track the tip with the probe as the needle is advanced. If not directly visualized, the needle tip may be inferred by tissue displacement along the needle path as well as hydrolocation.
- Aspirate, and then slowly inject local anesthetic while observing the fluid spread. Ideally, hypoechoic fluid should be seen spreading circumferentially around the hyperechoic nerve. Inject 20 to 30 mL of local anesthetic.

■ Ultrasound-Guided Continuous Catheter Technique

- Catheter placement provides a continuous infusion or additional boluses of local anesthetic to provide prolonged anesthesia or pain control.
- Strict aseptic technique is crucial for prevention of infectious complications.
- Both in-plane and out-of-plane ultrasound-guided approaches can be utilized.
- Catheter placement utilizes the same needle placement procedure as described above but requires a larger needle for passage of a perineural catheter. After the needle is confirmed to be the correct location, an

additional 5 to 10 mL bolus of saline or local anesthetic solution is injected to facilitate catheter advancement.

- Carefully advance the catheter about 3 to 5 cm past the needle tip. If catheter insertion is difficult, withdraw the catheter and try small adjustments of the needle. Before or after needle removal, confirm catheter tip location with injection through the catheter, watching for appropriate spread.
- Carefully withdraw the needle while simultaneously advancing the catheter in different tissues. Overfeeding additional catheter under the skin may help prevent accidental dislodgment.
- Carefully secure the catheter in place with an anchoring device and clear dressing. Use a total of 20 to 30 mL of local anesthetic.

PEARLS AND PITFALLS

Identification of nerve and structures

- Knowledge of both surface anatomy and ultrasound anatomy is essential.
- Tilt the transducer beam caudally toward the foot to direct ultrasound waves perpendicular to the nerve and enhance visualization.
- Asking the patient to plantar flex and extend their foot causes the tibial and common peroneal nerves to slide against each other, known as the “seesaw sign.”¹²
- At the popliteal crease, the vessels are immediately anterior to the tibial nerve. Reduce transducer pressure to visualize the popliteal vein. Trace the nerve proximally to where the common peroneal joins to form the sciatic nerve.

Nerve block coverage

- In combination with a saphenous nerve block, popliteal block provides complete sensory blockade below the knee.
- Popliteal block does not cover thigh tourniquet pain. The patient may require general anesthesia or a femoral nerve block instead of a selected saphenous when a thigh tourniquet is used.

Approach

- Ultrasound imaging allows for various patient positions and needle approaches. Choice of approach depends on patient and operator comfort.

Catheter placement

- For a continuous technique, once the needle is in optimal position, inject a small amount of saline or local anesthetic to facilitate

catheter advancement.

- Check the catheter tip location by injecting a small volume of saline or local anesthetic with ultrasound visualization.
- Feed additional catheter in the muscle or subcutaneous tissue to prevent inadvertent catheter dislodgment.

Postblock safety

- Always counsel patients on fall risk and injury risk to a numb extremity. Providing a boot will improve stability. Patients must not weight bear until the block has fully resolved.
- Both thorough preoperative counseling and clarification of patient expectations are essential to the successful management of the block.

POSTOPERATIVE CARE

- Block onset time varies dramatically from 10 to 45 minutes depending on patient, medication selection, and proximity of the injectate to the nerve.
- Thorough patient education is essential for the successful function and safety of the nerve block.
- All patients should be followed postoperatively for block resolution and to detect complications.
- All patients with nerve block catheters should be evaluated daily while in the hospital or contacted by phone if receiving nerve block infusion at home.
- Catheter leakage at the site of insertion and catheter dislodgment may occur. Patients should have additional analgesics available for breakthrough pain or in the event of catheter dislodgment.

COMPLICATIONS

- Injuries as a result of an insensate limb—Instruct patient, nurses, and caregivers on proper care of an insensate extremity including fall precautions and positioning. Avoid nerve blocks in patients who have a high risk of compartment syndrome.
- Infection—Use strict aseptic technique, avoid perineural catheter placement in patients with active infections, and limit duration of perineural catheter use.
- Hematoma formation—Ultrasound imaging and avoidance of vascular trauma or multiple needle passes may minimize risk.
- Nerve injury—Rare complication from direct needle trauma or intraneural injection; usually resolves in weeks to months. Risk may be increased in patients with preexisting nerve injury. More common causes of nerve injury

include surgical, ischemic, and compressive nerve injuries. Avoid tourniquet placement over nerve block site to decrease ischemic nerve injury. Avoid needle advancement or injection if the patient complains of pain or paresthesias or if increased pressure (greater than 15 psi) is felt during injection. Avoid needle advancement during an ultrasound-guided procedure if the target or needle tip is poorly visualized.

- Local anesthetic toxicity—Avoid intravascular injection by aspirating prior to injection and aspirating frequently during injection. Patients should be monitored following the nerve block. Have rescue medications, such as lipid emulsion, and emergency airway equipment readily available.

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CHAPTER Ankle Block

Andrew Lyons and Fred Mihm

DEFINITION

- Ankle block is a highly effective peripheral nerve block that results in anesthesia of the entire foot. This block has been shown to reduce both postoperative pain and opioid consumption following foot surgery.^{1,2}
- Though a number of injections are required, a low total volume of local anesthetic injectate is required to successfully perform an ankle block.
- The ankle block can be useful due to its relatively low-risk profile, technical ease, and efficacy.
- Typical plastic surgery procedures that utilize this block include tendon repair and distal foot or toe amputation.

ANATOMY

- An ankle block is the selective blockade of both the saphenous nerve and the four terminal branches—deep and superficial peroneal, tibial, and sural nerves—of the sciatic nerve.
- Ankle block is considered to be an easy block to perform because the terminal nerves of interest are generally superficial and are reliably located next to readily identifiable surface landmarks.

POSITIONING AND PREPARATION

- Ankle block is most commonly performed with the patient in the supine position.
- Elevation of the foot by bolstering the calf with a pillow will facilitate access to the ankle (**FIG 1**).
- It is helpful to have an assistant available to gently place the leg in either

internal or external rotation.

MATERIALS

- Topical disinfectant (chlorhexidine, betadine, or equivalent)
- Sterile gloves
- Ultrasound with a small, high-frequency linear probe
- 20-mL sterile syringe
- 22-gauge short-bevel block needle
- Non-epinephrine containing local anesthetic

GENERAL CONSIDERATIONS

- The goal of the ankle block is to deliver local anesthetic adjacent to the five nerves that innervate the foot.
- Needle insertion can be either in-plane or out-of-plane for each of the terminal nerve blocks that comprise an ankle block.
- 3 to 5 mL of local anesthetic per nerve is required for a successful block.
- The tibial nerve should be addressed before blocking the other nerves because of its relatively larger size and resultant resistance to the effects of local anesthetics.
- The use of ultrasound guidance augments the clinical efficacy of an ankle block, especially for the tibial and deep peroneal nerves, which are relatively deep.³⁻⁶
- A small high-frequency linear ultrasound transducer is recommended.



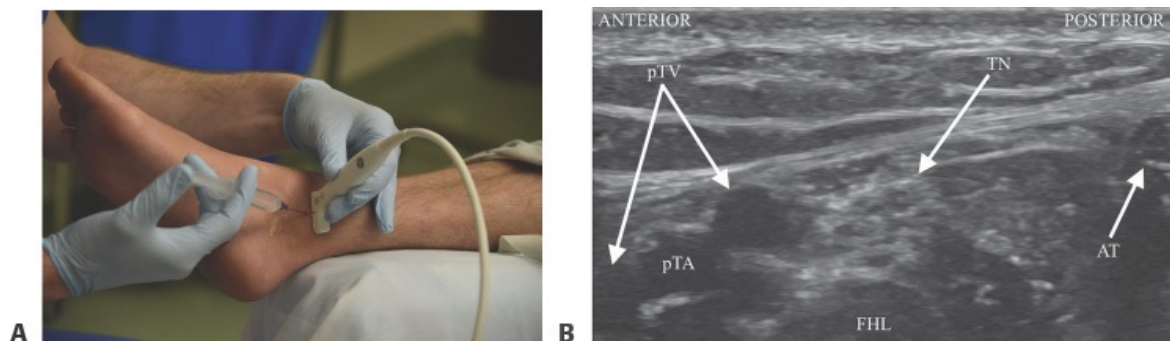
FIG 1 • Proper positioning of the foot is essential when performing an ankle block. The patient is placed supine

and a pillow is used to facilitate access to the ankle.

TECHNIQUES

■ Tibial Nerve

- Landmark technique: Inject 3 to 5 mL of local anesthetic in the deep tissue of the ankle posterior to the medial malleolus and the posterior tibial artery. The injection is typically performed after the needle contacts the underlying bone (tibia) and is withdrawn 0.5 to 1 cm.
- Unlike the other nerve blocks that comprise an ankle block, a nerve stimulator can be used as an adjunct for nerve block; plantar flexion of the toes indicates proper needle placement with tibial nerve stimulation.
- Ultrasound-guided technique: Place the ultrasound probe horizontally just superior and posterior to the medial malleolus to visualize the tibial nerve (**TECH FIG 1A**).
 - The tibial nerve is superficial to both the belly and the tendon of the flexor hallucis longus.
 - The tibial nerve lies immediately posterior to the posterior tibial vessels of the ankle; at this level, the nerve and vessels may be easily mistaken for one another. Sometimes, a fascia separates the nerve from the vessels, placing the nerve deeper and partially behind the vessels (**TECH FIG 1B**).
 - Color Doppler imaging may be helpful in distinguishing the posterior tibial artery from surrounding structures.

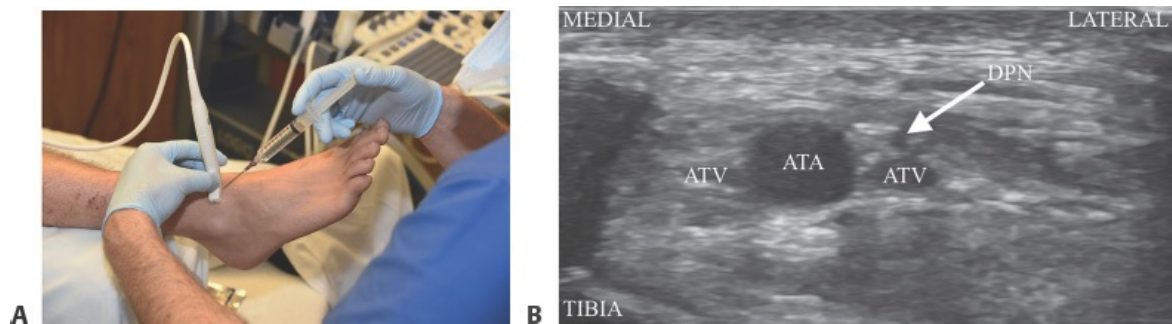


TECH FIG 1 • **A.** Tibial nerve block is performed by injecting local anesthetic into the deep tissue of the

ankle. **B.** Ultrasound image of a tibial nerve block demonstrating the nerve (*TN*) in the deep tissue of the ankle just posterior to the vascular complex formed by both the posterior tibial artery (*pTA*) and the posterior tibial vein (*pTV*). Note the flexor hallucis longus (*FHL*) is found deep to the nerve. The Achilles tendon (*AT*) serves as the most posterior boundary of the image.

■ Deep Peroneal Nerve

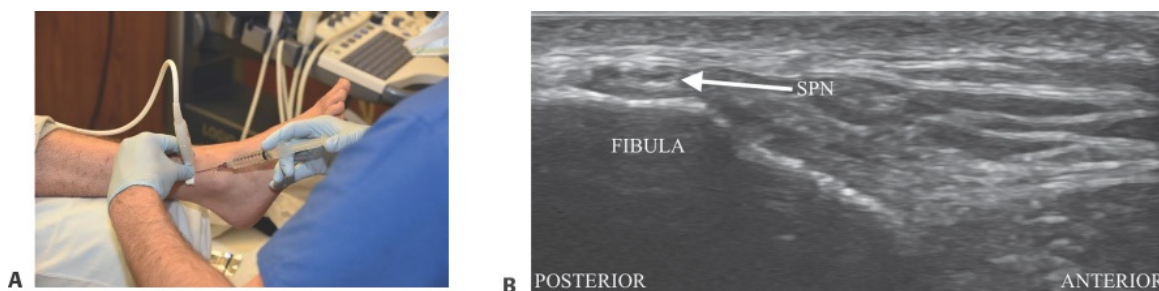
- Landmark technique: Identify the extensor hallucis longus tendon and the dorsalis pedis pulse on the dorsal aspect of the ankle. Insert the block needle between these two landmarks perpendicular to the skin and inject 3 to 5 mL of local anesthetic into the deep tissue.
- Ultrasound-guided technique: Place the ultrasound probe in a transverse orientation over the anterior foot just above the line joining the malleoli (**TECH FIG 2A**) to visualize the deep peroneal nerve adjacent to the dorsalis pedis artery (**TEHC FIG 2B**).



TECH FIG 2 • A. Deep peroneal nerve block is performed by injecting local anesthetic into the deep tissue of the anterior ankle. **B.** Ultrasound image of a deep peroneal nerve block demonstrating the deep peroneal nerve (*DPN*) located lateral to the distal-most branch of anterior tibial artery (*ATA*), also known as the dorsalis pedis artery. Branching of the anterior tibial vein (*ATV*) is common at this location.

■ Superficial Peroneal Nerve

- Landmark technique: Identify the line between the injection point for the deep peroneal nerve block and the lateral malleolus. Inject 3 to 5 mL subcutaneously along this line.
- Ultrasound-guided technique: Place the ultrasound probe in a transverse orientation just lateral to the deep peroneal nerve (**TECH FIG 3A**) to allow for visualization of the superficial peroneal nerve (**TECH FIG 3B**).

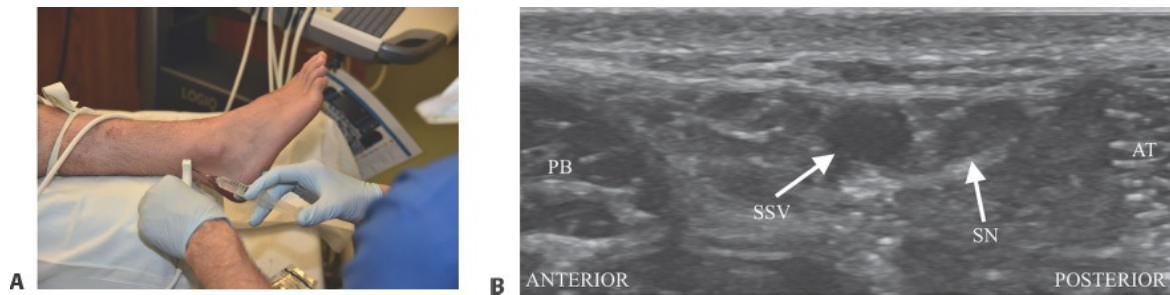


TECH FIG 3 • A. Superficial peroneal nerve block is performed by injecting local anesthetic into the subcutaneous tissue of the ankle just lateral to the location of deep peroneal nerve block. **B.** Ultrasound image of a superficial peroneal nerve block demonstrating the superficial peroneal nerve (SPN) in the subcutaneous tissue along the line between the location of the deep peroneal nerve and the lateral malleolus. This nerve is sometimes difficult to visualize using an ultrasound.

■ Sural Nerve

- Landmark technique: Inject 3 to 5 mL of local anesthetic in the subcutaneous plane along the line formed between the lateral malleolus and the Achilles tendon.
- Ultrasound-guided technique: Place the ultrasound probe just posterior to the lateral malleolus to visualize the sural nerve (**TECH FIG 4A**).
 - The sural nerve lies adjacent to the short saphenous vein in the groove between the Achilles tendon and the peroneus brevis muscle (**TECH FIG**

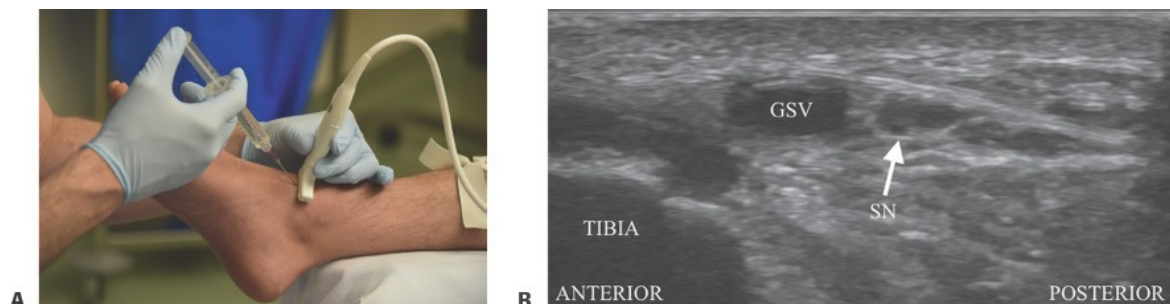
4B).



TECH FIG 4 • A. Sural nerve block is performed by injecting local anesthetic into the subcutaneous tissue of the groove between the lateral malleolus and the Achilles tendon. A calf tourniquet may facilitate the ultrasound imaging of this block by enlarging the short saphenous vein. **B.** Ultrasound image of a sural nerve block demonstrating the sural nerve (SN) in the groove between the Achilles tendon (AT) and the peroneus brevis (PB) muscle. The short saphenous vein (SSV) is anterior to the sural nerve.

■ Saphenous Nerve

- Landmark technique: Inject 3 to 5 mL of local anesthetic in the superficial tissue of the ankle 1 cm anterior to the medial malleolus.
- Ultrasound-guided technique: Place the ultrasound probe in a transverse orientation, just anterior to the medial malleolus (**TECH FIG 5A**) to visualize the saphenous nerve traveling lateral to the great saphenous vein (**TECH FIG 5B**).



TECH FIG 5 • A. Saphenous nerve block is performed by injecting local anesthetic into the subcutaneous tissue of the ankle just anterior to the medial malleolus. A calf tourniquet may facilitate the ultrasound imaging of this block by enlarging the great saphenous vein. **B.** Ultrasound image of a saphenous nerve block demonstrating the saphenous nerve (SN) just posterior to the great saphenous vein (GSV).

■ Complications

- Multiple injections about the ankle may result in significant patient discomfort. IV sedation can be used to enhance patient comfort during the procedure.
 - Intravascular injection is uncommon and the risk for local anesthetic toxicity is low, as small volumes of local anesthetic are generally used. The absence of epinephrine from the local anesthetic solution eliminates the risk of intravenous epinephrine toxicity and reduces risk of ischemia of the anesthetized foot.
 - Induration of the superficial tissues around injection sites is not uncommon.
 - Ankle hematoma as a result of vascular injury may also occur, but is usually self-limited.
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CHAPTER Epidural Anesthesia

Rachel C. Steckelberg, Jean-Louis Horn, and Sarah Madison

DEFINITION

- Neuraxial anesthesia is a type of regional anesthesia technique in which anesthesia medication is injected into the tissue surrounding the nerve roots as they exit the spine (eg, epidural anesthesia) and/or directly into the cerebrospinal fluid (eg, spinal anesthesia or subarachnoid anesthesia).
- Continuous epidural anesthesia is a neuraxial anesthetic technique that may be used for postoperative analgesia, surgical anesthesia, and obstetric analgesia.
- Epidural anesthesia may be used to provide anesthesia at any level below the chin, either alone or in combination with general anesthesia.
- Epidural anesthesia may be administered as a single injection or as a continuous infusion via a catheter.
- The location of the epidural placement determines the distribution of analgesia. An epidural block may be performed at the cervical, thoracic, lumbar, or sacral (eg, caudal) levels.
- A continuous infusion of local anesthesia and/or opioid pain medication may provide postoperative pain control for several days after surgery.
- Motor block with an epidural may range from none to complete, depending on the choice of drug, concentration, dosage, and/or level of administration.
- Epidural analgesia is often part of a multimodal regimen that also includes systemic medications.

ANATOMY

- The epidural space surrounds the spinal meninges (eg, dura mater) and the spinal nerve roots as they course outward to become peripheral nerves. It also contains venous plexuses, lymphatics, and fat tissue.

- Knowledge of surface anatomy landmarks is essential for safe and reliable epidural placement (Table 1).
 - In the cervical area, the most prominent spinous process is usually C7.
 - The inferior angle of the scapula can be used to estimate the level of the T7 spinous process with the arms located at the side.
 - The spinal cord terminates at level L1 in adults. The dural sac terminates at S2.
 - The body of L4 and/or the interspace between L4 and L5 spinous processes typically can be found by drawing a line between the highest points of both the iliac crests (Tuffier line).
 - The line connecting the posterior superior iliac spine (PSIS) crosses at the level of the S2 posterior foramina.
 - The sacral hiatus is located by palpating for a depression (eg, the sacral hiatus) just above or between the gluteal clefts and above the coccyx. This is the point of entry for caudal epidural blocks.
 - By counting up or down from these surface anatomy reference points, other spinal levels can be identified.
- Epidural anesthesia may be performed at any level of the spinal cord. However, each epidural location (cervical, thoracic, and lumbar) has unique anatomic features (Table 2).
- The angle of the spinous processes become progressively less angled closest to the base of the spine. For example, the spinous processes of the cervical and lumbar spine are more horizontal than the spinous processes in the thoracic spine, which are typically slanted in a more caudad direction and can overlap significantly. Thus, the technique for placement of the epidural needle varies considerably depending on the level selected.
- The ideal location of epidural placement is at the same dermatome of the surgical incision.

Table 1 Anatomic Landmarks for Identifying Vertebral Levels for Epidural Injection

Anatomic Landmark	Features
C7	Vertebral prominence (most prominent spinous process in neck)
T3	Root of spine of scapula
T7	Inferior angle of scapula

L4	Line between iliac crests
S2	Line between posterior inferior iliac spines
Sacral hiatus	Depression or groove above or between gluteal clefts directly above the coccyx

Table 2 Anatomic Features of Cervical, Thoracic, and Lumbar Spine Regions

Anatomic Feature	Cervical	Thoracic	Lumbar
Size	Small	Larger	Largest
Spinous process	Slender, often bifid (C2-C6)	Long and thick, project inferiorly	Short and blunt, project posteriorly
Transverse process	Small	Large	Large and blunt
Size of intervertebral discs	Thick (compared to vertebral bodies)	Thin (compared to vertebral bodies)	Very large

PATIENT HISTORY AND PHYSICAL FINDINGS

- A preoperative history and physical must be performed prior to epidural placement. Particular attention should be paid to anesthetic history, preexisting neuropathies, history of bleeding diatheses, medication history (especially any use of blood thinning medications), medication allergies, a history of prior neuraxial anesthesia and/or spine surgery (including spinal fusion surgery), and any history of spine disorders (including spina bifida and/or scoliosis). If imaging of the spine is available and would be useful for epidural placement, it should be reviewed.
- Physical exam should pay particular attention to any localized infections, masses, or other irregularities at the site of the planned epidural placement or surrounding areas.
- Contraindications to epidural anesthesia include patient refusal, bleeding disorders, severe hypovolemia, elevated intracranial pressure, infection at the site of epidural needle placement, flow-limiting cardiac lesions such as mitral or aortic valve stenosis, and local spinal pathology.

IMAGING

- When available, previous imaging of the spine should be reviewed, but routine imaging is not typically required prior to epidural placement.
- Preinsertion ultrasound will assist in accurate identification of the vertebral level of interest, the midline, and the depth of the epidural space (**FIG 1**).^{1–3}

NONOPERATIVE MANAGEMENT

- The balance of risks and benefits must be considered for every interventional technique, including epidural anesthesia. Depending on a number of factors (including patient history, anatomy, surgery type, etc.), it may be more appropriate to employ alternative methods of analgesia, including peripheral nerve blocks and/or systemic medications for pain control.
- Careful attention must be paid to the maximum dose of additional opioid or other local anesthetic medications used for pain control when an epidural is in place.
- Nonopioid pain medications can also be useful adjuncts to epidural anesthesia/analgesia.

SURGICAL MANAGEMENT

- Epidural anesthesia is indicated for postoperative analgesia of any surgical procedure below the level of the neck.
- Thoracic epidurals are rarely used for primary surgical anesthesia, but more commonly for intraoperative and postoperative analgesia.
- Single injection or catheter techniques are useful for chronic pain management.
- Infusions via an epidural catheter are helpful in providing prolonged analgesia and may enhance postoperative ventilation in patients with underlying lung pathology following thoracic or chest wall surgery.
- Local anesthetic via epidural administration will block sympathetic, sensory, and motor nerves. The effects are dependent on the volume, concentration, and type of medication administered via the epidural.

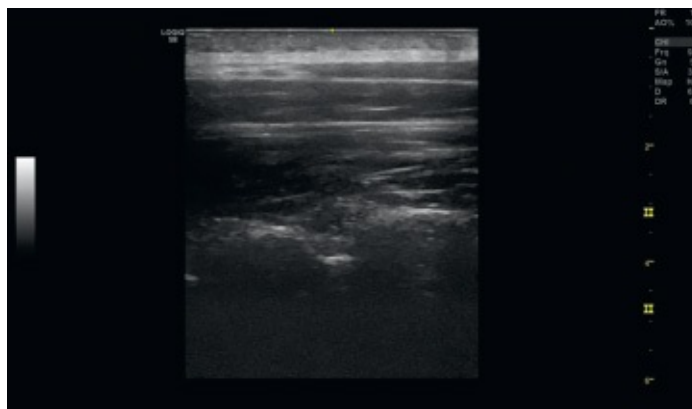


FIG 1 • Ultrasound of the lumbar and thoracic spine for epidural placement.

Preoperative Planning

- Surgical site, extent of incision, anticipated degree of postoperative pain, and/or any preexisting conditions (bleeding disorders, preexisting neuropathies, etc.) that may increase the risk of complications should be discussed among the care team prior to epidural placement.
- If an epidural anesthetic is under consideration, the risks and benefits should be discussed with the patient. The patient must be informed and prepared for neuraxial anesthesia and the epidural must be an appropriate anesthetic technique for the type of surgery.
- Epidural anesthesia is rarely considered an appropriate mode of analgesia for outpatient procedures.
- Neuraxial anesthetic techniques, such as epidural anesthesia, should only be performed in facilities that have the equipment and drugs needed for intubation, resuscitation, and general anesthesia available.

Positioning

- The most common patient positions for epidural placement are sitting and lateral.
- In very obese patients, it may be easier to appreciate the anatomic midline with the patient in the upright (eg, sitting) position.
- In the sitting position, the patient should rest the elbows on his or her thighs or a table, or should hug a pillow. The bed should be flat and the patient's hips level to the bed.
- The patient should be instructed to arch his/her back to provide spinal flexion.

- Arching the back like a “mad cat” maximizes the area between the adjacent spinous processes and brings the spine closer to the skin surface (**FIG 2A**).
- Alternatively, the lateral decubitus position may be considered for epidural placement. In this position, the patient lies on his or her side with knees flexed into the chest and pulled high, assuming the “fetal” position (**FIG 2B**). An assistant should help the patient hold this position.

Approach for Lumbar and Thoracic epidurals

- Depending on the level of desired epidural placement, the epidural space may be approached either medially (more common for lumbar epidurals) or paramedially (more common for thoracic epidurals).
- Midline Approach: The patient should be positioned with the back plane perpendicular to the floor, so that as the epidural needle passes through the back tissues into deeper tissues, it will stay midline. The needle entry site should be between two spinous processes at the level of interest.
- Paramedian Approach: The paramedian approach is preferred for thoracic epidurals, or when the placement is difficult (due to severe arthritis, kyphoscoliosis, and/or prior spine surgery, etc.).

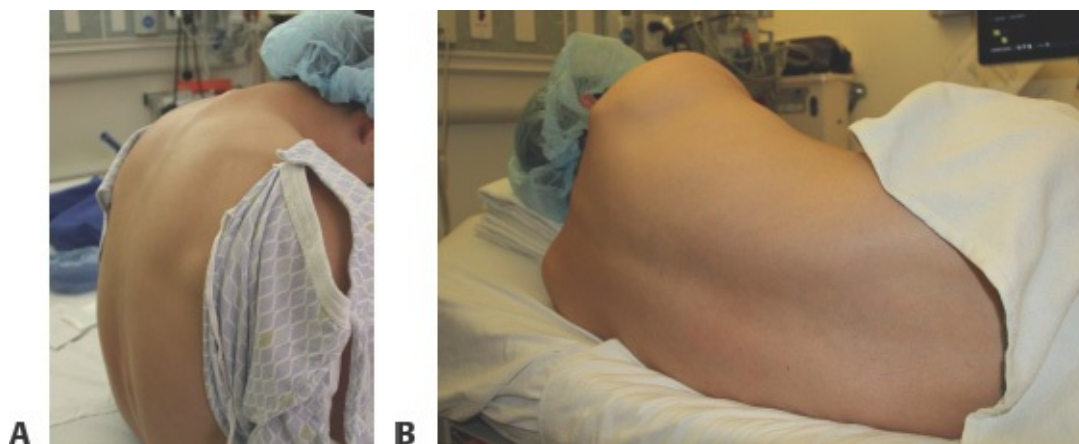


FIG 2 • A. Positioning for epidural placement (Sitting).
B. Positioning for epidural placement (Lateral).

TECHNIQUES

■ Preparation

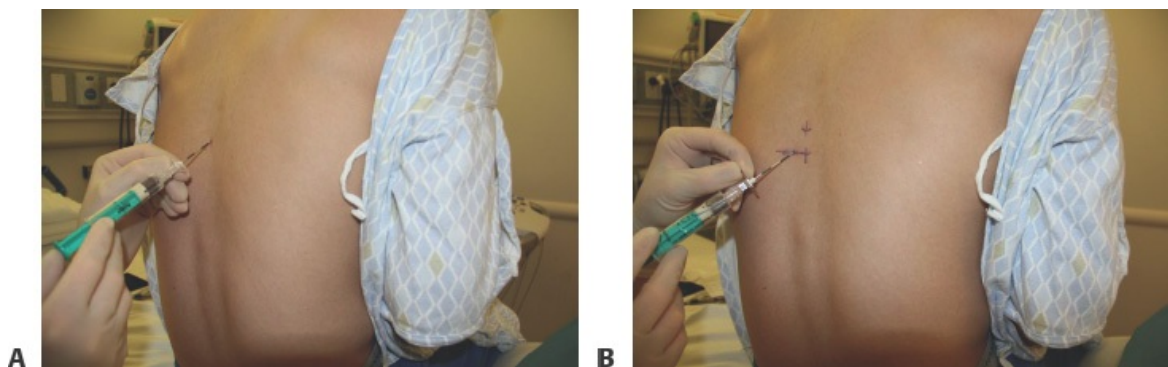
- Position the patient as described above and apply standard monitors: blood pressure, ECG (electrocardiogram), end tidal CO₂ (carbon dioxide), and pulse oximetry.
 - Intravenous sedation (such as midazolam and/or fentanyl) may be administered for patient comfort.
 - The spinous processes are typically palpable and can be used to identify the midline and the desired site of epidural needle placement, as described above.
 - A sterile field is obtained by cleansing the area with chlorhexidine or similar solution before placing a fenestrated drape.
-

■ Epidural Placement

- After sterile skin preparation, a skin wheal is placed using a small gauge needle (such as 27 gauge) to inject local anesthetic at the desired site of epidural needle placement.
- A 17- or 18-gauge Tuohy needle is generally used for epidural catheter placement in adults.
- When using a midline approach, the needle is introduced at the midline and directed slightly cephalad (**TECH FIG 1A**).
- When using a paramedian approach, the needle is introduced approximately 2 cm lateral to the inferior aspect of the superior spinous process of the desired level. The needle is then advanced at a 10- to 30-degree angle toward the midline (**TECH FIG 1B**).
- When performing a lumbar or cervical epidural block, the needle is directed only slightly cephalad. When performing a thoracic epidural block, the needle must be directed more acutely to access the epidural space.
- The initial subcutaneous tissues offer little resistance initially to the needle passage. Note: if the paramedian approach is utilized, often the needle is lateral to most of the interspinous ligaments and penetrates the paraspinal muscles; it may encounter little resistance initially.
- As the needle passes deeper, it will pass through supraspinous and interspinous ligaments, and resistance will begin to increase.
- Using the loss-of-resistance technique during epidural placement, a syringe with a freely moveable plunger is attached to the epidural needle and filled

with either saline or air.

- If the needle is correctly positioned in the ligament, the plunger will meet with resistance. However, once the needle passes into the epidural space, there will be a sudden loss of resistance, and the air or saline will freely inject with no rebound.
- Thus, the epidural space is located by the passage of a needle from an area of high resistance (ligamentum flavum) to an area of low resistance (the epidural space).
- Once the epidural space is located, a flexible epidural catheter is fed through the needle into the epidural space to the desired depth, typically 3 to 5 cm.
- After the epidural catheter is in place and secured, aspiration is recommended to ensure no CSF or blood can be aspirated.
- A test dose (typically 3 mL of lidocaine 1.5% with 5 µg/mL epinephrine) is injected via the catheter, and the patient is observed for signs and symptoms of intravascular, subdural, or subarachnoid injection.



TECH FIG 1 • A. Midline needle insertion technique for epidural placement. **B.** Paramedian needle insertion technique for epidural placement.

■ Anesthetic Administration

- Local anesthetic (with or without opioid) is then slowly titrated by bolus or continuous infusion through the catheter to provide analgesia.
- Local anesthetic selection is based on the desired speed of onset, degree of motor blockade, and duration of anesthesia. Chloroprocaine, lidocaine, and mepivacaine are short-acting local anesthetics commonly used for surgical

anesthesia. Longer-acting agents include ropivacaine and bupivacaine.

- Local anesthetic dose may be estimated by using 1 to 1.5 mL local anesthetic per desired dermatomal level of blockade. Once the initial blockade has regressed 1 to 2 dermatomal levels, a second dose of approximately 50% of the initial dose should maintain the original level of anesthesia. A continuous infusion can also maintain anesthesia. The rate of infusion depends on the concentration and type of local anesthetic chosen, the use of adjuvant medications in the infusate, and patient-specific factors. Typically, a rate of 6 to 8 mL/h is adequate.
- Dilute formulations of local anesthetics may be used in combination with fentanyl and/or hydromorphone to provide postoperative analgesia.
- Ropivacaine may produce less motor block than a similar concentration of bupivacaine while maintaining a satisfactory sensory block.
- The dose of epidural medication may need to be decreased in parturient, obese, and elderly patients. This may be due to several factors, including a potential for reduced CSF and/or a decrease in total epidural space in these patient populations. In addition, hormonal factors in the parturient patient population have been proposed to make neural endings more sensitive to local anesthetics.
- The addition of epinephrine to epidurally administered lidocaine may prolong the duration of nerve block by up to 50%. The prolongation of blockade with epinephrine added is less dramatic when using other local anesthetics, such as bupivacaine and/or etidocaine.
- Infusions are generally continued for 2 to 5 days following the surgery, depending on patient characteristics and the nature of the surgical procedure for which it was placed.

PEARLS AND PITFALLS

Sterility

- Sterile conditions must be maintained at all times when placing an epidural.

Locating the epidural space

- Placement of the needle should be done logically, based on 3D understanding of the anatomy. Needle redirection should not be random. Systematic small angle needle changes should be made.

Intravascular or intraneural injection/local anesthetic toxicity (LAST)	■ Aspiration for detection of blood or CSF is recommended prior to injection through the needle or catheter to avoid toxic side effects if epidural medication is injected intrathecally or intravascularly. Test dosing may be helpful to avoid accidental intrathecal or intravascular bolus.
Segmental block	■ May be due to septations within the epidural space. Spread of medication within the epidural space is gravity dependent. A patchy block may be corrected by injecting additional local anesthetic with the patient positioned to optimize coverage of the areas that are spared. Sacral sparing may occur due to the large size of the L5, S1, and S2 nerve roots.
Unilateral block	■ May occur if medication is delivered via a catheter that has either exited the epidural space and/or coursed laterally.
Failed epidural blocks	■ The loss of resistance technique is somewhat subjective. Local anesthetic injection may be misplaced between ligaments or paraspinal muscles. The paramedian approach can be more challenging since the needle travels through softer tissues with false loss of resistance. Epidural space anatomy may be variable, making the spread of local anesthetics less predictable.
Block assessment	■ The extent of sensory blockade may be assessed using a blunt needle tip, cold, and/or other stimulus.

POSTOPERATIVE CARE

- Following placement of an epidural, patients should continue to be monitored for local anesthetic toxicity as long as the epidural medication is infusing. Typically, this is done by clinical exam. Early signs and symptoms of local anesthetic toxicity include tinnitus, blurred vision, dizziness, tongue paresthesias, and/or perioral numbness. Symptoms may progress to seizures and/or cardiac arrest if toxicity is severe and/or not treated early.
- Maximum recommended dose(s) for some commonly used local anesthetics: chloroprocaine and procaine 12 mg/kg; lidocaine and mepivacaine 4 to 5 mg/kg (7 mg/kg with epinephrine); bupivacaine and ropivacaine 3 mg/kg.
- The dermatomal level of sensory blockade may be assessed to determine the level of sympathectomy.
- Patients should be assessed at least once daily until the epidural is removed.

This includes an evaluation of epidural function, query on side effects, determination of patient-controlled epidural analgesia (PCEA) usage, degree of motor block, and a check of the insertion site and dressing.

- Depending on the epidural medication in use, patients should be educated on possible weakness and fall risk and should be tested for muscle strength before ambulation.
- Patients should be encouraged to supplement their epidural analgesia with nonopioid systemic analgesics as needed.
- Routine dressing changes are not necessary and may increase the risk of infection or catheter dislodgement. The dressing covering the epidural insertion site should be left alone until the epidural catheter is removed.
- Patients should be continually monitored by nursing staff for signs and symptoms of epidural hematoma and/or epidural abscess, including back pain, fever, and numbness or weakness that is progressive or in excess of what is expected. These symptoms should prompt immediate evaluation by the anesthesia team. If epidural hematoma or abscess is suspected, imaging and neurosurgical consultation for surgical decompression should occur within hours of the onset of symptoms to reduce the risk of permanent complications.

OUTCOMES

- In addition to providing excellent postoperative anesthesia, epidural anesthesia has been shown to be an important factor in the survival rate of flaps in breast reconstruction plastic surgery cases due to the effects on the distribution of direct blood flow to the microcirculation.⁴
- A continuous thoracic epidural infusion is associated with reduced bleeding due to hypotension during combined plastic surgeries involving breast, abdomen, gluteus, and liposuction.⁵
- Pain management strategies that include epidural anesthesia may be associated with reduced morbidity and cost savings in abdominal wall reconstruction surgeries.⁶
- Epidural use is also associated with shortened length of hospital stay.⁶

COMPLICATIONS

- In general, the use of epidural anesthesia is associated with a very low rate of severe or disabling neurologic complications.
- Overall, long-term complications (neurologic or otherwise) are very rare with epidural placement. The incidence of serious complications following regional

anesthesia (including epidural, as well as spinal anesthesia, peripheral nerve blocks, and intravenous regional anesthesia) is estimated to be 0.01%.⁷

- Undiagnosed spinal stenosis has been identified as a risk factor for cauda equina syndrome and paraparesis.⁸
- Postdural puncture headache (PDPH) is a potential complication of epidural placement that may occur after a “wet tap,” in which the epidural needle passes through the epidural space and into the subarachnoid space. Subarachnoid placement of the epidural needle is often made immediately apparent by the free flow of CSF. Occasionally, however, the findings are subtler, and subarachnoid placement of the epidural catheter is detected by aspiration of CSF or by induction of a dense block with the test dose. Typically, PDPH is described as bilateral, frontal, or retro-orbital, with extension into the neck. It is characterized by symptom alleviation in the supine position, and worsening when upright (“postural headache”). PDPH is postulated to be due to leakage of CSF from a defect in the dura and intracranial hypotension. Initial treatment is conservative and includes administration of IV fluids, recumbent positioning, analgesics, and caffeine. Epidural blood patch may also be considered if conservative treatment fails, although many PDPH are self-limited.
- Neuropathies from epidural placement are rare. Epidural abscess and/or hematoma must be ruled out immediately (see below). Prolonged neuropathy related to epidural placement may be associated with paresthesias from the needle or catheter during placement, multiple attempts at block placement, and/or a technically difficult block. Peripheral neuropathies may be due to direct trauma to the nerve roots. Not all neurological deficits following regional anesthetic are always due to the block.⁸
- Epidural abscess is a rare complication of epidural placement and is a medical and surgical emergency. Symptoms of an epidural abscess are often insidious and delayed and progress from unexplained back or vertebral pain, to nerve root or radicular pain, then motor or sensory deficits, and finally paraplegia and/or paralysis. Prognosis is strongly related to the stage at the time of diagnosis. If suspected, catheter should be removed, antibiotics started, and neurosurgery consulted.⁸
- Epidural hematoma is another rare complication of epidural placement. Risk factors include a pre-existing bleeding diathesis or use of anticoagulation medication(s). The American Society of Regional Anesthesia (ASRA)

guidelines should inform timing of epidural placement/removal and dosing of anticoagulation when such medications are indicated. Symptoms of hematoma include severe, sharp back and/or leg pain with motor weakness, and/or sphincter dysfunction. Surgical decompression must occur within 24 hours, and as soon as possible to maximize the chance of recovery.

- Local anesthetic systemic toxicity (LAST) is a rare but potentially deadly complication. Minimize risks with careful dose calculation.

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Section II: Foot, Ankle, and Lower Leg

5 Fasciotomy of the Thigh, CHAPTER Lower Leg, and Foot

Graeme E. McFarland and Jason T. Lee

DEFINITION

- Fasciotomy is indicated to treat compartment syndrome and prevent nerve injury and myonecrosis.
- Compartment syndrome most often occurs in the setting of reperfusion of an acutely ischemic limb or in severe limb trauma.
- Compartment syndrome can also occur in the setting of occlusive deep vein thrombosis (DVT) of the iliofemoral veins resulting in phlegmasia.
- Fasciotomy is indicated for treatment of active compartment syndrome, prophylactically for patients at high risk for compartment syndrome, or for those in which a reliable exam is difficult to obtain (ie, head trauma) and heightened concern for compartment syndrome.
- Isolated compartment syndrome of the thigh is rare and often due to femur fracture. The anterior compartment of the thigh is most commonly involved.¹

ANATOMY

- There are three fascial compartments of the thigh all surrounded by the strong fascia lata.
 - Anterior:
 - Muscles: Sartorius, articularis genus, rectus femoris, vastus lateralis, vastus intermedius, and the vastus medialis

- Neurovascular: Femoral nerve
- Medial (adductor):
 - Muscles: Adductor longus/brevis/minimus, gracilis, pectineus, and external obturator
 - Neurovascular: Obturator nerve
- Posterior:
 - Muscles: Adductor magnus, biceps femoris, semitendinosus, and semimembranosus
 - Neurovascular: Sciatic nerve
- There are four fascial compartments of the lower leg.
 - Anterior:
 - Muscles: Tibialis anterior, extensor hallucis longus, extensor digitorum longus, and the peroneus tertius
 - Neurovascular: Anterior tibial artery and vein and the deep peroneal nerve
 - Lateral:
 - Muscles: Fibularis longus/brevis
 - Neurovascular: Superficial peroneal nerve
 - Superficial posterior:
 - Muscles: Gastrocnemius, soleus, plantaris
 - Neurovascular: Tibial nerve
 - Deep posterior compartment:
 - Muscles: Tibialis posterior, flexor hallucis longus, flexor digitorum longus, and popliteus
 - Neurovascular: Tibial nerve, posterior tibial artery and veins, and the peroneal artery and veins
- There are technically nine compartments of the foot.
 - Medial compartment:
 - Muscles: Abductor hallucis and flexor hallucis brevis
 - Lateral compartment:
 - Muscles: Flexor digiti minimi brevis and abductor digiti minimi
 - Superficial central compartment:
 - Muscles: Flexor digitorum brevis
 - Central central compartment
 - Muscles: Quadratus plantae
 - Deep central compartment

- Muscles: Adductor hallucis compartment
- Intrinsic compartment:
 - Muscles: Four intrinsic muscles (compartments) between the 1st and 5th metatarsals

DIAGNOSIS

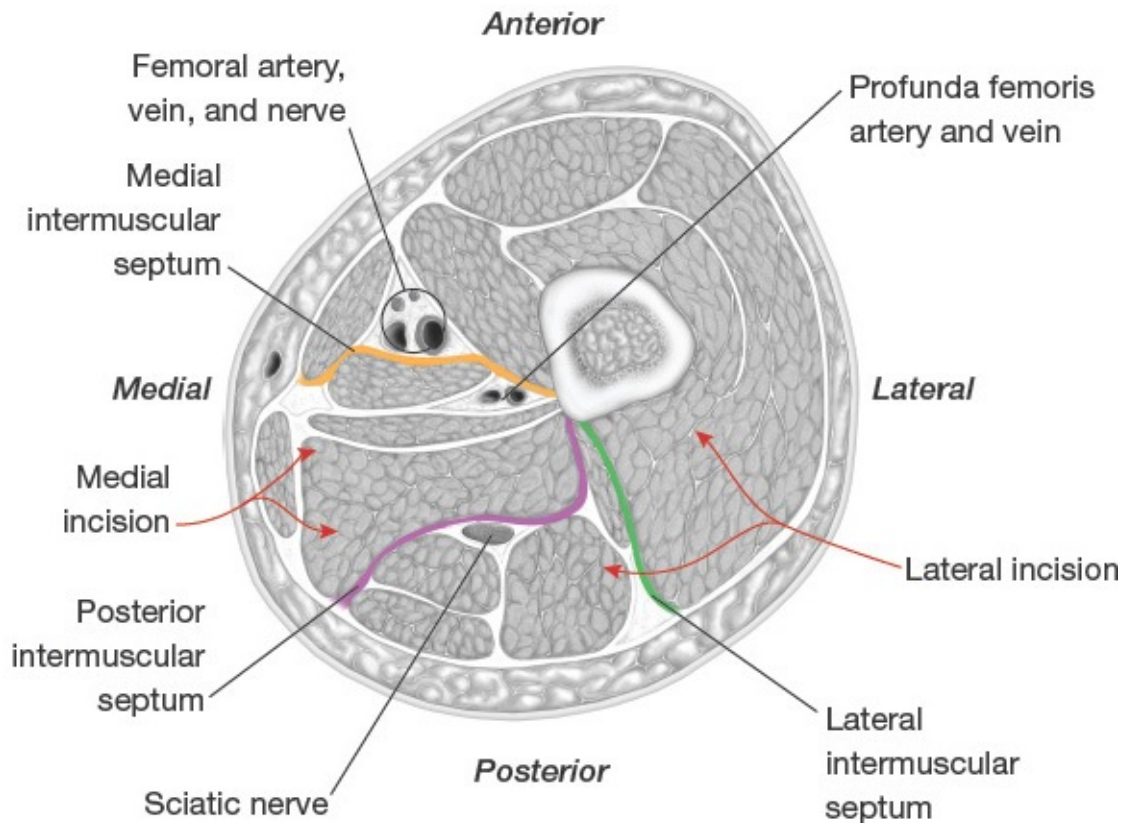
- Compartment syndrome can be diagnosed by directly measuring the compartment pressures with a Stryker monitor set or with an arterial line transducer system.
- Compartment pressures greater than 30 mm Hg are indicative of compartment syndrome.
- The “6 P’s” of the compartment syndrome exam are pain, paresthesia, paresis, pallor, pulselessness, and poikilothermia.
- “Pain out of proportion to examination” and pain with passive flexion are the most consistent signs of compartment syndrome.
- A clinical suspicion for compartment syndrome warrants surgical intervention regardless of compartment pressure measurement.
- Paresthesias and paresis are late signs of compartment syndrome and are indicative of poor functional outcomes.
- Severe pain of the foot along with dorsal swelling can indicate compartment syndrome of the foot.²

TECHNIQUES

■ Thigh Fasciotomy (TECH FIG 1)

- Anterolateral incision is made along the mid portion of the thigh for the length of the thigh.
- Make a straight longitudinal incision through the fascia lata and reflect the vastus lateralis medially off the lateral intermuscular septum to release the anterior compartment.
- Make a small 2-cm incision in the lateral intermuscular septum and extend proximally and distally for the length of the incision to release the posterior compartment.
- To release the medial or adductor compartment, make a medial incision

longitudinally for the length of the thigh. Incise the fascia lata for the length of the incision.



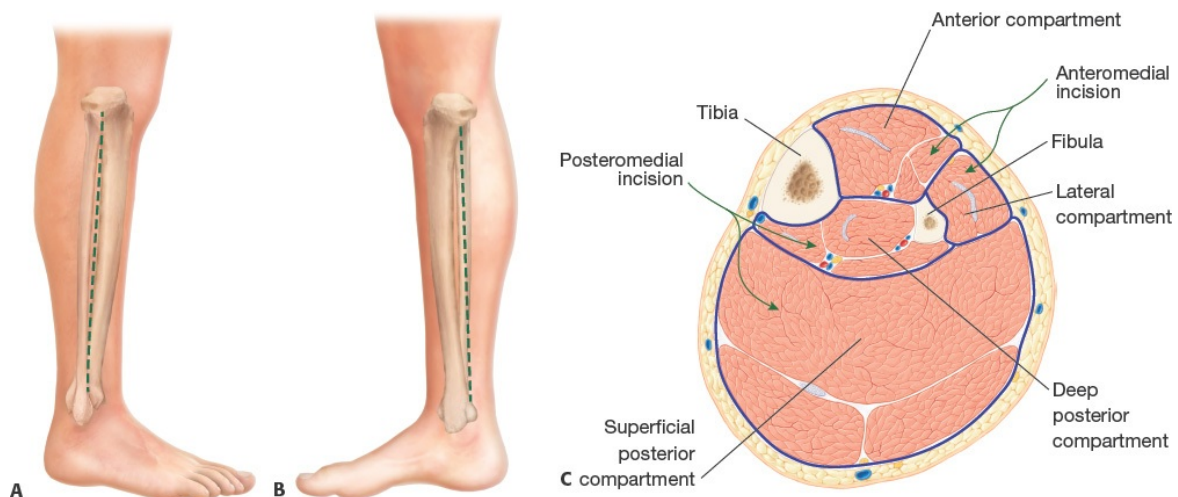
TECH FIG 1 • Thigh Fasciotomy. This figure demonstrates the two-incision approach for fasciotomy of the thigh. The medial incision carried deep through the fascia lata releases the adductor compartment. The lateral incision carried deep through the fascia lata releases the anterior compartment. The lateral intermuscular septum is then incised to open the posterior compartment. All important neurovascular bundles should not be exposed with this approach.

■ Lower Leg Fasciotomy

- Anterior and lateral compartments are released through a lateral incision

made approximately 6 to 8 cm lateral to the anterior shaft of the tibia (**TECH FIG 2A**).

- The incision is carried from approximately 3 to 4 cm distal to the lateral tibial tuberosity to approximately 2 to 3 cm proximal to the lateral malleolus.
- Subcutaneous dissection is carried deep to expose the underlying fascia.
- The anterior compartment is released by making an incision in the fascia 2 cm lateral to the tibia. The fascia is then cut for the length of the incision.
- Identify the intermuscular septum between the anterior and lateral compartments. Make an incision through the fascia 1 cm posterior to the septum and then carry proximally and distally for the length of the incision, taking care to protect the common peroneal nerve proximally which lies behind the head of the fibula.
- To release the superficial and deep posterior compartments, a longitudinal incision is made medially 2 cm posterior to the medial border of the tibia for the same length as the lateral incision (**TECH FIG 2B**).
- Expose the underlying fascia and make the incision 2 to 3 cm posterior to the tibia successfully releasing the superficial posterior compartment.
- The deep posterior compartment is released by taking down the soleus muscle from its attachment to the posterior aspect of the tibia and the interosseous membrane. This needs to be carried for the length of the incision (**TECH FIG 2C**).³

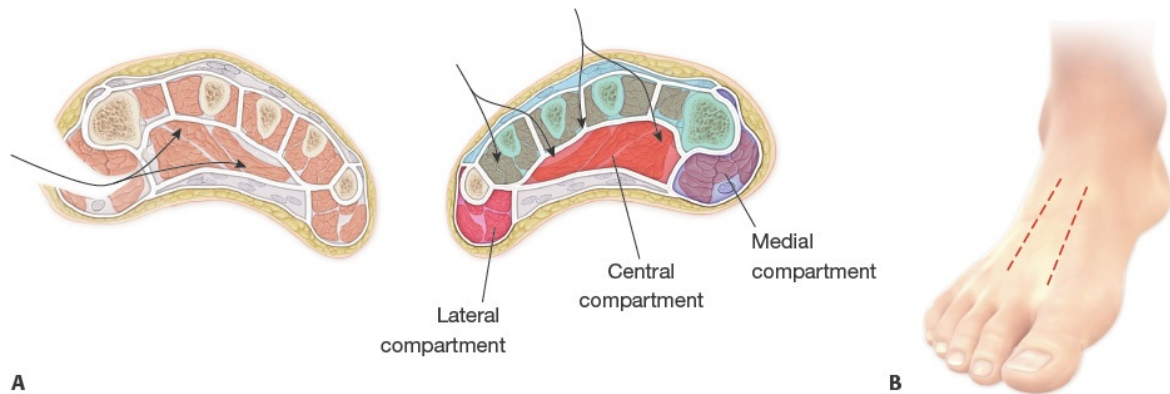


TECH FIG 2 • Lower leg fasciotomy. This figure demonstrates the two-incision approach to a four compartment fasciotomy of the lower leg. **A.** Lateral

incision is made 6 to 8 cm lateral to the anterior shaft of the tibia and carried proximally 3 cm distal to the tibial tuberosity and distally to 2 cm proximal to the medial malleolus. **B.** The medial incision is created 2 cm posterior to the medial aspect of the tibia and carried for the same length of the lateral incision. **C.** The anterior compartment is released by cutting the fascia anterior to the intermuscular septum and carried for the length of the incision. The lateral compartment is released in similar fashion through the fascia lateral to the intermuscular septum. The superficial posterior compartment is released by incising the fascia just deep to the medial incision. The deep posterior compartment is then released by freeing the soleus from its attachments to the tibia.

■ Foot Fasciotomy

- Dual dorsal incisions are used for release of all nine compartments.
- A dorsal medial incision is made over the 2nd metatarsal and carried medial and lateral to the 2nd metatarsal releasing the 1st and 2nd interosseous compartments. Blunt dissection is carried deep to release the central compartments and medial to release the medial compartment, if possible, posterior to the 1st metatarsal (**TECH FIG 3A**).
- A second dorsal incision is made over the 4th metatarsal and carried medially and laterally to the 4th metatarsal releasing the 3rd and 4th interosseous compartments. This can be carried laterally, posterior to the 5th metatarsal to release the lateral compartment (**TECH FIG 3B**).
- Occasionally, a medial incision is required to successfully release the medial and central compartments.



TECH FIG 3 • Foot fasciotomy. **A.** Occasionally, a medial incision is required to release the medial and central compartments. This is created along the medial border of the 1st metatarsal and carried through the medial compartment into the central compartment. **B.** Typically, a two-incision approach on the dorsal surface of the foot is all that is required. The first incision is made over the 2nd metatarsal and carried deep to the medial side to open the 1st interosseous compartment and then posterior to the 1st metatarsal to open the medial compartment. The incision is then carried deep to the lateral side of the 2nd metatarsal to open the 2nd interosseous compartment and the central compartment. The second incision is made over the 4th metatarsal. In a similar fashion, this is carried medial to open the 3rd interosseous compartment and deep to further open the central compartment. Finally, the incision is carried deep laterally to the 4th metatarsal to open the 4th interosseous compartment and then deep to the 5th metatarsal to open the lateral compartment.

Delayed diagnosis	■ Delayed diagnosis can often be catastrophic and result in functional losses, if not limb loss entirely.
Fascia release	■ Often the fascia can be released through smaller subcutaneous incisions by running scissors “blindly” along the fascia, superficially. This, however, can often result in troublesome bleeding from venous injury, or injury to the deep peroneal nerve.
Compartment release	■ Inadequate compartment release can result in ongoing compartment syndrome and disabling complications. Often, extending the subcutaneous incisions to fully expose the fascia and ensure adequate compartment release is the safest practice.
Nerve or vessel injury	■ Iatrogenic nerve or vessel injury can lead to certain disabling conditions similar to those in which the fasciotomy was initially indicated to prevent. The common peroneal and superficial peroneal nerve are the most commonly injured during lateral compartment release. To prevent this, terminate the proximal incision in the fascia 5 cm distal to the fibular head to prevent injury to the common peroneal nerve, and distally direct the incision towards the lateral malleolus to avoid injuring the superficial peroneal nerve.

POSTOPERATIVE CARE

- Patients require frequent neurovascular check every 1 to 2 hours for the initial postoperative period.
- Critical care monitoring and adequate IV fluid resuscitation are essential for renal protection in the setting of myoglobin release.
- Typically, fasciotomy wounds are initially dressed with wet to dry dressings that are changed 2 to 3 times daily to allow frequent evaluation of the underlying muscle.
- After the initial 24- to 48-hour period following compartment release, a wound vacuum dressing can be used to decrease the frequency of dressing changes and promote healing.
- Occasionally, if the limb is not too edematous, the fasciotomy incisions can be closed several days after the procedure to heal by tertiary intention.
- Frequently, skin grafting is required to ultimately heal the incision.

OUTCOMES

- Functional outcomes following fasciotomy depend mainly on the underlying

injury, as well as time to procedure and adequacy of compartment release.

- Appropriate timing of fasciotomy is essential for improved outcomes. For fasciotomies delayed greater than 12 hours from the onset of compartment syndrome, limb loss is as high as 50%, with only approximately 8% maintaining normal limb function.
- Fasciotomy wound closure can be attempted during the same hospitalization if the swelling allows for tension-free closure of the skin. Occasionally, skin graft closure is required.

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6 Drainage of Abscesses of Lower Leg and Foot

CHAPTER

Michael Holland and Scott L. Hansen

DEFINITION

- Infections of the foot, ankle, and lower leg range in severity from minor local cellulitis to rapidly progressive necrotizing fasciitis.
- Abscesses are a result of infection leading to inflammation and cell death, whereby a cavity is created that is filled with a mixture of bacteria, inflammatory cells, and necrotic tissue.
- Painful areas of fluctuance can be identified on physical exam and are most commonly surrounded by signs of inflammation (redness, warmth, pain, and swelling) but may also be found in isolation.
- Abscesses of the lower extremity and foot are frequently the result of trauma creating a break in the skin's natural barrier, allowing for colonizing or environmental pathogens to proliferate in the skin and deeper subcutaneous tissues.

ANATOMY

- The lower leg, ankle, and foot are comprised of 28 bones.
- Soft tissues include the overlying skin and subcutaneous tissue as well as muscles that are divided into anatomically distinct compartments in both the lower leg as well as the foot.
 - The four compartments of the lower leg include the anterior, lateral, superficial posterior, and deep posterior divided by fascia.
 - The nine compartments of the foot include the calcaneal—communicating with the deep posterior compartment of the leg, superficial, medial, lateral, adductor, and four interosseous.
- The primary neurovascular structures include the anterior tibial, peroneal, and

posterior tibial arteries and paired veins; superficial peroneal, deep peroneal (fibular), tibial, saphenous, and sural nerves; and greater and lesser saphenous veins in the superficial tissues (**FIG 1**).

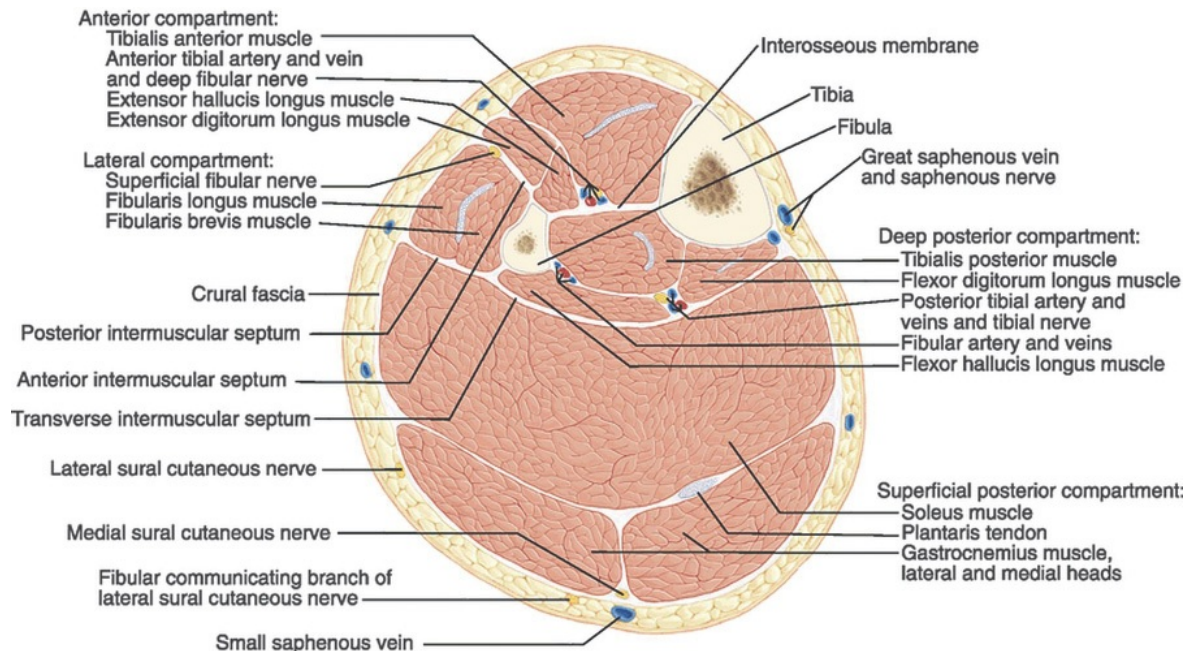


FIG 1 • Cross section of lower leg demonstrating four compartments separated by intramuscular septae, neurovascular structures, and soft tissue. (From Pansky B, Gest TR. Lower limbs. In: *Lippincott's Concise Illustrated Anatomy: Back, Upper Limb, and Lower Limb*. Vol. 1. Baltimore, MD: Wolters Kluwer; 2012:198.)

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient's initial complaint is typically of pain and swelling at the site of infection. They may also notice changes in skin color and drainage of fluid. There may be a history of antecedent trauma.
- Systemic symptoms such as fevers, chills, malaise may not be present early in the disease.
- Past medical history of diabetes mellitus, vascular disease, immunodeficiency, injection drug use prior fracture, and prior surgery may predispose to infection and abscess formation.
- Physical exam may reveal erythema, swelling, tenderness, warmth, fluctuance,

visible drainage, and eschar. Many times, erythema and tenderness will be the only physical exam findings, so a high index of suspicion for underlying fluid collection is necessary.

IMAGING

- Despite its inability to well characterize fluid collections, standard multiple view radiographs are the first initial test to identify any bony injury or radiopaque foreign bodies as well as gas from anaerobic bacteria. Subtle soft tissue changes may also be demonstrated but are harder to appreciate by the untrained examiner.
- Ultrasonography may show cobble stoning of the subcutaneous tissues, which is indicative of edema. Discrete, hypoechoic fluid collections may also be identified.
- When multiple abscesses are suspected or ultrasound findings are equivocal, CT with IV contrast of the lower extremity can be extremely valuable.
- MRI is similar to CT in its ability to diagnose soft tissue infections; however, its use is limited by cost and time required to obtain the study.

DIFFERENTIAL DIAGNOSIS

- Cellulitis
- Abscess
- Septic arthritis
- Necrotizing fasciitis
- Plantar fasciitis
- Seroma
- Hematoma
- Gout
- Cyst
- Tumor

NONOPERATIVE MANAGEMENT

- Antibiotic therapy alone is often insufficient to manage abscesses, and drainage is the primary treatment strategy.

SURGICAL MANAGEMENT

Preoperative Planning

- In patients who are hemodynamically unstable, antibiotic therapy should not be withheld while awaiting cultures.
- In patients who are otherwise stable, consider deferring antibiotics until cultures have been obtained.
- If hardware is present, consider need for removal with orthopedic surgery consultation, as well as need for bony debridement.
- Ensure medical comorbidities are addressed.
- Ensure appropriate laboratory investigations are obtained including complete blood count, basic metabolic panel, C-reactive protein, sedimentation rate, and blood cultures.
- Antibiotic selection should cover gram-positive organisms with methicillin-resistant *Staphylococcus aureus* (MRSA) coverage, and due to prevalence of gram-negative organisms in foot infections, gram-negative coverage should also be provided while awaiting culture results.

Positioning

- Supine position is sufficient for exposure.

Approach

- The goal is to completely drain the abscess cavity, remove any debris or dead tissue, thoroughly irrigate, and allow wound to heal by secondary intention.

TECHNIQUES

■ Abscess Drainage

- Identify abscess cavity by palpation of fluctuance and correlate to previous imaging (**TECH FIG 1A**).
- A linear incision is designed over the most fluctuant area, attempting to avoid making the incision over weight-bearing area or known neurovascular structures or tendons.
- An incision is made through the skin with a no. 15 scalpel. If the incision was designed immediately over the cavity, abscess fluid will be released immediately.
 - Ensure the incision is opened up sufficiently in a proximal and distal

direction (**TECH FIG 1B**).

- Obtain microbiology cultures, including bacterial cultures (aerobic, anaerobic) as they are most common. If there is clinical suspicion of other rare pathogens, send those as indicated such as fungal, yeast, mycobacteria, etc.
- Using a curved hemostat or Kelly clamp, spread gently throughout the abscess cavity for complete drainage.
- Gently probe the extent of the cavity in all directions to ensure that the cavity has been completely opened through the incision and that there are no residual fluid collections or loculations.
- Visualize cavity to ensure no necrotic tissues remaining. Adequately debride all necrotic tissues (**TECH FIG 1C,D**).
- If necrotic tissue, especially muscle, is encountered beyond the extent of abscess cavity, consider diagnosis of necrotizing soft tissue infection or necrotizing fasciitis, need for wide excision of all necrotic tissue, and addition of protein synthesis inhibiting antibiotics (eg, clindamycin).
- Irrigate the cavity with at least 3 L of saline.
- Pack the cavity with surgical packing, ensuring to apply enough packing to prevent the wound from closing prematurely.



TECH FIG 1 • A. Necrotic right lateral foot wound with underlying abscess. **B.** Sharp debridement and drainage of wound and abscess. **C.** Wound after debridement and drainage of abscess with continued necrotic tissue. **D.** Granulating wound prior to split-thickness skin grafting.

PEARLS AND PITFALLS

Preoperative workup	■ Failure to get bacterial cultures
Technique	■ Incomplete drainage: ensure that entirety of abscess cavity is explored and septations are taken down ■ Ensure incision is large enough ■ Use copious (generally at least 3 L of irrigation)
Postoperative care	■ Failure to ensure glycemic control
Dressings	■ Applying an occlusive dressing can result in reaccumulation of abscess and inability to monitor wound. Do not apply negative pressure wound therapy on grossly infected wound ■ Ensure enough packing is used to prevent wound from closing prematurely
Wound hazards	■ Do not probe wound with digit, as you may injure yourself with potential foreign body

POSTOPERATIVE CARE

- Surgical management with drainage alone has been recommended for small (less than 5 cm abscesses) without associated cellulitis or systemic signs of infection.
- However, a recent randomized control trial (RCT) has demonstrated superior cure rates for patients who received post drainage antibiotics for 7 to 14 days,

even in uncomplicated cases.¹

- Patients require at least twice daily dressing changes until wound heals by secondary intention.
- Negative pressure wound therapy e.g. Wound VAC may be considered for abscesses that result in large open wounds, however, should not be placed at time of initial debridement and should be placed only after wound appears healthy and without signs of residual infection.
- Blood sugar control
- Smoking cessation
- Early range of motion should be encouraged to prevent stiffness and contracture.

COMPLICATIONS

- Persistent infection
- Missed diagnosis of necrotizing infection
- Injury to neurovascular structures
- Hematoma

REFERENCE

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Excision of Soft Tissue Tumors of the Foot and Ankle

7

CHAPTER

Raffi S. Avedian, Robert J. Steffner, and Subhro K. Sen

DEFINITION

- Soft tissue tumors of the ankle may be benign or malignant (soft tissue sarcoma) and exhibit a variable natural history ranging from latency to rapid growth.
- Tumors located entirely above the muscle, fascia, or tendon are considered superficial, whereas tumors involving the fascia or located deep to it are considered deep.

ANATOMY

- The ankle is a synovial joint involving the tibia, talus, and fibula. Tendons of the leg muscles travel around the ankle in discrete groups each contained in a retinaculum (**FIG 1**).
- The anterior tibial artery and deep peroneal nerve travel anterior to the ankle joint just lateral to the anterior tibialis tendon.
- The posterior tibial artery and tibial nerve travel along the medial aspect of the lower leg, in the fascial plane between the deep and superficial compartments. At the ankle, they course posterior to the posterior tibial tendon along the medial malleolus.
- The tendons of the peroneus muscles travel along the posterior aspect of the lateral malleolus to their attachments in the foot.

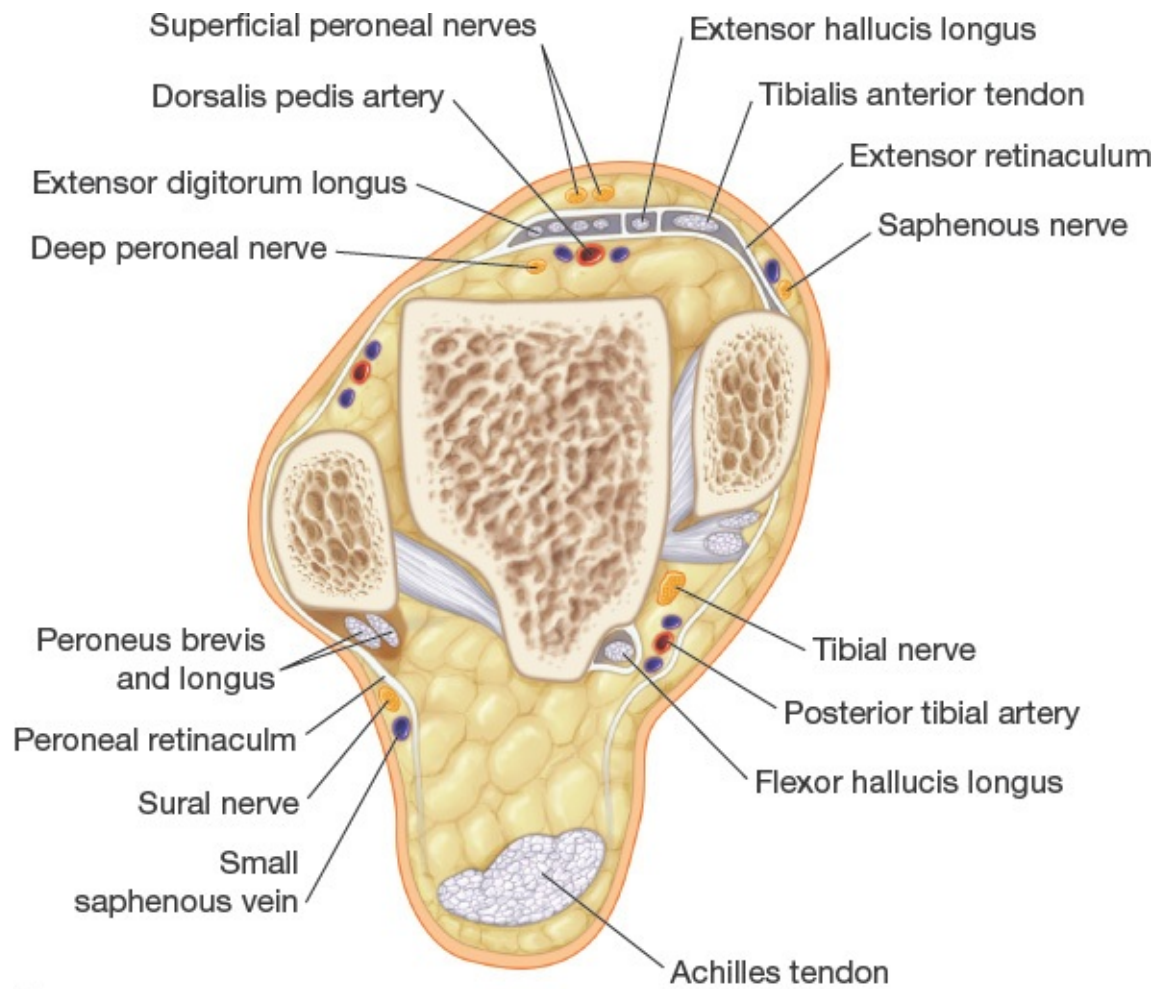
PATHOGENESIS

- The mechanism for soft tissue tumor formation is not known.
- Risk factors for sarcoma development include radiation exposure,

radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and retinoblastoma gene mutation.

NATURAL HISTORY

- All soft tissue sarcomas have the potential for local recurrence and metastasis.
- Soft tissue sarcomas exhibit a spectrum of natural history from slow-growing low-grade tumors with low risk of metastasis to high-grade sarcoma that may grow rapidly and pose a high risk of metastasis.
- Lungs are the most common site of metastasis. Lymph node involvement is rare.
- Angiosarcoma, clear cell sarcoma, epithelioid sarcoma, rhabdomyosarcoma, myxofibrosarcoma, and synovial sarcoma are associated with increased risk of lymph node spread compared to other sarcomas.
- Benign tumors by definition do not have metastatic potential but can grow to large sizes and cause symptoms.



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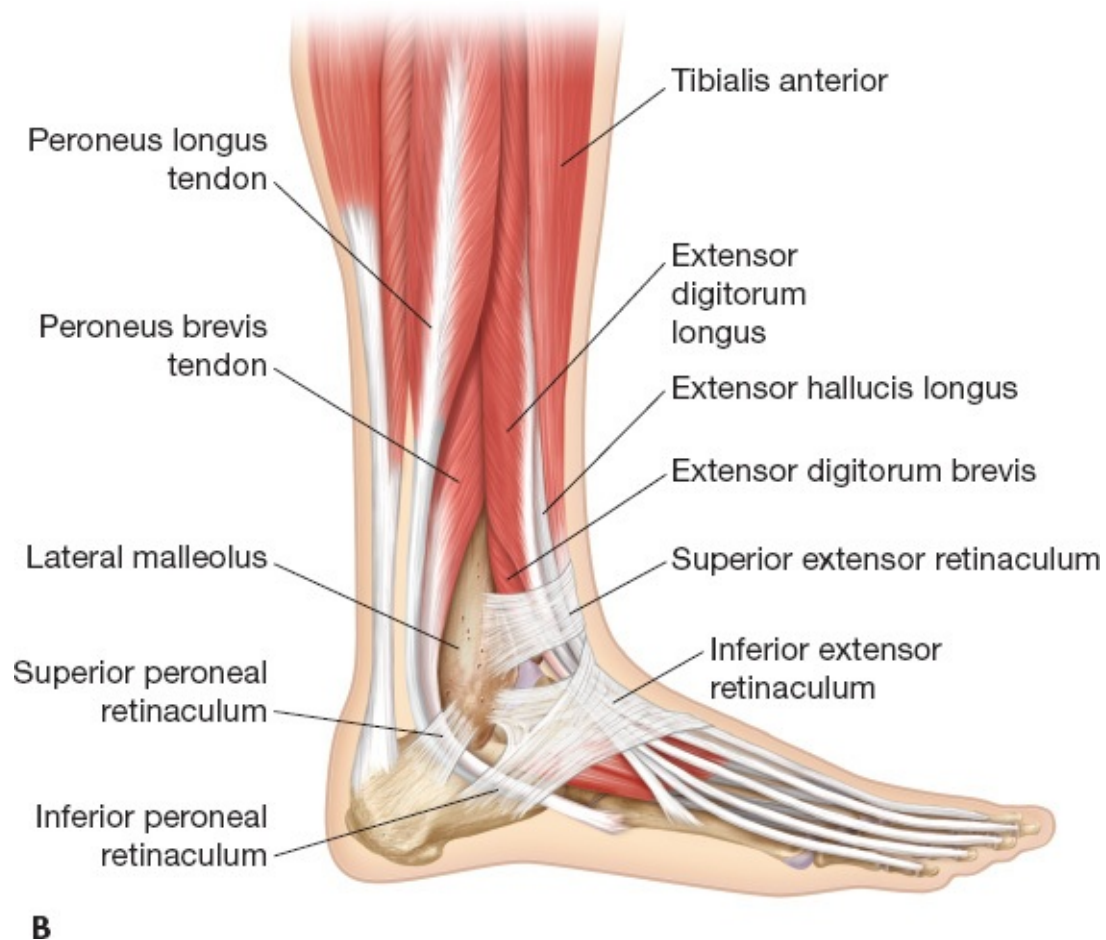


FIG 1 • A. Cross-sectional anatomy of the ankle. Notice that the tendons are contained within a retinacular layer.
B. Oblique view of the ankle anatomy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Conducting a thorough history and examination is important to assess duration of symptoms, comorbidities, physical dysfunction, organ involvement, overall health, and patient expectations in order to best tailor treatment strategy for the individual patient.
- Many sarcomas may be asymptomatic with the only patient complaint being the presence of a mass.
- Neurovascular examination is mandatory for any extremity tumor.

IMAGING

- Magnetic resonance imaging is the principal imaging modality used to

characterize tumors, formulate differential diagnosis, define local tissue infiltration, and devise a surgical plan.

- Plain radiographs are used if there is concern for bone involvement or to demonstrate mineralization within a tumor such as vascular malformations.
- Staging for soft tissue sarcomas consists primarily of lung imaging.

DIFFERENTIAL DIAGNOSIS

- The differential diagnosis for a soft tissue tumor includes benign tumors, sarcomas, lymphoma, infection, and inflammatory lesions (eg, rheumatoid nodules).
- There are over 50 sarcoma subtypes. Common histologies include pleomorphic undifferentiated sarcoma, synovial sarcoma, leiomyosarcoma, malignant peripheral nerve sheath tumor, and liposarcoma.

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Biopsy incisions are considered contaminated and must be resected at the time of definitive surgery. Care should be taken to place the biopsy in a location that does not interfere with the final surgical plan.
- Simple marginal excision is appropriate for most benign tumors, whereas wide resection with a clean margin is performed for soft tissue sarcomas.
- Given the relatively low volume of tissue in the lower leg and ankle, soft tissue reconstruction with local or free flaps is often needed.

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The retinacula and tendon sheaths around the ankle are robust tissues that act as barriers to tumor penetration. Careful assessment of preoperative imaging is needed; however, these tissues often can be used as a margin around the tumor (see **FIG 1**).
- When tumor abuts, but does not encase blood vessels or nerves, they can be dissected free by leaving adventitia and epineurium on the tumor as the margin.
- The surgical plan is created by thorough study of the preoperative MRI scan. Fluid-sensitive sequences and fat-suppressed contrast images show the extent

of disease that must be accounted for in the excision. T1 fat-sensitive images show the normal anatomy best including fat planes between tumor and critical structures such as nerves and vessels (**FIG 2**).

Positioning

- Patient positioning is based on the surgeon's assessment of the critical anatomy of the surgery and how best to visualize it during surgery. Supine and lateral positions are most common.
- If a flap is to be used, the harvest must be performed using a separate back table and instruments and the surgical sites completely isolated to avoid contamination.

Approach

- The surgical approach varies based on location of the tumor.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

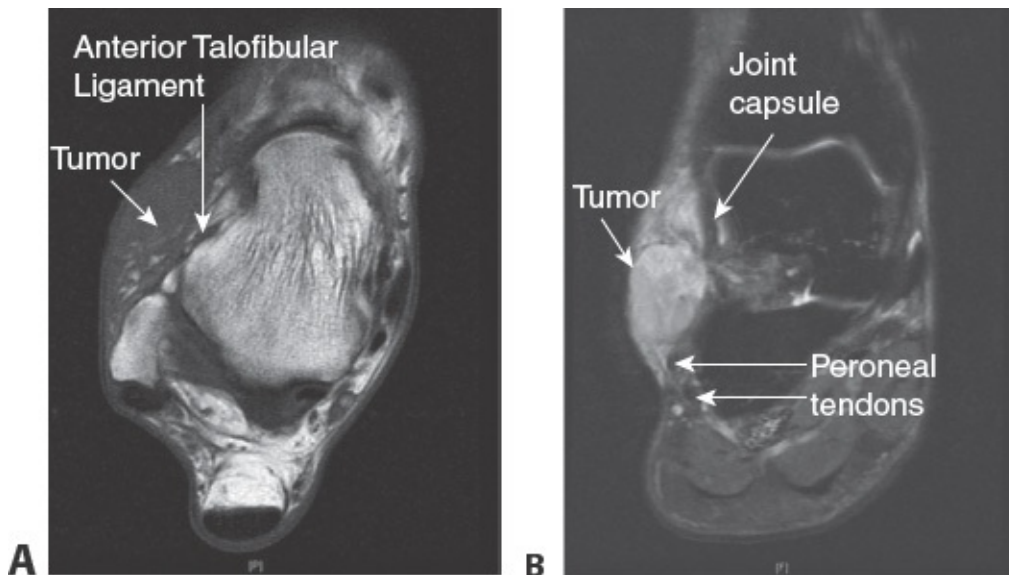


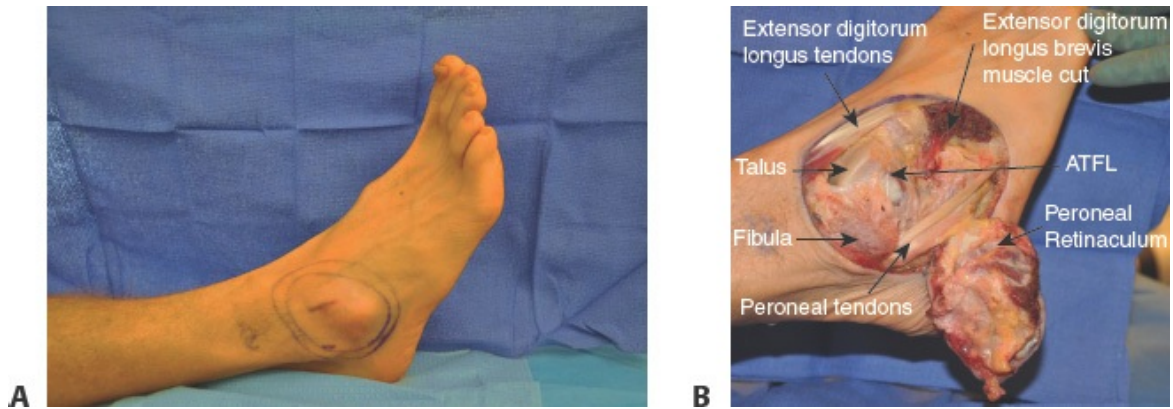
FIG 2 • **A.** Axial T1 MRI of a 57-year-old man with a myxofibrosarcoma on the lateral aspect of the ankle. Note that the tumor sits on the joint capsule and anterior talofibular ligament. **B.** Coronal MRI highlighting the tumor and its relationship to the surrounding anatomy. Notice that the joint capsule and

retinaculum around the peroneal tendons act as a barrier to tumor penetration.

TECHNIQUES

■ Excision of Soft Tissue Tumor of the Ankle

- Tourniquet is used at discretion of surgeon using gravity exsanguination rather than Esmarch to avoid tumor compression.
- A margin of normal skin is marked around previous biopsy incisions and incorporated into the surgical approach (**TECH FIG 1A**).
- The dissection is beveled away from the sarcoma through the subcutaneous tissue to the deep fascia or retinacular layer at a point that is clear away (ideally 1–2 cm if possible) from palpable tumor or tumor visualized on preoperative MRI.
- The deep fascia and retinacula are cut and used as the deep margin. Occasionally, the joint capsule may have to be included in the deep margin.
- Cutaneous nerves often are involved in the tumor. They should be cut away from the tumor and buried in the deep layers to minimize risk of symptomatic neuroma formation.
- If the tumor partially encases the tendons, the retinaculum or tendon sheath may be incised on the uninvolved side of the tendon and lifted off as the margin on the tumor preserving the tendon (**TECH FIG 1B**).
- An assessment of joint stability is performed, and ligament reconstruction or augmentation is performed if indicated.
- Free tissue transfer is performed to reconstruct soft tissue defects.



TECH FIG 1 • A. Photograph showing planned incision that includes wide excision of previous biopsy incision. Because the tumor is superficial, which is often the case for ankle tumors, a large paddle of skin is removed as the margin on top of the tumor. **B.** Photograph illustrating the deep dissection. The tumor was abutting the joint and partially encasing the peroneal tendons. The retinacular tissues around the tendons were opened and peeled off the tendons allowing the tumor to be removed safely while preserving the tendons. Similarly, the joint capsule, retinaculum of the extensor digitorum longus, and periosteum of the fibula serve as deep margin for the more anterior portion of the tumor.

PEARLS AND PITFALLS

Wound breakdown

- Soft tissue reconstruction should be without tension.
- Patients should be counseled about the importance of leg elevation and activity modification.

Positive margins (sarcoma excision)

- Appropriate preoperative planning is important to minimize risk of unplanned positive margins.
- Inability to primarily close a wound should not interfere with the decision to remove a tumor with a clean margin. Plan on soft

tissue reconstruction.

- Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings.

POSTOPERATIVE CARE

- The ankle is splinted ideally in the neutral extended position.
- Weight bearing may begin once soft tissues including flaps and ligament reconstructions, if performed, have healed sufficiently, typically 6 weeks after surgery.
- Extremity elevation is recommended while patient is in bed.
- Antibiotics may be administered while drains are in place.

OUTCOMES (FIG 3)

- Oncological outcomes include local recurrence and metastasis. Surveillance for recurrence should be managed by a multidisciplinary sarcoma team. Local recurrence is higher when margins are positive.
- Functional outcomes depend on the extent of tissue resection and patient overall health status. Most patients will experience some form of disability that is proportional to the volume of soft tissue resection. Estrella et al. reported on a small series of six patients who underwent resection of foot and ankle sarcoma followed by free flap coverage. The average Revised Musculoskeletal Tumor Society (Enneking) functional score was 92.8% at average 49-month follow-up.¹

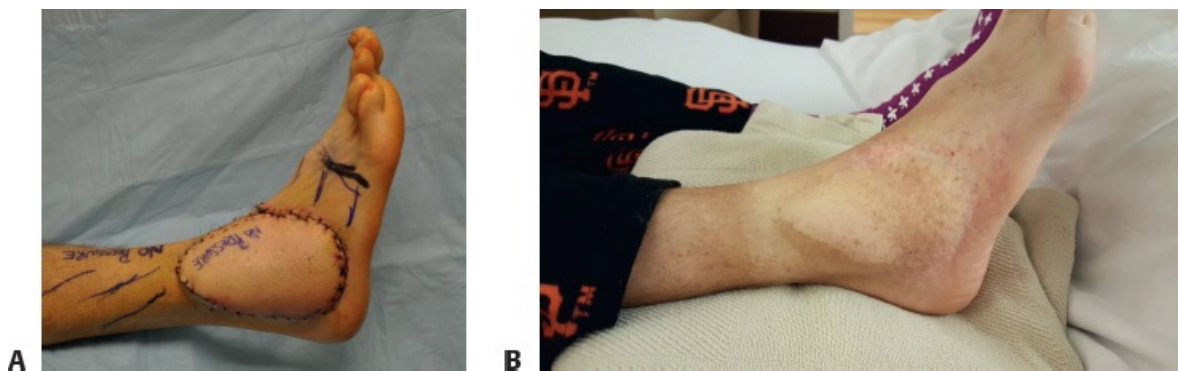


FIG 3 • **A.** Photograph immediately after completion of free anterolateral thigh flap. **B.** 5 years after surgery.

COMPLICATIONS

- Local recurrence occurs in a minority of patients with sarcoma and is more common in patients with positive margins.
- Deep infection can occur at any time after surgery and requires aggressive therapy including surgical debridement and antibiotic therapy to achieve limb salvage.
- Wound breakdown

REFERENCE

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8 Ankle and Foot Bone Tumors

CHAPTER

Robert J. Steffner, Raffi S. Avedian, and Sahitya K. Denduluri

DEFINITION

- Bone tumors of the foot and ankle are usually primary tumors. Metastatic bone cancer to sites below the knee is rare but not impossible.
- Primary bone tumors can be benign, low-grade malignant, or high-grade malignant.
- Surgery is considered for benign tumors with progressive growth or those producing symptoms. Malignant bone tumors are generally operative in both a curative and palliative setting.

ANATOMY

- There is minimal soft tissue coverage in the ankle and foot. Surgical resections requiring skin excision and/or placement of bulk cortical allograft should consider the need for soft tissue coverage to minimize the risk of infection and nonunion.
- When functional deficit and donor site morbidity for free tissue transfer are anticipated, consideration should be given to below-knee amputation. Patients may recover faster and have better long-term function with a prosthesis.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- It is important to ask patients about prior trauma and infections at the site of concern.
- A clinical history focusing on the duration of symptoms, presence of night pain, and systemic symptoms can help delineate benign from malignant etiologies.
- Physical exam focuses on the presence of prior incisions, skin mobility over

the tumor, and neurovascular status distal to the site of tumor involvement.

IMAGING

- Obtain plain radiographs of the involved site.
- Perform an MRI scan with and without contrast to assess the extent of tumor and involvement of critical structures such as tendons, nerves, and vessels. Also perform a whole bone MRI to demonstrate the extent of intramedullary involvement of tumor and look for skip lesions.
- Make every effort to obtain any prior imaging for comparison.
- Quality of imaging and the interpretation of imaging are vital for surgical planning.
- Upon diagnosis of a primary bone malignancy, staging studies are performed to assess for regional or distant metastatic disease. This generally requires a chest CT and whole body bone scan.

DIFFERENTIAL DIAGNOSIS

- Benign and malignant bone tumors can be found in the foot and ankle. Distinguishing between benign and malignant guides the extent of surgical management.
- Benign tumors include simple cyst, intraosseous ganglion, and enchondroma.
- Benign but active tumors include aneurysmal bone cyst (primary or secondary), giant cell tumor, osteoid osteoma, and, in pediatric patients, chondroblastoma.
- Malignant bone tumors include osteosarcoma, chondrosarcoma, Ewing sarcoma, primary lymphoma of bone, and metastatic carcinoma.

NONOPERATIVE MANAGEMENT

- Benign-appearing lesions that are not causing symptoms can be followed with serial imaging. Stable appearance on serial imaging studies supports nonsurgical management.

SURGICAL MANAGEMENT

- Symptomatic benign bone tumors and benign but active bone tumors are most often treated with intralesional curettage or marginal excision.
- Malignant bone tumors may require multidisciplinary management with the possible need for chemotherapy and/or radiation in addition to surgery.
- In nonmetastatic or oligometastatic primary bone cancer, the goal of surgery is

resection with negative margins.

Preoperative Planning

- If needed, size-matched fresh-frozen allografts should be coordinated from an appropriate vendor well ahead of time. The surgeon should assure that the graft has been delivered to the hospital. It is wise to have a back-up allograft available.
- Bone cuts are planned off T1-sequences from the first MRI scan. It is important to appreciate any soft tissue extensions and to look for fat planes around neurovascular structures to make sure they are free from tumor. Determination of appropriate margins is based on the specific diagnosis and the type of tissue at the level of resection.

Positioning

- Positioning depends on tumor location. Please see the “Techniques” section below.

Approach

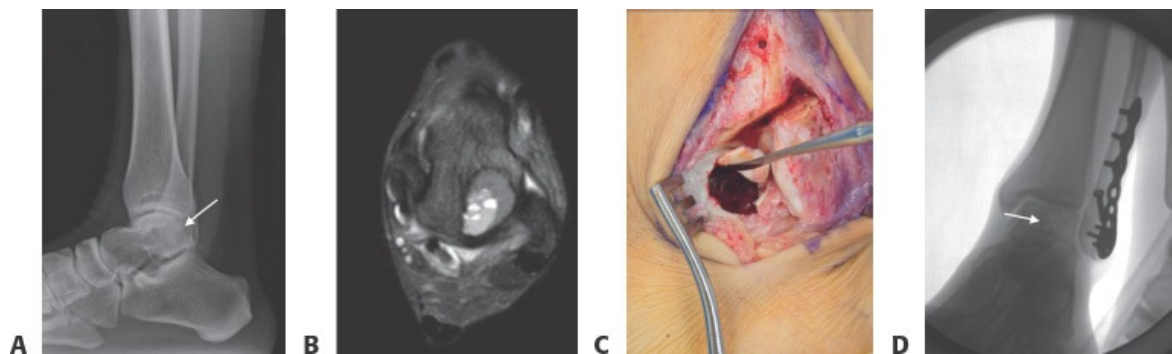
- An oncologic approach allows for a limited tissue biopsy while maintaining the possibility of wide resection in the setting of a malignant diagnosis. If oncologic principles are followed, the majority of patients will be eligible for limb salvage.²

TECHNIQUES

■ Benign Bone Tumor of the Talus (TECH FIG 1A,B)

- Patient positioned supine with an ipsilateral hip bump on a radiolucent table
- Tourniquet used after gravity exsanguination
- Localize tumor with intraoperative fluoroscopy
- To access talar body, an oblique osteotomy of the medial malleolus or distal fibula is often required. The surgeon may predrill bone in a lag-by-technique fashion before the osteotomy. This facilitates repair at the end of the surgery.
- A cortical window or cartilage flap is created with a curette or high-speed bur to access the bone tumor (TECH FIG 1C).

- Tissue is removed and sent for frozen section. If the pathology report is consistent with a benign tumor and matches the patient's clinical history and imaging, the surgery proceeds.
- The cortical window is expanded to adequately visualize and remove the tumor through intralesional curettage.
- Tumor margins are extended with use of a high-speed bur to smooth out the internal cavity of the cyst. Adjuvant treatments such as cryosurgery (liquid nitrogen) and argon beam coagulation can penetrate bone and further the zone of tumor kill. These measures lower the risk of local tumor recurrence.³
- Care should be taken near cartilage and growth plates to avoid damage to these structures. It is appropriate to accept a higher risk of local tumor recurrence in order to avoid injury to these structures.
- The resultant bone defect is filled with a substance of the surgeon's choice. In general, we use allograft in young patients; artificial bone void filler in young adults (mixture of calcium phosphate and calcium sulfate) and cement in older individuals.
- Supplementary internal fixation may be needed in weight-bearing locations and large defects (**TECH FIG 1D**).



TECH FIG 1 • **A.** Lateral radiograph of a secondary Aneurysmal Bone Cyst of the talar body (*arrow*). **B.** Axial Fat-suppressed T2 MRI image demonstrating fluid-fluid levels. **C.** Photo after oblique osteotomy of the distal fibula to access the talar body. A cartilage flap is made to access the bone tumor. **D.** Fluoroscopic image demonstrating cancellous allograft filler in the talar body and internal fixation of the distal

fibular osteotomy (*arrow*).

■ Malignant Bone Tumors of the Foot and Ankle

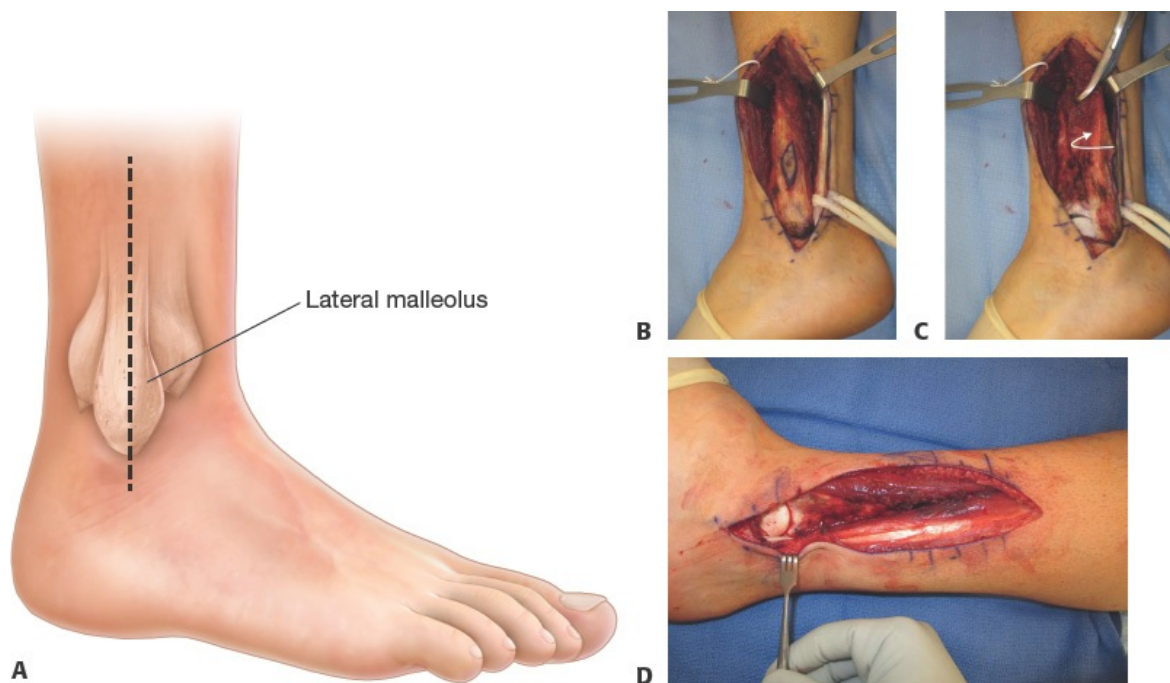
General Principles

- Use separate instruments for tumor resection and bone defect reconstruction.
- Obtain a thorough preoperative neurovascular exam.
- Consider an epidural catheter that can be test-dosed before surgery and used once a postoperative nerve exam is obtained.
- Use a thigh tourniquet and gravity to exsanguinate the leg.
- Hold paralytic medications if a nerve dissection is needed.
- Ellipse biopsy tract and keep in continuity with the resected tumor.
- Generally work from normal anatomy to abnormal anatomy.
- Clip or tie any arteries or veins that could be used for microvascular anastomosis.
- Measure bone cuts several times before cutting.
- After the bone cut, send a marrow margin for frozen section from the nonresection side.
- Orient resected specimens before sending to pathology.
- Fresh-frozen allografts are opened when frozen sections are negative. The allograft should be cultured and then placed in warm water bath with antibiotics for thirty minutes before use.

Distal Fibula Resection

- Lateral position on a beanbag. Straight lateral incision (**TECH FIG 2A**).
- Anteriorly, assess relationship of tumor with extensor digitorum longus and peroneus tertius.
- Posteriorly, assess relationship of tumor with peroneus longus and brevis and flexor hallucis longus (FHL).
- At the ankle joint, release the tibiofibular ligaments, talofibular ligaments, and calcaneofibular ligament.
- Make proximal bone cut early and roll fibula to expose the intraosseous membrane (**TECH FIG 2B,C**).
- Deep to FHL is the peroneal artery and vein; the latter may need to be ligated.

- Remove the tumor and send a marrow margin for frozen section.
- No bony reconstruction is necessary.
- Use a medium suture anchor to create a soft tissue sleeve for the peroneal tendons. This maintains length-tension relationships and avoids tendon subluxation (**TECH FIG 2D**).
- If possible, use absorbable suture to approximate the extensor digitorum longus muscle belly to the peroneus brevis.
- Immobilize for 6 weeks in a short leg splint with a mold in dorsiflexion and eversion.
- Obtain recovery room radiograph to check for any tibiotalar tilt. If present, the splint will need to be changed.
- Partial progressive weight-bearing begins at 6 weeks. Long-term, the patient may need a custom ankle brace.

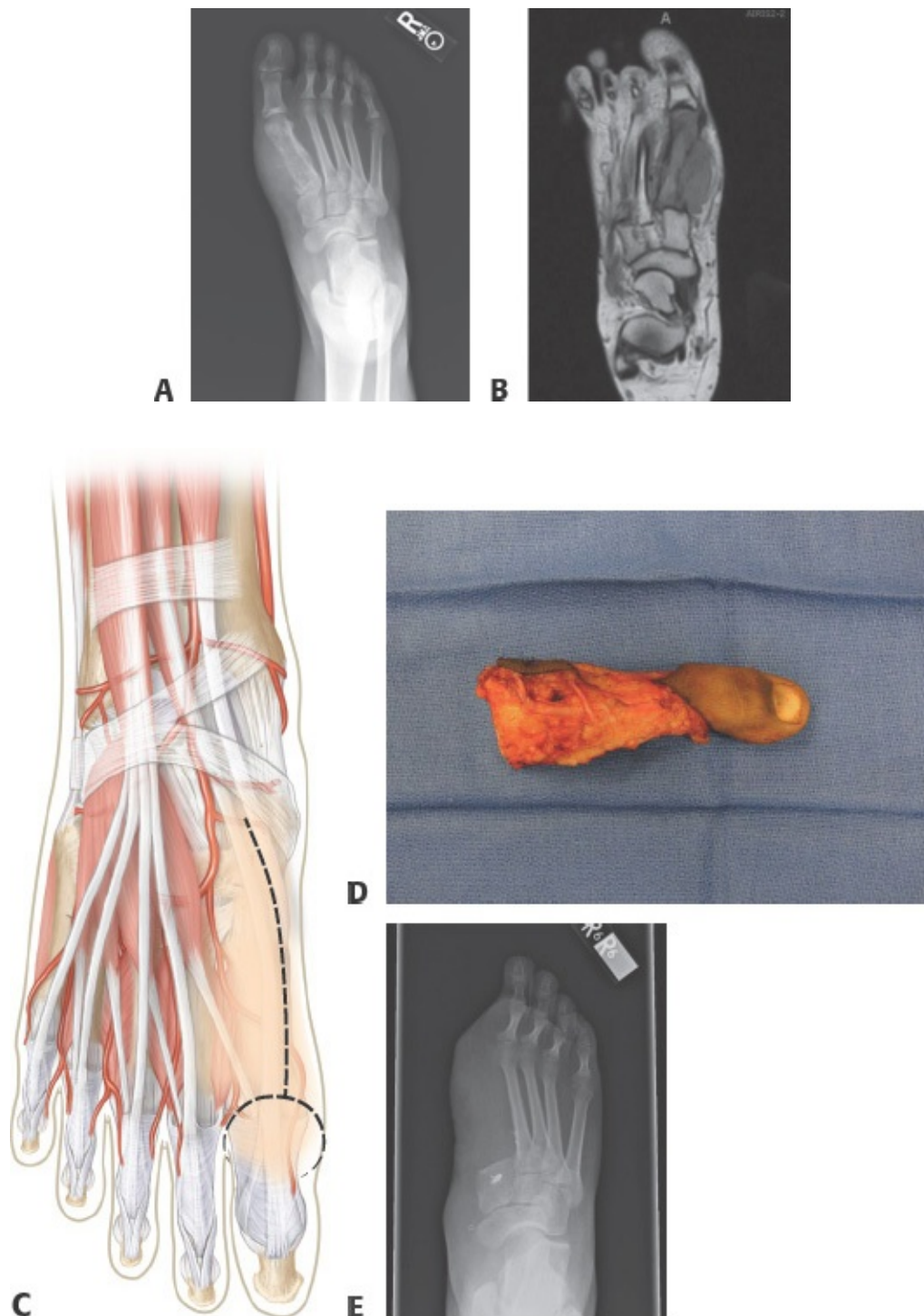


TECH FIG 2 • **A.** Illustration of the straight lateral approach for a distal fibula bone tumor. **B.** Anterior and posterior dissection with ellipse of biopsy tract. Notice the margin of normal tissue left with the malignant bone tumor. **C.** External rotation of the distal fibula after proximal bone cut (*arrow*). This exposes

the intraosseous membrane and posterior ligamentous structures. **D.** Use of remaining soft tissues to create a sling for gliding of the peroneal tendons. This also prevents tendon subluxation.

First Metatarsal (**TECH FIG 3A,B**).

- Supine position with a small contralateral hip bump.
- Dorsal incision that is just medial to the extensor hallucis longus (EHL) tendon. The tarsometatarsal (TMT) joint serves as the proximal extent of the incision (**TECH FIG 3C**).
- Ellipse circumferentially around the base of the great toe. If away from tumor, the skin around the great toe can be used for soft tissue coverage.
- Proximally, release the EHL tendon.
- Medially, dissect over the fascia of the abductor hallucis, leaving the muscle with tumor.
- Laterally, transect the extensor hallucis brevis.
- Come through the TMT joint proximally. The lateral aspect of the joint is close to the deep peroneal nerve and the deep plantar branch of the dorsalis pedis artery. Disarticulate and lift. Release the anterior tibialis tendon from the base of the first metatarsal and tag with suture.
- From plantar direction release the adductor hallucis and flexor hallucis brevis off the sesamoids. Transect the FHL tendon.
- Try to preserve the medial plantar artery and nerve.
- Release the intermetatarsal ligament and remove the resected specimen (**TECH FIG 3D**).
- Frozen section should be sent if there are any areas concerning for a positive margin.
- Scuff the medial cuneiform and attach the anterior tibialis tendon to this area with a suture anchor (**TECH FIG 3E**).
- Place a short leg splint for 2 weeks then allow heel weight bearing for the next 4 weeks.
- Once swelling is reduced, the patient is fit for a custom insert to go inside the shoe.
- Monitor postoperatively for lesser toe ulcers, flat foot deformity, and imbalance.



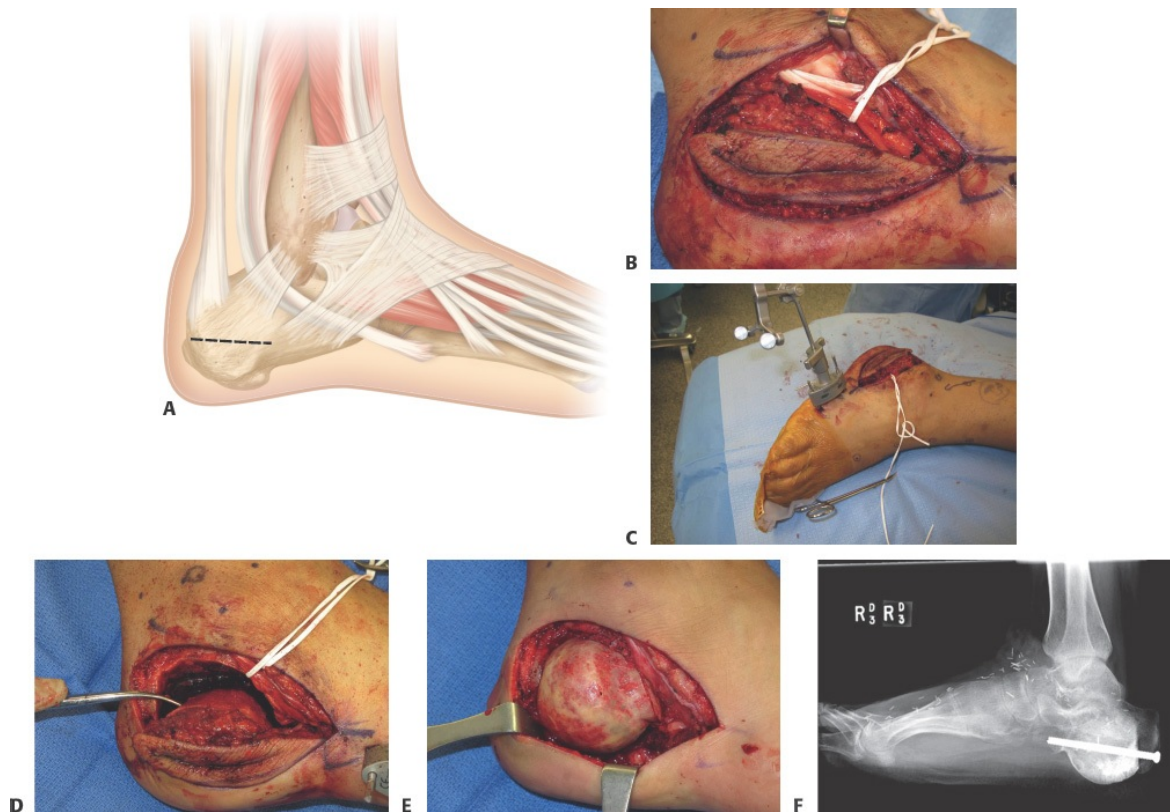
TECH FIG 3 • **A.** AP foot radiograph demonstrating an aggressive bone tumor of the first metatarsal. **B.** T1 coronal MRI showing Ewing sarcoma of the first metatarsal. **C.** Illustration of the dorsal incision with

circular ellipse around the great toe used for first metatarsal resection. **D.** Resected specimen after oncologic amputation of the first metatarsal. **E.** AP foot radiograph after surgery demonstrating suture anchor repair of the anterior tibialis tendon into the medial cuneiform.

Calcaneus

- Patient is positioned lateral on a beanbag. Blankets are used to create a platform for the top leg. Make sure the down leg will not obscure intraoperative fluoroscopic images.
- If there is concern for a postoperative equinus contracture, a gastrocnemius recession can be done before tumor resection.
- A lateral approach is made (**TECH FIG 4A**). Identify the peroneal tendons and sural nerve (**TECH FIG 4B**). Tumor extent will dictate the ability to salvage these structures. *As able, try to preserve the tenosynovium over the peroneal tendons.*
- A geometric tumor resection can utilize CT-guidance. To use this technology, a preoperative CT scan with *fiducials* or an intraoperative scan with an O-arm machine is needed. In the operating room, an array is placed close to the surgical site and points are cross-referenced between the CT scan and the patient's intraoperative position (**TECH FIG 4C**). This allows simultaneous localization in the axial, coronal, and sagittal planes.
- The angle of Gissane and posterior facet provide orientation.
- Using measurements from the preoperative MRI scans, use a sterile marker to draw the geometric cuts. If available, use CT guidance to confirm that the proposed geometric cuts are free from tumor.
- Use a microsaw to cut bone up to the opposite cortex. Use an osteotome to complete the resection. This will minimize risk to the medial plantar artery. Roll the resected bone and release the remaining soft tissue attachments (**TECH FIG 4D**).
- Perform frozen sections from the cut margins of the remaining bone as needed. Once frozen sections are negative, establish a new clean field and open reconstruction equipment.
- Use wax paper from surgical gloves to draw the bone defect.

- A fresh frozen femoral head allograft is opened and prepared as noted in “General Principles.”
- Fashion the allograft with a microsaw to fit the wax paper template. Maintain the subchondral bone of the femoral head for the plantar surface of the allograft (**TECH FIG 4E**).
- Place cancellous allograft at the femoral head allograft-host bone junction.
- Temporarily stabilize with k-wires.
- Using fluoroscopic views of the lateral foot and Harris axial, navigate percutaneous screws from the heel into the anterior process of the Calcaneus. Try to minimize the number of drill holes through the allograft (**TECH FIG 4F**).
- Soft tissue closure may be primary or require flap reconstruction.
- In general, a short leg splint is applied for 6 weeks. Front foot weight bearing is then allowed until 3 months postoperatively. Partial progressive weight bearing is then initiated.



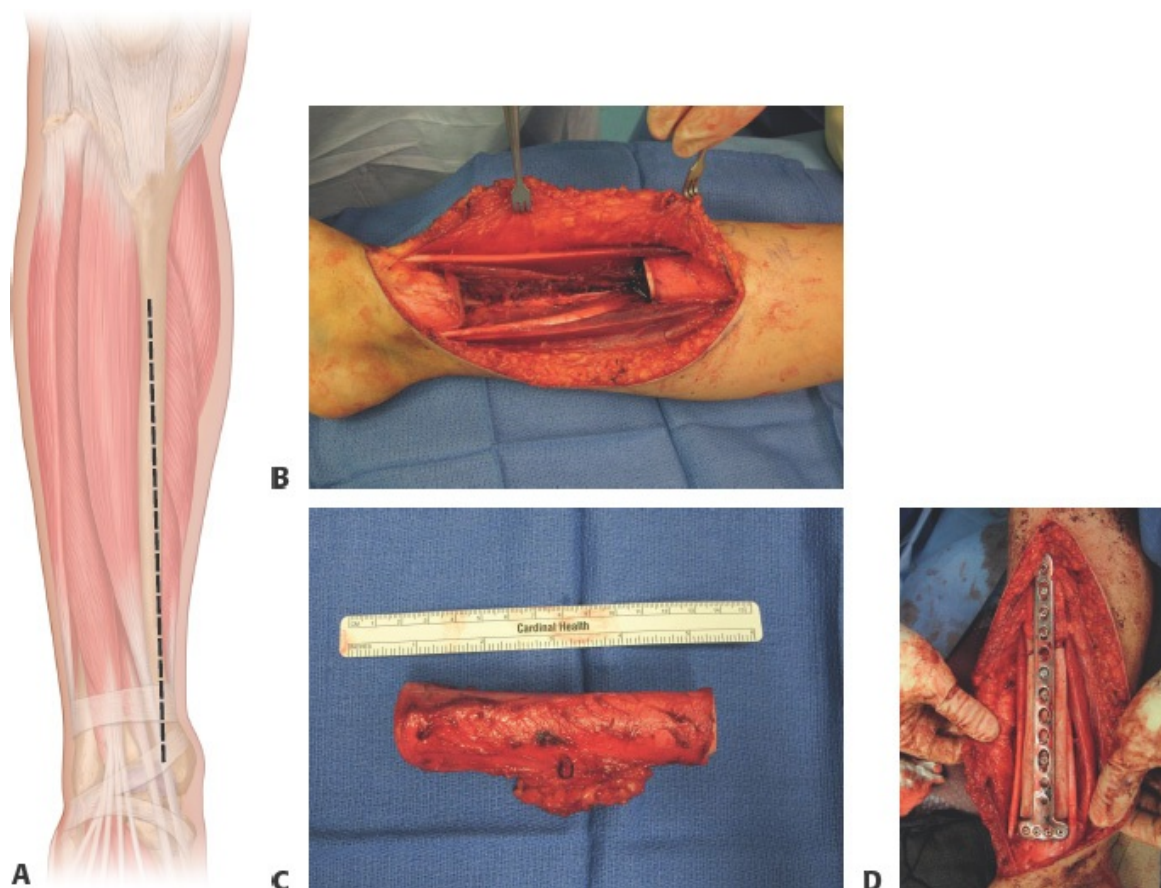
TECH FIG 4 • A. Illustration of the lateral approach to the calcaneus used for tumor resection. **B.** Ellipse of

the biopsy tract with identification of the peroneal tendons, which were amenable to preservation. **C.** Placement of the array into the fifth metatarsal. The array is used to couple the patient's intraoperative anatomy to a CT scan to facilitate localization during the geometric resection of tumor. **D.** The tumor is gently rolled out, and soft tissue attachments from the medial side are released to remove the tumor. **E.** Placement of the fashioned fresh-frozen allograft femoral head into the calcaneal defect. The subchondral surface is used on the plantar aspect of the foot. **F.** Follow-up lateral radiograph of the femoral head allograft stabilized with two percutaneous 2.7-mm screws. The host-allograft junctions appear healed. This patient required free tissue transfer for soft tissue coverage.

Distal Tibia

- Supine position without a hip bump.
- Incision is along the anteromedial tibia (**TECH FIG 5A**).
- Save the saphenous vein and nerve if possible.
- Release the posterior compartment fascia, identify and protect the tibial nerve and posterior tibial artery, which is found between the flexor digitorum longus and FHL muscles.
- Release the anterior compartment fascia, identify and protect the deep peroneal nerve and anterior tibial artery, which is found between the tibialis anterior and EHL muscles.
- The neurovascular bundle at the anterior ankle goes from medial to lateral relative to the EHL tendon.
- Measure resection lengths off the medial malleolus.
- Mark rotation on the nontumor side both proximal and distal to the bone cuts.
- Use retractors to protect the soft tissues around the tibia. Use the microsaw to cut bone while irrigating to prevent bone necrosis from heat.

- Roll the resected segment and release the intraosseous membrane.
- Check marrow margins from the intramedullary canal of the remaining bone at the proximal and distal ends (**TECH FIG 5B**).
- Measure the length of the resected specimen (**TECH FIG 5C**).
- Prepare the fresh-frozen allograft as described in the “General Principles” section. Start by making the allograft longer than the resected specimen.
- Make small cuts and recheck fit of the allograft.
- Check plain radiographs of the entire tibia in the operating room to assure proper fit of the allograft and confirm that a deformity is not being created.
- Select a plate that spans the intercalary defect and gets multiple points of fixation on both sides.
- Try to avoid open growth plates. If possible, consider compression plating across the host-allograft junctions. Be careful, too much compression and placement of cortical screws through a poorly contoured plate can lead to a fractured allograft.
- Hybrid fixation with locking screws is beneficial in short segments. Locking screws are also preferred on the allograft side as it minimizes risk of fracture (**TECH FIG 5D**).
- Only use enough screws on the allograft side to eliminate gross motion at the host-allograft junction. Too many screws can weaken the allograft.⁴
- A small second plate can be used to improve rotational strength if that is a concern.
- Closure is often primary. If there is notable skin loss, free tissue transfer may be needed.
- Patients are placed in a short leg splint. They are usually nonweight bearing for approximately six months. Partial progressive weight bearing is then started.



TECH FIG 5 • **A.** Illustration of the anteromedial incision for intercalary resection of the distal tibial diaphysis. **B.** Bone defect after resection of the distal tibia bone tumor. **C.** Length measurement of the resected segment of distal tibia. **D.** Spanning plate with hybrid internal fixation across the fresh-frozen intercalary allograft used to reconstruct the bone defect after tumor resection.

PEARLS AND PITFALLS

Imaging

- MRI scans are performed with and without contrast and done as a “tumor protocol.” Tumor protocol at our institution represents T1 axial, T2 fat-suppressed, and T1 fat-suppressed pre- and postcontrast

	images.
Localization	■ There are many small bones and joints in the foot and ankle. It is helpful to use intraoperative fluoroscopy to assure incisions are appropriately placed.
Biopsy	■ The oncologic approach to biopsy should be in-line with the incision necessary to perform a wide resection of the tumor.
Frozen section	■ Bone is too hard for frozen section processing. If sending a bone sample for frozen section, ask the pathologist to do a “touch prep” to examine cells inside the bone sample.
Implant selection	■ Future imaging will be needed to assess healing and look for recurrent tumor. Use of titanium implants can limit artifact on future MRI and CT scans. This benefit should be weighed against the need for a durable implant. New carbon implants may provide both strength and limited artifact on imaging.
Healing	■ Healing at the host-allograft junction can be augmented by step-cuts that increase the surface contact area between the two sides. Using microsurgery, vascularized bone, most commonly the fibula, can be set at the junction to aid healing and improve bone strength.

POSTOPERATIVE CARE

- Please see individual sections under “Techniques.”
- In all cases, patients are initially placed in a short leg splint and instructed to elevate the lower extremity at or above heart level for soft tissue rest.
- Structural fresh-frozen allograft used to fill defects in the lower extremity generally needs 6 months of nonweight bearing followed by partial progressive weight bearing to achieve full weight bearing over 4 to 6 weeks.
- Radiographs are done at 6 weeks and 3 months after surgery and then every 3 months for the first 2 years.
- Any mention of acutely worsened pain should trigger an assessment for infection and fracture.

OUTCOMES

- Very few studies have looked at outcomes of tumors about the foot and ankle, likely due to their rare incidence.
- Benign bone tumors of the foot and ankle are 3 to 4 times more frequently encountered than malignant bone tumors.^{5,6}
- In patients with malignant bone tumors of the foot, one center reported that

half were treated with some form of amputation.⁵

- A single-institution study found that the overall and disease-free survival rate at 9 years was 65% and 40%, respectively, for both benign and malignant bone and soft tissue tumors of the foot and ankle.⁶

COMPLICATIONS

- Leg length discrepancy: May develop from early physeal arrest. Two centimeters or less is well tolerated with a shoe lift. Anticipating this problem allows the surgeon to shut down the contralateral physis.
- Fracture: Fresh-frozen cortical allograft does not fully vascularize. The implant spanning the allograft will be needed for load-sharing forever and should not be removed. It is wise to restrict cutting and pivoting sports and activities.
- Nonunion: Allograft-host bone junctions can be slow to heal, especially at diaphyseal-diaphyseal junctions. Additional surgery to place cancellous autograft at the junction may be needed.
- Infection: Poor soft tissue coverage and lack of blood supply to bulk cortical allografts puts the surgical site at risk of infection. Generally, patients are maintained on oral antibiotics for three months after surgery. Infected allograft needs to be removed to clear the infection.
- Local recurrence: The surgeon should follow the patient for 5 years for high-grade and 10 years for low-grade malignancies to assess for local recurrence. MRI is generally the imaging modality of choice. The first postoperative scan is performed 3 months after surgery and serves as a baseline for future comparison.

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Debridement of Soft Tissue Infections of the Foot and Ankle

9

CHAPTER

Hunter S. Oliver-Allen, Michael Holland, and Scott L. Hansen

DEFINITION

- Soft tissue infections of the lower leg and foot include a spectrum of severity from superficial cellulitis to rapidly progressive necrotizing fasciitis.
- Soft tissue infections of the foot and ankle can involve skin, subcutaneous tissue, fascia, muscle, ligaments, tendons, joints, and around the nails.
- Secondary infections can be due to peripheral vascular disease (PVD), diabetes, metabolic conditions, and immunocompromised patients.
- Infections of the foot and ankle are often categorized into three groups: soft tissue infections, bone infections, and diabetic infections.
- Infections can be further characterized into nonpurulent (cellulitis and erysipelas), purulent (abscess), necrotizing soft tissue infections (NSTI) (including necrotizing cellulitis, myositis, and fasciitis) as well as tendonitis and septic arthritis.
- Immediate goal is to treat and control the infection.
- Long-term goal is for limb salvage, preserve limb function, and decrease risk for amputation.
- Infections are most commonly caused by bacteria, however can also be due to viral, fungal, or mycobacteria.
- Some may respond to treatment with topical, oral, or intravenous antibiotics alone, while others will require surgical debridement of devitalized tissue.
- Typically present as painful lesions with skin changes invariably present, with or without involvement of deeper tissues.

ANATOMY

- The lower leg, ankle, and foot comprise 28 bones.
- Soft tissues include muscles that are divided into anatomically distinct compartments in both the lower leg and the foot (**FIG 1**).
- The four compartments of the lower leg include the anterior, lateral, superficial posterior, and deep posterior divided by fascia.
- The nine compartments of the foot include the calcaneal—communicating with the deep posterior compartment of the leg, superficial, medial, lateral, adductor, and four interosseous.
- The primary neurovascular structures include the anterior tibial, peroneal, and posterior tibial arteries and paired veins; superficial peroneal, deep peroneal, tibial, saphenous, and sural nerves; and greater and lesser saphenous veins in the superficial tissues.
- Plantar surface is composed of thick glabrous epidermis and dermis, and a subcutaneous layer with vertical fibrous septae, densely adhering it to the plantar fascia and periosteum.

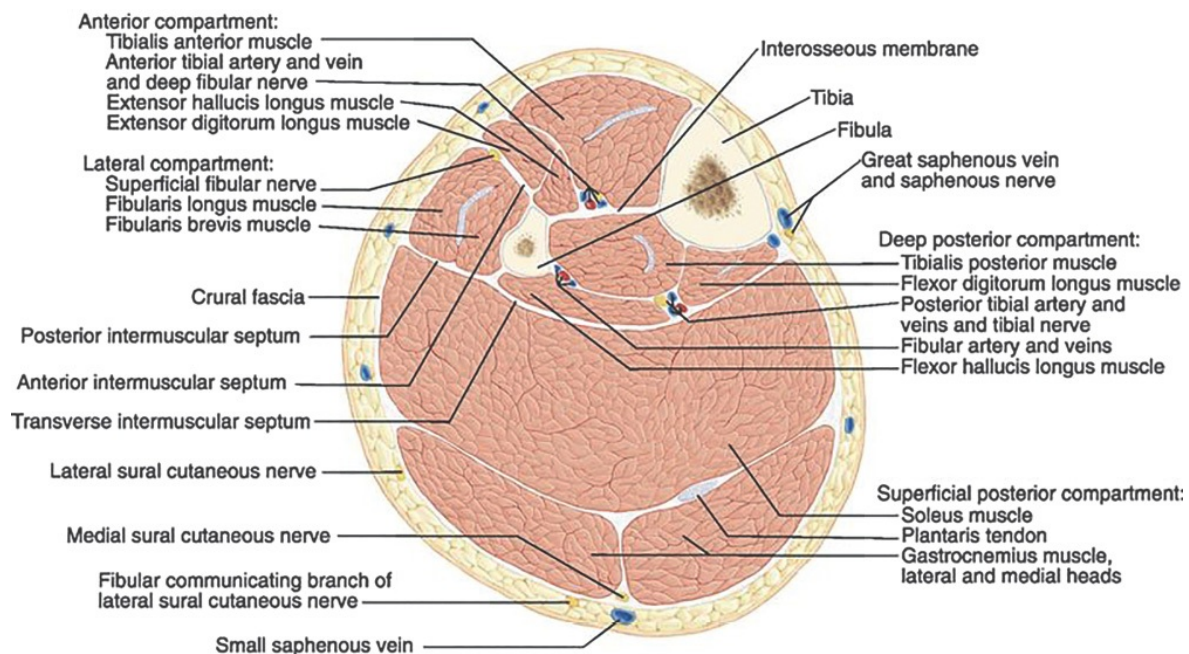


FIG 1 • Cross section of the leg showing the compartments. (From Pansky B, Gest TR. Lower limbs. In: *Lippincott's Concise Illustrated Anatomy: Back, Upper Limb, and Lower Limb*. Vol. 1. Baltimore, MD: Wolters Kluwer; 2012:198.)

PATHOGENESIS

- Infections result from breakdown of natural defenses in skin such as with trauma or open wound and invasion of resident skin flora or environmental pathogens.¹
- Patients with neuropathy and vascular disease and are immunocompromised have increased risk of infection.¹
- Group A beta-hemolytic streptococcus is the most common and second most common is *Staphylococcus aureus*.
- Infections are also commonly polymicrobial, especially in diabetic patients.
- NSTI result from bacterial invasion and subsequent angiothrombosis decreasing blood supply causing tissue necrosis They are classified into two groups:²
 - Type I is a polymicrobial infection consisting of anaerobic bacteria and aerobic bacteria.
 - Type II is monomicrobial infections typically of group A streptococcus or other beta-hemolytic streptococcus alone or with other pathogens.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient's initial complaint is typically of pain and swelling at site of infection. They may also notice changes in skin color and drainage of fluid. There may be a history of antecedent trauma.
- Systemic symptoms such as fevers, chills, malaise may not be present early in the disease but indicate an immune response to the infection.
- Past medical history of diabetes mellitus, vascular disease, immunodeficiency, heart failure, cirrhosis, or prior surgery may predispose to infection.
- Physical exam may reveal erythema, swelling, tenderness, warmth, fluctuance, visible drainage, and eschar.
- Open wounds may be present with exposed subcutaneous fat, muscle, fascia, or bone.
- Pain out of proportion to physical exam findings or crepitus are concerning physical exam findings for necrotizing fasciitis.

IMAGING

- Despite its inability to well characterize fluid collections, standard multiple view radiographs are the first initial test to identify any bony injury or radiopaque foreign bodies as well as gas from anaerobic bacteria. Subtle soft

tissue changes may also be demonstrated but are harder to appreciate by the untrained examiner.

- Ultrasonography may show cobble stoning of the subcutaneous tissues, which is indicative of edema. Discrete, hypoechoic fluid collections may also be identified. For patients with isolated abscesses, please see the chapter on drainage of abscesses of foot and ankle.
- Cross-sectional imaging with CT or MRI may better evaluate the extremity to determine the extent of infection.¹

DIFFERENTIAL DIAGNOSIS

- Cellulitis
- Abscess
- Necrotizing fasciitis
- Plantar fasciitis
- Gout
- Skin cancer
- Venous stasis ulcer or dermatitis
- Impetigo
- Erysipelas

NONOPERATIVE MANAGEMENT

- Simple infections such as folliculitis or impetigo may improve with topical antibiotics alone.
- Cellulitis and more superficial infections require oral or intravenous antibiotics.
- Infected open wounds without burden of necrotic tissue may be treated with local wound care and antibiotics with careful monitoring for clinical worsening in poor surgical candidates.

SURGICAL MANAGEMENT

- The goal of surgery is to identify and debride all nonviable tissue, and a planned second look operation may be considered in severe infections where debridement is limited by critical structures.

Preoperative Planning

- In patients who are hemodynamically unstable or with suspected necrotizing infection, empiric antibiotic therapy should be ordered while drawing blood

cultures and should not be delayed for wound cultures.

- In patients who are otherwise stable, consider deferring antibiotics until wound cultures have been obtained.
- If hardware is present, consider need for removal with orthopedic surgery consultation, as well as need for bony debridement.
- Ensure medical comorbidities are addressed. Patients with infected wounds due to vascular ulcers may require preoperative revascularization. Diabetics should have tight glycemic control.
- Ensure appropriate laboratory investigations are obtained including complete blood count, basic metabolic panel, C-reactive protein, sedimentation rate, and blood cultures.
- Antibiotic selection should cover gram-positive organisms with MRSA coverage, and due to prevalence of gram-negative organisms in foot infections, gram-negative coverage should also be provided while awaiting culture results.

Positioning

- Supine position is usually sufficient for exposure.

TECHNIQUES

■ Debridement of Soft Tissue Infections

- Identify the affected area of the leg or foot and prep well beyond the border with healthy tissue (**TECH FIG 1A**).
- Identify necrotic or nonviable tissue and sharply debride without the use of cautery.
 - Avoiding cautery will allow using the presence of bleeding to guide when sufficient debridement has been performed.
- Necrotic tissue is picked up with forceps and trimmed with curved mayo scissors, Metzenbaum scissors for finer tissue, or scalpel.
- Tissue may be sent to pathology and microbiology for culture and Gram stain.
- Presence of tunneling or disruption of fascial planes should be examined to identify necrotizing fasciitis.
- Probe the wound for any areas of tunneling. Areas of tunneling with fascial

disruption and/or presence of “dishwater-” appearing fluid raises concern for presence of necrotizing fasciitis.

- If tunneling found, most overlying tissue should be opened to explore extent of infection, debride overlying tissue that is nonviable.
- Irrigate the cavity with at least 3 L of saline, which is easily done with cysto tubing (**TECH FIG 1B**).
- Obtain hemostasis with electrocautery.
- Pack the open wound with surgical packing.
- Consider ultimate reconstructive goal, including healing by secondary intention with wound care, wound Vacuum-assisted closure (VAC), skin grafting, local flap, or free flap (**TECH FIG 1C**).



TECH FIG 1 • **A.** Infected lateral malleolar wound after trauma. **B.** Debridement with high-pressure water. **C.** Healed wound with split-thickness skin graft.

PEARLS AND PITFALLS

Preoperative workup

- Failure to obtain blood cultures
- Failure to identify patients needing revascularization before making larger wound
- Delaying antibiotic therapy in severe infections
- Nutritional optimization

Technique

- Incomplete debridement resulting in need for additional surgery
- Incompletely exploring extent of wound/tunneling
- Use copious irrigation

Postoperative

- Placing wound VAC on infected wound

POSTOPERATIVE CARE

- Continue broad spectrum antibiotics while awaiting culture speciation
- Continue local wound care with at least twice daily dressing changes until wound is confirmed to be clear of infection, afterward specialty dressings or wound VAC may be applied which may be changed less frequently.
- Silver sulfadiazine or other silver impregnated dressings controls both bacterial growth and facilitates wound healing.
- Continue to optimize medical comorbidities and smoking cessation.
- Allow for at least passive range of motion exercises if weight-bearing surface is affected.
- Elevation of the extremity and pressure off-loading.

COMPLICATIONS

- Persistent infection
- Missed diagnosis of necrotizing infection
- Injury to neurovascular structures
- Hematoma

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10 Debridement of Infected Bone of the Foot and Ankle

CHAPTER

Michael Holland and Scott L. Hansen

DEFINITION

- Osteomyelitis of the foot and ankle is defined by bacterial or less commonly fungal infection of bones of the lower third of the leg and foot.
- Spectrum of severity can range from chronic, indolent infections to acute, suppurative infections resulting in sepsis.
- Often resulting from existing soft tissue wound extending deep to underlying bone; however, seeding (eg, from bacteremia), direct inoculation (eg, trauma, puncture wounds), or healing of prior soft tissue defects can result in isolated osteomyelitis in the absence of soft tissue signs or symptoms.
- Frequently associated with hardware and prior fractures necessitating removal or replacement of hardware.
- The management of acute osteomyelitis is primarily medical, whereas the management of chronic osteomyelitis is mainly surgical in combination with antibiotic therapy.¹

ANATOMY

- The ankle is formed by the distal aspect of the tibia (medial) and fibula (lateral) articulating with the talus of the foot.
- The foot is composed of 26 bones functionally homologous to bones of the hand and wrist.
- The hindfoot is composed of the talus, which is seated on the calcaneus.
- The midfoot articulates with the bones of the hindfoot and is composed of the cuboid navicular and three cuneiform bones (medial, intermediate, and lateral).
- The forefoot is composed of the 5 metatarsal bones and 14 phalanges.
- Two sesamoid bones underlying the first toe metatarsal phalangeal joint also

are present in adults, with infrequently found accessory sesamoid bones at other joints.²

PATHOGENESIS

- Infection most often arises from soft tissue wounds, open fractures, complications from orthopedic reduction of closed fractures, hematogenous seeding from bacteremia or endocarditis, or inoculation from trauma

PATIENT HISTORY AND PHYSICAL FINDINGS

- History of diabetes mellitus, vascular insufficiency, venous hypertension, peripheral neuropathy, immunodeficiency, prior fracture, presence of hardware, prior surgery, and prior podiatric procedures are important to identify preoperatively in order to determine whether or not adjuvant therapy may be beneficial to precede operative intervention.
- Diminished sensation, paresthesias, and claudication are symptoms that may indicate the presence of these above comorbidities.
- Presence of open wounds with or without visible bone, erythema, fluctuance, and bony tenderness can indicate active infection.
- Decreased Semmes-Weinstein monofilament test, prior scars, palpable hardware, and venous ulceration are physical exam findings that may indicate higher-risk populations for developing osteomyelitis.

IMAGING

- Three-view plain radiographs of the foot and ankle are the first test to order, and will help give clear definition of bony anatomy, presence of hardware or radiopaque foreign bodies, and can detect subtle changes of osteomyelitis as early as 10 to 14 days but typically requires 3 weeks of active infection before changes will be found.³
 - Periosteal reaction (**FIG 1A**), lytic lesions, endosteal scalloping, loss of bone density, or trabecular architecture are findings indicative of osteomyelitis.⁴
- CT scan is useful for demonstrating extent of osteomyelitis and may detect radiologic changes earlier than plain radiographs; however, sensitivity is limited at around 67%⁵ and may have findings obscured by hardware artifact. Utility may be found in ability to evaluate extent of disease and to create three-dimensional reformats for reconstructive planning.
- MRI is the most sensitive and specific modality for diagnosis of osteomyelitis, as early as 3 to 5 days (**FIG 1B**).^{6,7}

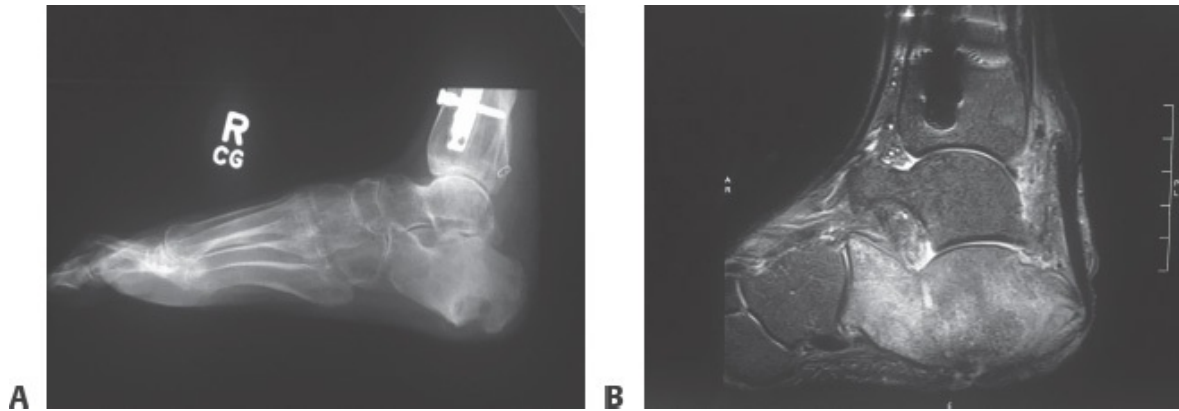


FIG 1 • A. Radiograph of the right foot demonstrating periosteal reaction of the calcaneus indicating osteomyelitis. **B.** Corresponding MRI of the right foot demonstrating the extent of calcaneus osteomyelitis.

DIFFERENTIAL DIAGNOSIS

- Gout
- Cellulitis
- Plantar fasciitis
- Sickle cell anemia
- Neoplasm (primary or metastasis)

NONOPERATIVE MANAGEMENT

- Acute osteomyelitis without abscess or necrotic component can frequently be treated with isolated intravenous antibiotic therapy for a duration of at least 6 weeks. However, if nonoperative management fails, operative management is indicated.

SURGICAL MANAGEMENT

- Surgical debridement should always be considered and is mandatory for osteomyelitis with any necrotic component and, in combination with antibiotic therapy, is the mainstay of treatment for chronic osteomyelitis.

Preoperative Planning

- Identify need for glucose control, preoperative revascularization, smoking cessation, nutrition optimization, initiation of antiretroviral therapy, address patients ultimate reconstructive goal (eg, flap vs amputation).

- Coordinate with orthopedic surgeon if hardware is in place in order to determine plan for replacement with antibiotic spacer or removal.
- Consider orthopedic surgery consult if large amount of debridement is expected with possible destabilization of ankle joint or foot requiring spanning ex-fix or other temporary stabilization.
- Obtain infectious disease consultation for antibiotic selection and duration.
- A second look procedure should be anticipated and discussed with patient.
- Laboratory studies including complete blood count, sedimentation rate, C-reactive protein, metabolic profile, and blood cultures should be obtained and trended throughout therapy.

Positioning

- Place patient in supine position.
- Prep affected extremity from toes to groin with Betadine.
- Apply either lower extremity drape or split sheet to create sterile field.

Approach

- Principles of therapy include wide debridement, stabilization of remaining bony architecture, culture-guided antimicrobial therapy, and reconstruction of resultant bony defects.⁸

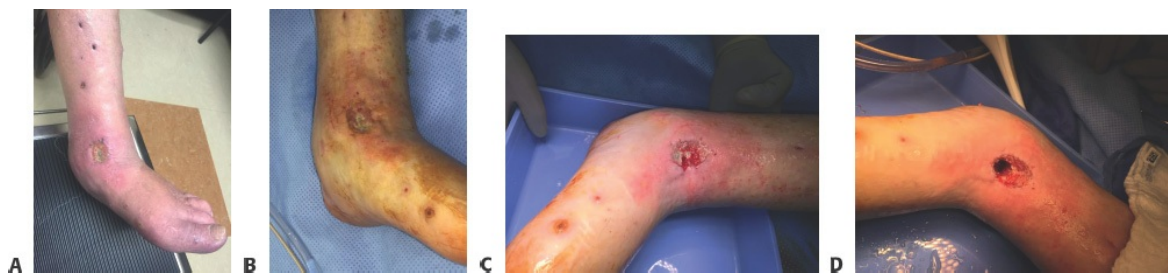
TECHNIQUES

■ Wide Debridement of Bone Infection

- If a wound is present with exposed bone (**TECH FIG 1A**), the wound edges are debrided sharply until healthy, bleeding tissue is reached (**TECH FIG 1B**).
- The underlying bone is inspected for viability.
- Any soft or necrotic bone must be removed with rongeur, curette, or osteotome, until healthy, viable bone is reached (**TECH FIG 1C,D**).
 - If hardware is present, it must also be removed at this time.
- Removed bone is sent to pathology and microbiology for culture and Gram stain.
- The resultant defect is examined for viability. Any remaining nonviable

tissue must be removed to prevent reinfecting compromised bone.

- The wound is irrigated copiously with at least 3 L of saline.
- Any dead space must be obliterated with antibiotic beads, cement, or soft tissue to prevent fluid accumulation.
- Bony stabilization can be further provided with plating, screws, or external fixation.
- A sterile, temporary dressing may be applied if second look is anticipated.
- After final debridement, soft tissue coverage must be applied by primary closure, local flap, or free flap.



TECH FIG 1 • **A.** Medial malleolar chronic wound with underlying bone involvement. **B.** After wound care, there is no significant change. **C.** Wound after soft tissue debridement. **D.** Wound after debridement of infected bone.

PEARLS AND PITFALLS

Preoperative planning

- Lack of patient optimization resulting in poor wound healing.
- Lack of plan with orthopedic surgeon for need for removal of hardware, stabilization.
- Not considering patient preferences for early amputation and reconstructive goals.
- 6-week antibiotics.
- Premature, early weight bearing and subsequent fracture.

Technique

- Not performing wide enough debridement to reach healthy margins.
- Not taking intraoperative cultures for culture-guided therapy.

- Not taking a second look.

Postoperative

- Inadequate antibiotic duration, failure to follow culture-directed therapy.

POSTOPERATIVE CARE

- The patient is continued on antibiotics that may be narrowed when culture data return.
- Laboratory values are checked every few days to monitor for response to treatment.
- Postoperative radiographs are obtained to document degree of bony resection.
- Infectious disease consultation is considered if not already obtained.
- The patient is allowed to work with physical therapy but is kept nonweight bearing until final orthopedic reconstruction is completed or stability determined to be sufficient. If soft tissue reconstruction performed, positioning restrictions may vary depending on appearance of flaps.

OUTCOMES

- Patients frequently require multiple surgeries for adequate debridement to viable tissue.
- With adequate debridement, need for subsequent amputation has been reported to be around 18%, minor 11.7% and major 6.3%.⁹
- Long-term limb salvage (avoiding need for major amputation) with surgical management is around 82%.⁹
- Persistent infection can be as high as 36% after debridement, underscoring need for adequate debridement of all nonviable tissue.¹⁰
- Overall perioperative mortality has been reported to be 1.6%¹¹

COMPLICATIONS

- Persistent infection
- Fracture
- Minor amputation
- Major amputation

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11 Bony Reconstruction of Foot and Ankle (Bone Grafts)

CHAPTER

Kenneth J. Hunt and Loretta Chou

INTRODUCTION

- Recent decades have witnessed a dramatic increase in available bone graft harvest techniques, bone graft substitutes, and orthobiologic technologies. Despite the extensive availability and marketing of bone graft substitutes, and their purported advantages, autogenous bone graft remains the standard for augmenting healing during arthrodesis and nonunion surgery.
- Autograft bone is the only naturally occurring material purported to possess osteoconductive, osteoinductive, and osteogenic properties. Still, the use of bone grafts in orthopedic surgery has given rise to a multibillion dollar industry but has by no means eradicated nonunions in foot and ankle surgery.^{1,2} This chapter will discuss current bone grafting techniques and technologies for foot and ankle procedures in the context of the most common conditions and patient risk factors requiring augmentation for effective healing.

DEFINITION

- Bone grafts in the foot and ankle are most commonly utilized for three indications: (a) increase the union rate for arthrodesis in revisions or joints with a known propensity for nonunion, (b) increase union rate for nonunited fractures, and (c) replace or add bone structure due to chronic or acute bone loss. The focus of this chapter is bone grafting techniques to illustrate these three indications. We include some specific, common foot pathology that requires bone grafting, but an inclusive review of foot and ankle pathologies and disease processes is outside of the scope of this chapter.
- By far, the most common use of bone graft in the foot and ankle is to aid in healing for joint arthrodesis. The degeneration of joints requiring fusion can

occur as a result of a number of disease processes, including post-traumatic arthritis, degenerative joint disease (DJD), posterior tibial tendon insufficiency, trauma, congenital deformity, inflammatory or crystalline arthropathy, Charcot neuropathy, diabetes, avascular necrosis, tumor, and many other causes.

- Bone graft is generally incorporated to aid in healing when the risk of nonunion is unacceptably high. This is the case in patients who might have a suboptimal biologic healing response, including those with a history of smoking, diabetes, neuropathy, obesity, or a history of nonunion.³⁻⁵
- The procedures in the foot and ankle that most commonly involve bone graft application include ankle, subtalar (ST), tibiotalarcalcaneal (TTC), triple, tibio calcaneal (TC), talonavicular (TN), calcaneocuboid (CC), naviculocuneiform (NC), and tarsometatarsal (TMT) arthrodesis, and most nonunion repairs. Due to the paucity and inconsistency of literature on the topic, the decision to use bone graft, and which type or material to use (ie, cancellous vs structural, harvest site, autograft vs allograft, bone graft substitutes, etc.), is dependent upon a host of patient factors and surgeon experience.
- Generally speaking, cancellous autograft generally has a higher surface area and greater content of growth factors and remains the standard for its ability to induce more new bone formation than cortical (ie, structural) autograft or allografts.⁶ Structural autograft is often required when significant bone loss or deformity is present, as a means of restoring length, height, and/or alignment. The fast-growing arsenal of “orthobiologics” as substitutes for autograft are purported to rival autograft in terms of timing and rate of healing, without the morbidity of autograft harvest.

ANATOMY

- The foot and ankle is composed of 28 bones. There are multiple joints, muscles, tendons, and ligaments. The foot can be divided into the medial and lateral columns. The medial column includes the talus, navicular, cuneiforms, and medial three metatarsals. The lateral column is made up of the calcaneus, cuboid, and lateral two metatarsals. Any injury, deformity, or defect can result in length alterations or stiffness in one or more columns of the foot. This can lead to pain, imbalance, and problems with weight bearing on a foot that is not plantigrade, unstable, or painful.
- The ankle joint allows for most of the extension and flexion. The subtalar joint provides inversion and eversion, whereas the transverse tarsal joint

(talonavicular and calcaneal cuboid) gives adduction and abduction.

- The foot and ankle is responsible for gait. The heel is the first point of contact in the normal gait cycle. As the foot rolls forward, the foot changes from a flexible valgus position to a rigid varus position for push off.
- The anatomy of the iliac crest, for the purposes of graft harvest discussed herein, is fairly easy to identify and superficial. The graft harvests described below are generally harvested from 2 to 4 cm above the anterior superior iliac spine (ASIS). The crest at this location can usually be palpated. Keeping the incision and dissection at least 2 cm proximal to the ASIS to avoid injury to the lateral femoral cutaneous nerve.

PATHOGENESIS

- The foot and ankle are the most peripheral structures in the body and are dependent during most physical activities. As a result, the foot and ankle are at higher risk of peripheral neuropathy, peripheral vascular disease, and other contributors to delayed or nonhealing of fusions or fracture fixation.
- The weight-bearing role of the foot and the complexity of biomechanics for normal foot and ankle function place many regions of the foot and ankle at higher risk for abnormal loading, further contributing to delayed- or nonunion of fractures, arthrodesis, or osteotomies.
- Patient risk factors known to contribute to nonhealing of bone include smoking, diabetes, age and osteoporosis, peripheral vascular disease, neuropathy, noncompliance, infection, and soft tissue injury.⁴

NATURAL HISTORY

- The disorders of the foot and ankle are broad and significant and include trauma, arthritis, congenital, acquired, sports injuries, and degenerative conditions. With severe deformities or trauma, structural loss or nonhealing of fractures or fusions frequently lead to worsening of the disorder and pain and function, over time. Reconstructive operations may be required to repair such problems. In cases where there is need to add structural bone, or add biology, bone grafting procedures are commonly considered.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history is essential preoperatively. Patients are asked about injuries, chronicity, comorbidities, previous operations, and nonoperative treatment. Also, the patient's occupation and social situation are important considerations.

- Medical history should be considered when determining risk factors and the best bone graft to use. Social history is also important because patients may have particular traditions and beliefs governing whether autograft or allograft materials are acceptable. The beliefs should, and generally can, be respected during development of a treatment plan.
- The physical examination takes place with the patient undressed from the knees to the toes. Gait is evaluated, as well as the skin, noting edema, scars, erythema, masses, and bony deformities. The neurovascular status is carefully examined. Evaluating potential graft sites is also important.
- The foot and ankle examination can help guide surgical approach and counseling. Incisions should be made where soft tissue disruption, particularly of the well-vascularized periosteum, can be minimized. Old incisions should be incorporated whenever possible, especially when the procedure was recent.

IMAGING

- Most nonunions and malunions of fractures, fusions, and osteotomies can be diagnosed on plain radiographs (**FIG 1A**).
- For joints that are difficult to see on plain radiographs, or for complicated procedures with a large fixation construct, a CT scan is the best study to diagnose nonunion (**FIG 1B**).
- MRI scan plays little role in diagnosing nonunion but can be helpful to evaluate soft tissue structures, which may contribute to symptoms, and is a sensitive study for osteomyelitis.
- Nuclear medicine studies can aid in diagnosis of infection and osteomyelitis, which is a common contributor to nonhealing of bone (**FIG 2**).

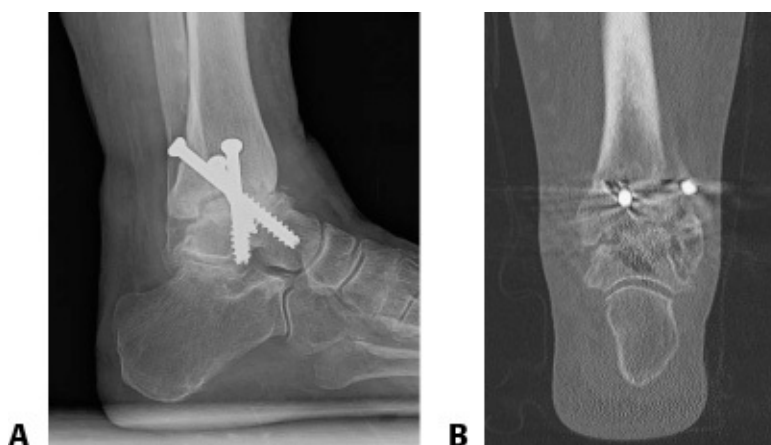


FIG 1 • **A.** Plain lateral radiograph. **B.** Coronal and

sagittal CT scan images depicting a nonunion of ankle arthrodesis.

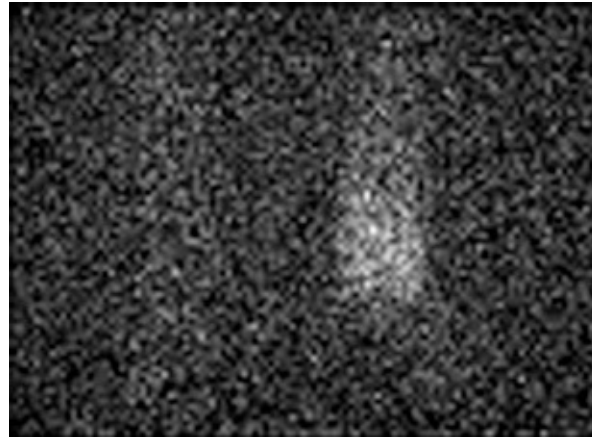


FIG 2 • Tagged WBC study demonstrating increased uptake in the left ankle compared to the right.

DIFFERENTIAL DIAGNOSIS

- Hypertrophic nonunion
- Oligotrophic nonunion
- Septic (infected) nonunion
- Malunion
- Avascular necrosis of bone
- Failure of fixation

NONOPERATIVE MANAGEMENT

- Nonoperative treatment for many foot and ankle disorders include activity modification, ambulatory aid, such as a cane or crutch. Physical therapy, brace, or orthotic device may be helpful. Oral medications can help reduce pain, although one must be aware of risks (eg, NSAIDs can contribute to delayed healing, narcotic analgesics carry risk of dependency).
- Severe deformities may be difficult to accommodate or fit into a brace, and surgical options should be considered.
- In general, if patients have persistent pain, dysfunction, problems working or participating in activities of daily living, or if there are risks to other structures or to the patient by continuing nonoperative management, surgery should be considered.

SURGICAL MANAGEMENT

- The decision to augment a fusion, osteotomy, or fracture with graft is dependent on many factors, including surgeon preference and experience. Grafts should, in general, be added to increase both the likelihood and the timing of bone union in cases where nonunion or delayed union is unacceptably high. Examples include revision cases and patients with risk factors outlined above.
- The authors prefer autograft iliac crest bone graft for most indications where there is high risk of nonunion. When structural grafts are necessary to span a cortical gap in bone, structural autograft from the iliac crest is generally sufficient for most procedures in the foot. Ankle and hindfoot bone loss often requires larger allografts, such as femoral head or fibular grafts.
- Orthobiologics can be used in lieu of, or in addition to, other graft materials, or to add a large dose of specific growth factors to the fusion site. Examples of such orthobiologic therapies include platelet-rich plasma (PRP), bone marrow aspirate concentrate (BMAC), bone morphogenetic proteins (BMP), and platelet-derived growth factor (PDGF). The enormous recent growth of the number of available biologic products carries with it a high cost and a paucity of data on safety, effectiveness, and clinical outcomes for many products, particularly compared to the iliac crest bone graft standard. It is the responsibility of the surgeon to judiciously utilize these products with a thorough knowledge of their mechanism(s) of action, approved indications, side effect profiles, and cost.
- The ultimate goal of any fusion, osteotomy, or fracture repair operation is bone healing, pain relief, and return to optimal function while avoiding complications, prolonged hospitalization, and revision operations. When a graft is selected, the surgeon must balance necessity, cost, comorbid factors, and risk and have a keen understanding of the selected graft(s) and technique.

Preoperative Planning

- Plain weight-bearing radiographs of the foot and/or ankle are necessary for complete evaluation (**FIG 3A**).
- Other imaging studies may be helpful. MRI may show extent of infection or the presence of avascular necrosis. CT scans confirm nonunion and show bone quality and structural bone loss, bony defects and deformities (**FIG 3B,C**).
- A complete evaluation of the skin and adjacent structures must be performed,

using radiographs when prudent. This should include the surgical site in the foot or ankle and any potential graft harvest site.

- A thorough discussion of risks and the postoperative course (which can be prolonged) should be had with the patient because compliance is vital to success.
- Ensure that appropriate equipment is available prior to starting the case. A good coring reamer is helpful for cancellous graft harvest (**FIG 4**). Osteotomes and retractors can help to expose and harvest cortical grafts. Allografts and biologics should be requested if these might be required.
- Plan for size and volume. It is important to estimate the amount of graft that will need to be harvested for a given procedure.

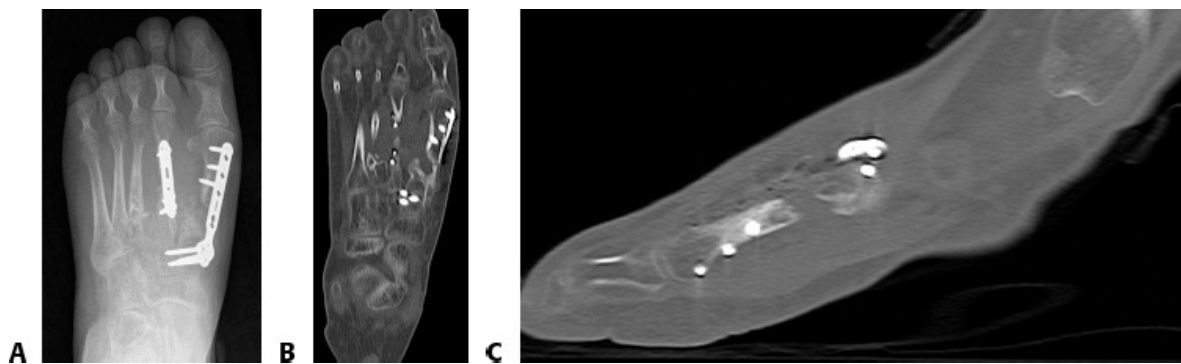


FIG 3 • **A.** Anteroposterior radiograph of nonunion of the first metatarsal. Axial (**B**) and sagittal (**C**) CT scans confirming the nonunion.



FIG 4 • Photograph illustrating components of a coring reamer setup for harvesting of autograft cancellous

bone graft. These include a coring reamer (7 mm diameter pictured here), a tipped trochar, and a T handle. Alternatively, power tools can be utilized with caution.

Positioning

- Most cases are performed with the patient in a supine position. This also facilitates graft harvest for most sites.
- The patient is typically positioned toward the edge of the bed to facilitate access to the foot and ankle.
- Generally, the autograft is harvested on the ipsilateral extremity. The graft site undergoes sterile preparation and draping along with the surgical extremity (**FIG 5A**).
- With distal lower extremity autografts, we advised that the patient have protected weight bearing in a cast or brace for the primary procedure, which also allows for healing of the harvest site.

Approach

- In the primary surgery setting, the decision to use bone graft is complex and based on the criteria outlined above. Once this decision is made, preoperative planning using available imaging should be undertaken. The surgical approach should ensure avoidance of injury to neurovascular structures and minimizing soft tissue disruption.
- For nonunion surgery, once a symptomatic nonunion is diagnosed and appropriate conservative measures have been taken toward healing and restoration of function, the use of bone graft is considered for revision surgical options.
- The approach for graft harvest is based on access to sufficient graft volume for the indication while avoiding large bone defects, bleeding, and injury to surrounding structures. We will specifically discuss and illustrate the four most common graft harvest sites for foot and ankle indications: the anterior iliac crest (structural and/or cancellous), the proximal tibia, and the calcaneal tuberosity.

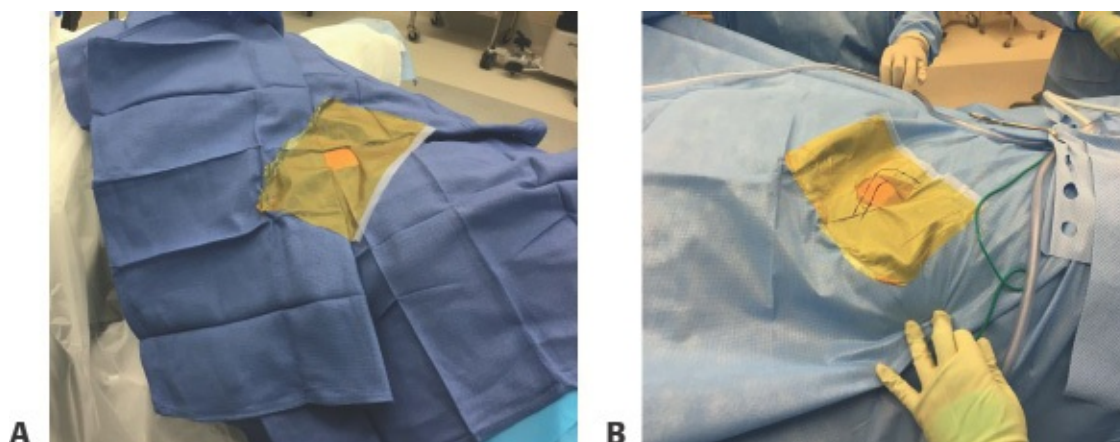


FIG 5 • A,B. Prep and draping of iliac crest harvest site.

TECHNIQUES

■ Technique 1: Iliac Crest Autograft Harvest (Tricortical Structural)

- This technique is described in another chapter.
- Briefly, the ipsilateral hip is positioned with a well-padded bump. The area is draped after sterile surgical prep. An iodine barrier may be placed (**FIG 5B**).
- The incision site may be injected with lidocaine plus epinephrine to decrease bleeding.
- The anatomic landmarks are palpated, and a longitudinal incision is made along the iliac crest, starting 2 cm above the ASIS. The soft tissue is bluntly dissected until the periosteum is exposed.
- The periosteum is incised in line with the incision and the crest. Once bone is identified, subperiosteal dissection is performed to expose the crest. Great care must be taken to avoid penetration of the medial structures, especially if the inner table is required as part of the graft harvest.
- The size of the graft must be determined at this point, based on the defect size (**TECH FIG 1A,B**).
- Structural cortical or tricortical graft is removed with a saw or osteotomes (**TECH FIG 1C**).
- The graft is shaped to fit the defect (**TECH FIG 1D–F**). Additional

cancellous graft can be harvested from the crest if needed to fill gaps.

- Appropriate fixation is applied to stabilize the graft (**TECH FIG 1G,H**).
- Following harvest, the iliac crest area can be packed with Gelfoam and thrombin to aid in hemostasis.
- Allograft cancellous chips can be used to pack the harvest site. This can provide hemostasis as well as filling of the defect.
- Periosteum is closed after hemostasis is achieved followed by layered closure of the overlying soft tissue and skin (**TECH FIG 1I**)

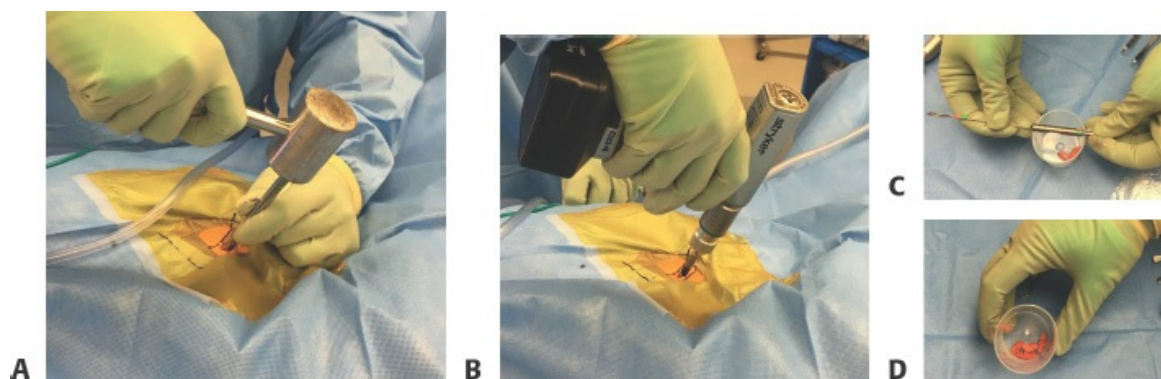


TECH FIG 1 • **A.** Clinical photograph of bone defect requiring structural graft. **B.** Intraoperative fluoroscopic image showing the defect. **C.** Photograph of sagittal

saw used for iliac crest structural harvest. **D–F.** Harvesting of iliac crest bone segment measuring 1.3 cm, appropriate to fill defect. **G.** Anteroposterior. **H.** Lateral radiographs showing fixation of structural graft. **I.** Closure of iliac crest harvest site with absorbable subcuticular stitch.

■ **Technique 2: Iliac Crest Autograft Harvest (Cancellous)**

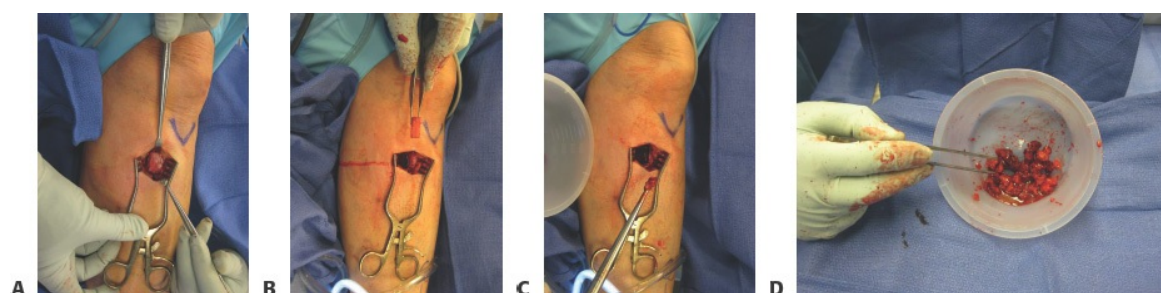
- This technique is for cases where cancellous autograft is indicated. The iliac crest cancellous bone contains the highest concentration of growth factors of the sites described in this chapter. Because it is a non–weight-bearing bone, this also mitigates risk of fracture postoperatively.
- As above, the ipsilateral hip is positioned with a well-padded bump. The area is draped after sterile surgical prep. An iodine barrier may be placed.
- The incision site may be injected with lidocaine plus epinephrine to decrease bleeding.
- The landmarks are palpated, and a small longitudinal incision is made along the iliac crest (usually about 1 cm in length), starting 2 cm above the ASIS. The soft tissue is bluntly dissected until the periosteum is exposed.
- The periosteum is incised in line with the incision and the crest. Once bone is identified, a trochar is used to create a defect in cortical bone (**TECH FIG 2A**).
- Next, a coring reamer is used to penetrate cortical bone penetrating up to 2 cm deep into the crest (**TECH FIG 2B–D**).
- Up to three passes (central, distal, proximal) can be made through one bone window. If additional graft is required, a second bone window should be created proximal to the end of the most proximal reaming pass.
- The periosteum is closed after hemostasis is achieved followed by layered closure of overlying soft tissue and skin.



TECH FIG 2 • **A.** Trochar and mallet used to create starting point in iliac crest for cancellous harvest. **B–D.** Coring reamer used to harvest iliac crest cancellous bone.

■ Technique 3: Proximal Tibia Autograft Harvest

- As with iliac crest autograft, it is ideal to obtain proximal tibia autograft from the ipsilateral tibia.
- The patient is placed in the supine position. A thigh tourniquet is used to create a bloodless field.
- A longitudinal incision is made medial to the tibia tubercle, about 1 cm (**TECH FIG 3A**).
- The periosteum is elevated, and the tibia metaphysis is identified. Small drill holes are made in a circular pattern.
- An osteotome is used to connect the drill holes, beveling the cortical window. The window is saved (**TECH FIG 3B**).
- Curettes or gouges are used to remove cancellous bone (**TECH FIG 3C,D**).
- The window is replaced and the wound closed in layers.



TECH FIG 3 • A. Incision for proximal tibia cancellous graft harvest. Marked V indicates tibial tubercle, **(B)** cortical window allowing access to cancellous bone of proximal tibia. **C.** Photograph illustrating curettage of cancellous bone from the proximal tibia, and **(D)** sample of typical harvest yield from proximal tibia.

■ **Technique 4: Calcaneal Autograft Harvest**

- Calcaneal bone graft is generally obtained from the ipsilateral calcaneus.
- In order to mitigate the risk of donor site fracture, this graft harvest is best selected in the setting of a procedure that will require a period of nonweight bearing.
- The patient is placed in the supine position. A calf or thigh tourniquet is used.
- Landmarks are identified first, including the tip of the calcaneal tuberosity, the peroneal tendons, and the distal fibula.
- A 2-cm oblique incision is made parallel and inferior to the peroneal tendons through the skin only, with blunt dissection down to bone and protection of the branches of the sural nerve (**TECH FIG 4A**).
- Elevation of the periosteum of the lateral calcaneus is performed to expose the cortical bone.
- A small diameter (7–8 mm) coring reamer is used to harvest cancellous bone from of the posterior tuberosity of the calcaneus (**TECH FIG 4B**). Multiple passes can be made through the same window, depending on volume need.
- The graft is collected in a small cup or receptacle such that appropriate volume can be assessed before discontinuing graft harvest (**TECH FIG 4C**).
- If required, additional bone can be curetted from the area, but use caution not to penetrate the far cortices.
- The skin is closed with 4-0 monofilament absorbable subcutaneous sutures, skin tape, and a period of nonweight bearing determined by the primary procedure.



TECH FIG 4 • A. Incision for calcaneal graft harvest. **B.** Coring reamer for calcaneal graft harvest. **C.** Resulting yield of calcaneal graft harvest.

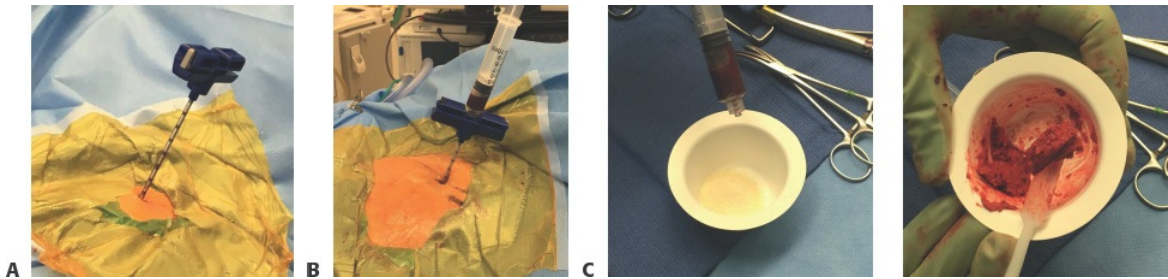
■ Technique 5: Bone Marrow Aspirate Concentrate

In cases where structural graft is not necessary, but there is a desire to supplement biology with autograft marrow rich in stem cells, autograft bone marrow can be a valuable adjunct. This is usually harvested from the ipsilateral iliac crest, because this is the location with the greatest concentration of growth factors.⁷

- Bone marrow aspirate can be administered in three ways:
 - As an isolated graft injection
 - Combined with demineralized bone matrix (DBM)
 - Bone marrow aspirate concentration (BMAC) of growth factors
- Harvesting of bone marrow from the iliac crest:
 - The iliac crest undergoes sterile prep at the same time as the ipsilateral foot.
 - A separate sterile drape is used after prep, using sterile towels, followed by sterile iodoform drape. After the final sterile drape is placed, a small hole is cut in the drape and a second iodoform drape is used to seal the crest site (see **FIG 5**).
 - Bone marrow should be harvested just prior to its administration to optimize the viability of cells. A small incision is made with a no. 15 blade. It is essentially a puncture, just the width of the blade, providing room for the Jamshidi needle.
 - A Jamshidi needle is advanced to the iliac crest. Direct palpation assures that the needle is centered in the crest and directed centrally, between the

inner and outer tables (**TECH FIG 5A**). It is important to ensure that the inner table is not penetrated during harvest.

- Advance the needle about 1 to 2 cm into the crest and aspirate 2 cc. Then, redirect and advance the needle about 2 cm and withdraw an additional 2 cc. This can be repeated until sufficient volume has been harvested (**TECH FIG 5B**). The highest concentration of cells is in the first 2 cc at each location.⁸
- The BMA can be combined with DBM to create a cellular putty (**TECH FIG 5C**). This can be administered where small defects are present in joints and fractures with oligotrophic nonunions. This can be injected percutaneously in some cases to avoid disruption of blood supply.⁹
- Alternatively, larger volumes of bone marrow can be harvested and concentrated using a commercially available system and injected into the fracture or fusion site.¹⁰



TECH FIG 5 • **A.** Jamshidi needle placed in iliac crest through percutaneous incision. **B.** Syringe attaches to Jamshidi needle and 2 cc of iliac crest withdrawn. **C.** Bone marrow aspirate can be combined with DBM to create a cellular putty to fill small defects.

■ Technique 6: Concentrated Synthetic Growth Factors

There are many synthetic growth factors available to help augment healing of nonunions and at-risk procedures in the foot and ankle. Although a more thorough discussion is beyond the scope of this chapter, this is an important consideration for bone graft options.

More detailed descriptions can be found elsewhere in the literature.^{11–13}

- Examples of available bone graft substitutes along with a brief description include the following:
 - Bone morphogenetic protein (BMP-2)
 - Platelet-derived growth factor (PDGF)
 - Demineralized bone matrix (DBM)
 - Hydroxyapatite
- Limitations to utilization of these substances can include cost, FDA approval status (often limited for foot and ankle indications), and availability.

PEARLS AND PITFALLS

Hemostasis	■ Hemostasis must be obtained at the graft site prior to closure of skin in order to avoid bleeding, hematoma, and wound complications.
Controlling hemostasis	■ Lidocaine with epinephrine helps to control bleeding from the subcutaneous tissue. ■ Gelfoam and thrombin helps reduce postoperative bleeding.
Volume yield	■ The iliac crest bone graft harvest yields the greatest amount of cancellous graft. ■ Autograft from the proximal tibia may yield sufficient cancellous graft for many foot and ankle procedures.
Technique	■ Beveling the cortical window will prevent the window from falling into the tibia.
Wound closure	■ Closure with an absorbable monofilament subcuticular stitch and skin tape can provide a more cosmetic and less painful scar.
Plan ahead	■ Ensure that appropriate equipment for harvest and/or graft material is available for the procedure. ■ Estimate the volume and quality of graft required such that appropriate harvest sites and techniques can be utilized.

POSTOPERATIVE CARE

- Generally, the autograft is harvested from the ipsilateral limb, to facilitate protected weight bearing and frequently with a splint or cast. Crutches or knee

scooter devices are used in many of the procedures. The harvest site may heal in 6 to 12 weeks. Sutures may be removed at 2 weeks. Range of motion exercises may then begin at that time.

OUTCOMES

- There are a considerable number of reports in the literature addressing bone grafting techniques and their impact on fusion rates following reconstructive surgeries. Contributing factors include the breadth of procedures and diagnoses, the impact (or poor reporting) of patient factors, and inconsistent indications for bone grafting. Although most available data come from level IV and V data, some meaningful conclusions can be drawn.
- Lareau et al.¹⁴ reported a systematic review of the literature on bone grafting for the foot and ankle. While underscoring the need for more level I and II evidence to better guide our use of bone graft adjuvants during foot and ankle surgery, their pooled data demonstrated a trend toward favoring the use of cancellous autograft, structural autograft, or cancellous allograft over using no graft material during fusion surgery.¹⁴ They suggest that using no graft leads to nonunion rates of only about 10% (ie, a greater than 90% union rate), whereas the addition of cancellous autograft, structural autograft, or cancellous allograft reduced the nonunion rate by half.

COMPLICATIONS

- Complications from autograft from the iliac crest include infection, nerve injury, painful scar, nonunion, and pain. Harvest from the proximal and distal tibia or calcaneus may result in infection, numbness, and rarely fracture through the graft site. Superficial infections may be treated with local wound care and oral antibiotics. Rarely, the infection is deep, requiring surgical debridement and intravenous antibiotics.

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12 Reconstruction of the Forefoot

CHAPTER

Rachel E. Hein and Scott T. Hollenbeck

DEFINITION

- The primary goal in forefoot reconstruction is to preserve function of the lower extremity. Given the unique bony and skin arrangements in the foot as well as the high functional demand for this area, an understanding of multiple reconstructive approaches is necessary.

ANATOMY

- The forefoot contains the distal third of the foot from the base of the metatarsals to the distal phalanges of the toes on both the plantar and dorsal surfaces of the foot.
- The plantar surface of the foot has highly specialized glabrous skin with a thick epidermis. Beneath the skin and subcutaneous tissue is the plantar aponeurosis, which is a thick fibrous band adherent to the skin. This resists shearing forces as it attaches to the skin via the retinaculum cutis ligaments distal to the metatarsals. In contrast, the dorsal skin of the forefoot is extremely thin and relatively mobile.
- The bones of the forefoot are somewhat analogous to the hand with the first toe containing only a distal and proximal phalanx. The second through the fifth toes have a middle phalanx. There are five metatarsal bones, which span from the midfoot bones (cuneiforms and cuboid) to the proximal phalanx of each digit.
- There are four separate plantar fascia compartments and one dorsal fascial compartment that are divided by intermuscular septa. These separate the intrinsic muscles of the foot.
- The medial and lateral compartments are the most relevant for reconstruction

as the muscles are most superficial and amenable to flap use. Of note, the medial compartment contains the abductor hallucis (AH) and flexor hallucis brevis (FHB) whereas the lateral compartment contains the abductor digiti minimi (ADM) (**FIG 1**).

- There are extrinsic and intrinsic muscles of the foot.
 - The extrinsic muscles originate in the leg and insert onto the bones of the foot.
 - The peroneus tendons insert onto the 5th metatarsal and allow for foot eversion.
 - The extensor digitorum longus (EDL) tendons insert onto an extensor mechanism of each of the lateral four digits.
 - The extensor hallucis longus (EHL) tendon has its own muscular unit and inserts onto the first phalanx.
 - In addition to the digit extending muscles, the foot may be brought into extension by the tibialis anterior (TA), which inserts onto the medial cuneiform/first metatarsal junction.
 - Preservation of at least one of these three systems is needed to prevent a functional footdrop. The digital flexors have a similar arrangement to the extensors, with the flexor digitorum longus (FDL) inserting onto each of the lateral four digits and the flexor hallucis longus (FHL) tendon inserting onto the first toe.
 - Plantar flexion is primarily driven by the Achilles mechanism of the heel, but digit flexors do have some importance as it pertains to the toe push off phase of the gait cycle.
 - The intrinsic muscles are contained in the compartments of the foot and primarily act on the toes.
 - The flexor digitorum brevis (FDB) occupies the central aspect of the superficial muscles of the plantar surface of the foot. There are two additional deep layers of muscles in the plantar foot that are not commonly used in reconstructive surgery.
 - Secondary action of intrinsic muscles includes maintaining posture and foot concavity.
 - The dorsal aspect of the foot is primarily made up of the extrinsic tendons, deeper intrinsic digit extensors, and still deeper interosseous muscles.
- The main vascular supply to the foot comes from the posterior tibial artery. The artery splits into the medial and lateral plantar arteries beneath the flexor retinaculum. These two arteries join at the base of the metatarsals to form the

deep plantar arch.

- The lateral plantar artery is the dominant artery supplying the fourth and fifth toes through metatarsal and then proper digital arteries.
- The medial artery supplies the first through third toes in a similar fashion. The dorsalis pedis artery supplies the dorsum of the foot and also gives terminal branches completing the plantar arch. For reconstructive purposes, the plantar intrinsic muscles of the foot are typically supplied via the medial and lateral plantar arteries (**FIG 2**).
- Cutaneous sensation to the forefoot is supplied via terminal branches of the sciatic nerve. The plantar surface of the forefoot sensation is mainly derived from the medial plantar nerve (tibial origin) and the lateral plantar nerves (tibial origin).
- The dorsal forefoot sensation is mainly derived from the superficial peroneal nerves (common peroneal origin) and the unique first web space distribution of the deep peroneal nerve (common peroneal, sciatic, L5 origin).
- Motor innervation of the intrinsic foot muscles is mainly through the medial and lateral plantar nerves¹ (see **FIG 2**).

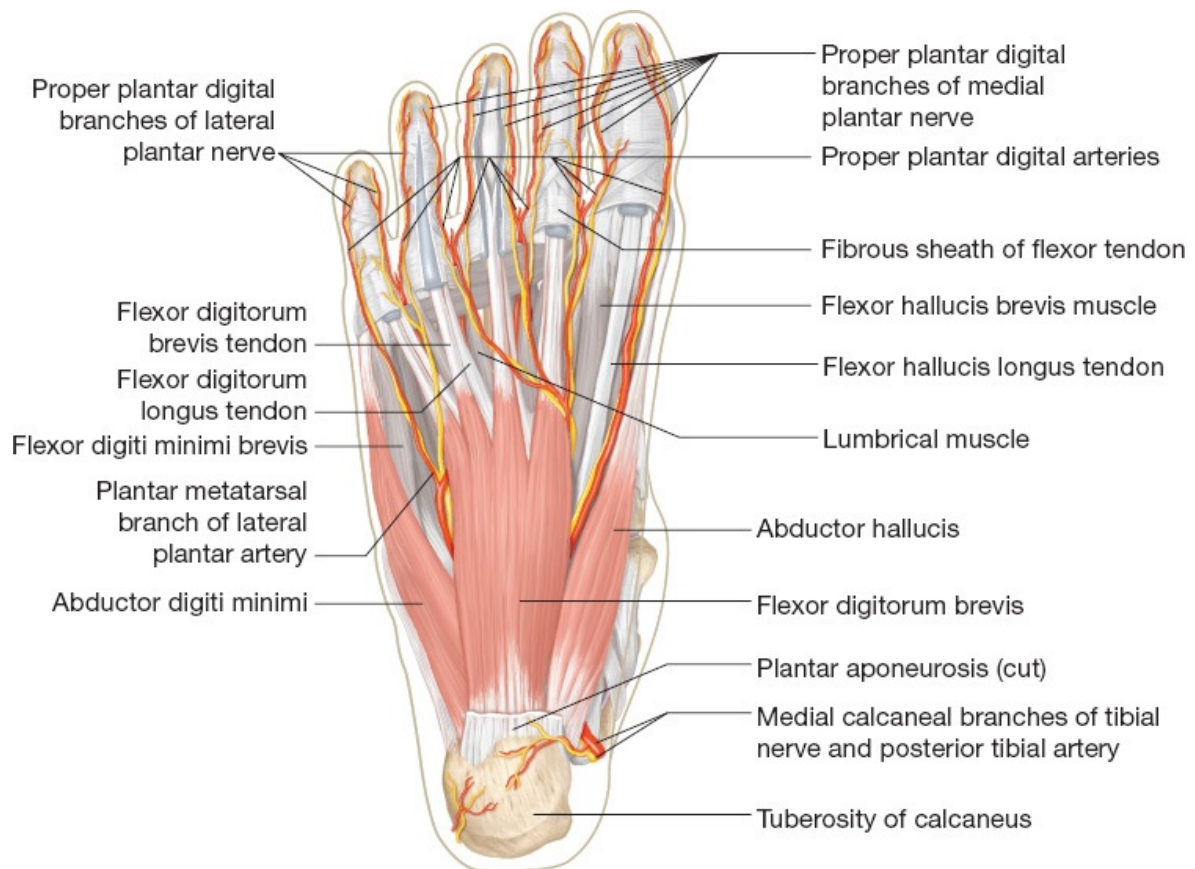


FIG 1 • Sole of foot.

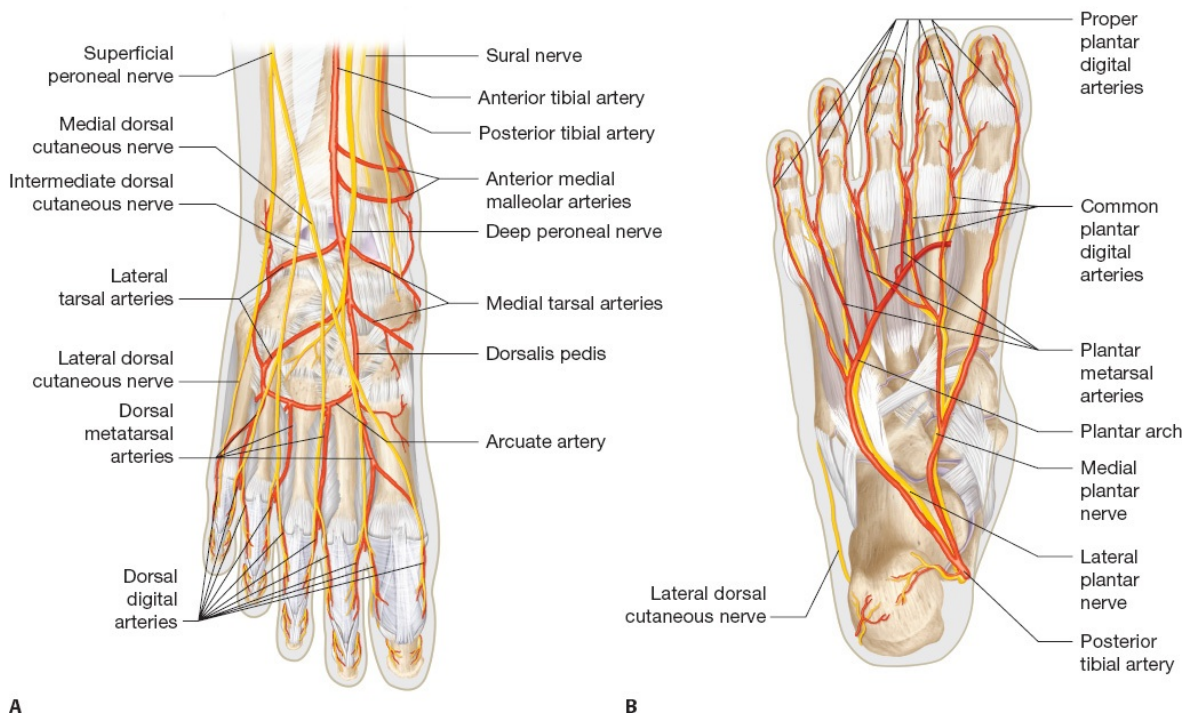


FIG 2 • A,B. Anatomy of the foot, vessels, and nerves.

PATHOGENESIS

- Traumatic foot injuries are typically associated with high-energy events. This may lead to extensive and complex wounds involving lacerations, contusions, skin degloving, open fractures, and severe crush injuries.
- Cancerous lesions may require extensive surgical resection and reconstruction within the foot. Many of these are amenable to isolated digit or ray amputation but some may require large skin resections on weight-bearing areas of the foot.
- Postsurgical complications following foot and ankle surgery may also present with complex problems involving necrotic skin, exposed tendons, colonized hardware and bony nonunion.
- Chronic vascular disease including venous stasis and peripheral vascular disease can be a cause of tissue loss within the forefoot. This should mainly be addressed by controlling the inciting factor. Amputation and debridement are often needed in these cases prior to any consideration of reconstruction.
- Diabetes is a major contributor to forefoot wounds and ulcers. Many of these patients have diabetic neuropathy and develop pressure-related ulcers over the

metatarsal heads. Prior to consideration of reconstruction, the patient's status should be optimized and nonsurgical options should be considered. This may include weight-bearing restrictions and/or use of shoe inserts to deflect pressure away from the affected area.²

NATURAL HISTORY

- The lower extremity is commonly involved in motor vehicle injuries, and this is the most common scenario requiring forefoot reconstruction. These are often complex injuries and may involve multiple levels of the lower extremity and multiple systems within the patient. Standard principles of trauma care must be followed. Once the patient has been stabilized, foot reconstruction may involve a multidisciplinary limb salvage team including plastic and orthopedic surgeons.
- A unique trauma scenario involving the forefoot is that related to lawn mower injuries and amputations. These are often isolated foot injuries but may be severe in nature.
- Replantation of amputated digits is not typically performed in the lower extremity.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Gait cycle and biomechanics
 - Reconstructive surgeons managing wounds of the foot should be familiar with the gait cycle as it pertains to functional outcomes. Classically, there are three cycles of the stance phase of ambulation including heel strike, midstance, and propulsion. This is followed by the noncontact swing phase.
 - For the purpose of forefoot injuries, it is important to note that high pressures occur during propulsion and include the final contact point at the first toe. Higher pressures and abnormal gait may lead to skin breakdown and development of wounds over the forefoot.³
- Evaluation of forefoot wounds
 - Initial evaluation of a patient with an acute traumatic injury to the foot includes assessment of the mechanism, energy, and contamination associated with the event. This often occurs during the initial washout and debridement of the wound. The associated soft tissue injury and underlying bony injury should be appreciated as well as the integrity of the vascular and neurologic systems within the foot.
 - Understanding a patient's underlying comorbidities as well as preinjury

functional status and work demands is also important.

- Doppler examination is useful to determine arterial perfusion as well as planning for operative intervention. However, severe edema may prevent accurate Doppler assessment, and additional angiographic studies may be required. Any presumed acute arterial injury warrants a vascular surgery consultation and subsequent evaluation for compartment syndrome.⁴
- Neurologic evaluation of the injured foot may be limited due to associated neuropraxia and tissue edema. Declaration of a nonsalvageable foot based on neurological injury should be deferred during the acute injury phase.
- For chronic wounds, duration of wound and measurements should be taken including length, width, and depth. Involvement of skin, dermis, fascia, muscle, tendon, and bone should be noted as well as any concurrent cellulitis. Photographs should be taken, and previous therapies should be noted. Gait analysis is also important in these patients as disease processes can affect weight bearing over the forefoot. Vascular and neurological status is also important to take into account.

IMAGING

- The physical exam will dictate the imaging studies needed when evaluating foot wounds. In the trauma setting, plain films are typically obtained first to rule out fractures. In some circumstances, a CT scan or MRI is obtained for better bony and ligamentous imaging. Angiography is typically reserved when evaluating more proximal injuries, but may be useful on certain occasions.
- Chronic infectious wounds such as diabetic ulcers and postoperative wound breakdown require plain films to rule out pathologic fractures and gas in the subcutaneous tissues along with MRI to rule out osteomyelitis. Bone biopsies are the standard, but MRI may help delineate operative management in these cases. Ankle-brachial indices and duplex arteriogram should be obtained to assess arterial insufficiency and need for possible vascular intervention.

DIFFERENTIAL DIAGNOSIS

- Traumatic
- Postsurgical
- Infectious
- Diabetic
- Acute arterial
- Venous ulceration

- Connective tissue disorder

NONOPERATIVE MANAGEMENT

- Traditionally, dressing changes are helpful for managing small superficial wounds through healing by secondary intent. Negative pressure wound therapy (NPWT) may also be used to achieve secondary healing or to prepare a complex wound bed for a skin graft or flap.
- Newer wound dressings have also aided in the treatment of open forefoot injuries including semipermeable dressings, hydrocolloids, and hydrogels. These new dressings can aid in chemical debridement as well as hydration of the wound. Additionally, synthetic products and xenograft products exist and may have some utility in managing these wounds. More data are needed to prove the clinical efficacy of these treatments.
- Hyperbaric oxygen (HBO) treatment may be used as an adjunct to traditional wound healing methods but remains somewhat unproven in its efficacy for foot wounds. HBO works by promoting angiogenesis and ultimately increasing the amount of vascularity in the wound bed, thereby promoting wound healing. It may be indicated in crush injuries, refractory osteomyelitis, and gas gangrene.

SURGICAL MANAGEMENT

Preoperative Planning

- Debridement remains one of the most important preoperative principles in lower extremity salvage. For an acute wound, it is important to perform serial debridement if necessary until all nonviable tissue has been removed. Chronic wounds should be serially debrided until negative cultures are obtained. Comorbidities should be managed for optimization.
- Once a decision has been made to proceed with reconstruction, the timing of intervention should be determined. Typically, this will be based on the underlying source of the wound.
 - In acute trauma settings, debridement and bony fixation should be complete. An understanding of vascular and nerve injury should be established. At this point, the extent of the reconstruction will be known and a proper approach may be determined.
 - The ideal window to operate on traumatic injuries is within the first week, if not sooner. Bacterial contamination and traumatic edema make reconstruction more difficult and warrant delay.

Positioning

- A modification of standard supine positioning is required for most procedures. For plantar defects, it is often best to place the patient in a lateral decubitus or possibly prone position. Of course the positioning will be influenced by the planned reconstruction. A thigh or calf tourniquet is often used during these procedures to optimize visualization. Bipolar cautery should be available when procedures involve deep structures near the neurovascular bundles.

Approach

- Reconstructive options for forefoot wounds include secondary closure, skin graft or skin substitute, local or random patterned flap, pedicled flap, or free flap with microvascular anastomosis.
- Function and aesthetics must be taken into account. For example, a split-thickness skin graft to a wound bed is not likely to be a durable option for a plantar defect. Likewise, a large bulky flap placed on the dorsal forefoot is likely to make shoe fitting difficult. The specific approach for each reconstructive option is listed below.
- *Delayed primary closure* is often difficult to perform secondary to refractory edema and minimal skin laxity of the foot.
- *Tissue expansion* is often not an option for the same reasons listed above.
- *Skin substitutes* have become popular in recent years and are used as dermal replacements in patients who would otherwise require flap reconstruction. A secondary skin graft is often needed. These products are directly applied to the wound bed after debridement.
- *Local random patterned flaps* are an option in patients with small foot wounds who may not be good free flap candidates. These flaps are inherently difficult to move in the foot.
- *Pedicled flaps* are useful in the forefoot due to rapid harvest and inset; however, for many of these flaps to reach the forefoot they must be based on unreliable distal perfusion. Another approach is to slide the flap with a component of plantar tissues in a V to Y pattern. These flaps can include both muscle and fasciocutaneous elements.
 - The reverse abductor digit minimi (ADM) flap is harvested along the lateral aspect of the plantar surface near the 5th metatarsal. The distally based flap and reverse based flap are useful for plantar forefoot wounds.
 - The reverse AH flap may be used for plantar defects of the forefoot. This muscle originates from the medial border of the calcaneus and inserts on the

base of the proximal phalanx of the great toe.

- The reverse FDB flap and the FDB based V-Y advancement flap are used in distal plantar surface wounds of the arch. For the reverse flap to be used, the dorsalis pedis and anterior tibialis must be intact as the medial plantar artery perforator is divided.
 - The toe fillet flap is a form of pedicled flap and is used after a toe amputation to cover a plantar- or volar-based wound associated with the effected digit.
 - The reverse dorsalis pedis fasciocutaneous flap can be designed up to 10 cm in size and is based on the dorsalis pedis artery. The pedicle of a standard dorsalis pedis flap is based on the dorsalis pedis artery; however, its reverse is based on the deep plantar arch and thus completeness of the arch must be assessed.
 - Reverse medial plantar artery flap: This flap contains the skin of the instep or non-weight bearing area of the plantar surface from the head of the first metatarsal to the navicular bone proximally.⁵⁻⁷
- *Free flaps* entail harvesting tissue from a different site along with its blood supply and transferring it to the recipient site. This requires a microvascular anastomosis. Both fasciocutaneous and muscle flaps work well on the forefoot and depend on goals of reconstruction.
- Important aspects of the approach for free flap reconstruction include choosing a donor flap that will easily cover the defect. If the flap is too small, the closure will be tight.
 - Vessel size needs to be considered to match the flap with the foot recipient vessels. Also, the vascular anastomosis needs to be performed outside of the zone of injury which may even be at or above the ankle. Finally, the flap must be of sufficient bulk to obliterate any underlying dead space.
 - Free flap choice: Considerations on choice of free flap include size of wound, defect composition, pedicle size and length, and state of wound. Location of wound also precludes itself to choice of flap. The foot may be broken into seven subunits, which have been established for functional and aesthetic reconstructive goals. With respect to the forefoot, there are four relevant subunits (**FIG 3**). Each has its own aesthetic and functional concerns with regards to reconstruction.



Subunit	Demands Tissue Needs	Optimal Flaps
1	Low functional, Moderate aesthetic: small, thin and pliable.	Radial forearm > lateral arm
2	High functional, Low aesthetic: durable and minimal bulk.	(*): Radial forearm > lateral arm > gracilis with STSG > ALT
3/4	Low functional, High aesthetic: smooth, thin and pliable	Radial forearm > ALT > scapular > latissimus dorsi
5	High functional Low aesthetic: durable and moderate bulk.	(*): ALT > gracilis with STSG > latissimus dorsi > scapular > lateral arm > radial forearm
6/7	Moderate functional, Moderate aesthetic: may vary from smooth, thin and pliable to Large and bulky.	Gracilis with STSG, latissimus dorsi, ALT, rectus abdominis, lateral arm, radial forearm, scapular

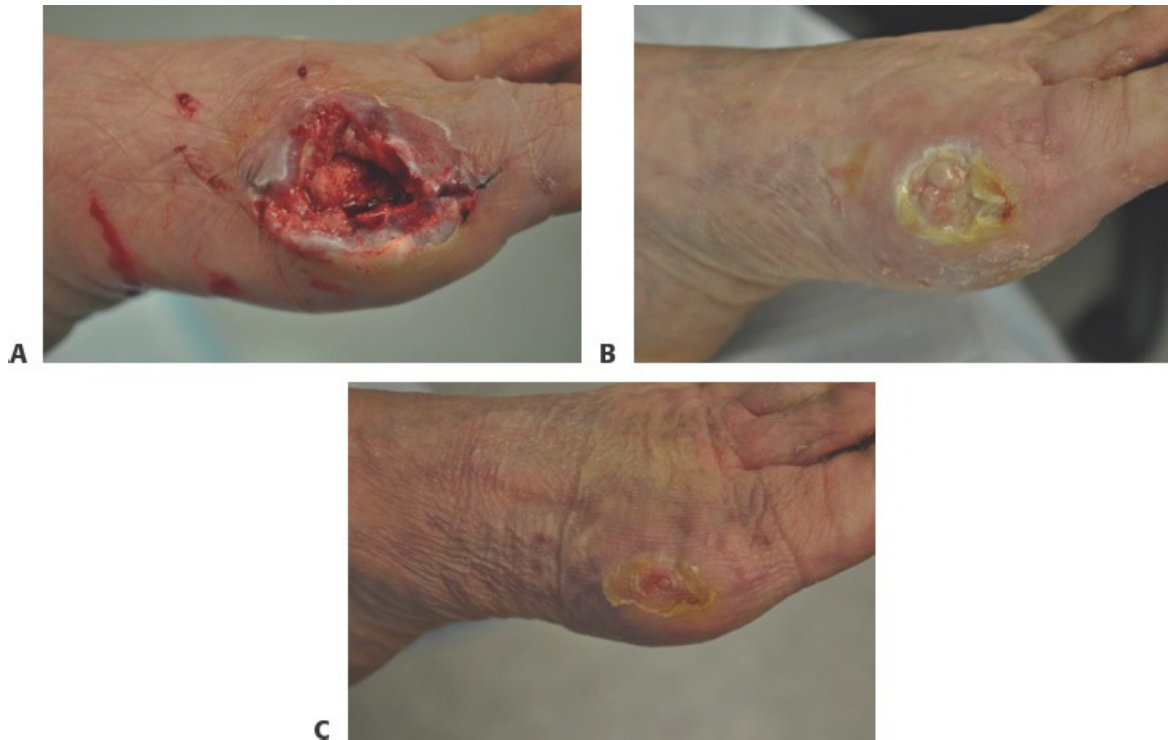
STSG: Split thickness skin graft
ALT: Anterolateral thigh
*: Nerve coaptation may be considered.

FIG 3 • Four separate views of foot and ankle demonstrating different aesthetic and functionally different subunits. There are four different relevant subunits of the forefoot. (Reprinted from Hollenbeck S, et al. Longitudinal outcomes and application of the subunit principle to 165 foot and ankle free tissue transfers. *Plast Reconstr Surg.* 2010;125(3):924-934, with permission.)

TECHNIQUES

■ Secondary Healing Using Regenerative Matrix

- Skin substitutes have become more popular in the recent years and are used in patients who may otherwise require flap reconstruction.
- Contraindications include exposed hardware; relative contraindications include exposed tendon or bone.
- Begin by obtaining adequate debridement. All nonviable tissue should be removed. Healthy bleeding tissue or bone should be visualized. If covering a chronic wound, ensure that negative cultures have been obtained (**TECH FIG 1A**).
- Apply the wound matrix to the exposed area generously. Similar principles to application of a skin graft applies and includes ensuring adequate contact of matrix to wound bed.
- After application, the matrix is fixated per surgeon preference including absorbable sutures such as chromic or staples that may be removed postoperatively. A hydrated dressing should be applied. This includes a negative pressure wound dressing or semipermeable colloid dressing. This remains in place for 1 to 4 weeks (**TECH FIG 1B**).
- Depending on the type of matrix applied, a bilayer may require removal around 4 weeks with the final result being total skin closure or a granulation bed that requires skin grafting (**TECH FIG 1C**)



TECH FIG 1 • A. The left foot with a full-thickness defect down to bone following elective orthopedic surgery. Adequate debridement is obtained to healthy bleeding tissue. **B.** After 4 weeks of application of regenerative matrix (porcine bladder elements), an appropriate dressing should be applied that obliterates the dead space and keeps the wound hydrated to encourage granulation. **C.** Six weeks postoperatively. Full closure with minimal eschar remains. Regenerative matrix may be sufficient for small wounds that would otherwise require flap coverage.

■ Reverse Fasciocutaneous Flap (Reverse First Dorsal Metatarsal Artery [1st DMTA] Flap)

- Begin by obtaining adequate debridement. All nonviable tissue should be removed. Healthy bleeding tissue or bone should be visualized. If covering a chronic wound, ensure that negative cultures have been obtained (**TECH FIG 2A**).

- A Doppler should be used to identify the first dorsal metatarsal artery on the dorsum of the foot. The flap is then designed around this using the measurements needed to fill the defect. The proximal extension of the flap is designed so that once rotated it will fit into the defect (**TECH FIG 2B**).
- Dissection begins around the marked flap, first beginning over the dorsal skin and continuing through the fascia exposing the underlying tendons. Care is taken to preserve the paratenon associated with the tendons (**TECH FIG 2C**).
- The flap is then rotated around the axis of the 1st DMTA, which is located typically underneath the first interosseous muscle and adjacent to the metatarsal bone. The flap can be kept as a peninsula or as an island (**TECH FIG 2D**).
- It is important to ensure that the inset is relatively tension free. The flap donor defect is covered with a split-thickness skin graft (**TECH FIG 2E**).⁹



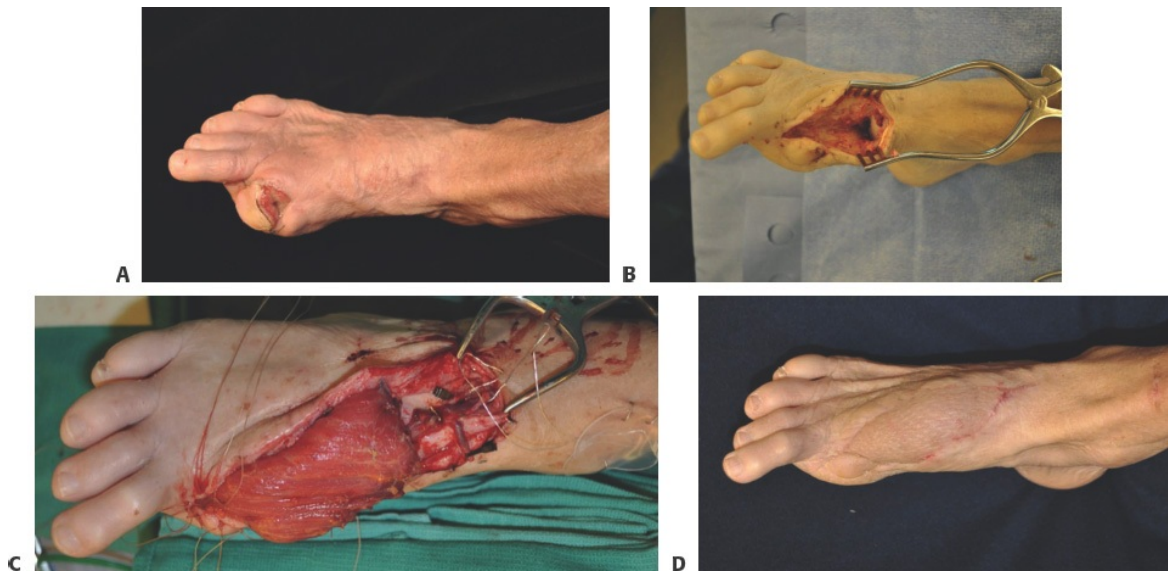
TECH FIG 2 • A. Chronic dorsal great toe wound,

debrided back to healthy tissue. Negative cultures obtained. **B.** First dorsal metatarsal artery flap, marked and dissected to level tendon, keeping paratenon intact. Flap is undermined taking care to ensure the perforator is not inadvertently divided. **C.** Proximal end of flap is rotated 180 degrees to fill the defect. One must ensure a relatively tension-free closure. **D.** A split-thickness skin graft is harvested to fill the donor site. There is typically some venous congestion of the distal portion of the rotated flap; however, in our experience this has done well with time. **E.** Six weeks postoperatively with a completely healed wound and donor site.

■ Free Gracilis for Osteomyelitis

- The gracilis free flap may be used over the plantar surface of the forefoot in weight-bearing areas. It is a Mathes and Nahai II flap with its main blood supply from the medial circumflex artery off of the profunda femoral artery. The muscle itself is 30 cm long, 5 cm wide and 2 cm thick.
- The gracilis muscle is an excellent option for chronic defects of a weight-bearing area in association with osteomyelitis (**TECH FIG 3A**). Debridement should include all nonviable tissues and affected areas. Negative cultures should be obtained.
- For this type of defect (**TECH FIG 3B**), local types of closure are not an option. A free tissue transfer (gracilis) has been chosen.
- The dorsalis pedis artery is dissected proximally out of the zone of injury and is isolated. Attention is now turned to the donor site.
- For harvest, the patient is placed in supine and frog-leg position. A line is drawn from the medial pubic tubercle to the medial femoral condyle.
- The gracilis should include the proximal portion along with the length needed to obliterate the defect.
- Transfer and inset takes place (**TECH FIG 3C**) via the dorsalis pedis artery. Primary closure of the donor site is obtained, and a split-thickness skin graft is used to cover the newly inset flap. This provides stable coverage and good

shoe fitting (**TECH FIG 3D**).¹⁰



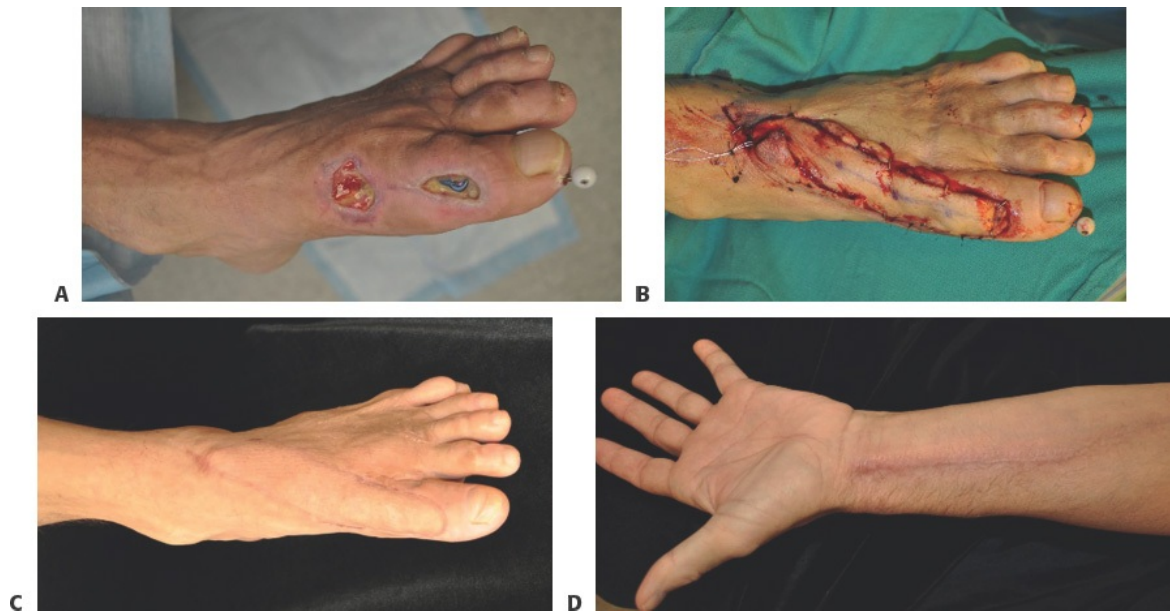
TECH FIG 3 • A. This patient suffered from chronic osteomyelitis of the first metatarsal head as a postoperative complication and eventually underwent ray amputation of the first toe as pictured. **B.** Debridement of entire affected segment and remaining metatarsal head and shaft. This has left the patient with a large defect that is not amenable to local types of closure. **C.** After inset of free gracilis. It is important that the tissue transfer obliterates dead space of the wound. Closure should be relatively tension free. **D.** Two months postoperatively. The patient has completely healed the wound and has an overall aesthetically pleasing result.

■ Free Flap for Distal Skin Defect

- The radial forearm free flap is the flap of choice for most forefoot reconstruction defects. This flap meets both the aesthetic and functional needs including being both thin and pliable. It varies in size and can be harvested from the wrist to the antecubital crease. This flap is primarily a

fasciocutaneous flap but may be harvested also as a myocutaneous or osteocutaneous. Its blood supply is the radial artery.

- In this example, free tissue transfer may be used in chronically infected wounds or in wounds with exposed hardware. This patient did not have a sizeable tissue defect and thus radial forearm flap was a great match due to pliability, coverage, and aesthetic result (**TECH FIG 4A**).
- First, obtain adequate debridement; in this patient debridement was conservative due to acute osteotomies with nonunion and exposed hardware.
- For harvest, the nondominant arm is typically utilized. An Allen's test is performed preoperatively to ensure that the palmar arch is intact.
- Doppler is utilized to identify the radial artery. A flap matching the size of the defect is marked with the radial most aspect over the radial artery.
- Dissection proceeds distally through skin, elevating fascia with the flap. Ensure to leave paratenon intact. The radial artery is dissected out proximally and ligated according to pedicle length need.
- The flap is then inset over the defect and anastomosed to the dorsalis pedis artery (**TECH FIG 4B**). Antibiotics are utilized due to exposed and presumed infected nature of the hardware. This will be kept for up to 6 weeks. Long-term coverage of the dorsal foot with a radial artery flap provides excellent contour (**TECH FIG 4C**).
- Donor site may be closed primarily depending on defect size and if tourniquet was used (**TECH FIG 4D**). If defect is large, split-thickness skin graft may be utilized.¹¹



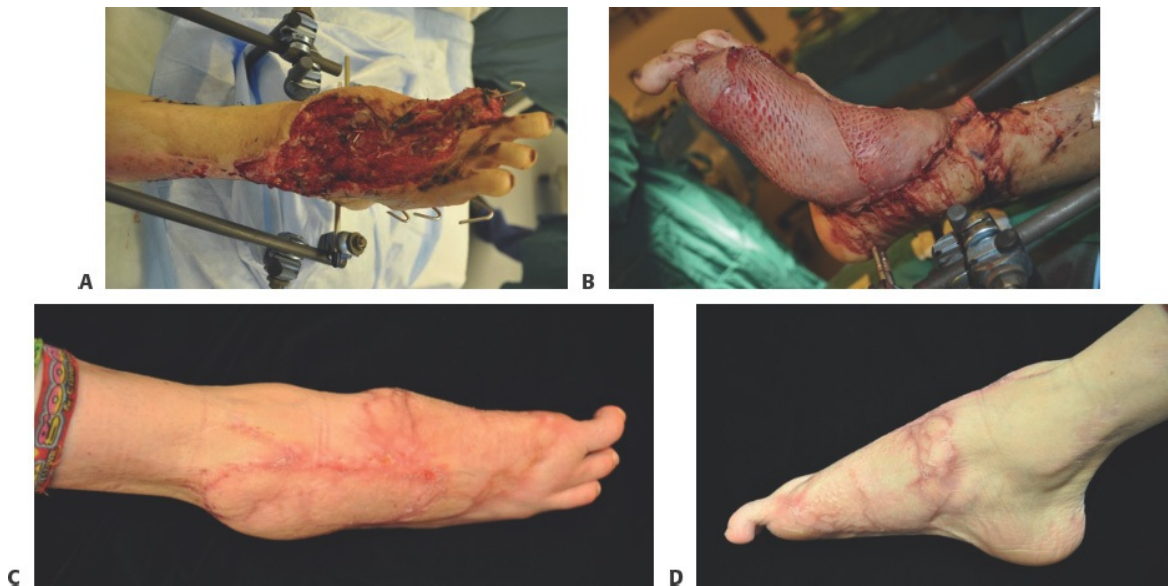
TECH FIG 4 • A. This patient has exposed hardware after orthopedic procedure presumed to be infected. This was unable to be removed due to nonunion. The patient was taken to the operating room for proper debridement. **B.** Radial forearm free flap after anastomosis and inset. Good size and thickness match is noted. **C.** Defect 2 months postoperatively. The forefoot is well healed with no signs of exposed hardware or chronic infection. The patient remained on a course of IV antibiotics for 6 weeks. **D.** Donor site. The patient's donor site was amenable to primary closure due to the small size of the defect. The patient has completely healed donor site with good perfusion of the hand and no chronic paresthesias.

■ Free Flap For Mangled Foot—Latissimus

- Latissimus is one of the largest muscles in the body and is used for covering large defects. The muscle may be harvested up to 35 cm in size and may be used as a muscle or myocutaneous flap. This is a Mathes and Nahai type V flap with the main blood supply coming from the thoracodorsal artery and

vein.

- In this example, the patient suffered from a severe mangled foot after a crush injury. Acute debridement is performed in several stages along with external fixation. It is important to determine the viability of the surrounding tissue prior to reconstruction (**TECH FIG 5A**).
- The free latissimus is chosen for reconstruction. The patient is placed in a lateral decubitus position for both harvest and inset.
- The harvest site is prepared; in this case, the anterior tibial vessels are used and dissected out proximally out of the zone of injury.
- The latissimus is now harvested as a muscle flap in its usual fashion. The donor site may be closed primarily over a suction drain.
- The muscular flap is inset over the defect and anastomosed to the anterior tibial vessels, taking care to obliterate the dead space (**TECH FIG 5B**). A split-thickness skin graft is used to cover the muscular flap. A tension-free closure should be obtained.
- A muscle flap with a split-thickness skin graft may provide excellent durable long-term coverage of the dorsal and plantar foot allowing for ambulation (**TECH FIG 5C,D**).¹²



TECH FIG 5 • A. The right lower extremity after a severe crush and degloving injury. The patient undergoes external fixation along with adequate debridement performed in several days. **B.** After inset

and skin grafting of latissimus flap over mangled foot. External fixator still in place. **C.** Two months postoperatively with acceptable contour. Wound well healed. **D.** Six months postoperatively, fully healed and with great aesthetic result that will fit in shoe or prosthesis.

PEARLS AND PITFALLS

Function	■ Amputation may be a reasonable option for wounds involving the forefoot. However, there will be some degree of functional loss associated with disruption of the propulsion phase of the gait cycle.
Tendon coverage	■ Reconstruction of the forefoot may involve wounds that are associated with flexors or extensors of the ankle. Preservation of these insertion points may impact leg function significantly.
Local flaps	■ Local flaps may be limited in the foot as there is minimal skin laxity for advancing and rotating these flaps. Ideally, incisions should not be placed on the weight-bearing areas of the foot.
Flap options	■ Free flap choices can be guided by consideration of the defect location and functional demand of the area in combination with aesthetic considerations and shoe fitting requirements. Microvascular anastomosis should be performed out of the zone of injury. Secondary thinning may be required especially for bulky fasciocutaneous flaps.
Outcomes	■ Free flap failure in the foot and ankle may be as high as 10% and is often related to a tight skin closure or poor distal extremity perfusion. Success is measured in stable skin coverage, bony healing, painless ambulation, and shoe fitting.

POSTOPERATIVE CARE

- At the time of reconstruction, patients are typically placed in a posterior slab splint to minimize movement. A hole may be cut as a window to view the surgical site. This splint is typically kept until the patient begins transfers at which a formal splint will be applied.
- Leg elevation is an important aspect of foot reconstruction, especially in the

setting of trauma. A typical protocol for free flaps is strict bed rest and leg elevation until postoperative day 4. At this point, the patient may begin working with physical therapy for dangling the lower extremity during transfers for 5 minutes 3 times daily. Weight-bearing status is dictated by orthopedic restrictions. Activity and dependent positioning should progress over the next several weeks. At this point, a compression garment may be applied to help with edema. During this course, it is important to utilize a prophylactic anticoagulant dose to prevent venous thromboembolism.

- CAM boots are typically used to offload pressure from the forefoot as the patient begins weight bearing. Sutures are typically kept in place for 3 to 4 weeks, but should be removed prior to ambulation to prevent callus formation or postoperative ulceration.
- Range of motion exercises are typically initiated in the noninvolved joints immediately postoperatively to prevent stiffness. Exercises in involved joints of reconstruction are begun somewhere between 5 days and 2 weeks.
- Postoperative follow-up should be frequent and consistent. This should involve a multidisciplinary team including plastic surgery, orthopedics, vascular surgery, podiatry, physical therapy, and wound care as needed. Many centers have limb salvage programs that incorporate these aspects of care for their patients.

OUTCOMES

- The majority of patients undergoing flap reconstruction with local or free flap transfer have a successful recovery. Free flap viability rates have been quoted to be 90% to 93% in lower extremity reconstruction. In those with primary flap failure, treatment consists of debridement and wound care with consideration for further reconstruction. Patients that experience flap failure are at increased risk for amputation.
- Some patients will have long-term wound healing issues, with ulceration around the site of flap inset. This may occur anywhere from months to years after surgery and typically occurs on the weight-bearing surfaces of the foot at the flap interface.
- Secondary procedures are common in forefoot reconstruction and are most commonly associated with debulking procedures, especially when free tissue transfer is performed. Instability or nonunion is infrequently seen in the forefoot.
- Amputation may be indicated in the primary setting or after reconstruction

failure. Functional loss of an amputation needs to be weighed against morbidity of limb salvage. For the forefoot, options include isolated digit amputation, ray amputation, or transmetatarsal amputation. For those with vascular disease or open fractures, a higher level of amputation may be required.^{8,12}

COMPLICATIONS

- Given the high risk nature of the patient population, complications can occur. Acute complications may be related to poor perfusion within the flap. This may occur when distally based flaps are used or when free flaps become compromised from pressure. Infections related to fractures and hardware placement are not uncommon in foot reconstruction. These are treated with flap elevation and further debridement.
- Long-term complications include flap ulceration or callus, typically around the flap–native skin interface. In these circumstances, excision of the ulcer with flap advancement is usually sufficient.

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CHAPTER The Medial Plantar Flap

Arash Momeni and Subhro K. Sen

DEFINITION

- The medial plantar flap is suitable for reconstruction of heel and lateral plantar defects.^{1,2}
- The medial plantar flap is harvested from the non–weight-bearing instep area of the foot.
- In the majority of cases, the donor site must be skin grafted. Narrow flaps up to 2 cm in width may be closed primarily.
- Volar hand and finger, as well as contralateral foot defects, may be reconstructed with the free medial plantar flap, as it is an excellent source of glabrous skin.^{3,4}

ANATOMY

- The medial plantar flap is centered on an axis extending from the medial aspect of the first metatarsal head distally to the medial horizontal calcaneal eminence (talar shelf) proximally (**FIG 1**).
- Perfusion to the flap is via perforators from the medial plantar artery and venae comitantes that course between the abductor hallucis and flexor digitorum brevis muscles (**FIG 2**).
- Subcutaneous veins can be incorporated into the flap to augment venous drainage.
- The medial plantar flap may be raised as a sensate flap by including branches of the medial plantar nerve.
- It is critical to avoid including the weight-bearing regions of the foot (plantar forefoot, lateral plantar area, and heel) when harvesting this flap (**FIG 3**).



FIG 1 • Design of medial plantar flap.

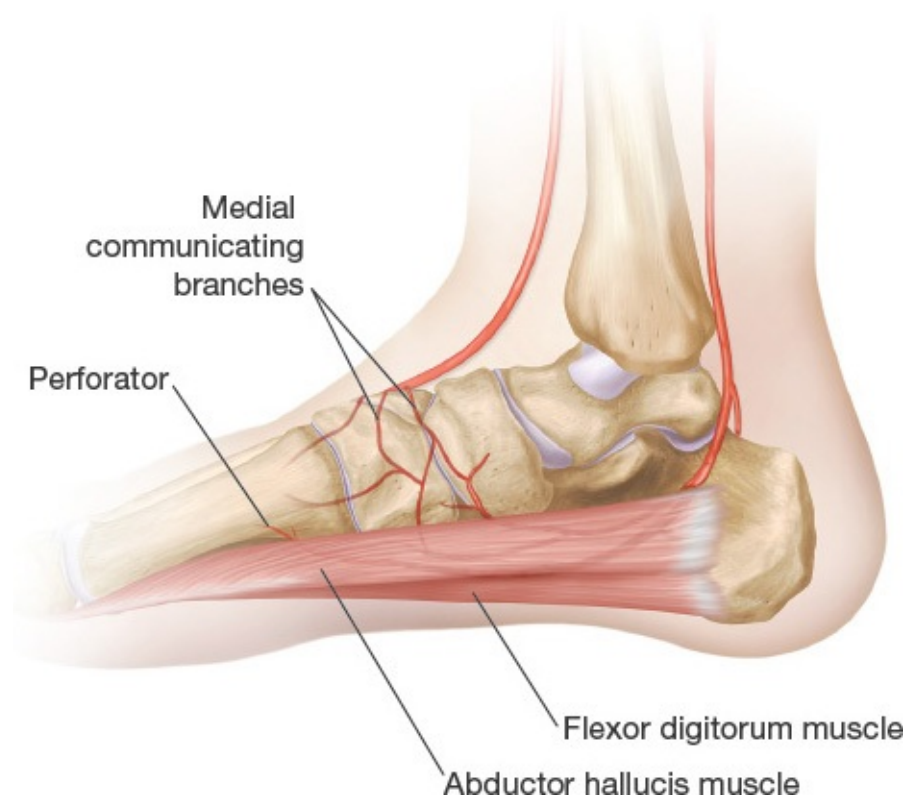


FIG 2 • Perfusion to the medial plantar flap is via perforators from the medial plantar artery and venae comitantes that course between the abductor hallucis and flexor digitorum brevis muscles.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Preoperative evaluation of patients with plantar foot wounds includes a detailed history, focused physical examination, as well as assessment of the functional limitations associated with the foot defect.
- History
 - A thorough history of pre-existing medical conditions as well as their severity must be obtained. Important conditions to identify and address preoperatively include peripheral vasculopathy, diabetes mellitus, and smoking.
 - Peripheral vasculopathy must be corrected prior to any attempt at reconstructing an existing ischemia-related soft tissue defect.
 - Diabetes mellitus management needs to be optimized to increase the likelihood of an uneventful recovery.
 - Preoperative smoking cessation is mandatory to decrease the risk of delayed wound healing.
 - A focused history of the foot wound with particular emphasis on etiology, duration, changes in size, previous wound-related complications (eg, infections), and previous attempts at treatment is critically important.
- Physical examination
 - The foot wound is inspected and its location and dimensions documented.
 - The foot is inspected for pre-existing scars that may preclude harvest of the medial plantar flap.
 - A thorough neurovascular exam of the lower extremity is performed.
 - Pulses, that is, dorsalis pedis and posterior tibial artery, are palpated.
 - Doppler examination is used to confirm the presence of the medial plantar artery and identify its course.
 - Absence of perfusion to the foot via the dorsalis pedis artery represents a possible contraindication to utilizing the medial plantar flap, depending on arterial inflow via the peroneal artery.
 - Sensory examination using Semmes-Weinstein monofilaments is performed in the distribution of the tibial as well as deep and superficial peroneal nerves.
 - The foot is evaluated for any acquired or congenital deformities, as these could influence the weight-bearing areas of the foot, thus, affecting flap design.



FIG 3 • Note that the medial plantar flap is designed in a manner to not include the weight-bearing regions of the foot.

IMAGING

- Preoperative imaging is not routinely required prior to harvest of the medial plantar flap.
- Traditional or CT angiography can be obtained to confirm the presence of suitable pedicle vessels for patients with peripheral vasculopathy in whom there is concern for involvement of the pedicle vessels or patients with traumatic defects with the possibility of involvement of the medial plantar artery/posterior tibial artery.
- Handheld pencil Doppler examination is typically sufficient to localize the medial plantar artery as well as intermuscular perforators emanating between the abductor hallucis medially and the flexor digitorum brevis muscle laterally.

SURGICAL MANAGEMENT

- Patients with defects of glabrous skin containing areas are generally considered for reconstruction with the pedicled medial plantar flap based on the principle of “replacing like with like.”
- Typical indications include heel and lateral plantar midfoot defects (**FIGS 4 and 5**).
- It may be transferred as a free flap for reconstruction of the contralateral foot as well as volar hand and finger defects.
- It is critical to examine the foot and identify weight-bearing areas so not to include these regions in the flap. The weight-bearing areas include the plantar

forefoot over the metatarsophalangeal heads, lateral plantar foot, and the heel.



FIG 4 • Heel defect.

Preoperative Planning

- Preoperative radiographs of the affected extremity are obtained to assess the bone underlying the defect. It is critical to establish whether osteomyelitis is present. If osteomyelitis is present, it should be adequately treated with debridement and antibiotics prior to reconstructing any existing soft tissue defect.
- Preoperative magnetic resonance imaging (MRI) may be indicated to preoperatively delineate the extent of osseous and soft tissue involvement.⁵
- Handheld pencil Doppler examination is performed to outline the course of the medial plantar artery.
- The medial plantar flap is centered on an axis extending from the base of the first metatarsal distally to the sustentaculum tali. The sustentaculum corresponds to the medial eminence of the calcaneus.
- It is critical to avoid incorporating weight-bearing skin areas of the foot into the flap.
- The flap can be designed with its proximal skin bridge intact or as an island flap depending on the needs of the defect.⁶



FIG 5 • Lateral plantar midfoot defect.

Positioning

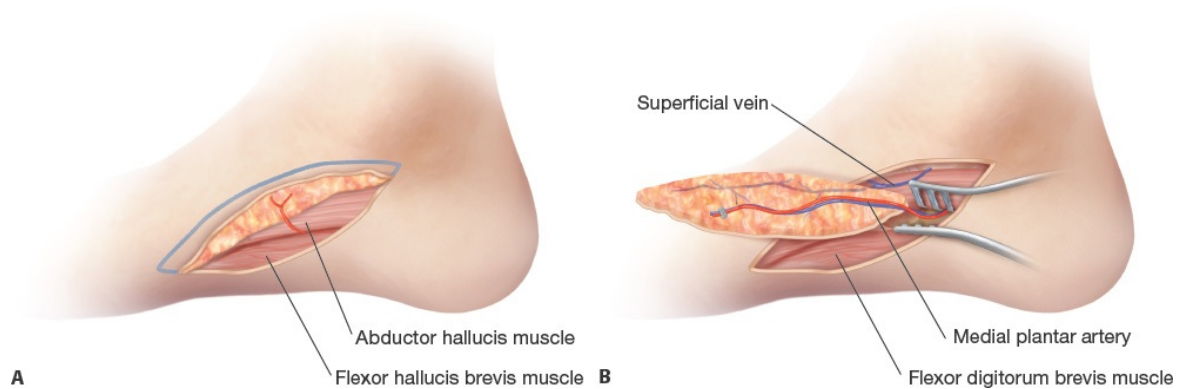
- The patient is typically placed in the supine position with the leg externally rotated and knee flexed (“frog leg”). Prone positioning is likewise possible depending on defect location and surgeon preference.
- A well-padded tourniquet is placed on the thigh to provide for a bloodless operative field, which substantially facilitates identification of key structures during flap dissection.

TECHNIQUES

■ Medial Plantar Flap Harvest

- Landmarks: first metatarsal head, medial calcaneal eminence, midline of the plantar surface of the foot, navicular bone.
- The flap is designed within the boundaries of these landmarks, with particular attention paid not to include any weight-bearing areas of the foot (see **FIGS 1** and **3**).
- The foot wound is debrided until healthy-appearing tissue is encountered.
- The lower extremity is elevated, exsanguinated with an Esmarch bandage, and the tourniquet inflated to 100 mm Hg above the systolic blood pressure value.
- Skin incision is made along the borders of the flap, extending through the plantar aponeurosis.

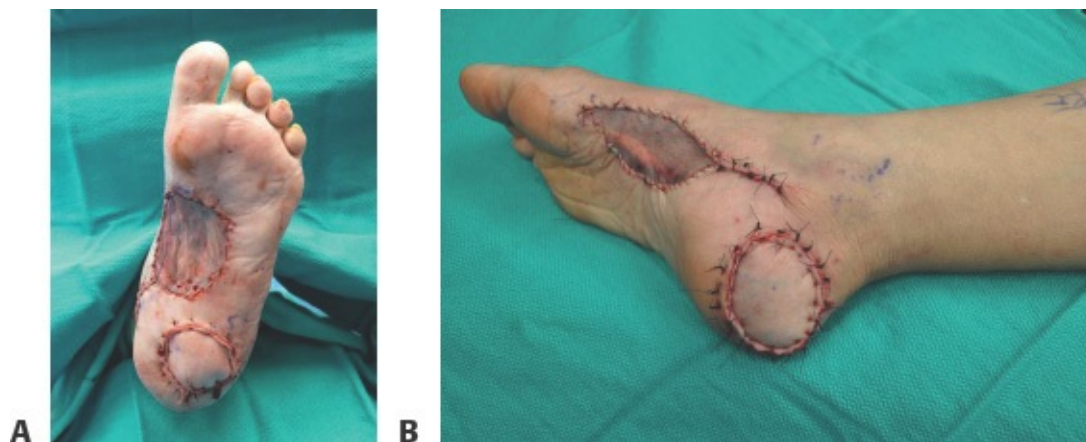
- Although the authors prefer to include the plantar aponeurosis, inclusion of this structure is not mandatory.
- Distally, the abductor hallucis and flexor digitorum brevis muscles are identified.
- Perforators between these muscles are identified, the abductor hallucis muscle is retracted medially, and the perforators are traced to their origin (**TECH FIG 1**).
- The medial plantar artery is visualized, along with the accompanying medial plantar nerve and venae comitantes.
- The medial plantar artery is distally ligated and divided, followed by a distal-to-proximal flap dissection.
 - It is important to maintain all superficial attachments between the medial plantar artery and the overlying skin to ensure flap vascularity.
- In order to avoid sensory loss of the distal medial plantar foot and toes, the medial plantar nerve is not routinely transected.
 - Instead, a nerve-splitting internal neurolysis technique is employed, in which the nerve fibers entering flap are split from the medial plantar nerve, thus preserving distal sensory innervation as well as providing for a sensate flap.
- Dissection is continued proximally until a sufficient arc of rotation is obtained to allow transposition/rotation into the defect.
 - Occasionally, it may be necessary to divide the lateral plantar artery, the abductor hallucis muscle, and the flexor retinaculum to increase the arc of rotation in pedicled flap transfer or to increase pedicle length in cases of microvascular transfer.
 - Release of the tarsal tunnel may be necessary. It may be necessary to follow the medial plantar artery to its origin from the posterior tibial artery. The posterior tibial vessels can also be used for microsurgical anastomosis in the case of free tissue transfer.



TECH FIG 1 • A. During flap harvest, the perforators between the abductor hallucis and flexor digitorum brevis muscles are identified. **B.** The abductor hallucis muscle is retracted medially, and the perforators are traced to their origin.

■ Donor Site Closure

- The donor site of narrow medial plantar flaps up to 2 cm in width may be closed primarily.
- The majority of donor sites require skin grafting for closure.
 - The exposed abductor hallucis and flexor digitorum brevis muscles are reapproximated to provide for a well-vascularized wound bed, amenable to receipt of a split-thickness skin graft (**TECH FIG 2**).
- A negative pressure wound dressing can be applied over the skin graft as a bolster.



TECH FIG 2 • A. Split-thickness skin graft to donor site. **B.** Split-thickness skin graft to donor site

PEARLS AND PITFALLS

Indications	■ Heel and lateral plantar defects (pedicled flap transfer). ■ Any defect requiring reconstruction with glabrous skin (microvascular-free tissue transfer).
Contraindications	■ Previous surgical intervention or injury that violate the area of medial plantar flap harvest. ■ Peripheral vascular disease with occlusion or stenosis of pedicle vessels of significant microvascular disease. ■ Occlusion of dorsalis pedis artery.
Imaging	■ Handheld pencil Doppler examination outlining the course of the medial plantar artery typically sufficient. ■ Routine use of preoperative imaging is not indicated. ■ In cases of peripheral vascular disease or traumatic defects with the pedicle vessels at risk, traditional or CT angiography is useful.
Flap dissection	■ Avoid incorporating weight-bearing skin areas into the flap. ■ Distal-to-proximal flap dissection. ■ Preserve the medial plantar nerve, ie, employ a nerve-splitting approach. ■ May increase pedicle length/arc of rotation by dividing the lateral plantar artery, abductor hallucis muscle, and flexor retinaculum, and dissect the pedicle to the posterior tibial artery.
Donor site closure	■ Up to 2 cm width can be closed primarily. ■ Typically donor site closure requires the use of a skin graft.

POSTOPERATIVE CARE

- The patient is instructed to keep the donor leg elevated for 2 weeks.
- The bolster dressing on the donor site skin graft is typically removed on

postoperative day 5, and routine skin graft care is initiated.

- In cases of soft tissue reconstruction only without any underlying fractures, patients are allowed to ambulate once the flap suture lines and donor site skin graft have healed and are stable. In cases on underlying fractures, weight-bearing status will be determined by orthopedic surgery.
- Meticulous foot care, particularly in patients with diabetes mellitus, is paramount.
- Referrals should be made to an experienced podiatrist for evaluation and possible alterations of foot wear to decrease the likelihood of wound recurrence.

OUTCOMES

- **FIGS 6 to 8** demonstrate representative cases of long-term postoperative outcomes following plantar reconstruction using the medial plantar flap (**FIGS 6 to 8**).
- Siddiqi et al. presented their experience in 18 patients who underwent reconstruction of the weight-bearing heel with the medial plantar artery flap.²
 - Indications for reconstruction included trauma, pressure sores, and unstable plantar scars.
 - No flap loss was reported. Merely one case of partial skin graft loss that healed by secondary intention was observed.
 - Patients were able to wear normal footwear.
 - No functional donor site morbidity was reported.
- Schwarz and Negrini reported on 51 medial plantar artery flaps that were performed in 48 patients.⁷
 - Indications included defects of the posterior heel ($N = 25$), lateral border of the foot ($N = 12$), anterior heel ($N = 10$), and an over the Achilles tendon ($N = 4$).
 - Complications were encountered in 25.5% of the procedures (13/51), with the most common complications being delayed wound healing ($N = 6$) and infection ($N = 3$).
 - One flap loss was reported in addition to 9 ulcer recurrences in 7 ft.



FIG 6 • Long-term outcome after heel reconstruction with the medial plantar flap.



FIG 7 • Long-term outcome after heel reconstruction with the medial plantar flap.

COMPLICATIONS

- Postoperative complications requiring surgical intervention are uncommon.
- Complications, however, can include the following:
 - Infection
 - Wound dehiscence
 - Delayed wound healing
 - Skin graft loss
 - Flap loss
 - Injury to the medial plantar nerve with consecutive altered sensation of the medial forefoot and toes

- Gait disturbance
- Pain
- Unstable scar



FIG 8 • Long-term outcome after reconstruction of a lateral plantar midfoot defect with the medial plantar flap.

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14 Reconstruction of Heel and Plantar Defects: Free Flap

CHAPTER

Goo-Hyun Mun and Kyong-Je Woo

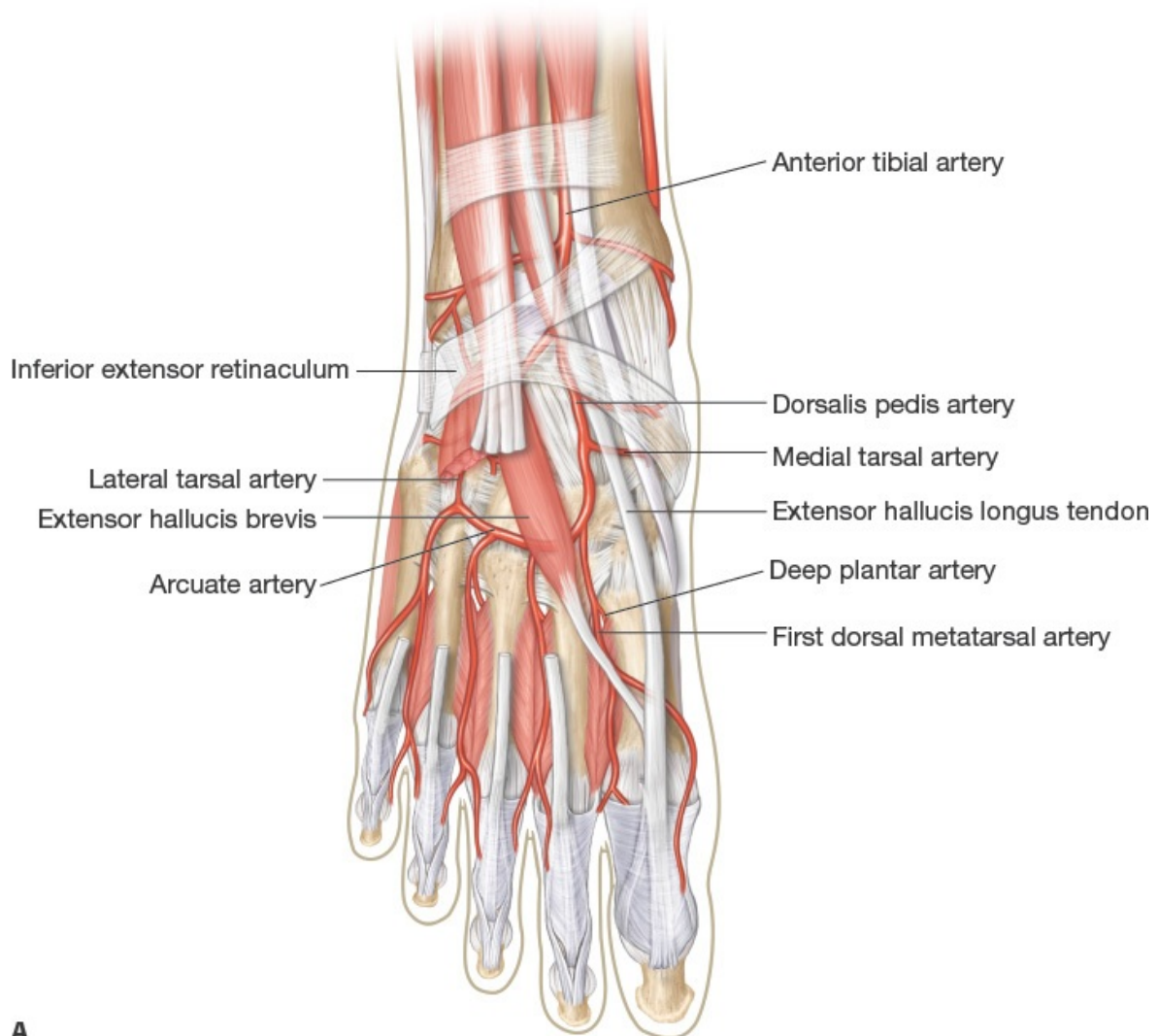
DEFINITION

- Heel and plantar soft tissues perform a special role of weight bearing while walking or standing. The heel sustains up to 115% of body weight during slow walking and up to 260% of body weight during running.¹
- Heel and plantar defects may result from several causes such as trauma, diabetes, infection, peripheral vascular disease, frostbite injuries, and tumor resections.
- The goal of reconstruction is aimed at not only providing stable wound healing but also achieving functional restoration of the salvaged limb and maintaining acceptable appearance.

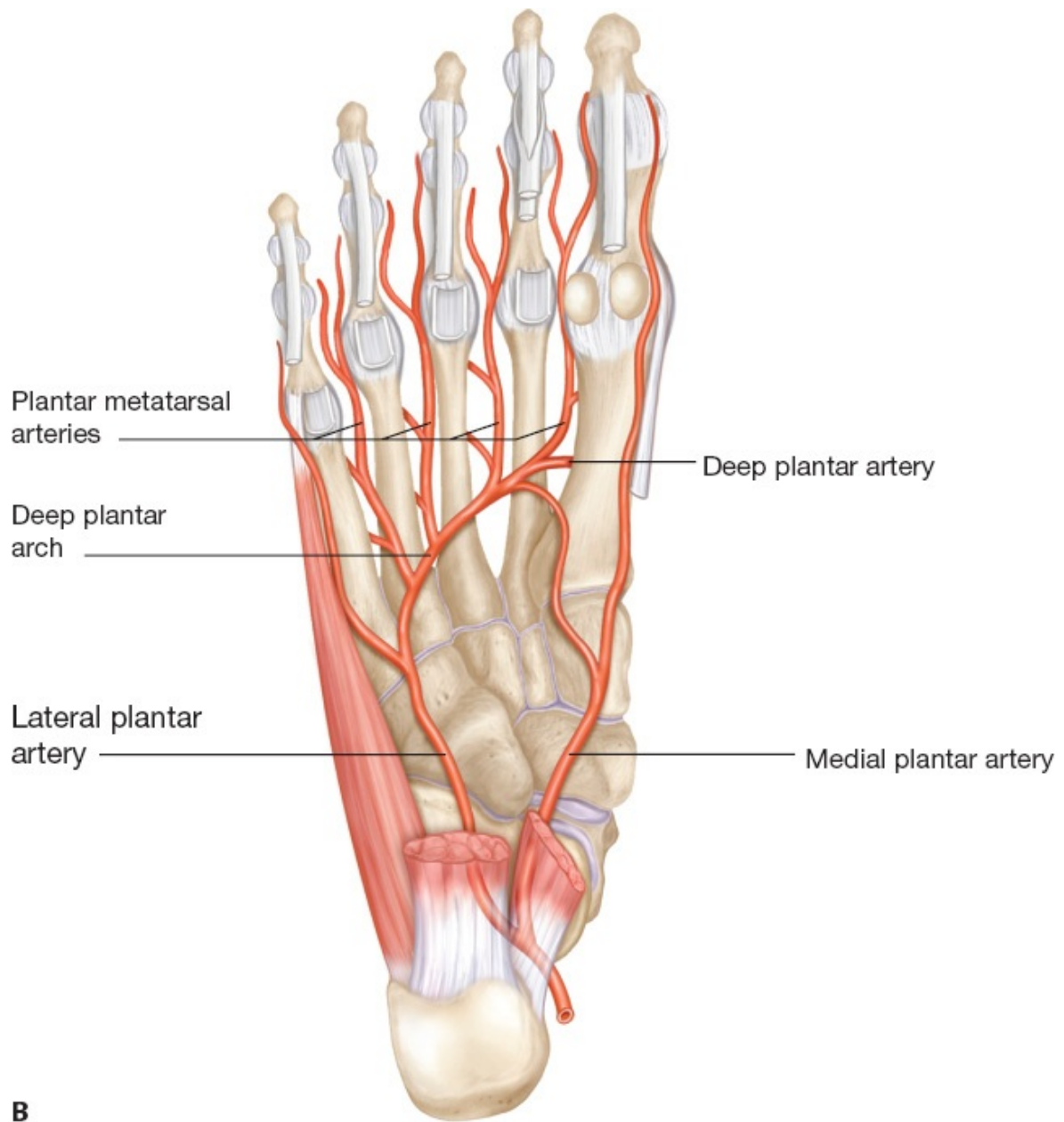
ANATOMY

- The weight-bearing plantar skin is a highly specialized part of the foot that is able to withstand and absorb the forces exerted during gait or running cycles. The epidermis and dermis are much thicker in plantar skin (“glabrous skin”) than in other parts of the body.
- Subcutaneous fat in combination with the vertical fibrous connective tissue provides a cushioning effect to weight bearing.
- The three arteries at the ankle level and their terminating branches in the foot that can be used as recipient vessels for free flaps include the anterior tibial-dorsalis pedis artery, posterior tibial-medial and lateral plantar artery, and peroneal-lateral calcaneal artery.
- Anterior tibial-dorsalis pedis artery: the dorsalis pedis artery passes under the extensor retinaculum at the midpoint between the medial and lateral malleoli. It usually runs across and beneath the extensor hallucis longus (**FIG 1A**). It

passes to the proximal end of the first intermetatarsal space, where it turns into the sole between the heads of the first dorsal interosseous to complete the plantar arch and provides the first plantar metatarsal artery (**FIG 1B**). In heel and plantar reconstruction with a free flap, the dorsalis pedis artery can be reached for the recipient vessel by using a remote incision and subcutaneous tunneling (**FIG 2**). The first plantar metatarsal artery can be used in the plantar forefoot reconstruction (**FIG 3**).



A



B

FIG 1 • A,B. Anterior tibial-dorsalis pedis artery. B.

- Posterior tibial-medial and lateral plantar artery: posterior tibial artery runs midway between the medial malleolus and the medial calcaneal tubercle under the laciniated ligament. It is located between the flexor digitorum longus and flexor hallucis longus tendons (**FIG 4**). The posterior tibial artery divides into the medial and lateral plantar arteries under the origin of the abductor hallucis. While the medial plantar artery runs between the abductor hallucis and flexor digitorum brevis (**FIG 5**), the lateral plantar artery, being usually

larger, travels from medial to lateral position under the proximal third of the flexor digitorum brevis and then continues distally between flexor digitorum brevis and abductor digiti minimi (**FIG 6**).

- Peroneal-lateral calcaneal artery: peroneal artery terminates into lateral calcaneal artery around the lateral malleolus (**FIG 7**). The lateral calcaneal artery was introduced as a pedicle for local flap, but a recent anatomical study suggests that it could be used as a recipient blood vessels for free flap.^{2,3} The lateral calcaneal artery originates either from peroneal artery (80.3%), posterior tibial artery (13.1%), or a common branch from both the peroneal and posterior tibial arteries (6.6%) and runs between lateral malleolus and Achilles tendon.^{3,4}
- The principal superficial veins are termed long (great) and short (small) saphenous veins (**FIG 8**). The long (great) saphenous vein passes anterior to the medial malleolus, whereas the short (small) saphenous vein ascends from the lateral side of the foot. It ascends posterior to the lateral malleolus, passing along the lateral border of the Achilles tendon. A deep venous system runs near the corresponding arteries and develops communication with the great and small saphenous veins. Both deep veins of the corresponding arteries and the superficial veins can be selected as recipient veins in the foot.



FIG 2 • A. The dorsalis pedis artery was used as a recipient artery for defect on lateral forefoot. A remote incision and subcutaneous tunneling was performed to reach the recipient vessels. **B.** Microvascular anastomosis. **C.** Immediate postoperative photo. **D.**

Another case with defect on the lateral heel. Dorsalis pedis vessels were used as recipient vessel through a remote incision and subcutaneous tunneling. **E.** Immediate postoperative photo.



FIG 3 • A,B. First plantar metatarsal artery and vein for the recipient vessel.

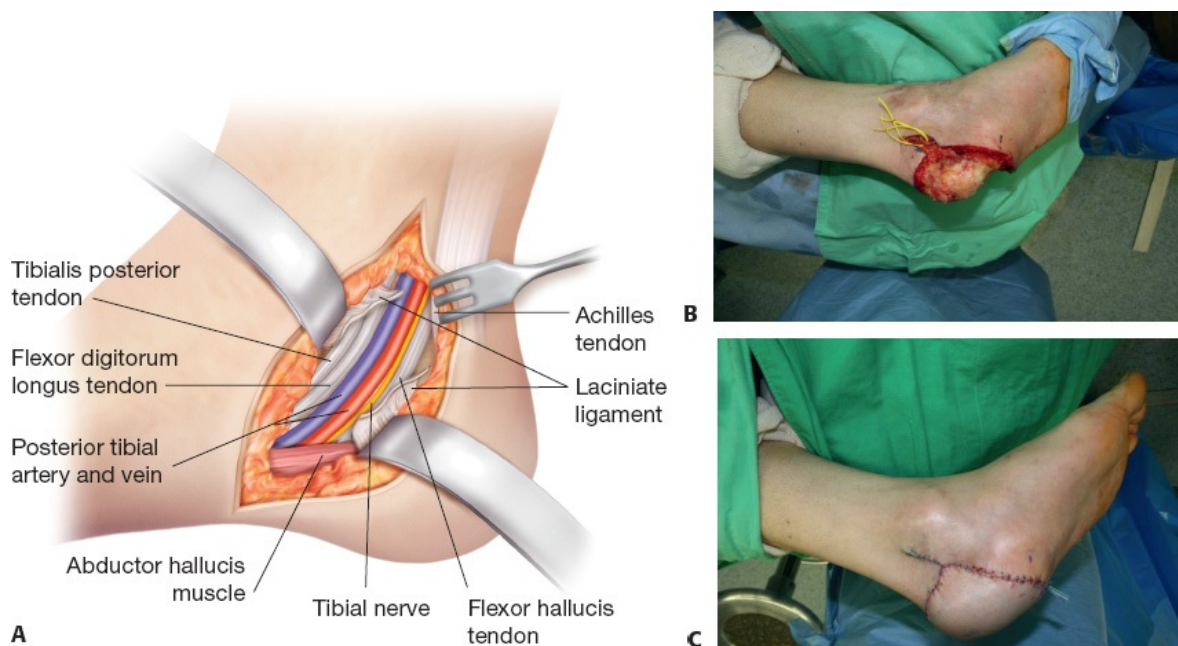


FIG 4 • A–C. The posterior tibial artery for the recipient vessel.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough medical history and examinations for sensation and presence of

diabetes, peripheral vascular disease, and existence of osteomyelitis need to be obtained. Deformities of the foot and a postoperative rehabilitation plan should also be considered in the selection of reconstruction methods.

- Vascular anatomy and patency must be evaluated. In this regard, noninvasive Doppler ultrasound exam is a simple and useful evaluation method. Recently, computed tomography (CT) or magnetic resonance (MR) angiography methods are also recommended for vascular imaging.

IMAGING

- The authors routinely perform preoperative CT angiographic examination of the lower extremities, except when contraindicated.
- Bone assessment includes plain radiography and bone scan or MR imaging for the diagnosis of osteomyelitis.

SURGICAL MANAGEMENT

- For large and extensive heel and plantar defects, the free flap transfer procedure is preferred because it can provide a large amount of tissue with various tissue components for obliterating deep and/or extensive wounds. The early and definitive reconstruction of compound defects leads to a dramatic improvement in the rate of lower extremity salvage and restoration of the weight-bearing function and normal gait pattern.

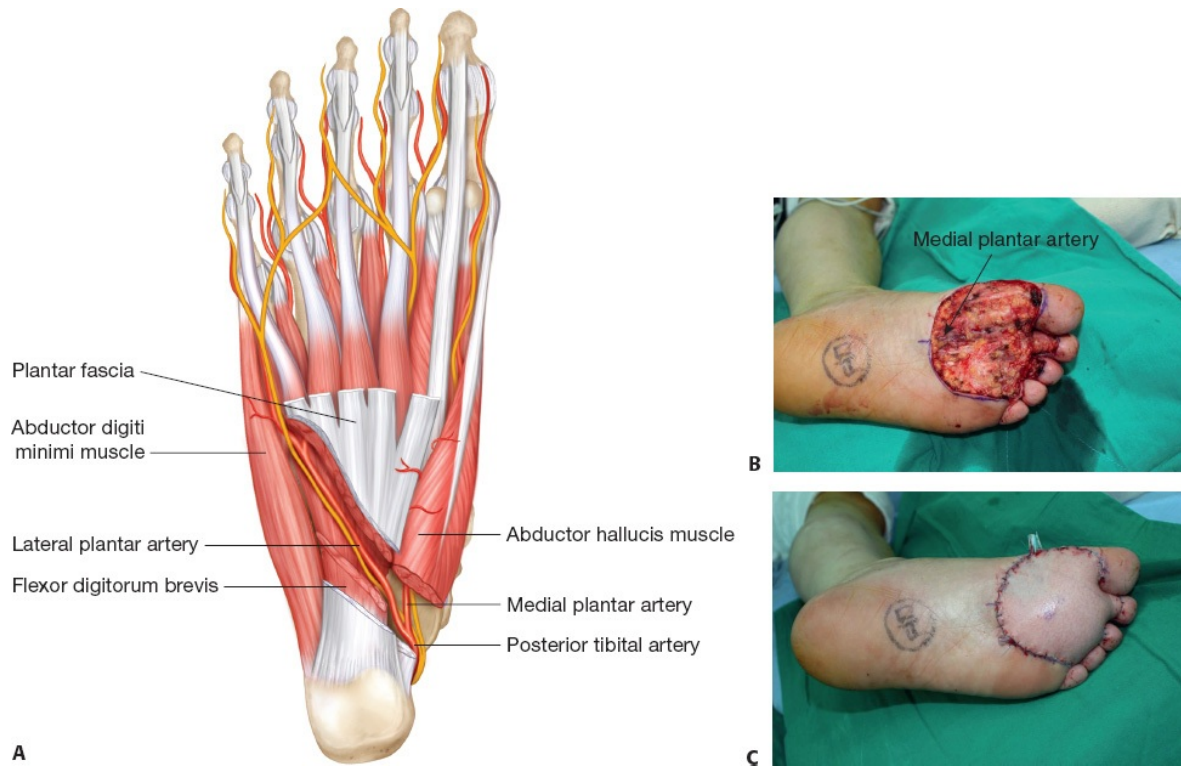


FIG 5 • A–C. The medial plantar artery for the recipient vessel.

- The final choice of most suitable flap depends on the surgeon's preference and the patient's needs. A form of durable, permanent, pain-free, and functionally and aesthetically satisfying coverage should be achieved in the heel and plantar reconstruction.

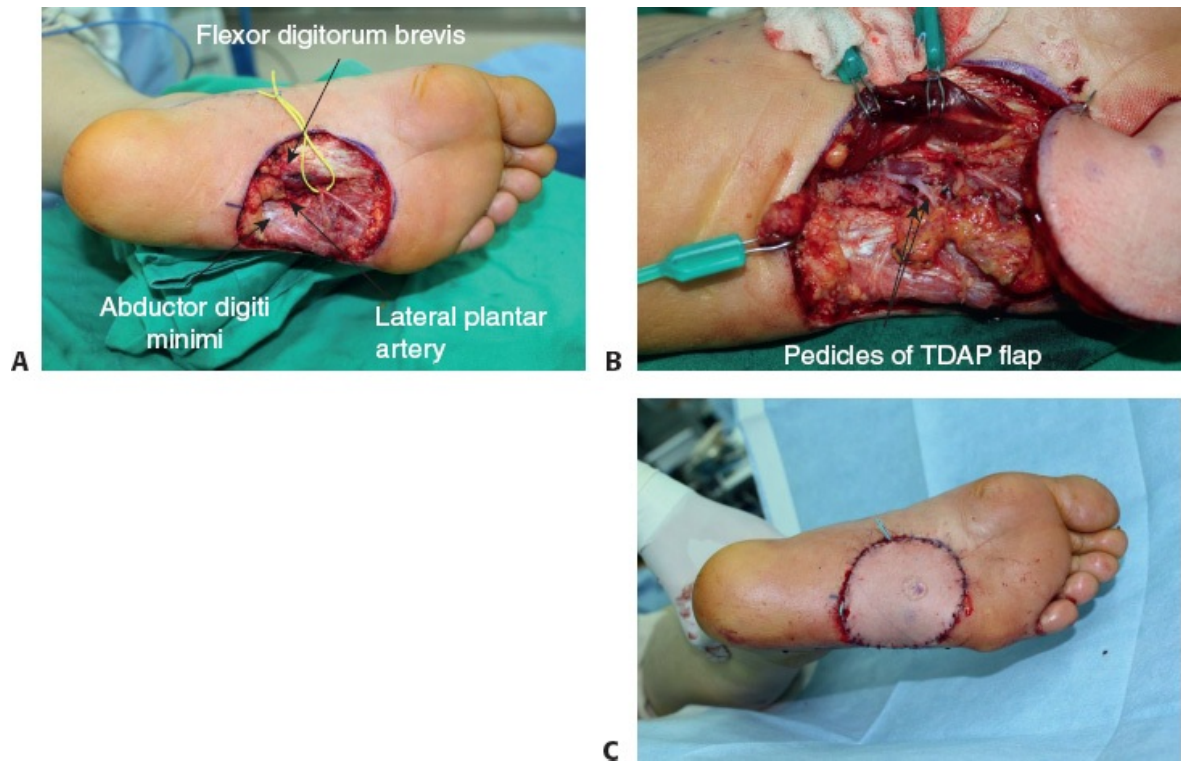


FIG 6 • A–C. The lateral plantar artery for the recipient vessel.

- Free muscle flap versus fasciocutaneous flap: free muscle flap (rectus abdominis, latissimus dorsi, or gracilis) has been used commonly for extensive foot defects. A muscle flap has advantages, including the large amount of tissue availability, and ability to obliterate dead space especially in defects with irregular contours, where there is greater ease to form three-dimensional (3D) shapes.⁵ In contrast, recent clinical studies have demonstrated that fasciocutaneous flaps (anterolateral thigh, thoracodorsal artery perforator [TDAP] flap) provide a sufficient amount of bulk, large, and pliable skin flap, with acceptable donor site morbidities.^{6,7} The donor site morbidities caused by harvesting the muscle flap and additional donor site for skin graft can be avoided by using the fasciocutaneous flap.

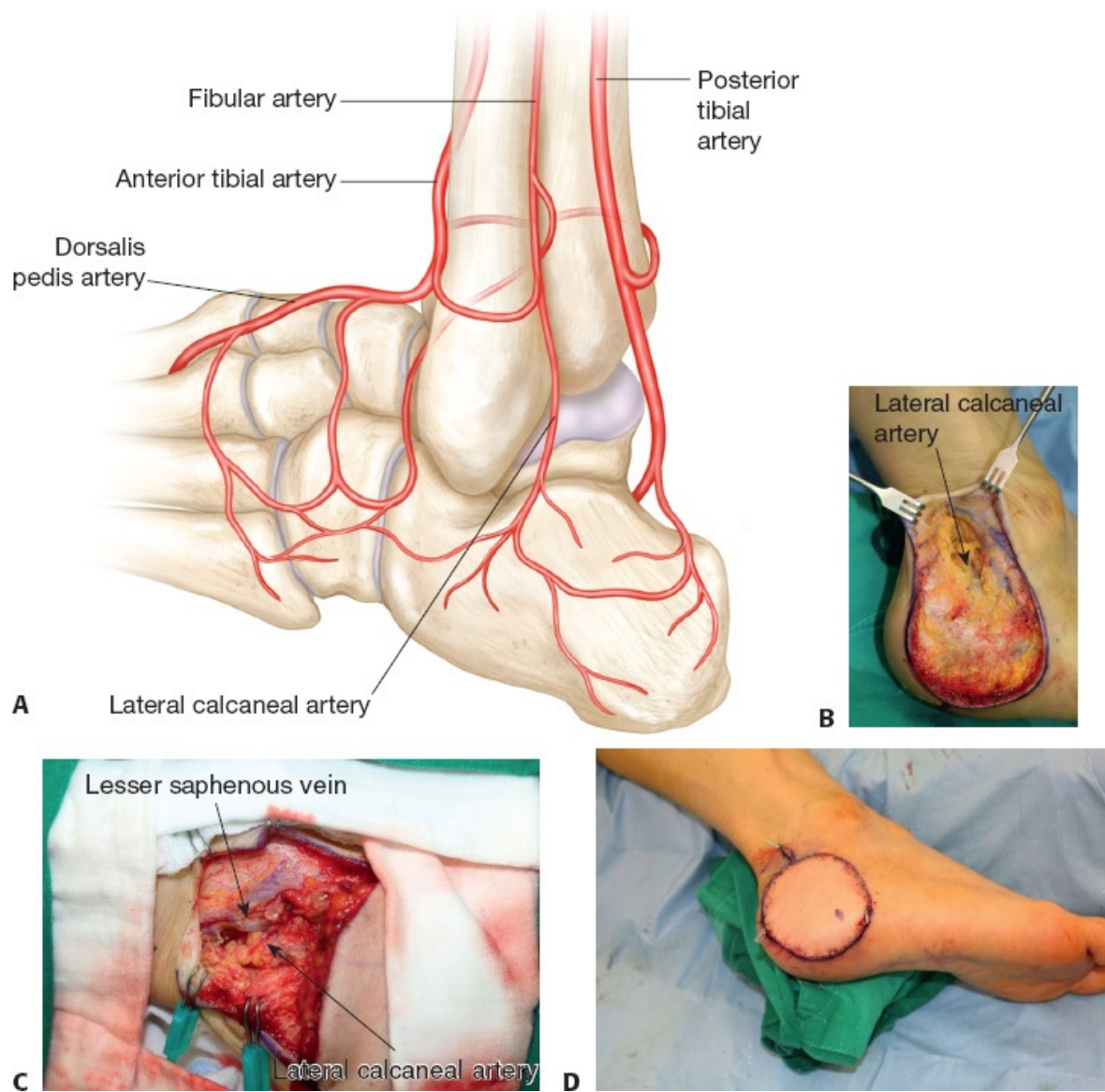


FIG 7 • A–D. The lateral calcaneal artery for the recipient vessel.

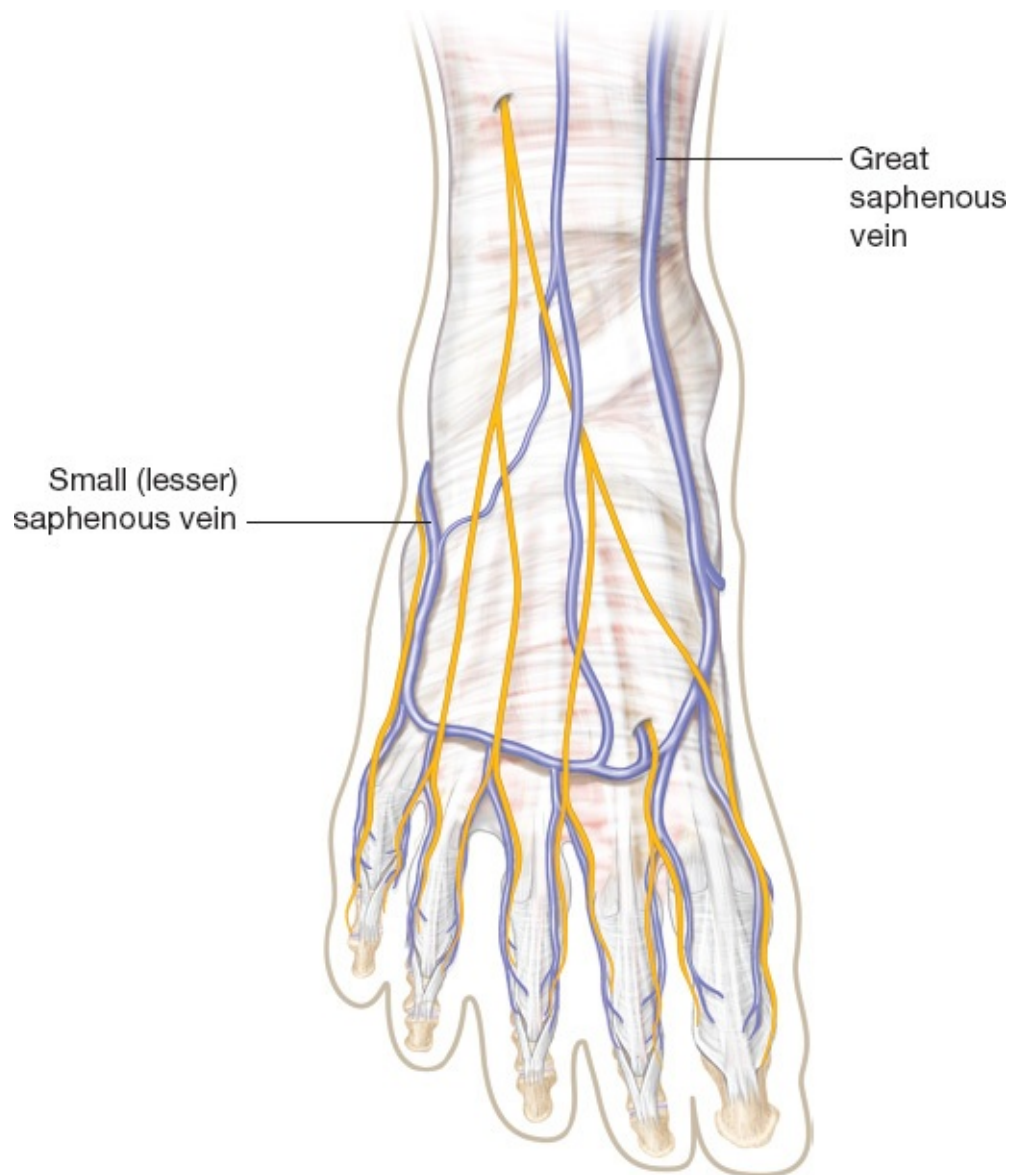


FIG 8 • A superficial venous system of the foot.

- The authors prefer the TDAP flap for many foot defects because it provides thick skin from the back that has negligible incidence of atherosclerosis of the vascular pedicle, which is relatively long. Furthermore, the TDAP can be tailored to include different tissue types such as muscle (latissimus dorsi) and/or bone (scapula) depending upon the requirements for reconstruction. The anterolateral thigh flap is also useful when supine position of the patient is favorable.
- Muscle-chimeric perforator flap is useful to obliterate dead space when it is necessary (see **FIG 12B,C**).

- Innervated (sensate) flap: although it seems reasonable to assume that plantar reconstruction requires a sensate flap to avoid recurrent ulceration, there is no evidence suggesting that innervated flaps on weight-bearing portion of the foot is superior in terms of rates of ulceration. A noninnervated fasciocutaneous flap showed progressive improvement in sensitive thresholds, achieving good protective sensitivity, similar to that of an innervated flap.⁹
- The status of an underlying skeletal anatomy is a critical factor in the durability of the soft tissue reconstruction. Abnormally high pressure points on the plantar surface lead to the recurrent breakdown after reconstruction, and the abnormalities should, therefore, be corrected.
- In the heel and plantar reconstructions, restoration of 3D configuration of the heel and plantar foot is essential to wear a normal shoe and to regain normal gait pattern. The primary defatting and wedge resection of the flap facilitates making 3D configuration.



FIG 9 • A clinical case with malignant melanoma on the left heel.

Preoperative Planning

- The patient had a large malignant melanoma on the left heel. Wide excision of the tumor and reconstruction of the heel were planned (**FIG 9**).
- CT angiographic evaluation showed all major vessels of the foot had normal anatomy with no atherosclerosis or vascular occlusion. The presence of a sizable lateral calcaneal artery on the patient's left foot was also confirmed, and the course could be followed by 3D reconstruction of the CT images (**FIG 10**).
- A TDAP flap, instead of an anterolateral thigh flap, was planned to be used for

several reasons in the described case. Lateral position was better than supine position for both tumor resection and inset of the flap. In addition, it might have been necessary to perform a skin graft for the anterolateral thigh flap donor site if the flap was more than 10 cm wide.

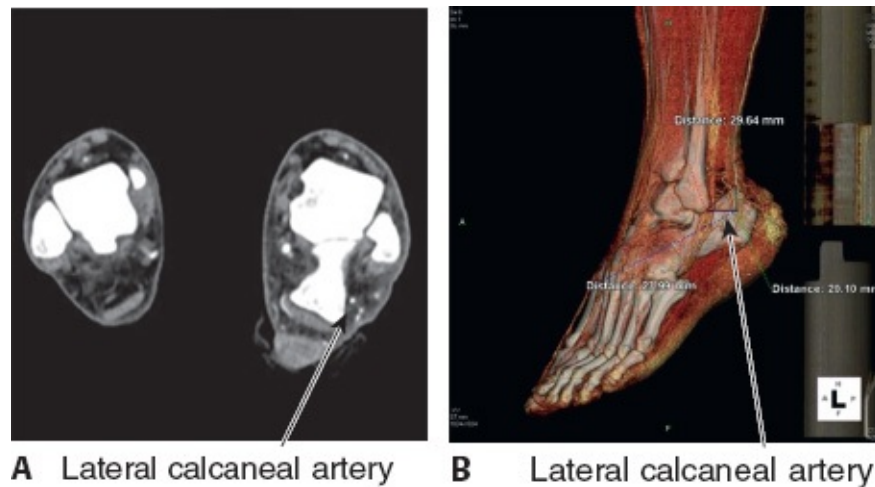


FIG 10 • A,B. CT angiographic image of lateral calcaneal artery.

Positioning

- The procedure can be performed in the lateral decubitus position, with the affected leg placed on the upper side. An ipsilateral TDAP flap can be harvested following tumor resection, without changing the position, at the same time as dissecting the lateral calcaneal artery as the recipient artery.
- When the posterior tibial artery is planned to be the recipient vessel, a TDAP flap is harvested from the contralateral side in a position of lateral decubitus with the recipient foot placed on lower side (**FIG 11**).



FIG 11 • Lateral decubitus position for harvesting TDAP flap on the contralateral side of the defect when the posterior tibial artery is used as recipient vessel.

Approach

- When a recipient vessel can be found in the defect, it is approached directly. Otherwise, an extended incision starting from the defect or a separate incision with subcutaneous tunneling is used as an approach to preparing the recipient vessels.

TECHNIQUES



Video p7-c014

Note: Each step of techniques is included in the video clip.

■ Wound Preparation

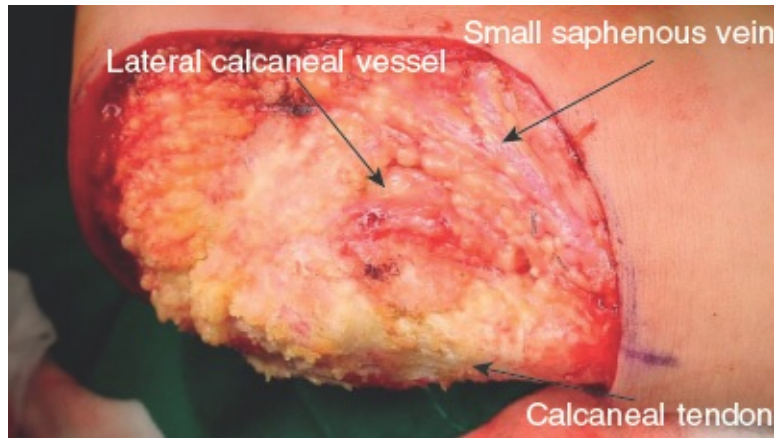
- It is critical that there is complete debridement or excision of pathologic, necrotic, or infected tissue under tourniquet control (**TECH FIG 1**).



TECH FIG 1 • A,B. Defect of the heel after tumor resection.

■ Recipient Vessel Preparation

- Patency and location of the lateral calcaneal artery for use as the recipient artery are checked using handheld pencil Doppler.
- Small saphenous vein is preserved and dissected for use as the recipient vein.
- The lateral calcaneal artery runs superficially between lateral malleolus and the Achilles tendon. The vessel traverses anterior to the calcaneal tendon and posterior to the small saphenous vein (**TECH FIG 2**). Opening the extensor retinaculum and deep fascia exposes the lateral calcaneal artery with its associated venae comitantes.



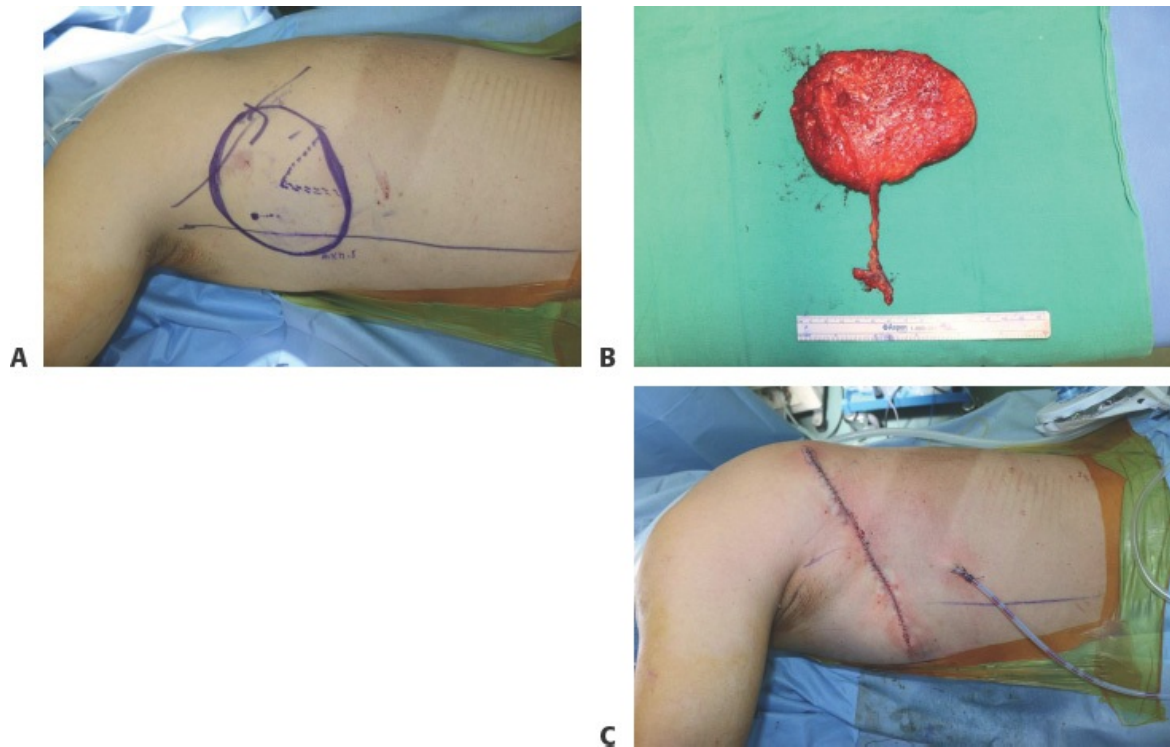
TECH FIG 2 • Dissection of lateral calcaneal vessels.

■ Assessment of the Defect

- After deflating the tourniquet, meticulous hemostasis is performed, which is followed by irrigation with saline.
- A template of the exact shape and size of the defect is made by using a transparent plastic or paper to be used when designing the flap.
- Wedge-shaped excision of the skin flap is necessary in case of the total heel resurfacing. The area for planned wedge excision is incorporated when estimating the flap dimensions.

■ Flap Harvest

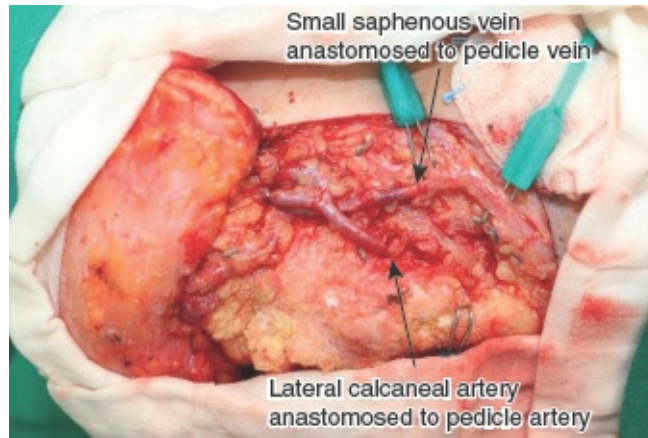
- Outline of the relevant muscle and landmarks are marked on the skin.
- Perforators are located using handheld pencil Doppler, and the flap is designed using a template of the defect. The perforator can be located eccentrically, considering the area of wedge excision (**TECH FIG 3A**).
- A limited incision is made, and a suprafascial dissection is performed until the targeted perforator is identified. Once the perforator is evaluated and deemed suitable, then the whole skin paddle is elevated and meticulous intramuscular dissection of pedicle with bipolar forceps is commenced.
- Motor nerve branches to the muscle are preserved, and the pedicle is divided when sufficient length is obtained (**TECH FIG 3B**).
- A closed suction drain is placed, and the donor site is primarily closed in layers (**TECH FIG 3C**).



TECH FIG 3 • A–C. Flap design and elevation.

■ Microanastomosis with Temporary Inset

- Temporary inset of flap can be performed using a skin stapler.
- It is critically important to avoid twisting of the pedicle. If excessively long, the vascular pedicle under the flap is positioned in lazy-S shape to avoid kinking.
- The pedicle artery is anastomosed to the lateral calcaneal artery, and the vein is anastomosed to the short (small) saphenous vein (**TECH FIG 4**).
- Vascular clamps are removed after completion of the anastomosis. Warm saline is applied onto the vessels and flap, and inflow and outflow of the flap are checked after waiting for several minutes.
- A thorough microscopic evaluation is conducted to find any bleeding points along the vascular pedicle.

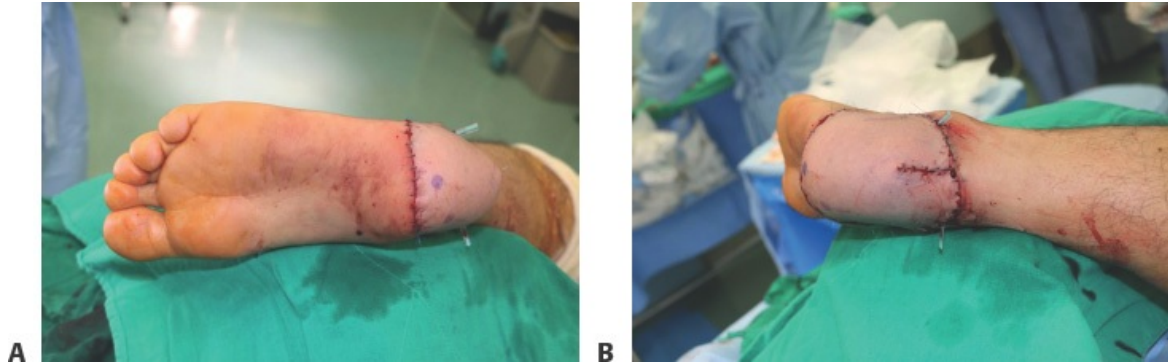


TECH FIG 4 • Microanastomosis.

■ Final Inset

- Defatting of the flap is performed before the final inset. The deep fat and part of the superficial fat may be carefully removed with scissors according to the required thickness of tissue. Thinning can be done with or without loupe, but microscope magnification is not usually necessary. This procedure is important to obtain an optimal contour of the reconstructed foot. The authors prefer primary (immediate) defatting to secondary (delayed) defatting because it provides well-contoured reconstruction in one stage, reduces tension of closure, and is a safe procedure. Alternatively, secondary defatting is a viable option, which can avoid potential risk of circulatory problem associated with primary thinning.
- In contrast to the conventional fasciocutaneous flap that includes deep fat and fascia, a perforator flap with a thin subcutaneous layer composed of the superficial fat lobules surrounded by dense fibers allows the skin to anchor tightly to the surface and to glide less.^{6,7} Generally, perforator flap is thinned accordingly to match the contour of adjacent plantar tissue.
- Redraping of the flap for the final inset is attempted only after the defatting procedure is completed because this may change the pliability and extensibility of the flap. Dimensional excess should be corrected at this stage by careful trimming to obtain durable weight-bearing surface against anticipated shear forces (**TECH FIG 5**).
- The wound is closed over a drain placed under the flap to prevent fluid collections.

- Fluffed gauze is gently applied to the flap, but the part of flap including the location of captured perforator is left exposed for postoperative monitoring using the handheld pencil Doppler.



TECH FIG 5 • A,B. Inset of the flap after defatting and wedge-shaped excision.

PEARLS AND PITFALLS

Reconstruction goal

- The weight-bearing plantar skin is highly specialized to withstand and absorb forces exerted during gait or running cycles.
- The reconstructive goal is not only to provide stable wound healing but also to achieve functional restoration of the salvaged limb with an acceptable appearance.

Flap selection

- Free muscle flaps (rectus abdominis, latissimus dorsi, and gracilis) have been commonly selected for the extensive foot defects.
- Cutaneous perforator flaps now provide favorable functional and aesthetic outcomes in heel and plantar reconstruction.

Selection of recipient vessel

- The three named arteries at the ankle level and their terminating branches can be candidates for recipient vessels; anterior tibial-dorsalis pedis artery, posterior tibial-medial and lateral plantar artery, and peroneal-lateral calcaneal artery.
- CT angiography is a valuable tool to evaluate the arterial and venous flows and the presence of atherosclerosis.

Assessment of the defect

- Before designing the flap, the size and shape of the defect are measured exactly by making a template.
- Required vascular pedicle length and flap thickness are also assessed.

Flap inset

- Defatting of the flap at the time of inset is important to obtain a desirable contour of the reconstructed foot. Alternatively, secondary defatting is an option.
- Excessive skin dimension is carefully corrected to have the flap closely tailored to the defect.

POSTOPERATIVE CARE

- The leg is elevated to help with edema for a better venous return while the patient is lying in bed.
- Care should be taken to avoid any compression along the course of the superficial vein of the leg when it is used as an outflow vessel.
- There is no consensus regarding the use of medications for thromboprophylaxis such as aspirin, heparin, and dextran. The authors do not routinely use any of these medications but low molecular weight heparin is given for chemoprophylaxis of the venous thromboembolism while patient is immobilized in bed.
- For postoperative monitoring, the flap can be checked every 1 to 3 hours for the first 48 hours, followed by every 4 to 6 hours for the next 48 hours after the surgery. Monitoring is done by physical examination and handheld pencil Doppler examination.
- Diet is usually allowed 24 hours after surgery in the authors' practice.
- Although the duration of immobilization time varies based on the orthopedic and bony status, in general, progressive weight bearing and ambulation are achieved once the flap maturation is assured. At 2 weeks, compressive garment is applied to prevent edema of the flap and foot. Bearing weight on the site of flap is usually allowed in 4 weeks after the surgery.
- Abnormal weight-bearing patterns and gait abnormalities correlate with the development of chronic ulcers. An early orthotic use and physical therapy in rehabilitation unit may prevent ulceration and wound breakdown.
- Patient education on meticulous foot care with frequent inspections to recognize any area of wound breakdown is essential for a successful and durable result.

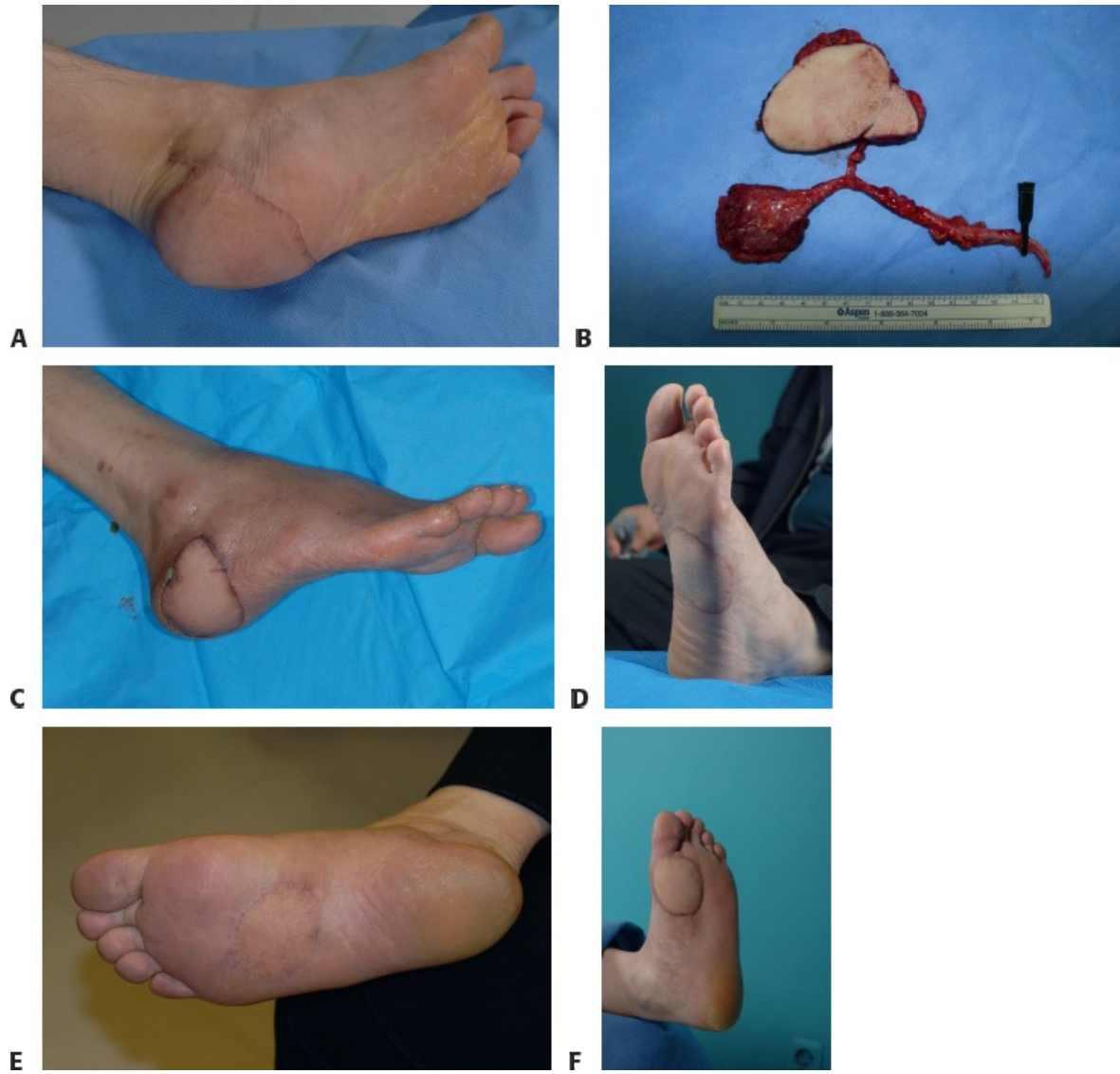


FIG 12 • A. Total heel reconstruction using TDAP flap. Posterior tibial vessels were the recipient vessels. **B,C.** Reconstruction for small heel defect with muscle-chimeric TDAP flap. Anterior tibial vessels are the recipient vessel. **D.** Reconstruction of the plantar midfoot with TDAP flap, using lateral plantar vessels as a recipient vessel. **E.** Reconstruction of lateral forefoot with TDAP flap, using posterior tibial vessels as a recipient vessel through subcutaneous tunneling. **F.** Reconstruction of medial forefoot with TDAP flap, using the first plantar metatarsal vessels as a recipient vessel.

OUTCOMES

- Microvascular free flap for foot reconstruction is, at present, a safe and reliable procedure, with high success rate.¹⁰ Recently, the plantar reconstruction using the perforator flaps showed a success rate of between 97.5% and 98.5%, with acceptable functional and aesthetic outcomes.^{5,6}
- Microvascular free flap is a reliable reconstructive option for a variety of size defects on various locations of the heel and plantar foot (**FIG 12A**). Multiple tissue components such as cutaneous and chimeric muscle (**FIG 12 B,C**) can be used according to tissue requirements.

COMPLICATIONS

- Vascular complications such as venous and arterial thrombosis.
- Hematoma: early diagnosis of a hematoma under the flap is critical for its evacuation to prevent the obstruction of anastomotic site from the expanding hematoma.
- Infection.
- Ulcerations: ulceration is one of the most common complications of free flap reconstruction of the heel. Although flap-specific factors may contribute to its development, it is possible that flap extrinsic factors such as the recipient bed, bony prominence, Contouring of the flap, and footwear may be more important.

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The Reverse Sural Artery Flap for Lower Extremity Reconstruction

15 CHAPTER

Ashkaun Shaterian and Amber Leis

DEFINITION

- The reverse sural artery flap was first described by Donski and Fogdestam¹ and later by Masquelet et al.² and represents a fasciocutaneous flap used in lower extremity reconstruction.
- As a one-stage or two-stage operation that does not require microsurgical techniques, the reverse sural flap is an option available to most reconstructive and orthopedic surgeons.

ANATOMY

- The blood supply for the skin paddle of the distal two-thirds of the leg depends on the sural arteries along its most proximal course and the peroneal artery perforators more distally.
- The reverse sural artery flap receives retrograde arterial flow through septocutaneous perforators that originate from the peroneal artery and directly anastomose with the superficial sural artery.
- There are typically two to five perforators located 5 to 7 cm proximal to the lateral malleolus.³
- The venous drainage for this flap is composed of a venous network of the superficial sural vein, the lesser saphenous vein, and the associated veins of the peroneal artery.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Assessment of the defect begins with evaluation for missing tissues, exposed vital structures, and presence of underlying orthopedic hardware.

- If healthy subcutaneous or granulation tissue presides, the wound may be amenable to skin grafting.
- If exposure of tendon, artery, vessel, or bone are present, more definitive coverage with fasciocutaneous or muscle flaps is often necessary.
- The size of the defect will also influence the reconstructive choice.
- The reverse sural artery flap can be used to cover defects of the posterior aspect of heel and Achilles tendon, anterior and lateral ankle, dorsum of the foot, lateral aspect of the hindfoot, and the anterior crest of lower third of the leg.
- Physical exam to evaluate the vascular status of the extremity, and to evaluate for peripheral artery disease or venous insufficiency, is necessary as they may influence flap survival.
- Patient comorbidities of diabetes mellitus, lower extremity venous insufficiency, and peripheral artery disease have been associated with flap necrosis and represent relative contraindications.
- The presence of an occluded anterior or posterior tibial artery does not represent an absolute contraindication to this flap; however, most consider occlusion of the peroneal artery to preclude its use.⁴⁻⁶

IMAGING

- Rarely are radiographs necessary except in the evaluation of bone abnormalities.
- Preoperative angiograms are not routinely obtained but may be useful in patients with pertinent exam findings or in traumatic wounds of the lower extremity.

SURGICAL MANAGEMENT

Preoperative Planning

- The reverse sural artery flap is a fasciocutaneous flap that can be designed with either a complete skin bridge overlying the pedicle or as an island skin flap with an adipofascial pedicle.
- Preoperatively, the peroneal perforators and lesser saphenous vein are identified with Doppler ultrasonography.
- The lesser saphenous vein is used to determine the oblique axis of the pedicle and the flap.
- The flap is designed on the posterior aspect of the calf between the two heads

of gastrocnemius at the junction of upper and middle third of the leg (**FIG 1**).

- The dimensions of the flap are determined by the arc of rotation and the size of the defect; however, a reliable flap should not exceed a ratio of length to width of pedicle of 4:1.
- The flap dimensions can reach 15 cm in length and 12 cm in width, but when the flap is less than 3 to 4 cm wide, the donor site defect can be closed primarily.
- The pivot point of the pedicle is dependent on the main perforator and is located 5 cm or three fingerbreadths proximal to the tip of the lateral malleolus and posterior to the fibula.
- The flap may also be designed based on more distal perforators, but the dissection becomes more risky, the width of pedicle decreases, and reliability of the flap declines.



FIG 1 • Flap markings for a reverse sural artery flap with a fasciocutaneous pedicle.

Positioning

- To provide the best exposure, the patient is placed in a prone or lateral position depending on the location of the defect.
- In the lateral position, flexion and adduction of hip and flexion of knee allow for easier access.
- The surgeon is positioned on the same side as the flap and the assistant on the contralateral side.
- All bony prominences should be well padded and the upper extremities and neck placed in positions of safety.

Approach

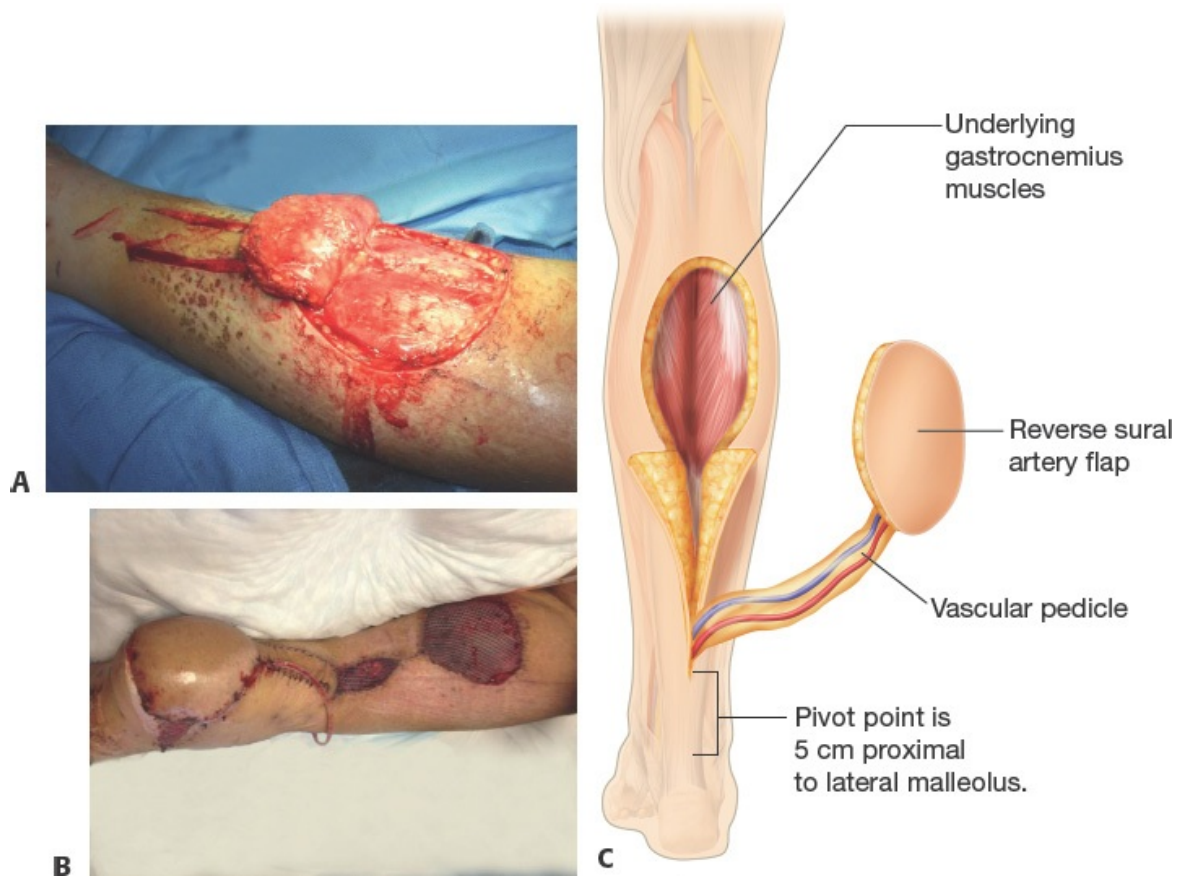
- The flap is approached from the posterior lower leg after identifying the vascular pedicle and completing the appropriate markings.

TECHNIQUES

■ Reverse Sural Artery Flap

- A well-padded lower extremity tourniquet is applied.
- The skin incision begins along the location of the pedicle and continues around the proximal edge of the flap (**TECH FIG 1A**).
- The subcutaneous tissue is dissected along the pedicle and most proximally to identify and expose the sural nerve, superficial sural artery, sural vein, and lesser saphenous vein.
- At the proximal margin of the flap, the nerve and the vessels are ligated and divided.
- The flap including the skin and subcutaneous tissues containing the neurovascular structures are elevated off the surface of the gastrocnemius muscle in a subfascial plane to the level of the chosen pivot point (**TECH FIG 1B,C**).
- These tissue layers are elevated as a single fasciocutaneous unit and continue distally to isolate the pedicle.
- The pedicle should be at least 2 to 3 cm in width after its dissection from the surrounding tissues.
- The pedicle is dissected free at the pivot point, mobilized, and the flap repositioned to cover the recipient site. It is important that the arc of rotation does not kink or place undue tension on the pedicle.
- Transposition of the flap through either a wide subcutaneous tunnel or an excised skin bridge allows for flap inset.
- The donor site is closed primarily or covered with a split-thickness skin graft.
- At the completion of the case, dressings are applied. The skin graft (if needed) is covered with nonadherent dressings and antibiotic ointment. Nonadherent gauze is used to cover suture lines.
- A well-padded posterior plaster splint with a window for flap monitoring is

applied to cover and protect the surgical site.



TECH FIG 1 • A. Flap dissection with the fasciocutaneous pedicle incised. **B.** Flap after inset (as a second stage following a delay procedure) with split-thickness skin grafting to the donor site. **C.** Reverse sural artery flap after flap dissection and elevation.

■ Delayed Reverse Sural Artery Flap

- The delayed reverse sural artery flap aims to improve longitudinal blood flow along the axial pedicle and decrease flap necrosis and is especially useful in patients with vascular comorbidities.
- The described techniques have included raising the flap in the typical subfascial plane but without incising the proximal portion of the skin island

flap.

- The skin is closed and 1 to 2 weeks later completely elevated and transposed.
- Others have described complete elevation of the flap at the first stage following flap transfer at the second stage.
- These staged techniques establish improved flap circulation prior to the trauma of flap transfer.

■ Supercharged Reverse Sural Artery Flap

- The supercharged reverse sural artery flap aims to improve venous drainage and bypass venous valves that prevent retrograde venous outflow.
- Described techniques include anastomosing the proximal segment of the less saphenous vein to a vein located at the recipient site or exteriorizing the proximal segment to allow for intermittent drainage upon signs of vascular congestion.⁴

PEARLS AND PITFALLS

Imaging

- Consider imaging to evaluate the patency of the peroneal artery in traumatic wounds of the lower extremity.

Technique

- A longer pedicle will allow for tension-free twisting; excessive pedicle rotation at the pivot point can result in a kinked pedicle and flap failure.
- It is preferable to incise the skin bridge between the pivot point and recipient site to prevent retractile tissue from compressing the pedicle.
- The pivot point of the flap can be revised at a later operation (ie, delayed flaps).
- The use of a skin pedicle (vs adipofascial) improves venous return but limits rotation of the flap.
- A pedicle width of at least 4 cm has been recently shown to improve venous drainage and flap viability.³
- The reverse sural flap is often at risk for venous congestion where impaired venous drainage is thought to be a major contributor to flap failure. Widening the pedicle, performing a delayed flap, or

supercharging the flap may overcome this problem.

POSTOPERATIVE CARE

- In the immediate postoperative period, direct pressure on the flap must be avoided and strict elevation of the lower extremity is instructed.
- The splint and dressings are removed at 5 to 7 days to allow for complete evaluation of the flap and assessment of skin graft viability.
- Prolonged use of a splint beyond the first week is discouraged but may be continued based on the underlying orthopedic status of the bone.
- Nonadherent dressings are reapplied and maintained for 2 to 3 weeks.
- The patient is maintained nonweight bearing for 1 to 2 weeks and restricted weight bearing for 4 to 6 weeks until flap viability and healing is established.

OUTCOMES

- The reverse sural artery flap has a low complication profile with 82% of flaps healing without any flap-related complications on meta-analysis.⁴
- Morbidity associated with selection of this flap includes loss of sensation over the donor site and lateral foot, presence of a donor site scar, and excess foot bulk that may preclude proper footwear.

COMPLICATIONS

- Rate of specific complications range in the literature and include partial or complete flap necrosis, venous congestion, infection, hematoma, delayed healing, wound dehiscence, and skin graft loss.
- Patients with vascular comorbidities (ie, diabetes, venous insufficiency, peripheral artery disease), for example, have a five- to sixfold increase in complication rate relative to their healthier counterparts.⁷
- Age over 40 has also been shown to correlate with flap failure.^{4,7}

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16 Ankle Reconstruction With Free Flap

CHAPTER

Sean S. Li, Ahmed Suliman, and Deepak M. Gupta

DEFINITION

- The ankle has limited soft tissue for protection of vital structures, and trauma or tumor extirpation often leads to exposed tendons, bone, vessels, or nerves.
- There are few reliable local flaps that can be used for coverage in this area.
- Impaired blood flow is also typical of the distal lower extremity especially in high-risk patients with comorbidities such as smoking, diabetes, peripheral arterial disease, and venous insufficiency, which may result in ulceration, infection, and necrosis of the soft tissues ultimately requiring free flap coverage.
- Due to the complexity of the ankle, reconstruction ideally should be approached in a multidisciplinary fashion consisting primarily of collaboration between plastic and orthopedic surgeons but also with consideration of consultation of infectious disease and vascular surgery.

ANATOMY

- The ankle is a hinge joint with articulations between the tibia, fibula, and talus.
- Defects in the ankle commonly expose bone or orthopedic hardware, usually at the tibia or the medial and lateral malleoli.
- Five nerves supply the foot and ankle—saphenous, sural, deep peroneal, superficial peroneal, and tibial nerves.
- Knowledge of the ankle's vascular anatomy is essential for limb salvage. The distal lower extremity's arterial supply is primarily supplied by three vessels: posterior tibial (PT), anterior tibial (AT), and peroneal.
- The AT artery branches from the popliteal artery, and its course across the ankle is shown (**FIG 1**, left).

- The PT and peroneal arteries originate from the tibioperoneal trunk, and their courses across the ankle are shown (**FIG 1**, right).

PATHOGENESIS

- Defects of the ankle requiring free flap reconstruction originate from trauma (**FIG 2**), tumor extirpation, and peripheral vascular disease.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Evaluation of the patient begins with history and physical focusing on the following:
 - Eliciting the etiology of the wound and presence of comorbidities including smoking, diabetes, obesity, and peripheral vascular disease
 - Assessing the overall function of the patient and considering the potential outcomes for the patient and bearing in mind the patient's rehabilitative potential, motivation, and compliance. Location, size, depth, character of the wound, and exposed structures
 - Neurological, vascular, and skeletal evaluation of the lower extremities utilizing physical exam, imaging, and Doppler

IMAGING

- Plain films of the defect should be obtained to evaluate for fractures and bony defects with further computed tomography imaging to be considered depending on complexity of the injury.
- If physical or Doppler exam reveals inconclusive vascular status or if peripheral vascular disease is suspected, preoperative arteriography may be obtained.
- Computed tomographic angiography (CTA) (**FIG 3**) can obtain vascular information valuable for flap planning and assessing the recipient site without risk of complications associated with arterial puncture of the groin.
- Selective preoperative CTA may be considered in patients who have lost peripheral pulses, had a neurological deficit secondary to the injury, or of a compound fracture that has undergone reduction and external or internal fixation.²

NON OPERATIVE MANAGEMENT

- Defects in the ankle that typically require free flap reconstruction have exposed hardware, tendon devoid of paratenon, vessels, nerves, open joint(s), or bone denuded of periosteum.

- These defects if managed nonoperatively will not heal and can potentially lead to further tissue loss, osteomyelitis, loss of function, or amputation.

SURGICAL MANAGEMENT

- The goal of reconstruction is to achieve a healed wound to allow function.
- In the ankle, the aims are to allow the patient to wear normal footwear, avoid bulky flaps, and return to weight bearing and ankle motion.
- Selection of flaps is based on morbidity of the donor site and accessibility of local tissue.
- Regardless of the flap selection, the principles for reconstruction include adequate debridement, restoring skeletal support, and anastomosing of the flap vessels outside of the zone of injury.³

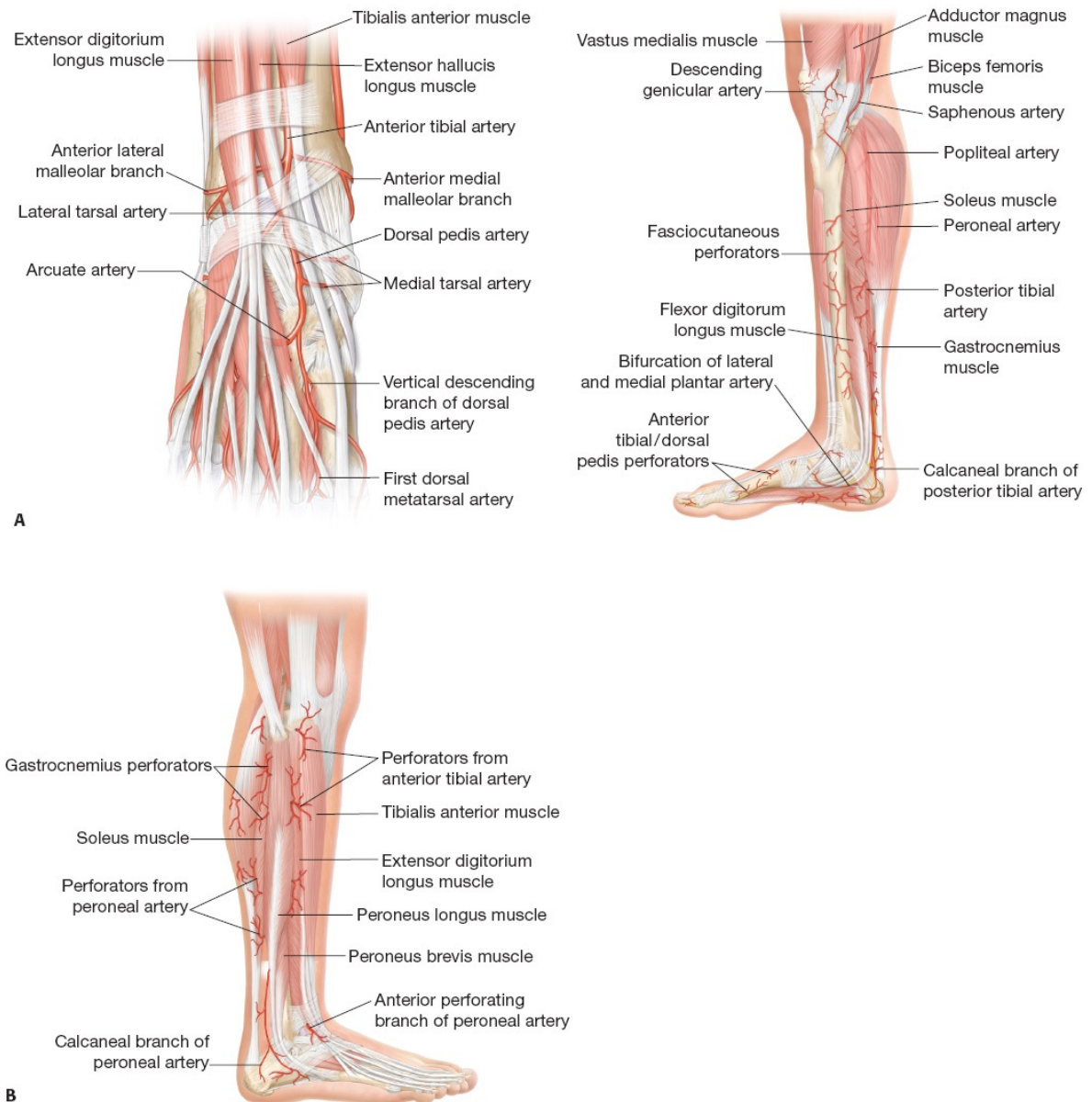


FIG 1 • *Left:* the anterior tibial artery course across the ankle.¹ *Right:* the posterior tibial artery and peroneal artery course across the ankle.¹

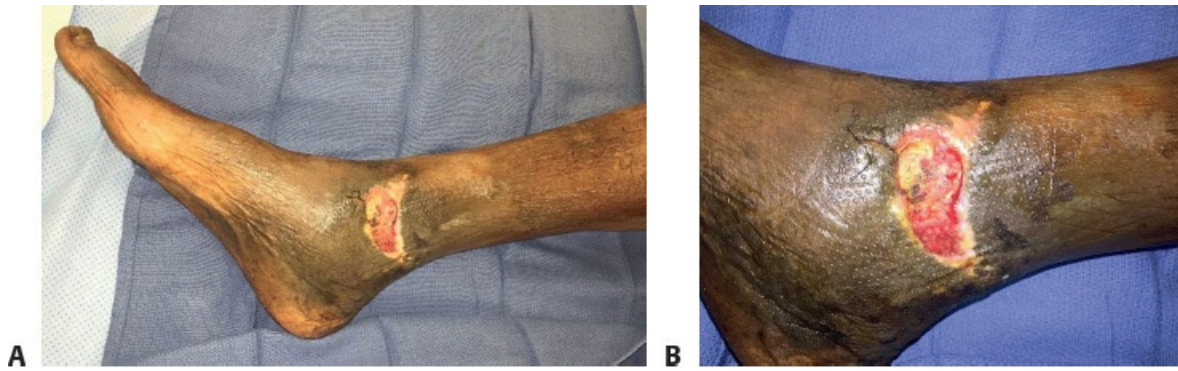


FIG 2 • A. Exposed bone of medial malleolus, denuded of the periosteum, chronic inflammation, and scarring of surrounding soft tissues. **B.** Necrotic bone within medial malleolus wound.

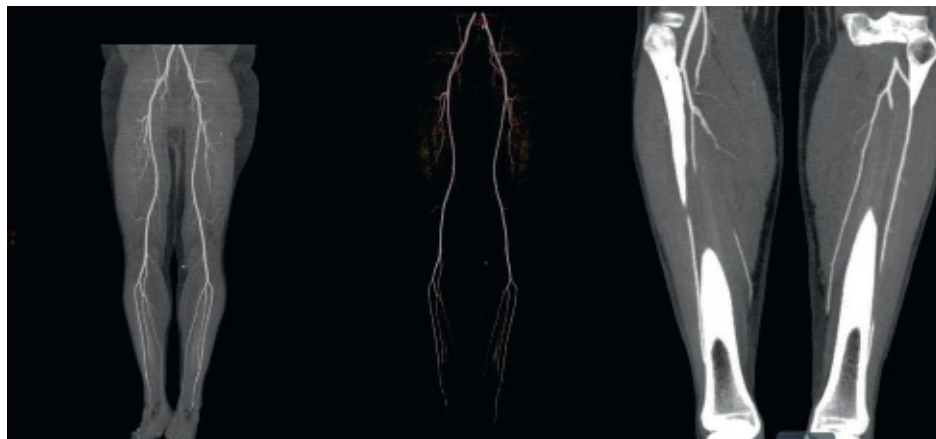


FIG 3 • CTA shows normal angiogram of bilateral thighs and three vessel runoff of the legs.

- After the evaluation of the patient as a whole in regard to their systemic conditions, socioeconomic factors, extent of injury, and rehabilitative potential, a decision for amputation versus salvage can be made.
- The decision for free flap reconstruction goes hand-in-hand with the patient's orthopedic injuries and potential for functional recovery.
- Scores such as the Mangled Extremity Severity Score (MESS), Predictive Salvage Index, and the Limb Salvage Index can be used to assist in the decision-making for amputation versus salvage.⁴
- Absolute indications for amputation include complete disruption of the

posterior tibial nerve in adults and crush injuries with warm ischemia time greater than 6 hours.

- Relative indications of amputation include serious associated polytrauma, severe ipsilateral foot trauma, and prolonged anticipated course to soft tissue coverage and tibial reconstruction.

Preoperative Planning

- If reconstruction is indicated, the following must be considered:
 - Bony stability is first established by utilizing external or internal fixation devices.
 - External devices are usually preferred if there is significant bone loss or bone devascularization.
 - In contaminated wounds, multiple stages of debridement may be required until an adequate wound bed without devitalized or infected tissues is achieved.
 - Vacuum-assisted closure decreases need for dressing changes and can promote healing.⁵
 - Osteomyelitis can follow severe open fractures with massive contamination or devascularized tissue; management includes resection of dead or infected bone, flap coverage with obliteration of dead space, and antibiotic treatment.⁶
 - Timing of reconstruction
 - If the general condition of the patient and the status of the wound are adequate, definitive coverage should not be delayed.
 - Ideally, the wound should be covered in the first week after injury in the acute phase as further delay causes the wound to enter into the subacute and chronic phases when there is a higher rate of infectious complications and flap failure.^{7,8}
 - Zone of injury⁹
 - Many lower extremity wounds result from high-energy trauma that creates a significant “zone of injury.”
 - This zone is highly thrombogenic and extends beyond what is macroscopically evident.
 - Failure to recognize the true extent of the zone is a leading cause of microsurgical anastomotic failure.
 - Within this zone, there is increased friability of the vessels and increased

perivascular scar tissue.

- Selecting a recipient vessel outside of this zone of injury with good vessel wall pliability and high-quality blood flow from the transected end of the vessel is essential for successful microsurgical anastomosis.

■ Coverage after tumor extirpation

- Free flap reconstruction must withstand radiation therapy and/or chemotherapy with the goal of preserving function and achieving an acceptable appearance and function.
- Close cooperation with oncologists and knowledge of prognosis/risk of recurrence/survival, tumor characteristics, behavior, and adjuvant treatment is necessary to plan for the correct type of reconstructive procedure.

■ Exposed hardware

- Traditionally management involved irrigation and debridement, antibiotics, and removal of hardware.
- However, if the hardware is clinically stable, exposure is less than 2 weeks, the infection is controlled, and the hardware is utilized for bony consolidation, then the likelihood of salvage with soft tissue coverage is increased.¹⁰

■ Reconstruction in patients with a two- or one-vessel extremity

- Consider vascular bypass surgery.
- End-to-side anastomosis during free flap reconstruction can preserve the existing main arteries.
- A flow-through free flap can be utilized where an anastomosis is made both proximally and distally to vessels in the leg (**FIG 4**).
- Some have reported that an anastomosis can technically also be made to a distal stump of a recipient vessel to rely on arterial backflow¹¹; however, this should be a last resort and consideration should be made for possible low flow state.

■ Muscle versus fasciocutaneous free flaps

- Controversy exists over selecting the type of flap for lower extremity defects.

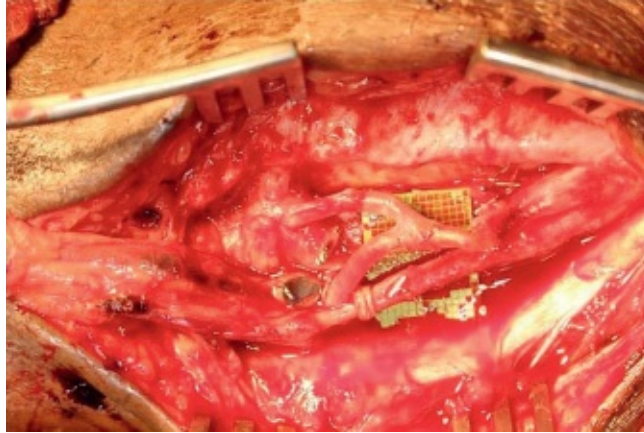


FIG 4 • The flap has been anastomosed end-to-end to the posterior tibial artery. After flowing through, another end-to-end anastomosis allows circulation to the foot through the posterior tibial artery via the rectus femoris branch.

- Reconstruction of wounds with muscle flaps has been shown experimentally to have increased blood flow and antibiotic delivery, increased oxygen tension, increased phagocytic activity, and decreased bacterial counts when compared to fasciocutaneous flaps.¹²
- Arguably muscle flaps are technically less challenging, can fill larger defects, and can be harvested with decreased operative time compared with fasciocutaneous flaps (eg, vastus lateralis flap versus anterolateral thigh flap).¹³
- Donor site morbidity of muscle flaps can be greater than fasciocutaneous flaps depending on the muscle selected.
- Selection of a flap depends on the defect, condition of the wound, goals of reconstruction, and surgeon and patient preference.

Positioning

- Patient positioning in free flap surgery is an important issue that needs to be considered preoperatively. Most cases can be done in supine, supine frog leg, or lateral decubitus position.
- The goal is to avoid unnecessary repositioning of the patient intraoperatively in order to save anesthetic and operative time.
- The location of the defect or choice of recipient vessels may determine the

positioning of the patient and to some extent, the flap choice.

- For example, anterior defects favor the use of the anterolateral thigh flap, gracilis flap, rectus abdominis flap, etc.
- Posterior tibial recipient vessels (medial leg approach) may favor either supine or lateral decubitus position and the concordant flap choices.

Approach

- The approach to flap harvest depends on the flap selection and considering the positioning of the patient as noted above.
- The approach to the ankle wound depends on the location of the defect and selection of recipient vessels.
- The posterior tibial artery is the most commonly used recipient vessel.
 - It is easily accessible by a medial approach and is found between the deep posterior and superficial posterior compartments. In other terms, it is deep to the soleus muscle.
 - The most favorable positioning for the patient is either lateral or with frog leg positioning.
 - It is the preferred vessel for defects of the posterior or medial ankle.
 - It may also be used for lateral defects, and there are several options for pedicle routing, such as under the Achilles tendon.
- The anterior tibial artery is the second most commonly used recipient vessel.
 - It is easily accessible in the anterior compartment.
 - The most favorable positioning of the patient is supine.
 - Some may favor the anterior tibial vessels for defects of the anterior and lateral ankle.
- The peroneal artery is usually the last choice for recipient vessel because of difficulty of accessibility, which may require removal of fibular bone.
- The two major superficial veins of the lower extremity are the great and small saphenous veins, which run superficial to the fascia cruris.
 - The great saphenous vein is accompanied by the saphenous nerve and is located anterior to the medial malleolus.
 - The small saphenous vein arises from the lateral side of the foot, posterior to the lateral malleolus, and passes along the border of the Achilles tendon.
 - Any superficial vein with adequate caliber can be used as a recipient vein in addition to the venae comitantes of the major arteries.
 - Anastomosis of two recipient veins for each artery is optional. If undertaken,

it is preferable to anastomose to separate drainage systems (eg, one deep vein and one superficial vein).

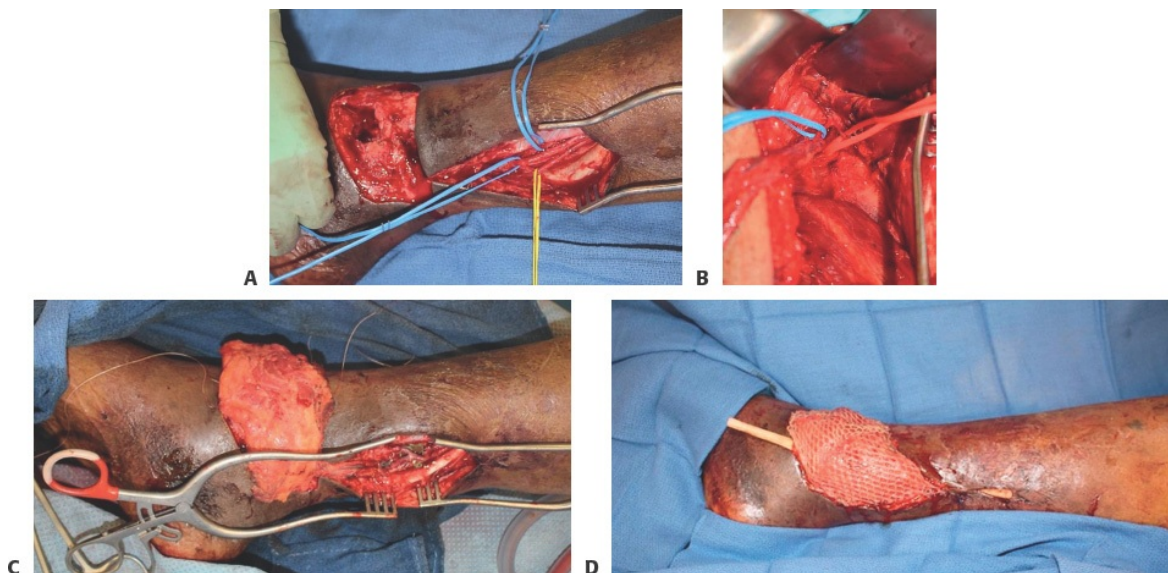
TECHNIQUES

■ Vastus Lateralis

- Take into account all of the preoperative factors as noted in the preoperative planning section.
- Assess the defect.
- Approach your recipient vessel as mentioned in the various approaches above, and dissect back to healthy vessel outside of the zone of injury (**TECH FIG 1A**). Use of tourniquet may be considered.
- Elevate the flap as previously described.¹³
 - With the patient positioned supine, a line is drawn between the anterior superior iliac spine and the superolateral corner of the patella on the donor thigh.
 - An incision is then made along the middle third of the line. Carry the incision through the muscle fascia until the interval between the rectus femoris and the vastus lateralis is identified. Extend the incision as needed as you go along. Take care to identify any branches of the lateral cutaneous femoral nerve so as not to injure them.
 - Separate the rectus femoris and vastus lateralis and identify and preserve the pedicle (the descending branch of the lateral circumflex femoral artery), which is generally visible along the medial border of the vastus lateralis.
 - Perform a lateral subfascial dissection superficial to the muscle until the width of muscle flap needed has been visualized. Continue this dissection proximal and distal along the superficial surface of the muscle until the dimensions of muscle flap needed have been achieved.
 - Identify the motor nerve branches, which typically enter the midportion of the muscle; only sacrifice branches directly involved in the transferred portion of muscle.
 - Dissect the pedicle from distal to proximal. Continue the dissection until adequate pedicle length and vessel caliber has been obtained. One may encounter vascular branches to the vastus intermedius or rectus femoris,

which can typically be sacrificed. Nerve branches should be spared.

- Divide the muscle along the required dimensions. Ligate and divide the pedicle when the recipient area is ready.
- Perform your anastomosis (**TECH FIG 1B**) and inset the flap (**TECH FIG 1C**). Consider use of penrose drains around the microvascular anastomoses. Some additional de-epithelialization or resection of leg skin may be required to accommodate flap and/or pedicle lie.
- Harvest split-thickness skin graft for the flap. Meshing of the skin graft may be considered (**TECH FIG 1D**).
- The donor site can usually be closed primarily over closed suction drains.



TECH FIG 1 • A. The posterior tibial artery and two venae comitantes have been dissected proximal to the zone of injury. **B.** The descending branch of the lateral circumflex femoral artery has been dissected (*blue loop*) to its origin along with the rectus femoris branch (*red loop*). **C.** The flap has been anastomosed in flow through configuration outside the zone of injury. The inset is partially completed with Vicryl sutures. Intervening leg skin was subsequently de-epithelialized to accommodate flap and pedicle lie. **D.** The flap has been inset and covered with a meshed

split-thickness skin graft.

■ Anterolateral Thigh (ALT)

- Take into account all of the preoperative factors as noted in the preoperative planning section.
- Assess the defect.
- Approach your recipient vessel as mentioned in the various approaches above, and dissect back to healthy vessel outside of the zone of injury. Use of tourniquet may be considered.
- Elevate the flap as previously described.¹⁴
 - With the patient positioned supine, a line is drawn between the anterior superior iliac spine and the superolateral corner of the patella on the donor thigh.
 - Draw a 3-cm circle centered at the midpoint of this line. Map the cutaneous perforators with a portable, handheld pencil Doppler probe. The majority of perforators will be found in the inferolateral quadrant of this circle.
 - The flap is centered over the location of these vessels, and its long axis should be parallel to that of the thigh. The maximum width of the flap is judged with a pinch test.
 - Incise the medial border of the proposed flap and continue dissection deep and through the muscle fascia until you have identified fibers of rectus femoris.
 - Continue the subfascial dissection from medial to lateral. Take care to identify the interval between vastus lateralis and rectus femoris and not cross it. At this point, the dissection should be slowed so that one can identify and preserve any septocutaneous or musculocutaneous perforators corresponding to the cutaneous Doppler signals.
 - Once the dominant perforator(s) have been identified, these are carefully dissected distal to proximal, to either free them from the vastus lateralis muscle or include them with a cuff of muscle.
 - Incise the skin paddle along its lateral aspect. Perform a subfascial dissection to the dissected perforators.
 - Depending on the vascular configuration, vastus lateralis muscle can also be dissected on a separate branch if a chimeric flap is needed.
 - Dissect the pedicle from distal to proximal. Continue the dissection until

adequate pedicle length and vessel caliber has been obtained. One may encounter vascular branches to the vastus intermedius or rectus femoris, which can typically be sacrificed. Nerve branches should be spared.

- Ligate and divide the pedicle when the recipient area is ready.
- Perform your anastomosis and inset the flap.
- The anterolateral thigh (ALT) donor site can usually be undermined and closed primarily over closed suction drains. The maximum width of the flap is judged with a pinch test. Donor sites that cannot be primarily closed may be skin grafted. Others have reported closing large donor sites using adjacent tissue transfer techniques.

■ Gracilis

- Take into account all of the preoperative factors as noted in the preoperative planning section.
- Assess the defect.
- Approach your recipient vessel as mentioned in the various approaches above and dissect back to healthy vessel outside of the zone of injury. Use of tourniquet may be considered.
- Elevate the flap as previously described.¹⁵
 - With patient supine, position the lower limb in external hip rotation, and knee and hip in flexion as needed. Palpate the adductor longus tendon in the medial thigh.
 - The gracilis is posterior to the adductor longus. An incision is marked two to three finger breadths posterior to the adductor longus tendon. Keep in mind that the neurovascular pedicle enters the muscle approximately 10 cm below its bony origin.
 - An optional distal incision at the knee can be made to transect the distal tendon if the entire length of the flap is needed.
 - Carry the proximal incision down through the fat and muscular fascia to the muscle. Take care to identify the greater saphenous vein during this step and protect it by retracting if necessary.
 - Dissect superficial to the gracilis muscle to expose its surface.
 - Identify the interval between gracilis and adductor longus. Enter the interval carefully to identify the pedicle—the medial circumflex femoral artery and veins.

- Dissect the pedicle from distal to proximal. Continue the dissection until adequate pedicle length and vessel caliber has been obtained. One may encounter vascular branches to the adductor longus, which can be sacrificed. Nerve branches should be spared.
- Divide the muscle along the required dimensions. Ligate and divide the pedicle when the recipient area is ready.
- Perform your anastomosis and inset the flap.
- Harvest split-thickness skin graft for the flap.
- The donor site can usually be closed primarily over closed suction drains.

■ Rectus Abdominis

- Take into account all of the preoperative factors as noted in the preoperative planning section.
- Assess the defect.
- Approach your recipient vessel as mentioned in the various approaches above, and dissect back to healthy vessel outside of the zone of injury.
- Elevate the flap as previously described.¹⁶
 - With the patient supine, the muscle can be exposed through a midline vertical, paramedian vertical, or lower transverse incision with the total length of the incision depending on the amount of muscle harvested.
 - Dissect down to the level of the rectus sheath, ligating perforators as they are found.
 - Divide the rectus sheath longitudinally and elevate the fascia medially and laterally taking care to tease off the inscriptions without damaging the muscle fibers.
 - Identify the deep inferior epigastric artery and its accompanying veins at the lateral edge of the inferior muscle within the fatty tissue. Dissect the pedicle from distal to proximal. Continue the dissection until adequate pedicle length and vessel caliber has been obtained.
 - Divide the muscle along the required dimensions. Ligate and divide the pedicle when the recipient area is ready.
- Perform your anastomosis, and inset the flap.
- Harvest split-thickness skin graft for the flap.
- Close the fascia with nonabsorbable suture. Close the donor site wound primarily. Use drains as needed.

■ Latissimus Dorsi

- Take into account all of the preoperative factors as noted in the preoperative planning section.
 - Assess the defect.
 - Approach your recipient vessel as mentioned in the various approaches above, and dissect back to healthy vessel outside of the zone of injury.
 - Elevate the flap as previously described.¹⁷
 - The flap harvest is usually done in lateral decubitus position with appropriate padding. The ipsilateral arm may also be prepped into the operative field depending on surgeon preference. The current authors prefer to use a padded and draped Mayo stand to position the arm.
 - The latissimus is marked by finding the surrounding landmarks—scapular tip superiorly, iliac crest inferiorly, spinous processes medially.
 - Choice of skin incision also depends on surgeon preference and size of flap needed. Incisions made include transverse (to hide within a bra line), oblique (extending from posterior axillary fold over the middle of the muscle belly), or vertical (uncommon).
 - Expose the latissimus by dissecting the skin and subcutaneous tissues off the muscle all the way to all its edges. Dissect the submuscular plane taking care not to elevate the serratus muscle or fat pad. It is easiest to begin this dissection anteriorly or superiorly.
 - Release the insertions near the midline of the back and then inferiorly. Proceed with the submuscular dissection from distal to proximal toward the axilla. The pedicle can be visualized along the deep surface of the muscle as one approaches the axilla.
 - Identify the branch to the serratus muscle. Ligate it if necessary. The circumflex scapular branch may also be ligated if additional pedicle length or larger caliber is needed.
 - Trim the muscle along the required dimensions. Ligate and divide the pedicle (including the thoracodorsal nerve) when the recipient area is ready.
 - Reposition the patient if necessary.
 - Perform your anastomosis and inset the flap.
 - Harvest split-thickness skin graft for the flap.
 - Close the donor site over suction drains.
-

PEARLS AND PITFALLS

Amputation vs limb salvage	■ Consider limb salvage on a case-to-case basis. If a long, protracted course for limb salvage is anticipated, consider the benefit of early mobilization and physical therapy after amputation.
Zone of injury	■ Microsurgical anastomosis outside the zone of injury is critical to success.
Timing of reconstruction	■ If possible, reconstruction within 7 days in the acute period leads to higher incidence of flap survival.
Sequence of salvage	■ Bony stability, thorough debridement to achieve favorable wound bed, flap reconstruction.
Flap selection	■ Select a flap with sufficient pedicle length to anastomose outside the zone of injury, does not require intraoperative repositioning, and has acceptable donor site morbidity.

POSTOPERATIVE CARE

- Immobilization of the extremity and bed rest is recommended for 5 to 14 days postoperatively.
- Dangling of the leg is then initiated, with increasing frequency and length continuously while the flap is carefully watched for swelling, congestion, or increasing pain.
- Compression stockings or wraps are applied after 4 weeks and continued for approximately 6 months.

OUTCOMES

- The goal is a healed wound, return to activity, and acceptable contour (**FIG 5**).
- Functional outcomes largely depend on the extent of the patient's injuries.
- Prognosis for bony union and adequate neurovascular recovery must be considered.
- Patient compliance is important for best long-term results.
- Patients at high risk for amputation can be advised that reconstruction typically results in 2-year outcomes equivalent to those of amputation.¹⁸



FIG 5 • The goal is a healed wound, return to activity, and acceptable contour.

COMPLICATIONS

- Osteomyelitis
- Chronic pain
- Nonunion
- Flap failure
- Contour abnormality
- Donor site morbidity
- Amputation

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Vascular Reconstruction of Lower Extremity, Foot, and Ankle

17

CHAPTER

Michael Sgroi and Jason T. Lee

DEFINITIONS

- Peripheral arterial disease (PAD) affects 8 to 12 million people worldwide.
- Up to 40% of these patients suffer from poor quality of life due to impaired walking ability, nonhealing wounds, and need for amputation.
- Risk factors include male gender, age, hypertension, diabetes, hyperlipidemia, renovascular disease, and smoking.
- Sixty to ninety percent of patients with peripheral arterial disease also have coronary artery disease, and up to 25% have carotid artery stenosis.¹
- The overall 5-year mortality rate among all patients with PAD is 15% to 30%, and the risk of nonfatal myocardial infarction or stroke is 20% at 5 years.²
- Patients with critical limb ischemia have an annual cardiovascular mortality of 25% and an annual amputation rate of 25%.³

ANATOMY

- Femoral artery usually lies one-third the distance from the pubic tubercle and two-thirds from the anterior superior iliac spine.
- Lateral dissection at the femoral artery should be minimized so not to disrupt the femoral nerve.
- Medial dissection at the femoral artery should be minimized so not to damage the femoral vein.
- Exposure of the common femoral artery should include the distal external iliac artery under the inguinal ligament.
- Care should be taken to identify all distal branches (superficial femoral artery (SFA) and profunda femoris).

- Anterior tibial artery runs in the anterior compartment of the leg.
- Anterior tibial artery is between the anterior tibialis and extensor digitorum longus muscles.
- Anterior tibial artery becomes the dorsalis pedis when it crosses the ankle joint.
- Dorsalis pedis can be palpated just lateral to extensor hallucis longus on the dorsum of the foot.
- Posterior tibial artery carries blood through the posterior compartment of the leg and plantar surface of the foot.
- Posterior tibial artery branches into the medial and lateral plantar arteries in the foot.
- Posterior tibial artery can be palpated midway between the medial malleolus and the Achilles tendon.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Ischemic claudication (ie, arterial perfusion inadequate to meet the demands of the muscle) leads to cramping, aching pain.
- Claudication will usually occur one vascular level below the stenosis or occlusion.
- Ischemic rest pain (ie, chronic ischemic neuropathy that is positional) is often described as diffuse aching or burning while legs are up in recumbent position, which is improved after legs have been put in the dependent position.
- Vascular and neurogenic claudication must first be differentiated.
- Infrapopliteal disease is most often going to lead to ankle and foot disease.
- Patients with tibial disease are more likely to experience rest pain or have nonhealing wounds rather than claudication symptoms.
- Ulcers to the medial side of the ankle are more likely due to venous disease.
- Ulcers to the lateral foot and ankle are more likely to be due to arterial disease.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- An ankle-brachial index (ABI) may be obtained by dividing the systolic blood pressure of the lower leg/ankle by the systolic blood pressure of the upper arm (brachial artery) (**FIG 1**).
- An $ABI \leq 0.9$ is considered abnormal.
- ABIs will most commonly be indeterminate because the tibial vessels

become noncompressible and waveforms will be monophasic.

- Toe-brachial pressures (TBIs) will be more diagnostic in patients with tibial disease.
 - A TBI < 0.4 will indicate a wound is unlikely to heal without intervention.
- Arteriography should be performed to evaluate the tibial vessels prior to any distal lower extremity or foot reconstruction.
 - Patients with diabetes and end-stage renal disease most frequently are affected by small vessel disease, including tibial vessels and the microvascular circulation.

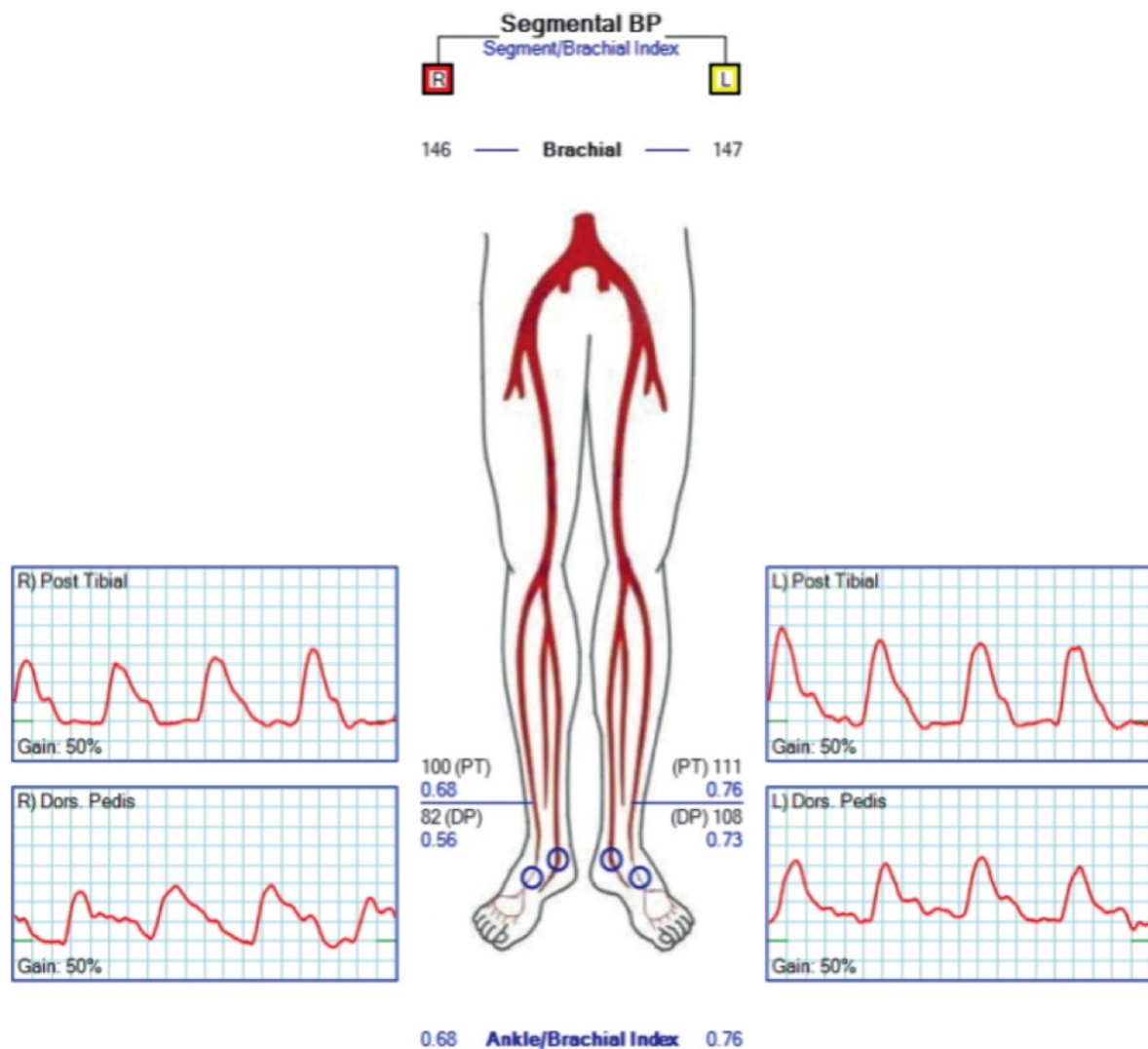


FIG 1 • Example of an abnormal ankle-brachial index study.

SURGICAL MANAGEMENT

- A patient must first have an appropriate inflow and outflow vessel identified for reconstruction.
- Autologous vein has superior rates of patency compared to prosthetic grafts.
- Vein mapping should be performed preoperatively, assuring at least a 3-mm conduit.
- Shorter bypass grafts have better patency.
- The most distal patent native vessel should be used as the proximal origin of the bypass graft.

- For example, if the patient has a patent popliteal artery, this should be chosen over a femoral artery.
- Primary patency (the patency of a graft without any adjunctive therapies to keep it open), secondary patency (the patency rate once the graft has been completely abandoned and no further interventions are performed to keep it open), and limb salvage rates are 56.8%, 62.7%, and 78.2%, respectively, at 5 years for pedal revascularizations.

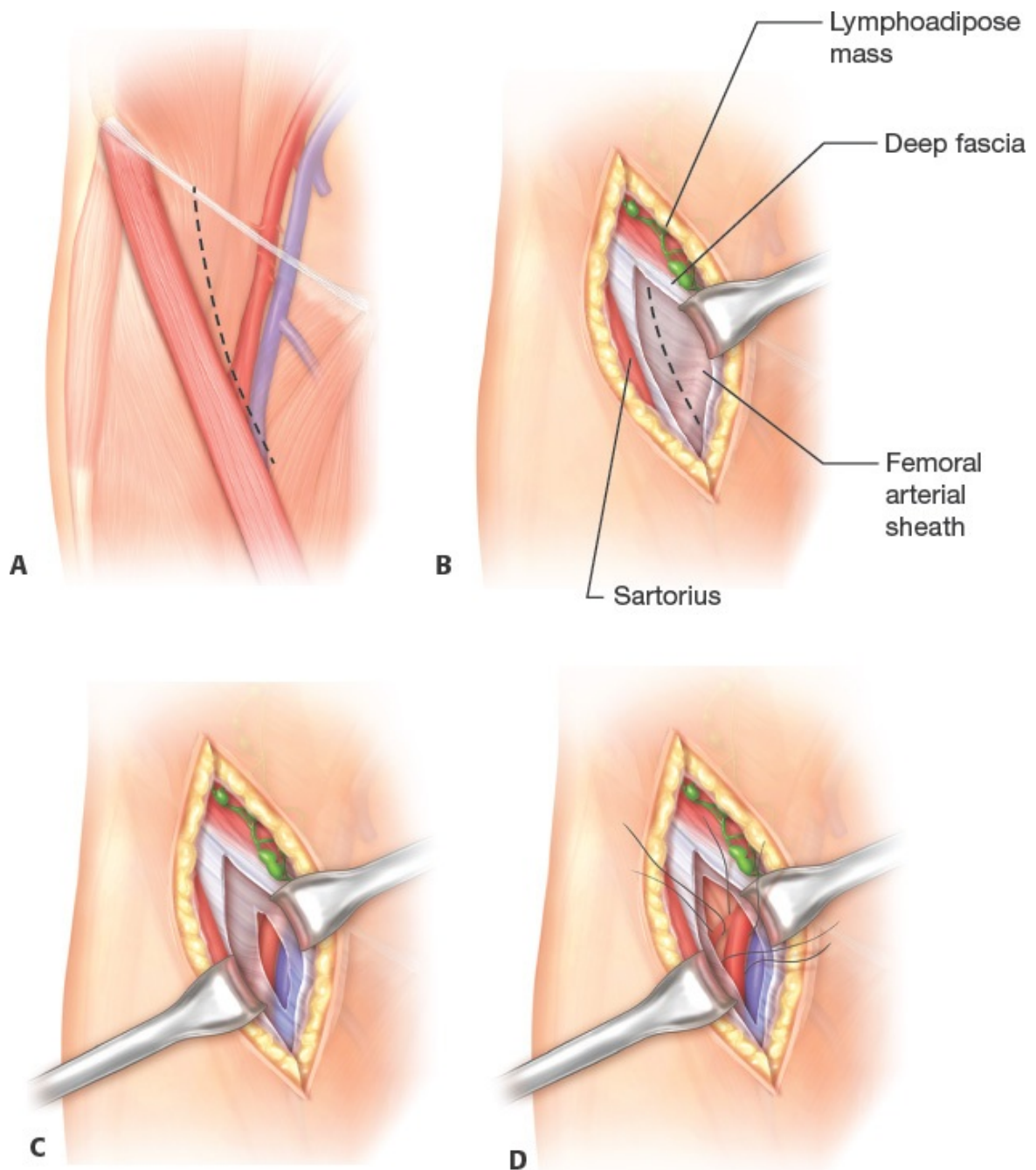
TECHNIQUES

■ Femoropopliteal Bypass

- Identification of the femoral artery should be within the femoral triangle.
 - Femoral triangle consists of the inguinal ligament superiorly, sartorius muscle laterally, and the adductor magnus medially.
 - The floor of the femoral triangle consists of the iliacus, psoas major, pectineus, and adductor magnus.
 - The femoral artery is a continuation of the external iliac artery below the inguinal ligament.
 - Common femoral artery divides into the profunda femoral artery and the superficial femoral artery.
 - The profunda femoral gives branches to the thigh and collaterals to the lower extremity.
 - The superficial femoral artery is a continuation of the common femoral artery and progresses to the popliteal artery.
- Longitudinal incision is made over the pulse in the groin, which is usually located below the inguinal ligament approximately one-third lateral to the pubic tubercle (**TECH FIG 1A**).
- Dissection is taken down through the fascia lata, keeping medial to the sartorius muscle (**TECH FIG 1B**).
- The superior limit of the groin dissection is the inguinal ligament. Retraction of the ligament exposes the external iliac artery.
- The inguinal ligament can be further retracted by laterally dissecting along the ligament releasing all attachments.
- Once under the ligament, the inferior epigastric vein should be identified and

ligated.

- Profunda femoral artery divides into the adductor fascia. Dissection along the anterior surface can be performed, identifying each of its branches (**TECH FIG 1C,D**).
- Care should be taken not to dissect into the deep lateral circumflex femoral vein, which lies across the proximal profunda.
- A lateral approach at the profunda can also be performed along the lateral surface of the sartorius.
 - The sartorius is then retracted medially while the rectus femoris and vastus medialis are retracted laterally.

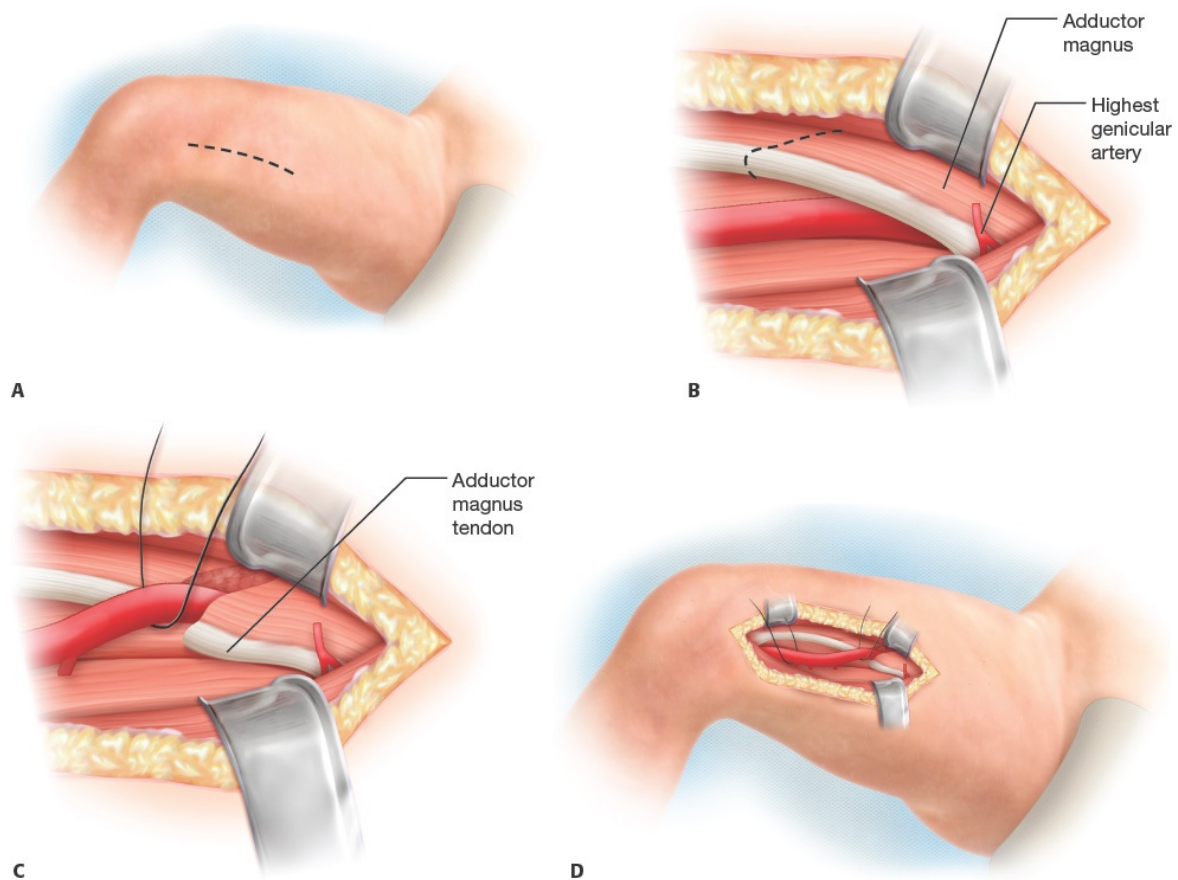


TECH FIG 1 • **A.** Longitudinal exposure of the common femoral artery. **B.** A longitudinal incision is medial to the sartorius muscle allowing exposure. **C.** The femoral artery sits in the middle of the femoral sheath between the nerve and vein. **D.** Proper exposure includes vascular control of the common femoral, superficial femoral, and profunda femoral

artery.

Above-Knee Popliteal Exposure

- Exposure of the above-knee popliteal artery starts with a longitudinal incision on the distal medial thigh in the intermuscular groove between the sartorius muscle and the vastus medialis (**TECH FIG 2**).
- Care should be taken not to damage the greater saphenous vein during this incision.
- Sartorius is then retracted posteriorly, while the adductor magnus is retracted anteriorly.
- Retraction of sartorius and adductor magnus gives exposure to the adductor canal.
- Dissection is then performed through the popliteal fat pad allowing exposure of the popliteal artery and vein.

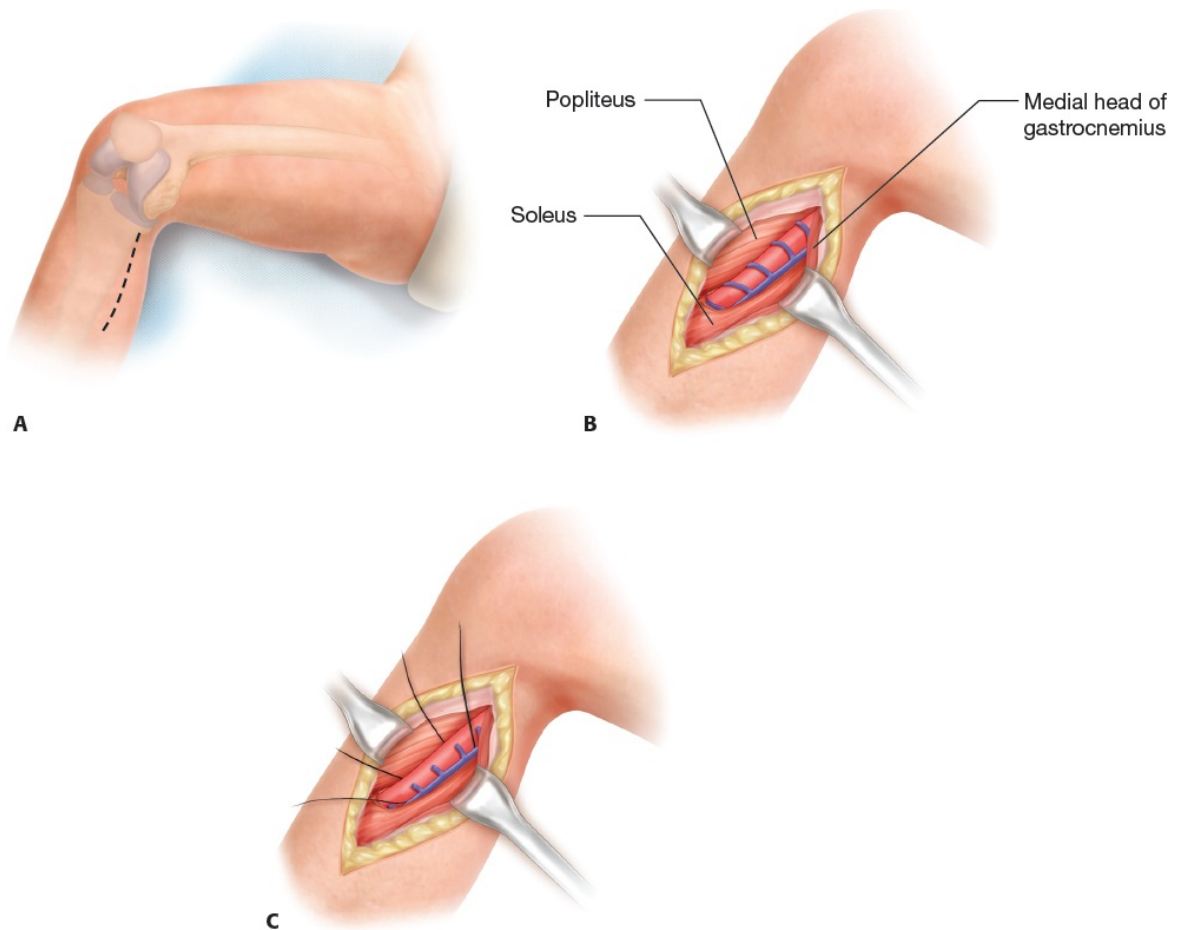


TECH FIG 2 • A. Exposure of the above-knee

femoropopliteal artery. **B.** Retraction of the sartorius muscle posterior and adductor magnus anterior allows for exposure of adductor canal. **C.** The geniculate collaterals should be saved if possible. However, they can be ligated for higher exposure if necessary. **D.** Adductor magnus can also be cut if needed for more proximal control.

Below-Knee Popliteal Exposure

- A longitudinal incision should be made on the medial calf from the tibial condyle distally (**TECH FIG 3A**).
- Keeping the medial head of the gastrocnemius posterior (**TECH FIG 3B**), the soleus muscle arch will be identified. Superior to the soleus is the popliteal fat pad where the popliteal neurovascular bundle is located.
- The paired popliteal veins will be surrounding the artery and will need to be mobilized (**TECH FIG 3C**).
- The soleus muscle can be dissected away from the tibia if more distal control is needed.
- Autogenous vein grafts provide the best patency for use in arterial bypass for all infrainguinal reconstructions, regardless of the distal bypass target.
 - Reverse and in situ vein have equal effectiveness.⁴
 - If an above-knee bypass is performed, PTFE has equivalent 2- to 3-year patency rates to autogenous vein.⁵



TECH FIG 3 • A. The below-knee popliteal artery is exposed from a medial incision starting at the tibial condyle and continuing distally. **B.** The medial head of the gastrocnemius muscle is then retracted posteriorly and popliteus muscle anteriorly. **C.** There are multiple crossing veins around the popliteal artery that will need to be controlled during popliteal artery exposure.

■ Vascular Reconstruction for Tibial-Peroneal Arterial Occlusive Disease

- Indications include rest pain, ischemic ulcerations, gangrene of the foot, and highly selected patients with short-distance claudication.
- Selection of conduit is most important. Autogenous vein should be used if possible. In general, adequate vein is larger than 3 mm.

- Ipsilateral vein is preferred over contralateral if possible.
- Inflow should be chosen based on preoperative imaging as well as available conduit length.
- Inflow vessels include common femoral, profunda femoris, superficial femoral artery, and above-knee popliteal artery.
- Outflow vessel chosen for bypass should be the one with in-line flow to the pedal vessels. However, peroneal can also be used despite lack of direct communication.

Anterior Tibial Artery Exposure

- Longitudinal incision lateral aspect of leg between the anterior tibialis and the extensor digitorum longus muscles.
- Dissection should be continued on the lateral aspect of the anterior tibialis muscle rotating it anterior and medial. The neurovascular bundle will be identified posterior to this muscle.
- Tunneling can be performed from a medial or a lateral approach.
- For a medial approach, a medial incision is made to expose the popliteal fossa. This is followed by an incision of the interosseous membrane to cross the conduit into appropriate position.
- If a lateral approach is used, then the graft is initially brought subsartorius from the femoral position and lateral through the tensor fascia lata. The tensor fascia will need to be incised to allow the conduit to come through. The graft will then lie in the subcutaneous tissue of the lateral thigh and calf.⁶
- Care should be taken with the lateral tunneling away from the fibular head to avoid injury to the peroneal nerve.

Posterior Tibial Artery Exposure

- Longitudinal incision is made 2 cm below the medial edge of the tibia.
- The gastrocnemius muscle is kept posterior until the soleus muscle is identified.
- Careful dissection is then performed with electrocautery dissecting the soleus off of the posterior tibia aponeurosis.
- Crossing tibial veins will need to be identified and ligated to allow the posterior tibial artery to be exposed.
- Tunneling for a posterior tibial bypass will be in the same anatomic position as a femoral popliteal artery bypass but extended down to the location of the

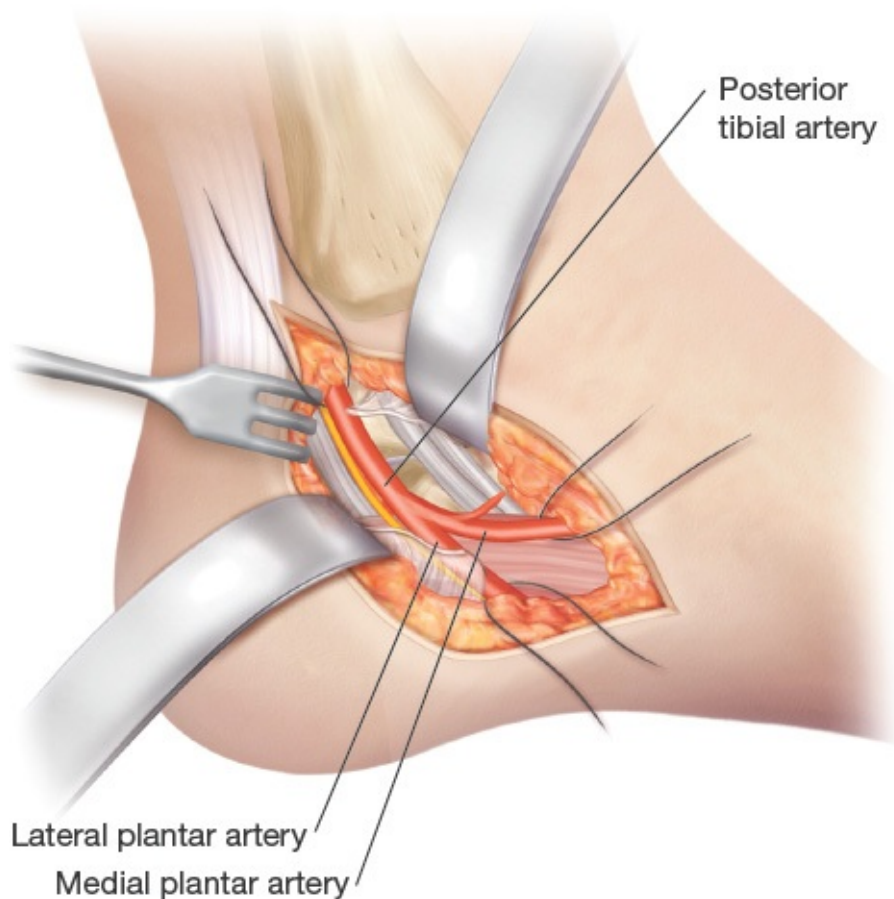
distal exposure.

Peroneal Artery Exposure

- Longitudinal incision on the medial leg 2 cm below the medial edge of the tibia
- The gastrocnemius and soleus are dissected posteriorly to expose the flexor digitorum longus muscle, which lies on the posterior aspect of the tibia.
- The fascia of the flexor digitorum longus is opened to enter the deep compartment. Dissection is carried until the peroneal vascular bundle is identified on the anterior aspect of the fibula on the flexor hallucis longus muscle.

Pedal Artery Exposure

- Exposure of the pedal vessels can be accurately identified with the assistance of ultrasound or handheld Doppler prior to making an incision.
- The dorsalis pedis artery will be on the dorsum of the foot just lateral to the extensor hallucis longus tendon.
- A longitudinal incision is made directly over the artery. Dissection will go through the dorsal sheath, and retracting the tendon medially should expose the dorsalis pedis.
- For the posterior tibial artery distally, a longitudinal incision is made half way between the medial malleolus and the Achilles tendon (**TECH FIG 4**).



TECH FIG 4 • Plantar exposure of the posterior tibial artery. Incision is made posterior to the medial malleolus. As the artery starts to cross the arch of the foot, it will branch into the medial and lateral plantar arteries.

PEARLS AND PITFALLS

Conduit condition

- If performing a vein bypass, always ensure careful handling of the venous conduit. If there is an area that appears sclerotic or injured, it is better to remove that segment.

Conduit length

- Obtain exposure of the proximal and distal location of your bypass prior to performing the vein harvest, as you want to make sure you have adequate length vein as well as an appropriate location for your

	proximal and distal anastomosis.
	■ Measure the distance of the bypass with the knee extended to ensure adequate conduit length.
Tourniquet use	■ A tourniquet can be used for arterial control of the distal anastomosis and is particularly useful if the patient significantly calcified vessels.
Imaging	■ A completion arteriogram is helpful if there is any question about the patient's outflow.

POSTOPERATIVE CARE

- Average length of stay for a bypass patient is 4 to 6 days.
- Leg elevation postoperatively is important as the patient will have swelling to the limb from both reperfusion and resection of the superficial venous system.
- All patients should be started on a daily 81 mg aspirin following surgery. Patients should also be restarted on their statin and beta-blocker if on them preoperatively.^{1,7}
- Dual therapy with antiplatelet and anticoagulation has demonstrated improved patency, particularly in patients who have a prosthetic conduit. However, these patients are also at increased risk of bleeding.
- Repeat ABIs with graft duplex can be performed at the first postoperative clinic visit in 2 to 4 weeks.

OUTCOMES

- Open surgical bypass is accepted as the most durable treatment for critical limb ischemia.
- Five-year overall patency rates range from 60% to 80% and limb salvage rate of 80% to 90% in patients with critical limb ischemia.
- Venous conduits have better patency than using prosthetic graft below the knee.
- Five-year expected patency rates for infrainguinal bypass a vein conduit^{4,8}
 - Femoral to above-knee popliteal—75%
 - Femoral to below-knee popliteal—70%
 - Femoral to tibial artery—65%
- Five-year expected patency rates for infrainguinal bypass with prosthetic graft^{5,8}
 - Femoral to above-knee popliteal—50%
 - Femoral to below-knee popliteal—35%

- Femoral to tibial artery—20%

COMPLICATIONS

- Patients with vascular disease often have other comorbid conditions. Systemic complications such as MI, stroke, renal failure, and pneumonia are all potential risks.
- Wound complications can occur with either incision but are particularly higher at the groin incision. Femoral incision complications occur in about 15% to 30% of patients, with underlying graft infection ranging from 1% to 7% depending on if autogenous vein or prosthetic graft were used.
- Early graft failures could be multifactorial.⁹
 - Technical failure due to imperfect anastomosis, or kinking of the conduit due to compression or graft redundancy.
 - Patients may have an undiagnosed hypercoagulable state.
 - Poor inflow. If depressed velocities with poor waveforms are seen in the conduit, further evaluation prior to the graft failing should be performed.

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18 Management of Diabetic Foot Ulcers

CHAPTER

Rahim Nazerali

DEFINITION

- Foot ulcers are the most common complication affecting patients with diabetes mellitus.¹
- A result of lower extremity neuropathic disease, trauma, and deformity.
 - May be compounded by ischemia, callus formation, and edema.

ANATOMY

- Resembles laceration, puncture, or blister with round or oblong shape.
- May be necrotic, pink, or pale with well-defined smooth edges.
- Peri wound often presents with callus.

PATHOGENESIS

- Origin and development have several components.
- Thirty-two unique casual pathways for developing foot ulcers.²
 - Peripheral neuropathy, structural foot problems, and minor trauma are present in the majority (63%).
 - Other less prevalent causes include edema, callus, and peripheral ischemia.
- Major common pathways involve pressure/trauma, ischemia/hypoxia, infection, cellular failure, and chronic inflammation.

NATURAL HISTORY

- 12.5% individuals with diabetes will develop lower extremity ulceration.³

PATIENT HISTORY AND PHYSICAL FINDINGS

- Basic history, including state of health, record of diabetic complications, shoe problems, pain in extremity, medications, glycated hemoglobin level.

- Risk factor assessment involving absence of protective sensation due to peripheral neuropathy, vascular insufficiency, structural deformities/callus formation, autonomic neuropathy, limited joint mobility, long duration of diabetes, long history of smoking, poor glucose control, obesity, impaired vision, past history, increased age, male gender, poor footwear.
- The Wagner scale for foot wound classification based on depth and presence of osteomyelitis and gangrene is the most widely accepted classification scheme⁴ (**FIG 1**) but does not address the critically important parameters of ischemia and infection.
 - Grade 0: intact skin
 - Grade 1: superficial without penetration of deep layers
 - Grade 2: deeper reaching tendon, bone, or joint capsule
 - Grade 3: deeper with abscess, osteomyelitis, or tendonitis extending to those structures
 - Grade 4: gangrene of some portion of the toe, toes, and/or forefoot
 - Grade 5: gangrene involving the whole foot or enough of the foot that no local procedures are possible
- Physical exam:
 - Adequate description of ulcer characteristics such as size, depth, appearance, location, etc.
 - Examine with blunt sterile probe to detect sinus tract, undermining and dissection into tendon, bone or joints



FIG 1 • Wagner scale for foot wound classification showing the natural history of dysvascular foot breakdown.

- Identify limb-threatening infection defined by cellulitis extending beyond 2 cm from perimeter, abscesses, or osteomyelitis
- Protective sensation testing with Semmes-Weinstein 5.07 (10-g) monofilament test or vibration tuning fork test (128 cycles per second) with on-off method
- Evaluate for musculoskeletal abnormalities that lead to focal areas of high pressure
- Vascular status evaluation via segmental pressures, toe pressures, or transcutaneous oxygen readings
- Evaluate skin and nail condition of the affected extremity
- Footwear evaluation including bulges on outside of shoes, wear patterns on soles, wearing down heels, worn lining, shoe cushion, and foreign object in shoe

IMAGING

- Duplex studies: ABI/TBI (ABI can be falsely elevated due to atherosclerotic hardened vessels.)
- X-ray, MRI, or bone biopsy to rule out osteomyelitis
- Lower extremity angiography

DIFFERENTIAL DIAGNOSIS

- Peripheral neuropathy

NONOPERATIVE MANAGEMENT

- Early prevention through careful and frequent inspection is important.
- Key therapeutic objectives include addressing global factors (glycemic control and nutritional support) and local factors.
- Aggressive treatment of infection through targeted antibiotic treatment from tissue cultures.
- Establishing if ischemia is present and revascularization is required.
- Topical wound care by optimizing wound bed moisture balance and exudate/odor control.
- Off-loading and redistribution of pressure involving bed rest, wheelchairs,

crutches, surgical shoes, custom sandals, healing shoes, cast shoes, and foam dressings.

- Pressure relief of plantar ulcers utilizing orthotics and total contact casting, which is considered the “standard” treatment for off-loading
- Adjunctive hyperbaric oxygen treatment can be an important aspect of the treatment armamentarium. Cochrane Review supported a 95% reduction in major amputations when adjunctive HBOT (Hyperbaric Oxygen Therapy) was used to treat chronic diabetic foot ulcers.⁵
- Patient has type 1 or type 2 diabetes and has a lower extremity wound.
- Wound is classified as Wagner grade 3 or higher.
- Failed adequate course of standard wound therapy.

SURGICAL MANAGEMENT

- Ensure appropriate blood flow prior to surgical management.
 - Stenting vs bypass coordinated with vascular surgery

TECHNIQUES

■ **Aggressive Wound Debridement**

- Initial surgical debridement
 - Removal of free-living bacteria and biofilms
 - Stimulation of growth factors, removal of senescent cells, and removal of hyperproliferative nonmigratory tissue
- Maintenance of surgical debridement
 - Weekly debridement depending on the formation of new necrotic tissue.
 - First 4 weeks of treatment reduces median wound area by 54%.

■ **Flaps and Grafts**

- Local flaps and grafts described elsewhere in this text can be used for definitive soft tissue coverage.
-

PEARLS AND PITFALLS

Blood flow	■ It is critical prior to any surgical intervention that blood flow/perfusion be determined and optimized.
Adequate debridement	■ Ensuring adequate debridement of soft tissue and bone is critical to minimize biofilm and senescent cells.
Off-loading	■ Minimizing pressure to the area of a diabetic foot ulcer helps ensure adequate perfusion.
Infection control	■ It is important to address subclinical infections as well as ensure that the underlying osteomyelitis is appropriately treated for the successful long-term treatment of diabetic foot ulcers.
Consideration for hyperbaric oxygen	■ Studies indicate that Wagner grade 3 wounds benefit from hyperbaric oxygen therapy.

OUTCOMES

- 85% of lower limb amputations in diabetics are preceded by unhealed ulceration.
- 50% to 75% of lower extremity amputations are caused by nontraumatic amputations.
- Five-year mortality after amputation in diabetics is 45%.

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Nerve Repair and Reconstruction—Peroneal Nerve

19

CHAPTER

Shawn Moshrefi and Catherine M. Curtin

DEFINITION

Peroneal Nerve Injury

- Peroneal nerve injuries vary in severity, mechanism, and needed treatment.
- The nerve injury type dictates the treatment and prognosis.
- Types of nerve injury¹
 - Neuropraxia: conduction delay with no axonal injury. These injuries will recover spontaneously without intervention.
 - Axonotmesis: axonal injury resulting in disruption of the axons; however, the supporting nerve scaffolding is intact. In these injuries, distal nerve segment will undergo Wallerian degeneration and proximal fibers will regenerate. Spontaneous recovery is possible.
 - Neurotmesis: complete disruption of the nerve. In these injuries, spontaneous regeneration will *not* occur.
 - Neuroma in continuity: disruption of the axons though the scaffolding seems to be intact. However, at the injury site, there is internal fibrosis, which prevents axons from regeneration. In these injuries, spontaneous regeneration will *not* occur.
 - Mixture of injury types: nerve patterns can be complex, and one nerve can have several different levels of injury.

ANATOMY

- The common peroneal nerve fibers originate from L4 to S3 nerve roots (**FIG 1**).

- The common peroneal nerve branches from the sciatic nerve in the popliteal fossa.
- The motor component of the peroneal nerve innervates the anterior and lateral lower leg compartment muscles as well as some intrinsic muscles of the foot.
- The sensory component of the peroneal nerve supplies the first dorsal web space of the foot and the top of the foot.
- The peroneal gives off the lateral sural cutaneous branch, which joins the medial sural cutaneous branch (contributed from tibial nerve) to form the sural nerve.
- The common peroneal nerve crosses from posterior to anterolateral around the neck of the fibula.
 - The peroneal nerve is susceptible to compression as it wraps around the fibula.
- Once the nerve crosses anterior to the fibula, it branches into the superficial peroneal and deep peroneal nerves.
- The superficial peroneal nerve passes straight down the lateral compartment.
 - The superficial peroneal nerve supplies motor to the lateral compartment (peroneus longus and peroneus brevis).
 - The superficial peroneal nerve supplies sensation to the top/lateral portion of the foot.
- The nerve transitions from within the muscle to a more superficial subcutaneous position at the junction of the middle and distal thirds of the lower leg. This transition site can be a point of compression.
- The deep peroneal nerve turns acutely around the fibular neck to enter the anterior compartment of the leg. The deep peroneal nerve then passes under the intermuscular septum between the anterior and lateral compartments to eventually course down between the tibialis anterior and extensor hallucis longus alongside the anterior tibial artery.
 - The deep peroneal motor nerve supplies the anterior compartment of the leg as well as some of the small foot extensor muscles: tibialis anterior, extensor digitorum longus, peroneus tertius, extensor hallucis longus, extensor digitorum brevis, and extensor hallucis brevis.
 - The deep peroneal nerve supplies sensation to the first web space of the foot.

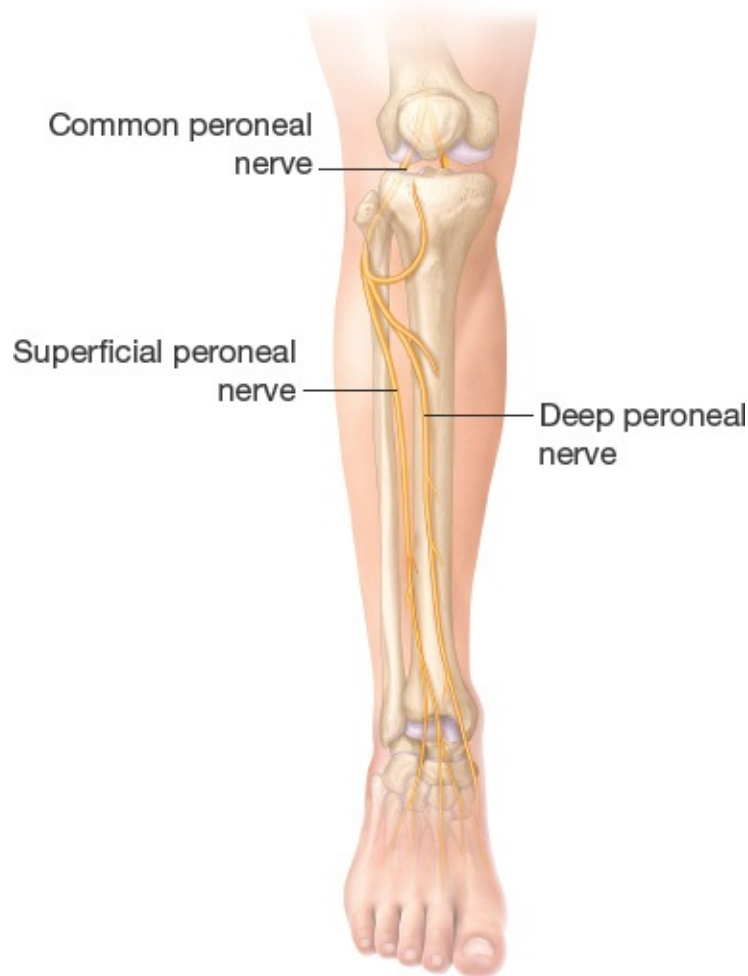


FIG 1 • Anatomy of the peroneal nerve.

PATHOGENESIS

- Direct trauma can injure the nerve along its course.
 - Fibular fracture can lacerate the nerve or result in neuropraxia.
 - Knee dislocation can result in a stretch injury or even a rupture of the peroneal nerve.²
 - Iatrogenic injuries that occur include prolonged tourniquet time, laceration of nerve during hardware placement, and compression of nerve from operative positioning.
- Swelling and compression can cause injury along the course of the peroneal nerve.
 - Ankle swelling can cause superficial peroneal nerve entrapment and resulting pain.

- Compression from tight splints or casts can result in common peroneal nerve injury.
- Soft tissue masses
 - Cysts, especially Bakers cysts, or other nerve compressing structures can result in peroneal nerve injury.
 - Neural tumors such as schwannomas can result in nerve deficits.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete and thorough history detailing patient's history of present illness, current injuries, history of prior injuries, prior surgeries (including spinal, buttock, and lower extremity procedures), comorbidities, occupation, and other case-by-case considerations should be obtained.
- Inspection
 - Is the leg/foot swollen?
 - Are there vascular changes?
 - Is there atrophy?
 - Is there a gait abnormality or foot drop?
- Vascular exam should assess for palpable pulses distally, temperature, and capillary refill of the foot.
- Sensory exam
 - Ten test: this quick test uses the contralateral area of normal sensation as a reference. The patient is lightly touched in the contralateral healthy distribution, and this normal sensation is a "ten." Then, both the healthy and affected side are lightly touched at the same time, and the patient is asked to grade the affected side using the scale 0 to 10.³
- Motor exam
 - Consists of testing the respective muscles that the peroneal nerve: extension of the foot and ankle.
 - Each muscle can be tested individually and compared to the contralateral side. Comparing to the healthy side allows for identification of subtle motor deficits seen in compression.
 - Motor examination remember mnemonic PED = **P**eroneal **E**verts and **D**orsiflexes or more correctly noted, Extends.
- Scratch collapse test⁴
 - This test can identify site of nerve entrapment.



FIG 2 • Large peroneal nerve schwannoma.

- Directly over the suspected nerve compression, the examiner gently scratches the skin. Then, the examiner immediately tests *arm* external rotation by applying force to the patient's dorsal forearm. The patient attempts to resist.
- A positive test on the scratch collapse test is when the patient briefly has decreased external rotation strength and “collapses” under the examiner's pressure.
- Tinel test

IMAGING

- X-rays are useful for suspected bony injury.
- Angiography may be required in complex trauma patients.
 - This is particularly important as the deep peroneal nerve runs intimately with anterior tibial artery.
- MRI
 - Standard MRI can assess for soft tissue masses such as Baker cysts, schwannomas, or tumors.
 - **FIG 2** shows a large peroneal nerve schwannoma with its typical smooth bright appearance.
 - MRI neurogram can identify areas of nerve compression and enhancement (**FIG 3**).
 - Nerve conduction studies and electromyelography.
 - For acute injuries, perform the first nerve testing at least 1 month after injury.
 - Studies can be repeated at 12 weeks, if there is no signs of recovery on physical examination.

- Nerve conduction studies may be normal for nerve compression that has not resulted in any axonal injury.

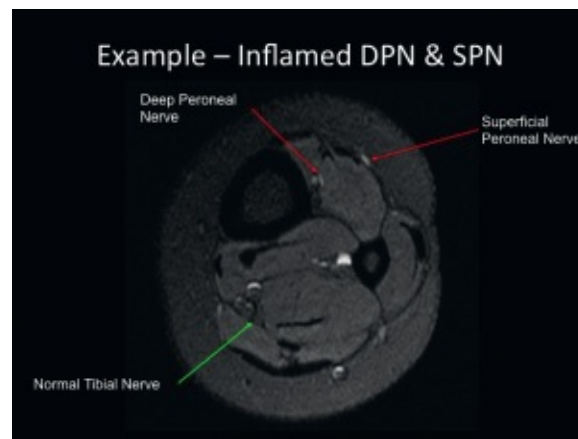


FIG 3 • MRI showing inflamed deep peroneal nerve and superficial peroneal nerve.

DIFFERENTIAL DIAGNOSIS

- Lumbar spinal pathology
- Sciatic pathology
 - If on physical examination, both peroneal nerve and tibial nerve distributions are involved, then sciatic pathology should be suspected.
 - Nerve studies should help differentiate.
- Neurologic problem
 - Peripheral neuropathy
 - Motor neuron disease
- Double crush⁵
 - A nerve may have more than one site of entrapment: for example, common peroneal at the fibular head and superficial peroneal at middle third of lower leg.
 - The theory is that an axon injured in one area may be more susceptible to secondary sites of injury.
 - Missing secondary sites of pathology will result in limitation of recovery if only one site is treated.

NONOPERATIVE MANAGEMENT

- For closed nerve injuries, nonoperative management is appropriate initially.

- Physical modalities
 - Edema prevention with lightly compressive wraps/garments and direct hands on physical therapy can be helpful.
 - Strategic splinting to prevent contractures.
 - Ankle-foot orthoses help improve mobility and stability in patients with a foot drop.
 - Gentle range of motion exercises to allow the nerve to glide and limit potential scarring in an injured soft tissue bed.
 - Desensitization to minimize pain and reeducate the nociceptive pathways.

SURGICAL MANAGEMENT

- Exploration and repair is indicated for open nerve injuries or closed injuries that are not showing signs of recovery.
- Nerve laceration
 - Urgent repair is indicated.
- Blast injuries should be explored no sooner than 6 weeks.
 - These injuries can have a surprising amount of recovery and should be followed until recovery plateaus before surgery.
 - Intraoperative nerve monitoring is critical to define the zone of injury.
- Traction injury should be explored if no signs of recovery at 3 months.



FIG 4 • Patient positioning for decompression of common peroneal and superficial peroneal nerves.

- Intraoperative nerve monitoring is critical to define the zone of injury.
- Be prepared for the need for long nerve grafts.

- Release of compressed common peroneal nerve (or branches) can be performed after thorough workup and no signs of recovery at 3 months.
- If injured superficial peroneal nerve resulting in painful neuroma in ankle or foot region, consider resection of nerve at junction of middle/distal third of the leg.
 - This will trade numbness for pain.
 - It will allow the surgeon to be out of the zone of injury.
 - Allows new placement of the neuroma deep in muscle and not crossing a joint.

Preoperative Planning

- Definitive fracture fixation should be performed prior to nerve repair.
- Arterial injury should be addressed prior to nerve repair.
- If possible, use a lower extremity tourniquet to aid in visualization of the nerve.
- If intraoperative nerve monitoring to be utilized, inform anesthesia team to not use paralytics.
- If pain is a concern, consider a more aggressive perioperative pain strategy.
 - 900 mg of gabapentin preoperatively⁶
 - Intraoperative ketamine
 - Regional block
 - Multimodal postsurgical pain management strategy
- If planning nerve resection of superficial peroneal nerve
 - Preoperative diagnostic block of the nerve at planned level of resection.
 - Ensure patient has significant relief of pain for hour after block.
 - Ensure patient will tolerate the numbness felt at the time of the block for the decrease in pain.

Positioning

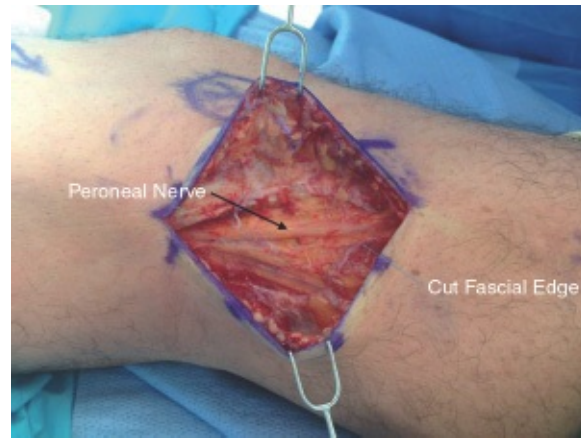
- Positioning depends on level of injury (above knee, at level of knee, or below knee).
- Access to popliteal area is easiest when the patient is in the prone position.
- Access to the lateral leg is managed either supine with a hip bump or a “sloppy” lateral with the unaffected side down. **FIG 4** shows positioning for decompression of common peroneal and superficial peroneal nerves.
- Access to compression sites at the extensor retinaculum is managed with the

patient supine.

TECHNIQUES

■ Common Peroneal Nerve Decompression

- Regional or general anesthesia
 - If no intraoperative nerve monitoring is required, regional anesthesia with a pain pump can provide several days of pain relief reducing opioid use.
- Thigh tourniquet is placed.
- Hip bump or slight lateral decubitus positioning to internally rotate the leg.
- Oblique incision 2 cm distal to the fibular head (on thin patients, you can palpate the nerve and design your incision above the nerve).
- Skin and subcutaneous tissue are divided down to the overlying fascia of the anterior lower leg muscles. Careful hemostasis is obtained as the dissection proceeds.
- Begin proximal and identify the nerve just posterior to the biceps femoris tendon.
 - The nerve is visualized with gentle longitudinal spread with a dissecting scissor.
- A vessel loop is placed around the nerve.
- The dissection proceeds distally releasing the fascia overlying the nerve. The fascia that overlies the muscles in the lateral muscle compartment is released. Then, the muscle fibers are spread/retracted allowing visualization of the thick fascia overlying the nerve, which is released (**TECH FIG 1**).
- The nerve will start dividing at the level of the fibular neck. In addition to the superficial and peroneal branches, the genicular branch that loops back proximal to the joint.
- Under direct visualization, follow the branches distally to ensure there are no unreleased fascial bands. The intermuscular septum can cause compression so inspect for any overlying compressive bands.
- This dissection can be performed with an incision that only goes about 2 cm anterior to the fibular head.
- Release tourniquet, achieve hemostasis, and close skin.
- Soft bulky dressing is placed.



TECH FIG 1 • Visualization of the peroneal nerve.

■ Common Peroneal Nerve Traction Injury (Knee Dislocation)

- General anesthesia is required as patient will be prone and intraoperative nerve monitoring will be used.
- Thigh tourniquet.
- Prone positioning.
- Intraoperative nerve monitoring available.
- Incision is angled from the center of popliteal fossa laterally toward the fibular head.
- The dissection is taken down to the level of the muscle fascia.
- The common peroneal nerve is identified as it branches off the sciatic nerve.
- A vessel loop is placed on the nerve, and the dissection is taken distally.
- The nerve is released from the overlying scar (often a very challenging dissection). The dissection is taken around the fibular head releasing the anterior muscle fascia.
- Intraoperative nerve monitoring is performed. Start with somatosensory evoked potentials can help establish the proximal level of intact nerve. Nerve-to-nerve monitoring can identify neuroma in continuity.
- If the nerve is ruptured or neuroma in continuity is identified, resect damaged nerve until two healthy nerve ends are revealed.
- Ensure that the proximal nerve is healthy by using the assistance of your neuromonitoring.

- For the nerve gap, harvest sural nerve graft.
 - Cable the graft and suture in place with a few 9-0 sutures using microscopic technique. The repair should be tension free to allow for knee motion.
 - Augment repair by sealing coaptation site with fibrin glue.
 - Close wound.
-

■ Superficial Peroneal Nerve Compression Release and/or Neurectomy

- Thigh tourniquet.
 - Regional anesthesia.
 - Supine position.
 - Approximately 3 cm longitudinal incision over seam between anterior and lateral compartments at juncture of middle and distal third of the leg.
 - The dissection is taken down to the level of the muscle fascia.
 - Identify the thin raphe located between the lateral and anterior compartments of the lower leg.
 - Of note, there is a wide fat stripe anterior to the superficial peroneal nerve. If you find this first, look about a 1 cm posterior and you will find the seam that contains the nerve.
 - Release overlying fascia proximally and distally.
 - If performing neurectomy for damaged superficial peroneal nerve, the approach to the nerve is the same.
 - Once the nerve is identified, divide nerve distally and free up the proximal nerve for several centimeters.
 - Place nerve stump deep within peroneus longus muscle. Bury the nerve stump in the muscle bed without tension.
 - Close wound and place bulky dressing.
-

■ Nerve Laceration

- The nerve is identified using the existing wounds or the approaches described above.
- The nerve can be directly coapted using microsurgical technique if a tension-free repair is possible.

- If there is tension, a bridging nerve graft is required.
- Nerve repair is done using microsurgical technique and should be tension free.
- Use 9-0 suture and the minimal amount of sutures needed.
- Fibrin glue can be used to seal the repair site and to hold cabled nerve grafts together.
- The wounds are closed.
- Repairs are protected for 3 weeks if concern about the repair with splints/braces to limit mobility at adjacent joints.

PEARLS AND PITFALLS

Nerve repair	■ Nerve coaptation must be without tension. If a 9-0 suture cannot hold the repair, there is too much tension and a graft is required.
Diagnosis of entrapment site	■ Confident location of entrapment can be made if the patient has a positive Tinel sign, positive scratch collapse, and sensory changes in the appropriate distribution. ■ Double crush is a risk so assess if nerve entrapped at both the superficial and common peroneal entrapment sites.
Intraoperative monitoring	■ Communication between neurology and anesthesia team is critical to ensure that patient does not receive medications that will hinder intraoperative monitoring. ■ SCD machine and warming machines can cause background that interferes with intraoperative monitoring. ■ Do not use prolonged tourniquet if planning intraoperative monitoring.
Meticulous hemostasis	■ If not using a tourniquet, preinject incision with bupivacaine with epinephrine before prepping. ■ To improve visualization, a mix of 1 ampule of epinephrine with 100 cc of saline can be used to moisten gauze pads. These can be dabbed in the wound and improve visualization and minimize the need for cautery adjacent to the nerve.

POSTOPERATIVE CARE

- Medications

- If neuropathic pain is a significant concern, consider multimodal pain control, which can include acetaminophen, NSAIDs, gabapentin, and opioids.⁶
- Therapy
 - At 2 to 3 weeks, consider therapy for scar management, nerve gliding, and desensitization.
- Nerve repair
 - Nerve repairs with slight tension need to be protected from disrupting forces for 3 weeks postoperatively. This can be performed through an immobilizer or splint. However, if reconstructed with a graft with some redundancy, early mobilization is possible.
- Nerve decompression
 - Soft dressing and early mobilization will prevent scarring and tethering of the nerve.

OUTCOMES

- Studies show approximate 80% functional nerve recovery in patients with a multitude of methods of common peroneal nerve injuries.⁷
- Other studies indicate a vastly significant difference in prognosis from incomplete nerve palsy (highly favorable functional outcome) to complete peroneal nerve palsy (less than 40% functional recovery).²
- Complete peroneal nerve injuries after knee dislocation still have poor functional outcomes with less than 40% recovering extension despite treatment.²
- Release of the superficial peroneal nerve has resulted in high rates of pain resolution.^{8,9}

COMPLICATIONS

- Most severe complication is iatrogenic nerve injury though this is very rare
- Bleeding
- Infection
- Fibrosis of the release site requiring revisionary surgery

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20 Achilles Tendon Reconstruction

CHAPTER

Hani Sbitany

DEFINITION

- Achilles tendon is the most frequently ruptured tendon in the body, with incidence reported as high as 34/100 000, most commonly seen in males in their 30s.¹
- The male-to-female ratio of this injury is 20:1.
- Classically seen when less active males engage in a new sport, without significant previous experience.

ANATOMY

- Most common site of rupture is 3 to 6 cm above the os calcis (ie, the calcaneus):
 - This area is a watershed zone in terms of blood supply.
- Achilles tendon is made up of gastrocnemius and soleus muscles, along with the plantaris tendon (**FIG 1**).
- This tendon begins in the midportion of the calf (superficial posterior compartment) and narrows to approximately 4 cm width at its insertion on the calcaneus bone.
- Achilles tendon helps to produce plantar flexion of the foot, which is powered through associated muscle innervation by the tibial nerve.

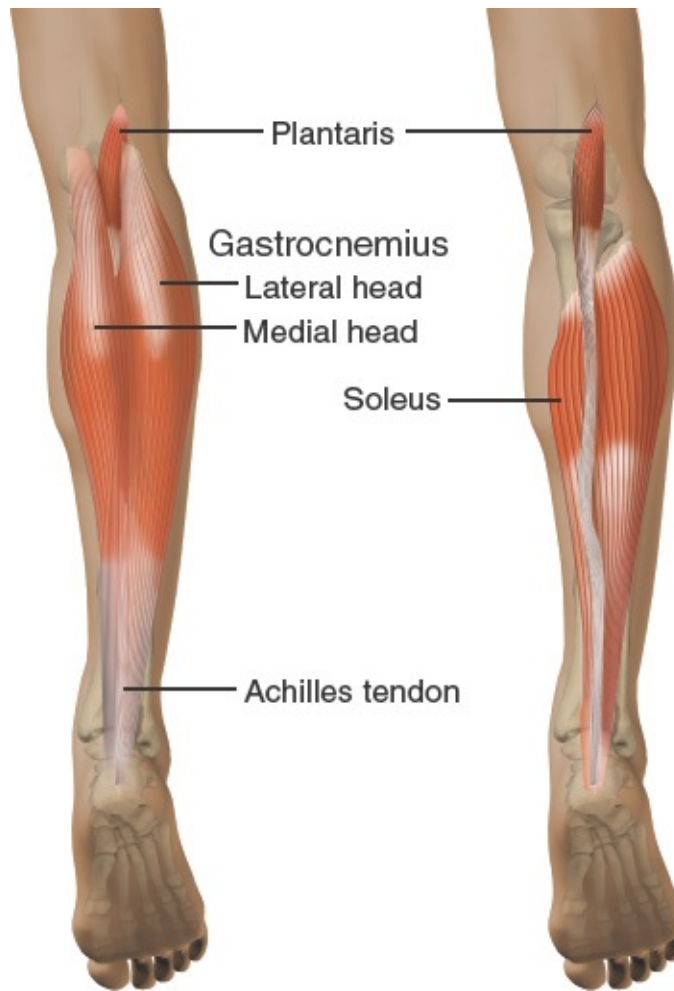


FIG 1 • The Achilles tendon is formed by the convergence of the medial, lateral gastrocnemius, and soleus muscles.

PATHOGENESIS

- With aging, there is an increase in type 3 collagen content on the Achilles tendon and a reduction in type 1 collagen content.²
- Increasing age is also accompanied by decreased orderly collagen cross-linking.
- All this results in reduced tensile strength of the tendon.

NATURAL HISTORY

- In addition to aging, there are numerous other risk factors associated with Achilles tendon rupture:

- Hypercholesterolemia
- Rheumatoid arthritis
- Hypercholesterolemia
- Long-term dialysis
- Renal transplantation
- Chronic steroid use

PATIENT HISTORY AND PHYSICAL FINDINGS

- A history of pain and weakening on plantar flexion is usually indicative of Achilles tendon rupture.
- On physical exam, there is usually a palpable defect in the tendon, in 75% of patients.
 - Up to 25% of tendon injuries can be missed when only clinical assessment is used for diagnosis.
- Simmonds/Thompson test: the patient lies face down with feet hanging off the edge of the bed. If there is no plantar flexion of the foot on squeezing the calf, then there is likely rupture of the Achilles tendon.
- O'Brien test: insert 25-gauge needle at right angle through the skin of calf muscle just medial to midline at a point 10 cm proximal to superior border of calcaneus. The needle should be within the substance of the tendon. Movement of the needle in a direction opposite that of the tendon during passive extension and flexion of the foot confirms an intact tendon distal to the level of needle insertion.
- Copeland test: the patient is prone with the feet hanging off of the exam table. A sphygmomanometer is placed around the calf with the foot in plantar flexion and inflated to 100 mm Hg. If the tendon is intact, then extension of the foot will lead to a pressure increase to 140 mm Hg. If the tendon is ruptured, then the pressure does not change.

IMAGING

- Imaging is always recommended when there is clinical concern for Achilles tendon rupture.

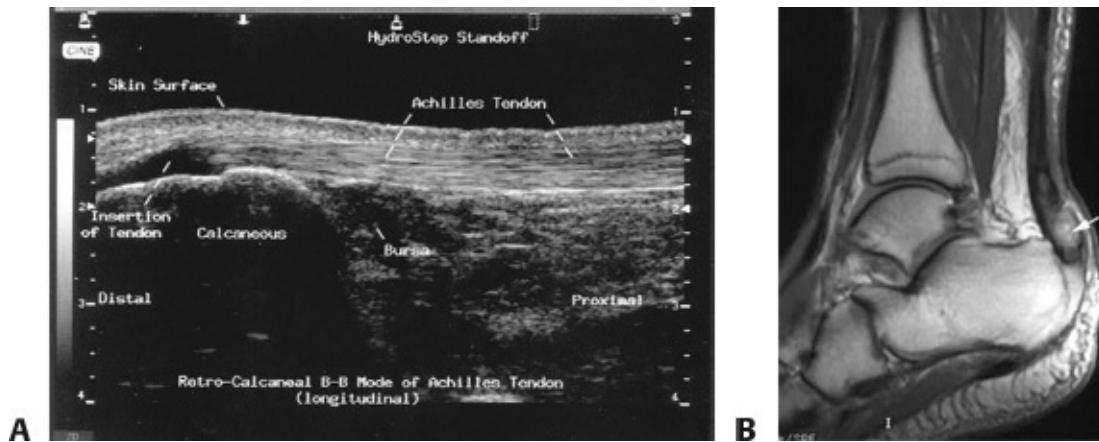


FIG 2 • A. Normal Achilles ultrasound image. **B.** Ankle MRI (T1-weighted image) showing a distal Achilles tendon rupture. (From Labib S. Open Achilles tendon repair. In: Wiesel S, ed. *Operative Techniques in Orthopaedic Surgery*. 2nd ed. Vol. 4. Philadelphia, PA: Wolters Kluwer Health; 2015:4967-4973.)

- Ultrasound is a useful first-line imaging technique, with sensitivity of 100% (**FIG 2A**).
- Ultrasound tendon gap greater than 4 mm with patient in equinus (plantar flexion) indicates the need for surgical repair.
- Ultrasound can differentiate partial vs complete tear:
 - This is more difficult with a tear at the proximal musculotendinous junction, in which sensitivity is much lower.
- MRI is the best imaging modality for Achilles tendon rupture, with sensitivity of 100% (**FIG 2B**).
- MRI should always be obtained if any uncertainty exists regarding location, completeness, or length of tear.

DIFFERENTIAL DIAGNOSIS

- Achilles tendon peritendinitis
- Gastrocnemius tear or strain
- Calcaneus fracture
- Posterior tibialis tendon injury
- Posterior tibialis stress syndrome

NONOPERATIVE MANAGEMENT

- Nonoperative treatment of Achilles rupture is only an option in cases of acute rupture, with immediate diagnosis.
 - In cases of delayed diagnosis, scarring and retraction of tendon ends make conservative management less effective and unlikely to heal properly.
- The purpose of nonoperative management is to appose the ruptured Achilles ends, in stable fashion, such that healing can occur.
- Treatment regimen consists of immobilizing the extremity below the knee, with a brace or rigid cast.
 - The foot is initially placed in full plantar flexion.
 - Ankle is slowly brought into neutral position over 8 to 12 weeks.
- Knee immobilization is not necessary for reapproximation of the tendon edges.
- Early, gradual weight bearing has also been shown to confer protection against repeat rupture in the future.
- Many nonoperative regimens now advocate early weight bearing in a custom or Sheffield splint.
 - This is particularly beneficial in frail patients for whom joint contracture is at high risk.
 - The Sheffield splint is a specialized device worn on the lower leg and foot that allows for early controlled mobilization of the Achilles tendon.
- Early weight bearing also facilitates faster resumption of mobility after complete healing.
- One preferred conservative regimen:
 - Patient in full equinus (30 degrees) with touch weight bearing for 2 weeks
 - Ankle then placed in partial equinus (15–20 degrees) with partial weight bearing for 2 weeks
 - Finally, placed in neutral (0 degrees) with full weight bearing for 2 weeks

SURGICAL MANAGEMENT

- Operative treatment is used for the majority of acute tendon ruptures in younger patients, as well as in all patients with chronic rupture or delayed diagnosis.
- This is the only treatment option when there has been scarring and retraction of the tendon ends, resulting in a lack of apposition.

Preoperative Planning

- As previously mentioned, ultrasound and MRI assessment of the injury is important, to identify the location of the rupture relative to the musculotendinous junction and the length of the gap.
- The patient's physical examination should also include a workup of mobility potential and strength, to ensure that early mobilization and weight bearing will be possible.

Positioning

- Surgical repair is commonly performed with the patient in the supine position, the hips abducted, and the knees flexed (frog leg position) (**FIG 3**).
- The operation can also be performed with the patient in the prone position, for easier, direct access to the posterior ankle.

Approach

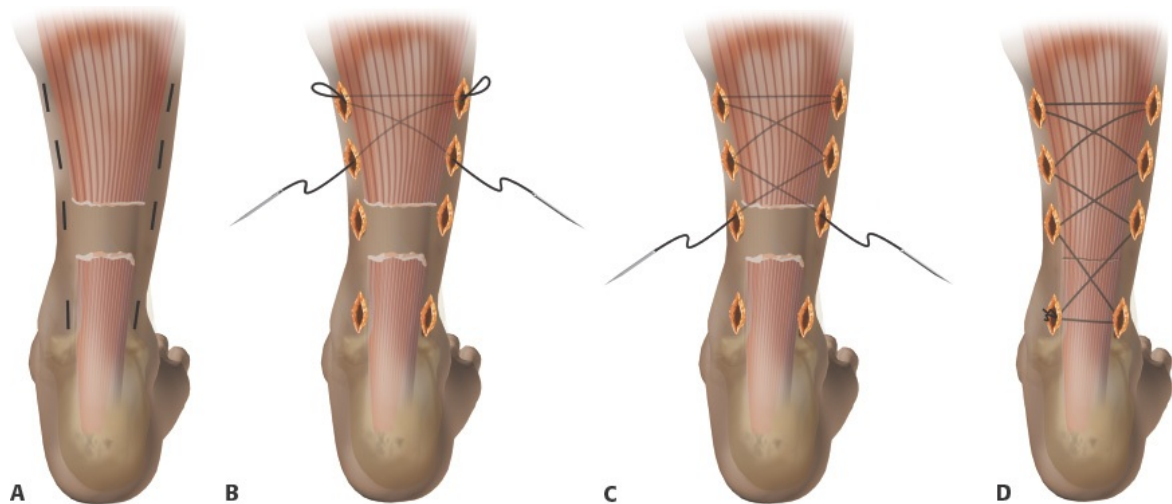
- Open surgical repair is performed with a direct longitudinal incision, directly over the Achilles to expose the entire tendon.



FIG 3 • Patient is placed in the prone position with both legs prepared and draped for surgery. (From Labib S. Open Achilles tendon repair. In: Wiesel S, ed. *Operative Techniques in Orthopaedic Surgery*. 2nd ed. Vol. 4. Philadelphia, PA: Wolters Kluwer Health; 2015:4967-4973.)

■ Percutaneous Repair

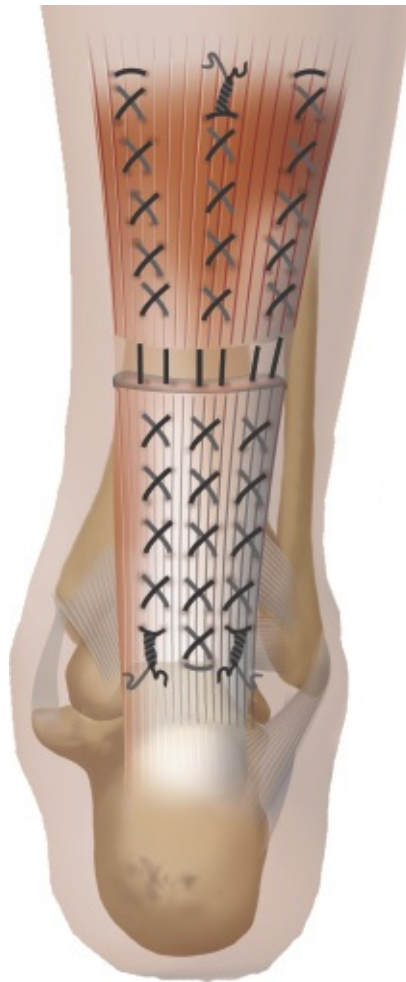
- Performed with patient in prone position.
- Skin incision is first made over site of rupture.
- Second skin incision made 4 cm proximal to initial incision.
- Third incision made 4 cm distal to rupture (**TECH FIG 1A**).
- The track of the entire tendon is defined under the skin and spread open.
- For this repair, a suture is first passed on a needle through middle incision and through tendon at this point (**TECH FIG 1B**).
 - A monofilament, permanent suture is used for this.
- Needle is then passed proximal and brought out through proximal incision (see **TECH FIG 1B**).
 - At this proximal incision, the suture is then passed through the proximal cut edge of the Achilles tendon.
- The needle is then passed back through the tunnel, brought out the middle incision, passed through the distal stump of the tendon, and brought out the distal end (**TECH FIG 1C**).
- Traction is then applied to ensure proper tension (**TECH FIG 1D**).



TECH FIG 1 • A-D. Pattern for suture passage for percutaneous repair of Achilles tendon rupture.

■ Open Direct (End-to-End) Suture Repair

- Performed in cases of acute rupture, less than 6 weeks old.
- Achilles tendon exposed along the entire length through vertical skin incision.
- Multiple figure-of-8 sutures are used to repair tendon at proper tension (**TECH FIG 2**).
- Similar to percutaneous, a large monofilament, permanent suture is used for repair.



TECH FIG 2 • End-to-end suture repair of Achilles tendon rupture.

■ Reconstruction With VY Advancement

- Used to repair chronic ruptures with defect less than 3 cm between tendon

ends.

- The entire posterior compartment, from the calcaneus to the midportion of the calf, is exposed with the incision.
 - The gastrocnemius/soleus/Achilles junction is exposed posteriorly from the prone position.
 - An inverted V incision is planned along the posterior superficial surface of the muscular complex, with the apex of the V placed at the proximal portion of the myotendinous junction.
 - The medial and lateral limbs of the V exit through the sides of the Achilles tendon.
 - The inverted V is incised through the tendinous, superficial portions of the tissue, leaving underlying muscle intact.
 - Then, the tendon ends are sutured to each other across the rupture, using permanent suture.
 - Can use monofilament or braided suture.
 - Done with locking knots, at least five suggested.
 - Tension is set with gentle traction, such that the muscle is not disrupted.
 - Finally, the limbs of the inverted V are rerepaired with suture.
-

■ Flexor Hallucis Longus Transfer

- Used to repair chronic ruptures with defect greater than 3 cm between tendon ends.³
- Requires a functional tibial nerve.
- The flexor hallucis longus (FHL) tendon can be harvested through the same posterior Achilles incision used for injury exposure.
- The dissection is carried down into the deep posterior compartment fascia, and underneath this, the FHL muscle and tendon sit.
- The FHL muscle belly extends more distal than others in this compartment, usually to the level of tibiotalar joint, which is the method of identification:
 - The muscle is confirmed by retracting manually and seeing flexion of the hallux.
- Medial to the FHL tendon, the neurovascular bundle of tibial nerve and posterior tibial artery is identified.
- The muscle is dissected distally, around the medial malleolus, taking care not

to injury the neurovascular bundle.

- Then, the FHL is transected as distal as possible, along its tendinous portion, with the ankle held in flexion and muscle under traction.
- Based on FHL tendon diameter, a bone tunnel is drilled into the calcaneus (posterior tubercle), just anterior to the area of Achilles tendon insertion on the bone.
- The length of the FHL muscle and tendon is set, after the tendon is passed through the tunnel using a suture and passer (**TECH FIG 3**).
 - At this length, the tendon is fixed into the calcaneus after passing through the tunnel, with an interference screw.
- The final resting tension, after repair, is compared to the contralateral uninjured side.
- Gentle extension is applied to test the repair, and then the skin is closed.⁴



TECH FIG 3 • Flexor hallucis longus tendon used to augment Achilles tendon repair. (From Labib S. Open Achilles tendon repair. In: Wiesel S, ed. *Operative Techniques in Orthopaedic Surgery*. 2nd ed. Vol. 4. Philadelphia, PA: Wolters Kluwer Health; 2015:4967-4973.)

POSTOPERATIVE CARE

- For most repair techniques, the ankle is splinted in equinus for 2 weeks.
- Strict nonweight bearing is employed for 6 to 8 weeks.

- After 2 weeks, once the healing skin is confirmed on examination, the patient is converted to postsurgical boot that gradually allows for passive extension in increasing increments over the next 4 weeks.
- At 6 to 8 weeks, patient is examined and tested for Achilles repair persistence, and weight bearing is started in ankle boot brace.
 - Physical therapy also started at this point.
 - Three sessions of PT for 8 weeks.
 - PT focuses on passive Achilles stretching and gait training.
- At 12 weeks, if the ankle is neutral alignment on exam, the patient is allowed to resume activity slowly.

COMPLICATIONS

- Bleeding
- Infection
- Tendon rerupture

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21 Excision of Soft Tissue Tumors of the Lower Leg

CHAPTER

Raffi S. Avedian and Robert J. Steffner

DEFINITION

- Soft tissue tumors of the lower leg may be benign or malignant (soft tissue sarcoma) and exhibit a variable natural history ranging from latency to rapid growth.
- Tumors located entirely above the muscle fascia are considered superficial, whereas tumors involving the fascia or deep to it are considered deep.

ANATOMY

- The lower leg is made up of the tibia and fibula and four muscle compartments: anterior, lateral, deep posterior, and superficial posterior (**FIG 1**).
- Three principal arteries travel in the lower leg.
 - The posterior tibial artery is located in the deep posterior compartment on the surface of the tibialis posterior.
 - The anterior tibial artery is in the anterior compartment located deep to the muscles on the surface of the interosseous membrane.
 - The fibular artery travels in the deep posterior compartment medial to the fibula under the flexor hallucis longus; it sends branches to the lateral and anterior compartments and a nutrient vessel to the fibula.
- The deep peroneal nerve travels with the anterior tibial artery. The superficial peroneal nerve is located in the lateral compartment; in the distal one-third of the leg, it travels between the peroneus muscles and extensor digitorum longus and pierces the deep fascia to become a cutaneous nerve.

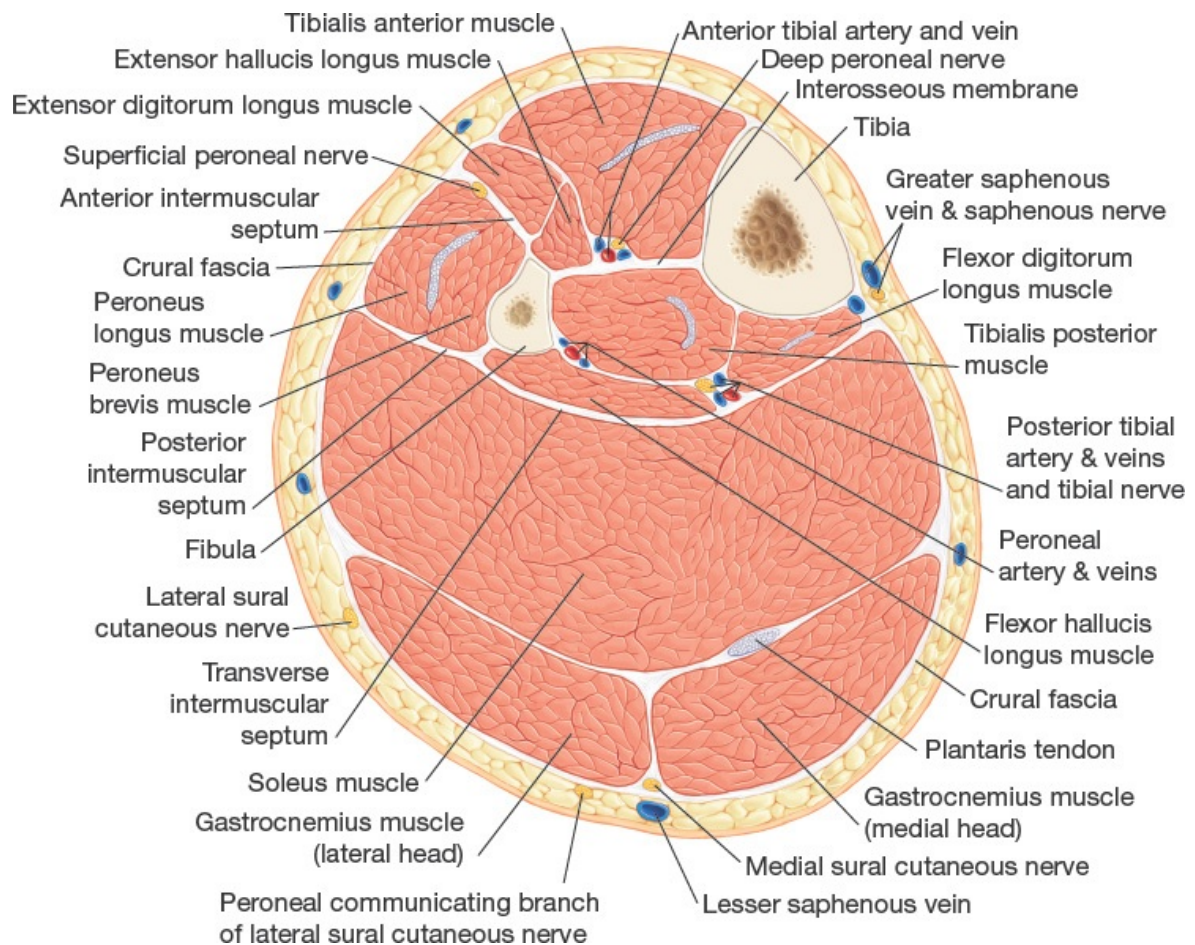


FIG 1 • Cross-sectional anatomy of lower leg showing the contents of the anterior, lateral, superficial posterior, and deep posterior compartments.

PATHOGENESIS

- The mechanism for soft tissue tumor formation is not known.
- Risk factors for sarcoma development include radiation exposure, radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and retinoblastoma gene mutation.

NATURAL HISTORY

- All soft tissue sarcomas have the potential for local recurrence and metastasis.¹
- Soft tissue sarcomas exhibit a spectrum of natural history from slow-growing low-grade tumors with low risk of metastasis to high-grade sarcoma that may grow rapidly and pose a high risk of metastasis.

- Lungs are the most common site of metastasis. Lymph node involvement is rare.
- Angiosarcoma, clear cell sarcoma, epithelioid sarcoma, rhabdomyosarcoma, myxofibrosarcoma, and synovial sarcoma are associated with increased risk of lymph node spread compared to other sarcomas.²
- Benign tumors by definition do not have metastatic potential but can grow to large sizes and cause symptoms.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history and examination are important to assess duration of symptoms, comorbidities, physical dysfunction, organ involvement, overall health, and patient expectations in order to best tailor treatment strategy for the individual patient.
- Many sarcomas may be asymptomatic with the only patient complaint being the presence of a mass.
- Neurovascular examination is mandatory for any extremity tumor.

IMAGING

- Magnetic resonance imaging is the principal imaging modality used to characterize tumors, formulate differential diagnosis, define local tissue infiltration, and formulate surgical plan.
- Plain radiographs are used if there is concern for bone involvement or to demonstrate mineralization within a tumor such as vascular malformations.
- Staging for soft tissue sarcomas consists primarily of lung imaging.

DIFFERENTIAL DIAGNOSIS

- The differential diagnosis for a soft tissue tumor includes benign tumors, sarcomas, lymphoma, infection, and inflammatory lesions (eg, rheumatoid nodules).
- There are over 50 sarcoma subtypes. Common histology types include pleomorphic undifferentiated sarcoma, synovial sarcoma, leiomyosarcoma, malignant peripheral nerve sheath tumor, liposarcoma.

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Biopsy incisions are considered contaminated and must be resected at the time

of definitive surgery. Care should be taken to place the biopsy in a location that does not interfere with the final surgical plan.³

- Simple marginal excision is appropriate for most benign tumors, and wide resection with a clean margin is performed for soft tissue sarcomas.
- Given the relatively low volume of tissue in the lower leg and ankle, soft tissue reconstruction with local or free flaps is often needed.

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The surgical plan is created by thorough study of the preoperative MRI scan. Fluid-sensitive sequences and fat-suppressed contrast images show the extent of disease that must be accounted in the excision. T1 fat-sensitive images show the normal anatomy best including fat planes between tumor and critical structures such as nerves and vessels.
- When tumor abuts, but does not encase blood vessels or nerves, they can be dissected free by leaving adventitia and epineurium on the tumor as the margin.⁴

Positioning

- Patient positioning is based on the surgeon's assessment of the critical anatomy of the surgery and how best to visualize it during surgery.
- Supine is the most common position for tumor excision of the lower leg. A hip bump may be used to access more lateral tumors; conversely, frog legging the extremity facilitates medial and posterior visualization.
- If a flap is to be used, the harvest must be performed using a separate back table and instruments and the surgical sites completely isolated to avoid contamination.

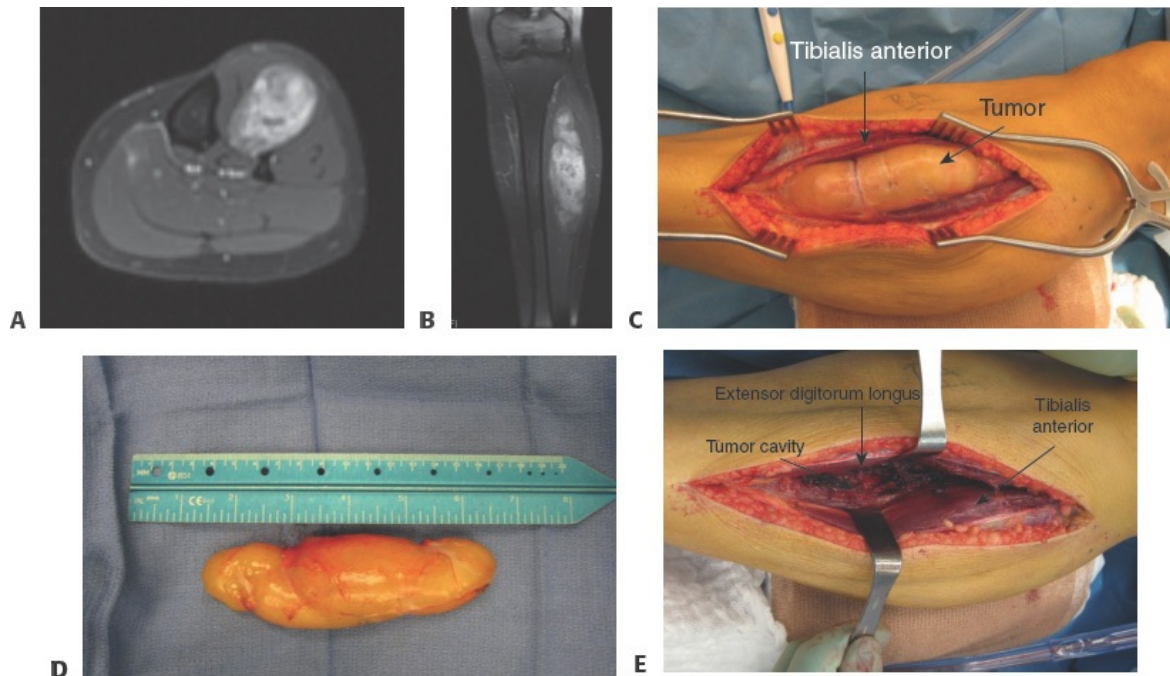
Approach

- The surgical approach varies based on location of the tumor.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

TECHNIQUES

■ Excision of Soft Tissue Tumor of the Lower Leg

- Tourniquet is used at the discretion of the surgeon by using gravity exsanguination rather than Esmarch to avoid tumor compression and potential risk of tumor spreading.
- A skin incision is used to approach the tumor.
- Superficial sarcomas require a large paddle of skin to be excised on top of the tumor to serve as the superficial margin and the deep fascia with a small cuff of deep muscle to serve as the deep margin. Deep sarcomas can often be approached with a longitudinal incision, but more extensive soft tissue excision is done in the deeper layers.
- A unique consideration for the lower leg is the relatively smaller volume of soft tissue compared to the thigh. Even a medium-sized sarcoma, eg, 5 cm, will occupy a large proportion of the leg. After excision, there is typically a relatively large defect that will require free tissue transfer for soft tissue reconstruction.
- Benign tumors may be excised through a longitudinal skin incision and simple dissection along the margin of the tumor by leaving most of the native tissues in place (**TECH FIG 1**).



TECH FIG 1 • **A.** Axial T1 fat-suppressed contrast MRI showing a tumor in the anterior compartment of the lower leg between the tibialis anterior and extensor digitorum longus. Biopsy confirmed benign schwannoma. **B.** Coronal view demonstrating craniocaudal extent of tumor. **C.** Intraoperative photograph showing dissection through deep fascia and separation of the tibialis anterior and extensor digitorum. Simple dissection around the tumor capsule was performed to deliver the tumor. **D.** Excised specimen on the back table. **E.** Photograph showing the defect after excision. Because the native muscles were not excised, a primary closure was possible.

PEARLS AND PITFALLS

Wound breakdown

- Dead space after tumor removal should be managed with drains, muscle flap, free tissue transfer, or a combination of

	these techniques.
	■ Have low threshold for aggressive soft tissue coverage.
Positive margins (sarcoma excision)	■ Appropriate preoperative planning is important to minimize risk of unplanned positive margins. ■ Inability to primarily close a wound should not interfere with decision to remove a tumor with a clean margin. Plan on soft tissue reconstruction. ■ Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings.

POSTOPERATIVE CARE

- Mobilization and weight bearing depend on the extent of surgery. Activity with no restriction may begin after simple tumor excision, whereas bed rest may be desired after free tissue transfer.
- Extremity elevation is recommended while the patient is in bed.
- May administer antibiotics in the perioperative period.

OUTCOMES

- Oncological outcomes include local recurrence and metastasis. Surveillance for recurrence should be managed by a multidisciplinary sarcoma team. Local recurrence is higher when margins are positive.
- Functional outcomes depend on the extent of tissue resection and patient overall health status. Most patients will experience some form of disability that is proportional to the volume of muscle and bone resected.

COMPLICATIONS

- Local recurrence occurs in a minority of patients with sarcoma and is more common in patients with positive margins.
- Deep infection can occur at any time after surgery and requires aggressive therapy including surgical debridement and antibiotic therapy to achieve limb salvage.
- Weakness with ankle and foot motion is not uncommon given the proximity of the nerves to most leg tumors and the need for extensive muscle excision.

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22 Excision of Bone Tumors of the Lower Leg

CHAPTER

Raffi S. Avedian and Rohit Khosla

DEFINITION

- Bone tumors of the tibia and fibula may be benign or malignant (bone sarcoma) and exhibit a variable natural history ranging from latent to rapid growth. Aggressive benign tumors and malignant tumors typically cause pain, dysfunction, and fracture.
- A bone tumor located in the tibia or fibula such that definitive treatment requires excision of an intercalary segment of bone, sparing the ankle and knee joints, is discussed in this chapter.

ANATOMY

- The lower leg is made up of the tibia and fibula and four muscle compartments: anterior, lateral, deep posterior, and superficial posterior (**FIG 1**).
- Three principal arteries travel in the lower leg. The posterior tibial artery is located in the deep posterior compartment on the surface of the tibialis posterior. The anterior tibial artery is in the anterior compartment located deep to the muscles on the surface of the interosseous membrane. The fibular artery travels in the deep posterior compartment medial to the fibula under the flexor hallucis longus; it sends branches to the lateral and anterior compartments and a nutrient vessel to the fibula.
- The deep peroneal nerve travels with the anterior tibial artery. The superficial peroneal nerve is located in the lateral compartment; in the distal one-third of the leg, it travels between the peroneus muscles and extensor digitorum longus and pierces the deep fascia to become a cutaneous nerve.

PATHOGENESIS

- The mechanism for bone tumor formation is not known.
- Risk factors for sarcoma development include radiation exposure, radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and retinoblastoma gene mutation.

NATURAL HISTORY

- Active benign tumors such as giant cell tumor of bone, chondroblastoma, and aneurysmal bone cyst will progress over time and may recur after excision but are not lethal.
- All bone sarcomas have the potential for local recurrence and metastasis.
- Some bone sarcomas such as low-grade chondrosarcoma exhibit a slow rate of growth and low risk of metastasis, whereas aggressive tumors like high-grade osteosarcoma and dedifferentiated chondrosarcoma grow rapidly and have a relatively high risk of metastasis.
- Tumor variables that are associated with increased risk of metastasis include high grade and large size (greater than 8 cm).
- Lungs and other osseous sites are the most and second most common location of metastasis, respectively.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pain is a common presenting symptom for aggressive bone tumors.
- A thorough history and examination are important to assess duration of symptoms, comorbidities, physical dysfunction, organ involvement, overall health, and patient expectations to best tailor treatment strategy for the individual patient.
- Neurovascular examination is mandatory for any extremity tumor.

IMAGING

- Plain radiographs are used to formulate a differential diagnosis and a preoperative plan.
- Magnetic resonance imaging is routinely used to determine the extent of intramedullary tumor involvement, presence of soft tissue extension, status of the neurovascular structures, and preoperative planning.

DIFFERENTIAL DIAGNOSIS

- The differential diagnosis for a bone tumor includes benign tumors, sarcomas, lymphoma of bone, infection, and metabolic lesions (eg, hyperparathyroidism).

- The most common bone sarcomas are osteosarcoma, chondrosarcoma, and Ewing sarcoma.

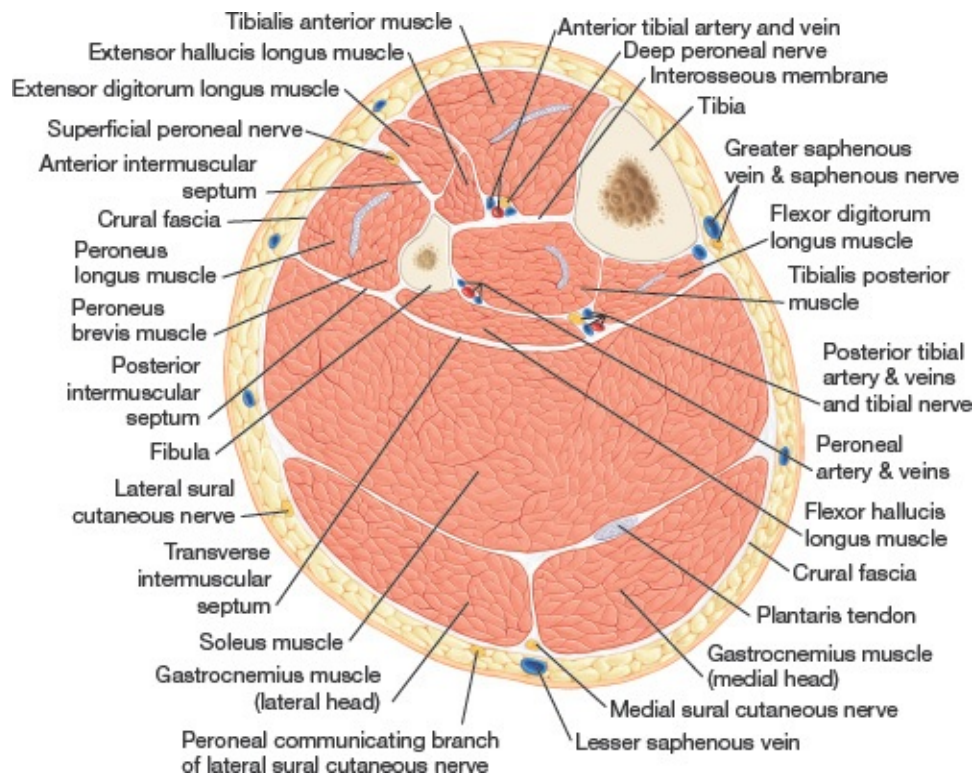


FIG 1 • Cross-sectional anatomy of the lower leg showing the contents of the anterior, lateral, superficial posterior, and deep posterior compartments.

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Biopsy incisions are considered contaminated and must be resected at the time of definitive surgery. Care should be taken to place the biopsy in a location that does not interfere with the final surgical plan.
- Intralesional curettage is the preferred treatment for benign tumors. Radical resection with a clean margin is required for bone sarcomas.
- Reconstruction depends on the extent of bone excision and may include simple bone grafting, endoprosthetic implants, structural allografts, vascularized fibula (ipsilateral centralized or contralateral free transplant), or combined allograft and vascularized fibula.

- The goal of surgery is to remove the tumor adequately to minimize recurrence and restore the mechanical integrity of the bone and joints so that the patient may have sufficient function to perform activities of daily living with minimal pain.

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The surgical plan is created by thorough study of the preoperative radiographs and MR imaging.
- Bone cuts are planned by measuring on preoperative imaging the distance from an intraoperatively identifiable landmark (eg, medial malleolus or tibial condyle) to the desired osteotomy site (**FIG 2A,B**).
- The soft tissue margin depends on the size and location of a soft tissue component to the tumor.
- When tumor abuts, but does not encase blood vessels or nerves, they can be dissected free by leaving the adventitia and epineurium on the tumor as the margin.

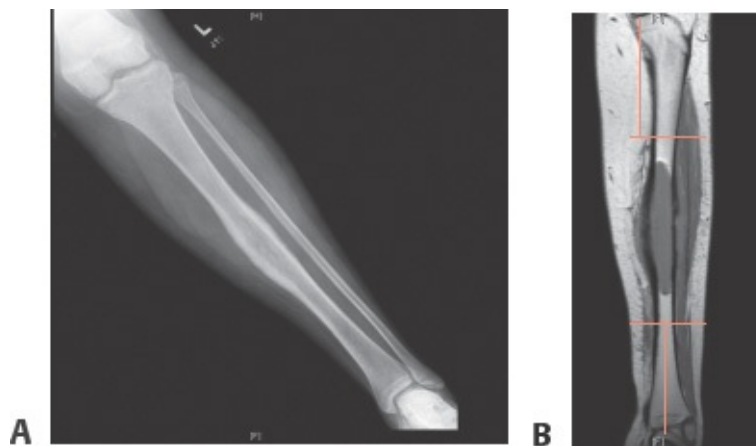


FIG 2 • A. Anteroposterior radiograph of a 16-year-old girl with a midtibia Ewing sarcoma. **B.** Sagittal T1-weighted MRI demonstrating the intramedullary extent of the tumor and measurements for bone resection.

Positioning

- Patient positioning is based on the surgeon's assessment of the critical anatomy of the surgery and how best to visualize it during surgery.
- Supine is the most common position for tumor excision of the lower leg. A hip bump may be used to access more lateral tumors; conversely, frog legging the extremity facilitates medial and posterior visualization.
- If a flap is to be used, the harvest must be performed using a separate back table and instruments and the surgical sites completely isolated to avoid contamination.

Approach

- The surgical approach varies based on location of the tumor.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

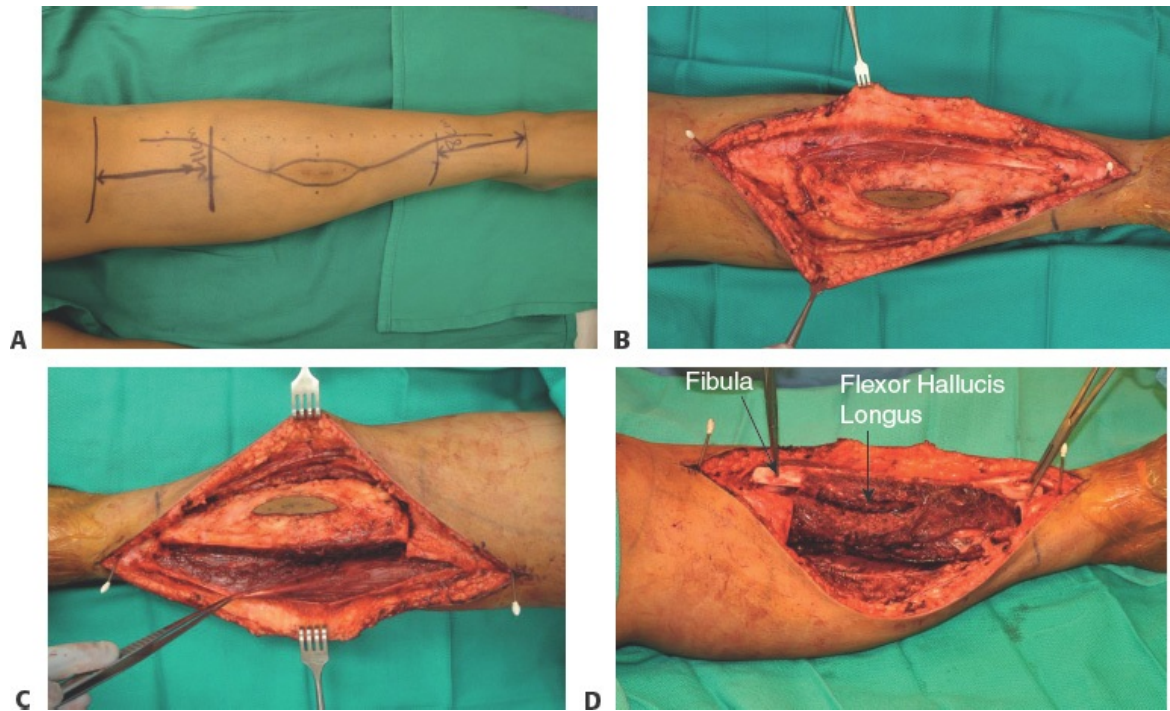
TECHNIQUES

■ Diaphyseal Tibia Tumor Resection and Reconstruction

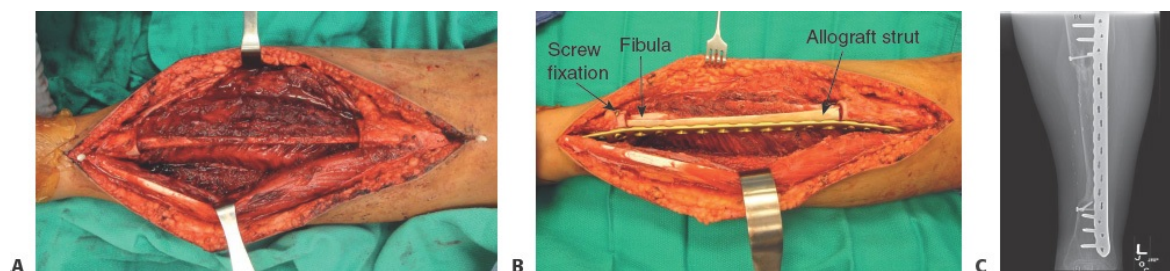
- Tourniquet is used at discretion of the surgeon by using gravity exsanguination rather than Esmarch to avoid tumor dissemination.
- A longitudinal incision is created that ellipses out the biopsy site. Skin flaps are created as needed to ensure adequate visualization of the tumor and critical anatomy (**TECH FIG 1A,B**).
- Soft tissue dissection around the tumor is performed with the following principles:
 - Adequate visualization must be achieved.
 - Margin of healthy tissue is kept on the tumor.
 - Nerves must be moved away from tumor. The epineurium may be used as margin if tumor abuts the nerve.
 - Vessels must be moved away from tumor; the adventitia may be used as margin if tumor abuts the vessels.
 - Single-vessel runoff to the foot may be acceptable depending on the extent of soft tissue and collateral circulation excision.
- Bone cuts are performed based on preoperative planning and measurements

to ensure complete tumor removal. Steinman pins may be inserted proximal and distal to bone cuts prior to osteotomy for the purpose creating reference points for leg length and rotation restoration (**TECH FIG 1C,D**).

- Alternatively, an external fixator may be applied prior to osteotomy to facilitate leg length and rotation restoration.
- Fluoroscopy may be used at the discretion of the surgeon.
- Hemicortical resection is an option if the tumor does not involve the entire diameter of the bone.
- Reconstruction is performed to restore mechanical stability of the extremity using one of the following options:
 - Endoprosthetic implants may be cemented or press fit into native bone.¹
 - Allografts are fashioned to fit the defect and secured in place with internal fixation.
 - Vascularized fibula may be inserted end-to-end to the native tibia or telescoped into the tibial canal to increase contact surface area (**TECH FIG 2A–C**).
 - A composite graft using vascularized fibula inserted into a structure allograft (Capanna technique) has the theoretical advantage of combining the structural support of a large allograft with the healing potential of a vascularized graft.²
 - Ilizarov technique for bone lengthening.³
- Allografts and endoprosthesis are at increased risk for infection; thus, aggressive soft tissue reconstruction is recommended to minimize risk of wound dehiscence resulting in exposed hardware.
- Often, primary closure is not possible, and a local rotational flap or free tissue transfer is used to reconstruct the soft tissues.



TECH FIG 1 • A. Intraoperative photograph of planned incision incorporating biopsy site. **B.** Dissection through skin and elevation of full-thickness flaps to visualize the extent of tumor. Steinmann pins are placed proximal and distal away from tumor as references for leg length and rotation. **C.** Bone cuts are made and muscle attachments released to allow excision of the tumor in its entirety. **D.** The ipsilateral fibula is dissected free keeping the flexor hallucis longus muscle and associated nutrient vessels attached. Notice that additional fibula length relative to defect is harvested to allow for intramedullary insertion.



TECH FIG 2 • A. Photograph showing fibula inserted into the proximal and distal ends of the tibia. **B.** The fibula is stabilized to the native tibia with internal fixation, and allograft strut is placed for additional support. **C.** Radiograph 14 months after surgery showing incorporation of the fibula and allograft to the native tibia.

PEARLS AND PITFALLS

Wound breakdown

- Dead space after tumor removal should be managed with drains, muscle flap, free tissue transfer, or a combination of these techniques.
- Have low threshold for aggressive soft tissue coverage.

Positive margins

- Appropriate preoperative planning is important to minimize risk of unplanned positive margins.
- Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings

Allograft nonunion/fracture

- May be minimized by good cortical apposition of graft to the native bone.
- Restrict weight bearing until evidence of bone healing is observed.
- Counsel patients that reoperation for nonunion is possible.

Malrotation/malalignment

- Provisional placement of internal fixation, reference pins, or external fixation away from tumor may be used to maintain anatomic alignment.

POSTOPERATIVE CARE

- Mobilization and weight bearing depend on the extent of surgery.
- Extremity elevation is recommended while the patient is in bed.
- Range of motion and therapy may begin after wound healing is sufficient.

- May administer antibiotics while drains are in place.

OUTCOMES

- Oncological outcomes include local recurrence and metastasis. Surveillance for recurrence should be managed by a multidisciplinary sarcoma team. Local recurrence is higher when margins are positive.
- Functional outcomes depend on the extent of tissue resection and patient overall health status. Most patients will experience some form of disability that is proportional to the volume of muscle and bone resected.
- Benevenia et al. showed an overall 27% nononcological complication rate for intercalary prosthesis and average 77% Musculoskeletal Tumor Society function score.⁴

COMPLICATIONS

- Allograft nonunion and fracture, endoprosthesis loosening, and infection are known complications and typically require additional surgery to achieve a limb salvage.
- Local recurrence occurs in a minority of patients and is more common in patients with positive margins.
- Malalignment of the reconstruction may occur and can be avoided by the use of provisional fixation prior to making bone cuts and intraoperative radiographs to ensure restoration of alignment and rotation.
- Deep infection can occur at any time after surgery and requires aggressive therapy including surgical debridement and antibiotic therapy to achieve limb salvage. Removal of implants and allografts is often necessary to eradicate infection.

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23 Debridement of Soft Tissue Infections of the Lower Leg

CHAPTER

L. Scott Levin Paul Magnuson, and Paulo Piccolo

DEFINITION

- The term *debridement* was coined by Joseph Pierre DeSault in the 18th century. The French term implies the removal of soft tissues and bone that are nonviable, with the goal of preventing infection. It is defined by the Oxford medical dictionary as the process of cleaning an open wound by removal of foreign material and nonviable tissue, so that healing may occur without hindrance.¹
- By removing molecular, physical, and microbiologic barriers to healing, debridement facilitates endogenous wound healing.

ANATOMY

- The lower extremity consists of four major regions: the hip, thigh, leg, and foot. It is specialized for support of body weight, adaptation to gravity, and locomotion.
- The thigh is divided in three compartments (anterior, posterior, and medial), and the leg is divided in four compartments (anterior, deep, superficial posterior, and lateral).

PATHOGENESIS

- Wounds may originate through a variety of causes, such as soft tissue infection (acute or chronic), trauma (thermal, electric, chemical, penetrating, or blunt), vascular issues (arterial, venous, or lymphatic), neuropathic (eg, diabetes), or malignancy.
- The pathogenesis of the wound will play a key role in the treatment plan. A wound from necrotizing fasciitis needs emergent attention and wide

debridement, as opposed to one caused by venous stasis, which can be dealt with in an ambulatory setting and may be amenable to a more conservative treatment approach.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history of present illness must be obtained. This is paramount in establishing the cause, timing, and clinical implications of that wound, the potential level of disability caused by it, and to plan further treatment.
- Patient's comorbidities such as obesity, diabetes, peripheral vascular disease, surgical history, nutritional status, previous trauma and, nicotine use should all be taken into account.
- A thorough physical exam of the extremity in question must be performed preoperatively, and many times, it should be completed in the operating room under anesthesia to minimize patient's discomfort and allow for a precise and thorough analysis of the area.
- Nerve integrity must be assessed before the patient is under anesthesia—both motor and sensory aspects must be checked from the proximal thigh to the distal toe.
- Peripheral pulses are of extreme importance when treating lower extremity wounds, as this will give vital information regarding limb perfusion, wound pathogenesis, and options for future reconstruction.
- Size and appearance of the wound, characteristics of the surrounding soft tissue, and skeletal stability of the extremity should also not be overlooked. The presence of exposed vital structures, including nerves, vessels, bones, and joints, must be appreciated and well documented on the patient's chart. The presence of foreign body on the wound bed must be ruled out (eg, a chronic wound caused by a retained piece of packing/dressing material).

IMAGING

- Preoperative imaging studies are not always mandatory but often provide valuable information to the reconstructive surgeon.
- Plain films are important to assess proper bony alignment in the setting of trauma or in acute infections to quickly assess for the presence of subcutaneous gas.
- Computed tomography (CT) with the aid of intravenous contrast (computed tomography angiography [CTA]) may determine proper vascularization to the extremity when there is any question regarding distal blood flow, be that acute

or chronic.

- Bone scans and magnetic resonance imaging (MRI) to assess for bone viability or osteomyelitis are important adjuncts when planning for debridement of a lower extremity wound with exposed bone.
- Other imaging modalities may aid the operating surgeon in evaluating vascularity of the bone such as PET scans.²

SURGICAL MANAGEMENT

- The decision to perform a surgical debridement of a lower extremity wound lies in the hands of the reconstructive surgeon.
- Before the era of free tissue transfer, debridement was often limited because removing questionable tissue could lead to exposure of vital structures, such as tendon devoid of paratenon, vessels, or nerves, and bone devoid of the periosteum. Surgeons were reluctant to make the traumatic defects larger by radical debridement. Subsequently, surgical techniques were more conservative, and healing by secondary intention with wound contracture, scar, and unstable soft tissues was the rule. Currently, free tissue transfer using large well-perfused flaps facilitates radical debridement and necrectomy (removal of dead tissue).

Preoperative Planning

- General anesthesia is preferred. If patient is not a suitable candidate for general anesthesia due to comorbidities, spinal anesthesia or regional block can be considered.



FIG 1 • Left lower extremity wound following high-energy trauma resulting in severe wound involving soft

tissue and bone. An external fixator was necessary for skeletal support due to severe bony comminution.

- As mentioned previously, a more thorough physical exam can be performed with the patient under anesthesia.
- Debridement should be performed with the use of the tourniquet. The tourniquet is inflated to 350 mm Hg after an Esmarch bandage is used to exsanguinate the limb. In cases of malignancy or infection, the use of the tourniquet is contraindicated. In these cases, elevating the leg for 5 minutes before inflating the tourniquet aids in limb exsanguination.
- In an ischemic operative field, it is simpler to distinguish between healthy and damaged tissues. The basic elements of this judgment are the appearance and consistency of the tissues. Healthy tissue in the exsanguinated field is bright and homogeneous in color. Subcutaneous tissue is yellow, muscles are bright red, and the tendons and fascia have a white and shiny appearance.
- Damaged tissues are recognized by the presence of foreign bodies, irregular tissue consistency, and irregular distribution of dark red stains, caused by hematomas or hemosiderin (**FIG 1**).
- Evaluating muscle viability may propose a challenge in some cases. Classically, the so-called 4 Cs—muscle color, consistency, contractility, and capacity to bleed—are generally used to assess muscle viability and guide debridement. Recent studies, however, show a potential tendency for normal muscle resection³ as the surgeon's impression of muscle viability does not correlate with histological findings of the debrided muscle in the majority of cases. Therefore, when large amounts of muscle appear of questionable viability in the first stage of debridement, a second trip to the operating room may be necessary to avoid over resection of viable muscle. This is in contrast with clearly necrotic muscle, which will be discussed further.
- Chronic wound
 - A: Chronic wounds present a different challenge to the surgeon. The presence of scarring in the wound bed may impair the surgeon's ability to appreciate important aspects of the wound such as occult infection, its true area and depth, and potential undermining and tunneling (**FIG 2**).
 - B: Due to the fact that these wounds remain open for a prolonged period of time, in addition to other factors such as poor blood flow and hypoxia, they are prone to become heavily colonized with bacterial or fungal organisms,

leading to biofilm formation (glycocalyx).



FIG 2 • Chronic right posterior ankle wound. One can appreciate the surrounding scarring and the exposed Achilles tendon with marked desiccation from prolonged exposure. Undermining may not be immediately appreciated, but further debridement may demonstrate tissue undermining and small pockets of fluid and nonviable tissue.

Positioning

- The patient is positioned supine on the operating room table.

Approach

- A “top-down” or “outside-in” approach to the debridement should be undertaken, starting with the skin and subcutaneous tissue, followed by the fascia and muscle, neurovascular structures, and bone.

TECHNIQUES

■ Sharp Debridement of the Acute Wound

- The patient is prepped with antiseptic solution and draped. The extremity is elevated (as described above), and the tourniquet is inflated to 350 mm Hg.
- Next, the wound is superficially washed gently with irrigating solution

usually attached to a cystoscopy tubing or through a bulb syringe to eliminate blood clots or superficial debris. Pulsed irrigation systems are advocated by some, but if used too vigorously with too high pressure or too close to tissue planes, particularly around tendons, nerves, and vessels, it can insufflate fascial planes, causing excessive tissue damage and increased edema. Furthermore, it may not be productive in removing bacterial contamination.⁴

- First, a no. 10 or no. 15 scalpel or sharp scissors are used to excise the skin and dermis, particularly around the edge of the wound, back to the normal tissue.
- Next, the subcutaneous layer is inspected, debrided sharply with a no. 10 or no. 15 scalpel to the level of the fascia. All fascia that is ripped, avulsed, or contaminated is then removed.
- The next layer encountered is the muscle. Necrotic muscle should be excised and removed from the wound bed regardless of the volume. Leaving unhealthy, necrotic muscle is most likely to result in subsequent infection. This is often difficult to assess in a crush injury or gunshot blasts where the zone of injury is less clearly defined (**TECH FIG 1**).
- Denuded tendon, if not frayed, should be cleaned or fixed with a suture to the surrounding tissue for later reconstruction.
- Severed vessels are ligated, provided they are of no significance in the viability of the injured extremity. If vessels are vital, they are excised to normal-looking margins, and continuity is restored with interposition vein grafts.



TECH FIG 1 • Left lower extremity wound caused by a gunshot resulting in severe soft tissue and bony

trauma. There is a large amount of injured muscle evidenced by the dark red stains, in contrast with likely viable muscle superiorly.

- The nerves are the only structures in which debridement is not radical. Those parts that are destroyed without any doubt are removed, and nerve stumps are tagged and anchored in the wound so as to avoid traction and allow later reconstruction with nerve grafts. We prefer that a large cystoclip or hemoclip be applied to the nerve stump so this can be seen on radiograph and appropriate secondary planning can be done in terms of surgical approach and location of the neuroma stump.
- The periosteum that is elevated from the bone should be excised to the level from which it is elevated. Small bone fragments devoid of the periosteum or free-floating large segments, although they may be of structural significance, should be removed for fear of colonization, contamination, and latent infection.
- At the conclusion of debridement, the wound is again irrigated and tourniquet is let down, and then all tissue planes, particularly muscle, are observed for bleeding as the arterial pressure increases in the limb.
- Areas that are persistently nonviable, particularly the dermis, skin, and muscle, are excised. Excision then can be done sequentially, watching for punctate bleeding from either the dermis or the muscle. If large flaps have been avulsed, excision is carried out through the skin to the level of bright red blood coming from dermis on incision.
- No attempt should be made to close the wound defect under any undue tension for fear of further ischemic damage to already compromised tissues.
- In cases of degloving injuries, the sequence of debridement remains the same; however, in the end of the procedure, the portions of the avulsed skin that appear viable may be used as a full-thickness graft after thorough in situ defatting with sharp scissors or blade and bolstered to the wound. Special attention is warranted in the postoperative period to ascertain skin graft take.⁵
- Avulsed flaps with impaired venous outflow may be salvaged with microsurgical venous anastomosis to more proximal veins.

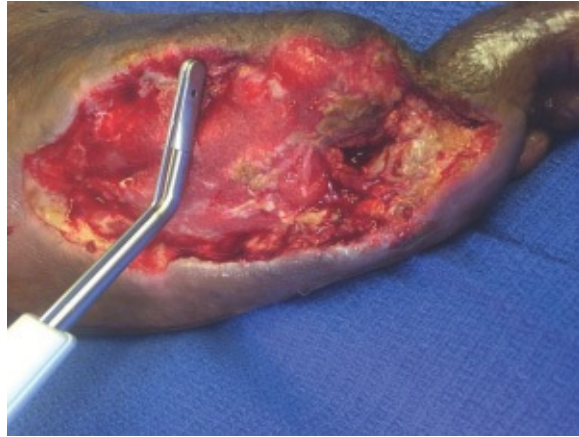
■ Debridement of the Chronic Wound

- Debridement of a chronic wound is also done with the limb exsanguinated with aid of a tourniquet.
- Superficial scar is excised completely so that the wound margins are in healthy skin and subcutaneous tissue appears normal. The goals are to treat the chronic wound like a tumor and excise it in its entirety down to normal tissue planes. All scar in the wound should be removed in the same manner as tumor surgeons operate; that is, the knife should always cut through healthy tissues.
- If a sinus tract is present or suspected, methylene blue dye may be injected to identify its limits and its course. This way the entirety of the sinus tract can be excised to its origin.
- If functionally important structures are entrapped in the scar, the dissection should commence in the healthy surrounding tissue, passing toward the scar entrapment, where the structures such as nerves or tendons are carefully dissected.
- All areas of the bone not covered with the periosteum are removed, and those that are exposed are burred with an iced saline bur. If punctate bleeding is encountered from the cortical bone, the bone is left behind. If not, the bone is removed until the so-called paprika sign, is identified. This is punctate bleeding from the Haversian canals and indicates bone viability.
- If there is sequestrum in the medullary canal, the anterior part of the bone cortex, such as in the anterior tibia, should be removed even if it is well perfused, to allow access to the medullary canal for placement of muscle flaps that eliminate dead space and help control infection.

■ Hydrosurgery System

- Recently, new modalities for wound debridement have emerged such as the use of hydrosurgery systems (VERSAJET, Smith & Nephew, London, UK). This novel modality allows accurate debridement of only unwanted tissue while precisely conserving viable structures for eventual repair. It employs a high-pressure water jet at 15 000 psi to create a Venturi effect, which eliminates debrided tissues in the water stream, extricating it from the underlying tissue (**TECH FIG 2**).⁶
- The cost-effectiveness of such systems is still controversial, and it may not be superior to conventional debridement so its use is left up to the surgeon's

preference and the capabilities of the facility in which he/she operates.



TECH FIG 2 • VERSAJET system for wound debridement.

■ Other Forms of Wound Debridement

- Many other forms and mechanisms for debridement have been described but are beyond the scope of this chapter such as biodebridement using maggots, enzymatic debridement using topical products such as collagenase, newer technologies such as ultrasound therapy, and plasma-mediated bipolar radiofrequency ablation.⁷
- These methods are measured against the current reference standard, which is the sharp debridement technique described, and the method of choice for a particular wound depends on various factors such as type, size and position of wound, quantity and character of the exudate, patient tolerance, cost-effectiveness and available equipment, and expertise of the treatment team.

PEARLS AND PITFALLS

Use of tourniquet

- The use of tourniquet decreases the amount of blood loss during the procedure.
- The use of Esmarch bandage is not necessary and sometimes discouraged (eg, presence of infection or malignancy) as elevating

	the extremity for approximately 5 minutes should exsanguinate the extremity satisfactorily.
Hemostasis	■ Thorough hemostasis is performed after tourniquet is let down and arterial pressure rises.
Necrotic muscle	■ Muscle that appears clearly necrotic should be excised. Leaving necrotic muscle behind is the surest way to acquire an infection.
Loupe magnification	■ Use of loupe magnification helps the operating surgeon better identify structures during the debridement. It also aids in differentiating between viable and nonviable tissues.
Technique	■ The surgeon should approach the debridement as one would a tumor, ie, excise its entirety down to healthy tissue.

POSTOPERATIVE CARE

- An occlusive dressing is applied according to the surgeon's preference. Dressing changes should be performed on a daily or every-other-day basis.
- Patient's comfort is of paramount importance, so proper postoperative pain control should be optimized and depending on size and location of the wound; dressing changes have to be performed in the operating room under sedation or general anesthesia.
- Wound surfaces must be continually moistened and tissue desiccation must be prevented.
- The use of splints may aid in postoperative comfort and should be considered for the postoperative period.
- Elevation of the limb is of utmost importance to decrease the amount of edema and aid in limb circulation.
- Finally, one should take care of the “whole patient, not the hole in the patient”—proper medical optimization, nutrition assessment, and physical rehabilitation must be arranged as part of the postoperative regimen.

OUTCOMES

- The primary outcome is wound healing. This may not be achieved by debridement and closure alone.
- Depending on the size and etiology of the wound, further treatment may be warranted. Frequent dressing changes, application of biomaterials, or coverage with a skin graft or flap may be necessary and are used at the discretion of the treatment team.

COMPLICATIONS

- Nonhealing wound. This may be caused by inadequate debridement of necrotic tissues or foreign bodies, persistent contamination, underlying metabolic disorder, noncompliance with postoperative care, or any other number of factors.
- Secondary infections. This is caused mainly by failure to debride necrotic tissue or to remove colonized foreign body from the wound bed, which serves as substrate for microorganism superinfection.

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DEFINITION

- Trauma and neoplasia, requiring segmental bone resection, are the most common causes for segmental defects of the tibia.
- Radiation-induced bone necrosis and infection, namely osteomyelitis, is also an indication for resection and possible reconstruction.
- Reconstruction requires technical expertise, careful operative planning, and a detailed understanding of the problem at hand.
- Large commitment by both the patient and the physician is paramount due to long complex rehabilitation period.
- Options for reconstruction include either allograft or autograft material, most commonly a vascularized fibular graft.
- Allografts were initially used but were associated with considerably high rates of complications and failures.
- The concept of reconstruction of the tibial shaft with a vascularized fibular graft was first suggested by Chacha and colleagues in 1981.¹ They used the ipsilateral fibula as a vascularized pedicle graft for nonunion of the tibia.
- It has since been shown to be a viable and reliable technique for tibial reconstruction.
- The main advantage of using a vascularized autograft for tibial reconstruction is the ability to use the normal biology of bone healing for incorporation rather than relying on creeping substitution innate to prosthetic material/nonvascularized graft use.
- The vascularized fibular graft undergoes hypertrophy overtime in response to continuous pressure load, which translates to remarkable long-term

durability.²⁻⁴

- Factors that make the fibula an optimal source for a vascular graft are as follows:

- Anatomic accessibility
- Independent blood supply
- Relatively dispensable in lower extremity function
- Capability to hypertrophy overtime in response to pressure

ANATOMY

- The tibia is the second largest bone in the human body, after the femur.
- Relevant leg anatomy includes four compartments (anterior, posterior, superficial, and deep posterior) (**FIG 1**).
- The tibia is the stronger of the two bones in the lower leg. It is found on the medial side and is connected to the fibula by the interosseous membrane. It forms a type of fibrous joint called syndesmosis with very little movement.

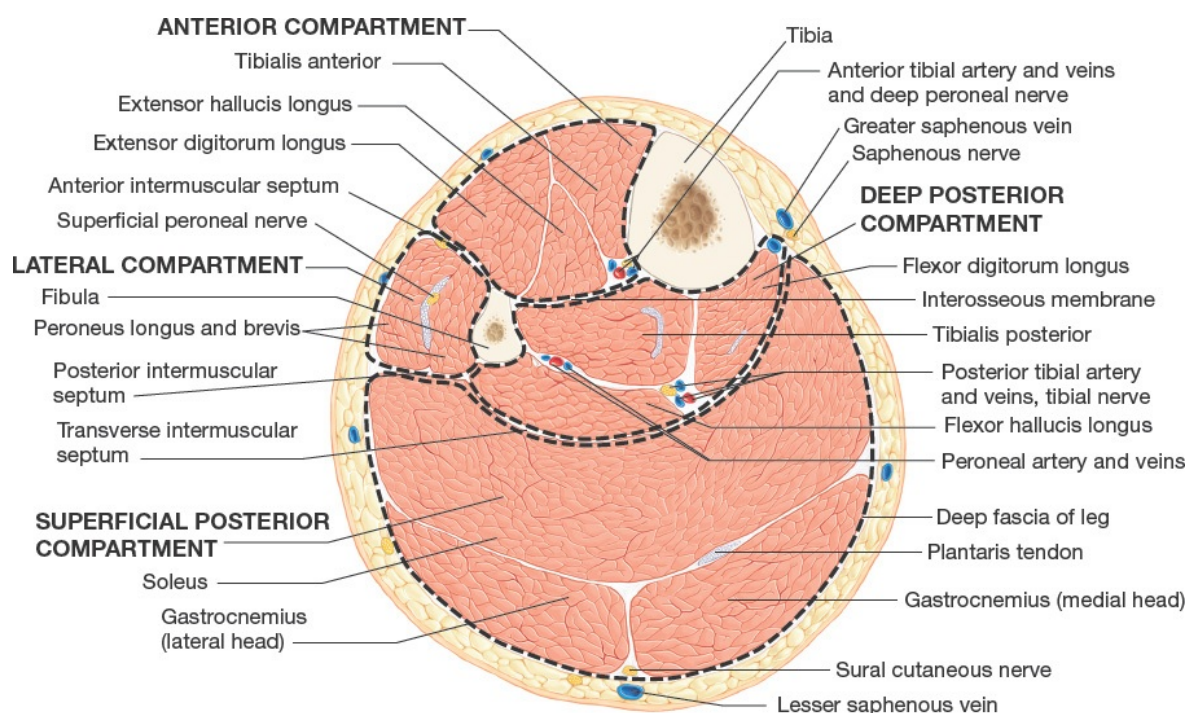


FIG 1 • Cross-sectional anatomy of four compartments at the midtibial level.

- The blood supply to the tibia is derived from a main nutrient artery and periosteal branches derived from the anterior tibial artery.

- The fibula is a long and thin cortical bone with a small medullary component. In adults, the width of the fibula is 1.5 to 2 cm with a length of 35 cm of which approximately 25 cm of the fibular diaphysis can be harvested for free grafting.
- Vascular supply to the diaphysis of the fibula is via a dominant nutrient endosteal artery and minor musculoperiosteal branches from the peroneal artery and veins. These vessels run parallel to the fibula and course between the flexor hallucis longus (FHL) and tibialis posterior muscle group.
- The dominant nutrient artery branches 6 to 14 cm from the peroneal artery bifurcation and enters the fibula posterior to the interosseous membrane. It then courses into the nutrient foramen located in the middle third of the diaphysis and further divides into an ascending and descending branch.
- Musculoperiosteal vessels are derived from the peroneal artery and travel within the posterolateral septum, through the flexor hallucis longus and tibialis posterior muscle, giving segmental rise to four to eight branches that supply the muscles in the anterior compartment, soleus muscle, and lateral leg skin territory. The majority of the periosteal branches are located in the middle third of the fibula.
- Soft tissue defect coverage is achieved with a skin paddle supplied by perforators traversing through the posterior crural septum with the majority concentrating at the proximal and distal ends of the fibula. These fasciocutaneous perforators supply a skin paddle up to 10 × 20 cm in size.⁵

PATIENT HISTORY AND PHYSICAL FINDINGS

- Detailed preoperative evaluation is required for patients undergoing extensive long bone resection and intercalary bone defect reconstruction.
- Determination should first be made as to whether reconstruction or salvage is a viable option.
- General health status should be carefully evaluated. An extensive reconstructive effort should not be undertaken on a patient with an overall poor health status.
- The patient should have the ability to be compliant with both treatment and rehabilitation.
- Pertinent history includes the presence of significant comorbidities such as deep venous thrombosis, peripheral vascular disease, lymphedema, trauma, venous insufficiency, diabetes, or social history such as smoking.
- Special attention should be to consider cardiovascular, surgical, or hematologic diseases that may affect peripheral blood flow.

- Physical exam should include a lower extremity and vascular examination. This includes an evaluation of knee and ankle joints for range of motion and laxity and a foot Allen test with a Doppler probe to assess dorsalis pedis and posterior tibial arteries.
- Peronea arteria magna is a congenital variant of the arterial inflow to the foot that affects about 1% to 8% of the population, where both the anterior and posterior tibial arteries are hypoplastic or absent with the peroneal artery serving as the single arterial supply below the knee. The artery may need to be reconstructed with a vein graft, or the other leg should be inspected.
- Patients with an abnormal vascular exam or a history of trauma to the affected extremity will need additional preoperative imaging such as computed tomography angiogram (CTA), duplex ultrasound, or magnetic resonance angiography (MRA) to identify atherosclerotic occlusive disease or congenital anomalies.

IMAGING

- Preoperative imaging of both the recipient and donor sites should include an evaluation of:
 - Recipient site:
 - The extent of bone resection, length and diameter of the intercalary defect, and potential soft tissue defect (**FIG 2**). This allows the surgeon to determine the extent of the tumor burden, traumatic bone loss, or chronic osteomyelitis and plan for reconstructive options.
 - Donor site:
 - Evaluate vascular supply with Doppler ultrasound (anterior tibial, posterior tibial, and dorsalis pedis arteries), and exclude any fibular deformities.
 - Angiogram to look for vessel patency and flow to the foot

SURGICAL MANAGEMENT

Preoperative Planning

- Determination must be made as to whether limb salvage is a viable option.
- Taking into account patient factors and the extent of disease and/or resection is imperative in determining the need for tibial reconstruction vs amputation.
- Assessment of defect must include the need for bone, muscle, and skin; all of which free fibular graft can provide.
- Four centimeters of bone must be left proximally, whereas 6 cm must be left at

the distal portions of the fibula for knee and ankle stabilization, respectively. Therefore, the maximum length of the graft obtainable will be the length of the donor tibia less 10 cm.

- Donor site should be the contralateral leg if used as a free flap. This allows for simultaneous preparation of recipient site during fibula harvest and avoids the use of potentially injured/involved donor site where the fibula may have been fractured in the setting of trauma.

Positioning

- Positioning depends mainly on the recipient site, as the fibula can be harvested in both supine and lateral positions.
- For contralateral free fibula flap harvest, the proper positioning facilitates two teams to work together for recipient preparation and donor dissection simultaneously (**FIG 3**).
- In a supine position, a roll is placed under the ipsilateral hip, and the patient's knee is bent to 90 degrees.



FIG 2 • Preoperative MRI showing left proximal tibial osteosarcoma.

- A heel stop can be placed on the operative room table to help knee at 90 degrees when harvesting in the supine position.
- If the patient is in a prone position, a roll is placed under the anterior ipsilateral hip, and bending of the leg is not required.
- All pressure points should be carefully padded and protected.



FIG 3 • If the contralateral fibula flap is desired, the patient can be placed in a supine position, which allows two teams to work simultaneously for recipient preparation and donor site harvest.

Approach

- Multidisciplinary team approach is taken involving both plastic surgeons and orthopedic surgical teams to coordinate resection of the involved tibial bone and reconstruction of the ensuing intercalary defect.
- Careful planning of the incision for the exposure is necessary for flap harvest and inset without compromising the skin envelope for coverage.
- Tibial reconstruction can be achieved with free or pedicled fibula graft, in a single- or double-barrelled fashion.
- Reconstruction of smaller intercalary defects up to 13 cm can be achieved with double-barrelled fibular flap, keeping the arterial blood supply intact while performing an osteotomy in the fibula flap.
- If a pedicled flap is desired, the ipsilateral leg will be used for both harvest and

inset. The advantages of pedicled flaps are that microvascular anastomosis is unnecessary, and distant donor-site morbidity is avoided, which can occur with free fibula graft.⁶

- Intraoperative preparation of the fibula flap includes marking of anatomical landmarks: head of the fibula, lateral malleolus, and anterior and posterior fibular border (**FIG 4**).
- If a skin deficit is present either in the setting of tumor/chronic osteomyelitis resection or trauma, a skin paddle can be harvested with the fibular flap sharing the same vascular pedicle, which facilitates early detection of flap compromise and provides tension-free skin closure of recipient site.
- A perforator is marked on the proposed skin paddle using intraoperative Doppler localization along the posterior border of the fibula, corresponding to the posterior intramuscular septum.



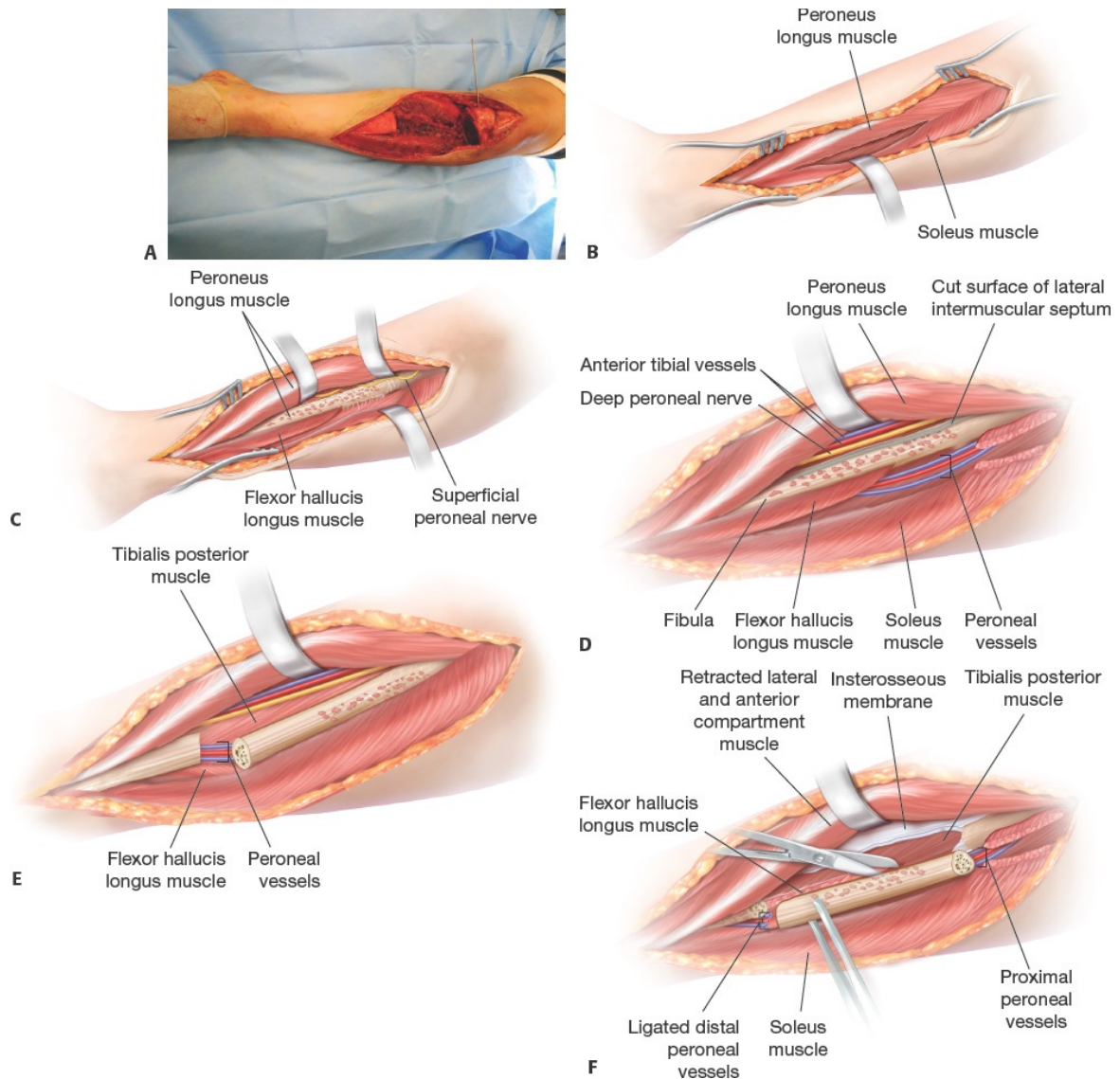
FIG 4 • Intraoperative marking of anatomical landmarks for a contralateral fibula harvest: head of the fibula, lateral malleolus, anteroposterior fibular border, and skin paddle if needed.

TECHNIQUES

■ Free Fibula Flap

- After the tibial bone resection is completed by the orthopedic surgical team, the dimensions of the intercalary bone defect are measured (**TECH FIG 1A**).

- Prior to flap harvest, a sterile tourniquet is placed on the midthigh while avoiding compression over the fibular head and common peroneal nerve.
- Using marked anatomical landmarks, a midlateral vertical incision is made over the fibula, and skin flaps are elevated at the level of the fascia.
- Dissection is carried through the investing fascia of the lateral compartment, anterior to the posterior intermuscular septum (**TECH FIG 1B–D**).
 - Care should be taken to preserve fasciocutaneous perforators traveling through the posterior intermuscular septum if a skin island is needed for osteocutaneous flap.
- During proximal dissection, identify and preserve the common peroneal nerve traversing around the head of the fibula to become the superficial peroneal nerve.
- The peroneal muscles are dissected off the anterior surface of the fibula and reflected anteriorly to expose the anterior intermuscular septum. After incising the septum to gain access to the anterior compartment, reflect the extensor digitorum and hallucis muscles to identify and preserve anterior tibial vessels and deep peroneal nerve.
- The interosseous membrane is incised to enter the deep posterior compartment, and the peroneal vessels are located between tibialis posterior and flexor hallucis longus muscles.
- Next, the peroneal vessels are identified proximally and distally, and dissection is propagated circumferentially around the fibula and staying medial to the vessels using a large right angle clamp. The vascular pedicle should be maintained during dissection.
- After adequate length of the fibula is marked for reconstruction, towel clamps are used to apply lateral traction on the proximal and distal fibula while osteotomizing with an oscillating saw or Gigli saw. A strip of periosteum overlying the osteotomy site should be included to overlap the osteotomy sites at the recipient site.
- Prior to performing osteotomy, a microvascular clamp can be applied to the peroneal artery distal to the osteotomy site to ensure adequate supply to the foot and then divided (**TECH FIG 1E**).



TECH FIG 1 • A. Intraoperative photograph of the left intercalary defect remaining after the tumor resection. **B.** Exposure of peroneus longus and soleus at the midtibial level. **C.** Dissection around the fibula and lateral muscle compartment. Proceed dissection proximally to identify and protect the superficial peroneal nerve. **D.** Dissection proceeds anterior to the fibula through the anterior intermuscular septum and protects the deep peroneal nerve and anterior tibial vessels. **E.** After the distal fibula osteotomy, the peroneal vessels should be ligated distally, which are

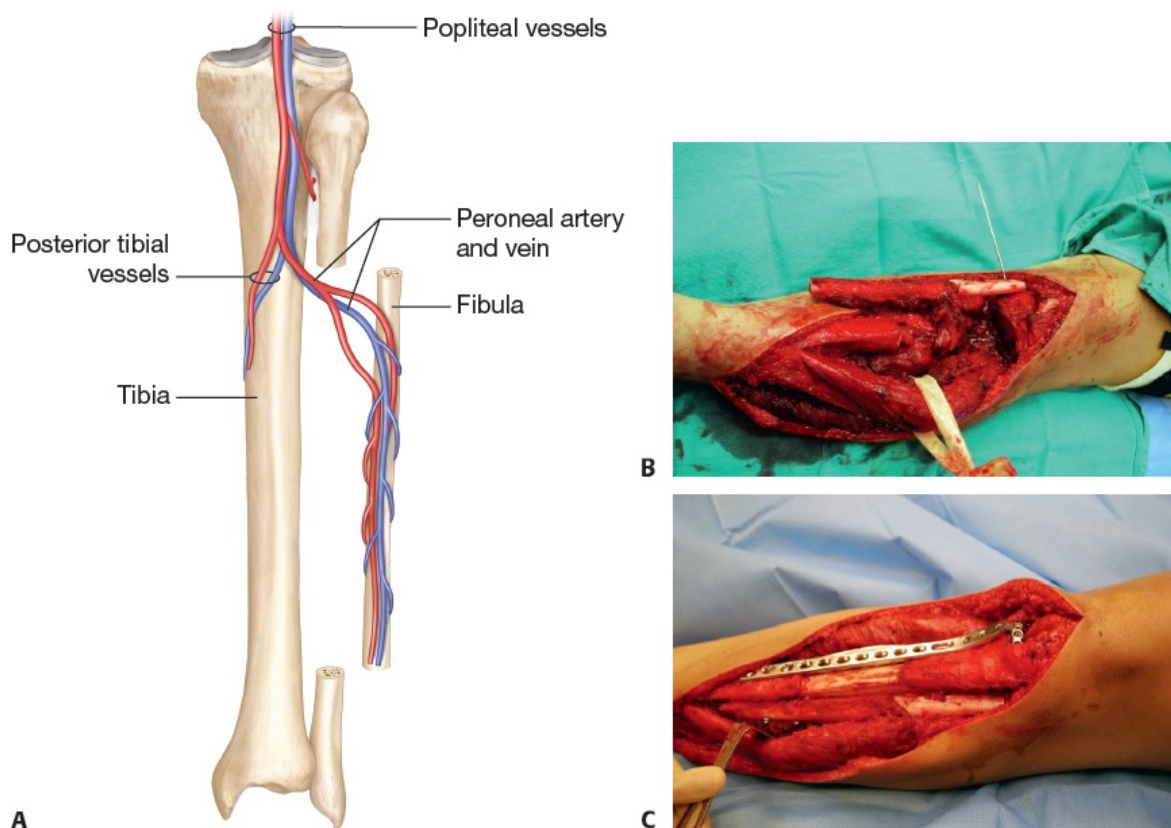
located between FHL and tibialis posterior muscle groups. **F.** Adequate fibula length is freed, and proximal osteotomy is performed carefully while protecting the pedicle vessels.

- The vascular pedicle is dissected starting distally, carried proximally up to the origin of tibioperoneal trunk, and ligated with approximately 2 to 6 cm of pedicle length.
- After the fibula graft is fully mobilized with the pedicle (**TECH FIG 1F**), the tourniquet is released with robust arterial inflow and venous outflow and healthy back bleeding from both the periosteum and intramedullary canal.
- An osteomuscular flap can also be harvested in similar fashion to include soleus and flexor hallucis longus muscles. This can aid in filling the dead space in patients with extensive soft tissue defect.
- If the distal osteotomy is close to the lateral malleolus, a screw fixation to the tibia can be utilized to prevent valgus deformity and ankle instability, which is more important in pedicle flap.
- In a clean and well-vascularized recipient bed, the proximal and distal tibial should be stabilized, and the medullary cavities should be prepared to receive the free fibula graft.
- The free fibula graft is then telescoped into the intercalary defect. Next, the graft is anchored to the tibia proximally and distally with long compression plates and screws spanning the bone defect. During this step, care is taken to prevent any damage to the peroneal vessels.
- Standard microvascular anastomosis is performed between the recipient vessels and peroneal artery and accompanying venae comitantes. Additionally, several fat grafts can be placed around the pedicle in an effort to prevent compression.
- After skin closure, a well-padded posterior leg splint is applied to keep the foot in extension to prevent an equinus deformity.

■ Pedicled Fibula Graft

- The recipient site defect is measured to estimate the length of the fibula required for reconstruction (see **TECH FIG 1A**).

- If the fibula flap is to remain pedicled (**TECH FIG 2A**), the flap is raised in standard fashion, but the proximal vascular pedicle is not ligated (**TECH FIG 2B**).
- The vascularized fibula flap is then transported through the space created between the tibialis posterior muscle and the tibialis anterior muscle.
- The distal-most segment of the bone will be used for the reconstruction. It can either be transposed or reversed, but whichever way the flap is oriented, it needs adequate pedicle length.
- If the fibula is reversed and rotated 180 degrees, the pedicle will make a U-turn, and care needs to be taken not to kink the pedicle on inset.

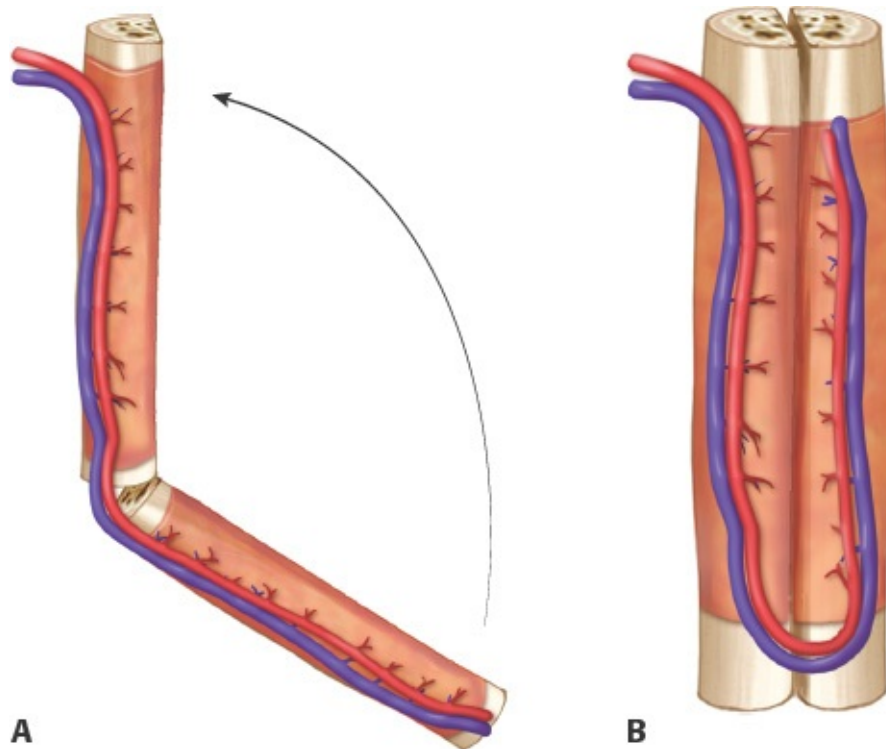


TECH FIG 2 • A. Illustration of pedicled fibula graft with intact peroneal vessels. **B.** Intraoperative photograph of an ipsilateral pedicled fibula graft. **C.** Intraoperative photograph showing an allograft spanning the defect and an onlay fibula graft being stabilized with long compression plates and screws.

- Additionally, if the length of the vascular pedicle of the graft is expected to be inadequate, it is necessary to harvest the graft as far from the base of the pedicle as possible and separate the periosteum with the vascular pedicle to make a longer vascular pedicle.
 - Once inset as an interposition graft, bone fixation of the fibula graft is achieved with long compression plates and screws traversing the tibial defect.
 - Alternatively, an allograft can be used as an interposition graft spanning the intercalary defect with an onlay fibula graft as a buttress, which can provide greater stability (**TECH FIG 2C**).
-

■ Double-Barrelled Fibula Technique

- Blood supply to the fibula is both endosteal and periosteal.
- This technique is useful for proximal tibial reconstruction when the defect is shorter than 13 cm.
 - Larger defects will not be able to be reconstructed with a single fibula in a double-barrelled fashion; both fibulas would be required, and the second fibula would need to be as a free fibula flap.
 - Additionally, this method provides two segments of bone, which doubles the cross-sectional area of the flap but only requires one anastomosis.
- Following the harvest, the graft is osteotomized at the midpoint, taking care to avoid the peroneal vessels (**TECH FIG 3**).
- At the site of the proposed osteotomy, the vascular pedicle is carefully elevated off the bone flap in the subperiosteal plane with an elevator over a segment of 2 to 3 cm, which will allow a malleable retractor to be placed to protect the pedicle.
- The graft is osteotomized at the midpoint and folded, with care taken to preserve the peroneal vessels.



TECH FIG 3 • In the double-barrelled fibula repair, free fibula is harvested with the peroneal vessels intact. The graft is then osteotomized at the midpoint and folded.

PEARLS AND PITFALLS

Peronea arteria magna

- A congenital variant of the arterial inflow to the foot, where both the anterior and posterior tibial arteries are hypoplastic or absent with the peroneal artery serving as the single arterial supply below the knee.

Injury to common peroneal nerve

- The nerve courses inferior to the head of the fibula and should be identified during proximal dissection to prevent injury.

Careful dissection

- Preserve the posterior intermuscular septum, which carries perforators to the skin paddle.

of skin perforators

Joint instability

- At least 4 cm of fibula bone is preserved proximally to preserve the stability of the knee.
- At least 6 cm of fibula bone is preserved distally above lateral malleolus to preserve stability of the ankle.

POSTOPERATIVE CARE

- Recipient and donor sites should be monitored during the postoperative period for vascular insufficiency and signs of free flap compromise, which can be monitored if a skin island is harvested.
- Flap function can be monitored with a combination of clinical exam and a Doppler probe every hour during the first 24 hours. The flap patency should be assessed until patient discharge.
- Initially, patients should be advised no weight bearing on the surgical limb up to 2 weeks. Afterward, partial weight bearing can be resumed with assistance and progressed to full weight-bearing status after bone union.

OUTCOMES

- Union time can range from 3 to 7 months.
- Union rates upward of 75%.
- Ambulation: all patients (100%) at an average 9.5⁵ to 14.3 months⁷.
- Joint stiffness (40%) and pain (18%) are frequent⁸.
- Fibular hypertrophy occurs secondary to microfractures and callous formation.

COMPLICATIONS

- Recipient site
 - Loss of flap primarily caused by vascular thrombosis
 - Nonunion
 - Infection
 - Hardware malfunction
- Donor site
 - Inability to flex the great toe due to damage to flexor hallucis longus:
 - Knee or ankle joint instability with secondary pseudoarthrosis
 - Common peroneal nerve injury

ACKNOWLEDGMENTS

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25 Soft Tissue Coverage of Lower Leg—Free Flap

CHAPTER

Goo-Hyun Mun and Kyong-Je Woo

DEFINITION

- Microvascular free flap transfer is a reliable and often ideal option for soft tissue reconstruction of a complex or large wound of the lower leg.
- The goal of reconstruction is to provide durable soft tissue coverage to maximize bony union in a traumatic wound and functional recovery and to restore the aesthetic contour of the lower leg.

ANATOMY

- Three main arteries branching from the popliteal artery are potential recipient vessels for microvascular free flap transfer for soft tissue coverage of the lower leg: the anterior tibial, posterior tibial, and peroneal arteries (**FIG 1A–E**).
- Apart from the concomitant veins of the named arteries of the lower leg, the two major superficial veins, which are the long (great) and short (small) saphenous veins, may be used as recipient veins. The superficial veins run superficial to the fascia cruris (deep fascia) of the lower leg (**FIG 1F**).
- Sizable perforators to the overlying skin derived from any of the three major vessels can also be recipient vessels when they are found near the defect.^{1,2}
- The specific recipient vessels are chosen according to the site of the defect.
 - Upper third of the lower leg: the upper third of the lower leg is technically the most difficult zone for microvascular repairs because of the deep location of major vessels. A long vein graft from the flap passing proximally to the side of the femoral artery was commonly used in the past. However, sural vessels (**FIG 2**) and the reversed descending branch of the lateral circumflex femoral vessels can also be effective recipient options in this region.³
 - Middle third of the leg: the anterior tibial vessels are often used because the

vessels become more superficial as they descend (**FIG 3**). The posterior tibial arterial and venous system may be easily exposed after retraction of the soleus muscle when the defect is on the medial side of the leg (**FIG 4**).

- Distal third of the leg: distal branches of all three major vessels are easily accessible in this region because there is less overlying soft tissues, which also makes them more susceptible to injury in traumatic defects. The peroneal artery or its terminating calcaneal artery can also be used in the lateral region of the leg (**FIG 5**). Perforators from the peroneal artery can be used as recipient vessels in the lateral region (**FIG 6**).

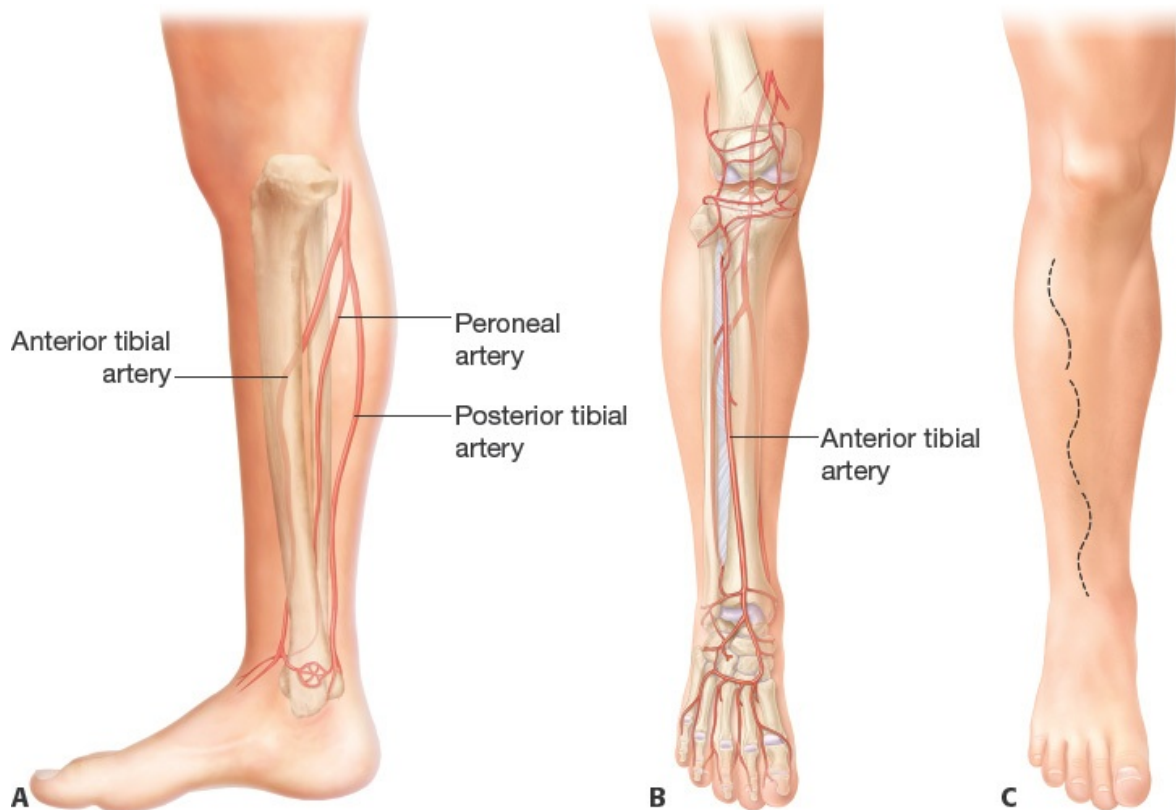




FIG 1 • Main arteries and veins of the lower leg and incisions for exposure of recipient vessels. **A.** Three named arteries of the lower leg. **B.** Anterior tibial artery. **C.** Incisions for exposure of the anterior tibial artery. **D.** Incisions for exposure of the posterior tibial artery. **E.** Incisions for exposure of the peroneal artery. **F.** Long (A) and short (B) saphenous veins.

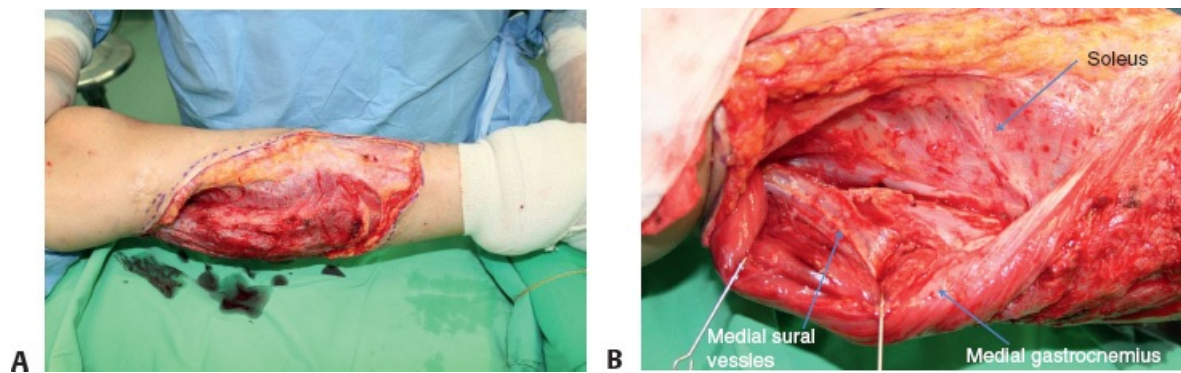


FIG 2 • **A,B.** Medial sural vessels as recipient vessel.

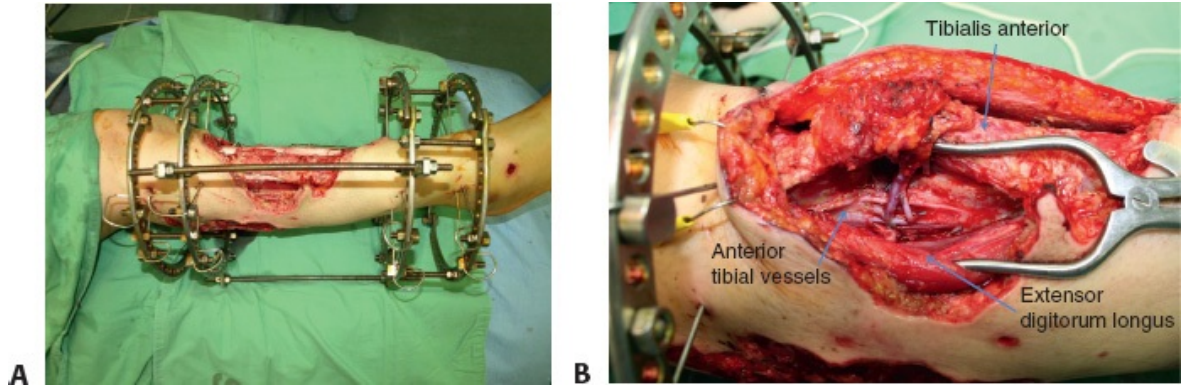


FIG 3 • A,B. Anterior tibial vessels for recipient vessel.

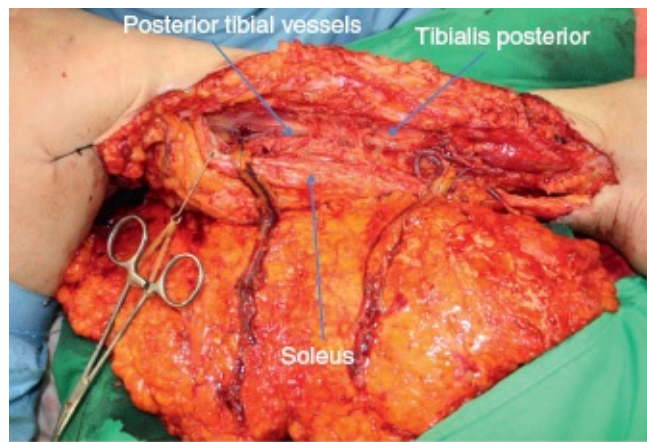


FIG 4 • Posterior tibial vessels for recipient vessel.



FIG 5 • Peroneal vessels for recipient vessel. **A.** Peroneal vessels. **B.** Muscle chimeric TDAP perforator flap. **C.** After inset of the flap.

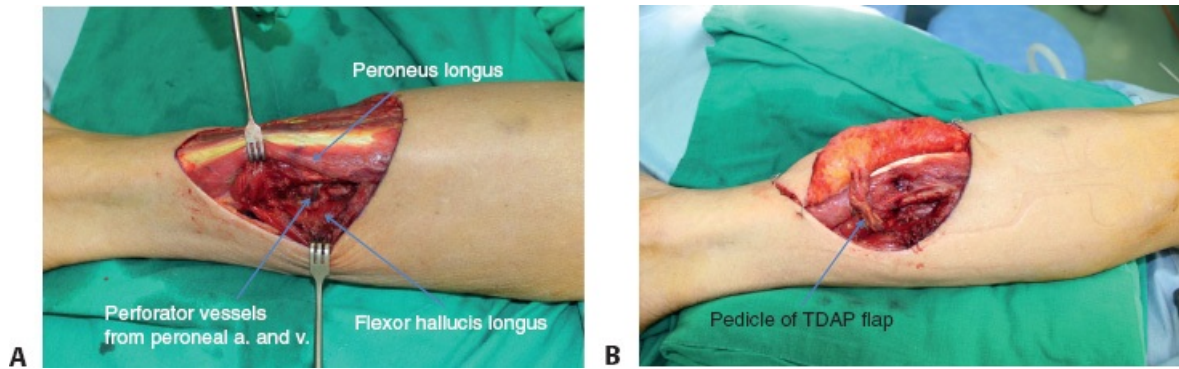


FIG 6 • A,B. Peroneal artery perforators for recipient vessel.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A multidisciplinary approach with comprehensive communication between the oncologist and/or orthopedic surgeon will allow better treatment outcomes.⁴
- Preoperative planning should be carried out by considering anticipated defect size, location, vascular anatomy, and comorbid conditions related to the outcomes of reconstruction.

IMAGING

- The authors routinely perform preoperative CT angiography to delineate the vascular anatomy of the lower extremity except when it is contraindicated.
- Detailed information of the vascular status helps determine proper reconstruction options and recipient vessels, which ultimately decreases the risk of reconstruction failure in the free flap transfer.⁵

SURGICAL MANAGEMENT

- Soft tissue stability and long-term durability are of paramount concern in the reconstruction of the lower leg.
- The simple method is not always the best and often, a more complex method of reconstruction, such as the free flap, is initially chosen to obtain better functional and aesthetic outcomes.
- Elaborate preoperative planning regarding recipient vessels, donor site, flap composition (cutaneous, fasciocutaneous, musculocutaneous, chimeric, composite flap), and positioning of the patient during the surgery is crucial for successful soft tissue reconstruction of the lower leg. A muscle chimeric perforator flap is useful for filling dead spaces created by soft tissue loss (**FIG**

5).⁶

- Vascular complications are significantly higher if anastomoses are carried out in the zone of injury, due to inflammation and trauma to recipient vessels. A sufficiently longer pedicle or vessel graft may be necessary to reach normal suitable vessels.
- Donor site morbidity should also be considered in the preoperative planning. The donor site that permits primary closure of the donor defect is always favored over the ones that require skin grafting. The exact measurement of the shape and size of the defect is valuable for donor tissue economy and acceptable aesthetic results at the recipient site. A customized flap may be effectively designed by using paper or transparent plastic template based on the final defect shape.
- The flap thickness can be controlled by defatting of the perforator flap at the time of inset, which facilitates aesthetic reconstruction. On the other hand, flap thickness can be controlled secondarily when tissue edema resolves completely.
- Fasciocutaneous flap vs muscle flap in contaminated wounds: A previous animal study demonstrated that muscle flaps have advantages over the fasciocutaneous flap for contaminated wounds.⁷ However, recent studies show that there is no difference in bacterial eradication and quality of wound healing between muscle and fasciocutaneous flap use.^{8,9}
- There is a controversy regarding how early a soft tissue defect should be closed in lower extremity trauma. Early definitive soft tissue coverage may be necessary where vital structures such as blood vessels and peripheral nerves or hardware are exposed.¹⁰ The recent advent of negative pressure wound therapy has helped provide additional time for better delineation of nonviable tissues before final reconstruction in large, complex open wounds.¹¹

Preoperative Planning

- Vascular anatomy and degree of atherosclerosis are evaluated by preoperative CT angiography (**FIG 7**).
- Donor site and components of the flap are often decided preoperatively according to predicted defect size, location, type of tissue requirement, required pedicle length, surgeon's expertise, and patient preference.
- Rectus abdominis, latissimus dorsi, and the gracilis muscle flaps have been commonly used for lower leg reconstruction. Popular cutaneous or

fasciocutaneous flaps for lower leg reconstruction are the radial forearm, sural, anterolateral thigh, and thoracodorsal artery perforator (TDAP) flaps.^{8,12–14} Each flap has its advantages and disadvantages.



FIG 7 • CT angiography of the patient described in the surgical technique in the text. All three main vessels of lower legs are patent, and no atherosclerosis or vascular occlusion exists in both lower legs.



FIG 8 • Positioning of the patient when the flap is to be harvested from the ipsilateral back.

Positioning

- Patient position is influenced by the donor site selection and planned recipient vessel approach. The lateral decubitus position is convenient for harvesting flaps from the back nourished by the subscapular vascular tree. When the

medial approach is used for the recipient vessel, such as the posterior tibial vessel or medial sural vessel, the contralateral side of the back is the favored donor site. When the anterior or lateral approach is to be used for the anterior tibial artery or peroneal artery branches, it is better to harvest the flap from the ipsilateral back, which helps to avoid patient repositioning during the free flap surgery (**FIG 8**).

- A tourniquet is usually applied on the thigh during defect preparation including debridement and recipient vessel approach.

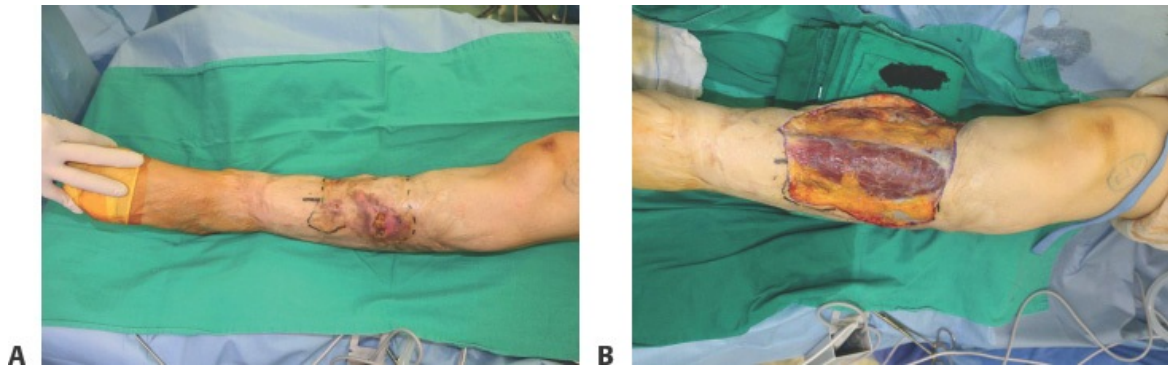
TECHNIQUES



Video p7-c025

■ Wound Preparation

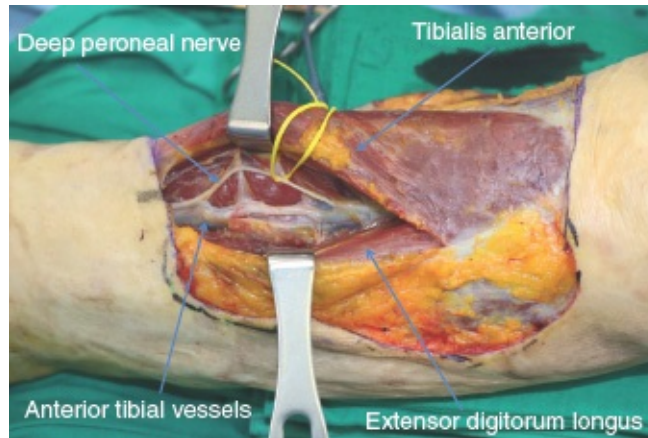
- Recipient vessel decided on preoperative planning is checked for patency using a handheld audible Doppler.
- The ultimate defect is made by the complete debridement or excision of pathologic, necrotic, or infected tissues under tourniquet control (**TECH FIG 1**).
- Limited undermining of the skin flap around the wound margin is performed to facilitate subsequent flap inset.



TECH FIG 1 • A,B. Wound preparation for free flap reconstruction.

■ Recipient Vessel Preparation

- Approach to recipient vessels
 - When the defect is extensive such as in oncologic resection or located in the distal lower leg over the course of the major vessel, the recipient vessel can be harvested directly inside the wound, which is advantageous for avoiding added incisional scars.
 - An incision extending from the defect may be used when the adjacent recipient vessel is to be utilized. A separate incision with subcutaneous tunneling may be effectively employed for distant recipient vessel approach.
- Anterior tibial vessels are exposed through a dissection through the intermuscular septum between the tibialis anterior and extensor digitorum longus muscles (**TECH FIG 2**).
- The deep peroneal nerve is carefully separated from the anterior tibial artery and veins.



TECH FIG 2 • Recipient vessel preparation. Anterior tibial vessels are exposed through a dissection through the intermuscular septum between the tibialis anterior and extensor digitorum longus muscles.

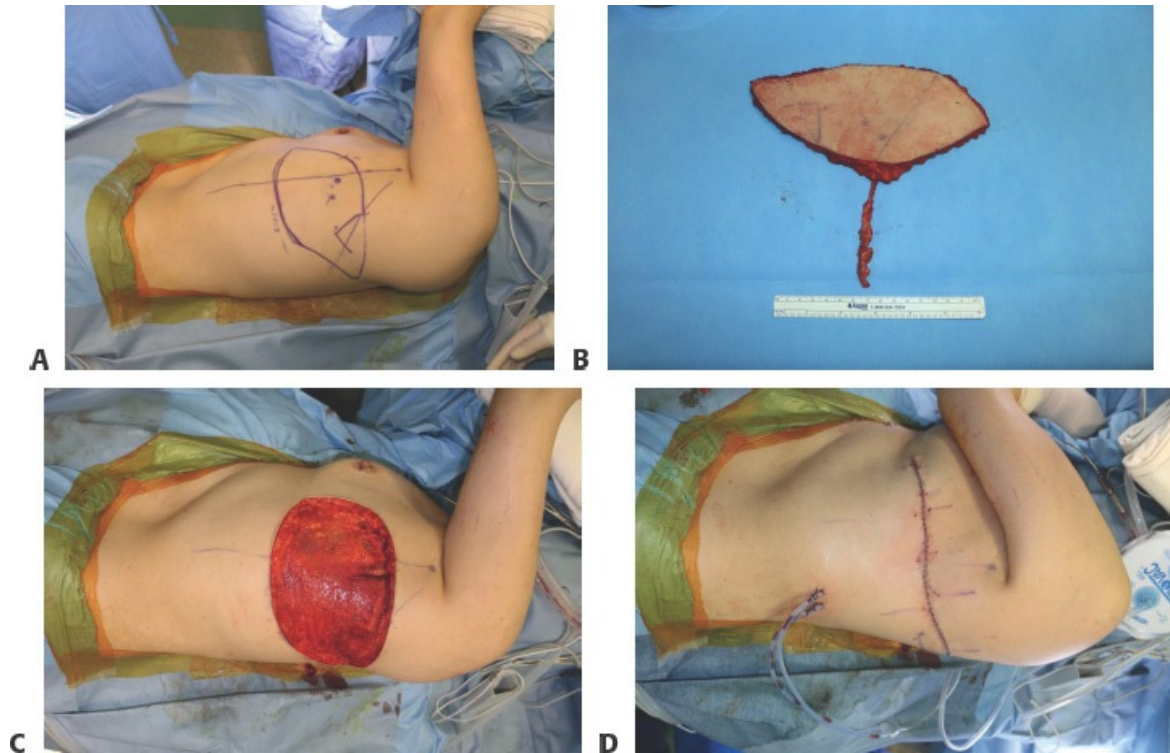
■ Assessment of the Defect

- The tourniquet is deflated and meticulous hemostasis is performed. Irrigation with saline solution is carried out.
- Defect size along with its shape can be exactly measured using transparent plastic or paper template, which will be used for flap design in the donor site.
- Dead space that needs to be filled is also marked on the defect template.

■ Flap Harvest

- Outline of relevant muscles and landmarks are marked on the skin (**TECH FIG 3A**).
- Perforators are located using handheld pencil Doppler and the flap is designed using the template of the defect.
- Once the targeted perforator is identified via a suprafascial dissection through a limited incision on superior border of the flap, then the whole skin paddle is elevated and meticulous intramuscular dissection of the pedicle with bipolar forceps is commenced.
- Motor nerve branches to the muscle are maximally preserved and the pedicle is divided when sufficient length is obtained (**TECH FIG 3B**).
- A closed suction drain is placed, and the donor wound is primarily closed in

layers (**TECH FIG 3C,D**).

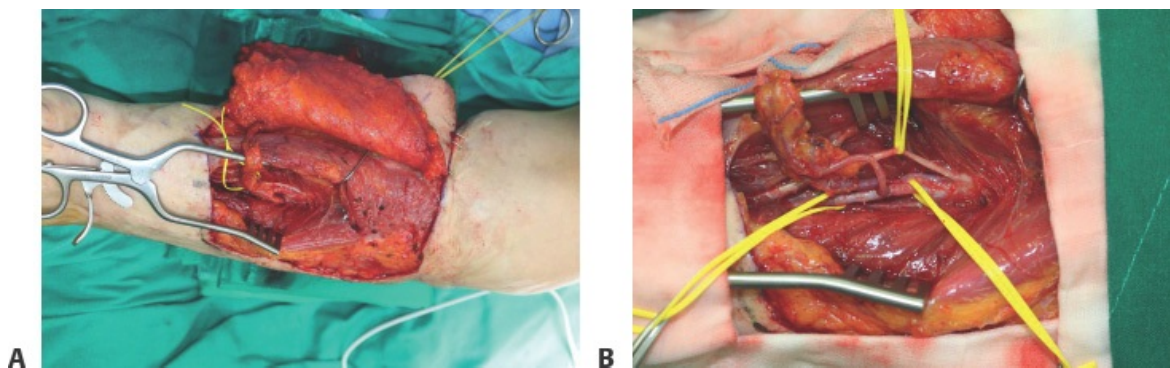


TECH FIG 3 • **A.** Design of the flap using transparent plastic template. **B.** Elevated TDAP flap. **C.** Defect of the donor site after elevation of the TDAP flap. **D.** Primary closure of the donor site.

■ Microanastomosis With Temporary Inset (**TECH FIG 4**)

- Temporary inset of the flap is performed using a skin stapler.
- It is important to avoid twisting or kinking of the pedicle. A useful way to mitigate twisting of the pedicle is to lift and hold the flap in the air and allow the vessels to dangle and unwind. If the pedicle is long, lazy-S-shaped positioning of the pedicle under the flap is performed to avoid kinking of the pedicle.
- Vascular tension should be avoided through prudent planning, harvesting a sufficient length of the pedicle, and judicious use of a vascular graft when needed.

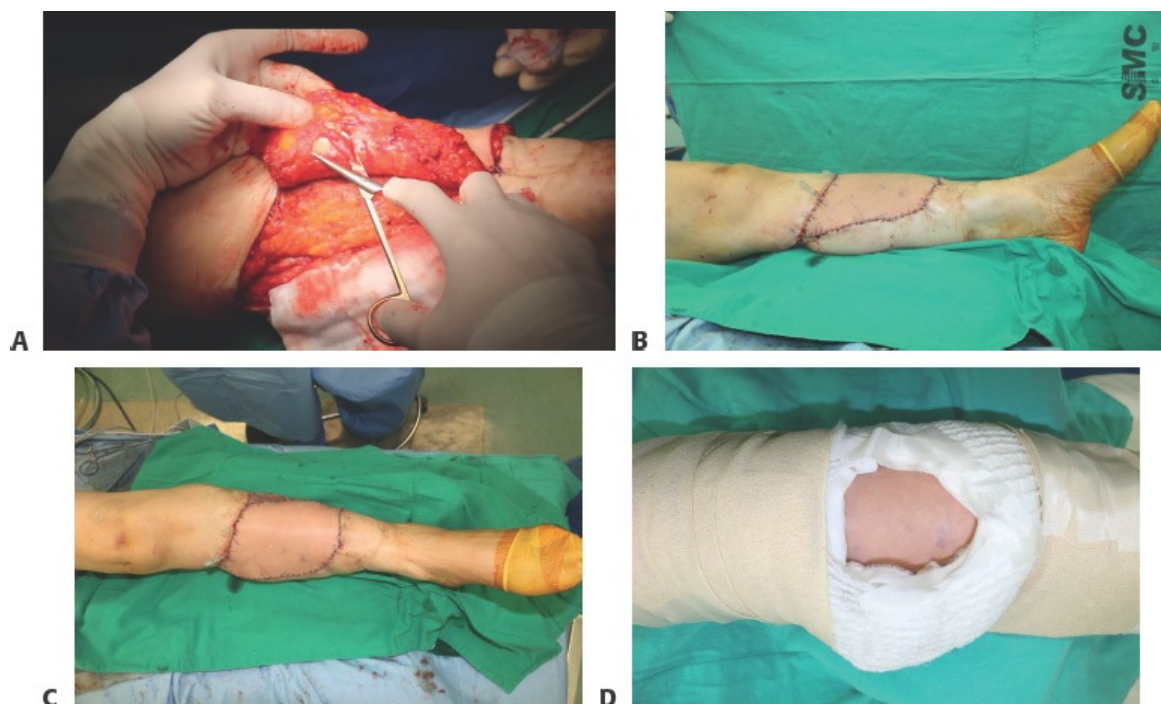
- Wide exposure of the field and ensuring a conducive atmosphere are critical for successful microvascular anastomosis.
- End-to-side anastomosis of the artery is preferred to maintain vascular flow in inherent arteries of the leg and to avoid iatrogenic ischemic complications of the leg.
- The deep vein system (comitantes vein) is usually given the first consideration because of the special convenience with dissection and inset. However, the superficial veins (long saphenous and short saphenous veins) can be used when there is significant size mismatch with the deep veins or if no adequate deep vein is suitable. Regardless of the use of the deep or superficial veins, the quality of the recipient vein should be checked based on intraoperative findings such as the absence of scarring around the vein, existence of backflow, absence of thrombi, and absence of resistance to an intraluminal heparinized saline flush.¹⁵
- The vascular clamp is removed after completion of the anastomosis. Warm saline is irrigated onto the vessels and flap, followed by waiting for several minutes to check patent inflow and outflow of the flap.
- Meticulous hemostasis is performed under the microscope to ensure that branches of the pedicle and recipient vessels are secured as hematoma is known to be one of the main causes of re-exploration after free flap reconstruction in lower extremities.¹²



TECH FIG 4 • A. Temporary inset of the flap for microvascular anastomosis. **B.** After completion of microvascular anastomosis. End-to-side anastomosis of the artery and end-to-end anastomosis of the vein were carried out.

■ Final Inset

- If a flap is too bulky, then meticulous defatting of the perforator flap can be performed at the time of insetting. The deep fat, superficial fascia, and deep layer of superficial fat can be safely removed, but not the area near the perforators (about 2–3 cm diameter), using scissors with or without loupe but microscope magnification is not usually necessary (**TECH FIG 5A**). This is a crucial procedure for obtaining a satisfactory contour of the reconstructed lower leg. However, to completely avoid tissue damage within the flap and risk of ischemic complication at the initial operation, secondary procedure for thinning is an alternative option.
- The final inset of the flap needs to be carefully performed because the pliability and extensibility of the flap may change after the defatting procedure.¹⁶ Excessive flap tissue is diligently excised to yield a more natural appearance (**TECH FIG 5B,C**).
- The wound is closed by placing drains under the flap to prevent fluid collection.
- A leg splint is frequently applied for immobilization. An elastic bandage is loosely applied. Part of the flap is left open for postoperative monitoring of the flap (**TECH FIG 5D**). Excessive compression over the vascular pedicle should be avoided.



TECH FIG 5 • **A.** Defatting of the perforator flap. **B,C.** Immediate postoperative photos. **D.** Dressings of the reconstruction site.

PEARLS AND PITFALLS

Planning

- Elaborate preoperative planning of recipient vessels, donor site, flap composition, and positioning of the patient is important for successful reconstruction.
- A multidisciplinary approach including comprehensive communication with the oncologist and/or orthopedic surgeon will allow better treatment outcomes.

Flap design

- The exact template created according to the final defect size and shape is helpful to avoid harvesting an unnecessarily large flap and to obtain an aesthetically pleasing contour of the lower leg.

Placement of the pedicle

- It is important to avoid twisting of the vascular pedicle.
- If the pedicle is excessively long, it is placed in a lazy-S-shaped position under the flap to avoid kinking of the

	pedicle. ■ Minimize tension on the pedicle. Sufficient acquisition of the pedicle can be a safe strategy.
Microanastomosis	■ End-to-side anastomosis of the artery is preferred to maintain distal vascular flow in named arteries of the lower leg and to avoid potential ischemic sequelae of the leg. ■ The deep vein system (venae comitantes) is usually given the first consideration as a source of outflow because of special convenience for dissection and inset and because it is less vulnerable to trauma than the superficial venous system.
Flap inset	■ Defatting of the perforator flap is a valuable technique for obtaining an aesthetic contour at the time of inset, but must be done meticulously to avoid compromising perfusion. ■ Dimensional excess of the flap is diligently corrected by careful trimming.
Hemostasis	■ Meticulous hemostasis needs to be performed during the entire surgical procedure because hematoma is known to be one of the main causes of re-exploration after free flap reconstruction in lower extremities.

POSTOPERATIVE CARE

- Proper patient positioning and avoidance of vascular pedicle compression (by splinting or inattentive wound dressings) play vital roles in the postoperative period.
- The leg is elevated for better venous return and to minimize edema while the patient is lying in bed.
- There is no consensus regarding the use of medications for thromboprophylaxis, such as aspirin, heparin, and dextran. The authors do not routinely use any of these medications.
- Enoxaparin (low molecular weight heparin) is considered for deep vein thrombosis prophylaxis in lower extremity reconstructions as chemoprophylaxis is recommended for general surgery patients scoring 3 or higher on the Caprini scale.¹⁷ Patients undergoing lower extremity reconstruction with free flap frequently fall into the high-risk group with Caprini scores of 5 or greater.¹⁸
- Postoperatively the flap can be monitored every 1 to 3 hours for the first 48 hours, and every 4 to 6 hours for the next 48 hours after the surgery. Monitoring is typically performed by physical examination and handheld

pencil Doppler.

- An oral diet is allowed 24 hours after surgery.
- Although the duration of immobilization time varies based on the orthopedic and bony injuries, generally progressive weight bearing and ambulation are achieved once the flap maturation is assured, which occurs in 2 to 3 weeks for isolated soft tissue reconstruction.

OUTCOMES

- Microvascular free flap for lower extremity reconstruction is currently a safe and reliable procedure with a high success rate. Recent advancements in technology and improvement in surgical techniques have led to reported success rates of between 94% and 100%.^{5,8,12,19}
- Microvascular free flap is a reliable reconstructive option for defects of various sizes in various locations of the lower leg, and multiple tissue components such as cutaneous, muscle, and muscle chimeric can be used according to tissue requirements (**FIG 9**).



FIG 9 • Cases of lower leg reconstruction with free flaps. **A.** Dual-pedicled deep inferior epigastric artery

perforator (DIEP) flap for extensive lower leg defect. Dual pedicles were anastomosed to the posterior tibial artery and vein with the end-to-side method. **B.** Reconstruction of small defect with TDAP flap. Anterior tibial vessels were used as recipient vessel. **C.** Reconstruction of extensive defects on the proximal lower leg using the DIEP flap. Medial sural vessels were used for recipient vessels, and the great saphenous vein was used for superdrainage. **D.** Reconstruction of the distal lower leg using the TDAP flap. Anterior tibial vessels were used as recipient vessels. **E.** Free muscle (latissimus dorsi) flap with skin graft. **F.** Muscle chimeric TDAP flap for distal lower leg reconstruction.

COMPLICATIONS

- Vascular-related complications such as venous and arterial thrombosis
- Hematoma: Early diagnosis of a hematoma under the flap is critical so that it can be evacuated promptly to prevent the compression and obstruction of the anastomotic site from the expanding hematoma. In particular, any time a postoperative hematoma is noted, the surgeon must consider venous thrombosis.
- Infection
- Partial flap necrosis

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26 Soft Tissue Coverage of Lower Leg—Soleus Flap

CHAPTER

Rahim Nazerali and Lee L. Q. Pu

DEFINITION

- Mathes and Nahai type II muscle
- Most commonly proximally based pedicled flap, but a distally based flap has been reported.

ANATOMY

- Broad, large, bipennate muscle
- Deep to the gastrocnemius muscle in the posterior compartment of the leg
- Occupies major portion of superficial posterior compartment of the leg in the middle third tibial level
- Two separate muscle bellies, medial and lateral with separate origins
 - Origin
 - Lateral belly: posterior surface of the fibula
 - Medial belly: middle third of the medial border of the tibia
 - Insertion
 - Lateral belly: dorsal lateral aspect of the Achilles tendon
 - Medial belly: dorsal medial aspect of the Achilles tendon
- Vascular supply (**FIG 1**)
 - Proximal portion of muscle receives independent axial vascular supply to its medial and lateral bellies.
 - Dominant pedicle: muscular branches of the popliteal artery and from proximal two branches of the posterior tibial artery and peroneal artery
 - Distal portion of muscle primarily receives segmental blood supply from two to four segmental branches from the posterior tibial artery.

- Innervation
 - Motor: posterior tibial and medial popliteal nerves
- Function
 - Plantar flexion

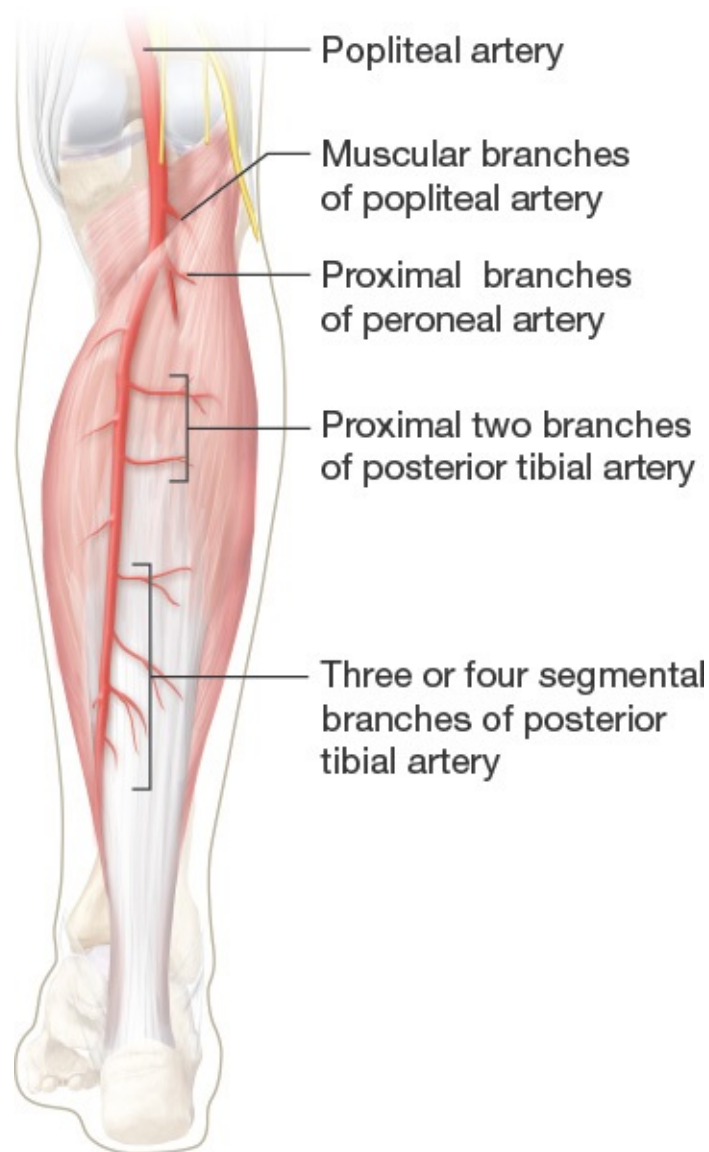


FIG 1 • A schematic diagram shows the vascular anatomy of a soleus muscle.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Just like any other major flap surgery for the lower extremity, a patient's

general medical condition and neurovascular physical examination should be evaluated carefully.

- Previous orthopedic trauma to the leg and ongoing orthopedic procedures should also be taken into a consideration when planning a soleus muscle flap.

IMAGING

- Preoperative angiogram is recommended if using a distally based medial hemisoleus muscle flap to assess the blood supply, which is typically from branches of the posterior tibial vessels.

SURGICAL MANAGEMENT¹⁻⁷

- Soleus is the standard muscle flap of choice for middle third defects of the leg.
- Numerous limitations with bulk, arc of rotation and weakening of plantar flexion when using the entire muscle.
- Medial hemisoleus muscle flap can be elevated based either proximally or distally depending on the location of the soft tissue reconstruction required.
- Medial hemisoleus muscle flaps should be chosen to reconstruct a less extensive wound (less than 50 cm² in most adult patients).
- Proximally based flaps can be used to cover middle third tibial wounds in the leg, whereas distally based flaps can be used for distal third defects. In addition, proximally based flaps can also be used to cover distal third defects if done properly.

Preoperative Planning

- Physical exam including pulse, neurological status, tissue quality
- Ensure that the soleus muscle has not been traumatized from previous injury.
- Standard ABI/TBI exam
- Evaluate and treat concerns for hardware infection or osteomyelitis.

Positioning

- Frog leg positioning

Approach

- Elevate under tourniquet control.
- Longitudinal skin incision made 2 cm medial to the medial border of the tibia and parallel to the tibia.
- Only the muscular portion of the soleus muscle is used as the flap, whereas the

tendon portion of the flap is left intact.

■ To cover a wound at:

- Middle and distal third of the leg: medial hemi-soleus muscle flap is elevated to the level just below the junction between the proximal and middle third of the leg for a middle third defect or just above the junction between the middle and distal thirds of the leg so that an adjacent perforator from the posterior tibial vessels to the flap can be preserved (**FIG 2A**).
- Distal third of the leg: medial hemi-soleus muscle flap is elevated only to the level just below the junction between the middle and distal thirds of the leg, preserving as many major perforators to the flap as possible, even in the distal third of the leg while allowing adequate arc of flap rotation (**FIG 2B**).

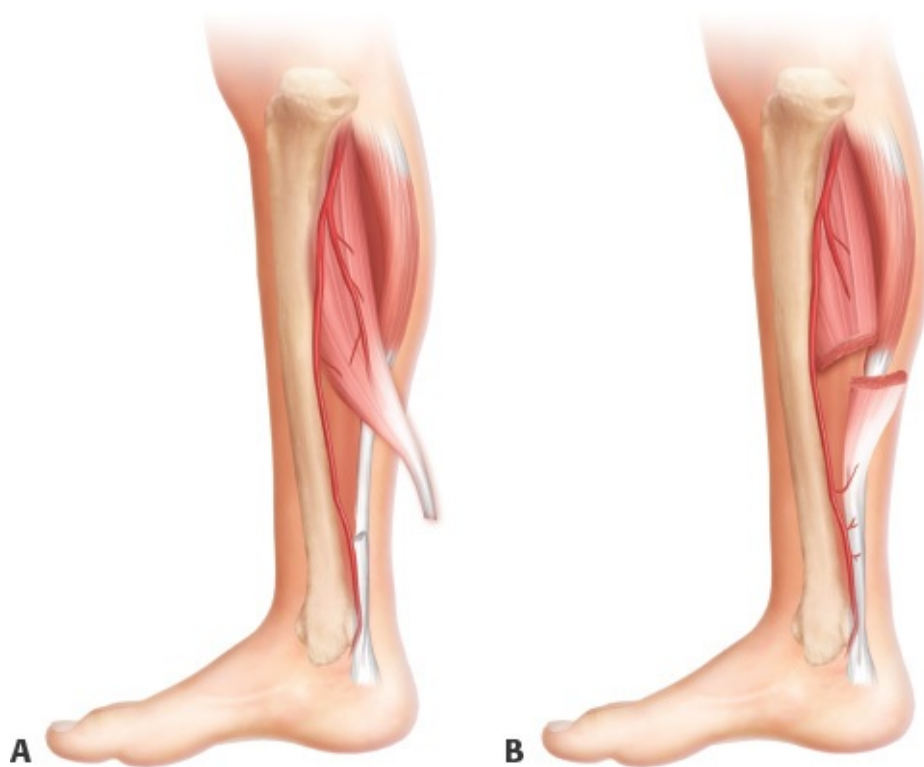


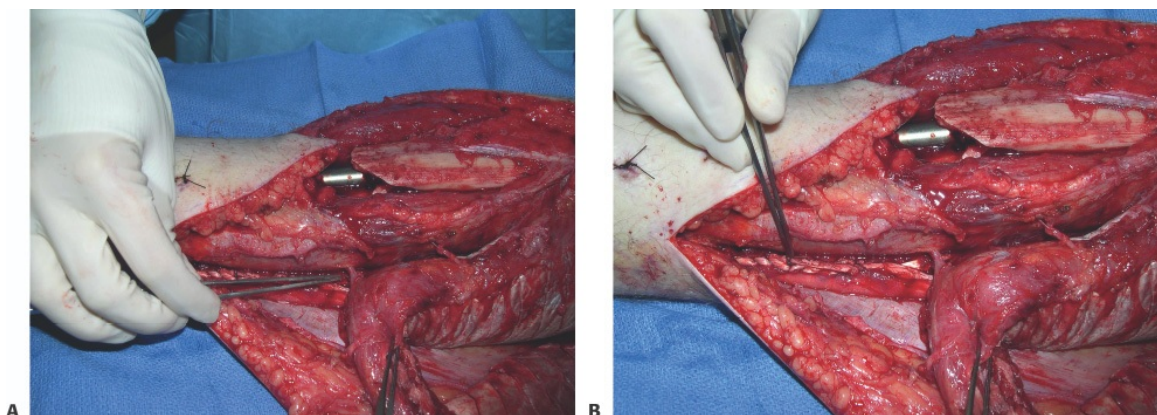
FIG 2 • A. Flap dissection and blood supply to the proximally based medial hemi-soleus muscle flap. The flap receives its blood supply primarily from the posterior tibial vessels. The flap also receives additional blood supply from one or two perforators from the posterior tibial vessels to its distal portion. **B.** Flap dissection and blood supply to the distally based medial

hemisoleus muscle flap. The flap receives its blood supply primarily from the most distal two perforators of the posterior tibial vessels. The flap also receives additional blood supply from the proximal source in a retrograde fashion.

TECHNIQUES

■ Proximally Based Medial Hemisoleus Flap^{1-3,5,6}

- Identify and dissect free from medial gastrocnemius muscle.
- Divide distally at the level of the junction between middle and distal thirds of the leg for covering a middle third defect of the leg or at the level close to the Achilles tendon if covering the distal third of defect in the leg.
- Medial half of the muscle is split longitudinally along with a raphe between the bellies of the soleus muscle.
- Only one or two distal perforators from the posterior tibial vessels to the medial hemisoleus muscle are divided so the flap rotation can be facilitated, but proximal major perforators should be preserved to maximize the blood supply to the flap (**TECH FIG 1A**).
- The spared tendon is approximated to the remaining lateral half of the soleus muscle with nonabsorbable sutures in a figure of eight fashion to help minimize the functional loss of the leg after flap harvested (**TECH FIG 1B**).
- The elevated hemisoleus muscle flap can be rotated to cover the defect and a split-thickness skin graft can be placed after flap transfer.



TECH FIG 1 • A. Intraoperative view shows an adjacent perforator (indicated by forceps) from the posterior tibial vessels to the medial hemisoleus muscle flap. Preservation of this perforator can be critical to ensure an adequate blood supply to the distal flap. **B.** The spared conjoint tendon is approximated to the remaining lateral half of the soleus muscle with sutures to minimize the functional loss of the leg after flap elevation.

■ Distally Based Medial Hemisoleus Flap^{3,4,6}

- Preoperative angiogram can be helpful for determining the presence of major perforators from posterior tibial vessels to the distal portion of the medial soleus muscle.
- Only one or two distal perforators from the posterior tibial vessels to the medial hemisoleus muscle are divided so the flap turnover can be facilitated; however, one adjacent proximal perforator should be preserved to maximize the blood supply to the flap (**TECH FIG 2**).
- The medial hemisoleus muscle flap is transposed or turned over into the defect and inset with absorbable half-buried horizontal mattress sutures. Scoring the fascia over the medial hemisoleus muscle belly can produce a few more centimeters of arc of rotation. The muscle flap is covered immediately with a split-thickness skin graft after flap transfer.



TECH FIG 2 • Intraoperative view shows the first large perforator (indicated by forceps) from the posterior tibial vessels to the distally based medial hemisoleus muscle flap. This perforator serves as a pivot point of the flap turn over and should be well preserved. Preservation of this perforator can be critical to ensure an adequate blood supply to this distally based flap.

PEARLS AND PITFALLS

Muscle damage

- Before dissecting the medial hemisoleus muscle flap, the surgeon should make sure that the soleus muscle has not been traumatized from the previous injury.

Blood supply

- When performing a proximally based flap, any perforators from the posterior tibial vessels to the distal medial half of the soleus muscle just at or above the level

of a tibial wound should be preserved while allowing adequate arc of flap rotation to cover a wound in the distal third of the leg.

- The modifications of surgical techniques emphasize the preservation of an adequate blood supply to the distal portion of the medial hemisoleus muscle flap after the flap is elevated. These techniques would maximize reliability of the medial hemisoleus muscle flap and expand its role in reconstruction of a wound in the distal third of the leg. With the aid of a preoperative angiogram, major perforators in the lower third of the leg can be identified when planning a distally based medial hemisoleus flap.
- The most proximal perforators from the posterior tibial vessels to the medial half of the distal soleus muscle within the upper distal third of the leg should be preserved while allowing adequate flap turnover to cover a tibial wound in the distal third of the leg. This perforator will serve as a pivot point for flap turnover and the level of the perforator will determine how far this flap can reach.
- The modified surgical techniques in flap dissection emphasize the preservation of an adequate blood supply to the distal portion of the distally based flap and maximize reliability of the medial hemisoleus muscle flap even when it is based distally.

Free tissue transfer^{8,9}

- Free tissue transfer should still be considered for a larger soft tissue wound in the middle or distal third of the leg or for a less extensive wound when either the soleus muscle or those perforators from the posterior tibial vessels are traumatized.

POSTOPERATIVE CARE

- Place patient in knee and ankle immobilizer with minimal pressure on the transposed flap.
- Effective leg elevation to reduce edema
- Placement of a warming unit around leg to maintain a warm temperature
- Monitoring frequently with clinical assessments

OUTCOMES

- Based on the author's experience, the proximally based medial hemisoleus muscle flap can be used for a relatively proximal tibial wound in the junction of the middle and distal thirds or in the distal third of the leg.
- The flap is fairly reliable and can often be done within 2 hours. In addition, the flap can provide just enough muscle bulk for soft tissue coverage of the tibial wound, and thus, reconstructive outcomes are usually quite good (**FIG 3**).
- The distally based flap can be used for a less extensive distal tibial wound (often close to the medial malleolus) in the distal third of the leg. The flap can be reliable in most healthy and compliant patients.
- The initial venous congestion may also become a problem in certain patients such as smokers or those with an inability for leg elevation during the postoperative period.
- In general, the distal flap necrosis occurs infrequently if the flap is proximally based but occurs in about 20% of the patients if the flap is distally based (**FIG 4**).

COMPLICATIONS^{3,4,6}

- Like any other pedicled flaps, the distal flap necrosis may occur, but total flap loss should not happen.
- The distal flap necrosis is usually insignificant and can be managed with debridement.
- The flap can then be readvanced adequately to cover the wound, and the final outcome can still be good.
- Further advancement of the flap is possible by dividing the most proximal perforator, which has served as a pivot point since the flap has been “delayed” after initial flap elevation.

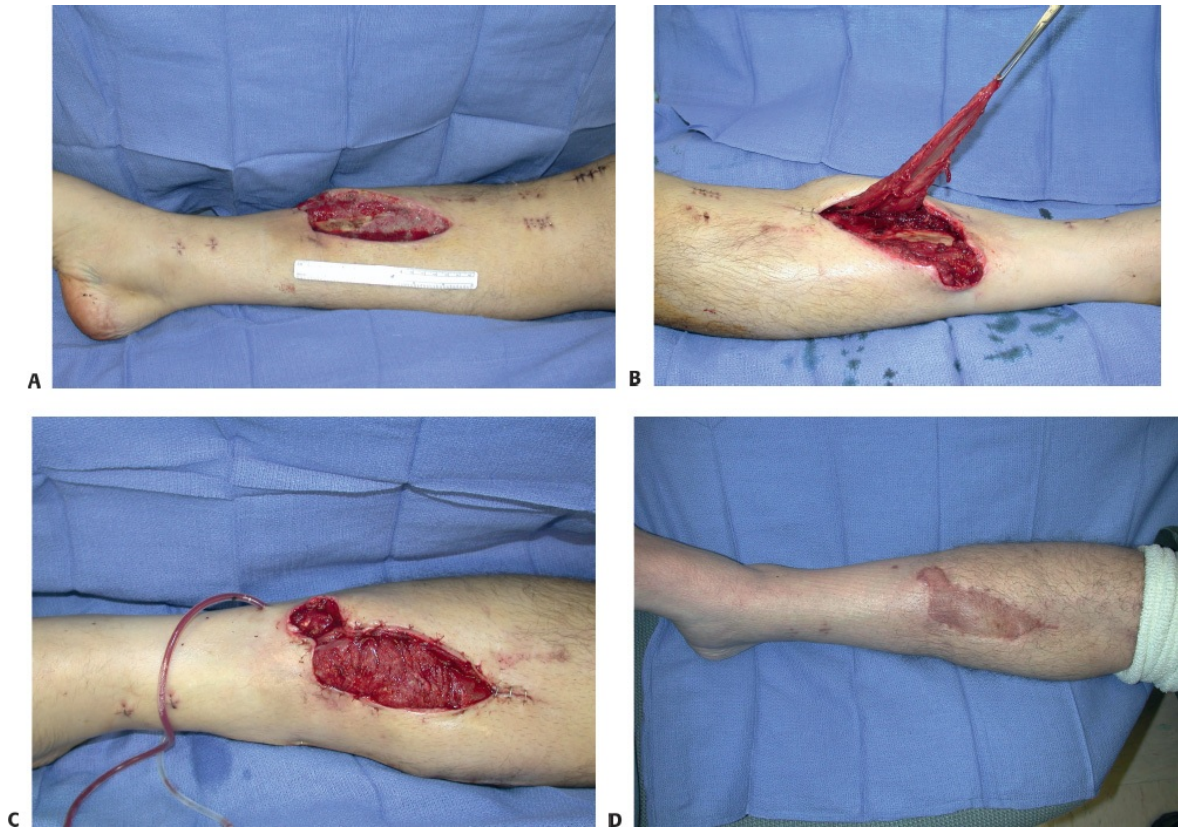


FIG 3 • **A.** A male patient had a 12 × 6-cm soft tissue defect in the middle third of the leg with exposed fracture site. **B.** A proximally based medial hemisoleus muscle flap was elevated and rotated to cover the defect. **C.** Completion of the muscle flap inset before placement of skin graft. **D.** Result at 3.5-month follow-up.



FIG 4 • A. A female patient had a 6 × 5-cm soft tissue defect in the distal third of the leg with exposed fracture site. **B.** A distally based medial hemisoleus muscle flap was elevated and turned over to cover the defect. **C.** Completion of the muscle flap inset before placement of skin graft. **D.** Result at 2-month follow-up before subsequent bone grafting.

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Section III: Knee

27 Nerve Repair and Reconstruction—Tibial Nerve

CHAPTER

Shawn Moshrefi and Catherine Curtin

DEFINITION

- Tibial nerve injuries can vary in severity, mechanism, and treatment.
- Nerve injury categories¹
 - Neurapraxia: conduction delay with no axonal injury. These injuries will recover spontaneously without intervention.
 - Axonotmesis: axonal injury resulting in disruption of the axons, but the supporting nerve scaffolding is intact. In these injuries, distal nerve segment will undergo Wallerian degeneration and proximal fibers will regenerate. Spontaneous recovery is possible.
 - Neurotmesis: complete disruption of the nerve. In these injuries, spontaneous regeneration will *not* occur.
 - Neuroma in continuity: disruption of the axons though the scaffolding seems to be intact. However, at the injury site, there is internal fibrosis, which prevents axons from regenerating. In these injuries, spontaneous regeneration will *not* occur.
 - Mixture of injury types: nerve patterns can be complex and one nerve can have several different types of injury.

ANATOMY (FIG 1)

- Tibial nerve originates from L4 through S3 nerve roots.
- The motor branches innervate the posterior calf compartment muscles and the majority of small muscles in the foot.

- The sensory branches supply the knee joint, part of the sural nerve distribution, and the sole of the foot.
- Tibial nerve branches from the sciatic nerve in the popliteal fossa.
- The first branch off the tibial nerve is a sensory contribution to the sural nerve.
- The next branches are the motor nerves to the gastrocnemius muscles.
- Then, the tibial nerve passes through popliteal fossa under arch of soleus. (This area is a potential area of tibial nerve entrapment called the *soleal sling*.)
- The tibial nerve courses distally adjacent to the tibia on undersurface of soleus in the leg running with the peroneal artery and vein.
- At the ankle, tibial nerve is posterior to the medial malleolus adjacent to posterior tibial artery beneath the flexor retinaculum (This is a potential area of entrapment known as the *tarsal tunnel*.) (**FIG 2**).

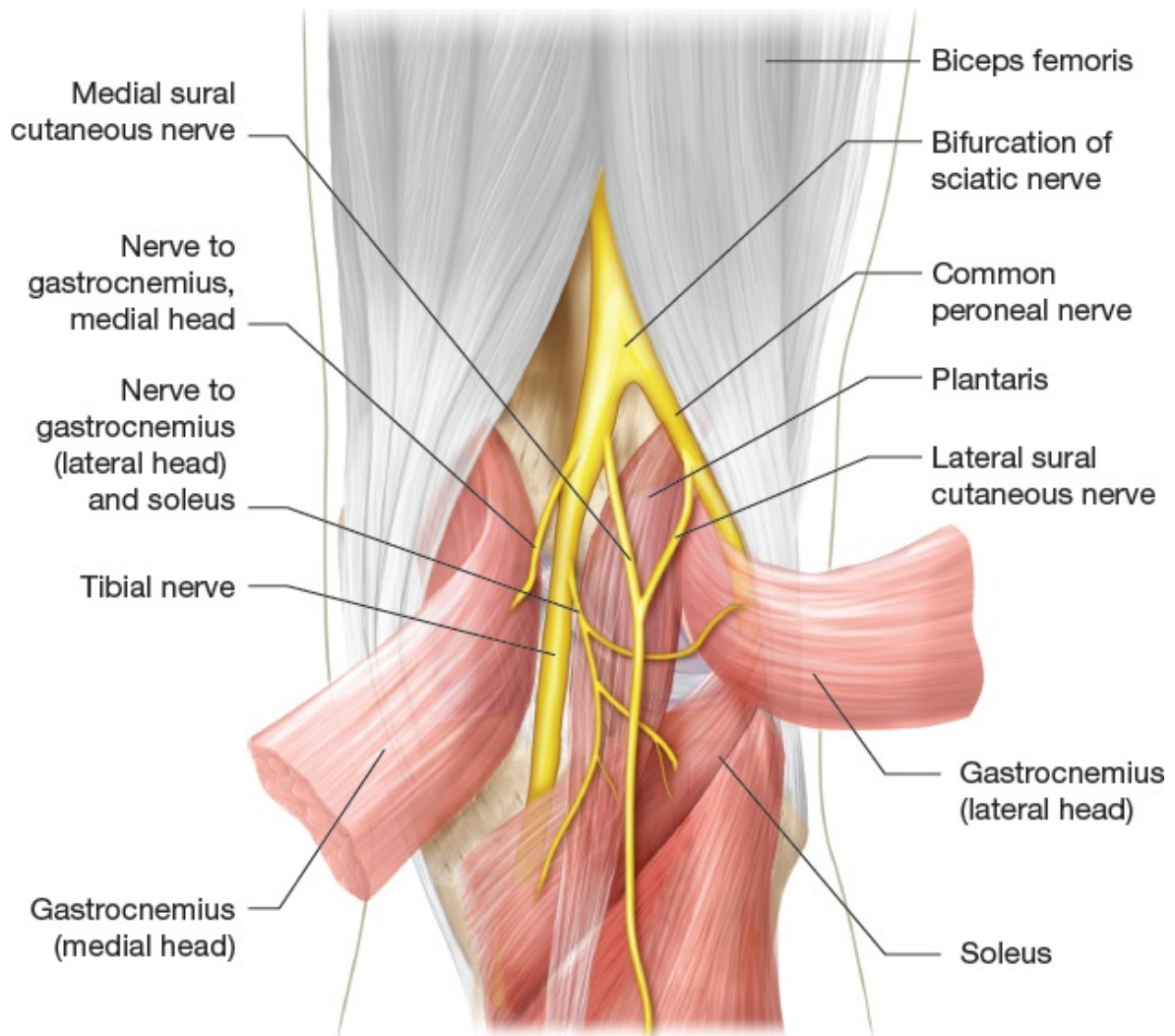


FIG 1 • Anatomy of the proximal tibial nerve.

- At the medial malleolus, the tibial nerve branches into the calcaneal, medial plantar, and lateral plantar nerves. The anatomy of the branching is highly variable between patients.²

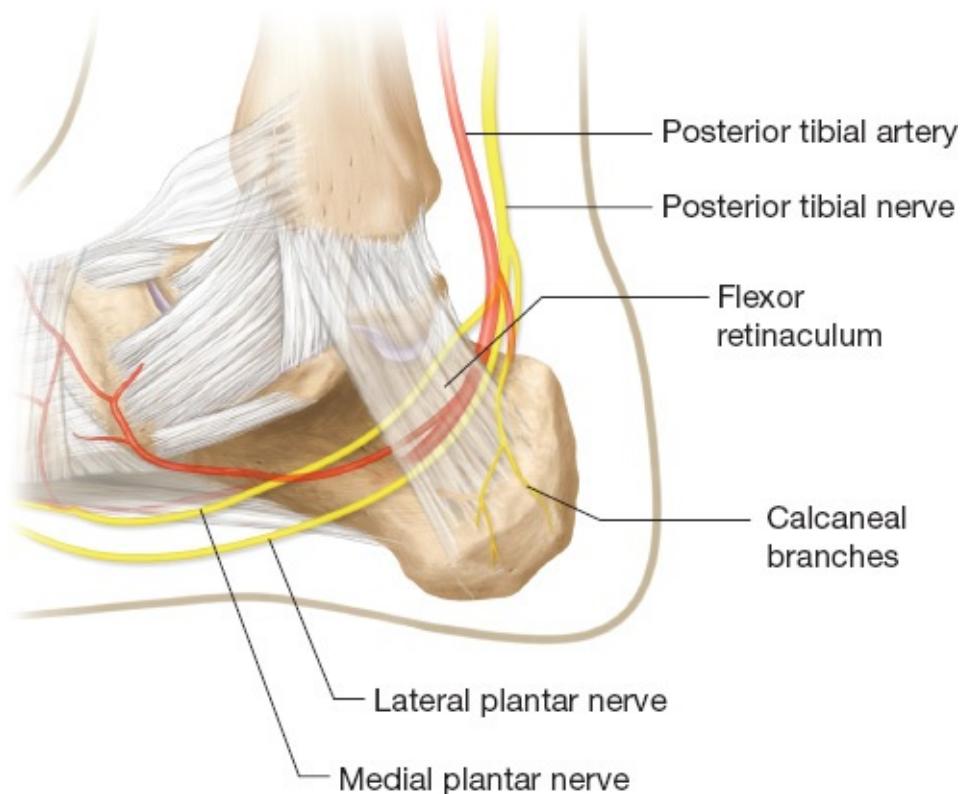


FIG 2 • Anatomy of the tarsal tunnel.

PATHOGENESIS

- Tibial nerves can be injured in many ways and in any location along its course. Listed below are some of the more common causes of tibial nerve injury.
 - Traumatic knee dislocation
 - Direct trauma to the popliteal area, both blunt or sharp
 - Iatrogenic prolonged tourniquet, hardware, or limb lengthening procedures
 - Ankle swelling or compression
 - Cysts or other nerve compressing structures (both in the popliteal fossa as well as at the medial malleolus)

PATIENT HISTORY AND PHYSICAL FINDINGS

- A complete and thorough history detailing patient's history of present illness, current injuries, history of prior injuries, prior surgeries (including spinal, buttock, and lower extremity procedures), comorbidities, occupation, and other case-by-case considerations should be obtained.
- Inspection
 - Is the calf or foot swollen?
 - Are there vascular changes?
 - Is there atrophy?
- Vascular exam—palpable pulses distally, temperature, and capillary refill of the toes and foot.
- Sensory exam—Ten test: an area of normal or baseline sensation is compared to an area of concern for sensory loss and the difference is rated from 1 to 10 with 10 being the best score possible.³
- Motor exam
 - Test the respective muscles that the tibial nerve and its branches supply (tibial nerve controls plantar flexion and inversion of the foot and ankle).
 - Each individual movement tested should be compared to the contralateral side. This allows the examiner to identify subtle weakness.
 - Motor examination remember mnemonic TIP = **T**ibial **I**nverts and **P**lantar flexes.
- Scratch collapse test.⁴ This tool originally described for the upper limb is also useful for assessing nerve entrapment in the lower limb. For this test, the examiner is testing external rotation of the arm.
 - To do this, the examiner has the patient sitting straight with arms adducted to their side and elbows bent to 90 degrees. The patient is told to keep the arm in this position.
 - The examiner then gently scratches the skin directly over the area of suspected nerve compression (eg, posterior to the medial malleolus for suspected tarsal tunnel).
 - After scratching the skin, the examiner then directly applies internal rotation force to the patient's dorsal forearm while the patient actively attempts to resist. The test is positive for nerve pathology if the patient is briefly unable to resist your force of internal rotation.
- Tinel sign
- Point tenderness: the tibial nerve can be compressed at the level of the soleal

sling. Patients are often tender to direct pressure over the site (posterior midline of the calf about 10 cm distal to the posterior knee crease).

IMAGING/STUDIES

- X-rays are obtained if there is a suspected bony injury.
- MRI can assess for soft tissue masses such as Baker cysts and also provide information on the nerve.
- Enhancement of fascicles on MRI can help identify tibial neuritis (**FIG 3**).
- MRI is increasing in resolution and is taking an increasing role in identifying nerve pathology (**FIG 4**).

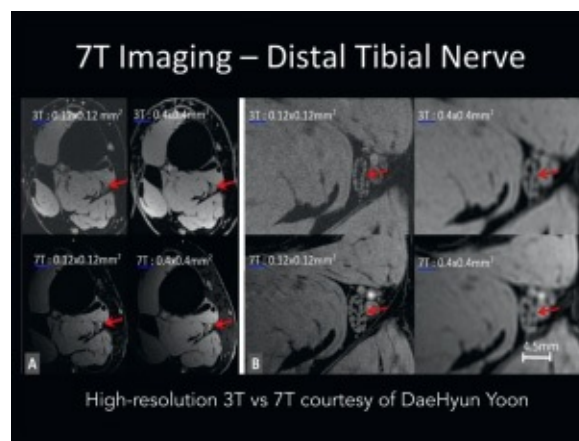


FIG 4 • Comparison of 3T and 7T MRI of tibial nerve. (Courtesy of Daehyun Yoon, Stanford University.)



FIG 3 • MRI of tibial nerve at soleal sling. Note that the tibial nerve is bright like the surrounding vessels, and normal nerve is isointense with the muscle. (Courtesy of Sandip Biswal, Stanford University.)

- Nerve conduction studies and electromyography (NCS/EMG) are a mainstay in the workup of nerve injury.
- NCS/EMG useful for closed nerve injury
 - Studies are performed at 4 to 6 weeks to achieve a baseline and assess type and severity of the injury.

- If there is no recovery on physical exam, the nerve studies are repeated at 3 months.
- If there is evidence of recovery, close follow-up is continued. If no signs of recovery at three months, operative intervention should be considered. Motor endplates begin to permanently degenerate at 3 months; thus, if surgery is required, earlier intervention improves functional outcomes.

DIFFERENTIAL DIAGNOSIS

- Spinal pathology
- Sciatic pathology
 - If on physical exam there are deficits in both peroneal nerve and tibial nerve distributions, then suspect possible sciatic pathology.
- Neurologic problems
 - Peripheral neuropathy
 - Motor neuron disease

NONOPERATIVE MANAGEMENT

- For closed nerve injuries, treatment starts with nonoperative management.
- Therapy
 - Edema prevention with lightly compressive wraps/garments and physical therapy with massage may be helpful.
 - Range of motion exercises to maintain supple joints and prevent the nerve from scarring.
 - Desensitization to decrease areas of sensitivity.
- Orthotics
 - Custom splint that keeps the hindfoot in the neutral position in order to maintain function and minimize discomfort.
 - Shoe inserts are a first step in people with suspected tarsal tunnel.

SURGICAL MANAGEMENT

- Surgical treatment is used for open nerve injuries, closed nerve injuries that are not showing any signs of recovery at 3 months, and nerve compressions that did not respond to conservative measures.

Preoperative Planning

- Definitive fracture fixation should be performed prior to nerve repair.
- Arterial injury should be treated prior to nerve repair.

- If possible, use of a lower extremity tourniquet is advisable to aid in visualization of injury.
- If intraoperative nerve monitoring is planned, inform anesthesia team to not use paralytics.

Positioning

- Positioning depends on level of injury (above knee, at level of the knee, or below knee).
- Access to popliteal area is easiest with the patient in the prone position.
- Access to the soleal sling is managed with the patient supine, hip externally rotated, and knee bent.
- Access to tarsal tunnel is managed with the patient supine.

Approach

- For the posterior knee approach, a curved incision rather than a straight incision across the joint is required to prevent scar contracture that can limit mobility.
- For access to the soleal sling, a medial incision on the posterior border of the tibia starting just distal to the tibial plateau (**FIG 5**).
- The tarsal tunnel is accessed posterior to the medial malleolus.



FIG 5 • Incisions for soleal sling and tarsal tunnel release.

■ Repair of Acute Traumatic Injury to Tibial Nerve

- Patient positioned supine.
 - Tourniquet placed above the knee.
 - If a wound is present, incorporate wound into exposure.
 - If wound orientation or access is inadequate, then either extend wound incision to match standard approach or create counter incisions.
 - Resect any damaged or scarred nerve until two healthy nerve ends are revealed. (The proximal healthy end should have fascicles clearly seen bulging out the end of the nerve.)
 - Use microsurgical technique to handle the nerve and align the internal fascicle anatomy.
 - Perform a tensionless repair. (If the 9-0 nylon suture cannot hold the repair, there is too much tension).
 - If there is a nerve gap, harvest a sural nerve graft.
 - Cable the graft and suture in place with a few 9-0 nylon sutures using microscopic technique.
 - Augment repair by sealing coaptation site with fibrin glue.
 - Closure of wound.
 - Place in a leg splint or knee immobilizer to protect repair.
-

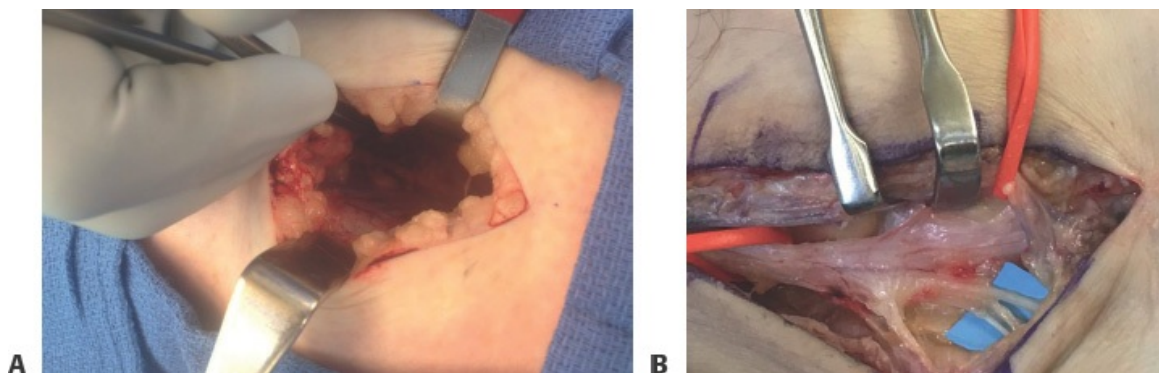
■ Release of Soleal Sling⁵

- Anesthesia options: regional anesthetic (popliteal/distal sciatic block and saphenous block) or general anesthesia
- Patient is supine and the hip is externally rotated, exposing the medial side of the leg.
- A thigh tourniquet is placed.
- The incision is placed at the medial tibial plateau and runs distally for about 10 cm and is placed about 1 cm posterior to the medial edge of the tibia (**TECH FIG 1A**).
- The subcutaneous tissue is carefully dissected, preserving the saphenous nerve and vein.
- The fascia over the gastrocnemius is opened and the plane between the soleus is identified.

- The gastrocnemius is retracted out of the way.
 - The soleal sling can be palpated with a finger as a fascial notch in the proximal border of the muscle.
 - The medial soleal muscle is reflected and perforating vessels are clipped.
 - The tibial nerve is identified and a vessel loop is placed.
 - Constricting fascial bands are released over about a 5 cm length.
 - Skin is closed and a bulky dressing placed.
 - Early ambulation is encouraged.
-

■ Release of Tarsal Tunnel

- Patient is placed supine.
- Regional block of the popliteal and saphenous nerve is performed.
- Tourniquet is placed on the calf.
- A bent incision is placed posterior to medial malleolus.
- Skin and subcutaneous tissue are divided.
- Care is taken to preserve the overlying sensory nerves.
- The flexor retinaculum is incised proximally and the posterior tibial vessels are visualized below. Small crossing vessels are clipped.
- The nerve is identified deep to the vessels and a loop is placed around the nerve.
- The dissection is taken distally and the branches are identified. (Note the calcaneal branches have variable anatomy and number) (**TECH FIG 1B**).
- The medial and lateral plantar nerves are identified and loops placed.
- The fascia overlying the medial and lateral plantar nerves is divided including the fascia overlying the abductor hallucis.
- All fascia must be released distally and the dissecting scissors can easily fit in the tunnels over the medial and lateral plantar nerves.
- Meticulous hemostasis is required.
- Closure and placement of a bulky dressing
- Early ambulation is encouraged.



TECH FIG 1 • A. Tibial nerve exposed through soleal sling. Note the deep exposure required. The tibial nerve is at the base of the wound identified by the forceps. **B.** Tibial nerve exposed in a tarsal tunnel release. Note the multiple calcaneal branches going posteriorly.

■ Tibial Nerve Traction Injury

- General anesthesia
- Thigh tourniquet (to obtain optimal nerve monitoring results the tourniquet needs to be released for 20 minutes). If tourniquet is not used, preinject with bupivacaine with epinephrine prior to prepping the patient.
- Prone positioning
- Intraoperative nerve monitoring should be available.
- Incision is angled from the center of popliteal fossa.
- The dissection is taken down to the level of the muscle fascia.
- The tibial nerve is identified as it branches off the sciatic nerve.
- A vessel loop is placed on the nerve and the dissection is taken distally.
- The nerve is released from the overlying scar (often a very challenging dissection). The dissection is taken posterior to the gastrocnemius muscles to release the soleal sling.
- Intraoperative nerve monitoring is performed. Starting with somatosensory evoked potentials can help establish the proximal level of intact nerve. Nerve to nerve monitoring can identify neuroma in continuity.
- If the nerve is ruptured or neuroma in continuity is identified, resect damaged or scarred nerve until two healthy nerve ends are revealed.

- Ensure that the proximal nerve is healthy by using the assistance of your neurologist performing the intraoperative nerve monitoring.
- If there is a nerve gap, harvest a sural nerve graft.
- Cable the graft and suture in place with 9-0 nylon sutures using microscopic technique.
- Augment repair by sealing coaptation site with fibrin glue.
- Closure of wound
- Place in a leg splint or knee immobilizer to protect repair.

PEARLS AND PITFALLS

Hemostasis (if no tourniquet)

- Preinject incision with bupivacaine with epinephrine.
- A solution of 1 amp of epinephrine diluted in 100 cc of saline can be used to moisten a gauze that is then dabbed in the wound to help with visualization.

Technique

- To ensure complete release of the tarsal tunnel, the distal compression of the medial and lateral plantar nerves must be released. The distal dissection is challenging due to the overlying vessels. Clip crossing vessels as needed to adequately expose the nerves.

Intraoperative monitoring

- Communication between neurology and anesthesia team is critical to ensure that patient does not receive medications that will hinder intraoperative monitoring.
- Sequential compression device machine and warming machines can cause background that interferes with intraoperative monitoring.
- Do not use tourniquet if planning intraoperative monitoring. The nerve can suffer neuropraxia after 30 minutes of ischemia.

Diagnosis

- MRI imaging can help if proximal nerve entrapment suspected.

POSTOPERATIVE CARE

- Postoperative splint utilized for 3 weeks if there is a nerve repair to protect
- Early mobilization for neurolysis patients
- Affected lower extremity should be elevated at all times initially to aid in

reduction of swelling.

- Multimodal pain management for postoperative pain
- Early therapy for desensitization, scar management, and nerve gliding

OUTCOMES

- The literature on results from tibial nerve surgery is sparse.
- Tarsal tunnel release is an effective procedure when performed properly. A case series found that patients improved their Maryland Foot Score from 61 to 80, 3 months after tarsal tunnel release.⁶
- Tarsal tunnel release can fail for several reasons including incorrect diagnosis, proximal compression, and intrinsic nerve damage.⁷

COMPLICATIONS

- Neuropathic pain
- Inadequate release
- Bleeding/hematoma

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28 Excision of Soft Tissue Tumors of the Knee

CHAPTER

Raffi S. Avedian

DEFINITION

- Soft tissue sarcomas are malignant tumors that arise from mesenchymal cells and are classified according to their cell of origin such as muscle, tendon, or fat.
- Peripheral nerve sheath tumors arise from neural crest cells but are typically grouped with sarcomas because of similarities in location, natural history, and treatment.
- The World Health Organization groups soft tissue sarcomas into 10 categories based on the tissue of origin.
- Most sarcomas occur in a deep location, meaning below the muscle and fascia, whereas one-third of sarcomas occur in a subcutaneous location.
- Patients with soft tissue sarcomas and patients with benign tumors often present with the same chief complaint of having a soft tissue mass.
- Rendering an accurate diagnosis prior to surgery is important because the treatment plan may vary based on the nature of the diagnosis. For example, a benign tumor may be monitored or removed with a simple excision, whereas in the case of a sarcoma, the goal of surgery is to remove the tumor with a wide margin. With appropriate planning, radiotherapy and/or chemotherapy is often incorporated into the treatment plan either before or after definitive surgery.

ANATOMY

- The knee is the largest joint in the body. It is made up of the patellofemoral, lateral, and medial compartments.
- Knee motion is primarily flexion and extension; however, bending and rotation

are important components of knee kinematics.

- The primary stabilizers of the knee are the extra-articular medial and lateral cruciate ligaments and intra-articular anterior and posterior cruciate ligaments.
- The knee has several layers of covering including the capsule and retinacular tissues. During tumor resection, superficial layers may be used as the deep margin for the tumor, whereas the deeper capsule may be preserved to keep the joint closed.¹
- The popliteal artery travels along the back of the knee and along with the tibial nerve travels between the lateral and medial head of the gastrocnemius. It branches into the posterior tibial artery, which travels deep to the soleus muscles; the anterior tibial artery, which passes from posterior to the anterior compartment distal to the tibia-fibula joint; and the peroneal artery, which branches off the tibiofibular trunk and is located medial to the fibula next to the flexor hallucis longus.
- The geniculate vessels branch off from the popliteal vessels and are often all ligated during tumor resection of the distal femur.
- The tibial nerve is located next to the popliteal vessels. The common peroneal nerve travels medial and deep to the biceps femoris muscle, a constant relationship that facilitates finding and protecting the nerve during tumor dissection.
- The common peroneal nerve wraps around the neck of the fibula and divides into the deep branch that innervates the anterior muscle compartment and the superficial branch that innervates the lateral compartment.
- The lateral sural cutaneous nerve, which branches off the common peroneal nerve, may be large in some patients and be confused with the common peroneal nerve.

PATHOGENESIS

- The mechanism for sarcoma formation is not known.
- Risk factors for sarcoma development include radiation exposure such as medical radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and neurofibromatosis.

NATURAL HISTORY

- All sarcomas have the potential for local recurrence and metastasis.
- Tumor variables that are associated with increased risk of metastasis include high grade and large size (greater than 5 cm).

- Lungs are the most common location of metastasis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Determining when the mass was first noticed and how rapidly it is growing can help the clinician differentiate between benign and malignant tumors.
- The presence of pain is often associated with a benign tumor, such as a schwannoma or vascular malformation, and may not be present with sarcomas until late in the disease course.²
- Determining the size of the tumor, manual muscle strength testing, and sensory examination are useful to determine if there is a neurological compromise. Limb edema assessment and pulse examination can help determine if the tumor is causing vascular or lymphatic compromise.
- Range of motion testing and gait assessment are helpful in assessing a patient's mobility and functional status to guide perioperative and postoperative counseling.

IMAGING

- Plain radiographs can help diagnose joint degeneration or joint-based lesions such as gout and synovial osteochondromatosis.
- Magnetic resonance imaging is the modality of choice for soft tissue tumor evaluation (**FIG 1A,B**).
- Fat-sensitive images such as T1-weighted sequences are best for identifying critical anatomic structures such as nerves and vessels.
- Fluid-sensitive images including T2-weighted and STIR sequences highlight pathology very well.
- Contrast-enhanced sequences are used to differentiate cystic from solid areas in tumors and identify reactive peritumoral edema, which will be high signal on fluid sequences but not enhance with contrast.
- Some benign tumors such as lipoma, lipoma arborescens, and schwannoma may be diagnosed on MRI; however, most soft tissue tumors require a biopsy for diagnosis.³

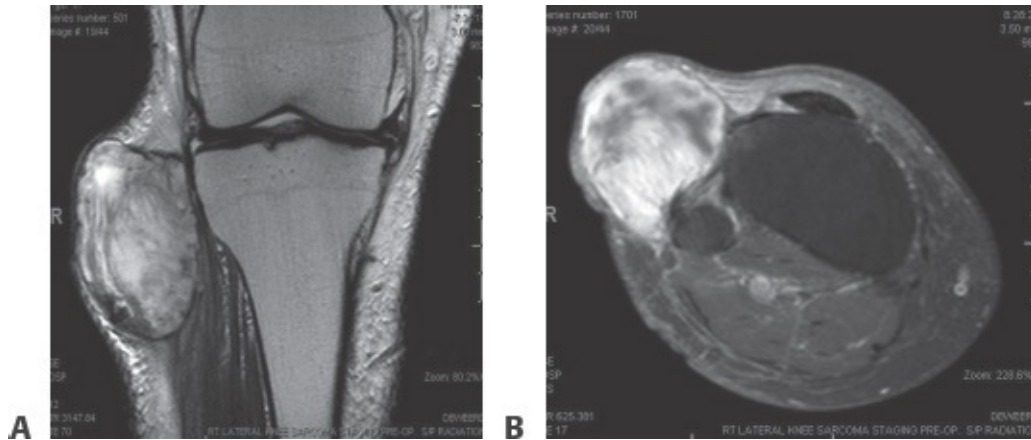


FIG 1 • A. Coronal and axial **(B)** MRIs demonstrating a high-grade soft tissue sarcoma abutting the proximal tibia and knee joint.

DIFFERENTIAL DIAGNOSIS

- Giant cell tumor of tendon sheath
- Synovial chondromatosis
- Lipoma arborescens
- Other benign tumors
- Sarcoma
- Reactive and inflammatory lesions such as gout or infection

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Performing a surgery without consideration of the diagnosis and the appropriate margin may cause harm to patients.⁴
- In cases where MR imaging is not diagnostic, a biopsy should be performed.
- Treatment strategy including the use of preoperative radiation and specific surgical plan should be formulated by a multidisciplinary team specializing in sarcoma care.⁵
- Treatment of knee tumors may require resection of the joint capsule, extensor mechanism, and/or stabilizing structures such as the collateral ligaments. Reconstruction of these structures should be accounted in the operative plan.

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The surgical plan is created by thorough study of the preoperative MR scan. A plane of surgical dissection is planned to remove the tumor in its entirety while maintain a clean margin around it.
- If the tumor encases important vascular structures, a plan for vascular reconstruction is made with a vascular surgeon.
- Anticipated soft tissue coverage needs are assessed such as skin graft, local rotation flap, or free tissue transfer.

Positioning

- The patient is placed in the supine position unless the tumor is in the posterior compartment in which case the patient is placed in the prone position.
- The site of a flap harvest must be completely isolated from the tumor site to avoid contamination and tumor spread. A separate back table and clean instruments should be used.

Approach

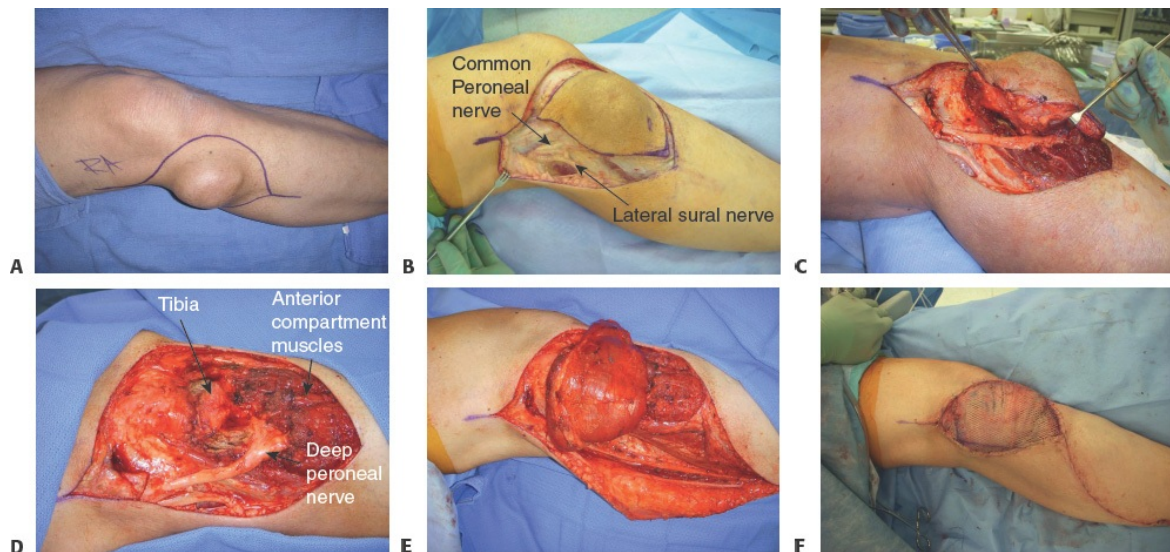
- The surgical approach varies based on location of the tumor.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

TECHNIQUES

■ Wide Resection of a Knee Sarcoma

- Most knee tumors are subcutaneous and require a paddle of skin to be removed as the superficial margin.
- An incision is made 2 to 3 cm peripheral to the edge of the tumor as determined by palpation and preoperative MRI (**TECH FIG 1A**).
- The dissection is carried through the subcutaneous fat angling away from the tumor (**TECH FIG 1B**).
- The deep fascia is identified and cut circumferentially around the tumor (**TECH FIG 1C**).

- For tumors abutting the joint capsule, the surgeon must assess if the tumor is adherent to the capsule, in which case the entire capsule must be removed, or if the tumor only abuts the capsule in which case only the retinaculum needs to be removed.
- Sutures may be used to secure the deep layer to the skin to prevent the tumor from “leaking out” of the superficial layer.
- Take care not to shear off the fat from the fascia during dissection.
- Avoid retractors on the tumor side of the dissection.
- Do not sacrifice margin in order to save tissue for a primary closure (**TECH FIG 1D**).
- Most surgeries require a skin graft or muscle flap for closure (**TECH FIG 1E,F**).



TECH FIG 1 • **A.** Planned skin incision. Notice the margin of skin around the palpable tumor. **B.** Superficial dissection of skin and subcutaneous tissue and identification of the common peroneal and lateral sural cutaneous nerves. **C.** The deep fascia is cut peripherally and a small cuff of muscle and retinacular tissue is removed as the deep margin. The muscular branches of the peroneal nerve are preserved. **D.** Defect after tumor removal. **E,F.** Lateral gastrocnemius muscle flap is rotated to cover the

defect and split-thickness skin graft applied.

PEARLS AND PITFALLS

Hematoma	■ Dead space after tumor removal should be managed with drains, muscle flap, free tissue transfer, or a combination of these techniques. ■ Seroma drainage in the clinic may be necessary.
Wound breakdown	■ Negative pressure dressings, aggressive dead space management, and maximizing patients' nutrition may reduce wound problems. ■ Patients should be counseled about potential need for reoperation for wound management.
Positive margins	■ Appropriate preoperative planning is important to minimize risk of unplanned positive margins. ■ Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings.

POSTOPERATIVE CARE

- Mobilization and weight bearing depend on the extent of surgery.
- Extremity elevation is recommended while patient is in bed.
- Range of motion and therapy may begin after wound healing is sufficient.
- Postoperative radiotherapy, if needed, may be take place 4 to 6 weeks after surgery.

OUTCOMES

- Oncological outcomes include local recurrence and metastasis. Surveillance for recurrence should be managed by a multidisciplinary sarcoma team.
- Functional outcomes depend on the extent of tissue resection, patient overall health status, and late effects of radiation. Aggressive wound care and physical therapy may help maximize patient function.

COMPLICATIONS

- Wound healing problems that require operative intervention can occur in up to 33% of patients who undergo preoperative radiotherapy and 17% of patients who undergo postoperative radiotherapy.⁶
- Local recurrence occurs in a minority of patients and is more common in

patients with positive margins. Radiotherapy decreases the risk of local recurrence.

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29 Excision of Bone Tumors of the Knee

CHAPTER

Raffi S. Avedian

DEFINITION

- Bone tumors of the knee may be benign or malignant (bone sarcoma) and exhibit a variable natural history ranging from latent to rapid growth.
- A bone tumor located in the distal femur or proximal tibia such that definitive treatment requires excision of part or all of the knee is discussed in this chapter.
- Treatment for a bone tumor of the knee requires reconstruction of the knee articulation.

ANATOMY

- The knee is the largest joint in the body. It is made up of the patellofemoral, lateral, and medial compartments.
- Knee motion is primarily flexion and extension; however, bending and rotation are important components of knee kinematics.
- The primary stabilizers of the knee are the extra-articular medial and lateral cruciate ligaments and intra-articular anterior and posterior cruciate ligaments.
- The popliteal artery travels along the back of the knee and along with the tibial nerve travels between the lateral and medial head of the gastrocnemius. It branches into the posterior tibial artery, which travels deep to the soleus muscles; the anterior tibial artery, which passes from posterior to the anterior compartment distal to the tibia-fibula joint; and the peroneal artery, which branches off the tibiofibular trunk and is located medial to the fibula next to the flexor hallucis longus.
- The geniculate vessels branch off from the popliteal vessels and are often all ligated during tumor resection of the distal femur.
- The tibial nerve is located next to the popliteal vessels. The common peroneal

nerve travels medial and deep to the biceps femoris muscle; a constant relationship that facilitates finding and protecting the nerve during tumor dissection.

PATHOGENESIS

- The mechanism for bone tumor formation is not known.
- Risk factors for sarcoma development include radiation exposure, radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and retinoblastoma gene mutation.¹

NATURAL HISTORY

- Active benign tumors, such as giant cell tumor of bone, chondroblastoma, and aneurysmal bone cyst, will progress over time, may recur after excision, but are not lethal.
- All bone sarcomas have the potential for local recurrence and metastasis.
- Bone sarcomas have an *estimated incidence of 3260* in the United States.
- Lungs and other osseous sites are the most and second most common location of metastasis, respectively.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pain is a common presenting symptom for aggressive bone tumors.
- A thorough history and examination are important to assess duration of symptoms, comorbidities, physical dysfunction, organ involvement, overall health, and patient expectations in order to best tailor treatment strategy for the individual patient.
- Neurovascular examination is mandatory for any extremity tumor.

IMAGING

- Plain radiographs are used to formulate a differential diagnosis and a preoperative plan.
- Magnetic resonance imaging is routinely used to determine extent of intramedullary tumor involvement, presence of soft tissue extension, status of the neurovascular structures, and presence of tumor within the joint space.

DIFFERENTIAL DIAGNOSIS

- The differential diagnosis for a bone tumor includes benign tumors, sarcomas, lymphoma of bone, infection, and metabolic lesions (eg, hyperparathyroidism).
- The most common bone sarcomas are osteosarcoma, chondrosarcoma, and

Ewing sarcoma.

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Biopsy incisions are considered contaminated and must be resected at the time of definitive surgery. Care should be taken to place the biopsy in a location that does not interfere with the final surgical plan.²
- If a bone sarcoma extends into the knee joint space by direct growth, pathological fracture, or iatrogenic contamination, an extra-articular resection (keeping the knee joint closed) should be performed.
- Reconstruction depends on the extent of bone excision and may include simple bone grafting, endoprosthetic implants, bulk allografts, osteoarticular implants, or vascularized fibula.
- The goal of surgery is to remove the tumor adequately to minimize recurrence and restore the mechanical integrity of the bone and joints so that the patient may have sufficient function to perform activities of daily living with minimal pain.

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The surgical plan is created by thorough study of the preoperative radiographs and MR scan.
- Bone cuts are planned by measuring on preoperative imaging the distance from an intraoperatively identifiable landmark (eg, femoral condyle, epicondyle) to the desired osteotomy site.
- The soft tissue margin depends on the size and location of a soft tissue component to the tumor. For example, an anterior soft tissue mass along the distal femur can be safely resected by incorporating a portion of the vastus intermedius as the margin.
- When tumor abuts but does not encase blood vessels or nerves, they can be dissected free by leaving adventitia and epineurium on the tumor as the margin.

Positioning

- The patient is placed in the supine position; a hip bump may be placed if more

lateral exposure is desired.

- A sterile or nonsterile tourniquet may be used.
- A leg holder may be used in cases where an endoprosthetic knee replacement is being performed.

Approach

- The surgical approach varies based on location of the tumor.
- The guiding principles for the approach to the knee in the setting of a bone sarcoma are to maintain a sufficient margin around the tumor and preserve as much normal tissue as possible without sacrificing cancer treatment.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

TECHNIQUES

■ Distal Femur Resection and Endoprosthetic Reconstruction

- Tourniquet is used at the discretion of the surgeon by using gravity exsanguination rather than Esmarch to avoid tumor compression
- A longitudinal incision is made that includes a fusiform skin excision of the biopsy site. Skin flaps are created as needed to ensure adequate visualization of the tumor and critical anatomy.
- Soft tissue dissection around the tumor is performed with the following principles:
 - Adequate visualization must be achieved.
 - Margin of healthy tissue is kept on the tumor.
 - Nerves are dissected free; epineurium may be used as margin if tumor abuts the nerve. Sciatic nerve branches to hamstring muscles may be cut as needed to adequately mobilize the nerve away from the tumor.
 - Vessels are mobilized; adventitia may be used as margin if tumor abuts the vessels.
- Tumor removal may be broken down into four steps:
 - *Knee disarticulation*: perform an arthrotomy and cut collateral and cruciate ligaments, joint capsule, gastrocnemius origins, and popliteus tendon.

- *Neurovascular mobilization*: the popliteal vessels must be mobilized by dividing the geniculate branches and dissecting the vessels free from the adductor canal. The tibial nerve is located next to the vessels and the common peroneal nerve is located medial to the biceps femoris. They should be identified and mobilized away from the tumor as needed.
- *Muscle dissection*: often bone sarcomas of the distal femur or proximal tibia will have a soft tissue component. The muscle layer immediately covering the tumor is removed as the margin. For example, the vastus intermedius serves as good margin for anterior soft tissue masses. The lateral and medial intermuscular septa must be divided as close to the bone as tumor margin permits.
- *Osteotomy*: Measure the length of bone to be resected on preoperative MRI and translate that to intraoperative landmarks such as a measurement from the femoral condyle to the femoral diaphysis above the tumor. Bennett or Hohmann retractors are placed around the bone to prevent iatrogenic neurovascular injury and an oscillating saw is used to complete the osteotomy.
- The remaining posterior soft tissue attachments are cut, and the specimen is removed.
- Leg length can be restored by measuring the contralateral leg from the anterior superior iliac spine to the medial malleolus and recreating this on the operative side or measuring and recreating the length of bone removed from the affected side (**TECH FIG 1**).

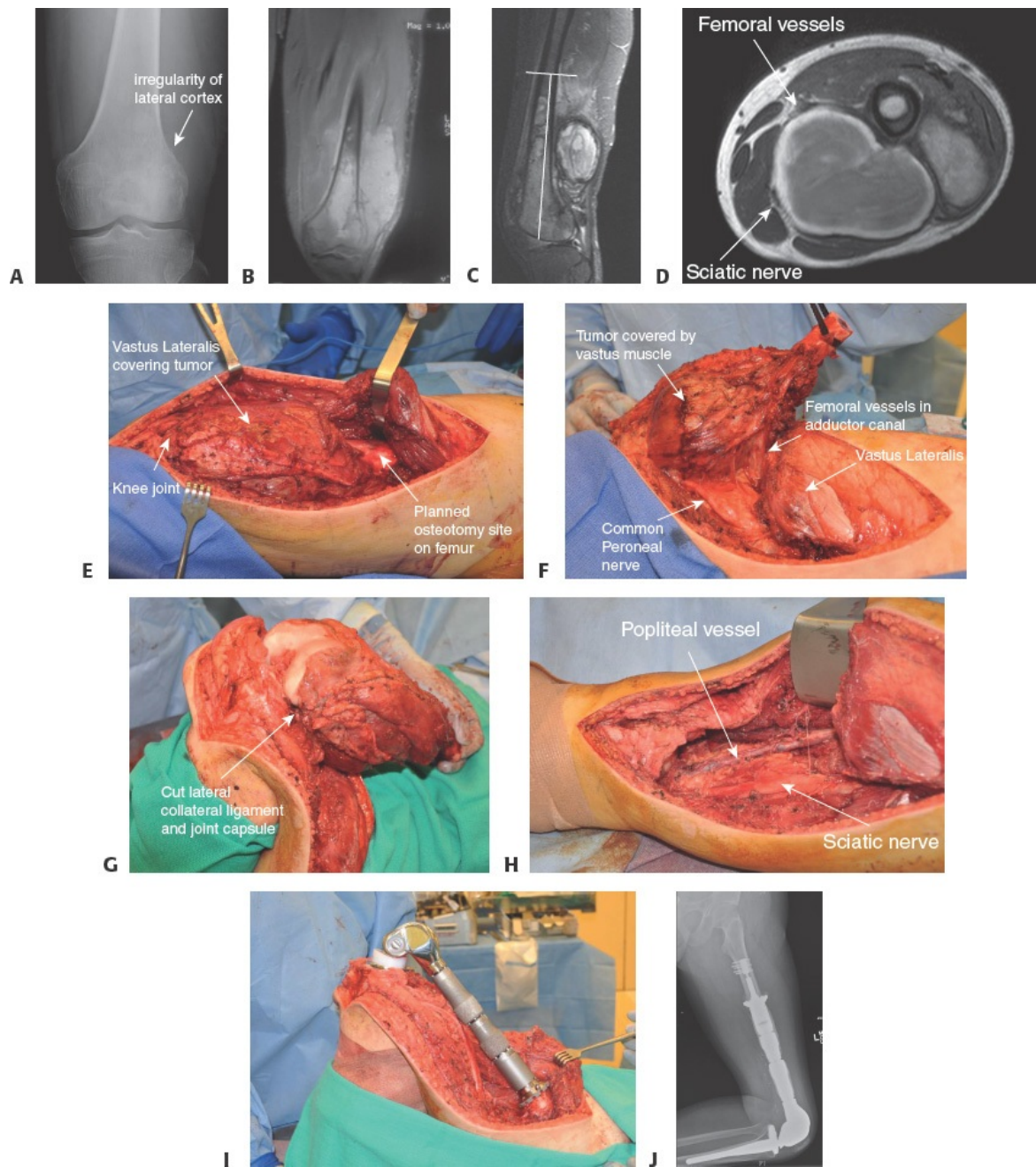


TECH FIG 1 • Intraoperative photograph demonstrating technique for leg length recreation.

Trial implants are measured side by side with femur and tibial plateau to ensure what goes into patient matches exactly what was taken out.

■ Reconstruction

- The femur is prepared for endoprosthetic reconstruction using one of the currently available fixation techniques: a cemented stem, uncemented stem, or compress compliant prestress device (**TECH FIG 2**).
- Rotational alignment can be achieved by using the linea aspera as a posterior landmark. Also, trial implants may be placed and the knee taken through a range of motion check to ensure proper rotation of implants and patellar tracking. Once the surgeon is satisfied with the rotation, a mark is placed on the bone denoting anterior. This mark is used as a guide for correct insertion of the final implant.
- Deep drains are placed, and the deep fascia is closed over drains, followed by a subcutaneous fascia and dermal layer.



TECH FIG 2 • A. Anteroposterior radiograph of a 14-year-old boy with a distal femur osteosarcoma. **B.** Coronal MRI demonstrating large intramedullary extension and soft tissue mass. **C.** Sagittal MRI after induction chemotherapy demonstrating tumor extent and measurement for planned osteotomy. **D.** Axial MRI demonstrating soft tissue mass in vastus lateralis

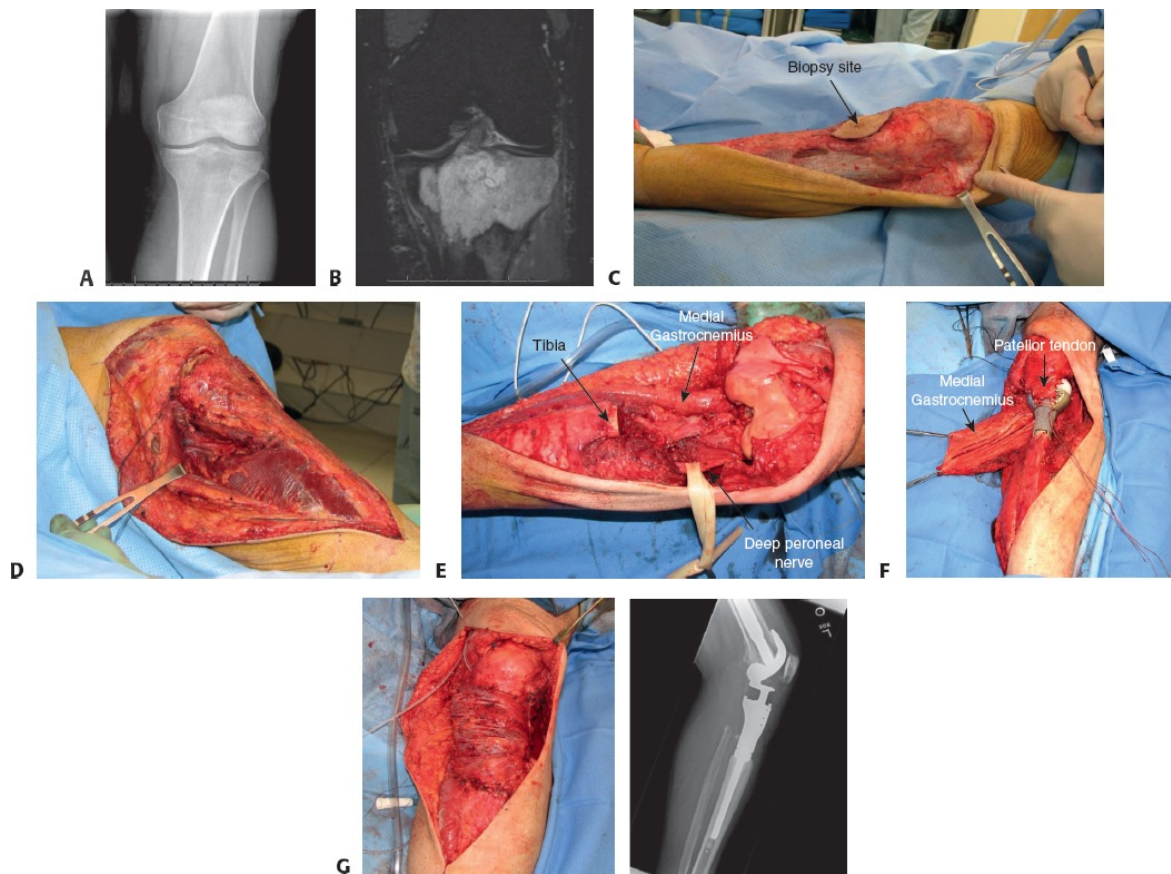
and popliteal fossa abutting sciatic nerve and vessels. **E.** Intraoperative photograph after initial dissection around tumor, note a portion of the vastus lateralis is left on the tumor as a margin and the femur is exposed proximal to the tumor in anticipation of osteotomy. **F.** After osteotomy, the femur is lifted out of the wound to facilitated dissection of the posterior anatomy including the sciatic nerve and femoral vessels as they pass through the adductor canal. **G.** Photograph showing that the ligamentous structures of the knee including the capsule are identified and cut. **H.** Photograph of defect after tumor removal. **I.** Endoprosthetic reconstruction is performed including large metal segment to replace bone and a hinged total knee arthroplasty. **J.** Lateral radiograph 4 months after surgery.

■ Endoprosthetic Reconstruction of the Proximal Tibia

- The principles of distal femur tumor resection outlined in the previous section apply to resection of tumors of the proximal tibia.
- Unique aspects of proximal tibia resection include the following (**TECH FIG 3**):
 - Large skin flaps must be raised to visualize critical anatomy.
 - Patellar tendon must be detached from the tibial tubercle and subsequently reconstructed.
 - The popliteus muscle can be used as the margin covering posterior soft tissue masses.
 - The anterior tibial artery often must be ligated and divided as it branches from the popliteal artery at the lower border of the popliteus muscle.
 - The proximal fibula may be excised along with the tibia depending on the lateral extent of the tumor.
 - The patellar tendon may be repaired using 5-mm Mersilene tape sewed into

the tendon using Krackow stitches, the ends of which are then tied into the endoprosthesis.

- The repair may be reinforced using no. 5 nonabsorbable to sew the tendon down into additional holes in the endoprosthesis either directly or after cerclage around the patella.
- A gastrocnemius flap is elevated and rotated to cover the prosthesis and provide biological augmentation to the patellar tendon repair.
- A deep drain is placed, and the wound is closed in layers. A split-thickness skin graft is often needed to cover a portion of the gastrocnemius flap.



TECH FIG 3 • **A.** Anteroposterior radiograph of a 61-year-old man with a proximal tibia chondrosarcoma. **B.** MRI demonstrating tumor extent. **C.** Intraoperative photograph showing initial dissection including large skin flaps to enable adequate visualization. **D.** Deep dissection is performed by identifying the popliteal vessels and tibial nerve and mobilizing healthy muscle

away from the tumor. The soleus muscle is eventually detached along its insertion on the tibia and the gastrocnemius muscle is isolated in anticipation of rotational flap. **E.** Defect after tumor removal, notice the deep peroneal nerve has been preserved. **F.** The patellar tendon is secured to the implant with a 5-mm Mersilene tape using Krackow stitches and reinforced with no. 5 FiberWire. **G.** The gastrocnemius flap is brought over and secured in place making sure to cover the prosthesis and anchoring into the patellar tendon and joint capsule to maximize healing of the extensor mechanism. The wound was otherwise closed in layers over drains and a small skin graft was applied to the portion of the flap that remained exposed after skin closure.

PEARLS AND PITFALLS

Hematoma

- Dead space after tumor removal should be managed with drains, muscle flap, free tissue transfer, or a combination of these techniques.

Wound breakdown

- *Incisional negative pressure dressings*, aggressive dead space management, and maximizing patients' nutrition may reduce wound problems.
- Low threshold to debride draining wounds to minimize risk of prosthetic joint infection.

Positive margins

- Appropriate preoperative planning is important to minimize risk of unplanned positive margins.
- Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings.

Venous thromboembolic events

- Risk of VTE compared to risk of hemorrhage into dead space should be balanced and patient counseled regarding risks.
- Aspirin and low molecular weight heparin are options for

	chemical prophylaxis.
	■ Mechanical compression is routinely used.
Prosthetic infection	■ Most common mode of failure in the long term. ■ May coat prosthesis with high doses of antibiotic bone cement at time of revision for local antibiotic delivery.

POSTOPERATIVE CARE

- Mobilization and weight bearing depend on the extent of surgery.
- Extremity elevation is recommended while patient is in bed.
- Range of motion and therapy may begin the first 1 to 2 weeks for distal femur reconstructions.
- Proximal tibia reconstructions require strict knee extension for 6 weeks to allow patellar tendon healing. Gradual knee flexion is begun at 6 weeks and progresses under the supervision of a physical therapist.
- May administer antibiotics while drains are in place.

OUTCOMES

- Oncological outcomes include local recurrence and metastasis. Surveillance for recurrence should be managed by a multidisciplinary sarcoma team. Local recurrence is higher when margins are positive.¹
- Functional outcomes depend on the extent of tissue resection and patient overall health status. Most patients will experience some form of disability that is proportional to the volume of muscle and bone resected.³
- Distal femur reconstructions do not require extensor mechanism reattachment and therefore generally function better than proximal tibia reconstructions.

COMPLICATIONS

- Prosthetic loosening may occur over time necessitating revision surgery. Generally, implant survival is approximately 80% at 20 years.
- Local recurrence occurs in a minority of patients and is more common in patients with positive margins.
- Deep infection can occur at any time after surgery and requires aggressive therapy including surgical debridement and antibiotic therapy to achieve limb salvage. Removal of implants may be necessary to eradicate infection.

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Bony and Soft Tissue Debridement Around the Knee

CHAPTER

Derek F. Amanatullah, Michael J. Chen, Sahitya K. Denduluri, and James I. Huddleston

DEFINITION

- Several conditions affect the knee that requires meticulous soft tissue and bony debridement for treatment: these include open fractures, osteomyelitis, and infected total knee arthroplasty (TKA).
- The expertise of plastic surgeons is frequently needed for soft tissue management and coverage as the knee is relatively devoid of surrounding soft tissues in comparison to the muscle bound femur.

ANATOMY

- The knee is a complex synovial joint composed of two joints: the tibiofemoral and patellofemoral articulations.
 - The tibiofemoral articulation functions as a hinge joint allowing for flexion and extension with minimal rotation.
 - It transfers body weight from the femur to the tibia and can experience high joint reaction forces.
 - The patella is the largest sesamoid bone in the human body and transmits tensile forces from the quadriceps tendon to the patellar ligament.
 - By increasing the lever arm of the extensor mechanism from the center of rotation of the tibiofemoral joint, the patella reduces the amount of work the quadriceps have to perform to extend the knee.
- The distal femur is trapezoidal in shape with two condyles that articulate with the two condyles of the tibial plateau, forming the medial and lateral compartments of the knee. The majority of the weight is borne through the

medial compartment in a native healthy knee.

- The mechanical axis of the lower extremity is characterized by a straight line that passes from the center of the hip through the center of the ankle. Ideally, this line passes through the center of the knee.
- Compared to the hip, which is a ball and socket joint, the knee is a relatively incongruent and relies on both static and dynamic forces for rotational, sagittal, and coronal stability.
- The dynamic stabilizers are the muscles and their tendons that cross the knee joint: these include the hamstrings, the iliotibial band, the pes anserine, the two heads of the gastrocnemius, the popliteus, and the extensor mechanism.
 - These muscles provide stability through compression of the joint when they are activated.
 - The hamstrings are composed of the biceps femoris, which crosses the posterolateral aspect of the knee to insert onto the head of the fibula, and the semimembranosus, which inserts onto the posteromedial aspect of the tibial plateau.
 - The semitendinosus, also a hamstring muscle, crosses the medial aspect of the knee to insert onto the anteromedial proximal tibia along with gracilis and sartorius to form the pes anserine.
 - The iliotibial band forms from the coalescence of the gluteus maximus and tensor fascia lata and crosses the knee laterally to insert onto Gerdy tubercle, a prominence found just below the joint line on the anterolateral tibia.
 - The popliteus originates from the posterior aspect of the proximal tibia and inserts on to the lateral aspect of the lateral femoral condyle.
 - The two heads of the gastrocnemius cross posteriorly and insert onto the medial and lateral aspects of the distal femur.
- The static stabilizers include the ligaments and joint capsule.
 - The medial collateral ligament (MCL) extends from the medial epicondyle of the femur to the medial aspect of the proximal tibia metaphysis and resists valgus forces across the knee.
 - The posterolateral corner (PLC) of the knee resists varus and external rotational forces at the knee: its main components are the lateral collateral ligament, which extends from the lateral epicondyle of the femur to the proximal fibular head, the popliteus muscle, and the biceps femoris tendon.
 - The anterior cruciate ligament (ACL) extends from the posteromedial aspect of the lateral femoral condyle and runs anteriorly to insert in between and in front of the tibial spines to resist anterior displacement of the tibia relative to

the femur.

- The posterior cruciate ligament (PCL) runs from the anteromedial aspect of the medial femoral condyle to the posterior tibial sulcus to resist posterior displacement of the tibia relative to the femur.
- The extensor mechanism crosses the knee joint anteriorly and inserts onto the tibial tubercle.
 - It is composed of the four muscle bellies of the quadriceps, the quadriceps tendon, the patella, the patellar ligament, and the medial and lateral patellofemoral retinaculum.
 - It is critical to normal ambulatory function.
- The superficial femoral artery courses down the femur on the medial side underneath the sartorius muscle and then passes through the adductor hiatus to run posterior to the knee in the popliteal fossa where it becomes the popliteal artery.
 - It provides the sole blood supply to the distal extremity and, if compromised, risks viability of the leg and foot.
- The main blood supply to the knee is provided from superior and inferior lateral genicular arteries, the superior and inferior medial genicular arteries, the anterior recurrent tibial artery, and the descending genicular artery.
 - These form an anastomotic ring around the patella.
- The femoral nerve crosses the knee at the medial aspect and becomes the saphenous nerve supplying sensation to the medial leg and foot.
 - It gives off the infrapatellar branch as it crosses the knee, supplying sensation to the anteroinferior skin of the knee.
 - This nerve is sacrificed frequently during anterior midline exposures.
- The sciatic nerve bifurcates just above the popliteal fossa into the tibial and common peroneal nerves.
 - The tibial nerve joins the popliteal artery and runs directly posterior to the knee into the leg.
 - The common peroneal nerve crosses laterally and runs superficially around the neck of the proximal fibula before bifurcating in the deep and superficial peroneal nerves.
- The blood supply to the skin of the knee typically arises from medial to lateral.
 - This characteristic deserves careful attention when choosing which incision to use on a knee with multiple scars.
 - Typically the most lateral incision is chosen so that the potential area of skin

at risk for necrosis is minimized.

PATHOGENESIS

- Conditions that warrant bony debridement around the knee include open fractures, chronic osteomyelitis, and periprosthetic joint infections (PJI) after TKA.
- Bony debridement is frequently required to prevent or eliminate bacteria capable of forming biofilms.
- Bacteria can exist in either a planktonic or biofilm state.
 - In contrast to planktonic microorganisms that are free-floating and rapidly dividing, a biofilm is characterized by sessile microorganisms that are embedded in a matrix capable of withstanding both the host's immune system and antibiotics.
- Once bacteria colonize and adhere to the necrotic bone or implants, they can rapidly form a biofilm.
 - Surgical debridement and removal of any implants are the most efficacious method to eradicate infection.

Open Fractures

- Open fractures involving the patella are the most common with an incidence of 6 per million per year in the general population, followed by the distal femur (5.6 per million per year) and proximal tibia (3.8 per million per year).
 - Road traffic accidents are the primary mechanism.
- The Gustilo classification system for open fractures was first published in 1976, modified in 1984, and arguably remains the most commonly used system in orthopedic surgery.^{1,2}
 - This system organizes open fractures in order of worsening prognosis according to the degree of soft tissue injury, need for soft tissue coverage and vascular insult.
 - Type I: usually low energy, clean, and involve an open wound less than 1 cm in size
 - Type II: intermediate-energy, moderately contaminated wounds greater than 1 cm (but less than 10 cm)
 - Type III: farm injuries or high-energy fractures with periosteal stripping and extensively contaminated open wounds greater than 10 cm:
 - IIIA wounds can be managed with local wound coverage and skin graft

only.

- IIIB requires rotational or free flap coverage.
- IIIC is associated with arterial damage.
- The risk of infection has been shown to directly correlate with the fracture grade.
- The true extent of underlying soft tissue damage can be appreciated only after surgical exploration and debridement in the operating room, rather than in the emergency department.
- All open fractures are considered contaminated with bacteria, and antibiotics must be administered as early as possible to prevent infection.
- Patzakis et al. found an infection rate of 4.7% compared to 7.4% when antibiotics were given within 3 hours of injury.³
- The choice of the antibiotic depends on the degree of injury and level of contamination.
 - Intravenous first-generation cephalosporins, such as cefazolin, are considered first line.
 - For Gustilo type III open fractures, extending the coverage to include gram-negative bacteria by adding an aminoglycoside is commonplace.

Osteomyelitis

- Osteomyelitis can arise from hematogenous seeding, contiguous spread from adjacent tissues or joints, or direct inoculation from surgery or trauma.
- Hematogenous spread of bacteria typically afflicts the metaphysis in skeletally immature patients but can also seed implants especially in the case of TKA.
- Contiguous spread and direct inoculation are seen after direct contamination from open fractures or surgical procedures.
- The duration of symptoms designates osteomyelitis as either acute or chronic and carries important implications with regard to biofilm formation and the need for surgical debridement.
- The Cierny-Mader classification system is commonly used to categorize osteomyelitis based on the extent of bony involvement and status of the host and carries prognostic value in addition to guiding therapy.
 - Type I involves only the medullary canal.
 - Type II involves a portion of the cortex.
 - Type III is an infection that permeates the cortex into the canal, but the bone

is axially stable.

- Type IV is similarly permeative but diffuse and places the bone at risk for fracture.
- The status of the host is divided into classes A, B, and C.
 - The A host is physiologically healthy.
 - The B host has compromised physiology from systemic effects of the infection or medical comorbidities.
 - The C host is classified as one in which the morbidity of the treatment is greater than the disease.
- Sequestrum is a key pathologic feature of osteomyelitis and represents the formation of necrotic bone.
- Bacteria persist in devascularized bone and evade host defenses and antimicrobial agents.
- The response of the host is to generally wall of the “bony abscess” by forming sclerotic bone around the sequestrum.
 - This is known as the involucrum.

Infection After Total Knee Arthroplasty

- Periprosthetic joint infection after TKA is a devastating condition that occurs in 0.5% to 1.9% of primary TKAs and in 8% to 10% of revision TKAs.⁴⁻⁶
- The implants provide an excellent surface for bacterial adherence, biofilm formation, and facilitate the spread of the microorganisms into the surrounding bone and soft tissues.
- Infections can occur in the perioperative period or years later after a previously well functioning TKA.
- The longer the duration of symptoms, the greater chance of biofilm formation on the implants and surrounding bone.
 - Symptom duration is commonly separated into acute (3 weeks after surgery or symptom onset) and chronic (greater than 3 weeks after surgery or symptom onset).
 - Aggressive surgical debridement and implant removal are key interventions to treat infections with suspected biofilm formation.
- Conditions that warrant soft tissue debridement around the knee include open fractures, septic arthritis, and PJI after TKA.
- Soft tissue debridement is frequently required to prevent or eliminate bacteria capable of forming biofilms.

PATIENT HISTORY AND PHYSICAL FINDINGS

Open Fractures

- Any patient presenting with an open fracture may have associated injuries to the head, chest, abdomen, pelvis, spine, and extremities.
- A standard evaluation according to the Advanced Trauma Life Support guidelines should be performed to evaluate for all potentially life-threatening injuries.
- The injury mechanism and details are helpful as high- vs low-energy injuries predict the extent of bony and soft tissue injury.
 - Low-energy trauma with an open fracture may be associated with a small inconspicuous poke hole created from inside-out injury.
 - High-energy trauma usually creates a much larger soft tissue defect or frank degloving of the skin and subcutaneous tissues.
- A detailed neurovascular exam of the lower limb involved should be done with focus on evaluating the function of the peroneal and tibial nerves, as well as the dorsalis pedis and posterior tibial pulses.
- Any suspicion of vascular injury may direct appropriate testing and consultation with a vascular surgeon.
- The soft tissues must be thoroughly inspected.
 - Any fracture with a nearby skin laceration or defect should be considered open until proven otherwise by surgical evaluation or saline challenge, utilized in evaluation of traumatic arthrotomy and to determine the presence of possible external communication with the knee joint.

Osteomyelitis

- Symptoms and signs of infection should be elicited from the patient including fever, chills, pain, and swelling.
- Prior injuries and surgeries including the presence of hardware are important to identify.
- The general medical status of the patient including factors that can contribute to an immunocompromised state should be investigated.
- The involved limb should be inspected for erythema, swelling, tenderness, and any opening in the skin that might suggest a draining sinus tract (**FIG 1**), which is indicative of chronic osteomyelitis.
- The neurovascular status of the limb should be evaluated as well as the quality

of the soft tissues.

- The erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) are markers of inflammation that are typically elevated and can be useful for monitoring response to therapy.
- The white blood cell count may be normal in cases of chronic infection.



FIG 1 • Draining sinuses as a result of chronic periprosthetic knee infection.

Infection After TKA

- PJI may present acutely after surgery with persistent pain and drainage from the incision with overlying cellulitis or in a delayed fashion with pain only (**FIG 2**).
- Any pain, stiffness, or instability should warrant consideration of an infection until proven otherwise.
- Special attention should focus on the scars about the knee and neurovascular status of the limb.
- Multiple scars or poor-quality tissues may necessitate the early involvement of a plastic surgeon for soft tissue coverage at the time of the planned surgery.
- An ESR greater than 30 and CRP greater than 10 mg/L are recommended as the thresholds indicative of chronic infections.
- If there is any suspicion of PJI, the knee should be aspirated and the fluid sent for cell count, gram stain, and culture.
 - Importantly, the entry point of the needle for aspiration should not involve any skin with overlying cellulitis.
 - An aspiration that yields greater than 1700 cells/ μ L with a neutrophil

percentage greater than 65% is highly suggestive of PJI.



FIG 2 • A. Wound dehiscence postoperative day 14 in a 55-year-old woman with diabetes mellitus s/p total knee arthroplasty for osteoarthritis. **B.** Skin necrosis in a 25-year-old woman after patellofemoral arthroplasty for post-traumatic arthrosis.

IMAGING

Open Fractures

- Orthogonal radiographs of affected area including the joint above and below are important for characterizing the fracture pattern and detecting concomitant injuries, which are frequent in high-energy trauma.
- For open extra-articular fractures involving the proximal tibia or distal femur, plain radiographs are typically all that is required for surgical planning.
- This is true also for isolated open fractures of the patella.
- Fractures involving the tibia plateau or distal femoral condyles may be complex and require computed tomography (CT) to better visual the fracture patterns and to facilitate optimal surgical planning.
- CT angiography may be considered if there is suspicion for vascular injury.
- Magnetic resonance imaging (MRI) is not typically warranted in the acute period but may be obtained eventually if ligamentous or meniscal damage is suspected.

Osteomyelitis

- Radiographs of the involved limb should be obtained in orthogonal planes.
 - In the acute stages of osteomyelitis, the films may be unremarkable.
 - A lytic lesion may be appreciated when enough of the bone has eroded.
 - In chronic situations, the sequestrum may form and is characterized by a sclerotic focus of infected and necrotic bone that may be surrounded by a thickening of the surrounding cortex known as the involucrum with periosteal reaction.
- Computed tomography is more sensitive and better shows the bony destruction from the lesion compared to plain films.
- Magnetic resonance imaging is the most sensitive modality especially in the early stages of osteomyelitis and will show the extent of intramedullary and soft tissue involvement.
- Nuclear bone scans are a sensitive modality but nonspecific.

Infection After TKA

- Standard radiographs should be obtained and may show osteolysis with component subsidence or loosening.
- CT scans, MRI, and nuclear bone scans of little use in preoperative planning and are not typically needed.

SURGICAL MANAGEMENT

Open Fractures

- Historically, the practice in orthopedic surgery has been to perform operative debridement within 6 hours after injury to minimize the risk of infection, but there may be no advantage to performing the debridement within this time frame compared to within 24 hours after injury.
 - A thorough debridement by an experienced team during daylight hours with the appropriate ancillary staff appears to be the critical factor in preventing infection.
- All devitalized and contaminated soft and bony tissue must be identified and removed in a systematic fashion.
- Bony damage can be highly variable and demands thorough intraoperative inspection.
 - The decision of whether to retain or discard bony fragments depends on the remaining soft tissue attachments and involvement of the diaphysis, metaphysis, and articular margins.

- Diaphyseal fragments that are stripped of their soft tissue attachments are effectively devascularized and must be removed, to prevent a nidus for infection.
- Metaphyseal fragments, in contrast, have a greater amount of cancellous bone, which has a greater capacity to revascularize and reintegrate.
 - Thus fragments that have minimal contamination may be retained.
- Cancellous fragments from the articular margins are also retained in order to anatomically reconstruct the articular surface.
- Repeat debridement may be necessary 24 or 48 hours later, as the zone of injury may be more extensive than initially appreciated.
- Thorough irrigation of the wound after debridement should be performed using the rationale that “the solution to pollution is dilution.”
- Once the wound has been debrided back to healthy and viable soft tissue and bone, attention must be turned to achieving skeletal stabilization.
 - Stabilizing the bone is critical for creating an environment conducive not only for bone healing but soft tissue healing as well.
 - Stabilization also facilitates early mobilization of adjacent joints, preventing stiffness and further disability of the injured limb.
 - Options for stabilization will depend on the need for repeat debridement and soft tissue coverage.
 - The wound should be definitively closed within 48 to 72 hours after fracture fixation.
 - If injury is a type IIIB open fracture, then external fixation may be preferred to allow unimpeded access to the wound for soft tissue coverage followed by definitive internal fixation after the soft tissue envelope has been re-established and healed.
- High-energy injuries may result in substantial bony or soft tissue loss from the initial injury with subsequent debridement procedures creating extensive dead space.
 - Temporary antibiotic-impregnated polymethylmethacrylate (PMMA) cement beads can be placed into bony defects and used to deliver high doses of antibiotics locally.
 - Alternatively, negative pressure wound therapy may be used for similarly large soft tissue defects.

Osteomyelitis

- Once the diagnosis of osteomyelitis has been made, it requires proper staging and a multidisciplinary approach with involvement of infectious disease specialists, orthopedic surgeons, and plastic surgeons especially if the need for soft tissue coverage is anticipated.
- Though acute hematogenous osteomyelitis without associated implants may be amenable to intravenous antimicrobial therapy alone, infections that are chronic, are associated with implants, or have an identified sequestrum will require aggressive surgical debridement if the goal is to eradicate the infection.
- All dead and nonviable bone should be removed until punctate bleeding bone is encountered.
- In the case of intramedullary infections, intramedullary reaming of the canal is an effective way to debride contaminated bone while preserving cortical stability.
- The placement of antibiotic impregnated PMMA cement into the bony and soft tissue defect to deliver high concentrations of antibiotics to the local tissue has become standard in the surgical treatment of osteomyelitis.
 - Current techniques include using an antibiotic coated intramedullary nail for situations involving the medullary canal of the tibia or femur.
 - For well-localized areas and bony defects created after the debridement, antibiotic-impregnated cement may be packed into the defect or rolled into beads and attached to suture for easy extraction and to provide a high surface area to volume ratio in order to maximize drug elution.
 - As the cement is not biodegradable and may continue to elute low levels of antibiotics for up to 5 years following implantation, a repeat procedure is typically required for removal of the cement and bone grafting of the defect to restore skeletal stability and eliminate dead space.
 - Bioabsorbable composites such as calcium sulfate have been examined as an alternative for dead space fillers and antibiotic delivery vehicles.
 - These materials have the benefits of being resorbed and possibly being replaced by bone, thus potentially eliminating the need for a second procedure.
 - McNally et al. reported an excellent eradication rate of chronic osteomyelitis treated with one stage debridement and placement of an antibiotic-impregnated bioabsorbable composite.

Infection After TKA

- The timing and duration of the infection have important implications with regard to treatment.
- An early infection is defined as occurring within 3 weeks after undergoing the procedure or within 3 weeks after becoming symptomatic in cases of late hematogenous infection.
- Late infections are considered all cases that present more than 3 weeks after the above.
- The designation of 3 weeks is based on the theoretical time period that it takes for bacteria to form biofilms.
- To prevent the morbidity of explanting components, early infections are typically treated with aggressive debridement and irrigation, exchanging the polyethylene liner, and retaining the femoral and tibial components.
- Late infections are most commonly treated by a two-stage exchange arthroplasty in the United States.
 - The microorganisms by this time have likely adhered to the implants and formed biofilms, undermining the efficacy of systemic antibiotic therapy.
 - The first stage is composed of removal of all implants, cement, and infected tissue.
 - Although minimizing bone loss is a priority, the surrounding bone can contain biofilm and must be debrided back to healthy punctate bleeding bone.
 - Irrigation is then performed, and an antibiotic-impregnated cement spacer is placed to provide stability, fill dead space, and deliver high concentrations of local antibiotics.
 - The spacer can be dynamic or static.
 - Dynamic spacers involve the use of articulating components that allow for knee range of motion.
 - Static spacers typically involve antibiotic cement-coated humeral nails that bridge the knee after being placed in the distal femoral and proximal tibial canals.
 - Intravenous antibiotics that target the identified organism are then given for 4 to 6 weeks. Once the patient has finished the course of antibiotics and has been off therapy for 2 weeks, repeat inflammatory markers are drawn. If the ESR and CRP are normal, and the clinical exam is negative for any suspicion of persisting infection, reimplantation is then considered.
 - This entails removal of the antibiotic spacer, a thorough repeat irrigation and debridement and obtaining several intraoperative tissue specimens for

cultures.

- It is important to remove the pseudomembrane that forms between the cement and the bone in the intramedullary canal with instruments such as a ringed curette.
- If there is no suspicion for residual infection, the distal femur, proximal tibia, and patella are prepared for reimplantation of the components, and the knee is balanced to achieve symmetric flexion and extension gaps.
- Depending on the degree of bone loss encountered, metal augments, stems, porous cones, or sleeves may be needed to reconstruct the bony defect.

Positioning

- Supine
- Tourniquet applied to the thigh
- Bump under ipsilateral hip to internally rotate the operative leg
- Povidone-iodine (preferred) or chlorhexidine skin prep

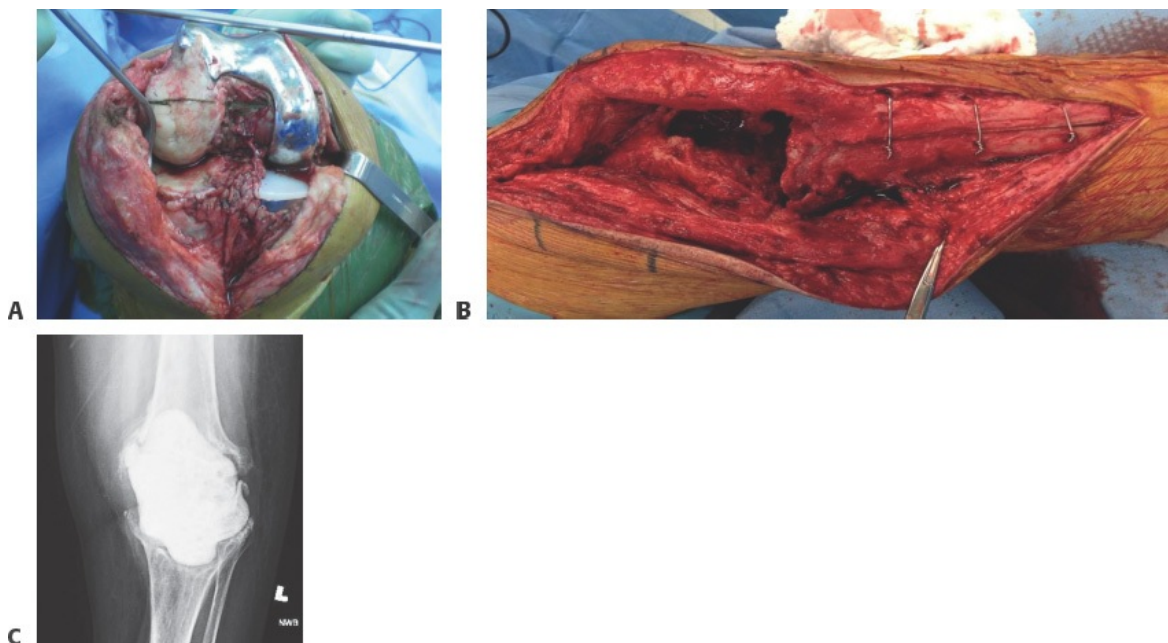
Approach

- Medial parapatellar approach: most commonly used approach for septic arthritis of the knee and open periarticular fractures with excellent exposure to anterior structures of the knee
- Landmarks: borders of the patella, tibial tubercle
- Longitudinal midline or medial incision, extending proximally to 5 cm above superior pole of patella and distally to tibial tubercle depending on desired exposure
- Develop skin flaps to expose interval between vastus medialis obliquus and quadriceps tendon proximally, medial border of patella, and medial border of patellar tendon distally
- Medial parapatellar arthrotomy performed sharply or using cautery
- Depending on amount of exposure needed, patella can be dislocated and flipped laterally to provide access to lateral joint structures.

TECHNIQUES

■ Bone Infection Management

- The goal of bony debridement in all of these conditions is to resect all bone that is necrotic or contaminated with potential biofilm formation.
- Debridement is typically accomplished with rongeurs, curettes, and osteotomes, as well as round or pencil tipped high-speed burs.
 - The bur can be especially useful for quick debridement of the bone or removing a well-fixed implant and cement.
- The debridement should continue until punctate bleeding bone is encountered.
 - To allow this, a tourniquet should not be inflated during the debridement, if possible.
- Bony resection may be extensive and can create dead space and structural instability (**TECH FIG 1A,B**).
- Antibiotic impregnated PMMA cement may be used to temporarily manage dead space and deliver antibiotics to the local tissues (**TECH FIG 1C**).
- Bone loss management is beyond the scope of this chapter but includes the following techniques: induced membrane technique, allograft reconstruction, autograft reconstruction including vascularized fibula, bone transport and distraction osteogenesis, and primary shortening of the limb.



TECH FIG 1 • **A.** Bicompartamental knee arthroplasty being removed for chronic periprosthetic infection. **B.** Knee after extensive bony debridement and tibial

tubercle osteotomy required for removal of a chronically infected total knee arthroplasty. **C.** Radiograph showing an antibiotic-impregnated polymethylmethacrylate spacer placed after removal of an infected total knee arthroplasty in the first of a planned two-stage procedure.

■ Soft Tissue Infection Management

Irrigation and Debridement

- Although there is no consensus, a high volume of low-pressure irrigant appears to be sufficient, such as with gravity irrigation using cystoscopy tubing.
 - High-pressure irrigation, though potentially beneficial for removing more bacteria and debris with less solution, may cause damage to soft tissues and the bone.
 - Pulsatile devices have also not been shown to improve outcomes compared to gravity irrigation and may actually have a decreased irrigation rate overall.
 - Bulb irrigation may not be as efficacious.
- Normal saline is the favored irrigant, with or without the use of added antibiotics in the final liter of irrigation.
 - In the setting of open fractures with a traumatic arthrotomy, the amount of irrigant used generally depends on the extent of injury. For example, employing the Gustilo classification, type I injuries can be effectively irrigated with 3 L of saline, type II with 6 L, and type III with 9 L.
- In open fractures, debridement should involve a systematic inspection of all tissue types, including the skin, subcutaneous fat, fascia, muscle, and bone.
 - Remove all necrotic tissue until a healthy bleeding wound bed is achieved.
 - Muscle viability can be determined by color, contractility, consistency, and capacity to bleed.
 - Debridement should be performed sharply, centripetally, and radically, removing any tissue that may even appear questionably viable.
 - The cortical bone without soft tissue attachments should be removed, as it will be nonviable, though articular fragments should be retained if joint

reconstruction can be achieved (**TECH FIG 2**).

- A repeat debridement can be performed after 24 to 48 hours if tissue viability or adequacy of initial debridement is in question and at the time of definitive closure in wounds requiring a muscle flap.



TECH FIG 2 • The knee in **FIG 1** after debridement and placement of an articulating spacer made from antibiotic-impregnated PMMA.

Adjuncts

- Hydrogen peroxide
 - May be synergistic in conjunction with chlorhexidine or povidone-iodine with regard to bactericidal activity
 - Can result in wound complications, local cytotoxicity against healthy tissue, and increase risk of air embolism
- Local antibiotics
 - Antibiotic-loaded polymethylmethacrylate (PMMA, bone cement): vancomycin and aminoglycosides, such as tobramycin and gentamicin, can be effectively incorporated during mixing process and are thermostable to withstand the exothermic polymerization of the cement.
 - Can be formed into beads and placed into wound bed
 - Implants used for fracture fixation can be coated for delivery to tissues.
 - Antibiotic powder placed directly into wound
- Negative pressure wound therapy
 - Has a role in wounds left open or closed primarily
 - Reduces edema

- Improves local microcirculation
- Can be used to stage coverage for open wounds requiring delayed flap closure

PEARLS AND PITFALLS

Bone management	■ Do not strip viable bone. Remove all stripped bone not attached to cartilage as these represent a nidus for future infection.
Soft tissue management	■ Maintaining or reconstructing a viable and well-vascularized soft tissue envelope in the case of open fractures is key to preventing infection and enhancing bone healing. Maintain all viable bone. Do not pinch the skin. Use atraumatic technique.
Necrotic tissue	■ Remove all hardware and nonviable tissue as these represent a nidus for future infection.
Cartilage	■ Preservation of metaphyseal and periarticular fragments stripped of soft tissue is the exception as they may reintegrate in contrast to diaphyseal fragments and may be critical to reconstructing the joint line or articular surface.
Negative pressure wound dressing	■ Do not apply over bone directly as it can desiccate the location that requires further debridement. Do not apply in active infection.
Antibiotic beads	■ Consider for temporary management of an infected wound bed.
Well-fixed implant	■ Cemented implants should be carefully freed from the underlying cement with a bur or saw before attempted removal to avoid fracture of key supporting structures.
Amputation	■ If reconstruction and preservation of the limb are not feasible, amputation should be strongly considered.
Wound edges	■ Debride rounded skin to fresh edges to facilitate healing.
Plastic surgery	■ Consult plastic surgery early in the process of wound closure or defect management to assess primary, secondary, or flap-based closure.

POSTOPERATIVE CARE

- Open fractures
 - Antibiotics should be administered for 24 hours after definitive closure of the wound.
 - The weight-bearing status of the patient will depend on the type of fixation used and location of the injury.
 - Diaphyseal fractures treated with intramedullary nailing can typically be treated with weight bearing as tolerated, whereas periarticular fractures require several weeks of nonweight bearing to allow anatomic healing of the articular surface.
 - Early mobilization of neighboring joints is critical to prevent adjacent stiffness.
- Osteomyelitis
 - Intravenous antibiotics for at least 6 weeks is typically required with the choice depending on the sensitivities of the identified microorganism.
 - ESR and CRP levels are monitored at routine intervals.
 - Early mobilization of the patient and maintaining motion at adjacent joints is similarly critical to overall functional outcome.
- Infection after TKA
 - Intravenous antibiotics specific to the organism are continued for a minimum of 6 weeks after the initial debridement and explanation until ESR and CRP levels have resolved.
 - After the patient has completed antibiotic therapy, the ESR and CRP are evaluated at least 2 weeks later.
 - Reimplantation is then considered only if the ESR and CRP levels are normal.

OUTCOMES

- Open fractures
 - Successful treatment of open fractures depends on the thoroughness of the debridement, the presence of a well-vascularized soft tissue envelope, and the bony reconstruction.
 - The overall infection rate for open fractures has been shown to be around 2% to 4%, whereas Gustilo type IIIC injuries can become infected at rates as high as 20% to 40%.^{7,8}
 - In open fractures treated with antibiotics at the time of admission, there is no

significant difference in infection rates when debrided within or after 6 hours of injury.

■ Osteomyelitis

- Units experienced in the treatment of osteomyelitis typically achieve the best outcomes.
- Cierny reported a cure rate of 84% at 2 years of follow-up.⁹

■ Infection after TKA

- Eradication of infection following two-stage protocol using an antibiotic spacer followed by reimplantation has reported success rates between 74% and 91%.
- The data on articulating vs static spacers are conflicting; however, some studies have shown improved patient satisfaction, range of motion, and an easier exposure at the time of reimplantation when an articulating spacer is used.

COMPLICATIONS

- Open fractures can result in infection and osteomyelitis, nonunion, malunion, hardware failure, and amputation.
- Inadequate treatment of osteomyelitis can lead to persistent infection, sinus formation, and malignant transformation.
- Osteomyelitis may also require amputation.
- Inadequate treatment of PJI can lead to persistent infection or reinfection requiring repeat debridement and antibiotic spacer exchange, chronic suppression with antibiotics if the patient is not a surgical candidate, or amputation.

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31 Bone Reconstruction of the Knee

CHAPTER

Robert J. Steffner and Raffi S. Avedian

DEFINITION

- For this chapter, we will be discussing segmental bone loss with a specific example of a metadiaphyseal hemicortical bone defect below an intact knee joint.
- Above and below the knee is a common area for segmental bone loss due to trauma, tumor, and infection.
- Bone loss in the proximal tibia with an intact joint that compromises the extensor mechanism is often best reconstructed with an intercalary fresh frozen allograft with soft tissue attachments. This facilitates extensor mechanism reconstruction.
- Joint loss is generally reconstructed with an allograft-prosthetic composite or endoprosthetic reconstruction.

ANATOMY

- Anatomy relevant to reconstruction on the medial knee includes the adductor tendon insertion on the medial distal femur and the pes anserinus tendons inserting on the proximal tibia. The surgeon will encounter the femoral artery and vein just below the medial intermuscular septum moving through the adductor hiatus to enter the popliteal fossa.
- Pay close attention to identify and preserve the saphenous nerve branch and saphenous vein.
- The medial collateral ligament (MCL) connects the medial distal femur to the medial proximal tibia. The deep portion of the ligament inserts on the proximal tibia approximately 1 cm below the joint line. The superficial portion is broad and inserts on the proximal tibia 6 to 7 cm distal to the joint line.

- The MCL may need to be reconstructed as part of the surgical procedure.
- On the lateral knee, the iliotibial band inserts on the proximal lateral tibia at Gerdy tubercle and the bicep femoris tendon spans the knee to insert onto the fibular head. Posterior to the bicep femoris tendon lies the common peroneal nerve. The nerve divides at the anterior fibular neck into deep and superficial branches.
- The lateral collateral ligament connects the lateral distal femur to the fibular head. Reconstruction may be required with bone defect management at the lateral knee.
- Soft tissue loss around the proximal tibia can create a precarious situation that is at increased risk of infection. The surgeon should maintain a low threshold for soft tissue coverage with a gastrocnemius flap or free tissue transfer.

PATHOGENESIS

- This technique is applicable to bone loss from bone tumor excision, bone loss from trauma such as an open fracture, and osteomyelitis requiring debridement.

NATURAL HISTORY

- Management of bone defects around the knee are a challenging problem that frequently requires multidisciplinary management between general surgery, orthopedic surgery, plastic surgery, and infectious disease.
- Before instituting the described procedure, the surgeon must obtain a clean bone defect with viable tissue that is free of infection.
- This may require multiple surgeries focusing on debridement, antibiotic cement spacer placement, bone stabilization, soft tissue coverage, and intravenous antibiotics to prepare the area for the described definitive procedure.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient presentation and reason for the bone defect influence the treatment approach and time interval to the definitive bone grafting procedure.
- Trauma and infectious etiologies often require serial debridement and temporary stabilization with definitive stabilization and soft tissue coverage performed once a clean tissue bed is achieved.
- The surgeon should assess the neurovascular status of the involved extremity. A functional limb is a candidate for limb salvage. A severely compromised limb may be better with an early amputation.

- When pursuing limb salvage, the stability of the collateral ligaments should be tested by applying a varus and valgus stress to a slightly flexed knee.
- The patient should be asked to extend the knee against gravity to test the competency of the extensor mechanism.
- Laboratory studies depend on patient specifics and can be used to assess nutritional status, blood count recovery after chemotherapy, and inflammatory markers to assess for infection or response to antibiotics.

IMAGING

- Radiographs are used to assess defect size and provide an estimate of how much bone graft will be needed (**FIG 1A**). Further, the surgeon can plan implant needs to provide sufficient stabilization of the involved bone.
- Computed tomography and magnetic resonance imaging (**FIG 1B,C**) provide a detailed assessment of cortical bone and offer a volumetric assessment of the defect.

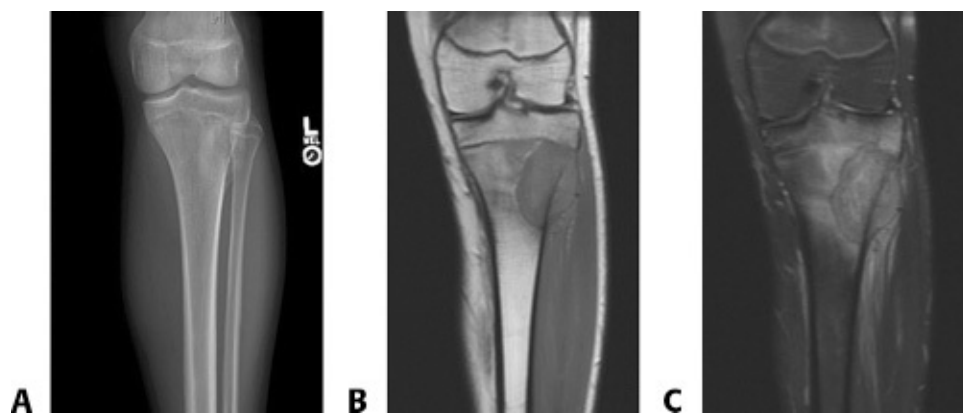


FIG 1 • **A.** AP radiograph, **(B)** coronal T1 MRI, and **(C)** coronal T2 MRI of a primary bone tumor of the lateral proximal tibia.

SURGICAL MANAGEMENT

- In the setting of a large bone defect (≥ 6 cm), surgery is generally necessary to improve function and facilitate weight bearing. The described technique has been utilized for defects up to 2.5 cm.¹
- The treatment goal is to create a clean and viable tissue bed that is then filled with a cement spacer to maintain the defect space and induce formation of a biologically active, vascularized membrane (**FIG 2**).

- After 4 to 6 weeks, the cement spacer is removed, and the defect is optimized for placement of autogenous bone grafting to facilitate reconstitution of the defect.²
- The cement spacer provides structural support to the bone, offloads the implant bridging the defect, maintains the bone void, facilitates formation of the induced membrane, and can be a conduit for local antibiotic elution.
- Bone graft is obtained using a reamer-irrigator-aspirator (RIA) system (Synthes, Paoli, PA).
 - This is a single-pass, negative pressure reaming system for obtaining intramedullary nonstructural autogenous bone graft.
- Compared to the traditional iliac crest bone used for the harvest of autogenous bone graft, RIA obtains more graft volume (on average 60 cc from the femur and 40 cc from the tibia)^{3,4}, and the graft appears to have equivalent osteoconductivity and better osteogenicity and osteoinductivity.⁵⁻⁷ Studies also suggest a greater concentration of stem cells. Harvest of bone graft with RIA is also less invasive and associated with less donor site morbidity.⁸
- Use of RIA to obtain autogenous bone graft is indicated in skeletally mature patients with normal femur anatomy. Relative contraindications include metabolic bone disease, presence of metastatic bone cancer in the donor bone, active osteomyelitis in the donor bone, known bleeding disorder, and osteoporotic patients with thin cortices.⁵
- Bone graft volume can be extended with cancellous allograft and demineralized bone matrix. Extension is common, and when used, we add fresh bone marrow aspirate to provide osteogenic mesenchymal stem cells to the structural allograft.⁶
- The induced membrane is a vascularized soft tissue layer that forms around the cement spacer. It is composed of an outer layer of fibroblasts and collagen and a synovium-like inner layer. It is rich in growth factors and osteoinductive elements that include BMP-2. Upon placement of autogenous bone graft, the membrane prevents graft resorption and facilitates the formation of new cortical bone.⁸

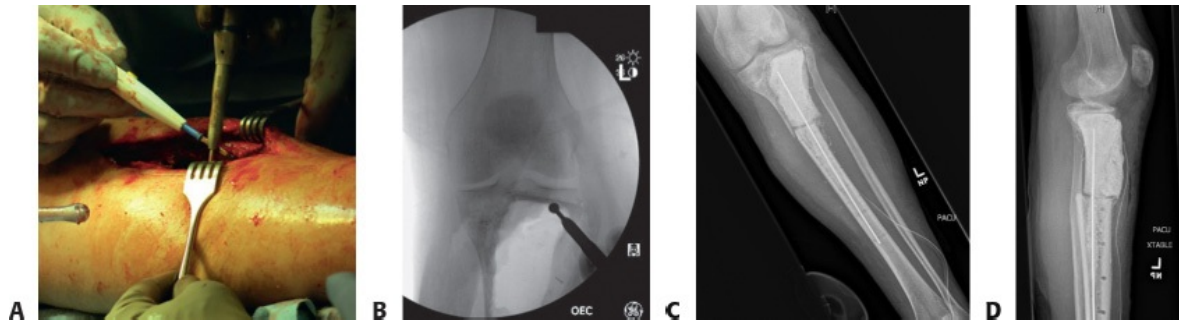


FIG 2 • A. Intraoperative preparation of the bone defect. **B.** Fluoroscopic view of debridement with high-speed bur. **C,D.** Placement of an antibiotic spacer into a proximal tibia bone defect.

Preoperative Planning

- Bone reconstruction is a two-stage process.
- Bone defects from infection or trauma may require serial debridement with placement of a temporary cement spacer and temporary stabilization of the bone with an external fixator or long plate. The cement spacer is often loaded with antibiotics to provide a local elution.
- A clean defect can be judged by negative cultures, bleeding tissues, and maintained continuity of the defect with the intramedullary canals.
 - Once clean, the patient is eligible for stage 1 of this procedure.
- For infection, intravenous antibiotics are generally given for the 4 to 6 weeks that the cement spacer is implanted. These antibiotics are an adjuvant and do not make up for an inadequate debridement.⁹
- Patients are followed with serial inflammatory markers such as C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) to judge eradication of the infection.
 - At this point, the patient has a clean bone defect that is free of infection.
- The patient should be counseled on the risks of surgery, which include fracture of the donor bone, infection of the recipient site, and possible need for blood transfusion(s).
- Patients should know that there may be a need to surgically stabilize the donor femur due to bone perforation by the reamer head or perceived postoperative fracture risk based on the assessment of cortical thickness after RIA use.
- Patient should be aware of the donor site location and possible weight-bearing

restrictions after surgery. In general, we try to use a donor bone on the ipsilateral side of the bone defect in order to maintain one good lower extremity to aid postoperative rehabilitation.

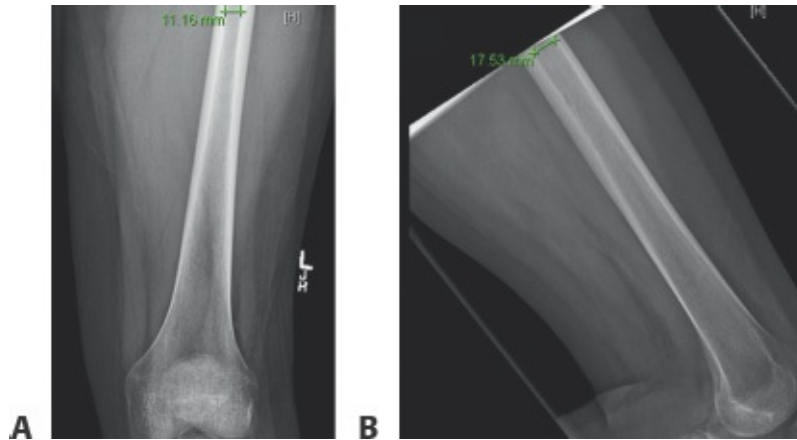


FIG 3 • A,B. Preoperative radiographs of the donor femur. The inner diameter of the isthmus is used to determine the reamer head size needed for bone graft harvest.

- Preoperative radiographs are done of the donor femur (**FIG 3**). The surgeon assesses cortical thickness, inner cortical diameter at the isthmus, and length of the femur. This facilitates decision-making on appropriate indications for RIA use, estimation of reamer head size, and determination of the appropriate length of the RIA drive shaft (360 or 520 mm).
- The size of the reamer head is determined by measuring the isthmus of the donor long bone on both AP and lateral radiographs. A head size 1 to 1.5 mm larger than the smallest measured inner cortical diameter at the isthmus should be used. If this measurement is done intraoperatively with fluoroscopy, the surgeon should factor in the distance of the ruler from the actual bone. The real canal is larger than the measurement. In general, the canal is 1 mm larger when the ruler is 2.5 cm away from bone and 2 mm larger when the ruler is 5 cm away.
- To use RIA, a power driver with 3.5 to 4.5 Nm of torque and 700 to 900 rpm should be used. Drills with torque greater than 6 Nm are too powerful and should not be used.
- In the operating room, the surgeon will need a radiolucent table, large

fluoroscopy machine, 3-L bags of normal saline, a separate Mayo stand to hold the RIA, and a source of negative pressure suction.

- A tourniquet may be used at the bone defect site if brisk bleeding is present during preparation of the area. Attempts are made to avoid tourniquet use as it can compromise the assessment of tissue viability.
- The patient may benefit from a preoperative discussion with the anesthesia team regarding use of regional or neuraxial anesthesia. This can provide optimal intraoperative and postoperative pain control.

Positioning

- Patient position and draping frequently requires coordination between orthopedic surgery and plastic surgery.
- Position should facilitate debridement of the bone defect, harvest of bone graft, and any soft tissue coverage procedures. It may be necessary to change the patient's position during the surgery; a repeat sterile prep and drape is then performed.
- For bone defects about the knee, a supine position with a bump under the gluteus is often sufficient.
- A large C-arm should be placed opposite the side where bone graft will be harvested. The monitor is positioned at the end of the operating room table.

Approach

- RIA bone graft harvest from the femur is generally obtained through an antegrade approach through a greater trochanter start side. This requires an approximately 3- to 4-cm incision, approximately one hand breath above the top of the greater trochanter and 2 to 3 cm posterior to the midline axis of the greater trochanter.
- Medial and lateral/anterolateral approaches to the distal femur and proximal tibia for the bone defect are well described in surgical approach textbooks.

TECHNIQUES

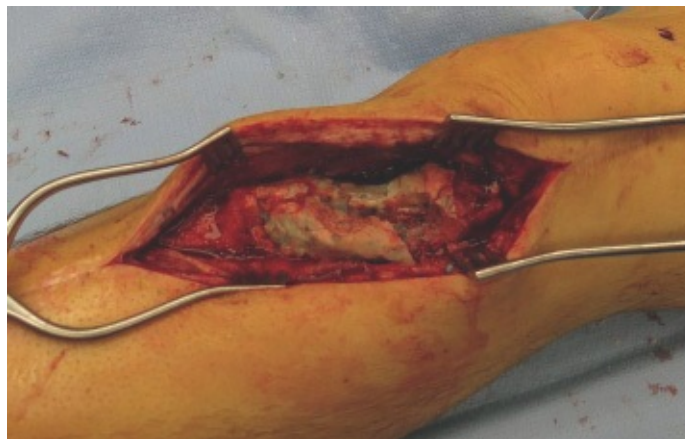
- **Induced Membrane With Intramedullary Autogenous Bone Grafting With Bone Marrow**

Aspiration and Intramedullary Nailing

■ Stage 1

Cement Spacer Placement and Internal Fixation

- For tumors, the patient starts stage 1 at the time of surgical excision of the malignancy.
- Stage 1 simply consists of placing a block of cement into a clean bone defect. The cement is hand mixed in a bowl and allowed to reach a doughy consistency. The goal is to maintain the defect space while avoiding the interdigitation of cement into the bone, which would make removal difficult (**TECH FIG 1**).
- It is important to overlap the bone ends with cement to induce a pseudomembrane longer than the defect itself.
- In the absence of infection, definitive internal fixation can be placed at this time. When possible, we prefer a titanium intramedullary nail to maintain the canal, facilitate early weight bearing, and prevent future central necrosis of the autogenous bone graft.
- Intramedullary implants can be placed antegrade or retrograde in the femur and antegrade in the tibia. New implants allow for fixation in short bone segments.
- In defects close to the joint, a strong 4.5-mm periarticular plate with fixed-angle locking screws into the short segment is most often used.



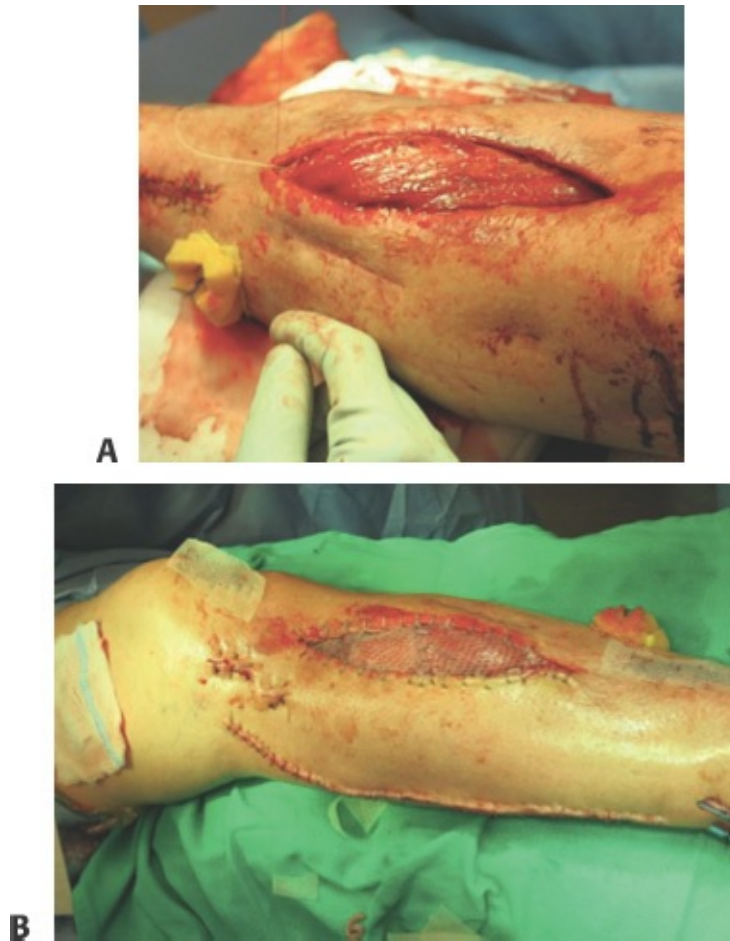
TECH FIG 1 • Placement of cement spacer into defect

to generate an induced membrane.

- In the setting of infection, it is best to avoid metal implants altogether and rely on splints. Sometimes it is necessary to place antibiotic intramedullary nails or bridge plates coated in antibiotic cement for adequate bone stabilization.

Soft Tissue Coverage and Monitoring

- If soft tissue coverage is needed, it is done after placement of the cement block spacer. Defects in the proximal tibia are often augmented with a medial gastrocnemius flap (**TECH FIG 2**).
- If soft tissue coverage is not an urgent concern, muscle flap coverage can also be done at the time of definitive bone grafting.
- The patient is monitored for the next 4 to 6 weeks.
 - Weight bearing on the affected lower extremity is dictated by the strength of the cement/implant construct. At a minimum, the construct must provide enough stability to allow knee range of motion.
- Patients with infection have periodic checks of inflammatory markers.
 - At the end of intravenous antibiotics, these patients are followed for an additional 2 to 3 weeks off antibiotics to monitor for any signs of recurrent infection before proceeding with stage 2 of this procedure.



TECH FIG 2 • A,B. Medial gastrocnemius rotational flap of a proximal tibia bone defect.

■ Stage 2

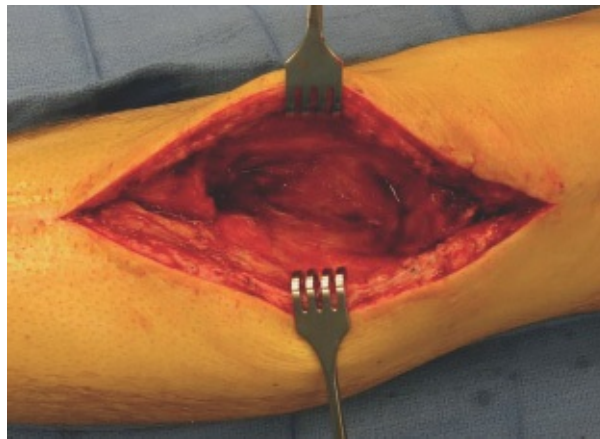
Spacer Removal and Bone Preparation

- The second stage begins by accessing the bone defect through the prior surgical incision.
 - Patient positioning should allow access to the bone defect and the hip selected for RIA bone graft harvest.
- When exposing the bone defect site, it is very important to carefully incise the induced membrane longitudinally and use a Cobb or periosteal elevator to isolate the membrane off of the cement spacer.
- The spacer often needs to be fractured with an osteotome and removed piecemeal.

- Bone ends are gently debrided of any fibrous tissue, and if no intramedullary implant, the intramedullary canals are accessed with a flexible reamer or high-speed bur to assure continuity.
- With infection, the surgeon should maintain a high level of suspicion for persistent infection.
 - Intraoperative frozen section for high-powered fields can be done for an objective measure of continued infection.
 - In general, a finding of more than 5 to 10 WBC/HPF warrants consideration for irrigation and debridement with another 6-week cycle of cement spacer and intravenous antibiotics.
- When the bone defect site is clean with a nice induced membrane (**TECH FIG 3**), attention is turned to the intramedullary harvest of autogenous bone graft using RIA.

Inserting the Guidewire

- A large C-arm fluoroscopy positioned on the opposite side of the patient is used to localize the top of the greater trochanter.

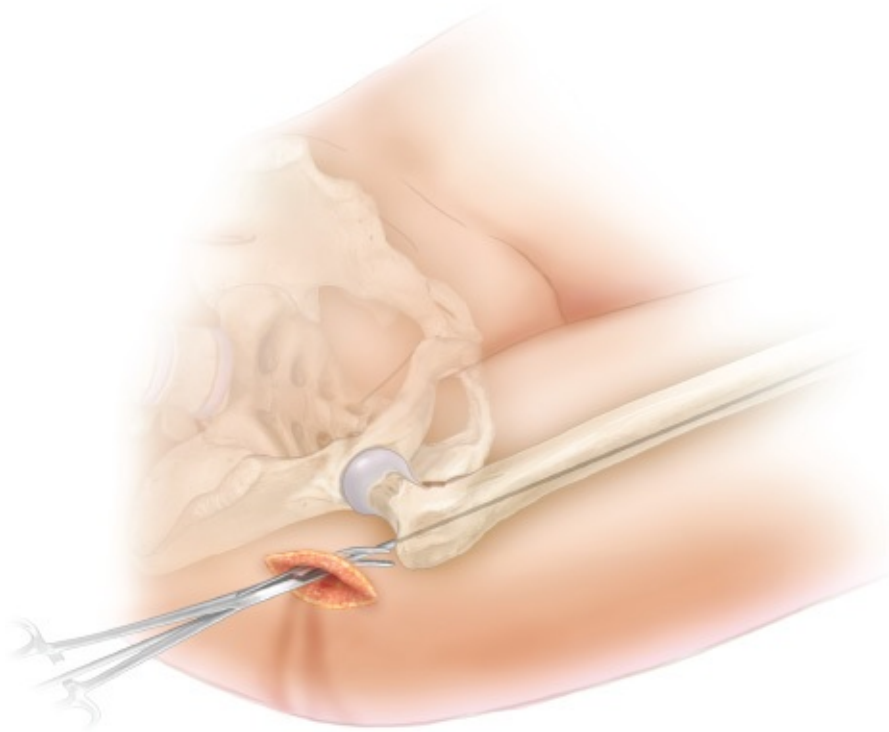


TECH FIG 3 • Clean bone defect after removal of the cement spacer. The defect is contained by the induced membrane.

- A 3- to 4-cm incision is made approximately 5 cm proximal and 2 cm posterior to the midline of the greater trochanter.
- A 3.2-mm guide pin is positioned at the tip of the greater trochanter on AP fluoroscopy and in the midline of the greater trochanter on the lateral view. The guide pin should aim for the center of the intramedullary canal at the

level of the lesser trochanter (**TECH FIG 4**).

- Once the guide pin is driven 5 to 6 cm into the bone and the position confirmed on fluoroscopy, the skin and deep fascia are incised with a scalpel around the guide pin to cannulate the guide pin with a soft tissue protector.
- A 12-mm cannulated reamer is used through a soft tissue protector to drill 3 to 4 cm into the greater trochanter to create a start site.
- The power source should be set to “drill,” and the surgeon should allow the drill to spin at full speed before contacting greater trochanter bone. This will create a clean entry site.
- Limited entry into the bone will allow more bone to be harvested.



TECH FIG 4 • Illustration of the antegrade start site for RIA bone graft harvest. The guide pin is placed in-line with the center of the femoral canal.

- A 2.5 mm diameter, 950 mm in length, ball-tipped guidewire is placed through the greater trochanter start site and inserted down the intramedullary canal of the femur to roughly 2 to 3 cm above the physeal scar of the distal femur.
- AP and lateral fluoroscopy is undertaken to assure the guidewire is within

the intramedullary canal.

- A T-chuck handle may be placed onto the guidewire and gently tapped with a mallet to aid the guidewire passing through the metaphyseal bone of the proximal femur.
- A slight bend is often required in the distal aspect of the guidewire to direct the guidewire into a center-center position in the distal femur.
 - This helps avoid eccentric reaming and minimizes the risk of cortical perforation by the sharp reamer head.
- Measure the length of the guidewire within the femur to select the proper length of the RIA drive shaft. Length options are 360 and 520 mm.

Preparing the RIA

- The RIA system comes with a ruler that overlay the patient's skin (**TECH FIG 5A**).
 - With intraoperative fluoroscopy, the inner isthmic diameter of the femur in both AP and lateral planes can be measured to determine the size of the reamer head needed to obtain the necessary volume of bone graft.
 - The intramedullary canal is often elliptical, and one measure will be smaller than the other.
 - A reamer head that is 1 to 1.5 mm larger than the smallest isthmic diameter is recommended.
 - Reamer heads are available in 12 to 19 mm diameters.
- As noted earlier, measurement of the isthmus at the skin level by intraoperative fluoroscopy requires a correction for magnification. The actual size of the isthmus is larger than the measurement. This is important when selecting the size of the reamer head.
- On a separate Mayo stand, the RIA device is assembled according to manufacturer specifications (**TECH FIG 5B**).
 - The reamer head is front-end cutting and sharp. The surgeon should assure several things: that the reamer head is mated correctly with the drive shaft, that the rubber seal is placed over the proximal drive shaft before it is connected to the power source, and that the plastic casing protecting the rotating connection between the power source and the drive shaft is locked into place.
 - Connect irrigation to RIA, it is the most proximal, smaller port labeled "I."
 - Connect suction to RIA. It is the most distal, larger port labeled "A."
 - Attach the 100-cc filter to the suction ("A" port). This has a particulate

filter of 500 μ m to capture the viscous autogenous bone graft.

- Place the power source on the “drill” setting during reaming to allow for high speed and low torque.
- A 3-L bag of normal saline should be placed 3 ft. or higher above the RIA device to allow adequate gravity flow. The suction tubing should be attached to a closed, continuous suction canister with a large reservoir.



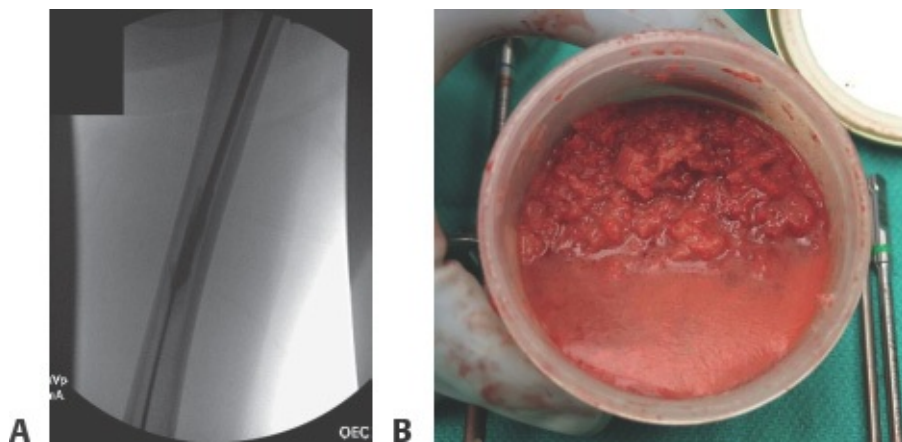
TECH FIG 5 • A. Intraoperative measurement of the femur isthmus using fluoroscopy. **B.** The reamer-irrigator-aspirator (RIA) device. The ports for fluid inflow and outflow are labeled. The aspiration port connects to a filter that captures the intramedullary bone graft.

Reaming the Graft Material

- Test the RIA device on the Mayo stand outside of the patient by starting the irrigation and suction. Activate the power source to assure the reamer tip is properly revolving.
- The RIA system is single pass and continuously irrigates and suctions within the intramedullary canal. This decreases intramedullary temperatures and decreases viscosity of the graft.
- Place the RIA system over the guidewire. Before entering the patient, verify flow of irrigation. Insert the device through the soft tissue protection sleeve and turn on suction when the reamer head is set into the insertion site at the greater trochanter.
- Before starting, warn anesthesia about possible blood loss due to the negative pressure suction.
- The power source should be fully activated.
- RIA is propagated through an advance-withdraw technique every 2 to 3 cm

to avoid clogging of the aspiration tubing by particulate graft (**TECH FIG 6A**).

- The surgeon should move slowly through the isthmus to allow time for appropriate emulsification of the graft (**TECH FIG 6B**). It is important not to forcibly push through resistance as incarceration of the reamer head or clogging of the aspiration tubing may occur.
- Fluoroscopy should be used liberally during active reaming to monitor the position of the reamer head.
 - The surgeon should continually assess for eccentric reaming, which most commonly takes place in the medial proximal femur and distal anterior femur.
 - It bears repeating that the surgeon must take great care to avoid incarceration of the reamer head at the isthmus and perforation of the anterior cortex as well as the knee joint distally.
- When reaming distally in the femur, a lateral fluoroscopic view is recommended to assess for perforation of the anterior femoral cortex.
- Aspiration tubing should be periodically checked to assure flow of bone graft and to assure the line is not clogged.
- When actively reaming, both irrigation and suction should be turned on. When reaming is paused, both lines should be stopped to avoid excessive blood loss.
- To obtain more graft volume, the surgeon can rotate the guidewire to capture the metaphyseal bone in the medial and lateral aspects of the distal femur.
- The RIA system should continue to be fully activated while withdrawing the drive shaft from the femur. If this is difficult, the surgeon can reverse the direction of the reamer head to facilitate removal.



TECH FIG 6 • A. Use of intraoperative fluoroscopy to follow the reamer head during RIA bone graft harvest. It is important to assure that the sharp reamer head remains central in the intramedullary canal. **B.** Appearance of RIA autogenous bone graft after harvest.

Completion of Reaming

- When the reamer tip is back at the top of the greater trochanter, turn off suction and irrigation. The device is removed.
- Pack the proximal femur skin incision with gauze or a hemostatic agent.
- View the collection canister, which has markings on the outside to estimate the volume of graft obtained.
- If more graft is needed, upsize the reamer head by 0.5 to 1 mm and perform another pass down the femur. Generally, one to two passes are sufficient.
- Once graft volume is adequate, disconnect the collection canister, and move it over the sterile operating room table.
- Remove the lid, and use a plunger to compress the graft.
- Invert the filter with the plunger in place to remove the inner filter. Turn the inner filter vertical, and use the plunger to remove the graft into a sterile basin.

Harvesting Bone Marrow

- Fresh bone marrow is then obtained by palpating the medius pillar of the ilium.
- Thumb pressure can be used to push soft tissues toward the abdomen to feel the thickness of the pillar.
- A small skin puncture with a no. 11 blade scalpel is made over the medius pillar.
- A disposable 14-gauge T-handle bone marrow biopsy needle is introduced. Tactile feel is used to center over the medius pillar bone (**TECH FIG 7**).
- Gentle, sustained pressure is applied with a back and forth rotation to puncture the bone and gain access to the marrow space between the inner and outer shelves of the ilium. The needle is generally inserted around 3 cm.
- The top of the T-handle is rotated 90 degrees to remove the stylet. A 12- or

20-mL syringe is engaged to the Luer-lock to aspirate bone marrow. The amount of bone marrow needed is proportional to the size of the defect. The goal is to saturate the final volume of bone graft.

- The syringe of bone marrow aspirate is disconnected, and the needle is withdrawn. Pressure is applied to the puncture site for 5 to 10 minutes, and a Steri-Strip is placed over the puncture site.

Graft Placement

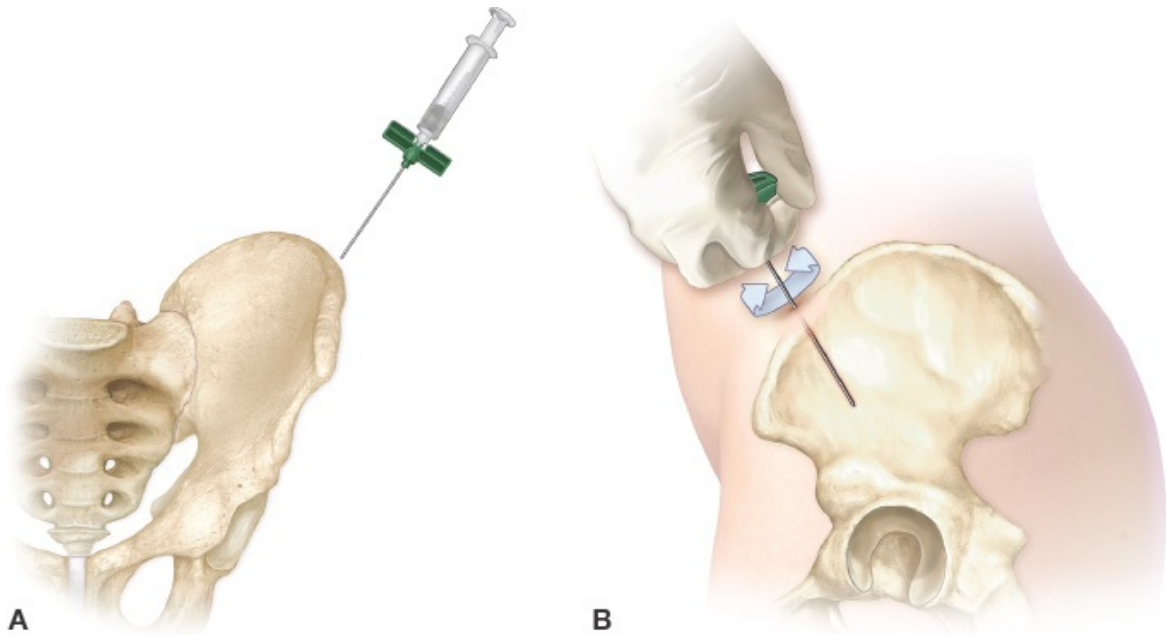
- The autogenous intramedullary bone graft and bone marrow aspirate are mixed together in a sterile basin.
- The graft is extended with 1- to 4-mm cancellous allograft and demineralized bone matrix to create an appropriate graft consistency and to achieve adequate volume. The goal consistency is equivalent to gritty toothpaste.
- The recipient bone defect undergoes a final low-pressure irrigation.
- The bone graft mixture is packed into the defect with thumb pressure. Avoid dense packing of the graft with instruments such as a bone tamp.
 - Highly compacted graft does not incorporate as well (**TECH FIG 8A–D**).
- Suture the induced membrane closed (Video 1). This should completely cover the graft as it prevents resorption and promotes the formation of the cortical bone.



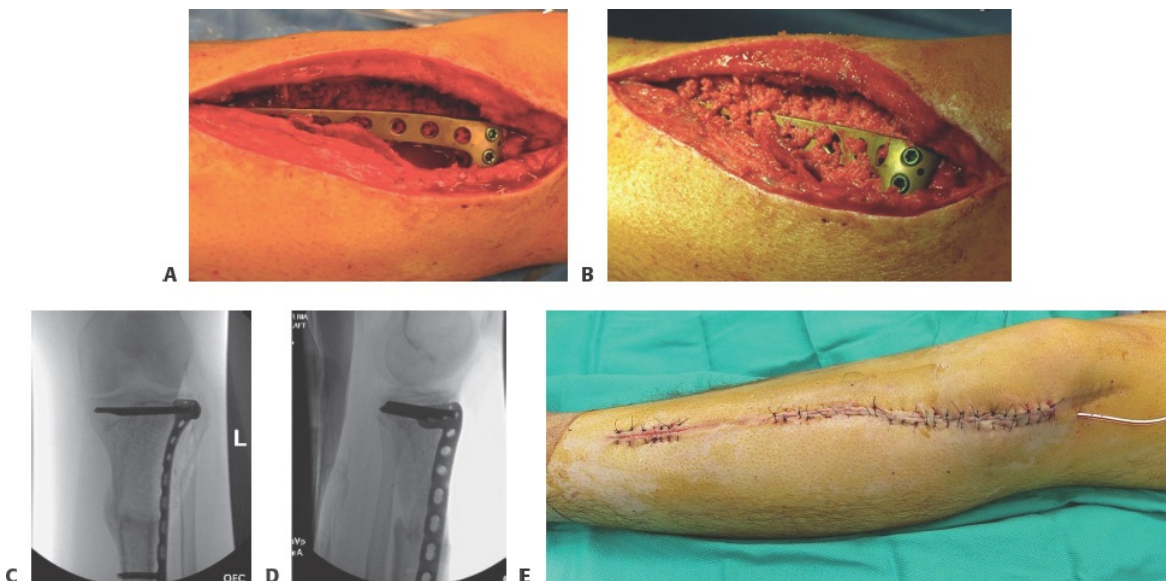
Video p7-c031

- All surgical sites should be closed in layers. Suture for skin closure is at the discretion of the surgeon (**TECH FIG 8E**).

- Sterile dressings are applied.



TECH FIG 7 • A. Bone marrow biopsy needle insertion site in the medius pillar of the pelvis. **B.** The needle is gently twisted back and forth as it is inserted.



TECH FIG 8 • A,B. The bone defect is filled with bone graft with fresh bone marrow aspirate. The graft completely fills the defect, but impaction of the graft is

avoided. In a different patient, **(C)** intraoperative AP and **(D)** lateral fluoroscopic views of the proximal tibia filled with autogenous bone graft and stabilized with a lateral plate. **E.** Skin closure after RIA bone grafting and stabilization into a defect with an induced membrane.

PEARLS AND PITFALLS

Bone graft harvest

- Try to harvest RIA from the femur ipsilateral to the bone defect. This maintains an unaffected lower extremity to facilitate postoperative rehabilitation.
- While using RIA, keep the filter for the bone graft in a vertical position to avoid over washing and loss of growth factors.
- When finished with RIA, disconnect the irrigation and aspiration tubing to avoid unsterile tubing coming up to the sterile field and causing contamination.

Union

- Central graft often remains avascular; the use of a nail or resorbable mesh to maintain the native intramedullary canal helps limit graft volume and improves the formation of cortical bone⁸.
- Bone stabilization with an intramedullary implant is preferred as this preserves the native medullary canal and helps to prevent the lack of incorporation seen in central graft in larger bone defects⁸. This is not always possible, however, and plate fixation may be necessary based on the defect itself (**FIG 4**).

Fracture

- Consider restricted weight bearing or placement of a prophylactic intramedullary nail after RIA use. Especially if the donor bone has narrow cortices or the patient is osteopenic or osteoporotic.³
- Consider use of iliac crest bone grafting in osteoporotic patients.
- Fluoroscopy in orthogonal planes is useful to assure a proper start site for RIA harvest and to assess cortical thickness of the femur after RIA use.
- A greater trochanter start site for RIA harvest minimizes the reamer entry angle and decreases the risk of postoperative femoral neck fracture.

	■ Reaming ≥ 2 mm of the inner diameter of the femoral isthmus decreases the torsional strength of the femur. ■ It is important to place the guidewire for RIA bone graft harvest in the center of the intramedullary canal to avoid eccentric reaming of the femoral cortex.
Blood loss	■ RIA suction can lead to rapid blood loss. It is important to communicate this to anesthesia. ■ Patients should be typed and crossed before starting the procedure. ■ Stop RIA suction when not actively reaming.⁵ ■ Pack the hip incision at the conclusion of RIA use to avoid a gluteal hematoma.
RIA irrigation water	■ Filtrate water contains viable cells including mesenchymal stem cells.¹⁰ ■ Adding filtrate to the harvested bone graft may improve incorporation and corticalization.

POSTOPERATIVE CARE

- Weight-bearing restrictions for the bone defect are advised. The length of time depends on the size of the bone defect, implant use, graft harvest technique, and patient bone stock. Implementation is at the discretion of the surgeon and is determined on a case-by-case basis.
- Restrictions for the bone graft harvest site are generally advised if multiple RIA passes are performed or thin femoral cortices are noted at the end of the procedure.
- A knee immobilizer is often used for 2 weeks to facilitate soft tissue healing. Physical therapy is then started to work on knee joint range of motion.
- First radiographs are done 6 weeks from surgery (**FIG 5**). Serial radiographs are used to assess the incorporation of bone graft.
- Bone defects stabilized with an intramedullary implant can often start partial progressive weight bearing at 3 to 4 months after surgery.
- Computed tomography can be used to further investigate bone graft incorporation and determine the necessity of additional bone grafting procedures.



FIG 4 • Fluoroscopic image showing stabilization of a proximal femur bone defect with a 4.5-mm periarticular plate. The small amount of residual bone at the joint level did not allow for an intramedullary implant.

OUTCOMES

- Union of a bone defect after autogenous bone grafting appears to be independent of defect length.¹¹ Defects up to 25 cm have been addressed with this technique (Norris).
- Radiographic healing is often seen by 4 months.
- Approximately 70% of defects heal by 6 months and 80% heal by 1 year.¹



FIG 5 • **A.** AP and **(B)** lateral radiographs of the bone defect after definitive bone grafting with autogenous, intramedullary bone graft with graft extension and fresh

bone marrow aspirate.

- Approximately 50% of patients heal with just one bone grafting procedure, 35% heal with more than one bone grafting procedure (McCall).
- Long-term donor site morbidity is less with RIA harvest compared to iliac crest bone graft harvest.^{4,12}

COMPLICATIONS

- The complication rate with RIA harvest is 1.96% to 6.2%.^{3,4}
- Iatrogenic fracture of the femur from RIA harvest is the most common complication, and it is related to technical aspects of the procedure including poor start site, eccentric reaming, and over-reaming.
- After RIA harvest, the femur is weakest in torsion.
- Femoral shaft fracture, femoral neck fracture, and anterior cortical perforation of the femur are described complications with RIA harvest.
- Heterotopic ossification of the abductors can be seen at the RIA start site and is generally asymptomatic.
- Problems encountered at the bone defect site include deep infection, nonunion, and implant loosening/failure.
- Nonunion rate is approximately 15%; causative factors include inadequate graft volume, suboptimal graft placement, and infection.⁸

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Soft Tissue Coverage of the

Knee: Gastrocnemius

Muscle Flap

32

CHAPTER

Hani Sbitany

DEFINITION

- Soft tissue defects around the knee, or the anterior third of the tibia, often cannot be treated with local fasciocutaneous flaps; instead, the most reliable local/regional coverage option is the rotational gastrocnemius muscle flap.¹
- This is taken as a pure muscle flap, and in defects that include skin loss, the muscle is immediately skin grafted.
- This rotational muscle flap is well perfused, given its axial blood supply, and provides excellent soft tissue coverage and reliable reconstruction of defects involving the underlying bone, tendon, or exposed surgical hardware.²

ANATOMY

- The gastrocnemius is a bipennate muscle, located in the superficial posterior compartment of the lower extremity.
 - Other muscles in this compartment include the soleus muscle and plantaris muscle.
 - These muscles come together, via their common insertion in the posterior surface of the calcaneus, to create the Achilles tendon.
 - These muscles act to cause flexion of the ankle, when the knee is extended.
- The gastrocnemius muscle is the most superficial of these muscles, situated just deep to the posterior calf skin and subcutaneous tissue, and consists of a medial and lateral muscle head.
- The blood supply to these gastrocnemius muscles comes from the sural artery and vein, which are direct branches from the popliteal vessels; the motor nerve innervation derives from the tibial nerve.

- The medial and lateral heads of the gastrocnemius muscles can be separated from each other at their midline confluence, and each muscle belly can be isolated on its medial or lateral sural vessel pedicle, respectively.
- The medial head of the gastrocnemius muscle is usually longer and wider than the lateral head and thus has a greater arc of rotation and reach as a rotational flap; for this reason, the medial head is most commonly harvested for proximal lower extremity reconstruction.³
- Because the Achilles tendon is made up of contribution from all four muscles in the superficial posterior compartment, the ankle can still safely flex following harvest of one belly of the gastrocnemius muscle.

PATHOGENESIS

- As stated, the gastrocnemius rotational muscle flap is most commonly used for soft tissue reconstruction of defects situation around the knee or the proximal third of the tibia.
- There are many possible causes of defects in this region:
 - Traumatic wounds
 - Oncologic resection wounds
 - Soft tissue infection/necrotizing fasciitis
 - Burn, or burn contracture release, wounds
 - Breakdown of surgical wound after total knee arthroplasty
 - These wounds often contain exposed surgical hardware.
 - Breakdown of wound following patella or patellar tendon repair

PATIENT HISTORY AND PHYSICAL FINDINGS

- The cause and chronicity of the soft tissue wound in this area must be carefully defined.
- The patient must be questioned for a history of prior lower extremity surgery or injury along the entire limb that may have altered soft tissue anatomy or neurovascular supply.
- The specific wound location and size must be recorded and examined carefully to ensure that a rotational gastrocnemius muscle flap will adequately reach this wound with minimal tension.⁴
 - With the patient contracting the calf muscles, and flexing the ankle, the distal portion of the gastrocnemius muscle belly can be visualized or palpated, and this is the point that should be used in assessing muscle flap reach.
 - If this is not the case, then free tissue transfer must be considered.

- Physical examination of the knee and ankle must be performed, with range of motion being carefully assessed.
- Range of motion at the knee (normal 135 degrees) must be defined, along with confirmation of normal flexion in all positions.
- Range of motion at the ankle (normal 70 degrees) must be defined, along with normal flexion with the knee extended.
- If exam reveals normal findings, then rotational medial or lateral gastrocnemius muscle flap is safe.

IMAGING

- Routine imaging of the lower extremity is not necessary prior to gastrocnemius rotational muscle flap.
- If the patient has a history of peripheral vascular disease, a preoperative angiogram or CT angiogram can be obtained, to assess patency of popliteal and sural arteries.
- If the patient has a history of deep vein thrombosis, or venous insufficiency, then lower extremity venogram can be performed.

SURGICAL MANAGEMENT

Preoperative Planning

- Once the gastrocnemius muscle flap has been chosen as the reconstructive option, the surgeon must determine location of the muscle flap donor incision.
- In most cases, for knee defects (anterior, lateral, or medial knee), the muscle harvest incision is separate from the wound being reconstructed, and the muscle is tunneled underneath the intervening skin bridge.
- For wounds over the proximal third of the anterior tibia, it is common to extend the harvest incision from the defect, so that they are in continuity.

Positioning

- The patient is most commonly placed in a supine position on the operative table.
- In some cases, based on wound location and dimensions, it is easier to harvest with the patient in a lateral decubitus position, and this is also acceptable.
- When the patient is supine, the entire lower extremity should be circumferentially prepped into the operative field, such that the leg can be

moved and manipulated during surgery.

- This allows for placement of the leg in a “frog-leg” position, with the knee flexed and turned out, and the foot brought in such that its plantar surface is against the contralateral lower extremity.
- This allows for easier harvest of the medial gastrocnemius muscle.
- It is also advisable to again check the arc of rotation and the reach of the gastrocnemius muscle, relative to the wound, to ensure successful soft tissue coverage, once the patient is positioned on the table.

Approach

- The incision is planned as a longitudinal incision of 10 to 15 cm length.
 - For the medial or lateral gastrocnemius muscle flap, the anterior border of the muscle is palpated through the skin and marked along its entire length.
 - The incision can be planned along this same longitudinal direction, usually one or two finger breadths posterior to this point, such that the muscle will be directly underneath the entire length of the incision, but it is still anterior enough that the harvest can easily proceed with the patient supine, and the legs in the “frog-leg” orientation.
- This incision location and length are adequate for the following necessary sites of surgical exposure:
 - Proximal exposure of the popliteal region and the sural vessel pedicle
 - Posterior exposure of the confluence between the medial and lateral gastrocnemius muscles
 - Distal exposure of the Achilles tendon
- The entire incision is made for muscle flap harvest, and dissection proceeds down through the skin, subcutaneous tissue, and superficial fascia, to enter the superficial posterior compartment of the leg.
- During this portion of dissection, when harvesting the medial gastrocnemius muscle, the saphenous vein should be identified and preserved.

TECHNIQUES

■ Elevation of the Gastrocnemius Muscle Flap

- The entire incision is made for muscle flap harvest, and dissection proceeds

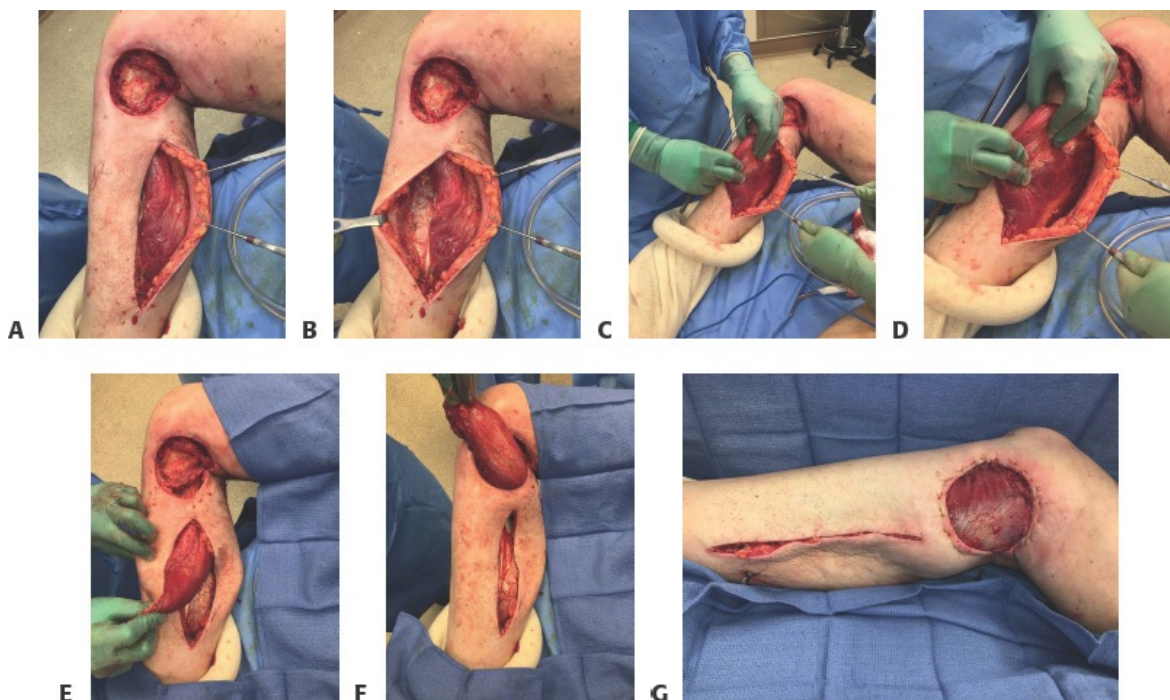
down through the skin, subcutaneous tissue, and superficial fascia, to enter the superficial posterior compartment of the leg.

- During this portion of dissection, when harvesting the medial gastrocnemius muscle, the saphenous vein should be identified and preserved. Once the posterior compartment is entered, the gastrocnemius muscle is immediately encountered along its posterior/superficial surface.
- The entire muscle belly should then be free from the entire deep surface of the posterior fascia overlying it (**TECH FIG 1A**).
 - This should be a relatively hemostatic dissection that can be done sharply or bluntly, as this plane between gastrocnemius muscle and overlying fascia is largely avascular loose areolar tissue.
- Once this has been done, the free border of the muscle, either medial or lateral, should then be identified along its entire length and used as the access point to dissect the deep surface of the muscle belly (**TECH FIG 1B**).
 - This space is entered, and the gastrocnemius muscle is dissected free from the underlying, deeper soleus muscle.
 - In this plane, the plantaris muscle and tendon (long and thin) will be encountered and should also be preserved (if present).
 - This deep dissection can be performed along the entire longitudinal length of the muscle, distally to the point of the Achilles tendon.
 - This dissection can stop at the point of confluence of the medial and lateral gastrocnemius muscles, along their deep surface, as only the half of the muscle being dissected will be elevated as a flap.
- At this point, surgical dissection should have fully freed up the deep and superficial/posterior surfaces of the gastrocnemius muscle belly (**TECH FIG 1C**).
- Next, the muscle will be elevated in a distal to proximal direction, moving up the leg.
- First, the muscle belly to be elevated is horizontally detached above the start of the Achilles tendon.
 - It is critical that the Achilles tendon not be disturbed and the entire fascial contribution of the gastrocnemius muscle within the Achilles tendon remains intact.
 - Thus, the muscle is transected one fingerbreadth above the point where the tendons of all the muscles in this compartment join to form the Achilles.
 - At this point, the gastrocnemius muscle will contain some tendon, and this

can be used for suture anchoring on inset of the muscle flap in the defect.

- Next, the half of the gastrocnemius muscle being elevated then is lifted in a distal to proximal direction, by separating the medial and lateral gastrocnemius muscles from each other (the last remaining point of attachment).
 - This area must be carefully identified along its entire length based on changing directionality of muscle fibers (**TECH FIG 1D**).
 - Often times, this point between the medial and lateral heads of the gastrocnemius muscles is not a distinct plane, and thus, separation should be performed with electrocautery to minimize bleeding.
 - Numerous minor perforators exist between the medial and lateral heads of the muscle, and these must be ligated.
- This elevation of the muscle in the proximal direction, by separating the two halves of the gastrocnemius, should be performed just beyond the point at which the freed muscle can rotate into the defect with no tension or stretch (**TECH FIG 1E**).
 - Often times, the dissection can stop well before the point where the sural vessels enter the deep surface of the muscle, as elevation to this point is not necessary for adequate rotation.⁵
 - In such cases, the sural vessels are never directly visualized, and this will reduce risk of vascular pedicle injury.
 - However, if necessary for adequate muscle rotation, dissection can proceed to this point, and the sural vessels can be identified, dissected free, and preserved.
 - In some cases, due to the need for excessive rotation, the muscle origin on the femoral condyle can be identified and transected.
 - This will result in a significant increase in muscle rotation and length of transposition.
 - Without the stability of the muscle insertion to prevent excess stretch on the sural vessels, they must be carefully watched during rotation and inset, to avoid excess tension and possible vascular traction injury or avulsion.
- Once the muscle has been fully dissected and elevated, it can then be rotated into the soft tissue defect (**TECH FIG 1F**).
 - If the muscle is tunneled underneath a planned skin bridge, it must be ensured that the skin bridge is not excessively tight or compressive on the underlying muscle flap.

- The muscle is usually inset with the previous posterior/superficial surface of the muscle belly externalized in the wound, as this portion of the muscle does not contain aponeurosis or fascia and thus accepts a skin graft well.
- The muscle is then inset into the soft tissue defects and secured circumferentially to the lower extremity skin and subcutaneous tissue with sutures (**TECH FIG 1G**).
- The proximal portion of the muscle, in the area of the sural vessels, should then be again examined after inset, to ensure no tension or stretch on this area.
- Finally, a skin graft can be placed on the superficial surface of the muscle flap at this point.
- The donor site can then be closed primarily over a drain, at the fascia and skin level.



TECH FIG 1 • A. Patient with a medial knee soft tissue wound, adequately debrided, and ready for soft tissue reconstruction. Planned medial gastrocnemius muscle flap is exposed through longitudinal incision shown. Posterior leg skin, subcutaneous tissue, and fascia have been elevated off the superficial surface of the

muscle flap. **B.** Dissection of the deep surface of the gastrocnemius muscle flap from the underlying soleus muscle. The aponeurosis of the soleus muscle is visible deep to the gastrocnemius muscle. The plantaris tendon is visible distally in the donor site and runs along the border of the gastrocnemius muscle. **C.** Both the deep and superficial surfaces of the medial head of the gastrocnemius muscle have been fully dissected, and the muscle has more freedom of movement. **D.** The longitudinal midline border between the medial and lateral heads of the gastrocnemius muscle is visible, by its overlying streak of fat. This will be the point of separation of the two muscle bellies. **E.** Following transection of the medial gastrocnemius muscle proximal to the Achilles tendon, and separation of the medial and lateral bellies of the muscle in the midline, the medial gastrocnemius muscle flap has now been elevated. The vascularized soft tissue bulk (width and thickness) afforded by this flap is clearly visualized. **F.** The muscle flap passed under the skin bridge and into the soft tissue wound. The size and reach of the muscle provide adequate coverage for the wound. **G.** The medial gastrocnemius muscle flap, following complete inset into the wound. The muscle is well perfused, with no pressure or tension. At this point, the muscle belly can be skin grafted, and the donor site can be fully closed in primary fashion.

PEARLS AND PITFALLS

Muscle flap elevation	■ The muscle flap only needs to be dissected proximally to the point where it can safely be rotated and inset into the wound, without tension; often times, complete elevation proximally to the sural vessel level is unnecessary and to avoid risk of vascular disruption.
Tunneling	■ The tunnel or skin bridge that the muscle flap passes under must be relaxed and without underlying tightness, to avoid muscle flap congestion and flap loss; if necessary, the fascia on the underside of the tunnel skin can be incised to increase the size of the tunnel.
Long muscle transposition length	■ In cases where the muscle flap must be advanced a long distance, it can be detached from the femoral condyle, to allow for a significant increase in reach; in these cases, the sural vessels must be continuously examined for a relaxed state without stretch, as they are no longer stabilized by the proximal muscle insertion.
Hemostasis	■ Hemostasis is critical, in both the muscle donor site, and in the wound being reconstructed, as tension from a hematoma can occlude the venous outflow and result in muscle flap loss.

POSTOPERATIVE CARE

- Postoperatively, the lower extremity is placed in a stabilizing knee immobilizer.
- This reduces muscle stretch or tension in the acute healing phase and reduces muscle flap edema.
- During this period, the patient may be kept nonweight bearing if deemed necessary or may be placed on limited foot pressure on the effected extremity while ambulating with crutches.
- Immobilization is usually kept on for 2 weeks, at which point the patient can begin knee flexion and normal ambulation (**FIG 1**).
- The skin graft can be covered for 5 to 7 days with either negative pressure therapy or with a bolster dressing.

COMPLICATIONS

- Hematoma



FIG 1 • Healed medial gastrocnemius muscle flap and overlying split thickness skin graft, 3 months after coverage operation in **TECH FIG 1**. Patient has stable soft tissue coverage and is ambulating without difficulty.

- Bleeding in either the donor site or the wound bed underneath the muscle flap must be treated immediately with hematoma evacuation, to avoid pressure on vascular pedicle and resultant muscle flap loss.
- Infection
 - Proper wound bed debridement and removal of all nonviable tissue prior to muscle flap coverage will reduce this risk.
 - When infection occurs, re-elevation of the muscle flap and aggressive washout should be performed.
- Flap loss
 - With complete flap loss, a secondary free flap often must be performed for wound coverage.
- Venous congestion
 - The entire flap must be elevated, and if congestion resolves, this usually indicates pressure or kinking on vascular pedicle, which must be resolved.
 - The tunnel must be checked for excessive tightness, and if this is the case, it can be opened with an incision and the muscle externalized in this area.

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33 Soft Tissue Coverage of the Knee: Free Flaps

CHAPTER

Goo-Hyun Mun and So Young Kim

DEFINITION

- Although most soft tissue and bony defects around the knee are usually covered with locoregional tissues, free flaps should be considered when the desired donor territory is damaged or unsuitable or if the defect is extensive or complex. Free flaps offer benefits such as shortened recovery time, plentiful availability of donor tissue, and greater flexibility in flap design.¹
- Soft tissue defects of the knee can significantly influence gait; therefore, reconstruction should be done with proper planning and technique at an early onset.²
- Restoration of the thin and pliable skin for satisfactory appearance and function of the knee is an important reconstruction goal.

ANATOMY

- Popliteal vessels and vessels from the anterior knee can be recipients of microvascular free flap transfer for soft tissue coverage of knee defects.
- Recipient vessels for free flap.
 - Popliteal vessel and its branches (**FIG 1A**). The popliteal artery ranges from a proximal portion starting at the opening of the adductor canal to the distal portion lying behind the upper part of the tibia and fibula. The popliteal vessel and branches, including the superior medial and lateral genicular vessels (**FIG 1B**), medial and lateral sural vessels (**FIG 1C**), middle genicular vessels, and inferior genicular vessels, are considered the choice of recipient vessels for a free flap in the knee region. However, the approach to the popliteal vessels can be difficult when the anterior surface of the knee is reconstructed, and sural vessels are difficult to use in a free tissue flap to the region proximal to

the knee.³ Furthermore, there is a risk of increased complications caused by compression and twisting of the flap blood vessels, depending upon the postsurgical position of the patient.

■ Anterior knee (**FIG 2A**):

- Three vessels, including the descending genicular vessel and its branches (**FIG 2B,C**), and the descending branches of the lateral circumflex femoral vessels (**FIG 2D**) and anterior tibial vessels are considered the choice of recipient vessels for a free tissue transfer for the anterior knee region.
 - These recipient candidates have several benefits with supine positioning and easy accessibility to the recipient vessel. However, these branches may be very small vessels and, if so, may be of limited value and less reliable.³
- The perforators along the intermuscular septum of the upper leg and lower thigh can be used as recipient vessels for free flap reconstruction of the knee, but also note that these vessels may be small.⁴

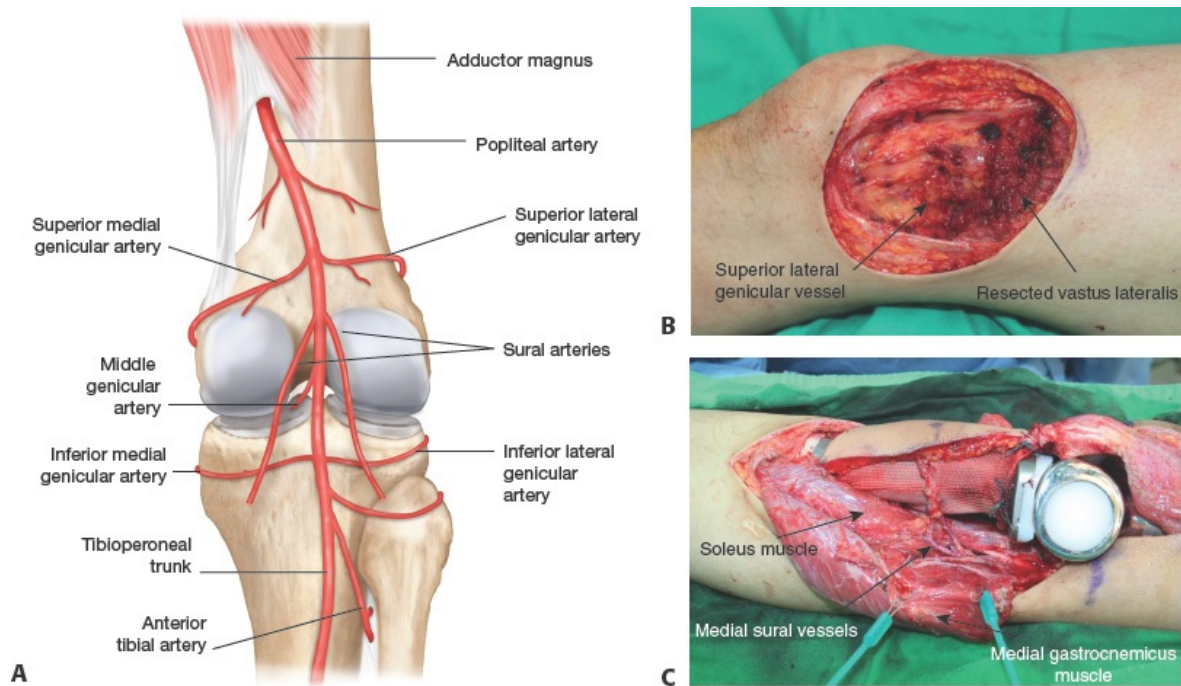


FIG 1 • A. Muscular boundaries and branches of the popliteal artery and deep neurovascular structures in the posterior knee. **B.** Superior lateral genicular vessel for recipient vessel. **C.** Medial sural vessel for recipient vessel.

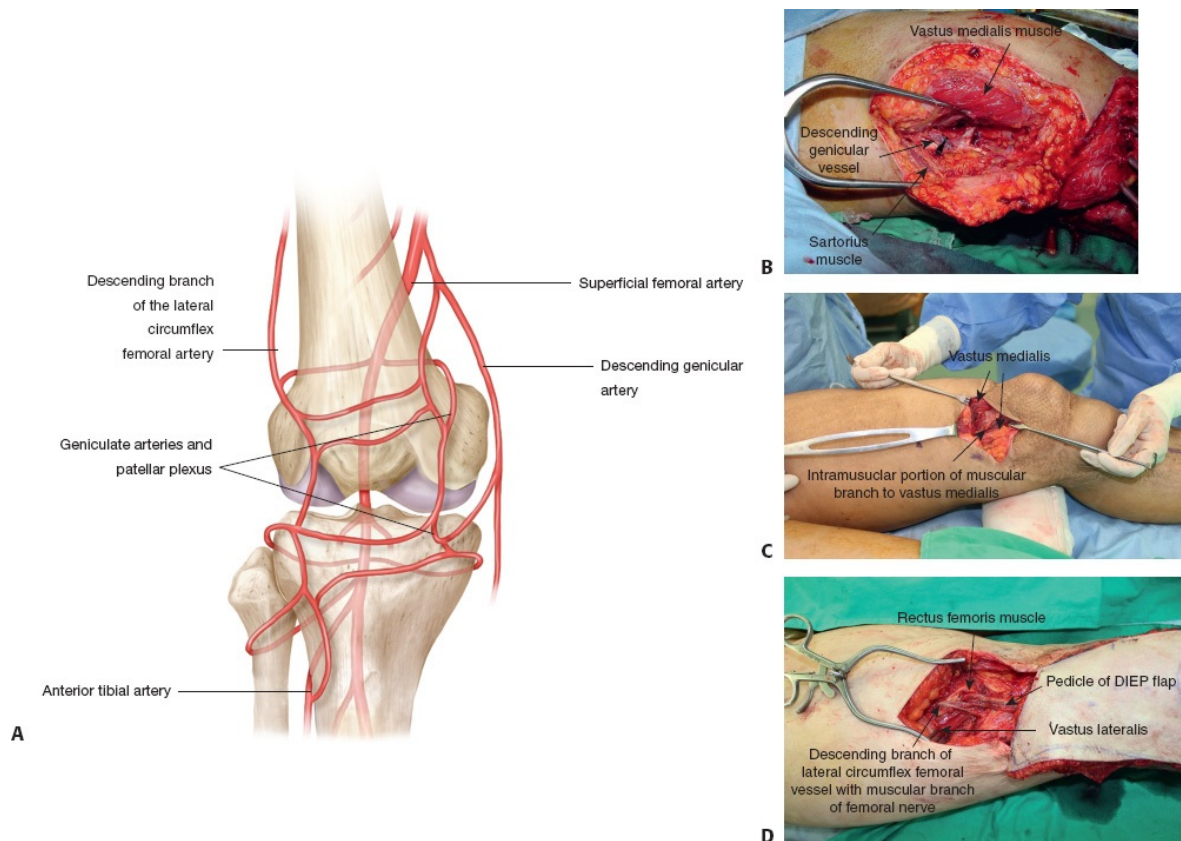


FIG 2 • A. Anatomy of recipient vessels of anterior knee region. **B.** Descending genicular vessels—vessel for recipient vessel. **C.** Descending genicular vessel—muscular branch to the vastus medialis for recipient vessel. **D.** Descending branch of the lateral circumflex femoral vessel for recipient vessel.

PATHOGENESIS

- Multiple prior operations and revision arthroplasties with atrophy/scarring of soft tissues
- Prior coverage of a total knee prosthesis and wound dehiscence due to infection
- Large post-traumatic defects
- Extensive soft tissue tumor excision
- Soft tissue necrosis and chronic infection after extremity radiation
- Necrotizing fasciitis and septic arthritis
- Burn scar contracture and post-traumatic stiff knee

PATIENT HISTORY AND PHYSICAL FINDINGS

- The patient history should focus on the exact mechanism and etiology of the defect.
- It is important to assess the medical history including vascular disease, systemic disease, and hypercoagulable state, which can influence the outcome of a microsurgical procedure.
- The preoperative evaluation for patients with a knee defect includes a detailed assessment of function limitations. The range of motion is a widely used measure of the knee joint, with a normal range of flexion of 45 to 105 degrees during routine activities and full extension to 0 degree.⁵

IMAGING

- The authors routinely perform preoperative computed tomography (CT) angiography of the lower extremity unless contraindicated to evaluate the regional vascular anatomy.
- Magnetic resonance imaging (MRI) can also be performed for evaluation of complex defects of soft tissue.

SURGICAL MANAGEMENT

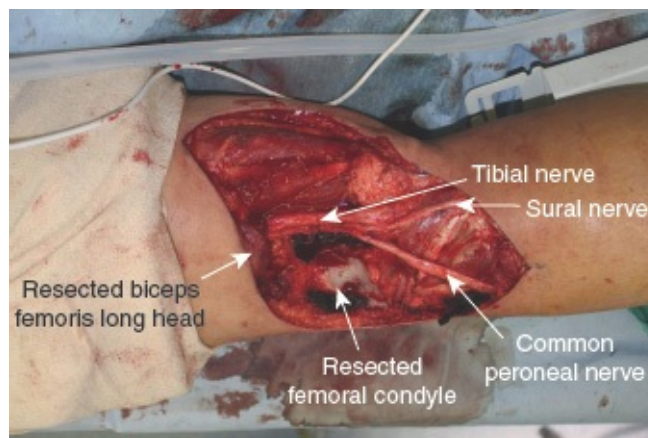
- The proper selection of recipient vessels is essential for the success of a free flap and is arguably the most important factor that can affect the outcome.^{4,6} Major considerations regarding the choice of appropriate recipient site for revascularizing the flap include performing the microanastomosis outside the zone of injury and avoiding the need for vein grafts.⁷
- Extending the incision from the defect is used when there is a suitable adjacent recipient; however, a separate incision with subcutaneous tunneling can be effective for a distant recipient vessel approach.
- Options of free flap:
 - Commonly chosen flaps for soft tissue reconstruction of knee defects are an anterolateral thigh (ALT) flap, rectus abdominis muscle flap, deep inferior epigastric artery perforator (DIEP) flap, tensor fascia lata flap, superficial circumflex iliac artery perforator (SCIP) flap, latissimus dorsi musculocutaneous flap, and thoracodorsal artery perforator (TDAP) flap. The TDAP flap is favored by the authors because of several advantages including generous dimensions of the back, tissue thinness, relatively well-hidden donor scar, a long vascular pedicle, and the versatility offered by composite tissue transfer.

- When complex knee trauma accompanies a patellar tendon defect, the patellar tendon is traditionally restored using an autogenous graft, such as the semitendinosus tendon, gracilis tendon, and fascia lata, or an allograft. Because of the problem of delayed healing, fascia lata failure, and infection, a composite ALT myocutaneous flap with vascularized fascia lata can be utilized for one-stage reconstruction of complex knee defects.⁸
- When there is post-traumatic loss of the quadriceps femoris muscles with subsequent loss of knee extension, free functional transfer of the latissimus dorsi muscle⁹ and contralateral rectus femoris muscle¹⁰ can be utilized to restore knee extension.
- For stump coverage in above or below knee amputations, the distal placement of a flap to cover the entire weight-bearing surface of the stump is required.¹¹

TECHNIQUES

■ Wound Preparation

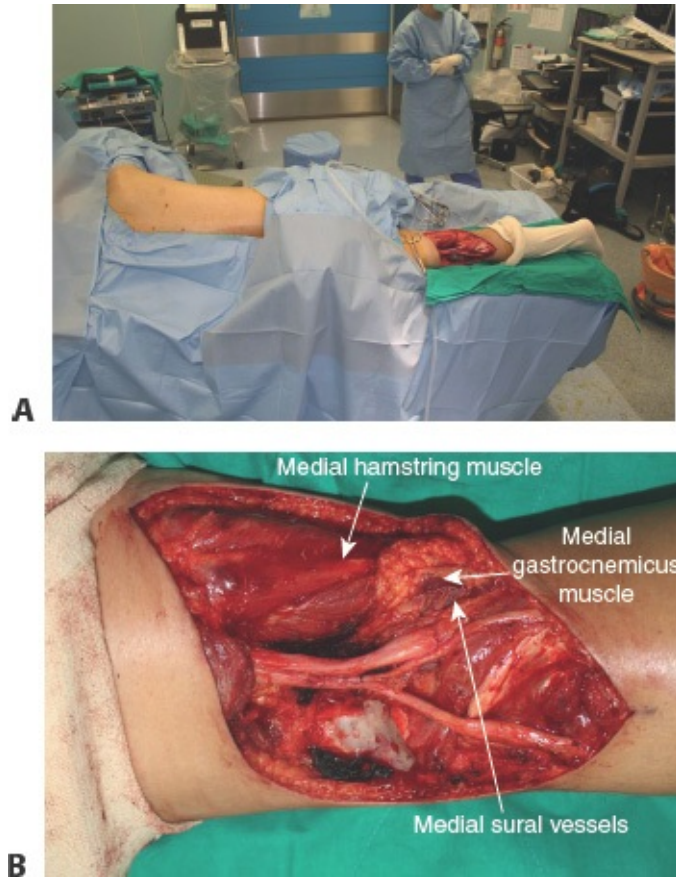
- The first goal of wound preparation is to debride all contaminated soft tissue or excise pathologic or necrotic lesions and to evaluate the extent of soft tissue defects in terms of size and components, including the bone, tendon, muscle, fascia, and skin (**TECH FIG 1**).
- A tourniquet is usually applied on the thigh during wound preparation.



TECH FIG 1 • Wound preparation of posterior knee defect after tumor extirpation.

■ Recipient Vessel Preparation

- Approach to the medial sural artery
 - The procedure can be performed with the patient in prone or semilateral decubitus position, with the recipient extremity down and the opposite leg crossed anteriorly, with simultaneous access to the contralateral back as a donor site (**TECH FIG 2A**).
 - Arising from the posterior aspect of the popliteal vessel, the medial sural vessel enters the deep surface of the medial gastrocnemius muscle. Between the muscular head of the medial and lateral gastrocnemius, the medial sural vessel is easily approached¹² (**TECH FIG 2B**). A branch of the tibial nerve usually accompanies the dominant vascular pedicle to the gastrocnemius muscle and should be preserved.⁷
- Approach to the descending genicular artery and its branches
 - The procedure is performed with the patient in the supine position, with the knee flexed and the thigh rotated externally.
 - The descending genicular vessel is divided into three equal branches:
 - A muscular branch to the vastus medialis muscle
 - A terminal articular branch supplying the periosteum of the medial condyle
 - A saphenous (superficial) branch
 - After medial retraction of the sartorius muscle, the descending genicular vessel can be identified immediately posterior to the vastus medialis muscle⁴ (**FIG 2B**). The intramuscular portion of muscular branch to the vastus medialis can be a candidate recipient vessel and is exposed through retrograde intramuscular dissection of a perforator overlying the vastus medialis⁴ (**FIG 2C**).
- Approach to the descending branch of the lateral circumflex femoral artery (LCFA)



TECH FIG 2 • A. Lateral decubitus position with the recipient extremity down and the opposite leg scissored anteriorly for the approach to the medial sural artery. **B.** The medial sural vessel is prepared for the recipient vessel.

- The procedure can be performed in the supine position.
- The descending branch of the LCFA with adequate size as a recipient vessel can be found in an area 10 to 15 cm above the upper margin of the patella; therefore, a donor flap must have a long enough pedicle.² After separating the rectus femoris medially from the intermuscular septum between the vastus lateralis and the rectus femoris, the descending branch of the LCFA is exposed. It travels with the muscular branch of the femoral nerve along the anterior border of the vastus lateralis toward the knee joint (**FIG 2D**).
- Approach to the superior medial and lateral genicular artery
 - The superior genicular vessels arise on either side of the popliteal fossa and

wind around the femur immediately above its condyles to the front of the knee joint.⁴

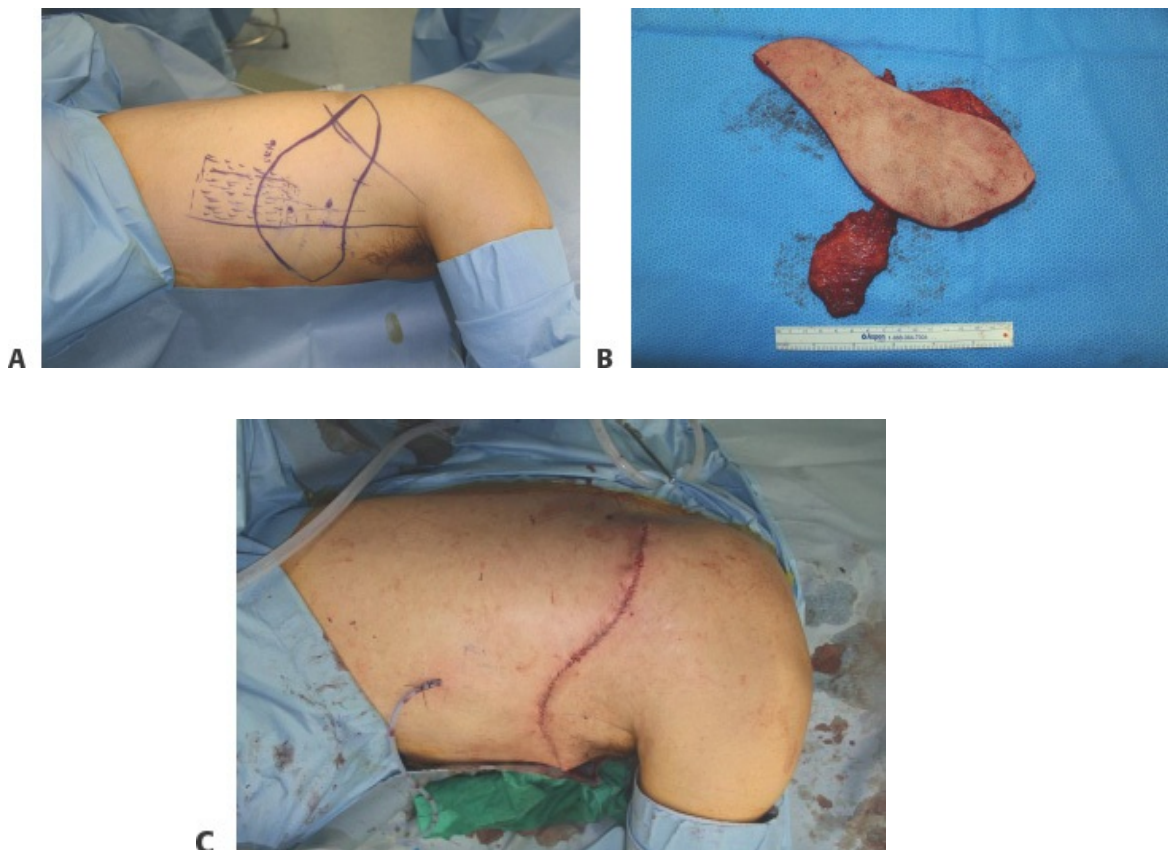
- In cases of a defect in the posterior knee, the superior medial genicular vessel is exposed after gentle retraction of the semimembranosus muscle at the level of the upper edge of the femoral condyle when the popliteal artery is in sight.³
- The superior lateral genicular vessel is identified above the lateral condyle of the femur as it courses laterally beneath the short head of the biceps femoris and the vastus lateralis¹³ (**FIG 1B**).
- Selection of recipient vein
 - Because the use of an accompanying concomitant vein as the recipient has the benefit of straightforward inseting of the flap, the deep vein system is usually considered the first choice of a recipient vein for a free flap in the lower extremity.
 - However, in this anatomical area of the knee, a superficial vein such as the great saphenous vein passing medial to the medial femoral condyle is sometimes in a more convenient position and is a better size match for anastomosis than the deep vein system.¹⁴

■ Assessment of the Defect

- Because the knee is a large diarthrodial (synovial) joint with an extensive range of motion, free flaps in this region should provide ample skin coverage to allow unrestricted joint mobility in flexion and extension and to facilitate ambulation.^{1,15}
- Final defect size and shape are exactly measured by making a transparent plastic or paper template that will be used for flap design. With the consideration both of minimizing restricted mobility of joint and avoiding redundancy of reconstructed flap, the measurement of anterior defect is usually conducted in slightly flexed knee status, and measurement of posterior defect is done in position of knee extension status.
- Dead space to be filled is also measured and accounted for in flap design/harvest.

■ Flap Harvest

- Outlines of the relevant muscle and other landmarks are drawn (**TECH FIG 3A**).
- Perforators are located using a handheld pencil Doppler, and the flap is designed using a template of the final defect.
- The targeted perforator(s) are identified by suprafascial dissection through a limited incision because the design of skin paddle could be potentially adjusted to capture the perforator securely within the flap, and then the whole skin paddle is elevated.
- Meticulous intramuscular dissection of the pedicle under loupe magnification with bipolar forceps is performed.
- A muscle chimeric perforator flap can be harvested as needed to fill dead space or to cover the artificial implant (**TECH FIG 3B**).
- Motor nerve branches to the muscle are maximally preserved during a perforator flap harvest, and the pedicle is divided when sufficient length is obtained.
- A closed suction drain is placed and the donor wound is primarily closed in layers (**TECH FIG 3C**).



TECH FIG 3 • A. Outline of the relevant muscle and landmarks are drawn on the donor site for flap design. **B.** Harvested muscle chimeric TDAP flap. **C.** Donor site that was primarily closed after flap harvest.

■ Microanastomosis with Temporary Inset

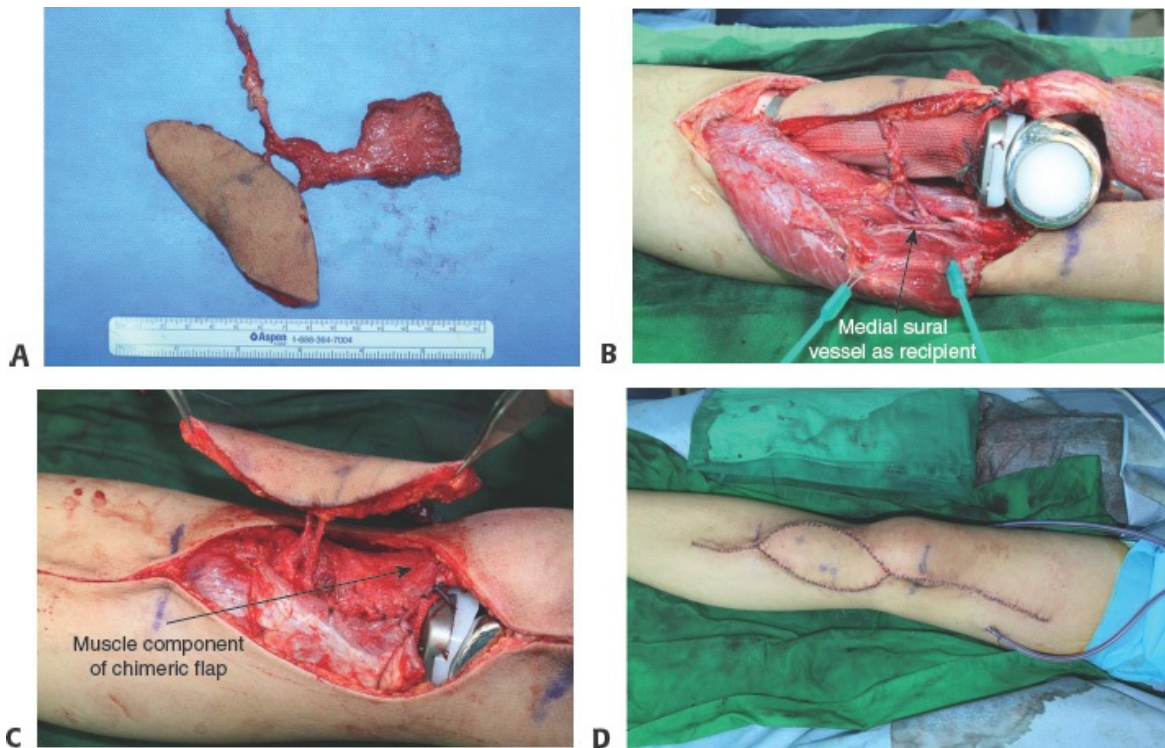
- Temporary inset of the flap is performed with a skin stapler.
- The vascular pedicle is comfortably laid to reach the recipient vessel without kinking, twisting, or tension. This is best accomplished by prudent preoperative planning and harvesting sufficient pedicle length.
- Wide exposure of the operative field and creation of a comfortable milieu are critical for successful microvascular anastomosis.
- Either end-to-end or end-to-side microanastomoses are performed and may depend on the size of the vessels.
- Vascular clamps are removed after completion of anastomoses. Warm saline is applied to the vessels and covered with moist gauzes for several minutes.
- After checking for patent arterial inflow and venous outflow, then perform careful hemostasis to evaluate for any bleeding points from the vascular pedicle or recipient vessels.

■ Final Inset

- Insetting of the flap is straightforward because it should have been harvested based on an exact template of the defect.
- The muscle component of a chimeric flap is placed to fill in dead space or to cover the prosthesis (**TECH FIG 4**).
- If the flap is too bulky, it may be thinned by carefully removing tissue from the deep fat layer and part of the superficial fat layer, except for a few centimeters of a cuff of subcutaneous tissue around the entry point of the perforator(s). The use of loupe magnification or even the microscope may be advised to avoid damaging small blood vessels traveling through the fat.
- The wound is closed with placement of closed suction drains under the flap to prevent fluid collection (**TECH FIG 5**).
- A leg splint is applied for immobilization, and an elastic bandage is loosely

applied so as to avoid compression over the vascular pedicle.

- Part of the flap is left open for postoperative monitoring of flap perfusion.



TECH FIG 4 • A. Harvested muscle chimeric perforator flap. **B.** After end-to-end microanastomoses to the corresponding vessels of the chosen free flap, exposed artificial bone and knee joint are seen in anterior knee. **C.** Muscle component of chimeric flap is arranged to cover the artificial implant. **D.** Transferred muscle chimeric TDAP flap in anterior knee after final inset, using the medial sural vessel as recipient.



TECH FIG 5 • A. Transferred muscle chimeric TDAP flap in posterior knee after final inset, using the medial sural vessel as recipient. **B.** Transferred TDAP flap in medial knee after final inset, using muscular branch of the descending genicular vessel as recipient. **C.**

Transferred DIEP flap in anterior knee after final inset, using muscular branch of the descending genicular vessel as recipient. **D.** Transferred TDAP flap in lateral knee after final inset, using the superolateral genicular vessel as recipient.

PEARLS AND PITFALLS

Planning

- Meticulous preoperative planning for recipient vessels, donor site, flap composition, and positioning of the patient is crucial for successful reconstruction.
- A multidisciplinary approach with comprehensive communication between oncologic and/or orthopedic surgeons will enable better treatment outcomes.

Selection of recipient vessel

- The recipient vessel option includes the descending genicular vessel and its branches, descending branch of lateral circumflex femoral vessel and anterior tibial vessel in the anterior knee, and superior medial and lateral genicular vessel, medial and lateral sural vessel, middle genicular vessel, and inferior genicular vessel in the popliteal area. Surgeons may choose a recipient vessel based on the proximity to the defect, concomitant injuries, vessel availability, and vessel size match.
- The deep vein system is usually considered as the first choice of recipient vein for a free flap in the lower extremity. However, in this anatomical area of the knee, a superficial vein such as the great saphenous vein is sometimes in a more convenient position and is a better size match for anastomosis than the deep vein system.

Assessment of the defects

- Free flaps in this region should provide ample skin coverage to allow unrestricted joint mobility in flexion and extension and to facilitate ambulation.
- Defect size and shape are exactly measured by making a template for subsequent flap design.

Microanastomosis and flap inset

- It is important to avoid twisting and kinking of the pedicle.
- Tension on the pedicle should be avoided and sufficient

acquisition of pedicle length is a safe strategy.

- Defatting of the perforator flap at the time of inset is an effective technique to obtain aesthetic contour but must be performed carefully to avoid compromising blood supply.

POSTOPERATIVE CARE

- Most surgeons who perform free flaps in the lower extremity rely upon clinical observations including subjective visual inspection, capillary refill, turgor, and temperature of the flap, in combination with a handheld pencil Doppler for monitoring the flap.¹⁶ The protocol varies according to surgeon, but the authors perform clinical assessment of flap status, combined with a handheld Doppler examination, every 3 hours for the first 48 hours and then every 6 hours for the next 48 hours after surgery.
- Although preferences regarding anticoagulation regimens vary widely among microvascular surgeons, medication for perioperative anticoagulation can be used to minimize the risk of postoperative thrombosis. The major classes include antiplatelet, heparin-based anticoagulant, and plasma expander drugs.
- Postoperatively, lower extremity edema and overly aggressive mobilization can compromise the free flap, especially causing venous congestion.¹⁷ Although the duration of immobilization time varies based on the orthopedic injuries, generally progressive weight bearing and ambulation are achieved when the patient is tolerating dangling at least 30 minutes, six times per day.¹⁷
- Postoperative rehabilitation to maintain knee movement is an essential part of treatment and should be commenced in the early postoperative period.¹⁵

OUTCOMES

- Published success rates for free tissue transfers to the knee vary according to the etiology of the defect, but a microvascular free flap in this region is a safe procedure, with a success rate ranging from 97% to 100%.^{1,15,18}
- A microvascular free flap is a reliable reconstructive option for defects of various sizes in various locations in the knee. The type of perforator flap, whether cutaneous or muscle chimeric (**FIG 3**), is selected according to tissue requirement.

COMPLICATIONS

- Vascular complications such as venous and arterial thrombosis
 - Prompt emergent exploration is demanded when these conditions are

suspected.

- Hematoma

- Early diagnosis of a hematoma under the flap is critical so that it can be evacuated promptly to prevent compression of the anastomotic site due to an expanding hematoma. Any time a postoperative hematoma is noted, the surgeon must suspect venous obstruction.

- Infection

- When the defect accompanies an infected prosthesis and chronic infection of the bone or joint, a late infection or recurrence of infection after free tissue transfer can develop.^{18,19} Therefore, it is critical that the wound be sufficiently debrided of necrotic, infected, or pathologic tissue before definitive flap reconstruction.

- Suboptimal knee range of motion

- Suboptimal knee range of motion may result from increased periods of restricted knee extension followed by allowance of very limited knee range of motion during free flap maturation.¹ Therefore, early range of motion is advised once flap viability is established.

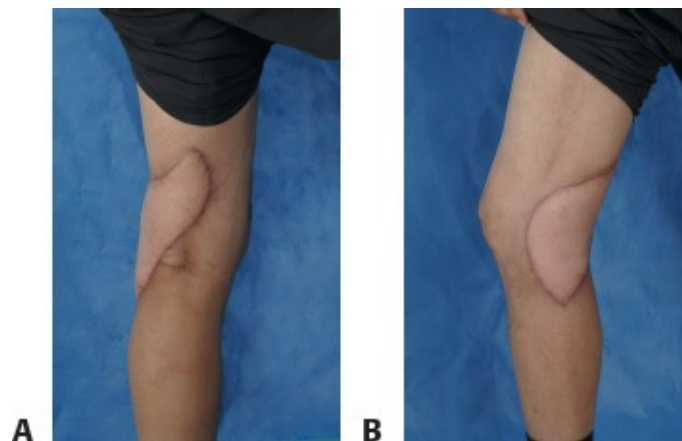


FIG 3 • A,B. Satisfactory result of muscle-chimeric free flap to the posterior knee defect.

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CHAPTER Repair of Patella Tendon

Patrick Horrigan, Michael Bellino, and Julius Bishop

DEFINITION

- Rupture of the patellar tendon is a disruption of the knee extensor mechanism between the patella and the tibial tubercle.
- Complete ruptures cause significant disability, pain, hemarthrosis, and an inability to extend the knee.
- Prompt treatment nearly always involves surgery and early motion during rehabilitation.
- Missed or delayed diagnosis and treatment can result in significant pain and dysfunction.¹

ANATOMY

- The patellar tendon is a continuation of the quadriceps tendon, a confluence of the vastus medialis, intermedius, and lateralis tendons and the rectus femoris tendon. It is derived primarily from extending fibers of rectus femoris traversing the anterior surface of the patella.
- The tendon itself consists of 90% type I collagen. Its fibers are arranged longitudinally relative to the axis of the lower extremity.
 - It measures approximately 32 mm in width and narrows by several millimeters near its insertion on the tibial tubercle.
 - Its thickness in normal knees is approximately 6 mm at its proximal extent and 6 mm distally.^{2,3}
- The blood supply of the patellar tendon is derived from the inferior genicular arteries proximally and from the anterior tibial recurrent artery distally. It shares a portion of its blood supply posteriorly with the infrapatellar fat pad.^{3,4}

PATHOGENESIS

- Because degenerative changes are present in most cases, tendinopathy is increasingly given the primary pathogenic role in rupture.⁵
- Rupture can also occur in the setting of direct trauma, recent corticosteroid injections for tendonitis, and systemic disease (patients with chronic acidosis or nephropathy requiring hemodialysis, systemic lupus erythematosus).⁶
- A classic described mechanism is forceful contraction of the quadriceps musculature with the knee in greater than 45 degrees of flexion.⁷

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients will typically describe an acute popping or tearing sensation during a brief period of forceful quadriceps contraction. This is often followed by acute-onset knee pain, swelling, and inability to bear weight.
- A palpable infrapatellar defect around a swollen joint can sometimes be appreciated on the symptomatic knee.

IMAGING

- Plain anteroposterior and lateral radiographs of the knee are usually sufficient for diagnosis of patella tendon rupture (**FIG 1**).⁷
- In cases of uncertain physical examination, MRI or ultrasonography may be useful for confirmation of diagnosis.

DIFFERENTIAL DIAGNOSIS

- Quadriceps tendon rupture
- Patella fracture
- Medial/lateral collateral ligament rupture
- Anterior cruciate ligament rupture
- Meniscus tear
- Patellar dislocation/subluxation event

NONOPERATIVE MANAGEMENT

- Management of patellar tendon ruptures in medically stable adults is surgical. Nonoperative treatment predictably results in tendon retraction and loss of active knee extension strength and extensor lag.⁷

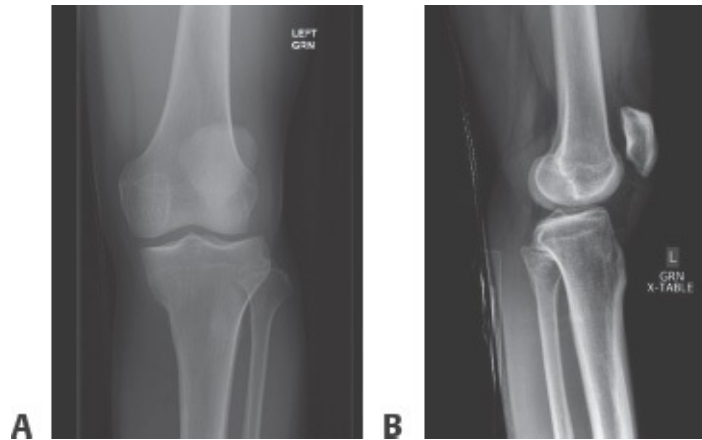


FIG 1 • A,B. Anteroposterior and lateral radiographs of a 32-year-old man with a sudden popping sensation and left knee pain after landing from a jump while playing basketball. Radiographs show a knee effusion, absence of fracture and patella alta best seen on the lateral projection.

SURGICAL MANAGEMENT

- Surgical goals include restoration of the knee extensor mechanism with strength to allow for early postoperative rehabilitation.
- Secondary goals include avoidance of overcorrection resulting in patella baja and altered knee kinematics.
- The most commonly described technique to date consists of an augmented primary repair using transosseous patellar tunnels and nonabsorbable suture fixation.⁸

Preoperative Planning

- AP and lateral radiographs of the affected and contralateral knee can be reviewed for comparison and to look for other concurrent abnormalities such as calcific tendonitis, abnormal patellar morphologies, or previous surgeries.

Positioning

- The patient is positioned supine on a radiolucent table with arms abducted. A bump is placed under the ipsilateral buttock and low back to facilitate internal rotation of the operative knee to neutral.
- A nonsterile tourniquet is applied.

- Hair over the operative site and anticipated dressing placement is trimmed with clippers.
- C-arm fluoroscopy may be available for confirmation of tunnel placement or for delineation of any occult fracture fragments not noted on initial radiography.

Approach

- An anterior approach to the patellar tendon provides the most direct and extensile access to the site of injury and planned repair.

TECHNIQUES

■ Transosseous Suture Technique

Anterior Approach to the Patellar Tendon and Extensor Retinaculum

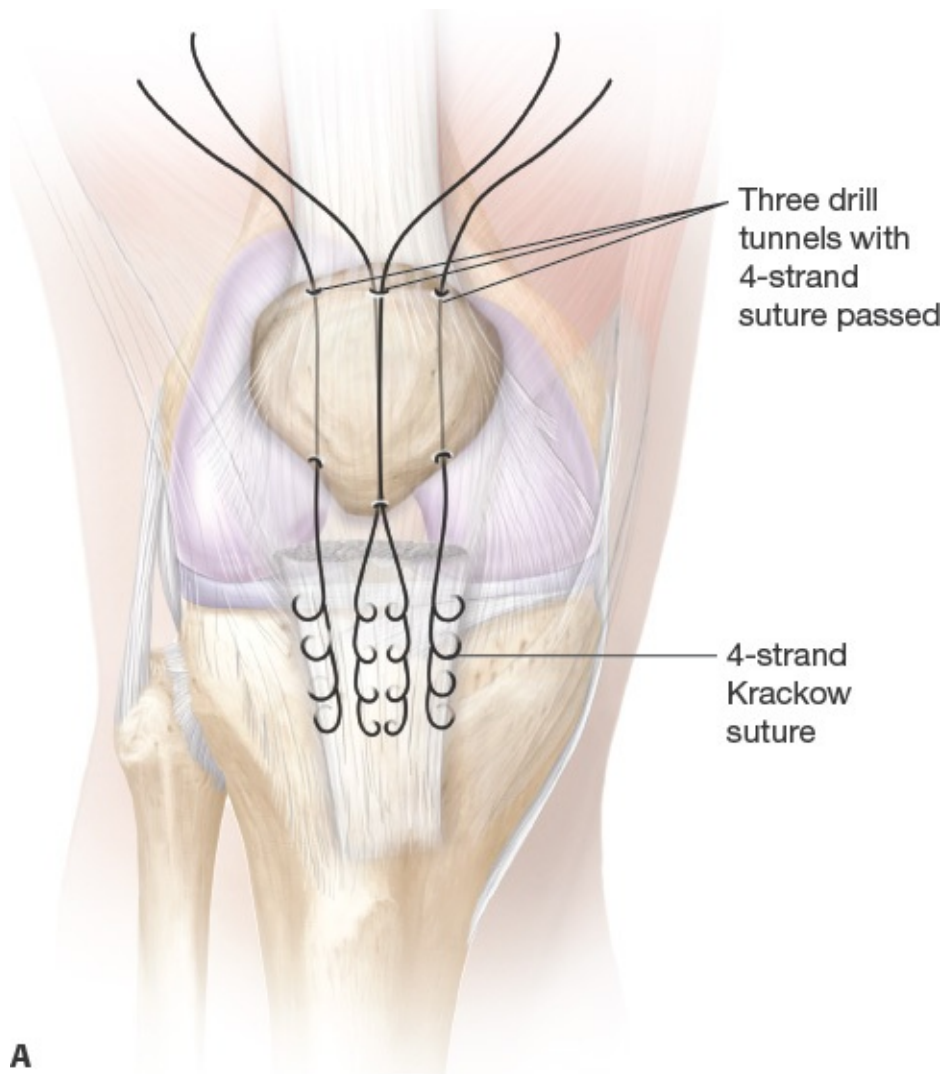
- Landmarks: patella, tibial tubercle, and patellofemoral joint line.
- Exsanguinate the leg and inflate a tourniquet as needed for hemostasis
- Make a midline incision longitudinally from the superior pole of the patella to the proximal aspect of the tibial tubercle.
- Elevate thick skin flaps to the prepatellar bursa. Hematoma is often encountered at this point.
- Identify patellar paratenon for later repair if not traumatically disrupted.
- Identify the area of patellar tendon rupture and the extent of retinacular involvement.
- Evacuate intra-articular hematoma.

Preparation of Tendon

- Identify the area of the tear; most patellar tendon ruptures are from the distal patellar pole, leaving a long distal limb for suture anchoring.
- Debride the tendon and infrapatellar pole of any nonviable strands or areas of degeneration and thickening. Excise any free bony fragments that originated from the inferior patellar pole that cannot be incorporated into the repair construct.
- Using two separate thick nonabsorbable braided suture (no. 5 FiberWire) and

starting at the most proximal aspect of the distal segment, pass the Krackow sutures on either side of the tendon, traversing for approximately four or five passes before creating a second row per suture and ultimately creating four total suture strands exiting near the suture's entry point (**TECH FIG 1**).

- Separate the four strands into three groups: one medial, two central, and one lateral. Cut the central strands to two different lengths that can still pass through the length of the patella and be tied down. This will differentiate them during suture fixation.



TECH FIG 1 • A. Diagram of Krackow suture repair of torn patellar tendon. **B.** Left knee patellar tendon repair with four-strand Krackow sutures placed.

Creation of Bone Tunnels

- Identify the medial and lateral borders of the patella. Divide this total width into fourths, taking into account areas of thin cortical bone, particularly at the lateral facet.
- Using a long 2.5-mm drill, create three retrograde drill holes at the central divisions of each of the zones described in step one (**TECH FIG 2**). Mark the entry point of each drill pass with electrocautery. Consider using multiple drill bits or saved fluoroscopic views to ensure the drill paths do not cross.

Suture Passage and Knot Tying

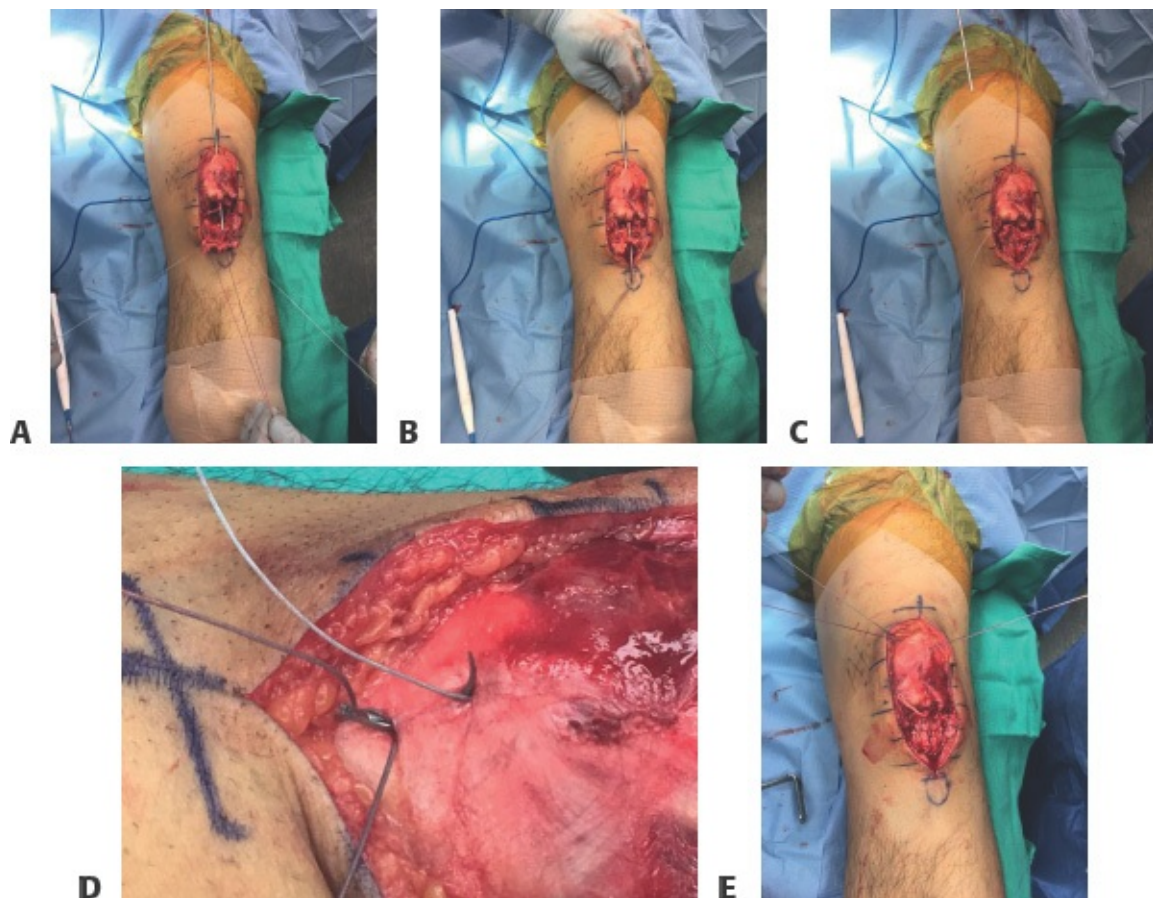
- Flex the knee to approximately 20 degrees with a small bump behind the knee. This is to ensure suture passage anterior to the quadriceps tendon to permit knot tying as close to the patella as possible.
- Use a 2.4-mm Beath pin with eyelet to pass each of the four suture strands through the three drill holes using the designation created earlier. All strands will then be superior to the patella (**TECH FIG 3A–C**).
- Pass the central limbs through the quadriceps tendon to their corresponding medial and lateral limbs using a free needle. This avoids soft tissue bridging and possible loosening (**TECH FIG 3D,E**).
- Hand tie at least five surgical knots, using a slip knot or needle driver to hold the initial knot tight. Leave 4-mm tails of suture.



TECH FIG 2 • Drill holes placed retrograde with long 2.5-mm drill.

Completion and Assessment of Repair

- Repair any ruptured retinaculum with large absorbable braided suture.
- Move the knee through passive motion under direct visualization of repair.
 - Note any gapping or opening of the repair. This will be the limit of range of motion in the early postoperative period.
- Deflate tourniquet, irrigate, obtain hemostasis, and close in layers with paratenon closure if possible.
- Apply a soft dressing and a hinged knee brace locked in extension.



TECH FIG 3 • **A.** Beath pin passed retrograde through each of three marked drill holes. **B.** Threaded Beath pin passing through central drill hole with two suture strands. **C.** Central thread strands now passed through drill hole and quadriceps tendon with knee slightly flexed. **D.** Free needle used to pass central suture strands closer to their respective medial and lateral strands so as to avoid soft tissue bridging. **E.**

All four suture strands ready for creation of two hand-tied knots.

PEARLS AND PITFALLS

Indications	■ Confirm diagnosis with examination under anesthesia to rule out the more proximally oriented quadriceps tendon rupture.
Tendon preparation	■ Ensure at least three passes of each row of Krackow suture to limit the possibility of suture pullout and subsidence of fixation.
Creation of bone tunnels	■ Avoid intra-articular penetration of drill, using fluoroscopic guidance or via proprioceptive feedback with the patella held between the thumb and index finger. ■ Oscillate when drilling tunnels so as not to bind suture in drill bit. ■ Mark bone tunnel placement in surrounding soft tissues with electrocautery for accuracy of Beath pin passage. ■ Avoid crossing of bone tunnels, which can create suture entanglement and prevent secure tightening of repair knots.
Suture passage and knot tying	■ Use a free needle to pass suture close to its accompanying strand and avoid soft tissue bridging. ■ Avoid over- or undertensioning of suture and subsequent alteration of patellofemoral mechanics.

POSTOPERATIVE CARE

- In isolated tendon injuries, the patient may be discharged to home with hinged knee brace locked in extension for 2 weeks. No active knee extension is permitted for 6 to 8 weeks.
- At the initial 2-week postoperative follow-up visit, the brace is unlocked for range of motion exercises up to the limit noted at the time of operation.
- Thirty-degree increases may be made every 2 weeks, and then knee brace is unlocked and weaned entirely for the remainder of rehabilitative therapy.
- Stretching and strengthening are permitted at 8 weeks, with return to full activity as tolerated at 12 to 16 weeks.

OUTCOMES

- Gilmore et al. analyzed the different techniques of acute and chronic patellar tendon repair in a recent review.⁹
- In searching techniques of primary repair, they noted 383 patellar tendon ruptures repaired primarily.
 - Seventy-seven percent of the primary repairs were with nonabsorbable suture.
 - Sixty-six percent of primary repairs underwent some form of augmentation.
 - The most common suture method was the Krackow technique.
- Five different outcome scoring systems were used to grade the success of repair.
 - While no comparisons in functional outcome could be made between specific techniques, primary repairs with augmentation demonstrated the best mean knee range of motion of 0 to 129 degrees.
- Augmented primary repair also demonstrated the lowest failure rate at 2%.

COMPLICATIONS

- In Gilmore et al.'s review,⁹ augmented primary repair demonstrated the lowest failure rate at 2%.
- Described complications of patellar tendon repair include¹:
 - Improper tendon tensioning leading to patella alta or baja
 - Failure of repair/ rerupture
 - Infection
 - Knee stiffness
 - Prominent suture knots requiring removal
 - Deep vein thrombosis

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Section IV: Thigh

35 Excision of Soft Tissue Tumors of the Thigh

CHAPTER

Raffi S. Avedian

DEFINITION

- Soft tissue sarcomas are malignant tumors that arise from mesenchymal cells and are classified according to their cell of origin such as the muscle, tendon, or fat.
- Peripheral nerve sheath tumors arise from neural crest cells but are typically grouped with sarcomas because of similarities in location, natural history, and treatment.
- The World Health Organization groups soft tissue sarcomas into ten categories based on the tissue of origin.
- Most sarcomas occur in a deep location meaning below the muscle fascia, whereas one-third of sarcomas occur in a subcutaneous location.
- Patients with soft tissue sarcomas and patients with benign tumors often present with the same chief complaint of having a soft tissue mass.
- Rendering an accurate diagnosis prior to surgery is important because the treatment plan may vary based on the nature of the diagnosis. For example, a benign tumor may be monitored or removed with a simple excision, whereas in the case of a sarcoma, the goal of surgery is to remove the tumor with a wide margin.
- With appropriate planning, radiotherapy and/or chemotherapy is often incorporated into the treatment plan either before or after definitive surgery.¹

ANATOMY

- The critical anatomic structures that should be preserved when performing an excision of tumor in the thigh are the femoral artery, sciatic nerve, and femoral nerve.
- The common femoral artery enters the thigh under the inguinal ligament. As it travels distally, it gives several branches, the largest of which is the profunda femoral artery (PFA). This branch travels on top of the adductor brevis until the muscle inserts onto the linea aspera at which point the distal half of the PFA continues just posterior to the femur.
- Several perforator branches from the PFA pierce the lateral intermuscular septum and go into the anterior compartment. In most patients, limb salvage can be performed even if the PFA is ligated near its takeoff from the common femoral artery.
- The superficial femoral artery (SFA) is the most important blood vessel when considering tumor excision. It must be preserved or reconstructed if excised to maintain viable limb perfusion. As the SFA travels distally, it is located on the anterior surface of the psoas, adductor longus, and then adductor magnus until it courses through the adductor canal into the popliteal fossa. The sartorius muscle acts as a cover to the superficial femoral vessels throughout the middle of the thigh.
- There are three muscle compartments of the thigh: anterior, medial, and posterior.
- The sciatic nerve travels in the posterior compartment. It branches into the common peroneal nerve, which can reliably be dissected and found just medial and anterior to the biceps femoris in the popliteal fossa. The tibial nerve portion of the sciatic nerve stays midline with the popliteal vessels.
- The femoral nerve divides into several branches that spread out and innervate the anterior compartment muscles soon after passing under the inguinal ligament. Unlike the sciatic nerve, which can be isolated throughout the thigh, the femoral nerve is rarely identified during tumor removal because it branches so proximally.

PATHOGENESIS

- The mechanism for sarcoma formation is not known.
- Risk factors for sarcoma development include radiation exposure, radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and neurofibromatosis.

NATURAL HISTORY

- All sarcomas have the potential for local recurrence and metastasis.
- Tumor variables that are associated with increased risk of metastasis include high grade and large size (greater than 5 cm).²
- Lungs are the most common location of metastasis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Determining when the mass was first noticed and how rapidly it is growing can help the clinician differentiate between benign and malignant tumors.
- The presence of pain is often associated with a benign tumor such as a schwannoma or vascular malformation and may not be present with sarcomas until late in the disease course.
- Determining the size of the tumor, manual muscle strength testing, and sensory examination are useful to determine if there is neurological compromise. Limb edema assessment and pulse examination can help determine if the tumor is causing vascular or lymphatic compromise.
- Range of motion testing and gait assessment are helpful in assessing a patient's mobility and functional status to guide a perioperative and postoperative counseling.

IMAGING

- Magnetic resonance imaging is the modality of choice for soft tissue tumor evaluation.³
- Fat-sensitive images such as T1-weighted sequences are best for identifying critical anatomic structures such as nerves and vessels (**FIG 1**).
- Fluid-sensitive images including T2-weighted and STIR sequences highlight pathology very well.
- Contrast-enhanced sequences are used to differentiate cystic from solid areas in tumors and identify reactive peritumoral edema, which will be high signal on fluid sequences but not enhance with contrast.
- Some benign tumors such as lipoma and schwannoma may be diagnosed on MRI; however, most soft tissue tumors require a biopsy for diagnosis.

DIFFERENTIAL DIAGNOSIS

- Benign tumors
- Sarcoma
- Lymphoma of soft tissue

■ Infection/abscess

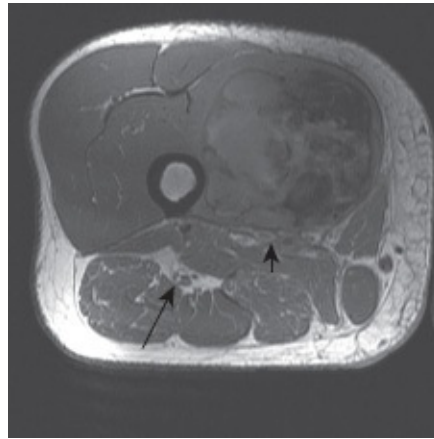


FIG 1 • Axial T1-weighted image demonstrating compartments of the thigh and relevant anatomy of the thigh. The *arrow* points at the sciatic nerve and the *arrowhead* at the femoral vessels, and there is a sarcoma in the vastus medialis.

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Performing a surgery without consideration of the diagnosis and the appropriate margin may cause harm to patients.⁴
- In cases where MR imaging is not diagnostic, a biopsy should be performed.
- Treatment strategy including the use of preoperative radiation and specific surgical plan should be formulated by a multidisciplinary team specializing in sarcoma care.

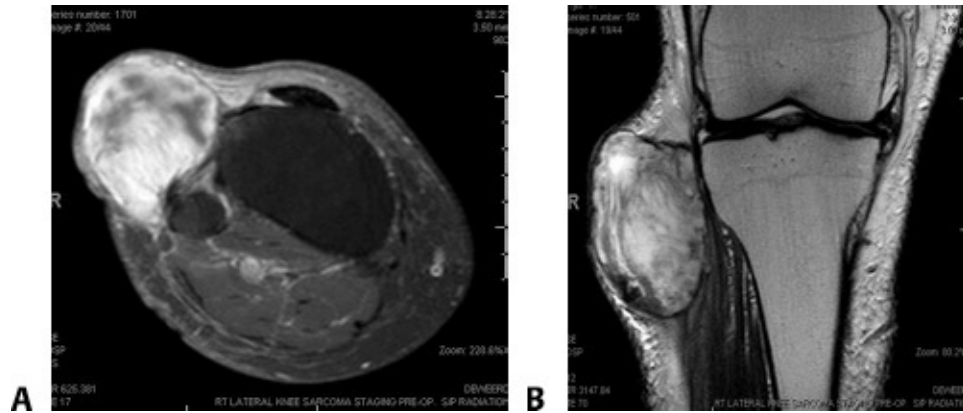


FIG 2 • A. Axial MRI of the thigh demonstrating a subcutaneous sarcoma. **B.** Coronal MRI of the thigh showing a subcutaneous sarcoma.

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The surgical plan is created by thorough study of the preoperative MR scan. A plane of surgical dissection is planned to remove the tumor in its entirety while maintaining a clean margin around it (**FIG 2**).
- If the tumor encases important vascular structures, a plan for vascular reconstruction is made with a vascular surgeon.
- Anticipated soft tissue coverage needs are assessed such as skin graft, local rotation flap, or free tissue transfer.

Positioning

- The patient is placed in the supine position when the tumor is in the anterior or medial compartment (**FIG 3**).
- The patient is placed in the prone position when the tumor is in the posterior compartment.
- The site of a flap harvest must be completely isolated from the tumor site to avoid contamination and tumor spread. A separate back table and clean instruments should be used.



FIG 3 • Intraoperative photograph demonstrating patient positioning.

Approach

- The surgical approach varies based on the location of the tumor.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

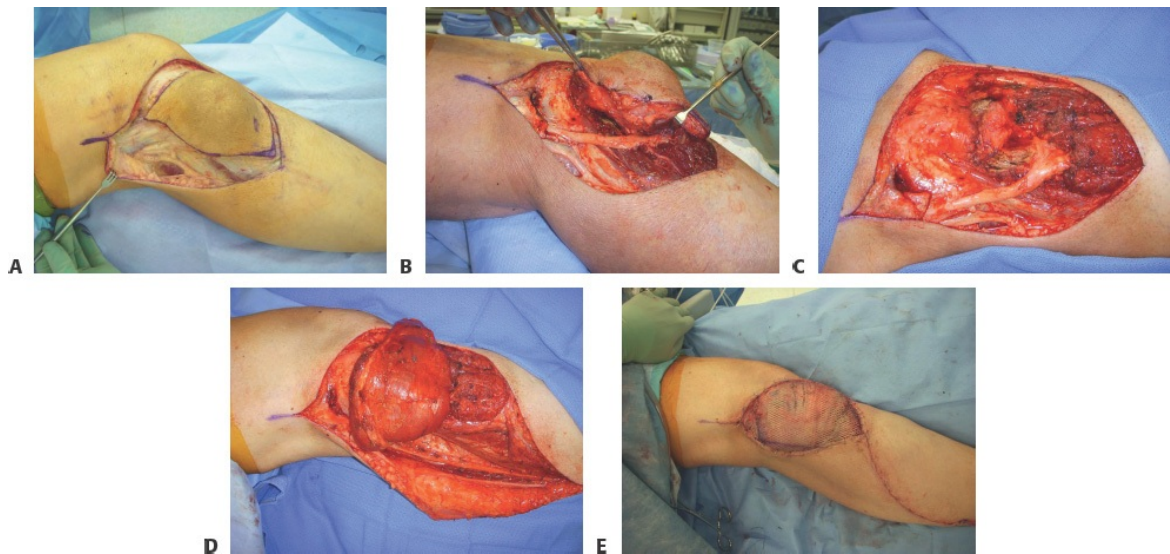
TECHNIQUES

■ Wide Resection of Subcutaneous Sarcoma

- Subcutaneous sarcomas are located in the adipose tissue above the muscle fascia. There is no anatomic barrier to longitudinal tumor spread in this location; however, the deep fascia can act as a natural barrier to deep penetration of the tumor. Careful review of preoperative MR imaging and physical palpation are important when determining tumor extent and the location of the surgical incision.
- A surgical incision is planned 2 cm to 3 cm peripheral to the edge of the tumor as determined by palpation and MRI. Typically, a large paddle of the skin is removed along with the tumor (**TECH FIG 1**).
- The dissection is carried through the subcutaneous fat angling away from the tumor.
- The deep fascia is identified and cut circumferentially around the tumor.
- The fascia and subcutaneous tissue containing the tumor are kept in

continuity, and a small cuff of muscle is removed with the fascia to ensure a clean deep margin.

- The tumor and surrounding fat, fascia, and muscle are removed in their entirety.
- Take care not to shear off the fat from the fascia during dissection.
- Avoid retractors on the tumor side of the dissection.
- Most surgeries require a skin graft or muscle flap for closure. Do not sacrifice margin to save tissue for a primary closure.

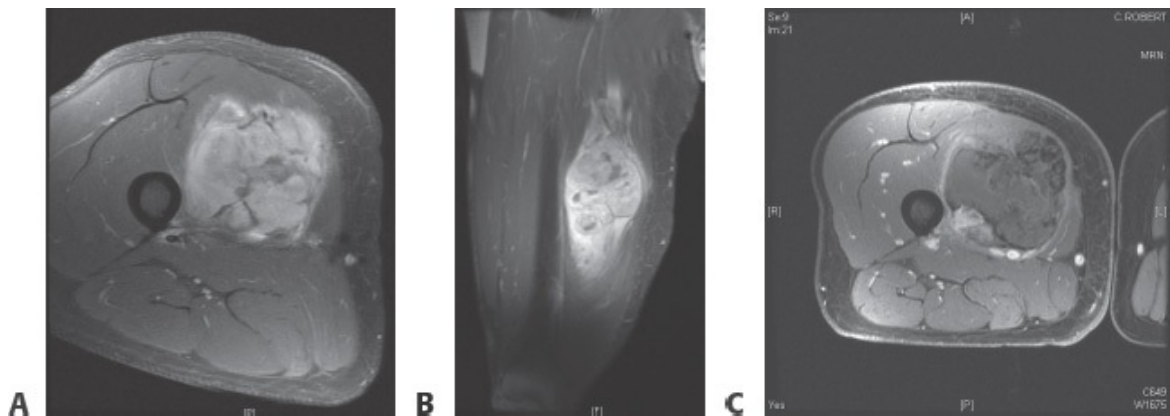


TECH FIG 1 • Operative technique for resecting a subcutaneous sarcoma. **A.** Dissection of the skin and subcutaneous tissue around the tumor, notice the large paddle of skin that extends approximately 2 cm beyond the palpable tumor to ensure adequate resection margin. **B.** Dissection through the deep plane leaving the fascia and small, approximately 1-cm, cuff of underlying muscle on the tumor that serves as the deep margin. **C,D.** The skin was then reapproximated, and preparation for skin grafting was completed. **E.** A split-thickness skin graft was obtained from the contralateral thigh using completely separate instruments, back table, and clean gowns and gloves

to avoid seeding the harvest site with tumor.

■ Wide Resection of a Deep Sarcoma

- Because fascia acts as a natural anatomic barrier, tumors tend to grow longest in a longitudinal dimension; as a result, larger margins in the longitudinal plane compared to the mediolateral/anteroposterior planes are recommended.
- Tumors often abut major nerves and blood vessels in which case the epineurium around the nerve and adventitia surrounding the vessel can be used as margins⁵ (**TECH FIG 2**).



TECH FIG 2 • **A.** Axial T1 fat-suppressed contrast MRI showing a high-grade sarcoma within the vastus medialis and abutting the femoral artery and vein. **B.** Coronal T1 fat-suppressed contrast MRI. **C.** Axial T1 fat-suppressed contrast MRI after completion of preoperative radiation showing decreased enhancement suggesting tumor necrosis.

■ Incision and Dissection

- A longitudinal incision is made over the tumor by incorporating the previous biopsy site.
- Subcutaneous skin flaps are raised circumferentially around the tumor making sure to keep the deep fascia intact as a margin around the tumor.

- Begin the deep dissection by palpating the tumor and incising the deep fascia several centimeters further out from the tumor. If the tumor abuts the fascia, then leave the fascia intact, trace it back to its insertion on the bone, and remove it in its entirety as a margin around the tumor thus avoiding inadvertent tumor penetration or exposure (**TECH FIG 3**).
- It is recommended that several centimeters of muscle be removed from cranial and caudal to the tumor. The decision on how much muscle to remove is based on preoperative evaluation of the MRI, palpation of the tumor, and visual inspection of the muscle to ensure the plane of dissection is outside of the tumor and any associated abnormal tissue such as a pseudocapsule.
- If the tumor abuts the bone but there is no evidence of bone penetration, use a periosteal elevator to lift the periosteum off the bone with the tumor on top. The periosteum acts as the deep margin.
- If there is bone penetration, then depending on the extent of bone involvement, either a hemicortical or complete resection should be performed and reconstructed with either allograft, vascularized fibula, or endoprosthesis.
- If the tumor encases the major blood vessels of the limb, they should be removed en bloc with the tumor followed by vascular reconstruction.



TECH FIG 3 • Operative technique for resection of a deep sarcoma of the thigh. **A.** Photograph showing deep dissection of tumor, * indicates proximal end of sartorius, X indicates cut distal end of adductor magnus. The adventitia of the vessels are dissected and left with the tumor. **B.** Photograph showing complete mobilization of the vessels, the medial intermuscular septum and vessel adventitia “*” serve as the deep margin. **C.** Photograph after the remaining muscles around the tumor are cut and the

tumor is removed with a clean margin. The wound is closed in layers with multiple suction drains.

■ Completion

- After tumor removal, irrigate the wound thoroughly and assess the dead space. An attempt to myodese (muscle-to-muscle approximation with sutures) surrounding muscles to eliminate as much dead space as possible is recommended.
- Other strategies to manage dead space are local or free muscle transfer, closing over multiple drains, and rarely delayed closure using a negative pressure dressing.

PEARLS AND PITFALLS

Hematoma	■ Dead space after tumor removal should be managed with drains, muscle flap, free tissue transfer, or a combination of these techniques. ■ Seroma drainage in the clinic may be necessary.
Wound breakdown	■ Incisional negative pressure dressings, aggressive dead space management, and maximizing patients' nutrition may reduce wound problems. ■ Patients should be counseled about potential need for reoperation for wound management.
Positive margins	■ Appropriate preoperative planning is important to minimize risk of unplanned positive margins. ■ Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings.

POSTOPERATIVE CARE

- Mobilization and weight bearing depend on the extent of surgery.
- Extremity elevation is recommended while patient is in bed.
- Range of motion and therapy may begin after wound healing is sufficient.
- Postoperative radiotherapy may take place 4 to 6 weeks after surgery.

OUTCOMES

- Oncological outcomes include local recurrence and metastasis. Surveillance for recurrence should be managed by a multidisciplinary sarcoma team.
- Functional outcomes depend on the extent of tissue resection, patient overall health status, and late effects of radiation. Aggressive wound care and physical therapy may help maximize patient function.^{6,7}

COMPLICATIONS

- Wound healing problems that require operative intervention can occur in up to 33% of patients who undergo preoperative radiotherapy and 17% of patients who undergo postoperative radiotherapy.¹
- Local recurrence occurs in a minority of patients and is more common in patients with positive margins. Radiotherapy decreases the risk of local recurrence.

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36 Excision of Bone Tumors of the Femur

CHAPTER

Raffi S. Avedian

DEFINITION

- Bone tumors of the femur may be benign or malignant (bone sarcoma) and exhibit a variable natural history ranging from latent to rapid growth. Aggressive benign tumors and malignant tumors typically cause pain, dysfunction, and fracture.

ANATOMY

- The femoral artery, sciatic nerve, and femoral nerve are important structures that need to be accounted for during surgery of the femur.
- The common femoral artery enters the thigh under the inguinal ligament. As it travels distally, it gives several branches, the largest of which is the profunda femoral artery (PFA), which travels on top of the adductor brevis until the muscle inserts onto the linea aspera at which point the distal half of the PFA continues just posterior to the femur.
- Several perforator branches from the PFA pierce the lateral intermuscular septum and go into the anterior compartment. The PFA is located near the linea aspera and is often ligated when resecting segments of the femur.
- The superficial femoral artery (SFA) is the most important blood vessel when considering tumor excision. It must be preserved or reconstructed if excised, to maintain viable limb perfusion. As the SFA travels distally, it is located on the anterior surface of the psoas, adductor longus, and then adductor magnus until it courses through the adductor canal into the popliteal fossa. The sartorius muscle acts as a cover to the superficial femoral vessels throughout the middle of the thigh.
- The sciatic nerve travels in the posterior compartment. It branches into the

common peroneal nerve, which can reliably be dissected and found just medial and anterior to the biceps femoris in the popliteal fossa. The tibial nerve portion of the sciatic nerve stays midline with the popliteal vessels.

PATHOGENESIS

- The mechanism for bone tumor formation is not known.
- Risk factors for sarcoma development include radiation exposure, radiotherapy, pesticide exposure, and hereditary conditions including Li-Fraumeni syndrome and retinoblastoma gene mutation.

NATURAL HISTORY

- Active benign tumors, such as giant cell tumor of the bone, chondroblastoma, and aneurysmal bone cyst, will progress over time and may recur after excision but are not lethal.
- All bone sarcomas have the potential for local recurrence and metastasis.
- Some bone sarcomas such as low-grade chondrosarcoma exhibit a slow rate of growth and low risk of metastasis, whereas aggressive tumors like high-grade osteosarcoma and dedifferentiated chondrosarcoma grow rapidly and have a relatively high risk of metastasis.
- Tumor variables that are associated with increased risk of metastasis include high grade and large size (greater than 8 cm).
- Lungs and other osseous sites are the most and second most common location of metastasis, respectively.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Pain is a common presenting symptom for aggressive bone tumors.
- A thorough history and examination are important to assess duration of symptoms, comorbidities, physical dysfunction, organ involvement, overall health, and patient expectations to best tailor treatment strategy for the individual patient.
- Neurovascular examination is mandatory for any extremity tumor.

IMAGING

- Plain radiographs are used to formulate a differential diagnosis and a preoperative plan (**FIG 1A**).
- Magnetic resonance imaging is routinely used to determine the extent of intramedullary tumor involvement, presence of soft tissue extension, status of the neurovascular structures, and preoperative planning (**FIG 1B**).

DIFFERENTIAL DIAGNOSIS

- The differential diagnosis for a bone tumor includes benign tumors, sarcomas, lymphoma of the bone, infection, and metabolic lesions (eg, hyperparathyroidism).
- The most common bone sarcomas are osteosarcoma, chondrosarcoma, and Ewing sarcoma.

SURGICAL MANAGEMENT

- The appropriate treatment for any musculoskeletal tumor is based on its diagnosis and natural history.
- Biopsy incisions are considered contaminated and must be resected at the time of definitive surgery. Care should be taken to place the biopsy in a location that does not interfere with the final surgical plan.



FIG 1 • A. Anteroposterior radiograph of a 67-year-old man with high-grade chondrosarcoma of the proximal femur seen as a large lucent lesion. **B.** Coronal T2-weighted MRI of the same patient demonstrating extensive soft tissue component and intramedullary involvement by chondrosarcoma.

- Intralesional curettage is the preferred treatment for benign tumors. Radical resection with a clean margin is required for bone sarcomas.
- Reconstruction depends on the extent of bone excision and may include simple bone grafting, endoprosthetic implants, bulk allografts, osteoarticular implants,

or vascularized fibula.

- The goal of surgery is to remove the tumor adequately to minimize recurrence and restore the mechanical integrity of the bone and joints so that the patient may have sufficient function to perform activities of daily living with minimal pain.^{1,2}

Preoperative Planning

- A patient is considered ready for surgery after completion of staging and multidisciplinary review of pertinent imaging, pathology, and treatment strategy.
- The surgical plan is created by a thorough study of the preoperative radiographs and MR scan.
- Bone cuts are planned by examining preoperative imaging and measuring the distance from an intraoperatively identifiable landmark (eg, femoral condyle, greater trochanter) to the desired osteotomy site.
- The soft tissue margin depends on the size and location of a soft tissue component to the tumor. For example, an anterior soft tissue mass along the distal femur can be safely resected by incorporating a portion of the vastus intermedius as the margin.
- When tumor abuts but does not encase blood vessels or nerves, they can be dissected free by leaving adventitia and epineurium on the tumor as the margin.

Positioning

- Patient positioning is based on the surgeon's assessment of the critical anatomy of the surgery and how best to visualize it during surgery.
- Distal femur resections are typically performed in the supine position. Proximal femur tumors are often performed in the lateral position.
- If a flap is to be used, the harvest must be performed using a separate back table and instruments and the surgical sites completely isolated to avoid contamination.

Approach

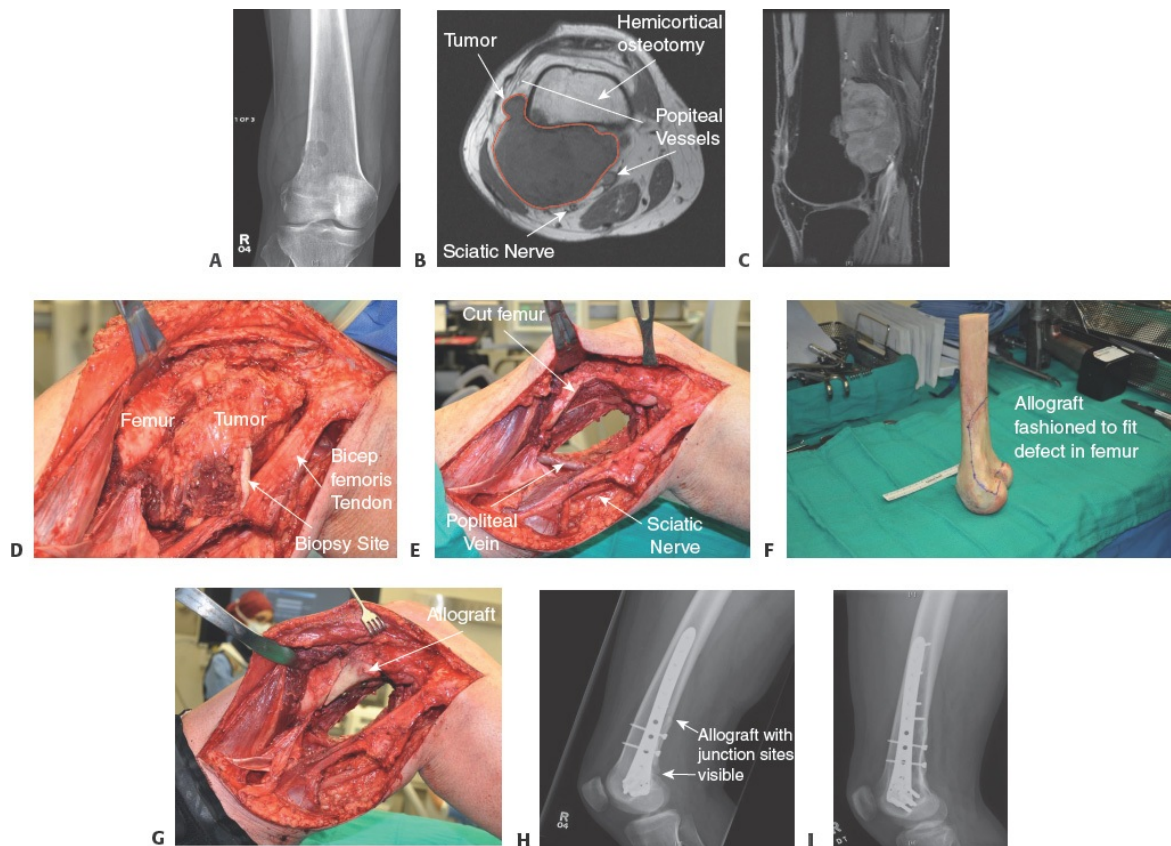
- The surgical approach varies based on the location of the tumor.
- Previous biopsy and surgical scars are considered contaminated and must be excised en bloc with the tumor.

TECHNIQUES

■ Femur Resection and Allograft Reconstruction

- Tourniquet is used at discretion of the surgeon using gravity exsanguination rather than Esmarch to avoid tumor dissemination.
- A longitudinally oriented incision is created that includes a fusiform skin excision of the biopsy site. Skin flaps are created as needed to ensure adequate visualization of the tumor and critical anatomy.
- Dual incisions may be useful for hemicortical resection, but otherwise are rarely used.
- Soft tissue dissection around the tumor is performed with the following principles:
 - Adequate visualization must be achieved.
 - Margin of healthy tissue is kept on the tumor.
 - Nerves are dissected free. The epineurium may be used as margin if tumor abuts the nerve. Sciatic nerve branches to hamstring muscles may be cut as needed to adequately mobilize nerve away from tumor.
 - Vessels are mobilized and the adventitia may be used as margin if tumor abuts the vessels.
- Bone cuts are performed based on preoperative planning and measurements to ensure complete tumor removal. Easily identifiable anatomic landmarks such as the femoral condyles, epicondyles, greater trochanter, and vastus ridge serve as reference points for measurements that can be transferred from preoperative plans to intraoperative execution.
- Fluoroscopy may be used at the discretion of the surgeon.
- Hemicortical resection is an option if the tumor does not involve the entire diameter of the bone.
- Reconstruction is performed to restore mechanical stability of the extremity.
 - Endoprosthetic implants, if used, may be cemented or press fit into the native bone.
 - Allografts are fashioned to fit the defect and secured in place with internal fixation (**TECH FIG 1**).
- The deep fascia, if available, is closed over drains, followed by a subcutaneous fascia and dermal layer. Deep drains are used to avoid

hematoma and minimize pressure on the skin repair.



TECH FIG 1 • **A.** Anteroposterior radiograph of a 74-year-old man demonstrating bone sarcoma with soft tissue mass. **B.** Axial T1-weighted MRI showing tumor eroding into femur and abutting sciatic nerve and popliteal vessels. **C.** Sagittal MRI showing craniocaudal extent of tumor. **D.** Intraoperative photograph demonstrating soft tissue dissection to expose tumor, mobilize popliteal vessels and sciatic nerve, and expose femur in preparation of osteotomy. **E.** Intraoperative photograph showing the femur after tumor resection. **F.** Allograft femur with ink lines outlining how the graft will be fashioned to fit the defect. **G.** Intraoperative photograph after allograft has been secured into the native femur. **H.** Lateral

radiograph of the distal femur 3 weeks after surgery. **I.** Lateral radiograph of the distal femur 36 months after surgery. The allograft has incorporated into the patient's femur.

PEARLS AND PITFALLS

Hematoma

- Dead space after tumor removal should be managed with drains, muscle flap, free tissue transfer, or a combination of these techniques.
- Seroma drainage in the clinic may be necessary.

Wound breakdown

- Incisional negative pressure dressings, aggressive dead space management, and maximizing patients' nutrition may reduce wound problems.
- Patients should be counseled about potential need for reoperation for wound management.

Positive margins

- Appropriate preoperative planning is important to minimize risk of unplanned positive margins.
- Planned positive margins around critical structures such as nerves and vessels may be appropriate in certain settings.

Allograft nonunion/fracture

- Common complications may be minimized by good cortical apposition of graft to the native bone.
- Restrict weight bearing until evidence of bone healing is observed.
- Counsel patients that reoperation for nonunion is possible.

POSTOPERATIVE CARE

- Mobilization and weight bearing depend on the extent of surgery.
- Extremity elevation is recommended while patient is in bed.
- Range of motion and therapy may begin after wound healing is sufficient.
- May administer antibiotics in the perioperative period.

OUTCOMES

- Oncological outcomes include local recurrence and metastasis. Surveillance

for recurrence should be managed by a multidisciplinary sarcoma team. Local recurrence is greater when margins are positive.

- Functional outcomes depend on the extent of tissue resection and patient overall health status. Most patients will experience some form of disability that is proportional to the volume of muscle and bone resected.^{3,4}

COMPLICATIONS

- Allograft nonunion and fracture are relatively common and require additional surgery to achieve a limb salvage.⁵
- Local recurrence occurs in a minority of patients and is more common in patients with positive margins.
- Deep infection can occur at any time after surgery and requires aggressive therapy including surgical debridement and antibiotic therapy to achieve limb salvage. Removal of implants may be necessary to eradicate infection.

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Femoral Bone Debridement

CHAPTER

Robert J. Steffner, David W. Lowenberg, and Sahitya K. Denduluri

DEFINITION

- Femoral bone debridement is generally needed for osteomyelitis (acute or chronic), symptomatic nonunion, and open fracture.

ANATOMY

- The femur contributes to the hip and knee joints and withstands significant stress in motion.
- Vital structures around the femur include the sciatic and femoral nerves, the superficial and deep femoral artery and vein, and the extensor mechanism for knee extension.

PATHOGENESIS

- Open fracture leads to gross contamination, soft tissue stripping, and avascular bone. Direct inoculation occurs, which will lead to infection in the absence of prompt surgical care.
- Hematogenous spread of bacteria to the bone can create osteomyelitis. Acute infection tends to produce rapid symptoms and the accumulation of purulent fluid. Chronic infection is more indolent and produces waxing and waning symptoms. After a week or two of infection, bacteria form a protective avascular matrix called biofilm. Antibiotics cannot penetrate this layer.
- Nonunion is a fractured bone that will not heal. Hypertrophic nonunion comes from too much fracture site motion. Atrophic nonunion is from poor blood supply and inadequate substrate for bone healing. Infection can also lead to nonhealing bone and sometimes creates a false joint known as a pseudarthrosis.
- In all of these instances, surgical debridement is required to promote bone

recovery and healing.

NATURAL HISTORY

- Neglected open fractures and osteomyelitis can lead to systemic infection and sepsis, which is life threatening.
- Chronic infection can produce a nonhealing wound with drainage. This limits quality of life and can also lead to squamous cell carcinoma at areas of long-standing skin ulceration.¹
- Nonunion in the femur limits weight bearing and mobilization. Pain is often present with activity. Quality of life is significantly diminished.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Ask about prior trauma, surgical procedures, and any complications or wound healing problems.
- Specifically ask about cellulitis and draining sinus tracts.
- Assume infection until proven otherwise.
- Assess impact on the patient's quality of life.
- Inquire about recent antibiotic use.
- Determine host factors such as nutrition, nicotine use, medical comorbidities, use of immunosuppressive and anti-inflammatory medications, and any prior radiation exposure to the area of interest.
- Visually inspect the patient's thigh. Look for deformity, leg length discrepancy, and rotational change from the contralateral side.
- Lab work including WBC, ESR, and CRP can help determine the presence of infection.

IMAGING

- Plain radiographs can demonstrate nonhealing bone, erosive cortical changes seen in acute infection, and sclerotic thickening seen in chronic infection (**FIG 1**).

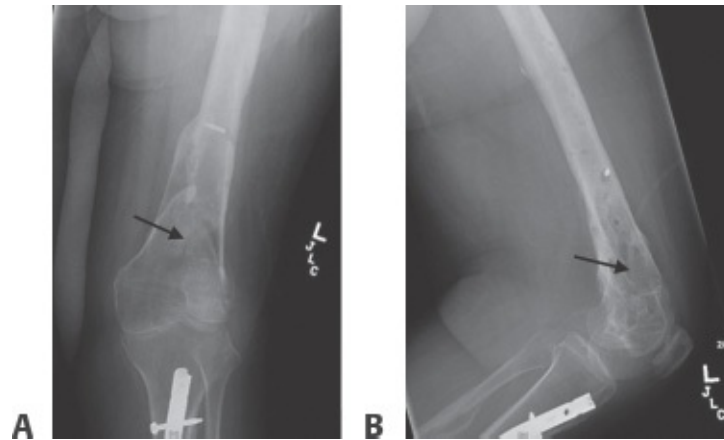


FIG 1 • **A.** AP and lateral **(B)** radiographs of a distal femur chronic osteomyelitis in the setting of prior internal fixation for an open distal femur fracture. Original hardware removed with exception of a broken screw. Radiolucent changes (*arrows*) seen in the metaphysis of a patient with clinical evidence of a draining sinus tract.

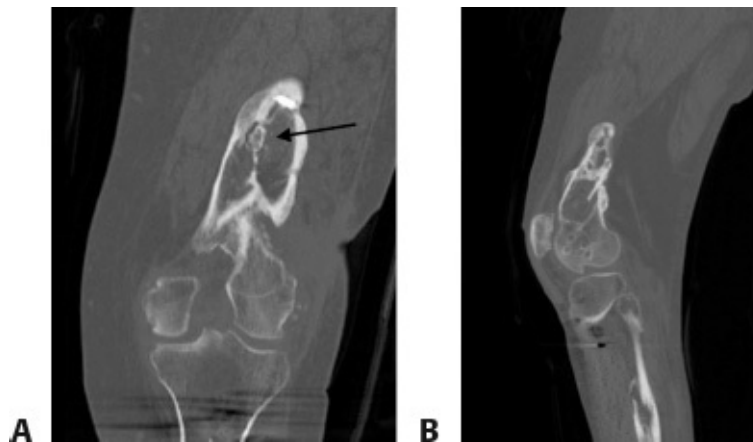


FIG 2 • **A.** Coronal and sagittal **(B)** CT scan of the distal femur with chronic osteomyelitis demonstrating sclerotic rim of the bone (involucrum) surrounding a spicule of the bone (sequestrum, *arrow*).

- Full-length, weight-bearing radiographs of the lower extremities show deformity and leg length discrepancy.

- CT scan is best for bony detail. It is the modality of choice to identify a nidus of dead bone (sequestrum) and surrounding sclerotic bone (involucrum) seen in chronic osteomyelitis (**FIG 2**).
- MRI imaging assesses the level of intramedullary bone and soft tissue involvement with bone infections. This is crucial in determining the extent of surgical debridement.

NONOPERATIVE MANAGEMENT

- Nonhealing bone and bone infection in the femur are almost always operative given the structural importance for weight bearing and ambulation.
- Exceptions include low-demand patients with minimal symptoms, patients who adapt well with assist devices, and patients at high surgical risk due to medical comorbidities.
- Nonunion patients without infection can try bracing and bone stimulation devices before surgery.

SURGICAL MANAGEMENT

- It is important to set patient expectations. Several debridement procedures may be needed to create a favorable bone and soft tissue bed for reconstructing and healing. Persistent or recurrent nonunion or infection may happen despite aggressive surgical management.

Preoperative Planning

- Address modifiable host factors including smoking cessation, nutrition, glycemic control, and medication use (anti-inflammatories, corticosteroids, etc.).
- In the lower extremity, quantify the degree of limb shortening, malalignment, and malrotation. Shortening greater than 2 cm and deformity greater than 10 degrees tend to limit a patient's quality of life.
- Anticipate the extent of debridement and appropriately plan for bony stabilization, dead space management, and soft tissue coverage.
- A reamer-irrigator-aspirator device can assist with intramedullary debridement in long bone osteomyelitis.²
- Hold antibiotics for culture. Multiple cultures should be obtained and sent for aerobic, anaerobic, fungal, and yeast assessment. Cultures will guide postoperative medical therapy.
- Send soft tissue and bone for surgical pathology. This will help determine the

presence and chronicity of infection, especially if cultures are negative.

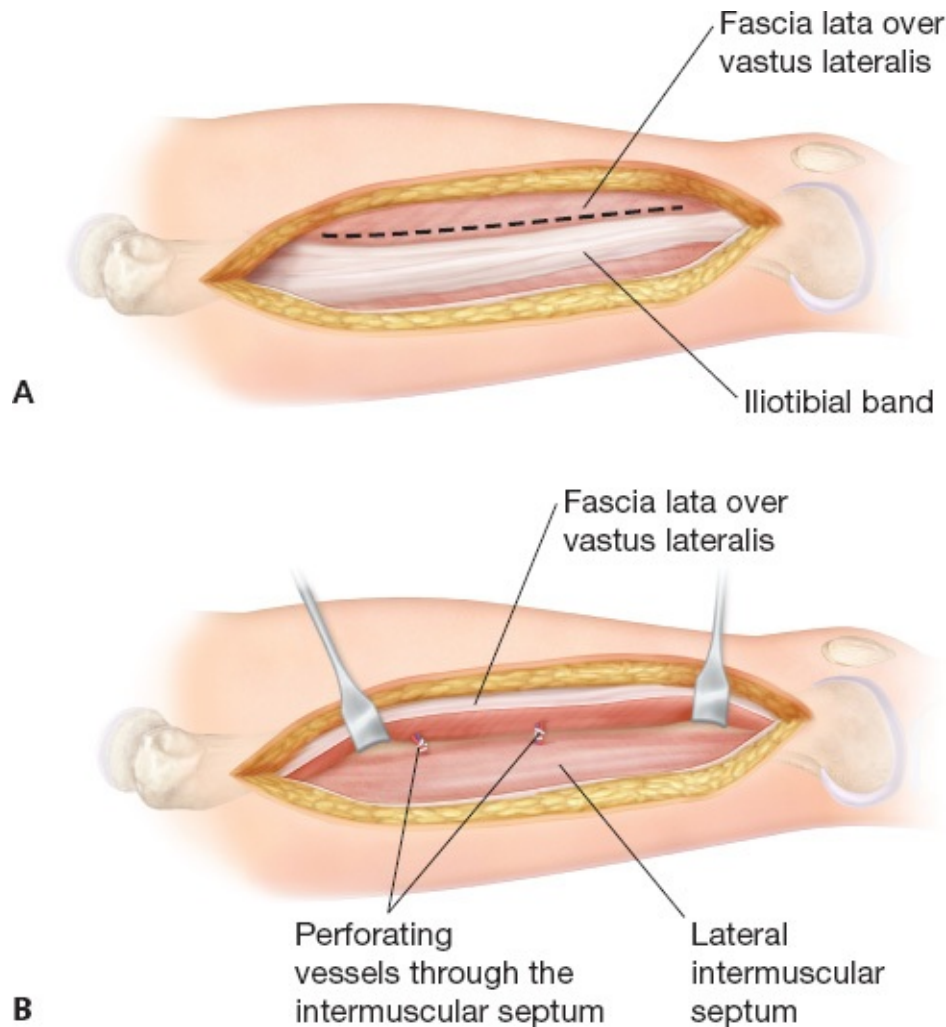


FIG 3 • Illustration of the lateral approach to the femur.

A. The iliotibial band is divided in-line with the skin incision, and the vastus lateralis is raised off the intermuscular septum with clips placed on perforating branches of the profunda femoris artery and vein **(B)**.

Positioning

- Both lateral decubitus with an axillary roll and supine position with hip bumps and a leg ramp are acceptable for a lateral approach to the femur.
- Lateral position is best for the upper half of the femur, and supine position with leg ramp is best for the distal half of the femur.

- Use a radiolucent table to allow intraoperative fluoroscopy.

Approach

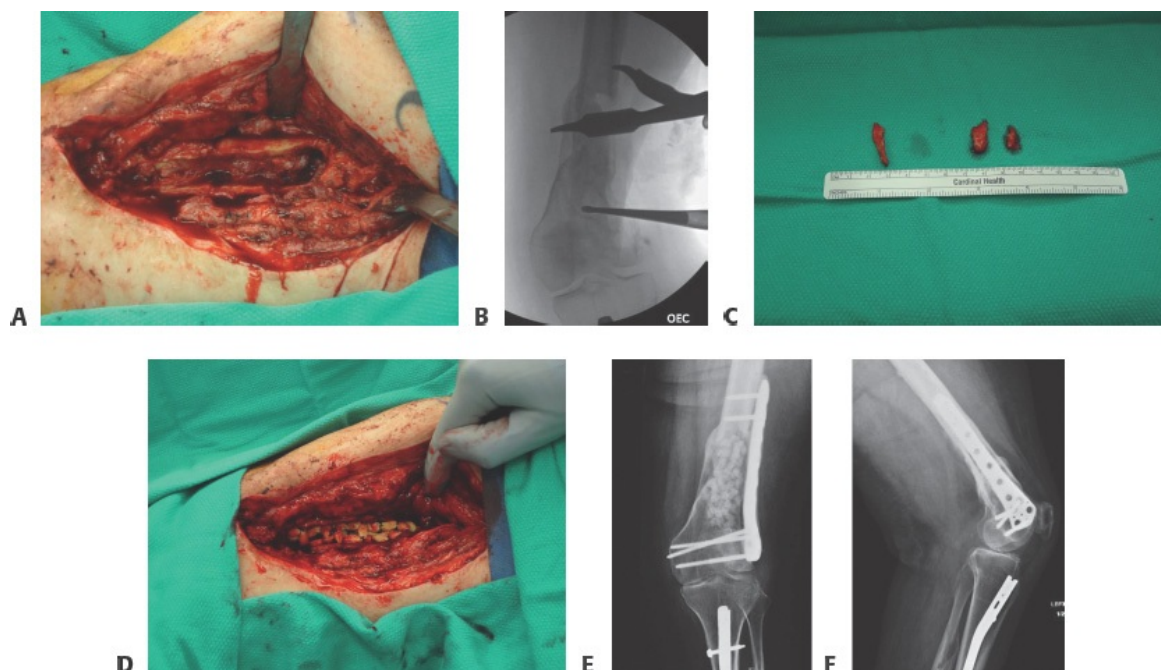
- Planned access to the femur is generally through a lateral approach (**FIG 3**). Traumatic wounds and prior incisions can sometimes lead to alternative approaches.

TECHNIQUES

■ Debridement of Chronic Osteomyelitis of the Distal Femur

- Patient is positioned supine with an ipsilateral hip bump on a radiolucent table. A small leg ramp can be added to facilitate intraoperative imaging.
- Antibiotics are held for culture and then given.
- Open wounds are prepped with Betadine scrub and paint.
- Before incision, the involved anatomic location is identified with intraoperative fluoroscopy.
- A straight lateral incision is made.
- Compromised skin is generally characterized as multiply operated, puckered, and adherent. This skin, in addition to any sinus tracts, should be sharply excised. Remaining skin should have bleeding edges.
- The iliotibial band is split in-line with the skin incision, and the vastus lateralis muscle is raised off the lateral intermuscular septum. The muscle is retracted upward to identify perforating vascular branches from the deep profunda artery and vein.
- Ligating branches with surgical clips preserves branches for possible microsurgical anastomosis.
- Using a combination of a microsaw, osteotomes, and high-speed bur, a long cortical window is created in the lateral femoral cortex. The high-speed bur is then used from inside-out to widen the elongated ellipse to improve access to the intramedullary canal (**TECH FIG 1A**). Irrigating during use of the bur can limit heat necrosis of the bone.
- Multiple cultures are obtained from the soft tissue and bone. The bone is sent for surgical pathology.

- Aggressive debridement involves excision of all nonviable soft tissue and bone (**TECH FIG 1B**), including sequestra (**TECH FIG 1C**). Surgical tools for debridement include curettes, rongeurs, osteotomes, high-speed bur, and fresh surgical blades.
- Wound irrigation is performed with low-flow cystoscopic tubing. Many liters of normal saline with antibiotics are advised.
- An adequately debrided field demonstrates bleeding tissues with normal color and properties such as contractility.
- Polymethyl methacrylate (PMMA) is mixed with medications to create filler for the defect created from the debridement. The medications used, which may include antibiotics, antifungals, and antiparasitics, should be discussed before surgery with infectious disease and pharmacy colleagues.
- Appropriate drug concentrations with PMMA should also be discussed with a pharmacist.
- PMMA beads can be made either by hand or with a mold. A line of beads is placed along a thick monofilament suture. It is important to document the number of beads being implanted.
- Pack the dead space with antibiotic beads (**TECH FIG 1D**).
- Surgical stabilization should bridge the defect. Options include external fixation, an antibiotic-impregnated cement intramedullary nail, or a locking plate coated in antibiotic cement (**TECH FIG 1E,F**).
- Final fluoroscopic or radiographic images should be taken to document implants.
- Deep drains are utilized to help with dead space management.
- Remaining soft tissues should be healthy and bleeding. Attempt to isolate deep fascial layers for a tiered closure. Primary closure should not have a lot of tension. The surgeon should maintain a low threshold for rotational or free tissue coverage.



TECH FIG 1 • **A.** Clinical photograph of an exposed distal femur with the creation of a long cortical window with evidence of infected soft tissue within the intramedullary canal. **B.** Fluoroscopic image showing debridement of the femur intramedullary canal with a curette. **C.** Photograph of sequestra removed during debridement of the distal femur. **D.** Photograph of cement antibiotic beads placed into the bone defect after debridement of chronic osteomyelitis. **E.** Postoperative AP and lateral (**F**) radiographs of the distal femur after debridement, placement of antibiotic beads, and stabilization of the defect.

PEARLS AND PITFALLS

Hip and knee

- In the setting of infection, consider aspirating adjacent joints to ensure there is no associated septic arthritis.
- Surgical stabilization should be robust enough to allow joint passive

	range of motion during recovery.
Debridement	■ Retained hardware likely has a bacterial biofilm. Efforts should be made to remove all foreign bodies during the debridement.
Tumor	■ Bone tumors can look like bone infection. If there is any uncertainty, a biopsy should be performed before debridement.
Bacteria	■ Some microbiology labs can run polymerase chain reaction (PCR) to identify microbial DNA.
Antibiotic nail	■ Bone defects can be supported with an antibiotic intramedullary nail. Inject a chest tube with cement mixed with antibiotics and let dry with a guide wire inserted into the cement. A small injection nozzle is often needed. Once dry, bend the guide wire at the top to facilitate removal of the nail. Bone must be reamed to a diameter 1.5 mm larger than the diameter of the chest tube.

POSTOPERATIVE CARE

- Dressings can be removed in 48 hours and the patient may shower with soap and water.
- Encourage early range of motion of surrounding joints to avoid stiffness.
- Intravenous medications are tailored to operative cultures and are determined in consultation with infectious disease specialists. Cultures may not grow because many patients receive antibiotic therapy before debridement and some bacteria require special media.
- Patients with infection are monitored clinically and with serial lab studies (ESR and CRP). After antibiotics are complete, the patient is observed for a few weeks for signs of recurrent infection. If there are no concerns, management of the bone defect can ensue. Many physicians will perform intraoperative frozen section studies assessing the number of neutrophils per high-powered field at any subsequent surgeries. It is wise to maintain suspicion of infection.
- Persistent or recurrent infection starts the process over again.

OUTCOMES

- Coagulase-negative *Staphylococcus* and *Staphylococcus aureus* are the most common causes of bacterial osteomyelitis.³
- Age (60 years and older) and diabetes are risk factors for osteomyelitis.⁴
- The most common cause of persistent infection is inadequate debridement.⁵ Often times, the site of inadequate debridement is the intramedullary canal.

COMPLICATIONS

- The bone that does not heal after debridement, stabilization, and possible antibiotic therapy should trigger additional workup to examine host factors, poor vascularity of tissues, presence of unidentified metabolic conditions, and possible persistent or new infection.
- Nonhealing bone should also consider the need for more stability (hypertrophic nonunion) or more biology (atrophic nonunion).

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Reconstruction of Femur

CHAPTER

Vishwanath R. Chegireddy, Michael J. A. Klebuc, and Anthony Echo

DEFINITION

- Femoral shaft bone defects usually result from tumor resection, traumatic loss, chronic osteomyelitis, congenital skeletal defects, failed allografts, or infected nonunions.^{1,2}
- Extensive resection of long bone can lead to large intercalary osseous defects necessitating reconstruction, which was traditionally achieved with allografts or allograft prosthetic composites. These allografts were associated with high rates of complications, including joint instability, fracture of the allograft, and infection of the allograft.³
- Vascularized bone flaps are essential for successful bone reconstruction due to their ability to incorporate into the recipient site and provide early bone consolidation while maintaining stability of the appendicular skeletal structure. Owing to its independent blood supply, such a flap is well incorporated into the recipient bone despite compromised surrounding tissue from previous surgery or radiation therapy.
- The advantage of vascularized bone flap over nonvascularized bone grafts is the intrinsic ability to integrate into the recipient bone similar to standard fracture healing instead of creeping substitution.
- The fibula is an ideal vascularized bone flap for femur reconstruction due to its ease of access for harvest while preserving the stability of the proximal and distal tibial-fibular syndesmosis despite segmental resection. It has a negligible influence on knee and ankle joint stability without compromising weight-bearing ability or function of the lower extremity.
- The vascularized fibular flap undergoes hypertrophy overtime in response to continuous pressure load, which translates to remarkable long-term

durability.^{4–6}

ANATOMY

- The femur is the longest and strongest bone in the body and is subject to large amounts of axial loading as well as significant rotational angular stresses.
- The fibula is a long and thin cortical bone with a small medullary component. In adults, the width of the fibula is 1.5 to 2 cm with a length of 35 cm of which approximately 25 cm of the fibular diaphysis can be harvested for free tissue transfer.
- Vascular supply to the diaphysis of the fibula is via a dominant nutrient endosteal artery and minor musculoperiosteal branches from the peroneal artery and veins. These vessels run parallel to the fibula and course between the flexor hallucis longus (FHL) and tibialis posterior muscle group.
- The dominant nutrient artery branches 6 to 14 cm from the peroneal artery bifurcation and enters the fibula posterior to the interosseous membrane. It then courses into the nutrient foramen located in the middle third of the diaphysis and further divides into an ascending and descending branch.
- Musculoperiosteal vessels are derived from the peroneal artery and travel within the posterolateral septum, through the FHL and tibialis posterior muscle, giving segmental rise to four to eight branches that supply the muscles in the anterior compartment, soleus muscle, and lateral leg skin territory. The majority of the periosteal branches are located in the middle third of the fibula (**FIG 1**).
- Soft tissue defect coverage is achieved with a skin paddle supplied by perforators traversing through the posterior crural septum with the majority concentrating at the proximal and distal ends of the fibula. These fasciocutaneous perforators supply a skin paddle up to 10 × 20 cm in size.⁷

PATIENT HISTORY AND PHYSICAL FINDINGS

- Detailed preoperative evaluation is required for patients undergoing extensive long bone resection and intercalary bone defect reconstruction.
- A thorough medical history should be obtained to evaluate the peroneal artery for free fibula graft. Pertinent history includes trauma, deep venous thrombosis, peripheral vascular disease, lymphedema, or venous insufficiency. Patients with peripheral vascular disease may not be a candidate for surgery.
- Physical exam should include an evaluation of knee and ankle joints for range of motion and laxity, and a foot Allen test with a Doppler probe to assess

dorsalis pedis and posterior tibial arteries.

- Peronea arteria magna is a congenital variant of the arterial inflow to the foot, which affects about 1% to 8% of the population, where both the anterior and posterior tibial arteries are hypoplastic or absent with the peroneal artery serving as the single arterial supply below the knee.
- Patients with an abnormal vascular exam or a history of trauma to the affected extremity will need additional preoperative imaging such as an arteriogram, computed tomography angiogram (CTA), duplex ultrasound, or magnetic resonance angiography (MRA) to identify atherosclerotic occlusive disease or congenital anomalies.

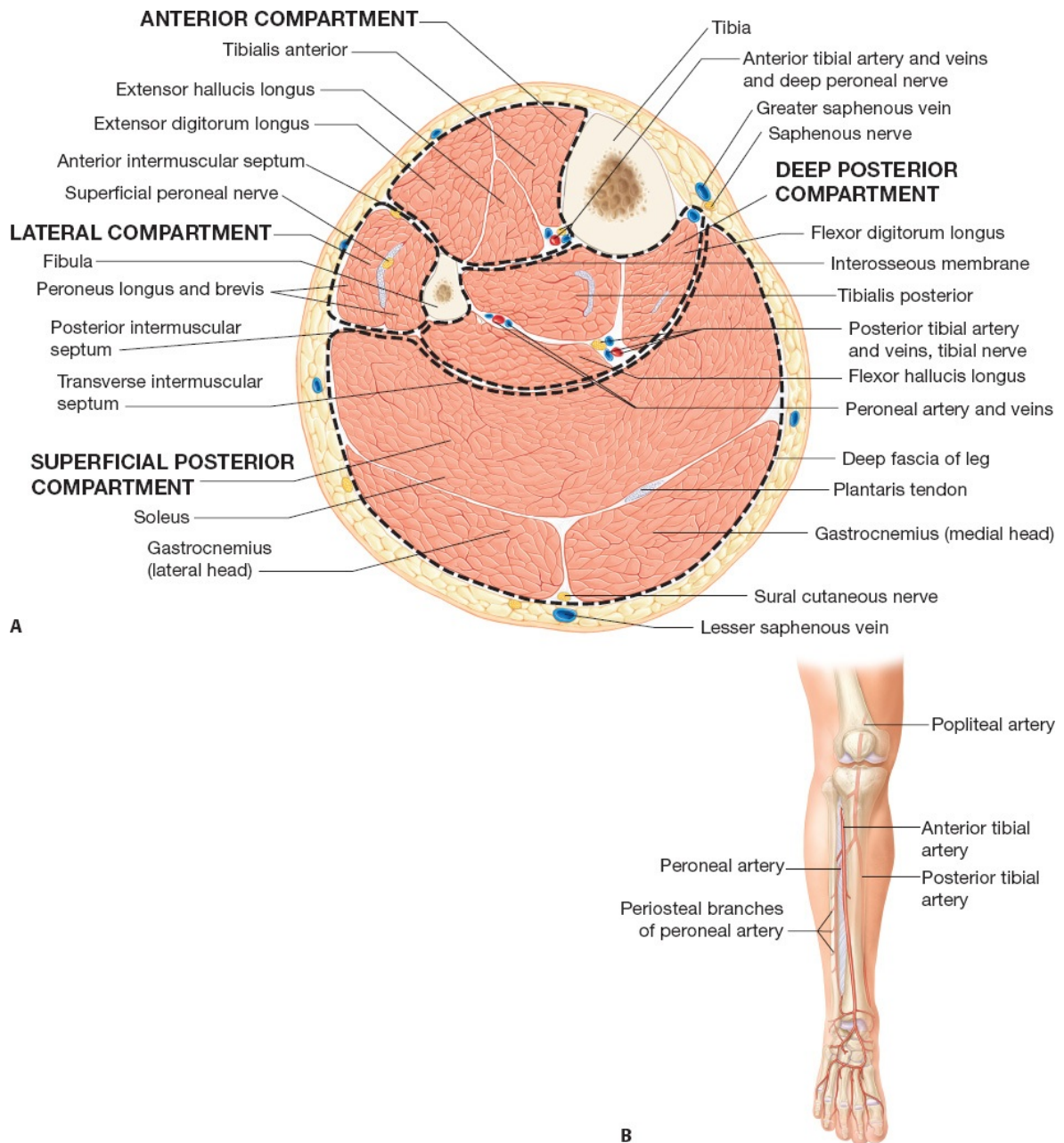


FIG 1 • A. Cross-sectional anatomy of four compartments at midtibial level. **B.** Vascular supply to the lower extremity.

IMAGING

- Preoperative imaging of both the recipient and donor sites should include an evaluation of:
- Recipient site:

- The extent of bone resection, length and diameter of the intercalary defect, and potential soft tissue defect (**FIG 2**). This allows the surgeon to determine the extent of the tumor burden, traumatic bone loss, or chronic osteomyelitis and plan for reconstructive options.
- Donor site:
 - Evaluate vascular supply with Doppler ultrasound (anterior tibial, posterior tibial, and dorsalis pedis arteries), and exclude any fibular deformities.
 - Angiogram to look for vessel patency and flow to the foot.

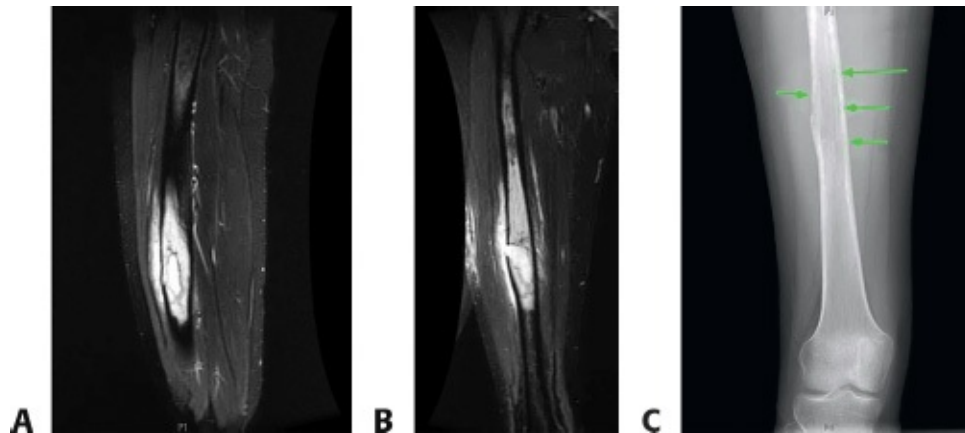


FIG 2 • **A.** Anterior and lateral (**B**) preoperative MRIs showing a right midfemur chondroblastoma. **C.** Plain radiograph of the right femur showing chondroblastoma.

SURGICAL MANAGEMENT

Preoperative Planning

- Free fibula bone graft can be transferred with a generous skin paddle and adjacent muscles such as soleus, peroneal muscles, or FHL.
- Either right or left leg can be used as a donor for fibula flap. The left side is preferable in most patients because it is the less dominant leg and used less frequently while driving a vehicle. However, thoughtful planning of vessel orientation in the recipient site should be considered, when deciding upon laterality.
- Prior to incision, anatomical landmarks including the head of the fibula, lateral malleolus, and anterior and posterior border of the fibula are marked. The posterior border of the fibula correlates with the posterior intermuscular

septum encasing the vascular supply to the skin paddle (**FIG 3**).

- Intraoperative Doppler probe is used to identify perforator vessels to design the skin paddle centered over the posterior crural septum. Sometimes, the perforators pass through the FHL and/or soleus muscles and lie posterior to the septum.
- Area of fibula bone resection is marked with superior margin 4 cm below the head of the fibula and inferiorly 6 cm above the lateral malleolus. By preserving the proximal fibula, the stability of the knee is maintained without disrupting the attachment of the tibia to the fibula, fibular collateral ligament to the head of the fibula, and biceps femoris muscle. Also, the common peroneal nerve courses inferior to the head of the fibula, and identifying this location can prevent injury during dissection.

Positioning

- Positioning can allow two surgical teams to work simultaneously, if the contralateral fibula flap is used (**FIG 4**):
 - The patient is placed in the supine position on the operative table with the donor side knee flexed 90 degrees. A roll is placed under the ipsilateral hip to internally rotate the pelvic girdle and keep the hip and knee flexed.
 - A heel stop can be placed on the operative room table to help knee at 90 degrees, when harvesting in the supine position.
- The patient can also be placed in lateral decubitus position if donor and recipient site is in the same limb:
 - A bean bag can help keep the patient in the lateral position.
 - All pressure points should be carefully padded and protected.



FIG 3 • Intraoperative marking of anatomical landmarks for an ipsilateral fibula harvest in the lateral decubitus position: head of the fibula, lateral malleolus, and anteroposterior fibular border.



FIG 4 • If the contralateral fibula flap is desired, the patient can be placed in a supine position, which allows two teams to work simultaneously for recipient preparation and donor site harvest.

Approach

- Plastic surgeons and orthopedic surgical team will need to work together to coordinate resection of the affected femur segment and reconstruction of the subsequent intercalary defect. Preservation of potential recipient vessels is of the utmost importance.

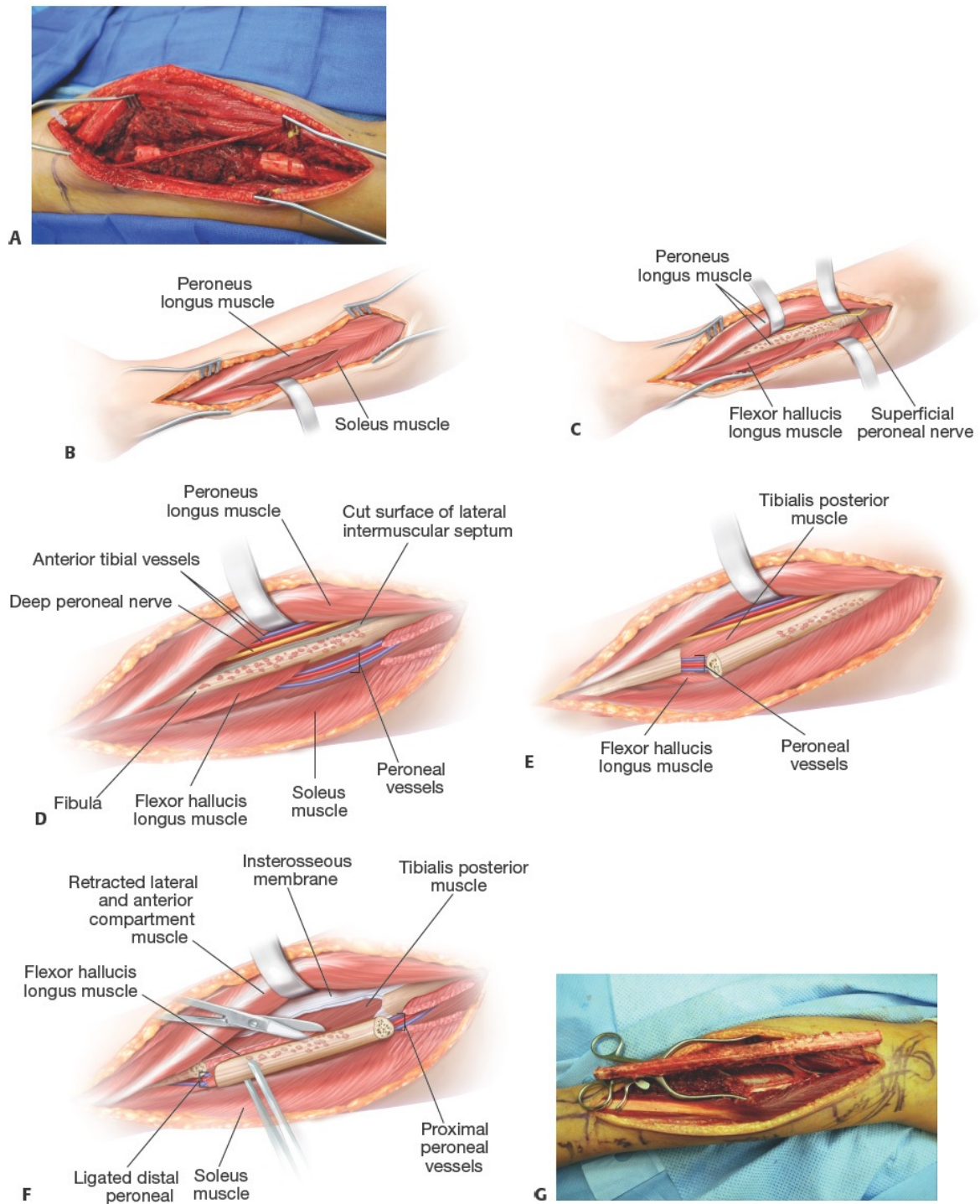
- Reconstruction of long femoral intercalary defects with vascularized fibula alone is not sufficient due to inadequate stability and fragility of the bone to tolerate early weight bearing. The Capanna method is ideal in this scenario, using a femoral allograft as a peripheral shell and telescoping the free fibula graft through the allograft segment.⁷
- Reconstruction of smaller intercalary defects up to 13 cm can be achieved with double-barrelled fibular flap, keeping the arterial blood supply intact while performing an osteotomy in the fibula flap.
- Initial exposure by the plastic surgeon serves to protect the recipient vessels for microvascular anastomosis at a later point. Although any artery or vein of adequate caliber can be utilized as the recipient vessel, the descending branch of the lateral femoral circumflex artery and vein is the preferred vessel because of its location.
- If extensive soft tissue defect is anticipated due to trauma or tumor/chronic osteomyelitis resection, then a skin paddle can be harvested with the fibular flap by sharing the same vascular pedicle, which helps with early detection of flap compromise and provides tension-free skin closure of recipient site.

TECHNIQUES

■ Free Fibula Flap

- After the bone tumor or chronic osteomyelitis resection by the orthopedic surgical team, the dimensions of the intercalary bone defect are measured (**TECH FIG 1A**).
- Prior to flap harvest, a sterile tourniquet is placed on the midthigh while avoiding compression over the fibular head and common peroneal nerve.
- By tracing the anatomical landmarks, a midlateral vertical incision is made over the fibula, and skin flaps are elevated at the level of the fascia.

elevated at the level of the fascia.



TECH FIG 1 • A. Right femoral intercalary defect remaining after the tumor resection. **B.** Exposure of peroneus longus and soleus at the midtibial level. **C.** Dissection around the fibula and lateral muscle

compartment. Dissection proceeds proximally to identify and protect the superficial peroneal nerve. **D.** Dissection anterior to the fibula through the anterior intermuscular septum and protecting the deep peroneal nerve and anterior tibial vessels. **E.** After the distal fibula osteotomy, the peroneal vessels located between FHL and tibialis posterior muscle groups should be ligated distally. **F.** Adequate fibula length is freed, and proximal osteotomy is performed carefully while protecting the pedicle vessels. **G.** Isolated fibula graft with intact peroneal vessels.

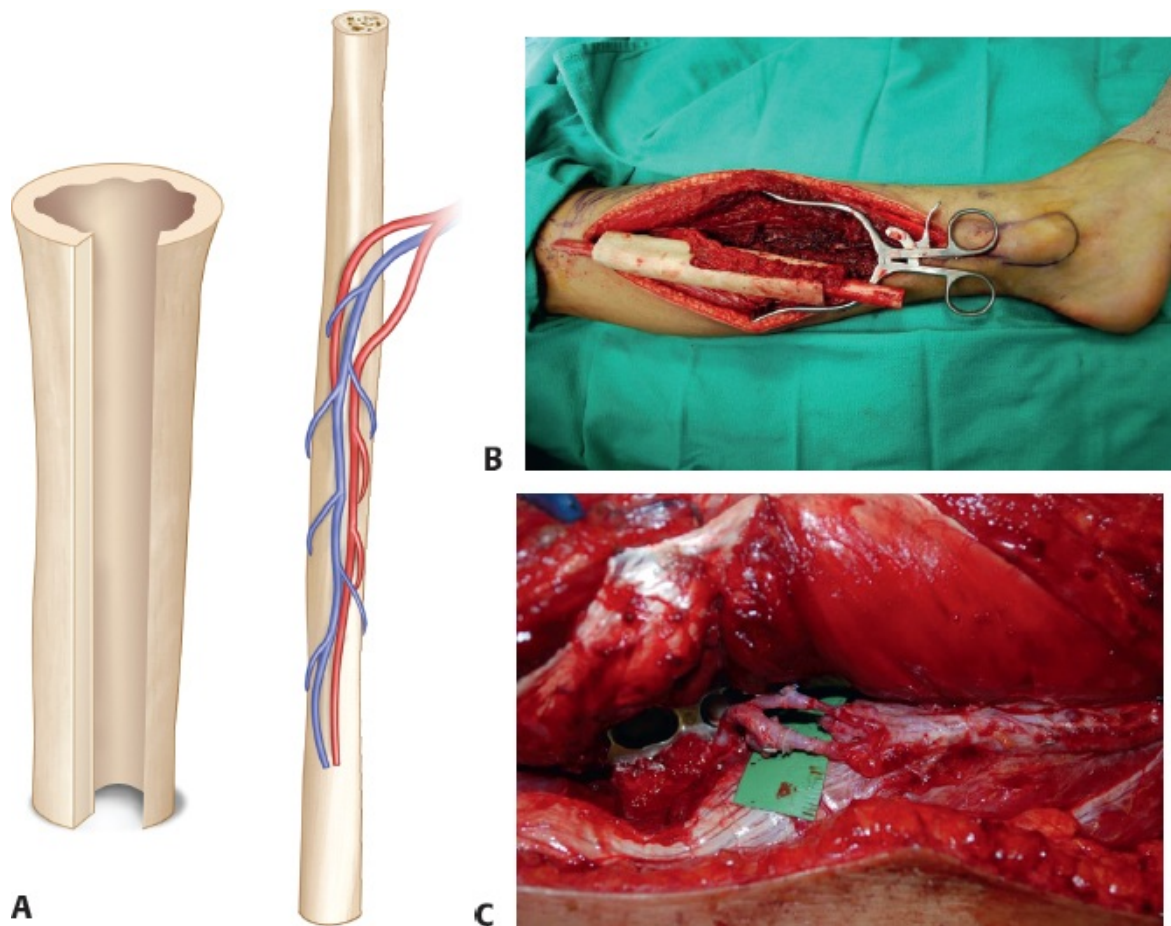
- Dissection is carried through the investing fascia of the lateral compartment, anterior to the posterior intermuscular septum (**TECH FIG 1B–D**):
 - Care should be taken to preserve fasciocutaneous perforators traveling through the posterior intermuscular septum if a skin island is needed for osteocutaneous flap.
- During proximal dissection, identify and preserve the common peroneal nerve traversing around the head of the fibula to become the superficial peroneal nerve.
- The peroneal muscles are dissected off the anterior surface of the fibula and reflected anteriorly to expose the anterior intermuscular septum. The septum is incised to gain access to the anterior compartment and reflect extensor digitorum and hallucis muscles to identify and preserve anterior tibial vessels and deep peroneal nerve.
- The interosseous membrane is incised to enter the deep posterior compartment, and the peroneal vessels are located between tibialis posterior and flexor hallucis longus (FHL) muscles.
- After adequate length of the fibula is marked for reconstruction, towel clamps are used to apply lateral traction on the proximal and distal fibula while osteotomizing with an oscillating saw or Gigli saw. If possible, a strip of periosteum overlying the osteotomy site should be included to overlap the osteotomy sites at the recipient site.
- Prior to performing osteotomy, a microvascular clamp can be applied to the peroneal artery distal to the osteotomy site to ensure adequate supply to the

foot and then divided (**TECH FIG 1E**):

- The vascular pedicle is dissected starting distally and carried proximally up to the origin of tibioperoneal trunk and ligated with approximately 2 to 6 cm of pedicle length.
- Next, the peroneal vessels are identified proximally and distally, and dissection is propagated circumferentially around the fibula while staying medial to the vessels using a large right-angle clamp. The vascular pedicle should be maintained during dissection.
- After the fibula graft is fully mobilized with the pedicle (**TECH FIG 1F,G**), the tourniquet is released. One should see robust arterial inflow and venous outflow and healthy back bleeding from both the periosteum and intramedullary canal.
- An osteomuscular flap can also be harvested in similar fashion to include soleus and FHL muscles. This can aid in filling the dead space in patients with extensive soft tissue defect.
- If the distal osteotomy is close to lateral malleolus, a screw fixation to the tibia can be utilized to prevent valgus deformity and ankle instability, which is more important in a pediatric patient.

■ Capanna Method

- The Capanna technique combines a vascularized fibula graft with massive allograft to reconstruct large defects of the femur to provide structurally competent reconstruction with vascular perfusion and osteogenic capability to achieve lower rates of infection, fracture, and nonunion.⁸
- The free fibula graft can be harvested in similar fashion mentioned earlier:
 - The allograft is cut to match the resected defect, and the medullary canal of the allograft is enlarged with a reamer to create a space for fibula graft (**TECH FIG 2A**).
 - A bur is used to create a window in the allograft to accommodate the vascular pedicle without external compression (**TECH FIG 2B**).



TECH FIG 2 • A. In the Capanna technique, the allograft is cut to match the femur defect size, and the fibula is telescoped into the intramedullary canal of the allograft. Care should be taken to accommodate the vascular pedicle. **B.** The Capanna technique using a femoral allograft. **C.** Microvascular anastomosis between the recipient vessels (descending branch of the lateral femoral circumflex artery and vein) and the flap vessels (peroneal artery and vein).

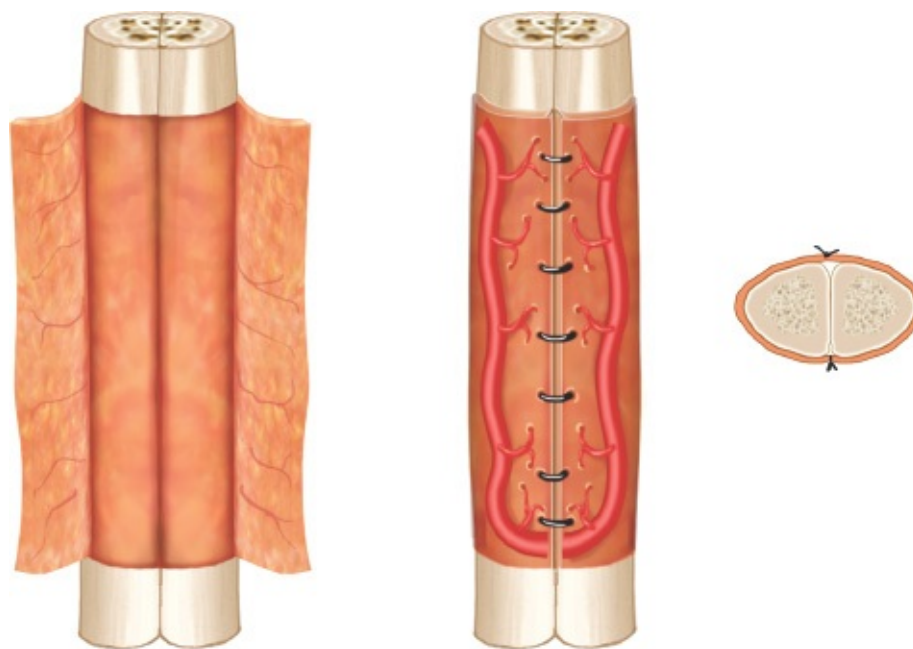
- The fibula is telescoped into the intramedullary canal of the allograft and delivered into the recipient site. This is anchored to the femur proximally and distally with compression plates and screws. During this step, care is taken to prevent any damage to the nutrient vessel.
- Standard microvascular anastomosis is performed between the recipient

vessels and peroneal artery and accompanying venae comitantes (**TECH FIG 2C**):

- Additionally, several fat grafts can be placed around the pedicle in an effort to prevent compression.
- A well-padded posterior leg splint is applied to keep the foot in extension to prevent an equinus deformity.

■ Double Barrel Fibula Technique

- This technique can be useful for reconstruction of smaller femur defect without the use of an allograft:
 - Larger defects will not be able to be reconstructed with a single fibula in a double-barreled fashion; both fibulas would need to be harvested which is not usually recommended.
- The fibula graft is harvested in similar fashion as described previously. This technique provides a graft that doubles the cross-sectional area of the flap but only requires single arterial and venous anastomosis (**TECH FIG 3**).
- At the site of the proposed osteotomy, the vascular pedicle is carefully elevated off the bone flap in the subperiosteal plane with an elevator over a segment of 2 to 3 cm, which will allow a malleable retractor to be placed to protect the pedicle.
- The graft is osteotomized at the midpoint, with care taken to preserve the peroneal vessels.



TECH FIG 3 • In the double-barrelled fibula repair, free fibula is harvested with the peroneal vessels intact. The graft is then osteotomized at the midpoint and folded.

PEARLS AND PITFALLS

Flap inset

- The goal is to maximize bone-to-bone contact between the recipient bone ends and fibula flap.
- Opposition and stability can be achieved by making wedges, steps, or another method that articulates the bone ends together. Creating adequate opposition helps with bone healing while minimizing the number of screws placed into the fibula flap for fixation.

Vascular pedicle

- Any fixation needs to consider the vascular pedicle of the flap. The plate should not be placed over the vascular pedicle. In some cases, the screws placed within the bone flap may need to be unicortical. The plastic surgeon should be actively involved with the fixation and inset of the flap.

Vascular variations

- Peronea arteria magna is a congenital variant of the arterial inflow to the foot, where both the anterior and posterior tibial arteries are hypoplastic or absent with the peroneal artery serving as the single arterial supply below the knee.

Injury to common peroneal nerve

- The nerve courses inferior to the head of the fibula and should be identified during proximal dissection to prevent injury.

Careful dissection of skin perforators

- Preserve the posterior intermuscular septum, which carries perforators to the skin paddle.

POSTOPERATIVE CARE

- Monitor donor site for signs and symptoms of vascular insufficiency or compartment syndrome.
- Assess the drains daily and remove if output is less than 20 to 30 cc/day.
- Monitor the flap postoperatively with clinical exam and using Doppler probe every hour for the first 24 hours. Flap monitoring should continue until discharge to check microanastomotic patency and skin island perfusion.
- An internal implantable Doppler can be utilized to monitor a bone flap without a skin paddle.
- No ambulation for 2 weeks postoperatively. Afterward, start with partial weight bearing with crutches until full weight bearing when bone union is achieved.
- If an osteocutaneous flap used for reconstruction fails due to vessel thrombosis, the skin island can be debrided or allowed to heal secondarily. The bone graft can remain in place, and hyperbaric oxygen therapy can be utilized to increase the chance of bone revascularization.

OUTCOMES

- Limb functionality varies depending on trauma, tumor, or infectious etiology.
- Patient counseling is crucial: numerous revision procedures (8.7 per patient)⁹ common for best results
- 64% of lower extremity flap complications resolve conservatively; 36% require additional bone grafting or flap revisions.¹⁰
- Full bone healing: 86% of patients
- Ambulation: all patients (100%) at an average 9.5⁹ to 14.3 months¹¹

- Joint stiffness (40%) and pain (18%) are frequent.⁹
- Return to work: 63.5% of patients with primarily salvaged limbs¹²

COMPLICATIONS

- General complications:
 - Wound infection (9.6%–23.2%)^{9,11,13,14}
 - Bleeding (6.7%)⁶
 - Delayed wound healing or dehiscence (10.0%)⁶
 - Cosmetically unpleasant scar
- Recipient site:
 - Flap failure (3.8%–5.8%)^{12,14} due to compromised flap perfusion (eg, anastomotic thrombosis)
 - Minor necrotic areas (11.5%)¹⁴ due to temporary interruptions of the vascular supply
 - Bone nonunion (15.5%–31.0%)^{12,13}
 - Osteomyelitis (8.6%–17.3%)^{12,13}
 - Revision surgery and need bone for grafting
 - Amputation as ultima ratio (3.9%–7.3%)^{12,13}
- Donor site:
 - Knee/ankle instability with secondary pseudoarthrosis (2.0%)⁹
- Prevention: sparing 6 cm at the proximal and 6 cm at the distal end of the fibula in order not to violate the connective structures:
 - Inability to flex the great toe due to extensive dissection of FLH
 - Loss of sensation of peroneal nerve (10.0%)⁹
 - Skin graft failure after donor site closure
- Because of the improvements of microsurgical training and techniques, the use of autologous tissue for lower extremity reconstructions is continuously increasing and offers lower complication rates compared to allografts.⁶

ACKNOWLEDGMENTS

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39 Soft Tissue Coverage of the Thigh—Pedicled Rectus Flap

CHAPTER

Brock Lanier and Alex Wong

DEFINITION

- Soft tissue defects of the thigh can involve critical anatomy including the neurovascular structures of the femoral triangle (i.e. common femoral artery, common femoral vein, and femoral nerve) and/or bone.
- Prior infection, radiation, trauma, tumor resection, or other pathologies can render local or pedicled flaps from the thigh unusable for reconstruction. In such scenarios the pedicled rectus flap is a reliable workhorse for thigh defects.
- The rectus flap is very versatile. It can be used as a pedicled muscle or myocutaneous flap. The available flap dimensions can range from a small segment of muscle to a large flap incorporating an extended skin component.¹

ANATOMY

- The rectus abdominis muscle spans the vertical length of the abdominal wall. It originates from the pubis, inserts at the fifth to seventh costal cartilage, and is situated in pairs along the paramedian axis of its anterior wall. It is a Mathes and Nahai type III muscle with two codominant vascular pedicles: the superior epigastric artery and the inferior epigastric artery (**FIG 1**).
- In order to use the pedicled rectus flap for thigh reconstruction, the superior epigastric artery is transected and the flap is rotated maintaining the blood supply from the inferior epigastric artery.
- Perforating branches from the inferior epigastric artery are concentrated around the umbilicus. As such, the periumbilical area should be incorporated into the design of any myocutaneous flap's skin paddle.
- If the periumbilical perforators to the skin are utilized, an almost infinite

number of skin paddle designs are possible. Large (*size*) skin paddles can be transposed to the thigh defect if needed.²

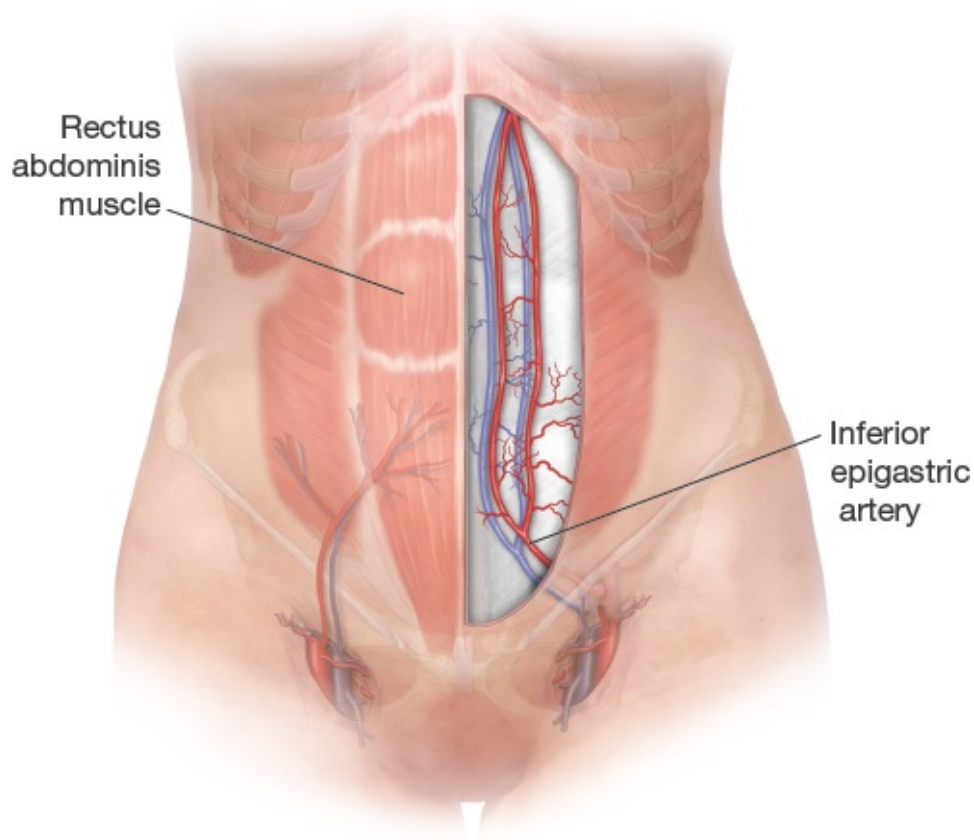


FIG 1 • VRAM clinical anatomy. The rectus abdominis muscle originates from the pubis and inserts at the fifth to seventh costal cartilage. It has codominant vascular pedicles: the superior epigastric artery and the inferior epigastric artery. The VRAM skin paddle must include periumbilical skin perforators.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Most soft tissue defects involving the thigh are associated with either trauma or cancer.
- Focused examinations of the abdomen and lower extremity should be performed:
 - The abdominal examination should evaluate for previous surgical scars, the

presence of abdominal wall hernias, and skin laxity if a myocutaneous flap is being considered:

- Transverse midabdominal laparotomy scars indicate that the rectus abdominis was likely transected.
- Low transverse scars associated with prior cesarean sections may or may not have violated the inferior epigastric pedicle.
- Check the neurovascular status of the lower extremities. Trauma or surgery, particularly vascular surgery, involving the external iliac artery or common femoral artery, may have compromised the inferior epigastric pedicle.

IMAGING

- Imaging is not mandatory but can be considered if the patient's physical exam is concerning regarding the integrity of the inferior epigastric artery.
- CT angiography can assess the pedicle and can concurrently evaluate the abdominal wall for occult hernias and other pathologies.
- MR angiography and ultrasonography are other modalities that can also be considered.

NONOPERATIVE MANAGEMENT

- Nonoperative treatment of soft tissue defects of the proximal thigh is limited, especially when critical structures of the femoral triangle or osseous structures of the lateral thigh are exposed.
- Temporary coverage using vacuum-assisted wound care devices can be considered depending on the contents of the wound.

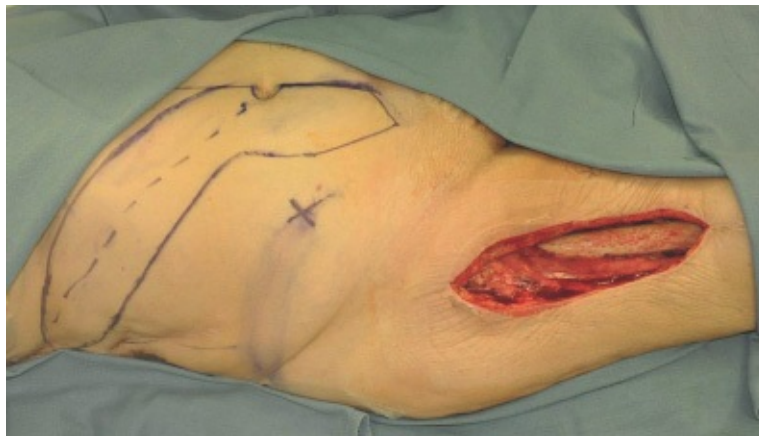
SURGICAL MANAGEMENT

- Surgical management decisions include timing (immediate vs delayed reconstruction) and choice of the flap.
- Flap options include local pedicled flaps of the thigh such as the anterolateral thigh flap, tensor fascia lata flap, gracilis flap, and sartorius flap.
- Free flaps are also an option if appropriate regional options do not exist.

TECHNIQUES

■ Flap Design

- The size and depth of the soft tissue defect should be defined following tumor resection or wound debridement.
- Critical landmarks include the symphysis pubis and the anterior superior iliac spine (ASIS), which defines the inguinal ligament.
 - The origin of the inferior epigastric artery is at the halfway point of the distance between the symphysis pubis and the ASIS.
- The paramedian location of the rectus abdominis muscle is marked.
- If desired, a template of the defect can be constructed (e.g., using wrapping paper from sterile gloves) to facilitate creation of the design of the skin paddle. It is suggested that the length of the muscle and the size of the skin paddle be slightly larger than the defect.
- The donor site of muscle flaps will almost always close primarily.
 - The donor site of skin paddle of a myocutaneous flap should be assessed during flap design. A pinch test can ensure that the donor site will be able to close primarily.
- In pedicled flaps such as the rectus abdominis, the pivot of the flap about its vascular pedicle should be considered during flap design (**TECH FIG 1**).
 - Typically, the flap will rotate externally to reach a lateral thigh defect and internally to reach a medial thigh defect. A sterile towel or laparotomy pad can be used to simulate the arc of rotation of the flap about its pivot point to ensure adequate length of the flap during flap design.

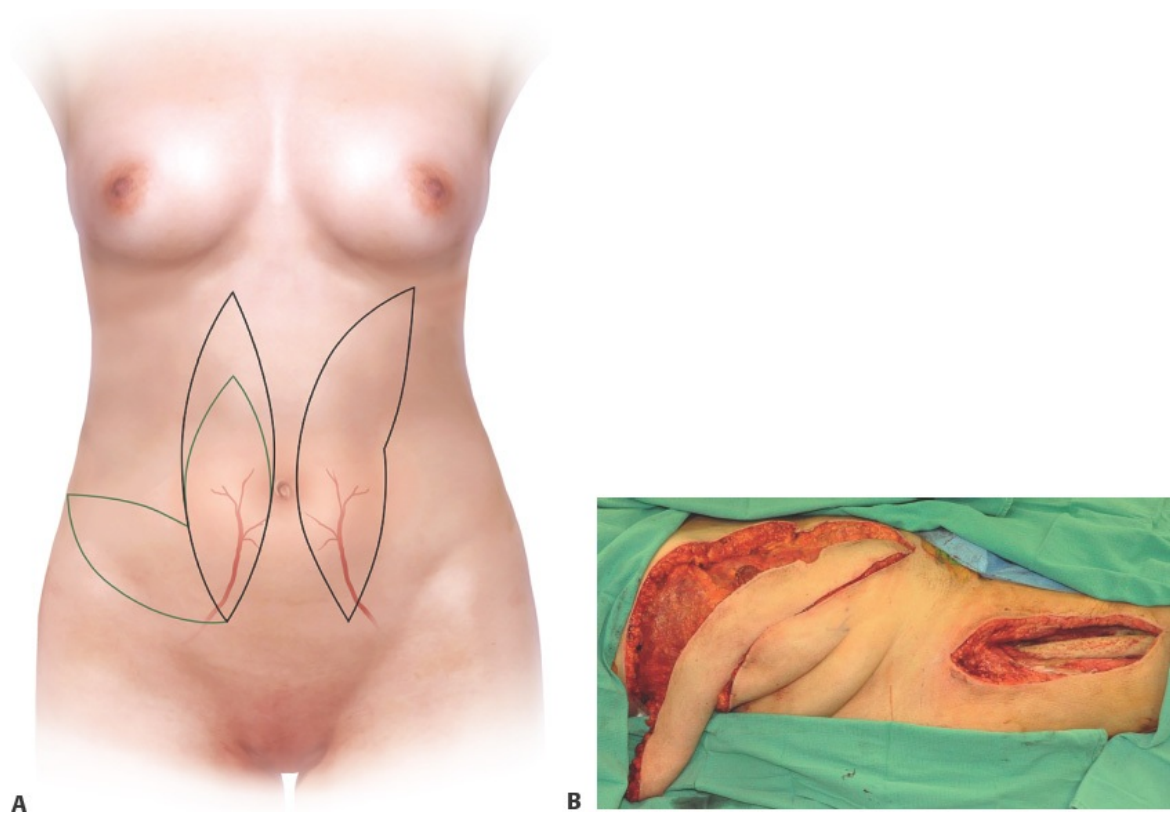


TECH FIG 1 • Lateral view of the abdomen and right thigh, demonstrating proximal anterolateral thigh full-thickness defect with exposed femur. The extended vertical rectus myocutaneous (eVRAM) flap has been

marked incorporating the flap's periumbilical perforators into its design.

■ Flap Harvest

- For a muscle flap without skin island, the approach may be via a paramedian incision directly over the muscle or a low transverse abdominoplasty incision.
 - Once the anterior rectus sheath is exposed, it is entered sharply in the middle of the muscle and reflected medially and laterally to expose the muscle.
 - For smaller defects of the thigh, a segment of the muscle can be harvested, leaving the remaining muscle supplied by the superior epigastric artery.
- For a myocutaneous flap (**TECH FIG 2A**), the skin paddle must be in continuity with the anterior rectus sheath to incorporate perforating vessels.
 - At the medial and lateral surface, the fat and skin can be elevated 1 to 3 cm off of the anterior sheath to allow for the donor site to be closed directly.
- To complete harvest, the muscle is circumferentially dissected off of the posterior rectus sheath (**TECH FIG 2B**).
 - Below the arcuate line, the posterior sheath is thin because it consists only of transversalis fascia.
 - Neurovascular bundles associated with intercostal nerves are controlled with either suture ties or clips.
 - The inferior epigastric pedicle is identified at the inferolateral aspect of the muscle approximately 4 cm cranial to the origin.
- The flap's pedicle can be dissected back to its external iliac origin to maximize the arc of rotation.
 - Care should be taken not to exert excessive tension or pressure on the pedicle during the dissection.
- The cranial aspect of the muscle is transected at the costal margin, taking particular attention to identifying the superior epigastric artery.
 - The caudal aspect of the muscle can also be divided from the pubic origin for additional length.



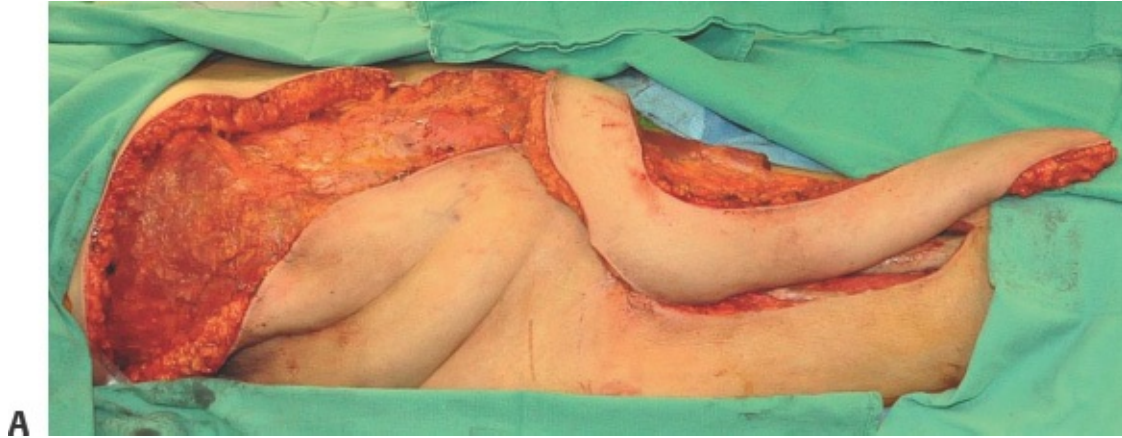
TECH FIG 2 • A. Examples of skin paddle designs of VRAM and extended VRAM. **B.** Dissected extended VRAM in situ at the donor site.

■ Flap Inset and Completion

- According to the location of the soft tissue defect, the flap can be rotated or tunneled to the defect (**TECH FIG 3A**).
 - With the flap in situ at the recipient site, its vascular status should be assessed before inset.
 - The pedicle can be checked to ensure there is minimal twisting and no acute turns compromising flow.
 - For myocutaneous flaps, the skin paddle's cutaneous Doppler signal sites should be examined and can be marked with ink or small suture (e.g., 5-0 polypropylene) to facilitate postoperative monitoring.
- The flap is inset in layers using suture and/or staples. A skin graft can be applied if appropriate (**TECH FIG 3B**).
- The anterior rectus sheath donor site is repaired directly with sutures (e.g.,

no. 1 PDS).

- When a skin paddle is incorporated into the flap, mesh is usually required to minimize tension on the repair.³



TECH FIG 3 • A. Rotation of VRAM flap demonstrates that it can reach past midthigh. Final intraoperative lateral view appearance of the abdomen and right thigh with the eVRAM donor site closed primarily and the flap inset after de-epithelization and tunneled through the subcutaneous space.

Artery preservation

- In the setting of large soft tissue defects involving the proximal thigh, it is essential to ensure that the origin of the inferior epigastric artery has been preserved.
- Radical resections involving the ipsilateral common femoral artery or external iliac artery will likely compromise the flap's pedicle. The need for vascular reconstruction of these vessels should alert the reconstructive surgeon.

Flap design

- The flap can be trimmed and customized to a smaller size during inset. It cannot be enlarged once it has been dissected.
- For this reason, a larger flap is recommended (longer rectus and/or larger skin paddle). Consider a 20% larger design than what is suggested by the initial measurements of the soft tissue defect.

POSTOPERATIVE CARE

- The abdominal donor site can be dressed with a sterile occlusive dressing (e.g., gauze, adhesive tape, or topical liquid bonding product).
- The dressing for the flap depends on the type of the flap (muscle with or without skin graft, skin paddle) and preference of the surgeon.
- Pedicled flaps to the proximal thigh are at risk with early postoperative motion. A short period of immobilization, especially for flaps with overlaying skin grafts, should be considered.
- Flap checks examining the color, turgor, temperature, and/or Doppler signal should be performed in accordance with institutional standards. Many protocols call for hourly flap checks during postoperative day 1, every 2 hours on postoperative day 2, and every 4 to 6 hours thereafter.

OUTCOMES

- The pedicled rectus abdominis flap has a constant blood supply, making it a safe and reliable option for small to large soft tissue defects of the proximal thigh (**FIG 2**).

COMPLICATIONS

- Obesity, smoking, uncontrolled diabetes, and prior abdominal surgery are factors that have been associated with an increased risk of complication.⁴
- Intraoperative vascular complications related to twisting or kinking of the pedicle during inset
- Acute venous insufficiency is rare but can occur in patients with a dominant superficial venous system. If this is encountered, then the flap can be returned

to its native position, and its inset can be postponed for a few days allowing for the delay phenomenon to occur.

- Partial flap necrosis may occur at the distal aspect of the skin island in myocutaneous flaps.⁵
- Postoperative hematoma or seroma⁵
- Donor site bulge or hernia (12%)⁵



FIG 2 • Result 1 year postoperatively, demonstrating the postoperative appearance of the healed eVRAM donor site and flap.

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40 Soft Tissue Coverage of Thigh—Free Flaps

CHAPTER

Ulrich Kneser and Thomas Kremer

DEFINITION

- Soft tissue defects of the thigh requiring free flap reconstruction are rare, because of a sufficient soft tissue envelope that frequently allows other reconstructive options such as split-thickness skin grafting, local random pattern, or pedicled flaps.
- Exposure of functional structures such as neurovascular bundles, tendons, or bone may require reconstruction using free microvascular tissue transfer.

ANATOMY

- Anatomy of the thigh is characterized by a sufficient number of strong muscles:
 - Anterior:
 - The quadriceps muscle (medial, lateral, and vastus intermedius muscle as well as rectus femoris muscle)
 - The sartorius muscle
 - Medial:
 - The adductor muscles (gracilis, adductor magnus, adductor longus, adductor brevis, and pectineus muscle)
 - Posterior:
 - Biceps femoris muscle
 - Semitendinosus muscle
 - Semimembranosus muscle
- Perfusion of the thigh is maintained by the femoral artery and its branches:
 - Profunda femoris artery (with medial circumflex and lateralis artery)

- Descending genicular artery
- Popliteal artery
- Peripheral branches of the inferior gluteal artery for the proximal dorsum
- Major nerves of the thigh are:
 - The femoral nerve (quadriceps, sartorius, and pectineus muscle)
 - Obturator nerve (adductor muscles)
 - Sciatic nerve (posterior muscles of the thigh)
- Venous drainage of the thigh is provided by deep veins and the saphenous vein.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Defects at the thigh may result from trauma, infection, or oncologic resection. Each of these entities should be evaluated and requires special focus during patient examination.
- Patients with traumatic soft tissue defects of the thigh should be asked for the mechanism of injury. This may help to identify the true extent of the defect and concomitant trauma consequences.
- Infections of the thigh should be evaluated for dynamics, systemic consequences (eg, fever, fatigue), pain, prior antibiotic treatment, as well as potential causes and infectious portals of entry.
- The major goal in patients after oncologic resection is to evaluate prognosis, prior treatment, and adjuvant treatment options, since this information strongly influences therapeutic as well as reconstructive choices.
- Additional important factors influencing reconstruction are patients' demands: patients who were ambulating normally prior treatment may require more extensive reconstructive attempts than patients who are chair- or even bed-bound.
- Inspection of the thigh in patients suffering from soft tissue loss should assess the extent and depth of the defect as well as exposed functional structures. Additionally, the surroundings of the defect should be carefully evaluated: scarring, tension, and former incisions should be noted. Prior radiation therapy may lead to wound healing disturbances and subsequent postoperative morbidity and should therefore be taken into account.
- When free flap reconstruction is required, potential donor vessels should be evaluated. The distance from these vessels to the most distant part of the defect should be measured and significantly influences flap choices. In some patient, even more invasive strategies such as arteriovenous loops or bypasses may be

necessary.

- Patients should be asked for varicosity or prior venous surgery (such as venous stripping or bypass surgery).

IMAGING

- Photographs of the defect should be performed including the complete thigh as well as detailed pictures focusing on the defect.
- Conventional x-rays of the femur in two perpendicular views (anteroposterior and lateral) may show concomitant fractures or nonunions in traumatic cases, osteomyelitis after infection, or oncologic osseous lesions in oncologic patients.
- Magnetic resonance imaging and computed tomography may reveal the real extent of the defect or sequelae of infection of the bone as well as soft tissue. However, both options should not postpone onset of treatment in special patients such as cases with necrotizing infections.
- Radiologic examination of donor vessels is required in patients prior to microsurgery for thigh defects. MRI or CT angiographies are sufficient in most cases. The advantage of conventional angiographies in these patients is that endoluminal interventions are possible, if necessary.
- Doppler or duplex ultrasound is indicated to evaluate the superficial venous system and for venous mapping if vein grafts may be required.

SURGICAL MANAGEMENT

- Indications for free flap reconstruction at the thigh are relatively rare. Most cases can be managed using local random pattern or pedicled flaps as well as split-thickness skin grafting. However, extensive defects with exposure of functional structures such as bone, neurovascular bundles, or tendons may require free tissue transfer.
- Another reason for microsurgical flap transplantation is radiation therapy. Tissues from distant donor sites that are not radiated may improve the healing capacity of irradiated wound beds. This is especially important because soft tissue sarcoma of the limbs most commonly occur at the thigh.¹ Here, defect reconstruction using free flaps can even be indicated when primary wound closure would be possible with tension. In these patients, complications rates can be reduced when reconstruction with nonradiated flaps is applied.
- Any reconstructive attempt should only be started when wounds are sufficiently debrided. No signs of infection or devitalized tissue should be

present.

- In some cases, vacuum-assisted closure (VAC) therapy can be performed to prepare wounds for soft tissue reconstruction.

Preoperative Planning

- Different parameters influence the choice for various reconstructive options:
 - The aim of reconstruction (eg, palliative vs curative intention, limb salvage vs major amputation; ability to walk or just to sit)
 - Structures or functions requiring reconstruction, extent of the defect (eg, soft tissue loss, bone damage, muscle function, nerve injury)
 - Perfusion of the wound bed (eg, in patients with peripheral arterial disease, after radiation therapy)
 - The patients' individual needs and compliance as well as concomitant diseases
 - Donor site morbidity
 - Adjuvant therapy options or further surgery
- Another important information is the distance from potential donor vessels to the most distant part of the defect. If this distance is too long, the risk of partial flap loss ("where you need it most") is increased. In these cases, arteriovenous loops or vessel interpositional grafts should be considered.
- Patients with atherosclerosis should be evaluated by angiography and should be presented to vascular surgeons or interventional radiologists prior to surgery.
- If multidisciplinary approaches are required (eg, osseous internal fixation, soft tissue reconstruction and/or vascular surgical interventions), a detailed preoperative discussion is required. The sequence and extent of different surgical steps, postoperative care, and operative strategy has to be considered. Here, interdisciplinary extremity boards similar to oncologic tumor boards have been shown to be very efficient.

Positioning

- Patient positioning depends on donor vessels, flap choice, as well as additional surgical interventions (eg, osteosyntheses, vascular surgery, harvest of vein grafts).
- Supine positioning allows:
 - Common flaps: anterolateral thigh flap, gracilis flaps, rectus abdominis myocutaneous flaps, tensor fascia lata flaps, vastus lateralis flaps, lateral arm

flap, forearm flaps

- Donor vessels: femoral artery and vein in the groin and adductors canal
- Lateral decubitus position (**FIG 1A,B**):
 - Common flaps: flaps from the subscapular system
 - Donor vessels: femoral artery and vein in adductor canal
- In some patients, it is not possible to perform the complete procedure in one position (eg, when internal osseous fixation is required). Here, intraoperative repositioning may be necessary.

Approach

- The surgical approach to defects at the thigh is defined by defect localization as well as extent and cannot be discussed here in detail.
- Recipient vessels at the thigh predominantly are the femoral vessels. These can best be approached in the groin and the adductors canal.
- In patients with unfavorable defect localization, microvascular anastomoses can be performed to arteriovenous loops (that can be performed in the same procedure or separately in prior procedures) or interpositional vein grafts.
- If different approaches to the defect, vessels, and bone have to be combined, the surgeons should carefully discuss operative incisions in advance to prevent skin malperfusion.

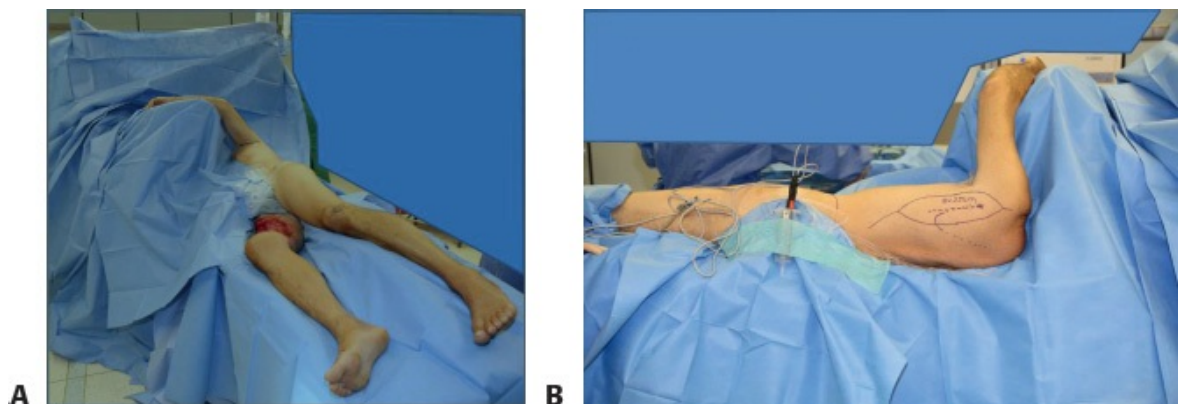


FIG 1 • The lateral decubitus position of patients allows exposure of the thigh and femoral vessels, if the contralateral leg is placed backward. **A.** Care has to be taken for the upper arm that has to be prevented from any compression to prevent compartment syndromes in lengthy procedures. **B.** Flaps from the subscapular

system can easily be harvested.

TECHNIQUES



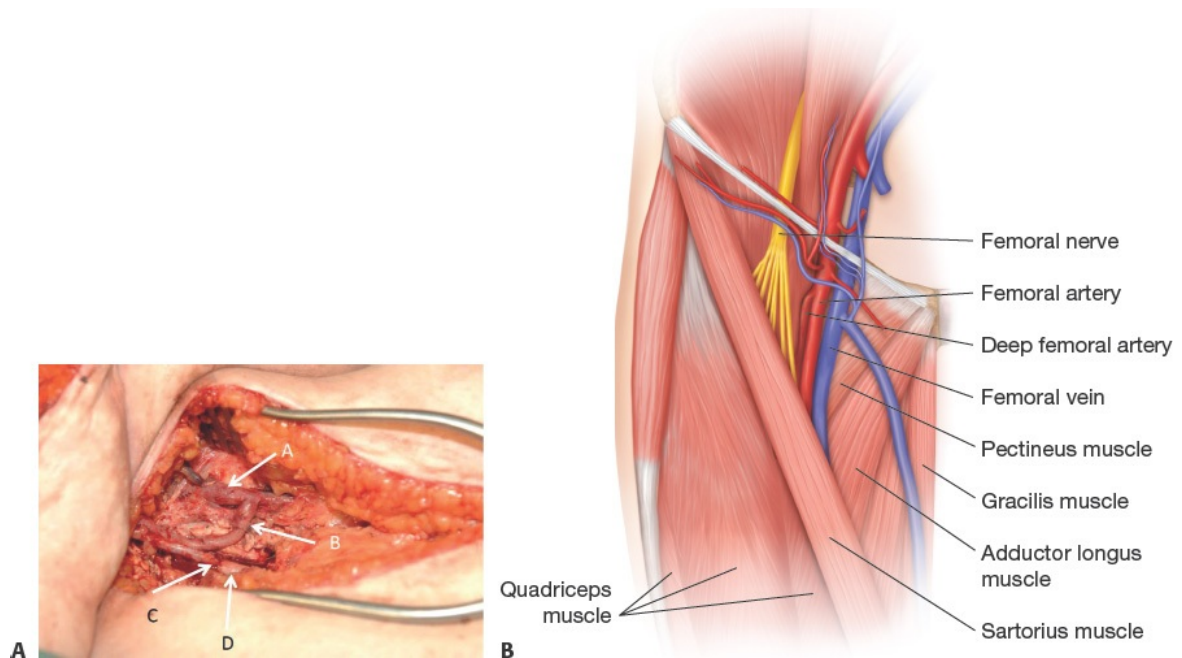
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■ Approach to the Groin

- The femoral artery and vein can easily be identified in the groin (**TECH FIG 1**). These vessels arise from the external iliac artery and course under the inguinal ligament into the thigh. Here, the artery can usually be found by palpation. The femoral vein is located medial to the artery, whereas the femoral nerve courses laterally.
- The course of the vessels across the thigh is between the vastus medialis muscle (laterally) and the adductor muscles. Distally, the sartorius muscle lies superficial to the vessels.
- Major arterial branches in the groin are the deep femoral artery, the superficial epigastric, and the circumflex iliac artery. The saphenous vein can likewise be identified in the groin.
- The skin incision is performed distal to the inguinal ligament over the vessels that were previously identified by palpation or Doppler probe. During subcutaneous preparation, the saphenous vein should be identified and preserved.
- Because the femoral vessels lie on the muscles in the groin, these structures

can easily be dissected. For safety reasons, the major branches should be identified (especially the deep femoral artery) and secured using vessels loops.

- After dissection of the femoral artery and vein over several centimeters, an adventitiectomy should be performed to prepare the vessels for anastomosis that is usually performed in an end-to-side fashion.



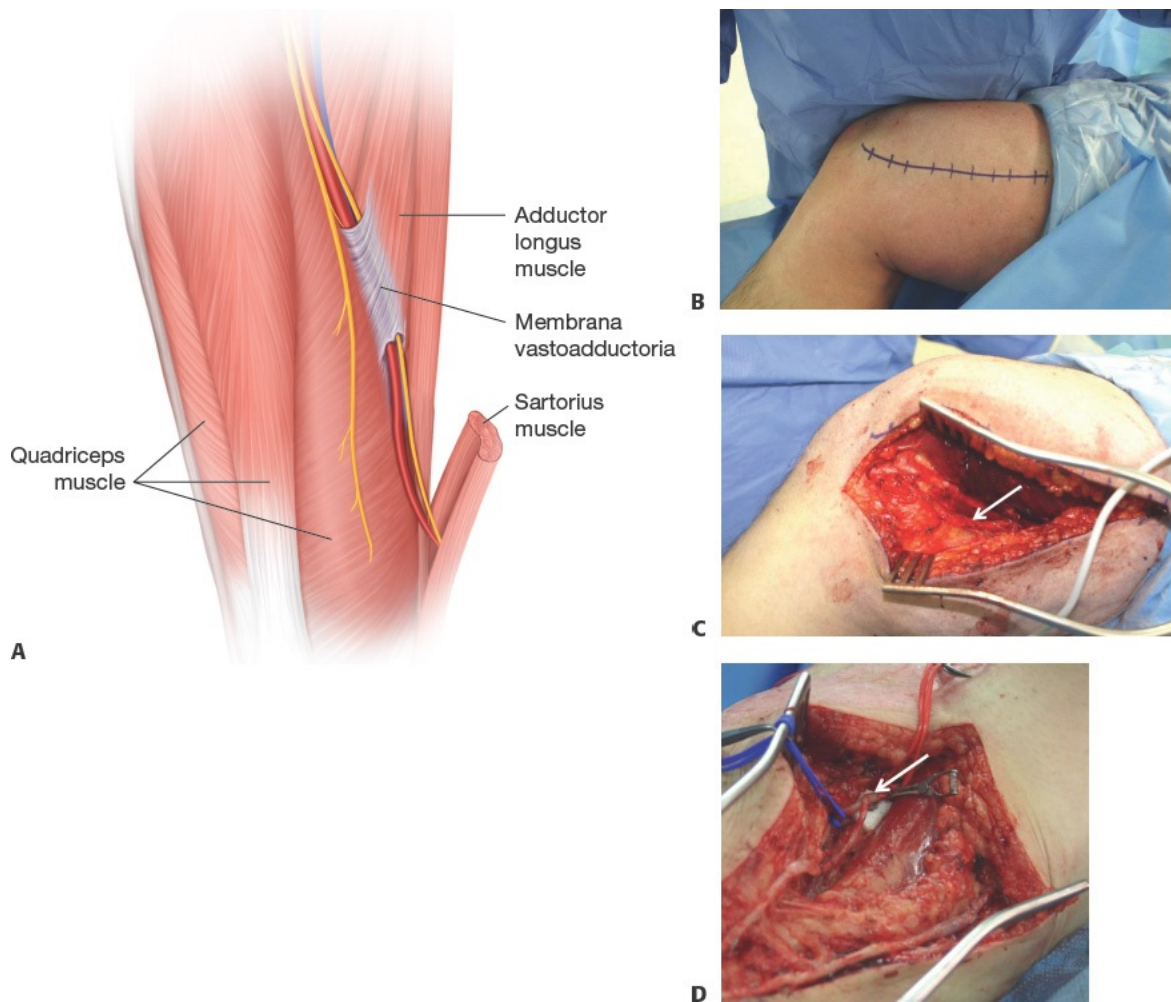
TECH FIG 1 • A. The femoral vessels can be exposed in the groin. Here, the femoral vein (A) is visualized caudal to the inguinal ligament. Dissection was performed to the entry of the saphenous vein. (B) Here, the saphenous vein is pulled cranially (left) to form an arteriovenous loop through an end-to-side anastomosis (C) to the femoral artery (D) in the groin. **B.** Illustration of the femoral vessels in the groin.

■ Approach to the Adductor Canal

- The anatomical borders of the adductor canal are:
 - Dorsally: adductor longus muscle (**TECH FIG 2A**)
 - Ventrally: vastoadductor membrane between the tendons of the vastus

medialis and adductor longus muscles (see **TECH FIG 2A**)

- Medially: adductor magnus muscle
- Laterally: vastus medialis muscle
- The femoral vein is located under (“deep”) the femoral artery.
- Additional structures in the adductor canal are the saphenous nerve and the descending genicular artery.
- The approach to the femoral artery and vein is possible in supine as well as lateral decubitus position.
- The skin incision is performed at the medial thigh (**TECH FIG 2B**). During subcutaneous dissection, the saphenous vein can be found and prepared for anastomosis.
- After incision of the fascia of the thigh, the descending genicular artery can be identified (**TECH FIG 2C**). This structure can be used as a guide into the adductor canal, and the femoral artery and vein can easily be found. Both vessels are then dissected (**TECH FIG 2D**).
- Care has to be taken to preserve the femoral vein behind (deep) to the femoral artery. Several arterial and venous branches arise from the femoral vessels in the adductor canals. Some of these generally seem to be sufficient for anastomosis. However, the authors recommend ignoring these vessels because complication rates are significantly higher when compared to direct end-to-side anastomoses to the “big” femoral vessels.



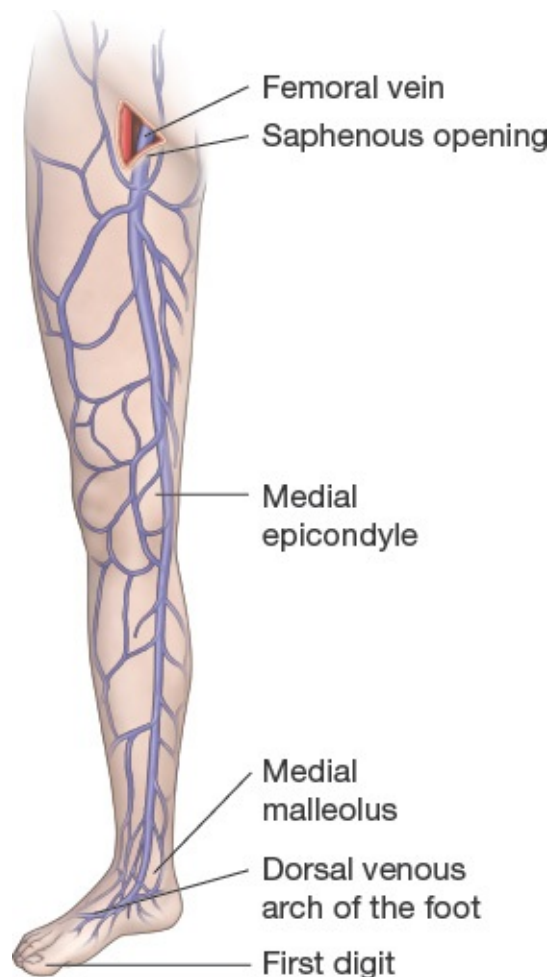
TECH FIG 2 • A. Illustration of the adductor canal. **B.** The adductor canal is exposed through a medial skin incision. **C.** After subcutaneous dissection and incision of the fascia, the descending genicular artery can be identified (*arrow*). **D.** This structure guides into the adductor canal, and the femoral artery can be identified and dissected as well as the femoral vein. Here, the saphenous vein is anastomosed to the femoral artery to create an arteriovenous loop (*arrow*).

■ Dissection of the Saphenous Vein

- The saphenous vein collects the blood of the dorsum of the foot and courses superficially at the lower leg. Around the knee, it courses dorsal to the medial

femoral condyle before it runs anteriorly at the thigh and penetrates the fascia in the groin where it enters the femoral vein (**TECH FIG 3**).

- The entire course of the saphenous vein is epifascially.
- During dissection, numerous branches can be identified. These should be ligated with sutures rather than vessel clips, because the latter often prove to be insufficient and postoperative bleeding occurs. This is especially important, when parts of the vein are inserted into the arterial system in arteriovenous loops, since vessel clips frequently fail to withstand arterial pressure.
- If the saphenous vein is exposed to arterial pressure, it significantly lengthens. This effect has to be considered when arteriovenous loops are performed. Here, the arterial part of the loop should be planned slightly shorter than the venous side.

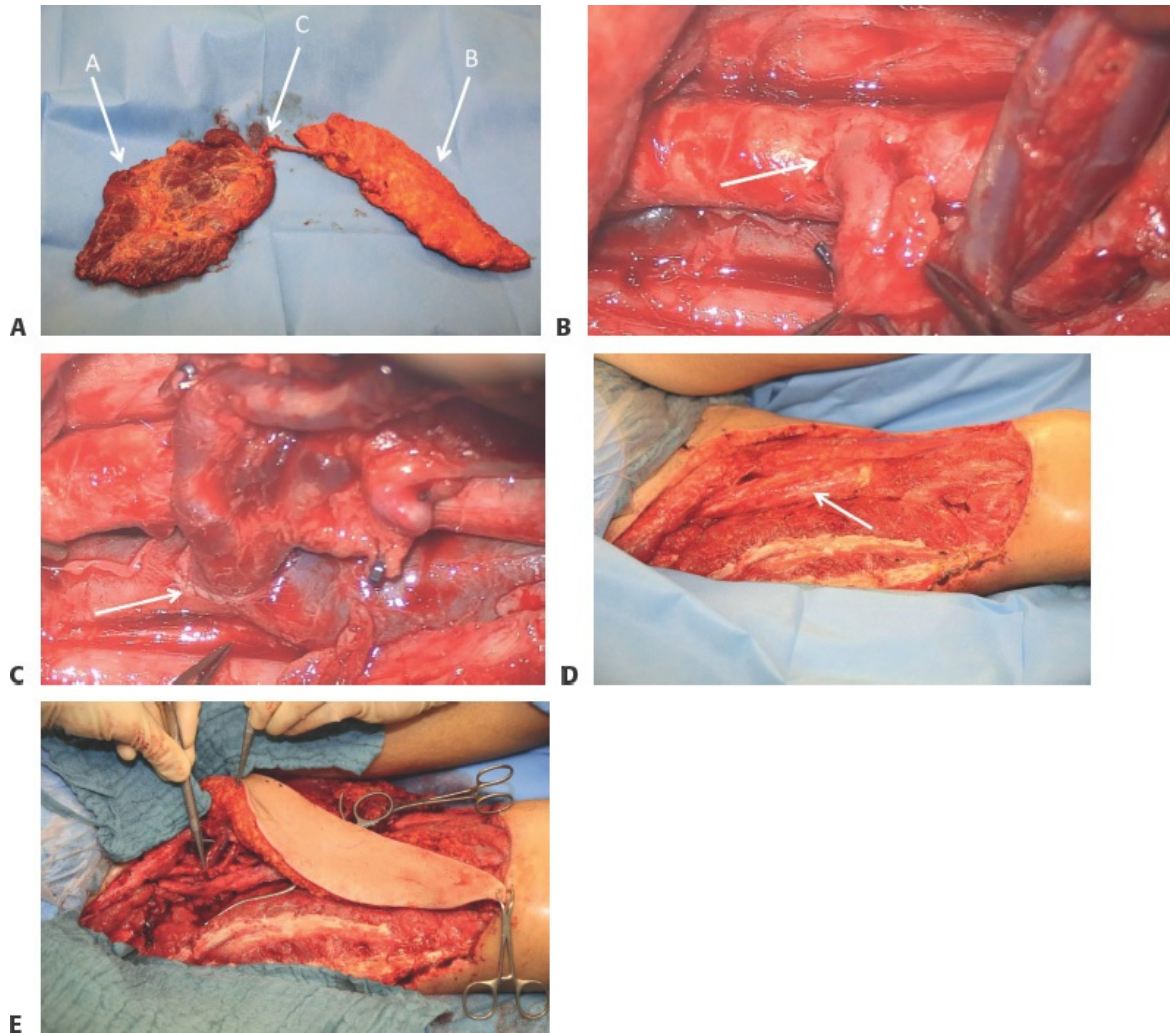


TECH FIG 3 • The saphenous vein collects the blood

of the dorsum of the foot and courses superficially at the lower leg. Around the knee, it courses dorsal to the medial femoral condyle before it runs anteriorly at the thigh and penetrates the fascia in the groin where it enters the femoral vein.

■ Flap and Anastomosis

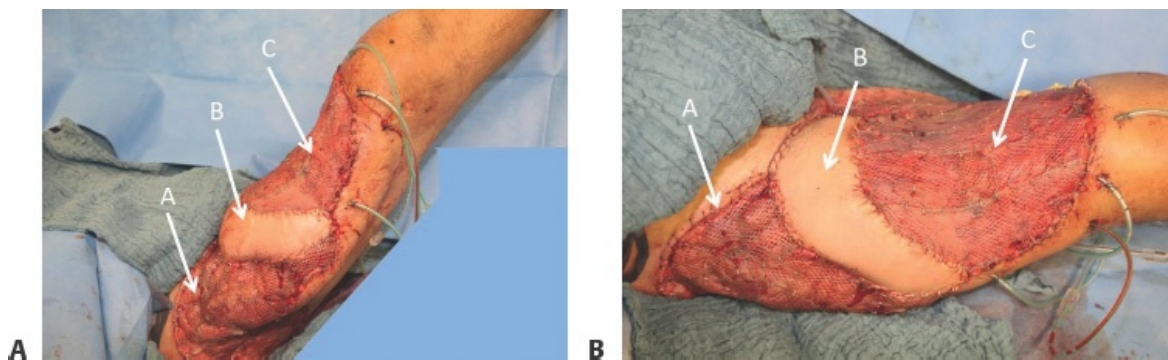
- If muscle flaps are performed, these should be harvested together with skin islands to allow postoperative supervision of perfusion. These skin islands can be dissected based on one perforator and can therefore be removed after 7 to 10 days just by ligation of the perforator and to not require a second procedure.
- After flap harvest (**TECH FIG 4A**), the flap is provisionally secured to the thigh, and the recipient vessels are approximated to the femoral vessels.
- End-to-side anastomoses should be preferred over end-to-end anastomoses to side branches for the arterial system, because the flow is higher and consecutive complication rates are reduced. Venous anastomosis is routinely performed in end-to-end fashion to side branches of the (**TECH FIG 4B–E**) femoral vein using coupler devices or standard suture. In cases of insufficient venous branches, direct end-to-side anastomosis to the femoral vein or end-to-end anastomosis to the saphenous vein is applicable.
- After the anastomoses are finished, it is useful to secure the anastomotic site using fibrin glue to prevent postoperative repositioning and subsequent vessel kinking.
- Adequate perfusion of the flap is either checked by capillary refill or by brisk capillary bleeding from the flap margins.



TECH FIG 4 • A. A combined latissimus (A) and parascapular (B) flap was harvested to reconstruct an extensive traumatic defect after a motor bike accident (C). The vascular pedicle was dissected to the subscapular artery and vein **B.** End-to-side anastomosis (*arrow*) was performed of the subscapular artery to the femoral artery. **C.** Venous anastomosis (*arrow*) was likewise done to the femoral vein. **D.** An extensive traumatic defect at the thigh with exposed femur required reconstruction using free tissue transfer because the femoral vessels were exposed (*arrow*). **E.** After anastomosis to the femoral vessels.

■ Flap Inset, Skin Grafting

- After flap reperfusion, manipulation to the anastomotic side should be avoided for some minutes. During this period, anastomotic flow is established and minor anastomotic bleeding terminates.
- Flap inset is performed temporarily using suture clips. The anastomotic site and flap pedicle are then checked for optimal positioning before the flap is definitely sutured to the defect. Skin-to-skin closure is preferred in fasciocutaneous flaps, whereas muscle flaps are fixed under the defect margins that should be elevated. Here, running sutures using absorbable monofilament material are preferred over nonresorbable sutures.
- Muscle flaps should be covered using split-thickness skin grafts (**TECH FIG 5**). In these cases, it can be useful to provide vacuum-assisted closure therapy to the skin-grafted area (using low pressures such as 75 mm Hg) to allow optimal wound healing.
- Split-thickness skin grafting can be performed under monitor skin islands already, if these are harvested based on perforators.
- Care has to be taken to prevent any compression to the anastomosis or flap pedicle when wound dressings are applied.



TECH FIG 5 • A,B. Flap inset was performed, and the latissimus flap as well as the proximal thigh musculature were skin grafted (A, proximal thigh muscles; B, parascapular flap; C, latissimus dorsi flap with split-thickness skin grafts).

PEARLS AND PITFALLS

Preoperative planning	■ A detailed analysis of the defect is necessary prior to surgery to identify every structure that needs to be reconstructed. ■ For flap choice, the distance from the anastomotic site to the most distant part of the defect has to be considered. ■ The bulk of the flap has to be considered, when skin-to-skin closure is attempted.
Arterial disease	■ If the patient suffers from peripheral arterial disease or varicosity, a vascular surgeon or interventional radiologist should be involved in the treatment team.
Patients' needs	■ The patients' needs have to be evaluated prior to surgery. The reconstructive aim significantly varies if the patient is ambulating normally or if he is chair- or bed-bound. ■ Palliative surgery vs curative attempts in oncologic patients.
Anastomosis	■ End-to-side anastomoses to the femoral vessels are preferred over end-to-end anastomoses to side branches, because blood flow is greater and complication rates are reduced.
Postoperative care	■ Flap perfusion has to be monitored on a regular base for the first postoperative days. ■ Monitoring is possible clinically in fasciocutaneous flaps, or monitor skin islands of muscle flaps. The latter can be harvested based on a perforator to allow removal without additional surgery.

POSTOPERATIVE CARE

- Postoperative positioning of the patient can be crucial. Compression of the pedicle or flap has to be avoided. Here, postoperative positioning has to be discussed with the patient preoperatively. This increases the patients' understanding and compliance.
- External fixators can be helpful to allow adequate postoperative positioning.
- Postoperative anticoagulation is part of an ongoing debate.² In general, less intervention is preferred over aggressive anticoagulation. The authors only prescribe low molecular weight heparin for thromboembolic prophylaxis. Higher doses or intravenous heparin are only applied in bypass free flaps or after revision surgery. If patients develop thrombocytosis or arterial clots, acetylsalicylic acid can be useful.
- Flap perfusion has to be monitored on a regular base (hourly) to allow

immediate revision surgery if arterial inflow or venous drainage is compromised.

- After 5 to 7 days, the flap should be exposed to gravity (so-called dangling procedure), and the patients should be mobilized.³
- Physical therapy has to be applied from the first postoperative days.
- Compression garments are usually required to avoid bulky flaps and scars as well as contractures. Scar massage is beneficial in most patients.
- Physical therapy and rehabilitation have to be planned in most patients. However, these are mostly defined as the individual defect and rarely depend on the microsurgical procedure itself (**FIG 2**).

OUTCOMES

- Outcomes after free flap surgery to thigh defects mostly depend on the underlying condition rather than on the microsurgical procedure itself.
- Outcomes in traumatic patients mainly depend on wound healing, osseous healing, and long-term function due to scarring or post-traumatic arthritis.
- Prognosis in oncologic patients depends on the tumor itself and is determined by size, location, tumor biology, immunology, and distant metastases.

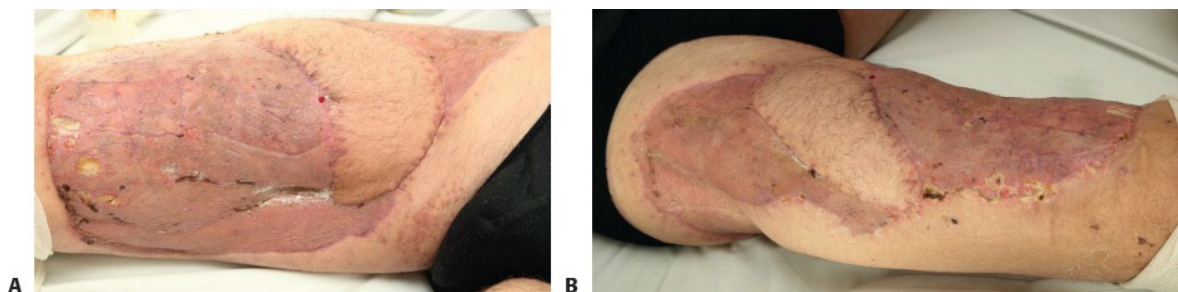


FIG 2 • Results after 2 months with uneventful wound healing (medial view **(A)**, lateral view **(B)**).

- Infectious control is of utmost importance in consecutive patients. Here, flap perfusion is as important as postoperative antibiotic treatment that can be required for long periods, when osteomyelitis is evident.

COMPLICATIONS

- Flap failure rates vary significantly depending on defect causes and localization. Failure rates between 1% and 10% are described internationally.⁴

- Other complications include wound infection, incomplete healing or ongoing infection, as well as partial flap loss. The latter can be as detrimental as a complete flap loss and should therefore be prevented if possible. Here, flap dimensions should not be extended as much as possible. If large defects have to be reconstructed, flaps should be combined, or microsurgical effort has to be increased for maximum safety (eg, inclusion of multiple perforators with in-flap anastomoses, use of arteriovenous loops, bypass free flaps, combined or chimeric flaps).

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41 Nerve Repair and Reconstruction—Sciatic Nerve and Femoral Nerve

CHAPTER

Gabrielle B. Davis and Catherine Curtin

Sciatic Nerve

DEFINITION

- The sciatic nerve is the largest peripheral nerve in the body.
- Its role is critical for lower extremity protective sensation and ambulation.
- Sciatic nerve injury in the setting of lower extremity trauma was historically an indication for amputation.
- Recent advancements in microsurgical techniques have led to improved outcomes and viability of the extremity.

ANATOMY

- The origin of the sciatic nerve is from the ventral divisions of L4, L5, S1, S2, and S3.
- The confluence of nerve fibers joins in the pelvis and exits via the greater sciatic foramen and below the piriformis muscle (**FIG 1**).
- In the buttocks, the sciatic nerve is located posterior to the gluteus maximus muscle and anterior to the superior gemellus, obturator internus, inferior gemellus, and quadratus femoris.
- It courses inferiorly, midway between the greater trochanter and the ischial tuberosity.
- In the posterior thigh, it travels deep to the long head of the biceps femoris.
- There are two distinct divisions of the sciatic nerve traveling within the same

sheath, the peroneal and tibial divisions.

- In the upper thigh, the tibial division gives off branches to all of the hamstring muscles (semitendinosus, semimembranosus, biceps femoris) except for the short head of the biceps femoris (**FIG 2**).
- The peroneal nerve distribution innervates the short head of the biceps femoris and the ischial portion of the adductor magnus muscle.
- The two divisions will separate completely at the level of the popliteal fossa.
- The posterior tibial nerve continues its course posteriorly to innervate the muscles in the posterior leg compartment.
- The common peroneal nerve will course laterally around the head of the fibula to innervate the muscles of the anterior and lateral compartments.
- The inferior gluteal artery provides majority of the blood supply to the sciatic nerve.

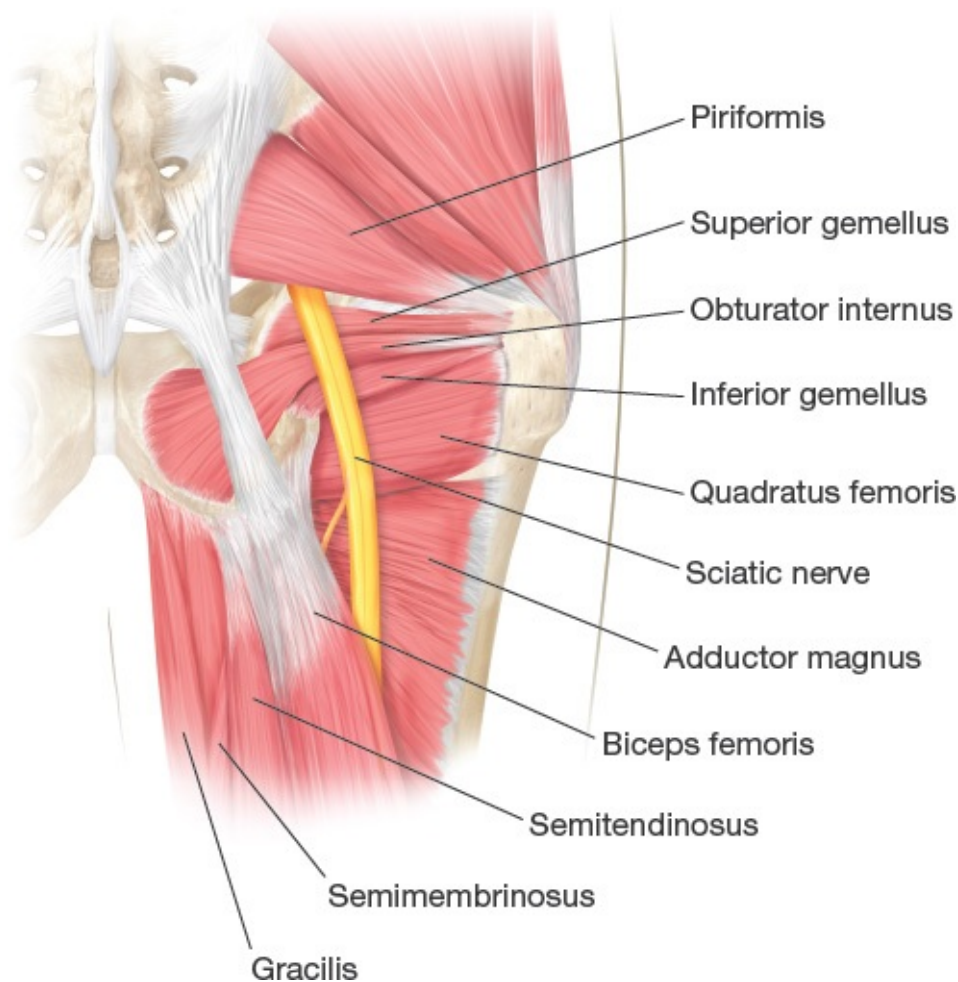


FIG 1 • Course of the sciatic nerve as it exits the pelvis

below the piriformis muscle.

Innervation/Function

- In the upper thigh, the sciatic nerve is responsible for motor function to the hamstrings muscles, which allow for flexion at the knee.
- The common peroneal and tibial branches are responsible for all of the motor function below the knee.
- It provides cutaneous sensory innervation to the posterior thigh.
- Its terminal branches provide sensation to the lateral aspect of the knee, lateral lower leg, and the dorsal and plantar surfaces of the foot.

Mechanisms of Injury

- The sciatic nerve is at risk for entrapment as it passes through the sciatic notch, especially in the setting of pelvic fractures.
- Traumatic injuries, particularly in penetrating trauma, can occur at any level with variable grades of severity.
- Iatrogenic injuries are not uncommon and result from pelvic and hip surgery, as well as injection site injuries.
- Revisional hip surgeries and patients with developmental dysplasia are at higher risk.¹
- Direct compression neuropathy is rare but has been described in comatose patients during prolonged anesthesia or long periods of sitting on a hard surface.² Piriformis syndrome is a compressive neuropathy of the sciatic nerve as it travels underneath the piriformis muscle.

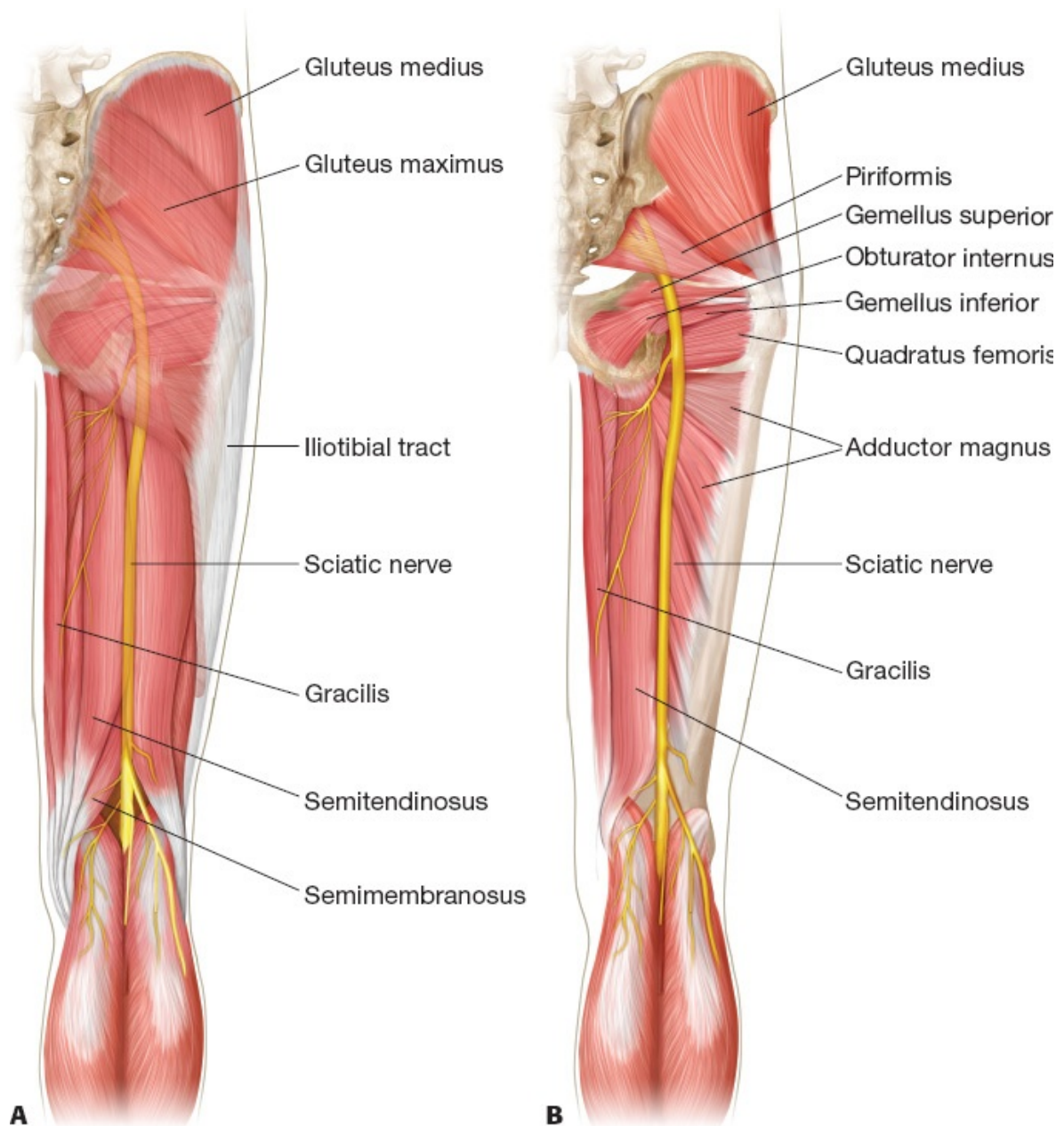


FIG 2 • A,B. The sciatic nerve path in the posterior thigh as it divides in the popliteal fossa into the peroneal and tibial divisions.

PATIENT HISTORY AND PHYSICAL EXAM

- Detailed history and physical examination must be obtained prior to the decision for operative management.
- Documentation of muscle strength using the Medical Research Council

(MRC) scale and sensory deficits by two-point discrimination along the cutaneous distribution of the nerve.

- The extent of sensory deficit can also be measured by the “ten-test for sensation.” The patient grades the level of sensation to touch on the injured side using a scale from 1 to 10. This number is compared to the level of sensation to similar touch on the uninjured side.
- Physical manifestations will be dependent on the level of injury, extent of each nerve division involved, and if it is a partial or complete injury.
- High injury can lead to significant morbidity, as buttock-level sciatic nerve lesions will result dysfunction of knee flexion, foot extension, flexion, inversion, eversion, and all movement of the toes.
- Sensory losses of variable degrees result in the posterior thigh and the entire foot and lower leg except for the medial aspect of the lower leg, which is supplied by the saphenous nerve.
- Injuries below the level of the hamstring can allow ambulation with an intact femoral nerve as the patient can have active flexion, extension, and locking of the knee.
- Patients with piriformis syndrome complain of buttock pain and numbness. This can also result in pain radiating down the leg and thigh “sciatica.”
- Patients with piriformis syndrome may have a history of buttock trauma, and symptoms are exacerbated by prolonged sitting or activities resulting in adduction and internal rotation of the leg.
- On physical exam, the proximal sciatic is tested by asking the patient to flex the knee against resistance with the lower leg extended.
- The peroneal branch is tested by assessing foot extension, eversion, and abduction of the toes against resistance.
- The tibial branch is tested by assessing foot plantar flexion and flexion of the toes against resistance.
- To test for piriformis syndrome, the “AIF” maneuver should be performed. The AIF maneuver consists of adduction, internal rotation, and flexion of the hip.
- Pain on AIF maneuver is diagnostic for piriformis syndrome.

IMAGING

- Detailed physical exam detailing sensory and motor deficits will help delineate the level of injury.

- Nerve conduction studies can also assist with localization of the injury.
- Of note, electromyography (EMG) has limited utility in the acute setting, as muscles may not demonstrate signs of denervation for several weeks.
- For piriformis syndrome, imaging may demonstrate hypertrophy of the piriformis muscle, anomalous vessels, or bands around the muscle.

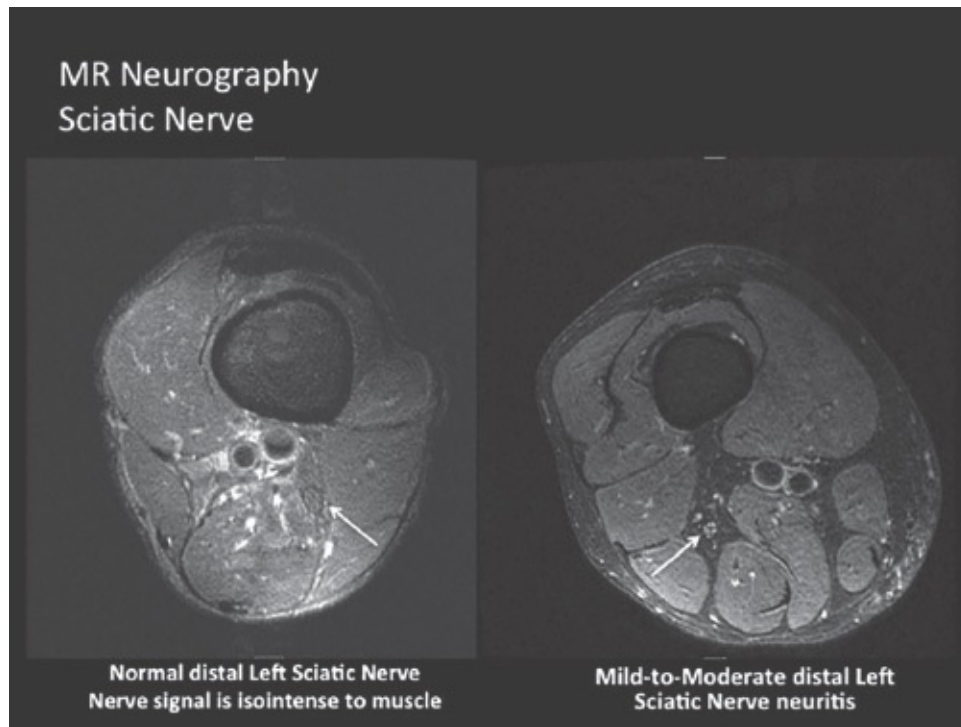


FIG 3 • MRI neurogram showing bright fascicles of the sciatic nerve.

- Magnetic resonance (MR) neurogram is an emerging technique in which edema or inflammatory changes around a nerve could help identify location of injury (**FIG 3**).

NONOPERATIVE MANAGEMENT

- If the injury is closed or due to compression, a trial of conservative management should first be attempted.
- Physical therapy should be initiated early, focusing on ambulation with bracing and orthotics.
- Pain management for relief of neuropathic pain includes pharmacologic modalities and therapy for desensitization.

- If no significant return of function is noted by 3 months, then surgical exploration is warranted.
- Unrelenting pain could indicate neuroma formation and may warrant surgical exploration even if signs of spontaneous recovery are evident.
- Treatment for piriformis syndrome is typically conservative including stretching of the muscle and image-guided steroid injections.
- If conservative treatment fails, then surgical release of the piriformis can be considered.



FIG 4 • Patient prepared for surgery of distal sciatic injury after knee dislocation. *Arrow marks the area of nonadvancing Tinel.* Note the needles in place for baseline motor responses during the intraoperative nerve monitoring.

SURGICAL MANAGEMENT

- Concern for laceration to one or both branches as demonstrated by significant motor or sensory deficits warrant early operative exploration.³
- Intraoperative electrophysiologic studies can serve as a guide to determine the area of injury for compression, stretch, or blunt injuries that have not spontaneously recovered (**FIG 4**).
- If nerve action potentials are detected across the injured site, external neurolysis should be performed.
- Nerve repair or reconstruction should be performed in the setting of a nerve not in continuity or intraoperative nerve testing that finds no recovery across

the zone of injury.

- Primary repair should always be attempted if there is not significant tension on the repair.
- If primary repair without tension cannot be performed, reconstruction should be performed with nerve grafting.
- Neuropathic pain is a common concern. The use of antineuropathic pain medications should be part of the patient's multimodal treatment.

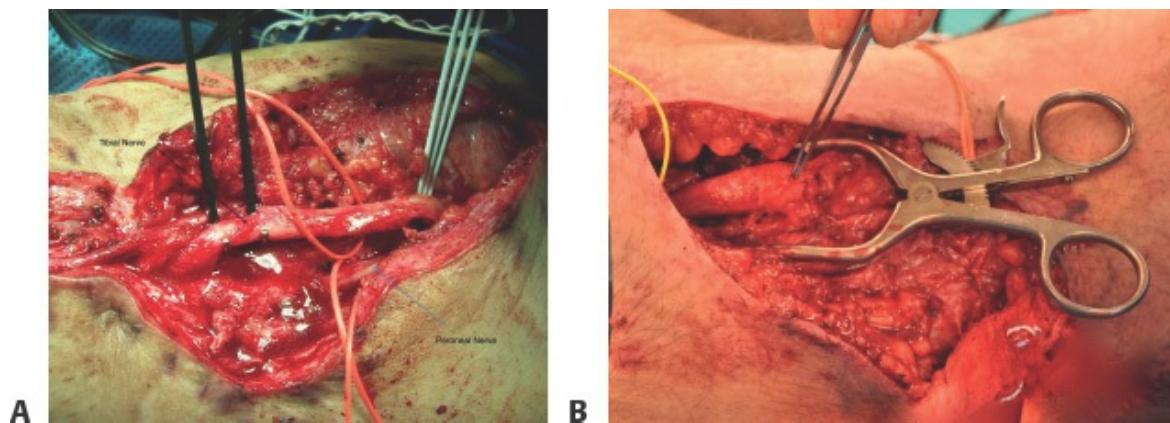
TECHNIQUES

■ Upper Sciatic Nerve: Hip and Buttock Pathology

- The patient should be placed in the prone position.
- A bump can be placed beneath the pelvis to provide flexion at the hips.
- The contralateral lower extremity should also be prepped and draped in the event a sural nerve graft is required for repair.
- A curvilinear incision is made starting at the posterior superior iliac spine, traveling laterally to the greater trochanter, and inferiorly to the gluteal crease.
- The dissection is carried down to the level of the gluteus maximus muscle.
- The superior and lateral aspect of the gluteus maximus muscle is released from the iliotibial tract.
- A 2- to 3-cm cuff of the muscle is left to the superolateral attachment to facilitate closure.
- An avascular plane below the gluteal maximus muscle should be developed by retracting the muscle medially to expose the sciatic nerve.
- Careful hemostasis using bipolar electrocautery is critical for good visualization.
- Care must be taken not to injure the hamstring branches as they typically run superior and medial to the main sciatic trunk.
- The gluteal neurovascular structures travel along with the sciatic nerve, and care must be taken to preserve these vessels.
- In some cases, the piriformis muscle will need to be detached from the femur laterally and retracted medially for improved exposure of the nerve at the sciatic notch.

■ Lower Sciatic Exposure: Thigh Pathology

- The patient is placed in the prone position.
- An incision is made over the suspected level of injury.
- Tourniquet may not be feasible, given proximal lesion and need for nerve monitoring; therefore, preinject suspected site prior to prepping with bupivacaine with epinephrine.
- Dissection can be carried down to the popliteal fossa for full exposure of the nerve depending on the level of injury (**TECH FIG 1A**).
- A plane is developed between the biceps femoris and the semitendinosus muscle.
- Careful hemostasis using bipolar electrocautery is critical for good visualization.
- The sciatic nerve can be exposed running deep to the biceps femoris (**TECH FIG 1B**).
- The sheath should be divided exposing the two divisions of the nerve for full inspection of injury.
- Further isolation of the nerve should be performed under an operating microscope, with adequate exposure of the nerve proximal and distal to the lesion.
- The nerve should be resected to healthy nerve fascicles.



TECH FIG 1 • A. Nerve-to-nerve monitoring of the sciatic nerve to tibial nerve to assess for neuroma in continuity. The *black arrow* represents the division becoming the tibial nerve, the *blue arrow* the peroneal

nerve. **B.** Lacerated sciatic nerve exposed in the posterior thigh. Note the large caliber of this nerve.

■ Primary Nerve Coaptation

- Nerve repair should be performed via end-to-end epineural coaptation with 9-0 monofilament permanent sutures.
 - Fibrin sealant can also be used to reapproximate and seal nerve ends.
 - A sural nerve graft can be interposed between the two ends if primary repair is not possible.
 - The peroneal and tibial components should be repaired separately aligning their respective fascicles.
-

PEARLS AND PITFALLS

Hemostasis

- Preinject incision with bupivacaine with epinephrine.
- A solution of 1 amp of epinephrine diluted in 100 cc of saline can be used to moisten a gauze, which is then dabbed in the wound to help with visualization.

Technique

- In the thigh, there are numerous branches of the sciatic nerve to the hamstring muscles, and care must be taken not to injure these branches during dissection.

Intraoperative monitoring

- Communication between neurology and anesthesia teams is critical to ensure that patient does not receive medications that will hinder intraoperative monitoring.
- The machines for the sequential compression device and warming blankets can cause background that interferes with intraoperative monitoring.
- Do not use tourniquet if planning intraoperative monitoring as ischemia of the nerve can result in neuropraxia.

Diagnosis

- Must determine sciatic nerve injury vs pelvic plexus trauma, as repair of the latter may be contraindicated.

POSTOPERATIVE CARE

- If there is concern for tension across the nerve repair, range of motion exercises should wait for at least 3 weeks.
- Physical therapy should be initiated early focusing on ambulation with the use of braces and orthotics.
- Early therapy for desensitization and scar management are useful to minimize postoperative pain.
- If pain is severe, a multidisciplinary approach with pain management, psychology, and therapy should be initiated.

OUTCOMES

- Factors associated with worse outcomes include delay in repair of more than 4 months, length of nerve defect, and division of nerve involved.⁴
- One of the largest series evaluating outcomes of civilian sciatic nerve injuries was performed at Louisiana State University Health Science Center:⁵
 - They evaluated outcomes of 353 patients with buttock-level and thigh-level sciatic nerve injuries over a 24-year period.
 - Mechanisms of injury included injection injuries, hip surgeries, fracture dislocations, blunt ant penetration trauma, and compression.
 - Patients with partial nerve deficits without severe pain or with significant spontaneous recovery were treated with conservative management and achieved good recovery of motor and sensory function.
 - Patients with detectable nerve action potentials intraoperatively only underwent neurolysis.
 - Overall, they found thigh-level sciatic nerve injuries achieved better outcomes than buttock-level injuries (Table 1).
 - In addition, for peroneal nerve injuries, both primary repair and nerve grafting had worse outcomes in comparison to tibial nerve injuries.
 - It is postulated that worse outcomes for peroneal nerve injuries results from less robust blood supply and connective tissue padding between fascicles compared to the tibial nerve.^{6,7}

COMPLICATIONS

- Neuropathic pain. There is a higher incidence of neuropathic pain with delayed repairs.⁶
- Development of complex regional pain syndrome (CRPS)
- Neuroma
- Rupture

Table 1 Percent of Patients Who Achieved At Least a Medical Research Council strength of at least 3

Level of Injury	All patients	Suture Repair	Nerve Graft Repair
Buttock	87%	73	62
Thigh	96%	93	80
Tibial	71%	30	24
Peroneal	79%	69	45

Kim DH, et al. Management and outcomes in 353 surgically treated sciatic nerve lesions. J Neurosurg. 2004;101(1):8-17.

Femoral Nerve

DEFINITION

- Femoral nerve injuries are more common than sciatic nerve injuries.
- Most injuries are iatrogenic, resulting from abdominal and pelvic surgeries.
- In general, femoral nerve injuries have a better prognosis than other lower extremity nerve injuries.
- Most patients typically maintain the ability to ambulate with the use of orthotics.
- Early identification and treatment are critical for prevention of muscle atrophy and the need for long-term rehabilitation.

ANATOMY

- The femoral nerve forms in the pelvis from the ventral rami of L2, L3, and L4 spinal roots (see **TECH FIG 1B**).
- The nerve travels in the retroperitoneum, anterior to the psoas muscle and medial to the iliacus.
- It enters the thigh deep to the inguinal ligament and travels through the femoral triangle, which is bordered superiorly by the inguinal ligament, laterally by the sartorius, and medially by the adductor longus muscle.
- In the femoral triangle, it runs lateral to the femoral artery.
- Approximately 1 to 4 cm distal to the inguinal ligament, it divides into the

anterior and posterior branches (**FIG 5**).

- The lateral circumflex femoral artery typically runs between the two divisions.⁸
- The anterior division provides motor innervation to the sartorius muscle and sensory innervation to the anterior and medial upper thigh.
- The posterior division provides motor innervation to the quadriceps muscles.

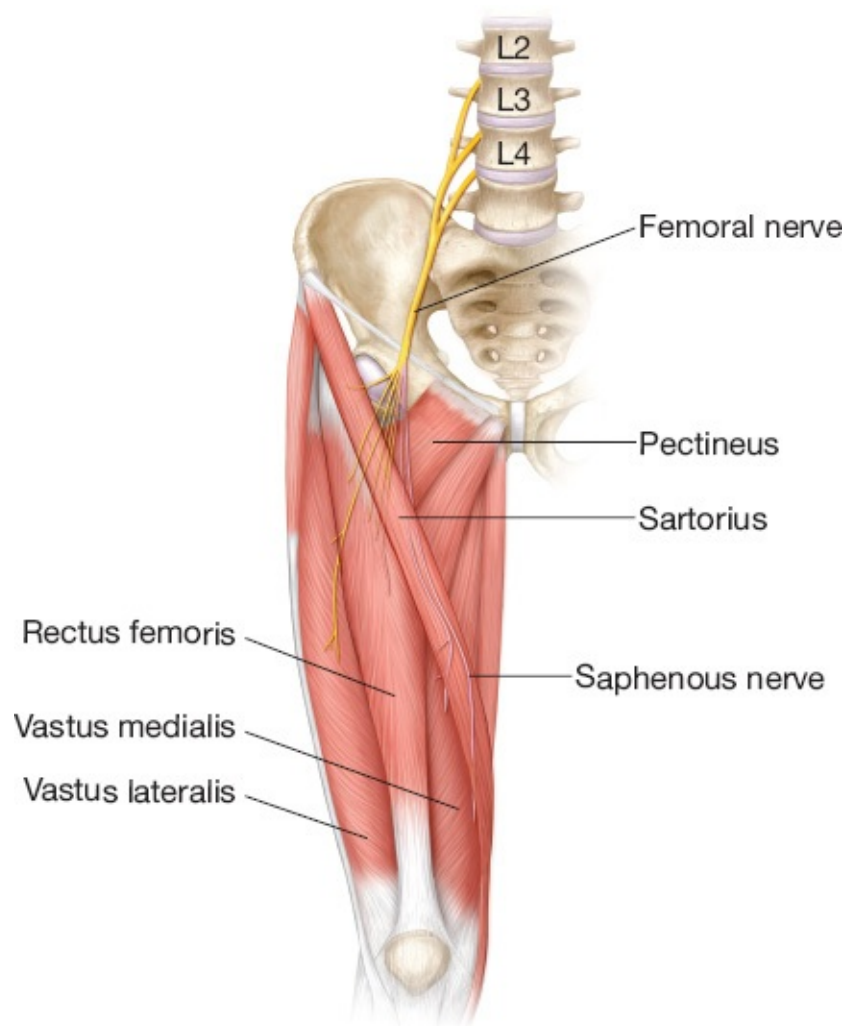


FIG 5 • Course of the femoral nerve in the anterior thigh.

- Its terminal division is the saphenous nerve, which runs with the greater saphenous vein and provides sensory innervation to the medial lower leg and foot.
- The blood supply to the femoral nerve is derived from the iliolumbar artery in

the pelvis and the deep circumflex iliac artery and lateral circumflex femoral artery in the thigh.

Innervation/Function

- In the pelvis, it provides motor innervation of the psoas and the iliacus muscles, which contributes to flexion at the hip.
- It also gives off a branch in the pelvis or upper thigh to innervate the pectineus muscle that aids in adduction of the hip.⁸
- In the thigh, it provides motor function to musculature of the anterior compartment including the quadriceps (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius) and the sartorius muscle.
- The quadriceps functions to extend the knee, and the sartorius contributes in flexion, abduction and lateral rotation of the hip, as well as flexion of the knee.
- The femoral nerve does not provide any motor innervation below the knee.
- Sensory innervation of the femoral nerve includes the anterior thigh.
- Its terminal branch, the saphenous nerve, provides sensory innervation to the medial knee and medial lower leg, as well as the medial aspect of the foot.

PATHOGENESIS

- Majority of the published femoral nerve injuries are the result of iatrogenic injury from abdominal and pelvic procedures, primarily from compression by self-retaining retractors.⁸
- The saphenous nerve especially the infrapatellar branch can be injured during knee surgery. This can result in chronic pain after total knee arthroplasty.⁹
- At the inguinal ligament, the femoral nerve can become compressed particularly with flexion, abduction, and external rotation of the legs, such as in lithotomy position.
- Inadvertent injury during arterial cannulation for cardiovascular procedures has also been described.
- Retroperitoneal hematomas, pelvic lymphadenopathy, and colon or rectal malignancies can lead to femoral nerve compression in the pelvis.
- Femoral nerve stretch injuries can also be caused by hip hyperextension in dancers or yoga instructors.
- Ischemic injuries can lead to nerve devascularization, such as in aortic or iliac surgeries.

PATIENT HISTORY AND PHYSICAL EXAM

- Motor and sensory exam techniques are same as sciatic nerve.
- Evaluation of a patient with femoral nerve injury employs the same principles as for sciatic nerve injury.
- Injury to the intrapelvic femoral nerve results in weakness with hip flexion, knee extension, and an absent or diminished patellar reflex.
- Sensory deficits can include numbness, paresthesias, or hyperesthesia along anteromedial thigh and medial lower leg.
- Hip flexion should be tested by supporting and flexing the knee while requesting the patient to flex hip against resistance.
- Loss of quadriceps function can result in knee hyperextension if there is a functional tensor fascia lata or gracilis muscle.
- On reflex examination, the patient will have loss of knee jerk.
- The saphenous nerve can be compressed at the adductor hiatus: tenderness, Tinel, and positive scratch collapse at the adductor hiatus can help identify this.

IMAGING

- Similar evaluation as for sciatic nerve injury

NONOPERATIVE MANAGEMENT

- Contusions, compression, traction, or partial injuries are initially managed with conservative strategies to determine the amount of spontaneous recovery.
- Early ambulation is encouraged with the use of knee or knee to ankle orthotics for weakness of quadriceps muscles.
- All patients should participate in aggressive physical therapy to prevent muscle atrophy and the development of deep venous thrombosis.
- Joints can also be maintained supple by dynamic and static splinting to prevent contractures, in the event early ambulation cannot be performed.
- If there is no recovery of motor or sensory function within 3 months, surgical intervention is warranted.

SURGICAL MANAGEMENT

- Complete lacerations require early surgical exploration and repair.
- If the patient's medical condition is stable, neurorrhaphy should be performed within the first 3 to 7 days of injury.
- Primary repair should be attempted when possible, and autologous nerve grafts from the sural nerves is an alternative.
- For high femoral nerve palsies, a transfer of the obturator nerve has been

described. These transfers have demonstrated good functional outcomes; however, there are limited data.¹⁰

TECHNIQUES

■ Retroperitoneal Femoral Nerve Exposure: Pelvic Pathology

- The patient should be placed in the supine position.
- Surgical bumps should be placed under the hip to elevate the affected side.
- Dissection is carried down to the level of the external and internal oblique muscles.
- The muscle-splitting technique is utilized to separate the muscles in the direction of their fibers.
- The transversalis fascia is opened and the peritoneum retracted superiorly away from the retroperitoneal fat.
- The retroperitoneal fat is carefully mobilized for exposure of the femoral nerve, just lateral to the femoral artery.
- The iliac vessels and ureter will be coursing medially to the nerve.
- Dissection can be carried superiorly to the iliopsoas muscle for high exposure of the nerve.
- Care should be taken not to injure the lateral femoral cutaneous nerve and ilioinguinal or genitofemoral nerves.
- The inguinal ligament can be divided if needed to facilitate exposure.

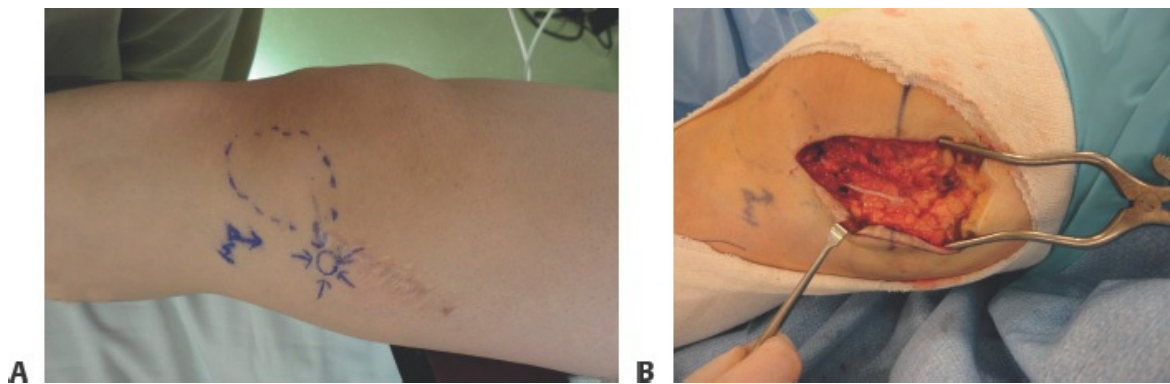
■ Lower Femoral Nerve Exposure: Thigh-Level Pathology

- The patient is positioned supine with the knee flexed 30 to 45 degrees.
- The femoral artery is palpated midway between the anterior superior iliac spine and the pubic symphysis.
- A longitudinal incision is made lateral to the femoral artery or the midaspect of the inguinal ligament.
- The incision is carried inferiorly to the midthigh, following the course of the

femoral nerve.

■ Painful Saphenous Neuroma

- The patient has had nerve blocked preoperatively, has had at least a 70% pain reduction, and is comfortable with the trade of decreased sensation for decreased pain.
- Identify area of pain and look for nerve proximally (**TECH FIG 2A**).
- If discrete nerve injury is identified, resect neuroma and reconstruct defect with allograft (**TECH FIG 2B**).
- If there is any question as to the extent of the zone of injury, it is advised to resect nerve proximally so it does not cross a joint and bury the end of the nerve within the muscle under no tension.



TECH FIG 2 • A. Patient with a painful neuroma in the saphenous nerve distribution after a laceration: *circle* denotes painful area and *dotted line* area of decreased sensation. **B.** Neuroma resected and defect reconstructed with nerve allograft.

■ Nerve Repair

- The nerve is identified using the existing wounds or the approaches described above.
- The nerve can be directly coapted if a tension-free repair is possible.
- If there is tension on the repair, a bridging nerve graft is required.
- Nerve coaptation is done using microsurgical technique.

- Use 9-0 suture with minimal amount of sutures placed.
- Fibrin sealants can be used to seal the repair site and to hold cabled nerve grafts together.
- Repairs are protected for 3 weeks with splints/braces to limit mobility at adjacent joints.

PEARLS AND PITFALLS

Pathogenesis	■ Similar to sciatic nerve injury. ■ The femoral nerve travels with the femoral artery and femoral vein, and concomitant vascular injuries are common.
Surgical management	■ Vascular injury must be performed prior to nerve repair.

POSTOPERATIVE CARE

- Physical therapy should be initiated early focusing on ambulation with the use of braces and orthotics.
- Therapy should also focus on desensitization and scar management.

OUTCOMES

- There is a paucity of robust studies on outcomes of femoral nerve repairs.
- For the majority of compression, stretch, or partial lacerations, good outcomes in motor function have been reported; however, most patients have residual sensory deficits.^{8,11}
- The Louisiana State University Health Science Center series published outcomes of 119 operative repairs of femoral nerve injuries over a 32-year period.¹¹
- Mechanisms of injuries included iatrogenic, hip or pelvic fractures, gunshot wounds, and lacerations.
- They demonstrated good functional recovery regardless of mechanism of injury, level of the lesion, or primary vs nerve grafting.
- In addition, they reported that the majority of patients who had neurolysis regained almost complete function, for both thigh- and pelvic-level lesions.

- They concluded that femoral nerve injuries overall have a good prognosis, consistent in other smaller series.⁶

COMPLICATIONS

- Chronic pain
- Development of complex regional pain syndrome
- Neuroma
- Rupture

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42 Keystone and Related Perforator Flaps

CHAPTER

Michael W. Findlay

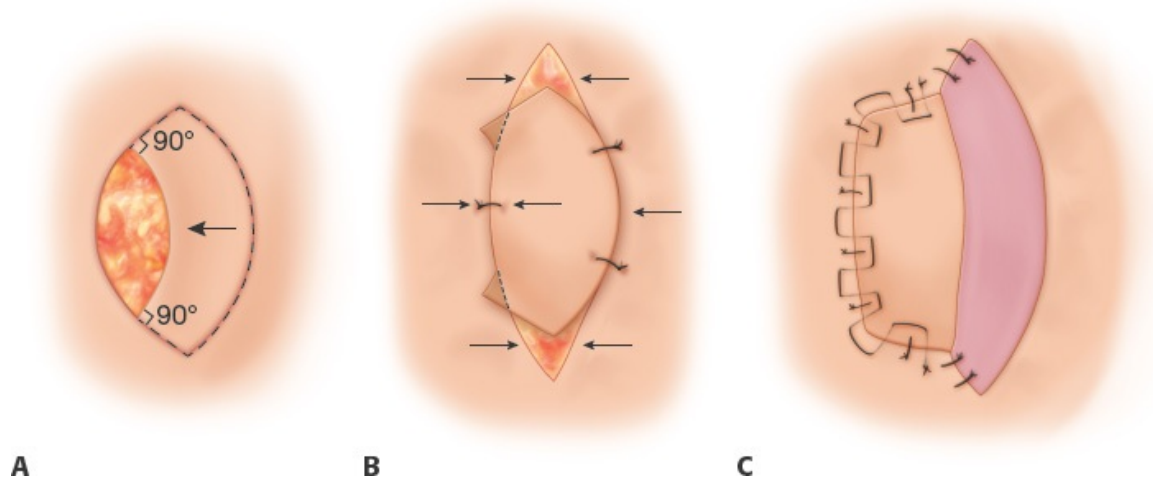
DEFINITION

- Keystone flaps encompass a group of related fasciocutaneous flaps first devised by Behan that share a common geometric design (a keystone shape similar to the keystone of stone arches) but can vary in the following ways:¹
 - Blood supply (perforator vs direct vs neurovascular vs composite)
 - Degree of islandization (complete vs incomplete, cutaneous or fasciocutaneous)
 - Method of transfer into the defect (advancement, transposition, combination)
 - Whether used alone or along with another keystone flap on the opposite side of the defect (double opposing keystone flaps).
- The classification of keystone flaps is based on the method of transfer and the number of keystone flaps involved (**FIG 1**).

ANATOMY

- Keystone flaps close defects by transferring fasciocutaneous tissue from an adjacent donor site to the defect while maximizing use of cutaneous arteries, superficial and deep venous drainage, and lymphatics without being defined by a specific form of the transfer (eg, transposition vs rotation).
- Human skin is well supplied with perforators and direct vessels for supply of keystone flaps with established patterns of cutaneous supply in the limbs (longitudinally oriented septocutaneous and musculocutaneous perforators), the trunk (segmental perforators with intercommunications in well-defined intermuscular planes), and the head and neck (profuse cutaneous supply dominated by direct cutaneous vessels in the head and perforators and direct vessels in the neck).²

- Conjoint supply to flaps refers to the incorporation of both cutaneous vessels and neurovascular supply within the flap (eg, incorporation of saphenous or sural nerves and their vasa nervorum) so as to augment blood supply. Codevelopment of arteries and nerves during development result in conjoint flaps that have a very strong axial blood supply that improves their robustness. An additional benefit is that blood supply from the vasa nervorum can be significant in some areas (eg, posterior thigh), further contributing to flap vascularity.
- Certain sites do not contain cutaneous perforators (eg, pretibial border, scalp) and hence represent problem areas for keystone flap elevation. Keystone flaps can be raised either side of the pretibial border for mobilization of tissue over a pretibial defect, but cannot reliably be designed directly over the pretibial skin as the basis for its blood supply due to the lack of direct cutaneous perforators.
- Superficial and deep venous drainage can be incorporated in most keystone perforator flaps through preservation of deep venous system along with arterial perforators and the subcutaneous veins by blunt dissection of subcutaneous tissues and islandization of the underlying fascia (if necessary) via the use of scissors through small windows in the subcutaneous tissue. Superficial veins are often numerous, and some may need to be divided to permit sufficient mobilization, but their division is performed sequentially, stopping once sufficient mobilization is achieved.



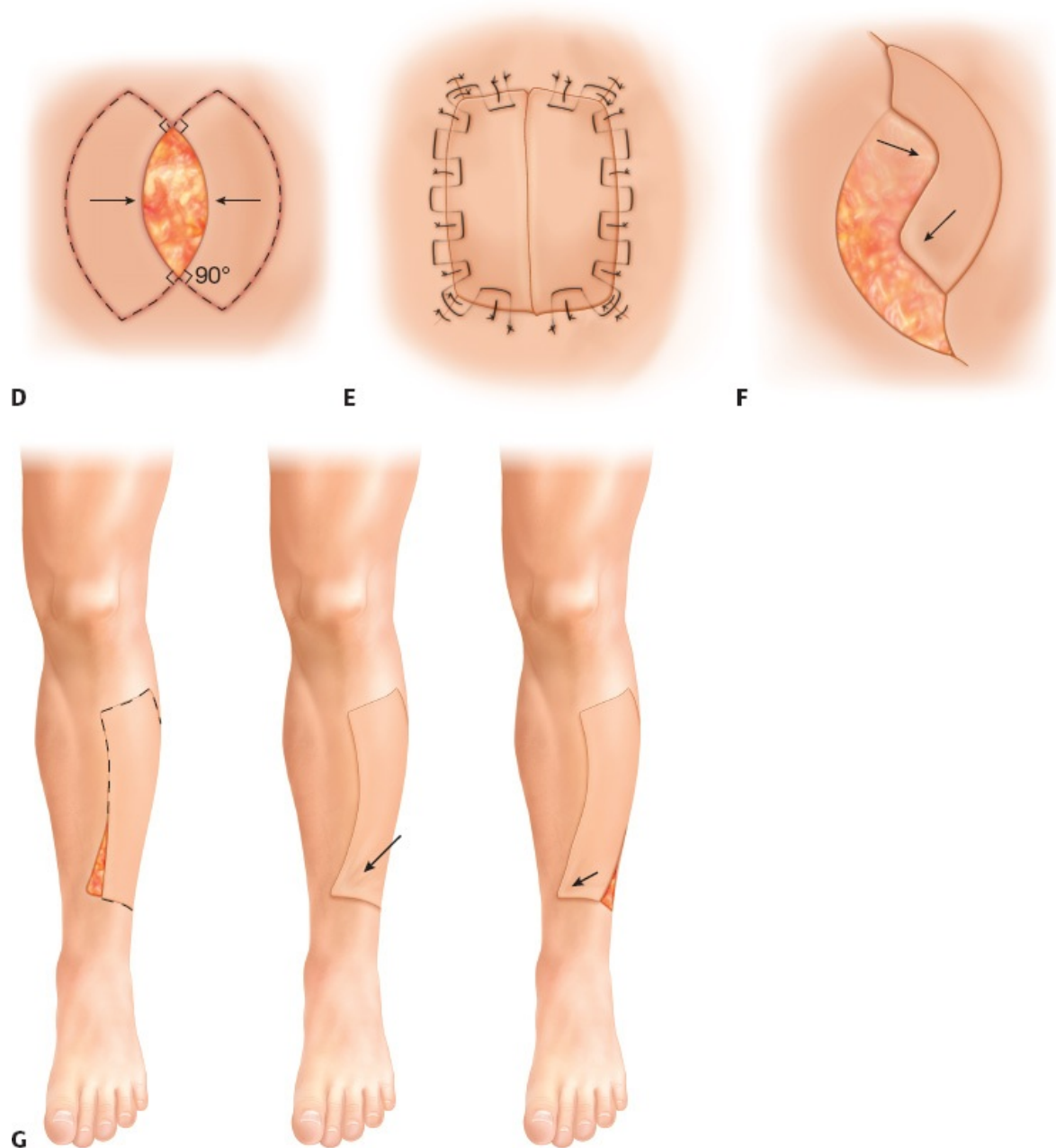


FIG 1 • Basic design and types of keystone flaps. **A.** An ellipse is formed as though the defect is to be closed primarily. Then, a keystone flap is designed beside it with sharp dissection undertaken through the skin and deep fascia. **B.** V-Y closure is performed at the flap margins during flap advancement. **C.** A skin graft may be used for closure of the secondary defect. **D.** Double opposing keystone flaps may be used on either side of

the defect. **E.** This is particularly useful for midline defects, for which the flaps can form mirror images. **F.** Yin-yang variant of double opposing keystone flaps. **G.** When one end of the keystone flap is transposed to fill a defect, skin grafting of the secondary defect may be necessary.

- The longitudinal orientation of fascial planes in many areas of the body (eg, limbs, paraspinous region) predispose to a longitudinal orientation for keystone flaps (slightly oblique orientations may help in limbs; see below), with the most appropriate mobilization of longitudinal keystone flaps being in a transverse direction. That is, the longitudinal orientation of the paraspinous musculature makes medial and lateral movement of keystone flaps relatively easy to cover central back defects, whereas the fibrous attachments between the skin and underlying spinous processes make superior or inferior movement problematic.
- Where there is circumferential limitation for flap mobilization and direct closure of the secondary defect (eg, distal limbs), orienting keystone flaps oblique to the long-axis provides an oblique (longer) circumference, thereby maximizing available donor tissue for closure.
- Placement of incisions in relaxed skin tension lines where possible is very helpful. The keystone shape is one that naturally hides well. Caution should be exercised in selection of any island flap in patients prone to abnormal scarring (eg, hypertrophic/keloid scarring). Partial flap islandization is a good option where feasible in such individuals or in patients very sensitive about the scar burden.
- Undermining and skeletonization of the perforator/direct vessel pedicle to the flap can be undertaken but is unnecessary in the vast majority of cases, and therefore, only the division of structures felt absolutely necessary for elevation, mobilization, and inset of the specific keystone flap are undertaken, thereby ensuring both surgical efficiency and safety.
- The design and flexibility in the blood supply, venous drainage, and mobilization of the keystone flap make it readily suitable for application in most areas of the body with local variation to optimize the outcome in specific areas.

PATIENT HISTORY AND PHYSICAL FINDINGS

- An understanding of the etiology of the defect to be reconstructed and relevant patient factors (health, comorbidities, activity levels, mobility, nutrition) help direct the most appropriate form of reconstruction in any potential flap case.
- As with all forms of flap reconstruction, particular interest should be focused on removal of the causative factor (eg, cancer, infection), identification and optimization of locoregional blood flow, selection of the best possible flap based on the needs of the defect and locoregionally available tissue, and optimization of the patient in the perioperative period.
- Any past history of conditions that affect local blood flow and wound healing should be elicited and mitigated where possible (eg, irradiation, peripheral vascular disease (micro and/or macroangiopathy), diabetes mellitus, smoking, and previous surgery/trauma).
- Examination findings of note include quality of surrounding donor sites for skin and tissue quality (including presence of radiotherapy tattoos, scars, fibrosis).

IMAGING

- The vast majority of patients do not require preoperative imaging or the use of intraoperative Doppler ultrasound to achieve reliable and timely reconstruction using the keystone flap or its variants as long as normal design principles are followed (see **FIG 1**).
- Computed tomography, angiography, and similar imaging modalities are the most useful to answer what direct or perforating vessels are available to the locoregional tissues, and delayed views can show the venous drainage to the area of interest.
- Fluorescence microscopy is invaluable for pre- and intraoperative imaging of the perforators and direct vessels to the skin but is rarely indicated for keystone flap elevation and has anaphylaxis as a risk factor.
- Imaging can be of use where previous surgery or trauma may have damaged the normal blood supply of the donor skin, or if there is significant arterial disease, and therefore, the selection of the most appropriate local vessels is necessary to ensure success.

NONOPERATIVE MANAGEMENT

- As with any fasciocutaneous defect, careful consideration should be given to the potential of the defect to be closed directly (under physiologic tension and

utilizing biological and mechanical creep as tolerated) or healed by secondary intention.

- The progression to flap reconstruction is considered where these options are either not possible or lead to unacceptable risks/complications.

SURGICAL MANAGEMENT

- Keystone flap reconstruction is reliable as long as a sequence of steps is undertaken in which the primary goal is sufficient mobilization of the flap to close the recipient and donor sites, while preserving as much arterial input, venous output, and lymphatic drainage as possible.
- No additional maneuvers are undertaken once recipient and donor-site closure can be achieved.
- If further mobilization of tissues is needed, then the flap can be fully islandized where the cutaneous vessels have been followed back through deep fascia and or freed where they exit muscles to facilitate mobilization; however, one must be cautious not to damaging perforating vessels as this can lead to tissue ischemia and necrosis.

Preoperative Planning

- The defect is assessed for its suitability for fasciocutaneous reconstruction, with a consideration of locally available tissue, including potential vascular pedicles, as the basis for the flap.
 - Keystone flaps can be performed in irradiated tissue¹ or even in the setting of lymphedema,² but caution should be exercised with flap planning in these settings so as to ensure adequate perforators/direct vessels and avoid unnecessary tension across suture lines.
- Where primary closure is unachievable, consider a keystone design and determine the form of mobilization that will work best to close the defect and match the local tissue shape (eg, transposition flaps are best for convex surfaces and advancements are best for flat surfaces).
 - There are circumferential limitations in the limbs (where the defect size represents over 30% to 40% of the circumference of the limb), as these defects may require grafting of the secondary defect or an alternate form of reconstruction.
- Defects are marked out as though they are to be closed directly as part of an elliptical excision/closure, and keystone flaps can be designed on one or both sides of the ellipse with the best side (or sides) chosen based upon local tissue

availability, suitability of local vessels, and the needs of the defect.

- The ellipse does not need to be excised. It simply gives a guide to the best orientation for the flaps.
- It is good practice to mark every excision or defect as though it will be closed by a keystone flap and then perform one if the defect cannot be closed primarily (if indicated). This maximizes experience with keystone planning.

Positioning

- Patient positioning is entirely dependent upon the ensuring easy access to the operative site. This is usually supine or lateral with circumferential draping in the limbs.
- Prone positioning is most useful for midline defects of the back that require bilateral keystone flaps.

Approach

- The design and mobilization of keystone flaps can be tailored to suit the needs of the defect and the area to be reconstructed, including variations in the following:
 - Design—eg, asymmetrical keystone in the calf
 - Mobilization—advancement, rotation, transposition, sliding
 - Grafting of the secondary defect
 - Single or double flaps—eg, yin-yang flap variant
 - Placement of V-Y points (best over convexities)
- Keystone flaps provide fasciocutaneous coverage of defects.
 - As a group, fasciocutaneous flaps are poorly suited to the reconstruction of complex three-dimensional defects where it is essential to obliterate dead space with filling with well-vascularized tissue.
- Keystone flaps are excellent at providing a simple and reliable approach to locoregional coverage and are sufficiently robust that they can be performed in conjunction with other flaps that will sit under the keystone flap (and can be tunneled under if necessary); thereby, providing vascularized soft tissue to fill a three-dimensional defect along with locally matching skin coverage.

TECHNIQUES

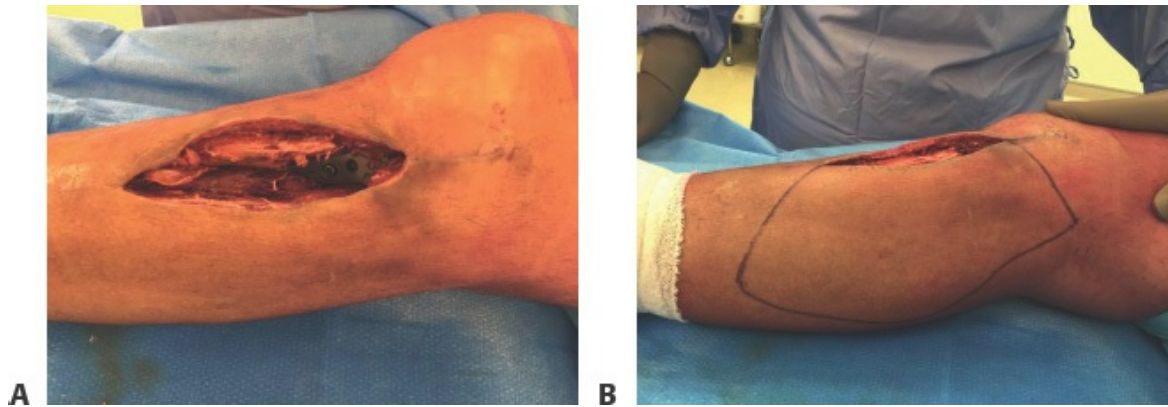
■ Keystone Flap Reconstruction of the Lower Leg

Markings

- Mark out the planned design that incorporates local pedicles and consider how the design will capture suitable venous drainage for the flap (**TECH FIG 1A,B**).
- Modify the design as required to maximize the potential for closure of both the defect and donor site (eg, the cone shape of the leg responds well to asymmetrical Keystone flaps (that are wider superiorly than inferiorly).
- Determine the nature of flap mobilization into the defect and plan in reverse around any pivot points.

Islandization of the Flap

- Apply a tourniquet to facilitate flap elevation where appropriate.
- Full islandization of the keystone flap promotes even tension across the flap (avoiding linear or point tension) and may augment cutaneous perfusion within the flap³ but must be weighed against the added scar burden.
- Where significant skin elasticity is present, it may be possible to minimize incisions on the donor defect side of the flap while still performing V-Y advancement of the rest of the keystone flap.
- The skin is sharply incised while preserving underlying neurovascular structures (particularly venous drainage) (**TECH FIG 2A**).
- Blunt dissection and targeted release of fascial or skin retaining ligaments and similar fibrous structures are undertaken as necessary while maintaining the integrity of the vasculature and lymphatics (**TECH FIG 2B**).
- Islandization of the fascia is undertaken if necessary, by sharp incision with scissors through small windows in the subcutaneous tissue (**TECH FIG 2C**).
 - Islandization is undertaken only to the degree to which is it required to achieve flap mobilization and closure.
- Dissection of perforators is rarely necessary but, when performed, care to should be taken to divide supporting connective tissue structures that might otherwise impede blood flow following mobilization of the flap.



TECH FIG 1 • A. A complex defect of the left leg involving an exposed plate for fixation of a compound tibial plateau fracture. Flap reconstruction is planned following debridement, washout, and confirmation of minimal bacterial contamination through wound swabs for microscopy, culture, and sensitivity. The anterior tibial artery was injured in the fracture, but the peroneal and posterior tibial vessels were intact. There was obvious undermining superiorly and inferiorly to the defect. Lateral tissues would be most appropriate as the basis for a keystone flap in this setting. **B.** An asymmetrical keystone perforator flap is designed to take advantage of cutaneous perforators from the peroneal and posterior tibial vessels. The flap makes good use of the lateral calf tissue but does not cross the axis of knee movement superiorly (on the right) and the diameter of the flap is larger than the defect width to ensure capture of perforators and ready availability of soft tissue to close the wound.



TECH FIG 2 • A. Islandization of the skin is performed by sharp incision while preserving the underlying soft tissues that contain important superficial venous drainage, lymphatics, and nerves. **B.** Blunt dissection is performed to retain important subcutaneous neurovascular structures (particularly superficial venous drainage seen on the right of the flap). The deep fascia is intact here with the exception of the existing defect. Flap closure of the defect was still not possible at this point; therefore, fascial islandization was performed. **C.** Fascial islandization is performed using partially open scissors and a pushing technique so as to minimize the risk of injuring nearby structures. This can be performed through small windows in the subcutaneous tissue so that neurovascular structures can be maintained. The leading edge of the flap is also mobilized (at the edge of the defect).

Assess Flap Viability and Achieve Definitive Hemostasis

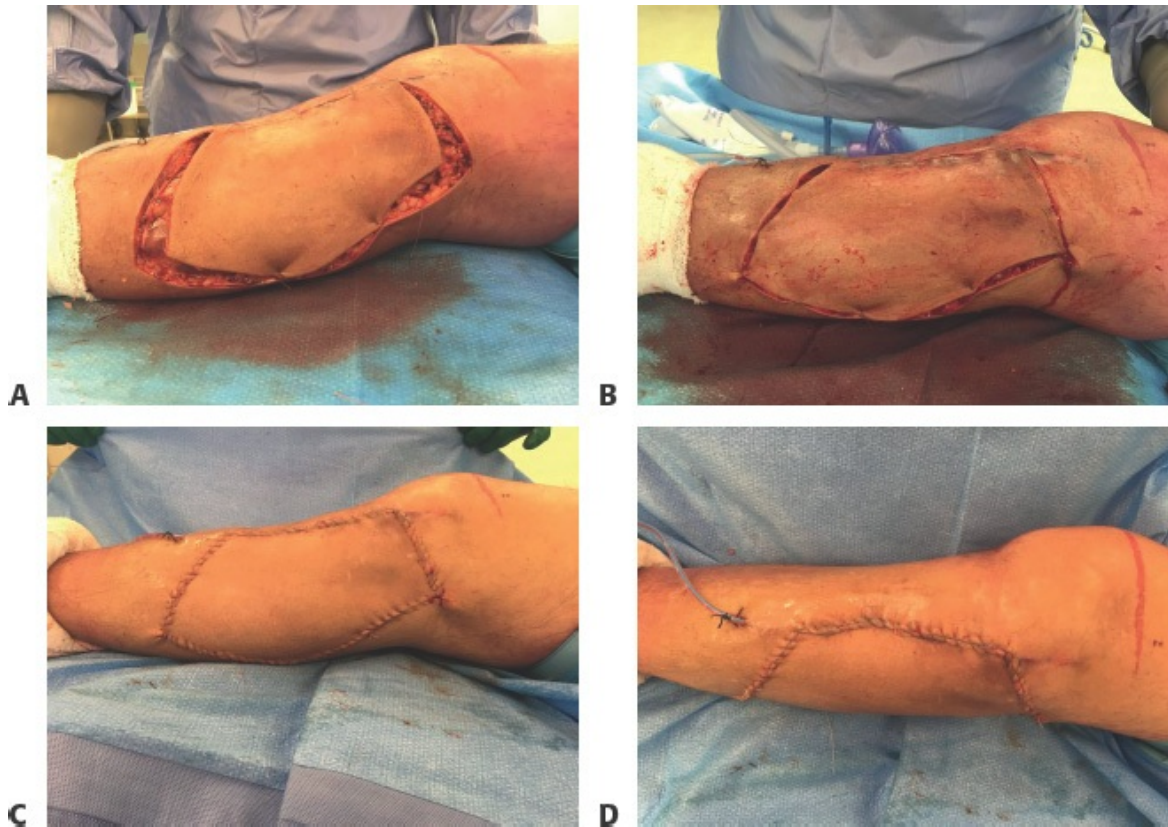
- Following mobilization of the flap, the tourniquet is released so the viability of the keystone flap can be assessed.
 - The site and contribution of individual perforators can be assessed at tourniquet release as blood flows back into the flap.
- It is typical for keystone flaps to demonstrate hypervascularity initially and they may display a 3% to 5% increase in cutaneous perfusion secondary to changes in blood flow from the process of flap islandization.
- Initially, the flap may resemble venous congestion, but venous changes should not be present beyond 10 to 15 minutes following release of the tourniquet (as assessed by the presence of rapid capillary return).
- It is ideal to achieve hemostasis at this time and consider whether a drain should be placed.

Strategic Suturing

- Even physiological wound tension is one of the key elements to the success and good long-term aesthetic results seen with well-performed keystone

flaps.

- Skin is normally under tension, and keystone flaps are typically under some tension upon closure.
 - Single lines of tension or point tension should be avoided as these are not tolerated well by the skin, including keystone flaps.
- Islandization can be helpful to ensure even tension across the flap.
- Excess flap tissue (common at the obtuse angles of the flap beside the defect) can be trimmed safely to facilitate wound closure.
- The generation of even tension begins with the placement of strategic sutures across both the defect and the donor site to induce creep across both wounds and the flap (**TECH FIG 3A,B**).
 - Creep results in some relaxation of the tissues and promotes a more even tension at final closure.
 - Mattress sutures are ideal as these provide for the induction of creep alongside wound eversion to improve the resulting scar.
- A fine continuous suture helps ensure eversion and even tension.
- The “hemming suture” (two horizontal mattress sutures followed by a simple suture) may be used as a means of closure (**TECH FIG 3C,D**).

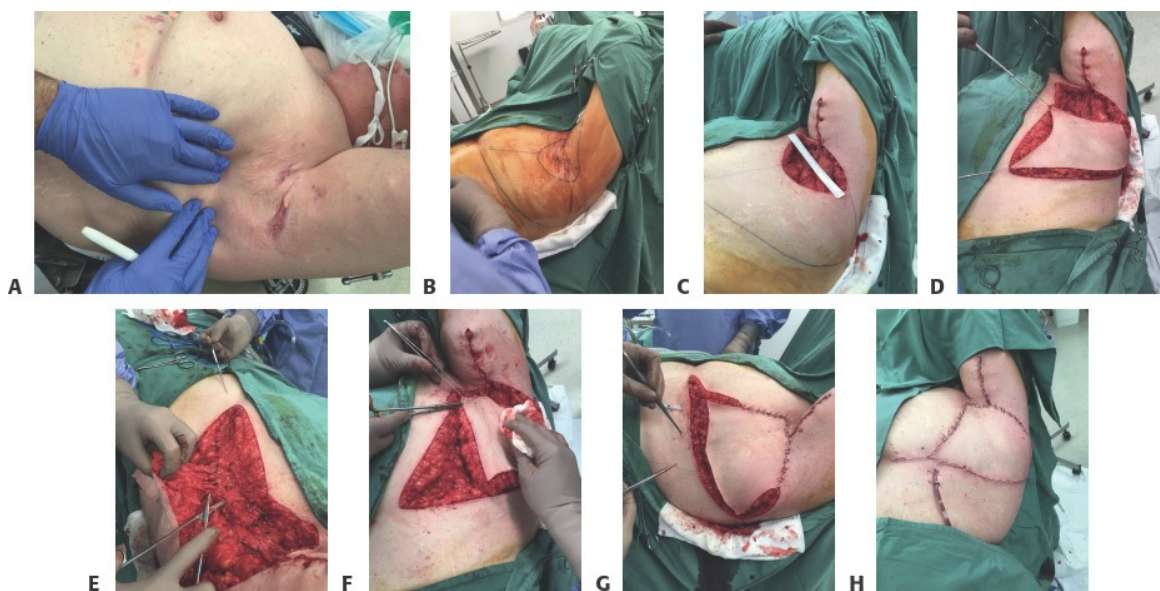


TECH FIG 3 • A. Following release of the tourniquet and hemostasis, strategic mattress sutures are placed, including tacking closure of the defect and the opposite side of the flap to induce creep and maximize even tension. The residual flap tissue at the leading edge of the flap has been trimmed. **B.** V-Y closure has been performed and further strategic mattress sutures have been placed to produce even physiological tension on the wound. **C.** A continuous skin suture (eg, Hemming mattress) is placed to ensure even tension and a nicely everted suture line for optimal aesthetic results. A suction drain is noted in the left of field, and this helped to minimize dead space in the otherwise planar defect. **D.** Anterior view of the flap at the point of V-Y closure to demonstrate even physiological tension and good contour following wound closure. Minor wound edge cones will resolve

on the convex surface of the leg in the following weeks to months without the need for revision.

■ Keystone Flap Reconstruction of the Axilla

- **TECH FIG 4** is the case of a patient with medically refractory hidradenitis suppurative of the left axilla who underwent excision of the involved axillary tissue and reconstruction with a lateral intercostal perforator-based keystone island flap (see **TECH FIG 4**).



TECH FIG 4 • A. Medically refractory hidradenitis suppurative in the left axilla prior to excision. **B.** The area to be excised is marked along with a lateral intercostal perforator-based keystone perforator island flap. The breast base is marked anteriorly with a dotted line to ensure that the reconstruction does not involve the breast directly. **C.** Following excision, partial closure is performed in the arm, analogous to a brachioplasty, leaving a defect that is 15 cm by 10 cm and not able to be closed directly while still maintaining shoulder movement. **D.** The skin of the flap is incised to form an island with elevation of the

tissues as necessary to facilitate transposition into the defect. **E.** Blunt dissection is performed to the undersurface of the flap to divide fascial attachments to the lateral chest wall, yet preserving all neurovascular structures where possible. **F.** Placement of strategic deep sutures begins with those for closure of the primary defect. **G.** Strategic suturing around the periphery ensures even tension before skin sutures are placed. Potential delays in wound healing are anticipated in the axilla, so interrupted sutures are used in this area. **H.** Full closure is completed with deep dermal and subcuticular sutures for the rest of the wound. Note that all of suture lines run around the perimeter of the breast, including into the lateral aspect of the inframammary fold and V-Y closures in the periphery, have maintained good contour and shoulder movement despite the size of the primary defect.

PEARLS AND PITFALLS

Poor donor sites

- The subcutaneous border of the tibia has no perforators and few direct vessels. Keystone flaps may be designed on either side of pretibial defects, but should not be designed directly over the tibia if possible. The scalp has direct vessels, but no perforators, and therefore, is not generally suitable for keystone flaps.

Flap mobilization

- Understanding the underlying muscle and fascial arrangements will facilitate ease of flap movement into the defect (eg, coverage of spinal defects using flaps on either side of the spine, but not above or below).

Aesthetics

- Consider modification of keystone flap margins to lie in natural skin creases or within aesthetic units as this improves their

	appearance and minimizes scar burden.
Dissection	■ Avoid overdissection of vascular structures. Only mobilize sufficiently to achieve wound and donor defect closure. Further dissection wastes time and puts important neurovascular structures at risk.
Skin grafting	■ Retain all skin trimmed from the keystone flap until the end of the case as this can be useful as donor skin for any skin grafting that might be necessary toward the end of the case.
Design experience	■ Plan a keystone flap for every defect but only use it if necessary and/or appropriate. This will rapidly increase experience with keystone flap planning.
Distal extremities	■ Use an oblique flap orientation to increase the available circumference for closure and have a low threshold for skin grafting of secondary defects.
Contour	■ Mobilization by transposition or elements of rotation produce a convexity, whereas advancement produces a more planar reconstruction. Consider matching the type of mobilization to suit the needs of the defect to enhance esthetics.
Documentation	■ An operative note that includes a diagram or photo of the flap planning and eventual closure is very useful. ■ In some circumstances, it may be difficult to identify the scars of keystone flaps, since scar generation is minimal in older individuals and the keystone design is not an obvious geometric pattern recognized by the human eye. ■ Where the defect was from oncologic surgery, positive margins may require a thorough understanding of the nature of flap mobilization so that further resection can be performed effectively if necessary.

POSTOPERATIVE CARE

- Following closure, if movements across joints adversely impact the integrity of the flap closure, then splinting is recommended.
- Splinting is rarely needed for more than 3 to 5 days.
- If the reconstruction is associated with an underlying musculoskeletal injury that requires immobilization, this takes precedence.
- Keystone flaps are very robust and are tolerant of being dependent for short periods in the immediate postoperative setting.
- Keystone flaps are suitable to ambulatory surgery.

- Encourage elevation of the limb to limit postoperative swelling, but it is rare to need to immobilize patients.
- If closure is tight, then splinting will limit the risk of wound dehiscence during the period of postoperative edema (3 to 5 days).
- Keystone flaps do not require specific monitoring in general.

OUTCOMES

- Keystone flap reconstruction is a straightforward approach to fasciocutaneous reconstruction that is well tolerated by patients and has a low complication profile relative to other forms of flap reconstruction.
- A retrospective analysis of 200 consecutive keystone flaps for head and neck reconstruction demonstrated a 2% flap revision rate for partial flap necrosis and a single complete flap loss.⁴ This compares very favorably to other forms of fasciocutaneous flap reconstruction in the head and neck.

COMPLICATIONS

- Keystone flaps are robust as evidenced by their relatively low partial and total flap loss rates.
- Minor complications can occur in up to 15% of cases in the head and neck with local wound issues including suture abscess, cellulitis, and wound dehiscence being the most common forms.⁴
- Donor site morbidity is very low, secondary to the conservative nature of flap dissection, including minimal dissection of muscle.

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Section V: Amputation and Replantation

43 **Amputation of the Lower Extremity: Toes, Foot, Ankle**

CHAPTER

Kedar S. Lavingia and Jason T. Lee

INTRODUCTION

- Partial foot amputation (PFA) is a common sequel to advanced vascular disease secondary to diabetes and its complications.¹
- PFA may also occur due to injury, infection, cancer, or birth defect.
- PFA affects approximately 2 per 1000 patients in western countries, making it the most common type of amputation surgery.²
- PFA is associated with a significant failure rate and numerous complications including skin breakdown, ulceration, and equinus contracture, which can lead to subsequent and more proximal amputation.
- Thoughtful patient selection, early involvement of neuropsychiatry and physical medicine and rehabilitation (PM&R) are fundamental to a successful outcome.

BACKGROUND/CONSIDERATIONS

Forefoot Amputation

- Toe disarticulations are quite challenging when dealing with the remaining cartilage of the involved metatarsal head and possible complications of residual osteomyelitis.
- Ray amputation, which involves the excision of the toe and part of the metatarsal, provides a more viable option of ensuring an adequate surgical

debridement of the septic margins if that is the indication.

- Indications may include a wet or dry gangrene of a toe, osteomyelitis of the metatarsal head and/or proximal phalanx, septic arthritis of the metatarsophalangeal joint, and gross infection of the toe.
- Suggested inclusion criteria by a variety of authors for this type of amputation may include one or two palpable pedal pulses, ankle brachial index (ABI) ≥ 0.8 , and toe brachial index ≥ 0.7 .³
- In recent studies, absence of pulses, delayed capillary filling, high erythrocyte sedimentation rate, high creatinine, and high neutrophil counts were found to be predictive factors for a poor clinical outcome.⁴
- Indications for transmetatarsal amputation may include wet or dry gangrene involving only the forefoot and/or infection involving the forefoot, whereas the inclusion criteria are the same as those mentioned above required for a ray amputation.
- Amputation at the metatarsal level causes a muscular imbalance due to resultant equinovarus deformity from unopposed action of gastrocnemius, tibialis anterior, and tibialis posterior tendons, which is coupled with the deficiency of the muscular tension of the extensor tendons.^{5,6}

Midfoot Amputation

- Lisfranc disarticulation is a disarticulation through the tarsometatarsal joint, whereas Chopart disarticulation is a disarticulation through the talonavicular and calcaneocuboid joints leaving only the hindfoot (talus and calcaneum) behind (**FIG 1**).
- These amputations are rarely performed in diabetic foot infections due to high failure rate and the proximity of infected tissue to the heel pad.⁷

Hindfoot/Ankle Amputation

- This category included the amputations such as Syme amputation and has the indications and inclusion criteria as mentioned in the forefoot amputation category (**FIG 2**).
- Syme amputation has been advocated for trauma cases; however, Syme amputation can give good results in patients with diabetic foot infections.⁸
- Syme amputation should be reserved for patients with at least a palpable posterior tibial pulse and an ankle-brachial index of more than 0.5.

SURGICAL MANAGEMENT

Preoperative Planning

- All patients undergoing an amputation should be evaluated by both neuropsychiatry and PM&R early.
- Prevention and early detection of future disease should be discussed with the patient.
- Education on pressure-area pathogenesis is important as part of a strategy to encourage the patient to prevent further problems.
- Cardiac optimization is important given the high incidence of cardiac disease among this patient population.
- If discussing limb viability from trauma, a multidisciplinary approach involving vascular, orthopedics, and plastics should take place prior to proceeding with amputation.



FIG 1 • Midfoot amputation.



FIG 2 • Hindfoot/ankle amputation.

TECHNIQUES

Toe Amputation

- Place the patient supine with a small bump under the ipsilateral foot if desired.
- Incision lines are marked on the skin as appropriate for the planned amputation.
- For a partial toe amputation, a plantar-based flap is commonly used. However, several other possibilities exist (eg, dorsal flap, side-to-side flap, and fish-mouth flap).⁹
- The most important principles are to ensure that the flap is viable before closure and to perform a tension-free repair.
- All necrotic tissue is debrided. If infection is present, the tendon sheaths must be drained of any purulent material, which often tracks along them.
- Microbiology samples may be sent for culture and sensitivity testing.
- Neurovascular bundles are ligated or cauterized as they are dissected.
- If the wound is left open, many dressing options are available. Commonly, the wound is loosely packed with gauze soaked in saline or povidone-iodine. Generous amounts of cotton dressing and ACE bandages are then applied.

- If conducting an osteotomy, dissection is carried down to the periosteum, and a bone cutter or pneumatic saw is used to perform the osteotomy at the appropriate level.
- It is important to be mindful of tendon insertions and to consider the biomechanical effects that sacrificing these will have; disruption may predispose to further surgical intervention in the future.

Transmetatarsal Amputation

- A curved fish-mouth incision is made just proximal to the infected tissue of the foot (**TECH FIG 1**).
- The incision runs from the midshaft of the fifth metatarsal laterally to the midshaft of the first metatarsal medially through a midplane axis and carried circumferentially. The plantar flap is left longer to allow for closure. Also, the residual flap should be little longer on the medial side than on the lateral side again to aid with closure.⁹
- The incision is again circumferential and extended downward to bone. As the incision is deepened, hemostasis is achieved by means of cautery and/or vessel ligation with ties. The bony landmarks of the metatarsals are identified and presented by means of a periosteal elevator. The metatarsals are cut with a saw, and the bony ends are rounded with a bone file.¹⁰
- The wound is copiously irrigated and adequate hemostasis is achieved.
- Standard synthetic braided suture is used for closure of muscular and subcutaneous layers. Skin closure with synthetic nonbraided suture results in low skin tension and good approximation. Staples may also be added and dressing applied.



TECH FIG 1 • A–D. Transmetatarsal amputation.

■ Midfoot Amputation (Lisfranc/Chopart)

Lisfranc Amputation

- The proximal incision passes over the dorsum of the foot at the base of the metatarsals. The plantar incision is placed distally so that the infected material is removed, but the flap is long enough that it may be tailored later to cover the ends of the resected bones.
- The tarsometatarsal joints are disarticulated at the first, second, and third metatarsal bases. The fourth and fifth metatarsal bases are cut through with a motorized saw and left in the residual foot.
- On occasion, it may be necessary to leave the third metatarsal base in place to provide a better surface to support the local soft tissues.
- The residual foot is then dissected from the plantar surface, starting at the level of the short flexor muscles. The flap is then beveled to the distal edge.
- The wound is then checked for any residual infectious tissues and for hemostasis. It is tailored to close without tension.

Chopart Amputation

- Amputation of the forefoot at the talonavicular and calcaneocuboid joints closely resembles that of amputation at the tarsometatarsal joints.
- The plantar flap is long enough to fold up to the dorsum of the foot. In infected cases, no bone trimming is performed. In noninfected cases, the distal surfaces of the calcaneus are rounded to relieve potential pressure points.

■ Ankle Amputation (Syme Amputation)

- The anterior incision of the Syme amputation extends across the ankle just distal to the tip of each malleolus.
- The posterior incision extends from the malleoli vertically and also transversely across the heel.
- The extensor tendons are all divided at the level of the skin incision.
- The dorsalis pedis artery and vein are then identified, ligated, and divided.
- The ankle joint capsule is incised while plantar-flexing the foot. The medial and lateral ankle ligaments are divided.
- The tendons of the posterior tibialis and flexor hallucis longus are transected,

taking care to avoid injury to the posterior tibial artery. This will be the sole blood supply to the flap.¹¹

- The heel fat pad is carefully dissected by staying close to the calcaneus to avoid creating a buttonhole, which can doom the operation. The ankle joint is disarticulated and the foot is passed from the table.
- In a single-stage amputation, the malleoli are divided with a saw at the level of the articular surface of the tibia and the width is reduced by vertical bone excision. Holes are drilled in the medial, anterior, and lateral parts of the distal tibia and fibula to secure the heel pad directly under the tibia.¹²
- In a two-stage Syme amputation, the wound is closed by suturing the heel flap to the dorsal fascia. Six weeks later, the malleoli are removed through separate vertical incision.¹³

PEARLS AND PITFALLS

Indications	■ A careful and complete history and physical examination are essential. Preoperative studies are necessary to plan the resection and reconstruction. Vascular supply to planned reconstruction and amputation must be assessed prior to procedure.
Surgical incision	■ A long plantar flap leads to a better end-bearing stump. Leaving a flap to short will lead to complications and wound break down.
Infections/flap necrosis	■ Intravenous antibiotics and surgical debridement may be necessary to treat deep infections. Early diagnosis and treatment can affect outcome. Do not delay treatment if suspected infection after amputation.
Postoperative management	■ Keep the wound wrapped in sterile soft dressings and a pressure wrap for 3–5 days and physical therapy and rehab should be consulted early in the course.

POSTOPERATIVE CARE

- Keep the wound wrapped in sterile soft dressings and a pressure wrap for 3 to 5 days.
- Staples/sutures will remain in place for approximately 2 weeks.
- Physical therapy and PM&R should be consulted early.

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Amputation of the Lower Extremity: Above-Knee Amputation, Below-Knee Amputation, Through-Knee Amputation

44 CHAPTER

Anahita Dua and Jason T. Lee

INTRODUCTION

- Approximately 1.7 million Americans are living with the loss of a limb, and this number is expected to nearly double by 2050.¹
- Amputations of the lower extremity may be performed for a myriad of reasons including infection, trauma, cancer, and pain.
- Thoughtful patient selection, early involvement of neuropsychiatry, and physical medicine and rehabilitation (PM&R) are fundamental to a successful outcome.

APPROACH CONSIDERATIONS

- Before considering an amputation, the patient should be evaluated by vascular surgery to ensure no other options (endovascular or open) exist.
- Patients who are suited for an above-knee amputation (AKA) include those who have limited or no mobility, a nonfunctional limb, infection that has progressed above the knee, inadequate overlying skin/muscle to provide stump coverage, and those patients who do not have adequate blood flow to heal a below-knee amputation (BKA) incision (popliteal pressures less than 50 mm Hg).
- BKA is suited in patients who wish to ambulate with a prosthesis, do not have extensive infection above the knee joint, and have popliteal pressures greater

than 50 mm Hg to heal the stump.

- Knee disarticulations (through-knee amputations) represent less than 2% of all amputations and are typically performed for trauma; they are best suited for patients who are unlikely to ambulate.
- AKA is also suitable for patients unlikely to ambulate, but cannot be performed in patients with inadequate femoral artery blood flow as the AKA stump will not heal.
- Severe infection that involves the femoral head or proximal femur also preclude AKA.²

PREOPERATIVE PLANNING

- All patients undergoing an amputation should be evaluated early by both neuropsychiatry and PM&R.
- Thorough physical exam and arterial pressures should be used to determine which level (AKA or BKA) is best for the patient (**FIG 1**).
- Cardiac optimization is important given the high incidence of cardiac disease among this patient population.
- If discussing limb viability status post trauma, a multidisciplinary approach involving vascular, orthopedic, and plastic surgery services should take place prior to proceeding with amputation.

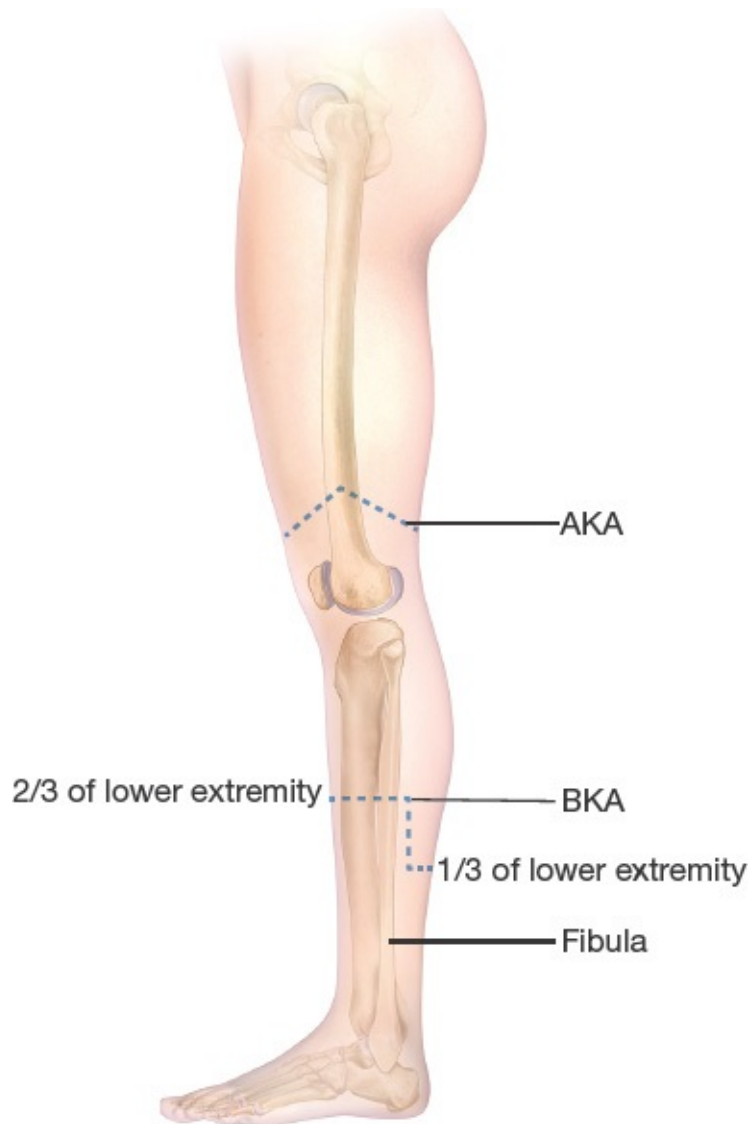


FIG 1 • Incisions for above-knee (AKA), below-knee (BKA), and through-knee amputation.

TECHNIQUES

■ Above-Knee Amputation

- Place the patient supine with a small bump under the ipsilateral hip to internally rotate the leg.
- Outline the circumferential incision (fish mouth configuration)—amputation

level should be at the proximal femur, midfemur, or supracondylar.

- Sharply dissect the skin, soft tissue, and muscle down to the femur.
- Identify the vascular bundle and individually suture ligate the artery, vein, and nerve—nerve should be transected as proximally as possible.
- Using a periosteal elevator, elevate the femoral periosteum.
- Transect the bone using a Gigli saw or battery-operated oscillating saw.
- Bevel the femoral edge using the saw.
- Utilize a rasp to smooth the bone edge.
- Irrigate the wound thoroughly.
- Complete the amputation with the amputation knife.
- Approximate the anterior and posterior flaps with 0-Vicryl for deep fascia and 2-0 Vicryl for superficial tissue using interrupted figure of eights.
- Staple or suture the skin with 2-0 nylon.
- Cover skin wound with antibiotic ointment, petroleum jelly dressing, and cotton dressings for padding. Wrap a circumferential compressive elastic dressing for the stump.

■ Below-Knee Amputation

- Place the patient supine with a bump under the ipsilateral thigh and place a thigh tourniquet.
- Prep the lower extremity circumferentially up to the midthigh.
- The anterior incision is placed 10 cm distal to the tibial tubercle (anterior incision 2/3 total circumference), and the posterior incision (1/3 total circumference) should be long enough to ensure flap coverage (typically 1.5 times the length of the anterior flap).
- Carry down the anterior incision sharply to the tibia.
- Carefully tie off the anterior tibial vessels with 2-0 silk suture.
- Dissect through the lateral and superficial posterior compartments of the leg.
- Using a periosteal elevator, remove the periosteum and soft tissue to expose a clean segment of bone to be transected.
- Using a Gigli saw or battery-operated saw, transect the tibia—bevel distal tibia cut at 45 degrees.
- Transect the fibula 2 cm proximal to the tibia.
- Remove the muscle and soft tissue with an amputation knife.

- In the posterior compartment, identify and ligate the peroneal and posterior tibial vessels with 2-0 silk.
 - Tie all nerves with 2-0 silk and transect sharply as proximally as possible.
 - Utilize a rasp to smooth the edges of the tibia.
 - Deflate the tourniquet and coagulate or tie off any bleeding vessels.
 - Close pretibial fascia with 2-0 Vicryl figure of eights in an interrupted fashion.
 - Staple or suture the skin.
 - Cover skin wound with antibiotic ointment, petroleum jelly dressing, and cotton dressings for padding. Wrap a circumferential compressive elastic dressing for the stump.
-

■ **Through-Knee Amputation**

- Mark the leg at knee level with a posterior soft tissue flap of sufficient length to close the incision without tension.
- Proximal thigh tourniquet is placed, the patient is prepped and draped, planned incisions are remarked, and the tourniquet is inflated without exsanguination.
- Incisions are created with sharp dissection and carried down circumferentially to the level of the knee, through the joint, and along the drawn posterior flap.
- Distal leg is removed from the operative field.
- Distal end of femur is shaved down from distal to proximal using a sagittal saw anteriorly, posteriorly, medially, and laterally.
- Do not manipulate the insertion of the adductor magnus muscle.
- Preserve cruciate ligaments and posterior capsule.
- Posterior articulating surface is shaved to cancellous bone.
- Identify the patella and advance it to cover the distal surface of the femur.
- Sew the quadriceps tendon to the cruciate ligament and posterior joint capsule so that the posterior surface of the patella is in direct contact with the distal end of the femur.
- Sew the hamstring muscles to the quadriceps tendon and posterior capsule using 2.0-polydioxanone (PDS) so the distal femur is covered.
- Place a closed-suction drain, such as a Jackson Pratt (JP) drain over the

myodesis, and trim the posterior flap so it can be sewn to the anterior flap using 2.0-Prolene vertical mattress suture.³

PEARLS AND PITFALLS

Posterior flap creation

- Ensure that the flap length is adequate for coverage without being too tight as a tight flap can result in necrosis of the closure.

Stump edema

- Swelling of the stump post operatively can result in wound healing complications as it places tension on the suture line. Wrapping the stump in a sterile ACE bandage for at least the first three days post operatively will assist with keeping the edema to a minimum.

Knee immobilizer

- A knee immobilizer is a good adjunct to help keep the knee joint straight during recovery. A straight and flexible knee joint is imperative to being able to use a prosthesis for ambulation. A knee immobilizer has to be used with caution as it can cause pressure wounds to the knee area of the stump. It should be removed under supervision daily during physical therapy to prevent pressure wounds.

POSTOPERATIVE CARE

- Keep the wound wrapped in sterile soft dressings and a pressure wrap for 3 to 5 days.
- Staples/sutures will remain in place for a minimum of 4 weeks.
- Drains may be removed when 24-hour output is less than 30 mL.
- Ensure no contractures by placing a knee immobilizer in patients with a BKA.
- Physical therapy and PM&R should be consulted early.
- Nonweight bearing for 2 weeks.
- Fit for prosthesis and advance rehabilitation in 3 to 6 months.⁴

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Section VI: Lymphedema

45 Lymphaticovenous CHAPTER Anastomosis

Ann-Charlott Docherty Skogh and Martin Halle

DEFINITION

- Lower extremity lymphedema can either be primary, occurring as a structural or anatomical birth defect, or secondary following surgery and/or radiotherapy, trauma, infection, and other causes.
- Chronic lymphedema is a progressive condition where tissue remodeling lead to fibrosis and fat deposition if not treated adequately.
- Lymphedema can be severely disabling and affect the patient's daily life with difficulties in range of motion, fitting into normal clothing, and can also cause psychological distress.

ANATOMY

- The lymphatic system is composed of collecting vessels and lymph nodes.
- The lymphatic system of the lower extremities includes a superficial and a deep system divided by the muscle fascia-aponeurosis. Perforating lymphatic vessels interconnect both systems.
- The superficial system includes the interfascial and epifascial subsystems, where the latter is the most superficial one, located between the skin and the saphenous fascia (**FIG 1**).

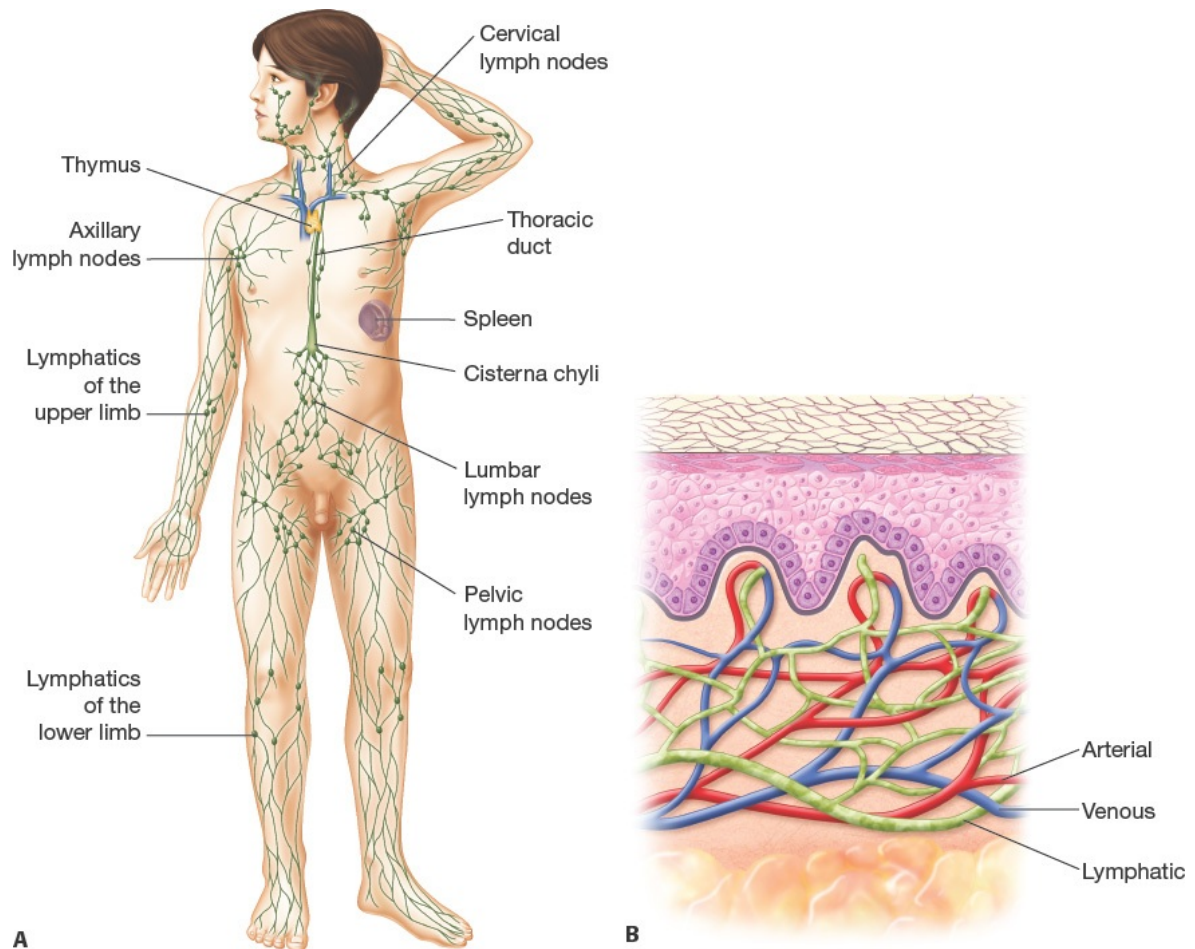


FIG 1 • A. The lymphatic vessels of the lower limb drain into the inguinal and pelvic system and proximally to cisterna chyli. **B.** The sub- and intradermal lymph capillaries drain into deeper lymphatic collectors located below the dermis.

PATHOGENESIS

- Lymphedema can be primary, occurring as a structural or anatomical birth defect in which genetics seem to play a major role. Secondary lymphedema may occur after surgery and/or radiotherapy, trauma, infection, and other causes. Lymphatic filariasis following infection of invading pathogens is globally the most common cause of secondary lymphedema.¹
- The transport capacity of lymphatic drainage may be reduced by damage that further affects the homeostasis of the interstitium, including both the cellular and extracellular compartments.

- Lymphostasis with fluid accumulation in the tissues leads to inflammation and subsequent tissue remodeling of skin and subcutaneous tissues with fibrosis and fat deposition.

NATURAL HISTORY

- Untreated lymphedema tends to deteriorate with time, leading to fibrosis and fat deposition that occur at later stages. Inflammatory changes make the patient susceptible to recurrent episodes of erysipelas and cellulitis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Initially, there is a phase with reduced transport capacity without clinical swelling.
- Stage 1 lymphedema includes pitting edema that subsides with limb elevation, whereas elevation is not effective in stage 2, when fibrosis of the tissues may already be seen.
- Stage 3 includes increasing volume of the extremity with congestive dermatitis, trophic skin, and fat deposition.²
- A pitting test shall be performed with pressure applied to the affected area (ideally over the tibial bone) for at least 60 seconds with the examiners fingers. The absence of pitting confirms tissue remodeling and fat deposition, where lymphaticovenular anastomoses may be less successful and suction-assisted lipectomy shall be considered.³

IMAGING

- Imaging methods for lymphedema include radionuclide lymphoscintigraphy, indocyanine green (ICG) lymphography, and magnetic resonance lymphangiography.
- Lymphoscintigraphy can indicate the location of lymph collectors, but does not provide information about specific areas of occlusion.²
- ICG lymphography, on the other hand, visualizes real-time superficial lymph flow without radiation exposure.⁴



Video p7-c045

- ICG lymphographic patterns are categorized from normal linear pattern (stage 0) to abnormal dermal backflow patterns; splash (stage I), stardust (stages II–IV), and diffuse stardust (stage V) patterns with lymphedema progression of the lower extremity⁵ (**FIG 2**).

DIFFERENTIAL DIAGNOSIS

- Venous insufficiency
- Deep vein thrombosis
- Thrombophlebitis
- Erysipelas
- Renal failure
- Cardiac failure
- Neurofibromatosis
- Lymphangioma
- Others

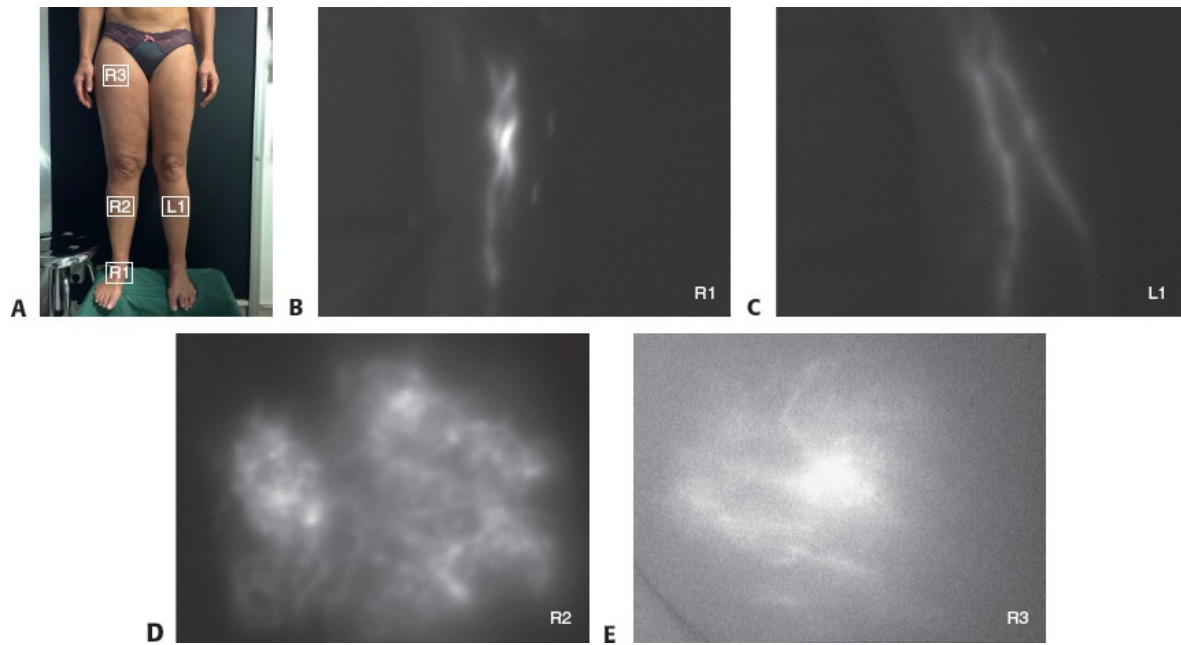


FIG 2 • **A.** Right leg lymphedema. **B,C.** ICG images illustrating different flow patterns. Linear pattern (**D**), stardust pattern (**E**), and diffuse pattern as described by Narushima M, Yamamoto T, Ogata F, et al.

NONOPERATIVE MANAGEMENT

- Decongestive physiotherapy and compression garments have been the most common nonsurgical treatment methods in reducing edema volumes, although they are not curative.

SURGICAL MANAGEMENT

- Surgical treatment of lymphedema includes debulking surgery, suction-assisted lipectomy, vascularized lymph node transfer, and lymphaticovenular, lymphaticovenous, and lymphatico-lymphatic anastomosis.⁶
- Suction-assisted lipectomy is usually performed for late lymphedema, when edematous tissues have remodeled to adipose tissue, without remaining signs of pitting edema. However, there is still a lack of consensus whether vascularized lymph node transfer or lymphaticovenous anastomosis is the primary choice in pitting lymphedema.
- Surgical treatment of lymphedema with lymphaticovenular anastomosis has recently gained popularity due to better imaging systems together with recent technical advances in supramicrosurgery, including high magnification

operative microscopes and supramicrosurgical instruments.^{7,8}

Preoperative Planning

- Positive pitting test is of paramount importance for the prognosis, because the absence of pitting may reveal a certain degree of irreversibility of the lymphedema.
- Lymphoscintigraphy facilitates confirmation of the diagnosis.
- ICG lymphography is commonly performed using a photodynamic eye (PDE) camera (Hamamatsu Photonics, K.K, Hamamatsu, Japan), ideally in an outpatient setting for patient selection and subsequently repeated perioperatively.
- Preoperative markings of linear flow as well as dermal backflow areas, based on ICG imaging, facilitate selection of anatomical sites for multiple LVAs.

Positioning

- The patient is usually positioned supine or in a unilateral “frog-leg” position for better access to medial structures, depending on results from preoperative ICG imaging.

Approach

- The procedure may be performed under local anesthesia, whereas general anesthesia is recommended if any movement during surgery is to be avoided.
- The use of two or three microscopes can facilitate the performance of multiple anastomoses.

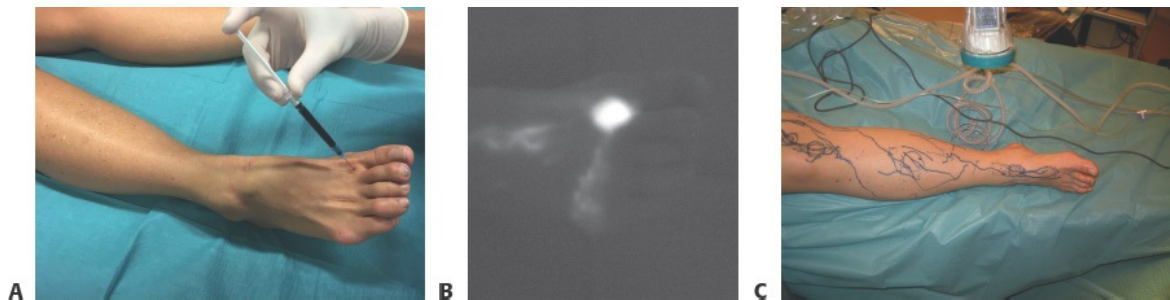
TECHNIQUES

■ Lymphaticovenous Anastomosis

- A volume of 0.3 to 1.0 mL ICG (Pulsion Medical Systems SE, Feldkirchen, Germany, 5 mg/mL) is injected intradermally into the first web space of the affected leg to locate lymphatic vessels suitable for anastomosis (**TECH FIG 1A,B**). Similarly, the technique can be used for upper extremity lymphedema, performed with intradermal injection into the first and fourth web space.
- A linear flow pattern segment confirmed by ICG lymphangiography is

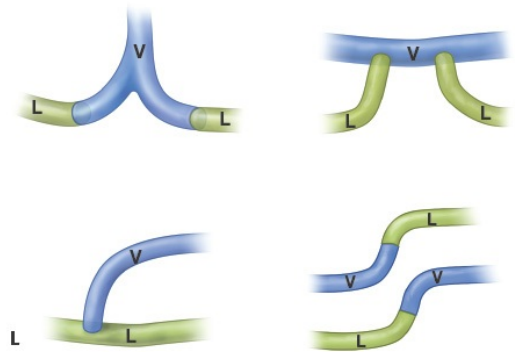
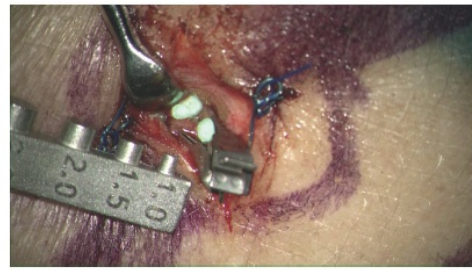
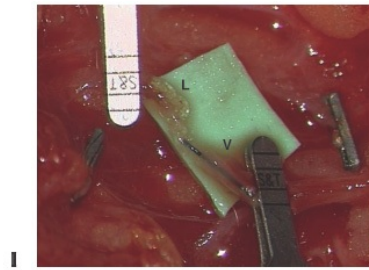
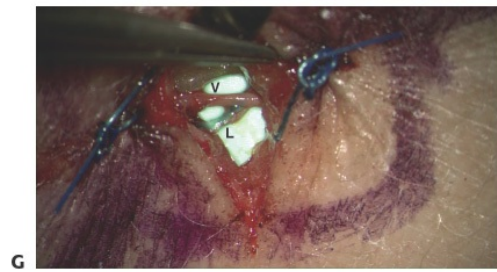
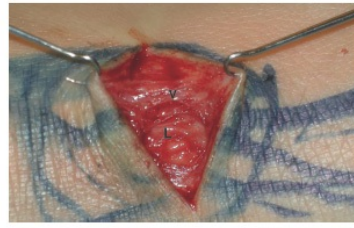
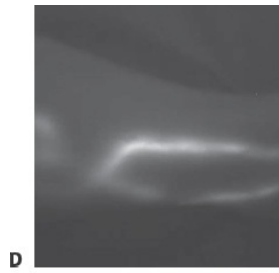
chosen (**TECH FIG 1C,D**).

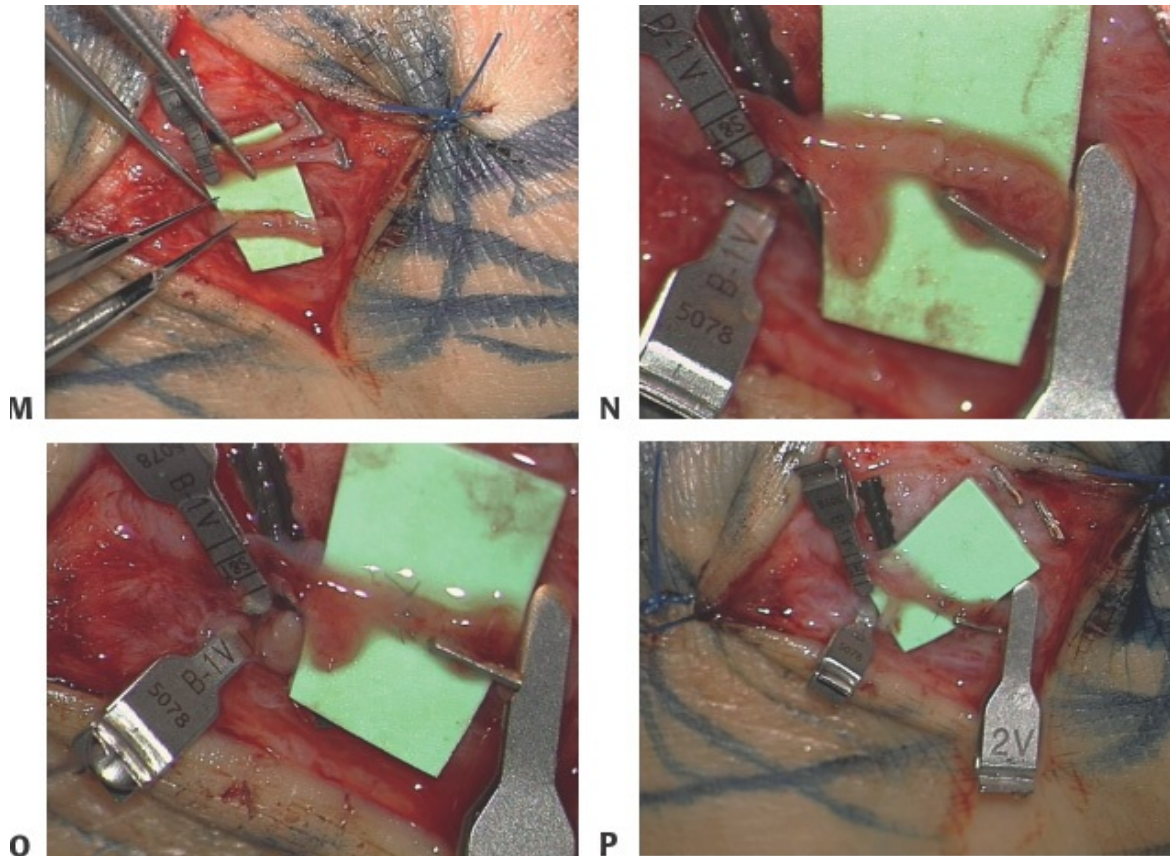
- A 15- to 30-mm incision transverse to the selected lymph vessel is performed into the deep layer of dermis. The remaining thickness of the dermis is gently dissected under meticulous hemostasis, avoiding injury to the subdermal lymphatic vessels and venules (**TECH FIG 1E**).
- If lymphatic vessels are difficult to locate, a complementary injection of 0.3- to 1.0-mL patent blue (Patentblau, Guerbet, Germany V, 25 mg/mL) can be administered intradermally, a few centimeters distal to the skin incision.
- Suitable subdermal venules (around 0.5 mm in diameter) are explored adjacent to the chosen lymphatic vessel (**TECH FIG 1F**).
- Preparation and alignment of vessels (**TECH FIG 1G,H**).
- A stent using 6-0 nylon suture that is placed into the lumen of the vessels may be used to facilitate anastomosis of the vessels, which range from 0.3 to 0.8 mm (**TECH FIG 1I,J**).
- Patent blue or ICG lymphography can be used to confirm patency of LVA (**TECH FIG 1K**).
- The venules of choice may differ in diameter compared to the lymphatic vessels, where different types of anastomoses may be applied. The first choice is an end-to-end anastomosis. If a Y-shaped venule is available, both afferent and efferent lymphatic flow can be diverted into the same venule⁹ (**TECH FIG 1L-P**).



TECH FIG 1 • **A.** Injection of indocyanine green into the first web space of the foot. **B.** ICG staining of lymphatic vessels in the foot as seen with PDE camera. **C.** Markings on the skin of the leg after injection of ICG. **D.** ICG staining of linear lymphatic vessels in the leg as seen with PDE camera. **E.**

Incision of the skin showing subdermal venule (V) and lymphatic vessel (L). **F.** Preparation of venule (V) and lymphatic vessel (L) stained with patent blue. **G.** Preparation of venule (V) and lymphatic vessel (L) stained with patent blue with background to facilitate anastomosis. **H.** Aligning of vessels before suturing. **I.** Stent using 6-0 nylon suture to prevent back wall stitches. **J.** End-to-end lymphaticovenular anastomosis with 12-0 nylon sutures. Vessels with luminal diameter of approximately 0.5 mm. **K.** Lymphatic flow over anastomosis as shown by patent blue staining in lymphatic vessel and venule. **L.** Different types of lymphaticovenous anastomoses according to Narushima et al.⁹ (V) Venule or vein, (L) lymphatic vessel. **M.** Preparation of Y-shaped vein and lymphatic vessel. **N,O.** Coaptation of vein and lymphatic vessel with antegrade and **(P)** retrograde flow.





PEARLS AND PITFALLS

- Choose small venules to avoid venous backflow.
- Tension-free anastomosis is of great importance due to the low-flow nature of lymphatic vessels and venules.
- Perioperative antibiotics are indicated due to long surgery time and an increased risk for erysipelas in lymphedema patients.
- The dorsum of the foot and lower leg are usually good locations to perform LVAs in the lower extremity. The lymphatic vessels are usually easy to find after examination with ICG, complemented with patent blue if necessary. The upper extremity presents a similar pattern, where it is easier to find suitable vessels on the dorsum of the hand and in the forearm compared to the upper arm.
- LVAs may be more difficult to perform in the thigh area due to the greater width of the epifascial compartment.

POSTOPERATIVE CARE

- Low molecular weight heparin is indicated the first postoperative week due to immobilization during surgery.
- Postoperatively, the leg is kept slightly elevated at night and a low-pressure bandage is applied the day after surgery to avoid interstitial swelling.
- Postop day 1, the patient is allowed to ambulate with full weight bearing with a low-pressure bandage applied (about 30 mm Hg), but with reduced physical activity.
- Normal physical activity can be resumed after 3 weeks.

OUTCOMES

- Several case reports of successful treatment of lower extremity lymphedema with LVAs are available, and multiple LVAs seem to be favorable.¹⁰
- Reduced number of episodes of erysipelas after LVAs has been reported.¹¹
- The outcome of lower extremity LVAs has been less investigated as compared to upper extremity LVAs, and data from prospective, controlled studies are scarce.

COMPLICATIONS

- Infections may occur in the postoperative period and shall be treated with antibiotics.
- Temporary local redness can occur due to venous backflow into the anastomosis.
- Deterioration of the lymphedema is a very rare complication, but can occur, after LVA surgery.

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46 Lymphedema: Lymph Node Transfer

CHAPTER

Adrian S. H. Ooi and David W. Chang

DEFINITION

- The lymphatic system is responsible for reabsorption of excess interstitial fluid, protein, and waste products, as well as filtration and removal of foreign material from interstitial fluid and absorption of lipids from intestines. Up to 50% of the body's circulating albumin is processed through the lymphatic system every day.
- Lymphedema is an abnormal accumulation of protein-rich fluid in the interstitial compartment resulting in edema formation.
- It occurs when the generalized or regional lymphatic load exceeds its transport capacity.
- Long-standing lymphedema leads to chronic inflammation, adipose tissue hypertrophy and fibrosis, and eventually lymphatic channel fibrosis.
- Lymphedema is a problem that affects about 200 million people worldwide.
- Distribution: Lower limb 90% greater than upper limb 10% greater than genitalia 1%.

ANATOMY

- Endothelial cells bud off from veins during early embryonic development and transdifferentiate to form the lymphatic vasculature.
- The lymphatic primary plexus is composed of capillary-like vessels and is further remodeled to form pre-collecting, collecting, and ductal components. The major lymphatic ducts are formed by two paired lymph sacs (jugular and iliac) and two unpaired sacs (retroperitoneal and cisterna chyli).
- Lymphatic channels are thin-walled vessels composed of endothelial cells connected by discontinuous junctions and surrounded by smooth muscle. The

basement membranes of the larger, deeper lymphatic vessels have multiple intercellular gaps, which form valves through which fluid flows unidirectionally.

- The superficial dermal lymphatics are unvalved and drain into the valved subfascial deep dermal system, which run with the superficial veins.
- Lymphatic fluid is then transported through afferent lymphatic channels to lymph nodes, which are gathered in basins throughout the body. After undergoing immunological processes within the lymph nodes, the fluid flows out through efferent lymphatic channels and ultimately into the thoracic ducts and subclavian veins where they rejoin the venous circulation.
- Lymph nodes are bean-shaped structures distributed along the lymphatic channels. They consist of a capsule, an outer cortex and an inner medulla. Multiple afferent lymphatics can enter via the outer cortex, and a lymph node is supplied by an artery and a vein at the hilar region, which accompany a single efferent lymphatic vessel. The lymph nodes contain lymphocytes and macrophages, which are responsible for removal of organisms, foreign substances, and tumor cells.
- Lymph nodes are distributed deep in the body along the respiratory and gastrointestinal tract and superficial in the cervical, thoracic, and inguinal regions.
- Lymphatic fluid transportation is under humoral influences and is propelled by a combination of:
 - Smooth muscle surrounding the collecting vessels that have an intrinsic autocontractile mechanism
 - Extrinsic compression by neighboring skeletal muscles
 - Negative intrathoracic pressure

PATHOGENESIS

- Lymphatic homeostasis is a function of filtration of plasma across the capillary walls into the interstitial compartment and absorption by the lymphatic system. This rate of filtration is governed by the Starling equation whereby net filtration is determined by intra- and extracapillary hydrostatic and oncotic forces.
- Lymphedema arises when the rate of filtration exceeds absorption by 2 to 4 L/d.
- This disruption can occur at the level of the lymphatic vasculature or the lymph nodes and can arise due to a primary or secondary disease process.

- True primary lymphedema can be classified as congenital (Milroy disease), pubertal/praecox (Meige disease), and tarda, which occurs in the adult age group. Lymphedema praecox is the most common form of primary lymphedema.
- Lymphedema can also arise secondary to acquired damage to the lymphatic system. These include infection, trauma, malignancy, surgery, and radiation.
- The most common cause worldwide is filariasis, caused by the parasite *Wuchereria bancrofti*. In the developed world, it is most commonly due to treatment for cancer.
 - For breast cancer treatment, it occurs in up to 40% of cases with lymph node dissection and radiation and 5% of cases with sentinel lymph node biopsy.
 - 41% after gynecological cancer treatment.
 - 12% to 55% after groin lymph node dissection.

NATURAL HISTORY

- When there is disruption in the lymphatic system and as lymphatic pressure builds, flow within the lymph vessels stagnates, leading to valvular incompetence and dermal backflow.
- Lymphedema is confined to the subcutaneous compartment as the deeper lymphatics are driven by the skeletal muscle pump.
- Over time, macromolecular protein and hyaluronan are deposited in the interstitium leading to increased tissue colloid osmotic pressure.
 - Fibroblast, monocytes, adipocytes, and keratinocytes also increase within the tissue, leading to increased collagen deposition, degeneration of elastic fibers, and fibrovascular proliferation.
 - The basement membranes of lymphatic vessels are obliterated and the vessels become fibrotic.
 - This combination results in nonpitting edema, and eventually a chronic inflammatory state ensues.
- The cytokines arising from the inflammation and the disruption in lymphatic flow of lipids leads to adipose deposition and hypertrophy in the interstitium.
- The verrucous appearance of long-standing lymphatic extremities is caused by hyperplasia of skin at the dermal-epidermal junction.
- Lymphatic stasis and decreased immunological function predispose the patient to an increased risk of local skin infections, erysipelas, and later, lymphangitis. The excess tissue can lead to symptoms of pain, heaviness, and decreased mobility. Long-standing chronic lymphedema can lead to development of

lymphangiosarcoma (Stewart-Treves syndrome). Lymphedema has significant adverse impact on patients' quality of life and psychosocial health.

- The International Society of Lymphangology (ISL) has classified lymphedema into three stages:
 - 0: Latent/subclinical period
 - I: Pitting edema which is reversible on elevation
 - II: Tissue fibrosis and edema, which is nonreversible on elevation
 - III: Elephantiasis and trophic skin changes

PATIENT HISTORY AND PHYSICAL FINDINGS

- The history is targeted at determining the diagnosis and etiology of lymphedema, duration, symptoms, and complications, and how the patient has been managing it.
 - Elucidating diagnosis and etiology include asking about risk factors for malignancy, travel history, prior surgical procedures, history of radiation therapy, trauma and infection, and family history. Obesity can contribute to lymphedema through the overload of lipids in the body. Other causes of extremity swelling such as congestive cardiac failure, venous insufficiency, and deep vein thrombosis have to be excluded (see differential diagnosis).
 - Important symptoms and complications to ask about include pain and infections in the affected extremity, a feeling of heaviness and difficulty in movement.
- The examination of the patient with lymphedema should include a general physical and a targeted examination of the affected part. The general examination is aimed at excluding any active infection or malignancy and general causes of extremity edema.
- Lymphedema is typically unilateral, with the swelling beginning distally and progressing over months to years.
 - The edema starts off soft and pitting and eventually becomes nonpitting as interstitial fibrosis sets in.
 - There is minimal pigment change or ulceration and peau d'orange indicating dermal fibrosis can be present.
 - Late changes in the extremity include hyperkeratosis, papillomatosis, and the development of a positive Stemmer sign in which the skin on the dorsum of the second web space of the foot cannot be pinched as a fold.
- Reproducible measurements of the limb should be taken to help with accurate follow-up. These can include circumference measurements and volumetric

measurements such as water displacement tests, perometry, and bioimpedance testing. Digital photographs are also useful for comparative analysis.

- Circumference measurements are typically taken at 4- to 10-cm intervals from consistent landmarks such as the patella in the lower extremity and the olecranon in the upper extremity. Figures that are used in the diagnosis of lymphedema include the following:
 - Greater than 2 cm difference from the nonaffected limb.
 - Severity can be graded as mild (greater than 10% difference), moderate (greater than 20%), and severe (greater than 30%).
- Water displacement has been the standard for volume measurement and is highly accurate but cumbersome. Lymphedema is diagnosed if the volume differential of the affected limb is greater than 10% of the normal limb.
- Perometry utilizes an infrared optical electronic scanner to calculate volume.
- Bioimpedance testing calculates the fluid composition of an affected limb using resistance to an electrical current.

IMAGING

- Lymphangiography is the visualization of lymphatic vessels using contrast medium. Vessels can be classified as anaplastic, hypoplastic, or hyperplastic. There are the direct and indirect forms of lymphangiography.
- Direct lymphangiography involves transecting distal lymphatic vessels and directly injecting water-soluble iodide contrast medium into them. This has largely been abandoned because of patient discomfort and damage to the lymphatic channels.
- Indirect lymphangiography injects contrast medium distally into the subepidermis and uses radiographic imaging to delineate the lymphatic system.
- Isotopic lymphoscintigraphy is the current standard for lymphatic imaging. It injects Technetium-99–labeled albumin into the subepidermis of the distal affected extremity and timed post injection imaging to determine lymphatic anatomy and function. It has a sensitivity of 97% and specificity of 100%. However, when done awake, the injection can be painful, and the length of time required can be distressing to the patient.
- The injection of indocyanine green (ICG) and imaging using an infrared camera have become widely used in the imaging of lymphatic vessels and are particularly useful intra-op when needing to delineate the superficial lymphatic system. A classification based on the appearance of the ICG has been

developed and correlated with the Campisi classification (Table 1).¹

- Computed tomography (CT) and magnetic resonance imaging (MRI) scanning are useful in determining the architecture of the affected limb and elucidating any underlying cause such as neoplasm. There is commonly a “honeycomb” appearance above the deep subcutaneous fascia. MRI with contrast has proven promising in outlining lymphatic vasculature.²

Table 1 Indocyanine Green Appearance to Classify Severity of Lymphedema

Stage	Description
0	No dermal backflow
I	Splash pattern around the axilla/groin region
II	Stardust pattern proximal to the patella/elbow
III	Stardust pattern distal to the patella/elbow
IV	Stardust pattern in the entire limb
V	Diffuse pattern

DIFFERENTIAL DIAGNOSIS

- Venous insufficiency
- Deep venous thrombosis
- Vascular malformations
- Lipedema
- Myxedema
- Fluid overload
 - Congestive cardiac failure
 - Renal failure
 - Liver failure
- Hypoalbuminemia
- Soft tissue tumors
- Morbid Obesity

NONOPERATIVE MANAGEMENT

- Nonoperative management is aimed at reducing the amount of swelling and treating any resulting complications. The former is accomplished by

compression and massage therapy, whereas the latter involves adequate skin care and early detection of infection and treatment with the appropriate antibiotics. In a compliant patient, this helps to slow down the progress of lymphedema.

- Patients should be educated about lymphedema and its complications, and given responsibility for their own care.
- Conservative treatment of lymphedema has been well researched and the regimen described is complete decongestive therapy (CDT). This should be started early to have the most benefit and is useful in cases of lesser than stage III lymphedema. Analyses have shown up to 40% to 60% reduction in lymphedema volume. It consists of two phases:
 - Initial reductive phase (up to 8 weeks) consisting of:
 - Manual lymphatic drainage—Circular tissue stretching massage with varying degrees of pressure
 - Compression therapy during waking hours
 - Regular skin care
 - Targeted exercise
 - Maintenance phase consisting of
 - Self-conducted lymphatic drainage
 - Continuation of compression garments
- Weight loss may help with lymphedema by reducing the flow of fatty acids through lymphatic channels and decreasing fatty deposition in the subcutaneous tissue.
- Exercises such as swimming can be useful in reducing the severity of lymphedema.
- Unsubstantiated nonoperative measures include coumarin (5,6 benzo-a-pyrone), diuretic use, microwave heating, and intra-arterial injection of lymphocytes.

SURGICAL MANAGEMENT

- Although significant advances have been made in the surgical treatment of lymphedema, no surgical technique offers a cure, and an aggressive trial of nonsurgical therapy should first be done.
- Indications for surgical treatment include failed conservative therapy, grossly impaired limb function, debilitating extremity size and weight, recurrent lymphangitis (greater than 3 episodes of infection per year), and uncontrolled

pain.

- Surgical techniques for the treatment of lymphedema are classified as excisional and physiological.
- Excisional techniques aim to reduce the amount of lymphatic tissue and tighten the skin envelope. They are described elsewhere in this book and include but are not limited to excision and skin grafting (eg, Charles procedure), staged excision, liposuction, and, more recently, radical resection with preservation of perforators (RRPP).³ Unfortunately, as the primary disease process is not addressed, there is a high risk of recurrence with these techniques, and the appearance can be undesirable.
- Physiological techniques attempt to replicate the normal lymphatic flow in the affected extremity. Procedures that have been developed and described elsewhere include buried dermal flaps, lymphovenolymphatic bypass, lymphatic bypass, and lymphovenous anastomosis (LVA).⁴
- The vascularized lymph node transfer (VLNT) is a physiological technique that transfers intact autologous lymph nodes from a nonlymphedematous region of the body to the affected extremity. In a sense, this is the most physiological method of addressing the problem in a patient whose lymphedema is due to damage to or paucity of lymph nodes in a particular basin.
- The lymph nodes are microsurgically anastomosed to the chosen recipient site vessels and allowed to develop collateral blood supply. Over time, reported mechanisms of lymphedema reduction include reduction of scarring at the recipient site, hydrostatic “pumping” of intraflap lymph via arterial inflow and venous outflow, and lymphangiogenesis aided by the production of VEGF-C by the transplanted lymph nodes.
- Though not curative, physiological techniques have proven to alleviate symptoms and reduce lymphedema volume.

Preoperative Planning

- Preoperative workup should include elucidating etiology of the lymphedema, comorbidities, the patient’s treatment to date, limb measurements, weight fluctuations, and ability to comply with therapy.
- Severity of lymphedema should be clinically staged according to the ISL grading system, and treatment planned accordingly:
 - Patients with mild to moderate stage 1 or 2 lymphedema are best candidates

for physiologic procedures such as VLNT and/or LVA.

- Patients with stage 3 fibrofatty lymphedema or elephantiasis may benefit from excisional procedures prior to physiologic procedures in order to offset the lymphatic load and optimize the result of physiologic procedures.
- Specific history to note with regard to vascularized lymph node (VLN) harvest includes previous surgery in the region of planned harvest or pre-existing lymphedema if harvest is planned from the groin. Scars and surface anatomical landmarks should be noted. Active infection in the affected extremity should be ruled out.
- Definitive diagnosis of lymphedema is made with lymphoscintigraphy, which evaluates lymphatic function.
- ICG imaging of the affected extremity prior to surgery aids in lymphatic mapping for the simultaneous performance of LVA.
- If groin VLNT is planned, reverse lymphatic mapping should be performed to determine the crucial deep groin lymph node basin of the lower extremity, which should be avoided in groin VLNT harvest.
 - This involves the preoperative injection of technitium-99–labeled albumin subcutaneously into the inner thigh and a gamma probe used intraoperatively to detect the sentinel lymph node of the deep groin lymph node basin.⁵
 - Harvest of this lymph node should be avoided at all costs to prevent postoperative lower extremity lymphedema.

Positioning

- For most VLN harvest, the patient is placed in a supine position.
- For TAP flap or split LD flap with LNT, the patient is placed in lateral decubitus position.
- If the lymph nodes are intended to be placed in the axilla, the arm is extended at right angles to the torso to access and prepare the recipient site.
- For specific points for each source of VLN, refer to the subheadings below.

Table 2 Comparison of Different Vascularized Lymph Node Transfer Donor Sites

Donor site	Average Number of Lymph Nodes	Advantages	Disadvantages

Supraclavicular	2–3	• Inconspicuous donor site • Low risk of causing donor site lymphedema	• Variable anatomy • Need for meticulous harvest technique
Submental	3–4	• Consistent anatomy • Low risk of causing donor site lymphedema	• Visible donor site scar • Risk of injury to the marginal mandibular nerve
Thoracic	Variable	• Ability to harvest with latissimus dorsi or thoracodorsal artery perforator flap • Inconspicuous donor site scar	• Risk of upper extremity lymphedema
Inguinal	5–8	• Ability to harvest with abdominally based flap • Inconspicuous donor site	• Risk of lower extremity lymphedema
Omentum	Unknown	• No risk of causing donor site lymphedema • If harvested laparoscopically, minimal donor site scar	• Need to enter abdominal cavity • No skin paddle possible

Approach

- For harvest of VLN, the common sources are the submental, supraclavicular, thoracic, inguinal, and omental lymph nodes. The advantages, disadvantages, and potential complications of each are listed in Table 2.
- For recipient sites in the limbs, placement location and the need for a skin paddle for the VLNT are debated.
- Some surgeons prefer proximal placement of the lymph nodes, whereas others prefer distal placement. This is dependent on which mechanism the lymph nodes are thought to work.
 - For the “pumping” mechanism, distal sites such as the ankle and wrist are

chosen as gravitational forces aid in the flow of lymphatics.

- For the argument that VLNT works by promoting lymphangiogenesis, more proximal sites near the vicinity of lymph node damage are chosen. It is thought that dual effect of scar release and placement of well-vascularized lymph nodes enhance the restoration of lymphatic flow.
- It is likely that both mechanisms contribute simultaneously to the resolution of lymphedema. A conservative approach to recipient site selection is therefore the best approach.⁶
- The proximal site is chosen when there is a definite area of scarring from previous surgery or radiation.
 - When it is difficult to access or remove scars, the VLNT can be done distal to the site of obstruction. An example is in patients whose pelvic lymph nodes were removed via intra-abdominal surgery.
 - In patients who have no definite site of injury, placement of the VLNs directly proximal to the area of the swelling is effective.
- VLNT should be monitored if possible in most cases as in any other free tissue transfers. A skin paddle can be helpful when closure of native skin over the lymph nodes is tight, such as at the wrist, but is not cosmetically appealing. This can be resolved by excision of the skin paddle at a second stage.
- Our preference is to harvest supraclavicular lymph nodes without a skin paddle, and place them at the axilla for the upper extremity and the groin for the lower extremity.
- We use an implantable Doppler probe postoperatively to monitor the microanastomotic patency.

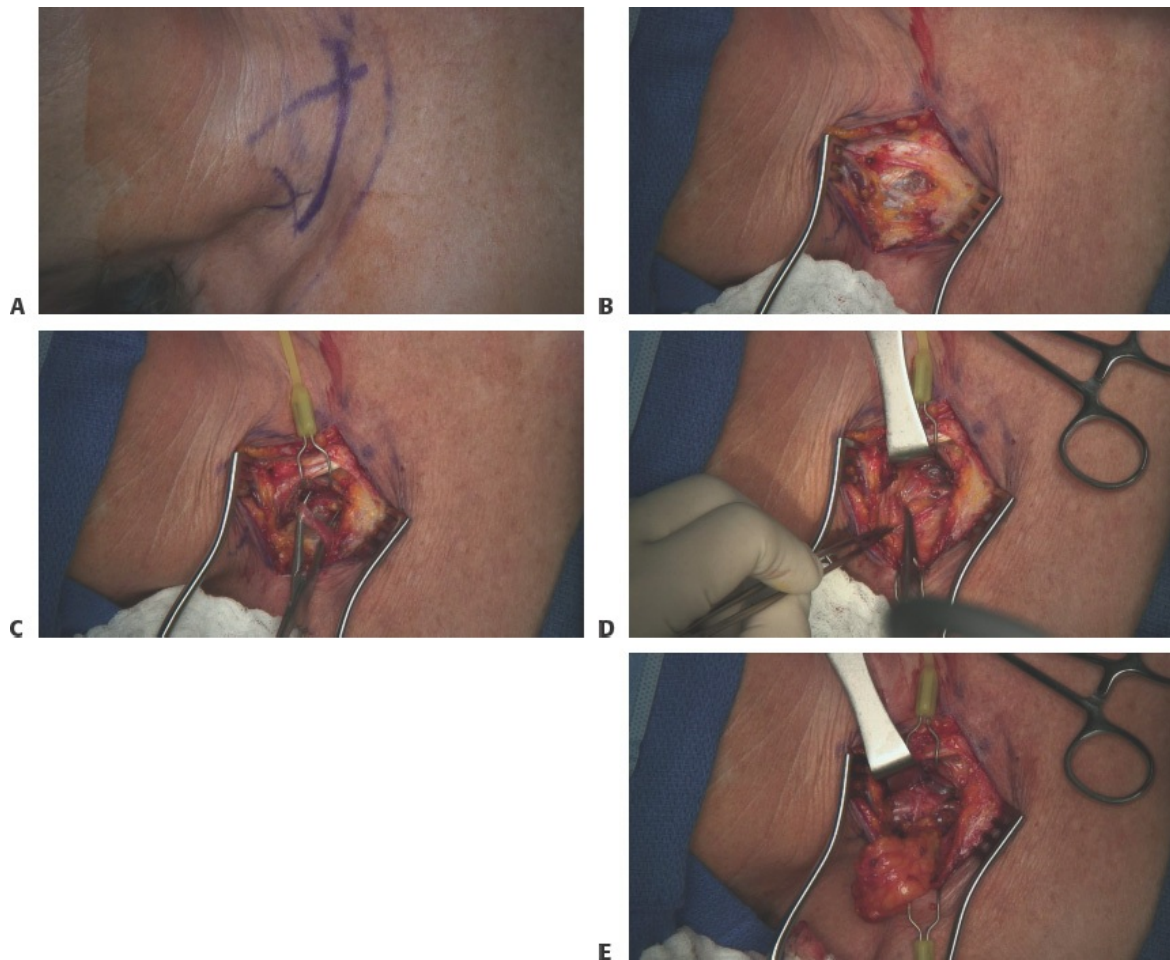
TECHNIQUES

■ Supraclavicular Vascularized Lymph Node Harvest

- Based on the transverse cervical (TC) artery.
 - The flap can be harvested with or without a skin paddle.
- Surface landmarks (**TECH FIG 1A**) are a triangle formed by the clavicle (inferior border), lateral edge of the sternocleidomastoid muscle (SCM;

medial border), and external jugular vein (lateral border).

- Lymph node harvest from the right neck is preferable to avoid the risk of damaging the thoracic duct in the left side of the neck. Lymph nodes are harvested from the left neck if the lymphedema involves right arm.
- In the supine position, the patient's head is tilted 45 degrees away from the side of harvest.
- A longitudinal skin incision is made 1 to 2 cm above the superior border of the clavicle between the medial and lateral borders (**TECH FIG 1B**).
 - If harvesting a skin paddle, the perforator to the skin should be marked with a Doppler probe prior to harvest and an ellipse marked encompassing the perforator along the line of the recommended skin incision.
- The platysma is breached with sharp dissection, and the omohyoid muscle or tendon is identified and cut to reveal fat and lymphatic tissue posteriorly (**TECH FIG 1C**).
- Medial dissection proceeds along the lateral border of the SCM. The internal jugular vein (IJV) is next identified, and the tissue within the triangle gently dissected off. The anterior scalene muscles are identified at the base.
- Proceeding inferiorly from the medial border, the TC artery can usually be identified arising from the thyrocervical trunk (**TECH FIG 1D**).
 - Pedicle length should be maximized by dissecting down to the source vessel.
 - There is usually an accompanying vein supplying the flap arising from the IJV or subclavian vein.
- The distal ends of the TC vessels are identified and ligated.
- Using the EJV as the lateral landmark, lateral dissection then proceeds in a natural plane medial to the trapezius muscle and stops once the anterior scalene muscles are identified at the base.
- Once the borders have been dissected, the supraclavicular VLN flap can be lifted off the anterior scalene muscles and the flap isolated on its vascular pedicle (**TECH FIG 1E**).
 - The phrenic nerve should be identified and preserved.
- When the recipient site is ready, the pedicle can be ligated.
- Donor site closure is done over a suction drain placed away from the IJV. The platysma is approximated with interrupted absorbable polyfilament sutures, and the skin is closed with a running subcuticular suture.



TECH FIG 1 • **A.** Surface marking of supraclavicular lymph node transfer. **B.** A longitudinal skin incision is made 1 to 2 cm above the superior border of the clavicle between the medial and lateral borders. **C.** The platysma is split with sharp dissection, and the omohyoid muscle or tendon is identified and cut to reveal fat and lymphatic tissue posteriorly. **D.** Proceeding inferiorly from the medial border, the thoracodorsal (TD) artery can usually be identified arising from the thyrocervical trunk. **E.** Once the borders have been dissected the supraclavicular VLN flap can be lifted off the anterior scalene muscles and the flap isolated on its vascular pedicle. (From Ooi AS, Chang DW. 5-step harvest of supraclavicular lymph

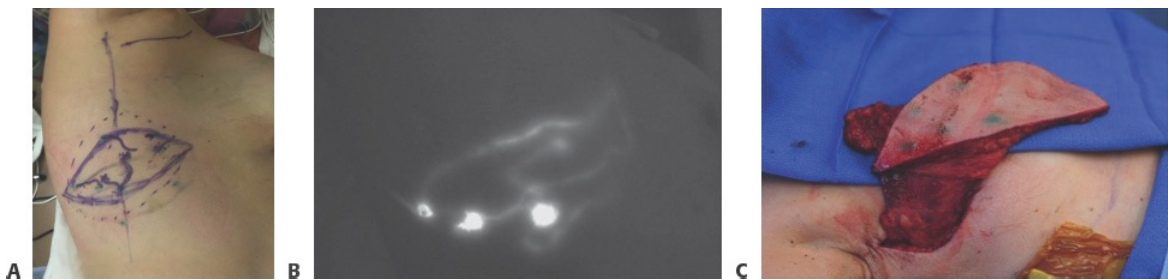
nodes as vascularized free tissue transfer for treatment of lymphedema. J Surg Oncol. 2017;115:63-67.)

■ Submental Vascularized Lymph Node Harvest

- Based on the facial artery and its submental branch.
 - The flap can be harvested with or without a skin paddle.
 - Surface landmarks are the symphysis, body and angle of the mandible, and facial artery.
 - The facial artery is palpated and marked as it crosses the inferior border of the mandible. The skin incision is made 1 cm posterior to the lower border of the mandible.
 - If a skin paddle is desired, a handheld Doppler probe is used to detect the perforators from the submental artery (SMA). An ellipse encompassing the perforators is designed extending from the symphysis medially to the angle of the mandible laterally, with the upper margin along the lower border of the mandible from the mandible angle to the symphysis. The initial skin incision is then initiated at the upper margin of the ellipse.⁷
 - The incision is deepened through the platysma, and the SMA is identified at its junction with the FA. The marginal mandibular branch of the facial nerve is identified as it crosses the FA and must be preserved. The SMA is dissected proximal to distal end along its axis.
 - The submental lymph nodes are found at the junction of the SMA and FA, and the soft tissue at this region is included to preserve the maximal amount of lymphatic tissue.
 - If a skin paddle is included, the septocutaneous perforator from the SMA to the skin paddle must be preserved. To aid with this, the anterior belly of the digastric muscle can be included with the perforator.
 - The distal ends of the facial vessels are ligated, and the submental lymph nodes are harvested with the submental vessels and the proximal facial vessels to maximize pedicle length.
 - The donor site is closed primarily over a suction drain. The platysma is approximated with interrupted absorbable polyfilament sutures, and the skin is closed with a running subcuticular suture.
-

■ Thoracic Vascularized Lymph Node Harvest

- Based on the thoracodorsal (TD) vessels or the lateral thoracic (LT) vessels:
 - The thoracic lymph nodes can be harvested as part of a muscle-sparing latissimus dorsi (LD) or thoracodorsal artery perforator (TAP) flap, which can be used for simultaneous pedicled breast reconstruction.
- A longitudinal line just anterior to the LD muscle and lateral to the breast is marked and incised (**TECH FIG 2A**).
- The TD pedicle is located as it enters the LD muscle, and the LT vessels can be identified just anterior to this as it hugs the serratus anterior muscle fascia.
- The lymph nodes to be harvested are located inferior to the lateral border of the pectoralis minor muscle (**TECH FIG 2B**). These are the level 1 lymph nodes of the axillary region, and harvest of these will avoid damage to the draining lymphatics of the arm.
 - If the lymph nodes alone are harvested, the LT pedicle is preferred as they are the preferential supply.⁸
 - If a pedicled LD or TAP flap is desired for breast reconstruction, the lymph nodes are captured as an anterior extension of the flap skin paddle. As the flap is transposed into the breast anteriorly the lymph nodes are swung upward and placed in the axilla (**TECH FIG 2C**).
- The donor site is closed primarily over a suction drain. The superficial fascia is approximated with strong absorbable polyfilament sutures, and the skin is closed with a running subcuticular suture.



TECH FIG 2 • **A.** A longitudinal line just anterior to the LD muscle and lateral to the breast is marked and incised. **B.** The lymph nodes to be harvested are located inferior to the lateral border of the pectoralis minor muscle. **C.** As the flap is transposed into the

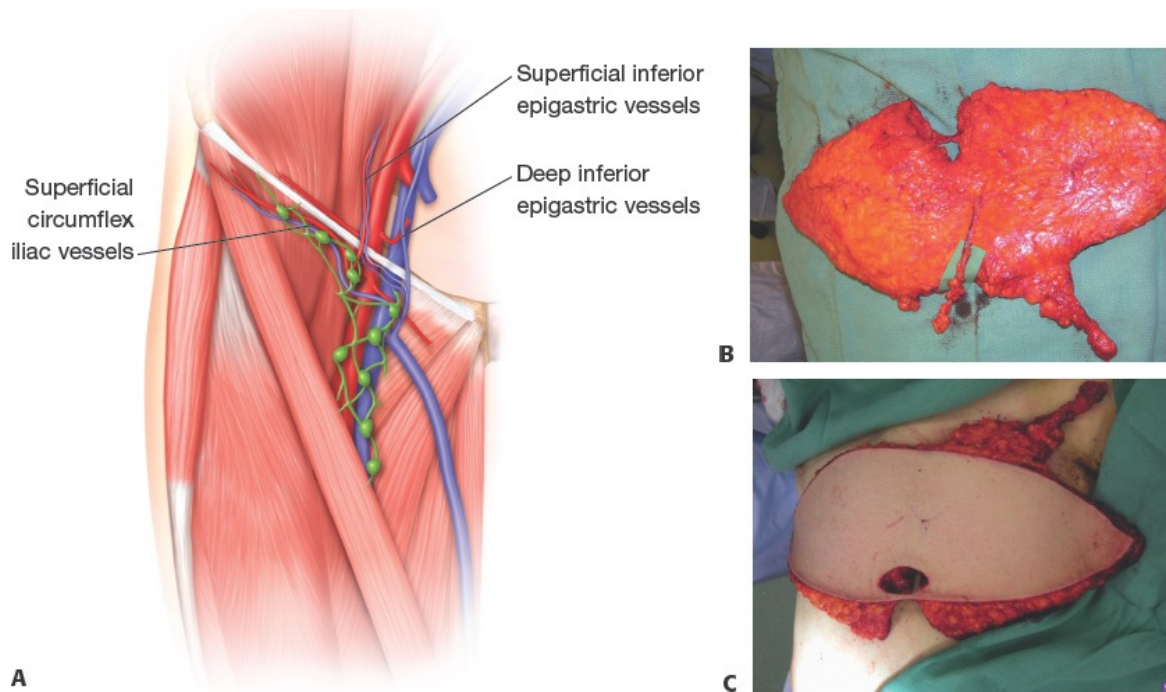
breast anteriorly the lymph nodes are swung upward and placed in the axilla. (From Ooi AS, Chang DW. 5-step harvest of supraclavicular lymph nodes as vascularized free tissue transfer for treatment of lymphedema. J Surg Oncol. 2017;115:63-67.)

■ Inguinal Vascularized Lymph Node Harvest

- Based on the superficial circumflex iliac artery (SCIA) or occasionally on the superficial inferior epigastric artery (SIEA).
 - The lymph nodes can be harvested alone or as part of an abdominal flap for simultaneous breast reconstruction and VLNT.
 - For lymph nodes alone, the flap can be harvested with or without a skin paddle.
- Surface landmarks (**TECH FIG 3A**) are the anterior superior iliac spine (ASIS), pubic symphysis, inguinal ligament, and the femoral canal.
- Reverse lymphatic mapping is done for the side that lymph nodes are to be harvested from. This first involves the preoperative injection of technetium-99–labeled albumin into the medial thigh.
- The skin incision is made 2 cm superior to the inguinal ligament and deepened to the level of the cribriform fascia.
 - If a skin paddle is desired, a handheld Doppler probe can be used to detect the perforators from the SCIA, along a line 1 to 2 cm inferior to the inguinal ligament.
- The SCIA and SIEA are identified. The lymph nodes are located in the fat lateral to the SIE vessels and around the SCI vessels, superior to the inguinal ligament (**TECH FIG 3B**). Their superficial border is the Scarpa fascia and the deep boundary is the muscular aponeurosis.
- A gamma probe is used to locate the sentinel lymph node in the leg via reverse lymphatic mapping.
 - It is imperative that the sentinel lymph nodes along with the deeper lymph nodes that drain the leg are not included in the flap.
- Once the deep lymph nodes have been identified and kept away from the dissection, lymph node harvest can be completed.
- If an abdominal flap for breast reconstruction is planned together with the

VLNT, the lymph nodes should be harvested in continuity with the abdominal tissue along the SIE and/or SCI vessels. The pedicle of the abdominal flap (be it a perforator or muscle-sparing flap) is then anastomosed to the internal mammary vessels, with supercharging of the lymph node vein to an axillary recipient vein (**TECH FIG 3C**).⁹

- The donor site is closed over a suction drain, ensuring that Scarpa fascia is approximated before a running subcuticular suture for the skin. If an abdominal flap is taken, this is closed in the usual fashion.



TECH FIG 3 • A. Surface landmarking of inguinal lymph node transfer. **B.** The lymph nodes are located in the fat lateral to the SIE vessels and around the SCI vessels, superior to the inguinal ligament. **C.** The pedicle of the abdominal flap is then anastomosed to the internal mammary vessels, with supercharging of the lymph node vein to an axillary recipient vein. (**B,C:** From Ooi AS, Chang DW. 5-step harvest of supraclavicular lymph nodes as vascularized free tissue transfer for treatment of lymphedema. *J Surg Oncol.* 2017;115:63-67.)

■ Omental Vascularized Lymph Node Harvest

- The omentum has been called the guardian of the abdomen due to its lymphatic and immunological capability.
- The omental flap is based on the right gastroepiploic artery and can be harvested via an open or laparoscopic approach. A skin paddle is not possible.
 - For the open approach, an upper minilaparotomy incision is used.
 - For the laparoscopic approach, the abdomen is accessed with four ports.
- The lymphatic territory of the omentum can be identified with methylene blue dye injection preoperatively. This can be done using upper gastrointestinal endoscopy or via direct injection using the open or laparoscopic approach.
- The free border of the omentum is first identified. This is then dissected along its natural anatomical plane toward the greater curve of the stomach. Gentle manipulation of the omentum is required throughout the harvest.
- The lesser sac is entered and the short gastric and left gastroepiploic vessels are identified and ligated, and the flap is dissected off the greater curve of the stomach with meticulous cautery.
- The flap is harvested in its entirety based on the right gastroepiploic artery, which is dissected to its origin. It can be debulked by up to 40% to aid in inset.
 - Preoperative dye mapping aids in preserving the critical lymphatic tissue.¹⁰
- Once the flap is rendered ischemic, delivery of the flap extra-abdominally can be done via the minilaparotomy incision or, in the case of the laparoscopic approach, a 3-cm infraumbilical extension of the umbilical port.
- The laparotomy or laparoscopic wounds are closed in the usual fashion.

■ Recipient Site Preparation and Microanastomosis

- As mentioned previously, recipient site is dependent on clinical indication and surgeon preference. The advantages and disadvantages of each are summarized in Table 3.
- In the upper extremity, the lymph nodes are commonly placed in the axilla or at the dorsal wrist.
- In the lower extremity, the lymph nodes are commonly placed in the groin,

anterior ankle and less commonly, the popliteal region.

Axilla

- A skin paddle is usually not required for VLNT to this region.
- If available, a previous axillary scar is used for the skin incision.
- The incision is deepened toward the axillary fat, releasing and removing any scar tissue. Care must be taken to avoid injury to vital structures within the axilla.
- The TD or LT vessels are identified and preserved. Arterial and venous anastomosis is done end to end (ETE) to these vessels. The flap is placed in the pocket created.
- The axillary wound is closed over a suction drain. An implantable Doppler probe can be used for monitoring of anastomotic patency.

Medial Elbow

- The VLN flap is usually harvested with a skin paddle for this recipient site.
- A curvilinear skin incision is made on the medial volar elbow area at the level of the epicondyle.
- A pocket is created for the flap placement.
- The anterior recurrent ulnar artery and the basilic vein are identified and used for ETE anastomosis.
- The flap is inset loosely over nonsuction drains.

Table 3 Advantages and Disadvantages of Different Vascularized Lymph Node Transfer Recipient Sites

		Advantages	Disadvantages
Upper extremity	Axilla	Hidden incision/scar Scar tissue release Multiple recipient vessels	Buried flap requiring implantable Doppler probe for monitoring of anastomotic patency
	Elbow	Hidden donor site scar medially	Difficult dissection of recipient vessels Interruption with elbow flexion
	Wrist	Tension-free closure with skin paddle Ease of monitoring	Aesthetically displeasing skin paddle May require skin graft

Lower extremity	Groin	Hidden incisional scar Scar tissue release	Potentially deep dissection Buried flap requiring implantable Doppler probe for monitoring of anastomotic patency
	Posterior knee	Hidden incisional scar	Difficulty with positioning and microanastomosis
	Ankle	Tension-free closure with skin paddle Ease of monitoring	Aesthetically displeasing skin paddle May require skin graft Difficulty with footwear

Dorsal Wrist

- The VLN flap is usually harvested with a skin paddle for this recipient site.
- A transverse skin incision is used to create a pocket within which the flap can be partially inset.
- Arterial microanastomosis is done ETE to a superficial branch of the radial artery at the anatomical snuffbox.
- Venous microanastomosis is done ETE to a branch of the cephalic vein.
- The skin of the VLN flap is loosely approximated to the wrist skin over nonsuction drains to avoid compression.

Groin

- A skin paddle is usually not required for VLNT to this region.
- A vertically oriented linear skin incision is made at the medial groin beneath the inguinal ligament and just above the femoral pulse.
- Dissection proceeds toward the superficial femoral vessels, carefully preserving any skin perforators or branches of the greater saphenous vein.
- Any scar tissue is aggressively released and removed to create a pocket for the VLNT.
- Arterial microanastomosis can be done ETE to a branch of the superficial femoral artery or an adequate skin perforator or end to side (ETS) to the superficial femoral artery.
- Venous anastomosis can be done ETE to a branch of the accompanying femoral vein or a branch of the greater saphenous vein.
- The axillary wound is closed over a suction drain. An implantable Doppler

probe can be used for monitoring of anastomotic patency.

Posterior Knee

- For the rare occasions where the flap is to be placed at the posterior knee, a skin paddle is usually not required.
- A vertical skin incision is made medially just below the popliteal region.
- A pocket is created for placement of the VLN.
- Microanastomosis can be done ETE to the medial genicular branches or ETS to the posterior tibial vessels.
- Closure of the wound is done over a suction drain.

Dorsal Ankle

- The VLN flap is usually harvested with a skin paddle for this recipient site.
- A curvilinear incision is made on the dorsal ankle and deepened to the deep fascia.
- The superior and inferior skin envelopes are undermined to allow for the inset of the VLN flap.
- The dorsalis pedis (DP) vessels are identified and preserved for microanastomosis. This can be done in an ETE or ETS fashion for both the flap artery and vein.
- The flap skin paddle is then loosely inset into the skin pocket over nonsuction drains.
- A split-thickness skin graft may be required in cases in which the sides of the flap are too large to fit into the created skin pocket.

PEARLS AND PITFALLS

Assessment	■ Confirm the diagnosis of lymphedema and find out what therapy has been tried. ■ Exclude smoking, hypercoagulable states, or bleeding tendencies.
Donor site selection and harvest	■ The surgeon should be comfortable with harvesting from the chosen donor site. ■ Avoid harvesting the deep lymphatic chain of the thoracic and groin lymph node basins to prevent donor limb lymphedema.
Recipient site	■ Selection of proximal or distal recipient sites is dependent on

selection	surgeon preference, familiarity, and comfort; also, the area of the lymphedema, as well as discussion with the patient. ■ Release of scar tissue and the introduction of well-vascularized lymph nodes can promote angiogenesis.
Postoperative care	■ The vascularized lymph node transfer is a free flap, and monitoring should proceed accordingly. ■ Compression therapy should be continued postoperatively.

POSTOPERATIVE CARE

- Immediate postoperative care would include monitoring of the free VLNT recipient site for anastomotic patency and local wound complications, as well as monitoring of the donor site. Postoperative free flap care is unit dependent, but usually would include:
 - Hourly monitoring of the flap using clinical parameters for the skin paddle or implantable Doppler probe for buried flaps
 - Monitoring for development of hematoma at the recipient site
 - Monitoring for development of hematoma or lymphorrhea at the donor site. The latter can usually resolve conservatively with prolonged drain use
 - Prevention of thromboembolic problems using mechanical and chemical prophylaxis
 - The patient being kept NPO overnight for emergent flap take back if required
 - Early mobilization of patients on postoperative day (POD) 1
 - Early use of compression wrapping by trained lymphedema therapists
- Patients are usually discharged on POD 3 or 4.
- Follow-up would include regular clinic visits for monitoring for wound complications and results of the VLNT. The latter is preferably done using the same techniques as preoperative assessment of lymphedema severity.

OUTCOMES

- The VLNT is like any free flap, requiring time for neovascularization and lymphangiogenesis. Typically, objective measurement results are not seen until 1 year postoperatively. Patients often report symptomatic improvement almost immediately postoperatively, especially in cases where scar tissue has been excised and vascularized flap is placed.
- As the technique of VLNT gains increasing popularity, the number of studies reporting on its results are growing, with reduction rates of 0% to 100%.^{8,9,11–15} It is difficult to directly compare outcomes because there is a

wide range of donor and recipient sites, as well as severity of lymphedema.

- In a 20-year follow-up of 1500 cases of VLNT, Becker et al. reported a response rate of 98%, with 40% of patients with stage I and II extremity lymphedema achieving a 100% reduction rate.⁸
- In a study of 13 cases in which the supraclavicular VLNT was used for lymphedematous limbs by Akita et al., there was an improvement in lower extremity lymphedema index of 27% and a 54% improvement in lymphatic function.¹¹
- In a study of seven patients receiving submental VLNT to the lower extremity with a mean follow-up of 9 months, Cheng et al. reported significant reduction in the volume of the lymphedematous limb of 23% above the knee, 22% below the knee, and 27% above the ankle, with reduction in episodes of cellulitis.⁷
- In a study on 29 patients receiving simultaneous inguinal lymph node transfer with abdominal-based breast reconstruction with a mean follow-up of 11 months, Nguyen et al. reported a 79% symptomatic improvement and mean volume differential improvement of 10% at 12 months after reconstruction.⁹

COMPLICATIONS

- Complications of vascularized lymph node transfer
 - Lymphedema of donor site
 - Donor site pain
 - Lymphorrhea
 - Wound infection
 - Flap failure
 - Hematoma
 - Recurrence of lymphedema
- Complications of long-standing lymphedema
 - Infection
 - Sensory disturbance
 - Pain
 - Reduction in mobility
 - Reduced quality of life
 - Stewart-Treves syndrome (lymphangiosarcoma)

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47 Fasciocutaneous Debulking of Extremity Lymphedema: The Charles Procedure

CHAPTER

Clifford C. Sheckter and Peter Johannet

DEFINITION

- Lymphedema is the accumulation of interstitial fluid and fibroadiposity in subcutaneous tissues as a result of dysfunction in the lymphatic system.
 - Compared with generalized edema, lymphedema by definition is caused by poor lymphatic outflow (compared to increased capillary leak).¹
- The disease is generally described in terms of primary vs secondary (ie, acquired) causes.¹
 - Primary lymphedema: congenital (less than 2 years), praecox (first to third decade of life), and tarda (greater than fourth decade of life).
 - Secondary lymphedema: malignancy, iatrogenic/surgery (most common in developed world), obesity, trauma, and infection/filariasis (most common worldwide).
- Although nonoperative treatment is the mainstay, each case should be evaluated individually. Surgical options including radical excision can offer significant improvement.

ANATOMY

- Lymphedema can occur anywhere in the body where lymphatics are present; however, the disease tends to be most problematic within the extremities and genitals.
- In the extremities, the lymphatic system courses within the soft tissue between the dermis and muscle fascia, and thus, the disease is confined to this area. Anatomic knowledge of the subcutaneous tissues and its contents is crucial for surgical treatment given many nerves run within or adjacent to muscle fascia.

- Lower extremity considerations:
 - Common peroneal nerve at fibular head
 - Sural nerve at posterior calf

PATIENT HISTORY AND PHYSICAL FINDINGS

- Generalized edema due to any underlying medical disorder (heart failure, renal failure, cirrhosis) or medication should be ruled out, given these causes are often reversible with proper medical management.
- Other limb-enlarging disorders should be considered including chronic venous insufficiency, deep venous thrombosis, congenital musculoskeletal limb discrepancy disorders, myxedema, and neoplasia.
- For lymphedema, determine primary vs secondary lymphedema based on the timing of onset, travel history (endemic filariasis), family history, and any personal history of injury, surgery, or radiation.
- Two-thirds of cases involve a single extremity; however, bilateral lymphedema is possible depending on the nature of injury (eg, pelvic lymph node dissection).²
- Examination of affected limb reveals supple tissue that often “pits” when gently pressed. Long-standing lymphedema causes skin changes including thickening of the dermis and thickening of the epidermis (hyperkeratosis).
 - The classic *Stemmer* sign is considered positive when the examiner is unable to pinch the skin on the affected side at the dorsum of second toe or second finger. The unaffected side will easily tent when gently pinched.³
- Measuring the affected limb is important both in terms of comparison to the normal side (if present) and assessing for improvement with anticipated therapy.
 - Volumetric measurements are the standard and can be achieved through either estimated circumference measurements or water displacement testing.
 - Circumference measurements, while easily accessible, can be plagued by poor interrater reliability.⁴
 - Water displacement testing, whereby the affected limb is submerged into large containers, is highly precise, albeit cumbersome. Volume in excess of 200 cc (compared to normal side) is considered diagnostic.⁴

IMAGING

- In general, imaging is not necessary for diagnosis with a convincing history

and physical exam. If there is uncertainty in diagnosis, tailored imaging can assist in excluding/confirming lymphedema. For surgical planning, some surgeons advocate for ultrasound to ensure competency of the deep venous systems.

- Ultrasound can evaluate for deep venous thrombosis.
- Computed tomography can evaluate for masses, lipodystrophy, venous thrombosis, and lymphedema with high sensitivity.
- Lymphoscintigraphy can help confirm the diagnosis through demonstrating both quantitative and qualitative impairment in trace.
- Indocyanine green lymphangiography can assist in delineating drainage patterns and is more often employed in the preoperative planning of lymphovenous anastomosis or vascularized lymph node transfer.

SURGICAL MANAGEMENT

- There are limited prospective studies comparing the different treatments of lymphedema, particularly surgical approaches. There is no defined period of waiting or algorithm for performing the different procedures.
- In general, nonoperative therapy is considered first line,¹ largely consisting of concentric extremity compression wrapping with or without mechanical compression. Surgery is usually reserved for those patients with the following characteristics:
 - Failed compression therapy
 - Recurrent soft tissue infection and/or cellulitis
 - Quality of life limitations such as pain, limited mobility, and psychosocial distress
- Operations are classified into two categories: physiologic and ablative.
 - Physiologic procedures involve three techniques
 - Creating new lymphatic anastomoses (lympholymphatic bypass).
 - Diverting lymphatic drainage into the venous system (lymphovenous bypass).
 - Autotransplanting lymph nodes from another part of the body (vascularized lymph node transfer). These techniques have their own chapter for further discussion on technique.
 - Ablative techniques involve directly removing tissue from the affected extremity and fall into two operations:
 - Liposuction

- Direct excision
- Direct excision is further characterized based on reconstruction modality: skin graft vs flap.
- Originally described by Sir Richard Henry Havelock Charles in the early 20th century from his proceedings in India, the surgery attributed to Charles involves radical debridement of all soft tissue superficial to skeletal muscle with placement of skin grafts from the excised tissue onto the limb muscle.⁵
- Staged excision: the lower extremity is excised in at least two operations staged 3 months apart. Thick tissue flaps are elevated 1 to 2 cm in thickness and then underlying soft tissue is excised down to muscle fascia. Flap skin edges are closed in a single dermal layer using permanent suture (eg, 3-0 nylon). This procedure shares eponyms including Homans, Sistrunk, and Thompson procedure.
- Though effective in terms of reducing limb volume, the Charles procedure unequivocally yields a poor cosmetic result, which some patients are willing to accept given the burden of lymphedema (**FIG 1**).
- Although the authors do not perform physiologic techniques for lymphedema, it is reasonable to attempt these procedures first, given the lower morbidity.
- More recent advances in lymphovenous anastomosis and vascularized lymph node transfer have shown some successes in reducing limb circumference, yet for patients with significant soft tissue redundancy, surgical excision still plays a significant role.
- Reports of combined lymph node transfer with a Charles procedure have been described.^{6,7}



FIG 1 • Preoperative photo of a lower extremity with severe lymphedema.

Preoperative Planning

- Volumetric measurements should be obtained as mentioned above. This allows for postoperative comparisons to demonstrate effectiveness.
- Ultrasound can be useful in assessing the deep venous system to ensure competency.

Positioning

- Majority of cases will only involve a single lower limb; however, even if multiple extremities are involved, only one extremity should be excised at any given time the significant morbidity of the procedure.
- The patient is positioned in supine with the leg prepped circumferentially and free. A sterile tourniquet will assist in accessing more proximal upper leg in the event this tissue is involved.

Approach

- This is an elective procedure and should only occur when the patient is free of infection (ie, cellulitis) and healthy. If soft tissue infection exists, there is higher likelihood of graft failure.
- General anesthesia due to pain and inability to use local anesthesia due to large surface area.
- Consider regional anesthesia blocks and even an epidural if feasible.

TECHNIQUES

■ Radical Fasciocutaneous Debridement With Split-Thickness Skin Grafts (Charles Procedure)

- After the limb has been prepped and draped in sterile fashion, all tissues planned for excision are marked and delineated.
 - Skin graft harvest trajectories are planned based on surfaces of greatest convexity with longest length (avoid anterior and posterior harvest over

knee and elbow).

- Skin graft donor site evaluation:
 - Evaluate the quality of the skin over the involved tissue planned for excision.
 - Lymphedema can cause hyperkeratotic skin, which is poor quality for skin grafting. In this event, split-thickness skin grafts may be harvested from a noninvolved area of the same leg (eg, upper thigh) or other sites such as contralateral leg, trunk, etc.
- The extremity is exsanguinated with Esmarch from distal to proximal, and the tourniquet is inflated at the proximal limb to 250 mm Hg.
- Split-thickness skin grafts are harvested with a dermatome device using the widest guard possible (usually 3–4 in.) with at least 0.012 to 0.015 in. of depth.
 - Thicker grafts yield better long-term results.
 - Sheet grafting (ie, nonmeshed) is the preferred method for cosmetic considerations, but this requires frequent graft rolling postoperatively, which may not be institutionally feasible.
 - Minimal meshing (such as 1:1.5) or graft fenestration can assist in seroma evacuation and graft take. However, graft meshing and expansion are not advised due to increased risks of secondary contracture and poor cosmetic result.
- Soft tissues are then excised down to muscle fascia using electrocautery.
 - Surgeons have the choice of preserving a thin film of adipose tissue overlying the fascia or excising the muscle fascia in entirety (**TECH FIG 1**).
 - Either way, avoid skin grafting directly on muscle fascia as this interferes with graft take.
- It is important to work systematically in excision.
 - It is often easiest to excise from proximal to distal given blood will run proximally when the leg is elevated.
 - Avoid excising distal to the ankle or proximal to the inguinal crease.
 - Take care to tie off or clip the large external veins of the leg (greater and lesser saphenous).
 - Also be careful to preserve the sural nerve and common peroneal nerve.
- Obtain meticulous hemostasis to increase likelihood of graft take.
 - Epinephrine-soaked sponges can assist in blood loss (even with

tourniquet).



TECH FIG 1 • Lower leg following adipofascial excision. Note that a layer of adipose tissue is preserved over the muscle fascia.

- Skin grafts are either stapled or sutured in place depending on surgeon preference.
- Skin grafts are covered with nonadhesive dressing such as N-Terface followed by a silver product (eg, Acticoat Ag) to prevent infection. This is then wrapped with Kerlix gauze and elastic ace wrap.
 - A knee immobilizer is placed in extension.
- Of note, skin grafting can be delayed for 1 week if there is concern for problems in graft take (ie, concern for serous drainage or infection).
 - In this scenario, skin grafts are banked, and negative pressure wound therapy is applied to the circumferential wound.⁸

■ Staged Excision^{9,10}

- Similar to the Charles procedure, the leg is prepped and draped circumferentially.
 - A vertical line is drawn on both the medial and lateral leg, dividing the leg into anterior and posterior halves.
- Skin is then incised vertically along the medial or lateral leg depending on which half is being excised.

- Adipodermal flaps are lifted in a suprafascial plane, preserving a cuff of adipose tissue (1–2 cm).
 - The elevation stops at the leg meridian.
- Soft tissues are then completely debulked from the adipofascial flap down to muscle.
- The anterior and posterior flaps are raised, and two drains are placed underneath.
 - The two flaps are secured to each other at midline using a single layer of 3-0 nylon sutures.
 - No deep sutures are used.
- Dressings are applied and the leg is wrapped circumferentially.

PEARLS AND PITFALLS

Hemostasis	■ When performing extremity adipofascial excision, use a sterile tourniquet, and limit runs to less than 2 hours. Let the tourniquet deflate to obtain hemostasis prior to placing skin grafts. Excise proximal to distal. Epinephrine 1:10 000 soaked sponges can assist in hemostasis.
Skin harvest	■ In general, it is easier to harvest the skin grafts prior to adipofascial excision given the difficulty in making a taught convex surface once the tissue is excised. ■ If excised donor leg skin is hyperkeratotic and poor quality, harvest skin grafts from contralateral leg or trunk.
Soft tissue excision	■ Leave a cuff of soft tissue around the ankle and knee (popliteal fossa, patella) to avoid exposing bone and vascular structures. ■ Be cautious when excising in the posterior calf and lateral upper lower leg to avoid the sural and common peroneal nerves.
Single vs staged	■ Consider staged excision in morbid patients who might not tolerate a complete leg debulking.
Cosmetic result	■ Appropriately set expectations with patients who these operations provide extremity debulking at the cost of poor appearance.

POSTOPERATIVE CARE

- As with any skin graft procedure, patients should be immobilized for 4 or 5 days to allow for graft take. This will almost always involve a hospital inpatient admission, which can allow for physical/occupational therapy assistance for mobility, and intravenous pain medication.
- All patients should be started on deep venous thrombosis prophylaxis such as subcutaneous heparin or low molecular weight heparin.
- Consider a 5-day course of intravenous antibiotics such as first-generation cephalosporin to prevent infection under the grafts.
- On postoperative day 5, all dressings are removed carefully with narcotic premedication. Wound care is targeted as needed to areas of healing difficulty.
- Prior to discharge, we recommend evaluation by occupational therapy and physical therapy for ambulation. Range-of-motion exercises are very important at the knee and elbow but are balanced against skin graft take. As soon as feasible, patients should be attempting full active range-of-motion exercises.
- Patients often require pressure garments for life to help prevent scar contractures. Lifelong follow-up with occupational therapy is advised.

OUTCOMES

- The largest series evaluating quality of life outcomes showed 63% satisfaction with limb-reducing surgery. 70% of all limb-reducing patients would opt for the surgery again.¹¹
- A common problem with the Charles procedure is poor appearance.
 - This results from the absence of subcutaneous tissues (ie, leg looks much thinner than normal leg).
 - There can also be a large step off at the junction of normal tissue and excised tissue from lack of contour between these sites (**FIG 2**).
 - Additionally, the skin grafts can become hyperkeratotic.

COMPLICATIONS

- These patients are at elevated risk of deep venous thrombosis given postoperative mobility limitations, diverting all venous blood into the deep system, and the significant inflammation from extremity excision.
- Suboptimal skin graft take is the most common complication that often results from local hematomas and seroma. Meticulous hemostasis along with meshed grafts can reduce this risk. Also, placing skin graft seems at lower tension points (avoiding joints) can ensure the highest graft take.
- Amputation has been reported.¹²



FIG 2 • Six months postoperatively with complete skin graft take. Note the hyperkeratotic appearance that is common following the Charles procedure.

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48 Liposuction for Treatment of Lymphedema

CHAPTER

Dung Nguyen and Joseph Baylan

DEFINITION

- Lymphedema is lymphatic transport alteration/damage resulting in the accumulation of proteinaceous fluid in the interstitial compartment.
- Liposuction is the surgical removal of local excess fat from under the skin by vacuum suctioning using a cannula introduced through small skin incisions.
- Dry liposuction is performed without the use of local anesthetic or dilute epinephrine.
- Superwet liposuction uses a 1:1 mL ratio of infiltrate-to-aspirate for large volume aspirate removal, decrease blood loss, avoidance of lidocaine toxicity, and to minimize resultant fluid shifts.
- The pitting test refers to the amount of depression of the tissue (in millimeters) after the thumb is pressed as hard as possible on the extremity for 60 seconds.
- Tissue edema that harbors more fluid will have more pitting and tissue edema that is mainly hypertrophied fat or fibrous tissue shows little or no pitting.

ANATOMY

- Vital structures, such as neurovascular bundles and tendons that travel beneath the skin, can be injured during liposuction.
- The key anatomical areas to avoid during liposuction in the upper extremity are the axilla, antecubital region, and the wrist.
- In the lower extremity, liposuction at the femoral triangle, popliteal fossa, and ankles should be avoided.
- Subcutaneous fat is divided into superficial, intermediate, and deep layer. Distribution of each layer varies depending on anatomical location and liposuction is carried out in the intermediate and deep layer.

- Lymphatic capillaries are present in a subdermal plexus, which merge together into larger lymphatic vessels to form a complex network that carries lymph through the body. The lymph fluid enters a lymph node basin (ie, inguinal region, axilla) via several afferent lymph vessels where it is filtered and then transported toward the lymphatic ducts by efferent lymph vessels. Deep liposuction in the region of a lymph node basin can disrupt the lymphatic network and cause neurovascular injury.

PATHOGENESIS

- Long-term accumulation of lymph fluid causes chronic tissue inflammation that induces excess differentiation of fat precursors, fat hypertrophy, tissue fibrosis, and hyperkeratosis.
- Hypertrophied adipose tissue and tissue fibrosis are late signs of lymphedema.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Candidates for liposuction are those with late stage II (spontaneously irreversible) to stage III lymphedema (lymphostatic elephantiasis).
- These patients have been treated and are refractory to complex decompressive physiotherapy (CDPT) and compression garments.
- Physical examination:
 - Presence of nonpitting edema on pitting test.
 - Intact skin without open wounds.
 - No erythema or signs of infection.
 - Negative Homans sign, defined as calf pain with extension of the foot.
- Treatment contract:
 - The success of the surgery relies on the patient being reliable and compliant with compression garment use 24/7 for life.
 - Patients who wish to proceed with surgery are asked to sign a treatment contract before surgery.

IMAGING

- Dual-energy x-ray absorptiometry (DXA) is used to estimate the excess fat, muscle, and bone tissue in the lymphedema limb.
- From the DXA scan, measurements are made in grams and transferred to volumes by density, which is useful in estimating the amount of excess fat to remove in patients scheduled for liposuction.

SURGICAL MANAGEMENT

- Preoperative preparation:
 - Optimize nonsurgical therapy to reduce residual pitting edema in the tissue as much as possible prior to surgery.
 - Patients who have history of deep vein thrombosis (DVT) should get a baseline venous duplex study.
 - Appropriate preoperative evaluation of cardiopulmonary status is always indicated prior to any surgical procedure.
- The patient must be aware of potential complications to include bleeding, infection, pain, numbness and tingling, contour irregularity, and wound healing problems.
- Garments:
 - Two sets of garments are made to match the size of the normal limb (Juzo, class II 30–40 mm Hg): one set is given to the surgeon to put on the patient immediately after surgery; the other set, the patient will bring to the first postoperative clinic appointment.
 - Upper extremity garments include Juzo compression sleeve from wrist to axilla with shoulder strap and gauntlet.
 - Lower extremity garments include Juzo open toe compression stocking with adjustable waistband, toe cap, and biker shorts for compression of the thigh and hip area.
 - Donning device to aid in putting on and removing garments.
 - These garments are not sterilizable in the United States.

TECHNIQUES

■ Anesthesia

- General endotracheal anesthesia is preferred.
- Epidural or peripheral nerve blockade performed by a regional anesthesia team is optional for postoperative pain management.

■ Position

- The patient is placed in supine position, and the affected extremity is rested on a hand table or a leg raise, respectively (**TECH FIG 1**).

- During surgery, the extremity is raised with the help of an assistant to access the posterior surface of the limb.



TECH FIG 1 • Positioning of affected extremity prior to suction-assisted lipectomy.

■ Equipment

- Sterile tourniquet.
- Liposuction set to include 3 and 4-mm cannulas.
- Suction-assisted or power-assisted liposuction machine.
- Wetting solution containing 20 mL of 1% lidocaine, 1 ampule of 1:1000 (1 mg/mL) epinephrine and 8 mL of sodium bicarbonate (8.4 mEq/L) in 1 L of lactated ringers.

■ Details of Procedure



Video p7-c048

- Preoperative antibiotic should be given prior to incision.
- Piperacillin-tazobactam (Zosyn) is preferred for broad-spectrum antibacterial coverage, particularly in patients with diabetes or significant comorbidities.
- After general endotracheal anesthesia is established, the entire affected extremity is prepped and draped circumferentially in the usual sterile fashion.

Superwet Liposuction

- Begin with superwet liposuction of the upper arm or thigh. Wetting solution is used in the proximal limb to minimize bleeding because tourniquet is not possible in this location.
- The amount of tumescent infused is the same as the expected amount of lipoaspirate removed. This is determined preoperatively by DXA scan.
- Using a no. 11 blade, 5 to 8 stab incisions, 3 mm in length, are made circumferentially in the proximal half of the arm or thigh.
- Wetting solution is injected in 1:1 infiltrate: aspirate ratio into the subcutaneous tissues of the upper arm or thigh using an infiltrating cannula. Wetting solution is infused until skin turgor is present at the desired location.
- After 10 to 15 minutes, liposuction is performed in the proximal extremity circumferentially.
- We prefer a 4-mm liposuction cannula for large volume liposuction and a 3-mm liposuction cannula for fine tuning and contouring with suction set at a medium setting.
- Start with the limb at rest on the table and begin liposuction of the anterior,

medial, and lateral surfaces first.

- The limb is then raised and held by an assistant or placed on a leg raise (for a lower extremity) to allow liposuction of the posterior limb.
- Liposuction should be performed in segments to ensure maximal volume reduction at each location.
- Avoid liposuction of the axilla or the femoral triangle, respectively, to avoid inadvertent neurovascular injury.
- The end point is achieved when no fat is seen in the suction tubing and the skin is loose and hanging (**TECH FIG 2**).



TECH FIG 2 • Tumescence liposuction is performed in the proximal thigh.

Dry Liposuction

- Dry liposuction is used for the remainder of the limb to avoid bleeding and excessive swelling of the tissue. This is beneficial in the immediate postoperative period for easier placement of the compression garment. It also facilitates quicker recovery as there is less postoperative edema.
- Place a sterile tourniquet on the proximal extremity with an Esmarch used to exsanguinate the limb.
- The tourniquet should be inflated to 175 mm Hg in the arm and 275 mm Hg in the leg.
- 10 to 20 skin stab incisions, 3 mm in length, are then made along the length of the extremity using a no. 11 blade to gain access for circumferential liposuction.
- Using a combination of 3 and 4 mm cannulas, gentle circumferential

liposuction of the limb down to the wrist or ankle is performed to remove the excess fibrofatty deposits.

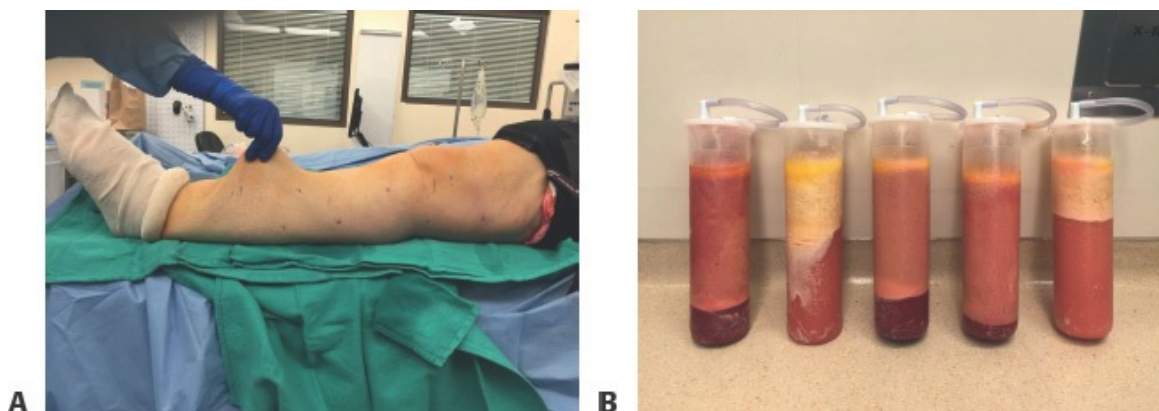
- Liposuction near the wrist and ankle should be done cautiously and with the smaller cannula to prevent excessive tissue trauma.

Irrigation

- All incision sites are irrigated with bacitracin solution (50 000 units/L) and cleaned.
- Apply antibiotic ointment to skin.
- With large volume of fat and lipoaspirate removed, there will be a noticeable reduction in the limb size and increased skin laxity in the extremity after liposuction is completed (**TECH FIG 3**).

Compression Garment Application

- The most challenging part of the operation is application of a clean custom compression garment, which is made preoperatively using the unaffected extremity as a sizer for the garment.
- We have found the most effective method is to be starting at the great toe and having an assistant lift the extremity while pulling force is being applied proximally to allow for the garment to span from the toes to the proximal thigh.
- Use of a donning device is also helpful to get the garment pass the hand or foot. The incisions are left open to drain through the sleeve.
- The tourniquet is then released once the garment is pulled to the level of the proximal thigh and secured.
- The entire extremity is additionally lightly wrapped with 6-in. Bias wrap to absorb the drainage.
- Total tourniquet time should be 120 minutes or less.
- There is typically minimal blood loss.



TECH FIG 3 • Liposuction is performed in segments. There is noticeable excess of skin envelope of the thigh and leg with reduction of large adipose volume. **A.** Dry liposuction is performed below the midthigh under tourniquet. **B.** Large volume of fibrofatty tissue is removed.

PEARLS AND PITFALLS

Patient selection	■ The ideal patient is one who has isolated nonpitting edema and can be compliant with 24/7 postoperative compression garment.
Approach	■ Use a systematic approach to liposuction by complete liposuction of each section of the extremity at a time. ■ Avoid liposuction at the axilla, the femoral triangle, or at the joints.
Tourniquet time	■ Allocate appropriate tourniquet time to each segment of the limb to avoid spending too much or inadequate time in one area. ■ Avoid liposuction at the axilla, the femoral triangle, or at the joints.
Compression garment application	■ Use a donning device to aid in garment placement.

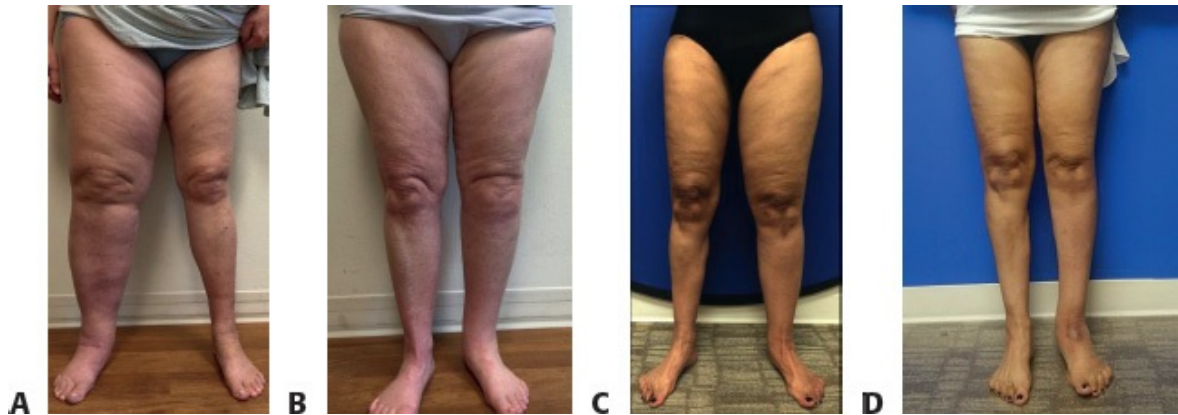


FIG 1 • A. 69-year-old female with 5 years history of right leg lymphedema status post hysterectomy, lymph node dissection, and postoperative radiation therapy. Preoperative DXA scan calculates 6150 mL of edema in the right leg. **B.** Results 1.5 years after liposuction of 6300 mL of fat from the right leg. **C.** 68-year-old female with 10 years history of left lower extremity lymphedema status post radical hysterectomy, pelvic lymph node dissection, and postoperative radiation therapy for cervical cancer. Preoperative DXA scan calculates 2583 mL of edema in the left leg. **D.** Results at 1 year after 3300 mL of fat tissue removed by liposuction.

POSTOPERATIVE CARE

- Due to the large amount of fluid (sometimes in excess of 10 L, depending on severity of lymphedema) removed from liposuction, overnight observation is indicated due to potential fluid shifts and for pain control.
- Patients are kept on an IV antibiotic for 24 hours and are discharged with a 2-week course of cephalexin (Keflex) or trimethoprim-sulfamethoxazole (Bactrim DS) for penicillin allergic patients.
- Prescription for oral narcotics is given for pain control.
- Patients are encouraged to ambulate regularly.
- Compression garment is to stay on 24/7 and may change the Bias wrap as needed when soiled.

FOLLOW-UP

- First postoperative appointment is on postoperative day 3, and the patient is asked to bring the second premade garment set to clinic to be changed by the surgeon.
- Patients are instructed to change their garment daily thereafter and to wear it 24/7.
- Subsequent visits are every 3 months in the initial 1 to 1.5 years with each visit adjustments to the garments are made as the edema improves.
- Once complete reduction is achieved, the patient is seen annually.

OUTCOME

- In patients who can remain compliant with 24/7 compression garment use, complete volume reduction can be achieved after 1.5 years and maintained long term (**FIG 1**).

COMPLICATIONS

- Blistering, particularly at the ankles, for which Mepilex may be used to protect areas of sensitive skin as needed
- Infection
- Contour irregularity
- DVT
- Paresthesias

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Section VII: Burns

49 Acute Management: Tangential Excision and Skin Grafting

CHAPTER

Yvonne Karanas

DEFINITION

- Tangential excision of a wound is defined as the sequential removal of eschar in thin layers until healthy tissue is reached. Punctate bleeding of the underlying wound bed signals the presence of viable tissue and the end point of excision.
- Tangential excision can be applied to any eschar of the skin in order to minimize the amount of tissue removed and preserve underlying viable tissue. It is most commonly used in burn surgery.
- This procedure was first described by Janecovic in the 1970s and has been adopted worldwide by burn and plastic surgeons.¹
- A split-thickness skin graft is a piece of skin removed from the body for the purpose of covering a wound in another location. The outer portion of the skin composed of the epidermis and some portion of the dermis is “split” from the remaining underlying dermis. Enough dermis is left in the “donor site” for re-epithelialization.
- A full-thickness skin graft is a piece of skin containing the “full thickness” of the epidermis and the dermis. Like a split-thickness graft, this piece of skin is removed from the patient and then transplanted to another site for wound closure or to add additional skin after contracture release. Unlike a split-thickness skin graft, no dermis is left behind so the wound must be closed primarily.

- Allograft is broadly defined as a tissue graft from another human being. In burn care and surgery, it refers to human cadaver skin used to provide temporary wound coverage.
- TBSA is Total Body Surface Area and refers to the amount of skin on the body that is burned.

ANATOMY

- Burns and traumatic injuries can result in partial-thickness and full-thickness injuries. These terms refer to the depth of the injury into the skin.
- Partial-thickness injuries involve the epidermis and some portion of the dermis.
- Full-thickness injuries involve the epidermis and the entire dermis and can even include the subcutaneous fat.

PATHOGENESIS

- Full- or partial-thickness skin necrosis may occur with trauma, burn injury, and severe soft tissue infections.
- There are approximately 486 000 burn injuries per year in the United States with 40 000 requiring hospitalization.²
- Worldwide, the magnitude of the problem is even greater.

NATURAL HISTORY

- Burns or traumatic injuries may initially appear as superficial injuries, but with time (72–96 hours), they may progress to full-thickness injuries.
- Judicious early debridement and serial wound care preserve all viable tissue while preventing wound infection.
- When the wound evolution is complete, areas of full-thickness and partial-thickness burns should be clearly delineated. Definitive surgical treatment may then be performed as needed.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Full-thickness injuries may present as white, yellow, or brown leathery, insensate areas that lack capillary refill. With time, they will progress to a black eschar (**FIG 1**).
- Partial-thickness injuries may be superficial with pink, moist, sensate tissue that has capillary refill.
 - Deep partial-thickness burns may be cherry red in color, lack capillary refill,

have decreased sensation, and may be dry. These burns are often described as “indeterminate thickness” as it is often unclear initially whether they will require surgical treatment or not.

- Burns and traumatic injuries may result in wounds that are a combination of different depths of injury (**FIG 2**).



FIG 1 • Lower extremity full-thickness necrosis from a severe soft tissue infection.

NONOPERATIVE MANAGEMENT

- Partial-thickness burns may be managed with wound care alone.
- In general full-thickness skin, necrosis requires surgical treatment. It may be managed conservatively in select situations, for example, small wounds that are less than 1% TBSA on the torso. A large burn is commonly defined as a burn greater than 20% TBSA.
- Wound care may be performed once or twice daily with silver sulfadiazine to soften and debride the eschar and prevent infection. Eventually the eschar will separate from the underlying wound bed; however, this process may take weeks or even months and lead to poor scarring and contractures.
- For large wounds, an expectant management strategy carries a high risk of wound infection.
- Surgical treatment remains the standard of care for large full-thickness wounds.



FIG 2 • A. Contact ankle burn with second-degree and third-degree components in a paraplegic patient. **B.** Flame burn to the thigh with mainly third-degree burns and small patches of second-degree burns.

SURGICAL MANAGEMENT

Preoperative Planning

- Equipment for Tangential Excision
 - Watson Knives (**FIG 3A**)
 - Weck/Goulian Knives (**FIG 3B**)
 - Epinephrine solution
- Equipment for Skin Grafting
 - Dermatome electric or air powered
 - Guards of different widths (**FIG 3C**)
 - Mineral Oil
 - Tumescent solution: 1 L crystalloid, 1 cc (1:1000) epinephrine, 0.25% Marcaine (30 cc)
 - Klein Infiltration Pump—allows for high-volume infusion of tumescent solution in a rapid fashion
- Tangential excision is performed using a variety of knives designed for this purpose, or a dermatome may be used.
- The choice of instrument is based on the location of the wound and the size and thickness of the eschar. Small burns or burns in delicate areas such as the hands, face, or feet are excised with a Weck knife. Larger, thicker burns on the extremities or trunk are excised with a Watson knife. The depth of the excision

can be set by adjusting the guard on the Weck knife or on the Watson knife itself.

- The Weck knife has three guards that can be placed over the blade to control for the depth of excision: 0.012, 0.010, and 0.008 in. The selection of the thickness of the excision is based on the surgeon's perception of the depth of the wound and the thickness of the skin in that region. The narrower guards of the Weck knife are used for less deep burns and areas of thin skin such as the dorsum of the hand, foot, or nose (**FIG 3D**).
- The Watson knife can be adjusted manually for thinner or thicker excisions. The knife is opened to its widest for large deep back burns, whereas more superficial leg burns would be treated with the knife only partially opened.



Video p7-c014_01

- Skin grafts are harvested using a dermatome which can be electric or air powered.
- A mesher is used to place holes in the skin, so that it can be stretched to cover a larger surface area (**FIG 3E**).

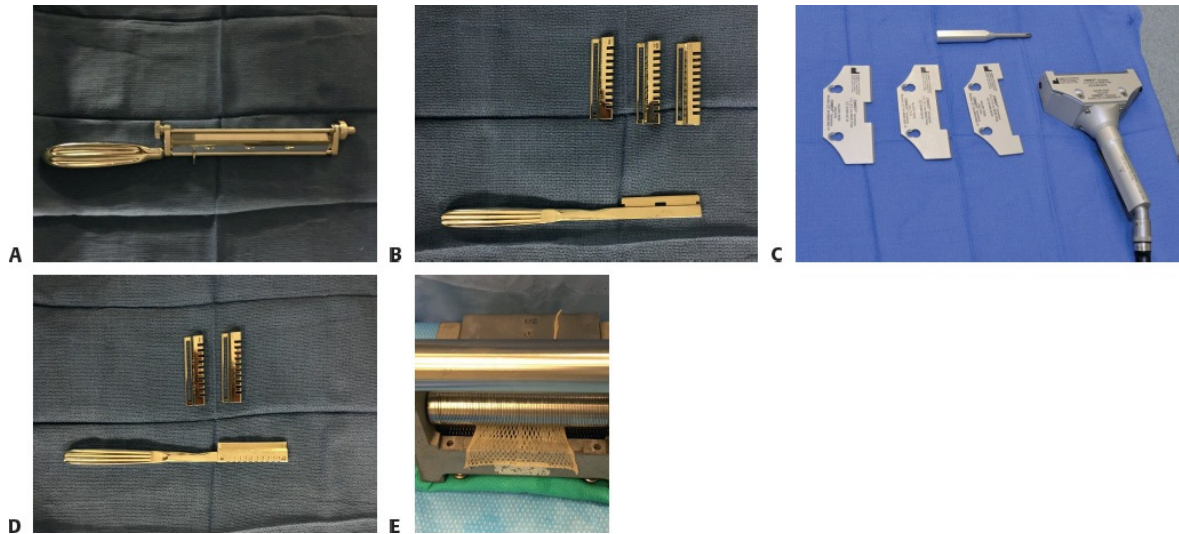


FIG 3 • A. Watson Knife. **B.** Weck knife with guards. **C.** Dermatome with 1", 2", 3", 4" guards. **D.** Weck knife with guard loaded on blade. **E.** Skin being meshed in a 2:1 fashion.

Positioning

- The patient is positioned to access the eschar and available donor sites. If necessary, the patient may be repositioned during the operation. For most lower-extremity wounds, the patient can be placed in the supine position.
- A plan to keep the patient warm during surgery should be formulated prior to the OR and implemented on arrival. Common strategies to maintain the patient's temperature include warming the room and all IV fluids, covering all nonoperative body parts with warm blankets and placing a heating pad or warming blanket under the patient.

TECHNIQUES

■ Tangential Excision

- Direct the blade of the knife at the skin in approximately a 30 degree angle to engage the eschar in the blade.
- Decrease the angle so that the blade is parallel to the skin through the remainder of the excision.

- Gentle pressure is applied as the blade is moved back and forth to slice off the eschar at a uniform depth. The motion of the blade is akin to playing the violin where the bow is slid back and forth across the strings.³
- Excise the most dependent portion of the eschar first, so that the bleeding will not obscure the remaining areas that require excision.
- This process should be repeated until the entire wound has healthy tissue present with punctate bleeding.



Video p7-c014_02

- Each area should be tangentially excised until a viable wound bed is obtained before moving to the next area. This will minimize blood loss and ensure that entire wound bed is adequately excised.
- After initial excision, the entire wound bed should be assessed to assure punctate bleeding is present throughout. If immediate skin grafting is planned, any areas of questionable viability should be excised again in the same method until the surgeon is satisfied with the appearance of the wound bed. If allograft is planned for areas of questionable viability, then these wounds can be left to see if they will survive. These areas can then be re-excised at the next surgical session as needed (**TECH FIG 1**).
- Epinephrine-soaked sponges are used for hemostasis followed by electrocautery to any bleeding that has not subsided.



TECH FIG 1 • Contact ankle burn after tangential excision and hemostasis.

- In the extremities, tourniquet control can be used while performing tangential excision.
 - A sterile tourniquet can be applied to the normal skin or even injured tissue proximally on the extremity.
 - The extremity is elevated and the brachial or popliteal artery compressed prior to inflation of the tourniquet. In general, exsanguination is not performed as the wounds may be contaminated or infected.
 - Excision then proceeds as outlined above. Given the inflated tourniquet, bleeding is not the end point of excision. The surgeon must become adept in assessing the underlying wound bed in the absence of bleeding. The dermal tissue should be glistening white and the fat a moist light yellow without hemorrhage. All thrombosed blood vessels should be excised. Once excision is completed, the tourniquet is deflated and the wound bed reassessed. Areas that do not bleed should be re-excised as outlined above.

■ Skin Grafting

- Split-thickness skin grafts are harvested using a dermatome.
- In general, 0.012-in. thickness is the standard setting for harvesting a split-thickness skin graft.
 - Thinner grafts may be used for large burns or when wound contraction is desired as is the case for fingertip injuries or plantar heel wounds.
 - Thicker grafts can be harvested for areas of functional importance and

where graft contracture should be minimized.

- The hands, face, feet, and genitalia are a few examples where thicker split-thickness grafts or full-thickness grafts would be utilized.
- Harvesting a skin graft is ideal when the donor surface is flat.
 - This can be achieved both by positioning the patient and manipulating the tissue with pressure and traction.
- For these reasons, the thighs are the preferred donor site for harvesting a skin graft.
- Local anesthetic can be injected prior to skin graft harvest for postoperative pain control.
- Other areas can be made smooth and flat by “tumescing” the underlying tissue similar to the technique used for liposuction.
 - This involves inflating or swelling the subcutaneous tissues with liquid.
 - A solution consisting of lactated ringers, local anesthetic, and epinephrine is injected into the subcutaneous tissue of the area of the planned harvest.
 - The amount of solution required is assessed for adequate “tumescence” by manual palpation to see if it is indurated and filled with fluid such that it is smooth and all bony prominences are now obscured.
 - Care must be taken to ensure the injection is subcutaneous and not within the deeper tissues.
- Tumescence is commonly performed over the back and chest where the ribs are palpable and the anterior lower extremities where the tibia is prominent.
 - If injected too deeply in the extremities, compartment syndrome could ensue.
- The tumescent solution also aids with hemostasis from the epinephrine effect and postoperative pain control from the local anesthetic.
- Mineral oil is applied to the skin and dermatome immediately prior to harvesting to allow the dermatome to slide more easily along the skin.
- Once the donor site has been prepared, the dermatome is turned on and applied to the skin at approximately a 45-degree angle.
- Light to moderate pressure is applied and the skin engaged by the dermatome.
- Once the graft is visible in the dermatome, the angle of harvest can be decreased to roughly 30 degrees.
- Under physician control, gentle forward pressure is applied to the dermatome along the entire length of the skin being harvested.

- The dermatome is then disengaged from the skin by angling it up akin to a “plane taking off from the tarmac.” The motor is engaged until the dermatome is off of the skin.



Video p7-c014_03

- After the skin grafts are harvested, topical epinephrine-soaked sponges can be applied to the donor site wound bed for hemostasis.
- Grafts can be kept on the technician’s table in moist saline soaked gauze until the surgeon is ready to apply them.
- The grafts can be applied as sheet grafts or meshed grafts. Sheet grafts contract less than meshed grafts, and their appearance is better. Grafts can be meshed 1:1 up to 9:1 as needed. Narrow mesh allows for fluid egress while minimizing the mesh appearance of the healed graft. Wider meshing allows for coverage of large wounds with minimal amounts of intact skin. The wider the graft is meshed, the longer the time to healing and the more wound contracture there will be. Widely meshed grafts can be difficult to work with as it may be challenging to identify the dermal side of the graft.
- Grafts should be placed with the dermal side in contact with the underlying wound bed. The surgeon should try to avoid having seams or joining areas over joints.



TECH FIG 2 • Meshed skin graft secured in place with staples.

- For the lower extremity, there are two techniques that facilitate grafting.
 - The first is to wrap the grafts circumferentially around the leg so that the seam is on the anterior surface of the leg.
 - The second is to place one long strip vertically on the posterior side of the leg.
- The remaining grafts can then be placed on the anterior, medial, and lateral sides.
- Both of these techniques minimize the amount of stapling or suturing that needs to be done to the posterior surface of the leg. Technically, this makes the surgery easier and allows it to proceed more expeditiously.
- The grafts can be secured with surgical staples (**TECH FIG 2**), sutures, and tissue glue or Steri-Strips/Hypafix (Smith & Nephew, London, UK) dressing tape.
 - Skin staples are the traditional method of fixation for large grafts.
 - Smaller grafts can be sutured in place obviating the need and pain of staple removal.
 - In recent years, Artiss fibrin sealant (Baxter, Westlake Village, CA) has become available and can be used to adhere grafts to the underlying wound bed.
 - Artiss is used in conjunction with staples, but these can be removed at the completion of grafting and when the Artiss has dried or alternatively a few critical staples may be left in place to be removed later.
 - Steri strips or other adhesive tapes can also be used on grafts that border

the normal skin.

PEARLS AND PITFALLS

Technique	■ If the Watson, Weck/Goulian blade is held in a too vertical position, it will incise the skin like a standard knife and can injure underlying structures. ■ Care should be taken over the Achilles tendon, malleoli, and the patella as overzealous excision will quickly result in tendon and bone exposure.
Tumescent technique	■ Care must be taken to ensure the injection is subcutaneous and not within the deeper tissues. ■ If injected too deeply in the extremities, compartment syndrome could ensue.
Excision	■ Adequate excision is the key to a successful outcome. It is critical that the surgeon ensure that all nonviable tissue has been excised prior to skin grafting.

POSTOPERATIVE CARE

- For larger grafts or in larger wounds, the grafts are covered with nonadherent gauze and silver impregnated dressings for antimicrobial protection. In the contaminated wound, the dressings are left in place for 72 hours, and then daily dressing changes are instituted. Early changing of bandages in these high-risk wounds helps identify infections and promote aggressive treatment to salvage skin grafts. Pseudomonas infection is a common culprit in these scenarios and can be treated effectively with mafenide solution-containing dressings. Smaller or less contaminated burns can be left in the postoperative dressing for 5 to 7 days, and then wound care can begin with any moisture-containing products. We commonly use Xeroform and Bacitracin. There is currently no conclusive data to support the use of systemic antibiotics after a skin graft procedure is performed.
- The vacuum-assisted closure (VAC) device can also be used to secure skin grafts during the early postoperative period. The VAC is placed in the operating room and left on for 5 to 7 days postoperatively depending on the surgeon's comfort with the cleanliness of the wound. After removal, standard daily dressing changes are instituted. The VAC is extremely helpful in getting

grafts to adhere to a wound bed that has concavities or irregularities. The VAC provides excellent fixation of the grafts so that movement of the extremity will not shear the grafts. This feature makes it an excellent choice for children who may not be compliant with immobilization instructions. In addition, the VAC provides a less painful wound environment often giving patients a break from the daily pain of wound care. In order to place the VAC, there must be a 1- to 2-in. border of the normal skin around the wound for tape placement (**FIG 4**).

- Grafts that cross joints should be immobilized with splints to prevent shearing of the grafts.
- Bolsters can be used to prevent movement of the graft and promote adherence of grafts in convex and irregular wound beds.
- Physical therapy with ambulation and range of motion is instituted on postoperative day 5 when the grafts should be adherent. For larger wounds and grafts, compression garments are worn once the wound is healed.



FIG 4 • VAC dressing in place.



FIG 5 • Six days after excision and grafting. The graft is pink and adherent.

OUTCOMES

- With experience, skin graft take should consistently be above 80% (**FIG 5**). Long-term outcomes from skin grafting depend on the severity of the injury, length of time to healing, and patient participation in therapy. Hypertrophic scarring, contractures, pigment changes, itching, and pain are long-term sequelae of the disease process and the treatment. Often, surgical release of contracture is necessary to regain full function after tangential excision and skin grafting.

COMPLICATIONS

- Graft loss (partial or total) remains the main complication.
- Causes:
 - Inadequate excision of the underlying wound bed
 - Hematoma
 - Seroma
 - Graft shear
 - Infection
- Contracture

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Reconstruction of Contractures: Z-Plasty, Skin Grafting, and Flaps

50

CHAPTER

Xiangxia Liu

DEFINITION

- Scar contracture is the result of tightening of the skin during and after the wound healing process.
- The continuous and progressive contraction of the scar will cause the impairment of appearance and significant dysfunction of the affected area.
- In the lower extremities, especially around the knee and ankle joint, the contracture scar can cause significant restriction in movement and, therefore, should be treated as soon as possible.
- There are many surgical interventions to treat scar contracture, including Z-plasty technique for mild scar contracture, skin grafting for a larger area of skin defects after the releasing of the contraction, and a skin flap, especially around the knee and ankle joint area or when there are any bone, tendon, nerve, and blood vessel exposure.

ANATOMY

- The scar contractures in the lower extremities usually only affect the superficial fascia layer. Sometimes there will be exposed bone, tendons, nerves, and vessels after scar resection or revision.
- Lateral femoral circumflex artery (LFCA) arises from the deep femoral artery; it goes deep to the rectus femoris muscle and divides into three branches: the ascending, transverse, and descending branch. The Anterolateral thigh flap (ALT) is designed base on the perforator of the descending branch of LFCA (**FIG 1A**).
- Pedicled reverse-flow ALT flap is a useful tool to repair the defects around the

knee joint. The descending branch of LFCA will communicate with the arteries around the knee joint, which perfuses the pedicled reverse-flow ALT flap (**FIG 1B**).

- Perforator flaps based on the peroneal artery or posterior tibial artery (**FIG 1C**) are powerful tools to repair the defects around the ankle joint and the heel (**FIG 1D**).

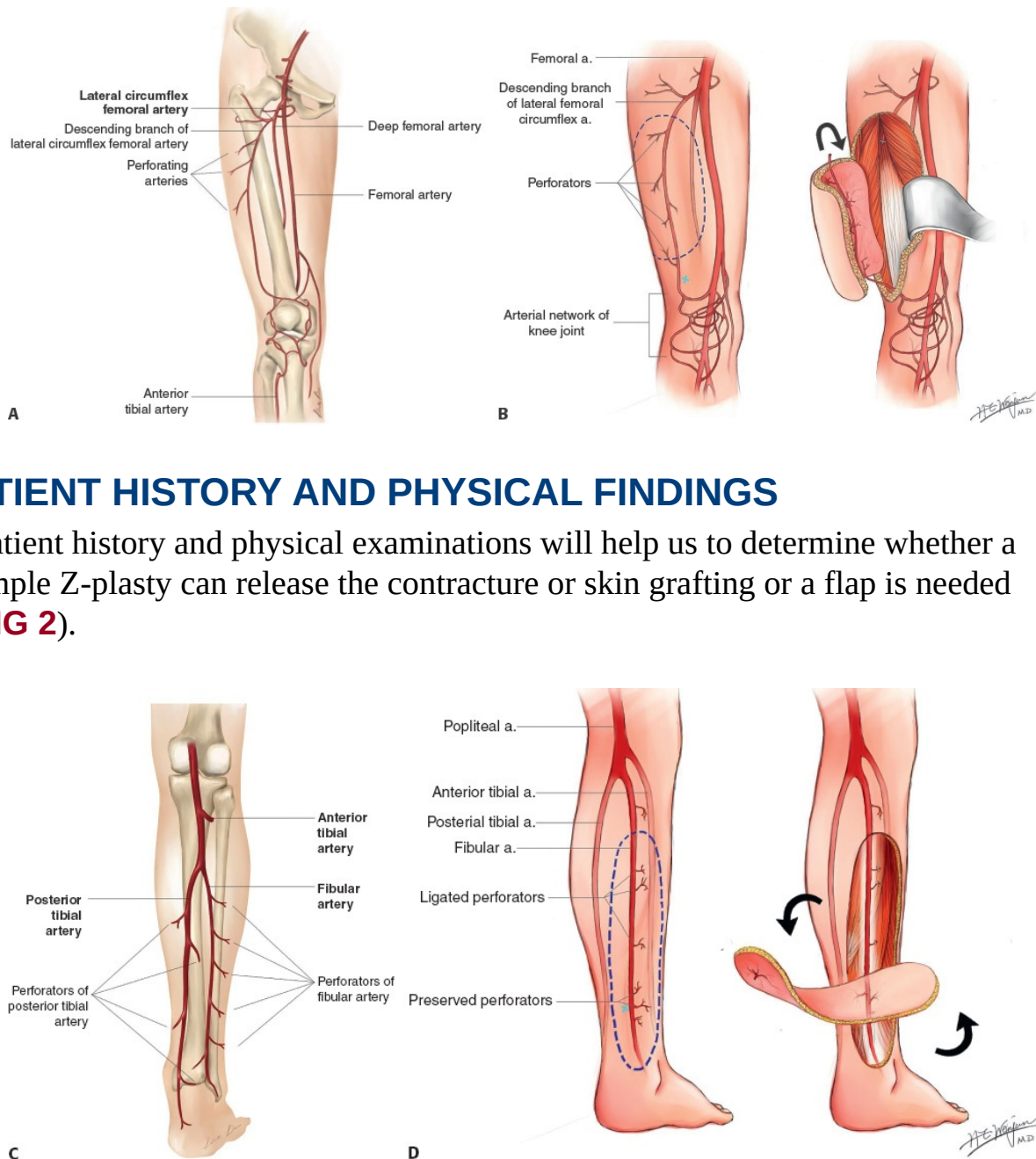


FIG 1 • A. Arising from the profunda femoral trunk, the

lateral circumflex femoral artery (LCFA) gives three branches: ascending, transverse, and descending branch. The descending branch of LCFA travels deep with the space between the rectus femoris muscle and the vastus lateralis muscle. As traveling distally, it distributes the perforators, in most cases musculocutaneous perforators to the flap. **B.** The distal communicating artery between the descending branch of LCFA and the lateral superior geniculate artery is the anatomic basis for the reversed ALT flap. **C.** Through its course in the leg, the posterior tibial artery usually gives two to four major septocutaneous perforators; these perforators arise from between the soleus and the flexor digitorum longus muscle or between the flexor digitorum longus muscle and the medial aspect of tibial bone. The distance between the lowest perforator and the medial malleolus ranges from 3.5 to 8.2 cm.¹ **D.** The perforators of peroneal/fibular artery arise from between the soleus and the peroneus longus/brevis muscle. They are usually located within 2 cm from posterior border of fibular bone and are closer to the fibular bone proximally than distally.

IMAGING

- Preoperative radiography can help to distinguish simple and complex scar contracture, especially if an underlying skeletal abnormality is suspected.
- CT and MRI scanning play an important role in the evaluation of skin cancer.
 - An MRI can well identify the relationship among the tumor, calcaneus bone, and Achilles tendon in the case of Marjolin ulcer, an aggressive squamous cell carcinoma presenting in an area of chronic inflammatory scar tissue (**FIG 3**).

SURGICAL MANAGEMENT

Indications

- Z-plasty is designed to elongate a less contracted linear scar or to break a scar tension line.
- Skin grafting is an option when the primary closure is impossible and there is a lack of adjacent tissue for coverage.



FIG 2 • A. For a superficial nonhypertrophic scar on right arm with minimal contracture, the simple technique of Z-plasty will release the contracture scar and break the tension line. **B.** For this patient, skin grafting is needed to replace the unwanted hypertrophic scar on the dorsum of the right foot and to release the dorsal contracture of the second, third, and fourth toes. **C.** Both the Z-plasty and skin grafting are needed to fully release the contracture bands of the left ankle and foot.

- Flap should be applied when there is an exposure of the bone, nerve, blood vessel, and other tissues, which are unsuitable for skin graft.

Preoperative Planning

- Prepare the donor site for skin grafting.
- Use Doppler ultrasonography to confirm the perforator before the operation.
- Pathological study of the chronic ulcer in the scar area before the surgery is important.

Positioning

- The patient is placed supine on the operating room table with the entire lower extremity prepared into the field.
- The ipsilateral or contralateral thigh is prepared into the field in the event that

a split-thickness skin graft is needed.

- The scalp is another option for harvesting thin split-thickness skin grafts if the patients do not want to leave a visible scar on the donor site.

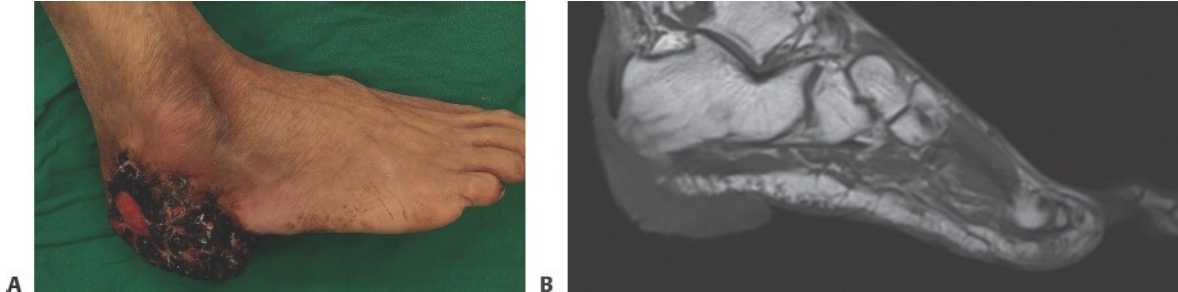


FIG 3 • A. Cauliflowerlike tumor on the right heel. **B.** MRI shows the tumor has a close relationship with the calcaneus bone and the Achilles tendon. A flap would be needed to cover this defect after tumor resection because there will be an exposure of both the bone and tendon.

- The groin is prepared in the event that a full-thickness skin graft is needed.
- A prone position will be helpful when the procedure is related to the posterior aspect of lower extremity.
- A lateral decubitus position will facilitate the exploration of the perforator of peroneal artery.

Approach

- Make the incision on the medial margin of ALT flap first as this will facilitate the exploration of perforators in the medial thigh in case that there is no perforator available in the lateral side.

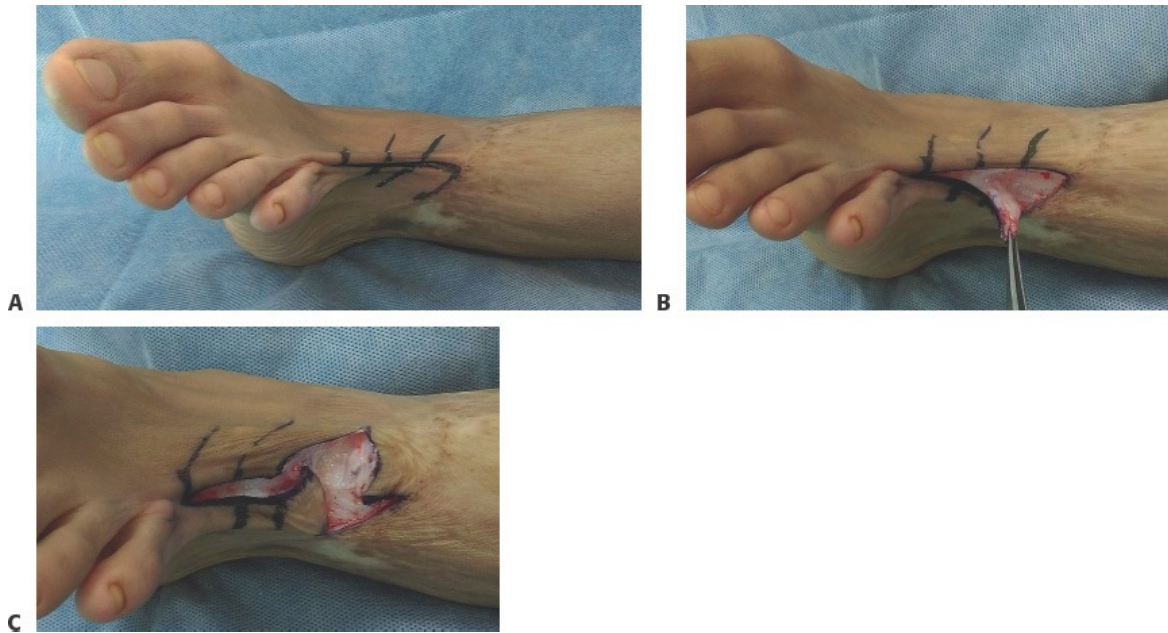
TECHNIQUES

■ Z-Plasty

- Draw the center line on the part of the scar with the most contracture.
- Make a paired and paralleled limb line on each side of the center line

(**TECH FIG 1A**).

- Try to set the angle around 60 degrees between the center line and limb lines.
- Cut the skin along the designed lines.



TECH FIG 1 • **A.** Multiple Z-plasties marked on a contracture band. **B.** The flap is elevated superficial to the deep fascia. **C.** The paired Z-plasty flaps are transposed initially.

- Release the subcutaneous bands.
- Elevate the flap superficial to the deep fascia (**TECH FIG 1B**).
- Transpose the paired skin flaps (**TECH FIG 1C**).
- Trim the dog ears and overly abundant subcutaneous tissues.
- Place several sutures in dermal layer of the key areas.
- Close the wound accordingly.

■ Skin Grafting

Preparation of the Recipient Site

- Release the contracture bands of the scar (**TECH FIG 2A**).

- Make multiple zigzag incisions along the cutting edge of the wound to lessen the tension of the scar (**TECH FIG 2B,C**).
- Remove the scar tissues in the wound.
 - Control bleeding with bipolar electrocautery.
- Make a template of the defect.

Harvesting the Skin Grafts

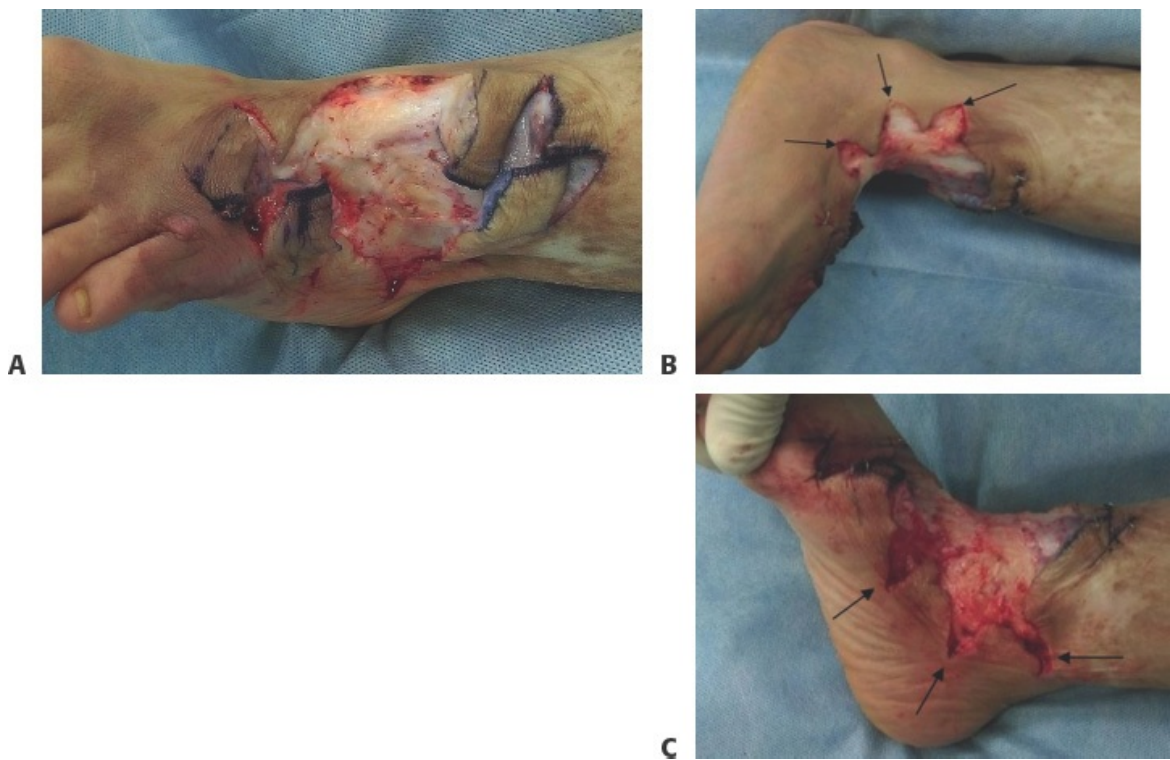
- Use the tumescent fluid to flatten the surface of donor site and reduce bleeding.
- Use a power-driven (**TECH FIG 3A**) or freehand dermatome to harvest the split-thickness skin grafts from the thigh or scalp.
 - Choose the width and the thickness of the harvested grafts by adjusting the dermatome (**TECH FIG 3B,C**).
 - A simple way to assess the thickness is by passing a no.15 blade between the guard and the blade.
 - Install and lock a new disposable blade.
 - Make a 30- to 45-degree angle between the handle and the surface of the skin (**TECH FIG 3D**).
- Apply gentle downward pressure, and advance the machine slowly during the harvesting (**TECH FIG 3E**).
- Assess the thickness of the cut during harvesting by observing the grafts through the guard and the wound of donor site.
- Angle the machine upward, and lift off from the donor site when the harvest is complete.
- Cover the donor site with petroleum jelly gauze (**TECH FIG 3F**) or Melgisorb (Mölnlycke Health Care, Gothenburg, Sweden) combined with Mepilex (Mölnlycke Health Care, Gothenburg, Sweden).
- Put the grafts on petroleum jelly gauze with the dermal side facing up (**TECH FIG 3G**). A graft tends to fold over on itself, and this will help to keep it extended.

Placing and Securing the Grafts

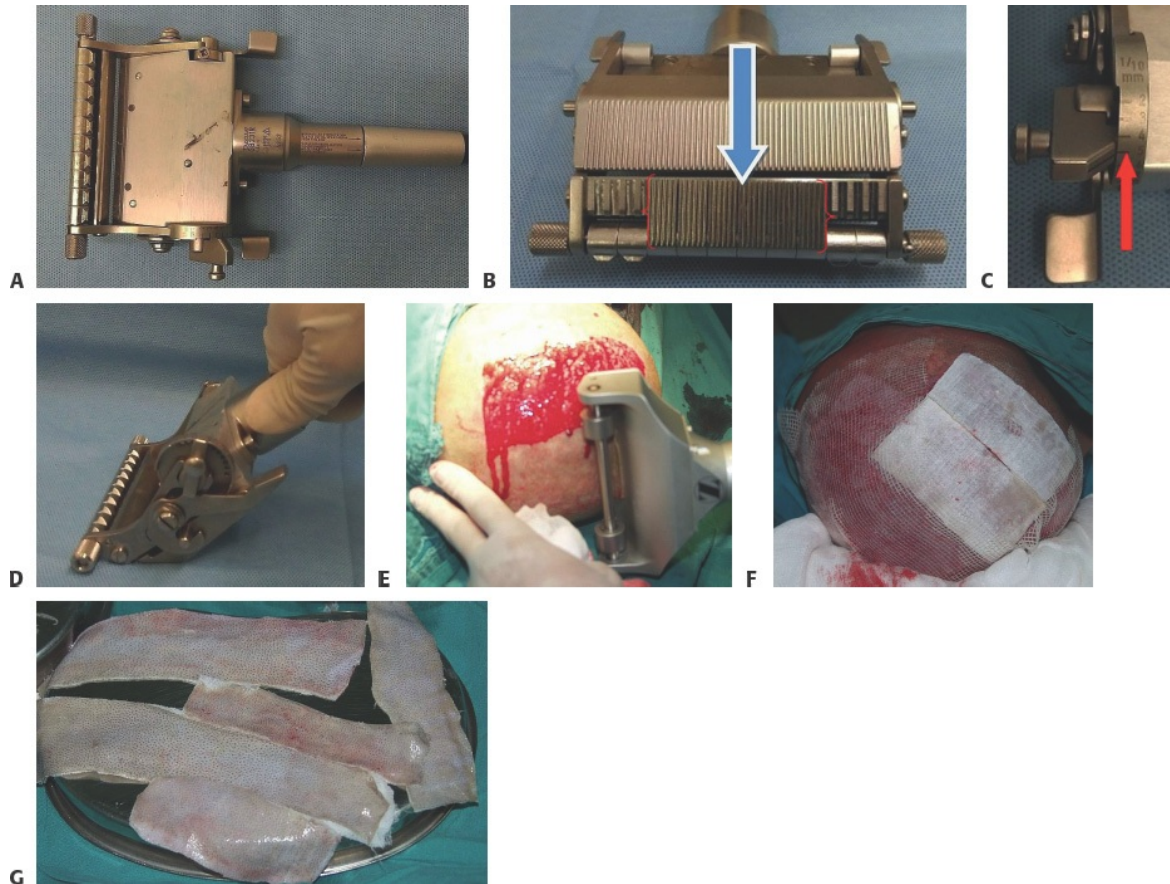
- Place the grafts on the wound.
 - Keep the dermal side downward, and attach to the wound directly. The dermis has a shiny appearance and sticky sensation.
- Tailor the grafts to the wound and staple the key area.
 - Adding a suture at the tip of a small full-thickness skin graft and holding it

against the index finger can help to trim the grafts with scissor (**TECH FIG 4A,B**).

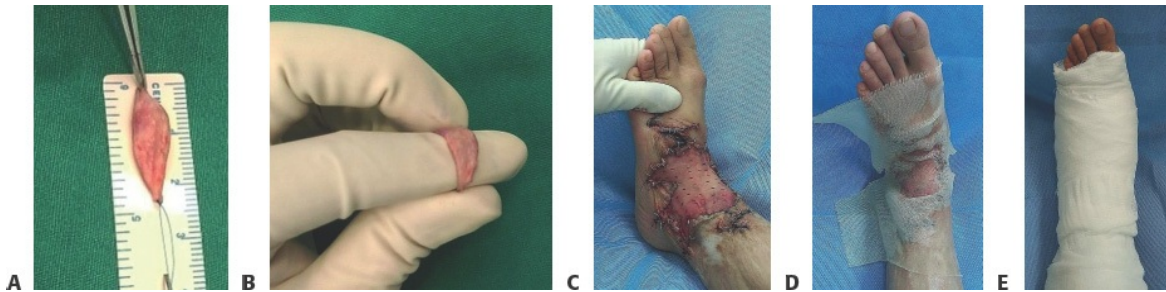
- Secure the grafts with suture, surgical staple, or fibrin glue (**TECH FIG 4C**), flushing beneath the grafts with normal saline before dressing.
- Place a petroleum jelly gauze directly on the grafts (**TECH FIG 4D**), and top that with a single layer of moistened gauze.
- Next, apply a circumferential wrap/tie-over bolster/negative pressure technique (**TECH FIG 4E**).
- A splint is applied to immobilize the extremity.



TECH FIG 2 • A. The contracture band is completely released. **B,C.** Zigzag incisions (*arrows*) are made along the cutting edge of the wound to minimize the scar contracture later on.



TECH FIG 3 • A. Aesculap model dermatome. **B.** Width is adjustable with 10 individual 8.0-mm cutting flaps. **C.** Cutting thickness varies from 0.2 to 1.2 mm in lockable 0.1 mm increments. The thickness reading indicates the maximal thickness the surgeon can harvest; grafts may be thinner depending on the pressure applied on the handle. **D.** The device is held at 30- to 45-degree angle between the handle and the surface of the skin. **E.** Split-thickness skin grafts being harvested from scalp. **F.** The donor site is covered with petroleum gauze. **G.** The harvested skin grafts are placed on the petroleum jelly gauze with dermal side facing up, which will facilitate placement in the wound.



TECH FIG 4 • **A.** A stitch is placed in the tip of the graft. **B.** Placing the graft on the dorsal of index finger and holding with thumb and middle finger helps with trimming. **C.** Graft in place and secured with staples. **D.** Petroleum jelly gauze is placed on the graft. **E.** Wrapped before splinting.

■ Skin Grafting Combined with Acellular Allodermal Matrix

- The recipient site is prepared by excising the scar as previously described.
- Acellular allodermal matrix is used to cover the defect (**TECH FIG 5A,B**).
- Split-thickness skin grafts are harvested and placed as described (**TECH FIG 5C**).



TECH FIG 5 • **A.** Premeshed acellular allodermal matrix. **B.** Placement of the matrix. **C.** Placement of split-thickness skin graft.

■ Flaps

Using an Expanded Flap to Repair a Contracture Scar

- Release the contracture scar.
- Harvest the expanded flap (**TECH FIG 6A,B**).
- Transpose and inset the expanded flap (**TECH FIG 6C**).
- Close the recipient and donor sites (**TECH FIG 6D**).

Using a Flap and Skin Graft

- In this patient, a pedicled reverse-flow ALT flap was used to reconstruct an ulcer of the scar in the knee area.
- The lesion is excised (**TECH FIG 7A,B**).
- The ALT (ALT) flap is designed, including the pivot point (**TECH FIG 7C**).
- The flap is elevated, rotated, and inset (**TECH FIG 7D–G**).
- Split-thickness skin graft is used to cover the donor site, and the recipient and donor sites are closed (**TECH FIG 7H**).

Using a Skin Flap to Repair a Heel Wound

- In this patient, lateral lower leg skin flap based on the perforator of peroneal vessel was used to repair a Marjolin ulcer on the heel.

Stage 1: Tumor Resection

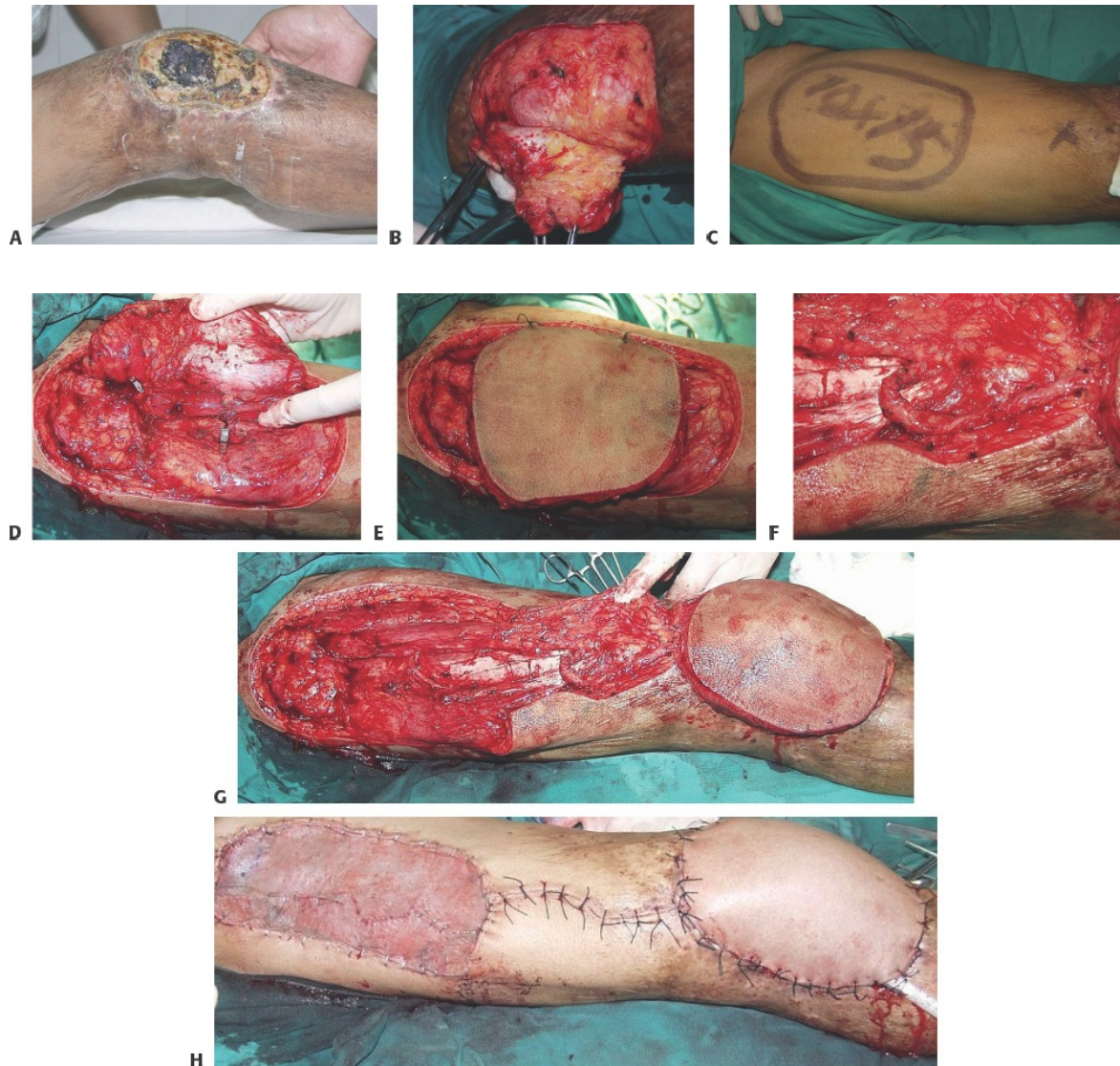
- A 2 cm margin is marked.
- Dissection plan is under the deep fascia.
- The periosteum of calcaneus under the tumor is resected (**TECH FIG 8**).
- The wound is packed with iodine gauze.
- The second stage of reconstructive surgery is delayed until the negative margin is confirmed by the final pathology report.

Stage 2: Wound Repair

- Perforator investigation
 - Mark the head of the fibula, lateral malleolus, and fibula bone.



TECH FIG 6 • **A.** Scar contracture of the popliteal fossa with tissue expander placed on the lateral aspect of the thigh. **B.** Inferior-based flap design. **C,D.** Contracture scar excised and flap transposed.



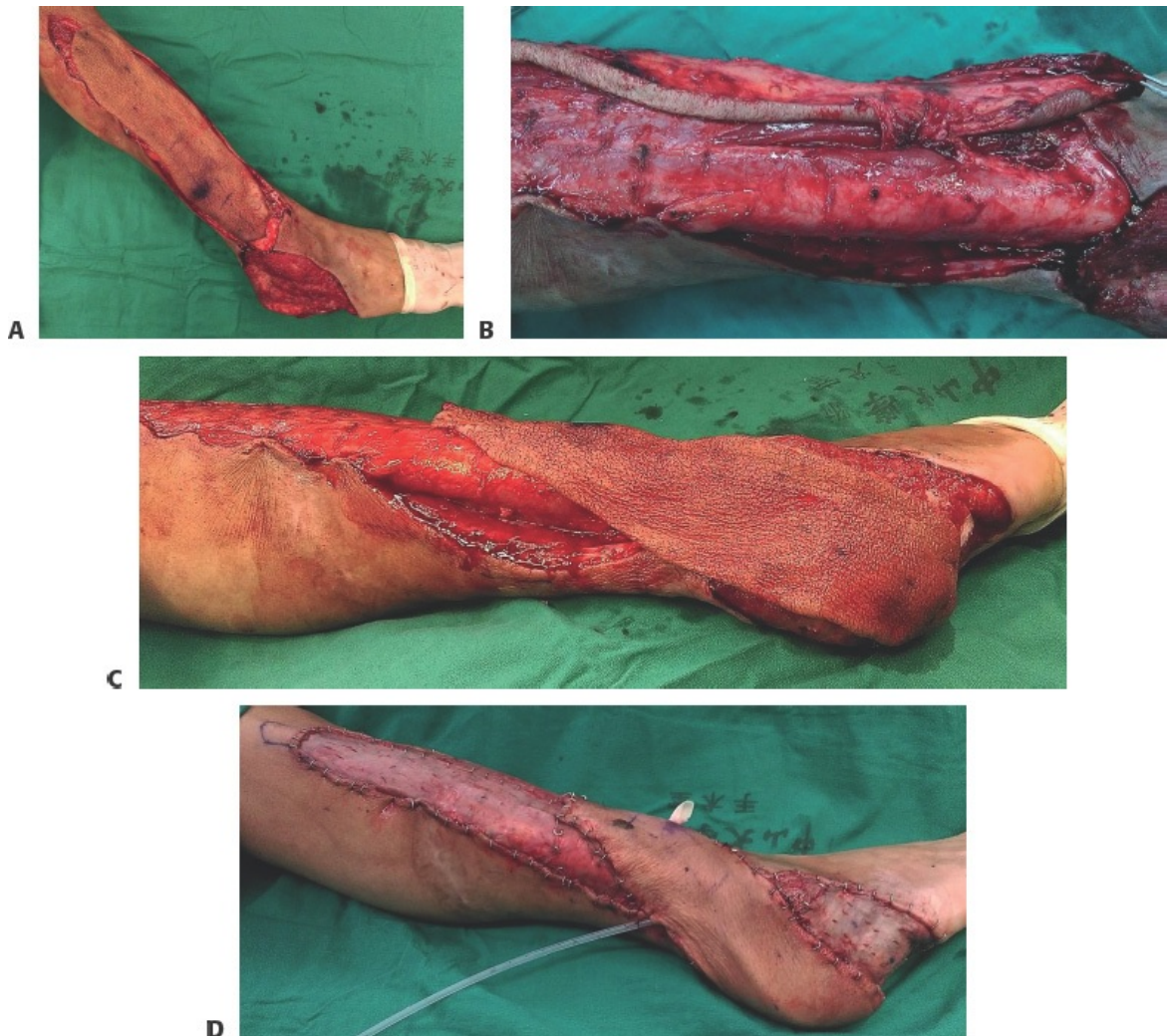
TECH FIG 7 • **A.** Chronic ulcerative scar on the anterior aspect of the right knee with limited knee extension function. **B.** Excise the lesion completely. **C.** Design of the ALT flap and the marking of pivotal point. **D.** Flap monitor is used during the surgery. **E.** The ALT flap is incised and elevated. **F.** The

perforator. **G.** The flap is rotated into place to repair the defect. **H.** Skin graft is used to cover the donor site, and both sites are closed.

- Make an incision at the posterior margin of the flap, usually 3-5 cm posterior to fibula bone and between 6 and 15 cm above the lateral malleolus.
- Dissect under the deep fascia, from posterior to anterior toward the fibula.
- Identify any perforators coming out from the septum (**TECH FIG 9A,B**).
- Flap elevation and coverage
 - The incision is complete all around the flap.
 - Elevate the flap under the deep fascia.
 - Microclamp the perforators that are going to be ligated.
 - Release the tourniquet and observe the flap perfusion.
 - If flap perfusion is good, all the perforators, other than the selected one, are ligated.
 - If flap perfusion is not satisfactory, wait for about 15 minutes.
 - If perfusion is still not good, an adjacent perforator should be reopened and the perfusion reassessed until a satisfactory vascularity of the flap is guaranteed.
 - Rotate the flap and cover the wound (**TECH FIG 9C**).
- Donor site closure with skin grafting
 - Temporarily staple the flap to the margin of the wound, and measure the defect of donor site and the uncovered one.
 - Use power-driven dermatome to harvest the split-thickness skin grafts from the thigh.
 - Tailor the skin grafts to the wound and staple it (**TECH FIG 9D**).
 - Soft bulky dressing is put on the flap.
 - The distant part of the flap is exposed without dressing for flap monitoring.



TECH FIG 8 • A. Cauliflowerlike tumor on the right heel. **B.** The defect after the excision surgery.



TECH FIG 9 • A. One week after the initial excision surgery, a flap based on the perforator of peroneal artery is elevated. The blue dot shows the location of

the perforator. **B.** The perforator is seen arising between the soleus and peroneus brevis muscle. **C.** Flap rotation to cover the area of the Achilles tendon and calcaneus bone exposure. **D.** Donor site is covered by split-thickness skin graft. No active suction drainage is placed around the perforator.

PEARLS AND PITFALLS

Z-plasty

- Flap angle of 60 degrees will get maximal elongation (**FIG 4**).
- The angles should set up to be a little more than 60 degrees when there is a severe contracture of the scar line because as the contracture scar is released, the angles tend to go sharper than designed.
- Place the lateral limbs parallel to the line in which the new central line will lie.
- Always cut the center line before cutting the limb.
- In scarred tissues, raise a thick flap that includes a layer of subcutaneous tissue to ensure adequate blood supply.
- In multiple Z-plasty, the designed flaps may not always interdigitate to each other perfectly.

Skin grafting

- Make sure the defect is suitable for skin grafting before harvesting the graft.
- Kirschner wire fixation can help in patients with severe contracture deformity (**FIG 5**).
- The formula for tumescent fluid: 500 mL lactated Ringer solution plus 1 mL/1 mg epinephrine.
- Harvest 5%–10% more grafts than the template because the graft always tends to shrink.
- Always keep the grafts moist.
- It is important to keep the dermal side downward and attach to the wound directly. False orientation will lead to a complete necrosis of the grafts.
- Inadequate wound preparation always contributes to the failure of skin grafting.

Flaps

- Locate the perforators by using ultrasound Doppler preoperatively to help dissection during the surgery.
- Always explore the perforator under tourniquet control before elevating

the flap.

- Modify the design of the flap based on the perforators discovered during surgery.
- Although the perforators that are identified by ultrasound preoperatively may be good, sometimes better ones will be uncovered during the dissection.
- Placing a drain near the perforator that can compress the vessel or putting excessive compression over the pedicle of the flap will jeopardize the blood supply of the whole flap.

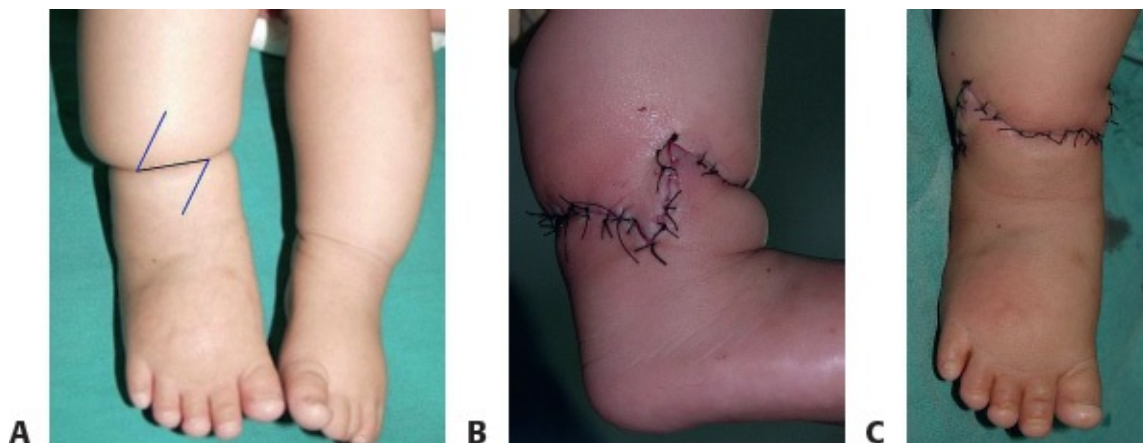


FIG 4 • A. The angle of a Z-plasty should be about 60 degrees, as shown on this congenital constriction ring of right lower leg. Black = center line; blue = limb lines. **B,C.** Immediately after Z-plasty, the constriction ring had been excised.



FIG 5 • A. Dorsal contracture of the second, third, and fourth toe of the right foot. **B.** Placement of K-wire fixation before the placement of acellular dermal matrix and split-thickness skin graft.

POSTOPERATIVE CARE

- A soft dressing is applied to the wound of Z-plasty. There is no need to restrict the mobility of patients with simple Z-plasty reconstruction.
- Dressing is applied to provide compression over the skin graft site.
 - Tie-over bolster technique or negative pressure wound therapy may be helpful to increase the take rate of the grafts.
 - The lower leg and foot cast or splint should be applied if the skin graft site is near to the knee or ankle.
 - The cast or splint can be removed after about 2 weeks. If the tie-over bolster technique was applied, remove the bolster carefully to avoid the shear injury to the grafts.
- After the flap surgery, mark the location of flap's pedicle where the perforators enter the flap and avoid pressure over it.
 - Postoperative flap monitoring is vital for the reconstruction.
 - Capillary refill time is still a secure and practical way to monitor the flap.
 - A cast or splint on the surgical site would be helpful if there is a skin grafting at the same time.
- The postoperative scar care, such as pressure garments and silicone gel, should be applied to all patients for a better functional and aesthetic result.

OUTCOMES

- Outcome photos for the cases in this chapter are shown in **FIG 6**.

COMPLICATIONS

- Potential causes of skin graft loss

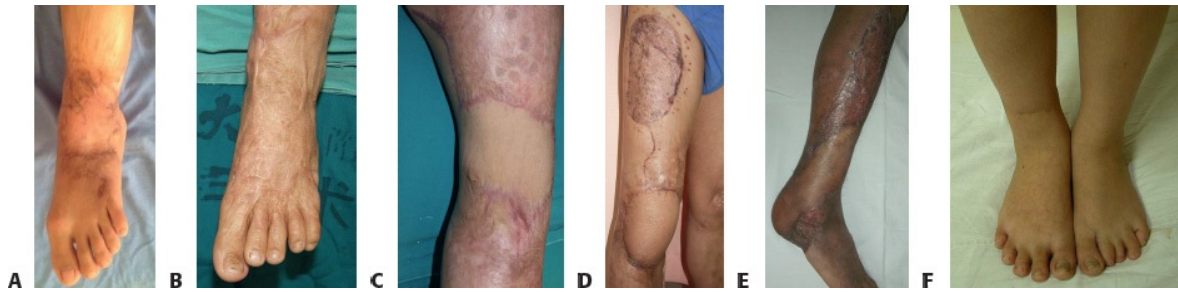


FIG 6 • Case outcomes. **A.** Two-year follow-up of split-thickness skin grafting in the patient in **TECH FIG 4**. **B.** One-year follow-up of skin graft combined with acellular dermal matrix in the patient in **TECH FIG 5**. **C.** Six-month follow-up of expanded thigh flap to repair a contracture scar in the patient in **TECH FIG 6**. **D.** One-year follow-up of an ALT flap in the patient in **TECH FIG 7** shows a pliable flap and full extension of the knee. **E.** Three-month follow-up of the patient in **TECH FIG 9**, who underwent skin flap repair of a Marjolin ulcer on the heel. **F.** Ten-year follow-up of the patient in **FIG 4**, who underwent Z-plasty for a congenital constriction ring.



FIG 7 • **A.** Epidermolysis of skin graft. **B.** Partial necrosis of skin graft caused by hematoma underneath. **C.** The distal part of an expanded flap became necrotic.

- Infection
- Hematoma/seroma
- Poor vascularization
- Irradiation

- Other complications
 - Epidermolysis of skin graft (**FIG 7A**)
 - Partial necrosis of the skin grafts (**FIG 7B**)
 - Partial necrosis of an expanded flap (**FIG 7C**)

ACKNOWLEDGMENTS

The author thanks Drs. Xunxun Lin and Wenjun He for their help in preparation of **FIG 1**.

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51 Soft Tissue Reconstruction with Propeller Flaps

CHAPTER

Adam Jacoby, John T. Stranix, and Pierre B. Saadeh

DEFINITION

- Propeller flaps represent one of the most recent technical advances in perforator flap dissection.
- Propeller flaps are especially useful alternatives to microvascular free tissue transfer when reconstructing distal lower extremity defects.
- The perforator propeller flap can provide soft tissue coverage on all parts of the body despite its original and most common use for lower extremity defects. Its adipocutaneous composition and ability to be rotated up to 180 degrees provide an excellent source of thin pliable tissue along with a faster and relatively simpler dissection compared with free flap harvest.
- To be considered a “propeller,” the flap must rotate between 90 and 180 degrees around its perforating vessels.

ANATOMY

- Propeller flaps can be classified based on pedicle anatomy, either the type of pedicle supplying the flap or the pedicle position.
 - Island propeller flaps are skeletonized along the perforator vessels and allow up to 180 degree rotation with relative protection from pedicle kinking.
 - Nonskeletonized propeller flaps can be either skin- or muscle-based pedicled flaps where the dominant perforator is not skeletonized. Although operative times are shorter and there is less risk of perforator injury from dissection with nonskeletonized flaps, pedicle kinking is more likely—especially when rotated greater than 90 degrees (**FIG 1**).
- Propeller flaps can also be classified as a central axis propeller (pedicle in the middle of the flap) or an eccentric axis propeller (at its periphery).

- The arterial supply to the lower extremity is provided by the posterior tibial, anterior tibial, peroneal, descending genicular, and popliteal arteries with its venous supply largely mimicking the arterial network.
- Perforators of the lower extremity form five vascular territories, separated by four organized rows of perforators originating within the intermuscular septa of the leg (**FIG 2**). Anterior tibial artery perforators are most often the smallest caliber.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Lower extremity defects are often caused by trauma, burns, or tumor extirpation. The defect size, depth, and location must be evaluated in addition to the surrounding skin quality. Additionally, exposed hardware (in the presence of orthopedic injuries), the bone, and the tendon must be taken into consideration when planning a durable reconstruction.
- If the patient has severe peripheral vascular disease or insulin-dependent diabetes, atherosclerotic disease may prevent adequate inflow to the flap.
- If the defect is from tumor ablation, the patient may undergo perioperative chemotherapy or therapeutic irradiation.

IMAGING

- While computer tomographic (CTA) or conventional angiography is not required for surgical planning, CTA may demonstrate the presence and location of larger caliber perforators, which can aid in flap design.

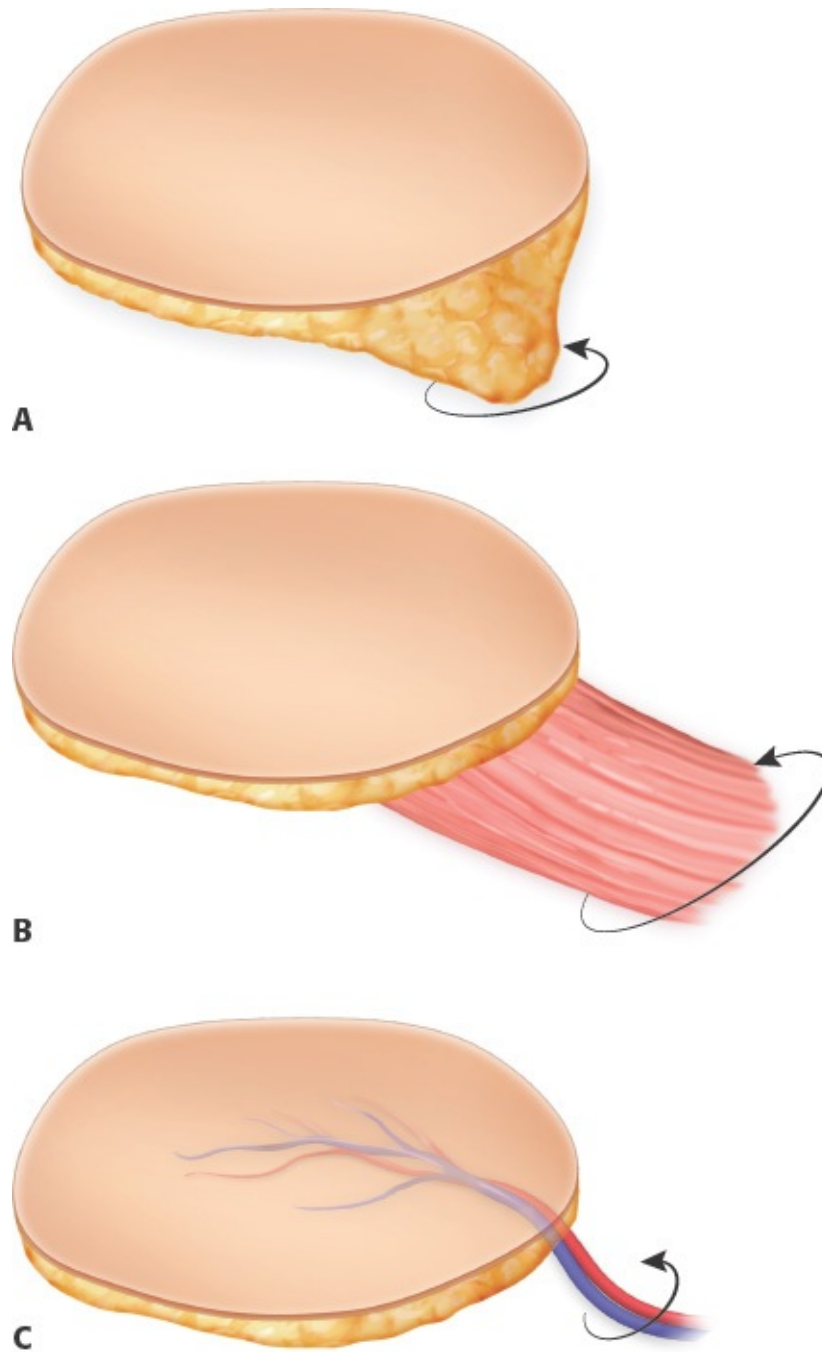


FIG 1 • Diagram of different pedicle dissections in propeller flap harvest; **A.** subcutaneous propeller flap, muscle-based propeller flap (**B**), and “true” skeletonized propeller flap (**C**). Note the relative bulkiness of the subcutaneous and muscular pedicles, placing them at higher risk for pedicle kinking with greater than 90

degrees of rotation.

SURGICAL MANAGEMENT

Preoperative Planning

- Unless contraindicated, general anesthesia with endotracheal intubation is preferred for these cases as the meticulous perforator dissection benefits from muscular paralysis intraoperatively. We routinely utilize preoperative Doppler detection of perforators for flap planning; however, it is not always necessary.
- Although we find the use of a Doppler to be helpful, perforator detection may be confounded by superficial feeding blood vessels. In the setting of normal lower extremity arterial anatomy, intermuscular perforators are reliably found during intraoperative dissection, making preoperative Doppler identification a useful adjunct rather than a requirement.
- If a Doppler is used, the length and width of the flap can be designed as follows:
 - The distance between the marked perforator and most distal aspect of the planned defect is measured; this distance is then transposed proximally, and 1 to 2 cm is added to determine the total length of the flap.
 - Half a centimeter is added to the anticipated defect width (to allow for contraction of the flap) to determine flap width (**FIG 3**).

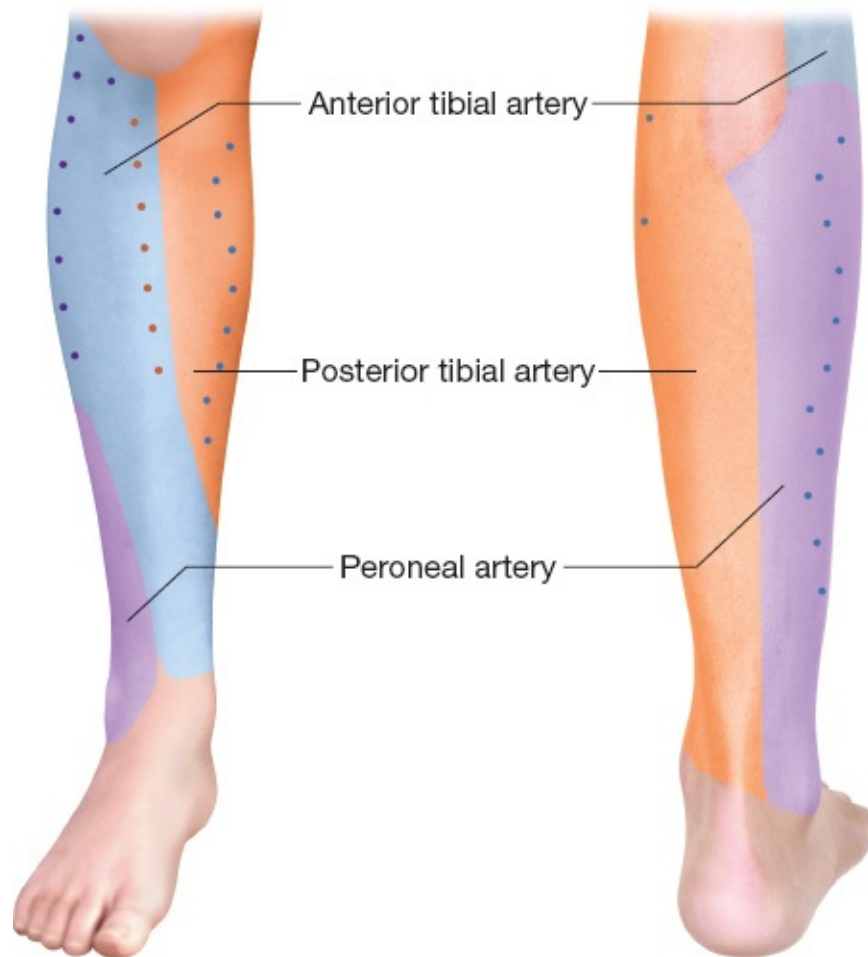


FIG 2 • Schematic of lower extremity vascular territories and their feeding vessels. ATA: anterior tibial artery, PTA: posterior tibial artery, PA: peroneal artery. Small dots represent location of reliably found septocutaneous perforators within each angiosome.

Positioning

- Location of the anticipated defect and dominant perforator dictate operative positioning as propeller flaps are useful in head-to-toe reconstruction.
- For propeller flaps supplied by the posterior tibial artery system, supine positioning is used with the hip in abduction and leg externally rotated. Propeller flaps based off the peroneal system also require supine positioning, but a “bump” is placed under the ipsilateral hip. The hip and knee are then flexed and internally rotated.
- For all flaps below the hip, a circumferential prep of the entire extremity is

used routinely to ensure full visualization and allow intraoperative repositioning as needed. This also facilitates split-thickness skin graft harvest if required for donor site coverage.

- For gluteal, sacral, or lumbar flaps, the patient is placed in prone position. The patient is sterilely prepped and draped widely—typically from the midthoracic region to the upper thighs.



FIG 3 • The distance between the marked perforator (red star) and most distal aspect of the planned defect is measured (distance a). This distance is then transposed proximally, and 1 to 2 cm is added to determine the total length of the flap (length = $2a + 1-2 \text{ cm}$). Half a centimeter is added to the anticipated defect width (to allow for contraction of the flap) to determine flap width ($b + 0.5 \text{ cm}$).

Approach

- When designing a propeller flap, it must be kept in mind that a skeletonized perforator can be rotated maximally 180 degrees around itself, whereas subcutaneous and muscle pedicled propeller flaps only allow for 90 degree rotation without kinking (see **FIG 1**).
- As mentioned above, though preoperative Doppler use may help identify perforator locations, for skeletonized perforator flaps, the target perforator is only chosen after a suprafascial or subfascial dissection allows for visual inspection and confirms palpable pulsatility. An exploratory incision must be planned for adequate perforator exposure and examination which should not violate bail-out local flaps or an adjacent propeller flap supplied by a different perforator.
- Predicted preoperative flap outlines (based off on-table Doppler examinations) often change after intraoperative dissection locates the dominant perforator.
- Maximum size has yet to be described, but there are case reports of a 22 × 8 cm peroneal artery perforator propeller flap^{1,2} and a 19 × 13 cm posterior tibial artery propeller flap¹ based off one perforator. Perforators off the anterior tibial artery are generally the smallest caliber in the lower extremity and require smaller flap designs accordingly.
- Skin grafting may be required for donor site coverage; however, in our experience, primary closure is often achievable when defects are lesser than 6 cm in greatest width.
 - Although primary donor site closure is ideal, it should not be done under excessive tension that could potentially compromise the flap or lead to wound breakdown. A small skin graft is preferable to either of those potential consequences.

TECHNIQUES

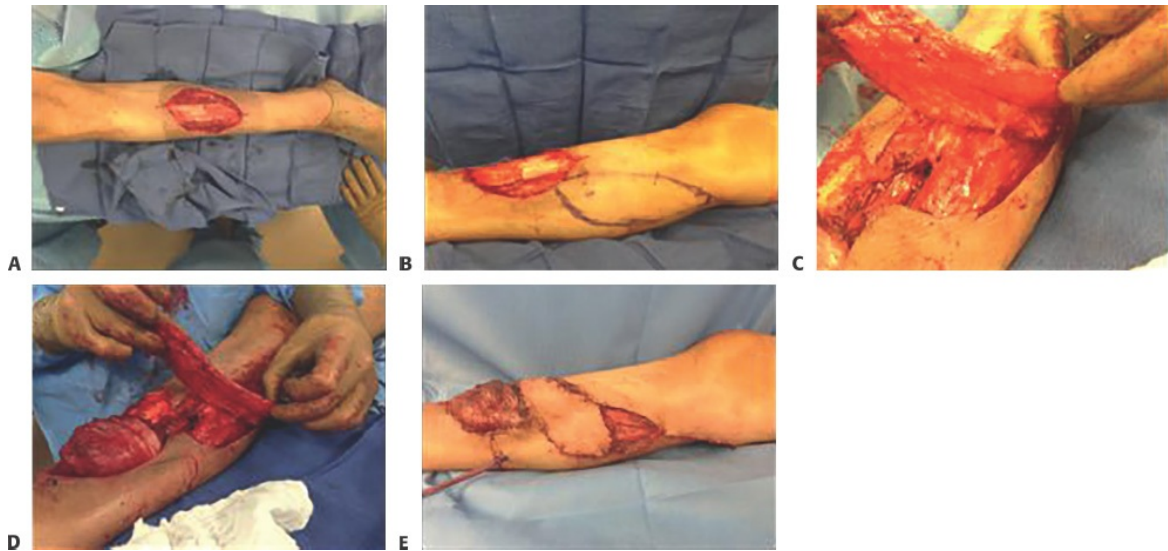
■ Islandized Propeller Flap

- The defect with its appropriate margins is first defined (**TECH FIG 1A**).
- A Doppler is then used to locate dominant perforators (most often originating from the intermuscular septa).
- The length between the perforator and most distal aspect of this defect is

transposed proximally (1 cm is usually added) to determine total length of the flap whereas 0.5 cm is added to the defect width to calculate flap width (**TECH FIG 1B**).

- If the defect is below the hip, a thigh tourniquet may be applied. The leg is elevated for 1 minute prior to tourniquet inflation, but not completely exsanguinated in order to assist with visual identification of perforators.
- After completion of the flap design, a no. 15 blade is used to incise only one edge of the planned flap.
- Using loupe magnification and microsurgical dissection technique, exploration of perforators is then carried out in either the supra- or subfascial plane.
- We recommend using 3.5× loupe magnification for optimal perforator visualization in addition to a subfascial approach as we find this dissection plane is often faster and safer.
- In either the supra- or subfascial plane, perforators are identified. The ideal perforator is large, associated with two venae comitantes, and has a strong palpable pulse (**TECH FIG 1C**).
- The tourniquet is released, allowing assessment of the vessel's pulsatility.
- Spasm may prevent a pulse from being palpable; it can take up to 10 to 20 minutes after tourniquet deflation for pulse appearance.
- To protect against vasospasm, papaverine or 4% lidocaine is used liberally on preserved perforators.
- If two or more perforators have characteristics capable of flap sustainability, they can be alternatively clamped after the tourniquet is released to determine the optimal source vessel.
- Once the ideal perforator is located, the perforator foramen is then enlarged to allow for 2 cm clearance of fascial strands and muscular side branches (to prevent pedicle kinking during rotation) (**TECH FIG 1D**).
- After complete skeletonization, the flap design is adjusted to optimize the perforator location for rotation into the defect. The remaining edges of the flap are then incised, and dissection is carried out in the same plane until the flap is fully elevated and isolated on the single perforator.
- The flap can be rotated up to 180 degrees (see **TECH FIG 1D**) clockwise or counter clockwise (whichever direction provides greatest coverage with the least amount of pedicle kinking).
- After rotation around the pedicle is complete, the edges of the flap are

evaluated for healthy bleeding, and the distal flap is inspected for any signs of venous congestion.

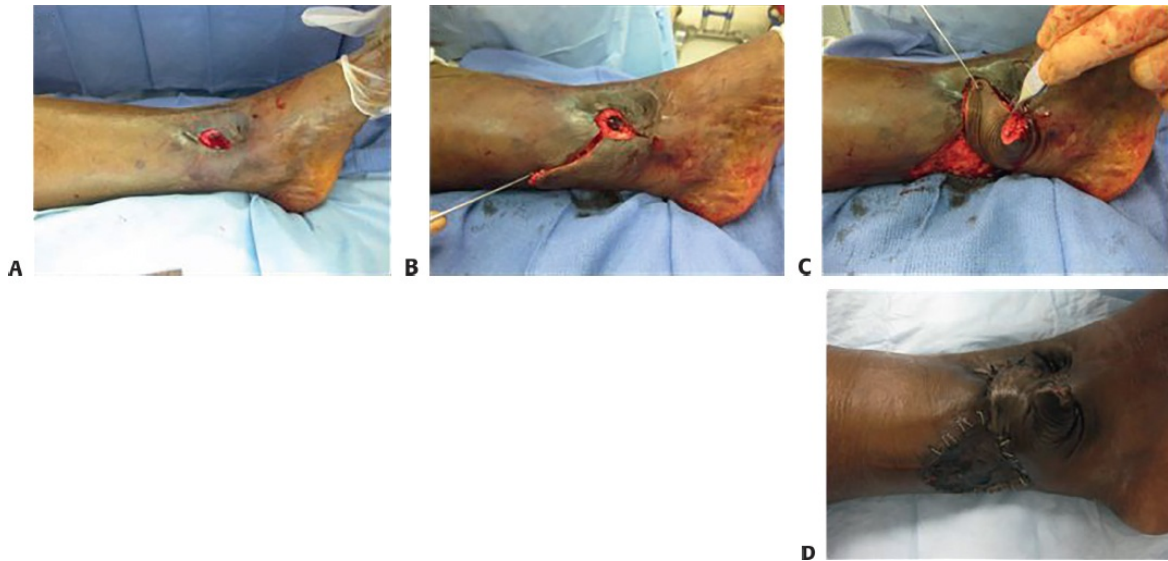


TECH FIG 1 • **A.** Defect with exposed tibia. **B.** The flap is marked adjacent to the defect. **C.** Subfascial dissection reveals a dominant perforator. **D.** The pedicle is appropriately skeletonized around the dominant perforator and rotated 180 degrees. **E.** Flap inset and closure can often be achieved without skin grafts and closed suction drains unless the donor site is too large to be closed primarily as seen above.

- Satisfied with flap viability, inset occurs in the following sequence:
 - Secure the flap in place with two to four deep (fascial) sutures (often 3-0 PDS), equally spaced along the perimeter of the flap.
 - If a closed suction drain is necessary, it is positioned away from the vascular pedicle.
 - Superficial, interrupted, skin sutures (3-0 nylon) complete the flap's inset.
 - Loose inset is preferable as postoperative swelling may cause venous congestion and/or ischemia.
 - If the donor is not amenable to tension-free primary closure, a skin graft is harvested for coverage (**TECH FIG 1E**).
-

■ Nonskeletonized Propeller Flaps

- The design and execution of a nonskeletonized propeller flap is similar to its islandized counterpart, and the initial steps are similar, but the dissection is significantly faster; the differences in planning and techniques will be outlined here.
- The defect is first defined (either by tumor ablation or adequate wound debridement) and converted into a circular shape (**TECH FIG 2A**).
- A Doppler is then used to locate dominant perforators within 360 degrees of the defect.
- Note that when planning these nonskeletonized flaps, tissue can only be rotated a maximum of 90 degrees to avoid pedicle kinking (see **TECH FIG 2C**).
- Once the ideal perforator is located, the flap can then be designed. Depending upon the degree of rotation, flap length must be greater than defect width as the effective length of a flap becomes shorter with increasing rotation (**TECH FIG 2B,C**).
- A subfascial plane is again preferred for dissection. After rotation around the pedicle is complete, the edges of the flap are evaluated for healthy bleeding, and the distal flap is inspected for any signs of venous congestion.
- Satisfied with flap viability, inset occurs in the following sequence:
 - Secure the flap in place with two to four deep (fascial) sutures (often 3-0 PDS), equally spaced along the perimeter of the flap.
 - If a closed suction drain is necessary, it is positioned away from the vascular pedicle.
 - Superficial, interrupted, skin sutures (3-0 nylon) complete the flap's inset.
- Loose inset is preferable as postoperative swelling may cause venous congestion and/or ischemia.
- If the donor is not amenable to tension-free primary closure, a skin graft is harvested for coverage (**TECH FIG 2D**).



TECH FIG 2 • **A.** Defect and surrounding indurated tissue around the medial malleolus. **B.** The defect is created and the anterior flap is raised; the perforators perfusing the flap are left in the subcutaneous tissue and not skeletonized, making a relatively easy and fast dissection. **C.** When the dominant perforator is not skeletonized, maximum rotation is 90 degrees. **D.** If the defect is too large for primary closure, a skin graft may be used.

PEARLS AND PITFALLS

Incision placement

- Incisions should not violate adjacent bail-out options or alternative flaps.
- Initial exploratory incision should be as wide as possible so multiple perforators can be evaluated.

Perforator choice

- Visual and manual inspection is key to determining the optimal perforator.
- When possible, the chosen perforator should be at least 2 cm away from the most proximal aspect of the defect.
- Venae comitantes are at high risk of kinking during rotation

and fascial attachments must be cleared liberally.

- Perforators from the anterior tibial artery are usually the smallest in the leg and allow for the smallest flap dimensions.

Flap inset

- After dissection of the flap is complete and only attached by the skeletonized perforator, the tourniquet should be released to assess viability and perfusion.
- Vasodilators (lidocaine, papaverine) should be used liberally.
- Before inset, the flap should be rotated clockwise and counterclockwise to determine which way causes less kinking.
- Excessively tight closure can result in vascular compromise with subsequent partial or complete flap loss.

Contraindications

- Poorly controlled diabetes
- Peripheral vascular disease
- Peroneal artery and its perforators are most likely to be resistant to atherosclerotic disease and can still be used in diabetic and peripheral vascular disease patients.

POSTOPERATIVE CARE

- Patients should rest with the reconstructed extremity or body part elevated above heart level where possible.
- A gentle ACE wrap can be applied to lessen postoperative edema but should not be too tight to cause ischemia; a small window should be cut in the dressing (especially over the most distal aspect of the flap) to monitor perfusion and congestion.
- An orthotic boot or plaster posterior slab can be applied to maintain optimal positioning for pressure offloading.
- Skin sutures can be removed 10 to 14 days after surgery.
- If a skin graft is placed over the donor site, a VAC dressing bolster should be applied over the skin graft and removed 5 to 7 days postoperatively.

OUTCOMES

- Complication rates of propeller perforator flap are close that of free flaps.^{3–5}
- Most flap loss is related to venous congestion from pedicle kinking.^{4,5}
- In the case of flap loss, outcomes are usually better than free flap loss as most often only the superficial portion of the propeller flap becomes necrotic, leaving vital structures covered by deep portions of the flap.^{2,4}
- If congestion or ischemia is suspected, flap can be deinset and derotated, or a

venous microsurgical anastomosis can be performed if feasible.

COMPLICATIONS

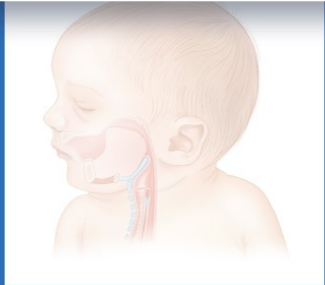
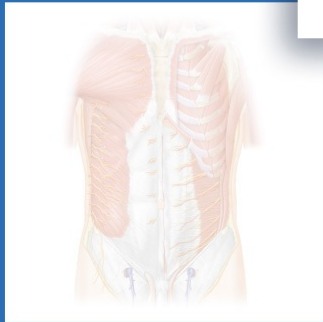
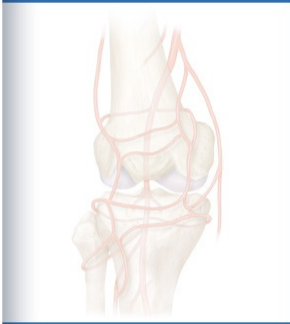
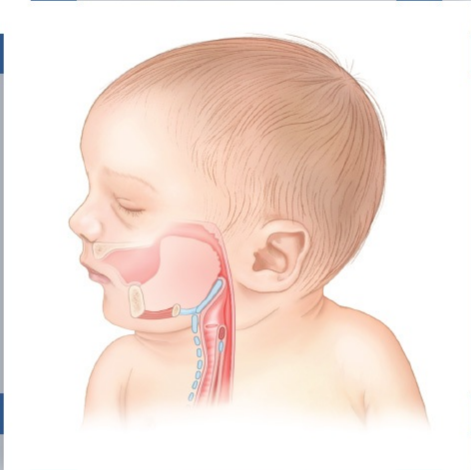
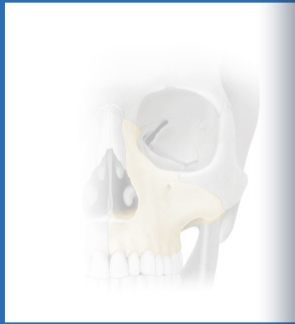
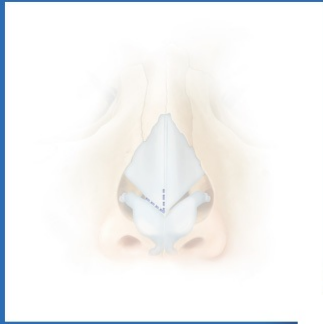
- Distal tip necrosis
- Pedicle kinking
- Venous congestion
- Flap loss
- Contour deformities, scarring
- Hematoma
- Infection

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PART 8

Pediatrics



Section I: Cleft Lip

1 Anatomical Subunit Repair of Unilateral Cleft Lip

CHAPTER

David K. Chong and Kathryn V. Isaac

DEFINITION

- Cleft lip is a congenital malformation in embryonic development leading to discontinuity of the upper lip. The cleft may be:
 - Complete or incomplete
 - Bilateral or unilateral
- Cleft lip may occur in isolation or in combination with a cleft palate. It may occur as part of a syndrome or in the absence of associated anomalies.
- A cleft lip has an associated cleft nasal deformity with characteristic features varying in severity depending on the type of cleft lip, width of the cleft, and presence of associated cleft palate.
 - The cleft lip nasal deformity affects the skeletal, cartilaginous, and muscular framework.

ANATOMY

- During the 5th to 7th weeks of gestation, cleft lip occurs as a failure of complete union of the medial nasal process and the maxillary prominence.
- Clefting occurs through the skin, muscle, and mucosa of the labial and nasal structures.
- The cleft of the lip distorts and/or disrupts several important anatomic structures.
 - Muscles
 - Orbicularis oris (pars marginalis and pars peripheralis)

- Pars alaris, depressor alae nasi
- Upper lip
 - Cutaneous lip: philtral columns, central dimple, cutaneous roll
 - Red lip: Cupid's bow, vermillion, mucosa
- Nose
 - Nasal floor, alar base, nasal cartilages, septum, columella

PATHOGENESIS

- The etiology of cleft lip is genetically complex and is due to multiple genetic and environmental risk factors.
 - Most cases are sporadic, but some are familial, X-linked, or autosomal dominant. Familial history of clefting is an important risk factor.
- Cleft lip and cleft lip with cleft palate are considered variants of an entity that differ in severity.
 - The environmental risk factors associated with clefting include maternal smoking, infection, poor nutrition, teratogen exposure (alcohol, phenytoin, valproic acid, retinoic acid), and advanced paternal age.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Diagnosis of a cleft lip is made by prenatal ultrasonography, by MRI, or by physical examination at birth. Detailed assessment is made of the child's breathing, feeding, growth, and development.
- Assessment of growth and weight is key to identify and monitor feeding difficulty and use of feeding aids (Haberman/Pigeon teat).
- The plastic surgeon should define the cleft lip type according to the anatomic structures involved, laterality, width of the cleft, and presence/absence of a cleft palate.
- Also, the child should be assessed for associated anomalies suggestive of a syndrome—craniofacial dysmorphism, airway compromise, cardiac defects, ocular and auricular abnormalities, and musculoskeletal anomalies. A genetics referral is suggested if suspicious of a syndromic etiology.

DIFFERENTIAL DIAGNOSIS

- Syndromic cleft lip with or without cleft palate
 - Van der Woude syndrome
 - Gorlin syndrome
 - CHARGE syndrome

- Ectrodactyly-ectodermal dysplasia-clefting
- Brachio-oculofacial syndrome
- Kabuki syndrome
- Kallmann syndrome

SURGICAL MANAGEMENT

- Cleft lip repair is ideally performed at age 6 months because the landmarks are larger and easier to identify.
- The principles of the anatomical subunit repair enable the surgeon to formulate a plan for the predictable and successful closure of any type of cleft lip.¹
- The labial cleft closure is designed, measured, and determined prior to skin incision. The operation is the execution of a formulated plan. This eliminates the potential of compromising landmarks and removes the fear of under-rotation, as well as lip height or length discrepancies.
- With this repair, the most visible part of the scar lies along the anatomical subunits, and the labial elements are perfectly matched in length to create an optimal continuity of vermilion, cutaneous lip, and alar-labial junction.
- Rotation of the labial elements is achieved by:
 - Skin triangle above the cutaneous roll
 - Muscle repair
 - Mucosal release
- Risks of the procedure are scar deformity, nasolabial asymmetry and/or deformity, wound dehiscence, and infection.
- The main objectives of the cleft lip repair are to (1) separate the nasal and oral cavities; (2) restore lip continuity and continence; (3) reconstruct a functional labial sphincter for facial expression, speech, and feeding; (4) and restore aesthetics of the labial and nasal subunits.
- The main steps of the procedures are as follows:
 - Marking key landmarks and designing closure of labial elements based on pre-incision measurements
 - Medial lip element release of skin, muscle, and mucosa to adequately balance the Cupid's bow, then composite elevation of lateral lip elements to insert into the created "jigsaw"
 - Restoration of muscle continuity
 - Closure of the mucosa
 - Closure of the nasal floor
 - Skin and vermilion closure

- Nasal correction with suture techniques
- In discussing this repair, the language used in Millard's description of the rotation-advancement cleft lip repair will be used.² The application of this language will help to clarify and describe this technique for surgeons who have adopted the Millard technique or modifications of it.

Preoperative Planning

- If the child has a cleft lip and cleft palate, dentofacial orthopedics are utilized for aligning the cleft maxillary arches and improving the nasal deformity (lower lateral cartilage shape and position and septal cartilage alignment). The device is discontinued prior to the cleft lip repair.

Positioning

- The patient is positioned supine with the neck neutral and head stabilized in a head ring.
- The surgeon must have the ability to freely examine the face from all angles throughout the procedure to ensure that three-dimensional balance is achieved. Corneas are protected with transparent tape to use the plane and position of the eyes in the surgical field as an aid to assessing labial and nasal symmetry. The transparent tape should still allow the cheek to move freely.
- Loupe magnification is helpful for accurate identification of anatomical landmarks, for precise tissue dissection, and for perfect approximation.

Approach

- Successful application of this cleft lip repair is facilitated by highlighting conceptual differences between the rotation-advancement repair and anatomic subunit repair.
- Important landmarks are marked out, never compromised, and incisions are made for closure that follows anatomical subunits.
 - Paradigm shift: Spend more time marking before any incisions are made and the surgeon is committed to the plan.
- Calipers are used to measure incisions for perfect length match.
 - Paradigm shift: The artistic "eye" is supplemented by precise measurements.
- Foundation of repair is in the muscle.
 - Paradigm shift: Extension of skin incision outside of the proposed philtrum to achieve rotation is not required.

- Inferior triangle is placed above the cutaneous roll. This location restores the cutaneous roll without interruption and achieves any additional lip lengthening required for the skin.
- Paradigm shift: Triangle is premeasured. Most measure 1 to 2 mm because the muscle repair and mucosal M flap both contribute to lip lengthening.

TECHNIQUES

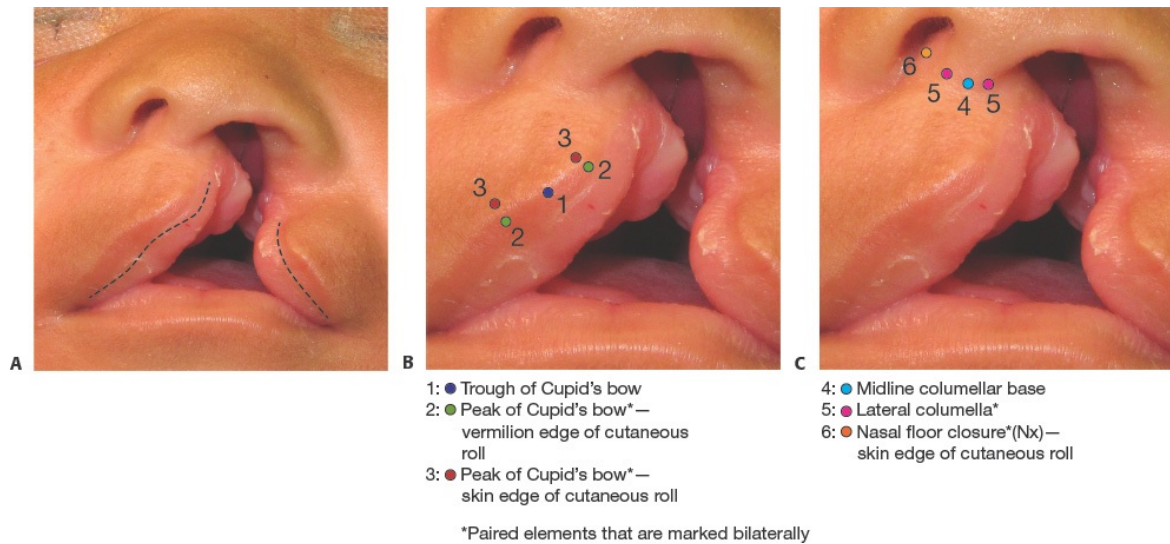
■ Planning the Repair: Medial Nasolabial Element

- Markings are made with methylene blue dye after the patient is prepped and draped.
 - Markings of landmarks and anatomic contours are made with dots at the landmarks listed below and along the line of interest for measurement, incision, or alignment of elements.
 - Tattoo all points to prevent loss of landmarks.

Vermilion, Cupid's Bow, and Nose

- Mark the junction of the vermillion and mucosa along both medial and lateral lip elements (**TECH FIG 1A**).
 - This helps determine the vermillion height discrepancy and points of closure and ensures a continuous natural curve is achieved.
- The following marks are placed on the *medial lip element* (**TECH FIG 1B**):
 - Mark the peak of Cupid's bow on the noncleft side with one point above and below the cutaneous roll.
 - Mark the trough of Cupid's bow.
 - Mark the peak of Cupid's bow on the cleft side with one point above and below the cutaneous roll. The point above the cutaneous roll guides the placement of the opening incision for insertion of the triangular cutaneous flap, if required. Choose this point just medial to the actual peak of the Cupid's bow because it is difficult to surgically create a curve. It is preferable to use the existing curve on the lateral lip element.
 - Mark the columellar points: one central and two adjacent that are symmetrically distanced from the center and lie at the superior end of the philtrum.
 - The noncleft side of the medial lip element will guide you to pick the

superior extent of the philtrum, and you can mirror this onto the anticipated created philtrum on the cleft side of the medial lip element (**TECH FIG 1C**).



TECH FIG 1 • Medial lip markings. A. Vermilion. The border between the vermilion and the mucosa is marked. **B.** Cupid's bow. **C.** Nose. (Copyright © David Chong.)

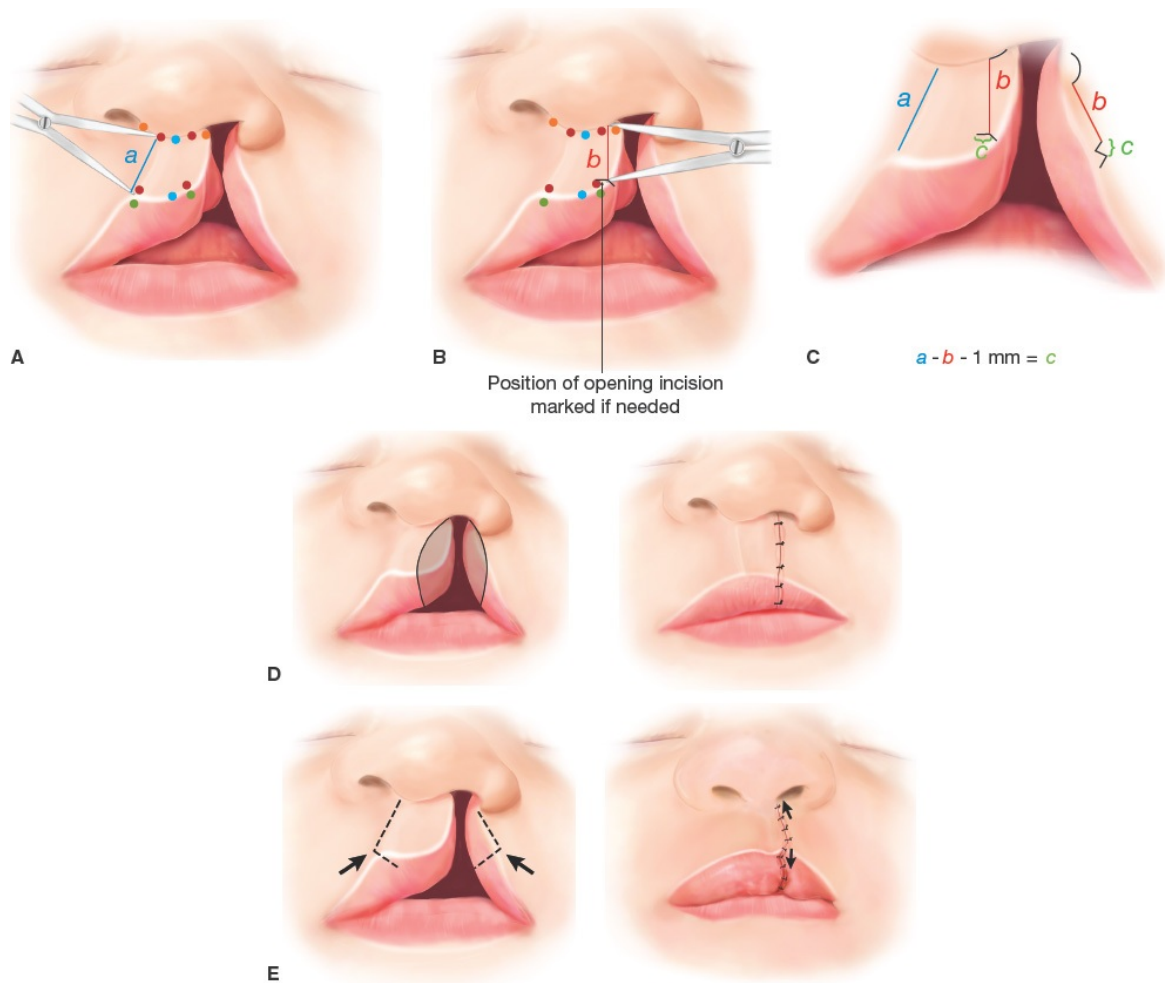
- Remember that the apparent curve of the noncleft side philtral column is due to the unopposed action of the unrepaired orbicularis oris and is almost always a straight line in the Caucasian population once repaired.
- In the noncleft nasal sill, mark the point where the medial footplate of the medial crus meets the nasal floor (Nx). This point is used to guide the nasal sill closure on the cleft side.

Measurements and Interpositional Triangle

- Measure the distance on the *noncleft side* from the superior extent of the philtrum to the peak of Cupid's bow above the cutaneous roll (**TECH FIG 2A**).
- This is the total height of the philtrum (*a*) on the noncleft side that you need to recreate on the cleft side philtrum.
- Measure the distance on the *cleft side* from the superior extent of the philtrum to the peak of Cupid's bow above the cutaneous roll with tissue

unfurled to mimic repair (**TECH FIG 2B**). This is the height of the cleft philtrum (b). It is key to unfurl the convex surface of the medial lip during this measurement; this maneuver aims to mimic the lengthening achieved with muscle dissection and repositioning with mucosal release.

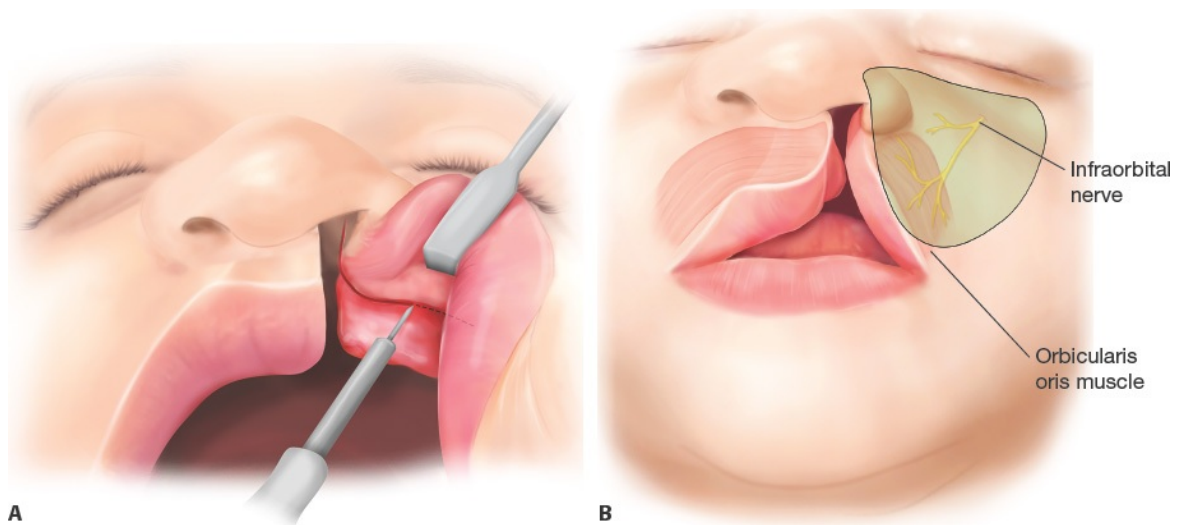
- Perform a simple calculation to decide the need for an opening triangle: subtract the distances between the philtrum of the noncleft side and the cleft side ($a - b - 1$) (**TECH FIG 2C**).
 - Note that 1 mm of length will be achieved by the Rose-Thompson effect (**TECH FIG 2D,E**). If greater than 1 mm of difference remains between the philtral lengths, a cutaneous triangle from the lateral lip element will be required, with its base equal to the distance deficit remaining.
 - Most cutaneous triangles have a base width of 1 mm (70% of cases), 1.5 mm (20% of cases), or no triangle (10%) depending on whether the cleft is complete or incomplete.
- Place a reference point in the nasal sill at the junction of the skin and mucosa on the cleft side of the medial lip. This point (N_m) will guide you to place the alar base at the correct vertical position. Ideally, this point is placed in mirror image to the contralateral side, where the medial footplate of the medial crura meets the nasal floor (N_x). Practically, you would like to maximize the amount of skin available for nasal closure when learning to perform this lip repair. Therefore, this reference point should be placed at the vermilion cutaneous junction. In the initial learning phase of this repair, there is a certain amount of “cut as you go” during closure of the nasal sill, as permitted by the laxity of the skin in this region.
- Tattoo all points listed above to prevent loss of landmarks.



TECH FIG 2 • Medial lip measurements. **A.** Noncleft philtral column length is measured (*a*). **B.** Length of the cleft philtrum is measured while placing gentle downward traction (*b*). **C.** To determine whether an interpositional triangle is needed, the difference between the philtral heights of the cleft and noncleft sides is calculated by subtraction ($a - b - 1 = c$ [height of equilateral triangle]). **D.** Rose-Thompson effect. Original description of lip lengthening with biconcave excision closure by Rose in 1879. **E.** Rose-Thompson effect applied to the anatomic subunit repair.

■ Elevate the Lateral Lip Element

- Before placing the lateral lip markings, release the gingivobuccal sulcus and lateral nose at the level of piriform aperture to facilitate marking the nasal closure in complete clefts. Incise along the gingivobuccal sulcus beginning at the junction point in the nasal floor between the vestibular mucosa, oral mucosa, and nasal skin.
- Continue the incision laterally and superiorly into the nasal cavity (**TECH FIG 3A**).
- Dissect the lateral lip element and alar base off of the maxilla in a supraperiosteal plane (**TECH FIG 3B**).
- Place one digit along the inferior orbital rim to help control the extent of dissection needed and to prevent inadvertent entry into the orbit, as the maxilla is vertically short in this age group.
- Blunt dissection will prevent infraorbital nerve injury.
- Dissect all attachments off the lateral and inferior portions of the piriform aperture to ensure that the aberrant connection between the lower lateral cartilage and the maxilla is released.
- Release is complete once the lateral lip element and alar base are sufficiently mobile to allow tension-free repositioning of the alar base, permitting visualization of the repair and symmetrical nasal closure.



TECH FIG 3 • A. Lateral labial element release. **B.** Supraperiosteal dissection of lateral lip element. The shaded area is undermined in the supraperiosteal plane to allow mobilization and medial advancement

of the muscle.

■ Planning the Repair: Lateral Nasolabial Element

Nordhoff's Point

- With the lateral lip element and alar base mobilized, you may now predictably mark the lateral lip:
- Mark the point of lip closure “Nordhoff’s point” with a point above and below the cutaneous roll³ (**TECH FIG 4**). Parameters used to select this point include the following:
 - Quality and shape of the cutaneous roll
 - The thickest portion of the red lip (vermilion)
 - The most anterior projecting point (need to assess from head of table)
 - The authors do not use the distance from commissure to the peak of Cupid’s bow for determining the point of lip closure. It is unreliable due to the variable extent of contraction that may be present from the orbicularis oris muscle.

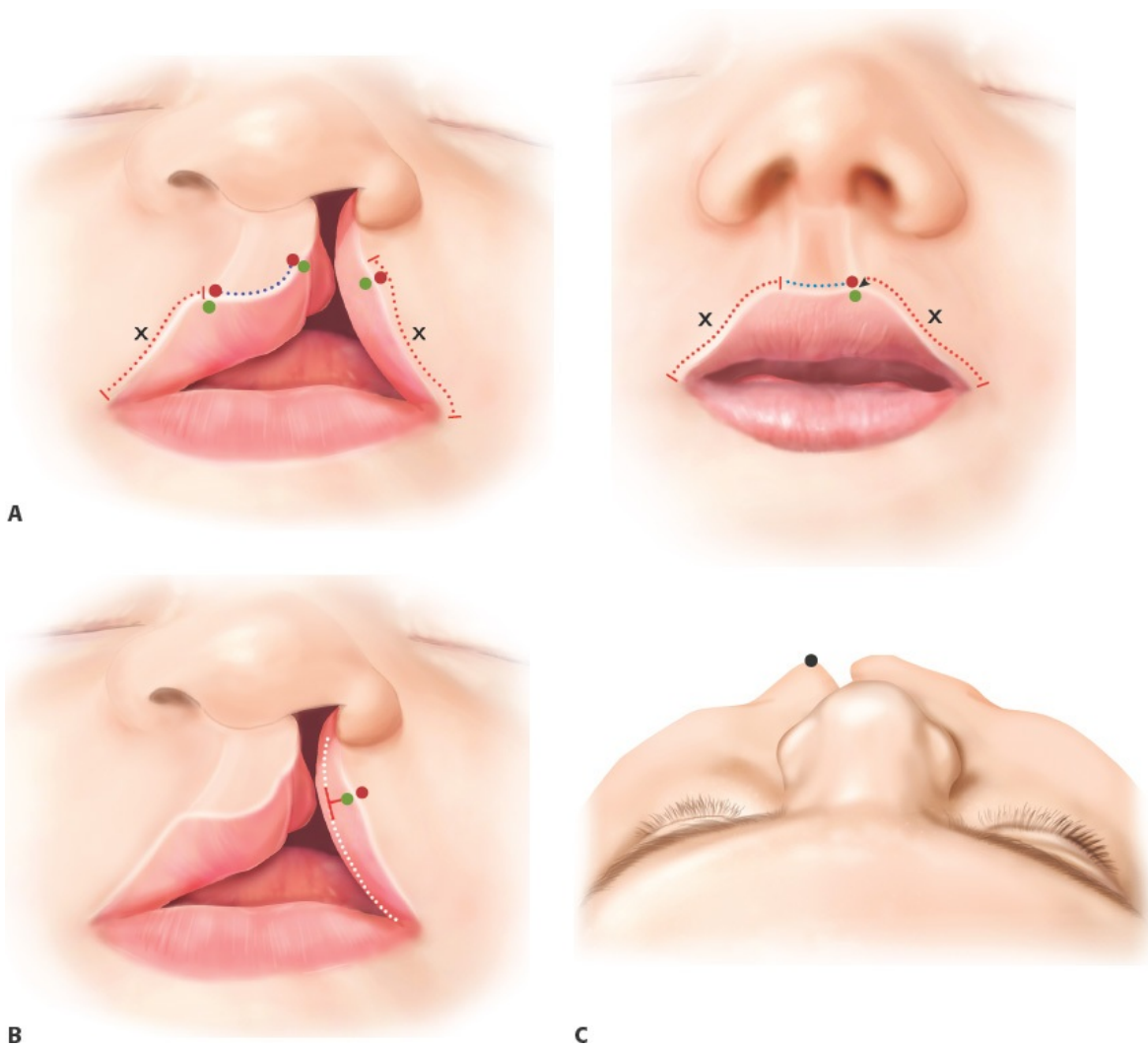
Nasal Sill

- Mark the point for the nasal sill closure (Nl).
 - It is helpful to have an assistant to simultaneously assess the symmetric positioning of the alar base in all planes.
 - Looking from the head of the bed, mimic nasal closure by moving the lateral lip element to the medial lip element and position the alar base on the cleft side at the same vertical height as the noncleft side.
 - From the submental view, the assistant should use forceps to elevate the slump of the alar rim and recreate an oval nostril shape with a symmetric diameter.
 - When the correct diameter of the nostril and the correct alar base position are determined compared to the noncleft side, place a point (Nl) on the lateral lip skin to mark closure to the equivalent point on the medial lip (Nm) (**TECH FIG 5**).
 - When these two points meet (Nm and Nl), the nostril should be of equal diameter, and the vertical position of the alar bases should be the same.
- The alar base vertical position (in the cephalad-caudal dimension) is most difficult to correct postoperatively if it is placed too low or too high relative to the noncleft side.

- In practice, you will find that minor adjustments in the width of the nasal floor are achievable so err on the side of placing Nl more medial during the initial application of this repair. This can then be adjusted by excising excess tissue during nasal closure. As you begin to use this repair with increasing confidence, you will trust the point you mark, minimizing the need to cut as you go.

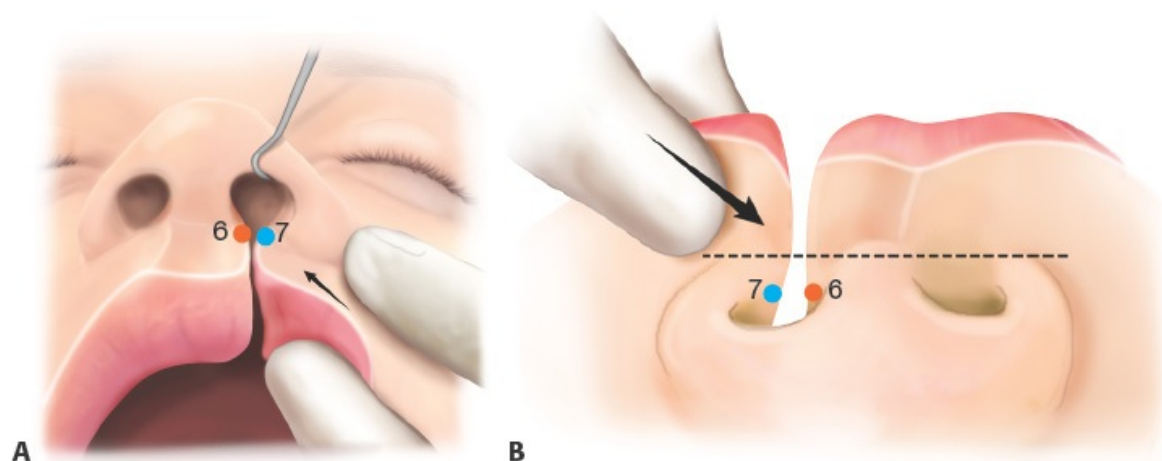
Matching Nasolabial Lengths

- Now, you have two points of closure: one on each side of the lip to match the vermilion and white lip and one on each side of the nasal sill to match and achieve the right vertical height for the alar base and symmetrical diameter of the nostril opening (**TECH FIG 6A**).
- Finally, you must mark the following on the lateral lip:
 - The dimensions of the inferior triangular skin flap
 - The labial and nasal sill incisions within the confines of the two fixed points of Nordhoff and nostril sill closure (**TECH FIG 6B**)
- Set the caliper equal to the distance of the noncleft philtral height (*b*). Orient the caliper to determine the inclination of the line *b* on the lateral lip.
 - Select the ideal orientation to account for the caliper distance (*b*), the inferior triangle size (*t*), and nasal floor distance (*d*) to tailor the “advancement flap” for precise lip and nasal closure (**TECH FIG 6C**).
- Mark the advancement triangle in the vermilion as required by the discrepancy in the vermilion height and volume between the cleft and noncleft sides. The red lip advancement flap includes mucosa.



TECH FIG 4 • Selection of Nordhoff's point. **A.** This point is selected along the vermilion border where the cutaneous roll is thick, just starting to flatten, and beginning to converge with the red line (*arrowhead*). The distances marked by x should be equal at the end of surgery but are not measured when marking as they are hard to determine prior to repair. **B.** When marking Nordhoff's point, it is important to always mark at 90 degrees to the cutaneous roll. With appropriate positioning of Nordhoff's point, closure of the labial elements should result in mirror-image symmetry of the cutaneous roll and red line of Cupid's

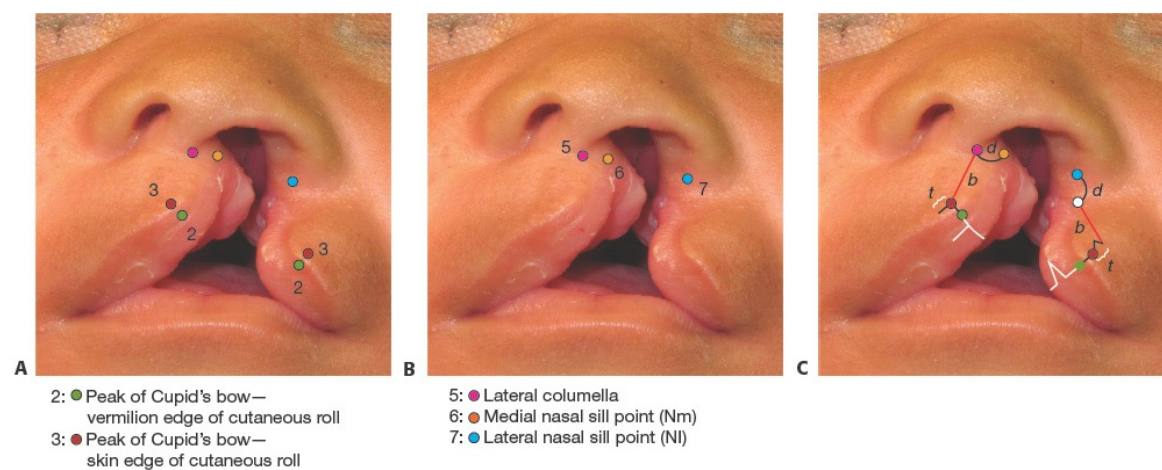
bow. **C.** The most anterior projecting point on the lateral lip.



6: ● Medial nasal sill point = Nm
7: ● Lateral nasal sill point = NI

TECH FIG 5 • Selection of nasal sill points of closure.

A. The lateral point of the nasal sill is determined by lifting the cleft ala medially. Use the noncleft side nasal sill point (Nx) to help select the cleft side nasal sill points of closure (Nm and NI). **B.** Alar bases are leveled.



2: ● Peak of Cupid's bow—
vermilion edge of cutaneous roll
3: ● Peak of Cupid's bow—
skin edge of cutaneous roll

5: ● Lateral columella
6: ● Medial nasal sill point (Nm)
7: ● Lateral nasal sill point (NI)

TECH FIG 6 • Lateral lip markings. Lip (**A**) and nasal (**B**) points of closure are marked, and then limbs are

drawn between those points (**C**). Like an articulated ruler, with the two end points fixed, the two intermediate points are selected by establishing best fit with known measurements. (Copyright © David Chong.)

- By planning the repair, one recognizes the variability of unilateral cleft lip presentations and individualizes the repair to the presenting deformity, much like a tailor would measure a suit for an individual. With this approach, you will achieve a balanced lip with:
 - The correct thickness of vermilion and mucosa of the red lip
 - A continuous cutaneous roll
 - A symmetric Cupid's bow
 - A length-matched closure of the lip incision that reflects the philtral column position
 - A nasal sill closure with the appropriate orientation, position, and diameter to match the contralateral naris
-

■ Dissection

Medial Labial Element

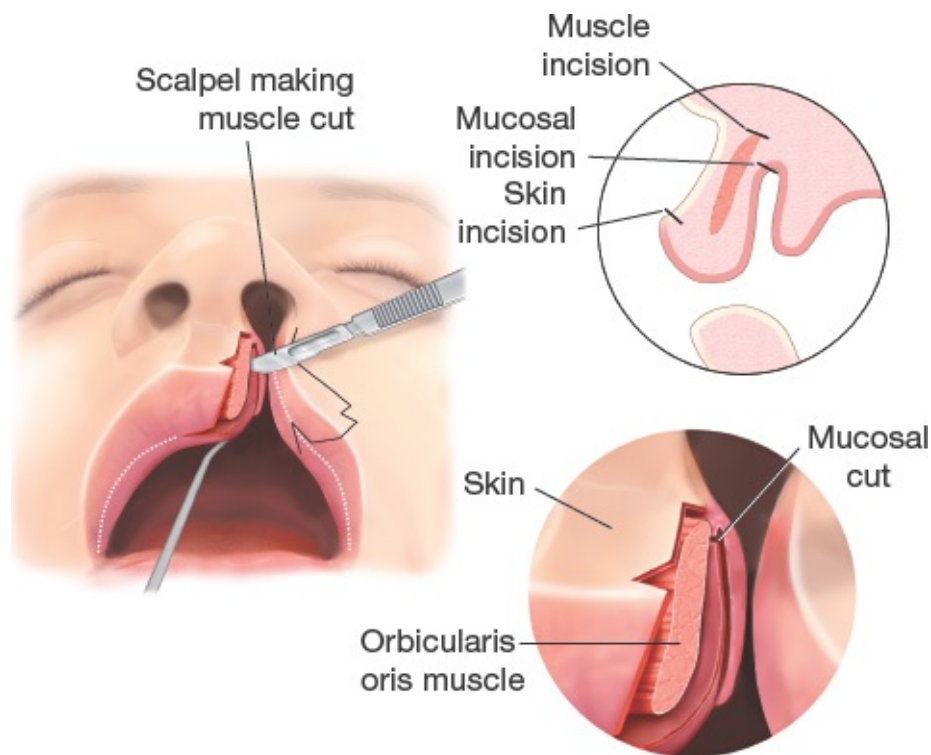
- Incise the medial lip element first (**TECH FIG 7**). This allows you to verify that prior to cutting the lateral lip element, you are able to achieve the necessary rotation to create a vertically balanced lip and ensure no adjustments are required to the size of the triangle.
- Use a no. 11 blade to incise along the medial lip markings. It is critical to precisely cut perpendicular to the cutaneous roll. If a triangle is planned, make the opening incision above the cutaneous roll as your final cut to level Cupid's bow and ensure its size is appropriate.
- Incise along the markings of the vermilion and continue the incision onto the mucosa and release the maxillary frenulum.
- Release the aberrant muscular insertions to the anterior nasal spine. Perform minimal dissection of the muscle from the skin and mucosa.
- Elevate the skin along the vermilion-cutaneous junction (analogous to C-Flap elevation) to facilitate nasal sill closure and allow access to the nasal

septum.

- Elevate the mucosa (analogous to M-flap elevation) off the medial cleft edge to inset at the site of the maxillary frenulum release and elongate the medial lip mucosa.

Nasal Structures

- Expose the caudal septum on the noncleft side with elevation of the mucoperiosteal flaps for direct visualization of the cartilage. Reposition the caudal septum with gentle traction toward the cleft side.
- The amount of lower lateral cartilage dissection varies according to surgical preference.⁴⁻⁷
- If nasal degloving is to be performed, place scissors carefully in the plane between the skin and medial crura. Gently dissect in this plane between the skin and the cartilage from the medial crus toward the lateral crus.



TECH FIG 7 • Medial labial incisions and dissection of the skin, muscle, and mucosa.

- Opponents of nasal cartilage degloving consider the risk of cartilage injury, tissue destruction, subsequent scarring, and impaired growth to far

outweigh the minimal benefit achieved with this degloving. In primary nasal correction without cartilage degloving, the correction is achieved with release of abnormal ligamentous attachments at the piriform and suture techniques, avoiding the risks listed above.

- The muscle release, repositioning, and approximation are the foundation of the lip repair.
- Verify the muscle is sufficiently released by measuring the lip length. Once committed to the opening incision, make the cut perpendicular to the philtral incision and above the cutaneous roll with a beaver blade.
- By incising and committing to the medial lip plan first, you can then adjust the lateral lip markings if the planned triangle size was incorrect. This is particularly helpful in the learning stages of this technique (the planned triangle may not be necessary or the wrong size).

Lateral Nasolabial Element

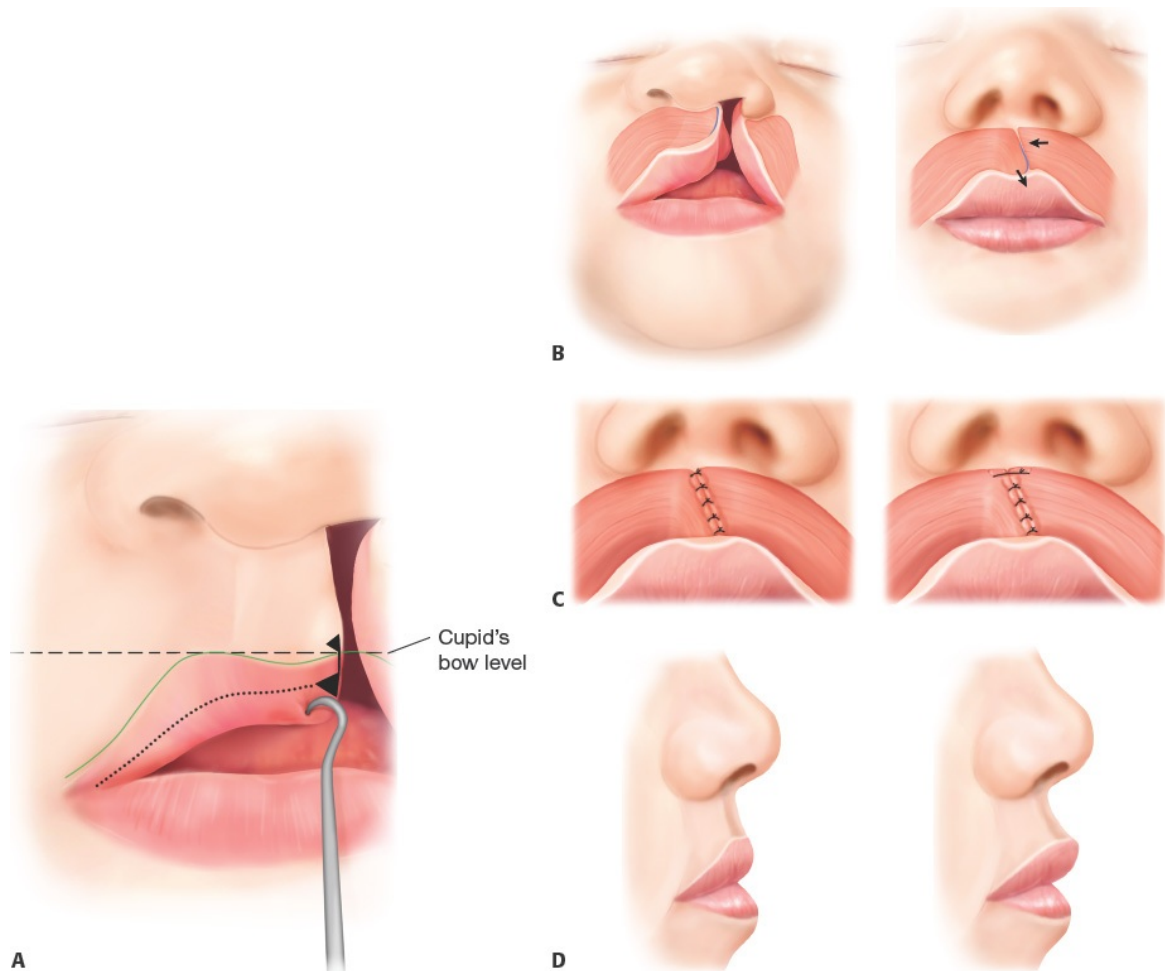
- Use a no. 11 blade to incise the lateral lip and a beaver blade to make the fine incisions around the triangle.
- Release the muscle from the alar base. Continue dissection laterally for a 2-cm distance dividing the muscle to allow for its advancement and to create a muscle of symmetric height for repair.
- Perform dissection between skin and muscle, especially along the superior portion of the lateral lip to allow for advancement. Perform minimal release of the muscle from the underlying mucosa.
- Elevate the nasal floor off the nasal vestibule to allow for repositioning in a horizontal plane for nasal floor closure.
- If cartilage degloving is being performed for primary nasal correction, complete the degloving in the plane between the skin and cartilage joining the previously dissected pocket.

■ Closure of the Lip

Muscle Repair

- The muscle repair sets the foundation for the lip repair. To correctly position the muscle elements for repair, have an assistant use a skin hook to lengthen the medial lip element to balance the Cupid's bow (taking care not to excessively elongate) and another skin hook to hold the lateral lip element at

the ideal position for a lip closure (**TECH FIG 8A**).



TECH FIG 8 • A. Level Cupid's bow to position the muscle elements for repair. **B.** A. In repair of a cleft lip, it is essential to release the aberrant orbicularis oris muscle insertions and reposition the muscle fibers to restore continuity. After release, repositioning, and repair of the orbicularis oris muscle, a superior gathering suture is placed (**C, right**) to improve the shape of the lip on profile view (**D**).

- With the setup outlined above, repair the muscle beginning superiorly. Place the initial stitch superiorly to set the lip length and set the alar base in a symmetrical vertical position. To ensure the cutaneous roll points of closure

are perfectly matched, check the alignment of the points of closure after each successive muscle stitch.

- After repairing the length of the muscle, consider placing a plication suture at the superior end of the muscle repair at the base of the columella. This accentuates the pout of the repaired lip (**TECH FIG 8B–D**).
- Repair the mucosal incision with eversion of the mucosal edges. Ensure correct approximation of the mucosal lengths and excise excess length at the cephalad margin as required.

Cutaneous Approximation

- Suture the labial skin and the vermilion without any cutaneous excision or alteration of the labial incisions. A perfectly approximated closure of the labial elements should be achieved based on the planned markings.
- The only “cut as you go” occurs at the nasal sill where some adaptation is often required to ensure the right diameter and shape of the nostril opening.

■ Primary Nasal Correction: Suture Techniques

- Suture techniques detailed below necessitate that the alar base and aberrant nasal attachments to the piriform and underling maxilla are completely released.
 - The alar bases must be symmetrically repositioned and the caudal septum must be centralized.
- If cartilage degloving was performed:
 - Place an alar shaping suture as an interdomal suture between the genua of the lower lateral cartilages (LLC).
 - Place a lower lateral hitching suture with an absorbable suture to secure the dome of the LLC to the contralateral nasal bone periosteum. This elevates the slumped LLC. Beginning from inside the nasal vestibule on the cleft side, pierce the suture through the nasal mucosa, capture the dome of the slumped LLC, exit the nasal skin with grasped nasal bone periosteum, and back through the same cutaneous needle puncture to return to the nasal vestibule through the same tissues.
- If cartilage degloving was not performed:
 - Place an internal nasal valve plication suture in the vestibule between the upper and LLC to recreate the scroll area.
 - Place an alar transfixion suture to lateralize the vestibular web. Beginning

from inside the vestibule, pierce through the nasal mucosa just below the caudal LLC and exit the skin at the alar-facial junction. Re-enter the same cutaneous puncture hole but exit more posteriorly in the nasal mucosa. Tying the knot will lateralize the nasal mucosa.

PEARLS AND PITFALLS

Planning

- Important landmarks are marked and never compromised.
- There should be no “cut as you go” on the lip. The labial closure should be precisely measured and tailored fitted because compromise in the lip closure point is unforgiving.
- Spend more time marking before any incisions are made and commit to a plan.
- It may be disconcerting initially as a lot more tissue seems to be discarded than when “hedging your bets” by unnecessary preservation of tissue.

Markings

- Choose the cleft side of Cupid’s bow point just medial to the actual peak of the Cupids bow as it is difficult to surgically create a curve. Pick a slightly more lateral point on the lateral lip element (which has the curve).
- The triangular cutaneous flap is smaller than anticipated for two main reasons:
- The skin is elastic and rests in a concave contour due to the aberrant insertion of the muscle. It will lengthen with release of the muscle and dissection between these layers.
- Rotation of the medial lip is also achieved by the muscle repair and the mucosal release.

Measurements

- Use calipers for measurements. This results in length-matched incisions and precise alignment.

Muscle repair

- The muscle is detached from its abnormal insertion, and the lateral lip muscle is advanced into the gap superiorly as the muscle released medially is drawn caudally to achieve lip length. This allows planning the skin incision to mimic the philtral column position rather than the misguided intention that it achieves rotation.

Inferior triangle above the cutaneous

- Creates a continuous cutaneous roll without interruption. Insert any required triangle in the shadow of the roll, that is, just above

roll

the roll.

- Achieves any additional lip lengthening required.
- Work out the precise size of triangle and confirm measurement by cutting medial lip element first.

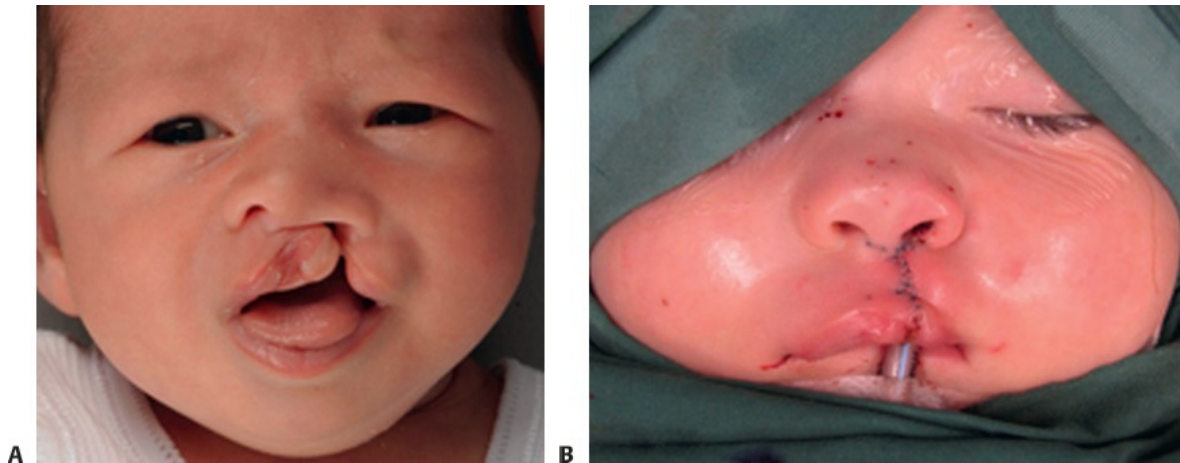


FIG 1 • Preoperative and postoperative images of an infant with cleft lip and palate following repair with anatomical subunit technique. (Copyright © David Chong.)

POSTOPERATIVE CARE

- Prevent crusting along the suture line with incision care.
- Apply saline as required to prevent scab and then emollient.
- Sutures are removed after 5 days.
- Nasal stents are kept for up to 6 weeks.

OUTCOMES

- Since 2008, Dr. Chong has performed 200 consecutive cleft lip repairs using the technique described (**FIG 1**).
- Nasolabial revisions were required in three cases (1.5%), one for alar repositioning and two for retained permanent suture.
- There have been no revisions required for a shortened lip.

COMPLICATIONS

- Infection
- Hemorrhage

- Lip or nasal revision required for asymmetry
- Poor scarring
- Nasal airway obstruction

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2 Unilateral Cleft Lip Repair: Millard/Mohler Modifications

CHAPTER

Roberto L. Flores and Gerald J. Cho

DEFINITION

- A unilateral cleft lip is a congenital separation of the upper lip. The degree of clefting can be microform, minor form, incomplete, or complete.
 - Microform
 - Discontinuity of the vermilion-cutaneous junction
 - Cupid's bow symmetrical
 - Slight notching of mucosal free border
 - Variable nostril deformity and alveolar defect
 - Minor form
 - Vermilion notch greater than 3 mm above the level of Cupid's bow on the noncleft side
 - Discontinuity of orbicularis oris
 - Nasal deformity
 - Alveolar cleft present
 - Incomplete
 - Complete full-thickness separation of upper lip with intact nasal sill or a Simonart band along the nasal floor
 - Complete
 - Complete full-thickness separation of upper lip

ANATOMY

- Both the soft (upper lip and nose) and hard tissues (maxilla, septum, lower lateral cartilages of nose) are affected (**FIG 1**).
- Upper lip—The deformities in this area can be categorized into those affecting

the medial and lateral lip elements.

- In the medial lip element, Cupid's bow is preserved but with vertical deficiency of the vermillion. The columella and philtral column are shortened on the cleft side. The orbicularis oris has an abnormal and unilateral insertion at the nasal base, and its disruption results in vertical shortening of the medial upper lip, superior rotation of the Cupids bow, and vertical shortening of the vermillion.
- In the lateral lip element, the height and transverse length are shortened. Medially, there is a distinct point where the white cutaneous roll and junction of the wet and dry vermillion start to converge medially (Nordhoff point). The pars superficialis on the lateral lip alters the direction of this muscle to run almost vertically in the area below the ala, leading to aberrant attachments to the nostril and periosteum of the piriform aperture. This leads to a vertically foreshortened lateral lip, sometimes producing a bulge in this area.
- Nose—The alar base on the cleft side sits on the piriform margin of the maxilla, which is laterally and posteriorly displaced. The malposition of the bony foundation combined with separation of the orbicularis oris causes unopposed action of the ipsilateral zygomaticus major. This results in widening of the nostril, depression of the alar dome, and canting of the columella toward the cleft side (see **FIG 1**). Unilateral attachment of the orbicularis oris to the medial crura footplates, anterior nasal spine, and caudal septum on the noncleft side exacerbates the columellar tilt and contributes to deviation of the caudal septum toward the noncleft side. Internally, the caudal portion of the ala has a vestibular web. The underlying cartilaginous structures are also malformed. On the cleft side, the medial crus of the lower lateral cartilages is shortened, and the lateral crus is elongated and inferiorly displaced. The septum is dislocated out of the vomer and bows toward the cleft side.
- Maxilla—The underlying skeleton forms the platform upon which the soft tissues rest. Thus, the skeletal abnormalities of the maxilla can explain many of the soft tissue abnormalities seen, particularly in the nose. The greater segment of the alveolus is anteriorly rotated due to the fetal protrusion of the tongue. The lesser segment of the alveolus rotates posteriorly. The medial buttress of the maxilla can be hypoplastic and posteriorly displaced.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative assessment of a patient with a unilateral cleft lip includes

complete physical exam with assessment for other comorbidities. Facial exam includes the side (left vs right vs midline), the degree of clefting (microform, minor form, incomplete, or complete), and the extent of nasal deformity.

IMAGING

- Typically not needed unless within the context of a midline or facial cleft

SURGICAL MANAGEMENT

- This surgery is often the first step in the larger multidisciplinary treatment plan for cleft care.
- The quality of the primary repair establishes the initial function and appearance for the patient and has great bearing on their future quality of life.
- Nasoalveolar molding (NAM) is strongly recommended for patients with a complete cleft or a significant nasal deformity.
- Microform clefts can be repaired with less extensive methods than a full rotation advancement.
- Minor forms can be repaired with a modified rotation-advancement-type repair with complete primary nasal reconstruction.
- Incomplete and complete clefts can be repaired with a full rotation-advancement-type repair.
- Initial lip and nose repairs are performed at approximately 3 months of age.

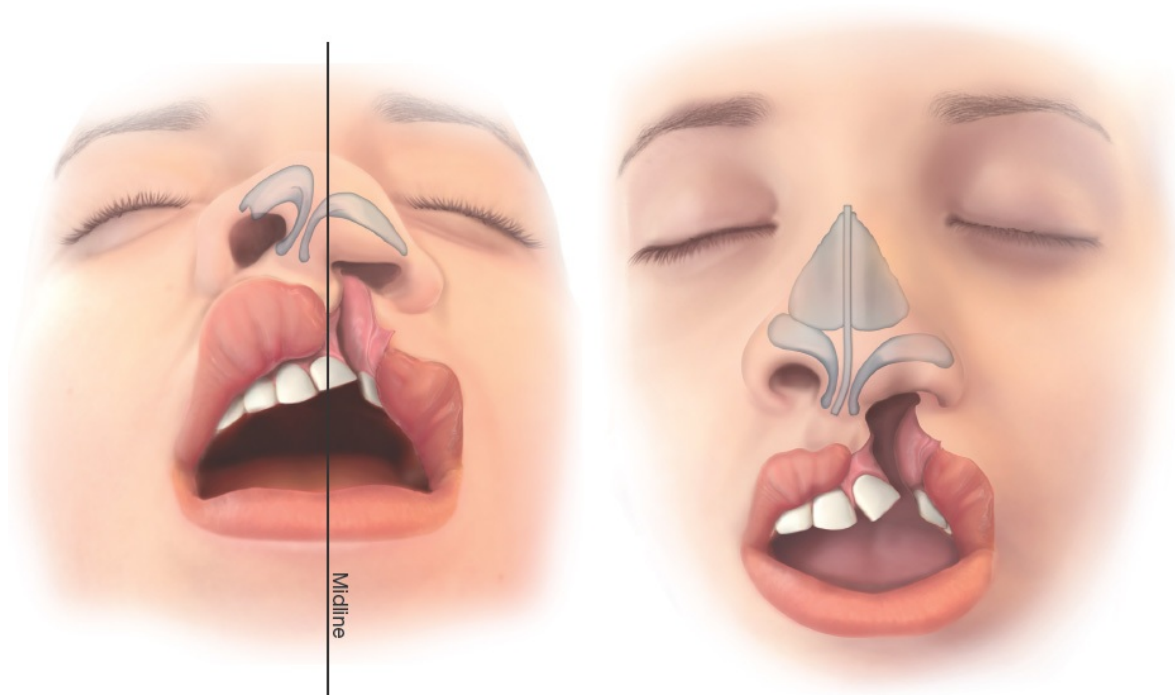


FIG 1 • The soft (upper lip and nose) and hard tissue (maxilla, septum, lower lateral cartilages of nose) anatomy of a left complete unilateral cleft lip.

Preoperative Planning

- The authors use NAM in patients with a complete cleft or a significant nasal deformity. As mentioned above, a cleft through the maxilla not only disrupts the platform upon which the soft tissues sit but also interrupts the dental arch. NAM can help correct the outwardly rotated greater segment and posterolaterally displaced lesser segment. The correction of the skeletal platform into an anatomic position helps place the lip and nose into a more favorable alignment. Furthermore, when the alveolar segments are aligned within 1 mm, a gingivoperiosteoplasty can be performed, which can avoid a secondary bone grafting procedure in 60% to 73% of patients without detriment to midface growth by midterm follow-up. For these reasons, we feel that NAM provides a more predictable lip and nose repair and potentially decreases the overall number of surgical procedures for the child.
- NAM typically commences 2 weeks after birth and is completed after 10 weeks of therapy in patients with a unilateral cleft.

Positioning

- Supine with gentle neck extension from a shoulder roll

Approach

- There are many techniques to repair a unilateral cleft lip, each with its own advantages and disadvantages. In this chapter, we will present Cutting's modification of the extended Mohler repair.
- In this approach, there are eight main steps to the operation: markings, incisions, medial lip dissection, lateral lip dissection, mucosa closure, nasal dissection, lip closure, and nasal refinement.

TECHNIQUES

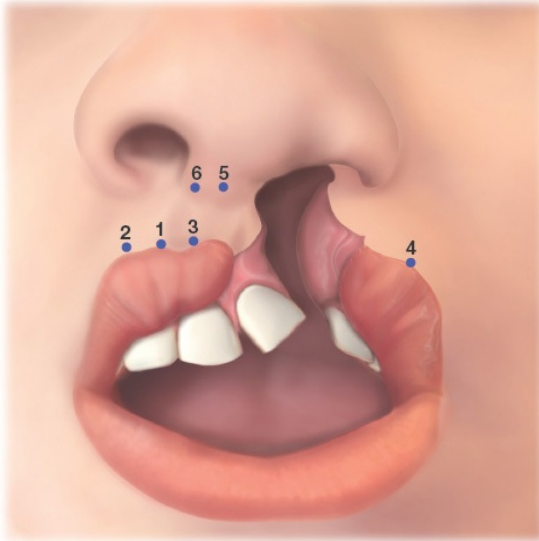
■ Millard/Mohler Modifications for Unilateral Cleft

Lip Repair

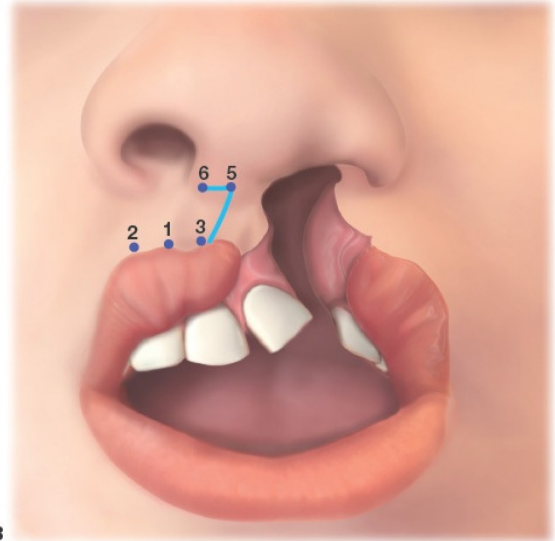
Markings (**TECH FIG 1A–D**)

- Medial and lateral lip elements (**TECH FIG 1A**)
 - Medial lip element: The depth (point 1) and height of the noncleft side (point 2) are identified and marked. The distance between these two points is used to mark the height of the Cupid's bow on the cleft side (point 3). The white roll usually starts to disappear at this point. If Cupid's bow is wide or indistinct, the marks can be placed more narrowly so that less downward rotation is required.
 - Lateral lip element:
 - The height of the lip from the alar base to the height of the Cupid's bow on the noncleft side is measured with a caliper, and the vertical distance is used to locate the corresponding white roll point on the lateral lip element (point 4). Some surgeons use the widest point of the vermilion (Nordhoff point) to determine point 4. However, in patients with a wide cleft, Nordhoff point will commonly result in a vertically foreshortened lip. Using the vertical height of the contralateral upper lip can sacrifice horizontal lip length for preservation of vertical lip height. The horizontal lip discrepancy will correct over time; however, a vertically shortened upper lip will remain.
- Mohler Back Cut (**TECH FIG 1B**)
 - The apex of the back cut is critical to the success of the design (see Pearls below). This point (point 5) is placed approximately 1.5 mm superior to the base of the columella and just over halfway (four-sevenths) across the noncleft side.
 - A line is drawn connecting point 5 to a point just lateral to point 3. This line should be bowed out to the same degree as the philtral column of the unaffected side to recreate the subtle curve.
 - A straight line is drawn from the apex of the Mohler backcut (point 5) to the height of the philtrum on the noncleft side but no farther (point 6). The angle formed by these two lines and length of the backcut will affect the degree of downward rotation of the Cupid's bow.
- C flap and M flap on the medial lip element (**TECH FIG 1C**)
 - C flap: A line is drawn along the skin/mucosa junction lateral to point 3. Care is taken to incorporate as much white lip into the C flap as possible while avoiding the mucosa (see Pearls below).

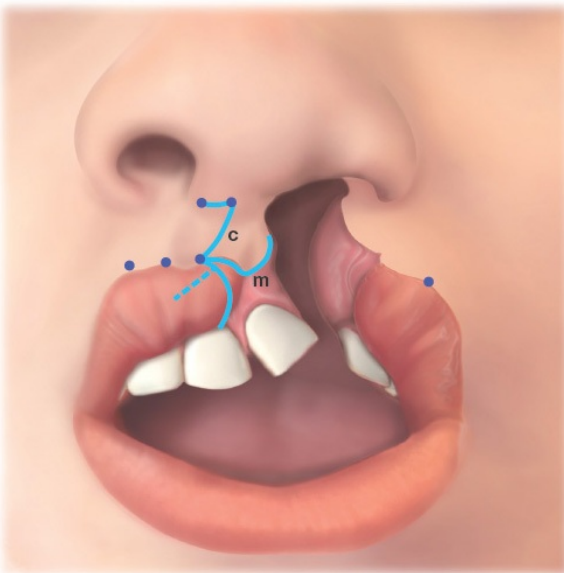
- M flap: The medial/inferior border of the M flap is drawn as a straight line starting from point 3 and perpendicular to the white roll. A second line is drawn on the vermillion of the medial lip element as an oblique line starting at a point 1 mm inferior to the white roll, traveling laterally and inferiorly to the red line. This is the receiving incision for the Nordhoff triangular flap.
- Alar base and L flap on the lateral lip element (**TECH FIG 1D**)



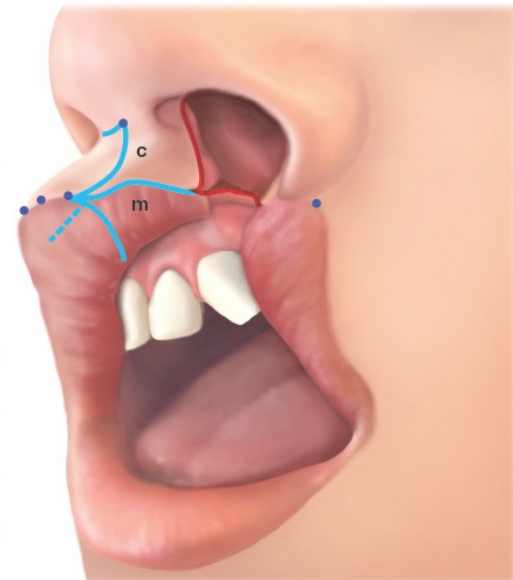
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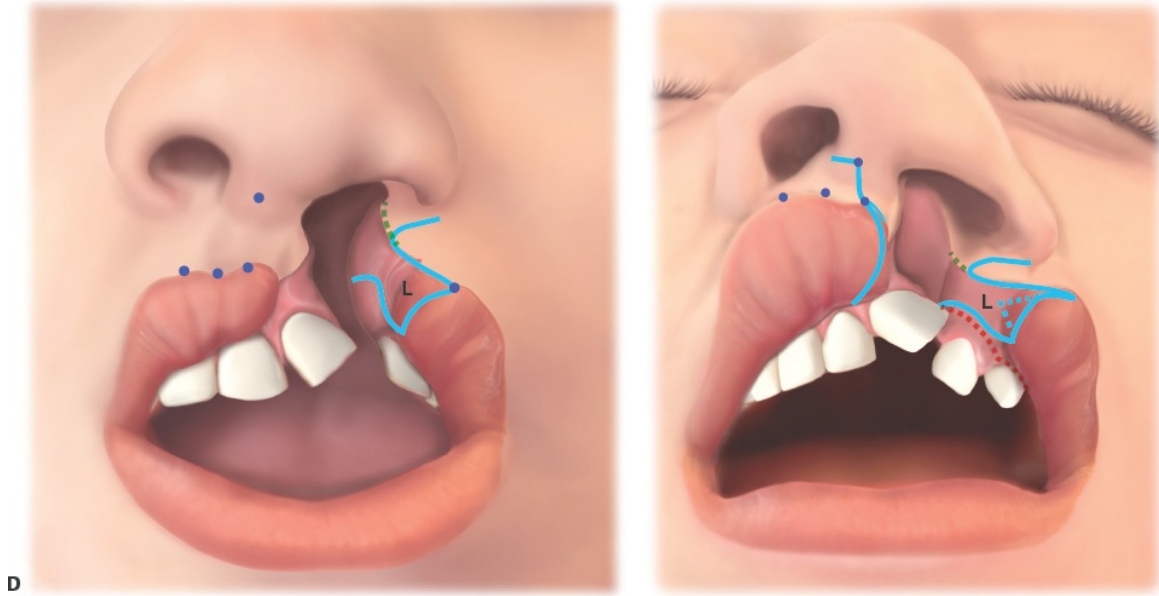


B



C





TECH FIG 1 • Markings. **A.** Key tattoo points. **B.** Mohler back cut. **C.** C flap and M flap. Dashed blue line represents the receiving incision for a vermilion triangular flap if used. The dashed red line represents the intranasal incisions on the septum and vomer made during nasal floor closure. **D.** Alar base and L flap (L) outlined in *blue*. The *dashed blue line* is the triangular flap as described by Nordhoff. *Dashed green line* is the intranasal incision at the piriform aperture, and the *dashed red line* is the gingivobuccal sulcus incision, which will be made at the time of the lateral lip dissection.

- Alar base: A small incision is marked along the alar crease on the cleft side with care not to extend this incision around the alar base.
- L flap: The border of the L flap is then marked by first marking an incision 1.0 mm inferior to the white roll on the lateral lip element. This mark then transects the white roll perpendicularly and then curves swiftly and softly to meet the medial edge of the previously made mark on the alar crease. The remainder of the L flap can then be made with or without the addition of a vermilion triangular flap, as described by Nordhoff. When marking the L flap, care is taken to extend the mark just superior to the alveolus. This

will base the L flap off of the lateral nasal wall and not the alveolus, as originally described by Millard.

- Points 1 to 6 are tattooed. The lip and nose are infiltrated with 0.5% lidocaine with 1:200 000 epinephrine.

Incisions

- All premarked incisions are made through skin and mucosa.

Medial Lip Dissection (**TECH FIG 2A,B**)

- M flap is elevated in a submucosal plane (**TECH FIG 2A**).
- C flap is elevated in the subcutaneous plane with care to preserve the underlying orbicularis oris (see **TECH FIG 2A**).
- Mohler back cut (**TECH FIG 2B**).
 - A transverse incision is made across the full-thickness orbicularis oris muscle where it abnormally inserts at the nasal base. This incision is made at the base, not the apex, of the Mohler back cut. If this incision is made at the apex of the back cut, the medial crura will be transected. Care should also be taken to avoid going through the underlying mucosa during this incision.
 - Complete full-thickness transection of the muscle should be confirmed by placing a small single hook into the medial lip element and pulling the lip down. The lip should rotate downward with no tension.
 - If additional downward rotation is still required, the labial frenulum is horizontally transected. This defect may be filled by the mucosa of the lateral lip element.
- Medial lip element preparation: The philtral skin is dissected free from the muscle in a subcutaneous plane up to but not past the philtral dimple.

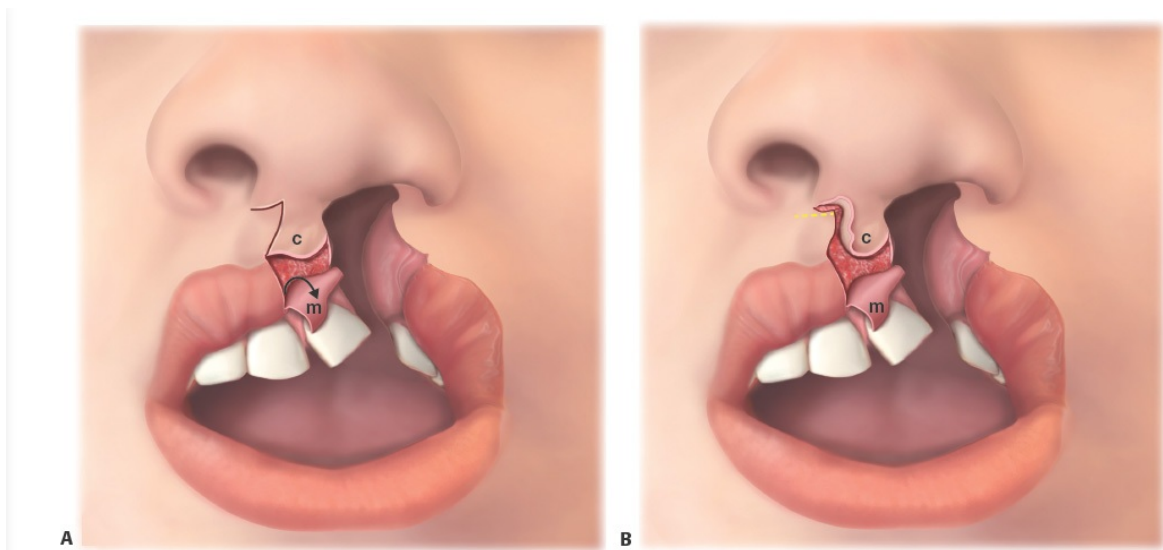
Lateral Lip Dissection (**TECH FIG 3**)

- L flap elevation:
 - The L flap is carefully elevated from the orbicularis oris in the subcutaneous and submucosal plane. As one approaches the area of the piriform aperture, the dissection plane changes from a submucosal to a subperiosteal plane.
 - A Woodson elevator is then used to create a subperiosteal pocket in the interior/lateral aspect of the piriform aperture. A horizontal incision is made at the exact border of the lateral nasal wall with the nasal floor. An incision

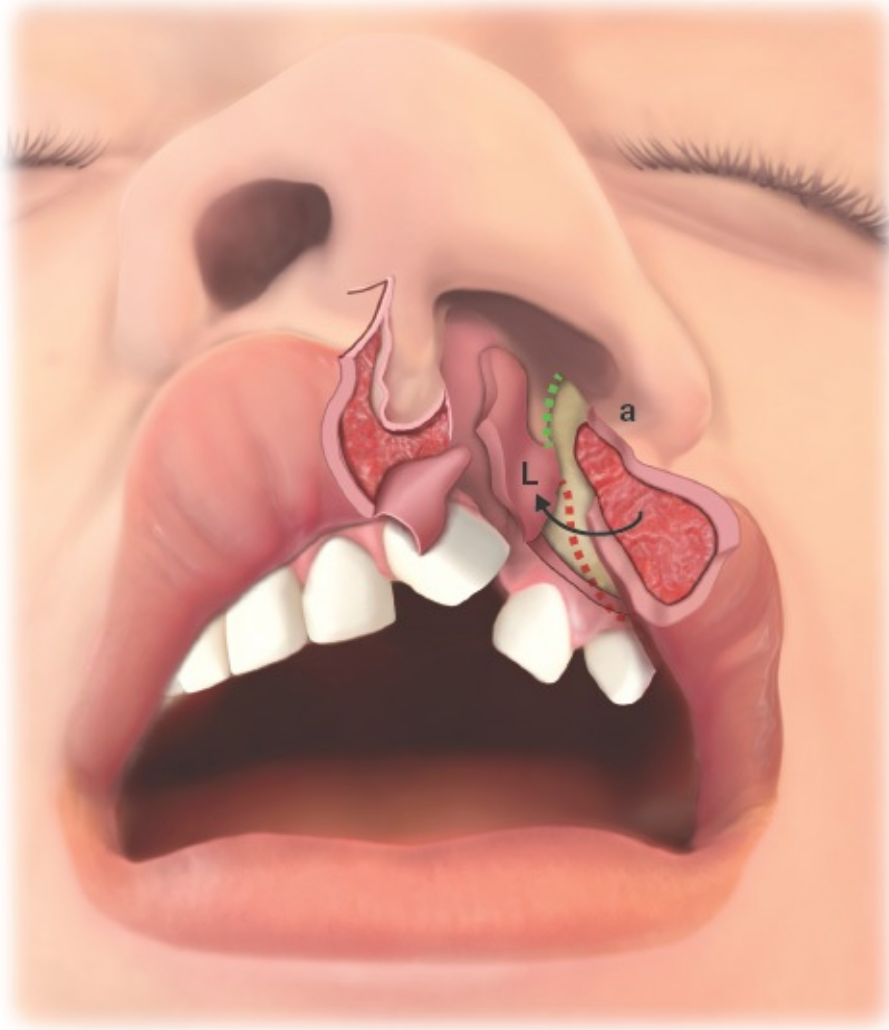
is made at the base of the vomer, and a vomer flap is elevated with the periosteal elevator. The lateral nasal wall flap and vomer flap will be used to close the anterior nasal floor later in the surgery.

■ Piriform aperture incision:

- A vertical intranasal incision is made at the border of the nasal mucosa and squamous skin to meet the superior border of the L-Flap. Sharp dissection is performed to reach the bone of the piriform aperture.
- Subperiosteal dissection will complete the elevation of the L flap posteriorly until it is based off the lateral nasal wall.



TECH FIG 2 • Medial lip dissection. **A.** M flap (m) elevated in a submucosal plane and turned down. C flap elevated in the subcutaneous plane. **B.** Mohler back cut. *Dashed yellow line* represents a transverse incision made across the full-thickness orbicularis oris muscle where it abnormally inserts at the nasal base. Complete full-thickness transection of the muscle should be checked by placing a small single hook into the medial lip element and pulling the lip down. The lip should rotate downward with no tension. The philtral skin is dissected free from the muscle in a subcutaneous plane up to but not past the philtral dimple.



TECH FIG 3 • Lateral lip dissection. L flap (L) elevated in a submucosal plane and shown retracted medially. The stippled area represents the L flap that will be trimmed before inset into the lateral nasal wall. As one approaches the area of the piriform aperture (*dashed green line*), the dissection plane changes from a submucosal to a subperiosteal plane. A gingivobuccal sulcus incision (*dashed red line*) is made in continuity with the piriform aperture incision, with care to preserve the L flap. A suprapariosteal dissection is made across the maxilla to fully mobilize the alar base and lateral lip element. The alar base skin (a) should

be elevated as a thick split-thickness skin graft so that a layer of dermis is present on the underlying dermal-muscular pennant flap.

■ Gingivobuccal sulcus incision:

- A gingivobuccal sulcus incision is made in continuity with the piriform aperture incision, with care to preserve the L flap. A supraperiosteal dissection is made across the maxilla to fully mobilize the alar base and lateral lip element. In cases where presurgical orthopedics is not used, this dissection may continue widely across the face in the maxilla.
- Tension-free translation of the alar base flap to the anterior nasal spine will demonstrate adequate dissection.

■ Alar base flap:

- The alar base skin should be elevated in a thick split-thickness skin graft plane so that a layer of dermis is present on the underlying muscular flap. The dermal-muscular pennant will be used to relocate the alar base.

■ Lateral lip element preparation:

- The lateral lip skin is mobilized from the orbicular oris as far lateral as the alar base incision.

Mucosa closure: If gingivoperiosteoplasty is to be performed, it should be completed before the mucosa is closed.

■ L flap inset (**TECH FIG 4A**)

- The L flap is sutured under tension to the base of the piriform aperture incision. Excess L flap is trimmed, and the remainder of the L flap is sutured into the defect created by the piriform aperture incision.

■ Nasal floor closure (**TECH FIG 4B**)

- The lateral nasal wall flap/L flap is sutured to the vomer flap using several absorbable sutures. The sutures are placed first in a simple fashion and then in a horizontal mattress fashion to create a watertight closure of the nasal floor. Closing the anterior nasal floor will facilitate successful gingivoperiosteoplasty and/or alveolar bone graft.

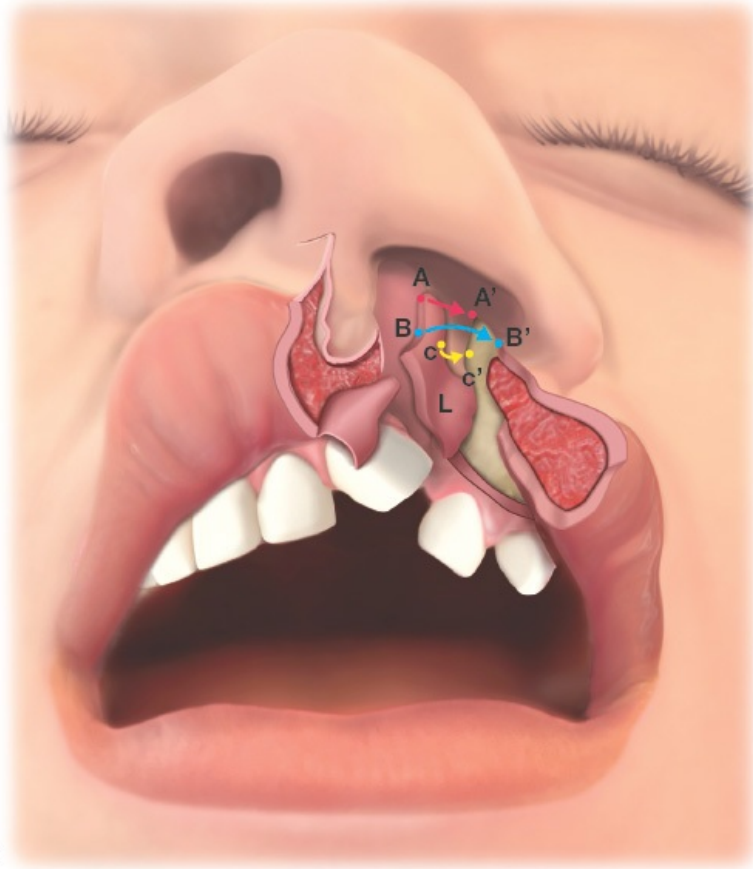
■ Oral mucosa (**TECH FIG 4C**):

- The gingivobuccal sulcus incision is closed using several oblique oriented sutures. This will relieve tension from the midline of the mucosal reconstruction. The mucosa of the upper lip is then closed with simple

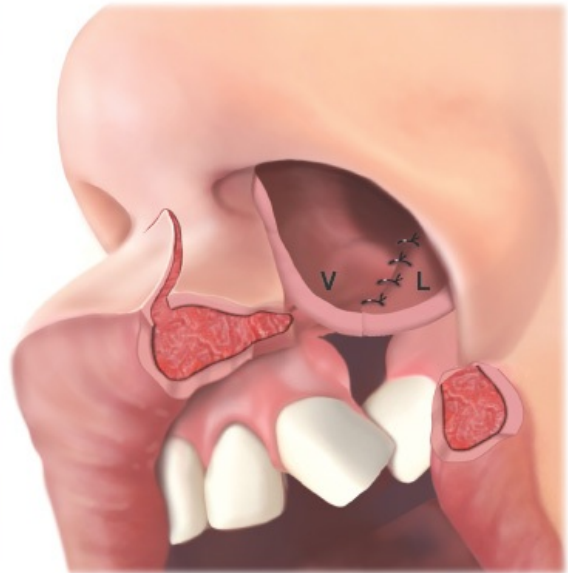
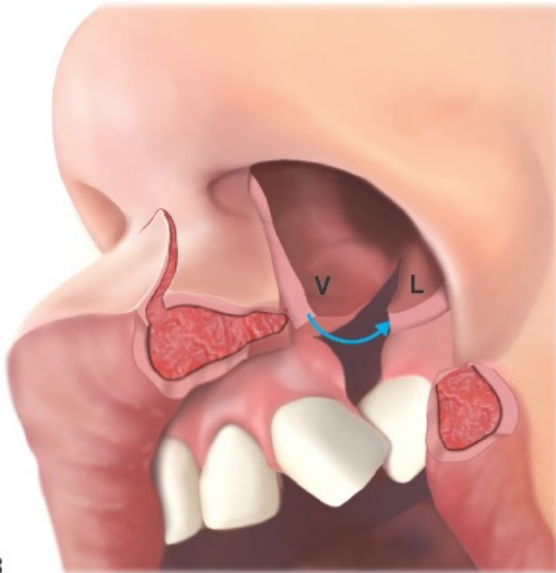
sutures, with care not to incorporate muscle in the mucosal reconstruction.

Nasal Dissection (**TECH FIG 5**)

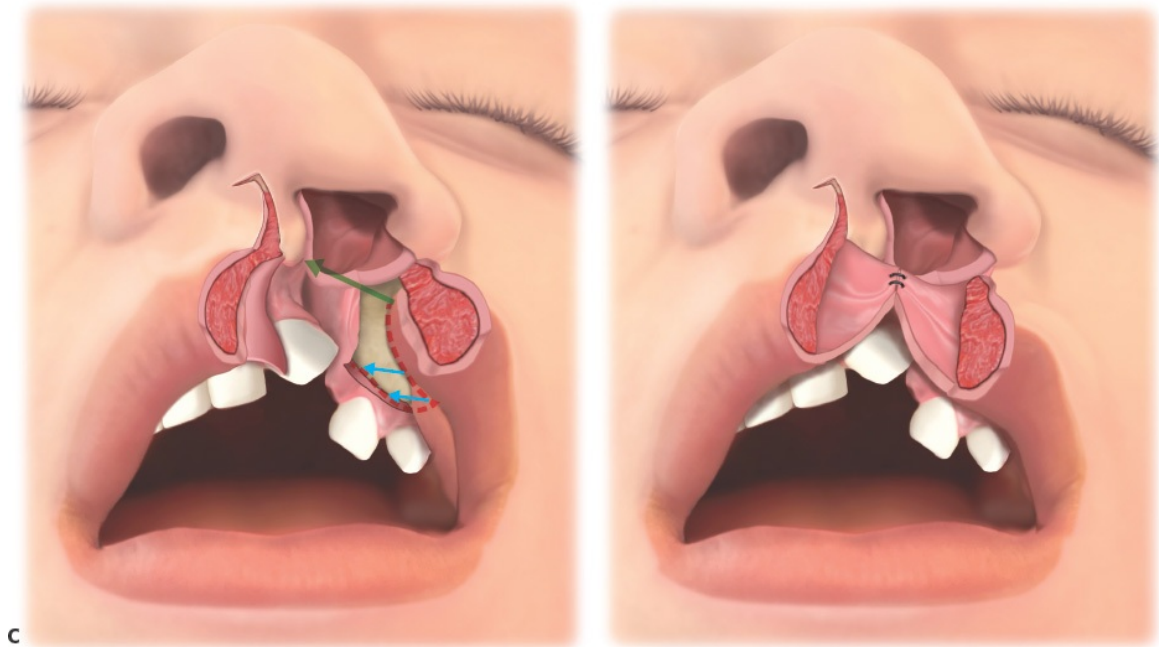
- The rhinoplasty portion of this procedure will elongate the columella and elevate the depressed lower lateral cartilage.
- A hemimembranous septum incision is first made on the cleft side.
- Through the apex of the Mohler backcut, blunt dissection is performed to create a dissection pocket between the medial crura. This dissection pocket is then connected with the hemimembranous incision in the septum, and this dissection is continued superiorly toward the septal angle.
- Dissection scissors are then inserted through this pocket and over the upper and lower lateral cartilages on the cleft and noncleft side.
- Careful blunt dissection will create a subcutaneous pocket over the upper and lower lateral cartilages in preparation for rhinoplasty. Care is taken not to close the dissection scissors in the dissection pocket, as it can lead to damage to the lower lateral cartilages.



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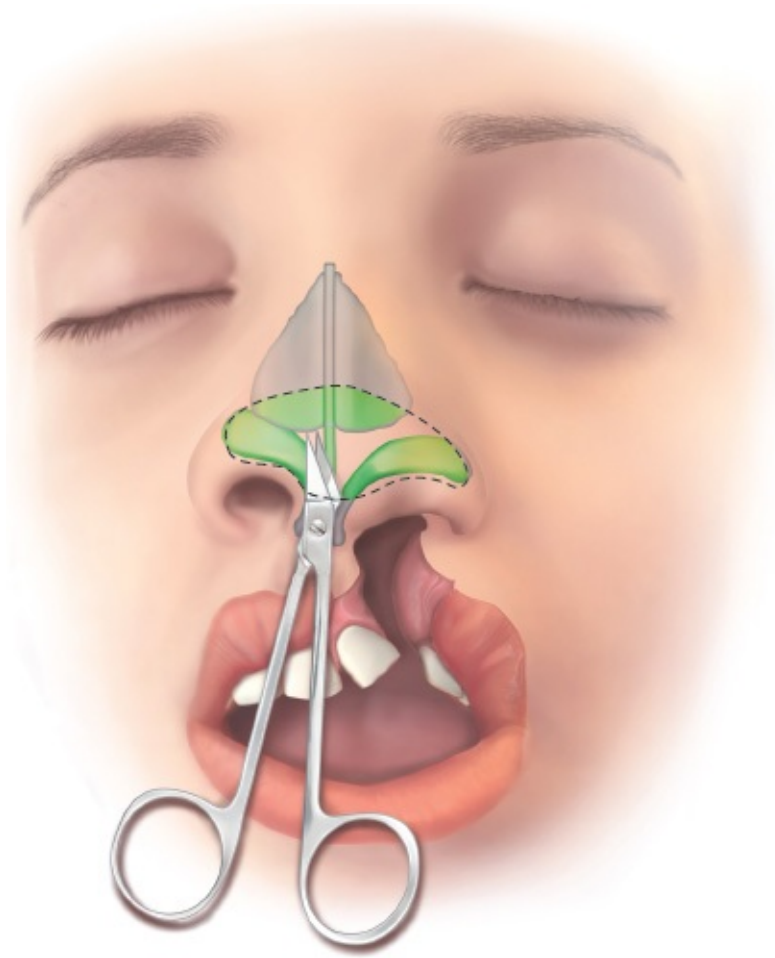


B



TECH FIG 4 • Closure. **A.** Excess L flap (*L*) is trimmed, and the remainder of the L flap is sutured into the defect created by the piriform aperture incision (*A* to *A'*, *B* to *B'*, *C* to *C'*). **B.** The L flap is then sutured to the vomer flap (*V*) to close the nasal floor. **C.** The gingivobuccal sulcus incision is closed using several oblique oriented sutures (*blue arrows*); this will relieve tension from the midline of the mucosal reconstruction (*green arrow*). The mucosa of the upper lip is then closed with simple sutures, with care not to incorporate the musculature in the mucosal reconstruction.

- If no NAM is performed, an additional nostril rim incision is made and a dissection pocket created to connect the rim incision to the subcutaneous pocket underneath the nasal tip.
- A retractor is used to elevate the depressed lower lateral cartilage in a supercorrected position.



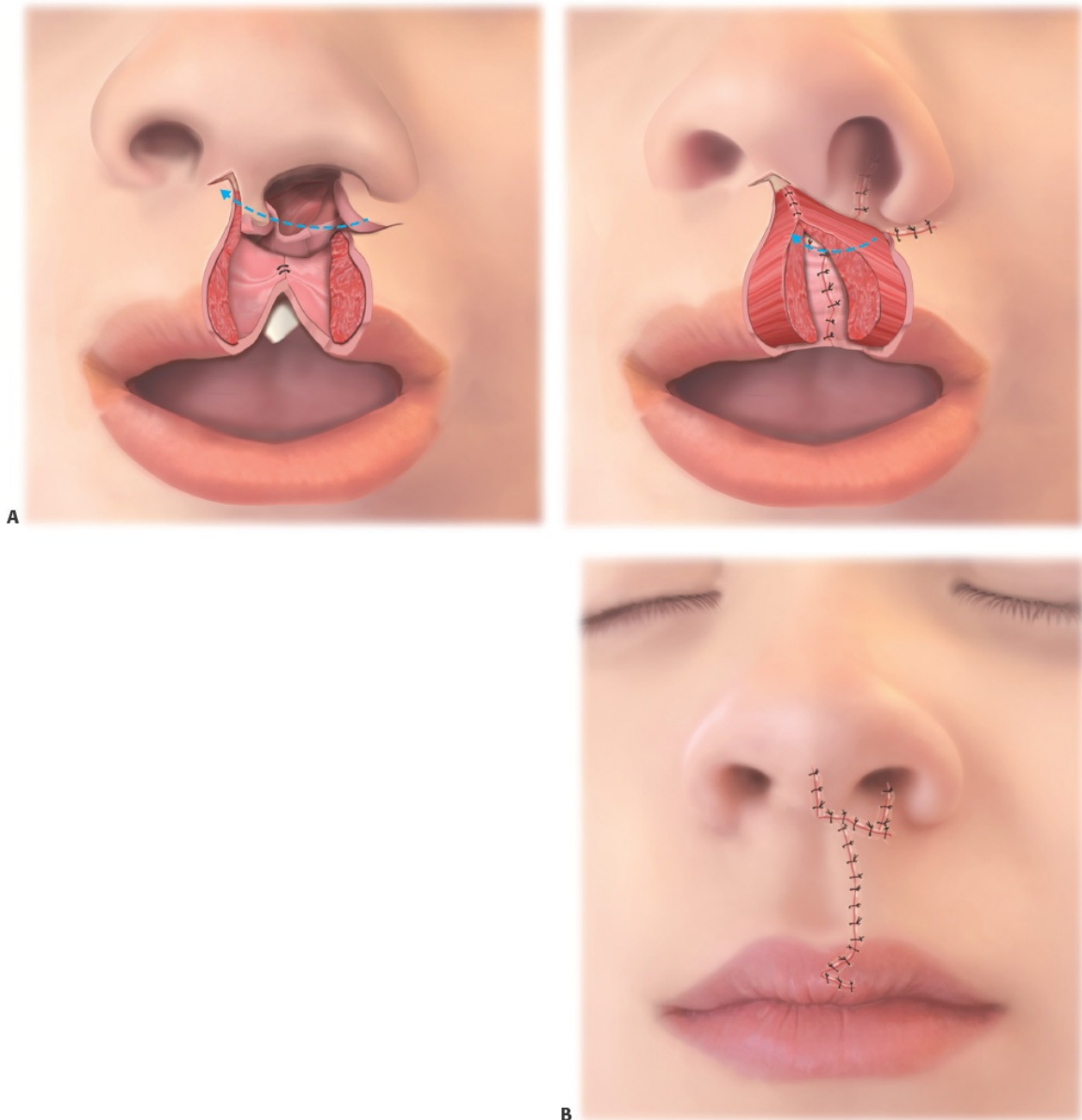
TECH FIG 5 • Nasal dissection. Blunt-tipped scissors are inserted through the apex of the Mohler back cut and at the intranasal incision made at the septal angle. Blunt dissection frees the underlying lower lateral cartilages.

- A long-lasting absorbable suture is then placed as a horizontal mattress to affix the medial crus on the cleft side in its newly elevated position. Several such sutures are placed from superior to inferior to affix the medial crus in its superior location and help shape the columella.
- An additional row of horizontal mattress sutures is then placed using transfixion sutures to affix the medial crura to the cartilaginous septum. Elongation of the columella should be appreciable at the end of this point of the procedure.
- If a nostril rim incision is used, a suture is placed from the cleft side lower

lateral cartilage to the upper lateral cartilage to further reinforce the elevated position of the lower lateral cartilage.

Lip Closure (**TECH FIG 6A,B**)

- Repositioning of alar base (**TECH FIG 6A**)
 - A long-lasting absorbable suture is first placed through the dermomuscular pennant underneath the alar base. Using this suture as a leash, the location of the caudal septum is sighted and then placed through this area and the medial crus on the noncleft side. Tying the suture down will set the alar base in an anatomic position, medialize the columella, and straighten the anterior septum.
 - A second such suture is placed to reinforce the first.
- Muscle (see **TECH FIG 6A**)
 - The orbicularis oris is then reconstructed from superior to inferior using several buried sutures. Prior to reconstruction, excess orbicularis oris is carefully trimmed so that the skin edges are perfectly opposing at the completion of the muscular reconstruction. The superior suture may be attached to the anterior nasal spine to prevent elongation at the upper lip.



TECH FIG 6 • Closure. **A.** The dermal-muscular flap at the alar base is sutured to the area of the anterior nasal spine and the medial crus on the noncleft side (*dashed light blue arrow*). The orbicularis oris is then reconstructed from superior to inferior. **B.** The white roll point is first reconstructed, and the remainder of the upper lip is meticulously closed using several fine permanent sutures. The vermilion is also inset at this time. If a triangular flap is used, this is trimmed and

inset.

- Upper lip skin (**TECH FIG 6B**)

- The white roll point is first reconstructed, and the remainder of the upper lip is meticulously closed using several fine permanent sutures. The vermilion is also inset at this time. If a triangular flap is used, this is trimmed and inset.

- C-Flap inset (see **TECH FIG 6B**)

- In the extended Mohler repair, the C flap is used to fill the defect created by the downward rotation of the Cupid's bow. The C flap is carefully scored and cut. The C flap is then inset into this defect, and the columellar incision is also closed with several simple sutures. The alar base incision is also closed at this time. Excess C flap and alar skin are also trimmed, and the nostril floor is closed.

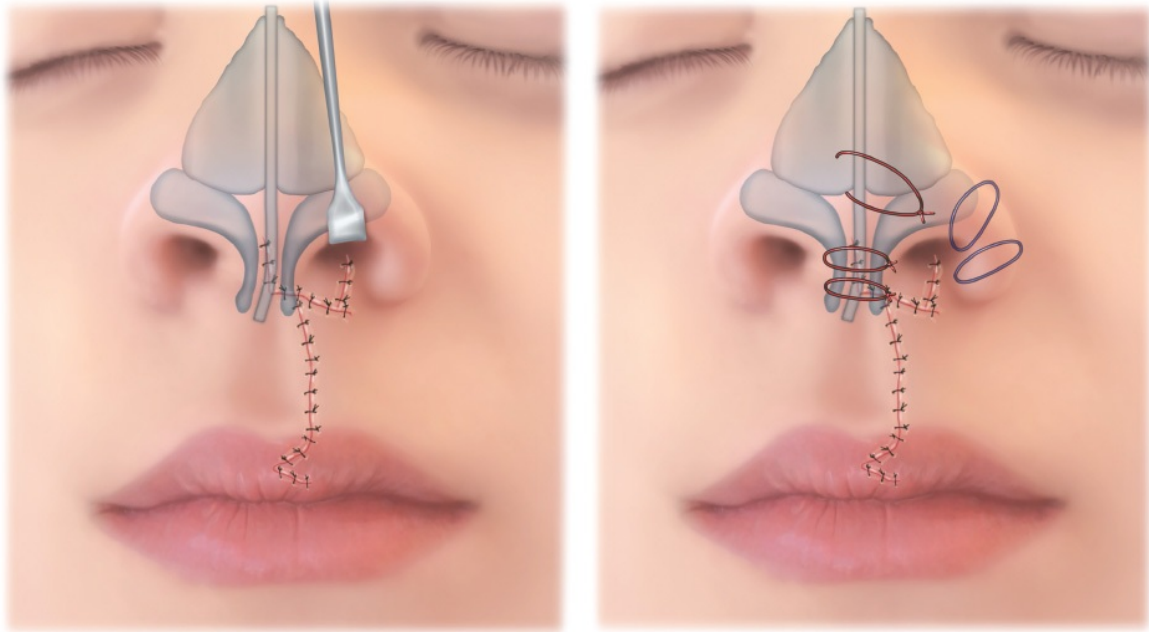
- Nostril floor (see **TECH FIG 6B**)

- Care is taken to close the nostril floor and the philtral incision in a stair-step fashion to avoid a confluence of four corners at the nostril floor incision.

Nasal Refinement

- Nostril apex elevation (**TECH FIG 7**)

- If NAM was used, the nostril apex overhang is addressed using a long-lasting absorbable suture that is placed just behind the nostril rim, through the depressed lower lateral cartilage on the cleft side, underneath the skin of the nasal tip, and out the nostril on the opposite side. The trajectory of this suture is oblique, directed laterally and posteriorly. The suture is then returned 2 mm behind the exit suture hole in the noncleft side, parallel to the first suture, and returning to the cleft side nostril. Tying down this suture corrects nostril apex overhang and adds to tip definition.



TECH FIG 7 • Nostril apex elevation (*red*) and vestibular web obliterating sutures (*blue*).

- In patients who did not undergo NAM, the depressed lower lateral cartilage is elevated by the previously placed suture from the lower lateral to upper lateral cartilage. A small rim of overhanging skin at the nostril apex is carefully trimmed and the rim incision is closed.
- Regardless of technique, there should be an overcorrection of the depressed lower lateral cartilage such that the cleft side is higher than the noncleft side.
- Vestibular web obliterating suture (**TECH FIG 7**)
 - The vestibular web can be addressed by placing a long-lasting absorbable suture behind the web out of the nasal facial groove; the suture can then be returned through the same cutaneous hole and back into the nostril anterior to the vestibular web. Tying this suture down will obliterate the vestibular web and accentuate the nasal facial groove. Multiple sutures may be required to achieve the full effect.

PEARLS AND PITFALLS

Anatomy	■ It is critical that the surgeon has a thorough understanding and ability to identify the pathologic soft and hard tissue deformities and individualize the surgery as needed.
The apex of the extended Mohler back cut	■ It should be high enough onto the columella to allow for full downward rotation of the Cupid's bow. If point 5 is too low, it will result in inadequate downward rotation. ■ If point 5 is too close to the cleft side, the C flap will be too narrow and inadequately fill the defect created by the downward rotation of the Cupid's bow. ■ Placing point 5 too far toward, the noncleft side will result in a narrow philtral column at the superior aspect of the upper lip.
C flap	■ In wide clefts where presurgical orthopedics (NAM) was not used, it is important to incorporate as much white lip into the C flap as possible because the C flap may be used in its entirety to fill the defect created by the downward rotation of the Cupid's bow. ■ Care must be taken to avoid incorporating mucosa, which will result in the transposition of mucosal tissue onto the nose and upper lip.
Tension-free closure essential for optimal wound healing	■ Medial lip element: Adequate release of the orbicularis oris muscle where it abnormally inserts at the nasal base to allow for full rotation downward ■ Lateral lip element: Supraperiosteal dissection is made across the maxilla to fully mobilize the alar base and lateral lip element. ■ Adequate release of abnormal attachment of cleft-side lower lateral cartilage from piriform rim
Multidisciplinary care	■ Essential for optimal outcomes

POSTOPERATIVE CARE

- Children are placed in elbow restraints for 5 to 7 days.
- A syringe feeder or cleft feeding nipple (ie, Haberman nipple) is used for feeding.
- Sutures are removed after 5 days and the lip taped in compression for 5 weeks.

OUTCOMES

- In experienced hands, primary cleft lip and nasal repair can achieve lasting symmetry to the lip and nose while camouflaging scars within the subunit

borders of the face.

COMPLICATIONS

- Relapse of the nasal deformity
- Scar contracture/widening
- Inadequate multidisciplinary care and follow-up during growth
- Maxillary growth inhibition

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3 Salyer Unilateral Cleft Lip/Nose Repair

CHAPTER

Kenneth E. Salyer

DEFINITION

- Cleft lip/nose deformity occurs during embryonic development when there is lack of normal migration and proliferation of neural crest cells leading to failure of the facial prominences to fuse.

ANATOMY

Normal Upper Lip Anatomy

- The foundation of the face is the facial skeleton. The upper lip is supported by the underlying maxillary and mandibular framework, with its teeth and alveolar bone. Alveolar bone develops and matures with primary and secondary tooth eruption.
- The orbicularis oris muscle consists of two well-defined and functional components: the pars superficialis and the deep pars marginalis.
- The pars superficialis is located under the skin of the lip and is related to other facial muscles of expression (levator labii superioris, alaeque nasi, and zygomaticus minor), and these retract the upper lip as a group. The pars superficialis consists of an upper and lower bundle.
 - The upper bundle represents the common insertion of the muscles of facial expression and itself inserts onto the anterior nasal spine, septopremaxillary ligament, and the nostril sill, passing deep to the alar base.
 - The lower bundle derives its fibers from the depressor anguli oris muscle on each side and decussates in the midline, inserting in the skin and forming the philtral ridges of the contralateral side.
- The deep portion of the pars marginalis muscle is responsible for sphincteric

action of the mouth and runs under the vermilion from one modiolus to the other.

- The two portions of the orbicularis oris muscle thus correspond to the double function of the upper lip. The deep pars marginalis, extending from one modiolus to the other, seals the extrinsic facial muscles to open the mouth as a retractor.
- Contraction of the deep pars marginalis, when the mouth is pursed, thickens the vermilion and lengthens the upper lip height. Simultaneous relaxation of the pars superficialis produces perioral fine wrinkles and accentuates the philtral columns while flattening the nasolabial folds.
- In contrast, when the mouth is opened, the contraction of the pars superficialis leads to flattening of the perioral wrinkles and philtral columns and accentuates the nasolabial fold. In addition, the upper lip height shortens. Simultaneous relaxation of the deep pars marginalis decreases the thickness of the vermilion.

Abnormal Cleft Lip/Nose Anatomy (FIG 1)

- Varying degrees of cleft dysmorphogenesis of the lip, alveolus, and palate result in skin, soft tissue, muscle, and skeletal deficiencies with functional and aesthetic imbalance.

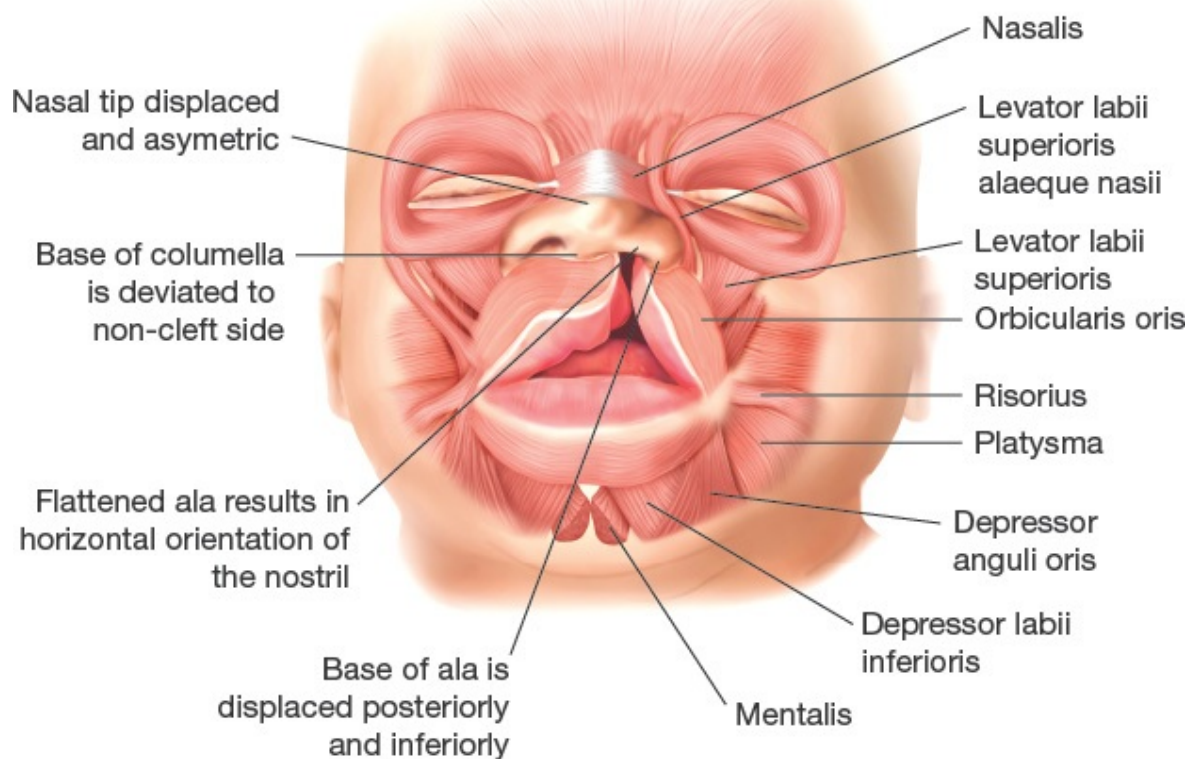


FIG 1 • Three-month-old with left unilateral complete cleft lip/nose and palate.

- This affects nasal symmetry in both complete and incomplete unilateral cleft lip/nose deformity by distorting the position of the ala base and shape of the nostril.
- With an interruption of the orbicularis oris muscle in the unilateral cleft lip/nose, the other attached facial muscles pull the ala base more laterally compared to the noncleft side. The existing muscle imbalance also changes the position of the alar cartilage, as well as the orientation of the nostril from an oblique to a horizontal orientation.
- When the muscle inserted on the base of the septum and columella is contracted on the noncleft side, the septum and columella is pulled toward that side. Thus, the severity of the cleft nasal deformity depends on the degree of separation of the orbicularis.
- Hypoplasia of the lesser segment, or base, of the cleft nose results in the displacement of the lower lateral cartilage laterally and inferiorly on the cleft side. The nasal dome is flattened and slumped in a downward position.

- The alar cartilage on the cleft side is flat, giving it the false appearance of having greater length when compared to the contralateral alar cartilage, which also is abnormally displaced to the noncleft side.
- The relationship of the lower lateral cartilage to the septum is normal; however, the septum itself is deformed, thereby tilting the base of the nose toward the noncleft side and the tip of the nose toward the cleft side.
- The following summarizes a list of characteristics typical of a unilateral cleft lip/nose deformity. The degree and severity of the deformities vary, and not all of them are present in each patient.
 - The columella is shorter on the cleft side with its footplate displaced and tethered inferiorly.
 - The base of columella is deviated to the noncleft side.
 - The medial crus of the alar cartilage is shorter on the cleft side.
 - The lateral crus of the alar cartilage on the cleft side is longer and, together with the adherent skin, is drawn to an S-shaped fold.
 - The alar cartilage on the cleft side is displaced in the backward and downward planes.
 - The nasal tip is displaced and asymmetric, with loss of the defining point on the cleft side.
 - The dome on the cleft side is obtuse.
 - The flattened ala results in horizontal orientation of the nostril on the cleft side, and it is usually larger than the opposite side.
 - The entire nostril is repositioned.
 - The base of the ala is displaced posterior and inferiorly where it is tethered to the displaced underlying bone on the cleft side.
 - The nasal floor is lower or absent on the cleft side.
 - The caudal septum and anterior nasal spine are deflected to the noncleft vestibule (**FIG 2**).
 - Septal deviation of varying degrees leads to posterior nasal obstruction on the cleft side due to the deviation of the septum and, often, the narrowing of the internal nasal valve.
 - The lower turbinate on the cleft side is hypertrophic.
 - Nasolabial fistula may be present.
 - The lesser maxillary segment is hypoplastic and displaced on the cleft side.
 - The nasal pyramid is asymmetric.

PATHOGENESIS

- Three major factors influence the nasal deformity in both complete and incomplete unilateral clefts:
 - Muscle imbalance
 - Tissue hypoplasia
 - Asymmetry of the skeletal base

NATURAL HISTORY

- Orofacial clefting is the most common craniofacial birth defect, occurring in 1:500 to 1:750 live births worldwide.
- The incidence of cleft lip in combination with cleft palate is estimated at 1:1000 with a gender ratio of 2:1 (male to female) with reverse gender ratio for cleft palate only.
- In the population of children with cleft lip and/or cleft palate (CL +/- P), approximately 50% have CLP, 30% to 35% CP, and 15% to 20% CL.
- Approximately 15% of CLP patients will have a syndrome, whereas 40% of CP patients are part of a syndrome.

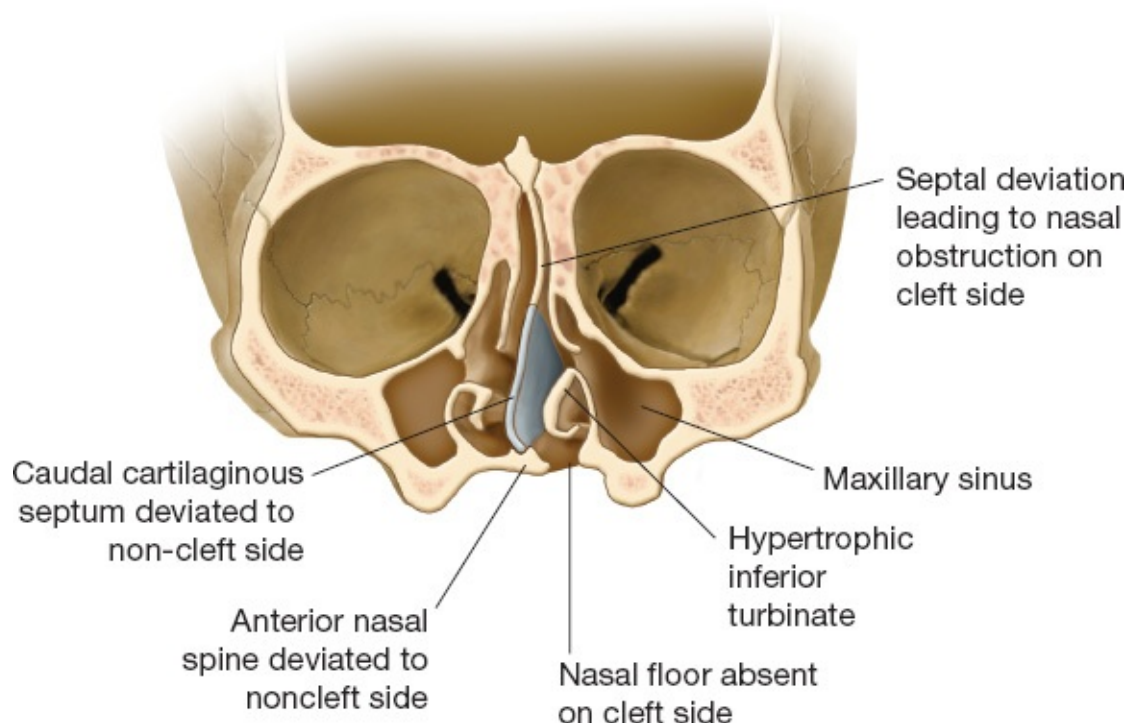


FIG 2 • Anterior nasal spine deviated to the right and noncleft side.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The diagnosis of a cleft lip and/or palate is made by prenatal ultrasonography or by physical examination at birth and in early infancy. A detailed assessment is made of the child's breathing, feeding, growth, and development.
- Airway assessment must exclude the presence of sleep apnea and micro-/retrognathia.
- Assessment of growth and weight is key to identify and monitor feeding difficulty, gastroesophageal reflux, and use of feeding aids (Haberman/Pigeon teat).
- Hearing and middle ear function must be assessed and treated early by an otolaryngologist when associated with cleft palate.
- The plastic surgeon should define in detail the cleft lip type according to the anatomic structures involved, ie, complete or incomplete, unilateral with or without a Simonart band or bilateral, and presence or absence of a cleft palate.
- The child should also be assessed for associated anomalies suggestive of a syndrome, including craniofacial dysmorphism, airway compromise, cardiac defects, ocular and auricular abnormalities, and musculoskeletal anomalies. A genetics referral is suggested if syndromic cleft palate is suspected.

IMAGING

- At 16 weeks gestational age or older, 3D, 4D, and HD in utero ultrasound provide early diagnosis readily available in the developed and, in certain places, in the developing world. Parents may seek consultation with experienced surgeons, genetics experts, and other team members for education and decision-making about treatment.

DIFFERENTIAL DIAGNOSIS

- One of the main questions to determine in the presence of a cleft lip or cleft lip and palate is, "Does the patient have an isolated, or syndromic, cleft, which plays a major role in prognosis of treatment and genetic inheritance?" Van der Woude syndrome is a prime example, diagnosed with the presence of lip pits and means 50% subsequent inheritance.
- If cleft lip and palate are present, then 15% will be syndromic.

Syndromic Cleft Lip and Palate

- Stickler syndrome
- Robin sequence

- 22q11.2 deletion syndrome
- Treacher Collins syndrome
- Nager syndrome
- Ectrodactyly-ectodermal dysplasia
- Klippel-Feil syndrome
- Others

NONOPERATIVE MANAGEMENT

- All cleft lip patients should be treated surgically unless in extreme cases where anesthetic risk for surgery is high.

SURGICAL MANAGEMENT

- Cleft lip repair is ideally performed at 3 months of age, with the infant weighing greater than 5 kg.
- Risks of the procedure are based on the risk of the anesthetic, which is minimal.
- Main objectives of the procedure:
 - Separate the oral and nasal communication
 - Completely release and restore orbicularis oris function
 - Reconstruct the lip and nose to restore normal oral and nasal function
 - Provide an aesthetic result, which is accepted by the society and the patient
- Main steps of the procedure:
 - Mark the lip.
 - Dissect, release, and mobilize all abnormally displaced structures of the lip and nose simultaneously: muscles of the lip and base of the nose with other abnormal soft tissue attachments including alar and septal cartilage of the nose.
 - A complete tension-free closure must be achieved, or further dissection is necessary.
 - Focus on creating 3D aesthetic balance and functional harmony of the lip and nose.
- Muscle repair:
 - The muscle alignment is more important than the design of skin incision in achieving an excellent result.
 - Repositioning the muscle is one of the keys to achieving a good and stable result whether sub- or suprapariosteal, as this provides the foundation and support of the repair, maintaining alar base and nasal tip projection and

symmetry.

- To achieve complete mobilization and reconstruction, the complete release of the abnormal attachments of the muscle, and proper alignment, is key. The muscle should be vigilantly aligned.
 - Any under- or over-rotation of a carefully planned repair is usually due to a malaligned muscle repair.
- Nose repair: Correction of the nasal cleft deformity is a necessary and integral part of the primary surgery.

Preoperative Planning

- Perioperative orthopedics
 - Preoperative passive appliance: Hotz of Zurich introduced the use of an appliance placed preoperatively to control the greater and lesser segments, providing guidance for positioning the segments after lip/nose closure. This is left in place to prevent arch collapse until palatoplasty is performed.
 - Definitive scientific proof that this improves the end result is lacking. Thirty years of experience in Dallas improves the dental skeletal result, maxillary deformity, septal deviation, and other related deformities.
 - Preoperative active appliance: Nasoalveolar molding (NAM) with active preoperative segmental positioning has become internationally popular and used by many centers and teams. It provides better positioning of the maxillary segments while expanding and positioning the nasal soft tissues. It makes the surgery easier, particularly for the inexperienced surgeon.
 - Latham's earlier techniques using active forces were proven to be detrimental to maxillary growth and alignment. Adverse effects on growth need further scientific investigation before the final outcome of all active techniques is known.
 - In my experience, excellent results can consistently be obtained without adding nasoalveolar molding in the unilateral cleft lip and palate patient. The technique can be labor intensive requiring family compliance and frequent visits to the orthodontist.
 - With NAM, the molding of the nose must be done carefully to prevent creating a mega nostril through the potential tissue expansion effect, rather than just the desired reshaping of the nostril.
- Skin incision.
 - After three decades of cleft surgery, we believe that the skin incision is not very important in and of itself. The final aesthetic and functional outcome is

determined by the extended dissection that allows the surgeon to free all the anatomic elements of the lip and nose that were displaced by the cleft in order to achieve complete repositioning of these elements.

- The concept of the Salyer lip/nose repair is one of totally freeing all elements of the lip and nose in a plane above the periosteum, so they are floating free above the abnormal skeletal base.¹
- The lip and nose elements are then placed in the proper position, visualizing the 3D reconstruction and attempting to make form and function as normal as possible. The aesthetic result always remains foremost.
- Repositioning the muscle is one of the keys to achieving a good and stable result, as this provides the foundation and support of the repair, maintaining alar base and nasal tip projection and symmetry. Lining up the muscle is the single most important maneuver in the repair, and it should be vigilantly aligned.
- Various techniques today put emphasis on exact preoperative markings, which commits the surgeon. The repair should be fluid, allowing for improvisation and artistry by the surgeon, especially with respect to the nose.
- For the first 20 years, I believed that an incision around the alar base was necessary to reshape the ala; however, today, this incision has been entirely eliminated, and we feel it only adds an unnecessary scar.²

Positioning

- The infant's head is stabilized on a small donut-shaped gel headrest placed at the edge of the head of the table.
- The surgeon sits at the head of the table operating upside down with the infant's head almost in the surgeon's sterile lap slightly hyperextended to provide complete visualization of the infant's face.
- The patient is orally intubated by the anesthesiologist with a prebent tube fixed in the midline providing no distortion to the face or lip with minimal protrusion so as not to interfere with the procedure but provide safe control of the airway.

Approach

- Delaire described a subperiosteal approach with a wide dissection and incisional release of the periosteum with anatomic muscle closure.
- Supraperiosteal dissection is preferred by most plastic surgeons. We believe that the dissection above the periosteum is less detrimental to growth. Whether this philosophy is totally valid needs to be established.

- Preperiosteal dissection offers the advantage of allowing the tissue to move more easily, which is especially important in wider clefts. The analogy can be drawn to a scalp flap, which mobilizes with greater freedom when raised in a preperiosteal (ie, subgaleal) plane vs a subperiosteal plane.

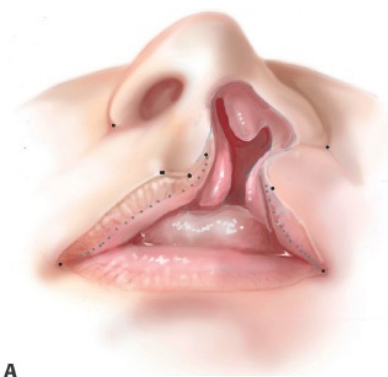
TECHNIQUES

■ Salyer Unilateral Lip/Nose Repair

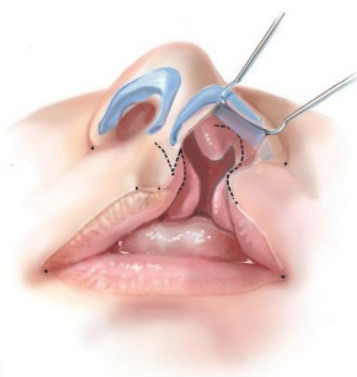
- Key identifiable points are marked on the lip and nose (**TECH FIG 1A**).
- The base of each ala is identified and marked using methylene blue or appropriate marking pen. The alar base on the cleft side is usually elongated and distorted compared to the normal side.
- The peak of the Cupid's bow is identified and marked on the normal side. The height of the lip, from the alar base to the peak of the Cupid's bow at rest and without tension on the noncleft side, is measured using a caliper or is just estimated.
- The height to be achieved on the cleft side is usually 6 to 11 mm and averages 7 mm in the 3-month-old.
- The midline nadir, or lowest point, of the Cupid's bow is identified and marked. An equal distance, from the height of Cupid's bow on the noncleft side to the midline of Cupid's bow, is used to identify the peak of the new Cupid's bow on the cleft side and is marked on the vermilion-cutaneous junction.
- The exact point may have to be altered a millimeter in order to have a lip that is long enough. The lip height needs to be equal to the normal side when completely dissected and placed on tension with a skin hook.
- The wet line is marked with dots along its course on the vermilion on both sides of the cleft. Identification of this line provides symmetry and improved color match of the vermilion.
- The peak of the Cupid's bow and height of the lip on the lateral lip segment are determined by the height of the lip on the normal side, based on the initial measurement. The distance along the vermilion and down the lateral lip segment may be altered according to the height of the lip desired.
- It may be necessary to go along the vermilion-cutaneous border, down the

lateral lip segment, a few millimeters more in order to create a lip, which is equal to the normal side. This may result in a shorter distance from the new peak of the Cupid's bow on the medial cleft side to the commissure of the lateral lip segment, as compared to the peak of the Cupid's bow to the commissure on the normal side.

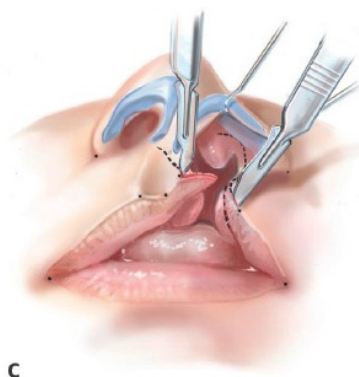
- The proposed operation is marked with methylene blue, shown in the illustration as dots forming broken lines (**TECH FIG 1B**). The incision is marked from the peak of the Cupid's bow on the cleft side on the medial lip element and extends up and below the columella, across the base of the columella, toward the opposite normal philtrum edge, but stops just short of this landmark.



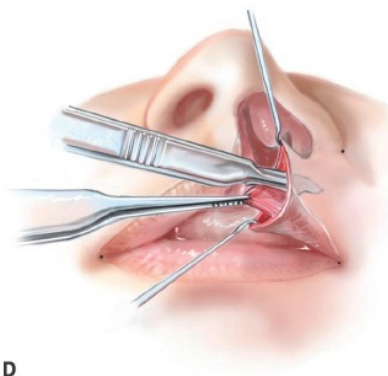
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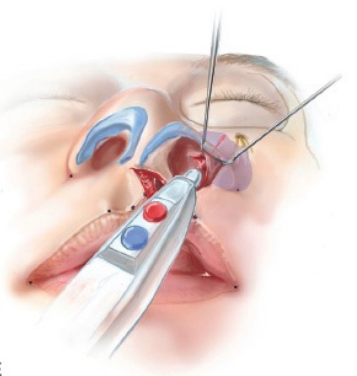
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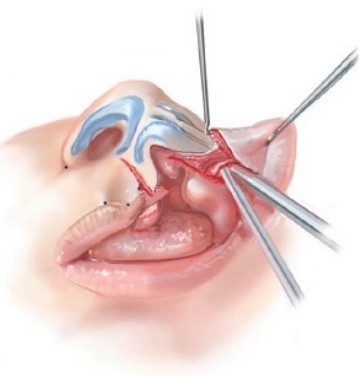
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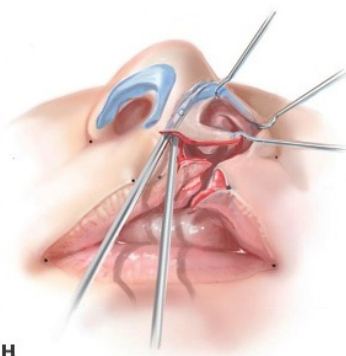
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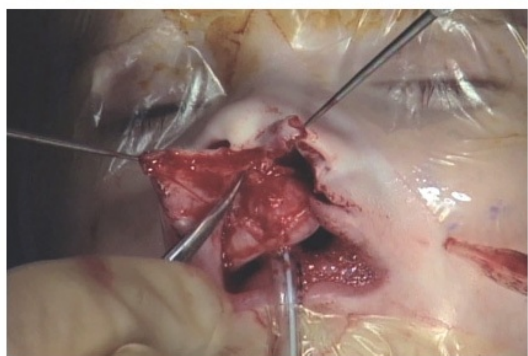
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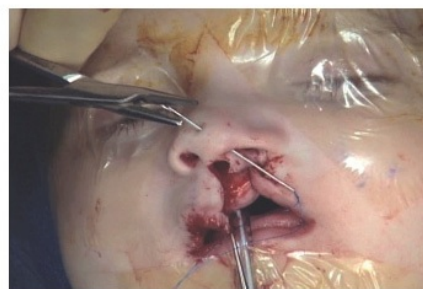
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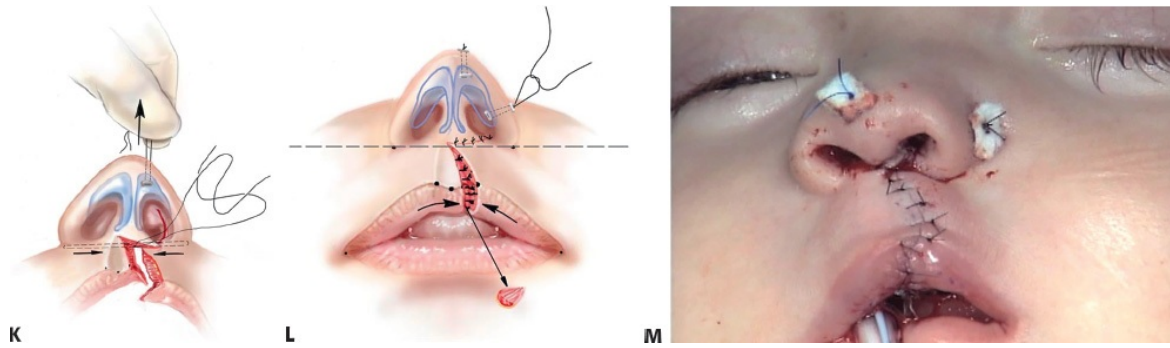
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TECH FIG 1 • A. Key landmarks identified on the unilateral cleft lip/nose. **B.** Cleft lip incisions marked with *dotted lines*. An alternative technique does not extend the incision into the nose above the inferior turbinate. **C.** Initial performance of the medial and lateral lip element incisions for Salyer lip/nose procedure. **D.** Skin of lateral lip element is undermined over the orbicularis oris muscle for a maximum of 4 to 5 mm, thereby holding and freeing the orbicularis oris muscle. **E.** Preperiosteal dissection of the lateral lip element up to the infraorbital nerve using a Colorado needle. **F.** Alar base approach for dissection and release of the lateral crus of the alar cartilage and muscles of the lip from their abnormal attachment to the alar base along with freeing the nasal skin envelope to shift the cartilage, reshaping and projecting the nasal tip. **G.** Intraoperative view showing the dissection demonstrating the technique. **H.** Medial incision approach for the subcutaneous dissection of the nasal tip skin and releasing the abnormal attachment of the medial crus of the alar cartilage so the entire alar cartilage can be shifted without exposure to create nasal tip projection. **I.** Intraoperative view demonstrating the dissection and technique of the medial approach. **J.** Intraoperative view of a Keith needle with Prolene with Dacron

pledget to shape and reposition the alar cartilage and secure it while it heals. Sutures can alternately be used. **K.** Alar base cinch and alar cartilage tip sutures. **L.** Suturing of the muscle and trimming excess vermillion. **M.** Immediate postoperative view showing use of Dacron pledges (other materials may be used) for nasal reshaping with lip sutures.

- The surgeon should pull the lip down with a single skin hook and hold the lip in its new position while marking. If the incision is carried past the philtral ridge on the normal side, there is a risk that over-rotation of the lip may occur and a long lip may be created.
- The lateral lip element is marked along the cleft margin down to the newly marked peak of the new Cupid's bow (**TECH FIG 1C**). The design of the lip repair is the Salyer modification of the rotation-advancement procedure and is noted by the dotted lines. The classic incision around the alar base is not necessary and only adds scar to the final result.
- The incision on the lateral lip element continues from the vermilion-cutaneous border, and enters the nasal cavity, onto the lateral nasal wall above the inferior turbinate at the level of the piriform aperture extending to the nasal bones as necessary.
- Through this incision, the displaced and abnormally attached soft tissues of the alar base are freed from the underlying abnormal skeletal base. The incision made on the medial lip element attempts to simulate the normal philtrum, creating a normal symmetric shield-shaped Cupid's bow. The incision can be made with a no. 15 or no. 11 standard type blade, or a no. 65 or no. 67 beaver blade, which is our preference.
- The medial incision is cut through and through, including the skin and muscle; while along the vestibule of the lip, the mucosa is released and partially separated from the muscle. The medial lip element is dissected and mobilized so that it can be gently pulled down, with a skin hook, to rest at the same height as the normal side, leveling the Cupid's bow.
- The excess vermillion, containing a small amount of muscle, is left attached to the medial lip element. The lateral lip element is likewise incised, leaving an excess vermillion-muscle flap attached to it.
- These two vermillion-muscle flaps are tailored as the lip is closed and used to

produce a full pouting vermilion of the lip. This helps eliminate vermilion notching of the lip at the suture line.

- The incision of the lateral lip element is carried along the free border of the lip.
- The muscle of the lateral lip element, overlying the lesser segment, is completely freed and released above the periosteum, so the muscle can be mobilized and sutured, creating a normal anatomic muscle with nice pout to the lip (**TECH FIG 1D**). In the incomplete cleft lip, there is usually more muscle available than in the complete cleft lip.
- The orbicularis oris muscle is pulled with pickups, and the dermis is undermined 4 to 5 mm, releasing it from the underlying muscle on the lateral lip element. The operation is estimated by an experienced surgeon.
- Laterally, the point corresponding to the new peak of the Cupid's bow is marked on the border of the vermilion-cutaneous junction, along the cleft margin, at a distance equal to the future height of the lip.
- This measurement should begin superiorly on the lip, however, not in the nose, so that the skin designated for the floor of the nose is not compromised. This is an important step in achieving an adequately reconstructed nose.
- The incision on the medial lip element begins at the newly marked peak of the Cupid's bow and continues up to, but not through, the philtral column on the noncleft side.
- If the incision is continued past the philtral column on the normal side, it has the potential to create an overly rotated philtrum and abnormally lengthen the cleft side, creating disproportion to the lip as well as an obviously abnormally placed scar that no longer mimics the philtral column.
- The vermilion and muscle on each side of the lip are cut and maintained until closure of the vermilion. Excess vermilion is tailored to create fullness of the vermilion, preventing notching.
- The incision on the medial lip element is made with a no. 15 standard blade but may be performed with a no. 67 beaver blade or a no. 11 standard blade, as shown on the lateral lip element in the image.
- This incision should be made perpendicular to the skin and include the muscle, creating the C-flap, or columellar flap. This flap is used as dictated by each case when all the elements are totally freed.
- The incision on the lateral lip segment is carried through and through along the vermilion-cutaneous border, dissecting a vermilion flap for orbicularis

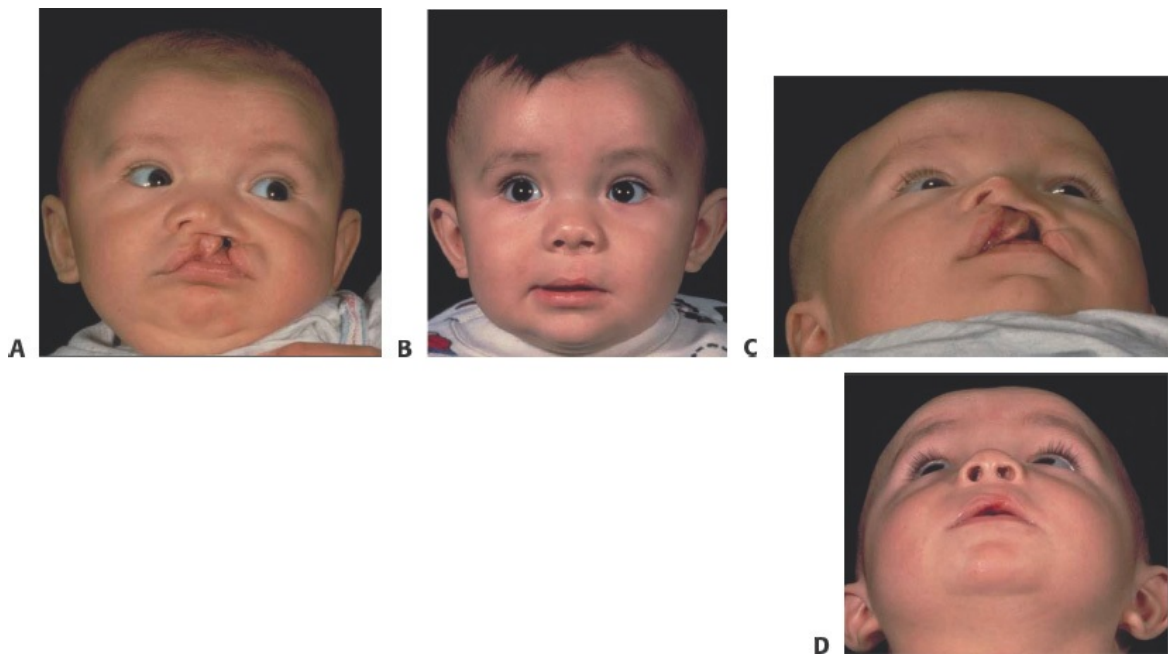
marginalis reconstruction. How the surgeon holds and cuts the lip determines the amount of muscle left in the vermillion.

- This lateral lip incision extends inferiorly, at least to where an adequate white roll begins, but may be continued down the lateral lip element as lip length is needed.
- The freshly cut orbicularis marginalis muscle is pulled with pickups, and the skin of the lateral lip segment is undermined from the underlying muscle for a distance of 4 to 5 mm from the edge of the incision.
- The medial lip segment is rotated downward and pulled with a skin hook until its height matches that of the noncleft side.
- The medial lip is freed from the underlying skeleton in a preperiosteal plane, using scissors. Additional dissection may be necessary to achieve adequate rotation of the philtrum and lengthening of the lip.
- Again, an opening incision above the white roll is used if additional rotation is required, and then a triangle is incorporated into the lateral lip markings. This is why the medial skin incision is always cut first.
- A Colorado needle (Stryker-Leibinger) is used to create the incision through the nasal lining just above the inferior turbinate (**TECH FIG 1E**). This provides a bloodless field for the dissection.
- Through this intranasal incision, as well as a vestibular buccal sulcus incision beneath the lateral lip element, the Colorado needle is used to dissect above the periosteum to the level of the infraorbital nerve.
- This maneuver provides for a bloodless dissection and the appropriate release of the abnormally displaced orbicularis oris muscle to provide symmetric closure. Complete preperiosteal release of the muscles facilitates complete reconstruction of the muscle of the lip.
- The beginning surgeon should be aware that the vertical height of an infant maxilla is short, and a guiding finger at skin level will ensure that inadvertent entry into the orbit is avoided as well as transection of the infraorbital nerve.
- Small curved tenotomy scissors with a round tip are inserted through the incision of the cleft-side alar base to dissect the skin from the lateral crus of the lower lateral cartilage (**TECH FIG 1F**).
- The nasal lining, if distorted, is dissected as well from the lower lateral cartilage as necessary. The nasal lining is left attached and never dissected at the region of the genu.
- The scissors are carried over the alar dome and into the subcutaneous pocket

to be created from the medial nasal approach over the tip of the nose (**TECH FIG 1G**). The intraoperative view shows the placement of the surgeon's finger as the tenotomy scissors dissect above the alar cartilage freeing the entire skin of the nasal tip on the cleft side.

- Attention is now turned to the nasal tip from the medial approach. Tenotomy scissors are placed through the medial lip incision and used to subcutaneously dissect the nasal dome (**TECH FIG 1H**).
- The scissors are inserted subcutaneously and between the medial crura, separating the skin of the nasal tip from the alar cartilage, and carried over to the nasal dome.
- The skin over the noncleft side alar cartilage is likewise freed in order to shift the nose and gain equal projection of the ala cartilages at the tip (**TECH FIG 1I**). The intraoperative photographic view shows this maneuver.
- Once all the elements of the lip and nose are totally freed, a Keith needle with Prolene suture and a Dacron pledget is used to shift the alar cartilage within the skin envelope without exposure of the cartilage to project and create a new symmetric nasal tip (**TECH FIG 1J**).
- The alar cartilage is shifted into its new position held by a surgical assistant as the surgeon places a key suture shifting the lateral orbicularis muscle.
- This may have to be repeated until the desired symmetry is achieved. It is a very important step.
- Simultaneously, a 4-0 Monocryl suture (Ethicon Inc., Somerville, NJ) is placed from below into each alar base to achieve symmetry shown by the dotted line (**TECH FIG 1K**).
- At the completion of the muscle repair with 3-0 and 4-0 chromic sutures, the orbicularis oris and pars marginalis have been positioned to provide symmetry of the lip as well as maintain projection of the nasal tip (**TECH FIG 1L**).
- The vermillion excess is trimmed until the proper volume to obtain a full lip remains, preventing notching of the free margin of the lip.
- An additional suture of nylon over Dacron pledgets is placed through the lateral ala, correcting intranasal webbing and providing additional contouring and projection of the nasal tip. Initiation of skin closure is begun with the nasal sill.
- The subdermis is closed with interrupted 6-0 PDS (Ethicon, Inc., Somerville, New Jersey).

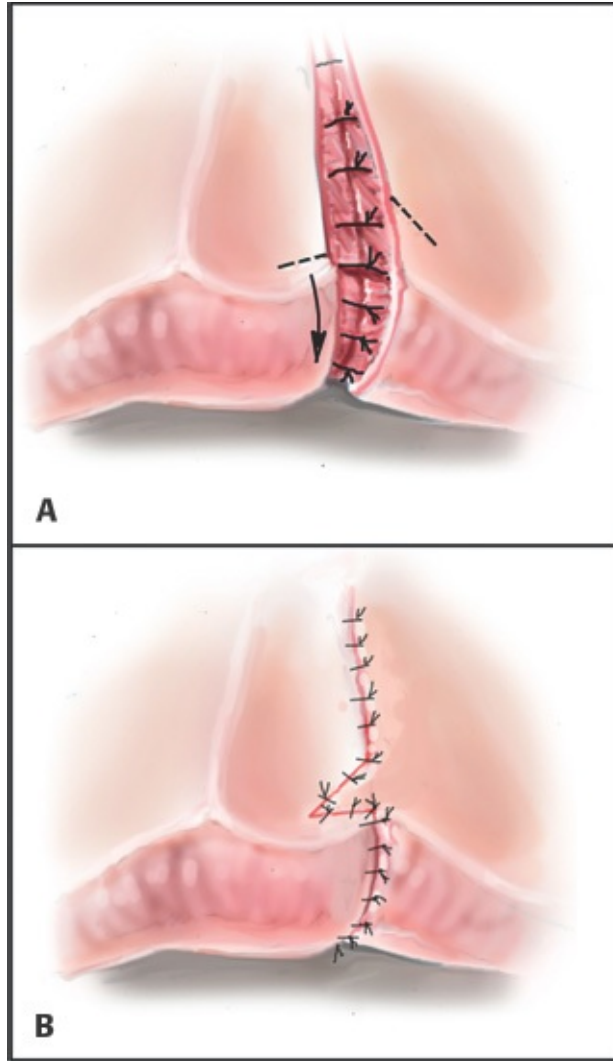
- Mucosal closure is performed with a 4-0 chromic suture, and 6-0 nylon is used for the skin closure. Intraoperative view at completion of the Salyer lip/nose repair (**TECH FIG 1M**).
- To diminish scarring, we utilize lip taping over the scar for 3 months postoperatively, and we educate parents on how to massage the upper lip in hopes of preventing hypertrophic scarring and diminishing postoperative redness.
- Preoperative frontal view of a left unilateral complete cleft lip/nose and palate patient (**TECH FIG 2A**). Postoperative frontal view 1 year postoperative following Salyer lip/nose repair (**TECH FIG 2B**).
- Preoperative submental vertex view of the same patient (**TECH FIG 2C**). Postoperative submental vertex view 1 year postoperative of the patient (**TECH FIG 2D**).



TECH FIG 2 • **A.** Preoperative frontal view of a 3-month-old patient. **B.** Postoperative view of the same patient 1 year following Salyer lip/nose repair. **C.** Preoperative submental vertex view. **D.** Postoperative 1-year submental vertex view.

■ Triangular Skin Flap for Lengthening the Lip

- At the time of closure, when the peak of Cupid's bow on the cleft side is too high (or short), an additional technique that provides lengthening of the lip can be performed.
- This can be executed at the time of lip closure when the peak of the Cupid's bow on the cleft side is not balanced and is short by 1 or 2 mm. The dotted lines demonstrate the design of the incisions (**TECH FIG 3A**). By placing an incision 2 to 3 mm in length in the lateral lip element at a 45-degree angle 3 to 4 mm above the vermillion, a flap is created that can be advanced into an incision in the medial lip. This opens to receive the flap, which becomes triangular in shape when sutured in place. This provides 1 to 2 mm lowering of the peak of the Cupid's bow on the cleft side. This is only needed in about 30% of the time in my experience. Fisher's repair designs a triangular flap as part of the lip repair.
- The medial lip incision opens to receive the insertion of the lateral lip triangular flap, and this lengthens the lip on the cleft side (**TECH FIG 3B**). The triangular flap should be designed 3 to 4 mm above the white roll, and should not be confused with the white roll flap, which I have found to be inadequate compared to the technique described.



TECH FIG 3 • A. The design of the triangular flap is shown by dotted straight lines as marked when determined at the time of closure that the peak of the Cupid's bow on the cleft side is too high (30%). **B.** The incisions create a lateral triangular flap that is advanced into the medial lip incision lengthening the peak of the Cupid's bow on the cleft side to match the height of the normal side.

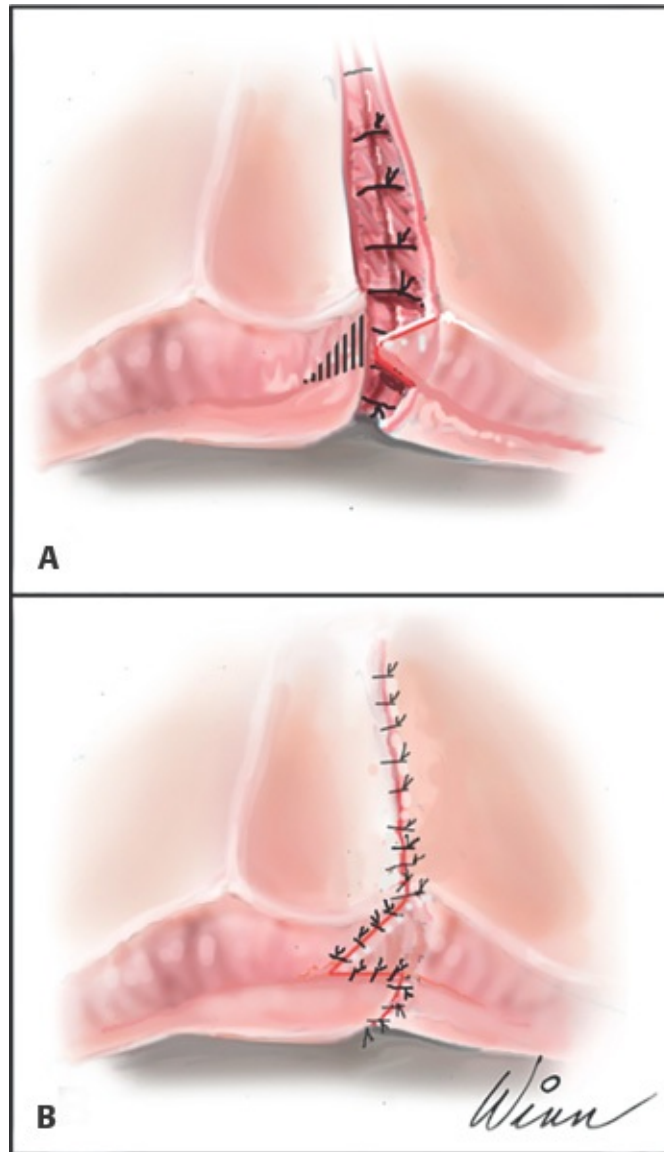
- We use this technique on innumerable occasions finding it to be quite helpful. Variations of this, first described by Bardach and now Fisher, are planned at the time of the initial marking and utilize a larger triangular flap.

This is needed in my estimation in 35% of cases and is unnecessary the rest of the time.

- The triangular flap is almost always used by Fisher and Chong and incorporated into the original planning. This provides a nicer lip with better anatomic proportions in their experience. (See Chapter 1: Anatomical Subunit Repair of Unilateral Cleft Lip.)

Noordhoff's Vermilion Flap Technique

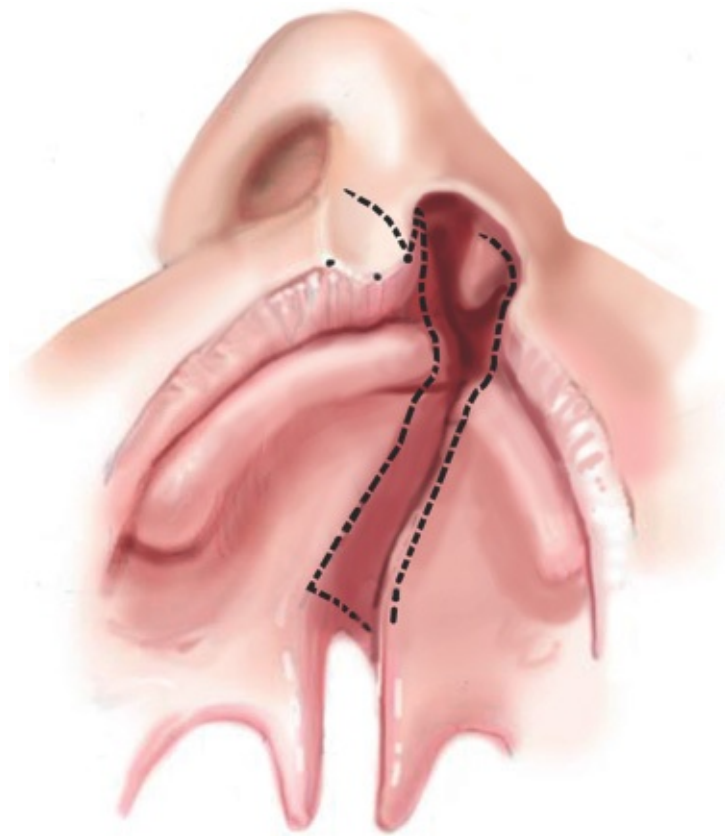
- Another useful technique for matching the wet and dry vermilion at the time of lip closure is Noordhoff's vermilion flap.³
- This is designed along the line where the color change in the vermilion occurs between the wet and dry vermilion. Frequently, the vermilion on the medial lip element cannot be adequately matched to maintain the width of both the wet and dry vermilion at the level of the peak of the Cupid's bow, because the height of the dry vermilion on the medial lip element is inadequate.
- To correct this mismatch, a triangular flap of dry vermilion is designed from the lateral lip element and sutured into an opening created in the medial vermilion along the wet line (**TECH FIG 4A**, upper).
- This eliminates the vermilion color mismatch that occurs in the vermilion border that acts as an obvious visual indicator of an abnormal lip (**TECH FIG 4B**, lower).



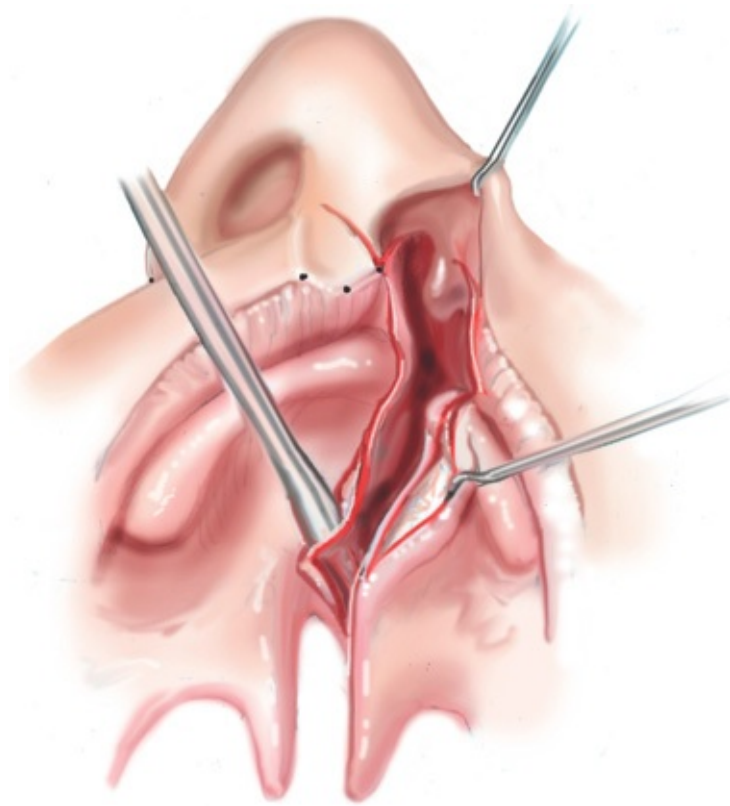
TECH FIG 4 • A. An incision along the *red line* in the medial lip vermillion receives a triangular flap created from the lateral lip wet vermillion when the excess vermillion is trimmed. This provides a uniform *red line* and vermillion. **B.** Suture closure of the lip using vermilion flap of Noordhoff to increase the height of the vermillion matching the red line.

■ **Abyholm Closure of the Anterior Palate**

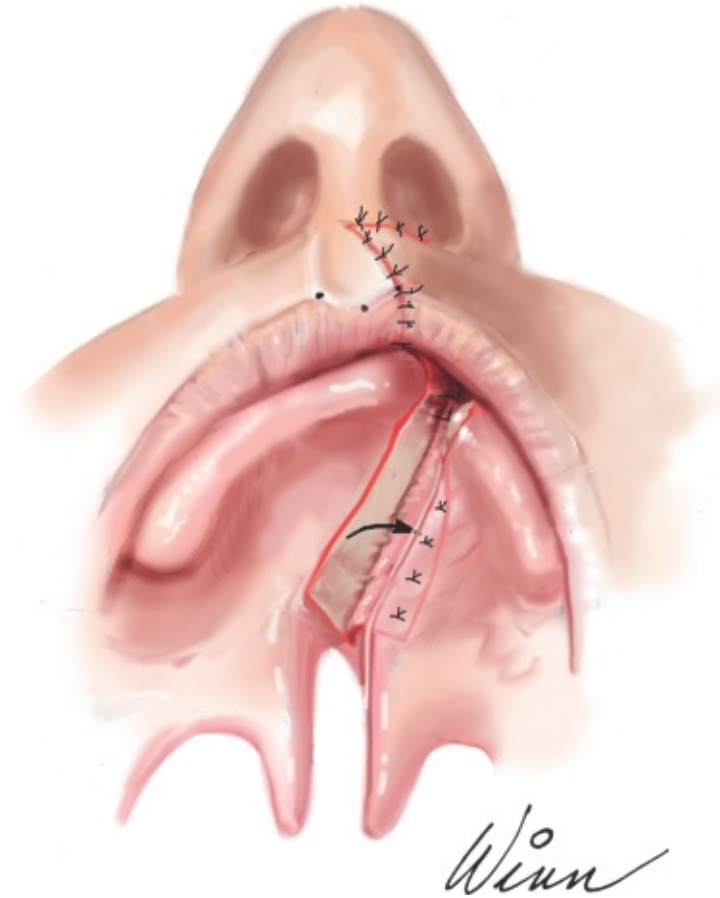
- Abyholm in Oslo used an anterior vomer flap closure at the time of primary lip closure. The results regarding growth produced the best results in the Eurocleft studies conducted by Semb and Shaw.^{4,5}
- This provides a simple and much less invasive approach that I highly recommend every surgeon to consider using. I use this in mission surgery where this is a good and simple technique to add to the Salyer lip/nose or whatever your preference for the lip closure.
- The technique is shown in combination with the lip closure in **TECH FIGS 5 TO 7**.



TECH FIG 5 • *Dotted line* shows lip closure with anterior vomer flap in combination with closure of floor of nose, alveolus, and anterior palate. Performing this while the lip is open facilitates closure of the anterior palate in one simple procedure, which is minimally detrimental to growth.



TECH FIG 6 • Incisions are made in the lip showing elevation of the vomer flap in the subperiosteal plane and opening of the palatal subperiosteal mucosa flap to receive it.



TECH FIG 7 • The lip is closed with sutures and the palate closed showing single layer closure of the anterior palate by fixing the mucosal or raw surface of the vomer flap below the elevated oral mucoperiosteal edge of the lesser segment creating a pocket to insert the vomer flap.

PEARLS AND PITFALLS

Age at operation

- Development of structures occurs by 3 mo or older, which is the best time to perform the operation.

Overview

- Surgeon must view the deformity as a lip/nose complex and repair both at the time of the primary repair. Technical skill and 3D

	visualization are important.
Dissection	■ All displaced and abnormally tethered structures must be completely released including the skin, cartilage, muscle, and mucosa.
3D puzzle	■ Float all structures freely in space 3D so they can be reconstructed. The biggest mistake seen repeatedly is inadequate release of the abnormal attachments of the alar base and alar cartilage medially and laterally resulting in relapse, which is really inadequate release of all the structures.
Nasal lining	■ Inadequate closure of the floor of the nose. Develop septal mucosa flap and lateral mucosa closing floor of nose as far back as possible.
Cleft nose	■ If technically capable, perform submucosal dissection of the septal cartilage, to straighten the caudal septum. ■ Create adequate skin pocket and totally free the alar cartilage so it can be translocated, shaped, and fixed.
Closure	■ Completely tension-free. The muscle is the key to the lip and nose and must be dissected, mobilized, and sutured into position setting up the lip and nose three-dimensionally.
Muscle alignment	■ Any under- or over-rotation of a carefully planned repair is usually due to a misaligned muscle repair.

POSTOPERATIVE CARE

- Routine suture line care is important. Keep the suture line clean from blood and other fluids.
- A liquid diet is recommended without the use of a nipple. Keep patient's hands and all objects away from the repair.

OUTCOMES

- Unless a simple lip repair, all cases require multiple procedures to achieve excellence, as illustrated by the patient in **FIGS 3 to 10**.⁶
- The patient underwent left unilateral cleft lip repair and primary cleft nasal repair at age 3 months, followed by palatoplasty at age 9 months. Very minor secondary lip/nose revision was required before 5 years of age. Orthodontic treatment with palate expansion was performed following eruption of the permanent first molars. This was followed by alveolar bone graft with cancellous bone at the time of eruption of the lateral canine tooth into the cleft.

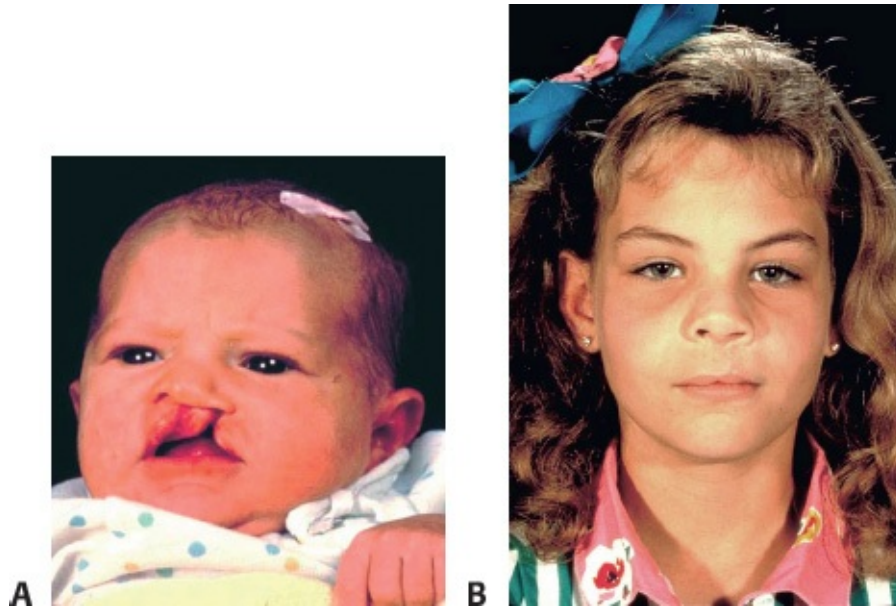


FIG 3 • A. Preoperative frontal view of a 3-month-old girl with a left unilateral complete cleft lip and palate. **B.** Postoperative view after primary stage 1 Salyer lip/nose repair demonstrates a slightly larger nostril on the cleft side performed so as not to constrict the nostril, anticipating a minor secondary procedure when the patient is older. The primary lip/nose repair at age 3 months corrected the major deformity at the time of the primary operation.

- In addition to good surgical technique, a coordinated team approach is critical to achieving excellence.⁷

COMPLICATIONS

- There should be no dehiscence of any closure. Tension-free closure is important.

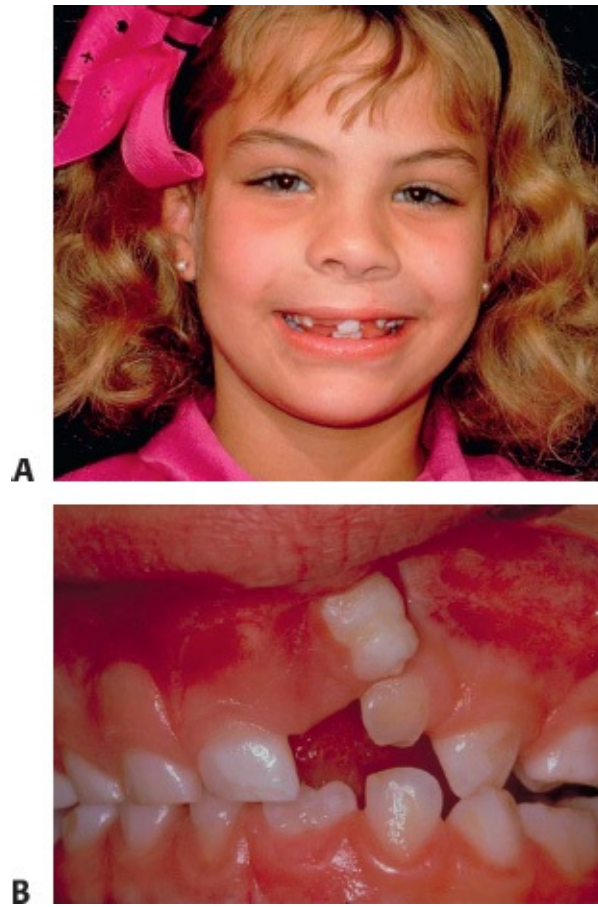


FIG 4 • A. Orthodontic treatment during mixed dentation stage. **B.** Demonstrates occlusion with mixed dentation before bone grafting.



FIG 5 • **A.** Frontal view after secondary cleft lip/nose repair. Stage 2. Cleft lip/nose. Stage 3. Palatoplasty. Stage 4. Cancellous bone graft. **B.** Smiling view after completion of treatment.



FIG 6 • **A.** Right lateral view. **B.** Left lateral view.



FIG 7 • Popular photographic view (nonclinical).

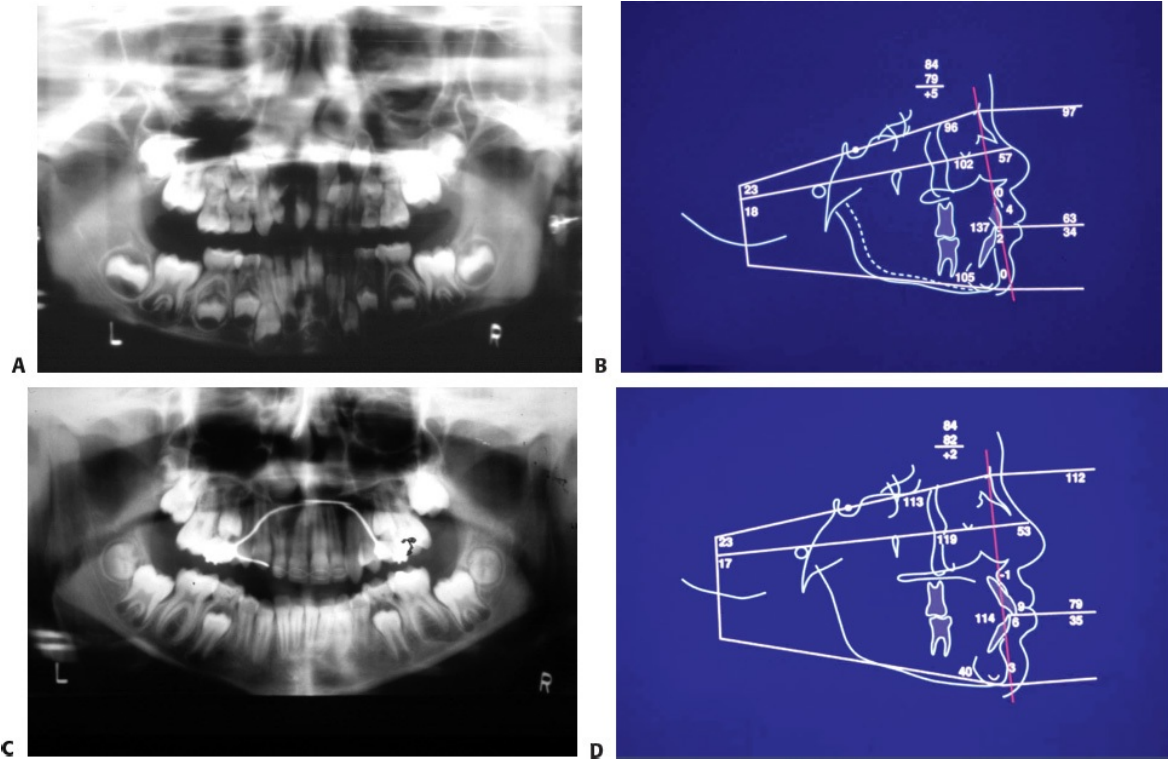


FIG 8 • **A.** Panoview before bone graph mixed dentition. **B.** Cephalometric view, age 6. **C.** Panoview after bone graft and completion of treatment. **D.** Cephalometric view, age 12, after completion of treatment.

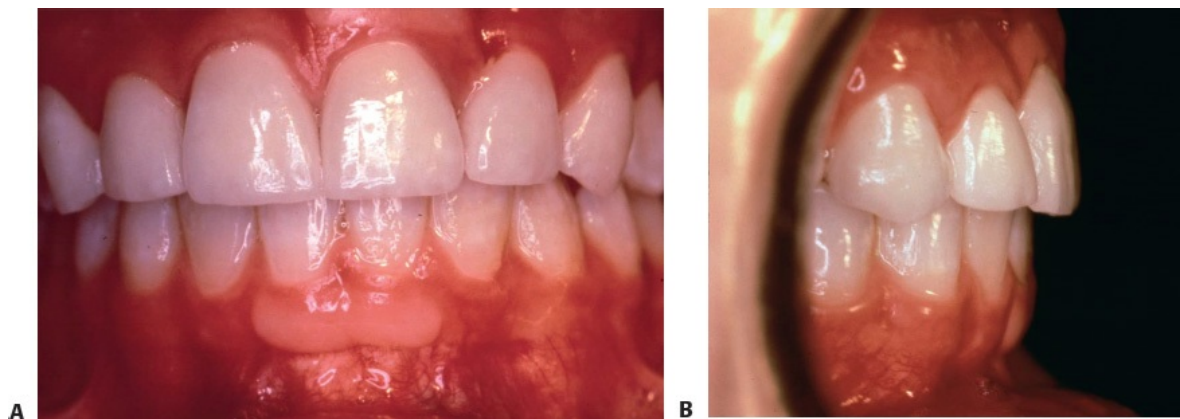


FIG 9 • Frontal view of occlusion of teeth showing also small anterior lower gingival graft below central incisors.

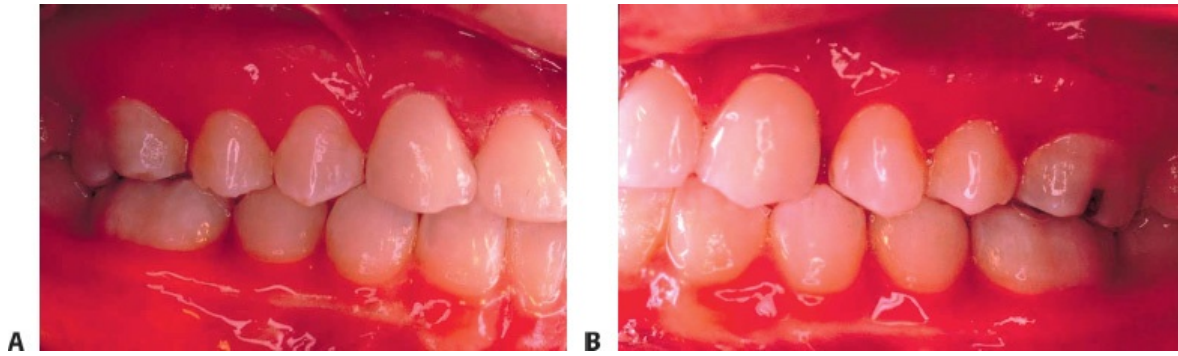


FIG 10 • A. Right lateral occlusion. **B.** Left lateral occlusion.

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Section II: Cleft Palate Repair

4

Lip Adhesion

CHAPTER

Catharine B. Garland, Jesse A. Goldstein, and Joseph E. Losee

DEFINITION

- For infants with complete unilateral or bilateral cleft lip, lip adhesion is an alternative to presurgical infant orthopedics (PSIO).
- Any child with a wide complete cleft lip may be a good candidate for some form of presurgical intervention to reduce tension and optimize symmetry prior to repair.
- Presurgical interventions include the following:
 - Lip adhesion surgery, which converts a complete cleft lip into an incomplete cleft lip
 - Presurgical orthopedics such as nasoalveolar molding (passive)¹ or use of a Latham device (active)²
- Lip adhesion decreases the tension on the final repair, improves symmetry of the nasal alar bases, and restores compressive forces on the alveolar segments to assist with alignment.³ In the wide unilateral or bilateral cleft lip, this may ultimately improve the final surgical outcome.⁴

ANATOMY

- A complete cleft lip distorts both the lip and nose anatomy.
- In the unilateral complete cleft lip (**FIG 1**):
 - The orbicularis oris muscle is not in continuity. In the lateral lip element, the orbicularis oris muscle inserts vertically into the alar base and piriform.
 - The alar base on the cleft side is typically positioned laterally, inferiorly, and

posteriorly on the collapsed minor alveolar arch.

- The caudal septum and columella are deviated to the noncleft side. The medial component of the orbicularis oris muscle inserts on these structures.



FIG 1 • Unilateral complete cleft lip and nose. Note inferior, lateral, and posterior positioning of cleft side alar base and deviation of columella. (Reprinted from Kirschner RE, Adetayo OA, Losee JE. Lip adhesion. In: *Comprehensive Cleft Care*. 2nd ed. Vol 2, Chapter 41. Boca Raton, FL: CRC Press; 2016:781-791, www.thieme.com, with permission.)

- In the bilateral complete cleft lip (**FIG 2**):
 - The premaxilla is often displaced anteriorly and may be twisted or locked out of the transversely collapsed lateral maxillary segments.
 - The lateral maxillary segments are relatively repositioned and often collapsed.
 - The orbicularis oris muscle is widely separated, inserting into the alar bases at the piriform bilaterally.
 - The alar bases are laterally displaced and often asymmetric.
 - The columella is shortened.
- Normalizing some of this anatomy prior to definitive lip repair may improve the outcomes of surgery with regards to lip and nose symmetry.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The sequence of surgical intervention for a complete cleft lip depends on

individual patient and family characteristics and the surgeon and cleft center experience. This determines whether a patient undergoes a single-stage lip repair, lip adhesion prior to formal lip repair, or PSIO prior to lip repair.

- On physical examination, the width of the cleft, the presence of nostril sill tissue (a Simonart band), the relationship of the major and minor alveolar segments in the unilateral cleft lip, or the size and position of the premaxilla in the bilateral cleft lip are all evaluated carefully.
- Patient history must include an assessment of the infant's feeding and growth and identification of any medical comorbidities that may alter treatment.
- Family characteristics that factor into decision-making include financial, geographic, or other constraints. These may influence the parents' ability to frequently travel for PSIO or to be compliant with the daily care required.



FIG 2 • Bilateral complete cleft lip and nose. Note wide alar bases, short columella, and the anterior displacement of the premaxilla relative to the lateral maxillary arches.

- Determining whether an infant is a good candidate for a lip adhesion includes weighing the advantages and disadvantages with the family:
 - Lip adhesion will convert the complete cleft lip to an incomplete cleft lip and reduce the alveolar gap as well as tension on the final repair.⁵
 - Compared with nonoperative PSIO, which requires frequent office visits, lip adhesion can reduce the burden of care on the family.⁶
 - In the bilateral complete cleft lip, labial adhesion may retract the prominent premaxilla and help to lengthen the columella.⁷

- Lip adhesion incurs the additional costs of a second operation⁶ and risks of an additional general anesthetic for the infant.

IMAGING

- None needed

NONOPERATIVE MANAGEMENT

- PSIO
 - Nasoalveolar molding (NAM)¹: NAM is a passive technique that aligns the maxillary arches, narrows the alveolar gap, and molds the nasal cartilage. It is typically initiated within the first several weeks after birth. The infant must wear the device daily, and the orthodontist adjusts it weekly.
 - Latham device^{2,5}: For the protruding premaxilla, the Latham device employs active lateral movement of the maxillary alveolar segments and retraction of the premaxilla posteriorly to realign the arch form.⁷ This is a more rapid repositioning than nasoalveolar molding but does require a general anesthetic for placement of the Latham device.
- Single-stage cleft lip repair: Some authors argue that lip adhesion is an unnecessary procedure, despite the width of the cleft, and that equivalent results can be obtained in a single-stage repair.

SURGICAL MANAGEMENT

- Indications for lip adhesion include patients with wide complete clefts who are unable to undergo nonsurgical PSIO.
- Risks of surgery include infection, dehiscence, and scarring.
- In the bilateral cleft lip and palate patient with a protuberant premaxilla, lip adhesion may be combined with a premaxillary setback to optimize alignment of the premaxilla. This is typically reserved for older patients whose tissues (ie, premaxilla) are unlikely to mold under the compression of the lip adhesion alone.

Preoperative Planning

- All infants with a cleft must undergo full physical examination to rule out any concomitant cardiopulmonary disease or airway abnormalities. If additional medical problems are identified, genetic evaluation may be warranted.
- After birth, feeding evaluation is performed by instructing parents in the use of specialized bottles as needed. Weight gain is monitored weekly to ensure that

nutrition is adequate.

- A complete blood count can be performed before surgery to evaluate for anemia of infancy. After birth, hemoglobin typically reaches a nadir between 8 and 12 weeks of life in healthy term infants. In premature infants, the nadir is more profound and occurs earlier.

Positioning

- General anesthesia is induced, and the patient is intubated with an oral Rae tube, which is taped in the midline of the chin to prevent any distortion of the upper lip.
- The patient is positioned supine with the head on a small gel donut.
- Lubrication ointment is placed in the eyes.
- The face is prepared with Betadine, and sterile drapes are applied.

Approach

- Loupe magnification is used to optimize precision of the procedure.
- The markings for a formal cleft lip repair are performed, as they would be at the time of definitive repair. Key points are tattooed with methylene blue.
- Importantly, the alar bases and alar-facial grooves are marked, so that the adhesion will lead to both vertical and horizontal symmetry of these features.
- The markings for the lip adhesion are then made within the tissues that would be discarded at the time of the formal repair or within the “L” and “M” flaps.
- Some surgeons perform primary nasal repair at the time of lip adhesion, while others defer this until the time of the formal lip repair.

TECHNIQUES

■ Unilateral Cleft Lip Adhesion

Markings

- The unilateral cleft lip repair is marked and key points are tattooed. The alar bases and alar-facial grooves are marked (**TECH FIG 1A**).
- Incisions for the labial adhesion are marked within the area of the vermilion that is normally discarded on both the medial and lateral lip element. The incisions are around 10 to 15 mm in length and symmetric (**TECH FIG**

1B,C). The inferior half of the incision is performed on the upper lip, and, the superior half is performed on the nasal floor—truly making this a “lip-nose adhesion.” On the medial lip element, the midpoint of the incision is centered at the columellar-lip junction. On the lateral lip element, the alar base denotes the midpoint of the incision. The position of these incisions is critical for alignment of the alar base. *The alar base must be symmetric with the contralateral side in both the horizontal and vertical plane*, or an asymmetric adhesion and repair will be performed and will make the subsequent definitive cleft lip and nose repair more challenging.

- The lateral buccal sulcus incision is marked to mobilize medially of the lateral lip element and ultimately a tension-free adhesion. This incision is carried up around the piriform aperture to just above the inferior turbinate (**TECH FIG 1D**).

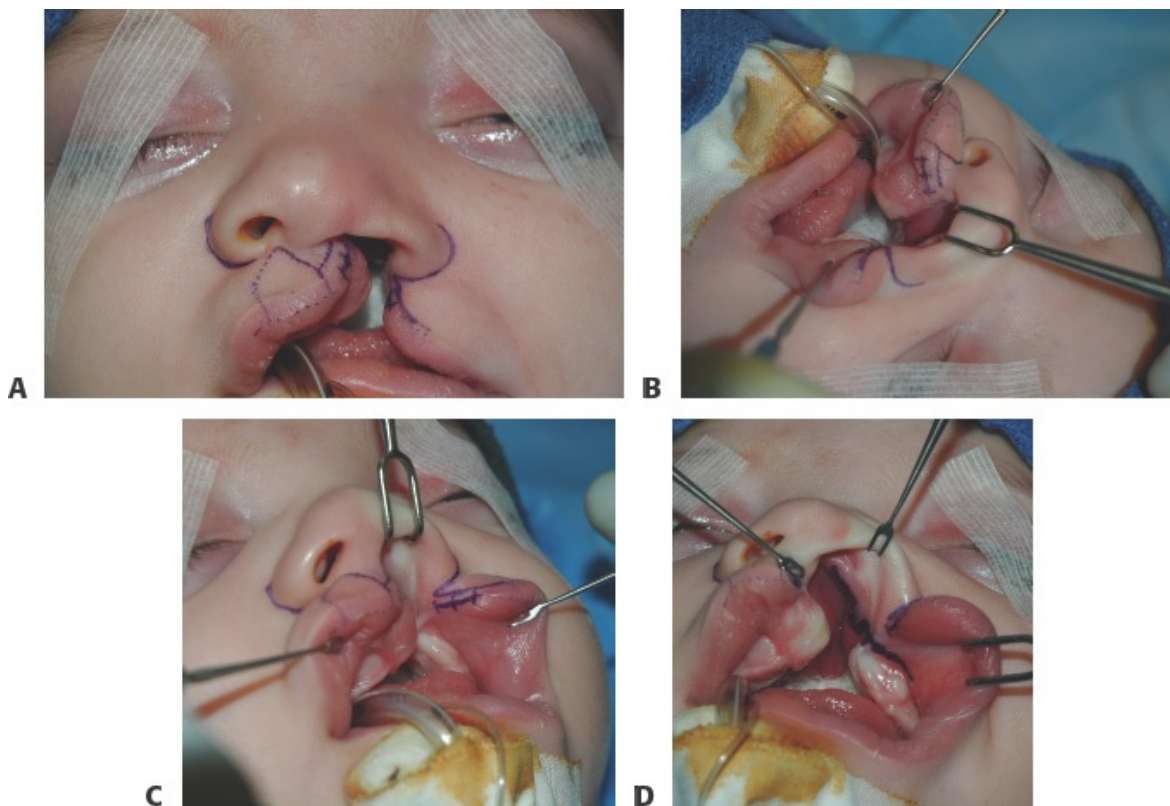
Incision and Dissection

- Epinephrine is infiltrated into the incisions.
- Incisions are made using a number 15 blade or ophthalmic knife.
- The buccal sulcus incision is dissected in a suprapariosteal plane. The alar base is released from the piriform rim and the lateral lip element is widely mobilized to reduce tension on the adhesion.
- During this mobilization, some surgeons may continue their lateral dissection up and over the lower lateral cartilage if they plan to perform primary nasal repair at the time of adhesion.
- The adhesion incisions on the medial and lateral lip elements are then made. The skin and mucosa are dissected to expose the orbicularis oris muscle.
- In the medial lip element, the dissection is carried toward the anterior nasal spine. Here the quadrangular cartilage is found displaced away from the cleft (**TECH FIG 2A**). The caudal septum may be repositioned now, rather than at the time of definitive lip repair. The quadrangular cartilage is released from the anterior vomer at the anterior nasal spine (for about 1 cm). This allows the caudal septum to be repositioned to the cleft side of the anterior nasal spine (**TECH FIG 2B**).

Suturing

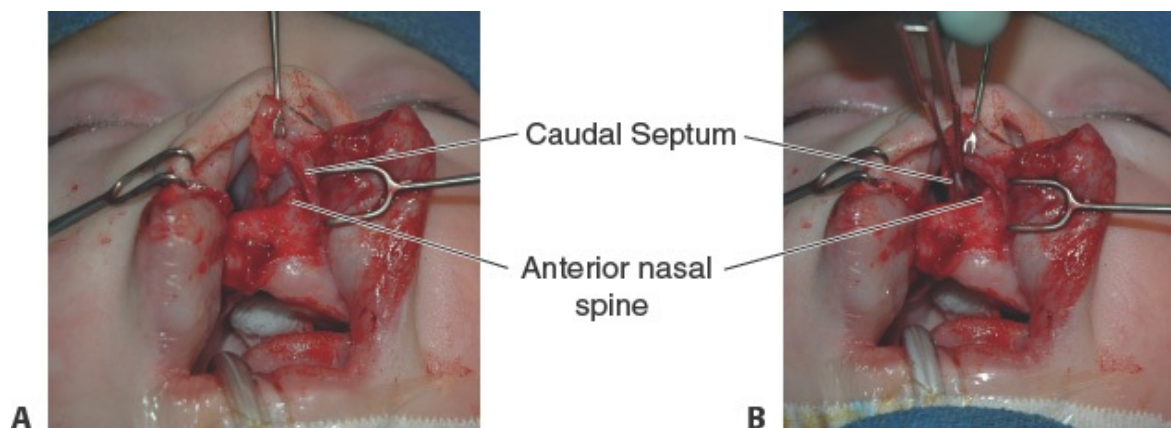
- The septum is brought back to the midline, and it is sutured into place using a 4-0 Monocryl suture.

- A 2-0 Prolene horizontal mattress retention suture (single armed on a large needle) is placed in the orbicularis oris muscle. This stitch begins at the inferior end of the lateral lip incision (**TECH FIG 3A**). It is passed in a subcutaneous plane laterally into the cheek, then deep through muscle, and exits in the buccal sulcus laterally (**TECH FIG 3B**). The Prolene suture is then passed back through the same exit site and is passed in the submucosal plane out through the superior end of the lateral lip incision (**TECH FIG 3C**). Care is taken to ensure that the skin does not dimple with this stitch. The process is repeated on the medial lip element, from superior to inferior (**TECH FIG 3D,E**). The stitches exit on the inferior aspect of the lip adhesion incisions on both sides (**TECH FIG 3F**). As much of the orbicularis oris muscle is captured in the loops of the sutures as possible (**TECH FIG 3G**). This allows the medial and lateral lip elements to be approximated through the orbicularis muscle (**TECH FIG 3H**). The ends of the suture are clamped and tied later.



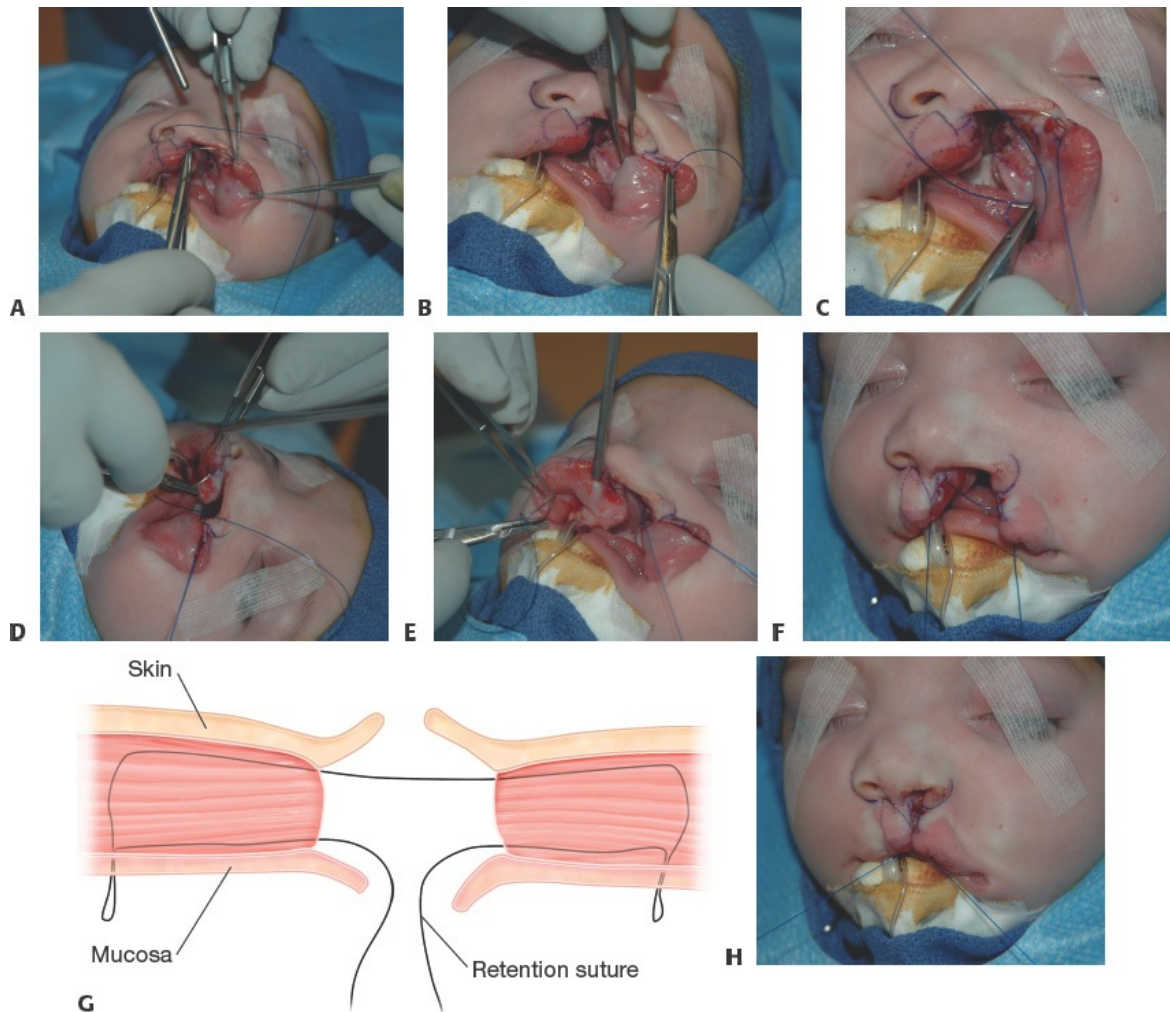
TECH FIG 1 • A. Preparation for a unilateral lip adhesion. An oral Rae endotracheal tube is positioned in the midline and taped into place. The markings for a

unilateral cleft lip and nose repair are marked and tattooed, including the alar bases. The lip adhesion incisions are made within the tissue that would normally be discarded. Design of the lip adhesion incisions on the **(B)** medial and **(C)** lateral lip elements. **D.** An upper buccal sulcus incision is carried up around the piriform aperture over the inferior turbinate. (Reprinted from Kirschner RE, Adetayo OA, Losee JE. Lip adhesion. In: *Comprehensive Cleft Care*. 2nd ed. Vol 2, Chapter 41. Boca Raton, FL: CRC Press; 2016:781-791, www.thieme.com, with permission.)



TECH FIG 2 • Repositioning the caudal septum. **A.** The anterior nasal spine and caudal septum are deviated away from the cleft in the native position. **B.** After the caudal septum is separated from the anterior nasal spine, it may be repositioned (forceps are mobilizing the septal cartilage).

- As the lateral lip element is advanced, the buccal sulcus incision back cut is closed with interrupted 4-0 chromic sutures.



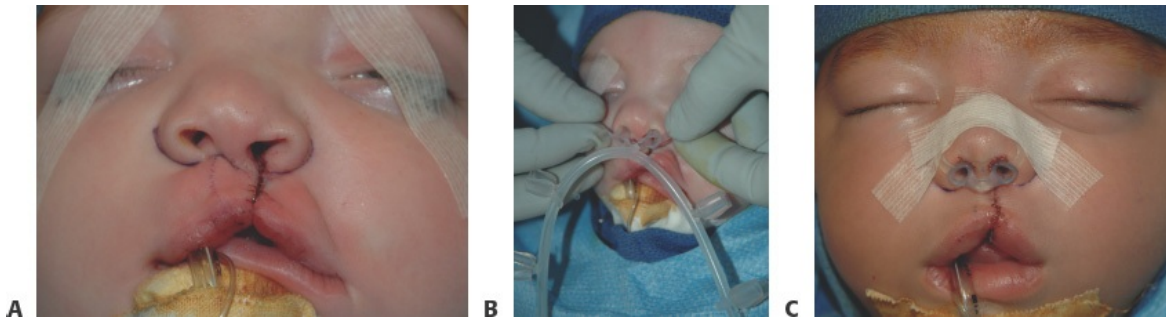
TECH FIG 3 • Placement of the internal retention suture. **A.** The suture is passed through the inferior aspect of the adhesion incision. **B.** After capturing the muscle, it exits laterally through the oral mucosa. **C.** The needle is placed back through the same exit site to exit through the superior part of the adhesion incision. **D,E.** The process is repeated on the medial lip element. **F,G.** The orbicularis oris muscle is captured in the loop of suture on both sides of the cleft. **H.** The ends of the suture are pulled together. The tension placed on a wide swath of orbicularis oris muscle reapproximates the lip and nose. (Reprinted from Kirschner RE, Adetayo OA, Losee JE. Lip

adhesion. In: *Comprehensive Cleft Care*. 2nd ed. Vol 2, Chapter 41. Boca Raton, FL: CRC Press; 2016:781-791, www.thieme.com, with permission.)

- The deep/posterior edge of the mucosal incision is then closed using interrupted 5-0 Vicryl sutures. Half of this suture line makes up the floor of the nose, and half makes up the superior lip.
- The Prolene suture is tied down, and care is taken to bury it into the muscle.
- The edges of the orbicularis oris muscle are approximated with three 4-0 Monocryl sutures.

Completion

- The anterior edge of the adhesion incision is closed last with interrupted 5-0 fast-absorbing plain gut sutures (**TECH FIG 4A**)
- If nasal repair is planned with the lip adhesion, this is performed now. The senior author, however, uses postadhesion nasal stents to mold the nose during the healing process and *defers* the rhinoplasty to the time of definitive cleft lip-nose repair. At that time, our preferred technique is open primary rhinoplasty through rim incisions to expose and reposition the lower lateral cartilage.^{8,9} A Tajima, inverted-U rim incision is utilized on the cleft side of the nose.
- Duoderm is placed on the cheeks bilaterally. While bringing the cheeks together, a Steri-Strip is placed across the lip to additionally take tension off the repair.
- Our practice is to use nasal conformers postoperatively to optimize nasal symmetry. These conformers are sized in the operating room (**TECH FIG 4B**) and subsequently taped into place (never sewn) and used daily by the parents at home in the months between lip adhesion and definitive lip repair (**TECH FIG 4C**).



TECH FIG 4 • **A.** Completion of unilateral cleft lip adhesion and **(B)** sizing of nostril conformers. **C.** The nostril conformers are taped into place and worn daily in the postoperative period after both the lip adhesion surgery and after definitive lip and nose repair, as shown here. (Reprinted from Kirschner RE, Adetayo OA, Losee JE. Lip adhesion. In: *Comprehensive Cleft Care*. 2nd ed. Vol 2, Chapter 41. Boca Raton, FL: CRC Press; 2016:781-791, www.thieme.com, with permission.)

■ Bilateral Cleft Lip Adhesion

- The bilateral cleft lip repair is marked and key points are tattooed (**TECH FIG 5A**).
- The incision for the adhesion is marked on both sides of the prolabium at the junction of the skin and mucosa, approximately 10 to 15 mm in length (**TECH FIG 5B**). The incision is centered at the junction of the columella and prolabium, such that half of the incision is on the prolabial lip element and half is intranasal.
- The lateral lip incisions are marked in the part of the vermilion that would normally be discarded or used as a “C” flap. These are also centered at the alar base, such that half of the incision is on the lip vermilion and the superior half is within the nose. The incisions are drawn so that the alar bases will be positioned symmetrically when the lip-nose adhesion is completed (**TECH FIG 5C**).
- Epinephrine is infiltrated into the incisions and these are made with a number 15 blade or ophthalmic knife. The orbicularis oris muscle is exposed

in the lateral lip element bilaterally.

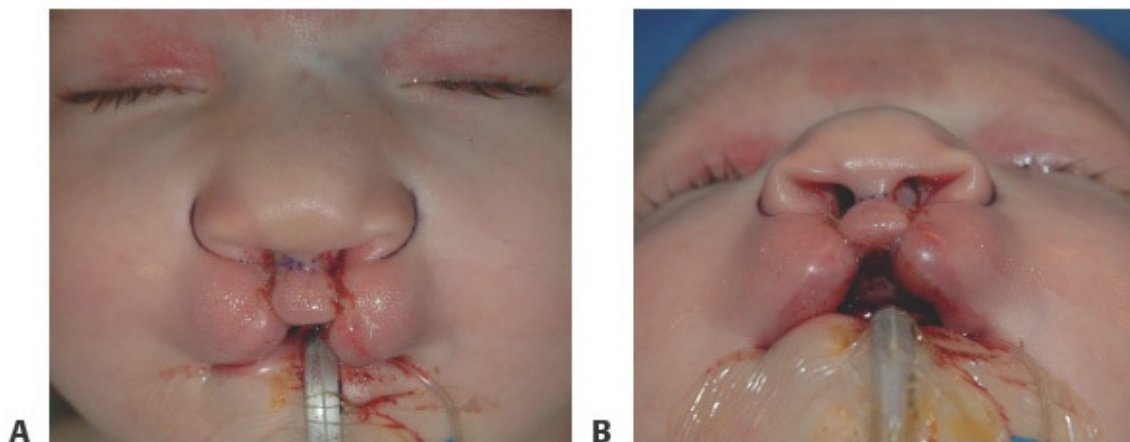
- The buccal sulcus incision on both lateral lip elements is marked and carried into the nose, around the piriform rim, and above the inferior turbinate. Supraperiosteal dissection is performed to completely release the lateral lip and alar base from the maxilla and piriform rim so that they may be advanced to reach the premaxilla.



TECH FIG 5 • A. Preparation for bilateral cleft lip adhesion begins with marking the bilateral cleft lip repair. Bilateral lip adhesion markings on the **(B)** prolabium and **(C)** lateral lip elements.

- A 2-0 Prolene retention suture is placed in the orbicularis oris muscle. This is performed similar to the unilateral case (see **TECH FIG 3**). The stitch begins at the inferior end of the lateral incision on the left side. It is passed in a subcutaneous plane laterally into the cheek then deep through muscle and exits in the buccal sulcus laterally. It is then passed back through the same exit site in the submucosal plane to exit the incision at the level of the nasal sill. Care is taken to ensure that the skin does not dimple with this stitch. After capturing the orbicularis muscle on one side, the suture is passed deep across the premaxilla in a preperiosteal plane, at the level of the nasal sill. This exits through the contralateral prolabial incision at the level of the nasal sill. The process is repeated on the right side, with the suture capturing the right orbicularis muscle, entering through the lateral incision at the level of the nasal sill, and exiting at the inferior margin. The suture is again passed deep across the prolabium through the inferior margins of the prolabial incisions. Once positioned, the ends of the suture are clamped. With tension through the orbicularis oris muscle, this suture brings the lateral lip elements to meet the prolabium.

- The posterior edge of the mucosa is closed with 5-0 Vicryl suture from the superior/nasal end of the incision down toward the inferior/labial end on both sides.
- The 2-0 Prolene suture is tied down and the knot is buried in the lateral muscle.
- Additional 4-0 Monocryl sutures are placed to secure the orbicularis oris muscle to the prolabium on each side.
- The anterior skin incisions are then closed using interrupted 5-0 fast-absorbing plain gut sutures.
- At the completion of the closure, the markings for the C flap and nasal sill on both sides should be perfectly lined up such that the alar bases are symmetric in both the vertical and horizontal planes (**TECH FIG 6**).
- Duoderm is placed on each cheek. While bringing the cheeks together, a long Steri-Strip is placed across the labial adhesion to reduce tension on the repair.

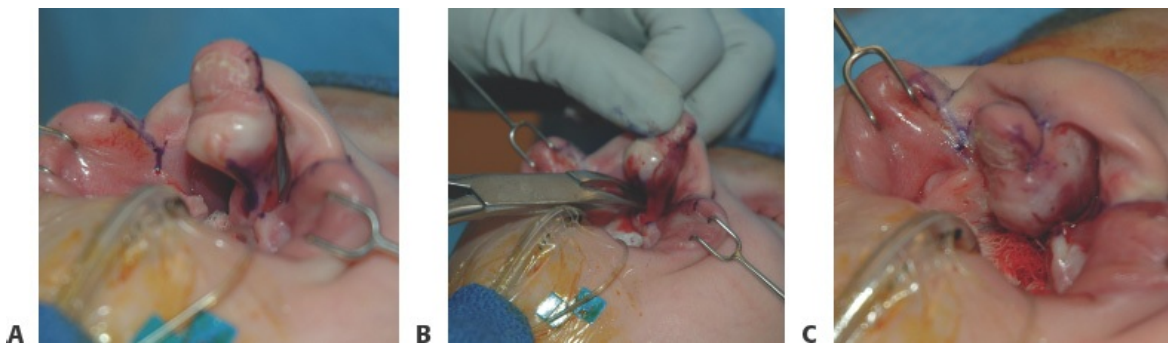


TECH FIG 6 • Bilateral complete cleft lip after premaxillary setback and lip adhesion (**A**) anteroposterior and (**B**) worm's-eye views.

■ Premaxillary Setback

- In the infant who is older than 6 months, the vomer is likely to be ossified. In these cases, a protuberant premaxilla will be unlikely to move when subjected to the forces of lip adhesion alone. In these cases, we will typically perform a premaxillary setback at the time of lip adhesion.

- A 10 mm vertical incision is marked along the anterior vomer, just posterior to the premaxillary segment (**TECH FIG 7A**).
- The periosteum is elevated off the vomer bilaterally to the level of the quadrangular cartilage.
- A closing wedge osteotomy is designed behind the premaxilla, and a small rongeur is used to remove this bone (**TECH FIG 7B**). No cartilage is removed. The closing wedge osteotomy is noted to be sufficient when the premaxilla can be repositioned posteriorly and in good alignment with the lateral alveolar segments (**TECH FIG 7C**).



TECH FIG 7 • Premaxillary setback. **A.** The incision is marked on the vomer just behind the premaxilla. **B.** After dissecting in a subperiosteal plane, rongeurs are used to create a closing wedge osteotomy. **C.** The premaxilla is repositioned in alignment with the lateral maxillary arches and affixed with 4-0 PDS sutures.

- A 4-0 PDS is sufficient to fixate the premaxilla into its new position, promoting bone-to-bone contact. This is secured from the premaxilla to the posterior vomer. Additionally, on each side, a 4-0 PDS suture can be passed directly through the mucosa of the lateral premaxillary alveolus and through the medial edge of the lateral arch alveolus (as an external stitch). When tied, this will secure the repositioned premaxilla to the lateral segments during healing.
- The vomer incision is closed using a running 5-0 Chromic gut suture.
- Combining a premaxillary setback and bilateral lip adhesion, as described herein, will not compromise the perfusion of the premaxillae. The authors do not perform a premaxillary setback and complete bilateral cleft lip and nose

repair, rather stage the late presenting patient with: stage 1: premaxillary setback and lip adhesion. Stage 2: complete cleft palate repair. Stage 3: complete cleft lip and nose repair.

PEARLS AND PITFALLS

Timing	■ Optimal timing is at 2 months of age.
Incisions	■ Incisions must be placed in tissue that will be discarded at the time of definitive lip repair. ■ Therefore, the markings for a definitive lip repair are performed first.
Permanent retention suture	■ A permanent suture is placed through the orbicularis oris muscle on both sides of the cleft. ■ It must capture a large swath of orbicularis oris muscle on both sides in order to reduce tension on the lip adhesion and decrease the risk of dehiscence.
Alar base positioning	■ Symmetrical placement of the alar bases during the lip adhesion is critical. ■ Alar bases must be symmetric in both the horizontal and vertical planes. ■ If the alar bases are asymmetric at the completion of lip adhesion, this deformity will be more difficult to correct at the time of definitive cleft lip repair.
Nasal stents and conformers	■ The use of nasal conformers after lip adhesion helps to lengthen the columella and mold the lower lateral cartilages to optimize nasal form prior to definitive lip repair.

POSTOPERATIVE CARE

- The patient is admitted postoperatively for monitoring and typically discharged home the following day if oral intake is adequate to maintain hydration.
- Patients may return to their usual bottle-feeding.
- Elbow splints are typically used to prevent inadvertent injury to the repair.
- Steri-Strips are utilized and can be replaced for 2 weeks following surgery to take tension off of the repair.

- Nasal conformers are used postoperatively. The parents are taught how to clean and replace the stents daily. If the adhesion was performed under more tension than desired, or if there is a tenuous soft tissue closure, nasal stenting can be started in 1 to 2 weeks after adequate healing has occurred.
- The nasal conformers are increased in size as the infant grows over the next 3 to 4 months.
- Definitive cleft lip and nose repair is then performed in 3 to 4 months, at approximately 6 months of age. At the time of the repair, the adhesion scar is excised and the permanent retention suture is removed.

OUTCOMES

- Labial adhesion has been shown to increase the vertical height of the medial and lateral lip elements in unilateral cleft lip¹⁰ and increase the bulk of orbicularis oris muscle tissue for closure and reconstruction of the philtral ridge.¹¹
- The adhesion of the orbicularis oris muscle molds the alveolar segments and reduces a wide alveolar gap by approximately 60% in both unilateral and bilateral cleft lips.^{3,12} If gingivoperiosteoplasty is planned, however, passive alveolar molding may still be required to align the maxillary segments.

COMPLICATIONS

- Dehiscence: Either partial or total dehiscence occurs between 4% and 17% of the time.^{6,10,12} Dehiscence is more common in the bilateral than the unilateral complete cleft lip, because the bilateral lip (without premaxillary setback) is often under more tension. Partial dehiscence may not require operative intervention if some of the alignment is maintained.
- Scarring: Scarring of the lip can occur, and some authors report that it can interfere with the final repair. When the incisions are planned carefully, however, the scarring will only occur in tissues that would normally be discarded at the time of definitive lip repair.

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CHAPTER Bilateral Cleft Lip Repair

John A. van Aalst

DEFINITION

- A cleft of the lip occurs when the maxillary prominence fails to fuse, first with the lateral nasal prominence and then the medial nasal prominence; when this failure of fusion occurs bilaterally, a bilateral cleft deformity is the result.¹
- Cleft lip occurs most commonly in patients from Southeast Asia and the southwestern United States (1/250 to 1/400 live births), is less common in Caucasians (1/1000), and is least common among African Americans (1/2000).¹

ANATOMY

- Bilateral clefts of the lip involve the tissues of the primary palate. This includes the skin, muscle, and mucosa of the lip and the alveolus, extending posteriorly to the incisive foramen.
- The premaxillary segment contains the central alveolus (maxilla) with the tooth buds of the central incisors; this bone is attached to the vomer, the bony underside of the septum.
- The premaxillary segment presents with variable anterior flaring, which may have variable presentation: it may be very anteriorly positioned or may be correctly positioned within the maxillary arch.
 - A complete bilateral cleft is likely to have significant anterior flaring, whereas the premaxillary segment of an incomplete cleft is likely to be positioned correctly between the lateral segments of the maxilla.
- Gingiva and mucosa cover the bone of the premaxillary segment and then transition to skin; this segment does not contain true lip vermilion. The skin is generally circular in shape and is without a true white roll. No muscle is

present in this region (except in incomplete clefts, where the muscle is in continuity with the lateral lip elements).

- Lateral segments of a bilateral cleft lip have all of the elements of the lip present lateral to the nasal ala (wet vermilion, dry vermilion, white roll, skin, and muscle); moving medially, the fullness of each of these components diminishes as the lip structures narrow and ascends toward the cleft of the nose.

PATHOGENESIS

- Lip fusion occurs on day 42 of gestation.
- Fusion may be interrupted secondary to genetic causes (MSX1 gene anomaly), environmental causes (including medications—steroid, anticonvulsants, retinoic acid—alcohol, tobacco use), or a combination of the two (alcohol consumption and cigarette use in the face of an MSX1 genetic anomaly).¹
- The medial migration of the maxillary prominence is arrested, leading to failure of fusion with the medial and lateral nasal prominences; failure of fusion of these latter two leads to clefting of the nostril floor.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Many children with bilateral cleft lip will be diagnosed in utero, prompting a prenatal visit with cleft team members, including the surgeon. The cleft team member describes the concept of team care to the family, the needs of the child immediately following birth, and the surgical preparation for cleft lip repair at approximately 3 months of age.
- Patient history should include the presence of family members with clefting; maternal exposure risks: cigarette and alcohol use; medications, including anticonvulsants and steroids; and folic acid supplementation during early pregnancy.¹
- Following delivery, the first visit to the surgeon is generally within the 1st week of life.
- In addition to a full physical examination, the tailored examination of the face detects whether the cleft is complete or incomplete, whether there is asymmetry between the two sides, and whether the premaxilla is proclined (**FIG 1**). In addition, the presence of clefts of the alveolus and of the palate must be documented.

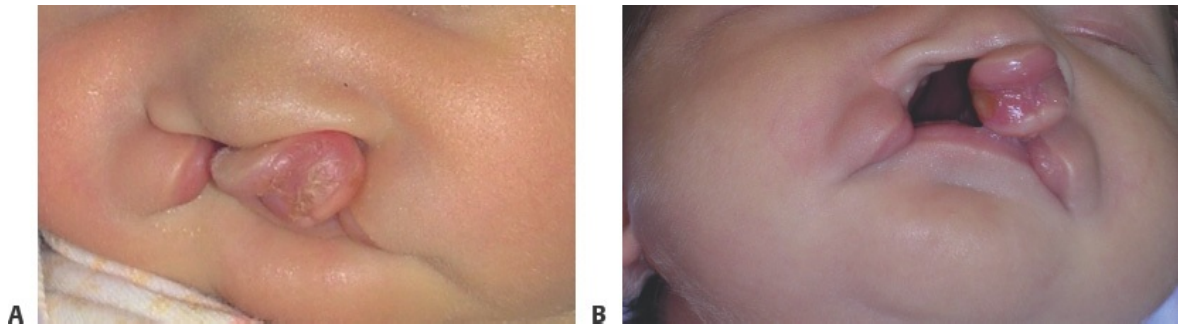


FIG 1 • Infant with bilateral cleft lip. Figure **A** demonstrates a frontal view of an infant with a bilateral complete cleft lip and palate; the premaxilla is anteriorly positioned (proclined). Figure **B** is a worm's eye view of the same infant, demonstrating the asymmetry of the cleft, with the premaxilla positioned more to the patient's left. As can be noted more clearly in this figure, the patient also has a cleft of the alveolus and palate.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- No routine imaging studies are required for children with bilateral cleft lip prior to surgical repair.
- Because these children may have other congenital anomalies, additional findings on physical examination will dictate the need for additional diagnostic studies.
- If the child has evidence of breathing difficulties, or sleep apnea, a sleep study may be warranted. If there is any evidence of feeding/swallowing difficulties with concerns about aspiration, a swallow study may be warranted; if other cranial abnormalities are present, a craniomaxillofacial computed tomography scan may be warranted.

NONOPERATIVE MANAGEMENT

- Although nonsurgical management of the bilateral cleft lip is not appropriate, presurgical management for control of the proclined maxilla is recommended.
- The proclined maxilla can be treated with a simple taping regimen (**FIG 2**), with nasoalveolar molding^{2,3} or actively with a Latham device^{4,5} to direct position of the alveolar segments prior to surgical repair.

SURGICAL MANAGEMENT

- Children are judged ready for surgery using the rule of 10s: approximately 10 lb (4.5 Kg), 10 week of age, and a hemoglobin count of 10.⁶⁻⁸
- If there are any other symptomatic comorbidities or concerns about appropriate weight gain, delay in surgery is warranted.

Positioning

- At the time of surgery, the child is positioned in the supine position and intubated with an oral Ring-Adair-Elwyn (RAE) tube (**FIG 3A**).
- A shoulder roll is placed to obtain gentle extension of the neck.
- The entire face is prepped and draped, and a throat pack is placed.
- Markings are made for lip repair with tattooing of key landmarks (**TECH FIG 1**).
- Local anesthetic with epinephrine is injected following the markings.

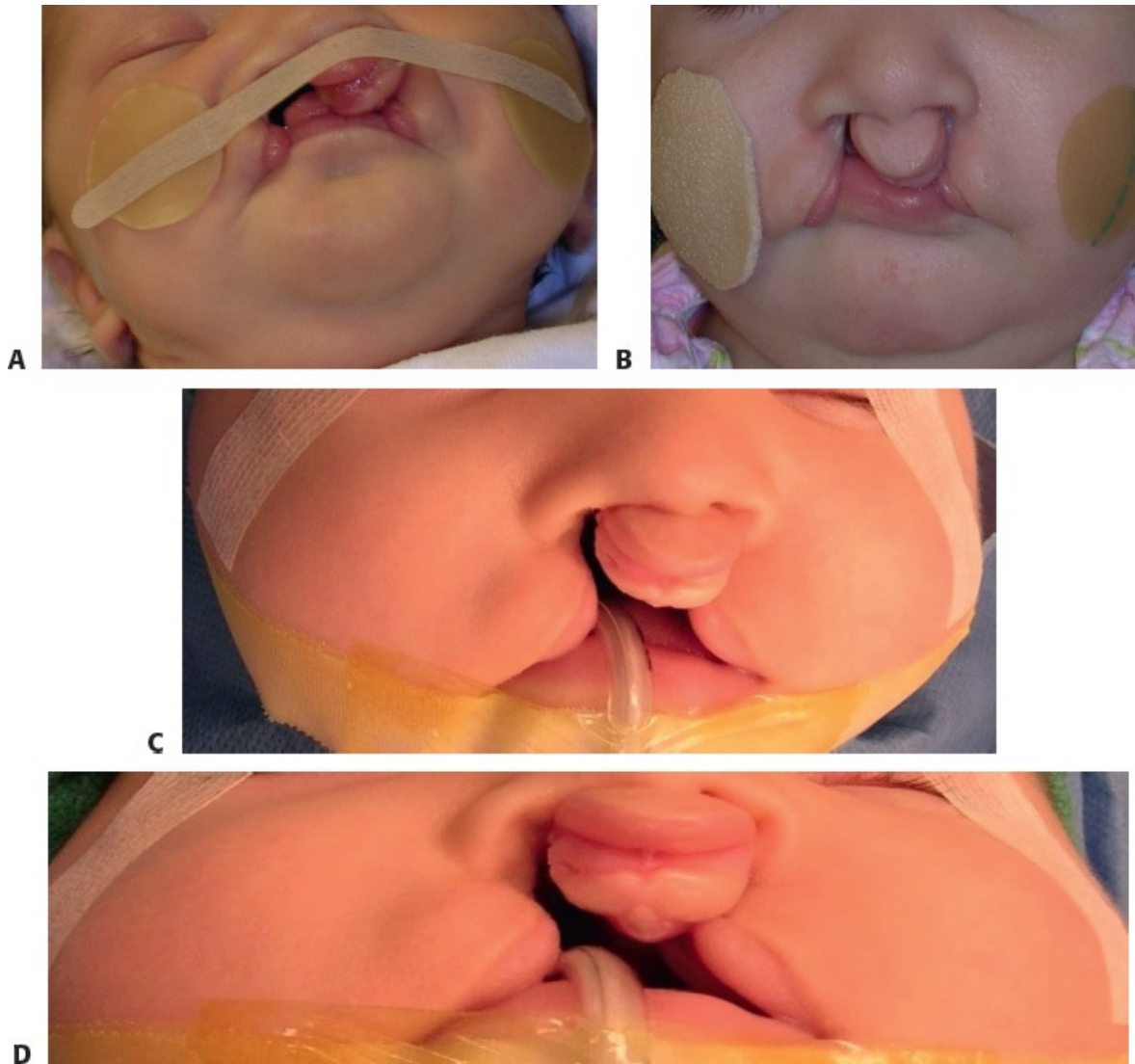


FIG 2 • Preoperative preparation of the patient in **FIG 1** with a taping regimen. This taping regimen needs to start shortly after birth to maximize the effect on premaxillary segment retroclining (an early start is also true for other forms of presurgical orthopedics, including nasoalveolar molding). **A.** During the taping regimen. **B.** At completion of the taping regimen. **C,D.** Immediate preoperative photographs demonstrate an improved position of the premaxilla in a more symmetrical position after taping regimen.

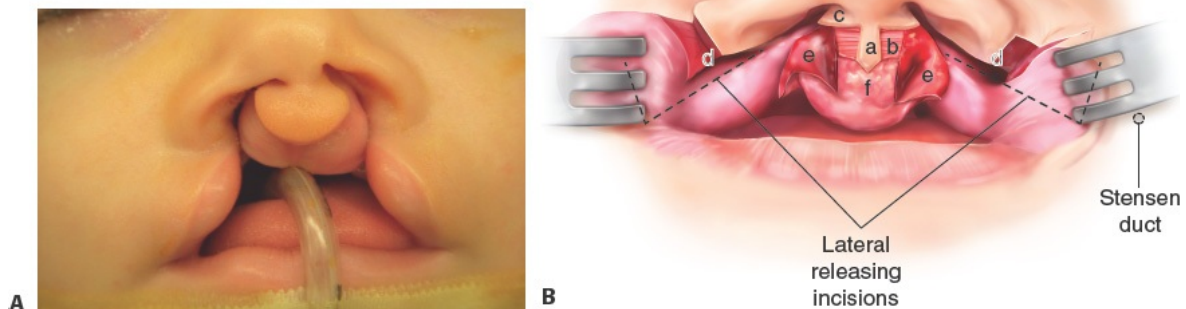


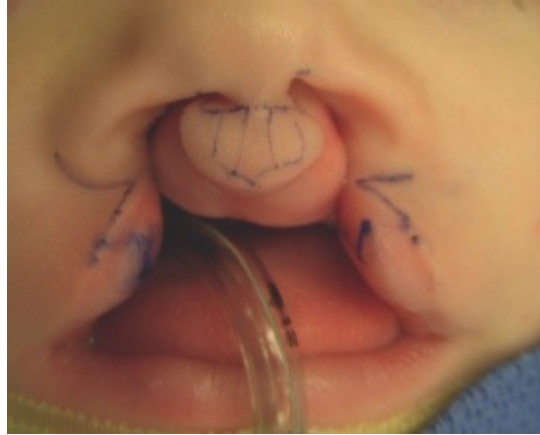
FIG 3 • A. The patient is positioned supine and intubated with an oral RAE tube, with taping on the chin so that the upper lip is not distorted. **B.** Landmarks. The central philtral column with skin (a) is 2 mm wide at the waist and 2 mm from low to high point of Cupid's bow. The lateral flanking de-epithelialized regions (b) are also 2 mm wide. The remnant skin and mucosa of the premaxillary segment have been incised into three parts. These areas are labeled (e) bilaterally and (f) centrally and inferiorly. At the superior philtral column (b-a-b) are extensions of skin (c) that will be eventually be used to close the floor of the nose. The central flap (f) is used to reconstruct the central upper buccal sulcus; the two lateral flaps (e) are turned out laterally and used to reconstruct the anterior surface of both alveolar clefts. Bilateral upper buccal sulcus incisions (d) allow medialization of cheek tissue to minimize tension at final closure. The vertical component of the incision is made medial to Stensen duct (the greater the height of this incision, the greater the capacity to medialize cheek tissue). The horizontal incision is made at the junction of the gingiva and oral mucosa to the base of the L flap (without injuring the L flap). A Freer

elevator is used to lift the periosteum from the maxillary surface, exposing the infraorbital nerve. The region of the nerve is the most significant area of tethering, which prevents medial movement of cheek tissue. The periosteum medial and lateral to the nerve is cut vertically, avoiding injury to the nerve and releasing the tethering effect of the periosteum.

TECHNIQUES

■ Markings

- The two most commonly used techniques to repair the bilateral cleft lip are the Millard technique⁶ and the Mulliken technique.⁷⁻¹⁰
- Based on modifications of the Mulliken technique, markings for the neophiltrum include the following:
 - 2 mm at the waist (at the junction of the columella with the premaxillary skin; **TECH FIG 1**)
 - 2 mm between the low and high points of Cupid bow
 - Flanking de-epithelialized regions, each 2 mm wide and the same height as the philtral column
- The three-part division of the premaxillary mucosa is marked.
- The bilateral advancement flaps are marked, with 2 mm of intact white roll retained with the vermilion component on both sides, with as much as possible skin conserved, but avoiding vermilion (see **TECH FIG 1**).
- Bilateral upper sulcus-releasing incisions are marked:
 - The vertical component is medial to Stensen duct.
 - The horizontal component is marked at the junction of the gingiva and upper buccal sulcus mucosa, extending medially to the edge of the L flap.



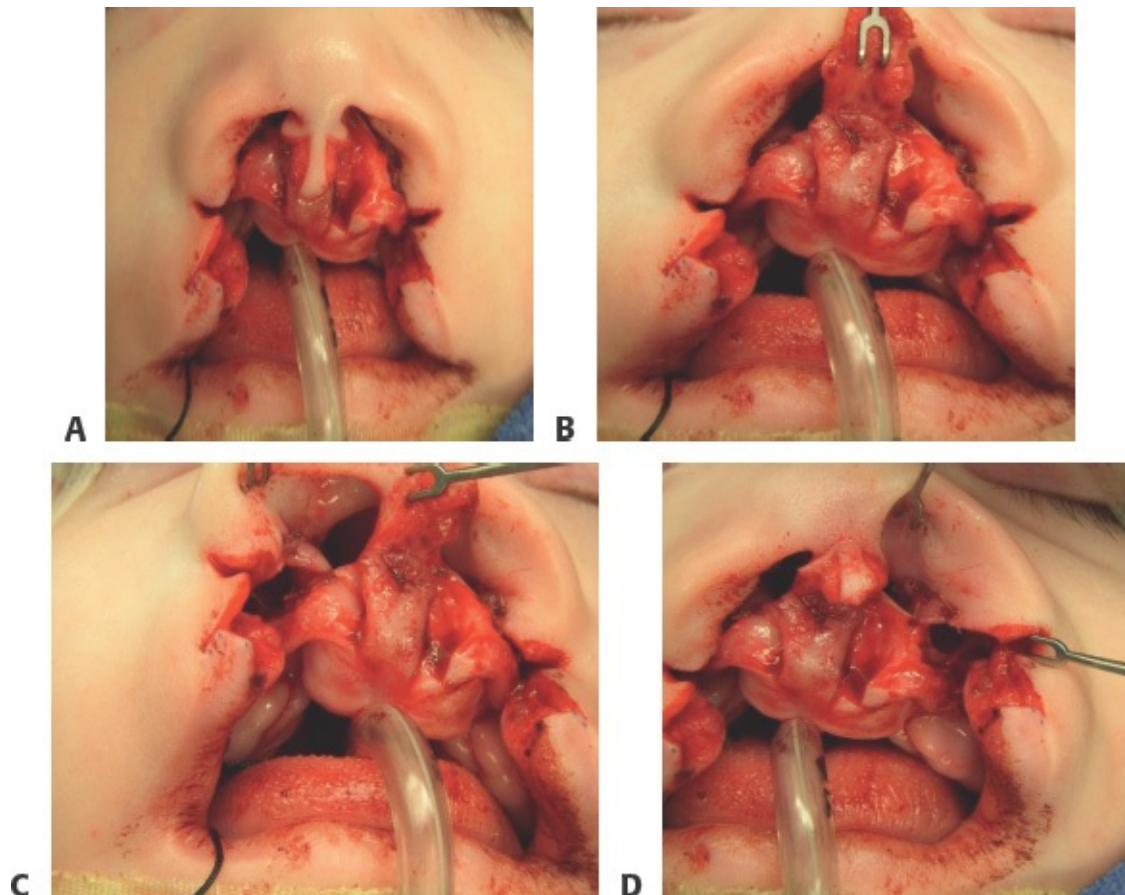
TECH FIG 1 • Attention to detail in the markings is key to an aesthetic outcome. Before making the marks, take note of the asymmetries present. Markings are made before injection of local anesthetic, and the points are tattooed into tissue with a 30-gauge insulin needle using either Bonnie blue or methylene blue. The high and low points of Cupid's bow are 2 mm wide; the waist of the philtral column is also 2 mm wide. The flanking regions that will be de-epithelialized on either side of the philtral column skin are also 2 mm in width. At the superior lateral position of the two areas marked for de-epithelialization, there should be a horizontal extension along the skin, which will be used for eventual closure of the nostril floor. The lateral lip markings begin with the medial marking for the white roll. This point should be marked at the medial-most position of full (complete) white roll (moving further medial from this position, the white roll tapers); a second point is marked 2 mm lateral to the first point. The medially curved line on the vermilion has its furthest medial extension at the junction of dry and wet vermilion; the 2 mm of white roll will remain with the vermilion and be used to reconstruct the white roll under the philtral column (also 2 mm in width). The

upper buccal sulcus—releasing incisions are also tattooed so the marks continue to be visible despite oral secretions or bleeding (shown in **FIG 3B**).

■ Incisions

- The neophiltrum is incised with de-epithelialization of the two flanking regions. These three regions are lifted as a single unit (**TECH FIG 2A**), improving blood supply to the philtral skin.
 - The three parts of the premaxillary mucosa are incised (see **TECH FIG 2A**). The central portion is used to reconstruct the upper buccal sulcus (**TECH FIG 2B**).
 - The lateral two flaps are used to provide coverage over each of the alveolar clefts (**TECH FIG 2C,D**).
- The advancement flap is incised, starting laterally, at the white roll, leaving 2 mm of intact white roll with the dry vermilion (see **TECH FIG 2B–D**), extending along the junction of skin and vermilion (carefully avoiding inclusion of vermilion with the skin flap).
 - The incision is then extended inferior to the nose, then laterally, along the crease between the nose and lip, but not extending beyond the alar margin (see **TECH FIG 2C,D**).
- The lateral vermilion flap (L flap) is incised, leaving excess dry and wet vermilion for lip reconstruction (this helps to create a pout of the central lip).
 - The inferior part of the incision is continued on the mucosal side toward the alveolus in a line parallel to the advancement flap incision.
- At the superior-medial incision of the advancement flap, the L flap incision is extended into the nose at the junction of skin and mucosa, extending toward the inferior turbinate.
- The skin margin of the advancement flap is then separated for 3 to 4 mm from the orbicularis oris muscle (during reconstruction, this separation will allow approximation of the muscle as a separate layer; see **TECH FIG 2D**).
- Next, the lateral releasing incision is made in the upper buccal sulcus: the vertical component is made 1 cm medial to the Stensen duct, extending down to the junction of the oral mucosa and gingiva; the horizontal component is then incised along the junction of the oral mucosa and gingiva, to the base of the L flap (see **FIG 3B**).

- Using the lateral releasing incision, maxillary tissue is dissected from the maxilla in a subperiosteal plane with a Freer elevator. The infraorbital nerve is identified.
- The periosteum is incised medial and lateral to the nerve, allowing medialization of cheek tissue.
- The right angle of the releasing incision can now be extended medially to decrease tissue tension during closure.



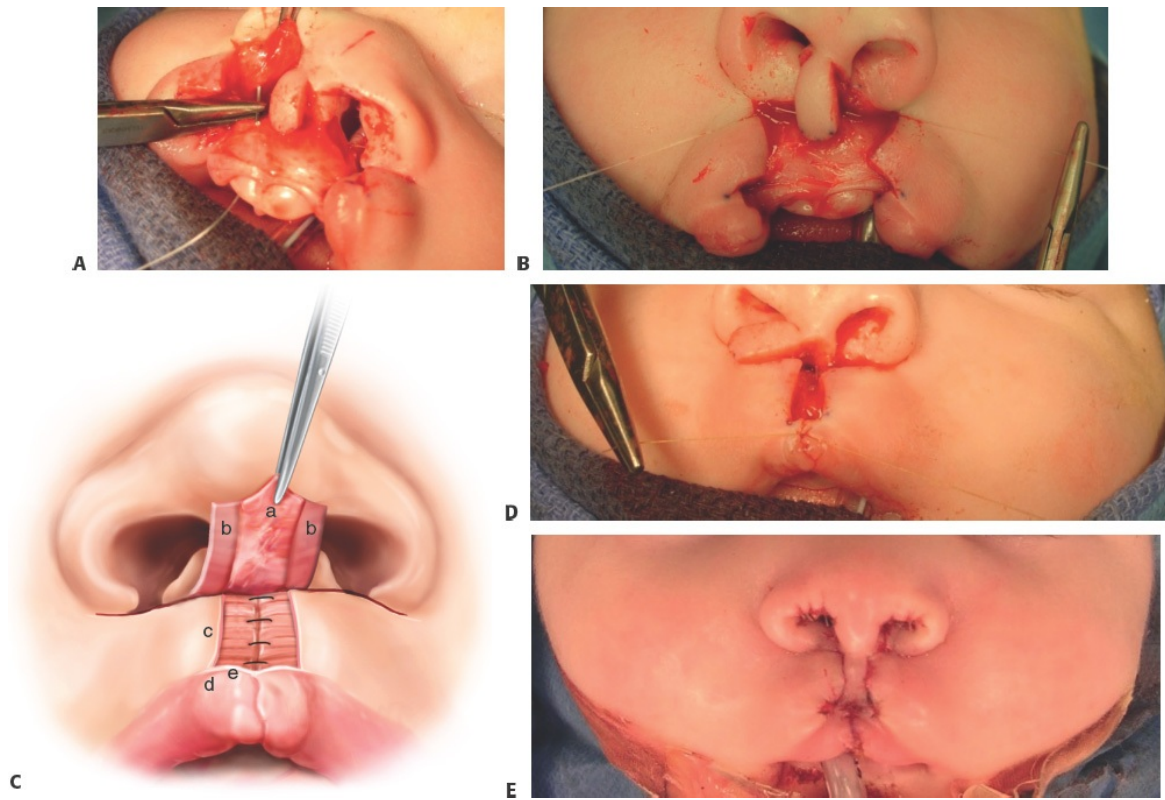
TECH FIG 2 • A. Incisions for bilateral cleft lip. A beaver blade is used to make all incisions. At the skin markings, part of the tattooed mark is maintained on the retained flap in order to clarify positioning of the flaps at final closure. **B.** Lifting of the philtral flap with flanking de-epithelialized regions. Note the inset of the central premaxillary mucosal flap to the periosteum of the premaxillary segment with a central stitch; this

reconstructs the central upper buccal sulcus. Closure of the right nostril floor with the L flap and the right turnover flap from the premaxilla. These two flaps are sutured to each other, simultaneously closing the nostril floor and the anterior surface of the alveolar cleft ((**C**) on the **left**, (**D**) on the **right**). Note that the nostril orifice is maintained despite approximation of these flaps.

■ Reconstruction

- The L flap is inset into the floor of the nose using 5-0 chromic with the intact mucosa facing down toward the oral cavity and raw surface up toward the lip (see **TECH FIG 2B–D**).
- The lateral premaxillary flaps are turned over (intact surface down) and sutured with 5-0 chromic to the periosteum of the maxilla at the lateral base of the L flap.
 - The two flaps are then sutured to each other, to close the floor of the nose.
- A 4-0 PDS is used as an alar cinch suture (**TECH FIG 3A**), setting the alar margins at the medial canthi bilaterally (**TECH FIG 3B**).
- Oral mucosa is reapproximated at the medial-most extension of the releasing incision (medializing tissue that was at a right angle into a straight line) using 4-0 and 5-0 chromic interrupted sutures.
- Muscle is approximated using 4-0 PDS interrupted sutures with buried knots (**TECH FIG 3C**).
- The dry vermillion and white roll are approximated with 5-0 plain interrupted sutures (**TECH FIG 3D**).
- The neophiltrum is inset with 6-0 Monocryl deep dermal suture at the lateral margins of the flap, which correspond to the high points of Cupid's bow, followed by 6-0 plain suture at the skin.
- 6-0 plain sutures are placed from philtrum to vermillion between the high and low points of Cupid's bow. 6-0 Monocryl is used for deep dermal closure along the philtral column.
- 7-0 PDS subcuticular stitch is used to close the skin. The nostril floor is closed using 5-0 chromic suture (**TECH FIG 3E**).

- Dermabond or Steri-Strips are applied to the lip incisions.

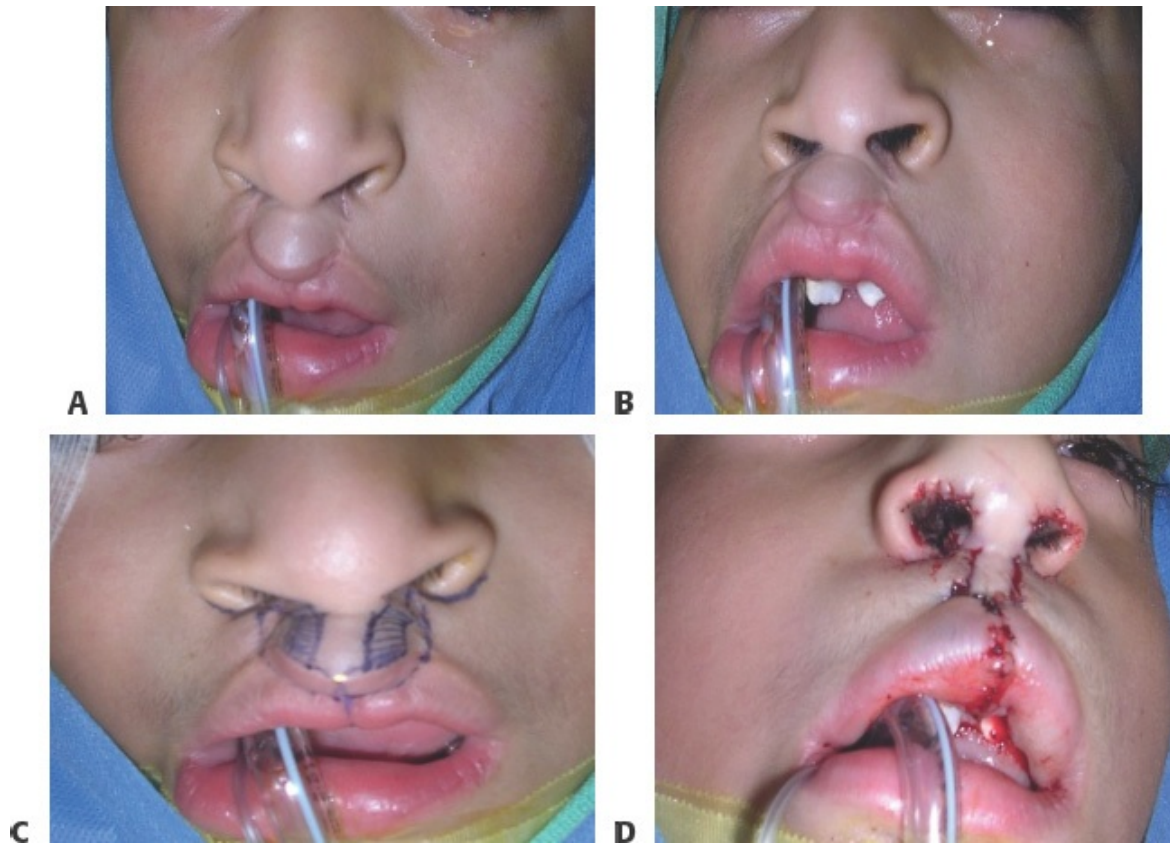


TECH FIG 3 • The alar cinch suture (which sets the lateral ala at the medial canthus bilaterally) is placed on the underside of the alae of the nose **(A)** and is used to set the lateral alae at the medial canthi bilaterally **(B)**. Importantly for the lip repair, positioning the base of the nose begins the process of medializing tissue to close the lip. **C**. Muscle closure is performed using 4-0 PDS interrupted buried sutures. Reapproximation of muscle must be accomplished throughout the full extent of the lip. The philtral tissue is visualized from the underside ((a) with skin and bilateral (b) regions that are de-epithelialized). The de-epithelialized regions will be placed under the skin advancement flaps (c) and will provide fullness in the lateral philtral column bilaterally. The philtral flap will

be inset at (d) bilaterally for final closure. Note the white roll (e) at the medial superior area of vermillion. The areas of white roll (e) will be approximated to each other. **D.** Reapproximation of the white roll with dry vermillion prepares for inset of the philtral column. **E.** Final closure of the lip.

■ Variations in the Technique

- The same technique can be used in older patients requiring correction of a wide philtrum (**TECH FIG 4**).
- Though the author's preferred sutures are delineated in this chapter, multiple sutures can be substituted during various junctures of the repair. For example, 4-0 Vicryl can be substituted for 4-0 PDS for reapproximation of the muscle.
- Although the width of philtral column skin flap in a 3-month old patient is recommended as 2 mm from low to high point of Cupid's bow, and 2 mm at the philtral waist (abutting the nasolabial junction), surgeons may choose to incorporate the flanking de-epithelialized regions (also approximately 2 mm wide) into the actual skin-based philtral flap, thereby increasing the width of the skin.



TECH FIG 4 • A 9-year-old with previous bilateral cleft lip repair. **A,B.** The high points of Cupid's bow are elevated bilaterally because the entire skin paddle of the premaxillary segment was used for lip repair. Retained mucosa of the premaxillary segment is present; the patient has a wide philtrum due to use of the central maxillary skin and mucosa as a vermilion substitute. The white roll remains laterally displaced. **C.** Markings have been made for repair of the cleft lip with central philtral column, flanking de-epithelialized regions, scar excision, and premaxillary segment mucosa excision. **D.** Final closure at revision surgery.

Physical findings	■ Be cognizant of asymmetries on initial examination; they may be correctable by presurgical molding techniques; if not, they must be accounted for during initial lip markings. ■ Retroclining the premaxilla is key to improving lip repair outcomes. ■ Failure to retrocline the prominent premaxilla often results in lateral maxillary arch collapse, thereby “locking out” the premaxillary segment in its abnormal anterior position. If this occurs, the premaxilla cannot be positioned properly until maxillary expansion is initiated, which is usually done during the phase of mixed dentition.
Markings	■ Make the philtral column as long as possible on the premaxillary skin. ■ An appropriately narrow philtral column avoids a too-wide philtrum with continued facial growth. ■ Borrowing white roll from the lateral lip segments is crucial because true white roll does not exist at the skin margin of the premaxillary segment. ■ Provide extra fullness in the central vermilion to avoid a whistler’s deformity.
Incisions	■ Avoid the mistake of making the incisions on the lateral lip elements too medial. This will make the height of the lip incongruent with the philtral column height.
Closure	■ Closure with tension is the primary cause of muscle dehiscence and scar widening. ■ Releasing incisions in the upper buccal sulcus provide tension-free closure. ■ If tension persists, re-examine the releasing incisions for further release in areas of periosteal banding. ■ Muscle closure should be performed along the full height of the lip.
Postoperative care	■ No change in feeding regimen is needed after surgery. ■ Scar massage at 1 mo

POSTOPERATIVE CARE

- Postoperative in-hospital stay is optional.
- Arm restraints should be considered.
- Gentle narcotic use for pain is recommended.

- Undertreatment of pain may hinder the child's ability to feed.
- Overtreatment can lead to constipation.
- Breast or bottle feeding is initiated in the recovery room following completion of surgery.

OUTCOMES

- Ideally, primary repair of the bilateral cleft lip should result in a symmetrical, aesthetically pleasing repair that does not require revision (**FIG 4**).



FIG 4 • The child in **FIGS 1** and **2** is shown at 1 month (**A**) and 4 months (**B**) after surgery.

- However, the reality is that revisions are often needed (**TECH FIG 4** and **FIG 5**).
- Timing for revision is controversial. Times for possible lip revision:
 - 5 years of age, on entry into kindergarten
 - Life changes, including transfer to a new school

- Timed with other surgeries, such as speech surgery or bone grafting
- After skeletal maturity following orthognathic surgery

COMPLICATIONS

- Early
 - Bleeding
 - Dehiscence of the repair, either partially or totally
 - Loss of the neophiltral column
 - Stitch spitting/abscess
 - Rarely, infection
- Late
 - Scar widening, including the philtrum becoming too wide in proportion to the overall size of the lip
 - Asymmetry: the most noticeable asymmetries are of the Cupid's bow, with one high point being higher than the other
 - Poor animation because of muscle dehiscence or heavy scar burden

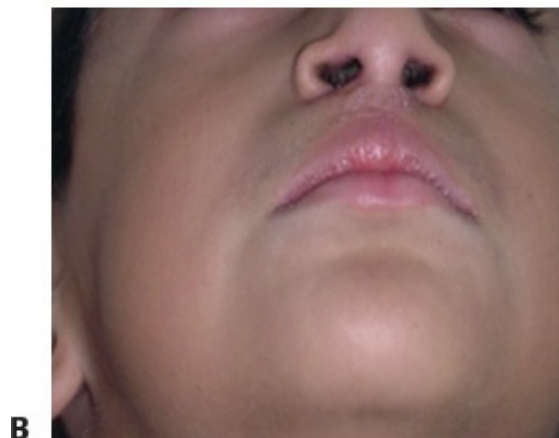


FIG 5 • Postoperative results of the lip revision shown in **TECH FIG 4**. The patient is seen in a frontal view (**A**) and a worm's eye view (**B**). Note that the patient has improved philtral width, Cupid's bow, and wet with dry vermilion balance.

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6

Secondary Deformities

CHAPTER

Catharine B. Garland, Jesse A. Goldstein, and Joseph E. Losee

DEFINITION

- After cleft lip and nose reconstruction, secondary deformities of the lip and nose are common. The actual incidence of deformity is difficult to quantify because of individual variability in assessing what constitutes a deformity. For example, the incidence of revisionary surgery ranges from 0% to 100%.¹
- Asymmetries leading to deformity can be encountered anywhere along the lip-nose complex. These are caused by inadequate tissue in some cases and excessive tissue in others.
- This chapter focuses on addressing secondary cleft lip deformities rather than secondary cleft rhinoplasty. Correcting asymmetries of the alar bases, however, is often an important component of secondary lip revision surgery.

ANATOMY

- The ideal lip and nose complex is composed of the following features:
 - A symmetric nostril shape, with symmetric nostril sills and alar base position
 - A balanced Cupid's bow with a smooth curve to the vermilion border
 - Symmetric philtral columns with a well-defined philtral dimple²
 - Smooth contour and balance of the mucosa
 - A central pouting tubercle in the vermilion
 - A functional orbicularis oris muscle sling that leads to symmetry with animation
 - Appropriate tooth show at rest

PATHOGENESIS

- Some secondary deformities are intrinsic, such as the nasal deformity

characterized by a hypoplastic and flattened lower lateral cartilage.

- Other deformities are iatrogenic from the primary cleft repair. These include deformities caused by scarring, inadequate correction, an unbalanced reconstruction, or altered growth and development.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most important part of the history is to ascertain what bothers the patient and the family. This may not always be congruent with what the surgeon sees as the most significant deformity. Realistic expectations of operative intervention must be discussed preoperatively.
- The physical examination must include a careful analysis of the deformity. The reconstruction is then tailored to address the specific anatomic abnormality.
 - Are the alar bases symmetric in shape and position? They must be symmetric in the vertical, transverse, and sagittal plane.
 - What is the nature of the cutaneous scar? Assess whether the scar is hypertrophic, atrophic, or pigmented. This helps to inform the surgeon about the patient's innate healing response.
 - Is the philtrum well defined and symmetric?
 - Is Cupid's bow balanced or is there a discrepancy in height on the cleft side? Are the vermilion border and white roll congruous structures?
 - Is the red line, wet-dry junction, in alignment? An excess of wet mucosa in a region that should be composed of dry vermilion often causes persistent chapping of the lip in that area.
 - Is there adequate lip length and appropriate tooth show? Is the buccal mucosa scarred and tethered?
 - Is the mucosa symmetric? Is there excess mucosa on the cleft side or deficient mucosa at the central tubercle? Is there a notch in the mucosa at the site of repair?
 - Is the lip symmetric in animation? Bunching of the lip may suggest dehiscence of the orbicularis oris muscle.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperative workup is per hospital routine.
- Under anesthesia, a careful analysis of the lip and nose is again performed to characterize the asymmetries.

- For more severe deformities, consideration must be given to a complete revision of the primary cleft lip and nose repair.^{3,4}

Positioning

- Supine
- We typically use an oral RAE endotracheal tube. This minimizes any asymmetry caused by taping a standard endotracheal tube in the corner of the mouth.
- The table is turned according to surgeon preference.
- The face is prepped with Betadine, and sterile drapes are applied. A head wrap or four towels may be used for draping according to surgeon preference.

Approach

- Markings: Mark all the key anatomical landmarks of the lip and nose (eg, alar bases, columella, peak and nadir of Cupid's bow, white roll, and wet-dry junction). Tattoo the key points with methylene blue.
- Measure: Measure both the normal and cleft sides with calipers to determine the exact discrepancy of height and/or width in the lip and nose that requires correction.
- Epinephrine: Consider whether epinephrine is needed for your surgery. The hemostatic benefit is helpful in many cases. However, for subtle contour abnormalities, epinephrine infiltration may obscure your ability to assess the result on the table. In these cases, pinch the lip between the thumb and index finger to occlude the labial artery while you are incising the tissues and use Bovie electrocautery sparingly.
- Skin repair: Although hypertrophic scarring may be inherent to the patient, all precautions are taken to minimize this risk. Care is taken to ensure a tension-free closure. The skin is approximated with 5-0 or 6-0 Monocryl buried dermal sutures. When these are placed precisely, additional cutaneous sutures may not be required. When cutaneous sutures are needed, we use strategically placed 6-0 fast-absorbing plain gut or 6-0 nylon sutures in the epidermis to align the skin edge. These are removed 4 to 5 days after surgery.
- Muscle repair: Muscular dehiscence may be suspected in patients who have a muscle bulge laterally with facial animation. In addition, muscular dehiscence can contribute to a shortened lip, notching of the mucosa, or widening of the cutaneous scar. When these are noted, reconstruction of the orbicularis oris musculature must also be performed with the repair. The orbicularis oris

muscle is dissected free from the skin and mucosa. When the muscle is found dehiscenced, it is reapproximated or overlapped. Some surgeons describe a benefit to tightening the orbicularis oris muscle with horizontal mattress sutures to evert the muscle and accentuate the philtral column.

- Mucosa repair: After the planned local tissue rearrangement or excision, the mucosa is typically repaired with 5-0 chromic gut sutures. These can be placed as everting horizontal mattress sutures to prevent a notch in the vermilion and mucosa.

TECHNIQUES

■ Deformities of Cupid's Bow

Small Vermilion Mismatch (Less Than 1 mm) or a Widened Scar at the Cutaneous-Vermilion Border

- This can be managed by a diamond or curved excision of the scar, similar to the classically described Rose-Thompson straight line repair (**TECH FIG 1A**).
- The Cupid's bow nadir and high points are marked (**TECH FIG 1B**). An equal distance from high point to nadir is transposed to the cleft side, and this is typically positioned on the medial side of the scar. The vermilion border is marked medially and laterally to the scar that is to be excised. These points will come together to create the new high point of Cupid's bow on the cleft side.
- The white roll is marked, as is the red line wet-dry junction. The diamond excision is marked to excise the scar or mismatch and allow realignment of the vermilion border and white roll.
- The critical points are tattooed with methylene blue.
- Epinephrine-containing solution is infiltrated into the tissues for hemostasis.
- Using an ophthalmic knife, the diamond is excised through the skin down to muscle. If the muscle repair is adequate, superficial scar is excised, but the muscle is left intact.



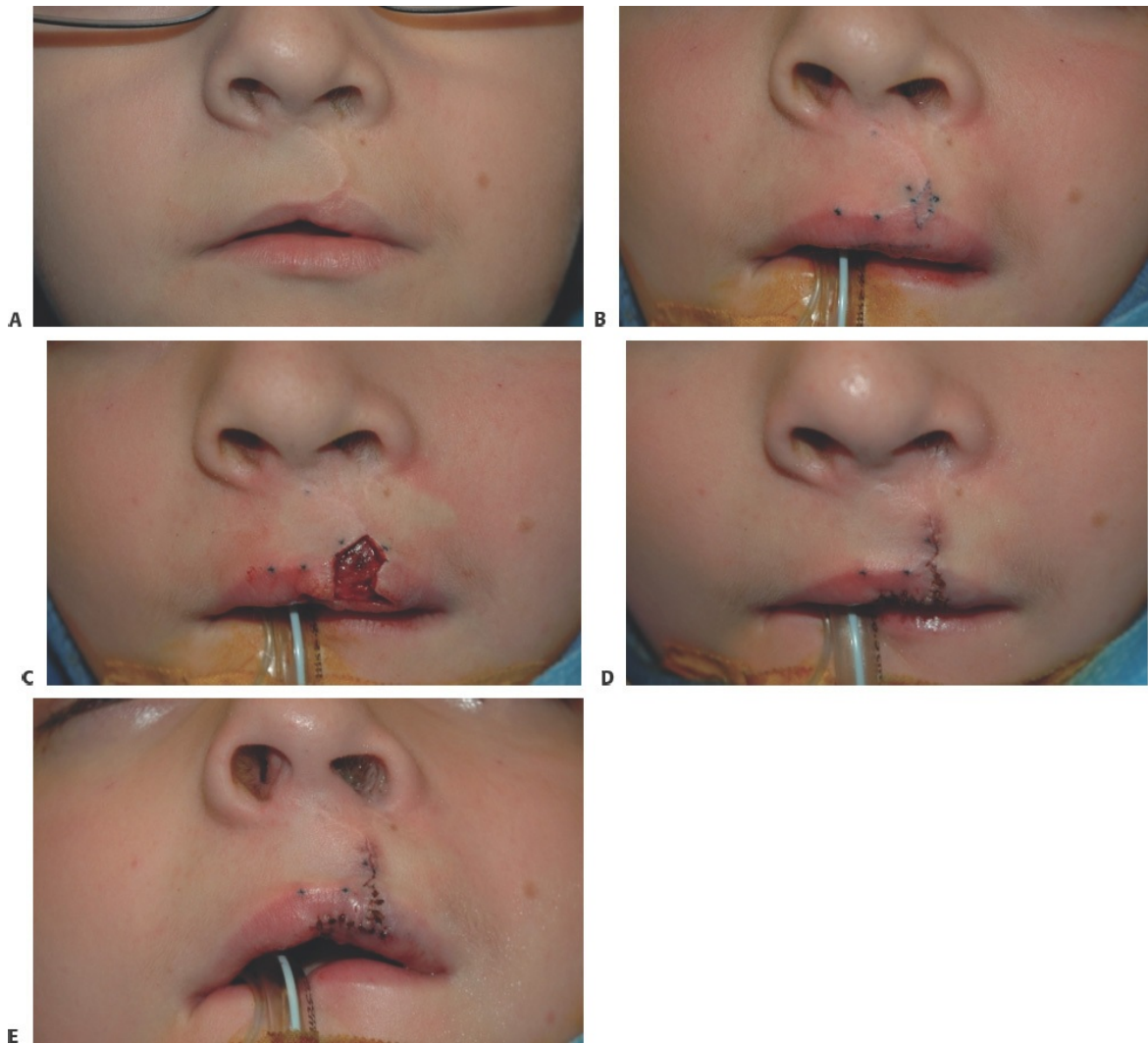
TECH FIG 1 • A. Hypertrophic scar at the vermilion border with slight shortening of Cupid's bow on the cleft side preoperatively. The remainder of the cutaneous scar is well healed. **B.** The peak and nadir of Cupid's bow are marked on the noncleft side and transposed to the cleft side. The white roll is marked and these points are tattooed. A diamond excision of the scar is marked at the vermilion border. **C.** The diamond excision realigns the vermilion border and white roll and provides adequate additional length to balance Cupid's bow.

- 5-0 Monocryl is used to realign the vermilion border with a deep dermal suture (**TECH FIG 1C**). Additional deep dermal sutures are used to realign the wound margins precisely.
- 5-0 Chromic is used to reapproximate the mucosa with everting sutures. To prevent a standing cone or “dog ear,” excess mucosa is excised as needed in this process.

Cupid's Bow Mismatch of 1 to 2 mm

- For a Cupid's bow mismatch of 1 to 2 mm (**TECH FIG 2A**), a small triangular flap is inserted at the cutaneous border.
- This excision and reconstruction are often similar to the microform cleft repair described by Mulliken.⁴
- The cutaneous-vermilion border, white roll, Cupid's bow peak on the normal side, low point, and peak on the cleft side are marked and tattooed (**TECH FIG 2B**).
- Using calipers, the distance from subnasale to the normal Cupid's bow peak is measured, and the equal distance from subnasale is marked on the cleft side.
- A laterally based cutaneous equilateral triangular flap is marked on the lip above the white roll, with the base of this triangle being the difference in the distance between subnasale and height of Cupid's bow peak on each side.
- An incision of equal length is marked on the medial lip element above the white roll.

- The length of vertical excision is long enough to excise any abnormal scar tissue or to prevent formation of a “dog ear.”
- If there is a deficiency of central tubercle vermillion, a laterally based triangle of vermillion may be designed as well.³ If there is an excess of lateral mucosa, a mucosal excision may be included (**TECH FIG 2C**).
- The tissue is infiltrated with epinephrine. It is excised with an ophthalmic knife or no. 15 blade.
- The scar tissue is excised and the skin flaps are separated from the underlying orbicularis oris muscle.
- The muscle is reconstructed if needed, and skin and mucosa repair proceeds as previously described (**TECH FIG 2D,E**).

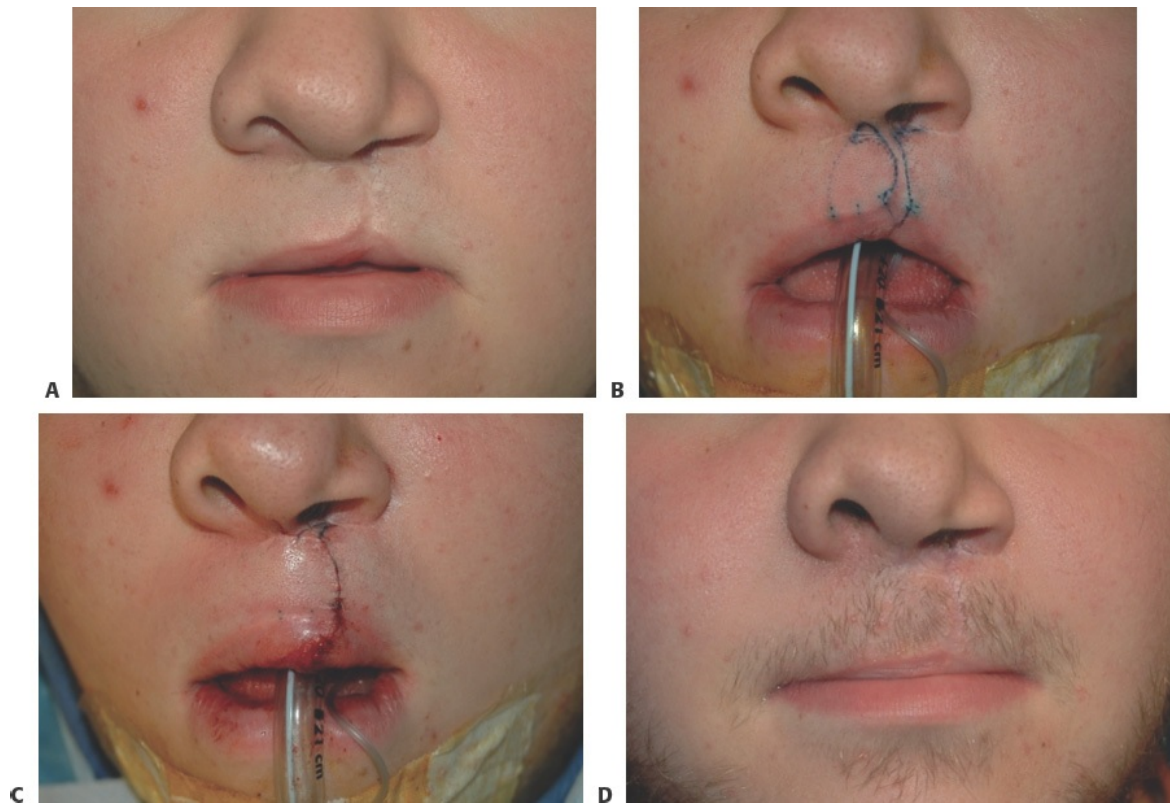


TECH FIG 2 • A. Lip deformity characterized by both shortening of Cupid's bow on the cleft side and lateral mucosal fullness. **B.** The peak and nadir of Cupid's bow are marked on the noncleft side, and the peak of Cupid's bow is marked symmetrically on the cleft side. The excision is designed with a laterally based triangular flap at the white roll. In addition, the lateral mucosal fullness is addressed with an excision planned along the red line or junction of wet and dry mucosa. **C.** After excision of the tissues, prior to repair. Mucosa is being excised in both the transverse and vertical planes. **D.** Closure includes the inset of a

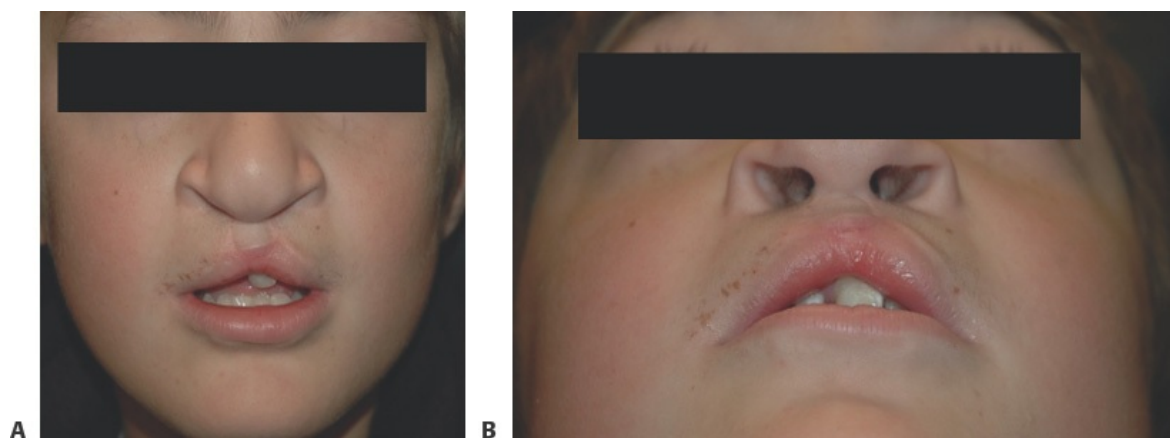
laterally based triangular flap above the white roll to increase the length of the lip on the cleft side. This realigns and balances Cupid's bow. **E.** After excision of excess mucosa, the mucosa is more symmetric. The scar is hidden along the red line and closed with 5-0 chromic sutures.

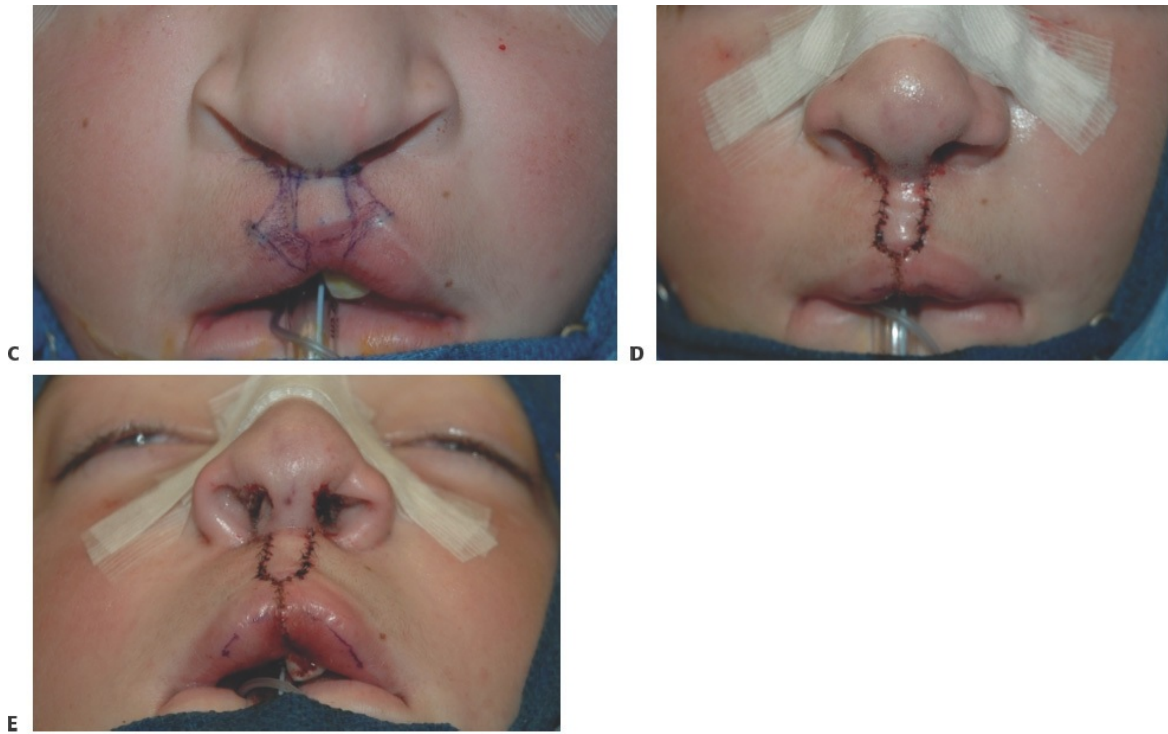
Cupid's Bow Asymmetry More Than 2 mm High

- For a larger asymmetry, a complete revision of the cutaneous scar is performed (**TECH FIG 3**).
- Many primary lip repair techniques may be adapted to achieve the necessary goals in these more complex deformities.
- The vermilion discrepancy may be addressed by rerotation of the medial lip element as in a classic Millard repair (**TECH FIG 3C**).
- Use of a triangular flap above the white roll in the manner first described by Tennison and Randall and subsequently modified by Fisher⁵ is also an option for a complete revision of the lip repair to address a major deformity.
- The orbicularis oris muscle may need to be reconstructed fully or in part to achieve adequate repair.
- In the bilateral cleft lip, complete revision is used for patients with a wide philtrum, significant philtral scarring, or a severe deficiency of vermilion in the midline (**TECH FIG 4**).



TECH FIG 3 • **A.** Shortening of the unilateral lip with mild widening of the cutaneous scar. **B.** A complete excision of the cutaneous scar is planned. A backcut is designed to allow secondary rotation of the medial lip element. **C.** After rotation of the medial lip element, Cupid's bow is now more symmetric. **D.** The improvement in the symmetry of Cupid's bow is maintained at 18 months postoperatively.





TECH FIG 4 • A,B. A 12-year-old boy with significant residual cleft lip and nasal deformity after bilateral lip repair. Cupid's bow is unbalanced, and there is a paucity of mucosa in the central tubercle. He has had no correction of his cleft nasal deformity with lateral displacement of the alar bases. **C.** With this degree of deformity, a complete bilateral lip and nose repair is planned and marked as if this were a primary incomplete bilateral lip repair. The peak of Cupid's bow is marked at Noordhoff point on the lateral lip element. The skin and mucosa between this and his existing scar are planned for excision. **D,E.** The bilateral lip and nose are completely reconstructed to restore balance to Cupid's bow and the vermilion. Note the improved positioning and symmetry of the lower lateral cartilages and alar bases after open reconstruction with inverted-U rim incisions to address the lower lateral cartilages.

■ Abnormalities of the Vermilion and Mucosa

- Minor notches in the vermilion, asymmetries of the mucosa, incongruity of the red line, or asymmetry of the dry vermilion may all be managed with small elliptical excisions or local tissue rearrangement.
- Incisions are confined to the mucosa and vermilion unless a cutaneous deformity must also be addressed.
- Each problem discussed here has a slightly different solution, but our typical step-by-step approach is as follows:
 - Assess the deformity and design the excision or flap for reconstruction.
 - Mark the red line for accurate realignment later. Tattoo this with methylene blue if needed.
 - We typically do not infiltrate the tissues with epinephrine-containing solution when addressing a mucosal defect. The infiltration will distort the tissues and prevent accurate intraoperative assessment. We find it is easier to determine if adequate tissue has been excised or rearranged without infiltration.
 - Rather than using epinephrine, the labial artery is pinched between two fingers while making an incision in the tissues with a no. 15 blade.
 - Electrocautery is used for hemostasis as needed.
 - Mucosal flaps are elevated from the underlying orbicularis oris muscle.
 - The orbicularis oris muscle is reconstructed as needed with 4-0 Monocryl mattress sutures.
 - The mucosa is redraped to assess contour of the lip. Additional excision, augmentation, or dissection is performed as needed to optimize the contour.
 - Closure of the mucosa is performed with interrupted 5-0 chromic sutures.

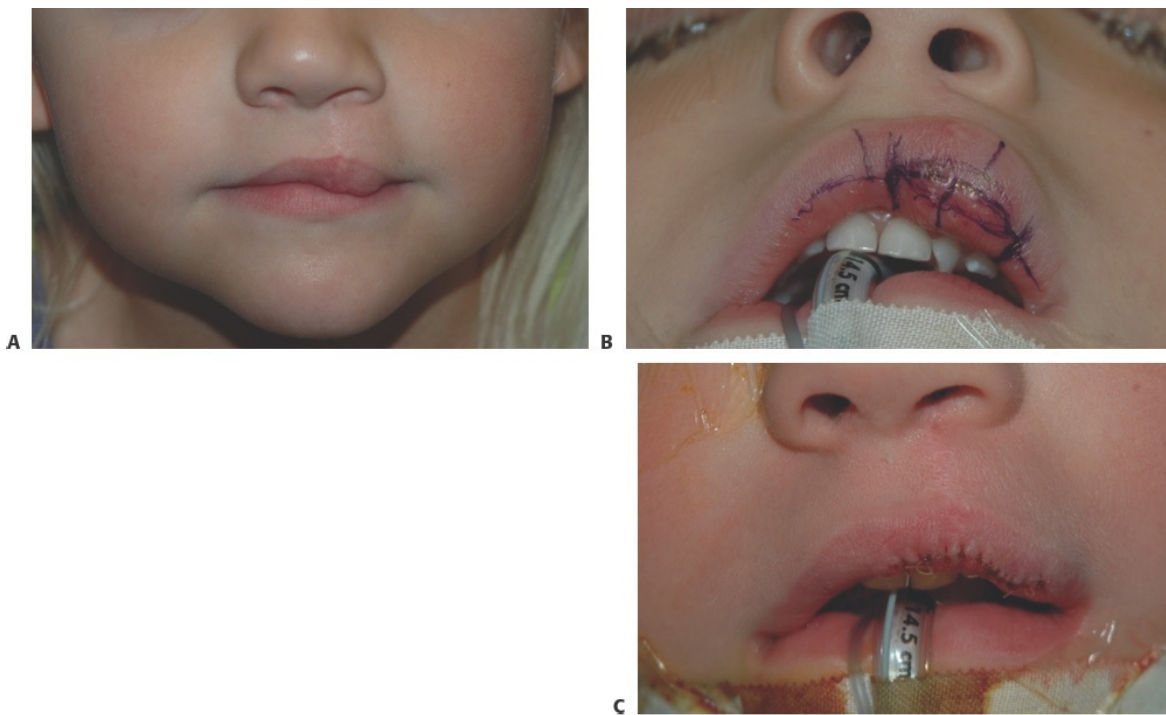
Malalignment of the Red Line

- This may lead to a notch in the border or an area of chapped mucosa interposed between dry vermilion.
- A notch caused by inadequate dry vermilion at the central tubercle can be addressed by advancing lateral vermilion excess. A small laterally based triangular flap of vermilion is raised above the muscle. An incision is made along the red line medially. After any necessary muscle repair, the lateral triangular flap is inset into the medial incision.
- Alternatively, when wet mucosa is interposed in the vermilion, this may be excised with a vertical ellipse of this tissue. The mucosa is elevated on both sides to reduce tension. After muscle reconstruction or reinforcement, the

mucosa is closed with the red line now in precise alignment.

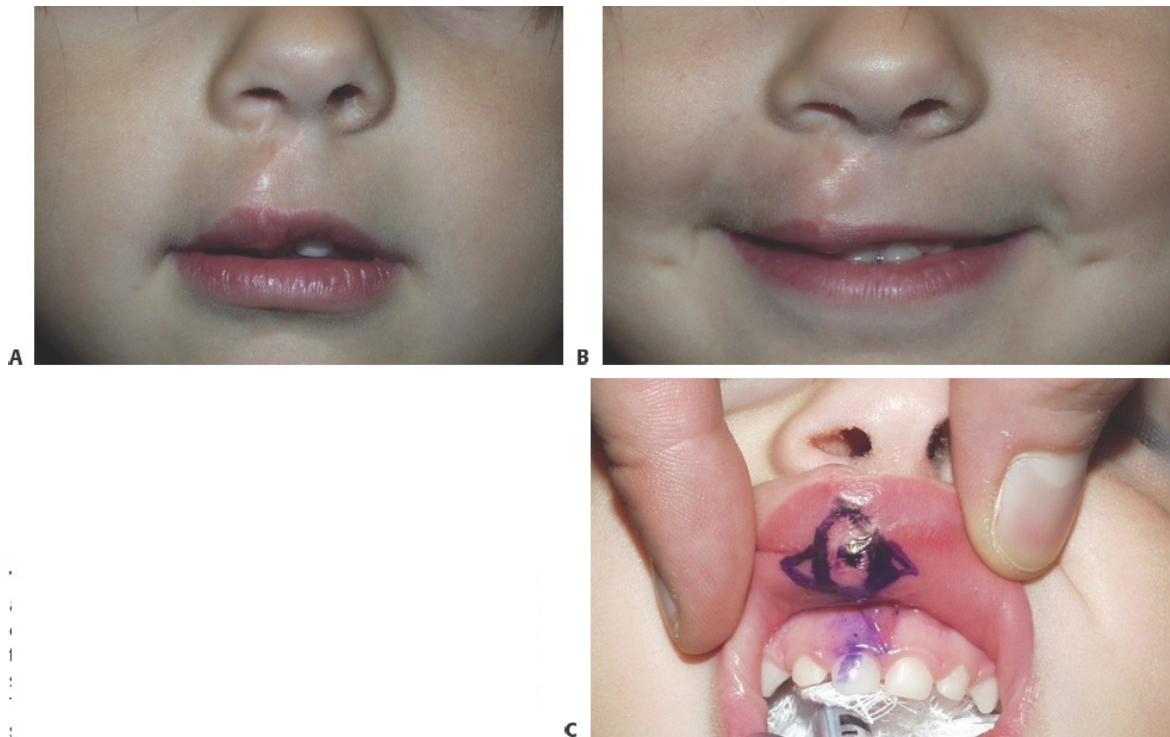
Lateral Mucosa Fullness

- This is common after unilateral cleft lip repair. It can often be corrected by excising an ellipse of tissue from the mucosa.
- A transversely oriented ellipse addresses excess in the anteroposterior direction. This may be placed along the red line if there is an excess of both dry vermilion and mucosa (**TECH FIG 5**), or it may be hidden in the labial buccal sulcus if the excess is composed only of wet mucosa.
- Festooning of the lip suggests excess mucosa in the transverse direction. This should be addressed with a vertical ellipse of mucosa along the cleft scar.
- We find that often both ellipses are needed (**TECH FIG 6**). In these cases, both are marked and the closure is usually in the shape of a “T.”



TECH FIG 5 • **A.** Lateral mucosal fullness is noted after unilateral cleft lip repair. **B.** The excess was primarily in the anteroposterior dimension. A transverse ellipse, centered on the red line, is marked for excision to address the region of excess. **C.** After

excision and closure, the contour of the lip margin is improved.



TECH FIG 6 • A. This child has lateral mucosa excess at rest and **(B)** with animation after unilateral cleft lip repair. **C.** On closer evaluation, the mucosal excess was felt to be in both the transverse direction and anteroposterior direction. For this reason, both a transverse ellipse and vertical ellipse were marked. The final closure will be in a “T” configuration along the cleft lip scar and in the buccal sulcus.



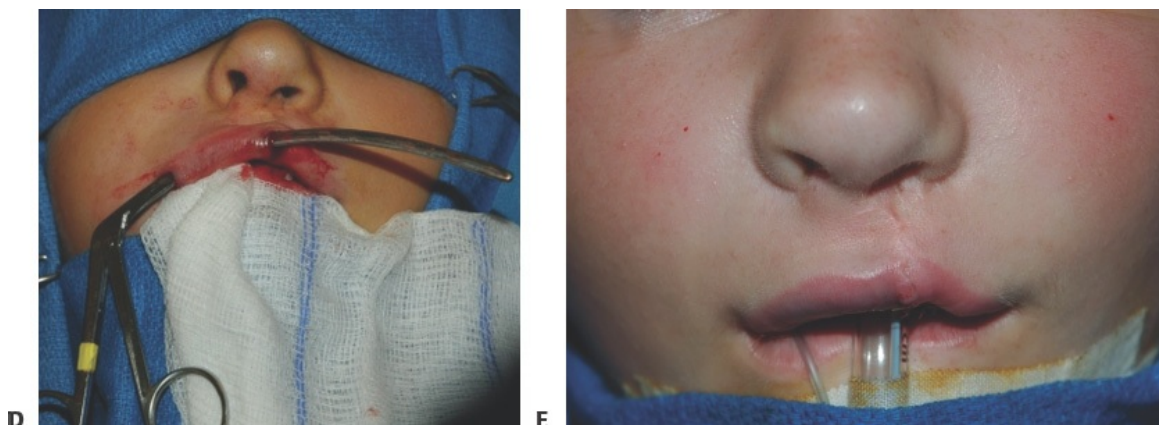
TECH FIG 7 • After fat is harvested from the lower abdomen, it is placed in 1-mL syringes for injection. This is typically injected via a fine fat grafting cannula or 18-gauge needle under the vermilion border.

Hypoplastic Medial or Lateral Lip Element

- In this case, soft tissue augmentation is required. Autograft, allograft, and synthetic tissue fillers have all been described. When possible, our preference is to use autograft either as a structural fat graft or dermal fat graft.
- Structural fat grafting may be used for secondary lip augmentation.
 - Autologous fat is harvested in the standard fashion from the lower abdomen and prepared according to the Coleman technique.
 - This can then be injected under the vermilion border using a very small cannula (**TECH FIG 7**).
 - Structural fat grafting is versatile. In addition to augmenting the vermilion, it may also be used to augment a deficient philtral column or nostril base.⁶ Limitations with fat grafting include unpredictable resorption and survival, as well as the risk of asymmetric hypertrophy with added weight gain over time.
- Autologous dermal fat graft is used when a larger augmentation is needed (**TECH FIG 8**).
 - The requisite size graft is typically harvested from the groin and de-epithelialized.

- The graft is ideally positioned between the mucosa and muscle under the vermilion border and dry vermilion.
- Two small counterincisions in the mucosa can be made to create a tunnel for the graft, which is passed with a tendon passer (**TECH FIG 8D**). Chromic sutures are placed on both ends of the graft prior to passing it through the tunnel. These are then used to anchor the graft into the appropriate location.
- If a Z-plasty or V-Y advancement of the buccal sulcus tissue is planned in addition to augmentation, this flap is raised and the dermal fat graft may be placed directly and sutured into place (**TECH FIG 9**). We commonly use this strategy to augment the central tubercle in the bilateral cleft lip.





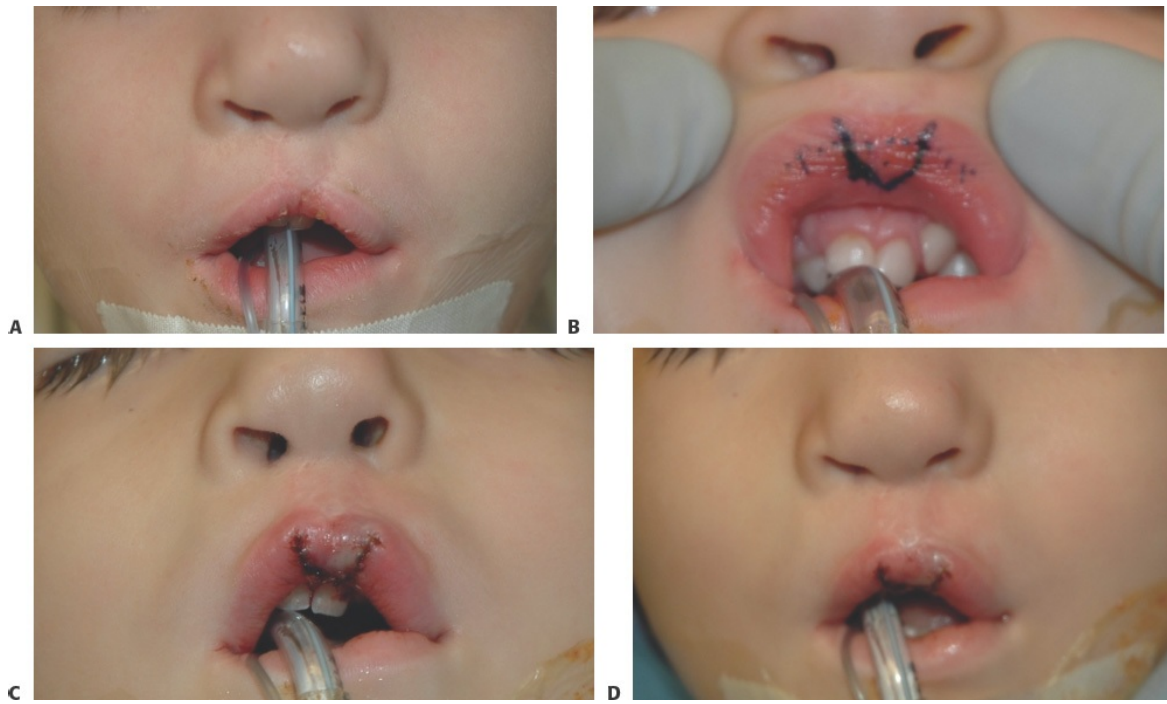
TECH FIG 8 • A. After unilateral cleft lip repair, this patient has an asymmetric free margin of the lip. She has mucosal excess on the left, with a relatively hypoplastic lip on the right side. Given the thin lip on the right side, augmentation with an autologous dermal fat graft was planned. **B.** Harvest from the right hip was planned, with the incision in a favorable location. **C.** The graft is de-epithelialized and thinned to the necessary size. **D.** In this case, a tunnel was made from the lateral commissure to the central lip. A tendon passer is used to introduce the graft into the planned location along the right lip. **E.** After graft inset, the lip thickness is more uniform across the upper lip.

- Dermal allograft is an alternative to autologous tissue and may be used in a similar manner to a dermal fat graft.⁷

Notch in the Free Edge of the Lip or Whistle Deformity

- This may be caused by inadequate tissue, dehiscence of the orbicularis oris muscle, or scarring of the mucosa that leads to tethering or shortening of the lip.
- When scarring is present, the buccal mucosa may be lengthened by local tissue rearrangements or grafts, such as:
 - Mucosa Z-plasty
 - V-to-Y advancement of the buccal sulcus tissue

- Transposition of a buccal mucosa flap⁸
- Interposition of a buccal mucosal graft harvested from inside the lateral cheek
- When the cause is a deficiency of tissue rather than scarring, augmentation with autologous fat may be adequate.
 - For a mild deficiency, structural fat grafting may be used.
 - Elevation of a buccal flap and augmentation with dermal fat graft are used for a moderate-size defect (see **TECH FIG 9**).



TECH FIG 9 • **A.** Persistent central vermilion deficiency after bilateral cleft lip repair. **B.** In the area of notching, an anteriorly based mucosa flap is designed. The flap and surrounding mucosa are elevated from the orbicularis muscle, and a dermal fat graft is positioned in the region of deficiency. **C,D.** After augmentation with a dermal fat graft, the fullness of the central tubercle fullness is improved.

- In more significant cases, or when vermilion deficiency is associated with a widened philtrum and nasal base, complete revision of the repair may be

performed to recruit additional lateral mucosa into the defect (see **TECH FIG 4**).

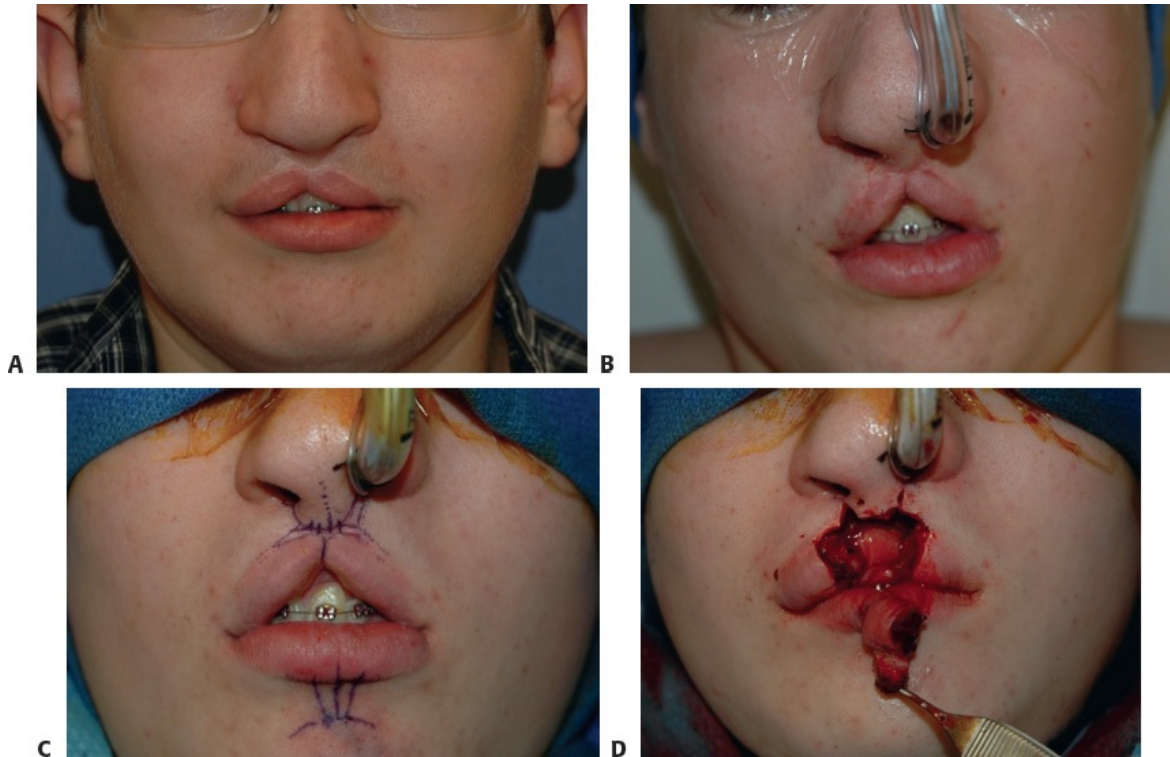
- In severe cases, usually after bilateral cleft lip repair, the whistle deformity may require reconstruction with an Abbe flap (see below).
- The orbicularis oris muscle must be reconstructed in all cases.

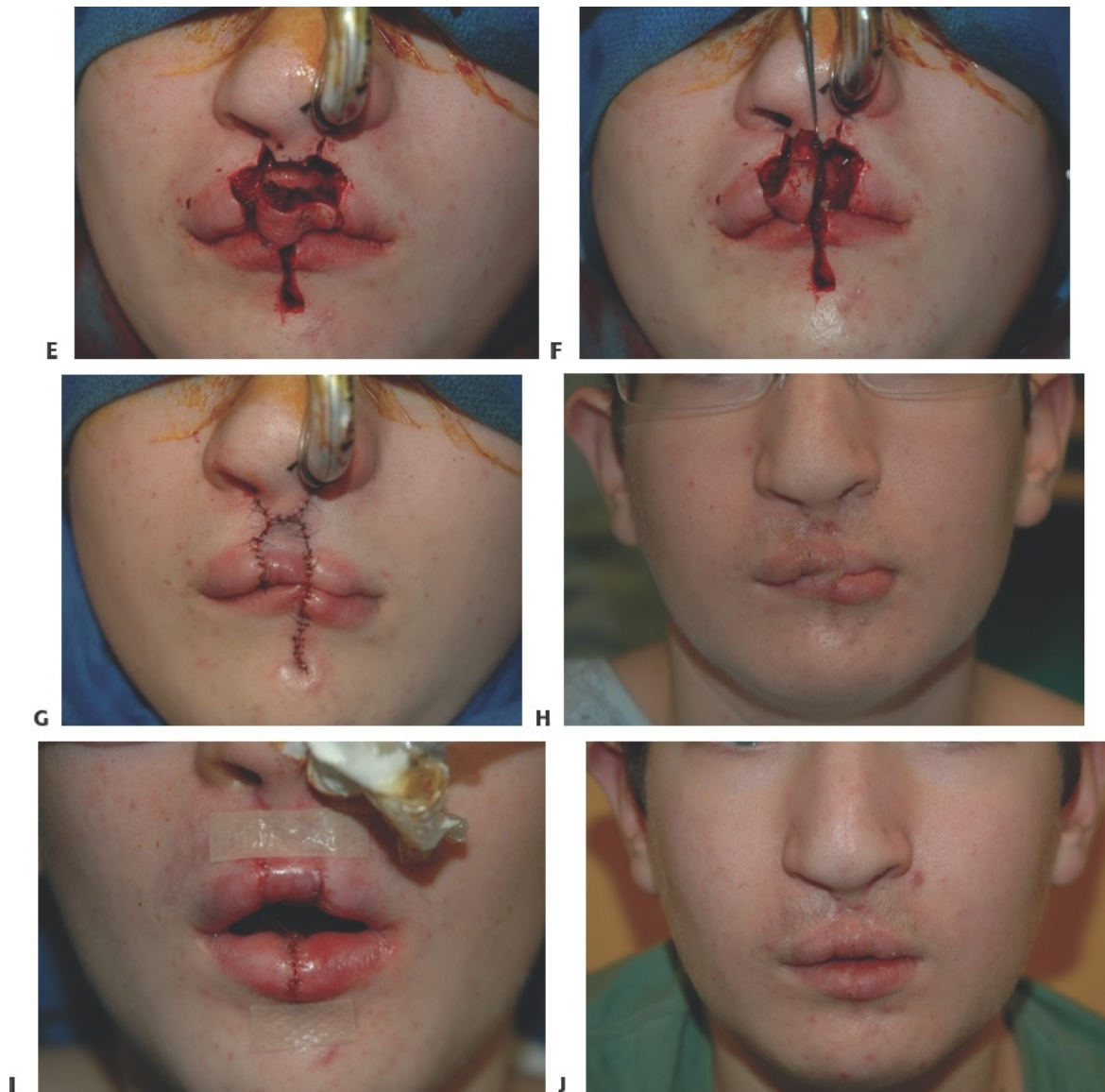
■ Abbe Flap

- The bilateral cleft lip often is accompanied by a deficiency of mucosa as well as a shortened philtrum. Furthermore, horizontal lip deficiency may limit the ability to reconstruct the central tubercle by borrowing tissue from the lateral lip elements.
- For these severe whistle deformities (**TECH FIG 10A**), an Abbe flap may provide the best option for reconstruction of the entire philtral unit.^{9,10}
- The patient is nasally intubated in preparation for surgery (**TECH FIG 10B**).
- If the patient is in braces, tight elastics are placed to prevent full mouth opening after surgery. Alternatively, intermaxillary fixation screws may be placed with tight elastics or wires.
- The flap is designed in the midline of the lower lip (**TECH FIG 10C**). The length and width of the new philtrum are designed and drawn onto the lower lip. The flap tapers slightly toward midline as it approaches the labiomental crease. Darts are made at the labiomental crease to address the donor site “dog ear” at closure.
- The vermilion border and white roll are marked and tattooed on the lower lip.
- The flap is incised full-thickness through the skin, muscle, and mucosa on one side (**TECH FIG 10D**). During this dissection, the location of the labial artery is noted, so that this area is well preserved on the contralateral side. A Doppler may be used to confirm the pedicle location if there is prior scarring in the area.
- The remainder of the flap is dissected with preservation of the labial artery. A small muscular cuff is preserved around the artery. The composite flap is then able to be rotated a full 180 degrees.
- The lower lip incision is closed in layers. The mucosa is repaired with 4-0 chromic gut, the lower lip orbicularis oris muscle is repaired with 3-0

Monocryl sutures, and the skin is closed with 5-0 Monocryl sutures in the dermis and 6-0 nylon in the skin.

- The critical points of the upper lip are marked. The columella, vermilion border, and white roll are marked and tattooed. The scarred prolabium is marked for excision.





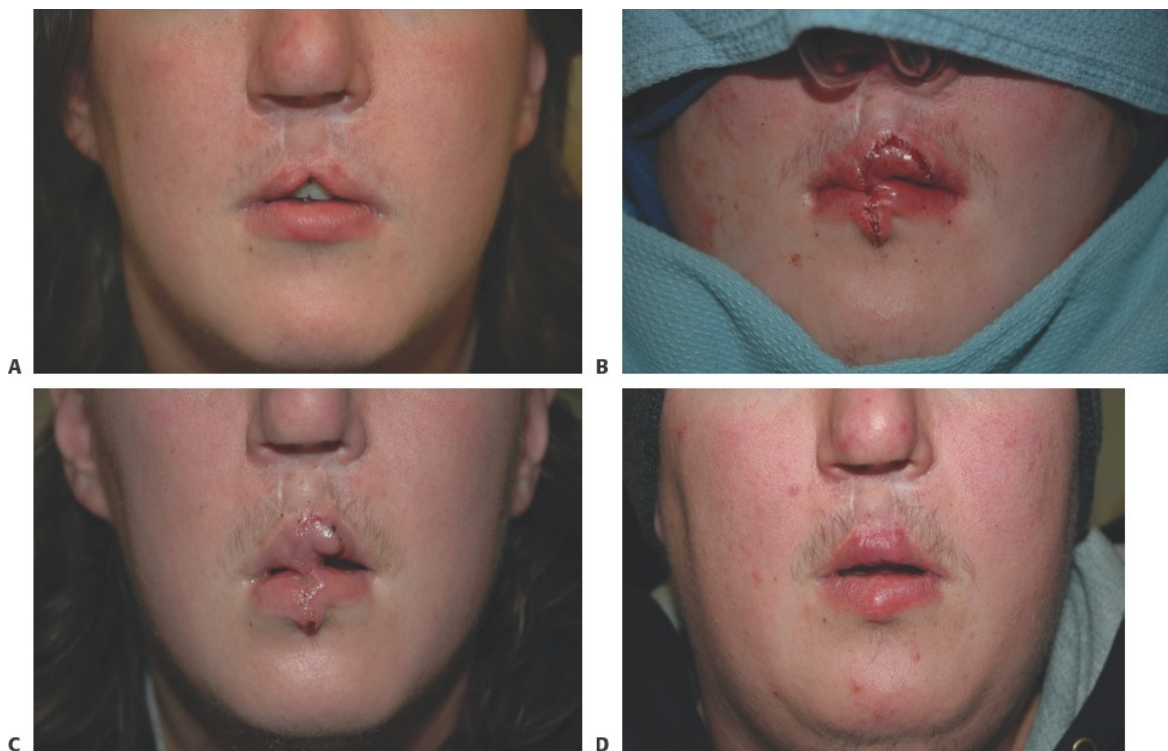
TECH FIG 10 • A. Bilateral cleft lip with significant whistle deformity composed of deficiency of mucosa, vermilion, and philtrum. On worm's-eye view, the patient also has a severely shortened columella. **B.** Preparation for Abbe flap includes nasal intubation. This patient's braces were used for intermaxillary fixation with heavy elastics. **C.** The Abbe flap is planned and marked in the midline of the lower lip. The flap is measured to the desired length and width of the new philtrum. The length is limited by the

location of the labiomental crease, but this crease is used to accommodate any dog ear at closure. The columella, scarred philtrum, and new high points of Cupid's bow are marked. The high points of Cupid's bow are marked to match the length and fullness of the lower lip flap. **D.** The central upper lip defect is created and the orbicularis oris muscle is dissected out for repair. The lower lip Abbe flap is cut full thickness through skin, muscle, and mucosa. One side remains pedicled on the labial artery. **E,F.** The Abbe flap is able to be rotated a full 180 degrees into the upper lip defect. **G.** The Abbe flap is inset with care taken to align Cupid's bow and the lower lip vermilion border. **H.** After 10 to 14 days, the flap is well healed and ready for division. The lip pedicle may be compressed to ensure there has been adequate vascular ingrowth. **I.** The mucosal bridge is divided, and the mucosa is repaired. Silicone tape is applied to the cutaneous portions of the scars to optimize healing. **J.** Several months after surgery, the patient has improved lip contour and increased philtral length.

- The new high point of Cupid's bow is selected. This is ideally at a height that matches the new philtral column created by the Abbe flap. Furthermore, this point is selected such that the thickness of the upper lip mucosa matches the lower lip tissue bulk to achieve a smooth mucosal contour.
- Prior to incising the upper lip, 0.25% bupivacaine is infiltrated as bilateral infraorbital nerve blocks. Epinephrine may be infiltrated into the upper lip tissues.
- The cutaneous incisions are made with a no. 15 blade, and the prolabial scarring is excised. The upper lip is divided at 90 degrees to the white roll and vermilion. The orbicularis oris muscle is dissected and preserved.
- Buccal mucosal incisions are made bilaterally to advance the lateral lip medially toward the new philtrum. The lateral lip is advanced and the buccal

mucosa backcut is closed with 4-0 chromic gut suture.

- After the defect has been created, the Abbe flap is rotated to fill the defect (**TECH FIG 10E,F**). The mucosa is inset with 4-0 chromic gut to the lateral lip elements.
- The orbicularis oris muscle of the upper lip is then repaired to the muscle of the Abbe flap.
- The vermilion and white roll are aligned at the previously tattooed points, and the remainder of the skin and mucosa is inset (**TECH FIG 10G**).
- During the inset, the color of the Abbe flap is monitored to ensure the flap remains adequately perfused. If perfusion is compromised, routine maneuvers for flap ischemia are taken, such as release of tension, replacement of flap to donor site, hyperbaric oxygen, etc.
- Flap division is performed 10 to 14 days later (**TECH FIG 10H-J**). After division, the mucosa of the upper and lower lip is closed with 5-0 chromic gut sutures.
- The vermilion Abbe flap may be modified from this pattern to address a severe defect of the mucosa only (**TECH FIG 11**). This eliminates the need for cutaneous scarring while augmenting a severe deficiency of tissue at the central tubercle.



TECH FIG 11 • A. In some cases, the philtral length is adequate, but the deficiency of vermilion is so severe that Abbe flap is considered. **B.** In this case, however, the Abbe flap is designed to stay within the mucosa and does not cross the vermilion on either the upper or lower lip. **C.** Two weeks later, the flap is ready for division. **D.** After several months, the mucosa is well healed with a significant improvement in upper lip contour.

■ Lip Pits

- Lip pits are commonly associated with cleft lip and palate in van der Woude syndrome. Most lip pits occur on the lower lip as paired structures lateral to midline; however, midline pits on the upper or lower lip are also possible. They can range from slight depressions to deep tracts lined with epithelium.¹¹
- The tracts are associated with serous or mucous glands along their course and track toward the labiogingival sulcus.
- Excision must include management of the mucosal deformity as well as removal of the entirety of the tract.
- The orbicularis oris muscle may need to be reconstructed after excision of the tract.
- A lacrimal probe is used to assess the course and depth of the tract. Methylene blue is then injected into the tract with an angiocatheter to mark the tract.
- The mucosal excision is planned to optimize contour. Authors have described multiple different approaches to address the concerns with mucosal contour.

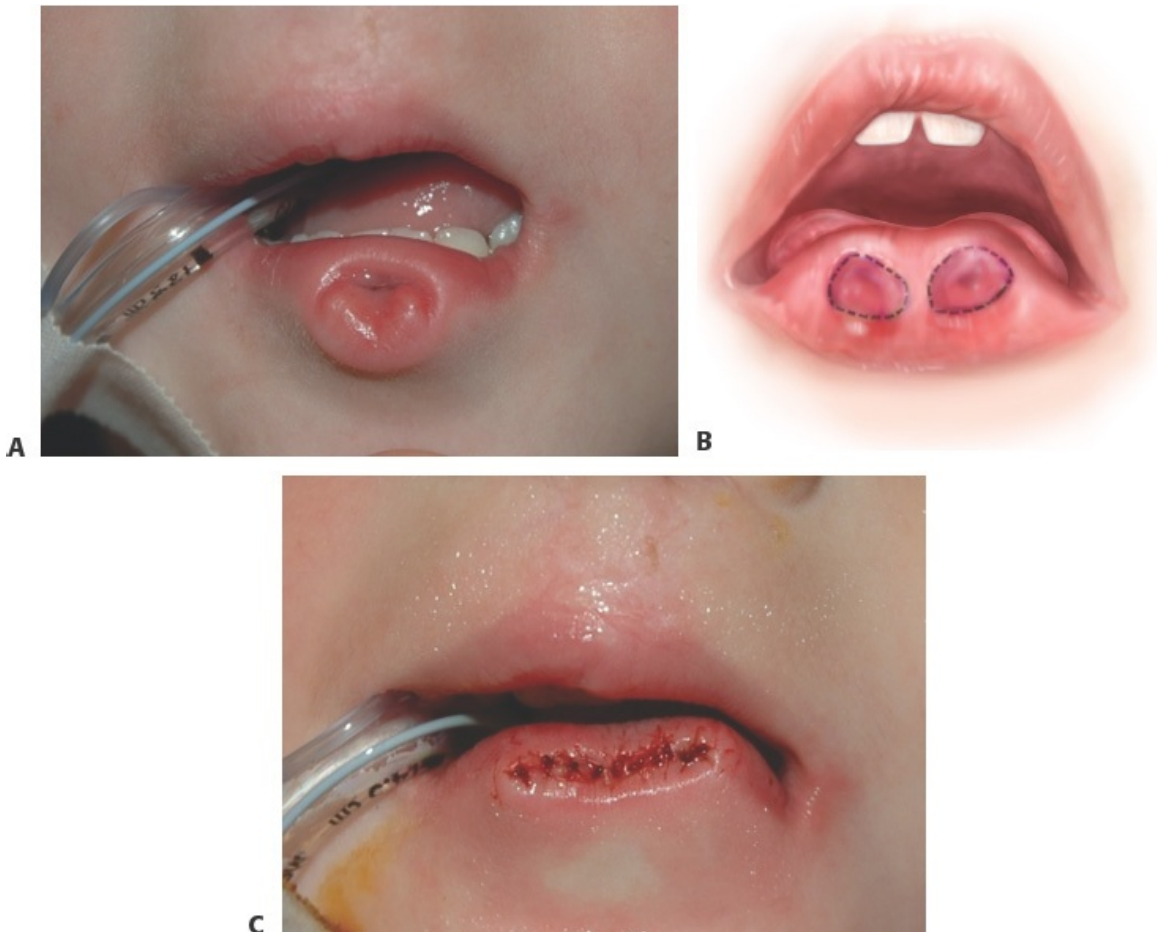
Simple Transverse Elliptical Excision of the Pit and Tract

- In this technique, a transverse ellipse is designed around each pit (**TECH FIG 12A,B**).
- Dissection is carried down around the tract until it is completely excised, using the lacrimal probe to guide the excision.
- The orbicularis oris muscle is reconstructed with 4-0 Vicryl sutures.

- The mucosa is closed using interrupted 5-0 chromic gut sutures (**TECH FIG 12C**).
- Simple excision may be adequate when a single lip pit is present or when lip pits are small and shallow.
 - Multiple deep pits may result in contour abnormalities of the lower lip.

Vertical Elliptical Wedge Excision

- A full-thickness vertical elliptical wedge of the lower lip is designed. This wedge extends to the mucosa internally and crosses the vermilion border onto the skin externally (**TECH FIG 13**).
- The lacrimal probe is used to verify that the sinus tract is contained within the wedge. The wedge is excised full thickness.
- The orbicularis oris muscle is repaired.
- The mucosa, vermilion border, and skin are closed.
- Though this technique may lead to a smoother contour of the lower lip, the scarring on the skin of the lower lip is a major drawback.



TECH FIG 12 • **A.** Central lower lip pit in a child with van der Woude syndrome. **B.** Simple transverse elliptical excision. **C.** After simple transverse elliptical excision of the lip pit.

Split Lip Advancement Technique (SLAT)¹²

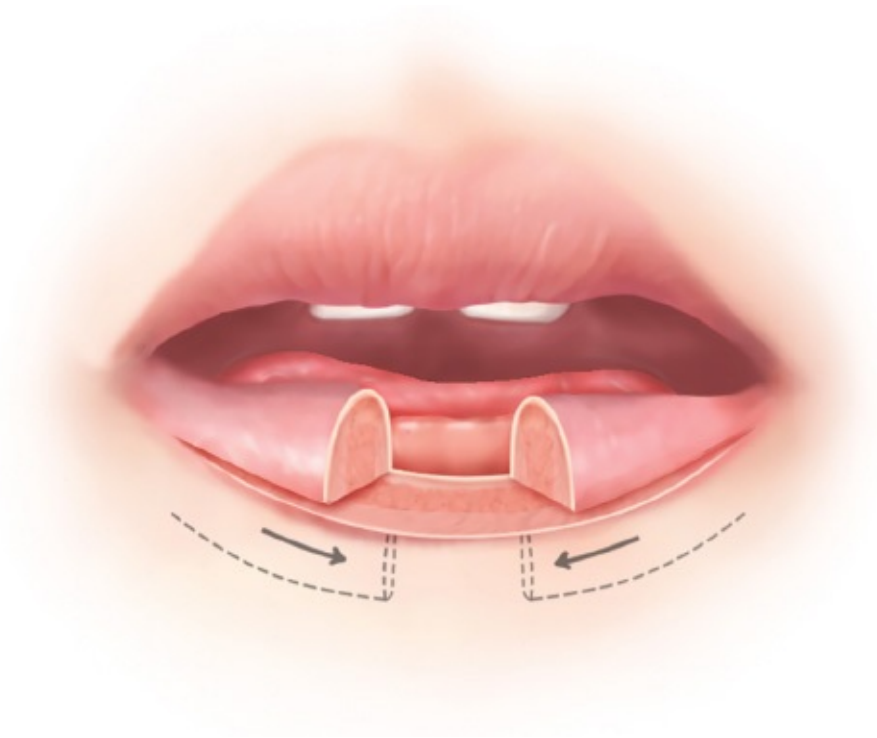
- In SLAT, the pits and tracts are excised in a central wedge of tissue from the vermilion border to the gingivobuccal sulcus.
- The lip is then split from the central incision to a point near the commissure.
- An incision is made along the vermilion border through the pars marginalis. This incision is then carried vertically and inferiorly in a plane between the orbicularis oris muscle and the submucosa (**TECH FIG 14**).
 - The labial artery is preserved within this posterior mucosa flap with the pars marginalis, whereas the skin and majority of the orbicularis oris muscle are maintained in the anterior flap.
- The posterior mucosa flap is advanced toward the midline, and the orbicularis oris muscle is reconstructed.
- Skin and mucosa closure is in a T from the midline along the vermilion border anteriorly.

Inverted-T Excision¹³

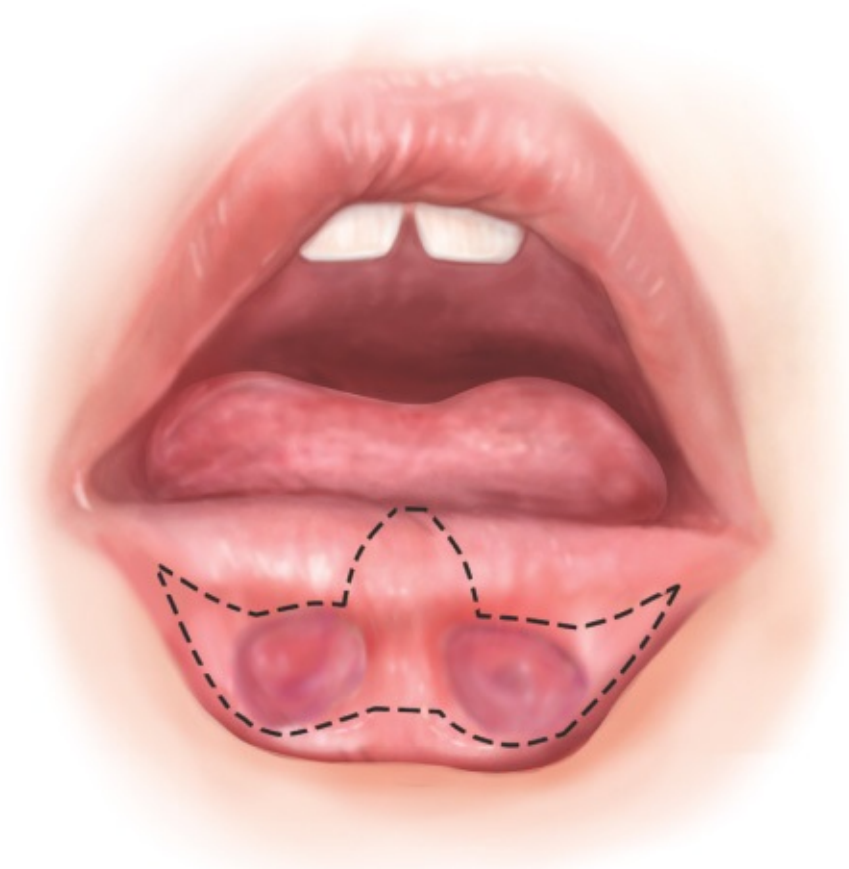
- The lip pits are both included in a large transverse ellipse. The outer edge of this ellipse is parallel to the white roll, which helps to maintain a constant thickness of vermilion.



TECH FIG 13 • Vertical wedge excision of lower lip pits.

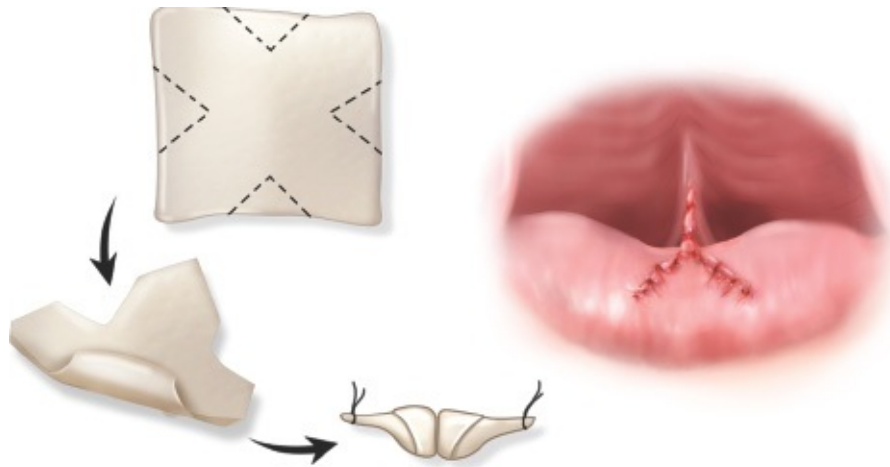


TECH FIG 14 • SLAT technique for lower lip pits.



TECH FIG 15 • Inverted-T excision of lower lip pits.

- Centrally, the ellipse meets a vertical inferior wedge that extends from the lip pits laterally toward the midline of the lower labiobuccal sulcus (**TECH FIG 15**).
- Using the lacrimal probe to identify the sinus tracts, these are fully excised within the vertical wedge of tissue.
- The vertical wedge is excised, and the orbicularis oris muscle is reconstructed.
- The transverse wedge is closed with chromic gut sutures.



TECH FIG 16 • V-Y mucosal flap with use of dermal allograft for augmentation.

Excision and Reconstruction of Lower Lip Fullness With Acellular Dermal Allograft¹⁴

- A large central V-shaped mucosal flap is designed with the apex in the midline of the inferior gingivobuccal sulcus. The lateral arms of the flap include ellipses that excise the lip pits.
- The pits and tracts are fully excised, and the orbicularis oris muscle is reconstructed.
- To restore fullness to the lower lip, an acellular dermal allograft, structural fat grafting, or autogenous dermal fat grafts are utilized to create a natural shape for augmentation (**TECH FIG 16**).
 - This is placed under the V-shaped mucosal flap and sutured into place with 4-0 Vicryl sutures at each commissure.
- The mucosa is closed as a V-to-Y advancement flap with chromic sutures.

PEARLS AND PITFALLS

Etiology of deformities

- Some secondary cleft lip deformities are intrinsic to the disease.
- Others are iatrogenic from the primary repair. Care must be taken to create a balanced lip and nose with release and repositioning of the lower lateral cartilage on the cleft side and complete reconstruction of

	the orbicularis oris muscle sling at the <i>first</i> operation to minimize the risk of iatrogenic deformities.
Analysis	■ Accuracy in analyzing the problem is essential. One must identify the underlying anatomic cause of the deformity in order to accurately reconstruct it. ■ Assess the entire lip/nose complex in planning your reconstruction. ■ Assessment must include all tissues from the underlying bony skeleton, mucosa, muscle, skin, cartilage, and soft tissue.
The repair must match the deformity.	■ Minor deformities may be addressed with minor scar revisions and insertion of triangular flaps. ■ A more complex deformity involving multiple elements is best treated by a complete revision of the lip and nose repair.
Mucosa excess	■ This may often be resolved by direct excision.
Mucosa deficiency	■ A minor deficiency of the central tubercle may be addressed by creation of a laterally based vermilion triangular flap, which can be inset in the central tubercle medially. ■ A larger deficiency of lip soft tissue can be treated by various techniques including autologous structural fat grafting, autologous dermal fat graft, or allograft.
Abbe flap	■ An Abbe flap is best used to reconstruct a deficiency of all tissues of the central lip unit—philtral skin, vermilion, muscle, and mucosa. ■ This treats the most severe forms of lip notching that cannot be addressed adequately by local flaps and augmentation alone.
Lip pits	■ The entire pit and epithelialized tract must be excised. ■ Reconstruction requires repair of the orbicularis oris muscle and reconstruction of the mucosa to achieve a natural lower lip contour.

POSTOPERATIVE CARE

- Antibiotic ointment is typically applied to the incision until it is healed.
- Patients often may resume their usual diet.
- With young children, elbow restraints may be used to keep the child from putting the hands in the mouth or traumatizing the incision.
- Special care is taken to optimize cutaneous scar healing after surgery.
 - When cutaneous absorbable sutures are used, we ensure that they have absorbed by 4 to 5 days postoperatively. We apply diluted hydrogen peroxide to them several times daily to speed this process along to avoid track marks

from the sutures.

- Permanent sutures are removed within 5 days after surgery to avoid scarring.
- Once the wound margins have healed, silicone tape is applied to the scar. It is changed every few days and used continuously for approximately 3 months.
- Patients and families are educated on techniques in scar massage and avoidance of sun exposure for the first year after surgery.
- If hypertrophy is noted in the early postoperative period, consideration is given to applying steroid-impregnated tape or performing steroid injections with triamcinolone.

OUTCOMES

- Outcomes after correction of secondary deformity are usually good.
- Depending on the severity of the deformity, asymmetry or contour abnormalities can be persistent.
- The degree of residual deformity and patient level of concern typically dictate whether additional revision surgeries are recommended.

COMPLICATIONS

- Inadequate correction of the deformity may be caused by an incorrect diagnosis and treatment plan, such as performing a minimal excision when a complete revision is necessary.
- Hypertrophic scarring is possible, and attempts are made to minimize it as described.
- Wound dehiscence and infection are rare.
- Intraoperative complications such as bleeding or anesthesia concerns are rare.

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7 Delayed Hard Palate Repair in UCLP Patients

CHAPTER

Jan Lilja

DEFINITION

- In UCLP patients, the cleft palate will lead to speech difficulties.
- Poor ventilation of the Eustachian tubes results in a high incidence of hearing problems due to middle ear infection.
- Early surgery on the palate may result in reduced maxillary growth.
- Late surgery on the palate may result in aberrant speech.

ANATOMY

- The palate can be thought of as an anterior bony part limited by the dental arch and a posterior mobile part where muscles, oral mucosa, and nasal mucosa are important functional structures.
- The anterior palate (hard palate) is a horseshoe-formed bony structure concave toward the mouth and convex toward the nose where it forms the nasal floor. Both sides are covered by mucosal epithelium.
- The muscles in the posterior part (soft palate) will act on the soft palate and produce tension, lifting, or lowering of the soft palate. Lifting of the soft palate is most important and is accomplished by the levator veli palatini muscles. In speech, the soft palate should be lifted as far back as the posterior pharyngeal wall and be able to stop airflow through the nose in order to produce distinct pronunciation of certain sounds.

PATHOGENESIS

- In a complete cleft of a unilateral cleft lip and palate, a cleft separates the lip, the alveolar bone, and the hard and soft palate. The lateral incisor on the cleft side is usually missing in both deciduous and permanent dentition. The cleft

separates the hard palate lateral to the vomer, establishing a cleft side and a noncleft side in the hard palate where the vomer is attached to the noncleft side. The soft palate is separated in the midline, but the cleft side is usually smaller.

- Feeding is often difficult for the child because there is an opening between the oral and nasal cavity. Food may pass into the nasal cavity and sucking is compromised because adequate negative pressure cannot be achieved during breast-feeding.
- In the soft palate, the muscles are not attached to each other; the muscles follow an anteroposterior direction along the cleft edges. Some of the muscles are attached to the posterior edge of the hard palate on both sides of the cleft.
- This morphological aberration impairs development of speech and hinders ventilation of the Eustachian tube.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- The diagnosis of a patient with complete unilateral cleft lip and palate is usually made by clinical examination.
- Photographs taken from anterior, lateral, and inferior views can be taken to document the condition.
- In some centers, plaster casts are made from both upper and lower jaws.
- Postoperatively, the patients are followed on a regular basis with photos, speech evaluation, cephalometric assessment, and plaster casts.
- When needed for evaluation of velopharyngeal incompetence (VPI), nasendoscopy and videofluoroscopy can be used.

SURGICAL MANAGEMENT

- There are numerous protocols for operating on the palatal cleft in patients with complete cleft lip and palate. These protocols differ in procedure and timing.
 - Early surgery of the soft palate is a prerequisite for good speech, but combined with closure of the hard palate, it will produce reduction of maxillary growth.
 - Closure of the whole palate at an older age will give less problems with maxillary growth but may give more problems with impaired speech.
- When delayed hard palate repair is performed in UCLP patients, soft palate closure is performed early to promote speech, and hard palate closure is delayed until 2 years of age to promote growth. The palatal closure is continued over to the oral side, where a pushback procedure can be done within the soft palate.

- Closure of the soft palate with a posteriorly based vomer flap will result in anchorage of the anterior part of the soft palate to the base of the vomer flap.
- This part of vomer is situated at the insertion of the vomer to the cranial base. The direction of the soft palate will therefore be posterior-upward, resulting in reduction of the openings toward the nose.
- This may explain the favorable speech results in our patients, improving the posterior positioning of the levator muscles and thereby reducing VPI.

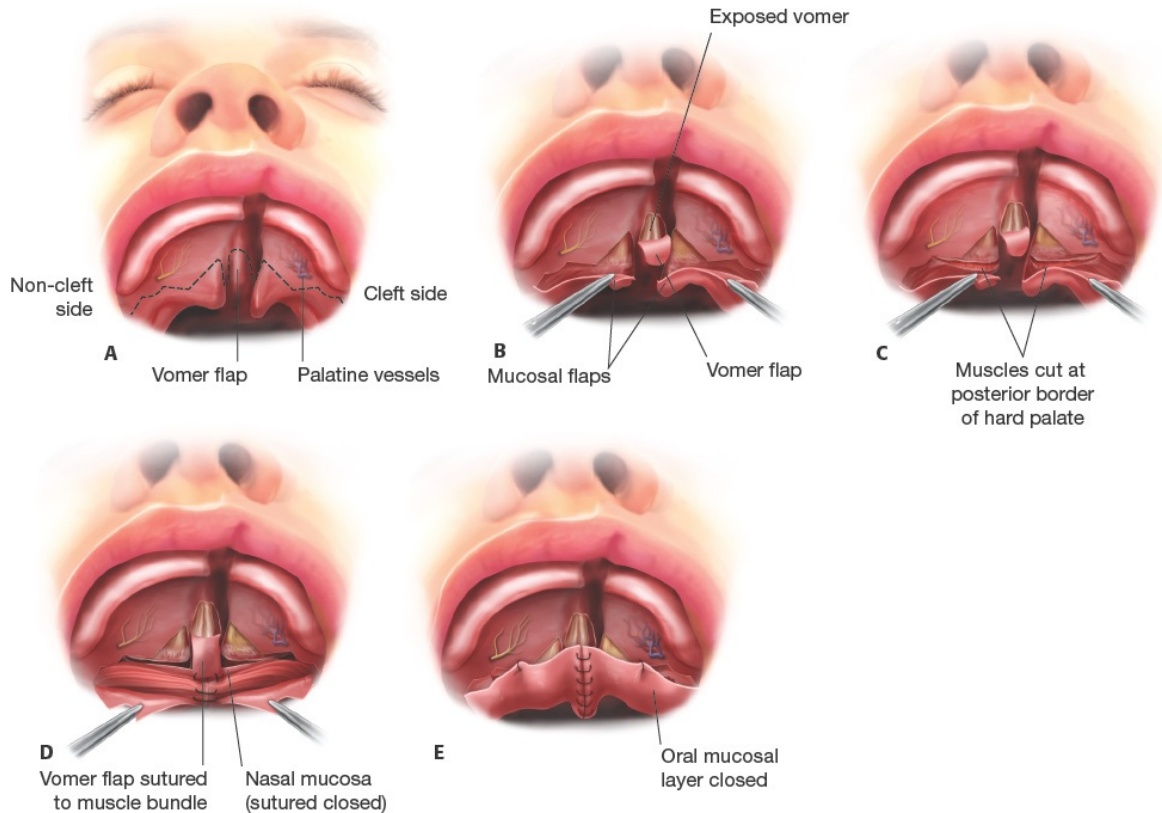
Positioning

- The patient is positioned supine on the operating table.
- A shoulder roll is placed, serving to tilt the head backward to facilitate visualization.

TECHNIQUES

■ Soft Palate Repair

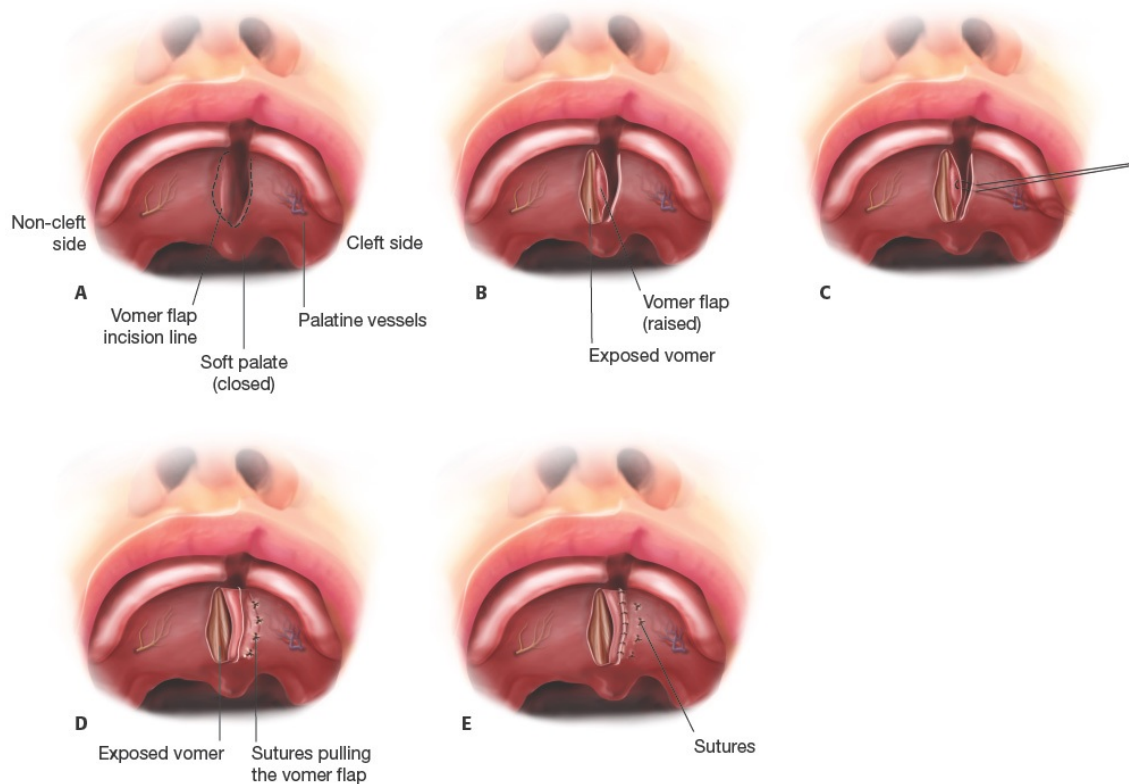
- Incisions begin around the posterior part of the maxillary tuberosities and then follow a zigzag route at the posterior border of the hard palate (**TECH FIG 1A**).
- A posteriorly based vomer flap is dissected, which does not reach the vomero-premaxillary suture anteriorly. The base of the flap lies at the junction of the vomer with the cranial base (**TECH FIG 1B**).
- Mucosal flaps in the soft palate are raised by blunt dissection. The hamulus is identified but not broken (**TECH FIG 1C**).
- The insertions of the velar muscles and the nasal mucosa at the posterior border of the hard palate are cut (**TECH FIG 1D**).
- A flap with the muscles attached to the nasal layer is then dissected free and mobilized.
- The palatal muscles, including the levators, are then reconstructed to a transverse course at the level of the opening of the Eustachian tube (**TECH FIG 1E**).
- The vomer flap is raised, and the nasal layer of velum can be closed anteriorly to the level of the muscular sling by use of the vomer flap. In this way, the vomer bone is connected to the anterior velum (**TECH FIG 1E**).



TECH FIG 1 • Soft palate closure. **A.** The incisions follow a zigzag line between the soft and hard palate. A posterior vomer flap is dissected, which has its base at the posterior-cranial part of the vomer. **B.** Both sides of velum are divided into two layers: the oral mucosa and the nasal mucosa. **C.** The muscles including the nasal mucosa are cut at the border of the hard palate. **D.** The muscles are redirected to a transverse course, sutured together medially in a posterior position, and also attached anteriorly to the backward-turned vomer flap. **E.** The muscles and the raw surface of the vomer flap are covered by the oral flaps, which are pushed in a medial-posterior direction.

■ Hard Palate Repair

- Incision lines are made for a flap on the noncleft side using palatal mucoperiosteum. The flap is based on the vomer (vomer flap). On the cleft side, an incision is made at the cleft border (**TECH FIG 2A**).
- The vomer flap is raised leaving a raw bone surface on the noncleft side (**TECH FIG 2B**).
- Suturing starts on the oral mucosa, going into the pocket between the bone and the mucoperiosteum. The needle catches the vomer flap from the mucosal side, coming out on the raw side, going back to the mucosal side and thereafter into the pocket and out on the mucosal side. Therefore, the knots are tied on the mucosal side (**TECH FIG 2C**).



TECH FIG 2 • Repair of a residual cleft in the hard palate. **A.** Incision lines. On the noncleft side, the incision goes into the flat medial part of the palate. On the cleft side, the incision is made at the cleft border between the oral and nasal mucosa. **B.** The vomer flap is raised. It contains some oral mucosa leaving a raw bone surface in the medial part of the palate on

the noncleft side. Sutures are put to bring the vomer flap into the incision on the cleft side. **C.** The vomer flap is brought into the pocket between bone and mucoperiosteum on the cleft side. Suturing starts on the oral mucosa going into the pocket between the bone and the mucoperiosteum. The needle catches the vomer flap from the mucosal side, coming out on the raw side and then going back to the mucosal side and thereafter into the pocket and out in the mucosa. Pulling the suture will bring the vomer flap into the pocket between the bone and the mucoperiosteum. Four or five sutures are placed. **D.** The vomer flap sutured in place. **E.** The mucoperiosteum on the cleft side is sutured to the vomer flap in order to ensure good attachment.

- Four to five such sutures are placed.
- Pulling the suture will bring the vomer flap into the pocket between the bone and the mucoperiosteum (**TECH FIG 2D**).
- When the vomer flap is well positioned under the mucoperiosteum of the cleft side, sutures are tied, keeping the vomer flap in place and also covering the residual cleft with a one layer closure (**TECH FIG 2E**).
- Additional sutures are put at the border of the cleft, keeping the raw surface of the vomer flap attached to the raw surface of the mucoperiosteum on the cleft side, thereby ensuring good healing (**TECH FIG 2E**).

PEARLS AND PITFALLS

Diagnostic studies

- Nasendoscopy and videofluoroscopy are reserved postoperatively for cases demonstrating persistent VPI following palate repair.

Rationale for

- Delayed hard palate repair is done to optimize both speech and palatal growth.

delayed hard palate repair	■ Soft palate closure is performed early to promote speech. ■ Hard palate closure is delayed until 2 y of age to promote growth.
Posteriorly based vomer flap for soft palate closure	■ Base of the flap lies at the junction of the vomer with the cranial base and does not extend anteriorly to the vomeropalatine suture. ■ Results in anchorage of the anterior part of the soft palate to the base of the vomer flap ■ Improves the posterior positioning of the levator muscles and thereby reducing VPI
Soft palate repair	■ Insertions of the velar muscles and the nasal mucosa at the posterior border of the hard palate are cut. ■ The nasomuscular flaps are reconstructed to a transverse course at the level of the opening of the Eustachian tube. ■ The nasal layer of the nasomuscular flap is connected anteriorly to the vomer flap.
Hard palate repair	■ Closure is performed with a mucoperiosteal vomer flap raised from the noncleft side and sutured to the mucoperiosteum at medial edge of the cleft side. ■ Lateral mucoperiosteal dissection is avoided to minimize subsequent restriction of maxillary growth.
Outcomes	■ Long-term outcomes for both speech and growth have not been surpassed by any other surgical procedure for palate closure.

OUTCOMES

- Long-term growth and speech outcome are excellent in patients with two-stage palatoplasty with early soft palate repair and delayed hard palate repair.^{1,2}
- Results from growth studies and speech evaluation have not been surpassed by any other surgical procedure for palate closure.

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CHAPTER Furlow Palatoplasty

T. Guy Thorburn

DEFINITION

- Furlow Palatoplasty is widely used technique for repair of either cleft palate (CP) or submucous cleft palate (SMCP). It can also be used in revision palate repair. Some surgeons who routinely use a Sommerlad repair for complete CP will instead use a Furlow for SMCP.
- The technique is based on the concept of lengthening the soft palate by use of “Double-opposing Z-plasties.” This involves mirror-image Z-plasties to the oral and nasal layers while also repositioning and reconstructing the levator muscle mechanism by keeping the levator palatini muscle on each side attached to the limb of the Z-plasty that moves posteriorly (**FIG 1**).¹
- Randall has described a variation for wider CP that involves using Langenbeck-type lateral releasing incisions to relieve the tension on the oral Z-plasty (**FIG 2**).²

ANATOMY

- The key functional issue in CP or SMCP is that the levator muscle mechanism is not in continuity on the two sides. In addition, the fibers become tethered to the posterior border of the hard palate. Successful functional palate repair therefore requires repair of the “levator sling” as well as just closure of the tissues across the cleft.
- The tethering to the hard palate seems to be an equal problem in differing types of cleft, whether unilateral or bilateral cleft lip and palate, cleft palate only, or SMCP.
- **Tip:** the oral layer of the soft palate is more elastic than the nasal layer, and the elasticity increases as you move from the hard palate–soft palate junction

toward the uvula. This means that the oral layer Z-plasty will tend to inset better with slightly wider flaps (closer to 80–90 degrees), whereas for the nasal layer, 60 degrees is sufficient. On the oral layer, the tissue elasticity is even greater in the posterior part of the palate, so the posterior limb is best designed slightly wider (around 90 degrees) as it will narrow after incision.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The initial assessment of the newborn with a cleft involving a palate would usually be alongside a pediatrician and will include:
 - Pregnancy and birth history (including information from any antenatal testing), gestation, birth weight, and Apgar scores.
 - Initial assessment of cleft type and any related anomalies, including any airway concerns suggesting Robin sequence.
 - Medical history, drug history, and allergy history.
 - Family history of clefts, other major health problems, or anesthetic problems and any genetic diagnosis.
 - Feeding history including bottle type (eg, squeezable bottle, free flow, Haberman, etc.), current weight, maximum percentage weight loss and number of days to regain birth weight, and volume/duration/frequency of feeds.
 - Physical examination to assess the upper airways, cleft type, cleft width, and how much deficiency there is of surrounding tissues, as well as any related anomalies or dysmorphic features. The pediatrician would then complete a fully newborn examination, looking in particular for related health issues such as cardiac, respiratory, renal, or neurological signs.

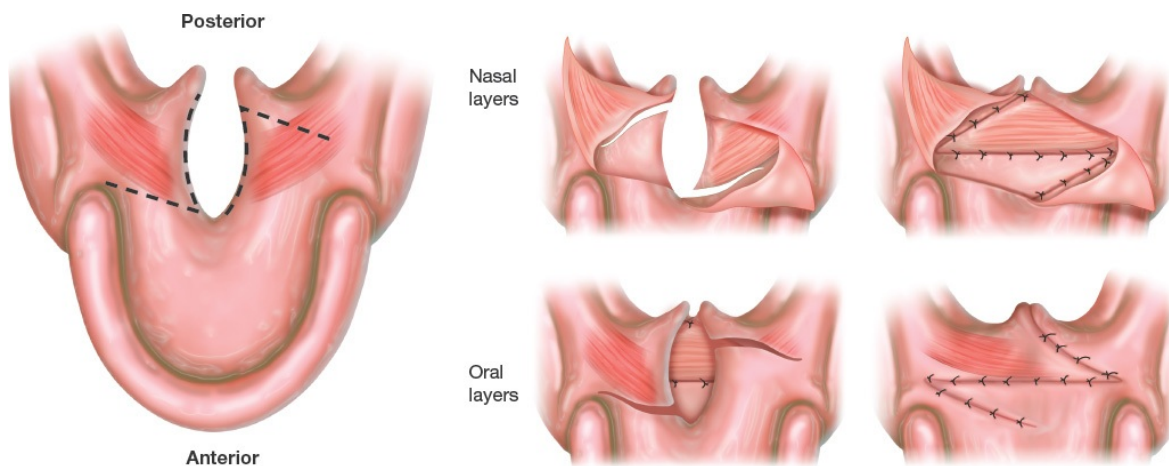


FIG 1 • Schematic diagrams of the Z-plasties of both

oral and nasal layers before and after inset.

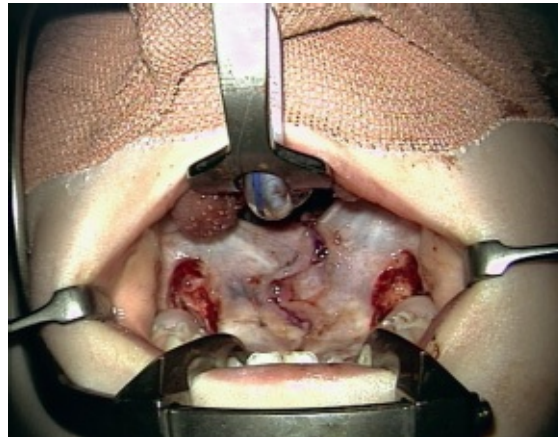


FIG 2 • The variation described by Randall utilizing lateral releasing incisions (von Langenbeck) for wider or more complete cleft palate.

IMAGING

- No routine preoperative imaging is required for typical clefts. For older children presenting with SMCP or velopharyngeal incompetence (VPI), assessment with a speech lateral videofluoroscopy helps to assess the position of the levators and relative size of the soft palate to the size of the pharynx.
- Standardized preoperative clinical photos should be taken as these are invaluable when assessing outcomes many years later.

SURGICAL MANAGEMENT

Preoperative Planning

- A key aspect of successful cleft palate repair is in optimizing the patient prior to surgery. A pediatrician is a crucial member of the Cleft team. Although there is much discussion of age at palate repair, different team protocols vary from around 3 months old to 15 months or more. Very young babies will tend to be more susceptible to airway compromise around the time of surgery. Delaying repair until much older and speech has developed has been associated with poorer speech outcomes, particularly related to articulatory errors.
- **Tip:** our team protocol is for palate repair around 8 to 12 months (corrected for prematurity), but our emphasis is much more on ensuring the child is well

and thriving in the run-up to surgery. If they are not growing along their expected percentiles (with growth plotted on the appropriate chart for syndromic children), then we would want to address this before surgery. We will also routinely postpone for about 4 weeks if children have upper respiratory tract infections. By following this approach, we have seen a significant reduction in fistulae and concerns with speech function.

- Routine blood tests or cross match samples are not required, unless the child is known to have a specific risk factor.
- For children, with cardiac or respiratory problems, an up-to-date echocardiogram or sleep study may be relevant.

Positioning

- A south-facing Rae uncuffed or microcuffed tube is used. The taping of the tube needs to be secure but avoiding taping the mouth closed or limiting access. Taping in a V shape along the line of the mandible avoids displacing the tapes when the gag is opened.
- The child is placed supine on a warming blanket, with the head at the very end of the operating table. A large horseshoe gel head ring is placed under the shoulders and around the head to provide support without overextending the neck.



FIG 3 • Applying a sticker across the head drapes as a warning that the throat pack is in place, so that the drapes cannot be removed without first removing the sticker.

- A head drape is applied, and the face is prepped.
- **Tip:** we use a clear plastic drape [3M Steri-Drape Fluoroscope Drape 90 ×110 cm] over the trunk, which allows the anesthetist to see their endotracheal tube and circuit without disturbing the surgical field. We avoid any adhesive drapes near the endotracheal tube as these have the potential to catch and dislodge the airway.
- The table is tilted to a slight head-up position. An operating microscope is used for the procedure. The height of the table is adjusted once the microscope has been brought in to place (adjusted according to whether the surgeon prefers to sit or stand).
- A modified Dingman mouth gag is placed.
- A throat pack is placed, and a marker sticker put across the drapes as a reminder to ensure it is removed at the end. The sticker is placed so that the drapes cannot be removed without needing to disturb the warning sticker (**FIG 3**). The throat pack is also included in the scrub nurse count as an additional precaution.
- The nose and mouth are rinsed with aqueous chlorhexidine solution.

Approach

- The width of the cleft is measured, and any unusual features are noted.
- The incisions are marked with pen and ink. Depending on tissue condition and tension, the limbs of the oral Z are usually about 8 to 10 mm long. The angles are usually 80 to 90 degrees (slightly wider on the limb in the posterior soft palate) (**FIG 4**).
- **Tip:** for a right-handed surgeon, the oral layer Z is typically marked with the posteriorly based limb (where the muscle remains attached to the flap but has to be dissected from the nasal layer) on the left. This will tend to give the easiest access to the hardest part of the dissection.



FIG 4 • Oral layer markings for a standard Furlow palatoplasty. Note the angles of the Z are wider than for the skin, approaching 80 to 90 degrees.

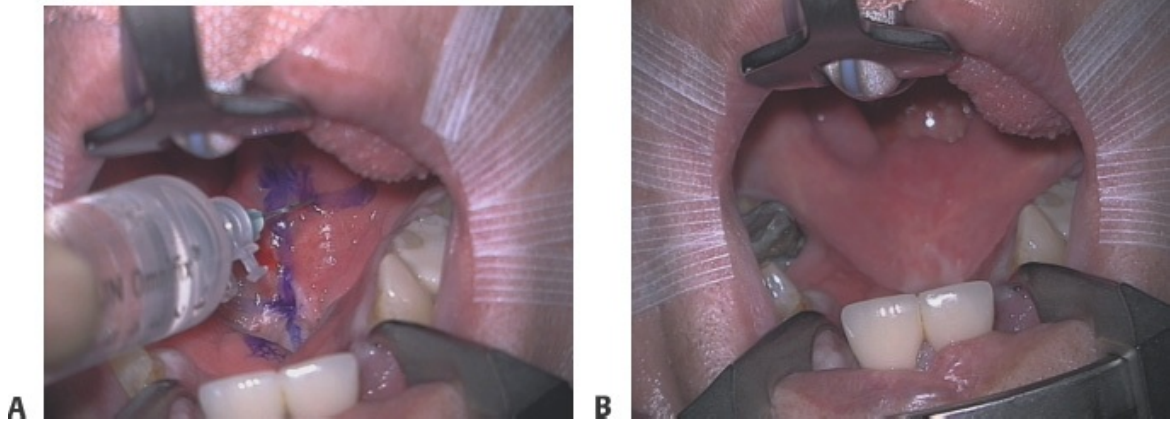
TECHNIQUES

■ Hard Palate

- Levobupivacaine or bupivacaine long-acting local anesthetic with adrenaline 1:100 000 is infiltrated and left about 7 to 8 minutes for vasoconstriction (**TECH FIG 1A**). The injection is used to help hydrodissect the hard palate subperiosteal layer.
- **Tip:** Steri-Strips are placed to protect the corners of the mouth from abrasion by instruments (**TECH FIG 1B**).
- The incision is begun along the cleft margin (or in the midline for a SMCP or rerepair).
- For clefts involving the hard palate, incise carefully down to the bone along the margin of the hard palate and 3 to 5 mm past the hard palate–soft palate junction and elevate subperiosteally with a raspatory or Warwick-James elevator. Be careful approaching the posterior nasal spine as the tissues are more adherent here, and it is easy to tear the oral layer if there is a tethered salivary gland at this point. Switching between 15 blade and raspatory is usually necessary. **Tip:** for incising the margin of the rest of the soft palate and back to the uvula, a 12 blade tends to be easiest.
- Depending on the cleft type, it may be necessary to raise vomer flaps to help

close the nasal layer without tension.

- After raising the vomer flaps, elevate the nasal layer off the hard palate (again in a subperiosteal plane) with a raspatory or dental flat plastic.

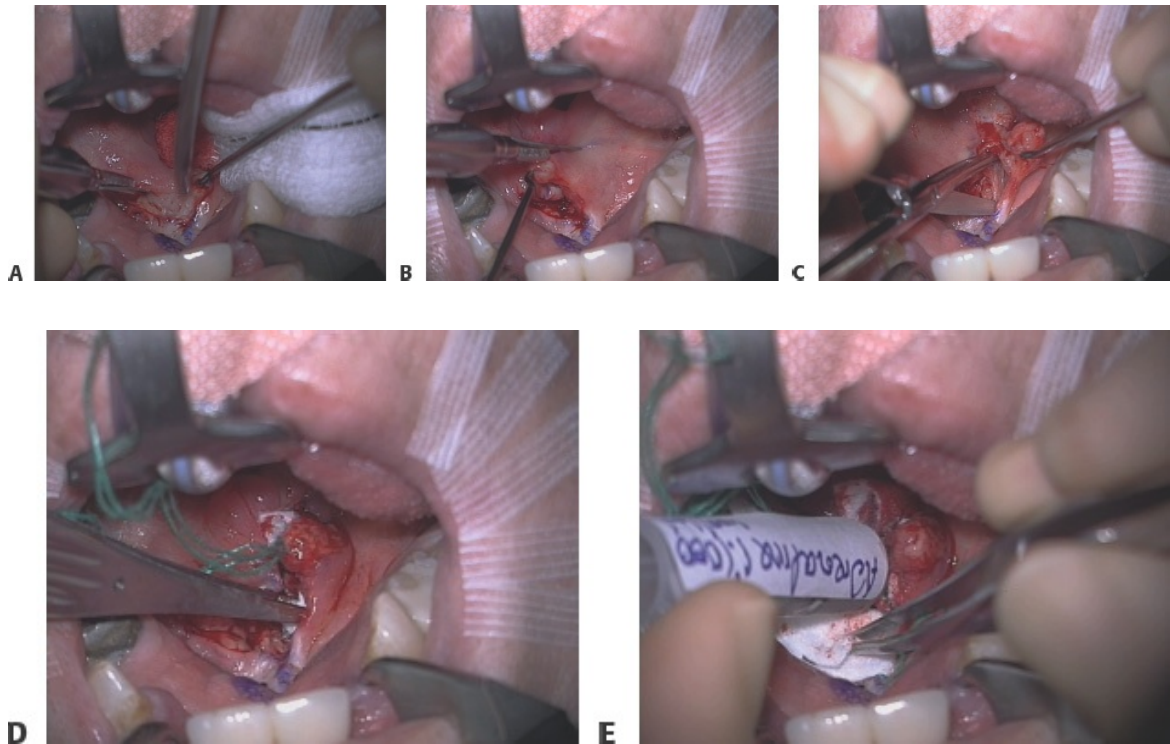


TECH FIG 1 • A. Infiltration of local anesthetic with a Luer-lock syringe, using the infiltration to hydrodissect. **B.** Steri-Strip “cat’s whiskers” to protect the oral commissures during the procedure.

■ Oral layer

- A skin hook is placed on the left margin of the cleft, where the incision has been marked to create the posteriorly based flap. Using the skin hook to tension, a 15 blade is used to incise the oral layer and muscle, down to the nasal layer (which is left intact) (**TECH FIG 2A**).
- The muscle is then freed carefully from the nasal layer with the 15 blade and/or dissecting scissors. Keeping tension on the muscle toward the midline (rather than posteriorly or superiorly) makes this dissection easier without buttonholing the nasal layer.
- The muscle is freed off the nasal layer out toward the hamulus, so it is dissected more laterally than the extent of the oral layer incision.
- On the right side, the opposite flap is raised in a similar way but leaving the muscle intact on the nasal layer (**TECH FIG 2B,C**).
- **Tip:** after incising the leading edge of the posteriorly based oral flap and elevating the anteriorly based flap, then applying topical 1:1000 adrenaline on neuro patties provides excellent vasoconstriction and facilitates the

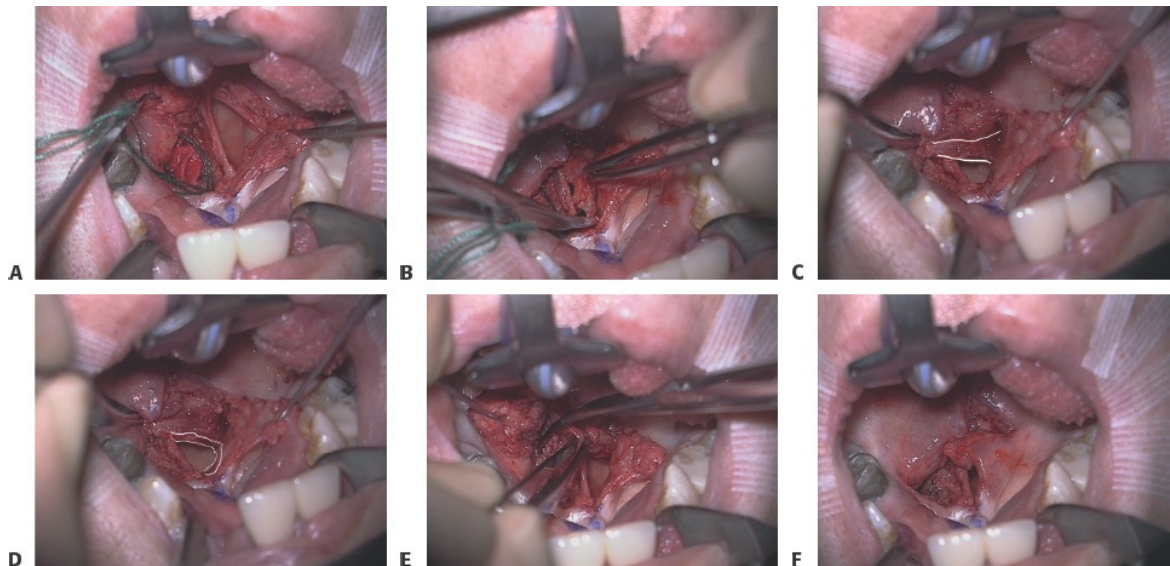
subsequent dissection (**TECH FIG 2D,E**).



TECH FIG 2 • A. Incising the oral layer posteriorly based flap (the muscle and mucosa flap on the left side of the palate). **B.** Raising the oral layer anteriorly based flap (the mucosa-only flap on the right side of the palate). **C.** Spread dissection with scissors can be very useful for identifying the plane between the muscle and the mucosal flap. **D,E.** After the initial dissection of the oral layer, topical 1:1000 adrenaline helps with the next stage of dissection by vasoconstricting. First, neurosurgical patties are placed in the wound to keep the solution in the desired area, and then 1 mL of 1:1000 adrenaline solution is dripped onto the patties.

■ Nasal layer

- To make access easier for the stage, a stay suture can be used to hold the oral flaps out of the way if the surgeon prefers, or the assistant can use a dental flat plastic or skin hook to do this (**TECH FIG 3A**).
- The nasal Z-plasty is a similar size to the oral layer. The angles are usually just over 60 degrees.
- On the nasal layer, the Z-plasty is a mirror image of the oral layer Z-plasty. At this stage, the muscle is present and attached to the nasal layer on the right side, while on the left, the nasal layer has already been dissected bare.
- A skin hook in the margin on the right side is used to place tension toward the midline. The posteriorly based flap is then raised by incising the nasal layer and muscle together with a 15 blade and/or dissecting scissors (**TECH FIG 3B**). The nasal layer is kept adherent to the muscle (**TECH FIG 3C**).
- **Tip:** when incising the muscle/nasal layer on the right, plan to keep a rim of the tensor aponeurosis tissue intact. This makes it much easier to inset the contralateral flap during closure.
- As with the muscle on the oral layer, it is necessary to free the muscle more laterally than the limit of the nasal layer incision.
- Once the posteriorly based flap is fully mobilized, hold it across to the opposite side to check the position of the nasal layer-only flap (**TECH FIG 3D**).



TECH FIG 3 • A. The longitudinal incision in the nasal layer. Note the effectiveness of the adrenaline, making

it much easier to see the correct planes. **B.** Incising the posteriorly based nasal layer flap (the muscle and mucosa flap on the right of the palate). Gentle traction of the muscle bulk toward the midline, as opposed to lifting or posteriorly, allows clean incision with either scissors or 15 blade. **C.** As the flap is incised and repositioned, the levator muscle (*marked*) comes into view on the nasal aspect of the other muscle fibers. **D.** Designing the flap in order to leave a rim of the tensor aponeurosis (*marked*) makes subsequent suturing of the flaps much easier. **E.** After checking the position with the right sided flap, the anteriorly based nasal layer flap is incised (the mucosa-only flap on the left side of the palate). **F.** Position of flaps at rest before inset. Assuming correct design of the flaps, they will tend to want to move toward their new positions, and the palate is already visibly lengthened.

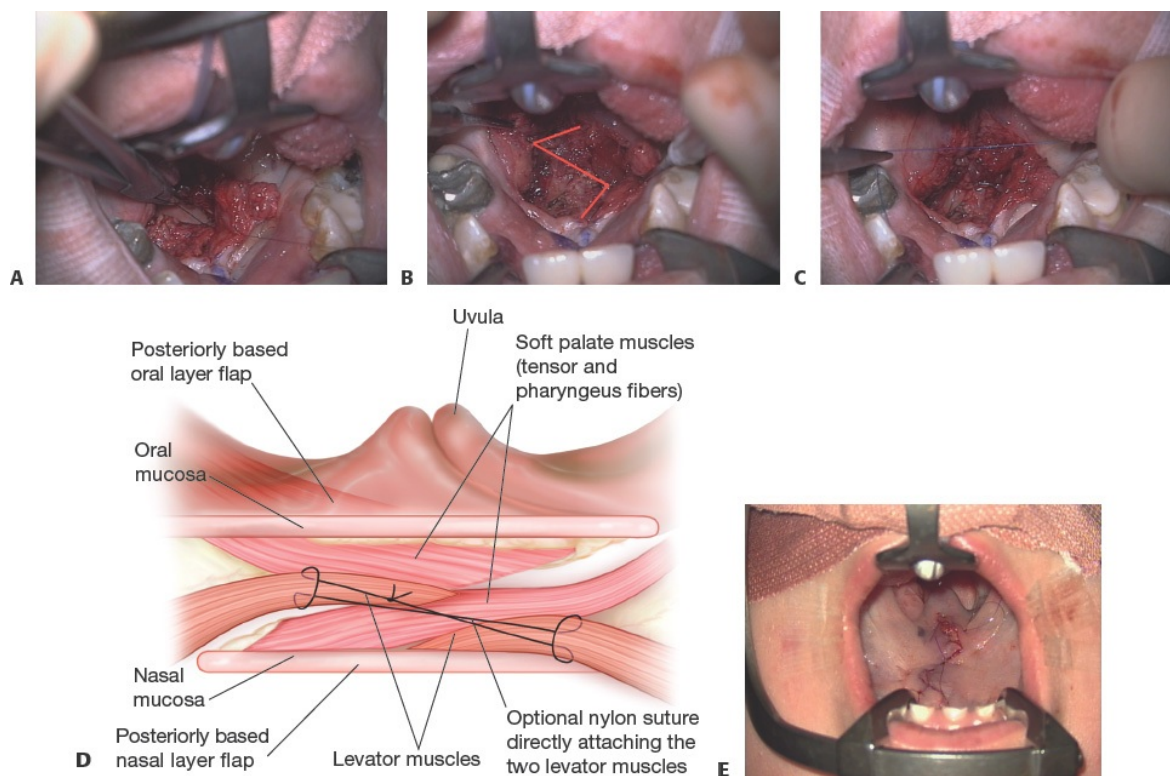
- Then incise the anteriorly based nasal layer flap on the left side (**TECH FIG 3E, F**).

■ Closure

- Start with the inset of the nasal flaps—it is usually easier to begin by inseting the posteriorly based flap. A resorbable monofilament suture is used, preferably with a round or tapercut needle to avoid inadvertent tears of the mucosa. We use 5-0 Monocryl plus on the nasal layer and 4-0 Monocryl on the oral layer (**TECH FIG 4A,B**).
- **Option:** although this technique provides good overlap of the muscle mass on two sides, it is worth noting that the two levator muscles are not directly opposed or joined. Some surgeons therefore choose to directly suture the levators as well. In this situation, first complete inset of the nasal layer. Then a 5-0 nylon suture is placed through the levator muscle which is visible on the underside of the left oral layer flap. The oral flap is then held out to

length to allow placement of the suture to pick up the levator muscle on the right side (**TECH FIG 4C**). This muscle is lying out of direct sight on the deep aspect of the muscle that is attached to the nasal layer on the right side (**TECH FIG 4D**).

- The oral flaps are then inset. McGregor corner sutures combined with Barron sutures to the flap edges allow the avoidance of knots or ischemic areas at the distal ends of the oral mucosal flaps (**TECH FIG 4E**). If the oral flaps appear too tight, they can be inset a little short with a raw area left laterally.
- The local anesthetic is topped up.
- The throat pack is removed.



TECH FIG 4 • A. The nasal layer flaps are inset first; the rim of tensor aponeurosis makes suturing the nasal layer easier. **B.** The position of the nasal layer flaps after inset is complete. **C.** With inset of the nasal and oral layer posteriorly based flaps, the levator mechanism has been repositioned. But in the classic Furlow, the two levator muscles are not directly

connected, which can give an asymmetric lift of the palate. Therefore, some surgeons prefer to place permanent nylon mattress sutures directly connecting the two halves of levator. **D.** A schematic diagram of the soft palate in cross section to show the layers of the oral and nasal Z-plasties and the inset of the levator mechanism. **E.** The position of the oral layer flaps after inset is complete.

■ **Alternative: Z-Plasty with Intravelar Veloplasty**

- It is possible to use a hybrid of a Sommerlad and a Furlow approach. This can be particularly useful in SMCP.
- Preparation, draping, and hard palate are the same as above.
- The oral layer is raised as per a Sommerlad repair but is marked out a Z-plasty as for a Furlow repair.
- Incision and retraction of the Z-plasty flaps can give easier access for the muscle dissection (radical intravelar veloplasty) which is the same as for a Sommerlad repair.



TECH FIG 5 • The marking for the nasal layer Z-plasty at the base of the uvula in the hybrid procedure.

- The muscle is dissected off the nasal layer on both sides.
- A Z-plasty is then made in the posterior 1/3 of the nasal layer (in a mirror

image of the oral layer Z-plasty) (**TECH FIG 5**).

- **Tip:** a principle of Z-plasties is that increased length is achieved by redistributing tension in a lateral direction. Therefore, placement of the Z-plasty on the posterior 1/3 of the nasal layer, toward the base of the uvula, means that the lateral tightening achieved by the process of inseting the Z-plasty also tightens the velopharyngeal port.
- The muscles on the two sides are sutured with three 5-0 nylon mattress sutures, aiming to pick up both the levator muscle and the tougher tensor aponeurotic tissue with each bite. The knots must be tied very carefully to allow the ends to be cut extremely short.
- The oral layer is then closed with inset of the Z-plasty.

PEARLS AND PITFALLS

Timing of surgery

- Careful optimization of the baby prior to surgery is important; good growth following percentile lines is a useful indicator—a thriving baby at the time of surgery is more important than a specific age.

Shared airway

- As with all “shared airway” surgery, it is important for the anesthetist and surgeon to communicate well with each other—the WHO checklist and team brief are very useful for this.

Operating microscope

- The routine use of the operative microscope for palate repair gives excellent lighting and visualization of the operative field. It is also very helpful for giving trainees a better view and involvement, as well as reducing the strain on the surgeon’s neck.

Postoperative elevation

- Nursing the baby “head-up” in the recovery room and on the ward after surgery is helpful for reducing postoperative swelling—cuddling the baby over the parent’s shoulder tends to give ideal positioning.

POSTOPERATIVE CARE

- Topping up the local anesthesia with a long acting agent at the very end of the operation is useful for postoperative comfort and feeding.
- Nurse the baby with head elevated.
- Babies can be offered feeds straight away once they are awake.

- Monitor airway and saturations especially over the first night after surgery.

OUTCOMES

- The main outcome measures for cleft palate repair are fistula rate, structural speech problem rate, need for secondary surgery, and impact on maxillary growth.³
- There has been a systematic review comparing Furlow with straight-line repairs. This shows considerable variation in outcomes according to the cleft type. The average fistula rate ranged from 2.6% to 11.6% with different cleft types. The hypernasality rate (indicating structural speech problems) ranged from 8.9% to 18.5%, and the secondary surgery for speech rate ranged from 0% to 11.4%. There is a lack of data on the effect of maxillary growth from Furlow repairs, even though that was a starting focus in Furlow original description.⁴

COMPLICATIONS

- Infection, significant bleeding, and transfusion are all rare after palate surgery.
- Airway compromise is a potential risk especially in babies with Robin sequence and in younger/smaller babies.
- Fistula is reported to have a lower incidence than in some other techniques of palate repair in some series, but there is wide variation between series, and the extent and width of the cleft palate play a major factor in the fistula rate.
- Speech problems—whether VPI or “cleft type characteristic” articulatory errors.

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9 von Langenbeck

Palatoplasty

CHAPTER

Kathryn V. Isaac and David K. Chong

DEFINITION

- Cleft palate is the failure of fusion of the palatal shelves during embryological development.
- There are many surgical techniques used for cleft palate repair. The repair technique chosen varies depending on the type of cleft palate and beliefs regarding facial growth and speech repercussions¹.

ANATOMY

- Embryologically, the cleft may affect the primary or/and secondary palate.
- Anatomically, the cleft is defined according to the involvement of the hard and soft palates.
- A complete cleft of the palate is defined as a cleft involving both the primary and secondary palates. Hence, a complete cleft involves the soft palate and the hard palate.
- The Veau classification (**FIG 1**) provides a clinically useful description of the cleft type according to the involvement of the alveolus, the hard palate, and the soft palate. It guides selection of the surgical treatment.²
- The von Langenbeck palatoplasty is most commonly employed for incomplete cleft palates, where the primary palate is unaffected (ie, soft palate and hard palate to incisive foramen) or where the primary palate was previously repaired (commonly with a superiorly based vomerine flap at the time of lip repair).^{1,3}
- Von Langenbeck palatoplasty is less commonly used to repair isolated clefts of the soft palate (Veau I) and mostly employed to repair clefts of the soft palate and secondary palate [hard palate posterior to the incisive foramen (Veau II)].

- This technique may also be modified for complete clefts and is named a hybrid procedure.⁴ This hybrid procedure employs the bipediced von Langenbeck flap on the greater segment and a unipedicled flap on the lesser segment. It is not used for the treatment of submucous clefts.
- Additionally, the von Langenbeck technique of a bipediced mucoperiosteal flap may be used for the repair of fistulae located in the hard palate or junction with the soft palate.

PATHOGENESIS

- The etiology of cleft palate is multifactorial: environment, teratogen exposure (alcohol, anticonvulsants, steroids, diazepam), nutrition, maternal infections (rubella, toxoplasmosis), and genetics.
- Cleft palate repair restores anatomical closure between the oral and nasal cavities.
- An unrepaired cleft palate may result in impaired breathing, feeding, speech, and hearing.

NATURAL HISTORY

- Orofacial clefting is the most common craniofacial birth defect, occurring in 1:750 live births.⁵
- The incidence of cleft palate alone is 1:2000, with a female-to-male ratio of 2:1.
- The incidence of cleft palate in combination with cleft lip is greater, estimated at 1:1000 with a reverse gender ratio.
- In the population of children with cleft lip and/or cleft palate (CL+/-P), approximately 50% will have CLP, 30% to 35% CP, and 15% to 20% CL.

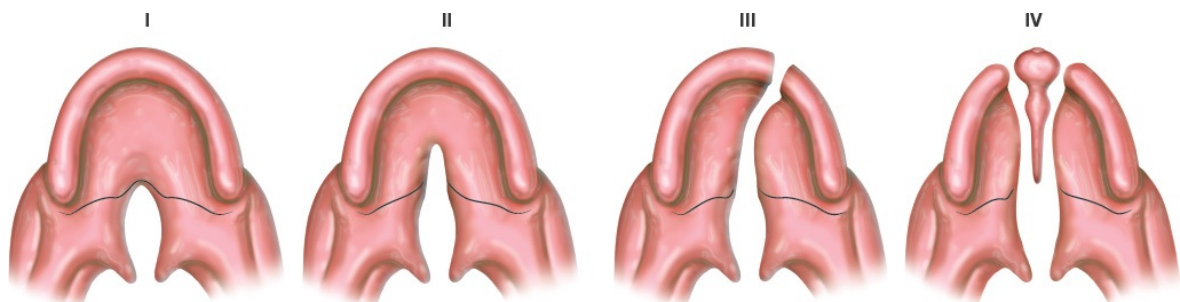


FIG 1 • Veau classification of cleft palate types. I. Cleft of soft palate only. II. Cleft of secondary hard and soft palates. III. Unilateral cleft extending through secondary

hard and soft palate, through right or left primary palate, and through the alveolar process. IV. Bilateral cleft through secondary hard and soft palate, through bilateral primary palate and bilateral alveolar processes.

- Approximately 40% of CP patients will have a syndrome, and 15% of CLP will have a syndrome.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The diagnosis of a cleft palate is made by prenatal ultrasonography or by physical examination at birth and in early infancy. A detailed assessment is made of the child's breathing, feeding, growth, and development.
- Airway assessment must exclude the presence of sleep apnea and micro-/retrognathia.
- Assessment of growth and weight is key to identify and monitor feeding difficulty, gastroesophageal reflux, and the use of feeding aids (Haberman/Pigeon test).
- Hearing and middle ear function must be assessed and treated early by an otolaryngologist.
- The plastic surgeon should define the cleft palate type according to the anatomic structures involved, the laterality, width of the palate, and the presence/absence of a cleft lip.
- Also, the child should be assessed for associated anomalies suggestive of a syndrome: craniofacial dysmorphism, airway compromise, cardiac defects, ocular and auricular abnormalities, and musculoskeletal anomalies. A genetics referral is suggested if suspicious for a case of syndromic cleft palate.

DIFFERENTIAL DIAGNOSIS

- Syndromic cleft palate
 - Van der Woude syndrome
 - Stickler syndrome
 - Robin sequence
 - 22q11.2 deletion syndrome
 - Treacher Collins syndrome
 - Nager syndrome
 - Ectrodactyly-ectodermal dysplasia

- Klippel-Feil syndrome

NONOPERATIVE MANAGEMENT

- It is very uncommon not to repair a cleft palate.
- If the child is unable to undergo surgical treatment secondary to airway concerns or medical fitness, a palatal obturator may be considered.
 - Such patients should be reassessed on a regular basis (at least annually), as they may become sufficiently stable for delayed surgical correction of the cleft palate.

SURGICAL MANAGEMENT

- Cleft palate repair is ideally performed between 9 and 12 months of age, with the infant weighing greater than 8 kg.
- Airway and middle ear disease assessment is performed and treated prior to or simultaneously with cleft palate repair.
- Risks of the procedure are hemorrhage/hematoma, airway compromise, wound dehiscence, infection, oronasal fistula, flap necrosis, velopharyngeal insufficiency, and reduced midfacial growth.
- The main objectives of the cleft palate repair are:
 - To separate the oral and nasal cavities
 - To reposition the velar musculature for restoration of the velopharyngeal sphincter, in particular the reconstruction of the levator muscular sling
 - To improve Eustachian tube function
 - To minimize detrimental effects on subsequent maxillary growth
- The goals of the palatoplasty are to improve feeding and speech.
- The main steps of the procedure are:
 - Marking and elevation of bipediced mucoperiosteal flaps off the hard palate
 - Dissection and separation of the nasal mucosa, velar musculature, and oral mucosa
 - Careful dissection of pedicles (greater palatine artery)
 - Tension-free closure of nasal mucosal layer
 - Reconstruction of the velopharyngeal sphincter with repositioning of the levator sling
 - Recreation of the uvula
 - Closure of the oral mucosal layer

Preoperative Planning

- With the patient anesthetized, the width of the cleft is measured at the junction of soft and hard palate. The width of the cleft is important to predict difficulty of the cleft palate repair and anticipated amount of dissection required for closure.
- The von Langenbeck technique provides less flap mobilization relative to other techniques (two-flap palatoplasty). Thus, this technique is best reserved for narrow clefts.

Positioning

- The patient is positioned supine with shoulder roll to allow neck extension. An oral Rae tube, with the circuit directed caudally, is carefully taped centrally. Corneas are protected with eye taping.
- Access and visualization of the entire palate are very important and cannot be understated. It is especially important to ensure visualization from the uvulae to the anterior extent of the palate.
- It is essential for the surgeon to ensure positioning is correct prior to scrubbing. This will facilitate the procedure.
- The surgeon should have a headlight or lighted instruments for optimizing visualization in the confined space and a skilled attentive assistant.
- It is advantageous to have a bed that has Trendelenburg positioning capability. Some surgeons stand to perform palate surgery from below, but having the baby's head supported with the surgeon seated operating upside down provides the best exposure and is the preferred position by most surgeons.

Approach

- The aim of cleft palate surgery is tension-free closure of the palate oral and nasal mucosal layers and restoration of the velopharyngeal muscular sphincter.
- Difficulties anticipated include:
 - Access
 - Lighting
 - Bleeding obscuring visualization
- Surgical approaches differ with regard to the amount of dissection performed to achieve tension-free closure and muscle repositioning.
- Critical step is adequate exposure and dissection of tissues to provide comfort for the operating surgeon to achieve tension-free closure.
- Oral layer mobilization is largely dependent on careful mobilization of the

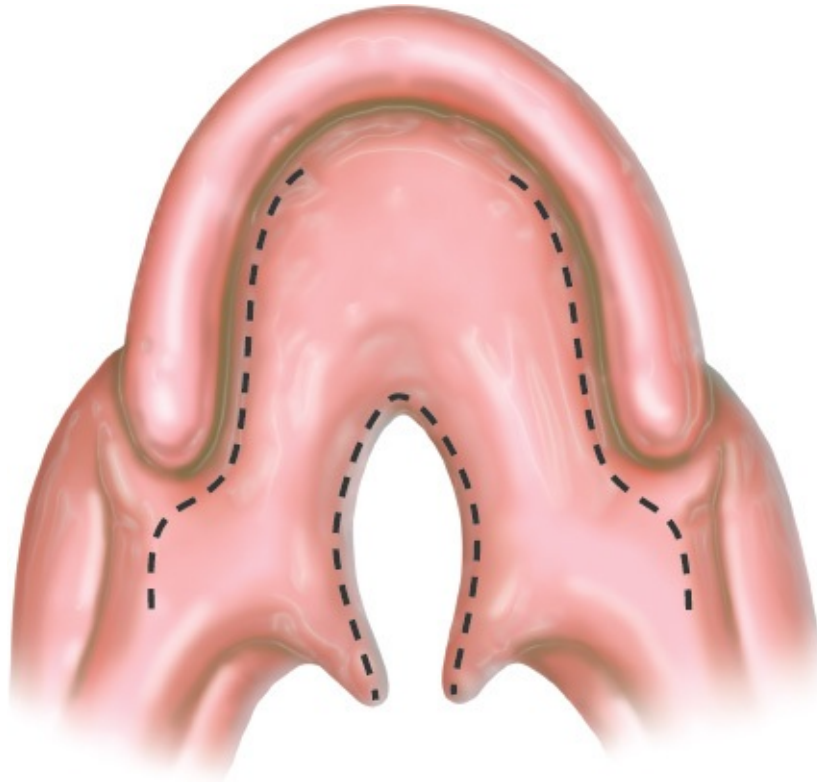
greater palatine artery from its periosteal sleeve.

- Nasal layer mobilization is largely dependent on careful mobilization of the mucosa as a sheet from its dense bony attachments.

TECHNIQUES

■ Markings

- Carefully insert an intraoral gag and a throat pack (it is the surgeon's responsibility to insert and remove).
- Mark the incision lines:
 - Along the medial edges of the cleft from the uvulae to the anterior extent of the cleft at the primary palate
 - Laterally at the junction of the hard palate and maxillary alveolus, extending from the posterior maxillary tubercle anteriorly to the level of the canine tooth (**TECH FIG 1**).
- Inject local anesthetic with adrenaline into the hard palate and soft palate (average of 8 mL).
 - The vasoconstrictive properties reduce blood loss and enhance visual field.
 - Local anesthetic also facilitates hydrodissection of the mucoperiosteal flaps off of the hard palate and tissue expansion for ease of layer dissection in the soft palate.
- Wait 8 minutes or until injection sites stop bleeding.

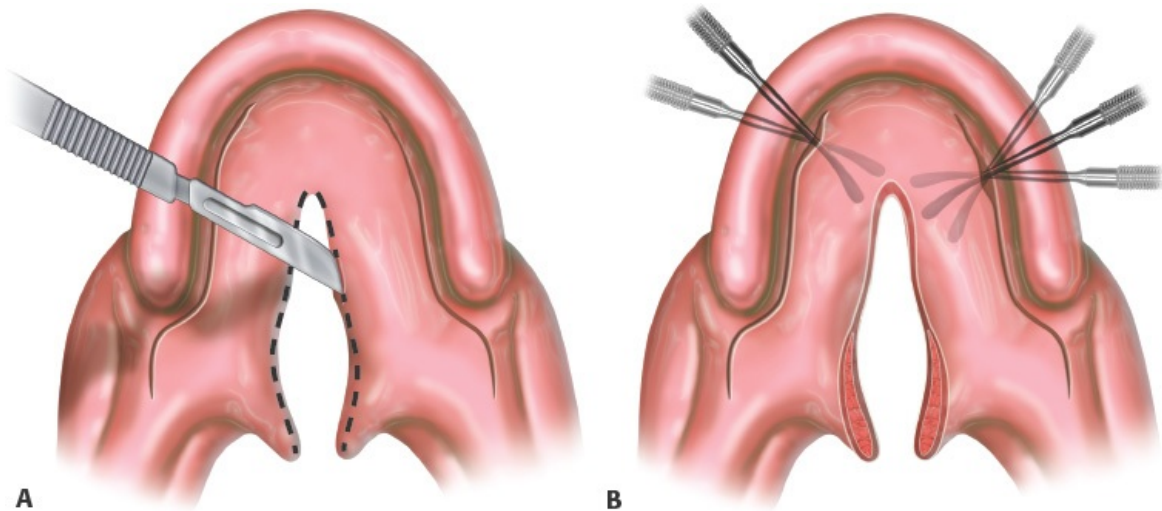


TECH FIG 1 • Incision markings of a von Langenbeck palatoplasty for cleft of the secondary palate.

■ Elevation of Oral Mucoperiosteal Flaps

- Perform incisions with needle tip cautery to reduce bleeding. Use a skin hook on the uvula or stay sutures for countertraction.
- Incisions, flap elevation, and pedicle dissection are done similarly on both the greater and lesser segments.
- Begin with lateral incisions: from the retromolar trigone along the junction of the alveolus and palate with diathermy down to the bone and slightly angled medially so as to avoid injury of developing teeth.
- For the medial incisions, palpate the posteromedial edge of the hard palate before incising to ensure the incision medially will be onto the bone (hard palate) as you can inadvertently cut into the nasal layer and do a “double cut” that reduces the available tissue for nasal layer closure (**TECH FIG 2A**).
- Oral palatal mucosa is susceptible to tearing so dissect continuously along the entire length of the lateral incision toward the cleft to elevate the mucoperiosteal flaps.

- Avoid “tunneling” as this can cause tearing of the hard palate mucosa due to dense periosteal attachments.
- Use a periosteal elevator to raise the mucoperiosteal flaps from lateral to medial beginning at the anterior extent of the incision (**TECH FIG 2B**).
- Dissect from anterior to posterior along the hard palate in sweeping motions toward the greater palatine foramina and posterior limit of the hard palate.



TECH FIG 2 • A. Incision of medial edge of cleft beginning at posterior-medial border of the hard palate, separating oral and nasal mucosal layers. **B.** Dissection of oral mucoperiosteal flaps.

■ Isolation of Greater Palatine Vessels

- As you approach the greater palatine artery at the posterolateral edge of the hard palate, the vessel becomes visible on the undersurface of the flap. The visibility of the pedicle is limited with this bipediced flap technique. Given the difficulty in visualization, the amount of dissection of the pedicle may be limited. Knowledge of the pedicle location will enable you to gently and circumferentially release the dense periosteal attachments around the pedicle.
 - A surface landmark for the pedicle is the dimpling in the mucosa near the posterior edge of the hard palate. This represents the dense periosteal attachments of the pedicle.
- Start laterally, and then work circumferentially around the foramina, staying

on the bone and taking care not to dissect into the artery or the leash of veins surrounding it.

- Staying on the bone during pedicle dissection is very important and rewarding for there are tethering ligaments that insert into the oral mucosa.
- Dissection directly off the bone facilitates the circumferential release of these ligaments, which otherwise make it exceedingly easy to tear the oral mucosa and injure the pedicle.
- Spreading of dissecting scissors parallel to the vascular pedicle will help to release some dense periosteal attachments; this should be done with care not to avulse the vessel.
- Previous hydrodissection during local anesthetic injection will also aid in finding the bloodless plane between the oral layer mucosal glands and the muscular layer.
- Complete circumferential pedicle dissection is achieved once the periosteal sleeve is released behind the greater palatine foramina, and the flaps can be mobilized toward the midline.
- It is critical for the surgeon to anticipate the location of the pedicle and appreciate the careful dissection to be completed with limited visibility, mainly using the lateral approach to perform the release.
- Once sufficiently mobilized, retract the flaps out of the surgical field with stay sutures, and secure to the intraoral gag/retractor.

■ Dissection and Separation of the Oral Mucosa, Nasal Mucosa, and Muscle

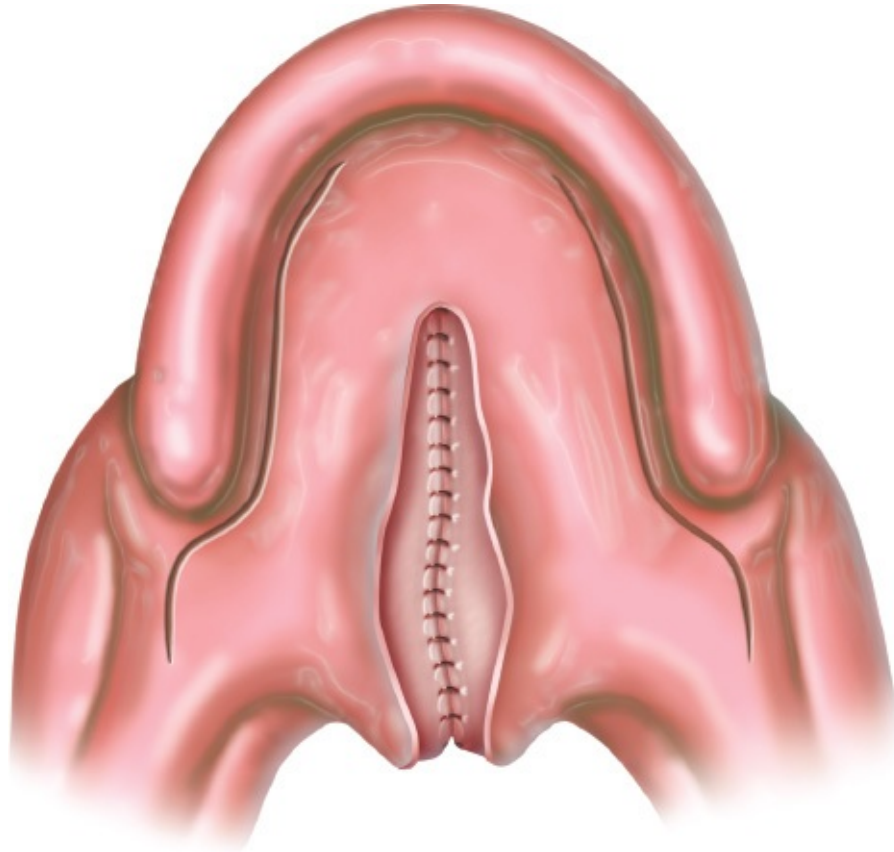
- Oral mucosa dissection: under magnification, dissect in the plane between oral mucosal glands and the muscle layer posteriorly in the soft palate from the edge of the bony palate to the uvula.
- Nasal mucosa dissection:
 - Mobilize the nasal mucoperiosteal layer with care, beginning on the lesser segment of the cleft. This requires the gradual and wide dissection of this continuous sheet of nasal mucosa, which is firmly attached to the hard palate along its medial and posterior edges, along the nasal surface of the bony palate and the medial surface of the medial pterygoid plate.
 - The elevation of the nasal layer anteriorly on the greater segment will necessitate elevation off the vomer.

- The nasal mucosa is even more unforgiving than the oral mucosa. Once a tear occurs, it is easy to propagate. Resist the temptation to tunnel before a whole edge has been liberated.
- To liberate the dense attachments of the medial hard palate, a Mitchell trimmer double-ended elevator or a similar blunt edged instrument is used.
 - The dissection starts at the cleft margin, scraping the oral surface of the bone until the edge of the nasal mucosa starts to be defined.
 - As the edge of the hard palate becomes apparent, elevate the nasal mucoperiosteum widely off the entire extent of the medial aspect of the hard palate.
- The judicious use of needlepoint diathermy on low setting can help to elevate firmly attached areas that are not easily released with the Mitchell trimmer.
- Once the edge of the nasal mucoperiosteal flap is defined, slide the trimmer around the corner of the hard palate onto the nasal surface of the bone staying right on the bone. If the edge is sufficiently liberated, sweep anteriorly and posteriorly to liberate the entire sheet off the nasal surface.
- If a portion of the edge is still attached, resist further sweeping until releasing the portion that remains tethered to prevent a tear.
- This dissection is continued to the posterior nasal spine.
 - At this juncture, there are always muscle attachments.
 - Release these aberrant velar muscle attachments with needlepoint diathermy.
- Continue dissection along the nasal surface following the posterior edge of the bone cephalad and lateral toward the medial surface of the medial pterygoid plate.
- Release the nasal mucoperiosteum directly off the bony surface of the medial surface of the medial pterygoid plate with careful dissection of the fibrous attachments.
 - Be patient and careful during the release of this densely adherent portion of the nasal mucosa working posteriorly and cephalad along the pterygoid plate and palatine bone.
 - Confirm complete release by directly visualizing the plane of the medial surface of the medial pterygoid plate.
 - If further release is required, the origin of the tensor veli palatini along the medial pterygoid plate may be severed to improve mobilization.

- The sheet of mucosa should now be freely mobile as one continuous sheet posteriorly and along the anterior medial hard palate.
- Attention is then turned to the greater segment.
 - The dissection of the nasal mucoperiosteal flap is identical posteriorly along the hard palate cleft margin.
 - Anteriorly, at the bony junction of the vomer and bony palate, the nasal mucoperiosteum is raised in continuity with the vomerine periosteum. This vomerine flap is raised cephalad directly off the bone and in continuity with the periosteum of the nasal surface of the hard palate.
- In a cleft of the secondary palate only, the caudal edge of the vomer is located in the midline of the two hard palate shelves.
 - The caudal vomer is incised in the midline and nasal mucoperiosteal flaps raised off each side of the vomer.
 - Both vomerine flaps are used for closure of the nasal lining anteriorly; each vomerine flap is secured to the ipsilateral hard palate nasal mucoperiosteal flap.
 - As you close the nasal lining from anterior to posterior, you will continue beyond the vomerine flaps and directly approximate nasal lining from the palatal shelves.

■ Closure of Nasal Mucosa

- Nasal layer closure is then commenced once assurance that the repair is tension free by checking that both sides are sufficiently liberated (**TECH FIG 3**).
- Meticulous closure is executed with knots tied on the nasal side.
- Small wedges are excised at the base of the oral surface of the uvula to assist closure.
 - Place eversion sutures during the closure of the uvulae to prevent notching or bifidity.
 - It is helpful to pare the musculus uvulae into a nasal and oral component during dissection so that musculus uvulae can be included in the suture closure of both oral and nasal layers of the uvula to further strengthen the closure.



TECH FIG 3 • Closure of nasal mucosal flaps from anterior extent of cleft to the uvula.

■ Dissection of the Muscle and Intravelar Veloplasty

- With the nasal layer completely closed, proceed with the muscle dissection and reconstruction of the velopharyngeal sphincter.
- Three steps are critical for muscle repositioning:
 - Identification and separation of levator veli palatini (LVP)
 - Velar musculature dissection and release from its attachments to the cleft margin and hard palate shelf
 - Velar musculature repositioning and repair
- Deep to the muscles inserted into the back of the bony hard palate, the LVP inserts abnormally at the cleft margin in the anterior half of the velum.
- Using a scalpel, sharply dissect the velar muscle layer off the nasal mucosa along the cleft margin. This is done with a paramedian incision lateral to the nasal mucosal closure line through the muscle until nasal mucosal surface is

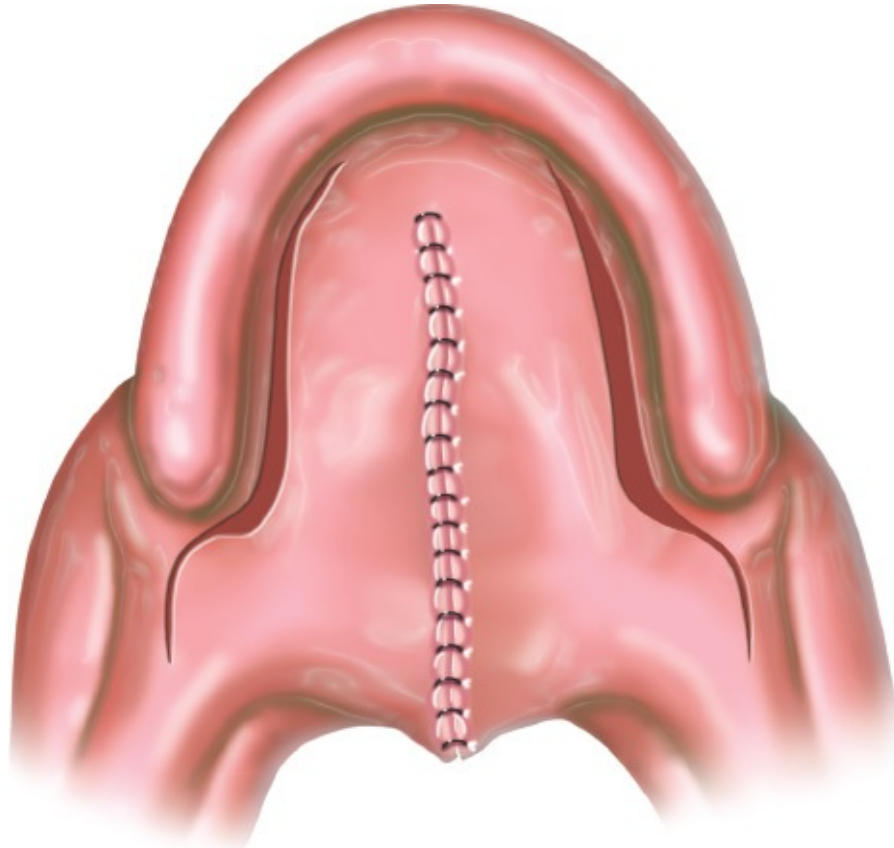
identified.

- It is easiest to separate the muscle layer once the nasal mucosa has been repaired to give a “trampoline” effect, providing tactile feedback and countertraction during this careful dissection.
 - The bulk and breadth of the muscle widen as you dissect laterally. This is analogous to the changing depth of a swimming pool, with a shallow end (paramedian) becoming deeper as one progressively dissects laterally.
 - The velar musculature is raised off the nasal mucosa and separated from the tendinous fibers of the tensor veli palatini (TVP). This separation is done laterally along the hard palate shelf at the junction of “salmon pink” velar muscle fibers and tendinous fibers of the TVP.
 - The velar musculature is further dissected until it can be freely mobilized to lie parallel to the posterior hard palate margin and overlying the contralateral velar muscle bundle.
 - You have completed the levator dissection when the “salmon pink”-colored longitudinal fibers of the levator are identified emerging from the skull base and the entire dissected muscle is free to be reoriented to a more functionally effective position in the posterior half of the soft palate.
 - The dissection of the velar musculature is performed on both sides.
 - Repair the muscles, and reconstruct the levator muscular sling by suturing the muscles and securing with multiple sutures, knots facing the nasal surface.
 - Ensure proper hemostasis is achieved.
-

■ Closure of the Oral Mucosa

- Close the oral layer beginning with stay sutures placed anteriorly and progressing posteriorly toward the uvulae with horizontal mattress sutures. There is no attempt of push-back of the flaps for lengthening with a V-Y closure (**TECH FIG 4**).
- During oral layer closure, place some full-thickness sutures through both the oral and nasal layers just posterior to the hard palate shelf (anterior to muscle repair) to help obliterate the dead space and position the muscle repair.
- Place interrupted simple sutures between each of the mattress sutures.
- Attempt to minimize raw bone exposure by closing palatal flaps to the alveolus wherever possible.

- Recheck for adequate hemostasis, irrigate, and remove throat pack.
- If concerned for airway during postoperative period, consider nasopharyngeal tube insertion and a tongue stitch. Note that a tongue stitch is rarely used in our practice.



TECH FIG 4 • Closure of oral mucosa after medialization of the bipediced flaps.

PEARLS AND PITFALLS

Headlight and positioning

- Good lighting and access to the palate are important

Pedicle dissection

- Visibility of the greater palatine foramina is limited. The release is accomplished with careful and near-

	circumferential dissection from the lateral approach. Complete the dissection from the medial approach.
Hemostasis	■ Ensure meticulous hemostasis throughout the case to optimize visualization. ■ Judicious use of needlepoint diathermy. ■ Failure to do so may result in airway compromise, flap necrosis, and wound dehiscence.
Use needlepoint diathermy to make hard palate incisions	■ Controls bleeding and persisting ooze.
Work on broad front	■ Avoid tunneling during dissection.
Patience and precision during dissection especially around palatine foramina	■ Bleeding obscures view, and careless dissection risks injury to pedicle and vascularity of the flap.
Handle tissues with care	■ The nasal mucosa is especially susceptible to tears.
Inset palatal flaps with stay sutures to help control closure	■ Helps to put the most difficult sutures anteriorly with stay sutures to judge closure and maintains good exposure.
Do not attempt closure until all layers are sufficiently mobilized	■ Prevents tearing. ■ If sutures are prematurely placed, further attempts to mobilize tissue are more likely to result in tears. Prematurely suturing may also result in tears if tension is still present.
Oronasal fistula	■ Critical to achieve adequate tissue dissection, perfect approximation, and apposition of tissue layers with meticulous suture technique to prevent fistulae.

POSTOPERATIVE CARE

- Nasopharyngeal tube as required.
- Remove tongue stitch in recovery if used.
- Analgesia to reduce blood pressure and distress (24 hours of intravenous opioids).

- Encourage feeding.
- Postoperative visit in 4 weeks.

OUTCOMES

- Primary von Langenbeck palatoplasty with levator reconstruction provides a reliable repair and good speech outcomes with 89% of patients having acceptable or normal speech.
 - Velopharyngeal insufficiency necessitated surgical correction in 11% of patients.
- The fistula rate of a cleft palate repair with a bipedicle flap technique is 10.2% (95% CI, 6.3% to 15%) according to a systematic review of international data.⁶
 - There was an observed trend toward higher fistula rates with bipedicle compared to unipedicle flap technique.
- The effect of palatoplasty on maxillary facial retrusion is controversial. Inherent maxillary growth deficiency, secondary scarring from palatal flap elevation, and timing of repair are all contributing factors to midfacial retrusion. Deleterious growth has been shown to be greatest in patients treated by Veau push-back technique.⁷
 - Further long-term studies are required to compare the effect of palatal flap technique on maxillary growth restriction.

COMPLICATIONS

- Bleeding is a feared complication as it may lead to an emergency with airway obstruction and respiratory compromise. Additionally, hematoma may lead to compression of the pedicle or flap, with resultant flap necrosis, wound dehiscence, and oronasal fistulae.
 - To prevent this complication, vigilant hemostasis is an absolute necessity, and adequate postoperative analgesia avoids stressing the repairs.
- Airway obstruction may occur in the absence of hemorrhage, and a tongue stitch or nasopharyngeal tube may assist in preventing obstruction in infants at risk.
- Flap necrosis is rare and avoidable with careful dissection and release of the periosteal sleeve of the greater palatine pedicle.
- Infection and wound dehiscence leading to oronasal fistulae are detrimental.
 - A small fistula secondary to delayed wound healing may heal with conservative measures.

- Failure of closure may necessitate reoperation with re-elevation and closure of oral and nasal flaps, as well as possible augmentation using local flaps and/or biologic adjuncts.

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CHAPTER Sommerlad Palatoplasty

T. Guy Thorburn

DEFINITION

- Cleft palate repairs can be broadly classified into straight-line repairs (such as the Sommerlad technique) vs Z-plasty repairs (such as the Furlow technique).
- Otto Kriens proposed the intravelar veloplasty based upon his work on the anatomy of the cleft palate.¹
 - Sommerlad then developed this dissection into a more radical procedure and popularized the technique.
- The underlying principle is identification and repositioning of the soft palate muscles, before connecting the levator muscle mechanisms from the two sides of the soft palate.

ANATOMY

- The key functional issue in CP or SMCP is that the levator muscle mechanism is not in continuity on the two sides. In addition, the fibers become tethered to the posterior border of the hard palate.
 - Successful functional palate repair therefore requires repair of the “levator sling” as well as closure of the tissues across the cleft.
- The tethering to the hard palate seems to be an equal problem in differing types of cleft: whether unilateral or bilateral cleft lip and palate, cleft palate only, or submucous cleft palate.
- The key functional muscle is the levator palatini, but the surrounding muscle/aponeurotic tissue is kept in continuity to allow more reliable tissue handling and repositioning and subsequent suturing.
 - Of note, the levator sits on the nasal aspect of the soft palate and so becomes visible only when the dissection is well underway.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The initial assessment of the newborn with a cleft involving a palate would usually be alongside a pediatrician and includes:
 - Pregnancy and birth history (including information from any antenatal testing), gestation, birth weight, and Apgar scores.
 - Initial assessment of cleft type and any related anomalies, including any airway concerns suggesting Robin sequence.
 - Medical, drug, and allergy histories.
 - Family history of clefts, other major health problems, or anesthetic problems and any genetic diagnosis.
 - Feeding history, including bottle type (eg, squeezzy bottle, free flow, Haberman), current weight, maximum percentage weight loss and number of days to regain birth weight, and volume/duration/frequency of feeds.
 - Physical examination to assess the upper airways, cleft type, cleft width and how much deficiency there is of surrounding tissues, as well as any related anomalies or dysmorphic features. The pediatrician would then complete a fully newborn examination looking in particular for related health issues such as cardiac, respiratory, renal, or neurological signs.

IMAGING

- No routine preoperative imaging is required for typical clefts. For older children presenting with SMCP or velopharyngeal incompetence (VPI), assessment with a speech lateral videofluoroscopy helps to evaluate the position of the velum during phonation and relative size of the soft palate to the size of the pharynx.
- Standardized preoperative clinical photos should be taken as these are invaluable when assessing outcomes many years later.

SURGICAL MANAGEMENT

Preoperative Planning

- A key aspect of successful cleft palate repair is optimizing the patient prior to surgery. A pediatrician is a crucial member of the cleft team.
- Although there is much discussion of age at palate repair, different team protocols vary from around 3 months old to 15 months or more.
 - Very young babies will tend to be more susceptible to airway compromise around the time of surgery.

- Delaying repair until much older and speech has developed has been associated with poorer speech outcomes, particularly related to articulatory errors.
- Our team protocol is for palate repair around 8 to 12 months (corrected for prematurity), but our emphasis is much more on ensuring that the child is well and thriving as surgery approaches.
- If the child is not growing along his or her expected centiles (with growth plotted on the appropriate chart for syndromic children), this should be addressed before surgery.
- We routinely postpone for about 4 weeks if children have upper respiratory tract infections.
- By following this approach, we have seen a significant reduction in fistulae and concerns with speech function.
- Routine blood tests or cross match samples are not required, unless the child is known to have a specific risk factor.
- For children with cardiac or respiratory problems, an up-to-date echocardiogram or sleep study may be relevant.

Positioning

- A Rae uncuffed or microcuffed tube is positioned in the midline and secured to the lower face.
- The taping of the tube needs to be secure but avoiding taping the mouth closed or limiting access. Taping in a V shape along the line of the mandible avoids displacing the tapes when the mouth gag is opened.
- The child is placed supine on a warming blanket, with the head at the very end of the operating table.
- A large horseshoe gel head ring is placed under the shoulders and around the head to provide support without overextending the neck.
- A head drape is applied, and the face is prepped.
- The table is tilted to a slight head-up position.
- An operating microscope is used for the procedure. The height of the table is adjusted once the microscope has been brought into place (adjusted according to whether the surgeon prefers to sit or stand).
- A modified Dingman mouth gag is placed.
- A throat pack is placed, and a marker sticker put across the drapes as a reminder to ensure it is removed at the end.

- The sticker is placed so that the drapes cannot be removed without needing to disturb the warning sticker.
- The throat pack is also included in the scrub nurse count as an additional precaution.
- The nose and mouth are rinsed with aqueous chlorhexidine solution.



FIG 1 • Marking the incisions at the margin of the cleft.

Approach

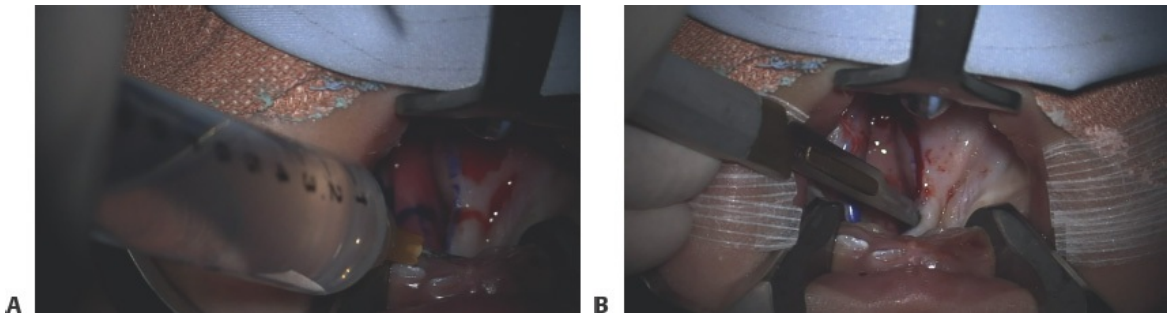
- The width of the cleft is measured. The extent of the cleft and any unusual features are noted.
- The incisions are marked with pen and ink (**FIG 1**).
 - Depending on the extent and shape of the anterior edge of the cleft, either a horseshoe shape or a triangular flap can be marked anteriorly.
 - The line of the incision in the soft palate can be identified by the pale line where the nasal mucosa meets the oral mucosa along the margin of the cleft.
- For very wide clefts, lateral von Langenbeck incisions can be marked at the outset, or these can be decided later in the procedure after the closing tension around the hard palate-soft palate junction is apparent.
- Tension is a factor of the soft tissue cleft width, the width of the lateral shelves of the palate, the elasticity of the tissue, and how vertical the shelves were sitting (which gives a “drawbridge effect”).

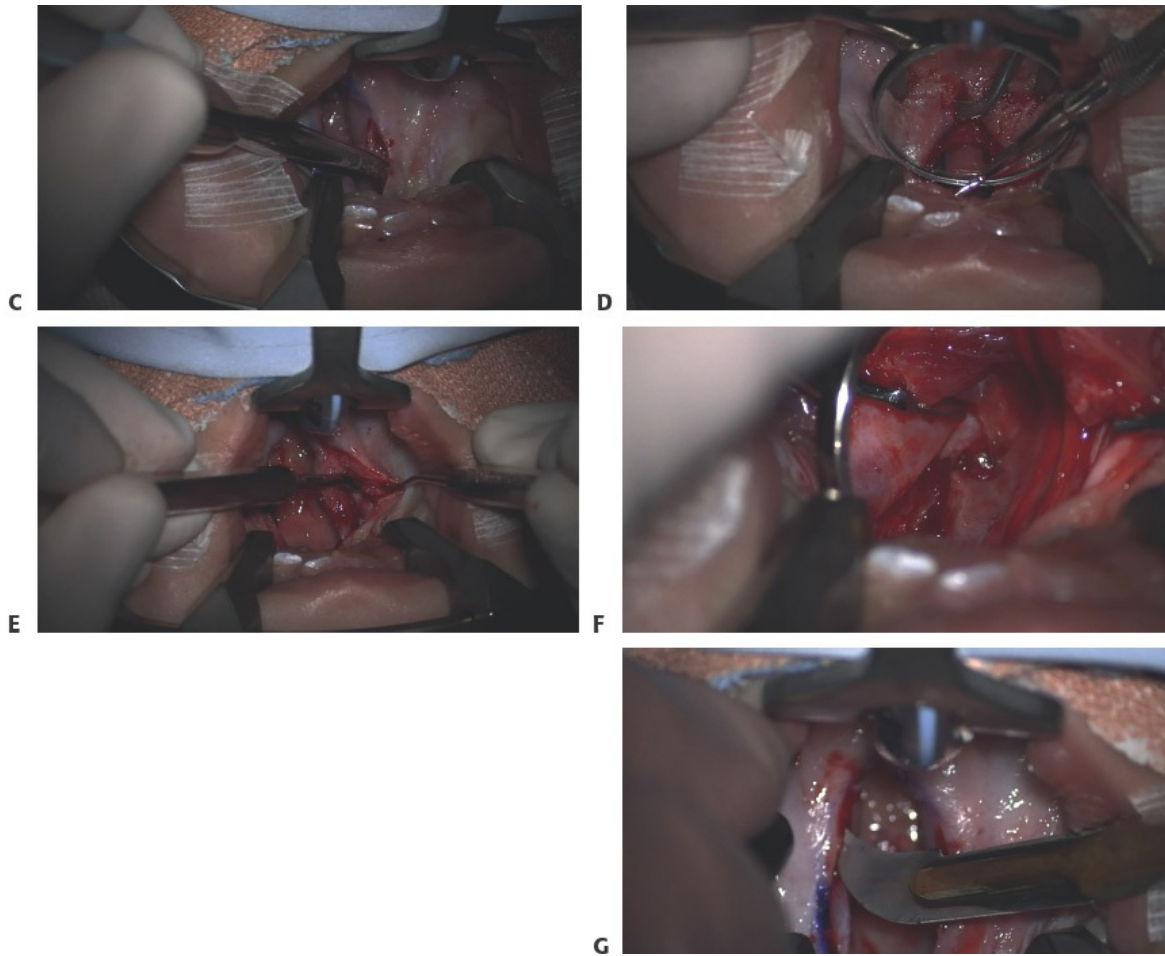
TECHNIQUES

■ Hard Palate

Incisions and Dissection

- Levobupivacaine or bupivacaine long-acting local anesthetic with adrenaline 1:100 000 is infiltrated and left about 8 minutes for vasoconstriction.
 - The injection is used to help hydrodissect the hard palate subperiosteal layer and the vomer flaps if these are being used (**TECH FIG 1A**)
- The incision is begun along the cleft margin (or in the midline for a SMCP or rerepair).
 - For complete clefts of the palate, it is usually easier to start with the posterior two-thirds of the hard palate extending across the hard palate-soft palate junction, then to move on to the very anterior portion of the cleft, and finally to move on to the posterior soft palate and uvula (**TECH FIG 1B**).
- For clefts involving the hard palate, use a no. 15 blade to incise carefully down to the bone along the margin of the hard palate and 3 to 5 mm past the hard palate-soft palate junction and elevate subperiosteally with a periosteal elevator or Warwick-James elevator (**TECH FIG 1C,D**).





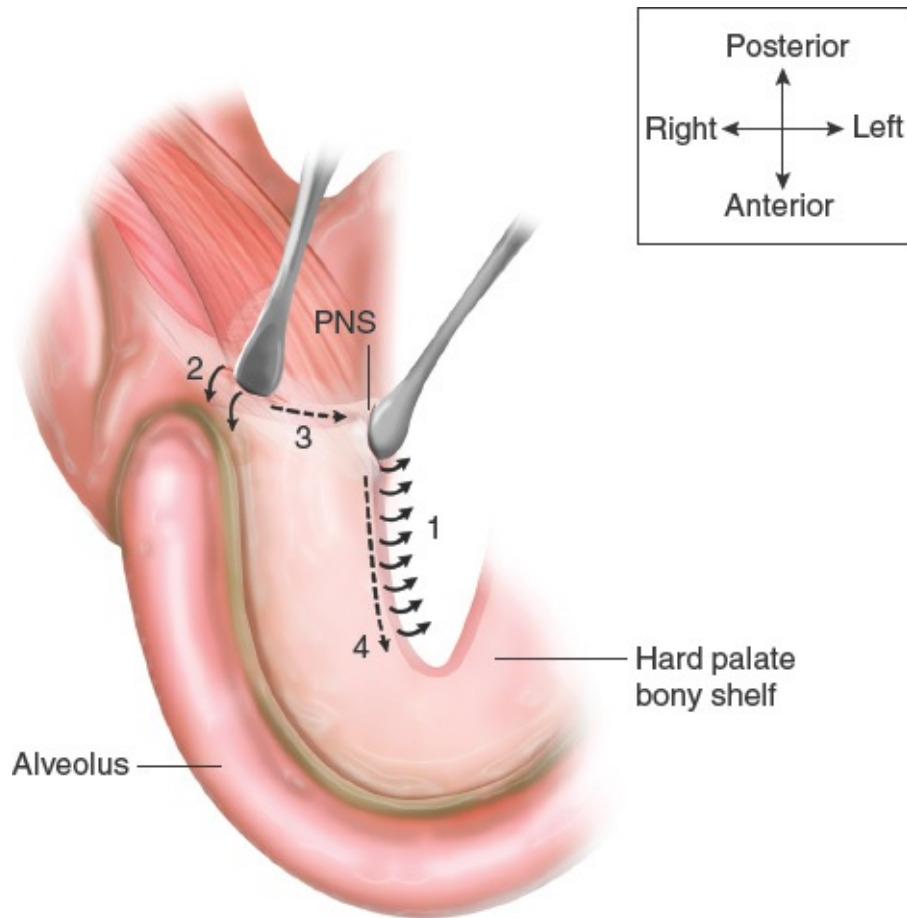
TECH FIG 1 • **A.** Local anesthetic is injected to hydrodissect the oral mucoperiosteal flaps. **B.** A no. 15 blade is used to incise the margin of the cleft, starting with the anterior third of the soft palate up to the posterior two-thirds of the hard palate at this stage. **C.** Using the Warwick-James elevator with a wriggling movement helps to elevate the oral flaps over the hard palate. Switching between the Warwick-James elevator and a periosteal elevator makes different parts of the dissection easier. **D.** The Warwick-James elevator is used to lift the most anterior portion of the hard palate flaps. **E.** Releasing the tethered salivary gland from just behind the posterior nasal spine. **F.** The dental mirror is showing

the underside of the oral layer flap to demonstrate the extent of the dissection laterally, including out toward the great palatine artery. **G.** A no. 12 blade is aimed posteriorly to incise the margin of the uvula and posterior third of the soft palate.

- Be careful approaching the posterior nasal spine as the tissues are more adherent here, and it is easy to tear the oral layer if there is a tethered salivary gland at this point. Switching between a no. 15 blade and periosteal elevator is usually necessary (**TECH FIG 1E**).
- For wider clefts, a more radical hard palate dissection is required to reduce the tension when closing.
- The Warwick-James elevators and dental flat plastic can be alternated to lift more laterally and, if needed, to free up the periosteal attachments around the greater palatine artery to improve mobilization (**TECH FIG 1F**).
- For incising the margin of the rest of the soft palate and back to the uvula, a no. 12 blade tends to be easiest (**TECH FIG 1G**).
- Depending on the cleft type, it may be necessary to raise vomer flaps to help close the nasal layer without tension.
- For wide clefts, it may be useful to incorporate a sphenoid flap in the nasal layer closure.
 - This is a flag-shaped extension to one of the vomer flaps, which rotates with inseting to provide additional tissue to the nasal layer around the hard palate-soft palate junction where it is usually tightest.²

Elevation of the Nasal Layer

- After raising the vomer flaps, elevate the nasal layer off the hard palate (again in a subperiosteal plane) with a periosteal elevator or dental flat plastic.
- Mobilize the nasal layer off the hard palate bony shelves, taking care not to damage the nasal layer (**TECH FIG 2**).



TECH FIG 2 • The stages of dissecting the nasal layer mucoperiosteal flap from the hard palate bony shelf. (1) Using a periosteal elevator with the spoon facing nasally, gently lift the periosteum off the margin of the bone with small movements. (2) Rotate periosteal elevator 180 degrees, so spoon faces orally, and insert it subperiosteally on nasal aspect of posterior edge of the bony shelf of the hard palate. (3) Wiggle and rotate spoon across the postnasal spine, the most adherent point. (Always return to position 2 if the periosteal elevator slips out of place.) (4) Continue to make wiggling and rotating movements with the periosteal elevator from the postnasal spine anteriorly.

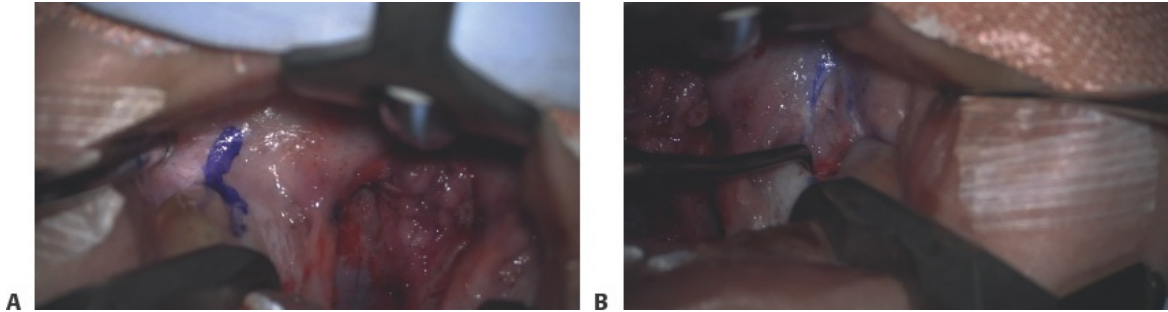
■ Start by using a periosteal elevator to gently free the periosteum off the

margin of the bone and postnasal spine.

- Next, use a periosteal elevator to wriggle beneath the bone shelf in a subperiosteal plane, working from the area of the tensor aponeurosis, around the postnasal spine, and then onto the medial margin.

von Langenbeck–Type Releasing Incisions

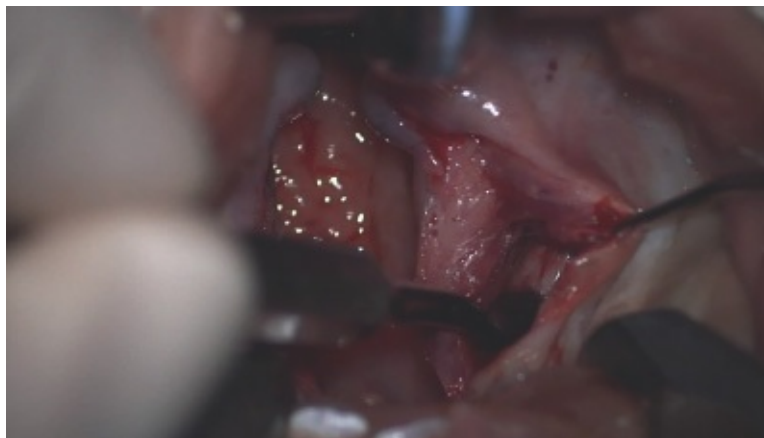
- For wide clefts, it may be necessary to use lateral von Langenbeck–type releasing incisions.
 - This decision may be clear at this point in the operation, in which case making early incisions can be efficient.
 - When the decision is less obvious, continue with the rest of the dissection, and the releasing incision can be made immediately prior to oral layer closure.
- When a von Langenbeck–type releasing incision is required, mark out a lazy S incision along the medial aspect of the alveolus and around its posterior limit to overlies the hamulus (**TECH FIG 3A**). The incision is kept as short as possible while allowing good mobilization of the oral layer flaps.
 - Local anesthetic with adrenaline is injected to help with hydrodissection and vasoconstriction: it is important to have a clear view to reduce the risk of damage to the greater palatine vessels.
- The incision is started in the hard palate with a no. 15 blade, incising down through periosteum at the medial base of the alveolus but ensuring that you stay lateral to the course of the artery.
- The incision is extended more superficially around the tubercle and over the hamulus.
 - A periosteal elevator is used to elevate the flap subperiosteally (**TECH FIG 3B**). It is often easier to have a second periosteal elevator to elevate simultaneously the tissues via the previous incision at the medial aspect of the palate until the two instruments meet.
 - It is then possible to work posteriorly, and one should elevate carefully the tissues around the greater palatine artery until the oral flap is sufficiently mobile to meet the opposite flap in the midline.



TECH FIG 3 • **A.** Marking for the incision of lateral releasing incision around the posterior aspect of the alveolus on the left, using a lazy S shape. **B.** Following incision of the mucosa, a periosteal elevator is used to lift under the periosteum and mobilize the flap.

■ Oral Layer

- To separate the oral layer from the muscle layer, the periosteal elevator or a dental flat plastic is swept back from the posterior margin of the palatal bone shelf (**TECH FIG 4**).
 - The plane is easier to develop laterally, near the hamulus, so the process starts here and then moves medially.
- A no. 12 blade is then used to incise posteriorly along the margin of the cleft toward the uvula.

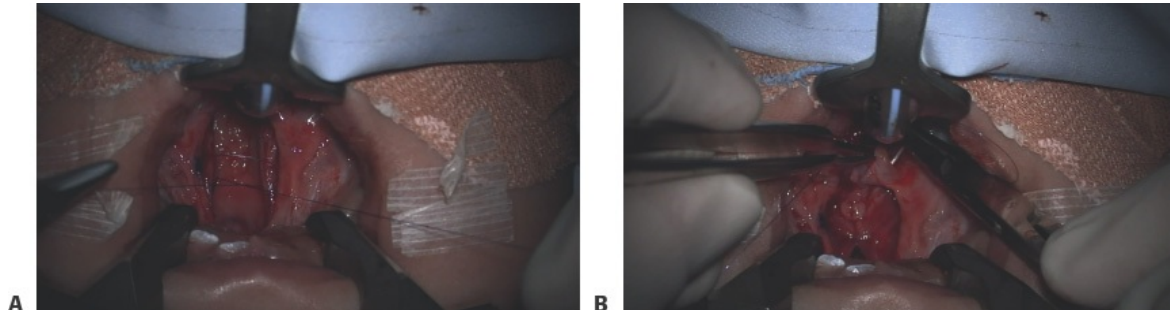


TECH FIG 4 • The periosteal elevator is slid off the

back of the hard palate shelf to separate the oral layer off the muscle fibers. Note the tip of the periosteal elevator is just reaching the hamulus, as the plane is easier to develop more laterally.

■ Nasal Layer

- Use interrupted sutures to close the nasal layer, incorporating vomer flaps anteriorly if available and needed.
 - A resorbable monofilament suture is used, preferably with a round or tapercut needle to avoid inadvertent tears of the mucosa. We use 5-0 Monocryl plus on a round-bodied needle for this closure.
 - The bites pick up more of the glandular tissue, with only a small amount of nasal mucosa, and knots are laid on the nasal aspect. This helps to evert the edges toward the nasal aspect (**TECH FIG 5**).
- If the nasal layer is too tight for closure around the hard palate-soft palate junction, then leave closure of this section until after the muscle dissection.



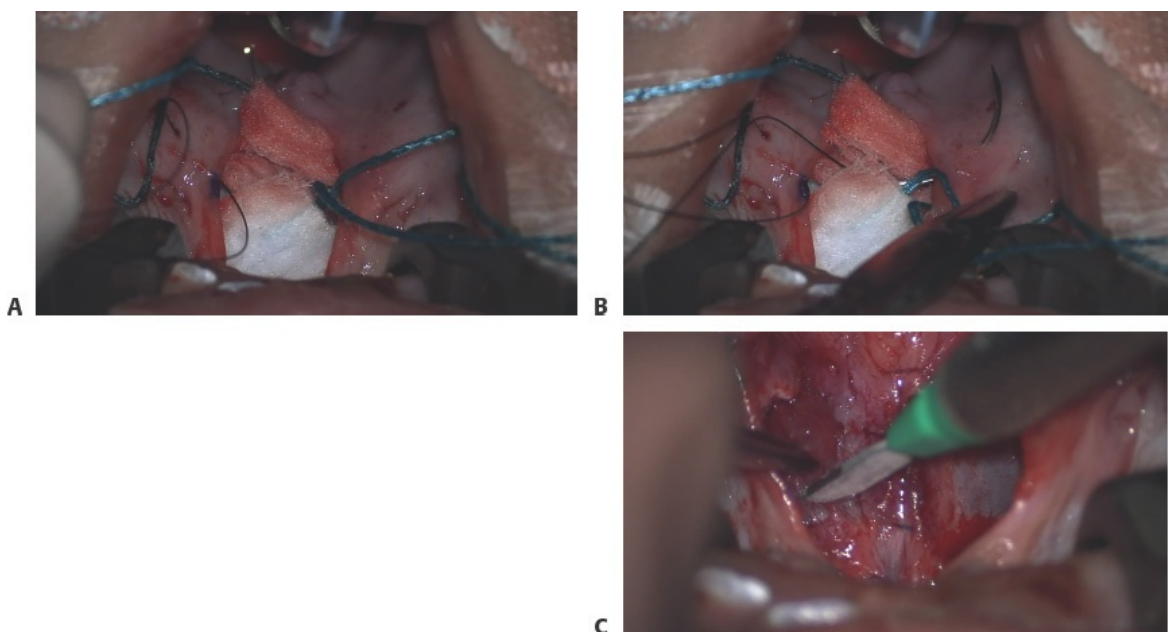
TECH FIG 5 • **A.** Suturing of the nasal layer, with the knots placed on the nasal aspect. Interrupted sutures are placed, working posteriorly toward the uvula. **B.** Suturing the uvula using horizontal mattress sutures to pick up the fibrous “core” of the uvula, as the mucosa tends to become friable in this area.

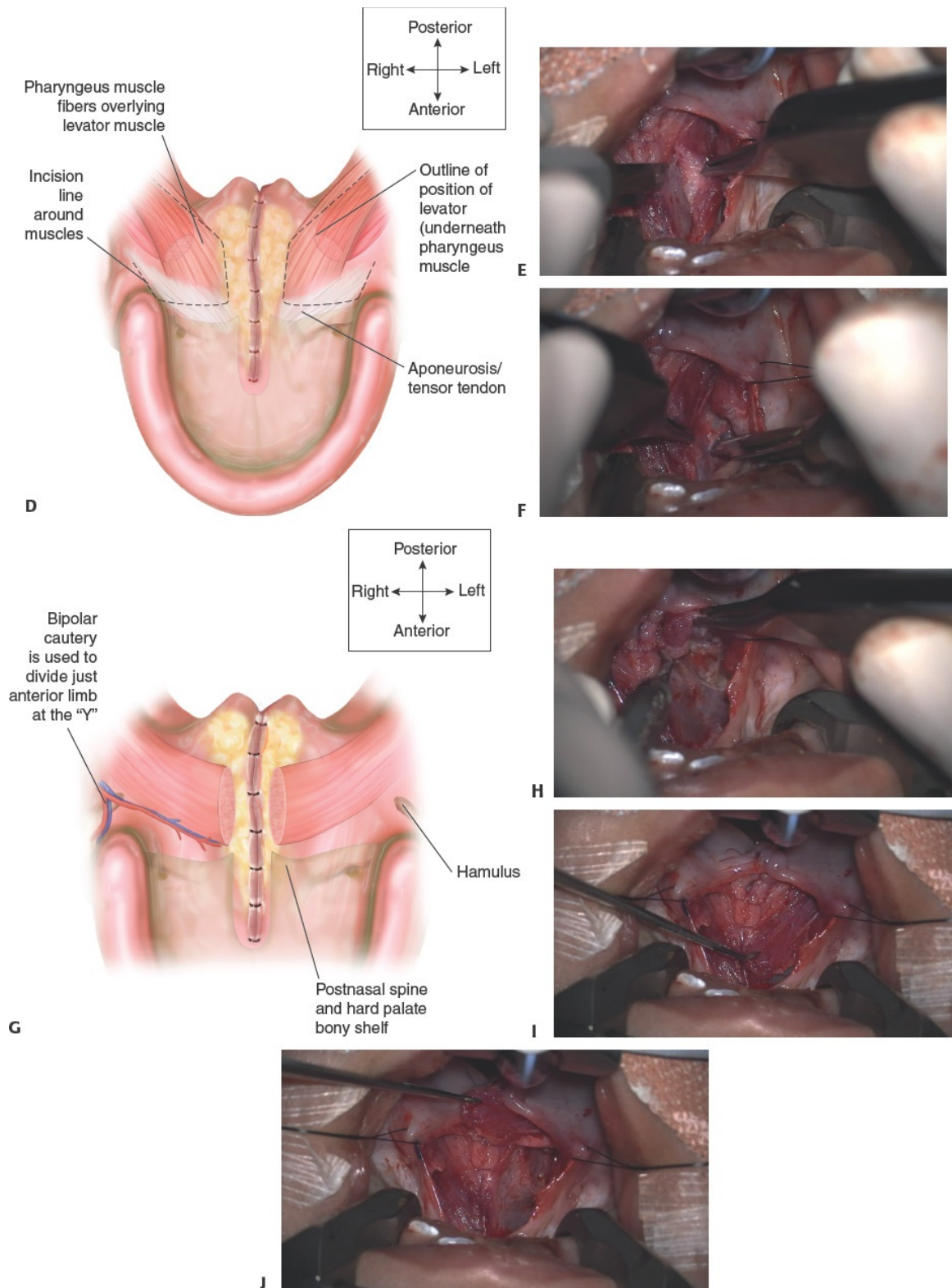
■ Muscle Dissection of the Nasal layer

- Applying topical 1:1000 adrenaline on neuro patties for about 5 minutes

before beginning the muscle dissection provides excellent vasoconstriction and facilitates the subsequent dissection (**TECH FIG 6A**).

- To make access easier for the next stage, a stay suture can be used to hold the oral flaps out of the way (**TECH FIG 6B**).
- Closure of the nasal layer has now pulled the soft palate muscles out to length, with the resultant tension helping with the next stage of dissection.
 - A fresh no. 15 blade is used for each side of the palate. Alternatively, some surgeons find it easier to use a straight Beaver blade (**TECH FIG 6C**).
- Start on each side by incising the posterior border of the muscles; this will leave behind a triangular block of fibrous/glandular tissue around the base of the uvula (**TECH FIG 6D**).
- Next, incise the medial margin of the muscle (**TECH FIG 6E**).
- Finally, incise the tensor aponeurosis anteriorly (**TECH FIG 6F**), and extend posterolaterally to divide the tendinous material from the hamulus.
 - Bipolar diathermy is then used sparingly to assist with the lateral dissection, but the aim is to preserve as much of the vascular supply to the levator muscle as possible (**TECH FIG 6G**).
- A dental flat plastic is then used to slide between the remaining levator and the nasal layer and particularly to free up any fascial sheath that can sit on the distal aspect of the muscle and restrict its repositioning (**TECH FIG 6H**).
- When it has been properly dissected, the levator muscle should easily be displaced to the posterior end of the soft palate (**TECH FIG 6I,J**).





TECH FIG 6 • A. Neurosurgical patties have been placed in contact with the exposed muscle and topical

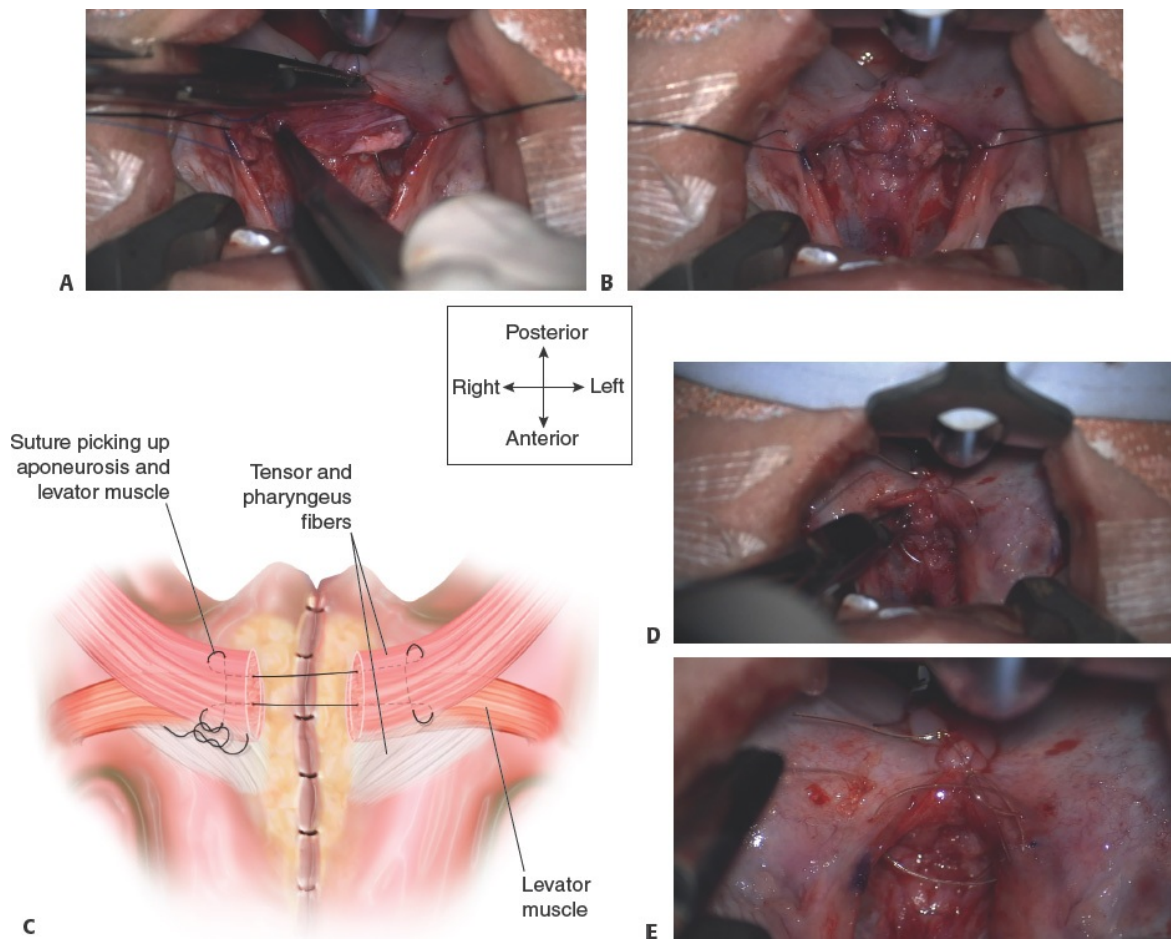
adrenaline dripped on with a 1-mL syringe. **B.** While the topical adrenaline is taking effect, a stay suture is inserted in the oral layer of the midsoft palate to help with retraction for the next stage. **C.** Using a straight Beaver blade as an alternative to a no. 15 blade. **D.** Diagram showing the dissection of the soft palate muscles. (Oral layer not shown to allow clearer visualization.) **E.** Dissecting the medial extent of the soft palate muscles. The levator muscle is still not yet visible at this point in the dissection. **F.** Incision of the tensor aponeurosis off the back of the hard palate. Note how the forceps are used to tension the muscle toward the midline, which helps the dissection and reduces the chance of “buttonholing” the nasal layer. The sharp incision continues laterally to free the muscle from the hamulus. **G.** Key landmarks when freeing to muscle and of bipolar dissection. **H.** A dental flat plastic is slid between the levator (just visible as the slightly bluish muscle fibers under the brighter pink pharyngeus muscle fibers) and the nasal layer to complete the dissection. Before **(I)** and after **(J)** views of the muscles on the right side of the soft palate to show the extent of repositioning after dissection is complete.

■ Closure

- The nasal layer closure can now be completed if necessary.
 - If the nasal layer has no holes, drainage holes can be incised laterally if required.
- The two sides of the muscle are now sutured across the midline (**TECH FIG 7A,B**).
 - We use a nonabsorbable monofilament suture such as 5-0 nylon to place reliable knots, minimize trauma to the muscle, and avoid inflammatory

reaction from resorption.

- There is also the potential benefit that the sutures act as a useful marker of the levator position if it becomes necessary to re-explore the palate in the future. A locked mattress suture (similar to a Kessler stitch) is used.
- It is important to avoid tying the suture too tightly as this would strangulate the muscle with any postoperative swelling.
- It is also essential to cut the suture extremely short, right on the knot, so the knots can be laid flat as reef knots.
- The oral layer is closed with looped mattress sutures using a resorbable monofilament suture such as 4-0 Monocryl.
- Modifying the mattress suture that sits just anterior to the muscle can close off the dead space between the oral and nasal flaps in the soft palate (**TECH FIG 7C**).
- By picking up a bite of the fibrous/glandular tissue that was left behind on the nasal layer as the muscle was dissected, the mattress suture closes the two layers together (**TECH FIG 7D**).
- Finally, after closure is complete, the mouth is rinsed out, a nasal suction catheter is used to ensure there is no blood clot in the postnasal space, and if a throat pack was used, this is removed (**TECH FIG 7E**).



TECH FIG 7 • A. The mattress suture is placed in the muscle, aiming with each transverse bite to pick up the levator fibers (on the underside) as well as the aponeurosis tissue for a more reliable closure. **B.** The muscles on each side sitting at the posterior extent of the soft palate after suturing. **C.** Illustration (oral layer omitted) of the suture to appose the muscles on the two sides, just prior to tying. Locked mattress sutures pick up both keratin fibers (underneath) and tough tender aponeurosis tissue (anteriorly and on top) with each bite. **D.** The needle picks up a bite of the fibrous/glandular tissue that has been left attached to the nasal layer. **E.** The looped mattress suture, including the bite of the nasal layer, just prior to tying.

PEARLS AND PITFALLS

Timing of surgery	■ Careful optimization of the baby prior to surgery is important, progressive gain in length and weight as documented in a growth chart is a useful indicator—a thriving baby at the time of surgery is more important than a specific age.
Shared airway	■ As with all “shared airway” surgery, it is important for the anesthetist and surgeon to communicate well with each other—the WHO checklist and team brief are very useful for this.
Protecting the mouth and commissures	■ Steri-Strips are placed to protect the corners of the mouth from abrasion by instruments.
Operative microscope	■ The routine use of the operative microscope for palate repair gives excellent lighting and visualization of the operative field. It is also very helpful for giving trainees a better view and involvement, as well as reducing the strain on the surgeon’s neck.
Muscle dissection	■ The key to dissecting the muscles (without putting holes in the nasal layer) is to place tension on the tissues by using a skin hook or forceps to draw the muscle bulk toward the midline and then to stroke the curve of the blade to get a neat division. The vascular plexus that is seen immediately superficial to the nasal layer is a useful marker.
Draping the patient	■ We use a clear plastic drape over the trunk, which allows the anesthetist to see the endotracheal tube and circuit without disturbing the surgical field. We avoid any adhesive drapes near the endotracheal tube because these have the potential to catch and dislodge the airway.
Postoperative elevation	■ Nursing the baby “head-up” in the recovery room and on the ward after surgery is very helpful for reducing postoperative swelling—cuddling the baby over the parent’s shoulder tends to give ideal positioning.

POSTOPERATIVE CARE

- Topping up the local anesthesia with a long-acting agent at the very end of the

operation is useful for postoperative comfort and feeding.

- Nurse the baby with the head elevated.
- Babies can be offered feeds straight away once they are awake.
- Monitor airway and oxygen saturation, especially during the first night after surgery.

OUTCOMES

- The main outcome measures for cleft palate repair are fistula rate, structural speech problem rate, and impact on maxillary growth.³
- Negative outcomes in any of these parameters can lead to the need for secondary surgery for their correction.
- Sommerlad reported approximately 5% secondary surgery rates for VPI with a 10-year follow-up.⁴
 - He reported fistula rates that vary considerably by cleft type—35% in bilateral cleft lip and palate but an average of 12% in other cleft types.

COMPLICATIONS

- Infection, significant bleeding, and transfusion are all rare after palate surgery.
- Airway compromise is a potential risk, especially in babies with Pierre Robin sequence and in younger or smaller babies.
- Fistula is often reported around the hard palate-soft palate junction, but there is wide variation between series and the extent and width of the cleft palate can be a major factor in the fistula rate.
- Speech problems may occur for a variety of reasons, to include VPI and/or articulatory errors characteristic of cleft type.

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11

CHAPTER Two-Flap Palatoplasty

David K. Chong, Kathryn V. Isaac, and Kenneth E. Salyer

DEFINITION

- Cleft palate is the failure of fusion of the palatal shelves during embryological development.
- Cleft palate may occur in isolation or in combination with a cleft lip. It may occur as part of a syndrome or in the absence of associated anomalies.
- A cleft of the palate may lead to feeding difficulties, speech impairment, chronic Eustachian tube dysfunction, hearing loss, and altered facial growth.
- Varying surgical approaches for cleft palate repair are utilized depending on the type of cleft palate and beliefs regarding facial growth and speech repercussions.

ANATOMY

- Embryologically, the cleft may affect the primary or/and secondary palate.
- Anatomically, the cleft is defined according to the involvement of the hard and soft palate.
- The hard palate is the bony palate, and surgical anatomy involves
 - Palatine process of maxilla
 - Horizontal plate of palatine bone
 - Hook of hamulus and pterygoid plates of sphenoid bone
 - Vomer/septum
 - Greater palatine foramina
- Soft palate is the mobile part of the palate, and surgical anatomy involves
 - Levator veli palatini
 - Tensor veli palatini aponeurosis
 - Palatopharyngeus

- Palatoglossus
- The Veau classification provides a clinically useful description of the cleft type according to the involvement of the alveolus, the hard palate, and the soft palate. It guides selection of the surgical treatment.
- The two-flap palatoplasty is most commonly performed for clefts of the hard and soft palate. It is not commonly used for isolated clefts of the soft palate and is not used for submucous clefts.

PATHOGENESIS

- The etiology of cleft palate is multifactorial: environment, teratogen exposure (alcohol, anticonvulsants, steroids, diazepam), nutrition, maternal infections (rubella, toxoplasmosis), and genetics.
- Cleft palate repair restores anatomical closure between the oral and nasal cavities.
- An unrepaired cleft palate may result in impaired:
 - Breathing
 - Feeding
 - Speech
 - Hearing

NATURAL HISTORY

- Orofacial clefting is the most common craniofacial birth defect, occurring in 1:750 live births.
- The incidence of cleft palate alone is 1:2000, with a female-to-male ratio of 2:1.
- The incidence of cleft palate in combination with cleft lip is greater, estimated at 1:1000 with a reverse gender ratio.
- In the population of children with cleft lip and/or cleft palate (CL+/-P), approximately 50% will have CLP, 30% to 35% CP, and 15% to 20% CL.
- Approximately 40% of CP patients will have a syndrome, and 15% of CLP will have a syndrome.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The diagnosis of a cleft palate is made by prenatal ultrasonography or by physical examination at birth and in early infancy. A detailed assessment is made of the child's breathing, feeding, growth, and development.
- Airway assessment must exclude presence of sleep apnea and micro-

/retrognathia.

- Assessment of growth and weight is key to identify and monitor feeding difficulty, gastroesophageal reflux, and use of feeding aids (Haberman/Pigeon teat).
- Hearing and middle ear function must be assessed and treated early by an otolaryngologist.
- The plastic surgeon should define the cleft palate type according to the anatomic structures involved, the laterality, width of the palate, and presence/absence of a cleft lip.
- Also, the child should be assessed for associated anomalies suggestive of a syndrome: craniofacial dysmorphism, airway compromise, cardiac defects, ocular and auricular abnormalities, and musculoskeletal anomalies. A genetics referral is suggested if suspicious of syndromic cleft palate.¹

DIFFERENTIAL DIAGNOSIS

- Syndromic cleft palate
 - van der Woude syndrome
 - Stickler syndrome
 - Robin sequence
 - 22q11.2 deletion syndrome
 - Treacher Collins syndrome
 - Nager syndrome
 - Ectrodactyly-ectodermal dysplasia
 - Klippel-Feil syndrome

NONOPERATIVE MANAGEMENT

- It is very uncommon not to repair a cleft palate.
- If the child is unable to undergo surgical treatment secondary to airway concerns or medical fitness, a palatal obturator may be considered.

SURGICAL MANAGEMENT

- Cleft palate repair is ideally performed between 9 and 12 months of age,² with the infant weighing greater than 8 kg.
- Airway and middle ear disease assessment is performed and treated prior to or simultaneously with cleft palate repair.
- Risks of the procedure are hemorrhage/hematoma, airway compromise, wound dehiscence, infection, oronasal fistula, flap necrosis, velopharyngeal

insufficiency, and reduced midfacial growth.

- The main objectives of the cleft palate repair are as follows:
 - To separate the oral and nasal cavities
 - To reposition to the velar musculature for restoration of the velopharyngeal sphincter, in particular the reconstruction of the levator muscular sling
 - To improve Eustachian tube function
 - To minimize detrimental effects on subsequent maxillary growth
- The main steps of the procedure are (a) marking and elevation of mucoperiosteal flaps off the hard palate; (b) isolation and lengthening of pedicles (greater palatine artery) for mobilization of the oral mucoperiosteal flaps; (c) dissection and separation of the nasal mucosa, velar musculature, and oral mucosa; (d) tension-free closure of nasal mucosal layer; (e) reconstruction of the velopharyngeal sphincter with repositioning of the levator sling; (f) recreation of the uvula; and (g) closure of the oral mucosal layer.

Preoperative Planning

- Active or passive dentofacial orthopedics is utilized for aligning the cleft maxillary arches by many teams today and is applied in the first few weeks of infancy. The orthopedic device is discontinued once the maxillary arches have been satisfactorily repositioned.
- With the patient anesthetized, the width of the cleft is measured at the junction of the soft palate and hard palate. The width of the cleft is important to predict difficulty of the cleft palate repair and anticipated amount of dissection required for closure. A cleft gap of:
 - Less than 11 mm closes with ease
 - 12 to 16 mm will require more extensive dissection to mobilize the greater palatine vessel and achieve nasal lining mobilization
 - Greater than 17 mm will require special maneuvers detailed below to achieve tension-free closure (greater palatine foramina osteotomy)

Positioning

- The patient is positioned supine with shoulder roll to allow neck extension. A south-facing oral RAE tube is carefully taped centrally with a mesentery. Corneas are protected with eye taping.
- Access and visualization of the entire palate is very important and cannot be understated. It is especially important to ensure visualization from the uvuli to the anterior extent of the palate.

- It is essential for the surgeon to ensure that positioning is correct prior to scrubbing. This will facilitate the procedure.
- The surgeon should have a headlight or lighted instruments for optimizing visualization in the confined space and a skilled attentive assistant. It is also advantageous to have a bed that allows for Trendelenburg positioning. Some surgeons stand to perform palate surgery from below but having the baby's head supported with the surgeon seated operating upside down provides the best exposure and is the preferred position by many surgeons.

Approach

- The aim of cleft palate surgery is tension-free closure of the palate oral and nasal mucosal layers and restoration of the velopharyngeal muscular sphincter.
- Difficulties anticipated include the following:
 - Access
 - Lighting
 - Unforgiving tissue
 - Bleeding obscuring visualization
- Surgical approaches differ with regard to the amount of dissection performed to achieve tension-free closure and muscle repositioning.
- Importance lies in adequate exposure and dissection of tissues to allow comfort for the operating surgeon to achieve tension-free closure.
- Oral layer mobilization is largely dependent on careful mobilization of the greater palatine artery from its periosteal sleeve.
- Nasal layer mobilization is largely dependent on careful mobilization of the mucosa as a sheet from its dense bony attachments.

TECHNIQUES

■ Two-Flap Palatoplasty for a Unilateral Complete Cleft Palate

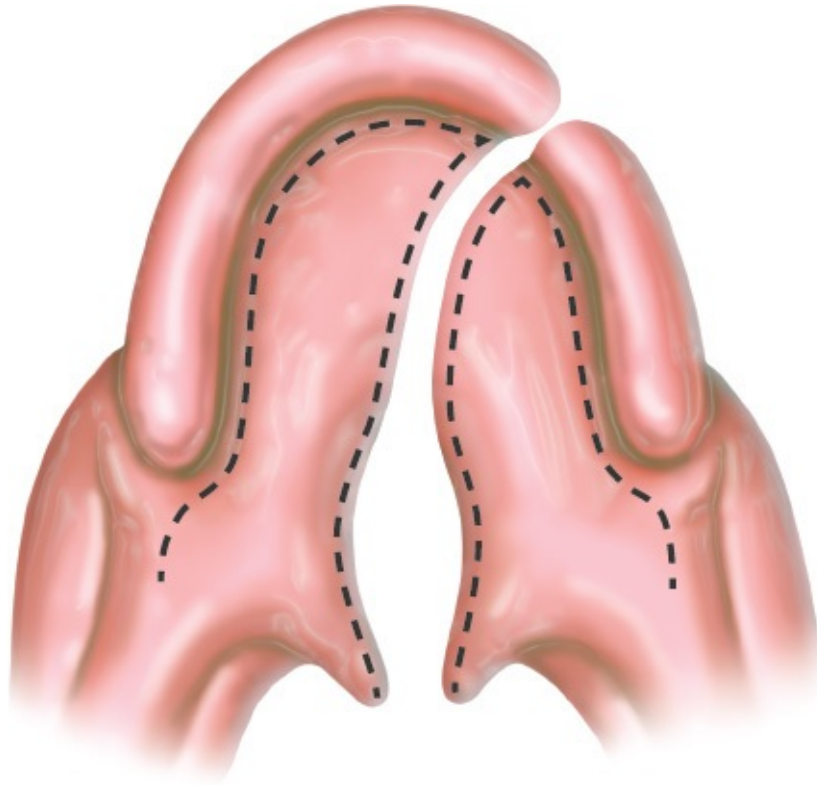
Markings

- Carefully insert an intraoral gag and a throat pack (it is the surgeon's responsibility to insert and remove).

- Mark the incision lines:
 - Along the medial edges of the cleft from the uvuli to the anterior junction of the hard palate and alveolus
 - Laterally at the junction of the hard palate and maxillary alveolus, extending from the posterior maxillary tubercle to the anterior medial marking (**TECH FIG 1**)
- Inject local anesthetic with adrenaline into the hard palate and soft palate (average of 8 mL). The vasoconstrictive properties reduce blood loss and obstruction of the visual field. Local anesthetic also allows for hydrodissection of the mucoperiosteal flaps off of the hard palate and tissue expansion for ease of layer dissection in the soft palate.
- Wait 8 minutes or until injection sites stop bleeding.

Elevation of Oral Mucoperiosteal Flaps

- Perform incisions with needle tip cautery to reduce bleeding. Use a skin hook on the uvula or stay sutures for countertraction.
- Incisions, flap elevation, and pedicle dissection are done similarly on both the greater and lesser segments.
- Begin with lateral incisions: from the retromolar trigone along the junction of the alveolus and palate with diathermy down to bone and slightly angled medially to avoid injury of developing teeth.
- For the medial incisions, palpate the posteromedial edge of the hard palate before incising to ensure that the incision medially will be onto the bone (hard palate) as you can inadvertently cut into the nasal layer and do a “double cut” that reduces the available tissue for nasal layer closure. The incision medially is made with a scalpel.

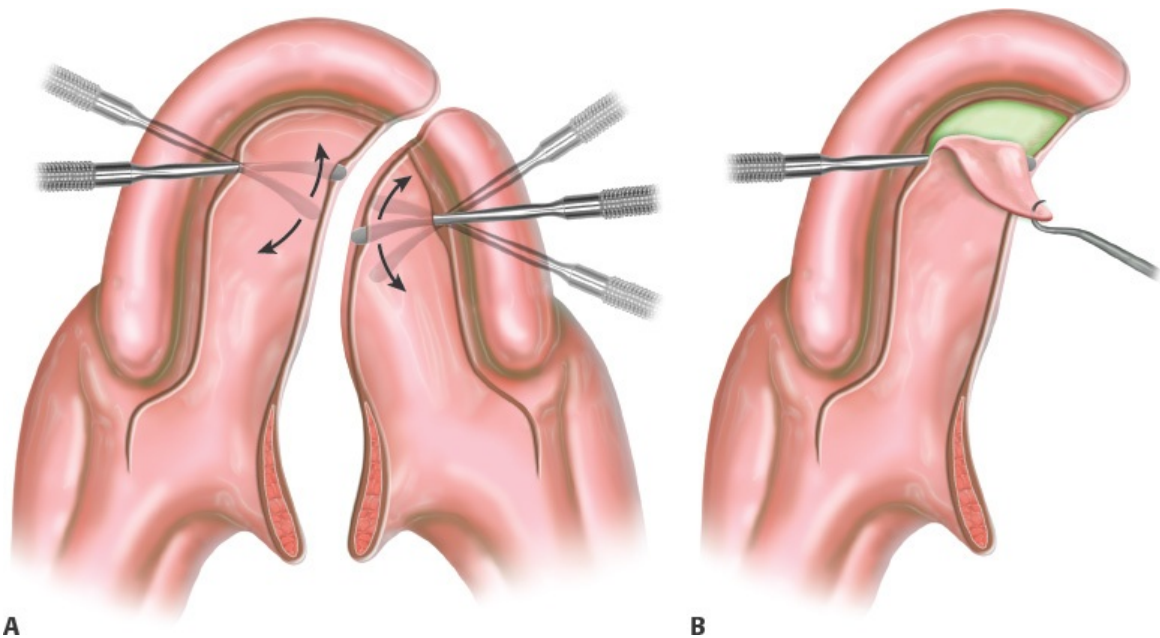


TECH FIG 1 • Markings of a two-flap palatoplasty for a unilateral complete cleft palate.

- Oral palatal mucosa is susceptible to tearing, so dissect continuously along the entire length of the lateral incision toward the cleft to elevate the mucoperiosteal flaps. Avoid “tunneling” as this can cause tearing of the hard palate mucosa due to dense periosteal attachments.
- Use a periosteal elevator to raise the mucoperiosteal flaps from lateral to medial (**TECH FIG 2A**).
- Then, use a skin hook at the leading anterior edge of the flap and dissect from anterior to posterior along the hard palate in sweeping motions toward the greater palatine foramina and posterior limit of the hard palate (**TECH FIG 2B**).

Isolation of Greater Palatine Vessels

- As you approach the greater palatine artery at the posterolateral edge of the hard palate, the vessel becomes visible on the undersurface of the flap.

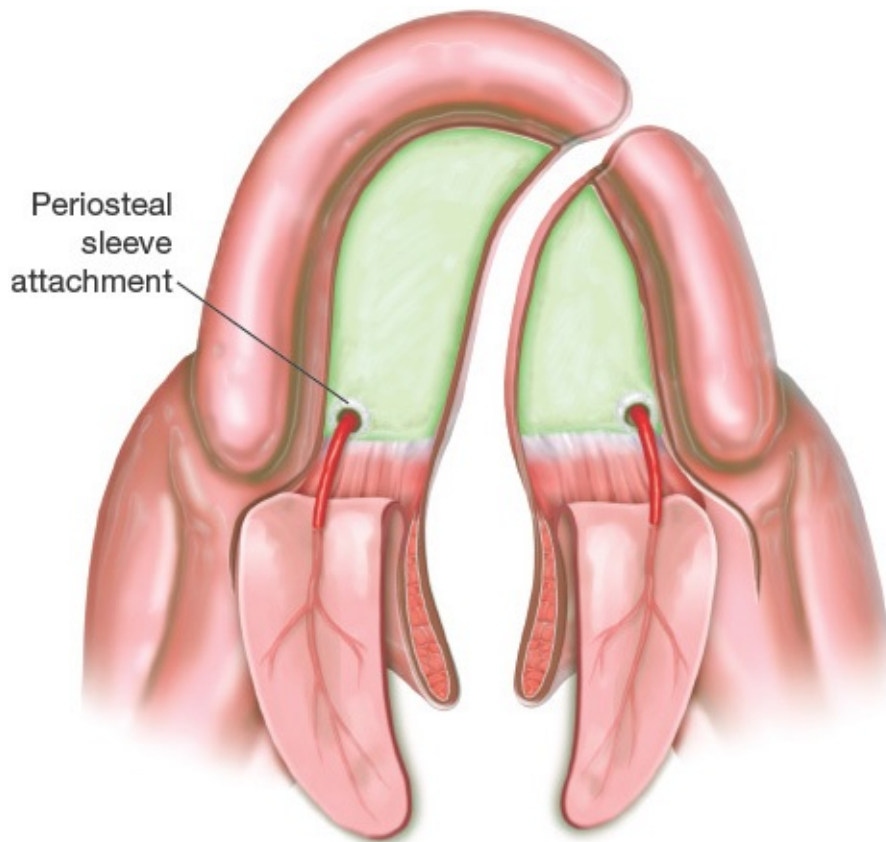


TECH FIG 2 • A. Dissection of the oral mucoperiosteal flaps. **B.** Elevation of the oral mucoperiosteal flap toward the pedicle, located posteriorly in the greater palatine foramina.

- The palatine artery has a circle of dense periosteal attachments around it.
- Carefully dissect starting anterior and then working circumferentially around the foramina, staying on bone and taking care not to dissect into the artery or the leash of veins surrounding it.
- To completely release the pedicle from its periosteal sleeve, careful and complete release of the periosteal attachments must be achieved by dissecting the flap directly off the posterior edge of the palatine bone.
- Staying on bone during pedicle dissection is very important and rewarding as there are tethering ligaments that insert into the oral mucosa.
- Dissection directly off bone facilitates the circumferential release of these ligaments, which otherwise make it exceedingly easy to tear the oral mucosa and injure the pedicle.
- Previous hydrodissection during local anesthetic injection will also aid in finding the bloodless plane between the oral layer mucosal glands and the muscular layer.
- Complete circumferential pedicle dissection is achieved once the periosteal sleeve is released behind the greater palatine foramina and velar muscle

attachments to the posterior edge of the hard palate are visualized (**TECH FIG 3**).

- It is critical for the surgeon to approach the release of the periosteal sleeve patiently with gentle dissection and successive wider approach, which will allow the palatine artery to finally be freed without tearing the mucosa or creating excessive bleeding.
- Once pedicle dissection is achieved, use gentle traction with scissors to tease the vessel free out of the foramina. This will create enough freedom to close most palatal clefts.
- Very occasionally in the widest of clefts (>16 mm), osteotomy of the posterior wall of the foramina is required.
- Once sufficiently mobilized, retract the flaps out of the surgical field with stay sutures and secure to the intraoral gag/retractor.



TECH FIG 3 • Oral mucoperiosteal flap elevation is completed: pedicles are mobilized and velar musculature is visualized attached along the posterior

hard palate.

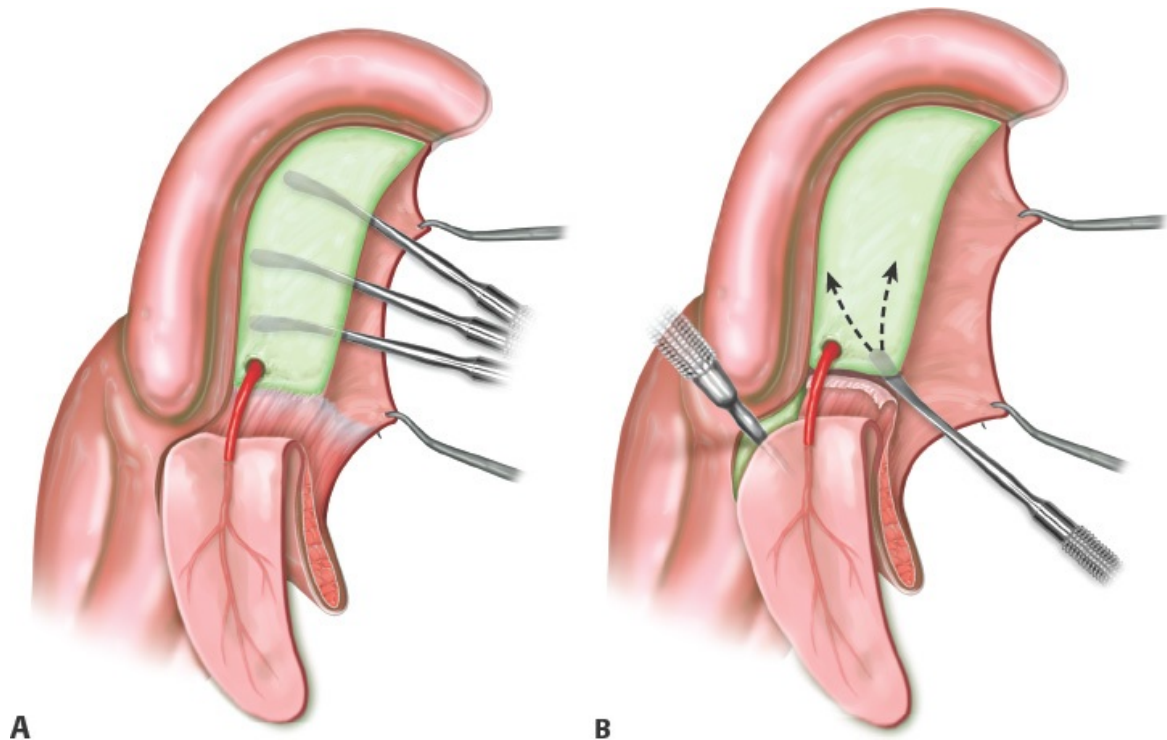
- Under magnification, dissect in the plane between oral mucosal glands and the muscle layer posteriorly in the soft palate from the edge of the bony palate to the uvula.

Dissection of the Nasal Mucoperiosteum

- Mobilize the nasal mucoperiosteal layer with care, beginning on the lesser segment of the cleft. This requires the gradual and wide dissection of this continuous sheet of nasal mucosa, which is firmly attached to the hard palate along its medial and posterior edges, along the nasal surface of the bony palate and the medial surface of the medial pterygoid plate. The elevation of the nasal layer anteriorly on the greater segment will necessitate elevation off of the vomer.
 - The nasal mucosa is even more unforgiving than the oral mucosa, and once a tear occurs, it is very easy to propagate. Resist the temptation to tunnel before a whole edge has been liberated.
- Use a Mitchell's trimmer or similar blunt-edged instrument, starting at the cleft margin, and scrape the oral surface of the bone until the edge of the nasal mucosa starts to be defined and liberate the dense attachments to the medial hard palate. As the edge becomes apparent, elevate the nasal mucoperiosteum widely off the entire extent of the medial hard palate.
 - Judicious use of needlepoint diathermy on low setting can help to elevate firmly attached areas that are not easily released with the Mitchell's trimmer.
- Once the edge of the nasal mucoperiosteal flap is defined, slide the trimmer around the corner of the hard palate onto the nasal surface of the bone staying right on bone. If the edge is sufficiently liberated, then sweep anteriorly and posteriorly to liberate the entire sheet off of the nasal surface (**TECH FIG 4A**).
 - If a portion of the edge is still attached, resist further sweeping until releasing the portion that remains tethered to prevent a tear.
- This dissection is continued to the posterior nasal spine. At this juncture, there are always muscle attachments. Release these aberrant velar muscle attachments with needlepoint diathermy.
- Continue dissection along the nasal surface following the posterior edge of

the bone cephalad and lateral toward the medial surface of the medial pterygoid plate (**TECH FIG 4B**).

- Release the nasal mucoperiosteum directly off the bony surface of the medial surface of the medial pterygoid plate with careful dissection of the fibrous attachments here. Be patient and careful during the release of this densely adherent portion of the nasal mucosa working posteriorly and cephalad along the pterygoid plate and palatine bone. Confirm complete release by directly visualizing the plane of the medial surface of the medial pterygoid plate. If further release is required, the origin of the tensor veli palatini (TVP) along the medial pterygoid plate may be severed to improve mobilization.
- The sheet of mucosa should now be freely mobile as one continuous sheet posteriorly and along the anterior medial hard palate. When extensive dissection is required for a wide cleft, there may be a noticeable reduction in the circumference of the oropharynx as the sheet mobilizes medially.



TECH FIG 4 • A. Elevation of nasal mucoperiosteal flaps. **B.** Nasal flap dissection toward the medial surface of the medial pterygoid plate.

- Attention is then turned to the greater segment.

- The dissection of the nasal mucoperiosteal flap is identical posteriorly along the hard palate cleft margin.
- Anteriorly, at the bony junction of the vomer and bony palate, the nasal mucoperiosteum is raised in continuity with the vomerine periosteum.
- This vomerine flap is raised cephalad directly off bone and in continuity with the periosteum of the nasal surface of the hard palate.

Nasal Closure

- Nasal layer closure is then commenced once there is assurance that the repair is tension free by checking that both sides are sufficiently liberated.
- Meticulous closure with knots tied on the nasal side
- Small wedges are excised out at the base of the oral surface of the uvula to assist closure. Place eversion sutures during the closure of the uvuli to prevent notching or bifidity.

Dissection and Reconstruction of the Velar Musculature

- With the nasal layer completely closed, proceed with the muscle dissection and reconstruction of the velopharyngeal sphincter.
 - Three steps are critical for muscle repositioning:³
 - Identification and separation of levator veli palatini (LVP)
 - Velar musculature dissection and release from its attachments to the cleft margin and hard palate shelf
 - Velar musculature repositioning and repair
 - Deep to the muscles inserted into the back of the bony hard palate, the LVP inserts abnormally at the cleft margin in the anterior half of the velum.
- Using a scalpel, sharply dissect the velar muscle layer off of the nasal mucosa along the cleft margin. This is done with a paramedian incision lateral to the nasal mucosal closure line through muscle until the nasal mucosal surface is identified.
 - It is easiest to separate the muscle layer once the nasal mucosa has been repaired to give a “trampoline” effect, providing tactile feedback and countertraction during this careful dissection.
 - Also, it is important to note that the bulk and breadth of the muscle widen as you dissect laterally. This is analogous to the changing depth of a swimming pool, with a shallow end (paramedian) becoming deeper as one progressively dissects laterally.
- The velar musculature is raised off the nasal mucosa and separated from the

tendinous fibers of the TVP. This separation is done laterally along the hard palate shelf at the junction of “salmon pink” velar muscle fibers and tendinous fibers of the TVP.

- The velar musculature is further dissected until it can be freely mobilized to lie parallel to the posterior hard palate margin and overlying the contralateral velar muscle bundle.
- You have completed the levator dissection when the “salmon pink”-colored longitudinal fibers of the levator are identified emerging from the skull base and the entire dissected muscle is free to be reoriented to a more functionally effective position in the posterior half of the soft palate.
- The dissection of the velar musculature is performed on both sides.
- Repair the muscles and reconstruct the levator muscular sling by suturing the muscles and securing with multiple sutures, knots facing the nasal surface.
- Ensure proper hemostasis is achieved.

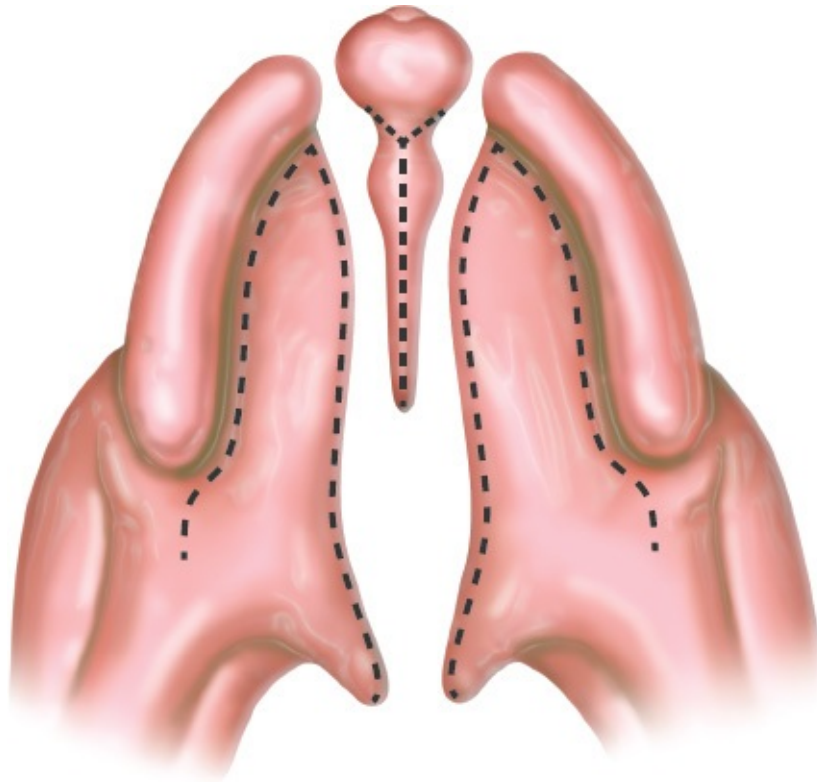
Oral Closure

- Close the oral layer beginning with stay sutures placed anteriorly and progressing posteriorly toward the uvuli with horizontal mattress sutures.
 - There is no attempt of push-back of the flaps for lengthening with a V-Y closure.
- During oral layer closure, place some full-thickness sutures through both the oral and nasal layers just posterior to the hard palate shelf (anterior to muscle repair) to help obliterate the dead space and position the muscle repair.
- Place interrupted simple sutures between each of the mattress sutures.
- Attempt to minimize raw bone exposure by closing palatal flaps to alveolus wherever possible.
- Recheck for adequate hemostasis, irrigate, and remove throat pack.
- If concerned for airway during postoperative period, consider nasopharyngeal tube insertion and a tongue stitch.

■ Two-Flap Palatoplasty—Bilateral Complete Cleft Palate

- In a bilateral cleft palate, the operative steps are similar to those outlined above except for the flap elevation and closure anteriorly along the junction of the primary and secondary palate.

- The oral and mucosal nasal incisions and dissections on the lesser segment are performed as outlined above.
- Bilateral vomerine flaps are raised from the premaxilla in continuity with the nasal mucoperiosteal flaps (**TECH FIG 5**).
- The anterior closure of the nasal and oral layers requires meticulous approximation and closure to eliminate the risk of an oronasal fistula at the junction of the primary and secondary palate.
- Careful and patient dissection is required to the dense attachments of mucoperiosteum to the posterior surface of the premaxilla to which the palatal flaps will be anchored.



TECH FIG 5 • Markings of a two-flap palatoplasty for a bilateral complete cleft palate.

Headlight and positioning	■ Good lighting and access paramount importance
Loupe magnification	■ Especially helpful for dissection around palatine foramina and muscle when surgeon is less experienced
Hemostasis	■ Ensure meticulous hemostasis throughout case to optimize visualization. ■ Judicious use of needlepoint diathermy ■ Failure to do so may result in airway compromise, flap necrosis, and wound dehiscence.
Use needlepoint diathermy to make hard palate incisions.	■ Controls bleeding and persisting ooze
Work on broad front.	■ Avoid tunneling during dissection.
Patience and precision during dissection especially around palatine foramina	■ Bleeding obscures view, and careless dissection risks injury to pedicle and vascularity of the flap.
Handle tissues with care.	■ Nasal mucosa is especially susceptible to tears.
Inset palatal flaps with stay sutures to help control closure.	■ Helps to put the most difficult sutures anteriorly with stay sutures to judge closure and maintains good exposure
Do not attempt closure until all layers are sufficiently mobilized.	■ Prevents tearing ■ If sutures are prematurely placed, further attempts to mobilize tissue are more likely to result in tears. Prematurely suturing may also result in tears if tension is still present.
Oronasal fistula	■ Critical to achieve adequate tissue dissection, perfect approximation, and apposition of tissue layers with meticulous suture technique to prevent fistulae.

POSTOPERATIVE CARE

- Nasopharyngeal tube as required

- Remove tongue stitch in recovery if used.
- Analgesia to reduce blood pressure and distress (24 hours of intravenous opioids)
- Encourage feeding.
- Postoperative visit in 4 weeks

OUTCOMES

- Two-flap palatoplasty yields excellent speech outcomes with minimal surgical morbidity.
- In a 20-year long-term follow-up, the authors have recorded a 7% to 11% incidence of velopharyngeal insufficiency with no significant difference between cleft subtypes.⁴
- Speech results were normal to mildly impaired resonance (92%), no or inaudible nasal air emission (80%), and no compensatory articulation errors (98%).
- The fistula rate of a cleft palate repair with a unipedicled flap technique is 6.2% (95% CI, 4.3%–8.4%) according to a systematic review of international data.⁵
- The effect of palatoplasty on maxillary facial retrusion is controversial. Inherent maxillary growth deficiency, secondary scarring from palatal flap elevation, and timing of repair are all contributing factors to midfacial retrusion.⁶ Deleterious growth has been shown to be greatest in patients treated by Veau push-back technique. Further long-term studies are required to compare the effect of palatal flap technique on maxillary growth restriction.

COMPLICATIONS

- Bleeding is a feared complication as it may lead to an emergency with airway obstruction and respiratory compromise. Additionally, hematoma may lead to compression of the pedicle or flap, with resultant flap necrosis, wound dehiscence, and oronasal fistulae. To prevent this complication, vigilant hemostasis is an absolute and adequate postoperative analgesia is necessary.
- Airway obstruction may occur in the absence of hemorrhage, and a tongue stitch or nasopharyngeal tube may assist in prevention of obstruction in infants at risk. Airway obstruction can also occur if a throat pack is utilized and the surgeon overlooks removal of the throat pack prior to extubation.
- Flap necrosis is rare and avoidable with careful dissection and release of the periosteal sleeve of the greater palatine pedicle.

- Infection and wound dehiscence leading to oronasal fistulae are detrimental. A small fistula secondary to delayed wound healing may heal with conservative measures. Failure of closure may necessitate reoperation with re-elevation and closure of oral and nasal flaps as well as possible augmentation using local flaps and/or biologic adjuncts.

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12 CHAPTER Tongue-Lip Adhesion/Floor of Mouth Muscle Release for Pierre Robin Sequence

Chad A. Purnell and Arun K. Gosain

DEFINITION

- Pierre Robin sequence (PRS) is a clinical triad of glossoptosis, retrognathia, and airway obstruction.
- Cleft palate is present in approximately 50% of cases.
- PRS is associated with an identified syndrome in 30% to 60% of cases.¹
- The most common syndromes associated with PRS are Stickler syndrome (11%–20%) and 22q11.2 deletion (velocardiofacial) syndrome (11%).²

ANATOMY

- The tongue in PRS is posteriorly displaced due to retrognathia. This results in an airway obstruction at the tongue base (**FIG 1**).
- Airway obstruction may also result from lesions lower than the tongue, such as laryngomalacia. Synchronous airway lesions are present in up to 28% of patients.³
- Cleft palate may be U- or V-shaped; a U-shaped palatal cleft is classically associated with PRS.

PATHOGENESIS

- Pathogenesis of PRS is incompletely understood and likely multifactorial.

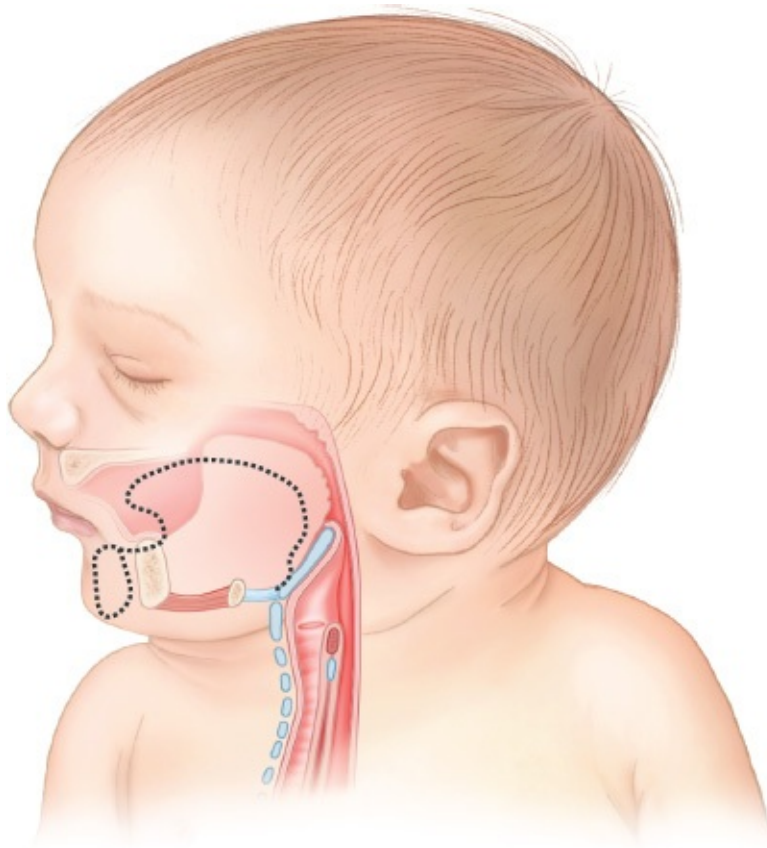


FIG 1 • Micrognathia results in a more posterior position of the mandible and tongue in PRS (*solid lines*) compared to a normal patient (*dotted lines*).

- Theorized mechanisms of PRS include mechanical obstruction to mandibular growth, delay in neuromuscular development of the tongue and oropharynx, connective tissue dysplasia, and teratogen exposure.^{4,5}

NATURAL HISTORY

- PRS occurs on a spectrum that ranges from mild asymptomatic hypoplasia to critical airway obstruction requiring emergent endotracheal intubation at birth.
- In more severe phenotypes, PRS is often associated with feeding issues such as gastroesophageal reflux, failure to thrive, and abnormal oroesophageal motility.^{6,7}
- Mortality has decreased dramatically with improved awareness and care. Mortality in 1946 was greater than 50% and has decreased to 16%, with all deaths occurring in syndromic patients.^{8,9}

PATIENT HISTORY AND PHYSICAL FINDINGS

- A full birth history and physical examination should be performed. A key point of examination should be documenting the maxillomandibular discrepancy with the child upright and the mandible closed.
- A careful examination for syndromic features should include hearing and ocular exam to evaluate for Stickler syndrome.¹⁰
- Evaluation and treatment of any patient with PRS should be performed by a multidisciplinary team, which includes craniofacial surgery, otolaryngology, speech and feeding therapy, critical care/anesthesiology, and genetics.

IMAGING

- If the child is not intubated, a polysomnogram should be performed, including a portion with a nasopharyngeal airway in place in order to determine whether there is ongoing sleep apnea if upper airway obstruction is removed.
- Fiberoptic nasendoscopy is performed to evaluate whether the airway obstruction is isolated to the tongue base or whether there are additional sources of supraglottic airway obstruction, including laryngomalacia.
- Prior to any surgical intervention, bronchoscopy should be performed to evaluate for subglottic synchronous airway lesions.

NONOPERATIVE MANAGEMENT

- The majority of patients can be treated nonoperatively.
- Initial airway management is prone positioning to displace the mandible anteriorly.
- Supplemental oxygen may be added as well.
- A nasopharyngeal airway should be placed if desaturations continue. This airway has been utilized successfully as end-treatment at home by several centers.¹¹
- If a nasopharyngeal airway does not resolve airway obstruction, emergent endotracheal intubation is indicated.
- Continuous positive airway pressure masks and palatal appliances have also been described for treatment.^{12,13}

SURGICAL MANAGEMENT

Preoperative Planning

- Prior to any surgical treatment, bronchoscopy should be performed. In the

presence of significant subglottic obstruction, tracheostomy is likely the only treatment option.

- Prior to performing a tongue-lip adhesion, a GILLS score should be calculated. One point is given for each of the following: gastroesophageal reflux, intubation preoperatively, late operation (greater than 2 weeks of age), low birth weight (less than 2500 g), and syndromic diagnosis. A score of 3 or more is predictive of failure of tongue-lip adhesion, and another option such as mandibular distraction osteogenesis or tracheostomy should be considered.^{14,15}

Positioning

- The procedure is performed supine.
- Endotracheal intubation may be nasotracheal or orotracheal, with the tube taped to the side out of the operative field.

Approach

- Soft tissue procedures for PRS include tongue-lip adhesion, subperiosteal release of the floor of mouth, or both procedures performed concomitantly.^{16,17}
- Subperiosteal release of the floor of mouth is an ideal addition to tongue-lip adhesion if the patient has a fixed, immobile tongue (ankyloglossia) and a tongue-based airway obstruction. This procedure is also performed in isolation for airway obstruction at some centers.
- Mandibular distraction osteogenesis is a skeletal technique to treat mandibular hypoplasia that may have more repeatable resolution of airway obstruction in a broader range of patients with PRS, with potentially higher complication rates.^{18–20}

TECHNIQUES

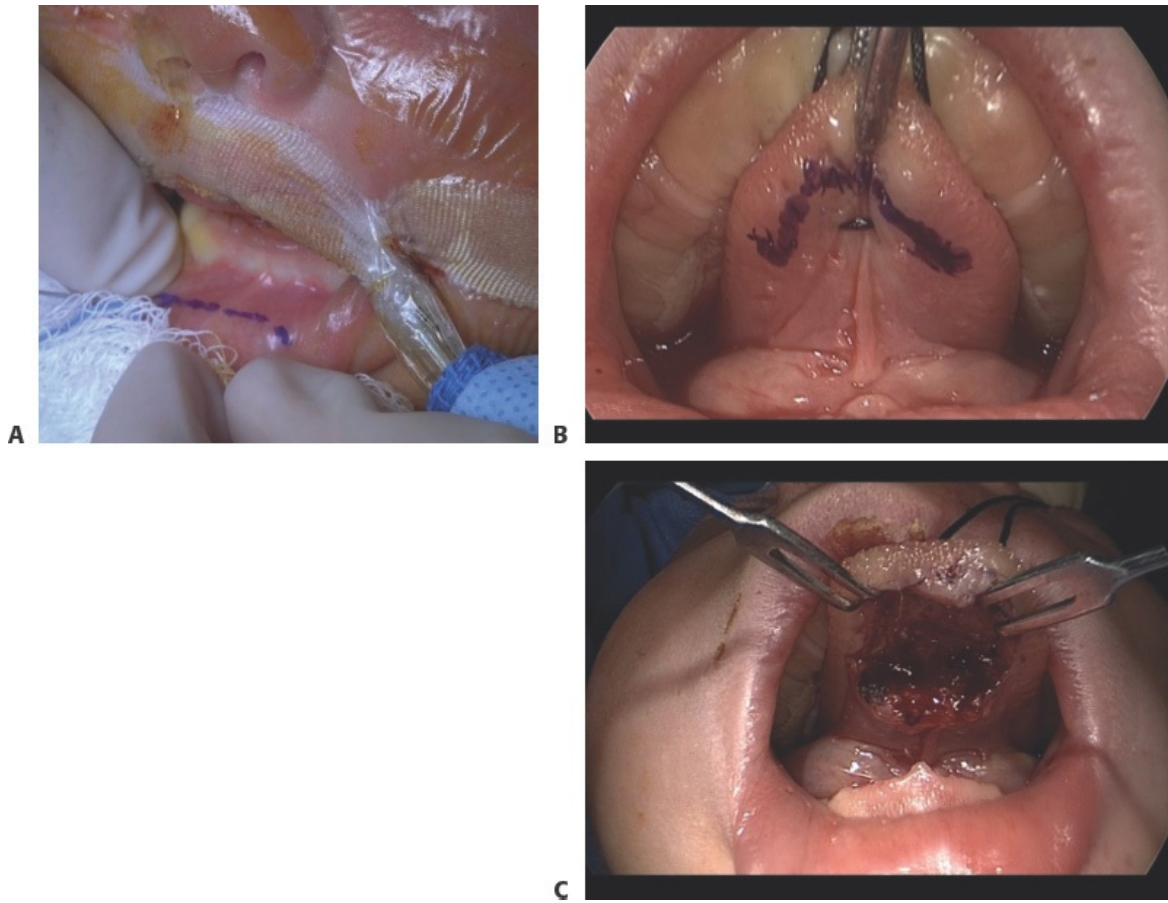


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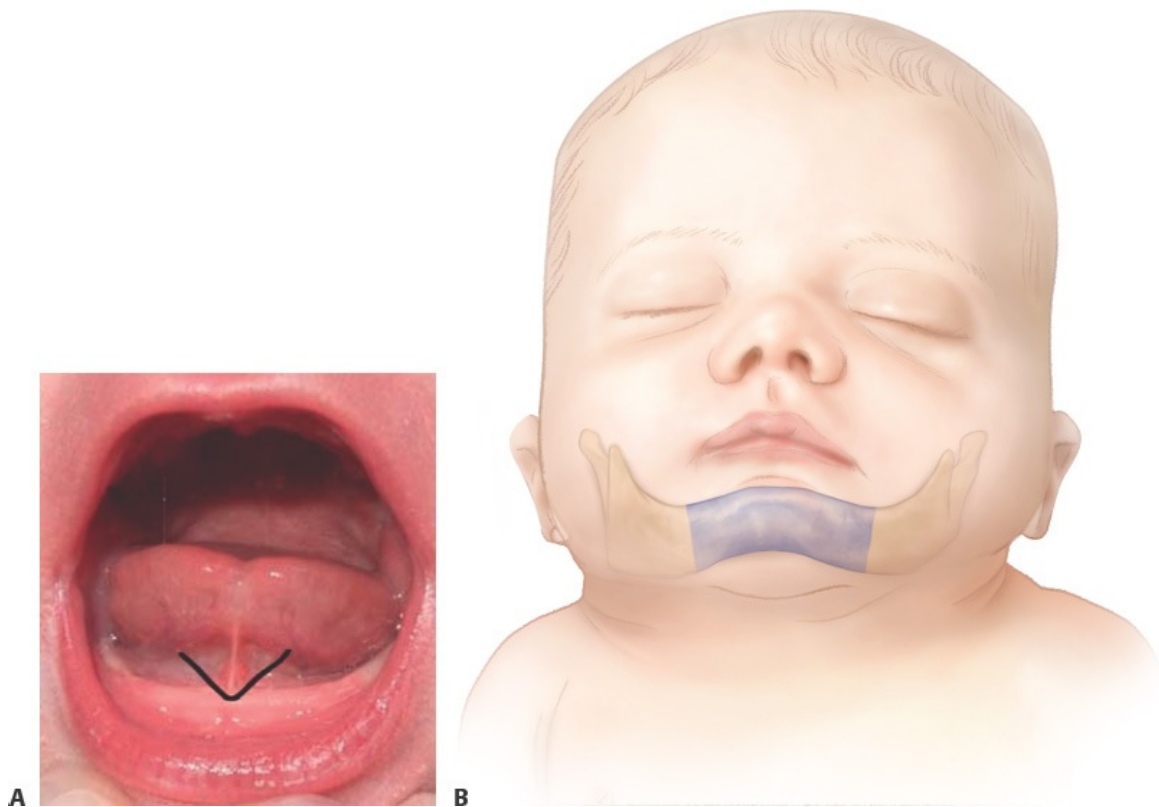
■ Subperiosteal Release of the Floor of the Mouth

Creation of Tongue and Lip Flaps

- 0.5% lidocaine with epinephrine is injected into all planned incisions for hemostasis.
- A transverse incision is made 1.5 cm in length in the lower lip (**TECH FIG 1A**).
 - Incision is carried obliquely posterior into the muscle of the lip to create a superiorly based flap approximately 1.5×1 cm in area.
- A 1.5-cm transverse incision is made in the undersurface of the tongue approximately 2 mm inferior to the rugae (**TECH FIG 1B**).
- An inferiorly based 1.5- $\times$ 1-cm musculomucosal flap is elevated (**TECH FIG 1C**).



TECH FIG 1 • A. A 1.5- × 1-cm flap is marked in the mucosa of the inferior lip. **B.** A 1.5- ×1-cm inferiorly based flap is marked on the inferior tongue. **C.** See **TECH FIG 4.** Tongue musculomucosal flap after elevation.



TECH FIG 2 • A. A V-shaped incision is placed on either side of the tongue frenulum for subperiosteal release of the tongue. **B.** Area of periosteal elevation of the lingual surface of the mandible.

Subperiosteal Release of the Floor of the Mouth

- A separate V-shaped incision is made around the base of the frenulum of the tongue (**TECH FIG 2A**).
- Dissection is carried anteriorly until the lingual surface of the mandible is reached. The periosteum of the mandible is incised.
- A periosteal elevator is used to completely elevate the periosteum of the lingual surface of the symphysis, parasymphyses, and bilateral mandible bodies (**TECH FIG 2B**).
- Incision is closed in a V-to-Y advancement fashion with 4-0 Vicryl in the muscle layer and 5-0 Monocryl for the mucosal layer.

Placement of Tongue Suspension Suture

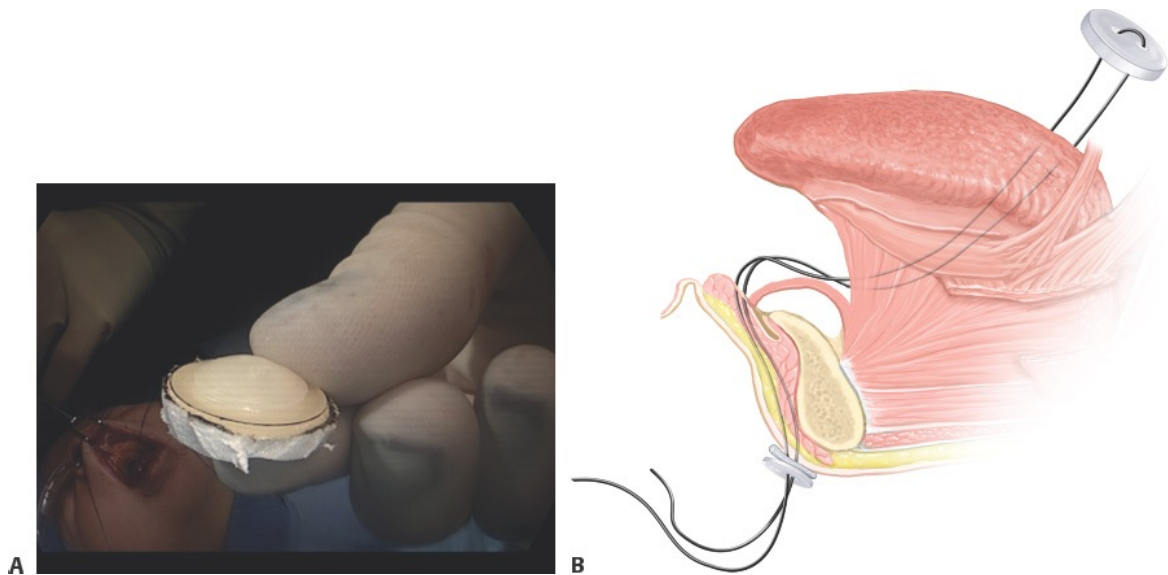
- A loop of 4-0 silk suture is tied through one hole of a surgical button and left

long as an emergency pullout suture.

- The button is placed on a backer of adhesive foam to help prevent pressure sores (**TECH FIG 3A**).
- 2-0 polypropylene suture on a long, curved taper needle (2-0 Prolene on a CT-1 needle; Ethicon, Somerville, NJ) is used after straightening the needle slightly to allow the needle to capture the anterior tongue mass.
 - This suture is passed through the raw area created by the tongue flap, through the mass of the anterior tongue musculature, and out the posterior tongue mucosa at a point where the tongue starts to curve toward the oropharynx in a more vertical orientation.
 - The needle is then passed through the button, then back through the tongue in a mattress fashion (**TECH FIG 3B**).
- The suspension suture is pulled forward to assess anterior movement of the tongue mass as the suture is brought under tension.
- If tongue movement is acceptable, the suture is brought through the incision in the lower labial sulcus, staying anterior to the mandible, to exit the skin in a submandibular crease.
 - The loose end of the suture can be threaded through a Keith needle and passed parallel to the first end to complete the mattress suture.
- Before removing the needles, both suture ends are passed through a foam-backed button, over which the suture will be tied. Foam should be firm and can be fashioned from the foam backing within an empty needle pack.
 - The button overlying the tongue mass does not require foam backing, whereas the submandibular button does require foam backing to avoid ulceration of the facial skin.

Closure and Tensioning of Tongue

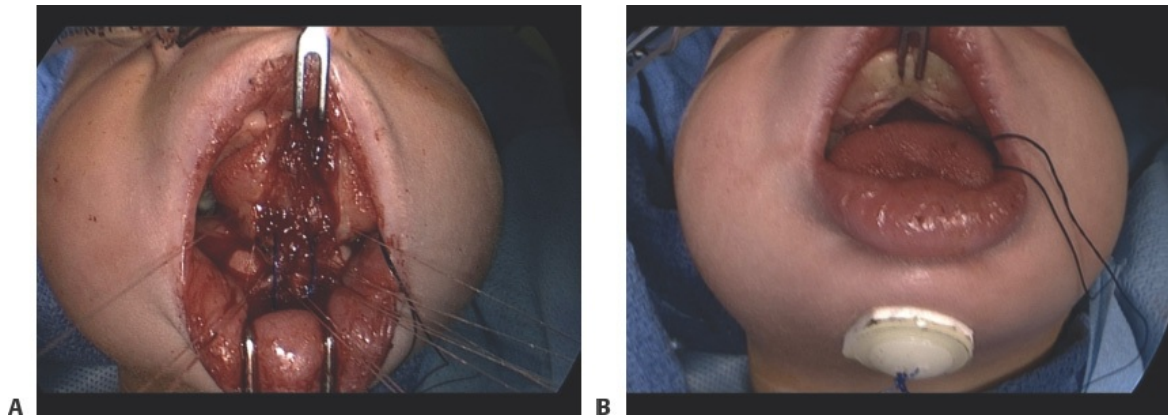
- The posterior mucosa of the tongue is approximated to the inferior aspect of the labial sulcus incision using interrupted 5-0 Monocryl suture (Ethicon, Somerville, NJ).
 - Sutures are placed sequentially from one side of the incision to the other, taking care to place the knots such that they lie on the mucosal side of the closure (**TECH FIG 4A**).



TECH FIG 3 • A. A backer of adhesive foam is placed on the back of the surgical buttons to prevent pressure sores from the buttons. **B.** Path of 2-0 polypropylene suspension suture through the tongue and surgical button and out the skin.

- The muscle of the tongue and the lip are approximated on either side and in the center of the limbs of the suspension suture using 4-0 Vicryl suture (Ethicon, Somerville, NJ). Three such sutures are usually sufficient.
- The anterior mucosa of the tongue is approximated to the superior aspect of the labial sulcus incision using interrupted 5-0 Monocryl suture. Sutures are placed sequentially from one side of the incision to the other, taking care to place the knots such that they lie on the mucosal side of the closure.
- Tension on the tongue suspension suture is determined by gently securing the first knot over the submandibular foam-backed button until the tongue mass just begins to move forward. No further tension should be placed so as to minimize pressure on the skin. Subsequent knots are placed to secure the suture (**TECH FIG 4B**).
- The purpose of the suspension suture is simply to take pressure off of the mucosal and muscular layers of the closure for the first 7 to 10 days, and sequelae such as tongue edema or skin ulceration can be minimized by placing the least amount of tension on the suture required to move the tongue mass forward.

- The safety silk suture tied to the button in the mouth is taped to the cheek.
- A nasogastric tube is placed to facilitate feeding.



TECH FIG 4 • A. Posterior layer of mucosal flaps is closed with 5-0 Monocryl sutures. **B.** Suspension suture is tied over a button under the chin. Note the safety silk suture used to retrieve the intraoral button.

PEARLS AND PITFALLS

Preoperative screening

- Nasendoscopy and bronchoscopy are essential prior to tongue-lip adhesion. The procedure should not be performed if there are any synchronous airway lesions.

Suspension suture

- The suspension suture should be tensioned to pull the base of the tongue forward but should not be pulled maximally as to cause tissue necrosis and increased tongue edema.

Postoperative care

- The adhesion should NOT be left in place until repair of cleft palate. This jeopardizes oromotor development and mobility of the tongue.

POSTOPERATIVE CARE

- Extubation is carried out when deemed appropriate by anesthesiology or critical care. A nasopharyngeal airway is left in place for several days to manage the airway while surgical edema is present.

- The suspension suture is left in place for 7 to 10 days.
- The child is monitored carefully for resolution of airway obstruction. Postoperative polysomnography is performed.
- If airway obstruction resolves, the patient is evaluated every 1 to 2 months. The tongue is monitored for active motion in response to touch, a sign of maturing tongue function.
- If tongue motion has matured and MMD has decreased to 3 mm or less, the adhesion is taken down, usually by 6 to 7 months of age.
- Early takedown of the tongue-lip adhesion is preferable so as to avoid oromotor delay in tongue function. Prior reports left the adhesion in place until the time of palate repair, often close to or later than 1 year of age. We believe that this can contribute to oromotor retardation. In addition, it is preferable to take down the tongue-lip adhesion well before the palate repair so as to assess adequacy of airway prior to further airway restriction that accompanies cleft palate repair.

OUTCOMES

- Resolution of airway obstruction is variable in studies of tongue-lip adhesion, ranging from 43% to 89%.^{15,21}
- Complete resolution of feeding difficulties also is variable, but many authors report an approximately 60% rate of ability to oral feed without any tube-feeding supplementation. Variabilities may exist due to institution-based protocols for surgical feeding tube placement.^{22,23}
- Few studies comprehensively assess polysomnographic findings after tongue-lip adhesion. Sedaghat et al.²⁴ describe improvement in sleep study findings in 7/8 patients after adhesion, but only 3 patients had reduction to mild or no sleep apnea. Flores et al.¹⁸ describe improvement in apnea-hypopnea index in 15 patients after adhesion, but improvement was significantly less compared to mandibular distraction patients.
- Tongue-lip adhesion has minimal effects on long-term speech development.²⁵

COMPLICATIONS

- Dehiscence (greatly reduced in techniques that utilize a suspension suture)
- Failure to completely resolve airway obstruction
 - In these cases, the airway should be reassessed for sites of synchronous airway lesions that may not have been appreciated, paying particular attention to supraglottic airway compromise and laryngomalacia.

- If the only other site of airway compromise is some element of laryngomalacia, the multidisciplinary team should be consulted regarding potential role for mandibular distraction osteogenesis with or without supraglottoplasty.
- If the patient is found to have laryngomalacia and is not felt to be a candidate for mandibular distraction osteogenesis with or without supraglottoplasty, or if synchronous subglottic airway compromise is identified (eg, tracheomalacia), then tracheostomy is recommended.
- Requirement for prolonged nasogastric feeds or gastrostomy tube

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13

CHAPTER Palatal Fistula

Gregory D. Pearson

DEFINITION

- A fistula is defined as an epithelialized tract between two cavities that are not meant to be communicating.
- A palatal fistula is an abnormal communication between the oral and nasal cavities.
- Palatal fistula can be intentional or unintentional.
 - Intentional fistulas are fistulas not repaired at the time of initial operation. Examples include:
 - The alveolar cleft with a Veau III or Veau IV (unless the surgeon elects to perform a gingivoperiosteoplasty)
 - A Veau IV with a “locked out” premaxilla
 - Unintentional fistula after palatoplasty^{1–3}:
 - These fistulas are unwanted and not planned for during the initial operation.
 - Veau IV clefts are associated with the highest fistula rate.
 - No difference in risk for palatal fistula related to gender, age at time of repair, and race.
 - The difference in fistula rate between straight line repairs and Furlow-type repairs appears to be surgeon/institution dependent with no clear lower risk between the two types of repair.
- Palatal fistula repair can be an extremely challenging problem to solve and prevention is the best option.

ANATOMY

- The Pittsburgh fistula classification system classifies fistulas as I to VII, from

a posterior to anterior location on the palate⁴ (**FIG 1**).

- Type I involves only the uvula (consisting of a bifid uvula).
- Type II involves the soft palate.
- Type III occurs at the junction of the hard/soft palate.
- Type IV arises within the hard palate.

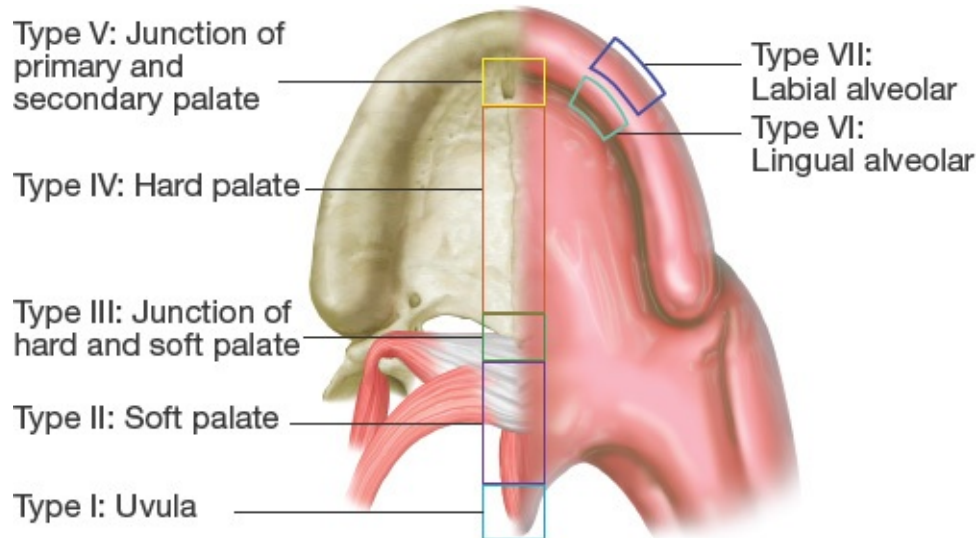


FIG 1 • Pittsburgh fistula classification system.

- Type V is located at the incisive foramen (reserved for Veau IV clefts).
- Type VI is a lingual alveolar communication on the alveolus.
- Type VII is located on the labial side of the alveolus.

PATHOGENESIS

- Occurrence rates of palatal fistula vary from 0% to 60% in reported literature.¹⁻³
- Several factors have been associated with the prevention of palatal fistula:
 - Tension-free and watertight closure
 - Relaxing incisions advocated by von Langenbeck for tension-free closure.
 - Jackson et al. proposed “CHOP modification” of Furlow palatoplasty for soft palate repair.²
 - Complete two-layer closure of nasal and oral flaps
 - LaRossa promoted liberal use of vomer flaps for closure of the nasal floor.⁵
 - Infection prevention
 - The use of perioperative antibiotics is debated in the literature.

NATURAL HISTORY

- Palatal fistula will remain patent until the time of closure.
- A fistula can be symptomatic or asymptomatic

PATIENT HISTORY AND PHYSICAL FINDINGS

- Palatal fistula can occur after cleft palate repair, oncologic resection, trauma, or illicit drug use.
- Patients may report that the fistula is symptomatic.
 - Nasal escape of food or liquids
 - May be intermittent
 - Typically, viscous liquids like yogurt
 - Nasal escape of air
 - May be noted by patient as change in voice
- May be noted by speech pathologist as nasal turbulence or hypernasality
- Physical examination will demonstrate a hole or communication from the oral to nasal cavity.
 - Fistulas can range from small to large and vary in location on the palate.
 - Small fistulas can be difficult to see, but the patient can typically state/point to the location.
 - An examination under anesthesia with a lacrimal probe can be useful to determine the location, size, and orientation of a fistula.
 - A dental mirror can be useful in evaluating anterior fistulas.
 - Deep crevasses or folds of mucoperiosteal tissue can simulate a fistula.
 - Palatal expansion may open an occult fistula that was already present.

IMAGING

- Radiographic fistulograms (such as those performed for an enterocutaneous fistula evaluation) are not necessary.
- Physical examination should determine whether a fistula is present.
- Nasopharyngoscopy or video fluoroscopy should be employed to determine velopharyngeal gap size in patients with fistula and velopharyngeal dysfunction.

DIFFERENTIAL DIAGNOSIS

- Hypernasality from velopharyngeal dysfunction (VPD)
- Nasal escape of liquids/food secondary to poor oral motor planning/retrograde

oronasal reflux

NONOPERATIVE MANAGEMENT

- Obturators/dental retainers can be fabricated by dentists or orthodontists to provide symptomatic relief (**FIG 2**).
- Obtaining patient compliance for wearing the retainer can be difficult.
- The dental brackets on the retainer may loosen and require retightening or fabrication of a new splint.
- The patient must have enough teeth to properly support a retainer.

SURGICAL MANAGEMENT

- Surgical management and operative options are largely dictated by the location of the palatal fistula based upon the Pittsburgh classification system.
- When determining whether to repair a fistula, the surgeon should strongly consider and assess whether the fistula is symptomatic.
 - Nasal escape of fluids or foods, hypernasality, and preventing further surgical or orthodontic interventions (eg, bone grafting or orthognathic surgery) are all reasons for attempted fistula repair.
- Pittsburgh type I
 - Bifid uvula rate ranges from 1.34% to 19% of selected populations, but the true fistula rate is probably underestimated in the literature.
 - Because these fistulas tend to be asymptomatic as well as concerns about anesthesia on pediatric brain development, these fistulas are the least likely to be repaired as a primary objective for an operation.
- Pittsburgh type II
 - When determining the type of reconstruction choice for a soft palatal fistula repair, a surgeon should also make a determination related to a child's resonance (specifically if VPD is present) and the type of previous repair performed.
 - If the child has VPD, the fistula may be fixed but hypernasality will likely persist unless addressed with the repair.
 - If a child has normal resonance regardless of the type of primary palatoplasty performed, augmentation/reinforcement with acellular dermal matrix (ADM) can be used.⁶
 - For patients with a fistula after straight-line repair and concurrent VPD, addressing the VPD with either a palatal lengthening procedure or VPD surgery should be strongly considered.

- A conversion to a Furlow double opposing Z-plasty typically allows repair of a type II fistula while addressing VPD in children with small velopharyngeal gaps on imaging.⁷
- The CHOP modification with bilateral relaxing incisions can facilitate tension-free closure.
- For larger velopharyngeal gaps and fistula or very large fistula (dehiscence), a superiorly based posterior pharyngeal flap may be necessary as conversion to Furlow may not lengthen the palate sufficiently.
- Pittsburgh type III
 - Traditional teaching reports that the junction of the hard palate and soft palate remains the most common site of fistula, particularly when employing a Furlow palatoplasty.
 - As for type II fistula, the patient's resonance and type of previous repair should influence the operation considered for fistula repair.
- Pittsburgh type IV
 - There is significant overlap for techniques used to repair type III and IV palatal fistulas.
 - The mucoperiosteal flaps tend to scar, become stiffer, and have less mobility compared to flaps used in a primary palatoplasty, thus limiting their advancement or rotation potential.
- Pittsburgh type V
 - This is the second most common location of fistula as well as the most challenging to repair given the relative lack of palatal tissue in this area.
 - These fistulas are often the result of either poor inset of the lateral palatal mucoperiosteal flaps into the premaxillary segment or more commonly a premaxillary segment that is so anteriorly displaced out of the arch (a "locked out" premaxilla and intentional fistula) that closure at the time of initial palatoplasty is not possible.

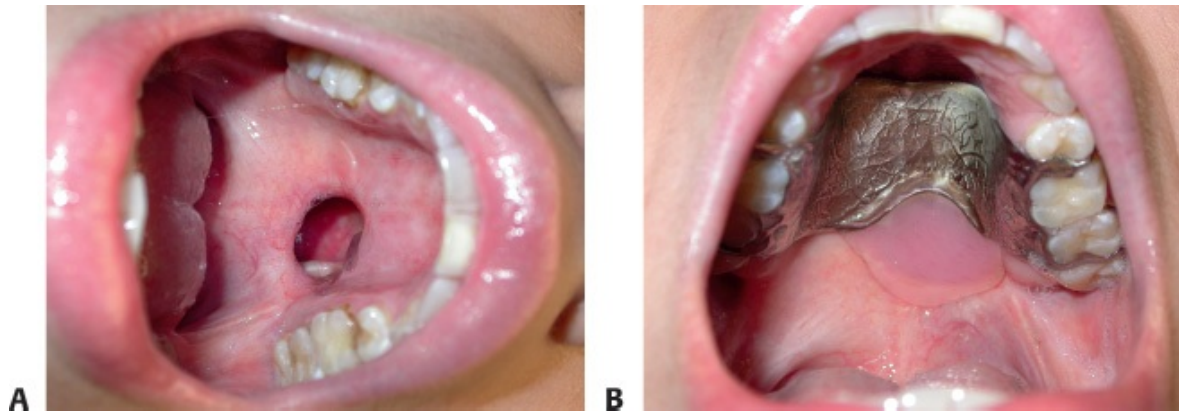


FIG 2 • Palatal fistula **(A)** covered with an obturator **(B)**.

- Pittsburgh type VI and VII fistulas pertain to the alveolar arch and labial sulcus and are addressed in the chapter on alveolar cleft repair.

Preoperative Planning

- The surgeon must discuss the possibility of palatal fistula recurrence after attempted closure with the patient and family.
- Assuring proper patient compliance with postoperative instructions prior to embarking upon repair is imperative.
- Depending on the type of repair technique used, a surgeon may consider having orthodontist fashion of a postsurgical retainer to protect repair while healing, particularly for type IV and V fistulas.
 - It is important to ensure the retainer does not put pressure on flaps or area of repair while still protecting the surgical site from tongue and food particulate.
- As previously stated, in rare instances, an examination under anesthesia with a lacrimal probe can be useful to determine the location, size, and orientation of a fistula.
- If a local flap is used, it must be protected from masticatory trauma during healing.

Positioning

- The patient should be orally intubated.
 - May use a regular endotracheal tube or oral RAE endotracheal tube depending upon surgeon and anesthesiologist's preferences.
 - The endotracheal tube may be positioned in the midline or laterally depending on the repair technique chosen.

- Typically, the patient should be placed in a horseshoe headrest with a shoulder roll and slight extension of the neck.
- A Dingman mouth prop or dental bite blocks (in which use depends on surgical technique to be employed) can be extremely useful for proper exposure of the intraoral cavity.

Approach

- Although multiple strategies can be performed for each site, the most common/useful approaches will be addressed according to the Pittsburgh classification system.
- Pittsburgh type I: Excision and reapproximation
- Pittsburgh type II:
 - Lateral relaxing incisions and rerepair
 - May consider augmentation with ADM
 - Conversion by Furlow palatoplasty
 - Posterior pharyngeal flap
- Pittsburgh type III:
 - Lateral relaxing incisions and rerepair
 - May consider augmentation with ADM
 - Posterior pharyngeal flap (if VPD present)
 - Buccal myomucosal flap
 - Facial artery musculomucosal (FAMM) flap
- Pittsburgh type IV:
 - Lateral relaxing incisions and rerepair with pushback technique
 - May consider augmentation with ADM
 - Elevation of mucoperiosteal flaps and pushback technique
 - Labial mucosal flap
 - If space in dental arch to pass through or if bite blocks employed
 - Buccal myomucosal flap
 - FAMM flap
 - Tongue flap
 - Free tissue transfer
- Pittsburgh type V:
 - Labial mucosal flap
 - FAMM flap
 - Tongue flap

- Premaxillary turnover flap
 - Primarily used as nasal lining flap for fistula at anterior incisive foramen in Veau IV cleft
- Free tissue transfer

TECHNIQUES

■ Excision and Reapproximation

- Midline oral endotracheal tube placement; head placed in headrest with slight extension.
- Perform proper surgical time-out.
- Place Dingman mouth prop.
- Prep and drape the patient.
- Mark out medial epithelialized areas that must be excised.
- Inject with local anesthesia of choice. Author prefers ¼% Marcaine with 1:200 000 epinephrine.
- Excise medial portions of fistula.
- Repair with resorbable sutures. Author prefers 4-0 chromic sutures.

■ Lateral Relaxing Incisions and Rerepair (TECH FIG 1)

Preparation for All Fistula Types

- Midline oral endotracheal tube placement; head placed in headrest with slight extension.
- Perform proper surgical time-out.
- Place Dingman mouth prop.
- Prep and drape the patient.
- Mark out lateral relaxing incisions (von Langenbeck style relaxing incision on the hard palate, soft palate, or both depending upon fistula type).
 - Relaxing incisions typically need to be longer than initially thought due to relative immobility of soft tissues.
- Inject with local anesthesia of choice. Author prefers ¼% Marcaine with

1:200 000 epinephrine.

Pittsburgh Type II Fistula

- Incise lateral relaxing incisions on the soft palate.
- Incise medial fistula.
- Separate nasal mucosa from levator muscles with sharp dissecting scissors.
- Separate oral mucosa from levator muscles with sharp dissecting scissors.



TECH FIG 1 • A. Lateral relaxing incisions. B. Rerepair.

- Make certain that levator muscles are not tethered to the hard palate, if so release sharply.
- Repair nasal mucosa with interrupted, buried (knot on nasal side) sutures. Author prefers 4-0 chromic.
- Repair levator musculature with re-establishment of levator sling. Author prefers 4-0 Monocryl.
- Repair oral mucosa with interrupted sutures. Author prefers 4-0 chromic.
- If augmenting closure with ADM, after muscle repair, place a thin piece of ADM over muscle with ample coverage beyond suture line. Author uses double-armed 4-0 Monocryl sutures suturing from underneath ADM through oral mucosa allowing knots to easily be placed and tied on oral mucosal side.
- Place tongue stitch and remove Dingman device.

Pittsburgh Type III Fistula

- Incise lateral relaxing incisions on the hard and soft palate.
- Incise medial fistula.
 - It is typically easier to recruit oral mucosa compared to nasal mucosa, so the initial markings should be slightly on the more lateral portions of the fistula to allow easier closure of the nasal mucosa.
- Use Joseph Periosteal Elevator to elevate mucoperiosteal flaps from the hard palate with care taken to preserve greater palatine vessels.
- Release soft palate lateral relaxing incision from hamulus and junction of the hard palate/end of alveolar ridge.

- Dean scissors can be a useful instrument to release medial tissue off hamulus.
- Separate nasal mucosa from levator muscles (if present) and release nasal mucosa from nasal side of the hard palate.
- Separate oral mucosa from levator muscles with sharp dissecting scissors (if present).
- Make certain that levator muscles are not tethered to the hard palate, if so release sharply.
- Repair nasal mucosa with interrupted, buried (knot on nasal side) sutures.
- Repair levator musculature with re-establishment of levator sling (if previously released).
- Place liberal ADM prior to closure of oral mucosal flaps.
- Repair oral mucosa with interrupted sutures.
- Ensure hemostasis of lateral relaxing incisions.
- Place tongue stitch and remove Dingman.

Pittsburgh Type IV Fistula

- Incise lateral relaxing incisions on the hard and soft palate (if necessary depending on location of fistula in hard palate).
- Incise medial fistula.
 - It is typically easier to recruit oral mucosa compared to nasal mucosa, so the initial markings should be slightly on the more lateral portions of the fistula for easier closure of the nasal mucosa.
- Use Joseph Periosteal Elevator to elevate mucoperiosteal flaps from the hard palate with care taken to preserve the greater palatine vessels.
 - Determine whether fistula is too large for closure and if pushback technique will be required.
 - If pushback is required, continue lateral relaxing incisions more proximally, depending upon the location of fistula either incise from medial portion of fistula toward alveolus or fashion-like Veau-Wardill-Kilner-type palatoplasty.
- Separate/release nasal mucosa from nasal side of hard palate to allow medial mobilization.
 - A double hockey or Pigtail instrument or Woodson can be extremely helpful for this dissection.
- Repair nasal mucosa with interrupted, buried (knot on nasal side) sutures.

- Place liberal ADM prior to closure of oral mucosal flaps.
 - Repair oral mucosa with interrupted sutures.
 - Resuspend flaps to lateral relaxing incisions without placing undue tension on medial repair.
 - Ensure hemostasis of lateral relaxing incisions.
 - Place tongue stitch and remove the Dingman device.
-

■ Conversion by Furlow Palatoplasty

- Refer to Chapter on Furlow Palatoplasty (Chapter 8), for description of this technique.
 - The CHOP modification should be encouraged if any concerns for tension on repair exist.
-

■ Posterior Pharyngeal Flap

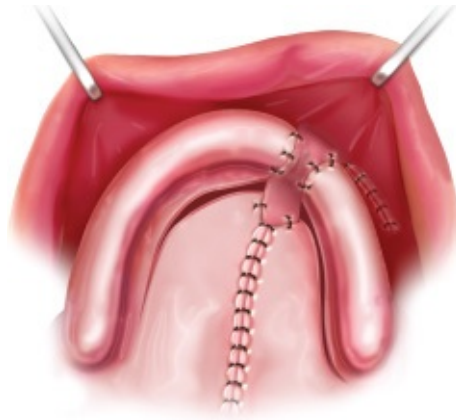
- Please see chapter on Velopharyngeal Insufficiency (Chapter 14) for description of this technique.
 - A palatal split technique (as described by Owsley⁸) should be considered over a fish-mouth technique as described by Argamaso.⁹
-

■ Labial Mucosal Flap

- Must be able to protect this flap from masticatory trauma by either having space to pass through dental arch or by having temporary bite blocks placed on the teeth.
- Midline oral endotracheal tube placement; head placed in headrest with slight extension.
- Perform proper surgical time-out.
- Placement of Dingman mouth prop.
- Prep and drape the patient.
- Mark out medial portions of the fistula.
 - Recruit tissue from oral side as previously described.
- Mark out flap on labial wet vermillion (this is a hinge- or finger-type flap).
 - The base of flap and point of rotation of flap can be unipedicle or bipedicle

depending upon the location of fistula and Veau-type cleft.

- Typically for Veau III clefts with recruitment of tissue from posterior segment.
- Make certain to place incision line several millimeters above the attached gingiva so that closure of donor defect is made easier.
- Inject with local anesthesia of choice. Author prefers ¼% Marcaine with 1:200 000 epinephrine.
- Incise and repair medial portions of fistula as previously described.
- Incise buccal flap and elevate with sharp scissors.
 - Elevate this flap off the orbicularis muscle to maintain as much blood supply because this is a random pattern flap.
- Rotate flap into defect.
- Sew flap to raw oral mucosal edges (preferably through dental arch defect) (**TECH FIG 2**).
- Close donor defect with interrupted sutures.
- Place tongue stitch and remove Dingman device.

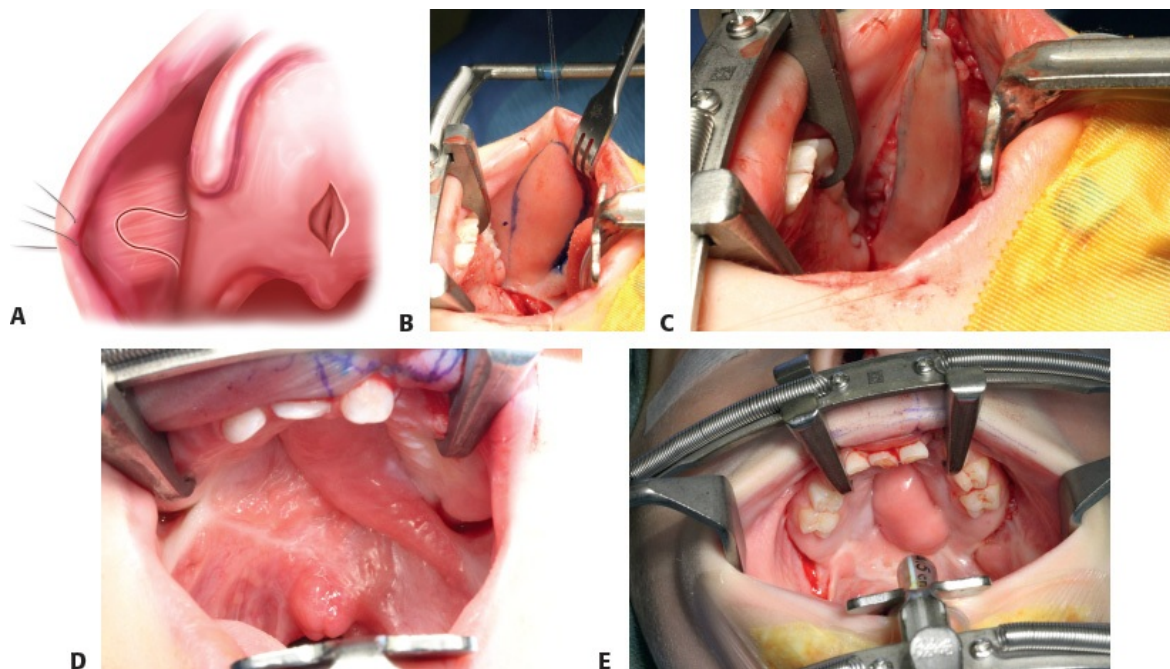


TECH FIG 2 • Design of a labial mucosal flap.

■ Buccal Myomucosal Flap

- Oral endotracheal tube placement; head placed in headrest with slight extension.
- Perform proper surgical time-out.
- Prep and drape the patient.
- Place Dingman mouth prop or dental mouth prop.

- Place several retraction sutures on the lip to aid in retraction/visualization.
- Identify Stensen duct.
 - The flap is caudal to the duct.
- Mark out flap from area over ascending ramus transversely oriented to oral commissure (stay on wet vermilion) (**TECH FIG 3A,B**).
 - The base of flap is about 1.5 cm.
 - Narrow the flap distally.
- Inject with local anesthetic.
- Incise mucosa and sharply dissect from the distal end of flap toward base of flap (**TECH FIG 3C**).



TECH FIG 3 • **A.** Design of a buccal myomucosal flap. **B.** Markings. **C.** Flap elevation. **D.** Flap inset into a palatal defect. **E.** Division of base of flap.

- A portion of the buccinator muscle is taken to improve the vascularity of the flap (as described by Mann,³ this is an intramuscular dissection).
- This flap can be elevated bilaterally if needed.
- Prepare fistula site so that some nasal mucosa can be rolled in (complete nasal mucosa closure is not critical).
- Make certain to elevate raw edges of oral mucoperiosteal tissue to inset the

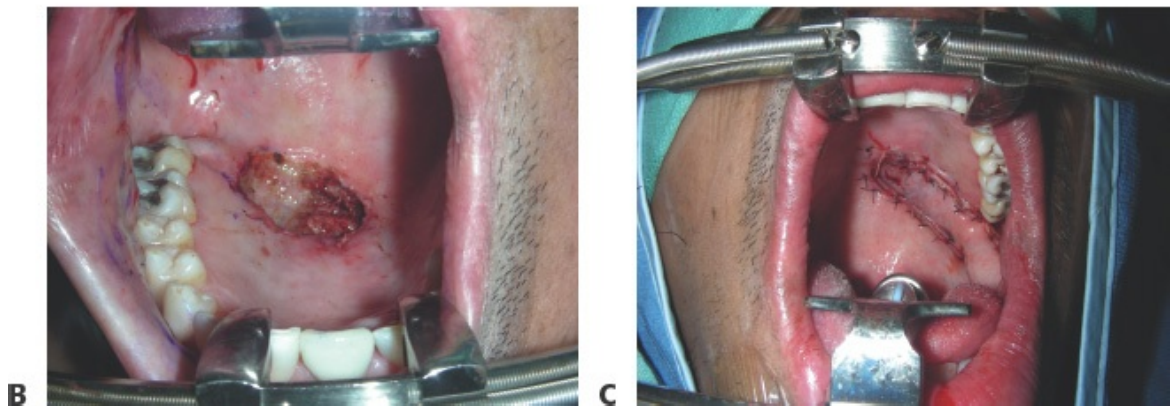
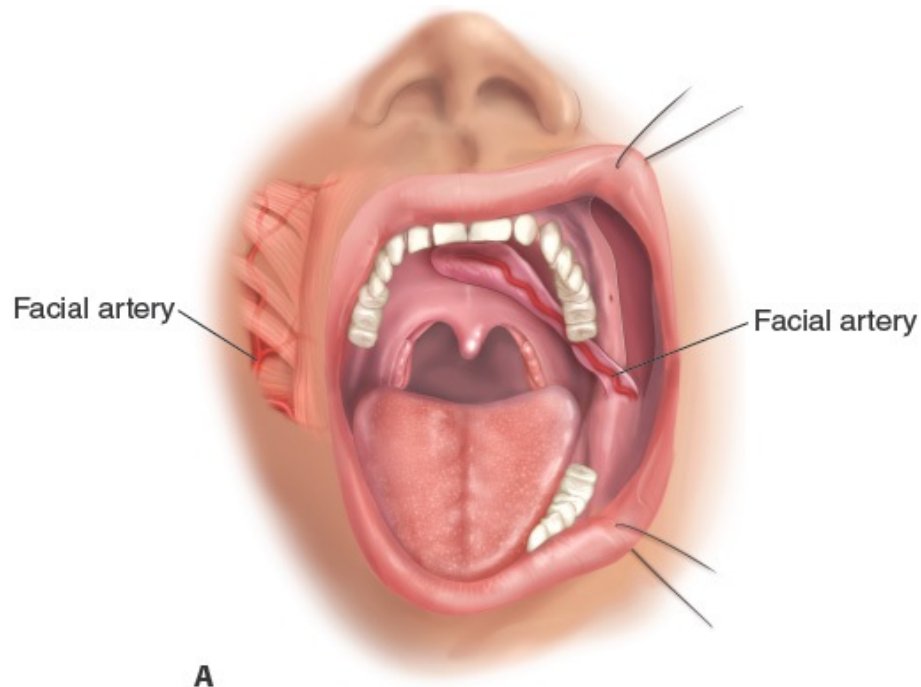
flap.

- Rotate flap into defect and sew in place attaining excellent approximation of mucosal edges (**TECH FIG 3D**).
 - Flap will need to be rotated posteriorly behind dental arch or through space in dental arch that can be protected from masticatory trauma (can use oral splints on teeth as well).
 - Close donor site in a single layer.
 - Place tongue stitch and remove Dingman/dental mouth prop.
 - The base of this flap may be subsequently divided after 3 to 4 weeks (**TECH FIG 3E**).
-

■ Facial Artery Musculomucosal Flap¹⁰

- Oral endotracheal tube placement, place head in headrest with slight extension.
- Perform proper surgical time-out.
- Prep and drape the patient.
- Placement of Dingman mouth prop or dental mouth prop.
- Place several retraction sutures on the lip to aid in retraction/visualization.
- Identify Stensen duct.
 - Artery and flap should be anterior to the duct.
- Use handheld Doppler to identify the course of the facial artery.
- An obliquely designed flap is centered over the artery from retromolar trigone area to gingival buccal sulcus at alar base (should be anterior to Stensen duct).
 - Flap is 1.5 to 2 cm wide.
- Incise mucosa at distal end (either superiorly or inferiorly based) through mucosa and buccinators.
- Identify facial artery and ligate.
- Elevate flap deep to the artery taking a small cuff of buccinator muscle and orbicularis muscle (**TECH FIG 4A**).
 - Flap can be 8 to 9 cm in length.
 - This flap can be elevated bilaterally if needed.
- Prepare fistula site so that some nasal mucosa can be rolled in (complete nasal mucosa closure is not critical) (**TECH FIG 4B**).

- Make certain to elevate raw edges of oral mucoperiosteal tissue to inset the flap.
- Rotate flap into defect and sew in place attaining excellent approximation of mucosal edges (**TECH FIG 4C**).
- Flap will need to be rotated posteriorly behind dental arch or through space in dental arch that can be protected from masticatory trauma (can use oral splints on teeth as well).
- Close donor site in two layers (buccinator muscle and then mucosa) taking care to avoid the Stensen duct.
- Place tongue stitch and remove Dingman/dental mouth prop.



TECH FIG 4 • A. Design of a facial artery

musculomucosal flap. **B.** Preparation of the fistula site.
C. Flap inset.

■ Tongue Flap (Anteriorly Based)^{9,11}

Raising and Insetting Flap

- Oral endotracheal tube placement to the right or left side; head placed in headrest with slight extension.
- Perform proper surgical time-out.
- Prep and drape the patient.
- Place bite block mouth prop.
- Inject palatal tissue with local anesthetic.
- Incise and elevate around palatal mucosa to become nasal floor.
 - Plan this incision so that you can have either complete nasal floor closure or at least significant nasal floor mucosa to place your tongue flap on.
- Close nasal floor if possible.
- Use the foil from a chromic stitch to make a template of the palatal defect.
- Place a traction suture through the tip of the tongue to improve exposure.
- Transpose the foil template onto the tongue with tip of flap at junction of anterior two-thirds and posterior one-third of the tongue.
- Mark out flap making certain to maintain at least a 2-cm pedicle base.
 - Can mark flap slightly larger than template for safety.
- Use a Colorado needle-tip Bovie to incise and elevate the flap from distal to proximal (**TECH FIG 5A**).
 - This dissection should include underlying longitudinal tongue musculature but can be thinned near the tip of the flap (down to 4 mm of muscle).
 - This dissection is not a natural tissue plane and can bleed from the raw muscle edge.
- Inset tongue flap into edges of raw mucoperiosteal palatal flaps (**TECH FIG 5B,C**).
- The use of 4-0 double-armed Monocryl sutures with the knots on the palatal mucosa makes inset of this flap much easier.
- This flap cannot be completely inset into the entire fistula as the pedicle width prevents complete inset (final inset is performed during division of

flap).

- Closure of donor site of the tongue with horizontal mattress sutures to prevent bleeding.
- Extubate patient.
- Place light elastics on orthodontic brackets for gentle MMF and patient comfort.
- Wait for 3 weeks for revascularization.

Division of Flap

- A gentle rubber shod clamp can be used to test if neovascularization has occurred in OR prior to division.
 - If concerns for insufficient vascularity, postpone division.
- Plan division so that a portion of the pedicled base will fill remaining portion of the palatal fistula.
 - For incomplete nasal floor closure, some secondary healing from margins can occur.
- Divide flap and debulk the new portion to inset (typically about 10%–15% of flap).
- Complete inset of flap.
 - Double-armed sutures make inset significantly easier.
- Return unused pedicled tissue to the tongue by opening previous incision and closing with chromic sutures.

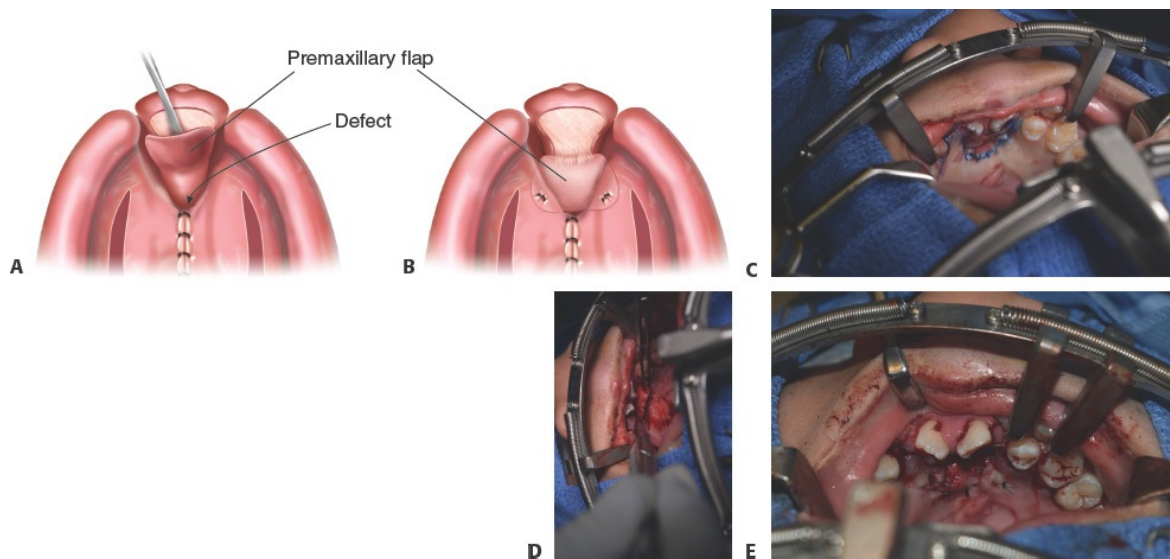


TECH FIG 5 • **A.** Design of a tongue flap. Fistula before **(B)** and after repair **(C)** with a tongue flap.

■ Premaxillary Turnover Flap (Fish-Mouth Technique into Hard Palatal Mucoperiosteal

Flaps)¹²

- Midline oral endotracheal tube placement; head placed in headrest with slight extension.
- Perform proper surgical time-out.
- Place Dingman mouth prop.
- Prep and drape the patient.
- Mark junction of premaxillary gingiva and lingual side of incisors with lateral markings down the premaxilla along the cleft margin (**TECH FIG 6A,B**).
- Mark edge of mucoperiosteal flaps and lateral relaxing incisions along alveolar ridge (**TECH FIG 6C**).
- Inject with local anesthetic.
- Incise junction of the gingiva and lateral premaxilla and perform subperiosteal dissection of this flap.
 - The base of this flap narrows as you ascend toward the nasal cavity, so care must be taken in elevation (**TECH FIG 6D**).
- Use an angled blade to incise the edge of the mucoperiosteal flaps and make lateral relaxing incisions.
- Use a combination of periosteal elevators from lateral side and sharp scissor or knife dissection to re-elevate the mucoperiosteal flaps.



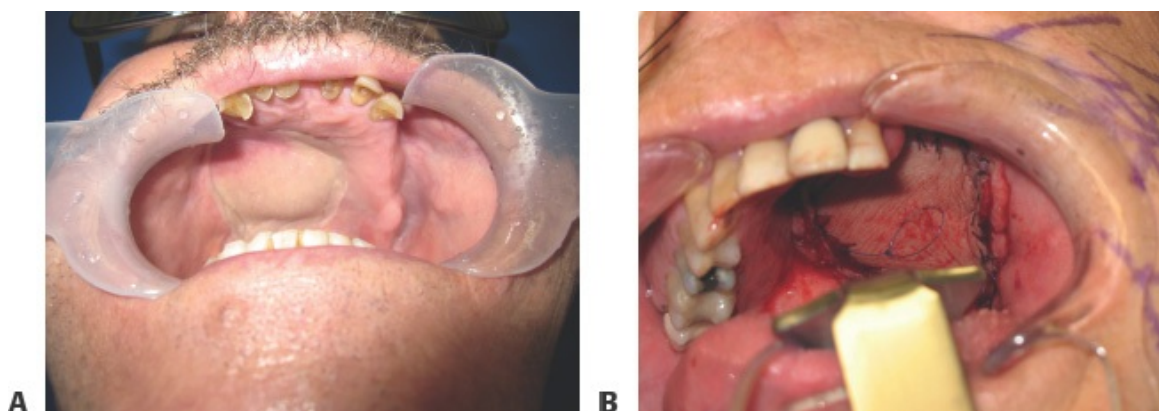
TECH FIG 6 • A,B. Design of the premaxillary turnover

flap. **C.** The mucoperiosteal flap is marked just behind the incisors and at the lateral borders of the premaxilla. **D.** Flap elevation. **E.** Flap inset in a parachute-type manner.

- Care must be taken to preserve greater palatine vessels if dissection occurs that distally.
- Advance mucoperiosteal flaps if possible.
- Turn over premaxillary flap for inset.
 - The premaxillary gingiva will become the new nasal mucosa, and the periosteum of the premaxilla will be the oral side for this flap.
- Use parachuting sutures to tack the periosteal side of flap to raw surface of mucoperiosteal flaps.
 - The use of double-armed sutures coming through the premaxillary flap and out the palatal mucoperiosteal flap makes inset and parachuting much easier (see **TECH FIG 6A**).
 - Do not attempt to tie these sutures until all have been placed for ease of placement.
 - Place sutures about 1 cm apart.
- After flap has been inset distally, close lateral aspect of flap to any raw areas of alveolus gingiva.
 - Work distally to proximally to close down posterior alveolar fistula.
 - Using a P2 needle and Castroviejo needle drivers facilitates this closure.
- May cover this flap with a thin piece of ADM if single layer closure is being performed.
- Place tongue stitch and remove Dingman device.

■ Free Tissue Transfer¹³

- Multiple donor sites have been described, including radial forearm free flap (**TECH FIG 7A**), anterolateral thigh free flap (**TECH FIG 7B**), and lateral arm flap.
- Thorough descriptions of and surgical techniques for the various free tissue flaps that have been described in the oncologic literature for palatal and maxillectomy defects are found in other chapters of this book.



TECH FIG 7 • A. Radial forearm free flap for palatal fistula closure. **B.** Anterolateral thigh flap for palatal fistula closure.

PEARLS AND PITFALLS

Obtain a preoperative retainer to protect repair for type IV and V fistulas

- Have this item made 2 weeks before surgery and have patient wear it to check for compliance and become habituated to it.
- Meet with your orthodontist and patient with retainer to make certain it fits but does not compress on your repair.

Postoperative compliance

- Must discuss and ensure proper postoperative compliance with diet and activities in the preoperative setting.
- This author has had recurrence secondary to poor postoperative compliance.

Preoperative orthodontia for tongue flaps

- Have orthodontic colleagues place temporary orthodontic brackets on the permanent teeth.
- Saves time of placing some form of appliance while under anesthesia.
- Use light elastics instead of true MMF to decrease intraoral opening while attempting to provide more comfort to the patient.

Preoperative evaluation for sleep-disordered breathing

- If planning posterior pharyngeal flap for type II or III fistula, evaluate for obstructive sleep apnea

	with preoperative polysomnogram.
Proper exposure and visualization	■ Make relaxing incision longer than expected. ■ Dissect around greater palatine vessels under direct visualization.
Mucoperiosteal flap rigidity	■ Remobilization of the mucoperiosteal flaps rarely provides as much mobility as desired as they are stiffer than primary repair.

POSTOPERATIVE CARE

- Patients should be observed overnight for pain control and to monitor for any airway issues.
- Patients should be started on a liquid diet for 24 to 48 hours after surgery (per surgeon's preference).
- Diet should then be advanced to a soft food diet for 3 to 4 weeks after surgery (per surgeon's preference).
- Some surgeons implement postoperative antibiotics, but the literature is divided about use.
- Peridex should be used (5 to 10 mL swish and spit) after every meal.
- Nasal precautions should be instituted.
 - No nasal suctioning while in hospital.
 - Avoid blowing of the nose.
 - Sneeze with an open mouth if possible.
 - No straws.
- If a postsurgical splint has been made, the retainer should be worn at all times and only taken out to clean.
- Follow-up within 1 week to assess healing.

OUTCOMES

- Recurrence rate is highly variable in the literature and dependent on technique/flap chosen and location of the fistula.¹⁴
- ADM shown to work in nine consecutive patients without recurrence for hard palatal fistula.⁶
- Buccal myomucosal flap has reported 7% to 18% failure rate for all uses.³
- FAMM flap has failure rates of 17% to 27%.¹⁰
 - Secondary to venous congestion and flap tip necrosis
- Lateral relaxing incisions and pushback technique have 10% failure rate.¹⁵

- All failures are reported in bilateral cleft lip and palate.
- Tongue flap reported failure rates range from 8% to 15%.^{9,16}
 - Sohail et al. found no difference in complications or recurrence rates between FAMM flaps and tongue flaps for closure of large anterior palatal fistula.
 - These authors found that the total operative time and fewer early postoperative complications with the FAMM flap.
- Free tissue transfer success rates are reported between 83% and 98%.¹³
 - Most studies did not address any donor site morbidity though.

COMPLICATIONS

- Acute postoperative airway obstruction
 - This situation can occur during emergence from anesthesia as tongue muscle tone can be slower to recover in patients compared with respiratory drive (effective glossoptosis).
 - Can also occur when a tongue flap has been used.
 - Prevention is key.
 - An oral airway device placed by the anesthesia team can disrupt/damage fistula repair.
 - Except in cases of tongue flap, I prefer to place a tongue stitch with 2-0 silk tied to a Raytec for resolution of acute postoperative glossoptosis.
- Bleeding
 - Raw surfaces are frequently left after fistula repair (particularly when relaxing incisions have been used).
 - Ensure hemostasis with normotensive anesthesia prior to extubation.
 - Tell family/patient to expect some oozing from the mouth or nose for 24 hours.
 - If nasal bleeding is severe, an endoscope can be used in the OR to evaluate the nasal repair.
- Recurrence¹⁴
 - The most common complication after palatal fistula repair
 - If a flap has been employed, usually from partial or full flap loss (see Outcomes section)
- Obstructive sleep apnea
 - Can occur if a PPF has been employed in Pittsburgh type II or III fistula repairs
 - May require modification, takedown of flap, or CPAP if persistent 6 months

after surgery

■ Halitosis

- Not a true complication but a frequent concern/question raised by family while wounds are healing

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14

CHAPTER Velopharyngeal Insufficiency

Jennifer L. McGrath and Arun K. Gosain

DEFINITION

- Velopharyngeal insufficiency (VPI) refers to a structural inadequacy of the velopharyngeal apparatus, resulting in inadequate closure of the velopharyngeal port during speech.
- VPI may be congenital or acquired.
- It is characterized by nasal air emission and hypernasality of speech, articulation errors, decreased speech intelligibility, and nasal reflux of food and liquids.

ANATOMY

- The velopharyngeal sphincter is a complex, 3D arrangement of muscles that serves to separate the nasal cavity from the oral cavity during speech and swallowing.
- Muscles of the soft palate: levator veli palatini, tensor veli palatini, palatoglossus, palatopharyngeus, and musculus uvulae.
 - Paired levators are primarily responsible for velum closure by moving the velum posteriorly and superiorly.
 - Superior pharyngeal constrictor moves the posterior and lateral pharyngeal walls centrally.
- Innervation:
 - Predominantly CN IX and X: levator veli palatini and pharyngeal constrictors
 - CN V₃: Tensor veli palatini
- Three patterns of closure have been described:
 - Coronal: majority of closure from posterior movement of the velum
 - Sagittal: majority of closure from medial movement of the lateral pharyngeal

walls to meet the velum

- Circular: contributions of both movement of the velum posteriorly and movement of the lateral pharyngeal walls medially. Passavant ridge may contribute to closure.

PATHOGENESIS

- The cause of VPI may be structural, functional, or dynamic.
- Four main categories of VPI are frequently encountered. They include
- Palatoplasty: after primary cleft palate repair
 - Inappropriate levator veli palatini positioning
 - Palatal scarring preventing functional contraction of repaired levator sling
 - Length discrepancy preventing contact with the posterior pharynx
- Submucous cleft palate (SMCP)
 - May be classic (bifid uvula, palatal muscle diastasis) or occult
 - Often present later than cleft lip and palate
 - Not always associated with VPI (see section Natural History below)
- Palatopharyngeal disproportion
 - No anatomic abnormality to reconstruct
 - Disproportion may result from a short palate and/or a deep nasopharynx.
 - May be seen after tonsillectomy and adenoidectomy
- Neurogenic
 - More common in adults than children
 - Etiology may be upper motor neuron, nuclear, or lower motor neuron or generalized hypotonia.
 - Examples: muscular dystrophy, neurofibromatosis, cerebral palsy, apraxia, dysarthria
 - This subset tends to do more poorly with surgery.

NATURAL HISTORY

- Transient VPI is common after primary palatoplasty.
 - Patients are referred to speech-language pathologist (SLP) as early as 2 weeks postoperatively.
 - Perceptual speech assessment (PSA) by a SLP is obtained when the patient is of a cooperative age, often age 3 or above.
 - The incidence of lasting VPI after primary palatoplasty is about 10% to 20%.^{1,2}
- Submucous cleft palate (SMCP)

- Not all patients with SMCP will develop VPI. Studies suggest roughly 5% to 10% of patients with SMCP will develop VPI warranting intervention.^{3,4}
- The incidence of VPI in the pediatric plastic surgery population is higher due to referral bias.
- Children with SMCP should undergo PSA by a SLP. Intervention should be delayed until reliable PSA can be performed by a trained SLP, which is usually after age 3 years.
- Some children with SMCP may improve with speech therapy. Surgery is indicated for SMCP only when VPI is present and cannot be corrected with speech therapy.
- VPI caused by palatopharyngeal disproportion tends to worsen as the tonsils and adenoids regress or are surgically removed.
- In general, if VPI is diagnosed on PSA by an SLP and is secondary to previous palatoplasty, submucous cleft palate, or palatopharyngeal disproportion, VPI will persist indefinitely.
- Speech outcomes are better when surgery is performed at a younger age, but there is not a specific age cutoff for surgical treatment. However, misarticulations are harder to correct as a child ages.

PATIENT HISTORY AND FINDINGS

- Patients are frequently identified by parents, teachers, and/or SLPs.
- Patients with a history of cleft palate are frequently followed by SLP as part of a multidisciplinary approach to cleft care.
- Patients and parents may report nasal regurgitation, liquids worse than solids.
- Hypernasal speech and nasal air emission are the classic findings. Nasal air emission is normally only observed in /m/ and /n/ sounds.
- Compensatory articulations occur when patients are unable to seal off the nasopharynx.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- PSA by an SLP. Note that PSA is a *subjective* assessment of speech, one component of which is nasal air emission.
- Nasometry: *objective* test of nasal air emission, which can correlate subjective assessment of nasal air emission on PSA
- Imaging is indicated when VPI is documented on PSA.^{2,4}
- Multiview videofluoroscopy
 - Quantify lateral wall motion on AP view

- Quantify velopharyngeal gap on lateral view
- Requires reference landmarks for quantification
- Nasendoscopy
 - Qualitatively assesses closure pattern
 - Helpful in identifying stigmata of SMCP in patients without overt clefting
 - Roughly quantifies closure ratio: fraction of the diameter of the velopharyngeal port that is closed off during attempted sphincter closure
 - Nasendoscopy does not provide reference landmarks, so it cannot quantify motion and gap as in videofluoroscopy. It does allow visualization of nasopharyngeal and oropharyngeal structures, such as the adenoids.

DIFFERENTIAL DIAGNOSIS

- Although the vast majority of patients will present with a history of previous palatoplasty or submucous cleft palate, it is important to recognize other mechanisms of velopharyngeal dysfunction that are less adequately treated with surgery.
- Velopharyngeal mislearning
 - Articulation errors with no anatomic disturbance; treat with speech therapy
- Velopharyngeal incompetence: neurologic or neuromuscular origin
 - Globalized hypotonia with no structural abnormalities
 - Poor muscular competence of the lip and tongue may predict poor surgical outcomes. However, many patients will benefit from traditional surgical approaches.

NONOPERATIVE MANAGEMENT

- Speech therapy: all patients should be evaluated and treated by an SLP prior to intervention to minimize articulation errors.
- Prosthetics
 - Speech bulb
 - Palatal lift
 - Disadvantages: compliance, fit, growth
 - Prosthetics may be a helpful training tool in conjunction with surgery to improve oromuscular coordination and articulation placement.
- If a true mechanical insufficiency exists, nonoperative management is not recommended if a patient can tolerate surgery.

SURGICAL MANAGEMENT

- The overall goal of surgical management is to recapitulate a velopharyngeal port that can be closed during speech.
- Surgical approach typically depends on deficiencies seen on videofluoroscopy and/or nasendoscopy. Common approaches include
 - Intravelar veloplasty
 - In cases of SMCP only, primary palatoplasty with intravelar veloplasty repositions the aberrant insertion of the levator veli palatine muscles to create a functional sling.
 - This approach does not increase palatal length and is often passed over for Furlow palatoplasty.
 - Furlow palatoplasty or double-opposing Z-plasty (DOZ)
 - Initially described by Leonard Furlow as a technique for primary repair of cleft palate, this technique has gained favor as an approach to the management of VPI due to its ability to lengthen the palate via Z-plasty while also opposing the levator veli palatini muscles to recreate an anatomic muscular sling.
 - The major benefits of this technique are as follows:
 - It does not mechanically alter the closure mechanism of the velopharyngeal port, leaving open the option of other surgical techniques for refractory cases.
 - It is not associated with airway obstruction as are other techniques.
 - Dynamic sphincter pharyngoplasty
 - Dynamic sphincter pharyngoplasty (DSP) uses myomucosal flaps transposed to the posterior pharynx to create a smaller, circular velopharyngeal port.
 - This procedure is typically selected for patients with a coronal or circular closure pattern. When lateral wall movement is poor, DSP narrows the velopharyngeal port and adds bulk to the posterior pharyngeal point of velum contact.
 - The senior author has advocated use of the DSP in conjunction with the DOZ in cases of large velopharyngeal gaps.⁵
 - Pharyngeal flap pharyngoplasty
 - Based on the palatopharyngeal adhesion described by Passavant in the 1800s, pharyngeal flaps have been described as a surgical treatment for VPI for over a century.
 - Superiorly based pharyngeal flaps are widely utilized as a preferred

treatment for VPI.

- We describe a high inset pharyngeal flap, which is used as a last resort procedure due to its association with airway obstruction.
- Posterior pharyngeal wall augmentation
 - In cases of small gaps, implants and injectables have been used to augment the posterior wall of the pharynx to reduce the velopharyngeal gap.
 - Like many other applications of implants, implants in the posterior pharynx have been associated with failure due to migration, extrusion, and infection.
 - Silicone, Teflon, Gore-Tex, and polyethylene implants and calcium hydroxyapatite injections have been used. Despite successful reports, these techniques have not enjoyed widespread acceptance.
 - Autologous fat grafting has gained popularity recently but is in need of standardized protocols and prospective studies to evaluate retention of the augmentation and its utility over time. Still, it is most likely only useful in small velopharyngeal gaps.⁶⁻⁸

Preoperative Planning

- Surgical procedures are usually selected based on the preoperative closure pattern and velopharyngeal closure gap.⁹⁻¹¹
- For sagittal closure, velum may be too short and/or not move well, but lateral wall movement is preserved; therefore:
 - For small gaps less than 9 mm, we recommend double-opposing Z-plasty (DOZ) to lengthen the palate.
 - For gaps larger than 9 mm, we recommend a superiorly based pharyngeal flap.
- For coronal closure patterns in which lateral movement is poor, we recommend dynamic sphincter pharyngoplasty (DSP).
 - For gaps less than 9 mm, we recommend DSP alone.
 - For gaps greater than 9 mm, we recommend DSP in conjunction with DOZ.
- For circular closure patterns, many approaches have been used. DOZ may be used in smaller gaps. Narrow pharyngeal flaps or sphincter pharyngoplasty is recommended for larger gaps.²
- Pharyngeal flaps may have better outcomes in noncoronal closure patterns.⁹
- DSP may be most appropriate in coronal and circular closure patterns.¹⁰
- Combined DOZ and DSP can be used in very large velopharyngeal gaps.^{2,5,12}

- Nasendoscopy can identify the point of maximal constriction and evaluate adenoid tissues for flap inset planning.

Positioning

- The patient is placed in the supine position on the operating table.
- A shoulder roll can be used to gently extend the neck.
- The head of the operating table can be extended to aid in visualization.
- The face and neck are prepped and draped such that the infraorbital face and submandibular region are adequately exposed.
 - Intraoral prep with chlorhexidine or Betadine swabs
 - Eyelids are taped closed to prevent corneal abrasions.
- A nasal RAE tube should be used for intubation.
- A Dingman retractor exposes the posterior pharynx and retracts the tongue inferiorly.

TECHNIQUES

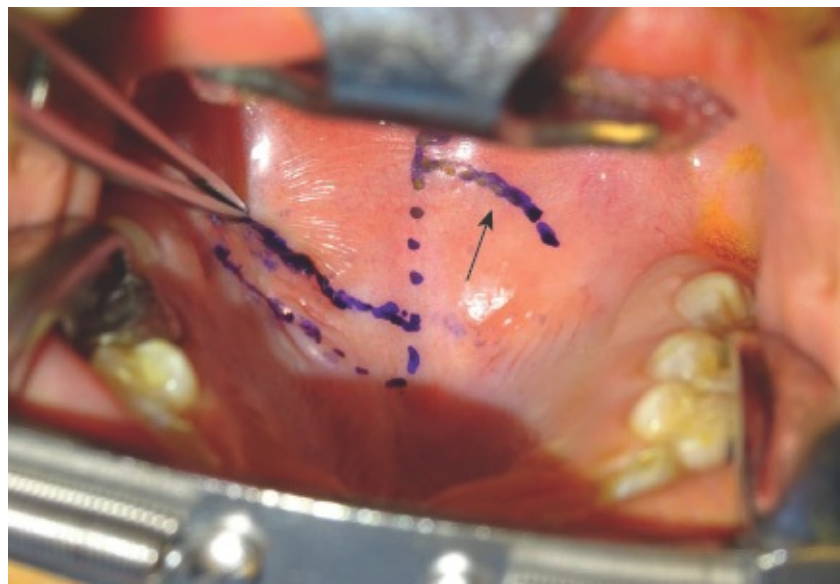
■ Furlow Palatoplasty or Double-Opposing Z-Plasty

Markings

- Z-plasty flaps are designed in two layers, oral and nasal, with one mucosal and one myomucosal flap in each layer.
 - Oral flaps: posteriorly based myomucosal flap and anteriorly based mucosa-only flap. By convention, the muscle-mucosa flap is on the patient's left side for the right-handed surgeon.
 - Nasal flaps: designed in opposite orientation to the oral flaps with a posteriorly based myomucosal flap (right side) and anteriorly based nasal mucosa flap
- The anterior limbs are designed near the junction of the hard and soft palate. Rather than the traditional 60-degree Z-plasty, we recommend a more obtuse angle, roughly 80 to 90 degrees.
 - Cheating the placement of the anterior limb to the more elastic soft palate tissue facilitates flap transposition (**TECH FIG 1**).

Dissection

- Oral flaps are incised and elevated. The surgeon should be conservative with the lateral extent of the mucosal incision as this dictates the inset location of the tip of the contralateral flap (**TECH FIG 2A,B**).
- It is critical to carefully identify the levator musculature within the myomucosal flaps to ensure recapitulation of the levator sling.
 - A muscle stimulator can aid in identification of functional muscle and facilitate complete release of muscle from scar in secondary palatoplasty. If a muscle stimulator is used, it is important to let the anesthesiologist know to avoid muscle relaxants or allow the relaxants to wear off prior to use of the muscle stimulator.
 - The muscle dissection often extends submucosally laterally to fully release the levator (**TECH FIG 2C**).
- Nasal flaps are transposed in the standard Z-plasty fashion, with the posteriorly based left-sided myomucosal flap rotated right and posterior and the mucosal flap left and anterior (**TECH FIG 2D**). The limbs of the nasal mucosa are closed with simple interrupted dissolvable sutures.
- Oral flaps are transposed in a similar manner. Transposition of the oral myomucosal flap completes reconstruction of a competent levator sling. The oral mucosal limbs are then closed (**TECH FIG 2E**).



TECH FIG 1 • Markings for double-opposing Z-plasty. Z-plasty marked on the oral mucosa. The posteriorly based oromuscular flap is marked on the patient's left

side for a right-handed surgeon (the end of the oromuscular incision is designated by the pointer). Note the curved arm of the anteriorly based Z-plasty (*arrow*) as well as its obtuse angle to the midline incision.



TECH FIG 2 • Double-opposing Z-plasty. A.

Posteriorly based oromuscular flap, held in forceps, is being elevated. **B.** Marking of anteriorly based nasal mucosa Z-plasty (*black arrow*) after dissection of the posteriorly based oromuscular flap, retracted posteriorly and laterally with forceps. Incisions have been made to elevate the anteriorly based oral mucosal Z-plasty (*white arrow*). **C.** Using a sweeping motion from anterior to posterior, the posteriorly based nasomuscular flap (*arrow*) is elevated and transposed posteriorly and toward inset on the patient's left side. **D.** Transposing the nasomuscular flap. Right-sided nasomuscular flap (forceps) is rotated posteriorly and to the left, bringing the levator muscle into anatomic position. **E.** Final closure of the double-opposing Z-plasty.

■ Dynamic Sphincter Pharyngoplasty

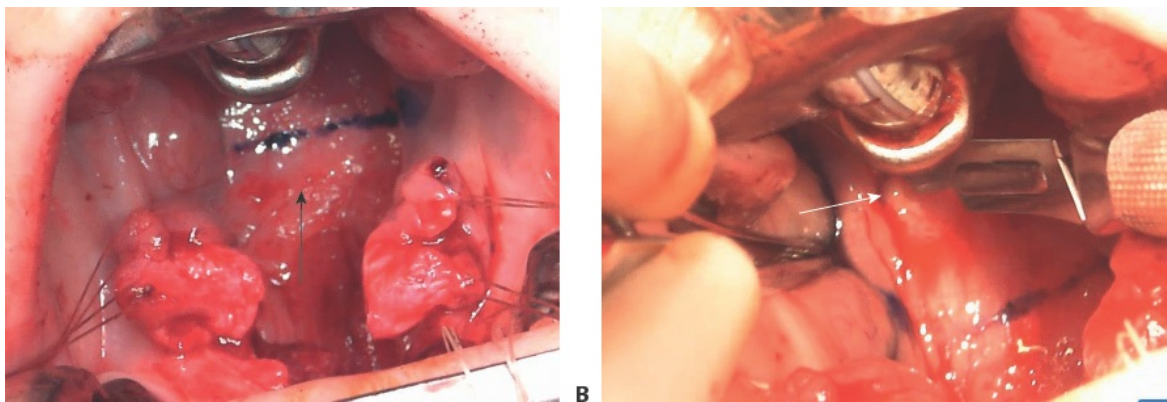
Markings

- The uvula can be reflected into the nasopharynx by suturing the tip to a red rubber catheter passed through the naris.
- The level of inset is based on the position of the adenoids (**TECH FIG 3A**).
 - Adenoids that extend inferiorly may hinder the ability to inset the flaps as adenoid tissue does not hold sutures well. Low-lying adenoid tissue should be identified preoperatively on nasendoscopy.

- If the caudal extent of the adenoids is thought to compromise cephalic inset of the sphincter pharyngoplasty, then an inferior adenoidectomy should be considered prior to sphincter pharyngoplasty. In this case, we recommend delaying sphincter pharyngoplasty for at least 3 months following adenoidectomy.
- Superiorly based myomucosal palatopharyngeus flaps are designed on the posterior tonsillar pillars.
 - The base of the flaps should be designed at the level of inset (**TECH FIG 3B**).
 - A high inset should be anticipated, as the inset should be designed at the anticipated level of velopharyngeal contact during phonation.

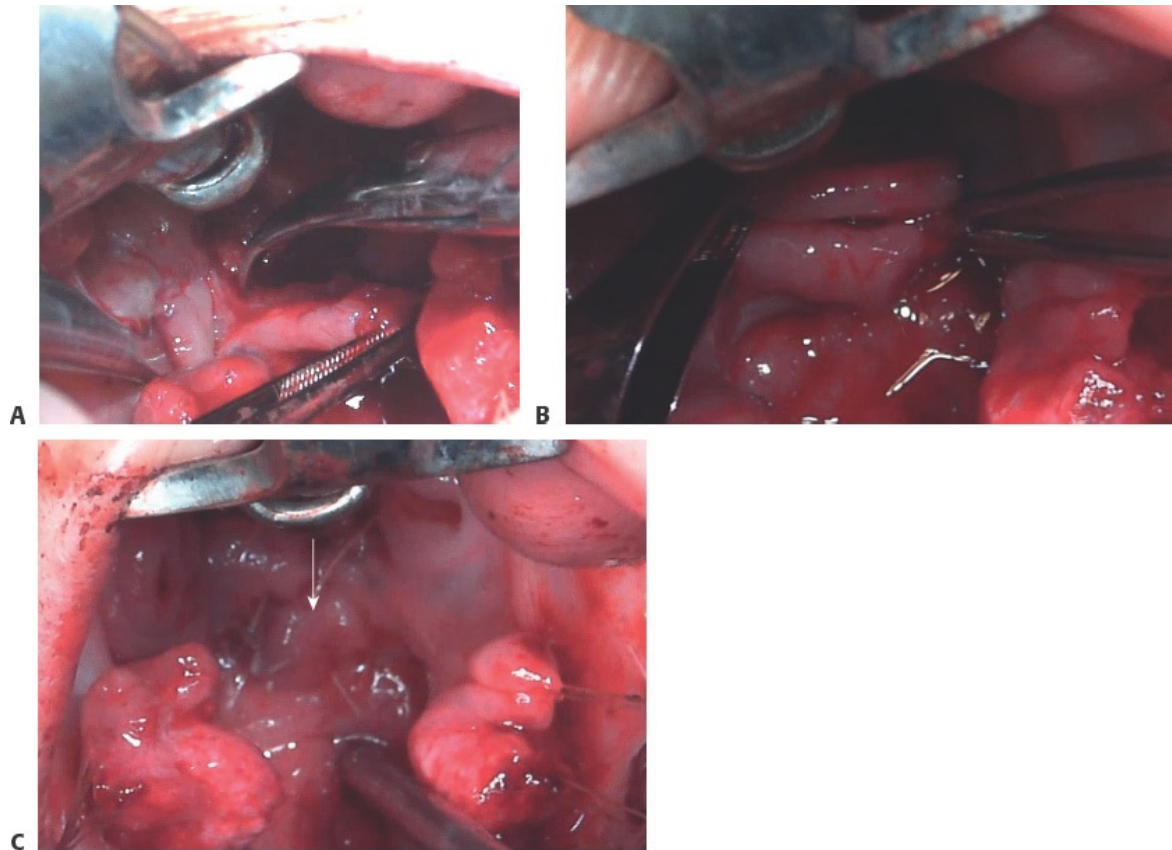
Dissection

- Palatopharyngeus flaps are elevated to the height of the desired new nasopharyngeal port, typically the level of velum opposition from preoperative videofluoroscopy (**TECH FIG 4A**).
- Flaps are transposed to the posterior pharyngeal wall and inset in a transverse arrangement directly posterior to the desired nasopharyngeal port location. Flaps may be inset in a stacked or end-to-end manner (**TECH FIG 4B**).
- The size of the new sphincter should be roughly one fingerbreadth.
- Donor sites in the posterior tonsillar pillars are closed primarily with dissolvable sutures (**TECH FIG 4C**).



TECH FIG 3 • A. Horizontal marking at the level of inset of the sphincter pharyngoplasty. The position of the adenoids (*arrow*) may limit the superior extent of

inset of the sphincter. **B.** Incision along the left posterior tonsillar pillar (*arrow*). Myomucosal flaps based on the palatopharyngeus are marked bilaterally.



TECH FIG 4 • A. Elevating the left posterior tonsillar pillar, held in forceps, to the level of desired inset at the base of the adenoids. **B.** Setting the tension of the bilateral myomucosal flaps (tonsillar pillars). Flaps can be inset end to end or overlapping, depending on the desired tension. In this illustration, the tonsillar pillars are held in forceps in an overlapping configuration. **C.** Final inset of dynamic sphincter pharyngoplasty. Myomucosal flaps are inset (*arrow*) and donor sites are closed primarily (not shown).

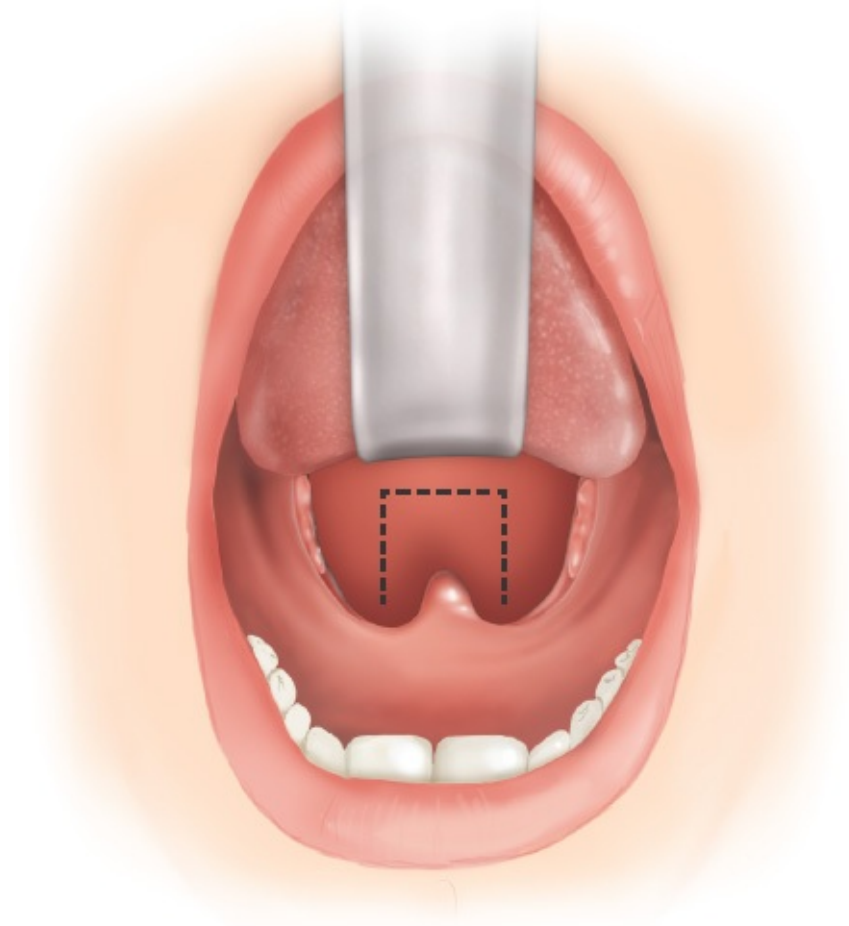
■ Posterior Pharyngeal Flap

Markings

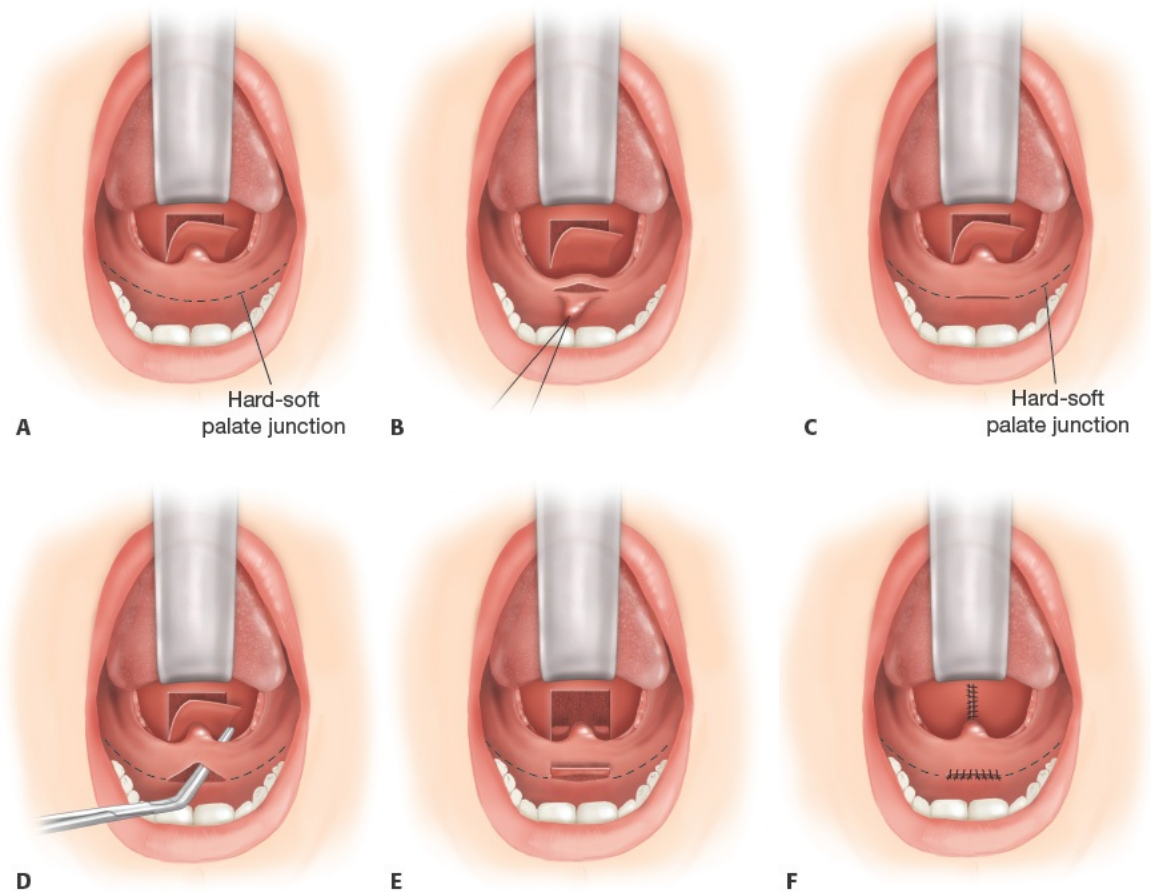
- Superiorly based myomucosal flap is marked on the central posterior pharyngeal wall. The base of the flap must be designed with awareness of the three-dimensional relationship of the flap to the velum. The width of the flap may vary depending on the velopharyngeal gap (**TECH FIG 5**).
- A transverse incision for flap inset is designed on the nasal side mucosa anterior to the uvula.
- A counterincision on the oral side creates a tunnel to pass and secure the flap. This transverse incision is located near the hard-soft palate junction. Incisions must be wide enough to accommodate flap width.

Dissection

- The pharyngeal flap is elevated deep to the pharyngobasilar fascia and superficial to the prevertebral fascia (**TECH FIG 6A**). This is crucial to safe use of this technique in cases of velocardiofacial syndrome (VCFS) in which the carotid arteries can be medially displaced.
 - The carotid vessels lie deep to the prevertebral fascia and therefore will not be damaged irrespective of possible medial transposition, as long as the dissection remains superficial to the prevertebral fascia.
- A tunnel is created through the nasal and oral palate transverse incisions. This then allows the pharyngeal flap to be passed through using a clamp or forceps (**TECH FIG 6B–E**).
- Flap is inset into the oral mucosal incision. The tip of the flap is anchored to the periosteum at the posterior aspect of the hard palate to provide resistance to constriction and descent during healing.
- The donor site is closed with dissolvable sutures if possible. If too large to close primarily, it can be left raw to mucosalize. The posterior soft palate incision is also left to heal secondarily (**TECH FIG 6F**).
- Port size is checked by manual palpation using a finger. The new ports are typically stented in some manner. We choose 3-Fr endotracheal tubes trimmed short and passed through the nares into the ports.



TECH FIG 5 • Marking of the superiorly based posterior pharyngeal flap. The location of the base of the flap can be determined by preoperative imaging.



TECH FIG 6 • A. Flap elevation. The pharyngeal flap is elevated in a plane immediately superficial to the pharyngobasilar fascia. **B–E.** Flap inset into the velum. Incisions are made on the nasal (**B**) and oral (**C**) mucosa of the posterior soft palate to allow flap inset. A tunnel (**D**) is created between these incisions, and the flap is passed through and inset into the oral incision (**E**). **F.** Final appearance after pharyngeal flap inset. The posterior pharynx donor site is closed primarily.

Tongue edema	■ Release of the Dingman retractor every 90 minutes for 2 minutes reduces tongue edema and eliminates the need for a tongue stitch postoperatively.
Velocardiofacial syndrome (VCFS)	■ VCFS disrupts the algorithm because outcomes are usually poorer. ■ Assessment is the same, and selection of operation is not necessarily different. However, care must be taken during dissection to ensure surgical plane is deep to the pharyngobasilar fascia and superficial to the prevertebral fascia

DOUBLE-OPPOSING Z-PLASTY

Flap design	■ Design mucosal flaps more obtusely (80–90 degree) and arch to the desired end point. ■ The oral myomucosal flap back cut should be posterior enough from the hard palate junction to lie within elastic soft palate tissue to facilitate closure. Placing the back cut too close to the hard palate will make it more difficult to achieve closure of the oral mucosa ■ Limit the back cut of the anterior limbs of the mucosal flaps again to reduce difficulty closing. Muscular incision and dissection can extend beyond the mucosal incision.
Flap handling	■ Careful flap handling, particularly of flap corners, is key to a satisfactory result.

DYNAMIC SPHINCTER PHARYNGOPLASTY

Low adenoids	■ Adenoid position should be assessed preoperatively. ■ Attempts to inset the flaps into the adenoids will be unsuccessful and the adenoid tissue does not structurally hold sutures well. ■ If adenoids are particularly inferior, consider preoperative inferior adenoidectomy. ■ Inferior adenoidectomy should be at least 3 months prior to pharyngoplasty.
Flap inset	■ Inset the flaps as high as possible, often immediately below the adenoids (2 mm inferior). ■ Flaps should be inset at the point of maximum constriction, Passavant ridge, if developed.
Flap tension on inset	■ Flaps can be inset overlapping or tip to tip. ■ They should be placed on slight resting tension with residual elastic tone. ■ Too tight at inset can cause airway obstruction.

- Too loose at inset can cause persistent VPI.

PHARYNGEAL FLAP PHARYNGOPLASTY

Flap design	■ Width of the flap should be tailored to the patient's needs.
Flap lining	■ Line as much of the pharyngeal flap as possible. The raw surfaces will contract and the flap will narrow, creating a larger distance for the lateral pharyngeal walls to move for closure.
Flap descent	■ Flaps tend to narrow and pull inferiorly over time. ■ High inset allows more lining of the raw surface as well as a better anchor to the hard palate, resisting contraction and descent. ■ High inset also shortens the exposed raw surface.

POSTOPERATIVE CARE

- Patients are observed in the hospital overnight for signs of airway obstruction.
 - Some surgeons place a tongue stitch at the conclusion of the procedure to assist in clearing tongue-base obstruction in the postoperative period.
 - Similarly, IV dexamethasone can be useful to reduce airway and tongue edema in immediate postoperative period.
- Although preoperative antibiotics are frequently given, postoperative prophylactic antibiotics are not routinely used, as there is no evidence to support their efficacy.
- Stenting of the reconstructed ports:
 - Pharyngeal flap: Nasopharyngeal stents are left in place for 1 week postoperatively to prevent synechiae, while the raw surfaces of the pharyngeal flap are remucosalizing to maintain the newly constructed nasopharyngeal ports. We opt to use two small endotracheal tubes cut short that are passed through each naris into the pharynx. These are sutured to the caudal septum for stability. Tube size depends on the size of the ports, but a size 3 is often adequate.
 - DSP: A larger caliber truncated endotracheal tube may be passed from the naris into the new port, but this is usually not necessary unless the reconstructed port is very tight. DSP is less prone to synechiae as there are fewer raw surfaces at the completion of the reconstruction.
- Oral rinses, especially after feeding, can help maintain oral hygiene. Older children may be prescribed chlorhexidine rinses if they are likely to be compliant with swishing and spitting. Alternatively, plain water rinses can aid

in clearance of food and liquids from the oropharynx and flaps. We recommend that all patients drink clear liquids after eating to assist in clearance of food debris.

- Patients are placed on a soft diet for 6 weeks postoperatively. They are also instructed to drink from a cup only—no straws or suction.
- Patients return for follow-up 1 to 2 weeks postoperatively for an early incision check and at 6 weeks for a final assessment. At 6 weeks, all restrictions are lifted. If a fistula were to develop, this would most likely be visible at the 6-week appointment.
- Nasal resonance and articulation speech therapy are resumed after 6 weeks.
- PSAs are delayed until a minimum of 3 months postoperatively to allow for complete resolution of edema.

OUTCOMES

- Correction of VPI occurs in 80% or more of surgical patients, with slight variation across techniques. Head-to-head comparisons of techniques are difficult because most studies are based on treatment algorithms with groups differing in both preoperative VPI characteristics and surgical approach.
- Randomized trials of DSP and pharyngeal flaps have shown no difference in residual VPI.^{1,13}
- DSP: 80% to 85% of patients demonstrated resolution of hypernasality.¹⁴
- Pharyngeal flap: 85% to 95% improvement or resolution of VPI^{1,11,15}
- DOZ: 75% to 85% improvement or resolution of VPI^{11,16,17}
 - DOZ may be slightly less effective in resolving VPI, but this is dependent on velopharyngeal gap size, supporting the use of an algorithmic approach to procedure selection.¹⁸

COMPLICATIONS

- Bleeding
 - Velocardiofacial syndrome: It is important to identify medial displacement of the carotids as this may alter surgical plan. Preoperative imaging with CTA or MRA is often obtained.
- Airway obstruction
 - Obstruction may occur acutely postoperatively or chronically.
 - Acutely, related to airway or tongue edema
 - Chronically, related to inadequate size of pharyngeal port

- Pharyngeal flap has the highest incidence of obstruction.
 - Incidence of acute airway obstruction is as high as 38%,¹⁹ but most resolve within the first few months postoperatively.
 - Chronic obstruction/obstructive sleep apnea incidence is roughly 10%. Pierre Robin sequence patients may be more susceptible.^{20,21}
- Sleep studies are useful in evaluating and quantifying obstruction.
- Obstruction can be treated with CPAP or flap takedown in severe cases.
- Dehiscence or fistula: may be assessed at the 6-week visit, but we recommend waiting at least 6 months to intervene surgically.
- Scarring: particularly in the DOZ, scarring can limit functionality of the repair. We again emphasize dissection of functional muscle free from scar. Use of intraoperative muscle stimulation can serve as a guide to the distinction of functional muscle from scar.

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Section III: Cleft Rhinoplasty

15

CHAPTER Secondary Cleft Rhinoplasty

Ali Totonchi and Ji H. Son

DEFINITION

- Rhinoplasty remains one of the most challenging plastic surgery procedures for cleft patients. These patients present years after the initial cleft repair to correct residual nasal deformities.
- The nature of the procedure varies from patient to patient depending on the nasal deformities. Systematic reorientation of distorted nasal architecture and creation of a balanced platform for the lower lateral cartilages constitute some of the cardinal principles for correcting the cleft lip nose deformities.

ANATOMY

- Radix is the depth of the nasal root at the nasofrontal angle. This angle connects the brow and the dorsum through a soft concave curve. Although this angle can vary from 128 to 140 degrees, it is ideally 134 degrees in females and 130 degrees in males.
- Nasal dorsum is assessed using the curvilinear dorsal aesthetic lines traced from the supraorbital ridge to the tip-defining points. Ideally, the width of the dorsal aesthetic lines should match the width of either the tip-defining points or the interphiltral distance.
- Nasal deviation is evaluated by drawing a line from the mid-glabellar area to the menton, bisecting the nasal ridge, upper lip, and Cupid bow. Deviation of the nose from this line would most likely require septal surgery for correction.
- The upper lateral cartilage (ULC) overlaps the nasal bones, septum, and the lower lateral cartilages (LLCs). The internal valve is the angle formed by

intersection of the nasal septum and the caudal margin of the ULC.

- LLCs comprise medial, middle, and lateral crura, which are connected to each other, the ULCs, and the septum by fibrous tissue and ligaments. Modification in any of these structures alters tip projection.
- The nasolabial angle is used to determine the degree of tip rotation. This angle is obtained by measuring the angle between a line coursing through the most anterior and posterior edges of the nostril and a line dropped perpendicular to the natural horizontal facial plane. This angle should be between 103 to 105 degrees in women and 95 to 100 degrees in men.
- The septum, turbinates, and nasal valves (internal and external) serve as the anatomic functional foundation for the nose, by contributing to respiration, filtration, humidification, temperature regulation, and protection.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Although nasal deformities are partially corrected during cleft lip surgery, patients often present years after the initial cleft repair to correct residual nasal deformities.
- Efforts to correct nasal deformity in patients between the ages of 4 and 14 years may have a significant chance of supratip deformity and loss of tip definition, with widening and thickening of the skin.
- Many patients with bilateral and complete cleft lip deformities have other craniofacial abnormalities, particularly deformities of the maxilla. Correction of the skeletal deformity sets the stage for a more successful correction of the nasal deformity.
- Approximately 60% of patients with cleft lip nasal deformity have difficulty breathing through the nose. Correction of physiologic function of the nose should be addressed at the time of correction of the nasal deformity.
- Many of the patients may have asymmetry involving parts other than the nose and the lip. Therefore, it is important to assess the entire face and note asymmetry before analyzing the nose in detail (Table 1).¹

Table 1 Detailed Nasal Analysis

Structure	Assessment
Skin	• Thickness • Quality of the tissue for reconstruction
Nasal bone	• Symmetry

	• Length • Distance from the midline • Depth of radix • Presence or absence of a dorsal hump
Midvault	• Upper lateral cartilage collapse • Vertical symmetry
Nasal tip	• Shape—bulbous, boxy, narrow, or parenthesis deformity? • Symmetry • Fullness • Projection • Infratip lobule size • Nasolabial angle • Direction of the columella
Alar base	• Comparison of thickness of the ala • Vertical position • Configuration of nasal sill
Nostrils	• Symmetry
Internal nose	• Stenosis of the internal and external valve • Presence or absence of a deviated septum • Size and shape of the turbinates • Synechiae • Septal perforation

Table 2 Features of Unilateral Cleft Lip Nasal Deformity

- The columella is shorter on the cleft side.
- The base of the columella is deviated to the noncleft side.
- The lateral crus of the lower lateral cartilage is longer on the cleft side.
- The nasal tip is displaced in both the frontal and the horizontal planes.
- The nasal tip is asymmetric.
- The ala is flattened, resulting in horizontal orientation of the nostril.
- The nostrils are asymmetric.
- The entire nostril is repositioned because of the deficiency in the underlying frame.
- The base of the ala is displaced laterally and/or posteriorly and sometimes inferiorly.
- The nasal floor is caudal on the cleft side.

- A nasolabial fistula could be present.
- The septum and anterior nasal spine are shifted toward the noncleft vestibule.
- The nasal septum is deviated, resulting in a varying degree of nasal obstruction.
- The inferior turbinate on the cleft side is hypertrophic.
- The maxilla is hypoplastic on the cleft side.
- The premaxilla and the maxillary segments are displaced.

From Guyuron B. MOC-PS(SME) CME article: late cleft lip nasal deformity. *Plast Reconstr Surg.*

2008;121(4):1-11, with permission.

- It is crucial to recognize common features of unilateral cleft lip nasal deformity (Table 2) and bilateral cleft lip nasal deformity (Table 3).¹

Table 3 Features of Bilateral Cleft Lip Nasal Deformity

- The columella is relatively short and the prolabium seems attached to the nasal tip.
- The nasal tip is flat and broad.
- The nasal alae are flat and sometimes drawn in an S-shaped fashion.
- The base of the ala is displaced laterally and sometimes inferiorly on both sides.
- Both nostrils are oriented horizontally.
- The lower lateral cartilages are severely deformed.
- The nasal floor is absent.
- The caudal cartilaginous septum and the nasal spine are displaced inferiorly relative to the level of the alar bases.
- The nasal tip and the nostril are commonly asymmetric.

From Guyuron B. MOC-PS(SME) CME article: late cleft lip nasal deformity. *Plast Reconstr Surg.*

2008;121(4):1-11, with permission.

IMAGING

- Imaging is not indicated for all of the patients undergoing secondary cleft rhinoplasty unless there is airway obstruction from sinus or cephalic septal pathology necessitating further imaging to aid in surgical planning.

SURGICAL MANAGEMENT

- One of the most important aspects of cleft lip rhinoplasty is the creation of symmetric nose.

- Patients commonly have maxillary deficiency and may need orthognathic surgery and maxillary bone grafting. Ideally, if maxillary surgery is contemplated, it should precede repair of the cleft lip rhinoplasty deformity.
- Maxillary advancement is not advised before the age of 14 to 15 years for a female patient and 17 to 18 years for a male patient, unless serial cephalograms or hand radiographs demonstrate completion of bone growth before this age.
- Otherwise, the patient may need another maxillary advancement if the maxilla is advanced and the mandible continues growing, which can alter the outcome of the initial cleft lip rhinoplasty.
- The operation may be performed through an endonasal or an open technique. Because of common asymmetry in the nasal frame, cleft lip–related nasal deformities are usually more successfully corrected through an open technique.
- The advantages of an open technique are excellent exposure, good hemostasis, and flexibility in corrective procedures.
- The main objectives of the operation are to restore symmetry and harmony to the face as well as improve functional outcome.
- The nature of the operation varies tremendously from patient to patient.

Preoperative Planning

- Discuss risks, benefits, and expectations with parents and patients on the day of surgery. Specifically outline the risks including asymmetry, incomplete resolution or suboptimal correction of nasal deformities, and additional operations.
- It is paramount to do a detailed facial and midface analysis to address each component of the nasal deformity before the operation.

Positioning and Approach

- The patient is positioned supine.
- Depending on the choice of cartilage graft, either the ear or the chest wall is prepped in addition to the face.
- Previous incisions are used to minimize creating new scars when possible.

TECHNIQUES

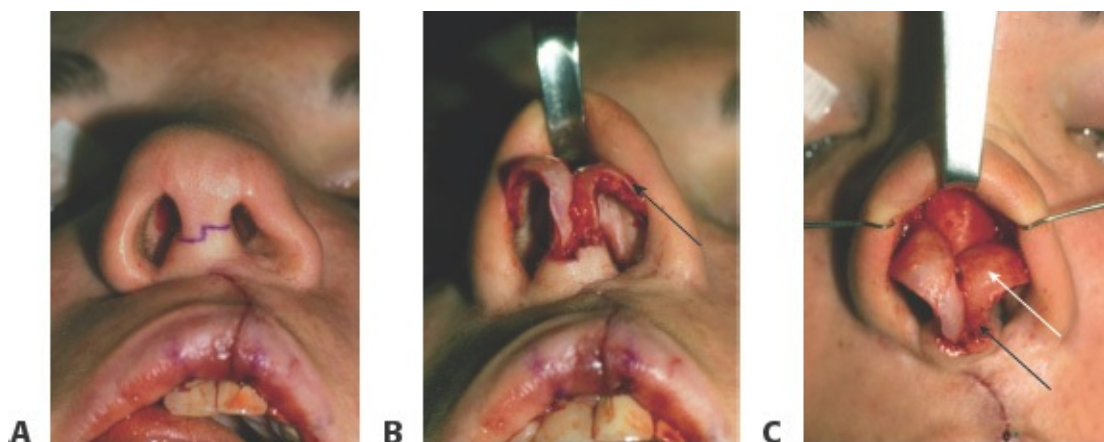
■ Open Cleft Lip Rhinoplasty

Incision and Dissection

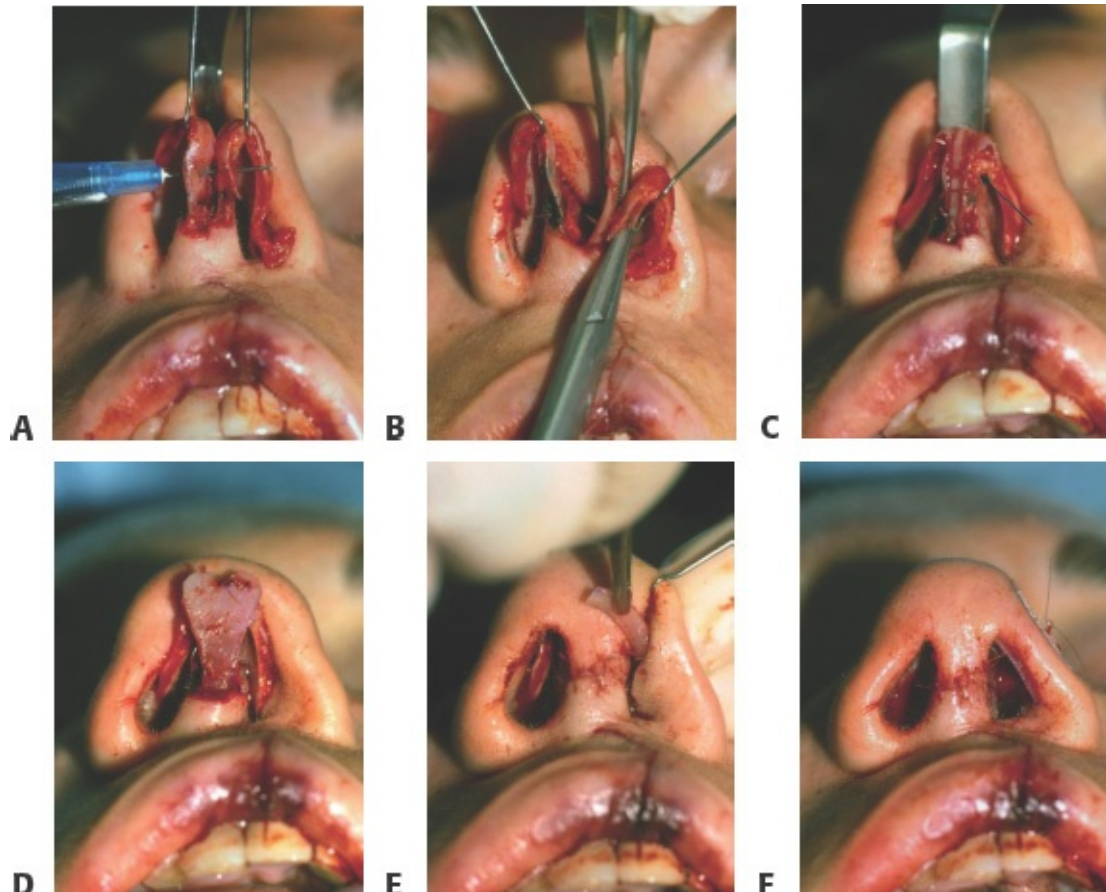
- Incise the columella at the mid-columella, a stair-step incision helps to realign the columella at the end of the procedure (**TECH FIG 1A**). When possible, use an old scar in the nasal vestibule and avoid making a new incision.
 - Extend the incision behind the columella and upward, continue as an infracartilaginous incision on the noncleft side.
 - On the cleft side, the incision is made to match the noncleft side, which may not coincide with an infracartilaginous incision.
- Dissect the columella. Find the loose areolar space between the medial crura and follow this upward in the lower lateral cartilage (LLC) to separate the LLCs from the fibrofatty tissue.
 - The dissection extends to the pyriform rim laterally and nasal bone superiorly and should be symmetrical on both sides to allow for symmetric contracture after the operation (**TECH FIG 1B**).
- The course of the operation varies from patient to patient depending on the nasal deformities.
 - In our example, we present a patient with short medial crus, low dome, and excessive soft triangle soft tissue (**TECH FIG 1C**).

Shape Correction^{1,2}

- After complete dissection and repositioning of the lower lateral cartilage on the cleft side, double hooks are placed to lift the alar domes symmetrically.
- A 30-gauge needle is used to facilitate alignment of the medial crura when the columellar strut is placed (**TECH FIG 2A**).



TECH FIG 1 • **A.** A columellar incision. **B.** In an open technique, the malformed lower lateral cartilage is exposed. The cleft lower lateral cartilage (*arrow*) has less projection relative to the noncleft side. **C.** Comparing the cleft side (*patient's left*) to the noncleft side (*patient's right*) with the skin retracted, the medial crus (*black arrow*) is shorter and the nasal dome (*white arrow*) is lower. From Guyuron B. MOC-PS(SME) CME article: late cleft lip nasal deformity. *Plast Reconstr Surg.* 2008;121(4):1-11, with permission.



TECH FIG 2 • **A.** Medial crus is tattooed to facilitate alignment when columellar strut is placed. **B.** Columellar strut is placed. **C.** Columellar strut is

secured using sutures. There is excessive soft triangle lining that will be trimmed (*arrow*). **D.** A shield graft is placed. **E.** Alar graft is placed for better shape and support. **F.** Internal and external splints are placed. From Guyuron B. MOC-PS(SME) CME article: late cleft lip nasal deformity. *Plast Reconstr Surg.* 2008;121(4):1-11, with permission.

- Tattoo marks can be made with methylene blue on either medial crus to mark the alignment.
- The columellar strut is fixed in position and 6-0 clear nylon sutures are placed in at least two or three sites guided by the previous tattoo marks (**TECH FIG 2B**).
- The final suture close to the domes will better align the medial crura. There is still excessive soft triangle lining that will be trimmed (**TECH FIG 2C**).
- A shield graft is placed in position to facilitate additional support and maintain central alignment of the nasal tripod (**TECH FIG 2D**).
- An alar rim graft is placed to support the ala in a better position, which will be further supported using external and internal stents (**TECH FIG 2E**).
- Upon completion of surgery, there is restoration of proper height and shape to the nostrils and the nasal tip; an external nasal silicone stent is positioned on the ipsilateral side to the cleft lip on the soft triangle (**TECH FIG 2F**).
- The columellar incision is closed using 6-0 fast-absorbing catgut.
- Turbinates are reduced to improve nasal airway passage, if needed.

■ Dorsal Correction

- Many patients require removal of a dorsal hump and reduction of the radix. Less frequently, there are patients with nasal deformities who may require augmentation of the radix and dorsum.
- Nasal bone deviation is corrected by nasal osteotomies when surgery is performed on skeletally mature patients. These techniques are discussed in the chapter on secondary rhinoplasty.
- If augmenting the radix and dorsum, diced cartilage graft can be utilized.
- Nasal bone asymmetry may require wedge osteotomy between the nasal

bone and the midline structures for medial repositioning of the nasal wall.

■ Nasal Framework Correction

- The upper lateral cartilage (ULC) usually needs correction through separation, trimming, and repositioning.
 - Most cleft lip noses benefit from spreader grafts.
- If required due to septal deviation, septoplasty should include resection of the posterior portion of the quadrangle cartilage, vomer bone, and perpendicular plate of the ethmoid bone, leaving a strong and straight L-shaped frame to support the nose.
 - This frame is straightened with or without scoring by application of bilateral spreader grafts anteriorly.
 - The septum is then splinted using either a pair of Doyle stents or custom-fabricated stents.
 - These stents are sutured in position using transseptal nonabsorbable sutures.
- The ULC is then fixed to the spreader grafts and the septum using 5-0 PDS suture (Ethicon Inc., Somerville, NJ).

■ Reshaping the Tip and Ala

- The dome on the affected side is posterior; the lateral crus extends laterally; and almost always, the medial crus is shorter than ideal, causing length deficiency in the columella.
 - A columellar strut is the most efficacious means of supporting the tip. Use of a columellar strut will:
 - Increase tip projection
 - Elongate the columella on the cleft side
 - Augment the subnasale, which is often deficient
 - Increase the nasolabial angle
 - Prevent the tip from shifting caudally
- Free up the lower lateral cartilage on the cleft side completely or bilaterally or advance in V-to-Y fashion to restore adequate projection on the cleft side.
- Reduce the thickness of the ala by removing some of the fibrofatty tissue, especially at the alar base and along the alar rim.

- Interdomal, transdomal, and lateral crural sutures may be required.
- A tip graft will only be used if the infratip lobule volume is inadequate, which is seldom the case.
- Placement of an alar rim graft and application of two stents externally and internally that are fixed with a through-and-through suture reduces the potential for recurrent alar thickening.

■ Nostril Correction

- Augmentation of the floor of the nostril and elevation of the nostril sill on the cleft side is achieved by placement of a cartilage graft.
- The alar bases are then narrowed as needed and repaired using 6-0 fast-absorbing catgut.

PEARLS AND PITFALLS

Physical findings

- Careful selection of patients at a suitable age is required along with a cooperative patient and a caregiver.
- Skeletal correction of the bony base must be performed before soft tissue correction.

Technique

- Use old scars and avoid new scars if possible.
- If length of the surgery lasts more than 1.5 hours, consider reinjecting vasoconstrictive agents to minimize bleeding intraoperatively and postoperatively.
- Restoration of the distorted structures should be based on normal anatomy.
- Careful tissue handling with meticulous alignment of landmarks is required.
- Forcing the cartilage anteriorly to achieve symmetry is doomed to failure, as the cartilage will gradually shift the tip to the cleft side of the nose.

POSTOPERATIVE CARE

- A nasal splint is applied for 7 to 8 days.
- Patients are asked to refrain from heavy exercise for 2 to 3 weeks and use of

eyeglasses for 4 to 5 weeks.

OUTCOMES

- Cleft lip rhinoplasty addresses both functional and aesthetic nasal disturbance following initial cleft lip repair.
- Patients are usually very satisfied following cleft lip rhinoplasty due to the resultant functional and aesthetic improvement.

COMPLICATIONS

- The most common complication of secondary cleft lip rhinoplasty is asymmetry. Patients should be informed that they might need additional surgery. Most common sites of asymmetry are the alar base and nostril.¹⁻³
- Owing to the underlying condition, these patients have a higher chance of nasal obstruction preoperatively and sometimes postoperatively.³
- Septal deviation may recur, or there may be residual septal deviation due to primary deformity. This may require additional procedures.

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2. Broadbent TR, Woolf RM. Cleft lip nasal deformity. *Ann Plast Surg*. 1984;12:216.
3. Rifley W, Thaller SR. The residual cleft lip nasal deformity: an anatomic approach. *Clin Plast Surg*. 1996;23:81.

Section IV: Atypical Clefts- Soft Tissue Component

16 Tessier 3 and 4 Clefts (Nasal-Cheek Region)

CHAPTER

Philip Kuo-Ting Chen and Vikram S. Pandit

DEFINITION

- The Tessier no. 3 facial cleft occurs at the junction of the frontonasal and maxillary process.
 - It involves the position of an ordinary cleft lip extending upward and passing through the alar base towards the medial canthal region.
 - The medial part of the eye is displaced laterally and inferiorly (**FIG 1A**).
- The Tessier no. 4 facial cleft is located lateral to the no. 3 facial cleft.
 - This cleft starts lateral to the philtral ridge and travels lateral to the alar base toward the medial canthal region.
 - The medial part of the eye is displaced laterally and inferiorly (**FIG 1B**).

ANATOMY

- The Tessier no. 3 and no. 4 facial clefts have similar soft tissue abnormalities resulting in shortened oculo-alar and oculo-oral distances.
- In the lip region, the cleft line is the same as ordinary cleft lip in no. 3 (**FIG 2A**) and is lateral to the philtral column in no. 4 (**FIG 2B**).
- Both clefts are accompanied by distortion or disruption of the orbicularis oris muscle. The cleft extends upward into the cheek with alar involvement in no. 3 and without alar involvement in no. 4.
- In both clefts, orbital dystopia is coupled with globe abnormalities and underlying skeletal deficiencies.

- The medial canthus is displaced inferiorly, and the lacrimal canaliculus on the lower eyelid is usually disrupted.
- Usually, it is possible to identify the punctum of the lower eyelid (**FIG 3**).
- There is a coloboma of the lower eyelid (**FIG 4**).
- The involved muscles of facial expression are distorted in their orientation.
 - The alar base and the lateral part of the nasalis muscle are displaced upward, and the medial part of the cheek muscles is displaced downward.
- The underlying maxillary bone is depressed or separated according to the severity of the cleft.
- Patients may have independent pathology in their cheek region and lip (eg, an intact lip with the cleft only seen in the cheek region¹⁻⁴) (**FIG 5**).

HISTORY AND PHYSICAL FINDINGS

- The history taking and physical examination are similar to other patients with craniofacial anomalies.
- The history should include the family history, medications during the first trimester, and prenatal diagnosis.
- Physical examination should include the extent and location of soft tissue cleft, eye condition, involvement of alveolus, palate, and also other associated systemic problems.⁵

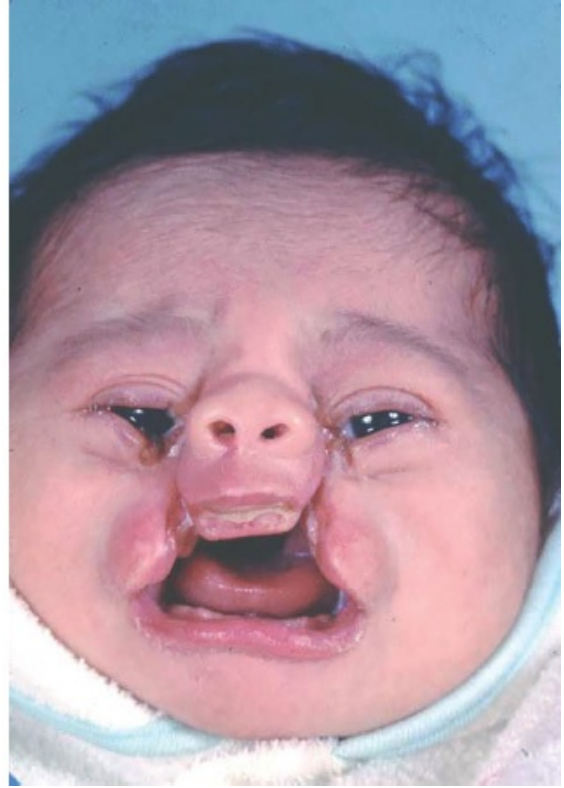


FIG 1 • **A.** Tessier no. 3 facial cleft. **B.** Tessier no. 4 facial cleft.



FIG 2 • **A.** The cleft lip of a Tessier no. 3 is similar to an ordinary cleft lip. **B.** The cleft lip of a Tessier no. 4 is lateral to the philtral column.

IMAGING

- Radiographic images are usually not necessary in the first visit.
- CT scanning is helpful to determine the extent of bony defect on orbital floor if the patient has severe orbital dystopia (**FIG 6**).



FIG 3 • The punctum can be identified lateral to the cleft.



FIG 4 • Coloboma of left lower eyelid.

- Panoramic x-rays and CT scans are also helpful to evaluate the necessity of bone grafting in the alveolar or cheek region when the patient is older (**FIG 7**).
- In the author's center, cephalometric and panoramic radiographs and CT scans with 3D reconstruction are routinely recorded every 2 years from ages 5 to 17 years to monitor facial growth.

SURGICAL MANAGEMENT

- Surgical correction of the soft tissue problems is undertaken between 3 to 6 months of age. This correction should aim at the restoration of normal facial appearance and protection of the eye.
- Bony reconstruction of the alveolar clefts is similar to the timing of alveolar bone grafting in cleft patients, ie, in the mixed dentition period before the eruption of the teeth in the cleft region.
- The bony reconstruction for the skeletal defects on the face and orbit is generally not undertaken till the patient is at least 3 years of age and more commonly at the age of 5 years.
- This allows the inner and outer tables of the calvarium to be split and therefore obtain a large amount of bone graft with minimal donor morbidity.
- However, when there is severe bony deficiency on the orbital floor causing a significant dystopia of the globe, orbital floor reconstruction should be considered at an earlier age.



FIG 5 • Tessier no. 3 cleft with cleft on cheek region and

intact lip.

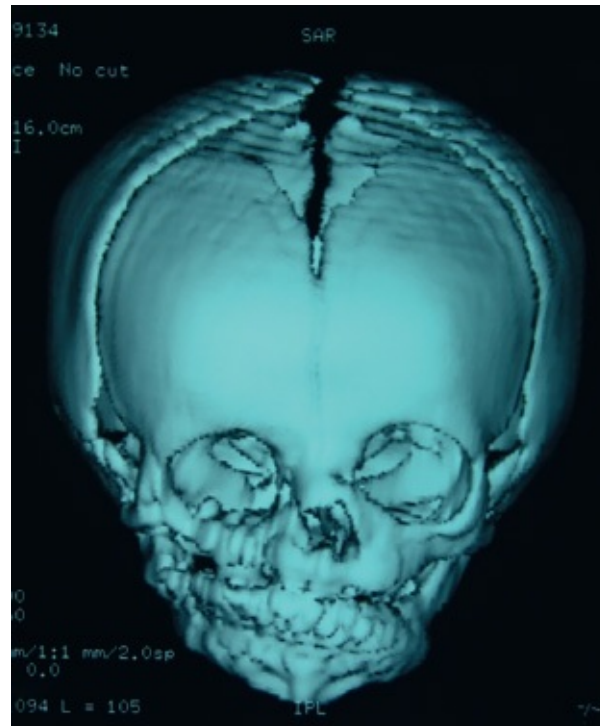


FIG 6 • 3D CT scan of a right Tessier no. 4 facial cleft.

- The repair of the soft tissue deficit in the Tessier no. 3 and no. 4 craniofacial clefts is based on five basic components as outlined.⁶
- A medial canthopexy with 2 mm overcorrection in an upward vertical position
 - The postoperative scar contracture will always pull the new medial canthus inferiorly.
- Midface rotation advancement is performed with rotation of the medially based nasal flap, advancement of the laterally based cheek flap, and repositioning of the facial muscles.
 - This helps to lengthen the shortened oculo-oral and oculo-alar distances while restoring normal facial expression.
 - This is similar to the rotation-advancement repair in ordinary cleft lip.
 - The lengthening achieved in the midface region should primarily be due to muscle repositioning rather than skin Z-plasties.
- Placement of the surgical scars should be along the junction of the facial units, rather than placing multiple Z-plasties on the cheek, to avoid color

mismatching due to skin differences in the nasal and cheek regions.

- Placement of the scar lateral to the junction of the facial units will result in visible scars on the cheek region.⁷⁻¹¹
- Repair the cleft lip using the standard technique (ie, discard the redundant tissue lateral to the proposed philtrum to avoid an unnatural-looking lip).^{12,13}
- Downward and medially repositioning the involved alar base with 1 to 2 mm of overcorrection in vertical dimension
 - The postoperative scar contracture in cheek will always pull the alar base upward.

Positioning

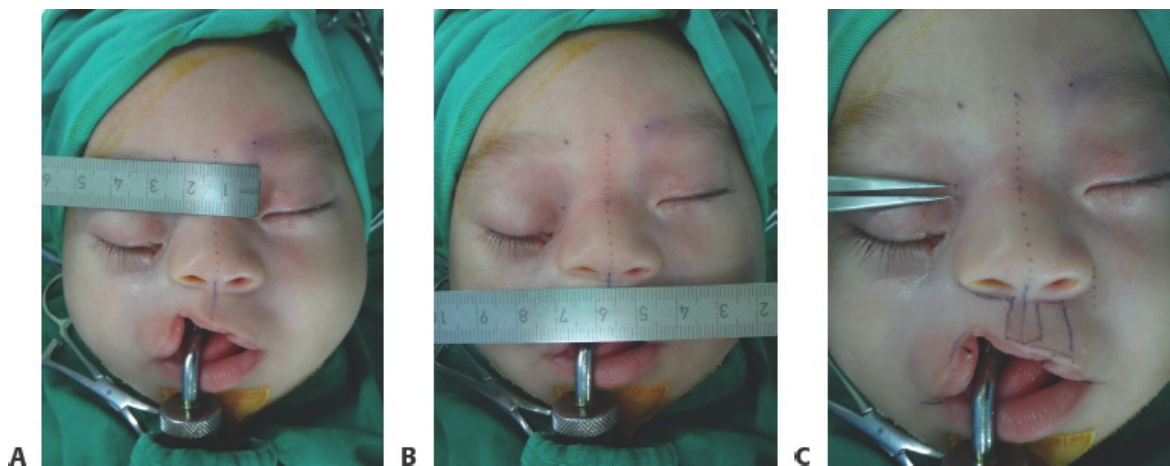
- The soft tissue repair is performed under general anesthesia.
- The endotracheal tube is usually fixed to the center of the lower lip with tape.
- The patient is placed in supine position with the face disinfected and draped.



FIG 7 • Panoramic radiograph of a bilateral Tessier no. 4 facial cleft.

■ Markings

- With the patient prepared under general anesthesia, the key elements of the cleft lip are marked, excluding the skin lateral to the philtral column on the cleft side.
- On unilateral facial clefts, the markings for the anatomical landmarks are relatively easy.
 - The positions of the displaced medial canthus, the alar base, and the peak of the Cupid's bow can be determined by comparison with equivalent landmarks on the noncleft side (**TECH FIG 1A**).
 - It should be emphasized that the position of the medial canthus and the alar base should be overcorrected, ie, 2 mm higher for medial canthus and 2 mm lower for alar base (**TECH FIG 1B,C**).
- It is much more difficult to determine these landmarks in the presence of bilateral facial clefts.
 - However, the position of the medial canthus can still be determined by the position of the lateral canthus, together with the width of the eyes.
 - The position of the alar base is determined by the position of the columella and the vertical height of the lateral lip, which is further determined by the vertical height of the prolabial segment.



TECH FIG 1 • A. A case of bilateral asymmetric incomplete no. 4 facial clefts. The cleft lip on the left side is not at the typical location of an ordinary cleft lip. The left medial canthus is also slightly downward

displaced. The reason that surgery is not performed on the cheek on the left side is because the deformity is so mild that it is not worthwhile to reposition the left medial canthus, with the resultant long paranasal scar. Hence, only the cleft lip is repaired in bilateral fashion, whereas unilateral repair is performed on the cheek. The ruler demonstrates the mirror-image position of the medial canthus on the cleft side. **B.** The ruler demonstrates the mirror-image position of the nasal floor and alar base on the cleft side. **C.** The new position of the medial canthus on the cleft side with 2 mm overcorrection.

■ Incisions

- Incision lines are marked along the margin of the nasal unit medially in a curvilinear fashion upward to the true medial canthus, then turning laterally, incorporating a triangular-shaped medially based flap on the upper eyelid.
- The incision then comes back medially to the proposed point of the new medial canthus.
- The lateral skin incision is made on the lateral cleft margin up to the medial canthus.
- The lip landmarks and incision lines are marked as regular unilateral or bilateral cleft lip repairs (**TECH FIG 2**).



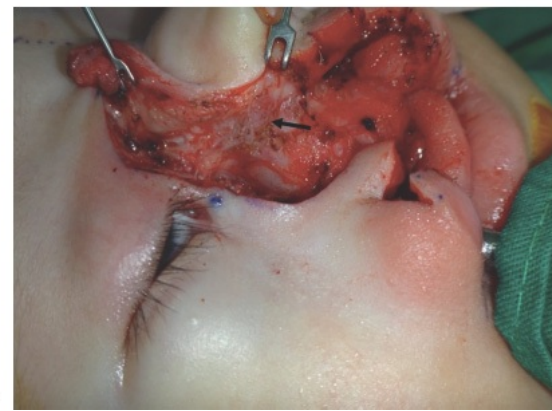
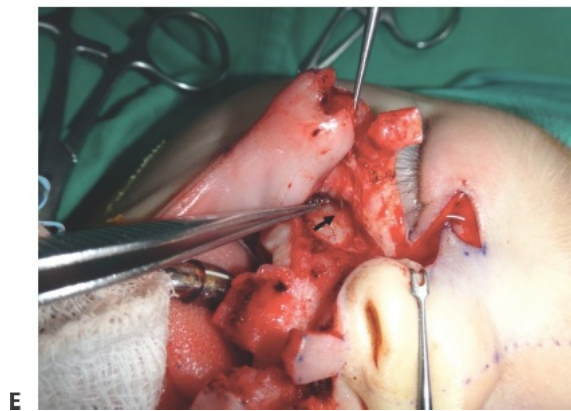
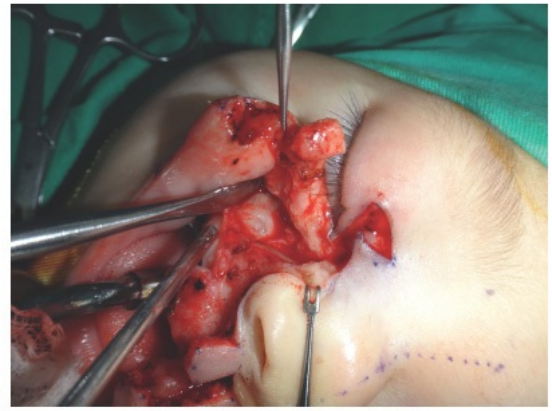
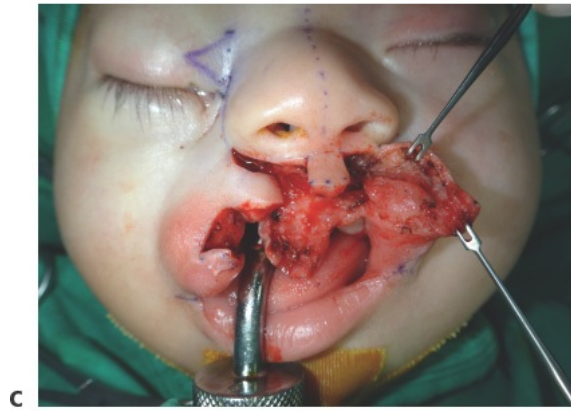
TECH FIG 2 • The incision lines: the prolabial width is similar to the design of an ordinary bilateral cleft lip. The tissue lateral to the proposed philtral column is discarded. A medially based triangular flap is designed on the upper eyelid.

■ Dissection and Facial Flap Elevation

- The redundant skin is excised and discarded to avoid an unnatural-looking repaired cleft lip.
- The extent of the muscle dissection is similar to that in an ordinary cleft lip repair (**TECH FIG 3A–C**).
- On the midface, the laterally based cheek flap is then elevated subperiosteally with a relaxing incision on the periosteum lateral to the infraorbital neurovascular bundle (**TECH FIG 3D,E**).
 - This allows the cheek flap to be advanced medially up to the lateral edge of the nasal flap and down to the philtral column.
- The muscle layer of the cheek is then separated from the skin for a few millimeters to facilitate the muscle approximation in later steps.
- The medially based nasal flap (in unilateral lesions) and the alar base are raised off the underlying nasal cartilages and the frontal process of the maxilla to allow downward rotation of the shortened oculolabial tissue. In patients with bilateral lesions, the nasal flap is based superiorly as there are

incisions along both sides of the nose.

- The nasalis muscle is identified and dissected from the overlying skin in a sheet for about 5 mm for later muscle reorientation (**TECH FIG 3F**).
- In cases of complete no. 3 facial clefts, the nasal lining and the lining of the eyelid are repaired by local turnover mucosal flaps between the nasal and cheek incisions (**TECH FIG 3G**).



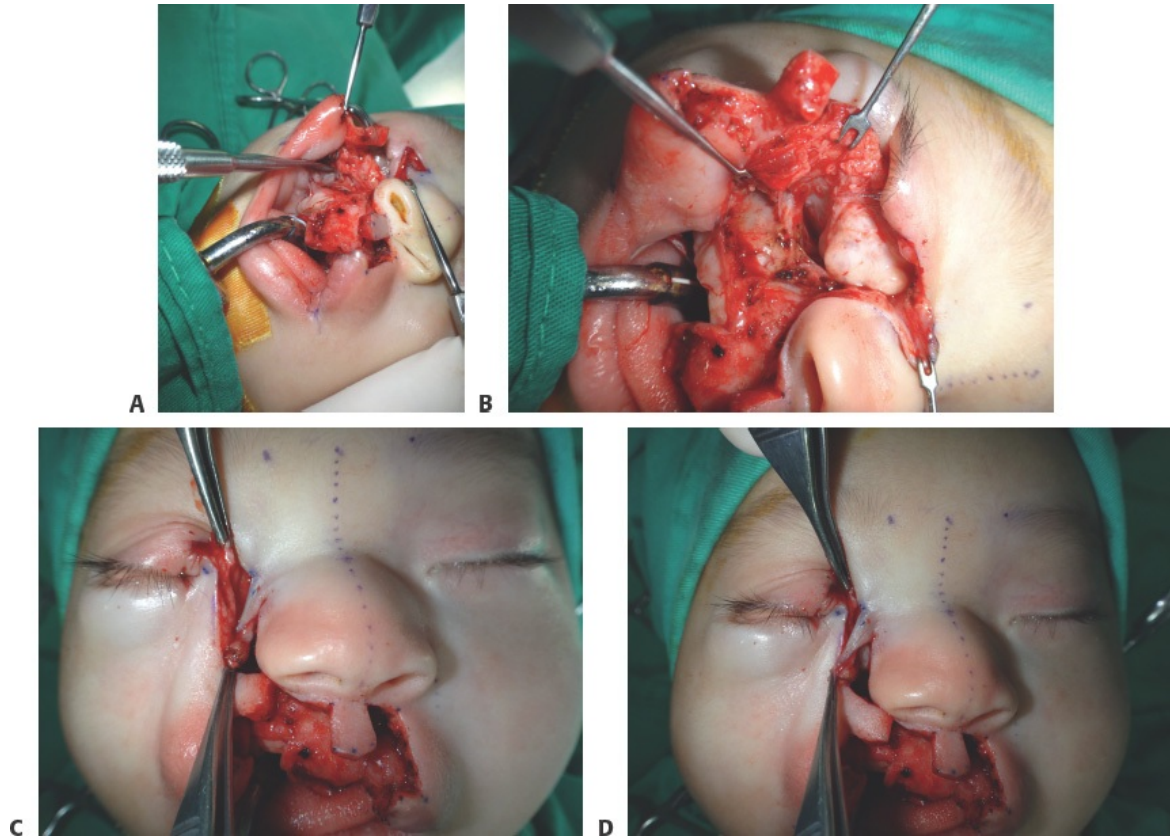


TECH FIG 3 • A. The incision of the lip part. The excessive tissue on the right lateral lip is preserved initially as it might be needed later for lengthening of the cheek region. **B.** The incision and dissection of the lip part is similar to a bilateral cleft lip repair. **C.** The extent of the muscle dissection on the lateral lip. **D.** Subperiosteal dissection of the cheek flap. **E.** A relaxing incision is made lateral to the infraorbital neurovascular bundle (*arrow*) to achieve adequate mobilization of the cheek tissue. **F.** The dissection of the nasalis muscle (*arrow*) in the nasal flap. **G.** Turnover flap along the cleft margin for reconstruction of the nasal lining.

■ Eyelid Correction

- Attention is then turned to the lower eyelid.
- After dissection and freeing of the displaced facial musculature, the subperiosteal mobilization of the laterally based cheek flap is extended superiorly up to and including the inferior orbital rim (**TECH FIG 4A,B**).
- Usually, it is not very difficult to identify the remnant of the medial canthal tendon (**TECH FIG 4C**).

- The overlying lower eyelid tissue incorporating the tarsus and the attached conjunctiva are then transposed medially.
- If necessary, a lateral canthotomy may be required to facilitate the medial movement of the lower eyelid, correction of the coloboma, and reconstruction of the lower eyelid (**TECH FIG 4D**).



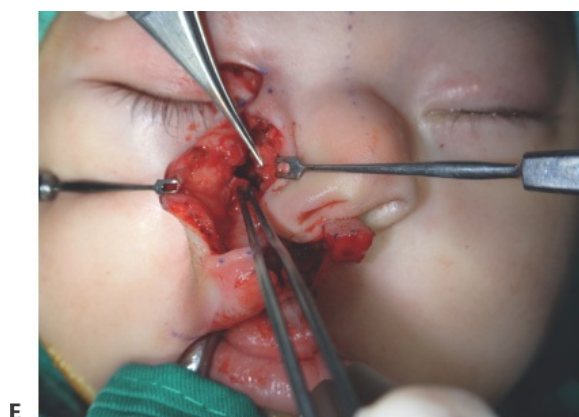
TECH FIG 4 • **A.** Dissection along the infraorbital rim. **B.** Dissection into the orbital floor. **C.** The remnant of the medial canthal tendon (upper forceps). **D.** The remnant of the medial canthal tendon and the lower eyelid are advanced medially and superiorly to the proposed position of the medial canthus.

■ Repositioning the Facial Musculature

- The lateral cheek flap is then advanced medially.
- A medial canthopexy is performed by transnasal wiring or directly suturing

to the local periosteum using the medial edge of the tarsal plate and the remnant of the medial canthal tendon (**TECH FIG 5A**).

- This will ensure adequate support for the lower eyelid.
- The orbicularis oculi muscle of the lower eyelid is identified and apposed to the superior limb of the newly created medial canthus (**TECH FIG 5B**).
 - It should be re-emphasized that this medial canthopexy always needs some overcorrection in cephalic direction for about 2 mm; otherwise, the position of the canthus will always be lower than its peer in the noncleft side after skin closure.
- The nasal complex of the medially or superiorly based nasal flap is then rotated downward matching the alar base on the noncleft side to achieve adequate oculoalar distance in unilateral lesions.
- For bilateral clefts, the positions of the alar bases are determined by the position of the columellar base (**TECH FIG 5C,D**).
- Repositioning of the remaining facial musculature, in particular the nasalis and the muscles of facial expression, is then performed.
- The sutures are placed more superiorly on the nasal muscles and more inferiorly on the cheek muscles to achieve a “rotation advancement” (**TECH FIG 5E**).
- With the redundant skin of the upper lip lateral to the philtral edge previously excised, a rotation-advancement repair of the cleft lip is performed in unilateral cases and bilateral cheiloplasty is performed for patients with bilateral lesions (**TECH FIG 5F**).
- The orbicularis oris is reconstituted and reapposed to the muscle bundle on the noncleft side.
- The medial edge of the cheek flap is then sutured to the lateral edge of the nasal flap with the suture line placed along the junction of the facial units.
- The medially based upper eyelid flap can be trimmed at this moment if the oculo-oral or oculonasal distance can be restored without difficulty, or can be placed as a small triangular flap on the lower eyelid under the medial canthus to further lengthen the oculo-oral or oculonasal distance, or to break down the straight line scar and to prevent possible postoperative scar contracture¹⁴ (**TECH FIG 5G**).
- Repositioning the facial musculature and placing the suture line along the junction of facial units results in a more natural facial expression and therefore a better aesthetic result.



TECH FIG 5 • A. The medial canthal tendon is sutured to the periosteum of the new position of the medial canthus using 4-0 Prolene suture. **B.** The orbicularis oculi muscle of the lower eyelid is identified and apposed to the superior limb of the newly created medial canthus. **C.** The alar base position on the cleft side is determined by the base of columella. **D.** Excision of the excessive skin on the cheek flap helps for the lengthening of the oculonasal distance. **E.** Approximation of the muscle layer in cheek flap and nasal flap. The sutures are placed higher on the nasal flap and lower on the cheek flap to achieve the “rotation-advancement” movement. **F.** The lateral lips are approximated to the prolabium. The marking under the right nasal floor shows the skin needs to be excised for further downward movement of the nasal floor. The medially based upper eyelid flap is still preserved at this moment. **G.** The medially based upper eyelid flap is excised finally as the length of the oculonasal distance is adequate after reconstruction. The suture lines are placed along the junction of the facial units.

PEARLS AND PITFALLS

Markings

- Precise marking of the anatomic position of the medial canthus and alar base

Incision

- Make an incision along the cleft to raise the laterally based cheek flap and medially/superiorly based nasal flap.
- The incision line of the lip is similar to ordinary cleft lip repair with special care not to preserve the redundant tissue lateral to the philtral column.

	■ Design a medially based flap on the upper eyelid.
Dissection	■ Extensive subperiosteal dissection of the cheek tissue lateral to the infraorbital foramen ■ Extensive perichondrial dissection of the nasalis muscle
Reconstruction	■ Local turnover flaps for the lining of eyelid and nose ■ Midface rotation advancement with approximation of the cheek muscles and nasalis muscles ■ Medial canthopexy in an overcorrected position ■ Adjust the lower eyelid by the medial-based flap from the upper eyelid.
Aesthetic concerns	■ Placement of the suture lines along the junction of the facial subunits ■ Design for overcorrection of the oculonasal or oculo-oral distance (eg, move the proposed medial canthus upward and alar base downward)

POSTOPERATIVE CARE

- The postoperative care is similar to that used for primary cleft lip repair.
- The airway maintenance and chest care are as important as that in any patient who received general anesthesia.
- The routine facial wound care in Chang Gung Craniofacial Center is to use normal saline wet dressing changed with the frequency of every 4 hours.
- This wound care can be replaced by local antibiotic ointment if the wounds are clean without much discharge.

OUTCOMES

- A retrospective review of the outcomes of surgical repair for rare facial clefts in Chang Gung Craniofacial Center was done in the early 2000s. The study reviewed the facial clefts over a period of 25 years.
- Among the 41 different Tessier craniofacial clefts seen, most (17 patients) were Tessier no. 3 and no. 4 clefts. Patients could be roughly divided into two groups: a group of eight patients treated by the traditional Z-plasty principles and second group of nine patients treated with the rotation-advancement technique described. Of these nine patients, five had Tessier no. 3 clefts and four had no. 4 clefts. Seven were primary cases, and the other two were secondary or tertiary revisions.
- None of the patients in the Z-plasty group had a satisfactory result in terms

of scar quality, color matching, or natural facial expression. The cases in the rotation-advancement group, while their medial canthus and alar base might not be well repositioned, still had much better results in their scar and facial expression⁶ (**FIGS 8** and **9**).

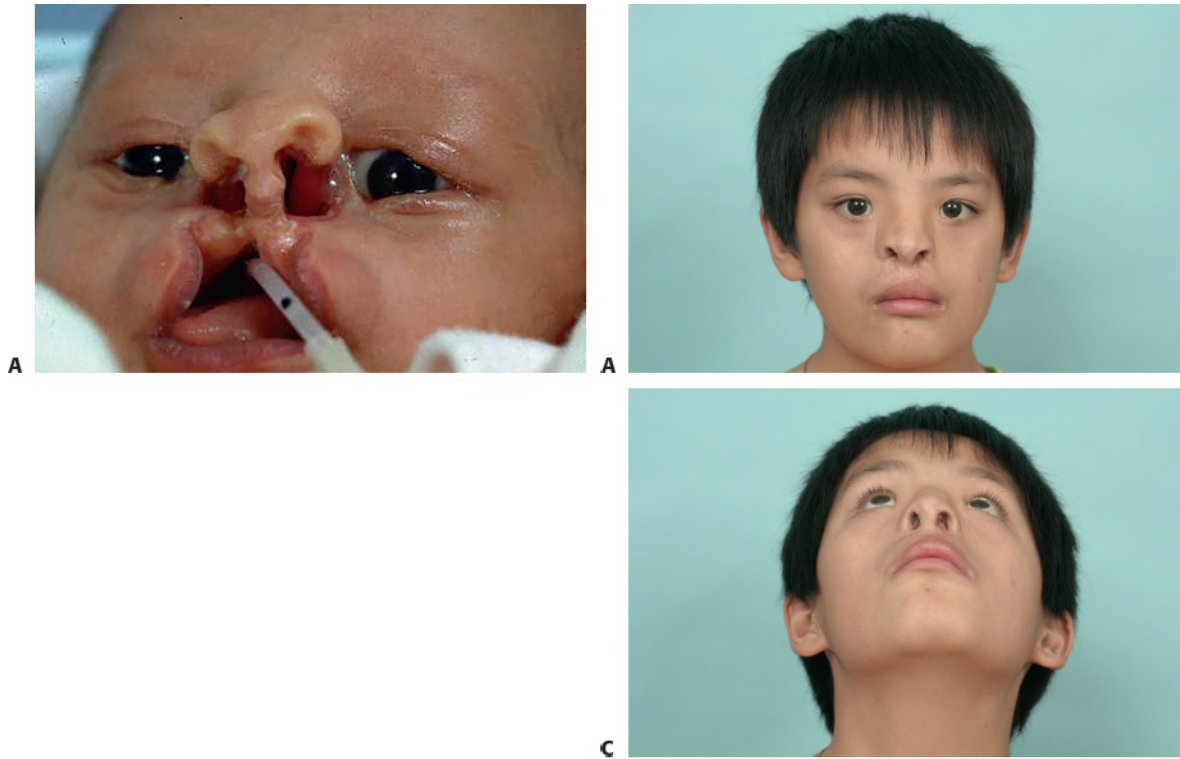


FIG 8 • An example of the midface rotation advancement on a Tessier no. 3 facial cleft. Before operation (**A**) and at 13 years old (**B** and **C**).



FIG 9 • An example of the midface rotation advancement on a Tessier no. 4 facial cleft. Before operation **(A)** and at 17 years old **(B–D)**.

COMPLICATIONS

- Postoperative bleeding
- Wound infection
- Wound dehiscence
- Hypertrophic scar formation
- Undercorrection with malposition of the medial canthus or alar base and persistent ectropion of lower eyelid.

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17 Tessier 7—Macrostomia Repair

CHAPTER

Patrick A. Gerety and Scott P. Bartlett

DEFINITION

- Macrostomia—enlarged oral aperture—related clefting of the oral commissure
- Tessier 7 cleft—lateral (transverse) facial cleft from the oral commissure to the zygomaticotemporal suture
- Cheilion—anatomic name for commissure point
- Commissuroplasty—recreation of oral commissure

ANATOMY¹

- Oral commissure (**FIG 1**)
 - Position
 - Normal position: at a vertical line dropped from the medial limbus (some variability)
 - Shape
 - Normal shape: The upper and lower lip vermilion comes to sharp corner.
 - Macrostomic commissure: Oblique angle, gaping at rest, round with smile
- Tessier 7 cleft resulting in macrostomia
 - Variable in presentation—may be slightly wider oral commissure or severe cleft of skin, subcutaneous tissue, muscle, and bone
 - Trajectory—the cleft occurs along a line from the oral commissure to the zygomaticotemporal suture.

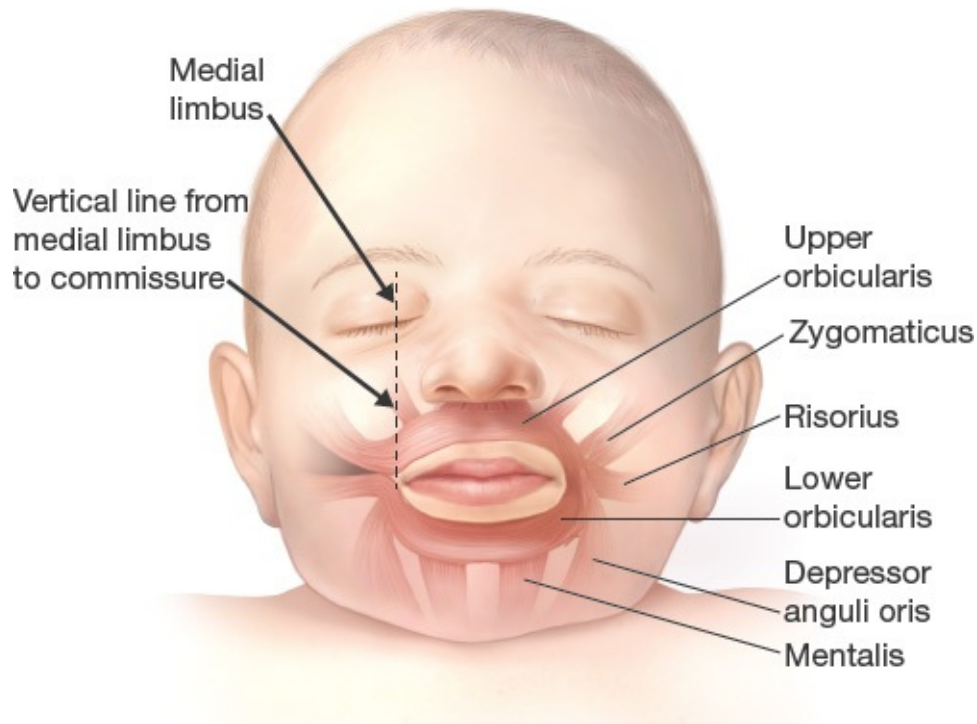


FIG 1 • Lateral facial cleft creates discontinuity of the orbicularis oris at the oral commissure. This in turn affects the location and insertion of the zygomaticus, risorius, and depressor anguli oris muscles.

■ Affected structures

- Commissure—laterally positioned, anatomically abnormal (ie, made of cleft tissue [lighter in color than normal vermilion])
- Orbicularis oris—interrupted and malinserted. The superior and inferior limbs contribute to the appearance of the lips on the macrostomic side (see **FIG 1**).

PATHOGENESIS

- Development of normal facial anatomy is dependent upon early first and second branchial arch embryology.
- The maxillary and mandibular prominences normally fuse in early embryologic development (weeks 4–6) forming the normal cheeks and lips.
- Stapedial artery is the blood supply before the external carotid system has developed.
- Stapedial disruption starves all tissue types—skin, fat, muscle, and bone.

- Macrostomia results as a presumed failure of this process.
- Interruption of embryologic development along the “orotragal” line can affect the oral commissure, muscles of mastication, muscles of facial expression, mandible, maxilla, and auricle.
- Isolated macrostomia is a disorder of the first branchial arch only.

NATURAL HISTORY²

- Incidence: rare, 1 in 225 000 live births
- Unilateral 80%, bilateral 20%
- As with cleft lip, the left side appears to be more commonly affected.
- May be associated with syndromes including the following:
 - Hemifacial microsomia
 - Including Goldenhar syndrome and variants of oculoauriculovertebral spectrum
 - May account for as many as 25% of macrostomia patients
 - Treacher Collins syndrome
 - Auriculocondylar syndrome
- Tessier 7: the most common of the rare craniofacial clefts (5%–14%)

PATIENT HISTORY AND PHYSICAL FINDINGS

- Laterally displaced oral commissure
- Clefted/interrupted orbicularis oris
 - Oral incompetence may be encountered.
 - Gaping oral commissure in repose related to cleft orbicularis oris muscle
- The cleft margin is demarcated. It does not contain normal lip elements (eg, white roll, dry vermilion), but it is mucosalized. The normal dark red vermilion can be seen to transition into a lighter colored cleft vermilion.
- Spectrum of the cleft³
 - Minor form—1 to 2 cm in length ending medial to the anterior border of the masseter muscle
 - Major form—cleft ends lateral to the medial border of the masseter. It may terminate at the tragus or at the tonsillar pillar with disruption of superficial and deep structures.
- The commissure is blunted/effaced, and when a baby with macrostomia cries, the commissural angle of an open mouth is more oblique than the normally formed commissure—this is thought to be related to disruption of the normally

intact orbicularis ring.

- Associated anomalies
 - Preauricular tags
 - Microtia/ear anomaly
 - Mandibular hypoplasia
 - Condylar abnormality
 - Zygomatic arch abnormality
 - Hearing loss

IMAGING

- 3D craniofacial CT—if bony involvement is suspected, this may be obtained to evaluate anatomy.

SURGICAL MANAGEMENT

- Trilaminar repair—repair of oral mucosal, orbicularis muscle, and facial skin
- Repair consists of
 - Excision of abnormal cleft margin tissue (mucosa)
 - Repair/repositioning of orbicularis muscle
 - Recreation of the oral commissure
 - Rearrangement of the cutaneous scar to avoid deforming contracture
- Repair types (external cutaneous scar):
 - Straight line
 - Z-plasty
 - W-plasty

Preoperative Planning

- Standard facial photos should be obtained preoperatively including repose and animated (smiling) if possible.
- Appropriate expectations should be created with the parents in terms of realistic commissure appearance and the risk of scar hypertrophy/contracture.
- Evaluation for other anomalies and comorbidities with specialist consultation or multidisciplinary team as necessary
- 3D CT scan if cleft is thought to involve skeletal structures
- Timing—as with cleft lip surgery, macrostomia repair may be done early in life. It is also reasonable to delay until late infancy if there is minimal functional or feeding issue. Late treatment reported in the literature is a function of later age at presentation and is usually not due to planned delay in

treatment.

Positioning (FIG 2)

- Nasal endotracheal tube allows unobstructed/distorted view of the mouth during surgery.
- Many groups use oral RAE intubation and midline taping that does not alter the lower lip (tape mesentery on chin).

Approach

- Determination of commissure position is most critical.
 - This can be mirrored from the contralateral lip in unilateral cases.
 - In bilateral cases, there are several considerations:
 - The cleft demarcation can be fairly obvious—normally demarcates with clefted tissue.
 - The normal position of the commissure lies below a vertical line that is dropped from the medial limbus. This can be marked.
 - Normative measures have been proposed for this use. However, these measures are highly variable and are not suitable for individual patient use.



FIG 2 • Securing of the endotracheal tube in order to avoid lip and commissure distortion. Tegaderm is used to keep tape secure in a wet (Betadine) environment. (Note the commonly associated preauricular skin tags.)

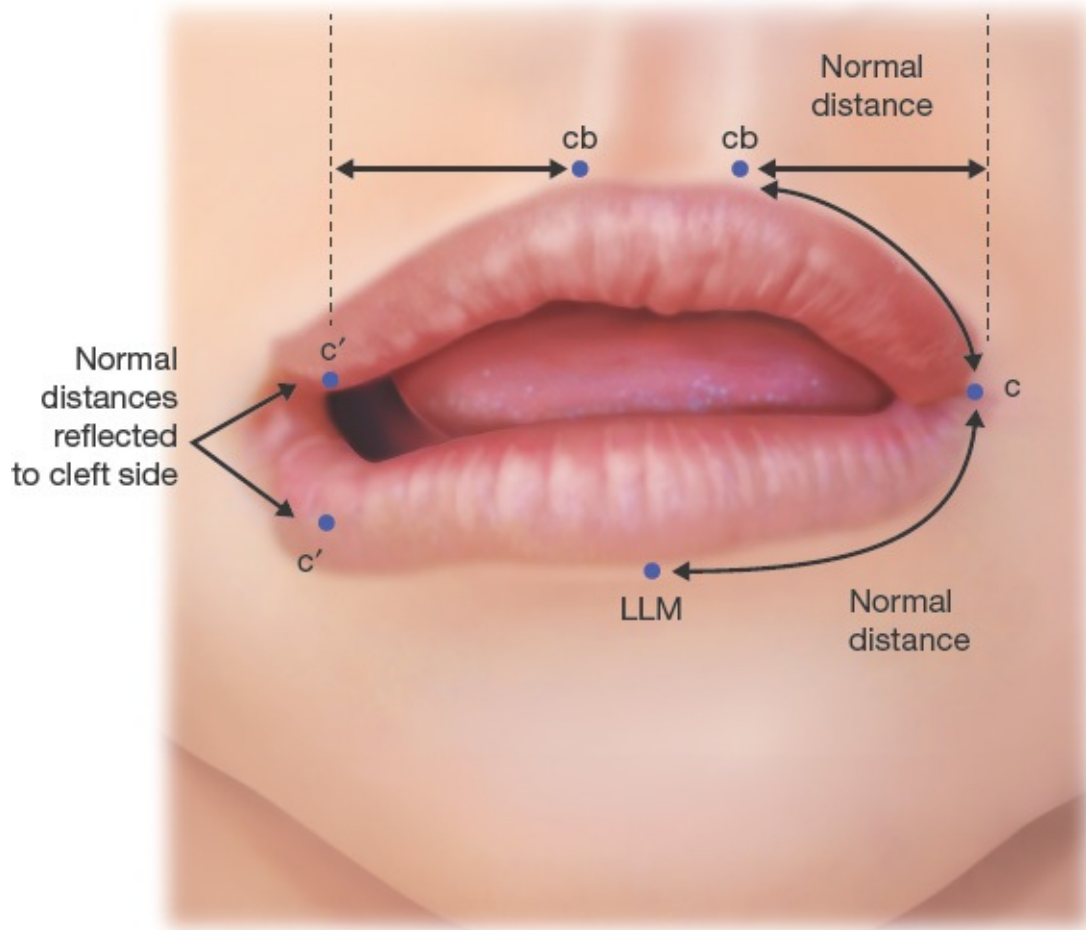
TECHNIQUES

■ Vermilion-Shifted Commissuroplasty With Optional Cutaneous Z-Plasty (Kaplan Technique)

- The senior author's (SPB) preferred technique for macrostomia repair was inspired by the work of Ernest Kaplan⁴ and expanded upon by John Mulliken.⁵
- This repair uses mucosalized flaps to avoid scars directly within the commissure.

Markings

- Markings are performed using methylene blue ink and a pen point instrument.
- Important landmarks include the following:
 - Normal commissure (if present)
 - Peak of right and left Cupid's bow
 - Lower lip cutaneous midline
 - Vertical registration marks are also drawn above and below the normal and proposed commissures as reference (**TECH FIG 1**).
- In unilateral cases, the distance from the Cupid's bow peak to the normal commissure is reflected onto the cleft-side white roll of the upper lip.
 - The distance from the lower lip midline to the oral commissure is then reflected onto the white roll of the lower lip at the cleft commissure.
 - Because it is difficult to measure these distances around the curvature of the lip, it is often easier to create a vertical registration marking on the unaffected side and to then reflect that measurement to the affected side (see **TECH FIG 1**).



TECH FIG 1 • Landmarks for unilateral macrostomia repair: (c) normal commissure, (c') upper and lower lip cleft commissure, (cb) peak of Cupid's bow on each side of the upper lip, (LLM) lower lip midline. The distance from c to the ipsilateral cb and to LLM is measured. These measurements are then reflected to the macrostomic side. Vertical registration marks can allow for more accurate measurements and design.

- In bilateral cases, the medial limbus is taken as the landmark for which to position the commissures upon repair.
- Vertical registration lines are drawn down from the medial limbus.

Design (see **TECH FIG 2**)

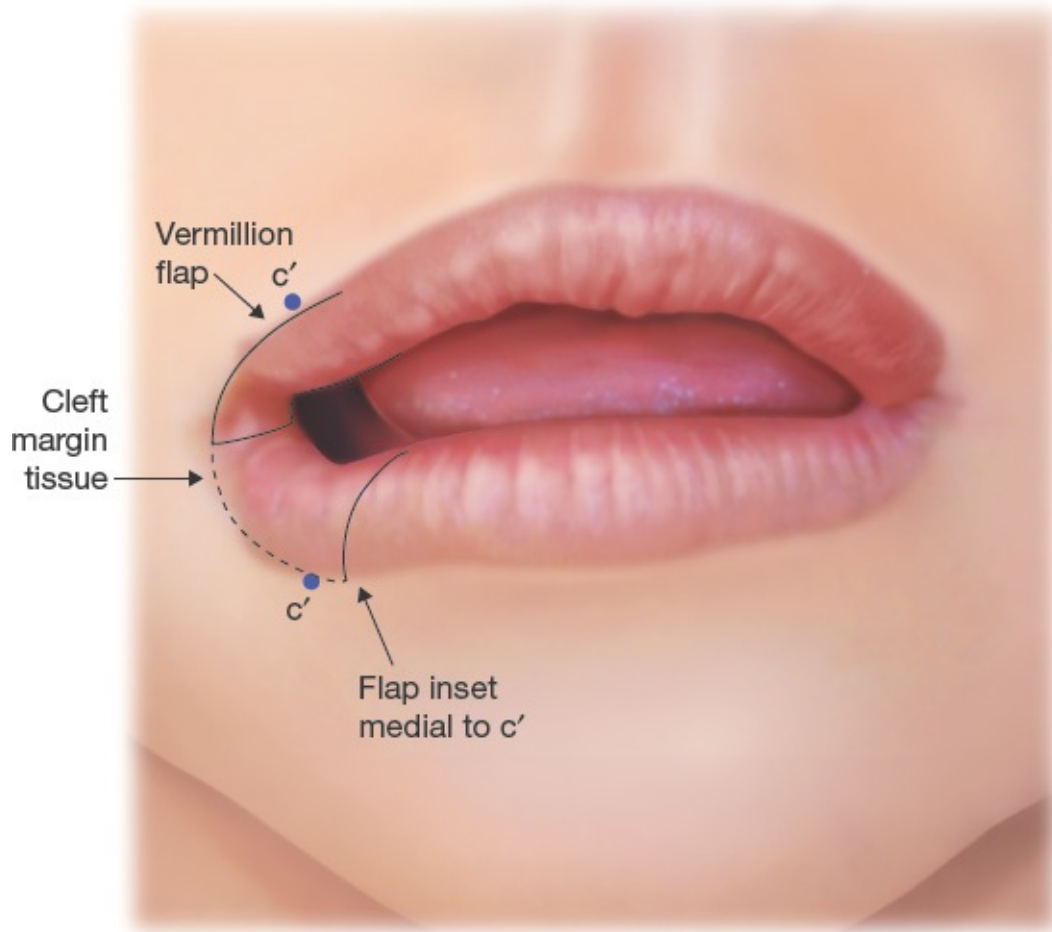
- The commissure points are decided upon and tattooed with methylene blue

at the upper and lower lip white roll.

- A vermilion flap is designed from either the upper or lower lip. The flap begins medial to the commissure (c) point on the chosen lip. It is rectangular in shape.
 - This flap will become the new mucosal commissure and importantly keep suture line outside of the commissure.
- The cutaneous margin of the cleft is marked—this tissue represents cleft/mucosal tissue that will be reflected initially into the mouth. Some tissue will be used for oral closure, and some will be discarded.
- On the lip (upper or lower) that will receive the vermilion flap, the incision at the cutaneous vermilion junction will also end medial to the commissure (c) point.
- The area of dissection is conservatively infiltrated with epinephrine-containing solution.

Dissection and Orbicularis Repair

- The markings are incised.
- The vermilion flap is incised and raised.
- The cleft mucosal tissue is freed and reflected intraorally with dissection to include the deep surface of the orbicularis muscles.

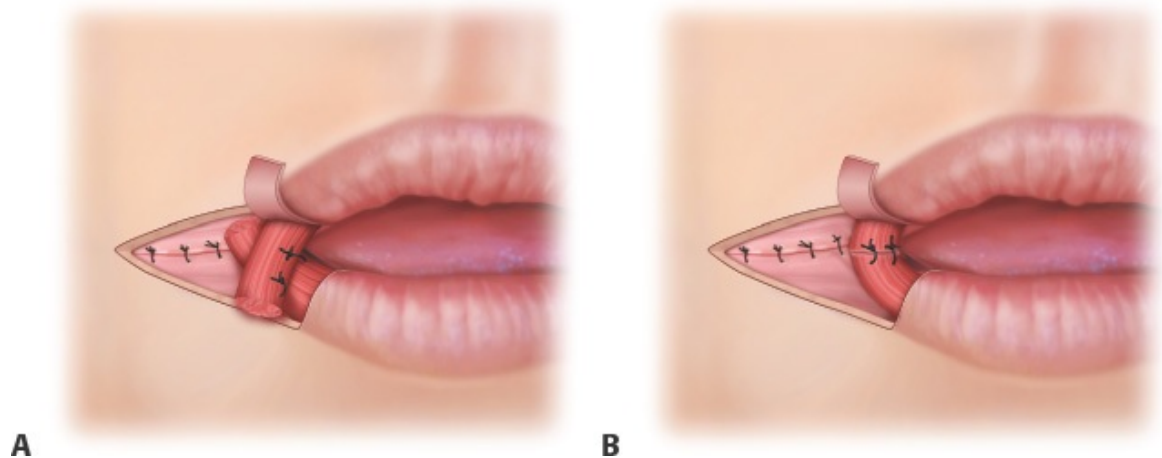


TECH FIG 2 • Repair design. A vermilion flap is designed that will bridge the new commissure in order to keep a scar line out of the repair. The cleft margin tissue shown with a *dotted line* is elevated and raised intraorally. The vermilion flap begins medial to the commissure point and will be inset medial to the commissure point on the recipient lip.

- The mal-positioned fibers of the orbicularis oris of the upper and lower lip are dissected free.
- The muscles are repaired in an overlapping fashion if enough muscle bulk exists for such a repair. Otherwise, they can be repaired end to end (**TECH FIG 3**).
- Repair is done with 3-0 or 4-0 Vicryl suture.

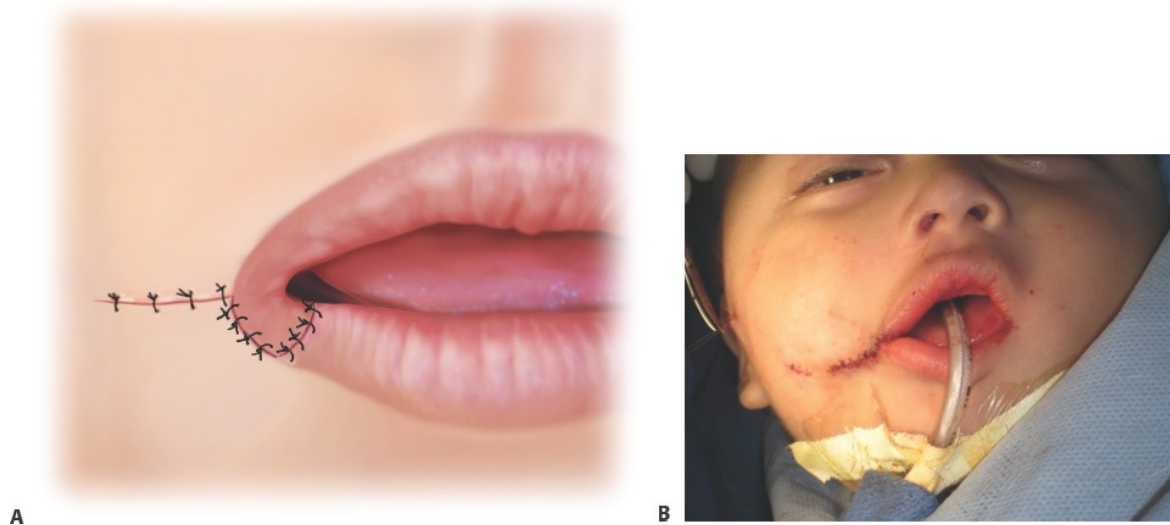
Commissuroplasty and Skin Closure

- The tattooed (c) points are united with a buried dermal suture.
- The vermilion flap is then inset with 4-0 chromic recreating the commissure.



TECH FIG 3 • Orbicularis repair in macrostomia. **A.** Overlapping. **B.** end to end.

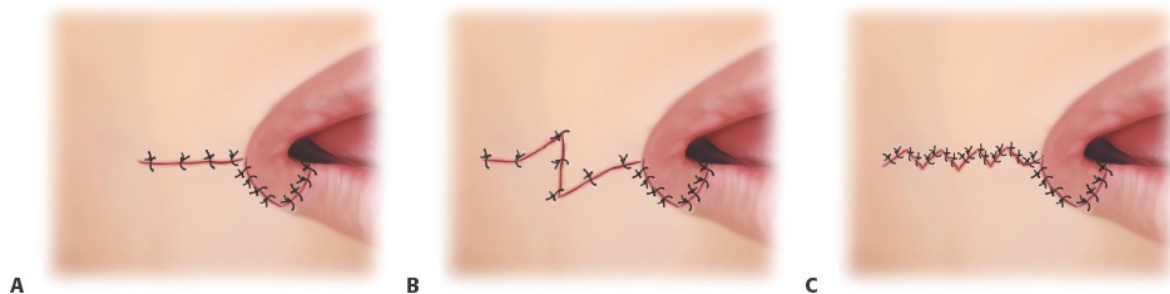
- Excess mucosa intraorally may be trimmed, and intraoral closure is completed with 4-0 chromic.
- Deep fascia is closed in the lateral skin wound.
- A small midincision Z-plasty is designed for transverse lengthening if needed.
- Skin closure is performed with buried deep dermal 5-0 Monocryl or with simple fast-absorbing gut sutures.
- Dermabond is used for the cutaneous incision with one Steri-Strip placed along the nasolabial fold.
- Franco et al. applied a similar concept, carrying the vermilion and orbicularis as a unit across the cleft to recreate the commissure (**TECH FIG 4**).⁶



TECH FIG 4 • **A.** Vermilion flap inset after repair. **B.** Repaired macrostomia. The use of Z-plasty for cutaneous closure is an intraoperative decision.

■ Modifications of the Cutaneous Scar (TECH FIG 5)

- Linear scar closure with no modification⁷
- Z-plasty closure along the nasolabial fold⁴
- W-plasty modification of the cutaneous scar for aggressive nonlinearization⁸



TECH FIG 5 • Cutaneous closure of macrostomia. **A.** Straight line. **B.** Z-plasty. **C.** W-plasty.

Endotracheal tube	■ If using an oral tube, the taping/securing must be closely guided by the surgeon. This ensures minimal commissure distortion and a secure tube throughout the case.
Local anesthesia	■ It is important to judiciously use epinephrine-containing local anesthetic. It helps keep the field relatively bloodless, but one must allow sufficient time for the effect to occur (ie, 5+ minutes). It is also important to not tumesce and thus distort the tissues.
Medial limbus	■ A critical landmark for commissure location in bilateral macrostomia cases.
Scar hypertrophy	■ Preoperative counseling, a proactive postoperative scar management program, and an established timeline for scar interventions are critical.
Lateralization and rounding	■ Many macrostomia repairs will result in lateral migration of the commissuroplasty and a nonanatomic commissure.

POSTOPERATIVE CARE

- For 3 to 4 weeks postoperatively, the scar is treated with massage and silicone gel.
- Hypertrophic scar may be treated with steroid injection at 3 to 6 months.
- Scar revision may be necessary 1 year or more postoperatively.

OUTCOMES

- Excellent, symmetric results can be achieved. Rogers and Mulliken (2007) reported on 13 patients⁵:
 - Age at surgery 11 months, follow-up 10.3 years
 - Commissure position averaged 1 mm difference
 - No lateral commissure migration

COMPLICATIONS

- Dehiscence
- Scar contracture with lateral commissure migration
- Scar hypertrophy

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Section V: Cutaneous Lesions

18 Tissue Expansion for Congenital Nevus

CHAPTER

Lee W. T. Alkureishi and Bruce S. Bauer

DEFINITION

- Congenital melanocytic nevi (CMN) are the most common congenital nevi.
- They are usually present at birth, but “tardive” CMN may arise within the first 2 years of life.
- CMN range from millimeter size to giant, covering the majority of the body.
- Implications include risk of melanoma, CNS involvement, and disfigurement.

PATHOGENESIS

- CMN result in a disturbance of neural crest cell migration between the 5th and 24th weeks of gestation, producing ectopic rests of immature melanocytes.¹
- This is thought to be related to mutations in NRAS and, to a lesser extent, BRAF oncogenes.²
- Nevus cells can extend deep into the subcutaneous tissue, fascia, muscle, and/or periosteum (rare).
- Involvement of the leptomeninges or brain parenchyma is known as neurocutaneous melanosis (NCM).
- Histologic findings specific to CMN include cell clustering, a round shape, and location within eccrine ducts, in follicular epithelium or blood vessels, and in deeper tissues.

NATURAL HISTORY

Malignancy Risk

- Malignant melanoma may arise within the nevus or in extracutaneous locations, most commonly the CNS.
- Population heterogeneity, lack of standardized descriptors, and multiple treatment modalities lead to difficulty ascertaining the true melanoma risk in CMN.
- Earlier studies reported lifetime risk of up to 40%.
- More recent studies suggest much lower lifetime risk: less than 5% for all patients with large CMN and under 2% for smaller lesions.³
- Factors associated with increased melanoma risk include larger nevus size, truncal location, and multiple satellite lesions. The greatest risk may be extracutaneous.
- Risk of melanoma arising within a small CMN prior to puberty is extremely low.
- The same is not true for large (LCMN) and giant (GCMN) lesions; 50% of those developing malignancy do so within the first 3 years of life.⁴
- To date, there has not been a confirmed case of melanoma arising within a satellite lesion.
- Other tumors associated with CMN include lipomas, schwannomas, sarcomas, malignant cellular blue nevus, and undifferentiated spindle cell neoplasms.
- Reduction of the risk of melanoma is still viewed as a valid medical indication for excision.

NEURO CUTANEOUS MELANOSIS AND IMAGING

- The presence of nevus cells within the leptomeninges, brain, or spinal column is NCM.
- Symptoms can range from none to progressive, severe neurologic impairment, hydrocephalus, seizures, and death.
- Problems arise from either benign proliferation of nevus cells blocking cerebrospinal fluid flow or malignant degeneration.
- Exact incidence is unknown but thought to be around 5%.
 - Approximately 5% of these patients will be symptomatic, the vast majority developing symptoms before age 3.
- Prognosis of symptomatic NCM is poor, with over 90% dying within 3 years of diagnosis.
- The highest risk of NCM is thought to be in patients with LCMN of the

posterior midline or greater than 20 satellite nevi. These patients should be strongly considered for MRI screening.⁵

- MRI demonstrates shortening of the T1 relaxation time and, less commonly, T2 relaxation time.
- For best sensitivity, MRI is recommended prior to 4 months of age due to the lack of myelinization in the newborn.
- In patients with symptomatic NCM, aggressive management of the cutaneous lesion needs to be decided on a case-by-case basis and is generally not recommended. This does not hold true for asymptomatic patients, in which the prognosis is more favorable.

DIFFERENTIAL DIAGNOSIS

- Blue nevus
- Mongolian spot
- Nevus of Ota/Ito
- Café au lait spot
- Nevus spilus
- Sebaceous nevus
- Spitz nevus

Classification

- Several classification schemes have been proposed, most of which use the projected adult size (PAS) of the nevus as the main feature.
- PAS is calculated by multiplying the largest diameter of the nevus in infancy by a factor that which varies by anatomical region (Table 1).
- Large CMN are considered as any nevus with a PAS of greater than 20 cm or greater than 2% of total body surface area.

Table 1 Projected Adult Size (PAS) of Congenital Nevi in Infancy (Data from Krengel et al., 2012)

Body Area	Projected Adult Size (PAS) Multiplication Factor
Head	1.7×
Neck, trunk, buttocks, arms	2.8×
Legs	3.3×

- The most inclusive classification system is that recently described by Krengel et al.⁶ (Table 2).

Nevus Distribution

- CMN may arise anywhere on the body.
- Large and giant CMN often occur in recognizable patterns or distributions.
- Size and extent of involvement vary considerably between patients.
- Extensive nevi often involve multiple adjacent areas and/or cross the midline.
- Commonly encountered distributions include:
 - Scalp, forehead, root of nose, and upper eyelid
 - Face: cheek, nose, and lower eyelid
 - Trunk (posterior, anterior, or circumferential “bathing trunk” nevus)
 - Upper extremity (sleevelike distribution)
 - Lower extremity (as part of bathing trunk or isolated lower extremity)



FIG 1 • Facial nevus, involving the unilateral cheek and abutting the lower eyelid.

- The surgical management of these patients is tailored to the location of nevus, extent of involvement, and presence of adjacent normal skin.
 - However, we describe common techniques and principles, many of which may be applicable for the management of nevi in any location.
- The example provided in this chapter focuses on a nevus involving the

unilateral cheek and lower eyelid (**FIG 1**).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients are often seen in infancy.
- Any changes in appearance of the lesion over time should be noted.

Table 2 Proposed New Classification of Congenital Melanocytic Nevi

CMN parameter	Terminology	Definition
CMN projected adult size	"Small CMN" "Medium CMN" "M1" "M2" "Large CMN" "L1" "L2" "Giant CMN" "G1" "G2" "Multiple medium CMN"	<1.5 1.5–10 cm 10–20 cm >20–30 cm >30–40 cm >40–60 cm >60 cm ≥3 medium CMN <i>without a single, predominant CMN</i>
CMN localization ^a CMN of the head CMN of the trunk CMN of the extremities No. of satellite nevi ^b Additional morphologic characteristics	"Face," "scalp" "Neck," "shoulder," "upper back," "middle back," "lower back," "breast/chest," "abdomen," "flank," "gluteal region," "genital region" "Upper arm," "forearm," "hand," "thigh," "lower leg," "foot" "S0" "S1" "S2" "S3" "C0," "C1," "C2" "R0," "R1," "R2" "N0," "N1," "N2" "H0," "H1," "H2"	No satellites 50 satellites 20–50 satellites None, moderate, marked color heterogeneity None, moderate, marked surface rugosity None, scattered, extensive dermal or subcutaneous nodules None, notable, marked hypertrichosis ("hairiness")

^aOne or more of these locations should be used to describe *preponderant* area of

involvement.

^bRefers to number of satellites within the first year of life; in case this number is not available, actual number should be mentioned.

CMN, Congenital melanocytic nevi.

Reprinted from Krengel S, Scope A, Dusza SW, et al. New recommendations for the

categorization of cutaneous features of congenital melanocytic nevi. *J Am Acad Dermatol*.

2013;68(3):441-451, with permission from Elsevier.

- Nevus size and location and the presence of multiple satellite nevi should prompt screening for NCM.
- A family history of melanoma should be elicited.
- Potential psychological problems associated with this diagnosis should not be underestimated, especially in older children and adolescents.
 - Emotional, behavioral, or social problems are present in 30%.
- On initial examination, the extent of the nevus should be noted, including involvement of critical structures and any areas of adjacent normal skin for treatment planning.
- Serial examinations every 3 to 6 months are recommended.
- Darker pigmented areas or raised nodules may represent neural nevus rather than malignancy.
- Selective biopsy can be used to exclude malignancy for any suspicious areas but is rarely indicated if excision and reconstruction are already contemplated.

NONOPERATIVE MANAGEMENT

- Treatment of CMN is most often surgical, with excision and reconstruction. Other modalities include dermabrasion, curettage, and laser therapy. Some cases are best approached with observation alone.
- Some giant nevi are so extensive as to preclude excision, and regular follow-up by a pediatric dermatologist is recommended.
- Although many LCMN are amenable to surgical excision and reconstruction, the surgical experience needed for successful surgical management is not readily available in many areas of the world.

Dermabrasion and Curettage

- Dermabrasion and curettage are used to reduce, but not eliminate, the number

of nevus cells within a lesion.

- Dermabrasion is used to abrade away the surface cells within the epidermis and upper reticular dermis.
- Curettage separates the cells at a natural cleavage plane between superficial and deep dermis.
- Both techniques are best performed within the first 15 days of life.
- Lightening of the nevus can be successful initially, but this is variable and the lesion may tend to redarken over time. Follow-up may also show marked hypertrichosis.⁷
- These techniques are theoretically less effective at reducing malignancy risk, due to persistence of nevus cells at deeper levels. Resultant scarring may also complicate surveillance of the lesion. Cases have been reported of melanoma arising within the field of previous dermabrasion.⁸

Laser

- Laser remains an attractive option, potentially reducing the level of pigmentation without scarring.
- Lasers used in the treatment of CMN include ruby, Q-switched, Er:YAG, and carbon dioxide, either alone or in combination with Nd:YAG or Q-switched ruby lasers.
- Serial treatments are required, and scarring can occur with aggressive treatment or improper settings.
- Hypo- and hyperpigmentation may also occur and may be transient or permanent.
- The disadvantages of laser treatment are similar to those of dermabrasion/curettage and include continued malignancy risk, scarring, difficulties with surveillance, and redarkening of the lesion over time.
- Despite their current limitations, nonoperative modalities do offer some benefits in certain situations.
 - For example, lightening a thin lesion on the eyelid
- Improvements in laser technology will likely continue to improve outcomes with this modality, expanding its usefulness in the future.

SURGICAL MANAGEMENT

- Surgical excision allows complete removal of nevus cells in the involved skin and subcutaneous tissue.

- Excision generally includes all tissue above the level of the deep fascia.
- Although skin grafts have been used for resurfacing, the mainstay of reconstruction is with tissue expansion.
 - Replacement of the excised tissue with similar thickness normal tissue (skin and subcutaneous fat) provides the most functional and aesthetic outcome.
- Early excision is recommended.
- Procedures can be safely carried out starting as early as 6 months of age.
- Those parents with concerns about multiple procedures under the age of 1 can delay initial surgery until after the first birthday (though in expander patients started at 6 months, the maximum additional surgeries under 1 year are only two).

FIRST STAGE: PLACEMENT OF TISSUE EXPANDER(S)

Preoperative Planning

- Treatment begins with the evaluation of the nevus extent and adjacent areas of unaffected skin amenable to placement of tissue expander(s).
- For lesions affecting the cheek and lower eyelid, a single expander placed in the lower cheek/neck is often appropriate.⁹
 - The size of expander chosen is dependent on the size of lesion, availability of adjacent unaffected tissue, and anticipated size of flap required.
 - For many infants, a 70- to 90-cc expander is the largest that can be placed.
 - With adequate expansion, the resultant flap can be designed to place incisions to lie less conspicuously at the junction of adjacent aesthetic subunits.
- For more extensive nevi involving the temporal forehead, scalp, or upper eyelid, an additional expander may be required in the forehead region.
- For nevus involving large portions of the nose, an expanded forehead flap based on the supraorbital or supratrochlear artery is the best option and must be done as the first expansion.
- The expanded forehead flap places the final scar along the brow rather than midforehead.
- For extensive forehead and nasal lesions, subsequent expansion and flaps can be safely done without risk to the prior nasal flap.
- Prior to surgery, the family undergoes extensive teaching regarding the procedures, postoperative care, technique of tissue expansion, and anticipated timing of the next stage.

- In the majority of cases requiring multiple rounds of expansion, each round is separated by at least 4 months.

Positioning

- The patient is placed supine on the operating table.
- A roll is placed under the upper back and shoulders, ensuring adequate neck extension.
 - This is especially important, as it is frequently necessary to dissect the pocket for the expander past the level of the mandible and into the neck.
- General anesthesia is administered via an oral RAE endotracheal tube.
 - Care is taken to ensure this is secured exactly in the midline, avoiding asymmetric distortion of the facial anatomy.
- If the nevus is hypertrichotic, a clipper is used to ensure the margins are clearly visible for incision planning.
- The face, scalp, neck, and shoulders are cleaned with surgical soap and saline, and drapes are applied.

Approach

- Considerations in planning the incision:
 - The length of the incision should be adequate to facilitate dissection of the pocket and insertion of the expander, but no longer than necessary.
 - The incision is generally placed within the nevus, at the inferior margin. By staying within the nevus, all healthy uninvolved skin is preserved.
 - In selected cases with a narrow inferior “finger” of nevus flanked by adjacent normal skin, it may be preferable to place the incision farther into the substance of the nevus. Although this will result in the nevus being partially expanded, it achieves maximal expansion of the normal skin.
 - In patients with fine hairs along the border of the nevus, it may be preferable to place the incision just beyond the margin of the nevus, as those hairs may complicate cleaning the incision and increase the likelihood of secondary infection.
- The dimensions of the pocket for the expander are measured and marked on the skin.
 - The pocket measures 1 cm greater than the expander in both dimensions.

TECHNIQUES

- The incision line is infiltrated with lidocaine 1% and epinephrine 1:200 000.
- Incision is made with a 15c blade and deepened to the level of the subcutaneous fat.
 - Care is taken to stay perpendicular, avoiding unnecessary undermining of the nevus.
- With Iris scissors, the supra-SMAS plane is carefully developed under direct vision.
- Once the plane is established, the skin flap may be laid flat, and the majority of the remaining pocket can be dissected using the scissors without direct visualization.
 - The scissor blades can be seen on the surface of the skin, and the depth of the dissection can be accurately gauged by paying close attention to the tips.
 - This approach helps to minimize trauma to the thin skin flap.
- Particular care must be taken in the region just anterior to the mandibular angle, where the marginal mandibular nerve may be encountered. In addition, the facial artery and vein can potentially cause troublesome bleeding in this region. The depth of dissection is critical in this region, to avoid injury to the nerve below while maintaining a robust skin flap of sufficient thickness above. Of note is that the marginal mandibular nerve lies deep to the platysma, and if dissection remains superficial to the SMAS plane, the marginal mandibular nerve is spared.
- The dissection is carried over the mandible into the neck, to the extent of the pocket previously marked.
- The pocket is packed lightly with gauze for hemostasis, and attention is then turned to the expander.
- The location for the expander port is chosen and the length of tubing adjusted as needed.
 - A remote internal port is used in all cases.
 - The port should be placed over firm underlying structures to facilitate palpation.
 - The port should be placed through a limited tunnel to minimize risk of displacement or flipping.

- For lower face expanders, the temporal scalp is a typical location for the port.
- A narrow tunnel for the port is created using scissor dissection, a malleable retractor of similar width to the port, a urethral sound, or a combination of all.
 - The width of the tunnel should be limited to the diameter of the port, to prevent migration of the expander along the tunnel.
- A narrow gauge suction drain is placed into the expander pocket through a separate stab incision (19-G butterfly IV, reconfigured as a drain).
- The expander is filled with a volume of injectable saline dependent on size and location of the expander, filling enough to ensure a smooth contour.
- The port is generally inserted into the pocket first and guided into position with finger pressure or using a malleable retractor.
- The expander is rolled lengthwise, forming a thin tube with the edges rolled underneath, which is then easily inserted into the pocket.
 - Once the majority of the expander is within the pocket, it can be unfurled to lie flat.
 - Care should be taken to ensure that there are no folds present on the top surface of the expander, particularly in the face where the overlying skin flap can be very thin.
- The skin is closed in layers with interrupted 5-0 clear nylon for the dermal layer and a running 5-0 Prolene over this.
- The expander port is then accessed, and an additional small volume of saline may be injected.
 - The skin is observed and palpated during injection, to avoid overfilling.
 - In general, a total of approximately 15 cc is well tolerated at this stage.
- The site is cleaned and dressed with bacitracin, Xeroform gauze, gauze fluffs, and a loose SurgiNet dressing.
 - A tight dressing should be avoided over the expander, as this can easily compromise the skin flap.

PEARLS AND PITFALLS

Physical findings

- The appearance of CMN is widely variable, ranging from relatively inconspicuous flat, pale hairless nevi to dark or variably

	pigmented, highly rugous/nodular nevi with hypertrichosis.
Technique	■ The use of Bovie electrocautery is limited, so as not to cause thermal injury in the dissection of thin, potentially tenuous skin flaps for the expander pocket. ■ A 19-gauge “butterfly needle” makes for an excellent drain. The end of the tubing is perforated and placed into the pocket through a separate stab incision. Standard blood draw vacutainers can be used to provide suction. ■ Avoiding folds and points on the superficial surface of the expander is key to minimizing the risk of skin breakdown and subsequent exposure of the expander.
Postoperative	■ The key to successful expansion is to pay close attention to the skin’s response to the fill. Aiming for a specified volume with each expansion will inevitably lead to problems. ■ The first postplacement expander fill is typically 8–10 days postoperatively, and expansion then continues weekly. This can increase to q4-5 days in select cases if the overlying skin relaxes sufficiently.

POSTOPERATIVE CARE

- Patients can generally go home on the day of surgery, depending on parent comfort.
- Dressings are changed twice daily, keeping the incision and skin flap moisturized with Aquaphor or similar dressing.
- Drains are usually removed within 3 to 7 days, after which the dressing may be minimal.
 - Postoperative antibiotics are continued until the drains are removed.
- Expansion is begun at days 8 to 10.
 - The first expansion is performed under supervision in the clinic.
 - Subsequent expansions may be carried out at home or in the clinic depending on parents’ preference.
- Parents are advised not to focus on a target volume for each fill but to assess the skin’s response to the additional volume.
 - Skin turgor
 - Blanching indicates excessive fill, and some volume should be removed.
 - Expansion should not be painful; discomfort indicates excessive fill.
- Expansion is usually carried out weekly, unless the child has symptoms of upper respiratory infection or fever of unknown origin.

- The frequency may be increased to q4-5 days in some cases.
- Total expansion time may range from 8 to 12 weeks.
- Expansion may continue up until a few days before surgery (**FIG 2**).

SECOND STAGE: EXCISION OF NEVUS WITH EXPANDED FLAP RECONSTRUCTION

Preoperative Planning

- The planning of the second stage procedure begins prior to the first stage.
 - Position of the expander should take into account the anticipated flap design.
 - When advancing tissue from the neck to the cheek area, a transposition design is optimal.
 - This allows greater flap movement and helps align scars optimally along the junction between aesthetic subunits.
- The surgeon must decide whether to base the transposition flap laterally (most common) or medially.
 - The size and location of the lesion help to determine this.
 - Where early experience involved use of medially based flaps, the inferolaterally based flaps used today allow better reconstruction of the aesthetic unit with less risk of downward traction on the lower eyelid.
 - Smaller lateral based cheek lesions may be reconstructed with expanded inferomedially based flaps.
 - Even with expansion, the size of nevus that can be excised laterally without undue traction on the eyelid or oral commissure is limited.

Positioning

- Positioning, prepping, and draping are the same as for stage I.



FIG 2 • A. Fully expanded lower cheek/neck tissue expander **(B)** ready for nevus excision and expanded flap reconstruction.

Approach

- The initial incision is planned to facilitate removal of the expander.
- The incision is marked around the inferior extent of the nevus, as before, but outside the nevus margin (**FIG 3**).
- If the nevus margins are very light or indistinct, it is better to err on the side of preserving potentially uninvolved skin. Any areas that subsequently darken may be removed at the time of later scar revision or satellite removal.
- In cases where the nevus margin is clear, a surgical margin of 1 to 2 mm is adequate.
- Similarly, if only partial excision is planned/possible, then it is often better to keep as much of the scars within nevus tissue that will later be excised. In these cases, placing the incision within the nevus margin is advisable.



FIG 3 • Marking the incision for expander removal. The extent of the inferior extension of the incision is determined after expander removal.

- For laterally based flaps, the incision is often carried inferiorly in the line of the nasolabial fold, to facilitate flap transposition. However, the extent of this inferior incision is determined later, after expander removal.

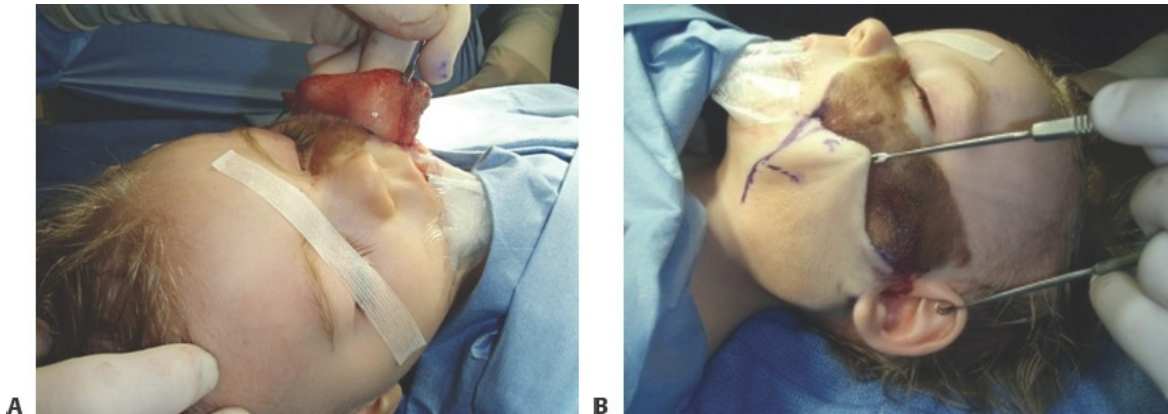
TECHNIQUES

■ Incision

- Incision is made with a 15c blade through the skin and deepened through the subcutaneous fat with electrocautery to the level of the expander capsule.
- The expander pocket is entered through the capsule.
 - The capsule is extremely important for the vascular supply of the flap. As such, it is important not to undercut the flap at this stage, as excessive removal of capsule can jeopardize the vascularity of the flap's extremes.
- The incision and deeper dissection are continued inferiorly for a short distance in the line of the nasolabial fold and marionette line, and once a large enough window has been created, the expander is removed.
 - The tubing connecting the expander to its port is cut, and the port is left in situ for now. Removal is often easier later in the procedure.
- The expander pocket is now fully accessible. The skin flap can be placed under moderate tension in the direction of the planned transposition, and

limited release of the capsule with electrocautery facilitates greater transposition without creating undue tension on the closure (**TECH FIG 1A**).

- Care must be taken not to perform too much capsular release, as the importance of its vascular contribution cannot be overemphasized.
- The extent of the dissection is a delicate balance between facilitating movement and preserving the viability of the flap.
- With the capsule is released, the skin becomes the limiting factor in achieving the desired transposition.
- Options for skin release include extending the incision further down the nasolabial fold/melomental fold, backcutting into the flap, or both (**TECH FIG 1B**).
- The type of extended incision or backcuts used is dependent on the extent and location of the nevus and the extent and location of uninvolved adjacent skin.
- Small triangles of uninvolved skin adjacent to the flap margins can often be used to fill in the defects created by backcuts.





TECH FIG 1 • A. Limited release of the capsule with the skin flap on tension allows greater transposition of the flap without undue tension. However, the extent of release must be balanced with preserving as much vascular supply as possible. **B.** Options for skin release include extending the incision further down the nasolabial/melomental fold, backcutting into the flap, or both. **C.** The transposed flap, which covers the entire cheek at this stage.

- These small areas would otherwise be discarded, as they are covered by the transposed/advanced flap.
- Their interposition serves to allow a greater backcut, relieving tension and affording greater movement.
- Careful design of these small flaps can also break up the linear scar and/or place portions of the incision in the relaxed skin tension lines.
- The flap is again placed on moderate tension, and the extent of transposition is evaluated. At this point, the flap will often cover the entire cheek to the level of the lid crease, nose-cheek junction, and nasolabial fold (**TECH FIG 1C**).
- It can be helpful to temporarily tack the flap in place under moderate tension, allowing the areas of tension to be fully assessed.

- Further movement of the flap may be needed in the following situations:
 - Nevus involvement of the root of the nose or nasal sidewall
 - Nevus involvement of the upper lip
 - In these cases, the inferior and medial-most extent of the flap can reliably reach these extremes. The additional backcuts into the flap should be designed to allow this.
 - For all backcuts and incisions within the substance of the expanded flap, care should be taken to include sufficient capsule with the smaller or more tenuous of the created flaps. This helps to maximize vascular supply within the flap, particularly the venous drainage.
 - This may require beveling of the incisions in some cases, capturing more of the subcutaneous tissue and particularly the capsule.
 - Upon flap transposition, a dog-ear of excess tissue will be apparent in the temporal region.
 - This is excised above the level of the lateral canthus, allowing secure flap fixation high enough to prevent the development of ectropion due to flap descent.
 - At this stage, the port for the expander is close to the level of dissection, and removal is relatively easy.
-

■ Excision

- Once the flap release is completed, the extent of nevus excision can be decided.
 - The defect created by excision should allow reconstruction without excessive tension on the flap.
 - In general, the superior extent of excision should be the lower eyelid-cheek junction. When the nevus also involves the lower eyelid, the very thin eyelid skin is best reconstructed with a full-thickness skin graft at a later stage.
 - The excision of nevus in this area should be delayed until the cheek flap is fully secured both medially and laterally.
 - If possible, the triangle of skin immediately lateral to the alar-cheek junction should be preserved if not involved by nevus.
 - This allows the scar in the nasolabial groove to terminate at the nose-cheek junction rather than the alar base.

- The nevus is excised at the level of the superficial musculoaponeurotic system (SMAS), and hemostasis is achieved with bipolar cautery (**TECH FIG 2**).
- This can be performed in stages, securing the flap to the deeper tissues at several points as the dissection progresses superiorly.
- This allows the most accurate determination of the flap's reach, ensuring that the distal portion of the flap is not placed under excessive tension due to overly aggressive nevus excision.



TECH FIG 2 • The nevus is excised at the level of the superficial musculoaponeurotic system (SMAS).

■ Suturing

- Deep sutures can be used to serve dual purposes.
 - Suturing the deeper tissue of the flap to the underlying periosteum with clear nylon can help prevent later downward migration of the flap.
 - Suturing the more superficial tissue of the flap to deeper tissues can help recreate anatomical grooves or folds (eg, at the alar base–cheek junction). At this site, through-and-through sutures into the nasal cavity are often used. Based on the requirements of the specific case, the flap can be anchored to the periosteum along the pyriform. On the flap side, the depth of the suture is dependent on how much of a groove is desired. Placing the

suture higher (eg, grabbing part of the dermis) will create a deeper groove. The flap may also be anchored through and through into the nasal cavity at the level of the alar-cheek junction, using an absorbable suture.

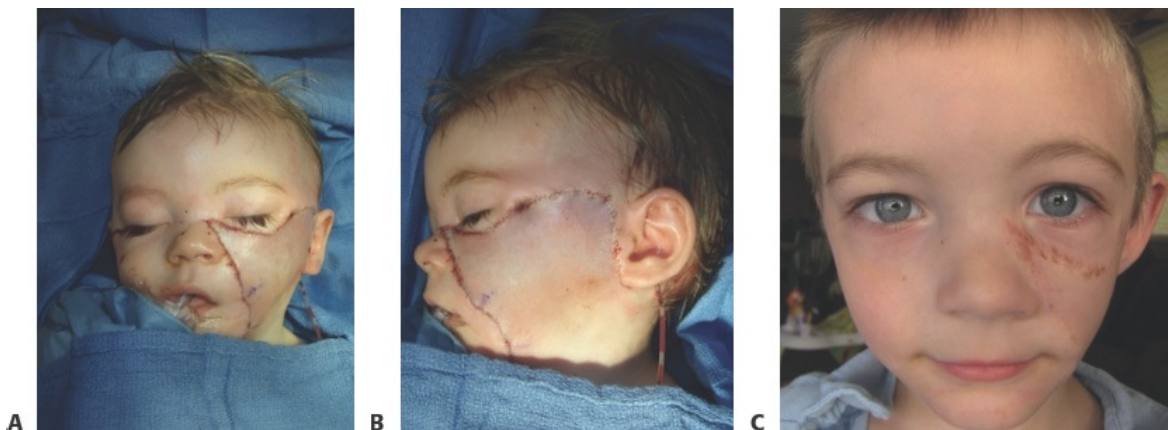
- Key sites for deep suture fixation of the transposed flap:
 - Lateral orbital rim
 - Medial orbital rim
 - Nose-cheek junction
 - Alar base–cheek junction
- The remainder of the flap is inset with deep dermal sutures.
 - 5-0 clear nylon is used in areas with sufficient flap thickness.
 - 5-0 Monocryl (Ethicon, Inc., Somerville, NJ) is used in areas of thinner overlying tissue.
- It is of utmost importance to include the expander capsule along the entire border of the flap in the closure of the deep layer and in the placement of dermal sutures.
 - This ensures that the capsule is “unfolded,” maximizing the venous return. Folds or wrinkles in the capsule due to incomplete or incorrect inset can significantly affect the viability of the flap.
 - The flap may often appear congested until the capsule is fully unfolded.
- The final excision and inset along the nasolabial groove and melomental fold are not carried out until the above flap inset is near complete in order to avoid traction on the upper lip and commissure where final nevus excision will be required, leaving the lip intentionally “long” and the commissure pushed medially. This allows final excision to achieve symmetry.
 - With scar contraction, there is a tendency for the ipsilateral nostril to be pulled downward and the lip to be pulled upward.
 - The inset of the flap is designed to compensate for this, with the nostril slightly higher and the lip lower compared with the contralateral side (**TECH FIG 3**).



TECH FIG 3 • Flap inset is designed to compensate for subsequent scar contraction, with the ipsilateral nostril slightly higher and the lip lower than the contralateral side.

■ Closure

- A single butterfly drain is placed through a separate stab incision and secured as before.
- Skin closure is with running 6-0 chromic and 7-0 Vicryl (Ethicon, Inc., Somerville, NJ) sutures (**TECH FIG 4**).



TECH FIG 4 • The completed reconstruction. **A,B.** On-

table. **C.** Mature postoperative result, prior to excision of the small areas of residual nevus.

PEARLS AND PITFALLS

Technique

- Transposition of the flap should be completed before completely excising the lesion, ensuring adequate flap coverage.
- The lower cheek/neck expanded flap can reach as far as the root of the nose or upper lip when needed.
- Deep suture fixation at several points is key to preventing downward migration of the flap and resultant ectropion.
- Through-and-through sutures at the alar base–cheek junction can help recreate the natural groove in this area.
- The thin skin of the lower eyelid cannot be satisfactorily reconstructed with a cheek flap and is best addressed with full-thickness skin graft at a subsequent procedure.

Postoperative

- Postoperative care is essentially the same as for the first stage.

POSTOPERATIVE CARE

- The face is cleaned and dressed with bacitracin, Vaseline gauze, gauze fluffs, and a loose SurgiNet dressing.
- Ophthalmic bacitracin should be used around the eye.
- Patients may go home on the day of surgery, depending on parent comfort.
- Postoperative regimen is unchanged from the first stage.

OUTCOMES

- In the authors' hands, expanded flap reconstruction with a laterally based lower face/neck flap provides the most pleasing results for this type of lesion.
- The quality and thickness of the expanded flap match that of the uninvolved skin.
- The contour of the lower cheek and neck is superior to that achieved with a medially based flap.
- Deep suture fixation is effective in preventing later ectropion with vertical descent of the flap tissue.

- For nevi involving the lower eyelid, a further stage is generally required.
 - This allows time for the flap to settle into its final position and any small adjustments to be made.
 - Medial or lateral canthopexy can be utilized to address any scar contraction or minor flap descent.
 - If further deep fixation is required at the lateral orbital rim, a permanent suture can be placed through a drill hole in the bone of the orbital rim.
 - The eyelid nevus is then excised and reconstructed with a full-thickness skin graft.
- When excision of nevus involves expanded flap reconstruction of the forehead and scalp as well as neck, the reconstruction should be sequenced to address the scalp, forehead, and cheek; the cheek should be reconstructed last.
 - The cheek excision and reconstruction can commence once the forehead flap is inset in final position. Skin closure may be performed at the same time.

COMPLICATIONS

- Infection during expansion can occur and is more common in the neck compared with other sites in the head and neck.
 - Infection can usually be managed with antibiotics, occasionally for the remainder of the expansion process.
 - Severe infection requiring removal of the expander is rare.¹⁰
- Extrusion of the expander is rare.
 - Maintaining a flap of sufficient thickness minimizes this risk.
 - In older children where a 250-cc expander may be used, the most important part of expander placement is ensuring that the dissected pocket is large enough for the expander to be placed with minimal folds or irregular points.
- The main complication of the second stage is vascular compromise of the expanded flap.
 - The increased vascularity afforded by expansion lowers this risk.
 - Flap compromise is always partial; total flap compromise does not occur.
 - Partial flap necrosis is generally limited to the distal aspect of the flap.
 - Sloughing is most often partial thickness and manageable with local wound care.
- Infection is very rare following removal of the expander.
- With placement of scars along the junctions of aesthetic subunits, the mature scar is very good in most cases. However, problems with hypertrophic or

widened scars can occur and may require scar revision. This can often be combined with other planned procedures (eg, excision of satellite nevi).

- When there is some extension of the nevus medial and inferior to the nasolabial fold, leaving that final excision until the scars have settled allows more precise final closure and may avoid the need for later scar revision.

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19 Surgical Treatment of Congenital Midline Nasal Mass

CHAPTER

Patrick A. Gerety and Scott P. Bartlett

DEFINITION

- Congenital midline nasal masses are a rare occurrence but require a thorough workup for an intracranial component, which then necessitates a transcranial resection.
- These masses typically represent one of three diagnoses: dermoid cyst, encephalocele, or glioma.
 - A nasal dermoid sinus cyst (NDSC) is lined by stratified squamous epithelium and contains dermal adnexal structures such as hair follicles and sebaceous glands. The cystic contents are sebum. If the mass has a punctum with drainage to the outside world, it is a dermoid sinus; otherwise, it is a dermoid cyst.
 - A nasal encephalocele is an extracranial protrusion of a cerebrospinal fluid (CSF)-containing dural mass. Twenty-five percent of all encephaloceles are in the nasofrontal region (sincipital). If brain matter is within the mass, this is referred to as meningoencephalocele.
 - A nasal glioma represents extracranial brain matter with no patent CSF connection.
- Intracranial extension—extension of midline nasal masses from extracranial nasal location to the anterior cranial fossa
- Transcranial approach—a combined extracranial and intracranial resection with reconstruction

ANATOMY

- Formation of a midline nasal mass results from disruption of early

embryologic processes. The exact theory of embryology responsible for the formation of transcranial nasal masses remains debated.¹ Several operating theories lend rationale to the occurrence and anatomy of these masses. Some of these theories include the prenasal space theory, the nonseparation theory, and the ectodermal inclusion theory.

- Transcranial nasal congenital masses are believed to exist for two important reasons (**FIG 1**):
 - Failure of normal regression of a transcranial embryologic structure (dural diverticulum)
 - Embryologic contact of surface and neural ectoderm
- Per one theory, a dural diverticulum from the anterior cranial fossa normally exits the cranium via the nasofrontal junction (the fonticulus (nasofrontalis) frontalis) and ends between the nasal bones and nasal soft tissues.
 - This diverticulum normally involutes and can be identified as the foramen cecum. This foramen has no contents typically but may contain a fibrous stalk.
 - If this process is disrupted, a persistent transcranial connection may be present at birth.
 - Importantly, the neural ectoderm of this diverticulum makes contact with the surface ectoderm of nasal skin. Normally, this connection also regresses. If it does not, it may pull skin elements beneath the nasal skin resulting in an NDSC.
- The transcranial connection may occur at a number of anterior cranial fossa midline structures: cribriform plate, crista galli, foramen cecum, nasofrontal junction, or any combination of these.
- Anterior cranial encephaloceles can also occur via the nasofrontal, nasoethmoidal, or naso-orbital bony junctions.

PATHOGENESIS

- The etiologic basis of this occurrence is likely multifactorial with a genetic component. Family history and multiple siblings have been identified with these masses. Midline nasal masses are not related to any known syndromes or other known congenital anomalies.
- Conceptually and for disease categorization, these masses particularly the encephalocele are related to the embryologic failure of anterior neuropore (normally embryologic day 24) during early embryologic development.

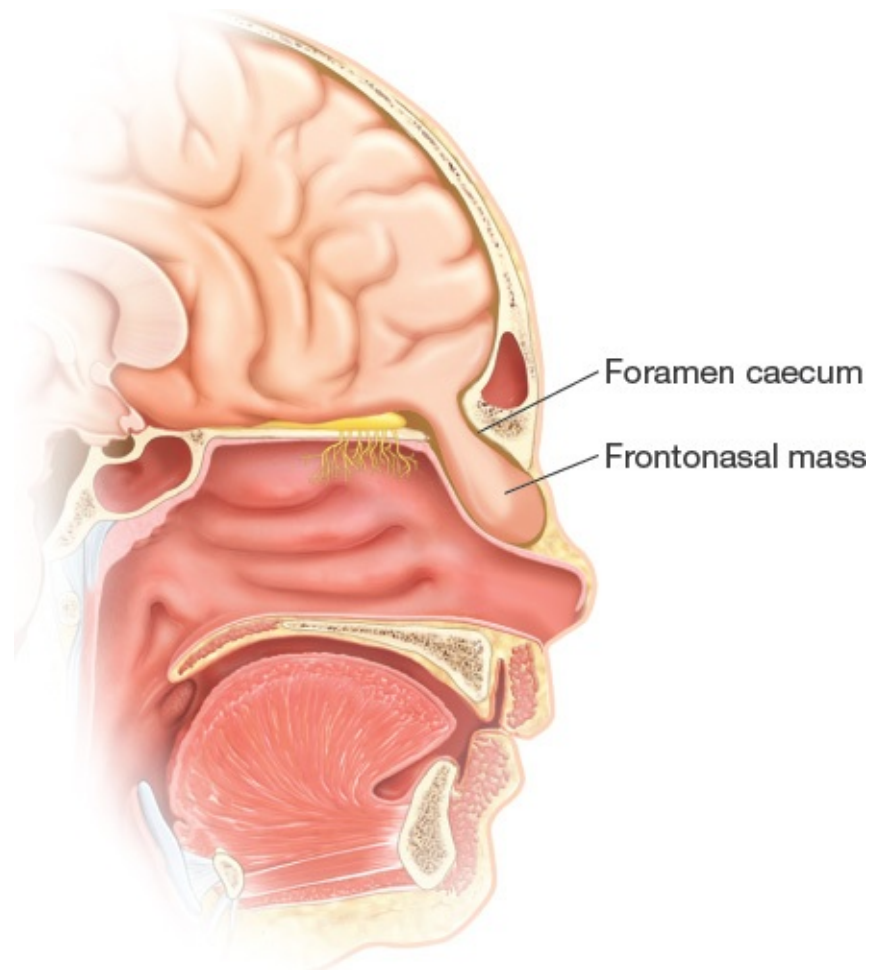


FIG 1 • Embryologic origin of congenital frontonasal masses. Early embryologic connection between the nasal space and the intracranial space may lead to the presence of the congenital nasal mass. The existence of NDSC may be related to neural and surface ectoderm, which as the diverticulum regresses may draw skin contents into a subcutaneous position and in some case maintain a transcranial connection.

- A cranial defect must be present for either of the three main masses to be seen nasally and transmitted transcranially.
- Dermoid cysts likely result from trapping of skin structures subcutaneously as the dural diverticulum involutes normally.
- Encephalocele represents a neural tube defect. Terminology varies depending

upon what the extracranial mass contains.

- Meningocele—meninges only
- Meningoencephalocele—meninges and brain matter
- Encephalocele and glioma represent neuroectodermal malformations.
- Dermoid cysts and sinuses represent a somatic (surface) ectodermal malformation.
- Intranasal gliomas and encephaloceles likely have a herniation point in the anterior cranial fossa that is more posterior (ie, posterior to the cribriform plate) as compared to masses that are seen on the nasal dorsum.

NATURAL HISTORY

- Congenital midline nasal masses are rare with an approximate incidence of 1 in 30 000 live births.
- These masses, particularly encephaloceles, occur in higher rates in Asia (Western incidence, 1 in 35 000; Asian incidence, 1 in 5000).
- NDSC—midline nasal cysts represent 3% to 12% of head and neck dermoid cysts.²
 - Intracranial extension of midline nasal dermoids has been found to be common among these masses on the order of 25% to 45% of cases.
- Encephalocele—approximately 80% are occipital and 20% frontonasal (sincipital).³
- Glioma
 - Approximately 15% have a transcranial connection; thus, nasal resection without intracranial exclusion can lead to CSF leak and meningitis.
 - 3:1 male predominance⁴
 - Sixty percent are extranasal, 30% are intranasal, and 10% are mixed.
- There is a reported association with other nonspecific congenital abnormalities (often quoted as approximately 40%). However, several series have not shown the same association. A transcranial midline nasal mass may occur in isolation.
- Risk of meningitis—with good soft tissue coverage and no sinus punctum, patients are likely at low risk of developing a meningeal infection even in the presence of intracranial CSF connection.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Visible and palpable midline nasal mass (**FIG 2**)
- May occur from the columella to the radix but most commonly along the nasal

dorsum

- Wide nasal bridge
- Hypertelorism—this may be true hypertelorism with total orbital widening or more commonly in this case interorbital hypertelorism with widening of only the medial orbital wall.
- May be present in 70% of encephalocele patients
- Normal interorbital distance increases from approximately 18 mm in infancy to 25 to 30 mm in adulthood.



FIG 2 • Physical appearance of congenital midline nasal mass. **A.** Dermoid sinus with pathognomonic hairs from punctum. NDSC may also present as subcutaneous firm mass with no punctum. **B.** Nasal glioma with pathognomonic telangiectasia. This may be indistinguishable from a nasal dermoid without a dermal sinus. **C.** Nasal encephalocele with bluish hue, large size, hypertelorism, and positive fluid wave on exam.

- NDSC are firm, round masses.
 - NDSC may present with a punctum. The punctum may contain hair, which is a pathognomonic sign of the diagnosis.
 - If a punctum is present, patients are more likely to present with infection.
- Gliomas are firm, round masses.
 - Surface telangiectasia is present and this is pathognomonic.
 - May be extranasal, intranasal, or both
 - Does not transilluminate or change in size
 - Intranasal glioma may cause nasal airway obstruction or nasolacrimal dysfunction. Airway obstruction is particularly problematic in neonates/infants who are obligate nasal breathers.
- Encephalocele may occur through one of three sutures (junctions): nasofrontal, nasoethmoidal, and naso-orbital.

- Often appear blue in color
- Transillumination is pathognomonic because of CSF content.
- Size change with crying may occur (Valsalva).
- Size change may also be elicited by compression of the internal jugular veins (Furstenberg sign).
- Patients may present with CSF leak or frank meningitis.
- The cranial exit point has been found to be fairly variable and may occur at the nasofrontal suture but also through other cranial bone junction points.
- This can be difficult to differentiate on physical examination.

IMAGING

- Because of the occurrence of transcranial extension, there should be a low threshold for obtaining cross-sectional imaging of congenital midline nasal masses.
- In general, both a maxillofacial CT scan and brain MRI are obtained.
- CT scan provides a better examination of bony distortion and bony relationships.
- MRI is thought to be more sensitive and specific for transcranial soft tissue extension and for brain structural examination.⁵
- Typical imaging findings (**FIG 3**):
 - Interorbital distance—widened
 - Frontonasal cranial defect
 - Nasal bone—displaced and angulated
 - Bifid crista galli
- Tissue diagnosis via biopsy is contraindicated in these masses before a noninvasive, cross-sectional imaging workup has been performed.

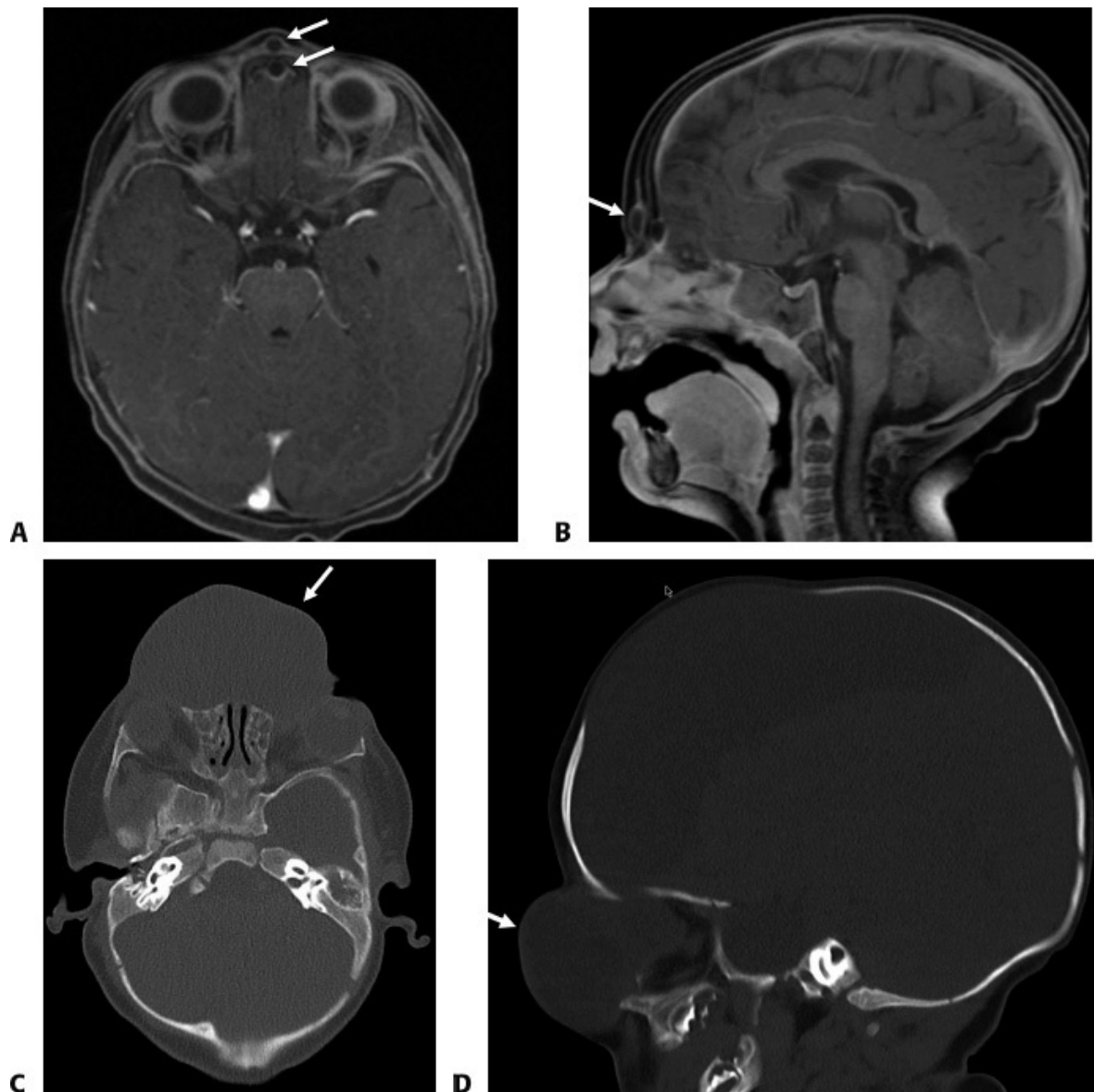


FIG 3 • A,B. MRIs reveal extra and intra components (*arrows*) in a 1-year-old girl with glabellar mass. **C,D.** Midline encephalocele is apparent in AP and lateral CT scans in a 4-month-old girl.

DIFFERENTIAL DIAGNOSIS

- The following are other diagnoses outside of NDSC, encephalocele, and glioma, which may occur on the nasal dorsum congenitally.⁶
 - Hemangioma/vascular malformation
 - Teratoma is pathologically distinct and contains all three layers, including

endoderm, which is not present in NDSC.

- Lipoma
- Neurofibroma is often seen in concert with other neurofibromatosis cutaneous findings.

SURGICAL MANAGEMENT

Preoperative Planning

- Multidisciplinary collaboration
 - Plastic surgery
 - Neurosurgery
 - Ophthalmology—preoperative exam (interorbital, intercanthal, and interpupillary distances as well as eye movements), postoperative management of strabismus, and nasolacrimal management
- CT and MRI
- Hydrocephalus should be managed preoperatively by neurosurgery possibly with ventriculoperitoneal (VP) shunt before definitive correction (only pertains to encephalocele).
- Timing of surgery should be for at least late infancy (8 to 12 months) to allow better perioperative physiology and maturation of bone, which aids osteotomies and fixation.
- Transfusion and postoperative critical care are required.
- Computer-based 3D surgical planning may play a role in hypertelorism correction in the future.

Positioning

- Resection and reconstruction are done in a supine position.

Approach

- **FIG 4** is a decision-making algorithm for resection choice.
- Extracranial approach
 - Transnasal excision
 - Reduction of excess frontonasal skin
 - Open rhinoplasty—has been demonstrated when skin excess is minimal and there is no punctum. This can avoid dorsal nasal scar.
 - Intranasal—excision may be done through nares or open rhinoplasty approach if the mass is intranasal (more often with glioma).

- Intracranial
 - Frontal craniotomy
 - Limited craniotomy
 - Endoscopic minimally invasive approach
 - Immediate interorbital hypertelorism correction
- Dual approach
 - Extracranial
 - Intracranial
- Aims
 - Divide nasal and meningeal tissue and seal them apart.
 - Correct nasal soft tissue excess as needed.
 - Repair cranial base dural and bony defects.
 - Move medial orbits/medial canthi into normoteloric position if necessary.

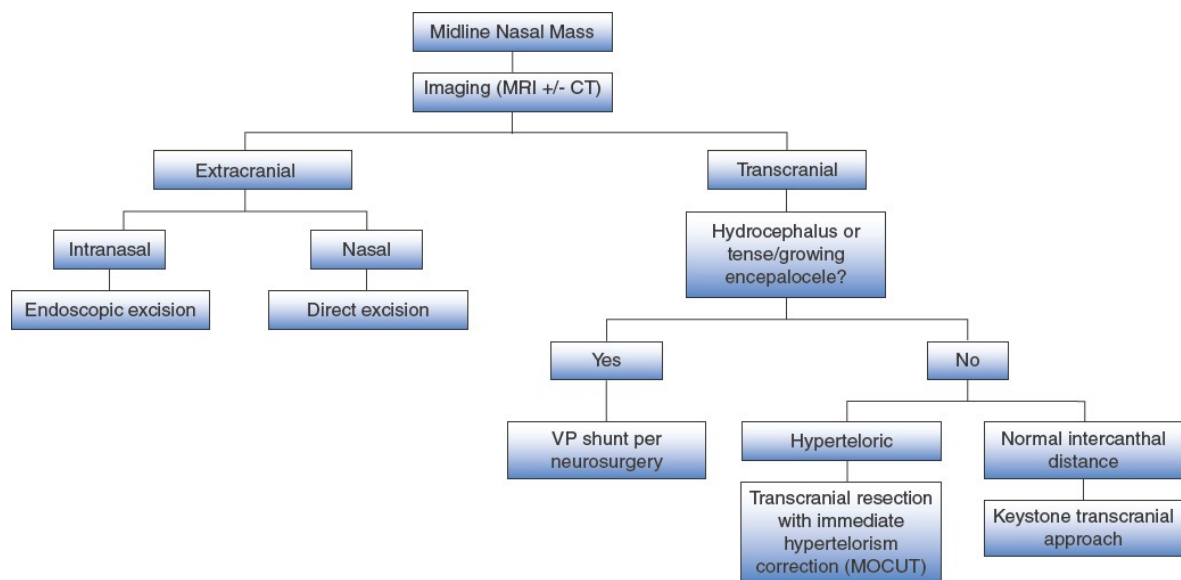


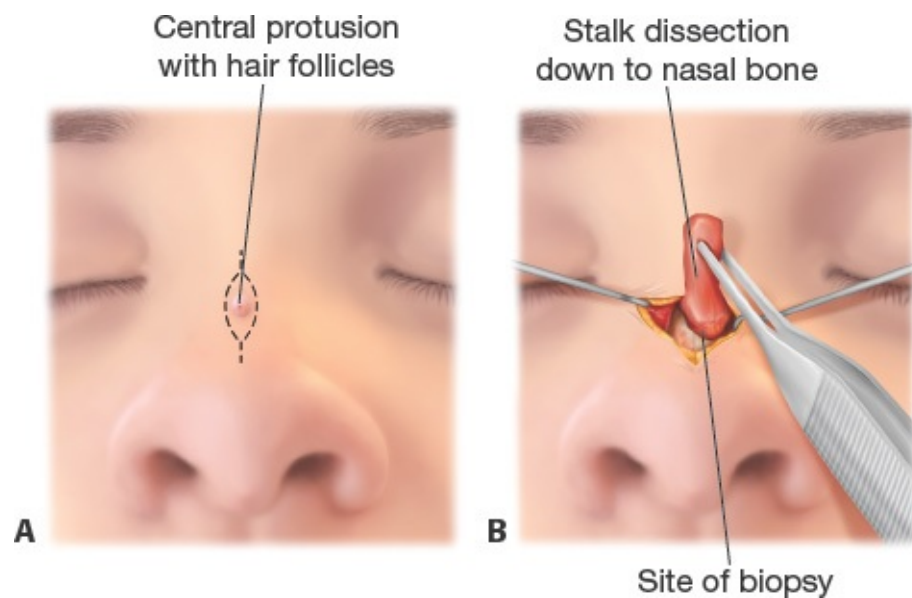
FIG 4 • Algorithm for choice of resection technique.

TECHNIQUES

- **Resection of Transcranial NDSC (“The Keystone Technique”)**
 - Havlik et al. are responsible for describing and popularizing this technique.⁷

Nasal Approach/Frozen Biopsy

- In the case of dermoids with uncertain transcranial component, the mass is dissected down to its stalk. The stalk is biopsied for frozen section.⁸
- If it does not contain dermal contents, then the procedure is terminated with extracranial excision only.
- If dermal elements are present, an intracranial approach is followed (**TECH FIG 1**).



TECH FIG 1 • External approach to midline nasal mass. This approach is combined with an intracranial approach when imaging, or intraoperative frozen biopsy confirms intracranial extension. **A.** Elliptical design for excising this nasal NDSC. **B.** The cyst and its stalk have been dissected down to the nasal bones, and a biopsy can be done at the deepest point.

Incisions, Dissection, and Craniotomy

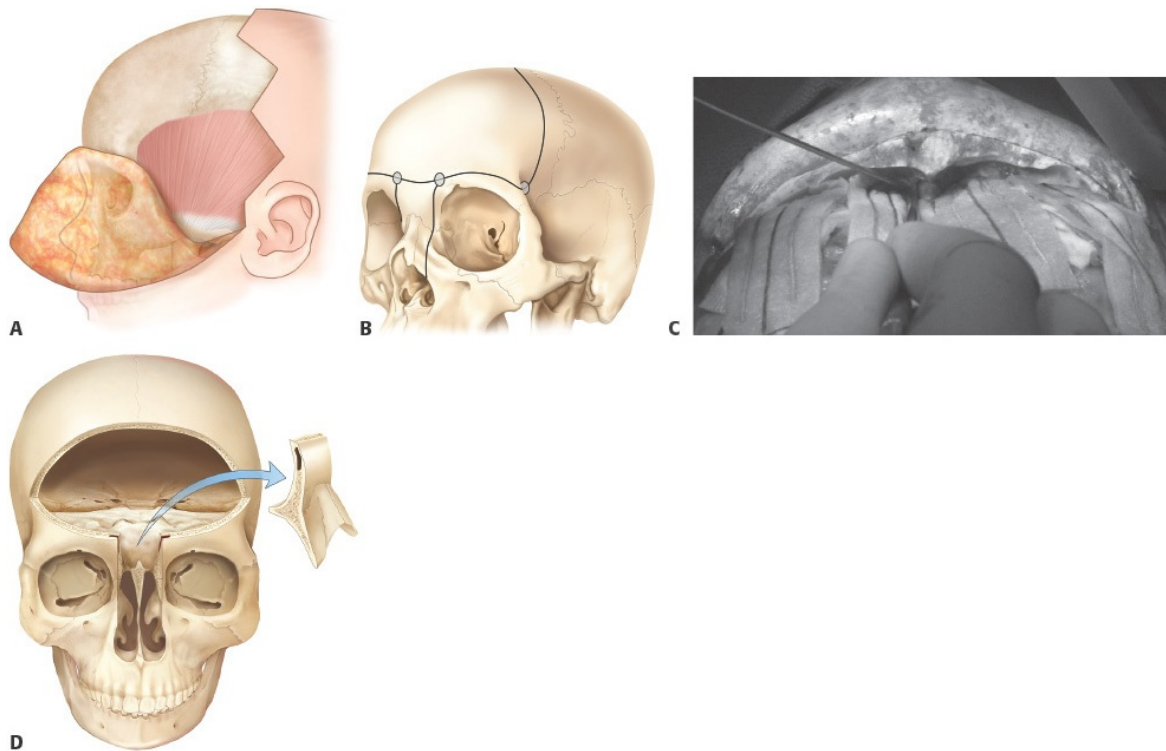
- Bicoronal incision is designed at a symmetric point in the hairline just above the helical root. This is designed as a zigzag pattern to decrease visibility.
- Dorsonasal—a conservative elliptical skin excision is designed for nasal skin reduction and as access for dissection of the mass.
- An anterior scalp flap is raised in the areolar subgaleal plane (**TECH FIG**

2A).

- The pericranium should be carefully preserved.
- Upon approaching the orbits and nasofrontal junction, a plan for raising a subpericranial flap and subperiosteal dissection should be formulated.
- A large pericranial flap should be marked and raised to keep it in continuity with the scalp. This also allows full subperiosteal dissection of the orbits.
- The medial orbits and frontonasal defect edges are dissected subperiosteally with an elevator.
- A bifrontal craniotomy approximately 1cm above the supraorbital bandeau is performed by neurosurgery (**TECH FIG 2B**).
- The frontal lobes can be dissected and retracted to reveal the cranial base and the intracranial/dural extension of the mass (**TECH FIG 2C**).

Keystone Osteotomy and Dermal Sinus Excision

- To visualize the dermoid sinus tract, the frontonasal junction is osteotomized and removed (**TECH FIG 3**).
- This is done via vertical parasagittal osteotomies.
- This can be done to take only midline frontal bone or to include the nasal bones.
- Both approaches require reconstruction of the frontonasal junction or of the keystone area depending upon what is osteotomized.

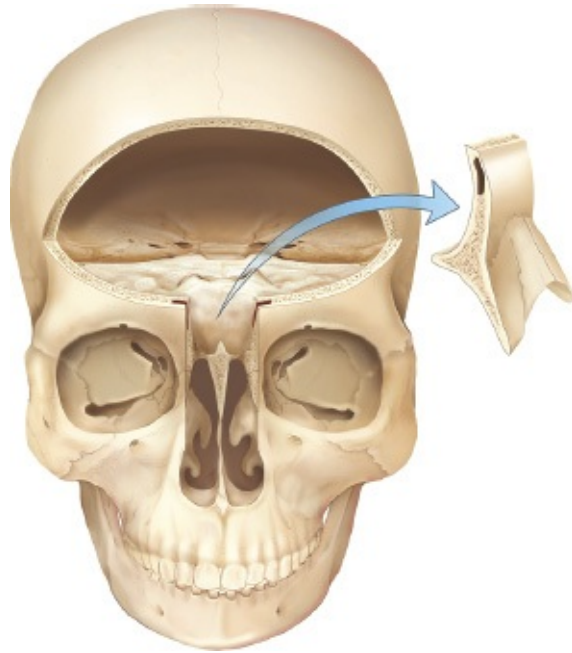


TECH FIG 2 • Transcranial approach to nasal dermoid. **A.** Design and reflection of coronal scalp flap. **B.** Design of frontal craniotomy and limited bandeau (so-called keystone approach—frontonasal osteotomy). **C.** Keystone osteotomy of frontonasal junction in order to access the transcranial component of the mass.

- The dermal sinus tract is resected from its dural connection following visualization.
- The NDSC, glioma, or redundant meningeal tissue is excised.
- At the site of the mass that is resected, a careful dural repair is performed by neurosurgery. Dural substitute is used as needed.

Bandeau/Frontal Bone Repair

- The keystone portion of the frontal bone is fixated back in place with resorbable hardware in infants and rigid hardware in older children.



TECH FIG 3 • View of the transcranial component of the mass after frontal craniotomy.

- Fixation of the frontal bone should not compress or strangle the pericranial flap.
- Sizeable full-thickness cranial defects such as large bur holes can be filled with cranial bone shavings/particulate.
- A subcutaneous, closed suction drain is placed and the scalp is closed.

Cranial Base Repair and Seal

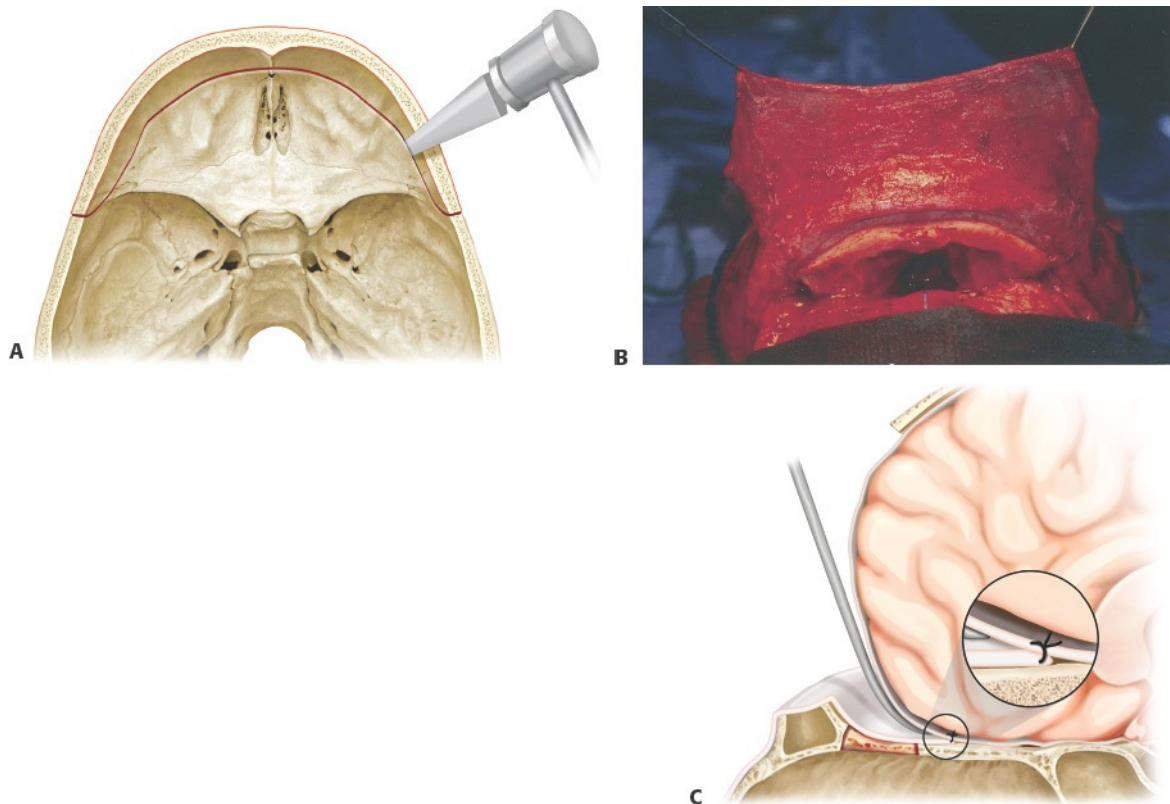
- If a bony defect is present in the cranial base, it should be treated with full or split calvarial bone graft (**TECH FIG 4A**). This bone is fashioned to the size and shape of the defect but not typically fixated.
- The pericranial flap harvested during scalp dissection (**TECH FIG 4B**) is then placed over the graft covering the cranial base.
- If possible, sutures are used to secure the flap. Fibrin glue is used to seal the edges of the flap (**TECH FIG 4C**).
- The pericranial flap acts to provide vascularized barrier both for the dural repair and the cranial base bone defect.

Completion

- The frontal sinus is not an issue in infants as the sinuses have not yet

developed.

- In patients with delayed presentation and treatment, the frontal sinuses should be cranialized and the frontonasal duct should be obliterated with cautery and bone graft.
- The nasal skin redundancy is evaluated and additional skin is removed if necessary. The nasal skin is closed.



TECH FIG 4 • Seal of the anterior cranial base after transcranial resection. **A.** Bone graft (either full- or split-thickness calvarium) is placed in the cranial base defect. **B.** A pericranial flap is planned preoperatively for coronal scalp flap dissection. **C.** The pericranial flap is placed over the bone graft, and fibrin tissue sealant is used along with sutures to ensure a watertight seal.

■ Medial Orbit Composite Unit Translocation

(MOCUT) Procedure

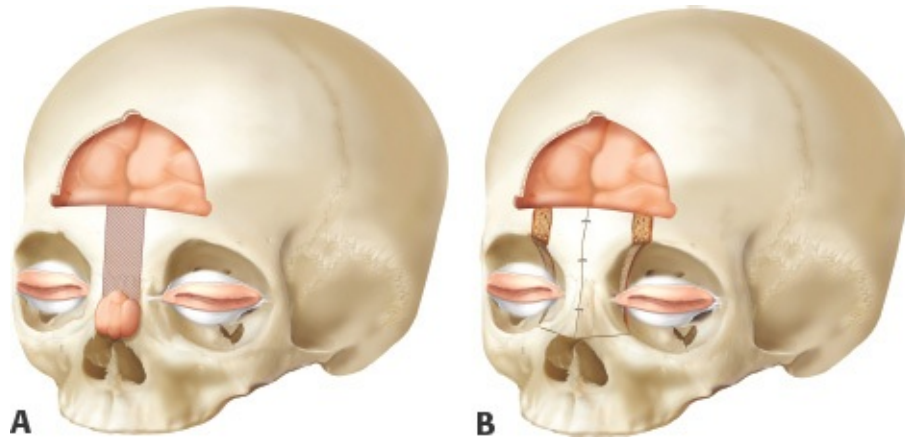
- This technique has been described and popularized by Boonvisut et al. for immediate hypertelorism repair in nasal encephalocele.⁹

Approach and Dissection

- The same coronal incision and bifrontal craniotomy as described for Resection of Transcranial NDSC above is utilized.
- The nose can be opened via either a vertical incision on the dorsum or through a conservatively designed vertical ellipse.
- Subperiosteal dissection is performed at the supraorbital bandeau into the orbits.
- Orbital dissection is limited to the medial aspects of each orbit between the supraorbital notches. Care is taken to keep the medial canthal tendon insertion intact.
- Careful subperiosteal dissection is used to ensure that the orbital and soft tissues are moved in concert in an uninterrupted fashion.
- The subperiosteal dissection is carried medially to the bone edges at the frontonasal defect.

Osteotomies, Resection, and Reconstruction

- Medial orbital wall is cut vertically from the craniotomy at the level of the supraorbital notch down to the inferior orbital rim (**TECH FIG 5A**).
- Via the nasal incision, a transverse osteotomy is performed from the piriform aperture to the inferior orbital rim to free the composite medial orbital unit.
- In the midline, bone will need to be removed from the medial orbital unit to establish the final interorbital distance.
 - This distance is planned preoperatively using a CT scan.
- Osteotomies are performed with a combination of conventional osteotomy, reciprocating saw, and ultrasonic scalpel.



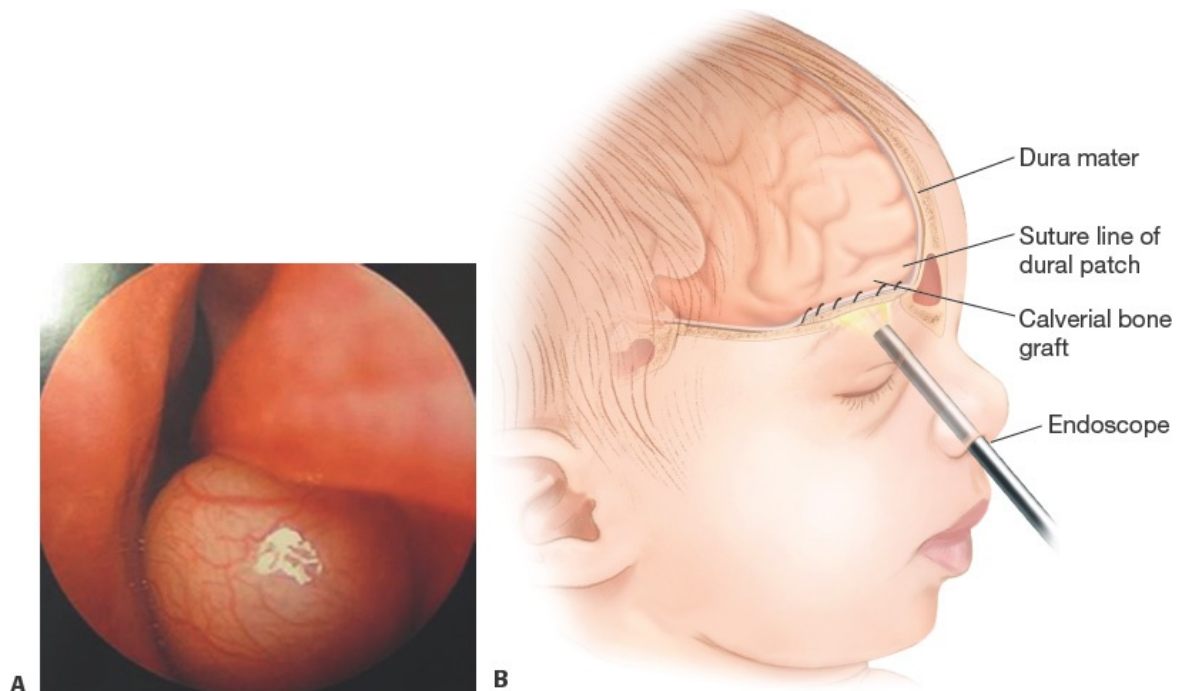
TECH FIG 5 • Encephalocele resection with transcranial approach and immediate hypertelorism correction. **A.** Bifrontal craniotomy is performed. Laterally vertical osteotomies are planned to descend from just medial to the infraorbital notch. A variable bony resection at the midline will be performed to allow medialization of the orbit and canthal units. The inferior horizontal osteotomy may be completed through the nasal incision. **B.** The medial orbit composite unit technique (MOCUT) can be seen here to immediately produce hypertelorism correction.

- Completion of the osteotomies mobilizes the orbital units allowing for improved exposure.
- The mass, typically an encephalocele with this approach, should be dissected free from its surroundings.
 - This is done via the nasal incision and the frontal craniotomy.
- Dural repair and cranial base/frontal sinus repair are as described above.
- The medial orbital units are joined at the midline with fixation (**TECH FIG 5B**).
 - This is typically done with a 30-gauge wire but may also be done using suture, permanent plates, or resorbable plates and screws.
- Transverse bony gaps at the supraorbital bandeau that have been created through orbital medialization should be treated with fixated interposition calvarial bone graft.

- Any disruption of the nasal cartilages to bone or of the nasofrontal junction should be repaired with suture.
- Redundant nasal skin should be conservatively resected. The nasal skin is closed.
- Some have argued for more complex nasal skin flaps. Our preference is for nasal skin revision at a second stage if necessary.

■ Endoscopic Excision of Intranasal Glioma

- The approach to intranasal gliomas also includes an external rhinoplasty approach and a lateral rhinotomy approach.¹⁰ These specific approaches will not be discussed here.
 - In general, this approach has been used by those who practice endoscopic surgery and skull base approaches.
 - Many have argued that with evidence of transcranial extension, a traditional craniotomy should be performed to separate the nasal-intracranial connection. Others have demonstrated that intranasal glioma with intracranial extension can be successfully excised endoscopically, thereby avoiding craniotomy.
- An angled endoscope is introduced intranasally to visualize the mass (**TECH FIG 6**).
- Electrocautery is used to incise the nasal mucosa along the mass.
- Retraction and blunt dissection define the mass.
- After defining the stalk, it is divided using electrocautery and the mass is removed.
- The base is examined for CSF leak. If necessary, it may be oversewn. Fibrin tissue sealant may also be used to ensure a seal.
- The nasal mucosa is closed with simple sutures.
- The affected nasal passage is packed. Nasal packing is removed in the early postoperative period.



TECH FIG 6 • Excision of intranasal mass. **A.** Endoscopic appearance of purely intranasal glioma. **B.** An endoscope may be used to visualize and aid excision of intranasal glioma. Endoscopic approaches to the cranial base are also well described.

PEARLS AND PITFALLS

Biopsy	■ Congenital nasal masses, particularly those occurring at or near the midline, should not be biopsied for diagnosis. Biopsy can lead to CSF leak and ascending/meningeal infection.
Radiologic evaluation	■ Congenital nasal masses should be evaluated radiographically. This often includes both a CT scan and MRI.
VP shunt	■ Decompression by neurosurgery in the setting of a large or growing encephalocele can allow surgery to be delayed until the patient is a better candidate for surgery.
Age at surgery	■ Timing of treatment, particularly with large lesions and encephaloceles, is a balance between the risk of

infection/meningitis/family stress and the safety of surgery/quality of bone for reconstruction. We recommend waiting until late infancy if there are no other time-sensitive factors.

Intracranial seal

- Transcranial approach requires careful reconstruction of the cranial base defect including bone grafting, pericranial flap, and fibrin glue seal.

POSTOPERATIVE CARE

- Pediatric ICU is mandatory with expected hospital stay of 5 to 7 days.
- Neurologic monitoring
- Routine labs for bleeding and infection
- Monitoring of nasal and drain output for CSF leak—the drain should be in place for at least 5 days.
- Close outpatient monitoring for the development of CSF leak, meningitis, and hydrocephalus
- Secondary nasal scar revision is often necessary.

OUTCOMES

- Complications
 - In these rare conditions, most case series are small.
 - Minor complications in any transcranial approach with nasal-intracranial communication should be expected to be moderate to high.
 - Catastrophic complications should be rare.
- Aesthetic outcome
 - Disruption of nasal growth and form is a high risk.
 - Revision of nasal scar/form and nasal reconstruction with rib graft should be expected.
 - Second hypertelorism correction may be necessary.

COMPLICATIONS

- CSF leak
- Meningitis
- Death
- Scar hypertrophy
- Residual hypertelorism
- Residual nasal deformity and skin excess
 - May require re-excision, local tissue rearrangement, onlay grafting of the

nasal dorsum, and formal rhinoplasty at maturity

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Section VI: Soft Tissue Masses

20 Surgery of Neurofibromatosis in the Pediatric Patient

CHAPTER

McKay McKinnon

DEFINITION

- Patients with cutaneous neurofibromatosis (NF), the most common of the myriad of phenotypic manifestations of the disease (and Von Recklinghausen's original case reports), can usually expect permanent relief of individual lesions by full-thickness excision. For those patients with so-called plexiform NF and/or malignant peripheral nerve sheath tumors (MPNST), the puzzlement of a permanent treatment (medical or surgical) has remained largely unsolved for most patients.
- For well over a century, the textbook recommendation for children with NF1 plexiform tumors has been to defer surgery until after puberty or until serious morbidity is evident. When surgery has been deemed necessary, it has most often been a superficial resection of the tumor, commonly referred to as "debulking." Subsequent recurrence of tumor has led to a default strategy of withholding surgery for pediatric patients, based upon fear of iatrogenic injury to normal structures, uncontrollable hemorrhage, and perceived inability to achieve permanent tumor removal.
- Over the past 30 years, the author has observed that radical resection of plexiform tumors in adults has resulted in permanent "nonrecurrence" of nearly all tumors, even those over 50 kg and some MPNST.¹ Despite a higher

propensity for active tumor growth in children and adolescents, it seemed logical to extend the concept of radical surgical resection to pediatric patients.

ANATOMY

■ Craniofacial

- Most facial and frontotemporal scalp tumors derive from sensory branches of cranial nerve V. The ophthalmic division of the trigeminal nerve (**FIG 1A**) includes some sensory nerves that are within the musculofascial cone (annulus of Zinn) of the orbit. This area presents special risks of injury to the optic nerve and the extraocular muscles and should be avoided.

- Orbital NF is often accompanied by a defect of the sphenoid greater wing, which may permit herniation of the temporal lobe into the orbit and subsequent orbital dystopia, pulsatile exophthalmos or enophthalmos, and pressure on the globe and optic nerve. Destruction of bone, ligaments, fascia, muscle, and skin may be present.
- Tumor confined to the optic nerve (optic glioma) deserves neurosurgical management.
- Motor nerves are not intrinsically involved with NF tumor.

- NF tumors of the mandible, parotid, ear, and temporal scalp develop largely from the mandibular division of the trigeminal nerve, including the auriculotemporal nerve.

- Tumors of the neck and posterior scalp derive from upper cervical sensory nerves (C1–C4), including the occipital nerves. Lower cervical nerves (C4–C8, sensory and motor) constitute most of the brachial plexus.

■ Trunk and extremity

- Plexiform NF can exist anywhere from the spinal cord to the sensory nerve terminus in the skin, bone, or viscera (**FIG 1B**).

- Plexiform tumors most commonly appear between the deep fascia and the skin but may involve and destroy skin, muscles, bones, joints, and visceral organs. Careful dissection proximal to the tumor mass (toward their CNS origin) often reveals the specific sensory nerve origin. Large truncal lesions over time can develop paraspinal hypervascularity, which resembles an arteriovenous malformation. Scoliosis is common with posterior trunk lesions, and limb hyperplasia is common with extremity lesions.

PATHOGENESIS

- NF is an autosomal dominant condition, which can be attributed to a defect on

chromosome 17, but mosaicism can also occur. The consequential lack of neurofibromin (a tumor inhibitor) permits growth of myelinated axonal tumors in any bodily location. Tumor types are cutaneous or plexiform. So-called plexiform tumors are solid tumors, which have an obligatory angiogenic influence, similar to other solid tumors. They express multiple angiogenic and neurogenic factors. Puberty, pregnancy, and childhood growth spurts can exacerbate their growth. Tumor vascularity increases proportionate to tumor growth. Transformation of benign NF tumors into MPNST can occur in plexiform tumors. This transformation may have a direct correlation to numerical tumor cell replication events.

- Tumor vessels in NF are pathologic arteries that reveal absent media and abnormally thin adventitia. Established tumors can exhibit vascular lakes and/or nests of abnormal vessels resembling a congenital vascular malformation.

NATURAL HISTORY

- Neurofibromas, once established as plexiform tumors, do not regress spontaneously. Their growth is unpredictable and nonregular, including possible onset throughout a patient's life of new lesions. Malignant transformation is more common in truncal/extremity lesions but is also unpredictable. Café au lait cutaneous spots do not necessarily signal plexiform tumors, although they themselves represent microscopic tumor. If present at birth, plexiform tumors may have already inflicted defective tissue development of the newborn.

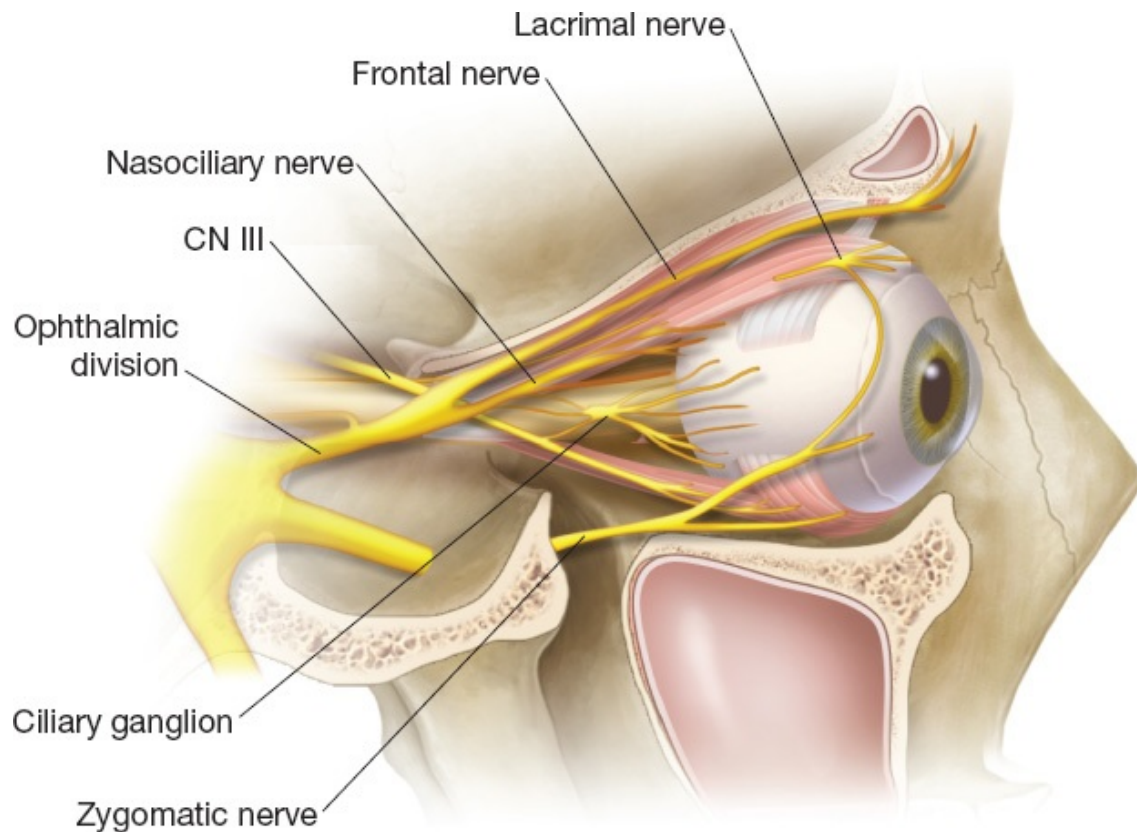


FIG 1 • Nerves of the orbit.

- Eventual destruction by tumor of adjacent skin, bone, and other tissue should be expected without intervention. Hyperplasia and/or fragility of bone occurs in extremity lesions. Craniofacial tumors can also produce osteoclastic or osteoblastic pathology, likely as a consequence of tumor growth rate. Tumors involving the sphenoid and orbit can cause progressive orbital dystopia, blepharoptosis, and blindness. Paraspinal tumors inflict progressive scoliosis on the growing patient.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The myriad presentations of NF tumors should not deter accurate diagnosis, even in infancy, by the observant neurologist or experienced surgeon. If doubt of the diagnosis exists, a biopsy should be performed with exception at least of the optic nerve.
- Physical findings are too numerous to justify an inclusive list, but palpable tumor, pain, and confirmatory imaging should precede surgical intervention in virtually all cases.

IMAGING

- Pediatric patients with suspicion of plexiform NF tumor should have an MRI study, preferably with and without contrast. MRI of the CNS is appropriate as an early screening measure for all NF patients, even those without known tumors. T2- and STIR-weighted images usually give the clearest depiction of NF tumor.
- MRI, especially with higher Tesla power, can frequently reveal the specific cranial or spinal nerve involved with tumor. This information (nerve mapping) should be sought out with the neuroradiologist.
- High-resolution CT scans should only be ordered when and if the patient with skeletal destruction or high risk of skeletal pathology is being evaluated preoperatively.

DIFFERENTIAL DIAGNOSIS

- NF tumors have been mistaken for vascular malformations, particularly by their hypervascular imaging on CT or MRI.
- Hyperpigmentation of NF lesions has been confused by the inexperienced physician with congenital nevus. A biopsy can readily produce the correct diagnosis.
- Most patients, even infants, with NF will present with at least three or more cutaneous lesions and/or café au lait lesions, axillary freckling, ocular Lisch nodules, or a subcutaneous plexiform mass.
- Congenital ptosis can usually be differentiated from NF-derived ptosis by detection of an orbital mass, presence of enophthalmos or exophthalmos, and by MRI findings. Rapid increase of ptosis may be associated with orbital malignancy such as rhabdomyosarcoma, for which immediate incisional or excisional biopsy is required.
- Diagnosis of MPNST or other orbital malignancies cannot be reliably made by symptoms, by imaging, or by clinical examination.

NONOPERATIVE MANAGEMENT

- This default management decision is historically common but deserves renewed challenge because it is controversial. Observation of growing NF tumors is patently nontherapeutic yet may be justified if surgery is high risk, the patient has significant comorbidity, or the tumor has not reached a level of irreversible morbidity to vital structures. The surgeon and his or her medical colleagues should be prepared to intervene to prevent irreversible morbidity,

even in young patients.

SURGICAL MANAGEMENT

- An accurate diagnosis is the sine qua non of surgical management. With plexiform NF this should include determination of the tumor nerve origin(s), the degree of vascularity, bony deformity, proximity to other vital anatomy, and degree of skin destruction. In the craniofacial tumors, accurate diagnosis also should determine presence of brain herniation into the orbit (or elsewhere), orbital dystopia, ptosis vs pseudoptosis, ophthalmic pathology, and airway and carotid/jugular risks.
- Because all NF1 tumors are caused by pathologic sensory nerves, either of brain or spinal cord origin,¹ if a total interruption of the responsible sensory nerve(s) can be achieved (eg, a Sunderland V injury), permanent nonregrowth of tumor may also be achieved.¹ Thus, surgical strategy should aim to:
 - Radically resect the plexiform tumor and identify and amputate the responsible sensory nerve(s) proximal to the tumor
 - Dissect and preserve any motor nerves in the tumor proximity
 - Undertake tumor resection even in the pediatric patient because progressive tumor growth over time equates to more complex surgery, higher risk of morbidity to normal adjacent structures and function, and possibly more risk of malignant transformation of previously benign tumors
- All techniques are subservient to the principles of reconstructive surgery. A knowledge of and adherence to principles permit the surgeon to methodically approach virtually any surgical problem to arrive at an organized plan. The reconstructive surgeon's "creed" has been summarized by Millard: "Know the ideal beautiful normal. Diagnose what is present, what is diseased, displaced, or distorted, and what is in excess. Then, guided by the normal in your mind's eye, utilize what you have to make what you want—and when possible go for even better than what would have been!"
- No clinical condition presents to the surgeon a more variable array of pathology than neurofibromatosis. The NF surgeon needs, therefore, to first make a strategy from application of principles. When the principles (such as making an accurate diagnosis, establishing priorities, making a plan and a backup plan, replacing lost tissue in kind, etc.) are applied, the surgical techniques will devolve naturally. The surgeon, much like his or her military counterpart, elucidates the goals and strategy of a military-type campaign before determining the specific technique(s) required.

Preoperative Planning

- Pertinent consultations with other specialists should be completed well prior to surgery, if feasible.
- Adequate warning to blood bank and ICU is made.

Positioning

- Most craniofacial procedures are done in the supine or lateral position with a standard OR table with a gel headrest.
- Trunk and extremity procedures are done in standard positions according to tumor site(s).

Approach

- Orbital tumors are approached via coronal, superior lid crease, and transconjunctival incisions as needed. Inferior orbital nerve (maxillary) tumors are accessed via a lower eyelid incision as in orbital floor exploration or via a nasojugal incision.
 - The surgeon should anticipate repeat procedures (ie, a subciliary incision is always a higher risk for ectropion).
- Posterior trunk tumors should be accessed via incisions that can resect not only the palpable tumor but also any feeding paraspinal sensory nerves (**FIG 2**).

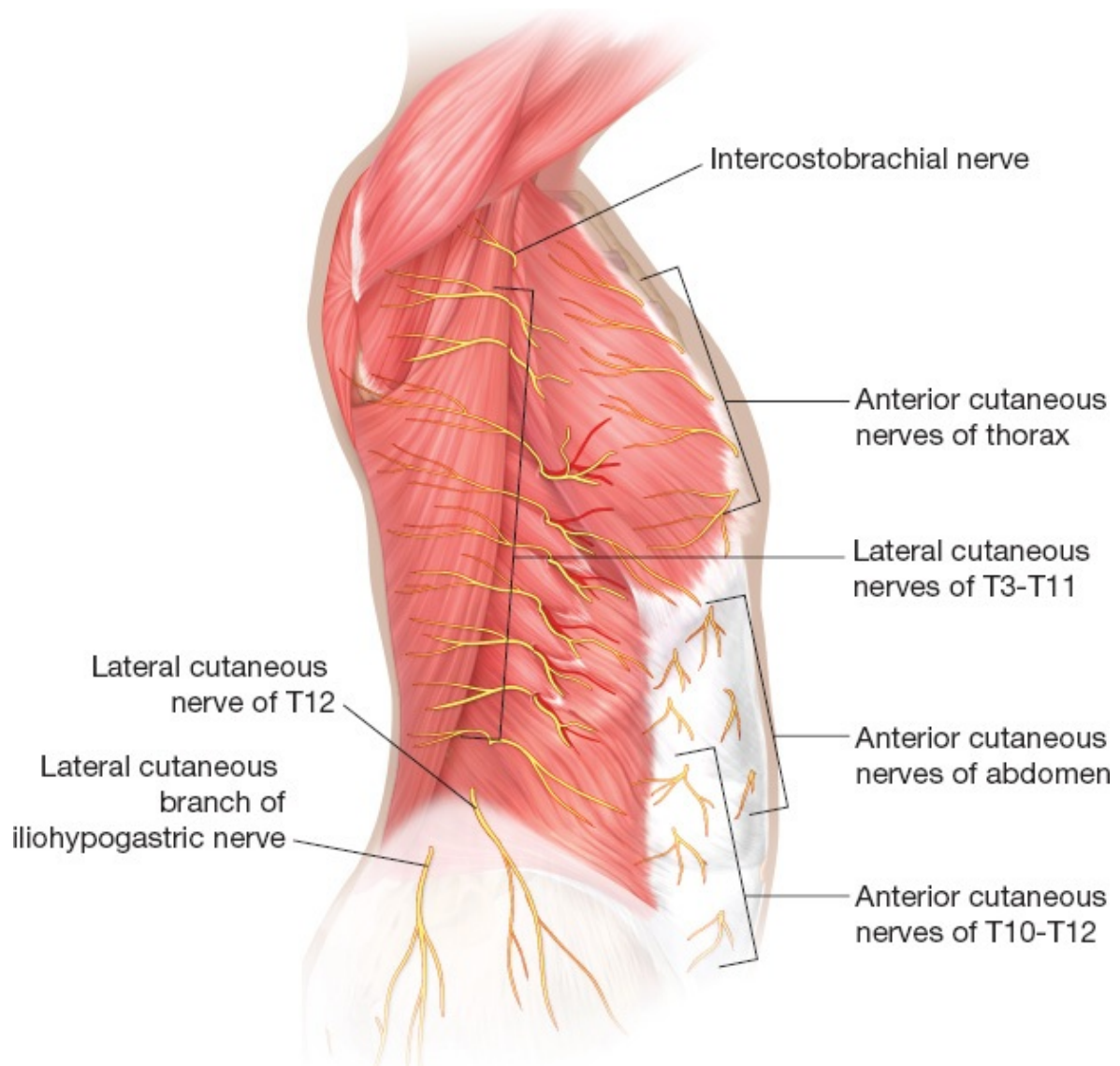


FIG 2 • Spinal sensory nerves of the trunk.

TECHNIQUES

■ General Principles

- The first priority of surgery in the child with NF is resection of tumor and reconstruction of bone. Large tumor resections can be aided by cautery devices such as LigaSure, but the surgeon should be facile in vascular surgical techniques.

- Autogenous bone reconstruction is superior in virtually all cases to alloplastic reconstruction in NF, especially in the growing child.
- Because resection of cranial nerve V tumors into the cavernous sinus is dangerous (and some tumor will necessarily remain there), reconstruction of the sphenoid defect should be undertaken with a combination of bone and plate/mesh to ensure permanence of brain-orbit separation (even in the enucleated patient). Bone should face the orbit to allow possible attachment of the levator muscle origin.
- Early ptosis correction is important to avoid amblyopia, but definitive ptosis correction should be performed when the child can tolerate a nongeneral anesthetic for refinement of the correction by patient participation and tumor is not significantly present.
- When approaching a large plexiform tumor, the surgeon should begin dissection in normal tissue and proceed to identify the plane at the tumor margin. Motor nerves that are within the tumor field should be identified by direct nerve stimulation.

■ Illustrative Cases

Case 1: Inferior Orbital Nerve Tumor

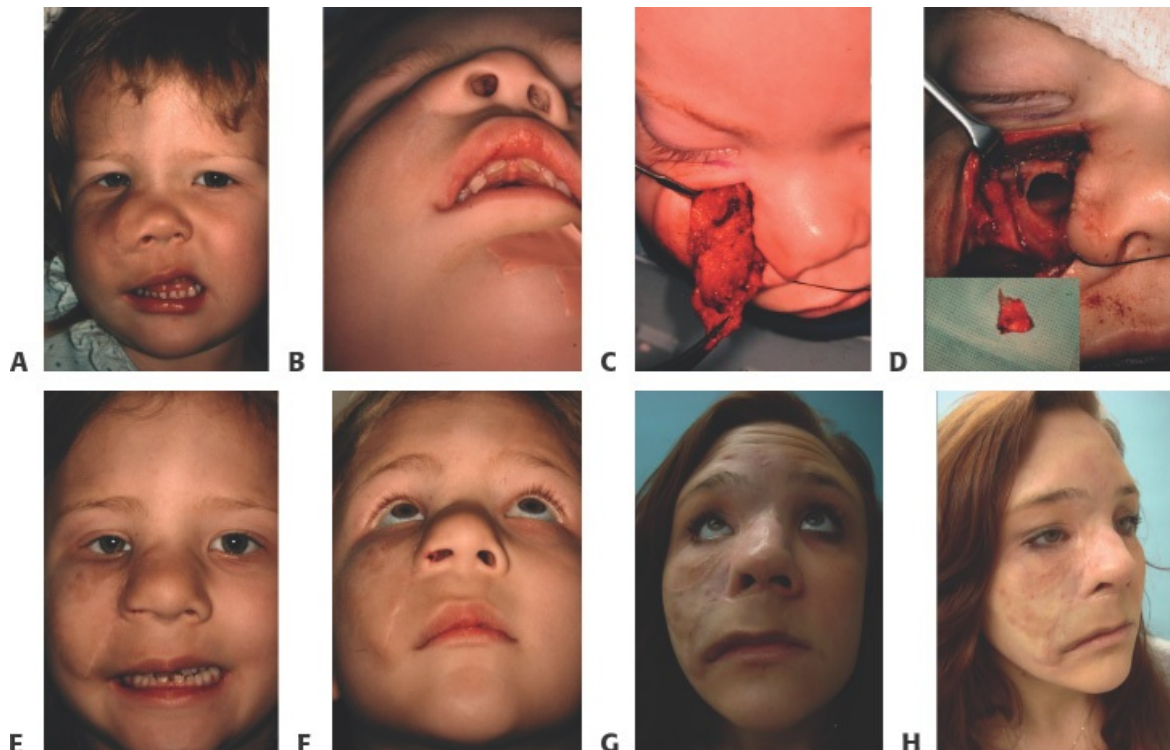
- A 4-year-old girl demonstrated a rapid regrowth of a right inferior orbital nerve NF tumor 6 months following partial resection at an outside institution. The tumor was creating a vertical orbital dystopia (**TECH FIG 1A,B**).
- A resection of the inferior orbital nerve tumor from the cheek to the posterior orbit was performed via the old nasojugal vertical scar (**TECH FIG 1C,D**).
 - Alternative approaches in an unoperated patient would be a transverse lower lid incision and a separate nasolabial fold incision, or even an intraoral incision, depending on extent of tumor.
- Following resection, the marginotomy was repaired with a stainless steel wire in a corrected (inferior) reposition.
- Over the subsequent 20 years, the patient presented multiple other tumors of alternate branches of the trigeminal nerve, but not of the inferior orbital (maxillary) nerve (**TECH FIG 1E,F**).

Case 2: Hypogastric Plexiform Tumor

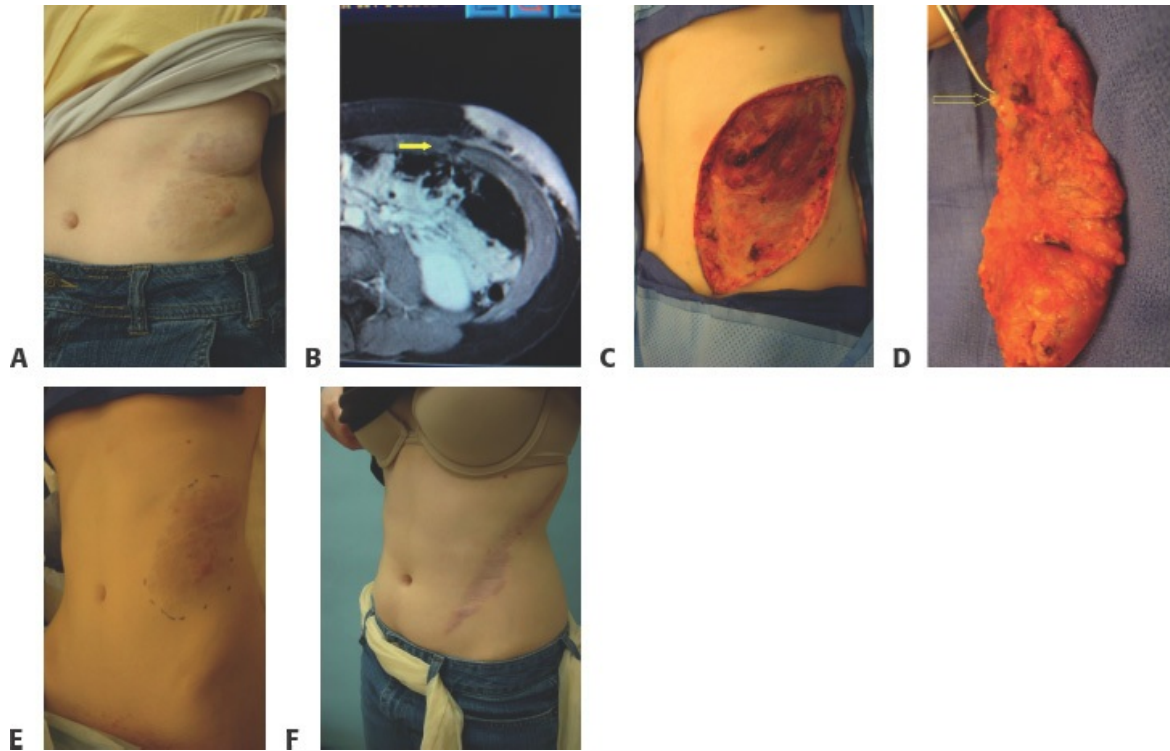
- A teenage girl presented a painful left hypogastric plexiform tumor

recurrence 2 years after an attempted resection at an outside hospital (**TECH FIG 2A**).

- MRI revealed the tumor extending from the skin to the deep abdominal fascia (**TECH FIG 2B**).
- Resection via an extension of the old scar included dissection and resection of the pathologic hypogastric nerve lying deep to the external oblique muscle (**TECH FIG 2C–E**).
- There had been no recurrence in 10 years of follow-up.



TECH FIG 1 • **A,B.** A 4-year-old girl with right inferior orbital nerve NF tumor 6 months after partial resection. **C,D.** A marginal osteotomy (a la Tessier) of the orbital rim allowed visualization and tumor resection in the posterior orbit to the cranial base. **E–H.** Postoperative photos.



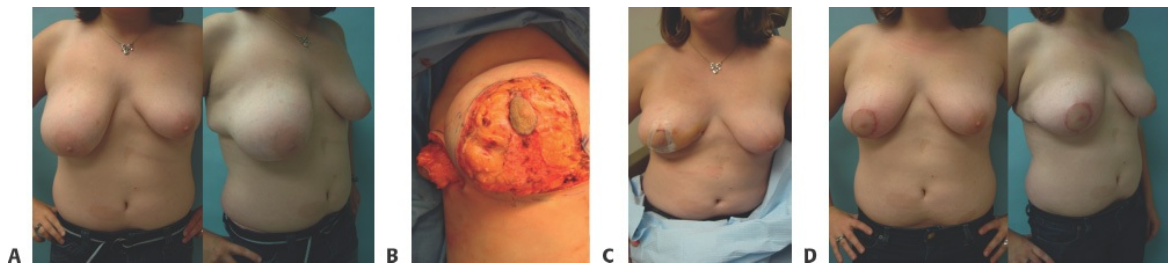
TECH FIG 2 • A. Teenaged girl with left hypogastric plexiform tumor recurrence 2 years after attempted resection. **B.** The tumor extended from the skin to the deep abdominal fascia, as shown on MRI. **C,D.** Dissection and resection of the pathologic hypogastric nerve lying deep to the external oblique muscle. **E,F.** The result 1 year after direct wound closure.

Case 3: Breast and Chest Wall Plexiform Neurofibromatosis

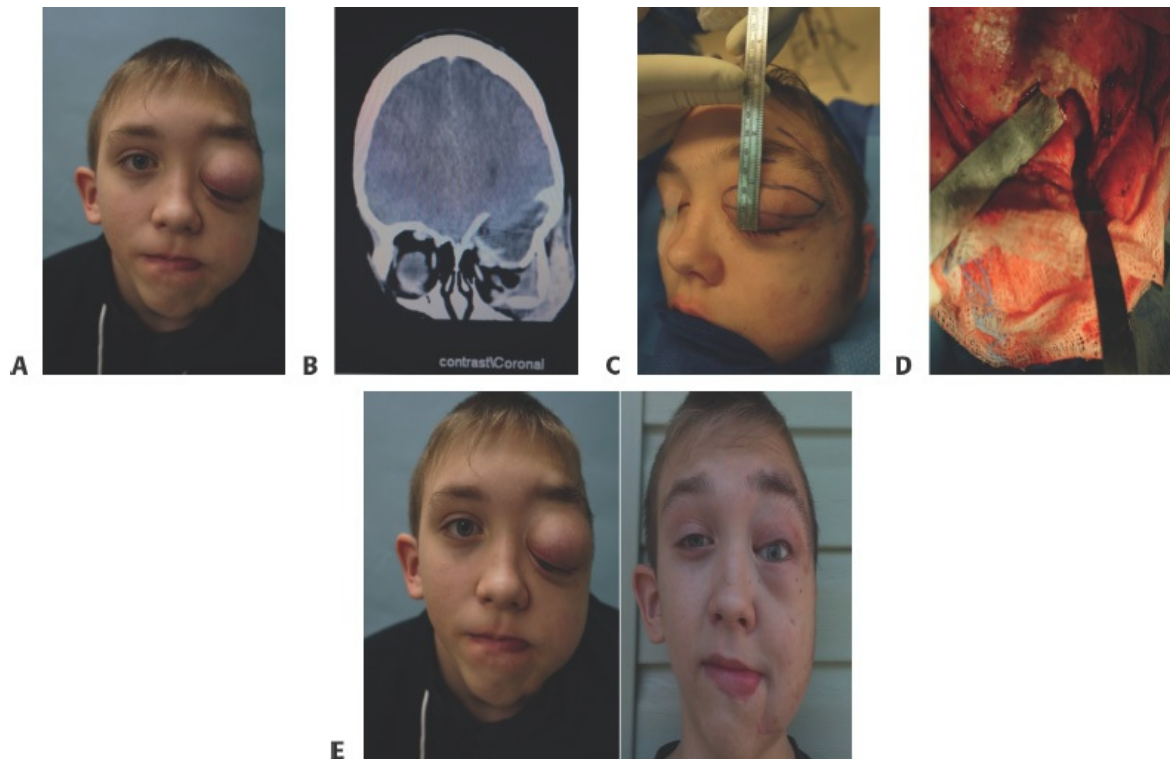
- A 15-year-old girl presented with right breast and lateral chest wall plexiform NF (**TECH FIG 3A**).
- At surgery, a simultaneous resection of a right intercostal tumor and a right breast reduction/tumor resection were performed (**TECH FIG 3B,C**).
- The intercostal nerve proximal to the tumor mass was located and amputated at the rib.
- No recurrence had been observed in over 8 years of follow-up (**TECH FIG 3D**).

Case 4: Left Orbital and Mental Nerve Neurofibromatosis 1

- A 12-year-old boy presented with left orbital and mental nerve plexiform NF1 (**TECH FIG 4A,B**), severe ptosis, and pulsatile exophthalmos.
- Through a coronal, left upper eyelid, and left nasolabial incisions (**TECH FIG 4C**), the tumor was radically resected.
- Via the coronal approach (without osteotomy), the temporal lobe dura was located inside the posterior orbit and dissected from the periorbitum (**TECH FIG 4D**) and then the brain/dura was repositioned into the cranial cavity and separated from the orbit by a cranial bone graft/titanium mesh reconstruction.
- The graft/implant was placed from the orbit into the cranial cavity and held in position by autoretention.
- In the same procedure, a cranial bone graft to the orbital floor and a moderate reduction of eyelid skin excess was performed.
- Vision was preserved (**TECH FIG 4E**). The patient will need future additional floor elevation and definitive ptosis correction.



TECH FIG 3 • A. A 15-year-old girl with right breast and lateral chest wall plexiform NF. Simultaneous with resection of a right intercostal tumor (**B**), a right breast reduction/tumor resection was performed (**C**). **D.** Appearance at 8 years postoperatively.



TECH FIG 4 • A. A 12-year-old boy with left orbital and mental nerve plexiform NF1, severe ptosis, and pulsatile exophthalmos. **B.** MRI demonstrated a plexiform tumor of the superior orbit and mental nerve, a large defect of the sphenoid greater wing, and prolapse of the temporal lobe into the orbit. **C.** Markings for coronal, left upper eyelid, and left nasolabial incisions. **D.** Dissection of the temporal lobe dura inside the posterior orbit from the periorbitum via the coronal approach. **E.** Postoperative appearance.

PEARLS AND PITFALLS

Diagnosis

- The most common pitfall in NF surgery is inaccurate diagnosis.
- When recommending a tissue biopsy for definitive diagnosis, avoid

	biopsy within a highly vascular region of NF tumor or adjacent to the optic nerve. ■ Tumor heterogeneity on MRI may indicate a benign tumor adjacent to a malignant tumor.
Surgical strategy	■ The NF surgeon should avoid underestimation of tumor extent and potential hemorrhage, underdissection with nerve stimulation of motor nerves along the path of the tumor, and underestimation of a surgical strategy that anticipates tumor recurrence in young patients. ■ Lifetime surveillance by the surgeon should be assumed because the medical specialists are ill prepared to have a surgical perspective of NF. ■ The occasional NF surgeon will inevitably experience high morbidity and low patient satisfaction.
Technique	■ The surgical term “debulking” in NF1 represents a common pitfall of partial, superficial resection. Rapid recurrence of tumor normally ensues. Debulking of intraorbital tumors may, however, be justified to save vision. ■ It should be clear to the NF surgeon that vision is also at risk due to possible glaucoma, hemorrhage, tumor/brain pressure on the optic nerve, glioma of the optic nerve, severe orbital dystopia, severe ptosis (amblyopia), and palpebral incompetence.
Other specialists	■ Orthopedic surgeons, neurosurgeons, and ophthalmologists frequently treat pediatric patients with NF. ■ If limb hypertrophy or spinal scoliosis is present in conjunction with a tumor that is resectable, the plastic NF surgeon should champion primary tumor resection prior to orthopedic attempts to reduce epiphyseal growth, reconstruct joints, to correct scoliosis, or even to amputate parts. This should be intuitive as correct general surgical principle, not a pearl of wisdom. Likewise, strabismus and/or ptosis surgery should not precede tumor resection and orbital bone reconstruction.

POSTOPERATIVE CARE

- The NF surgeon should use drains freely due to the vascularity and vessel pathology of NF tumors, following extensive resections, which predispose to seroma formation.
- Suction drainage may be hazardous near the dura and may exacerbate hemorrhage near fragile-walled, residual tumor vessels.
- Since many NF surgeries overlap into other surgical specialties, the plastic NF

surgeon should include those specialists in the postoperative care but remain the captain of care and assume ultimate responsibility.

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CHAPTER Vascular Anomalies

Arin K. Greene and Jeremy A. Goss

DEFINITION

- Vascular anomalies are a group of lesions that can affect any part of the vasculature.
- Lesions are divided into tumors (with dividing endothelium) and malformations (structural anomalies with minimal endothelial turnover).¹
- Eight types of vascular anomalies (four tumors and four malformations) constitute approximately 95% of lesions.

ANATOMY

- Vascular anomalies most commonly involve the integument (although they can affect any anatomical structure).
- The most common morbidity is lowered self-esteem because of a deformity.
- Lesions involving the head and neck are more likely to be problematic.

NATURAL HISTORY

- The somatic mutations responsible for most vascular anomalies recently have been identified.
- Some vascular tumors improve over time (infantile hemangioma, rapidly involuting congenital hemangioma, kaposiform hemangioendothelioma).²
- Vascular malformations slowly worsen, particularly during adolescence.
- Following treatment of vascular malformations, recurrence is common and patients often require repeated procedures.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Ninety percent of vascular anomalies can be diagnosed by history and physical

examination.

- Before considering management, the type of vascular anomaly must be identified because lesions have different natural histories and treatments.³
- The most common vascular anomalies encountered in clinical practice are (in order of frequency) pyogenic granuloma, infantile hemangioma, and capillary malformation.
- A handheld Doppler can determine whether the lesion has fast flow, which aids the diagnosis.
- Lesions with fast flow include infantile hemangioma, congenital hemangioma, kaposiform hemangioendothelioma, and arteriovenous malformation. Slow-flow anomalies are capillary malformation, lymphatic malformation, and venous malformation.

IMAGING

- Less than 10% of patients require imaging to diagnose their vascular anomaly.
- If the diagnosis is unclear by history and physical examination, ultrasound is the first-line imaging study because it is easy to perform and does not require sedation in children.
- If the diagnosis remains uncertain after ultrasonography, then MRI with contrast is obtained.
- Imaging is not required prior to resection of hemangiomas, pyogenic granulomas, or capillary malformations.
- Before operative intervention for a venous malformation, lymphatic malformation, or arteriovenous malformation, MRI typically is obtained to determine the extent of disease.

DIFFERENTIAL DIAGNOSIS

- Fibrosarcoma
- Neurofibroma
- Pilomatixoma
- Teratoma

NONOPERATIVE MANAGEMENT

- Nonoperative intervention is the mainstay of treatment for vascular anomalies; lesions are benign and often can be observed.
- Less than 10% of infantile hemangiomas require treatment. Problematic lesions during the proliferative phase can be managed with topical timolol,

corticosteroid injection, prednisone, propranolol, or rarely, resection.

- Kaposiform hemangioendothelioma is treated with vincristine or sirolimus.
- First-line intervention for problematic vascular malformations typically is nonsurgical: capillary malformation (pulsed-dye laser), venous malformation (sclerotherapy), lymphatic malformation (sclerotherapy), arteriovenous malformation (embolization).⁴⁻⁷

SURGICAL MANAGEMENT

- Operative treatment of vascular anomalies generally is performed for symptomatic patients who are not candidates or have failed nonoperative interventions.
- Residual infantile or congenital hemangiomas causing a deformity can only be improved with resection (or pulsed-dye laser for telangiectasias).
- The primary treatment of pyogenic granuloma is full-thickness skin excision or cautery (curettage, laser, and cryotherapy have a recurrence rate as high as 50%).
- Capillary malformation can cause overgrowth of tissues beneath the stain, which can be improved by resection.
- Operative intervention for venous malformation is reserved for small lesions that may be removed for cure or for a residual deformity following sclerotherapy.
- Macrocystic lymphatic malformation may have redundant skin following sclerotherapy that can be resected. Microcystic lesions are not amenable to sclerotherapy, and thus, excision often is first-line treatment.
- Arteriovenous malformations generally are removed if they remain symptomatic following embolization.

Preoperative Planning

- A critical principle is that vascular anomalies are benign and thus do not require radical resection; the scar and reconstruction should not cause a worse deformity than the appearance of the lesion.
- Vascular anomalies typically are diffuse and involve multiple tissue planes; consequently, most resections are subtotal.
- The goal of operative management is to improve the patient's symptoms by removing enough of the lesion to reduce pain, bleeding, and/or ulceration and/or improve appearance.

- Symptomatic infantile hemangiomas are best excised between 3 and 4 years of age after they have completed involution.
- If possible, resection should be postponed until the child is at least 6 months of age to reduce the anesthetic risk.
- Consideration should be given to improving deformities before 4 years of age to minimize impact on self-esteem.
- Venous, lymphatic, and arteriovenous malformations usually are removed after they have been treated with sclerotherapy or embolization; these interventions reduce the size of the lesion, decrease bleeding, create fibrosis, and facilitate the operation.

Positioning

- The table is turned 90 degrees during resection of head/neck lesions.
- To limit blood loss, the head of the bed is elevated for facial vascular anomalies.

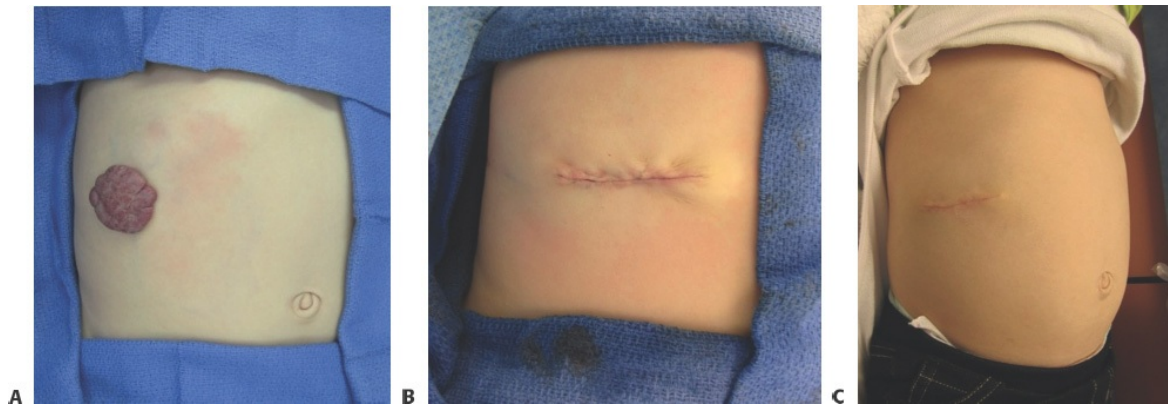
Approach

- Intraoperative antibiotics are not administered except when resecting large lymphatic malformations because they are prone to infection.
- After marking the extent of the resection, bupivacaine with epinephrine is infused throughout the operative site to reduce blood loss and pain.
- Markings are tattooed for lesions located on the vermillion or mucosa.
- To reduce blood loss, cold epinephrine-soaked sponges can be applied to the operative field; clips may be applied to the skin edges to decrease bleeding.
- After making the incision, hemostasis should be obtained prior to proceeding with further excision to avoid significant blood loss.
- Margins are not required; the least amount of tissue as possible should be removed to achieve the operative aims.
- A pressure dressing usually is applied to minimize the risk of postoperative hemorrhage.

TECHNIQUES

■ Lenticular Excision and Linear Closure

- Most vascular anomalies act as a tissue expander, and thus, adequate skin is available to close the wound (**TECH FIG 1**).
- The majority of resections are subtotal, and thus, missing integument is rare.
- Skin grafts or local/regional flaps rarely are necessary to reconstruct an area following extirpation.
- Incisions are designed to be as inconspicuous as possible (eg, relaxed skin tension lines, hairline, etc.).
- Vascular anomalies often cause local ischemia because of insufficient oxygen delivery; consequently, interrupted rather than continuous sutures are preferred for closure.
- After resecting a facial lesion in children who are less able to tolerate suture removal, 7-0 chromic followed by cyanoacrylate glue and tape can be used.



TECH FIG 1 • A 3-year-old with an involuted infantile hemangioma managed with lenticular excision and linear closure. **A.** Preoperative appearance. **B.** Following resection. **C.** Early postoperative view.

■ Circular Excision and Purse-String Closure

- This technique is useful for round lesions to limit the length of the scar, which would be 2 to 3 times the diameter of the lesion if it was excised lenticularly (**TECH FIG 2**).^{8,9}
- Circular excision is most commonly performed for infantile hemangiomas after they have involuted, but can be used for any round skin lesion.
- Almost all procedures are conducted on the face where it is important to

limit the length of the scar; round lesions involving the trunk or extremity usually undergo lenticular excision because the linear scar is concealed and appears favorable in a relaxed skin tension line.

- A contraindication to circular excision is the scalp because there is minimal tissue laxity, a circular scar can cause visible alopecia, and it is not critical to limit the length of a scar in the scalp because it is camouflaged by hair.
- When closing the circular excision, it is important to undermine the skin edges to reduce tension; I usually prefer a Vicryl purse-string suture. After the purse-string closure, I approximate the epidermis/dermis with interrupted chromic or nylon suture (depending on the age of the patient) followed by cyanoacrylate glue and tape.
- Disadvantages of this technique are that there is an increased risk of wound dehiscence compared to linear closure and a second stage may be required to convert the circular skin into a line.

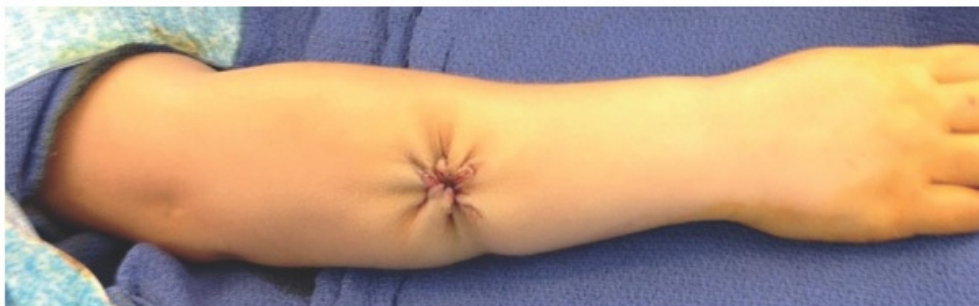
A



B



C



D



E



TECH FIG 2 • A 3-year-old with an involuted infantile hemangioma of the arm. The lesion was managed with circular excision and purse-string closure to limit the length of the scar in a visible location on the dorsum of the extremity. If the lesion was removed as an ellipse, the scar would be at least twice the diameter of the lesion. **A.** Preoperative view. **B.** Following circular resection. **C.** Purse-string closure. **D.** Appearance prior to second stage conversion of the round scar and residual telangiectasias into a line. **E.** Linear scar 6 weeks postoperatively approximates the diameter of the hemangioma that was removed.

- Approximately 50% of patients are satisfied with the round scar and do not wish to have a second procedure (the circular scar can look like an acne or chickenpox scar).
- If the circular scar is converted to a line during a second stage, its length will approximate the diameter of the original lesion.
- I wait 6 to 12 months after the circular excision before considering a second stage to convert it into a line.

■ Transverse Mucosal Resection and Linear Closure

Video p8-c021

- Vascular anomalies involving the lip often cause overgrowth and a deformity.
- Unlike malignant labial lesions, subtotal resection of benign vascular anomalies can be performed to improve the patient's appearance.
- This technique avoids the placement of a scar on the cutaneous lip (**TECH FIG 3**).
- An elliptical excision is designed along the keratinized and nonkeratinized vermillion; the markings are tattooed prior to injection of local anesthetic.
- Diseased vermillion, mucosa, submucosa, and a portion of orbicularis muscle are removed.
- The incision is closed with interrupted Vicryl and chromic suture.
- The patient is maintained on a full-liquid diet for 2 weeks.
- If the lesion regrows, it can be debulked again using the same incision.

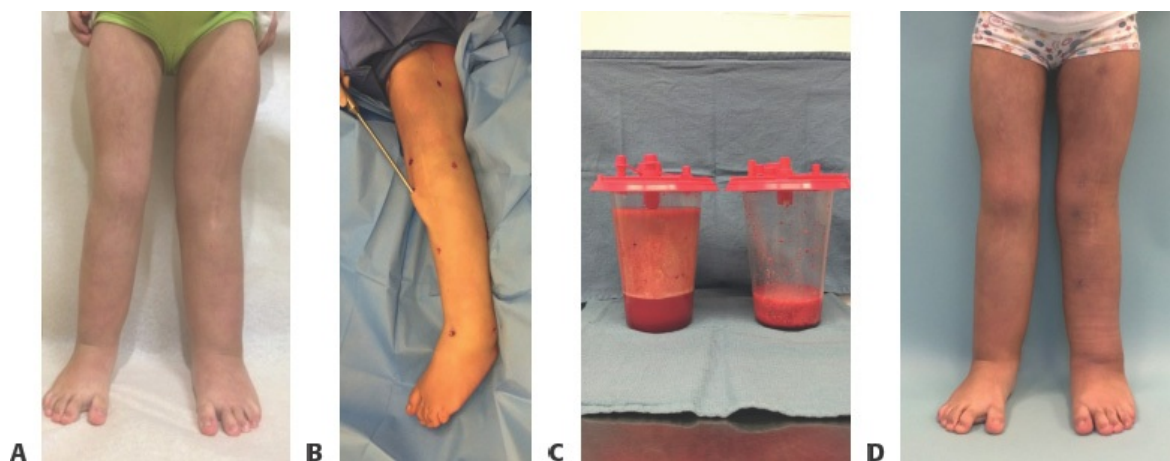


TECH FIG 3 • Transverse mucosal resection of an involuted infantile hemangioma of the lip. **A.**

Appearance of the lesion at 3 years of age. **B.** Markings for excision. **C.** Suture line following resection. **D.** Postoperative appearance.

■ Suction-Assisted Lipectomy

- Several types of vascular anomalies are amenable to suction-assisted removal when they are located primarily in the subcutaneous plane: infantile hemangioma, capillary malformation, lymphatic malformation, and other lesions that have a significant adipose component (**TECH FIG 4**).¹⁰
- This technique allows the removal of diseased tissue without long incisions, raising skin flaps, and “open” excision, which has increased morbidity and recovery compared to liposuction.
- Stab incisions are placed in nonconspicuous areas and tumescent solution is infused (1 mL of epinephrine 1:1000, 1000 mL normal saline, 50 cc 1% lidocaine) not to exceed 35 mg/kg of lidocaine.
- Cannulas of 3 mm typically are used for the face, 4 mm for the upper extremity, and 5 mm for the trunk or lower extremity.
- The aspirate is one-half to equal the amount of tumescent that was infused.
- I usually do not use a tourniquet for extremity lesions.
- A pressure dressing is applied, and the incisions are closed loosely to allow drainage.



TECH FIG 4 • A 10-year-old female with a capillary malformation and overgrowth of her left lower

extremity managed with suction-assisted lipectomy. **A.** Preoperative appearance. **B.** Intraoperative view. **C.** Lipoaspirate. **D.** Reduced circumference of her leg postoperatively.

PEARLS AND PITFALLS

Diagnosis	■ Vascular anomalies are commonly misdiagnosed. ■ Ensure accurate diagnosis prior to operative intervention to prevent erroneous treatment.
Nonoperative management	■ First-line treatment of vascular anomalies often is not operative intervention.
Operative indications	■ Resection of vascular anomalies is indicated for small lesions or those that have failed or are not candidates for other treatments.
Hemostasis	■ Despite being vascular, significant intraoperative hemorrhage rarely occurs. ■ Blood loss can be reduced using epinephrine, elevation, cold saline gauze, cutaneous clips, and careful hemostasis with cautery.
Operative technique	■ Complete excision is not required. ■ Subtotal resection to improve symptoms typically is the goal of operative intervention. ■ Most lesions outside of the face are excised using lenticular excision and linear closure. ■ Round lesions on the face often are best removed using circular excision and purse-string closure.

POSTOPERATIVE CARE

- Individuals who have had significant resections of the head/neck spend 24 to 48 hours in the hospital and are given Decadron to reduce swelling.
- Generally, patients may shower 2 days postoperatively and the occlusive dressing and underlying Steri-Strips are allowed to “fall off.”
- Children are managed with dissolvable sutures whenever possible.
- Individuals are examined 2 to 3 weeks postoperatively and 6 to 12 months

later if a second stage is being considered.

- Incisions are reinforced with Steri-Strips and are protected from the sun for 1 year.

OUTCOMES

- Patients and their families are counseled that the area involving the vascular anomaly cannot be made to look exactly like the anatomy without the lesion.
- The best outcomes typically are obtained by improving the area of deformity with the simplest approach rather than radical resection and reconstruction.
- The most favorable results are by surgeons who have experience managing vascular anomalies.

COMPLICATIONS

- Operative management of vascular anomalies has a higher risk of perioperative hemorrhage compared to resection of other types of lesions.
- Because the tissues usually are ischemic, suture line dehiscence is more likely than removal of nonvascular lesions; interrupted sutures that are not removed too early can reduce this risk.
- Intraoperative blood loss can predispose the patient to iatrogenic injury of important structures.
- Circular excision and purse-string closure is more likely to have dehiscence than lenticular resection and linear closure.

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Section VII: Pediatric Burns and Wounds

22 Functional Burn CHAPTER Reconstruction

David A. Billmire and Kim A. Bjorklund

DEFINITION

- The hallmark of burn injury in children is burn scar and burn scar contracture.
- The tendency toward hypertrophic scarring in children is a major challenge.
- Hypertrophic scars tend to develop in wounds that require greater than 3 weeks to close.
- These scars are raised, red, tight, hard, and often itchy.
- Hypertrophic scarring after burns is common and creates a wide range of cosmetic and functional problems.¹
- Contractures (inability to perform full range of motion) result from factors such as limb positioning, duration of immobilization, and muscle, soft tissue, and bony pathology.²
- Scars result in restriction in movement, particularly when they cross a joint, and increase the likelihood of contracture development.
- A similar burn injury in an adult that requires only initial resurfacing of the wound may require repeated releases and other procedures during subsequent growth and development of a child.
- Growth can be affected with restriction, distortion, and, in some cases, elongation.
- Heterotopic ossification (HO) resulting from ectopic bone formation in the soft tissue around joints can significantly affect extremity motion and function.

- Functional issues are frequently coupled with aesthetic concerns regarding loss of structures, obliteration, and distortion of normal anatomy.

ANATOMY

- Major problems tend to occur across joints and sites of active movement.
- The shoulder, elbow, and hand are most commonly affected by contractures.²

PATHOGENESIS

- In normal acute wound healing, myofibroblasts provide collagen and fibronectin deposition and aid in wound contraction over approximately 7 to 10 days.³
- However, the presence of myofibroblasts following a burn injury can result in excessive extracellular matrix deposition leading to a pathologic contracture and hypertrophic scarring.³
- Although in adults scars typically mature within 12 months, in children, the scarring diathesis may take years to resolve.

NATURAL HISTORY

- The natural history of a burn wound is to heal with re-epithelialization in superficial partial-thickness burns within 10 to 14 days.
- Deep partial-thickness or full-thickness burns heal by combination of contracture and re-epithelialization and are unlikely to heal within 14 days.
- Accordingly, burn wounds that are unlikely to re-epithelialize by 2 weeks should be treated with early operative intervention for excision and split-thickness skin grafting (STSG).
- Sheet grafts should be used in critical areas such as the face and hands.
- Less cosmetically sensitive areas can be covered by mesh graft techniques.
- We have found early sheet grafting of burn wounds (where adequate donor sites allow) to dramatically reduce the need and extent of subsequent reconstruction.
- Wound coverage is followed by an aggressive rehabilitation program with appropriate splinting and positioning in the immediate postoperative period, followed by ongoing physiotherapy, splinting, and the use of pressure garments.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Examination should focus special attention on critical areas, beginning with

the airway (neck) and eyes.

- A history of previous airway problems such as inhalation injury and need for tracheostomy should be noted.
- The presence of dry eye symptoms can be subtle in children, and coverage of the globe needs to be ascertained.
- Major joints and hands should be examined closely for restriction of growth and movement.
- Range of motion and functional limitations from scar contractures or HO should be carefully documented.
- In females, the breast buds and/or breasts should be examined to evaluate need for release or reconstruction.
- A systematic anatomic approach to catalogue affected structures is important. Complete or partial loss of limbs, digits, eyes, ears, nose, breast buds/breasts, genitalia, skull, and hair-bearing scalp should be noted.
- Previous donor sites and uninjured skin should be evaluated for future reconstructive efforts.
- Putting all of this together allows one to plan and sequence the reconstructive effort.

IMAGING AND DIAGNOSTIC TESTS

- X-rays should be obtained for significant hand burns.
- Most major joints usually do not require imaging unless the burn wound extended into the joint.
- Joints with functional limitations may benefit from x-rays to look for HO.
- Facial burns (especially those requiring face masks in a growing child) may benefit from monitoring with serial cephalograms to track facial growth and change.

NONOPERATIVE MANAGEMENT

- Nonoperative management begins in the acute phase of the burn injury.
- Many of the secondary problems in pediatric burn injuries can be avoided or lessened by the initial wound management.
- The use of sheet grafting in sensitive areas such as the head and neck and hands can dramatically reduce the need for subsequent reconstruction.
- A rehabilitation program using splinting, stretching exercises, and pressure garments can be effective in modifying the maturing burn wound and scar.

SURGICAL MANAGEMENT

- Secondary burn reconstruction ideally begins when the burn wound matures.
- Burn maturation is a lengthy process that is unpredictable and may take years in children.
- Immature burn scars are hyperemic, red, and raised and should become softer, pale, and flatter as they mature.
- While the scar is maturing, nonoperative methods previously described above should be employed.
- Certain problem areas require early intervention with the knowledge that they may need to be treated multiple times.

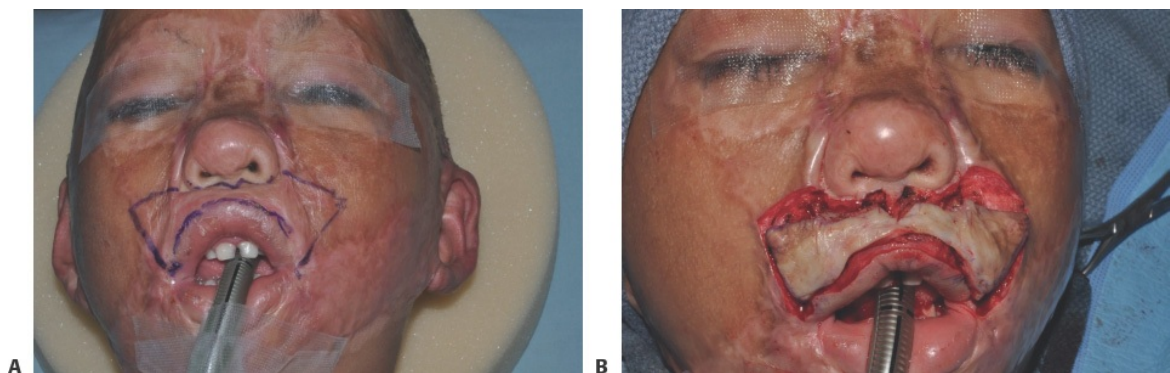
TECHNIQUES

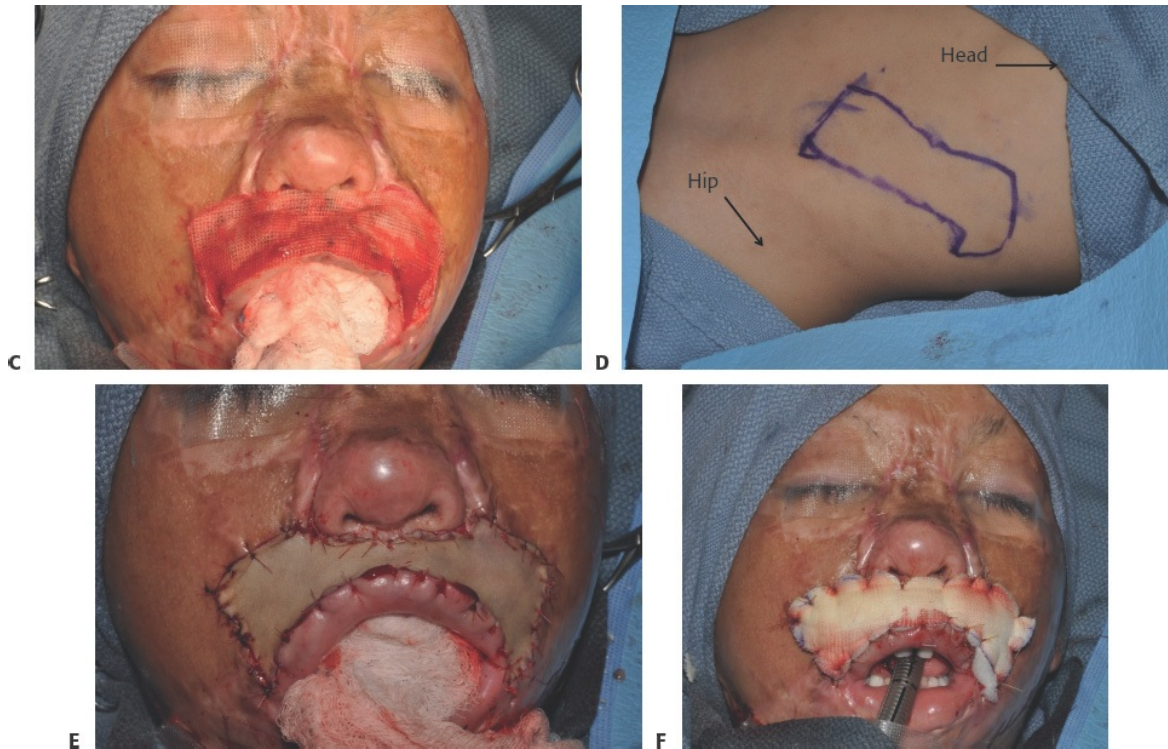
■ Contracture Release

- Contractures that may interfere with growth in a child should be addressed surgically.

■ Airway, Eyes, and Lips

- The airway (neck contracture), eyes (ectropion/lagophthalmos), and contractures of the lips result in significant functional deficits including exposure keratitis, blindness, and oral dysfunction that limits eating and mouth care.⁴
- These critical areas should be treated first and early in secondary burn reconstruction (**TECH FIG 1**).

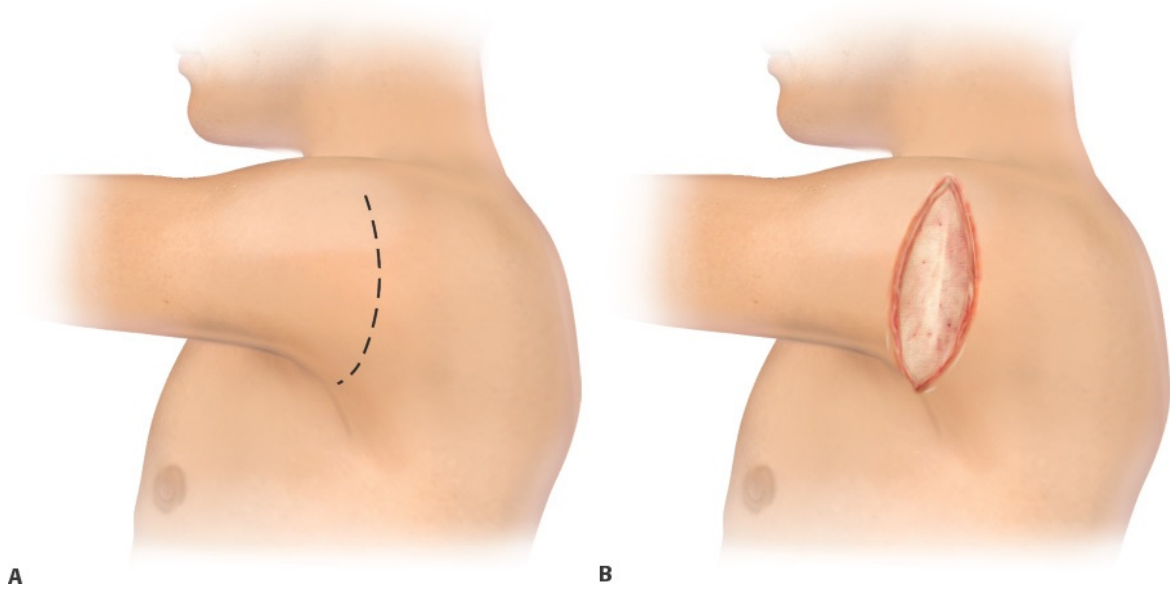




TECH FIG 1 • **A.** Planned release dart into adjacent unit. **B.** Appearance following release prior to excision of scar. **C.** Creating a template pattern for skin graft; the mouth is packed to expand the site. **D.** Full-thickness harvest site based upon template. **E.** Graft sewn in place. **F.** Stented with bolster tie over dressing.

■ Burn scar contractures

- In approaching burn scar contractures, one should start centrally and work peripherally.
- The neck, axilla, and elbow should be addressed first to allow access to the hand and provide a safe airway (**TECH FIG 2**).
- Depending on donor-site availability, numerous releases can be performed with a variety of techniques from thick-split grafts to free flaps.
- The most common reconstructive techniques include split- or full-thickness skin grafts and local flaps.



TECH FIG 2 • A. Planned incision for tight axillary region release. **B.** Appearance of axilla following release and skin grafting.

PEARLS AND PITFALLS

Contractures

- Burns unlikely to re-epithelialize by 2 weeks should be treated with early excision and split-thickness skin grafting to reduce the likelihood of hypertrophic scarring and contractures.
- Early initiation of splinting, stretching, and pressure garments can help prevent contractures and improve functional motion, especially in burn injuries across joints.

Reconstructive planning

- A systematic approach that examines all affected areas and potential donor sites should always be employed when undertaking burn reconstruction.
- Critical areas (neck, eyes, lips, and hands) are a priority and should be treated early in secondary burn reconstruction.

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CHAPTER Harvesting a Skin Graft

David A. Billmire and Kim A. Bjorklund

DEFINITION

- Skin grafts are an integral part of burn reconstruction.
- Various graft options include full thickness, split thickness, allografts, cultured (engineered) skin, dermal substitutes Integra, and Alloderm.
- Full-thickness grafts consist of the entire dermal layer with the overlying epidermis.
- Split-thickness grafts include a portion of the dermis and the overlying epidermis.
- Allografts or skin substitutes are used for temporary coverage and may be biologic or synthetic.
 - Human cadaver allograft, porcine xenograft, and amniotic membrane are biologic temporary skin substitutes.¹
 - Biobrane double-layer dressing (silicone with nylon-containing collagen) and TransCyte double-layer dressing (silicone with nylon-containing neonatal fibroblasts) are examples of synthetic skin substitutes.¹
- Cultured skin such as cultured epithelial autograft (CEA) is typically grown from the patient's own cultured keratinocytes and may be coupled with an engineered dermal substrate.
- Dermal substitutes provide an engineered dermis (Integra) or allograft dermis (Alloderm) in preparation for eventual grafting with split-thickness grafts.

Advantages

- Virtually all reconstructive grafting needs can be met by either autogenous full-thickness or split-thickness grafts.

- Allografts may be used temporarily to stabilize burn wounds and create an acceptable bed.²
- Dermal substrates may allow the use of thinner split-thickness grafts in donor-limited patients.

NATURAL HISTORY

Split-Thickness Skin Grafts

- Scarring of the donor site is dependent on the site and depth of harvest, patient age, and genetic makeup.
- Once healed, the graft may exhibit dyschromia, increased scar contracture, and decreased durability.

Full-Thickness Skin Grafts

- Typically closed primarily, but in large grafts may require closure with a split-thickness graft
- Less color change and scar contracture and greater elasticity and durability

Prognosis

- Highly dependent on the quality of the wound bed and influenced by factors including vascularity, bacterial contamination, fluid collection under the graft, and shearing

ANATOMY

- Skin grafts can be harvested from virtually any part of the body.
- Physical, functional, and aesthetic characteristics of the recipient site may dictate the preferable donor site location.
- Glabrous or hairless skin can typically be harvested from areas including the sole of the foot, hypothenar eminence, retroauricular, inner upper arm, and potentially the lateral flank areas, depending on the patient.
- Full-thickness grafts can be harvested in areas with redundant skin such as the abdomen, groin, upper arms, and supraclavicular regions.

SURGICAL MANAGEMENT

Preoperative Planning

- Wound bed preparation is critical and must be debrided to healthy well-vascularized tissue. If uncertain of the readiness of the wound bed, it may be

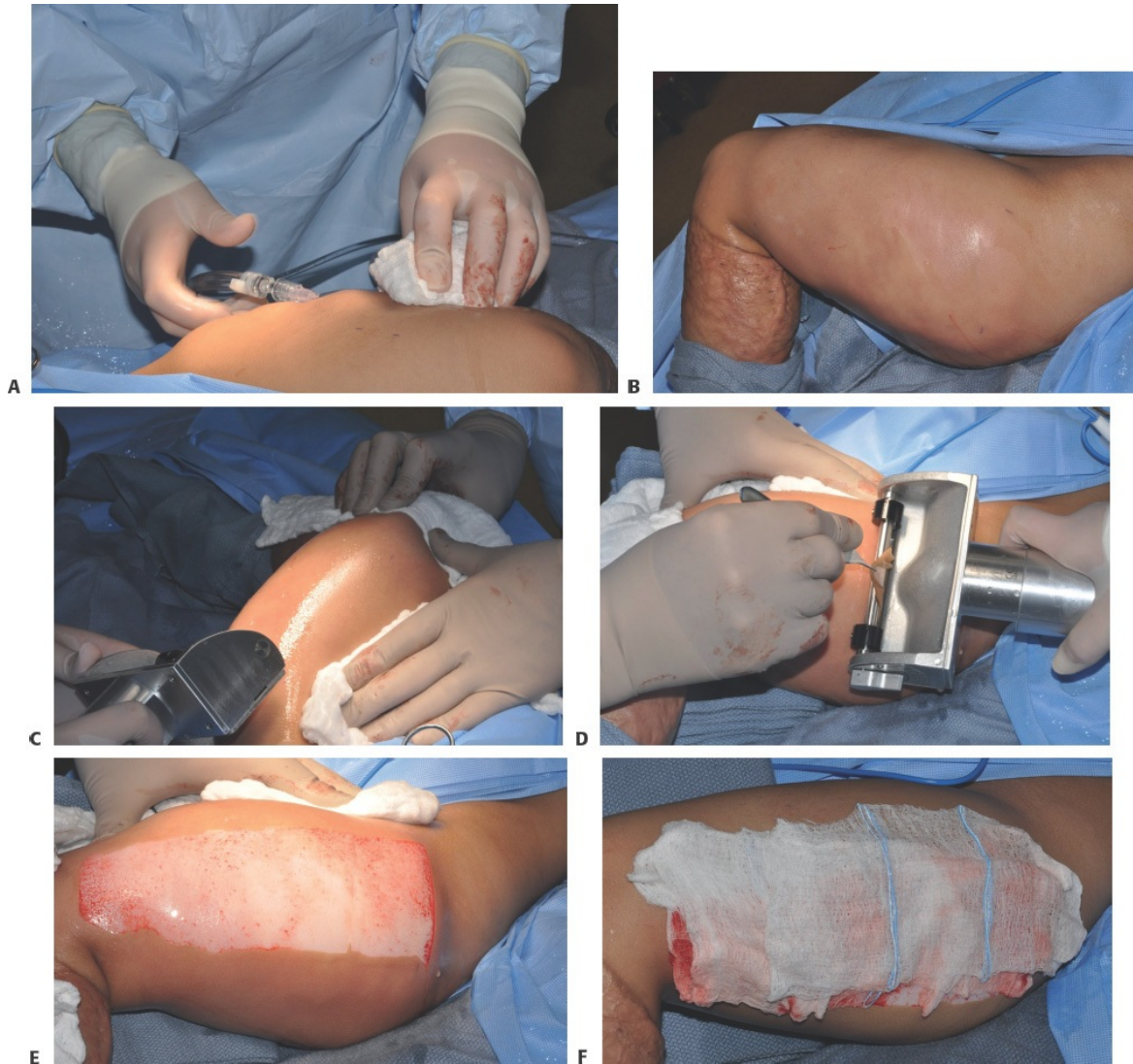
prudent to temporize with a skin substitute following debridement.

- Donor-site choice should be matched to the recipient site for characteristics such as color, hair bearing, thickness, and texture.
- Type of graft (split or full) is chosen based upon donor availability and recipient needs.

TECHNIQUES

■ Split-Thickness Graft Harvest

- Tumescence of donor site is frequently performed to facilitate harvest, as well as reduce pain and blood loss. A Pitkin solution (1 L of Normosol with 2 mg of epinephrine [1/500 000]) and ropivacaine 0.5% (maximum dose 3 mg/kg or 10 mL spread out over the entire volume of solution needed) or other tumescent solution of choice may be used (**TECH FIG 1A,B**).
- Split grafts are typically harvested using a dermatome, which is electric, drum, or air powered (**TECH FIG 1C**).
 - For average depth split-thickness grafts, the appropriate depth of the dermatome is 12 to 15 thousandths of an inch (**TECH FIG 1D–F**).
 - For thick split-thickness grafts, the depth is set to 20 thousandths of an inch, whereas for thinner grafts, it is set around 10 thousandths of an inch.
- Manual harvesting knives such as the Humby, Watson, or Braithwaite may be used as an alternative to a dermatome. These typically require experience to ensure grafts are harvested at a uniform thickness.
- The graft may be meshed depending upon recipient site goals and availability of donor sites for harvest.
- Meshing will increase the graft surface area and allow for egress of fluid but is not cosmetically desirable.
- Grafts are typically meshed 1:1.5; however, the ratio may be increased to cover a recipient greater area.



TECH FIG 1 • A. Infiltrating Pitkin solution. **B.** Postinjection. **C.** Harvesting with powered dermatome. **D.** Stopping to check thickness. **E.** Harvested site. **F.** Dilute lidocaine with epinephrine soak.

Fixation

- Absorbable sutures, tissue glue, and staples may be used to tack the graft in place.
- The recipient bed should be healthy, well-vascularized tissue with no evidence of infection. The site should be dry to avoid a hematoma.
- Donor site can be covered with bulky dressing (**TECH FIG 2**).



TECH FIG 2 • A. Applying Kaltostat alginate dressing.
B. Bulky occlusive dressing.

■ Full-Thickness Graft Harvest

- A template or specific measurements of the recipient site defect should be used to avoid harvesting unnecessary graft.
- The full-thickness graft is typically harvested in an elliptical fashion to allow for primary closure without dog ears.
- Depth of harvest should include the epidermis and complete dermis.
- Subcutaneous tissue should be removed completely prior to inseting the graft.
- The donor site should be closed primarily in layers.
- Sutures are typically used to secure the graft to the recipient site.

Graft Dressing

- Nonadherent gauze, antibiotic ointment (Bacitracin), bulky dressing, tie over bolster, Reston Foam, and splint should be applied with either a split- or full-thickness graft.

PEARLS AND PITFALLS

Dermatomes	■ Always stop and check dermatome thickness prior to beginning split-thickness harvest.
Tumescent solution	■ Use of tumescent solution facilitates harvest by stabilizing and smoothing the surface, and reducing pain and bleeding.

Boluses

- Reston foam boluses sewn with absorbable sutures allow excellent fixation, protection, and mobility and may aid in splinting the site.

POSTOPERATIVE CARE

- The graft should remain immobilized until an initial dressing change at 5 to 7 days for split-thickness grafts and 7 to 10 days for full-thickness grafts.
- Erythema, drainage, or foul odor at the graft site should prompt a concern for graft infection and necessitate an earlier graft takedown.

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24 Burned Hand Reconstruction

CHAPTER

David A. Billmire and Kim A. Bjorklund

DEFINITION

- More than 80% of all severe burns involve the hand.¹
- These injuries may be devastating with long-term functional consequences and significant morbidity.
- Burns of the pediatric hand are common and are most frequently thermal type injuries (scald, contact, or flame burns).²
- Injuries tend to occur accidentally as children explore their environment with their hands.
- However, a glove or stocking appearance to a burn, or an injury not consistent with the history, should prompt concerns for abuse.
- Hand function may be affected through tissue loss, burn scar contractures, impaired growth, and abnormal sensation.

ANATOMY

- Pediatric skin is thinner and has not yet developed the thickened palmar epidermis of an adult.³
- Dorsal skin is thin and pliable and provides less protection for underlying extensor tendons and bone.

PATHOGENESIS

- Thin dorsal skin places underlying structures at particular risk for exposure and stiffness.
- Extensor tendons are particularly at risk at the PIP joints where the central slip may attenuate or rupture with exposure, resulting in a boutonniere deformity.
- Burned hands tend to assume a position of wrist flexion, MCP hyperextension,

PIP flexion, thumb adduction, and interphalangeal hyperextension.⁴

- Early elevation, splinting, and escharotomies when indicated affect postburn edema and help prevent the development of burn contractures.
- Altered sensation and motor and nerve function may occur secondary to the burn.

NATURAL HISTORY

- Untreated or inadequately treated hand burns frequently result in contractures and long-term functional impairment.
- Early involvement of a multidisciplinary team with aggressive elevation, splinting, hand therapy, and early excision and grafting for deep burns is essential.
- Hand burns that are unlikely to heal within 2 weeks of injury should undergo tangential excision and skin grafting.⁵
- Palmar burns are more likely than dorsal burns to heal spontaneously from glabrous skin appendages and may be less likely to require grafting.
- Approximately 78% of pediatric palm burns heal without the need for grafting; however, flexion contractures of the fingers and/or shortening of the thenar-hypothenar distance may occur when burns take greater than 2 to 3 weeks to heal.^{6,7}
- Secondary burn deformities may occur as a child grows because burn scars do not grow at the same rate as the rest of the child's hand and may impede overall bone and soft tissue growth.³
- Secondary burn deformities include intrinsic minus deformities ("claw hand"); palmar cupping deformity; web space deformities; hypertrophic scars and/or scar bands; finger deformities including boutonniere, swan neck and mallet deformities; and deformities of the nail.⁸

PATIENT HISTORY AND PHYSICAL FINDINGS

- Evaluation of the location, size, depth, and previous treatment of the burn
- Mechanism of injury (thermal, contact, chemical, electrical)
- Previous splinting and hand therapy
- Nature of the contracture (extension, flexion)
- Skin and soft tissue adequacy and contracture
- Tendon function—flexor and extensor
- Assessment of sensation and vascular status of the hand and digits

- Joint contractures—passive and active range of motion
- Bony deformities and inadequate growth
- Assessment of the entire upper extremity
 - Wrist or elbow contractures may need to be addressed to adequately position the hand in space.

IMAGING AND DIAGNOSTIC TESTS

- Plain radiographs of the hands and digits should be assessed for bony deformities, joint contractures, or destruction.

SURGICAL MANAGEMENT

- Surgical intervention is warranted for functionally significant contractures not improving with stretching and splinting.³
- Multiple surgeries may be required as a child grows for recurrent contractures.
- Thumb reconstruction
 - The thumb contributes up to 50% of function of the hand, and secondary reconstruction is critical in restoration of hand function.
 - When thumb loss remains distal to the interphalangeal joint, function is reasonably well preserved.⁹
 - Web space deepening in these cases can help maximize function with techniques such as the 4 or 5 flap Z-plasty and release with full-thickness skin graft (FTSG) as described above.
 - As the thumb loss extends proximal to the interphalangeal joint, function becomes increasingly more impaired.
 - Procedures to lengthen the thumb in these cases include pollicization of the index finger, osteoplastic reconstruction, distraction lengthening, and toe-to-thumb transfer.
 - Soft tissue is frequently limited and groin flaps or free tissue transfers are often necessary as a first stage to provide a sufficient soft tissue envelope for the transplanted toe.⁹

Preoperative Planning

- An operative plan should be developed based upon the structures affected: skin, tendon, joint, and bony structures should be addressed based upon their involvement in the contracture.
- Advanced joint destruction may warrant arthroplasty or arthrodesis.
- Hand mobility, strength, and sensation are important to overall function and

should be carefully assessed in conjunction with an experienced hand therapist.

- It is important to consider how the burn has previously been treated and if previous surgery has been performed, as it may change the operative approach.

Positioning

- The patient is positioned supine on the operating table. A hand board is attached to the table and centered on the patient's axilla. The affected extremity is then extended with the hand positioned either dorsal or volar on the table.
- A malleable lead hand may be used to secure the hand and fingers.
- A nonsterile tourniquet may be used on the upper arm.

TECHNIQUES

■ Z-Plasty (Standard, 4- or 5-Flap, Multiple Z-Plasties in Series) for Thumb Reconstruction

- Z-plasties are used to break up a tight linear scar when there is unscarred soft tissue that can be transposed and is particularly useful for the web spaces of the hand (**TECH FIG 1A**).⁹
- In circumstances where flaps to be transposed are significantly scarred, consider an alternative procedure such as release and grafting.

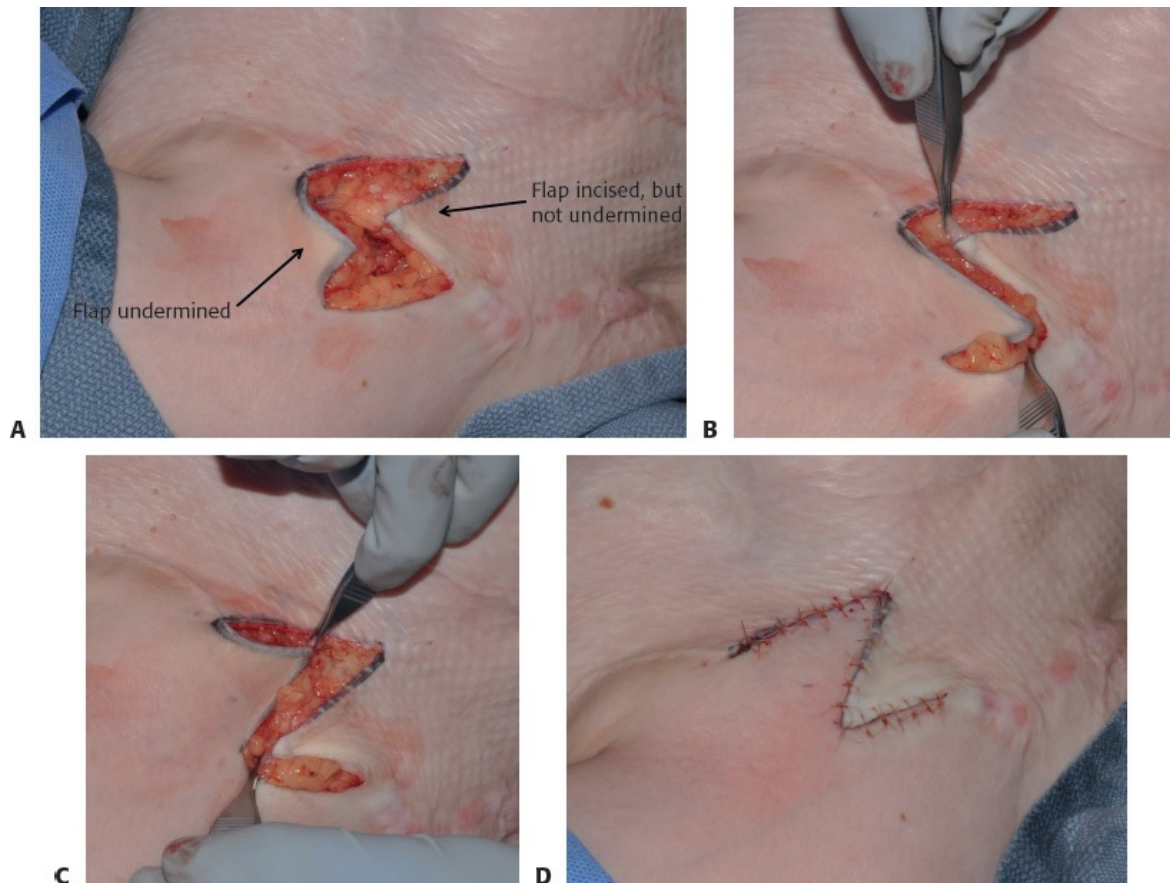


TECH FIG 1 • A. Scar band across axilla. **B.** Z-plasty in series. **C.** Final appearance of Z-plasty in series following closure.

- 4-Flap or 5-flap “jumping man” Z-plasties are typically used for web space contracture release and are designed with the transverse limb parallel to the web space and all limbs being equal in length.
- With the 4-flap Z-plasty, 90-degree flaps are drawn at the end of each central limb and bisected to give 45-degree flaps.
- Multiple Z-plasties in series should be used to break up a long vertical scar band (**TECH FIG 1B,C**).
- Incisions are made down through subcutaneous tissue and flaps are elevated as thick as possible, allowing for preservation of blood supply (**TECH FIG 2A**).
- Flaps should be dissected until they transpose easily without any tension

(**TECH FIG 2B,C**).

- In the 1st web space, care should be taken in the dissection to avoid injury to the index radial neurovascular bundle, which lies beneath the flap.
- The tourniquet should be released and flaps checked for viability. Hemostasis should be achieved with pressure and cautery.
- Flaps should be transposed into position and secured with 4-0 or 5-0 suture (**TECH FIG 2D**).



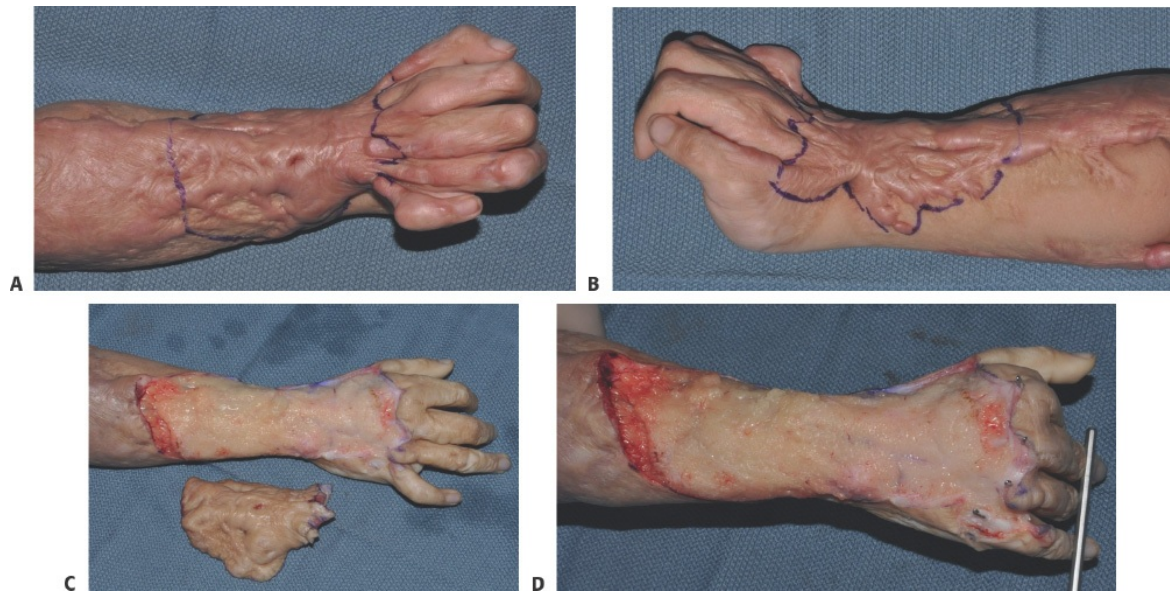
TECH FIG 2 • **A.** Flaps elevated. **B,C.** Transposition of flaps. **D.** Closure.

■ **Contracture Release With Full-Thickness Skin Grafting**

- Indicated for flexion contractures of the digits, contractures of the dorsal or volar of the hand, and web space contractures or syndactylies

Incision and Release

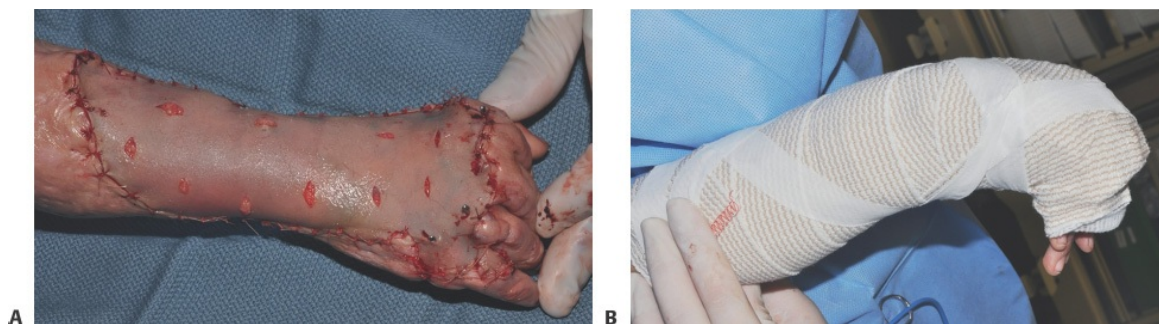
- Scar contracture is assessed for area of maximal tightness and transverse incision marked at this location (**TECH FIG 3A,B**).
- Incision must extend into unscarred tissue on either side of the contracture band to provide complete release (**TECH FIG 3C**).
- Release is performed by pushing into the scar contracture with the blade while counter tension is applied to the digit by stretching it into extension. The tight thick scar will give way in the release using pushing movement with a fresh blade, whereas the underlying neurovascular bundle will be unharmed, under the appropriate pushing tension.
- Continue to use pushing technique against scar until complete release is achieved.
- Identify underlying flexor tendons and neurovascular bundles and avoid injury.
- Slow passive stretch on a digit can help further stretch soft tissue.
- Following soft tissue release, the contracture is reassessed to determine if any release of checkrein, collateral ligaments, or volar plate is required.
- The tourniquet is released and digits assessed for capillary refill and color. If the digit appears pale with slow capillary refill, it may not tolerate the extent of the contracture release due to the stretch on the neurovascular bundles. In this case, the digit should be extended only to the point where it retains normal color and capillary refill.
- Meticulous hemostasis of the defect site is achieved.
- If there is significant memory of the digit following contracture release, a K-wire can be placed across the joint to maintain its position in extension (**TECH FIG 3D**).
- Color and capillary refill should be checked again after K-wire placement to ensure the digit can tolerate the extended position.



TECH FIG 3 • A,B. Dorsal hand burn. **C.** Following release. **D.** Following release and pinning of MCPs.

Graft Placement

- The defect from the soft tissue release outlined using a template from suture packet or Esmarch bandage.
- The template is transposed to desired site of full-thickness skin graft (FTSG) harvest (upper arm if available) and outlined in ellipse.
- FTSG is harvested and defatted. Donor site is closed in layers.
- FTSG is secured at the defect site with 5-0 chromic or plain gut suture.
- A thick split-thickness graft may also be used (**TECH FIG 4A**).
- Saline irrigation with a syringe and catheter tip beneath the graft to flush any clots is performed.
- A compression dressing with wet cotton and gauze is applied to the graft site, followed by a splint to maximally protect position of release and graft (**TECH FIG 4B**).



TECH FIG 4 • A. Resurfaced with thick split graft. **B.** Dressed with dorsal block splint.

PEARLS AND PITFALLS

Neurovascular limitations

- It is critical to recognize signs of digital neurovascular compromise intraoperatively and ensure the digit is returned to a position where the neurovascular structures are under less tension, in particular with the PIP joint release when the neurovascular structure may be under tension with full stretching of the joint after release.

Incomplete contracture release

- Soft tissue contractures must be completely released and joint and ligamentous structures examined in sequence if the contracture remains.

Immobilization of the graft site

- An inadequate compression dressing or failure of extremity immobilization may result in suboptimal skin graft take.

Therapy

- Postoperative splinting is critical to preventing recurrence of contractures.

POSTOPERATIVE CARE

- To avoid any mobility at the graft site, a cast is applied (long arm in young child).
- Healing and graft take is assessed at 7 to 10 days, and daily dressings are performed if healing is incomplete.
- If a K-wire is present, it is removed at 4 to 6 weeks. The patient should remain

in a cast to protect the K-wire for the duration.

- Activities may be resumed once grafts are completely healed and K-wires removed.
- Night splinting in maximal extension to prevent recurrence of the deformity should continue for 3 to 6 months.

COMPLICATIONS

- Infection
- Wound healing problems
- Limited mobility from recurrent contractures
- Hypertrophic or keloid scarring
- Pain

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25 Reconstruction of Burned Eyelids

CHAPTER

David A. Billmire and Kim A. Bjorklund

DEFINITION

- The majority of ocular sequelae following facial burns occur as a result of secondary eyelid deformities.¹
- Burn scar contracture can lead to cicatricial ectropion and lagophthalmos, which may in turn produce exposure keratopathy and in severe cases result in corneal scarring.

ANATOMY

- The eyelids are complex structures providing protection and lubrication for the surface of the globe.
- They contain an anterior and posterior lamella, which are separated by the orbital septum.
- In children, the levator muscle is rarely involved.
- Eyelid skin is naturally thin and may result in a deeper burn than a similar heat exposure elsewhere in the body.
- Contractures most often affect the lower lids.
- Reduction of motion and coverage may be the result of direct scar contracture to the lid itself (intrinsic) or burn scar contracture in sites remote to the lids such as the cheeks, mouth, neck, and forehead.

PATHOGENESIS

- Burn scar contracture affects the motion and excursion of the lids and consequently the coverage of the cornea.
- With deeper burns, lagophthalmos of the lids develops and places the eye at risk.

- Bell phenomenon reflex helps prevent corneal epithelial defects and may be problematic if absent such as in heavily sedated or paralyzed patients.¹

NATURAL HISTORY AND PHYSICAL FINDINGS

- Patients frequently present with an inability to fully close their eyes and may complain of irritation and discomfort.
- The eyes should be carefully examined to determine the etiology of the dysfunction, noting if the anterior or posterior lamellae are affected and whether there are additional extrinsic burn scars contributing to the contracture.
- These symptoms tend to be better tolerated in children than adults.
- The depth and extent of the eyelid burns should be noted, as well as presence of eyebrows and eyelashes.¹
- The eyelids tend to demonstrate stiffness and fail to completely cover the eyes, which may be most noticeable when the patient is asleep. Parents should be queried about the status of the lids when the child sleeps. It is also easily noticed when the child is under anesthesia.
- The conjunctiva of the lower lids may be everted and pulled down onto the cheeks.
- The upper lids may demonstrate “clotheslining” where a band of scar runs from the lateral canthus to medial canthus and functions as a fixed point holding the lid up and preventing closure.
- Reconstructive planning should include examination of both upper and lower eyelids, extent of surrounding scar, including cheek and forehead, and donor sites for potential FTSG.

NONOPERATIVE MANAGEMENT

- In mild to moderate cases, eye drops and lubricants and taping can be used temporarily until definitive release is performed.
- In the acute burn phase, corneal exposure may be managed by a temporary tarsorrhaphy, which is replaced as soon as the patient is stable with a formal eyelid release-resurfacing.
- The eyelids are delicate structures and tarsorrhaphies routinely pull out and fail and should not be relied upon for an extended period of time.

SURGICAL MANAGEMENT

- Operative intervention to protect the cornea and counteract lid retraction should be considered a priority in burn reconstruction.

- The timing of surgery is dictated by evidence of lagophthalmos with signs and symptoms of corneal exposure.¹
- If both lids will require release, it is best to stage them by addressing the more involved lid first for appropriate overcorrection.
- Lower lid
 - Both extrinsic and intrinsic sites of the contracture should be released, but even in a minimally involved lower lid attention should first be directed to the lid itself.
 - As with all burn scar contractures, it should be overcorrected.
 - Although an extrinsic contracture with an unaffected lower lid may be released, often the lower lid will still not achieve a normal position. In these cases, the lower lid will need to be released and overcorrected, even though there is no scar.
- Upper lid
 - The surgical approach is similar to the lower lid.
 - Again the levator muscle is rarely involved and when involved actually results in ptosis. This could be the result of dehiscence or destruction.
 - The lid should be resurfaced and released prior to addressing the ptosis.
 - Depending on the state of the levator, it can be repaired or a suspension technique utilized.

Preoperative Planning

- Review photographs and carefully examine the patient to determine etiology of the problem.
- Choose an appropriate donor site, preferably glabrous and thin. Acceptable sites are an unburned opposite lid, retroauricular or preauricular, supraclavicular, or the inner upper arm for full-thickness skin grafts.

Positioning

- Supine, with shoulders elevated by a shoulder roll.
- Ensure the donor site is accessible.

TECHNIQUES

■ Lower Lid Reconstruction

- The approach is the similar to a blepharoplasty approach for both the upper and lower lids.
- Local anesthetic with epinephrine should be injected.
- In the lower lid, a subciliary incision is performed with a 15 blade and dissected down to the orbicularis oculi muscle.
- The incision should be continued from canthus to canthus, extending beyond the medial and lateral canthi to ensure a complete release.¹
- Hooks or a Frost suture is used to apply steady traction to the lid margin pulling superiorly as you release the scar.
- The release should continue until the lid margin easily approximates the globe.
- Orbicularis muscle may require dissection if scarred, but typically, the orbital septum is not involved and should not be violated.
- A lateral canthotomy and cantholysis with subsequent canthoplasty may need to be performed.

■ Upper Lid Reconstruction

- Approach is similar to a blepharoplasty with an incision along the likely tarsal crease, approximately 1 cm along the lash line (**TECH FIG 1A**).
- The incision should be extended more medially and laterally than in a standard blepharoplasty (**TECH FIG 1B**).
- Apply gentle traction and continue to divide the scar until the lid comes down.
- As with the lower lid, the release should be overcorrected.
- Do not violate the orbital septum.
- The conjunctival surface should easily redrape over the globe.
- A pattern of the defect is made and transferred to the donor site (**TECH FIG 1C**).
- Harvest a full-thickness graft and defat as necessary.
- In extensive burn cases, a split-thickness graft may be necessary.
- Sew the graft in place with an absorbable suture, such as 6-0 chromic.
- A bolster should be applied such as a thin Reston foam tailored stent over a nonadherent gauze (Adaptic) impregnated with an ophthalmic ointment. The

bolster should be sewn in place again with an absorbable suture and left for 7 to 10 days (**TECH FIG 1D**).

- A tarsorrhaphy is unnecessary with this technique as the bolster holds the eyelid in position and allows the child to have some vision in the affected eye.
- Using this method, release and reconstruction of both eyes may be performed at the same time.



TECH FIG 1 • **A.** Planned incision. **B.** Lid released with medial and lateral extensions. **C.** Post auricular donor site. **D.** Graft placed and stented.

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26 Burn Neck Contracture Release

CHAPTER

David A. Billmire and Kim A. Bjorklund

DEFINITION

- Burn scar contractures of the neck are relatively common and should be a priority in surgical reconstruction when indicated.
- Burn contractures of the neck may result in deformities that impair functions such as eating and speaking.
- If severe, the contracture can compromise the airway, make intubation difficult, and distort growth of the facial skeleton.¹

ANATOMY

- Anterior neck contractures have been classified based upon the location of the band and the degree of flexion and extension away from the anatomical position of the neck and jaw.²
- The width of the contracting segments and availability of supple surrounding skin is also considered in the classification of the deformity.²
- The key anatomical considerations are the burn scar crossing the mobile cervical-mental angle or the manubrium.
- Burn scarring above the cervical-mental angle will primarily affect the chin, lower lip, and mandible.
- When the burn crosses the angle, the mandible and head are pulled into flexion.

PATHOGENESIS

- Neck burn scar contractures in the pediatric patient can be severe secondary to the propensity to hypertrophic scarring, which may develop rapidly in the initial weeks following the injury.

- Significant neck burn scarring creates a persistent downward force on the lower lip, chin, and eyelids resulting in ectropion and AP growth restriction of the mandible.³
- Contractures may be severely disfiguring and functionally impair neck motion, making eating and communication problematic.
- The airway may become compromised and intubation difficult.
- In extreme cases, scarring pulls the chin down to the chest wall, elongating the mandible and severely affecting the airway.

NATURAL HISTORY

- The natural history and progression is dependent on the depth of the burn wound, the inherent tendency toward scarring, the age of the child, and the initial treatment and management.
- Neck burn scar can exert considerable pressure on the growing mandible and adversely affect growth.
- Depending on the vector of pull, the AP growth of the mandible can be negatively affected and require later genioplasty or even a BSSO with advancement.¹
- In the most severe cases where the mandible is drawn down to the chest, mandibular lengthening and eventual setback may be required.

PATIENT HISTORY AND PHYSICAL FINDINGS

- A detailed assessment of the patient's functional limitations is documented.
- Previous treatment of the neck burn injury should be noted as well as compliance with stretching and splinting.
- Note the specific anatomic location of the neck burn contracture, width of scar bands, and whether supple nonburned soft tissue is present.
- Deformities such as lower lip and eyelid ectropion affected by the neck contracture should be noted.
- Occlusion is assessed—loss of chin projection and class II occlusion may develop over time.
- Range of motion and ability to extend the head and neck should be measured.
- The patient should be assessed for potential intubation difficulty.
- Availability of potential donor sites for surgical planning should be assessed.

IMAGING

- Imaging is rarely required unless growth disturbances are suspected.

- A standard lateral cephalogram is useful to follow the patient.

NONOPERATIVE MANAGEMENT

- In the scar maturation phase of the burn wound, splinting and stretching are recommended to reduce the contracture.

SURGICAL MANAGEMENT

- Depending on the severity and extent, contracture releases may be accomplished by a variety of techniques including split-thickness or full-thickness skin grafting, local flaps, tissue expansion, and local flaps or a free flap.
- Operative intervention is warranted for functional deformities that are not amenable to stretching and splinting.
- The majority of neck contractures can be managed with a thick split-thickness skin graft and may also be staged by initial release with a skin graft to assure a safe airway and at a later date resurfaced with tissue expansion or flap.
- In a growing child, releases may need to be repeated.
- Recurrence is also significantly affected by the use of long-term postoperative splinting:
 - In a study of 143 neck release procedures with Z-plasties or STSG, the postoperative use of a neck hyperextension brace for over 1 year following skin grafting decreased the recurrence rate by 40% to 50%.⁴

Preoperative Planning

- Consultation preoperatively with anesthesia is critical for any potential for a compromised airway and difficult intubation.
- Although fiberoptic intubation has facilitated the process, in severe cases, it is appropriate that the surgeon be at the bedside to do an emergent release if the anesthesiologist is unable to establish a safe airway.

Positioning

- The patient is positioned supine on the operating table.
- A transverse shoulder roll is placed to allow maximum extension of the neck.

TECHNIQUES

■ Incision and Release

- Local anesthesia with epinephrine may be injected to help with hemostasis and developing a dissection plane.
- The neck is typically incised along the cervicomenal angle and extends from mid axis to mid axis or further if necessary to obtain complete release (**TECH FIG 1A,B**).
- The incision is carried down to a scar-free plane, which usually includes division of the platysma with the lateral extension into the unburned skin on either end.
- The wound is then spread using digital traction or retractors to achieve release of the scar.
- This is aided by extending the neck as much as possible and using continuous slow traction to release the contracture as much as possible.
- It is important to overcorrect the contracture release as there will be subsequent secondary contracture with healing.
- Care should be taken to avoid injury to neurovascular structures deep to platysma.



TECH FIG 1 • Incision for neck flexion contracture release, anterior view (**A**) and lateral view (**B**). **C**. Appearance of neck following release and grafting.

■ Reconstruction

- When the wound is spread to its fullest extent, meticulous hemostasis is achieved.
- A thick split-thickness graft (14 to 16 thousands of an inch) sheet graft is harvested, pie crusted, and sewn into place (**TECH FIG 1C**).
- The graft is then stabilized with a tailored Reston foam stent sewn over a nonadherent gauze (Adaptic) coated with Bacitracin ointment.
- Alternatives to Reston foam include a bolster dressing.
- In difficult recurrent cases, it may be necessary to consider the use of a flap as opposed to a graft. Options include trapezius fascial or myocutaneous flaps,⁵ supraclavicular flaps,^{6,7} or a free flap of choice.
- Integra dermal substitute has also been described as a reconstructive option.⁸

PEARLS AND PITFALLS

Contractures	■ Burn contractures of the neck require early treatment to prevent compromise of the airway and impairment of functions such as eating, speaking, and growth of the facial skeleton. ■ Anatomically, it is critical to note burn scars crossing the cervical-mental angle, which result in a flexion deformity as the mandible is drawn to the chest.
Airway	■ Preoperative anesthesia assessment is critical for potential compromised airway and difficult intubation.
Surgical technique	■ Ensure complete contracture release in plane deep to platysma with incision along the cervical-mental angle.
Postoperative splinting	■ Postoperative management with neck splinting to prevent recurrence of the contracture until the scar is fully mature is essential.

POSTOPERATIVE CARE

- The foam bolster is left in place for 10 to 14 days.
- Following removal, a neck brace is crafted to hold the neck in an extended position.
- It will be worn ideally 24 hours a day until the scar matures and may be beneficial for up to a year.

- For small releases one can also consider a soft collar.

OUTCOMES

- Despite a successful release, it may have to be repeated due to subsequent contracture secondary to growth in children.
- Factors include the age of the patient, the degree of scar response and the adherence to the postoperative regimen.⁹
- Failure due to significant hypertrophic scarring may require the use of a flap; however, even flaps can fail as surrounding scar may create tension and result in vascular compromise to the flap.
- Once a stable neck release is obtained, it is often possible to replace the grafted area at a later date by using tissue expansion to expand the unburned skin on the lateral neck and supraclavicular area if available.

COMPLICATIONS

- The major complications are graft loss and recurrence of the contracture.

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27 Adolescent Burned Breast Reconstruction

CHAPTER

David A. Billmire and Kim A. Bjorklund

DEFINITION

- Burned breast contractures and loss are a common occurrence in females who sustain major burns injuries prior to adolescence.
- Knowledge of the importance of preserving the breast bud in preadolescent females has lessened the need for complete reconstruction.^{1,4}
- In the acute burn phase, debridement should be kept to a minimum in the area of the nipple areolar area.²

PATHOGENESIS

- With the onset of puberty, the breast bud will begin to grow and expand the overlying skin acting much like a tissue expander.⁴
- Any overlying scar can cause restriction and/or distortion of the maturing breast mound.
- Additionally, full-thickness tissue loss from the burn injury surrounding the breast bud will cause additional loss in the eventual volume of the breast.
- Complete loss of the breast bud itself will result in a smaller or absent breast.
- Burn wounds may also result in the loss of the nipple areolar complex, despite the development of an acceptable breast mound.

NATURAL HISTORY

- Full-thickness and deep second-degree burn injuries to the female chest warrant special care in the acute burn wound and careful management in the subsequent time period prior to development of the breast.³⁻⁵
- Care should be taken with axillary releases, especially when considering the use of Z-plasties. An inappropriately designed Z-plasty can unknowingly

transpose the breast bud into the axilla.

- As the breast develops, the amount of constriction and distortion will become apparent.
- It is advisable to delay release/reconstruction until the breast has reached its full size.
- Rarely, the release may be warranted prior to growth completion and will most likely need to be repeated.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Long-term follow-up for young females with significant chest burns is critical to identify any problems during adolescence.⁴
- Once the breast has begun developing, the patient should be evaluated about every 6 months to assess potential problems.
- The soft tissue envelope of the breast, breast tissue, and nipple areolar complex should be assessed, noting location and degree of scar contracture.
- Age and stage of breast development should be determined at each visit.
- Restriction can be complicated by inherent underlying congenital deformations such as constricted breast, tubular breast deformity, or Poland syndrome. These should be considered in addition to the burn injury deformity.

SURGICAL MANAGEMENT

Preoperative planning

- All areas of constriction and distortion should be noted.
- Breasts are treated with almost entire release and grafting and/or resurfacing.^{4,5}
- Typical areas of release are the inframammary, intermammary, and the periareolar sites.
- Reconstruction is typically performed with split-thickness sheet grafts, although dermal templates such as Integra have been described.⁶

Positioning

- The patient is placed supine on the operating table with a shoulder roll and the arms abducted at 60 degrees.
- Graft donor site should be exposed, typically the thighs or legs. The back is also a good choice but requires turning the patient.

Approach

- Both inframammary and intermammary releases are frequently performed at the same time.
- The inframammary release should be at the level of the inframammary fold (which is frequently obliterated by burn scar) and will curve up at the midline, joining the incision from the opposite side (**FIG 1**).



FIG 1 • Incision design for breast release along inframammary fold.

TECHNIQUES

- The incision is made as indicated.
- The underlying breast mound is pulled superiorly to open the release and define the inframammary fold.
- At the midline, the breasts are retracted laterally to separate the breasts into

two distinct mounds and define the cleavage (**TECH FIG 1**).

- A periareolar release may be performed following the curve of the areolar, although it may be delayed to a second operation if necessary.
- Sheet grafts (approximately 15/1000ths thick) are harvested with a dermatome from the chosen donor site.
- Grafts are sewn in place and tacking sutures are placed along the inframammary crease. The graft may be piecrusted to allow escape of underlying fluid.
- The grafts are dressed with nonadherent gauze and antibiotic ointment. Moist fluffed gauze is molded along the inframammary fold followed by a tailored Reston foam bolus, which can be sewn or stapled into place.



TECH FIG 1 • Appearance of breasts following release and grafting—inframammary and intermammary definition apparent, anterior view (**A**) and lateral view (**B**).

PEARLS AND PITFALLS

Burned

breast deformity

- In the burned breast with inherent congenital deformities (such as constricted or tuberous breast), release and correct the burn deformity first and approach the congenital deformity secondarily.
- Address the nipple areolar deformity at a later date once scars have matured and edema has settled.
- Volume loss can be treated with fat grafting at a later date.

Loss of the breast

- Complete loss of the breast can be approached by any of the techniques used in breast cancer reconstruction ranging from tissue expansion,⁷ pedicled flaps such as latissimus dorsi⁸ or TRAM flaps, to free tissue transfer.
- The reconstruction should consider the state of the breast site, the quality of the tissue, and available donor sites.
- Nipple areolar reconstruction likewise can be addressed by the standard techniques used for breast cancer patients.
- Contralateral breast procedures to address asymmetry may be required if only one breast is affected.

POSTOPERATIVE CARE

- Bed rest is not required, and early ambulation should be encouraged.
- The dressings are left on for 10 to 14 days.
- After the initial dressings are removed, the patient is dressed in a light padded gauze dressing and a longline or surgical bra until the grafts are stable.
- The patient is then switched to silicone inserts molded for the inframammary fold to apply pressure the maturing graft.

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28 Pressure Injuries (Sacral and Pelvic Region, Columella—From CPAP)

CHAPTER

David A. Billmire and Kim A. Bjorklund

DEFINITION

- A pressure injury is a localized injury of skin and underlying tissue secondary to prolonged pressure, frequently in combination with shear forces.
- Severity ranges from nonblanchable erythema to full-thickness tissue loss.
- Common locations are over bony prominences such as the sacrum, coccyx, ischium, and heels.
- In the pediatric population, children with special needs and those who are critically ill are at particularly high risk for pressure injuries.¹

PATHOGENESIS

- Pressure injury formation is a complex process that involves numerous factors.²
 - Extrinsic contributing factors include pressure, friction, and shear.
 - Intrinsic factors include local tissue ischemia, decreased autonomic control, infection, loss of sensation, decreased mental status, fecal or urinary incontinence, anemia, and hypoproteinemia.^{3,4}
- As muscle is more sensitive to pressure than is skin, areas with a significant amount of muscle may be susceptible to an inverted cone pattern of injury, in which most of the necrosis is deep to the skin.⁵
- Particular risk factors in the pediatric population have been identified^{1,6}:
 - Paraplegia, sensory impairment
 - Cognitive impairment
 - Kyphoscoliosis or kyphosis

- Chronic fecal or urinary soiling
- Trauma
- Immobility
- Poor nutrition

NATURAL HISTORY⁷

- Nonblanchable erythema may be observed within 30 minutes of unrelieved pressure and typically disappears within 1 hour after pressure is eliminated.
- Ischemia develops after pressure is present for 2 to 6 hours.
- Necrosis may occur if pressure is not relieved within 6 hours.
- Ulceration tends to occur over bony prominences within 2 weeks after development of necrosis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Determine factors contributing to the pressure injury (extrinsic and intrinsic) and whether they can be eliminated postoperatively.
 - Note any chronic medical conditions contributing to the pressure injury, such as myelodysplasia, cerebral palsy, paraplegia, and scoliosis.
 - Note any temporary conditions contributing to the pressure injury (prolonged immobility, repetitive trauma) that require resolution.
- Ambulatory status
- Previous pressure injuries
- Compliance and motivation with treatment
- Assess risk factors using Braden Scale, including mobility, activity, sensation, moisture, friction/shear, and nutrition.
- Assess sensation and lower extremity motor function, including spasticity.
- Palpate for any fluctuance or bony prominences.
- Note any signs of infection such as warmth, erythema, tenderness, purulent drainage, and systemic signs of infection.
- Assess ongoing factors that may be contributing to wound breakdown, such as items causing pressure, spasticity, and fecal or urinary incontinence.
- Staging of pressure injuries based on the updated guidelines of National Pressure Ulcer Advisory Panel⁸:
 - Stage 1: Nonblanchable erythema of intact skin
 - Stage 2: Partial-thickness skin loss with exposed dermis
 - Stage 3: Full-thickness skin loss

- Stage 4: Full-thickness skin and tissue loss
- Unstageable pressure injury: Obscured full-thickness skin and tissue loss
- Deep tissue pressure injury: Persistent nonblanchable deep red, maroon, or purple discoloration

IMAGING AND DIAGNOSTIC STUDIES

- Nutritional assessment (including albumin, prealbumin, electrolytes)
- Wound cultures if concern for infection
- WBC and ESR if concern for infection/osteomyelitis
- MRI or CT scan may help in identification of osteomyelitis and communicating sinus tracts.
- Bone biopsy and culture if concern for osteomyelitis prior to treatment with antibiotics

NONOPERATIVE MANAGEMENT

- Generally indicated for stage 1 and 2 pressure injuries
- Correct nutritional deficiencies and medical comorbidities.
- Control spasticity.
- Treat infection with local wound care and culture-directed antibiotics.
- Cleaning, debridement (mechanical, autolytic, enzymatic, sharp), and local wound care of pressure injuries
- Local wound care should be adjusted based on the nature of the wound (exudative, granulating, fibrinous).
- Pressure relief through frequent repositioning and protective padding; support surfaces that minimize pressure and reduce shear.
- Prevent contamination from urinary and fecal soiling.
- Routine inspection by caregivers for early pressure changes and timely referrals during growth spurts for assessment of orthotics, prosthetics, or wheelchairs are critical.

SURGICAL MANAGEMENT

- Surgery is indicated for large stage 3 or 4 pressure injuries that require debridement and reconstruction.
 - Goals include preventing osteomyelitis and protein loss through the wound; improving function, hygiene, and quality of life; and reducing rehabilitation and wound care costs.⁸
- Ischial pressure injuries: Common reconstruction options include gluteal

muscle rotation flaps, posterior thigh V-Y advancement flap (hamstring muscles may be included if nonambulatory), or gracilis musculocutaneous flap.

- Sacral pressure injuries: Common reconstruction includes bilateral V-to-Y gluteus advancement, gluteus maximus myocutaneous flap, and superior gluteal artery perforator flap.⁸
- Coccygeal pressure injuries can be treated with coccygectomy.
- Trochanteric pressure injuries are typically reconstructed with tensor fascia lata flap.

Preoperative Planning

- Identify and address causes of the pressure injury.
- Control comorbidities.
- Optimize nutritional status, including serum albumin and hemoglobin.
- Consider diverting colostomy and catheterization to minimize urinary and fecal soiling.
- Careful consideration of future pressure sores in planning of operative technique

Positioning

- The patient is positioned prone on the operating table with pressure points well padded.
- General anesthesia is administered.

TECHNIQUES

■ Debridement

- Completely excise injured area, bursa, scar, and all necrotic tissue.
- Debride all nonviable bone and calcifications.
- Bony debridement should continue until healthy bleeding bone is apparent.
- Biopsy of underlying bone should be sent for culture and pathology.
- Reconstruct by filling dead space with well-vascularized muscle or fascial flaps inset without tension.
- Pressure injury recurrence or formation in new locations should be carefully considered in reconstructive planning.

- Drains should be placed under the flap.

■ V-Y Advancement Flap for Ischial Pressure Injuries

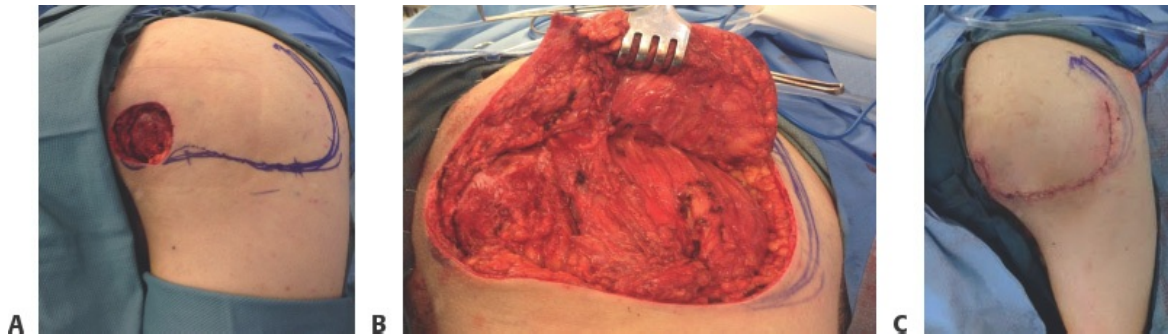
- V-Y biceps femoris musculocutaneous advancement flap design for ischial pressure injury (**TECH FIG 1A**).
- Reconstructed ischial pressure injury with V-Y biceps femoris flap (**TECH FIG 1B**).



TECH FIG 1 • A. V-Y biceps femoris musculocutaneous advancement flap design for ischial pressure injury. **B.** Reconstructed ischial pressure injury with V-Y biceps femoris flap.

■ Gluteus Maximus Myocutaneous Flap

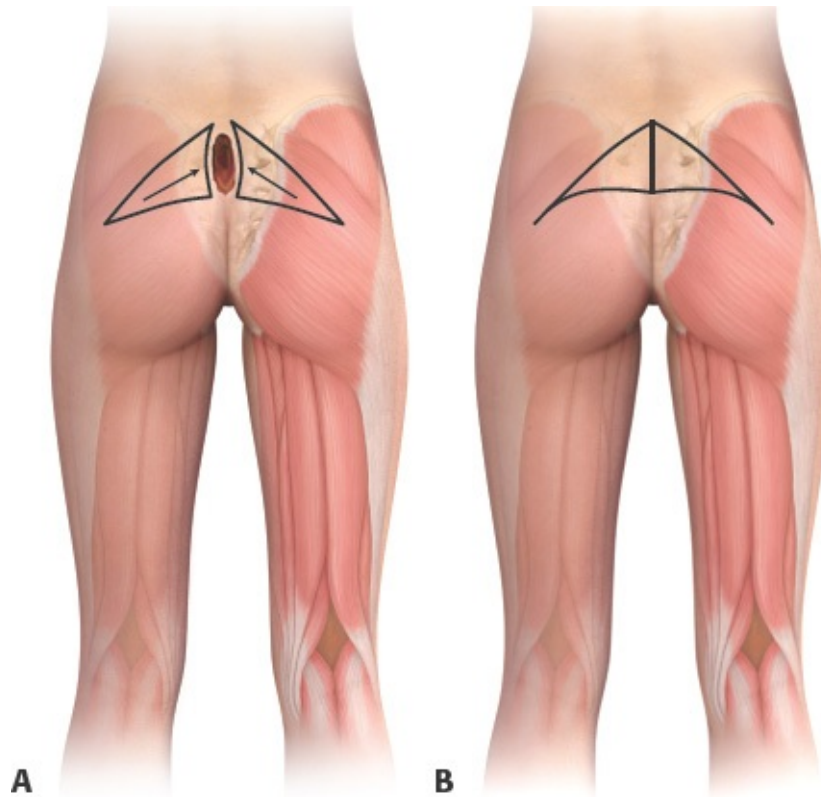
- Unstageable right ischial pressure injury prior to debridement (**TECH FIG 2A**)
- Following debridement, a gluteal rotation flap design is outlined (**TECH FIG 2B**).
- The defect from the pressure injury is triangulated with the apex toward the flap pedicle.
- Rotation flap is outlined approximately 5 times the length of the defect base.
- Gluteal skin and muscle are incised, and the flap is elevated until it can be mobilized into the defect (**TECH FIG 2C**).
- A small back cut can be performed at the end of the rotation flap.
- Flap should be closed in layers over suction drains (**TECH FIG 2D**).



TECH FIG 2 • A. Ischial defect following debridement with gluteal rotation flap design outlined. **B.** Gluteal skin and muscle are incised and the flap elevated until it can be mobilized into the defect. **C.** Flap should be closed in layers over suction drains.

■ Bilateral V-to-Y Advancement of Gluteal Muscles

- Following debridement of sacral pressure injury, bilateral V-Y gluteal flaps are marked extending from the edges of the debrided pressure injury at the sacrum medially and including the entire gluteal region (**TECH FIG 3A**).
- Skin incisions are performed, and the gluteus maximus muscle is identified.
- It is detached from sacral attachments medially and iliac crest attachments superiorly.
- Superior and inferior gluteal vessels must be preserved.
- The lateral and inferior aspects of the myocutaneous flap are incised and elevated at the edges to allow for advancement.
- Gluteus myocutaneous flaps are then advanced to the midline.
- Closure is performed in a V-to-Y fashion (**TECH FIG 3B**).
- Suction drains are placed under each flap.
- Large absorbable sutures such as 2-0 Vicryl or PDS should be used for deep tissue approximation.
- Deep dermal and subcuticular layers should then be closed.



TECH FIG 3 • A. Bilateral V-Y gluteal myocutaneous flaps extend from the edges of the sacral pressure injury at the sacrum medially and include the entire gluteal region. **B.** Closure is performed in a V-to-Y fashion.

PEARLS AND PITFALLS

General

- Ensure the underlying etiology of the pressure injury is corrected prior to surgical reconstruction.
- Comorbidities, nutritional deficiencies, fecal/urinary contamination, infection/osteomyelitis, and postoperative pressure relief plan must be addressed prior to reconstruction.
- Plan flap reconstruction accounting for possible recurrence of the pressure injury and new pressure injury.

Debridement

- Adequate debridement for the pressure injury is critical to a successful outcome.

Ischial, sacral, trochanteric pressure injuries

- Complete excision of the bursa as well as any nonviable tissue is essential.
- Failure to adequately debride bone or bursa may lead to failure of the reconstruction.
- Consider staging the reconstruction if there are uncertainties regarding infection or tissue/bone viability.
- Ambulatory status of the patient must be determined if considering use of gluteal or hamstring muscles in flap reconstruction.
- Gluteal rotation, posterior thigh, and TFL flaps must be designed with adequate dimensions to fill the defect.
- Ensure the vascular pedicle is preserved in design and dissection of flap.
- Ensure the flap is not inset under tension.
- Do not excise dog ears or extra tissue.
- Always close flaps over a drain.

POSTOPERATIVE CARE

- Patients should be non–weight bearing on the operative site for up to 6 weeks postoperatively.
- Prone or lateral decubitus positioning should be maintained to avoid pressure on the site.
- Pressure relief adjuncts such as low air loss beds should be used to prevent development of additional pressure injuries.
- Nutrition status should be closely monitored in the postoperative period to promote good wound healing.
- After wounds are healed, sitting protocols should be used to gradually increase the amount of time spent sitting.
- Pressure relief should be performed every 15 minutes when in the seated position.⁹

OUTCOMES

- Pressure injuries represent a major burden of illness, affecting the quality of life of patients and their families.¹⁰
- For patients at high risk for pressure injuries, it is critical that pressure relief measures—such as specialized support surfaces, frequent repositioning, and efforts to minimize shear, moisture, and spasticity—are adhered to.
- Optimizing nutrition and limiting medical comorbidities are also essential in

avoiding a high likelihood of recurrence.

- High-risk patients should be followed regularly by a physiatrist for evaluation and care.
- Education on prevention and treatment of pressure injuries is critical to successful outcomes.

COMPLICATIONS

- Hematoma
- Seroma—important to maintain suction drain beneath reconstruction until minimal output
- Wound dehiscence—if small, may heal with local wound care and offloading pressure
- Wound infection
- Recurrence is high if patients who are noncompliant or do not have medical management optimized preoperatively are at high risk of postoperative recurrence.

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CHAPTER Pressure Injuries

Lawrence J. Gottlieb and Maureen Beederman

DEFINITION

- A pressure injury is a soft tissue injury due to the complex interplay of tissue deformation, stress, strain and ischemia from unrelieved pressure, shear, and friction typically overlying bony prominence.¹
- The standard for classifying pressure injuries is based on the four grades originally described by Shea in 1975.²
- Grades I and II have potentially reversible acute inflammatory reactions involving all soft tissue layers; grade III has full-thickness tissue loss, extending to fascia; and grade IV extends through the deep fascia to bone.
- Skin loss in grades I and II is thought to be more likely due to shear, friction, and maceration rather than pressure per se.
- Over time, refinements have been made to this classification with the most recent being a six-stage classification by The National Pressure Ulcer Advisory Panel during their 2016 Staging Consensus Conference.³

ANATOMY

- Pressure injuries typically occur over bony prominences and are dependent on patient positioning.
 - Supine: greatest pressure overlying heels, sacrum, occiput, and scapula
 - Sitting: greatest pressure at ischial tuberosities, elbows
 - Lateral decubitus: greatest pressure over greater trochanters (often accompanied by hip flexion contractures), fibular head, and malleoli
- Pressure injuries also occur due to inadvertent pressure from external objects pressing on the skin (ie, IV connectors, side rail of bed pressing on the skin or small object in shoe of the patient with neuropathy) or securing devices too

tight (ie, nasal tubes, CPAP devices).

- Extrusion of internal objects (ie, hardware or internal prosthetic or tubing) is generally caused by the same pathophysiology of classic pressure injuries over bony prominences.

PATHOGENESIS

- Unrelieved pressure
 - External pressure greater than capillary pressure leads to decreased blood flow and tissue ischemia, eventually causing tissue necrosis.
 - Pounds-per-square-inch pressure highest in thin patients over bony prominences. Obese patients are able to distribute pressure better.⁴
- Reperfusion injury
 - Tissue loss after restoration of blood flow and generation of oxygen free radicals after relief of pressure
- Deformation injury of cells
 - Local cell damage and death
- Tissue breakdown may also occur due to
 - Friction
 - Shearing forces
 - Moisture/maceration
- Tissue breakdown is more likely with circulatory disturbances.
- The presence of infection and edema can influence the wound environment and ultimately the extent of necrosis.

NATURAL HISTORY

- Pressure injuries are “inside-out” injuries caused by soft tissue damage from unrelieved pressure on the skin, typically overlying bony prominences.
- Tissues most sensitive to pressure die first.
 - Nerve and muscle are the most sensitive to ischemia from pressure, which is why there is no muscle or major nerves between the skin and bony prominences in any area of the body.
 - Subcutaneous fat dies first in the typical pressure injury occurring over bony prominences.
 - Skin is one of the most resistant tissues to pressure. The earliest changes seen in the skin (ie, swelling and erythema of stage 1 pressure injuries) generally reflect injury to the tissues beneath.
 - Skin breakdown without underlying tissue loss (stage II) is generally due to

shearing, friction, and maceration and not pressure per se.

- The tissue type most resistant to pressure is fascia, which has very low metabolic demands.
- “Iceberg effect”: by the time that there is any evidence of pressure injury in the skin, there is significant tissue destruction beneath; the skin findings are only the “tip of the iceberg.”
- Although pressure injuries are typical in debilitated, immobile, and/or insensate patients, they are not inevitable and indeed should be preventable in most situations.
- Prevention is directly related to educating and motivating patients and or caregivers in
 - Recognizing risks in various situations
 - Pressure-relief training
 - Relieving pressure every 15 minutes when seated or for 5 minutes every 2 hours when in decubitus position will generally prevent pressure injuries.
 - Providing resources (eg, cushions for seats)
 - Compliance
- Change in caregivers and/or intermittent psychological disturbance (such as depression) correlate with pressure injury development and recurrence.
- Evaluation and coordination with a rehabilitative team preoperatively leads to the least incidence of recidivism.^{5,6}

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients at risk
 - Patients with diminished mobility
 - Paralyzed patients
 - Spinal cord injury, disease, or dysfunction
 - Patients under anesthesia or deep sedation during surgery or undergoing procedure or treatment requiring prolonged immobilization (eg, ECMO)
 - Patients requiring others to move them
 - Patients with quadriplegia
 - Patients who are debilitated due to cerebral dysfunction (stroke, intoxication, infection)
 - Debilitated patients in acute care and long-term care facilities
 - Patients with diminished sensation
 - Spinal cord injury, disease, or dysfunction

- Peripheral neuropathy
- Assess for muscle spasticity, which increases the risk of shearing forces and friction and postoperative healing issues if not controlled.
- Assess for joint contractures, which make avoiding pressure on bony prominences very difficult for health care providers.
- Assess for tunneling and pseudobursa formation.
- Assess for involvement of joint spaces and other adjacent structures.
- Assess for bone exposure.
- Assess for infection: soft tissue and bone.
- Assess for urinary tract infections, in patients with spinal cord dysfunction.
- Assess patient and caregiver knowledge, home resources, likelihood of being compliant, and potential social/psychological issues, all of which can affect incidence of recurrence.

IMAGING

- X-rays are helpful for assessment of osteoporosis, fractures, and heterotopic ossification.
- Radionuclide bone scans are helpful in assessing activity of heterotopic ossification.
- MRI is the best diagnostic imaging to evaluate for acute osteomyelitis; however, bone biopsy remains gold standard for the diagnosis of osteomyelitis.
- CT scan or MRI and sinograms are helpful to evaluate for sinus tracts, fluid collections, and tunneling in the pelvis or possible involvement of rectum.

NONOPERATIVE MANAGEMENT

- Nonoperative management of pressure injuries is appropriate in patients who
 - Are prohibitive surgical risk due to comorbidities
 - Demonstrate that they would not be compliant with postoperative regimens
 - Need to be prepared for possible operative management in the future
- Optimize nutrition (sufficient protein, vitamins/minerals).
- Monitor prealbumin levels.
- Check vitamin D levels.
- Promote optimization of general medical care.
- Evaluate cardiovascular, pulmonary, and genitourinary systems.
- Promote smoking, alcohol, and drug cessation.
- Promote treatment of depression.

- Optimize wound conditions.
 - Quantitative bacteriologic assessment of wound with wound tissue biopsy
 - Pathologic assessment of long-standing (more than 5 years) wounds with wound tissue biopsy
 - Offloading/frequent turning for pressure relief
 - Air mattresses/cushioning
- Provide patient and caregiver education.
- Prevent spasticity.
 - Medical management: baclofen, dantrolene, diazepam, botulinum toxin
 - Surgical management: rhizotomy, baclofen pump, peripheral nerve blocks
- Infection control
 - Assess colonization vs infection of wound using quantitative cultures.
 - If quantitative culture shows greater than 10^5 organisms per gram, use a topical antimicrobial (eg, silver sulfadiazine, mafenide acetate, dilute hypochlorite solution).
 - If unable to control bacteria with topical, it may need surgical debridement.
 - Systemic antibiotics used for treatment of cellulitis, osteomyelitis, or joint space infections as well as for any distant infection of genitourinary or respiratory tracts
 - If repeat quantitative culture shows greater than 10^5 organisms per gram, consider additional debridement and/or change in topical antibiotic treatment prior to definitive closure.

SURGICAL MANAGEMENT

- All patients are candidates for surgical debridement, but not all patients are candidates for surgical closure.
 - Candidates for closure should demonstrate (along with their caregivers) an understanding, commitment, and motivation to prevent future injuries.
 - In addition, they must demonstrate compliance with nonoperative management (including nutrition, pressure relief, and wound care) and have the necessary resources available prior to definitive surgical closure.
 - Evidence of improvement of wounds with nonoperative management is a good indicator that patient/family are motivated, have the appropriate resources, and will likely abide by postoperative protocols.
- Surgical options for pediatric patients and adult patients are similar.
 - Consider whether child (or adult) has the potential to become ambulatory in

the future when deciding best reconstructive option.

- Optimize nutrition, minimize muscle spasms, and obtain bacteriologic balance in the wound prior to definitive surgical closure.
- Ensure that adequate debridement is performed prior to definitive closure.

Preoperative Planning

- Preoperative evaluation and coordinating with the multidisciplinary rehabilitative team that will care for patient postoperatively has been shown to minimize recurrence.^{5,6}
- Assess location, size, and depth of wound.
 - Is there a pseudobursa that needs resection?
 - Is there a bony prominence that needs to be flattened?
 - Is there evidence of osteomyelitis?
 - Does it need to be resected?
 - Is there heterotopic ossification?
 - Does it need to be resected?
- Review previous surgical interventions and incisions.
- Consider ambulatory status of the patient.
- Plan closure with skin graft or flap depending on location of wound and goal.
 - If the wound is amenable to closure with a graft, is it the best technique to use or would a flap give a better result?⁷
 - If a flap is chosen; determine whether it should be a muscle, musculocutaneous, fasciocutaneous, cutaneous, or perforator flap.
- Plan obliteration of anticipated dead space.
- Plan flaps with the understanding that recurrence of pressure injuries is frequent and the ability to reuse a flap is frequently helpful.

Positioning

- Need to ensure that all bony prominences and pressure points are protected and padded to avoid creating new pressure injuries during surgery.
- Posterior wounds are generally best positioned prone but may be put in lateral decubitus position if needed.
 - Airway needs to be secured well.
 - The hips should be flexed for inset of thigh-based flaps.
- Ischial injuries may be addressed in lithotomy position.

Approach

- Adequate debridement includes removal of the pseudobursa and all necrotic, devitalized, and infected tissue as well as removal of all scars if possible.
- Preliminary bedside debridement can be helpful to obtain tissue cultures and decrease the wound burden of nonviable tissue.
 - Long-standing (greater than 5 years) wounds should be biopsied to rule out Marjolin ulcer.
- Bedside debridement is rarely adequate because of inability to remove all dead tissue without too much bleeding or pain in patients with sensation.
- The use of methylene blue dye during operative debridement will assist in removing pseudobursa and ensuring all surface tissue is removed, especially in irregular wounds with tracts and tunneling.
- Bony prominences should be flattened.
- All nonbleeding infected bone should be removed.
- Pre- and postdebridement tissue cultures should be obtained of soft tissue and bone.
- Many patients require more than one operative debridement to optimize the wound or allow for optimization of a systemic condition prior to definitive surgical closure.
- Once a wound is adequately debrided, determine if the next goal is to close the wound or to reconstruct the part.

TECHNIQUES

- Closure should be preceded by adequate debridement.
- The techniques below describe typical debridement techniques and examples of closure or reconstructive options utilizing standard principles and concepts.

■ Surgical Debridement

- Paint the wound (and/or inject sinuses) with methylene blue dye to stain the pseudobursa, granulation tissue, and other surface tissue to ensure complete removal (**TECH FIG 1A,B**).
 - This is particularly important in irregular wounds with tracts and tunneling.
- An incision should be made through normal skin circumferentially around

the wound (**TECH FIG 1C**).

- Incision should be carried down through normal subcutaneous tissue, beneath all blue-stained as well as indurated tissue and scar converging on any bony prominences if present.
- Wounds that have bony prominences such as ischial and trochanteric pressure injuries should have these prominences flattened, typically with an osteotome.
- Pre- and postdebridement samples of soft tissue and bone should be sent for quantitative bacteriologic assessment.
- Postdebridement bone biopsy samples should be sent for pathologic assessment to rule out osteomyelitis.
- The entire debrided wound should be sent for pathologic assessment, especially in long-standing chronic ulcers (**TECH FIG 1D**).

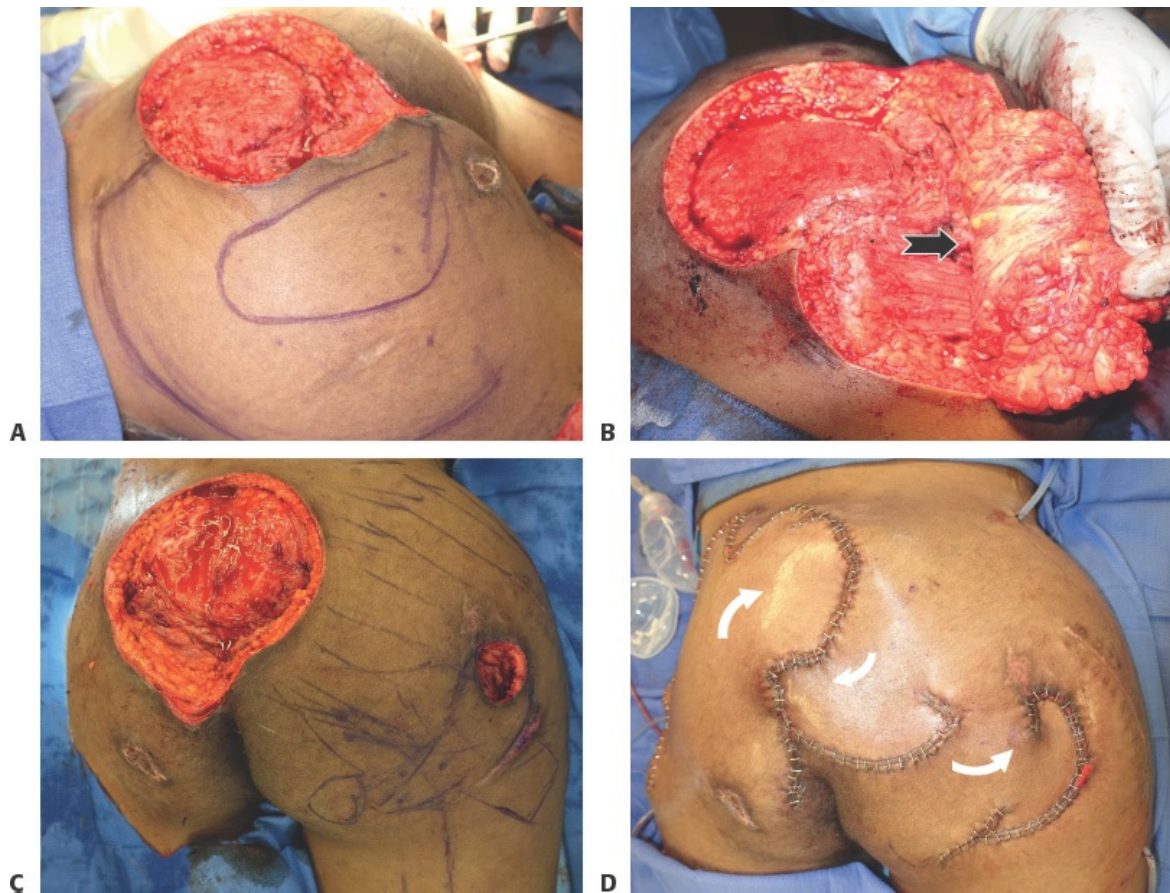


TECH FIG 1 • Debridement. **A.** Sacral and trochanteric pressure injuries after bedside

debridement. **B.** After application of methylene blue to help guide debridement. **C.** Immediately after excisional debridement of sacral and trochanteric pressure injuries. **D.** Five weeks later after nutritional repletion.

■ Sacral Pressure Sore Closure

- Sharp surgical redebridement into normal tissue as described above.
- Determine location of perforator vessels with handheld Doppler.
- Large left-sided inferiorly based rotation perforator flap is designed (**TECH FIG 2A**).
- Incisions are made and the flap is elevated above the muscle to large medial perforator (**TECH FIG 2B,C**).
- Skin overlying the left gluteal muscle rotated clockwise to close most of the wound and contralateral skin overlying the right inferior gluteal muscle rotated to close the rest without tension (**TECH FIG 2D**).



TECH FIG 2 • Sacral and trochanteric pressure injuries. **A.** Design of the left superior gluteal perforator fasciocutaneous rotation flap. **B.** Flap elevated. *Arrow* points to perforator. **C.** Design of the right inferior gluteal myocutaneous flap. **D.** Sacral and right trochanteric pressure injuries closed. *Arrows* demonstrate direction of skin rotation.

■ Ischial Pressure Sore Closure

- Sharp surgical debridement into normal tissue as described above.
- Previously used left posterior thigh flap, based on the descending branch of the inferior gluteal artery, was re-elevated and transposed, and along with a gluteal perforator rotation flap, the left ischial pressure sore was able to be closed.
- Right ischial pressure sore closed with a crescent VY inferior gluteal

myocutaneous flap with distal muscle extension to be “tucked” underneath to fill dead space (**TECH FIG 3**).



TECH FIG 3 • Bilateral ischial pressure injuries. **A.** Left side recurrent, note design of previous posterior thigh flap. **B.** After debridement. **C.** Design of right ischial closure with inferior gluteal myocutaneous flap with the skin designed to be moved as a V-Y and muscle extension to be folded under to fill dead space. **D.** Inferior gluteal muscle before it is folded under to fill

dead space. **E.** V-Y closure of cutaneous portion of flap. **F.** Six-month follow-up of left ischial closure by transposing previous posterior thigh flap and right with inferior gluteal myocutaneous flap.

■ Medial Inframalleolar Perforator Flap

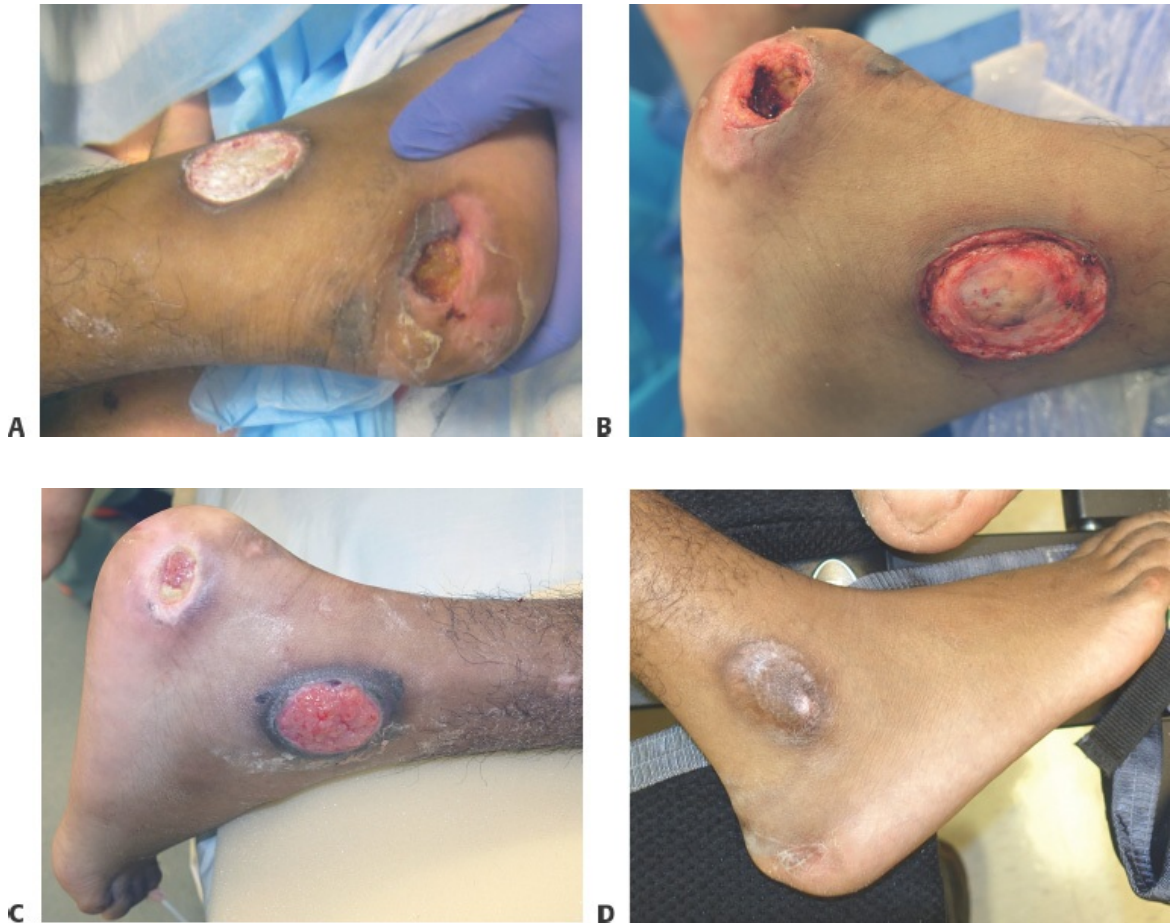
- After determining location of perforator vessels and direction of venous flow, the flap can be designed with the anticipated pivot point centered over perforator vessels.
- Incision is made and carried down through the subcutaneous tissue.
- The flap is elevated toward the perforator.
 - Transposition of flap is less than 90 degrees, so the perforator vessels do not need to be skeletonized.
- The flap is transposed and inset.
- Donor site is closed with a split-thickness skin graft (**TECH FIG 4**).



TECH FIG 4 • Pressure injury of left medial heel. **A.** Initial eschar. **B.** After debridement. **C.** Design of medial inferior malleolar perforator flap. **D.** Elevation of flap (*arrow* points to perforator). **E.** Flap transposed and donor site closed with a skin graft. **F.** Stable closure demonstrated 6 months later.

■ Skin graft

- Flaps are not required for all wounds.
- A well-vascularized wound bed may be closed with skin grafts or allowed to close by secondary intention (**TECH FIG 5**).



TECH FIG 5 • **A.** Right lateral malleolus and heel pressure injuries. **B.** After debridement **C.** Five weeks after wound care and nutritional repletion wound closed with a skin graft. **D.** Six months stable coverage of malleolus. Heel closed by secondary intention.

■ Propeller flap

- After debridement as described above make an incision to verify location of the perforator.
- Elevate the flap and skeletonize the perforator.
- Turned 180 degrees and flap inset (**TECH FIG 6**).



TECH FIG 6 • **A.** Left elbow pressure sore. **B.** After debridement and incision to verify location of

perforator. **C.** Propeller flap elevated. **D.** Propeller flap turned 180 degrees. **E.** Flap inset. **F.** Stable closure demonstrated 6 months later.

PEARLS AND PITFALLS

Debridement	■ All patients are candidates for surgical debridement, but not all patients are candidates for surgical closure. ■ Wide local debridement prior to definitive surgical closure is necessary for successful pressure ulcer coverage.
Methylene blue	■ Paint wound and inject sinuses to help facilitate adequate debridement.
Infection	■ Obtain bacteriologic balance prior to definitive closure. ■ Assess soft tissue and bone by tissue biopsy cultures.
Flaps	■ Flaps should be well vascularized, inset without tension, and able to obliterate dead space. ■ Do not burn bridges with closure options; consider flaps that can be reused if recurrence occurs.
Skin grafts	■ Skin grafts tolerate pressure but do not tolerate shear forces well.

POSTOPERATIVE CARE

- Use perioperative antibiotics only, unless postdebridement cultures are positive.
- Closed suction drains should be used to help obliterate dead space, improve tissue apposition, and minimize fluid collections.
- Patients should be nursed on a specialized mattress, air fluidized bed, or in prone position for 3 to 6 weeks postoperative.
- Gradually progress advancement of activity.
- Control/prevent spasticity.
- Continue optimization of nutritional support.

OUTCOMES

- Despite optimization, recurrence rate is high for many patients.

- Minimize recurrence by working with multidisciplinary rehabilitative team preoperatively and postoperatively.^{4,5}

COMPLICATIONS

- Acute wound breakdown is generally related to poor surgical planning, with either ischemic flap edges or excess tension on suture lines or a complication such as hematoma.
 - Hematomas are thought to be more common in patients with spinal cord injury due to loss of sympathetic vascular tone and inability to vasoconstrict blood vessels.
- Subacute recurrence (wound breakdown) is generally related to failure to obliterate dead space with fluid collection, which may subsequently get infected.
- Delayed recurrence is generally related to inadequate compliance with pressure preventing protocol.

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CHAPTER Vascular Lesions

Benjamin C. Garden and Jerome M. Garden

DEFINITION

- Vascular lesions can be classified into two main categories: proliferative and malformations.¹
- Vascular proliferative lesions are characterized by a proliferation of blood vessels.
 - Infantile hemangiomas are the most common form of vascular proliferative lesions.
 - Other vascular proliferative lesions include kaposiform hemangioendotheliomas, tufted angiomas, and pyogenic granulomas.
- Vascular malformations are characterized by vessels with abnormal structure and normal endothelial cell turnover. Types of malformations include capillary, venous, lymphatic, arterial, and arteriovenous malformations (AVMs).
 - Capillary malformations include nevus simplex (salmon patch) and nevus flammeus (port-wine stain, PWS).
 - Venous malformations (VM) are a fairly common slow-flow type of vascular malformation present at birth. Various names used to describe these lesions include venous angioma and cavernous angioma.
 - Lymphatic malformations (LM) are composed of interconnected lymphatic channels.²
 - Older terminologies used include cavernous lymphangioma, lymphangioma circumscriptum, and cystic hygroma.
 - LM can be further differentiated into macrocystic and microcystic depending on the size of the involved channels.
 - AVMs are rare vascular malformations consisting of both arterial and venous

components with AV shunting.²

ANATOMY

- Vascular lesions may occur on any cutaneous surface but are most commonly found on the head and neck.
- Hemangiomas have been noted to have a nonrandom distribution, with the majority of lesions occurring on the central face at sites of development fusion.³
- Capillary malformations are often, but not always, unilateral.

PATHOGENESIS

- Hemangiomas are thought to occur due to a first-trimester developmental error regarding angiogenesis or a result of embolized placental cells. There is a suggested autosomal dominance inheritance.⁴
- Although their exact cause is unknown, PWSs evolve due to a progressive ectasia of the superficial vascular plexus. This progression is likely due to an abnormal neural regulation of blood flow. PWSs have significantly less nerve density and a higher vessel to nerve ratio.⁴

NATURAL HISTORY

- Infantile hemangiomas become evident in the first weeks of life and exhibit a proliferative phase, with continued growth, until around 8 to 12 months. This is followed by a plateau phase, followed by a period of spontaneous regression as the lesion involutes.
- Initial involution is usually noted with a color change from the original bright red to dull red or gray.
 - It is estimated that completed involution occurs at a rate of 10% per year, such that 30% have involuted by 3 years of age, 50% by 5 years of age, and greater than 90% by 9 to 10 years of age.³
 - These lesions occasionally have residual changes, including telangiectasias, atrophy, scarring, or fibrofatty material.
- Ulcerations occur in 5% to 13% of infantile hemangiomas.
 - Most frequent locations include the lip, perineum, and intertriginous areas.
 - Ulcerations are painful, increase the risk of infection, and can cause scarring and textural changes.³
- Vascular malformations tend to be present at birth and persist for a lifetime.
- PWS may darken progressively over many years, and occasional lesions

develop secondary vascular blebs on their surface. They may also become hypertrophic later in life.

- VMs are present at birth but may not become obvious until later in life. Occasionally, a patient first notices the lesion after trauma to the overlying area. In those cases, the trauma may cause the underlying vessels to temporally enlarge allowing the patient to notice it for the first time.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation for patients with vascular lesions includes a detailed history and exam to determine the type of lesions and to assess the risks of the patient having any associated complications or syndromes.
- Infantile hemangiomas may occur as superficial, deep, or mixed lesions.
- Superficial lesions tend to appear as bright red nodules or plaques (**FIG 1A**).



FIG 1 • **A.** Superficial infantile hemangioma. **B.** Port-wine stain. **C.** Venous malformation. **D.** Mixed microcystic lymphatic and venous malformation.

- Deep hemangiomas are subcutaneous nodules, and usually present with an overlying blue hue, venous network, or telangiectatic vessels.

- Hemangiomas in certain locations may suggest a higher probability of complications or associated findings.³
 - With periorbital hemangiomas, an ophthalmologic examination is generally recommended in many cases.
 - Larger lesions of the beard area require evaluation for potential airway obstructions.
 - Hemangiomas on the tip of the nose, the lip, and the parotid areas can have very slow involution periods.
- PWSs are normally easy to recognize with their well-defined red macular stains (**FIG 1B**). They do not proliferate, but will grow proportional to the child's growth. Patients with PWS should be assessed for any associated syndromes that would necessitate additional referrals.
 - The most common syndrome is Sturge-Weber syndrome (SWS), which most commonly occurs with a PWS occurring in the distribution of the ophthalmic branch of the trigeminal nerve (V1).
 - PWS can be associated with many other syndromes including Klippel-Trenaunay, Parkes-Weber, Proteus, Cobb, Rubinstein-Taybi, and Beckwith-Wiedemann syndrome.
- VMs usually present as blue to purple nodules in the skin (**FIG 1C**). They may have prominent surrounding veins and calcified phleboliths within the lesion. These lesions may expand with dependent drainage of venous blood; this may be elicited by placing the patient in the Trendelenburg position or by performing the Valsalva maneuver.²
 - Most VM are asymptomatic, although they may occasionally become painful in association with their gradual enlargement and pressure on surrounding structures.
 - They may be found in association with syndromes, including Maffucci and blue rubber bleb nevus syndrome.
- Macrocystic LMs, sometimes referred to as cystic hygromas, present as large, translucent masses under normal-appearing skin. Microcystic LM usually present as erythematous to flesh-colored papules, which may be somewhat translucent, and have traditionally been compared to the appearance of frog spawn (**FIG 1D**).
- AVMs may be clinically pulsatile and warm and have a thrill. They present as a vascular stain at birth, with increasing erythema and size with age. They can spontaneously bleed.

IMAGING

- One should strongly consider doing a liver MRI in those patients having five or more hemangiomas due to the increased potential of having visceral lesions.³
- Large segmental facial hemangiomas should prompt imaging to assess possible PHACES syndrome:
 - *Posterior fossa malformations*
 - *Hemangiomas*
 - *Arterial anomalies*
 - *Coarctation of the aorta*
 - *Eye abnormalities*
 - *Sternal or supraumbilical raphe*
- Perineal hemangiomas should prompt evaluation for PELVIS syndrome:
 - *Perineal hemangiomas*
 - *External genital malformations*
 - *Lipomyelomeningocele*
 - *Vesicorenal abnormalities*
 - *Imperforate anus*
 - *Skin tags*
- In patients with a PWS, imaging may be necessary if there is concern for a related syndrome, such as SWS. MRI is the preferred screening modality of SWS. Patients with a vascular malformation located in the midline lumbar location may have an underlying AVM, as seen in Cobb syndrome, which would be imaged by an MRI.
- VM can be confirmed or the depth of involvement can be ascertained with MRI with and without contrast.

NONOPERATIVE MANAGEMENT

- Generally, appropriate treatment for infantile hemangiomas is nonintervention.⁵ However, in those lesions where there is high visibility, social concern or functional impairment, as well as complications such as ulceration, infection or bleeding, therapy may be warranted.^{4,6}
 - Topical timolol can be useful in the treatment of superficial hemangiomas.
 - Treatment using oral propranolol may be indicated for functional impairment, significant ulceration, or lesions with potential for significant disfigurement.
 - Topical wound care is also necessary for ulcerated lesions.

SURGICAL MANAGEMENT

- Lasers are designed to deliver energy precisely into the target chromophore with minimal damage to surrounding tissue.
- To keep the laser from causing widespread damage to other tissues, the laser exposure should occur faster than the amount of time it takes for the heat to extend significantly beyond the target.
- Safe and effective heating occurs using a pulse duration equal to or less than the target's thermal relaxation time (TRT). TRT is the amount of time for the tissue to lose half the heat gained from the laser.
 - For PWS, the target venules have a TRT of tens of milliseconds.⁴
- Surgical intervention with lasers for hemangiomas should be used cautiously but can be very helpful, especially for lesions in areas of high visibility or areas of high risk for ulcerations, such as the anogenital area.
- Laser treatment of ulcerated hemangiomas can lead to decrease in pain and more rapid healing. However, care must be taken because aggressive laser treatment can occasionally induce ulcerations.
- Lasers can also be used for the treatment of involuted lesions with residual telangiectasis or residual dermal vascular involvement.⁷
- Lasers can be used successfully in conjunction with propranolol.⁸
- Excisional surgery of hemangiomas can lead to a more unsatisfactory result than an untreated lesion, and therefore, the risks and merits of surgical intervention should be discussed with the family and surgical removal performed on a case-by-case basis.
- PWS should be treated with laser surgery as early as possible with the natural evolution of these lesions to become more hypertrophic over time. Additionally, children younger than 1 year seem to have the most effective lightening and require fewer treatments than older patients.⁴
- One should note that laser surgery can be helpful in treating PWS, but some PWSs can partially recur over an extended period of time with aging.
- PWS lesions on the periorbital region, midforehead, lateral cheeks, chest and proximal arms respond best to treatment, whereas the other areas are more resistant.⁶
- The superficial components of VMs may be treated with laser therapy. However, more extensive malformations may be treated via sclerotherapy prior to eventual surgical excision.²
- Carbon dioxide lasers used in a nonfractional mode can be used to treat the

superficial blebs of lymphatic lesions, vaporizing the tissue nonselectively and sealing the lymphatic channels.

- Embolization and surgical resection are the mainstay of treatment of AVMs.

Preoperative Planning

- A pretreatment consultation is advisable to discuss potential lesional response, number of treatments, expected and potential adverse effects, and aftercare.
- Visual examination of lesion and of patient skin type assists in planning of laser treatment. Optimal coherence tomography, three-dimensional photography, and reflectance spectrophotometry are newer technologies that are being evaluated to assist in objective quantification of preprocedure and postprocedure lesional depth, volume, and color.⁹
- Patients should be advised to practice strict sun protection for at least 4 to 8 weeks prior to treatment. Treatment of a patient with a tan can result in permanent hypopigmentation.
- Patients with darker skin are at risk for hypopigmentation and hyperpigmentation.
- An assessment of the child's ability to tolerate treatment should be made prior to choosing an anesthesia option. Options include topical, intralesional, and general anesthesia.
 - Although topical anesthetics such as topical liposomal lidocaine and a eutectic mixture of local anesthetics (EMLA cream, 2.5% lidocaine/2.5% prilocaine) have been used, topical anesthetics may cause significant blanching of the vascular lesions, making them more difficult to be effectively treated with the laser, as there is less hemoglobin to act as a target chromophore.
 - Special care should be used with prilocaine in infants as it is associated with an increased risk of methemoglobinemia.
 - Most infants less than 1 year of age are restrained and treated without general anesthesia.
 - General anesthesia is appropriate in older children. However, general anesthesia also may be associated with blanching of the lesion. Care should be taken to limit the use of the general anesthetic to as low a dose as safely possible to reduce blanching.^{6,9}
- Photographs should always be taken before the initial treatment. Photographs before subsequent treatment sessions to the same area are at the discretion of

the clinician.

- Flammability is a risk when using lasers. Water or clear non-alcohol-based viscous lubricants can be used to diminish singeing terminal hairs.

Positioning

- The patient should be placed in a position that allows the clinician to manipulate the laser handpiece without difficulty.
- Infants and young children, who will be undergoing the treatment without general anesthesia, are recommended to be held and restrained with a bear hug by a parent or assistant. Placing an infant in a papoose may be of help in addition to immobilization by an assistant.

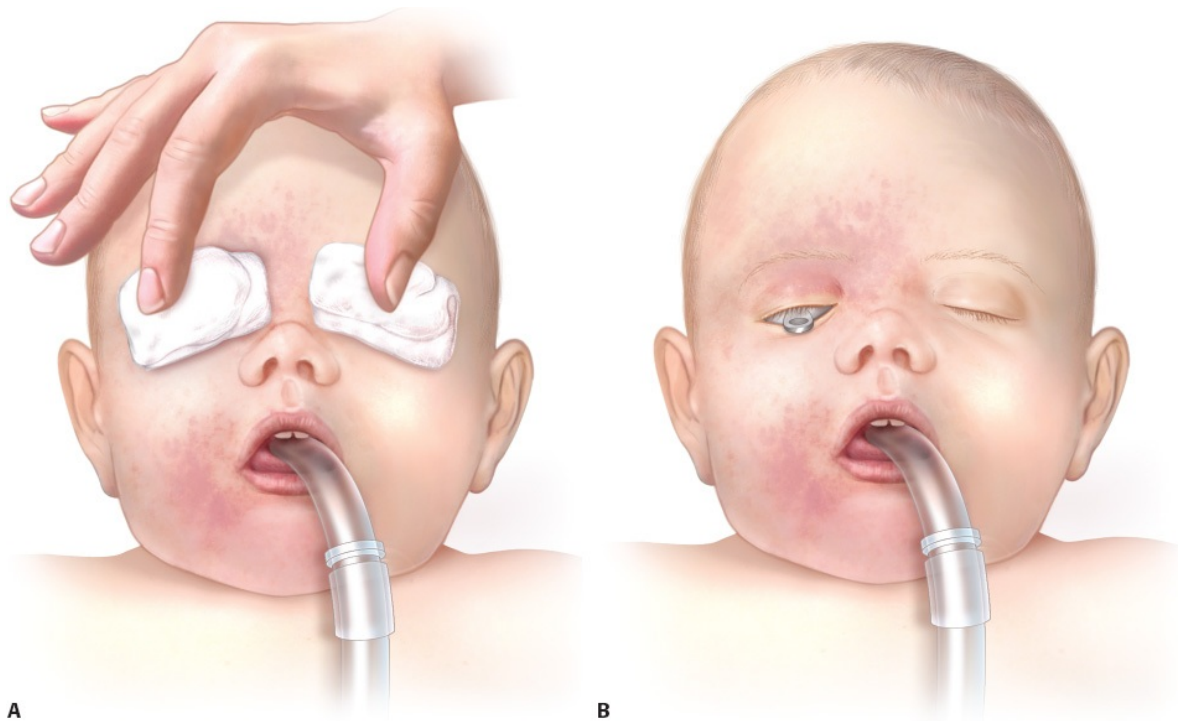


FIG 2 • A. Overlapping white gauze held with a firm hand should be used to cover the periorbital area in young children in whom the protective eye glasses would be too large. **B.** Globe eye shields should be used when lasering close to the orbit. Note the postoperative purpura from the pulsed dye laser.

- Everyone present must use appropriate eye protection during laser treatment.

- Most glasses and goggles may be too large for small children.
- Overlapping white gauze held with a firm hand should be used to cover the periorbital area, as these will reflect laser light (**FIG 2A**). The gauze should be moistened with water if used with general anesthesia. Pressure should be placed on the orbital rim and not on the eye itself.
- Globe eye shields must be used if lasering close to the eye (**FIG 2B**).

Approach

- The most commonly used laser for superficial or ulcerated hemangiomas is the pulsed dye laser (PDL). Suggested settings are dependent on the various chosen parameters and may include wavelengths of 585 to 595 nm, fluences of 4 to 8.5 J/cm², pulse durations between 0.45 to 3 ms, spot sizes of 5 to 10 mm, and a concomitant cooling device.
 - Deeper parts of the lesion can respond to long-pulsed Nd-YAG or alexandrite lasers, although there is a higher risk of scarring and pigmentary complications.
 - The PDL is the most commonly used laser for PWS treatment. General settings to be used could include 585 to 595 nm for wavelength, 5.5 to 11 J/cm² for fluence, 0.45 to 3 ms for pulse duration, and 7 to 12 mm for spot size. Lasering is most safely performed in combination with epidermal cooling (Table 1).
 - A larger spot size allows the laser beam to penetrate deeper into the lesion. However, lower fluences are used for larger spot sizes to maintain a high safety profile.
 - Changing the pulse duration may allow targeting of different sized vessels. Treatment often begins at 1.5 ms, and this can be adjusted down to 0.45 ms and up to 3 ms. Lower fluences are required for shorter pulse durations.
 - PWS have a nonuniform response to laser surgery, likely due to variously sized blood vessels, different flow rates, and different depths of involvement.
 - One should not use a cookbook approach to the settings used. Each lesion is unique. It is strongly recommended that test sites be placed with each patient. Or, if there are overriding reasons not to place test sites, initially use only very low-energy parameters for the first treatment, especially in infants. If one is in such a situation that limits the placement of test sites, one may treat a larger area at a low-energy setting and place discreet test sites with slightly higher settings during the first treatment session.
-

Table 1 General Settings Used With Pulsed-Dye Laser

Vascular lesion	Wavelength (nm)	Fluence (J/cm ²)	Pulse Duration (ms)	Spot Size (mm)
Hemangioma	585–595	4–8.5	0.45–3	5–10
Port-wine stain	585–595	5.5–11	0.45–3	7–12

- For older patients who prefer a treatment without purpura, one can use an intense pulsed light (IPL) device (**FIG 3**). These systems are less safe around the eyes and with higher skin types. Each IPL system is manufactured differently and is applied in a unique approach appropriate to the particular system. It is recommended to be very familiar with the device that is to be used and always place test sites.



FIG 3 • Use of an intense pulsed light (IPL) device on a partially treated port-wine stain.

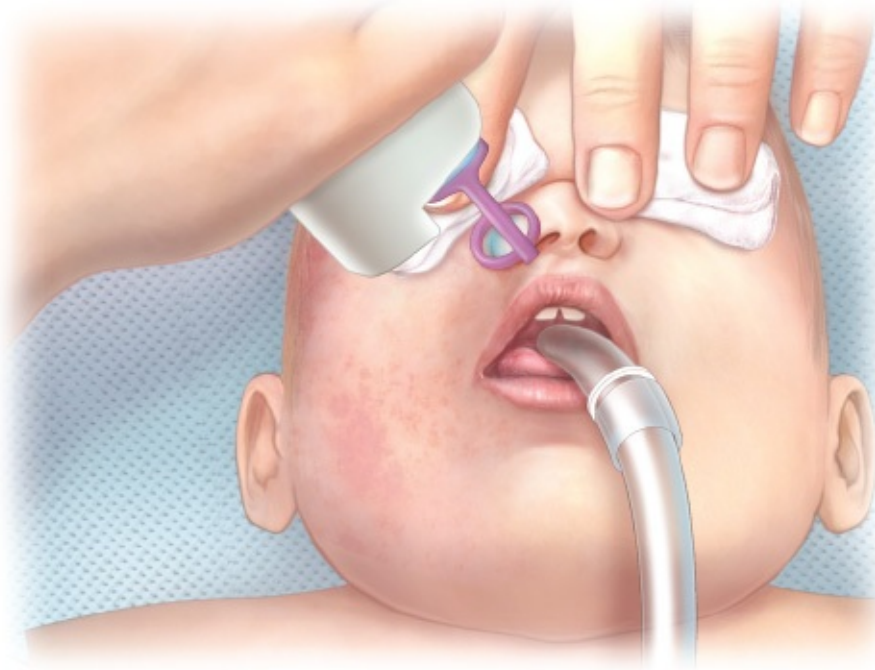
TECHNIQUES

■ Test Sites

- One should perform test sites prior to treatment of the entire lesion. In larger lesions, especially over multiple anatomical regions, test pulses should be performed over the various regions and clinical lesional variations. Patients are evaluated dependent on their age anywhere from 4 to 8 weeks after test site placement to assess response of the test sites.

■ Laser Treatment of Vascular Lesion

- Once the clinician has determined appropriate settings from the test pulses, one can treat the entire lesion. If the test site outcomes were not decisive, one should not hesitate to place additional test sites with even the same and other parameters until one feels comfortable proceeding. One often treats different anatomical regions with different parameters. Even the same anatomical region may be treated with different parameters dependent on symmetry of lesional involvement.
- In those patients having ill-defined borders and especially for those patients receiving general anesthesia that induces fading of the lesions, prior to treatment, it may be helpful to outline the borders of the lesion. Place the outline marker slightly beyond the margin of the lesion because the marker material itself may absorb laser energy resulting in undesired damage to the skin.
- The laser handpiece should be pressed gently, perpendicularly, against the skin (**TECH FIG 1**). Avoid aiming tangentially at the skin, as this may alter the fluence and the cooling device effectiveness.
- To regulate the amount of laser energy impacting the skin, thus reducing the chance of undesired adverse effects, only single passes are generally placed with pulsed dye laser and intense pulsed light (IPL) systems. Pulse overlap should also be avoided or at least limited to less than 10% overlap.
- Throughout the treatment, the clinician should always be monitoring the tissue for the desired tissue changes such as tissue darkening or edema. When there is any deviation, stop the procedure and check the laser and parameters or reassess the lesional area being treated. In those patients who are not anesthetized and are old enough to give reliable feedback, a change in pain level is also an indicator that parameters should be reconsidered. Ask the patient to inform the clinician if there is any change in baseline procedural discomfort.



TECH FIG 1 • The laser handpiece should be pressed gently, perpendicularly, against the skin. Note the physician is protecting the patient's eye with white gauze.

PEARLS AND PITFALLS

Eye protection

- For children, cover the periorbital area using overlapping white gauze held firmly.
- Pressure should be placed on the orbital rim and not on the eye itself.
- If there is use of inhalation anesthesia, the gauze should be thoroughly wetted with water or saline. Tape or similar nonflammable material may be placed on the closed eyelid to ensure it remains closed.
- With any lasering near or into the orbital rim, a full global eye shield should be placed.

Clinical endpoint

- Always pay attention to tissue response to each pulse.
- Any deviation from previous responses or blistering or vesiculation is a cause of serious concern, mandating stopping the procedure and

	reassessing the laser and parameters.
Therapeutic outcome	■ Ideally, total lesional resolution is desired. With port-wine stain vascular malformations, this is achieved only in a small minority of cases after a series of many treatment sessions. ■ If after an initial trial no further lesional regression is accomplished, it is probable that one has achieved the maximum lesional reduction possible with the current therapeutic approach. Either another approach should be tested or therapy should be suspended, and the family should be informed of the ineffectiveness of further therapy using the current approach.
Skin color	■ The higher the skin type the greater is the absorption of laser energy by melanin in the epidermal layer and the increased chance of cutaneous damage resulting in permanent hypopigmentation. ■ This concern is greatly enhanced if the patient has additional coloring from the sun. Since even a modest amount of darkening from the sun is associated with a significant increased risk, do not treat patients who have any appreciable color from the sun. Wait for it to fade.

POSTOPERATIVE CARE

- After treatment, all patients experience local swelling and discomfort. The discomfort is transient with the intensity dramatically reducing over the first 30 to 60 minutes. Ice packs, cooling gels, and nonsteroidal anti-inflammatory medications may minimize discomfort.
- Patients should practice proper sun protection for weeks after the treatment to minimize risk of pigmentary changes.
- Emollients should be applied routinely until clearing of the immediate postlaser changes.
- Topical antibiotics should be initiated if crusting or scabbing occurs, as these can raise risks of secondary bacterial infection.
- Postadjuvant antiangiogenesis therapy is currently being evaluated. Treatment with topical imiquimod 5% and topical rapamycin in between laser treatments has been shown to prevent reformation and reperfusion of blood vessels in small trials.^{10,11}

OUTCOMES

- Approximately 20% of PWS can be lightened completely or almost completely with the PDL. About 70% will lighten by more than 50% and about

10% to 20% of lesions will only respond minimally.¹²

- For best results, vascular lesions will require multiple treatments. Very rarely does a lesion clear after a few sessions. Typically, lesions would be treated for at least 8 to 10 treatments at a minimum of 4- to 12-week intervals.
- More resistant or hypertrophic PWSs may not respond to PDL and may be better suited for treatment with longer wavelength lasers. Proven lasers include the long-pulse alexandrite (755 nm), long-pulse 1064 nm Nd-YAG, and dual 595 nm/1064 nm lasers. These lasers are only recommended for skilled laser surgeons, as there is a very small therapeutic window, and the risk of scarring is higher.^{4,6,9}

COMPLICATIONS

- Skin darkening usually will develop immediately with PDL treatment and may persist for 10 to 14 days.
- Transient erythema and swelling typically persists for 4 to 8 days with the PDL and less with the IPL.
- Blistering and crusting can also develop, more commonly with higher fluences or with overlapping pulses.
- Transient or permanent hyper- and hypopigmentation can occur, especially in darker-skinned patients and if one treats patients with a tan.
 - Pigmentary risks can be reduced in darker skin types with using appropriate epidermal cooling, longer pulse durations and lower fluences. Treatment efficacy is also likely to be reduced when using longer pulse durations and lower fluences.
- Alopecia can occur if using lasers in areas that have pigmented hairs. Care, especially over the eyebrows, is necessary to prevent permanent hair loss.
- The risk of scarring after PDL treatment of PWS is very low (less than 1%). These risks can be minimized by using test sites.

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CHAPTER Laser Burn Scar Revision

C. Scott Hultman and Yuen-Jong Liu

DEFINITION

- Mortality from burn injury has markedly decreased in the second half of the 20th century as wound sepsis, wound coverage, kidney failure, and shock have been largely overcome.
- Burn injury is the result of high-energy transfer to a significant surface area of the skin or soft tissues and can be categorized by the form of energy:
 - Contact with high temperature solids (contact), liquids (scald), or gases (flame)
 - Contact with low temperatures (frostbite)
 - Exposure to chemicals (acids, alkalines, or other caustic reagents)
 - Electricity
 - Friction or abrasion
- Burn wounds frequently heal in the form of hypertrophic scars, which hamper functional and aesthetic outcomes.
- Symptoms include pruritus, burning pain, and hyperesthesia, which may be treated with antihistamines, narcotic analgesics, and non-narcotic analgesics.
- Functional deficits may vary from tightness or tethering of the surrounding skin to contractures that limit range of motion.
- Hypertrophic burn scars may be erythematous due to hypervascularity.
- Treatments include occupational therapy, physical therapy, compression garments, moisturizing agents, sunblock, and scar massage.^{1,2}
- Evidence for the efficacy of laser therapy in the treatment of hypertrophic burn scars is now well documented in individual cohort studies,³ review articles,⁴ and a rigorous meta-analysis of 28 well-designed clinical trials.⁵

- The exact biologic mechanism for improvement has yet to be elucidated, but pulsed dye laser (PDL) improves the inflammatory component of hypertrophic burn scars, which have excess pathologic vascularity, whereas fractional carbon dioxide (CO₂) laser improves remodeling of dermal collagen, which is disorganized and abnormal in hypertrophic burn scars.
- Best practices involve six to eight laser sessions, performed every 4 to 6 weeks, using a combination of these two lasers, plus on occasion the Alexandrite laser, to ablate hair follicles in cases of chronic folliculitis of the burn scar.
- Substantial, rapid improvement in hypertrophic burn scars is now observed through objective measures, such as the Vancouver Scar Score (height, erythema, pliability), as well as subjective reports, such as the UNC 4P Scar Score (pruritus, paresthesias, pliability, and pain).⁶
- A major benefit to both the patient and the payer is that multiple, minimally invasive laser sessions may decrease or prevent the need for more complex and more invasive surgical procedures, decreasing patient risk, reducing overall cost, and potentially achieving outcomes not previously possible.

ANATOMY

- Burn scars may affect any part of the body.
- Hypertrophic scars across joints may cause contracture.
- Contractures on the face may interfere with competence of the eyelids or the mouth.
- Burn scars are especially disfiguring on the face due to its high aesthetic importance.
- Neuropathic pain may be observed in burned areas, grafted regions, and even donor sites.

PATHOGENESIS

- The incidence of hypertrophic scarring after burn injury ranges from 5% to 40%, depending on anatomic location, depth of burn, method of closure, and genomic response to healing.
- Hypertrophic scarring and contractures can develop in burn scars that heal by secondary intention or re-epithelialization, in split-thickness skin grafts over excised burns, along the seams of full-thickness grafts, and in donor sites that had delayed healing, due to infection of excessive depth of harvest.
- Hypertrophic scars may be associated with an imbalance of collagen types 1

and 3, as well as TGF beta 1 and TGF beta 3.

- Hypertrophic scarring can be viewed as an abnormal physiologic response after wound closure, in which collagen deposition and angiogenesis continue beyond their desired end points.

NATURAL HISTORY

- Neuropathic symptoms, such as pruritus, searing pain, hyperesthesias, and paresthesias, are a source of frustration for the patient, can limit quality of life, and may prevent return to school, work, and social functions.
- Hypertrophic scarring may cause disability ranging from minor discomfort to joint contracture.
- Hyper- or hypopigmentation, erythema, and abnormal texture may cause the burn scars to be aesthetically unacceptable.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Complete patient history should be elicited, focusing on the type of energy delivered: scald, electrical, flame, contact, chemical, cold, friction, abrasion, or other.
- Previous treatments and their effects should be noted, including skin grafting, laser treatments, topical scar treatments, moisturizing agents, sunblock, systemic medications, occupational therapy, physical therapy, compression garments, and massage.
- The patient should have had no significant improvement in symptoms for at least 3 months on maximal medical therapy.
- Relative contraindications to laser therapy include connective tissue disorders, utilization of systemic steroids or immunosuppressive medications, and chemotherapy or radiation therapy. Patients with moderate to severe lymphedema should also be treated with caution, as healing from ablative lasers may be delayed.
- Complete physical exam should be performed, focusing on the burned area, noting whether it is a native burn scar or burn scar after skin grafting.
- The burned areas should be well healed without open wounds or evidence of cellulitis.
- Total body surface area of the burn injury should be noted, as extremely large areas should be staged, in terms of laser treatment.
- Functional deficits should be recorded, such as loss of range of motion or loss of sensation.

- Aesthetic concerns should also be considered, especially in burns of the face and the hands.
- The patient's Fitzpatrick skin type should be documented, and this will advise the initial energy settings for the laser.
- Photographs are useful for insurance submission and to track progression of the scar between laser treatments.

IMAGING

- Imaging is not required. However, medical photography is often needed for preauthorization from insurance companies.
- For patients enrolled in a clinical trial, other imaging modalities might be helpful to measure extent of hypertrophic scarring and quantify changes:
 - Ultrasound to measure thickness of scar
 - Chroma meter to measure light-dark axis and degree of redness from erythema
 - Cutometer to measure elasticity of scar

SURGICAL MANAGEMENT

- The patient is routinely consented for a series of laser treatments, involving selective photothermolysis with the PDL, ablative resurfacing using the fractional using CO₂ laser, and either Alexandrite or diode lasers to rupture hair follicles.
- A series of 6 to 8 sessions is submitted for insurance coverage at a time, though a patient may reach maximal benefit before 6 to 8 sessions or may continue to experience symptomatic improvement beyond eight sessions.
- We strongly recommend maintaining a burn scar registry, which includes preoperative, operative, and postoperative data, which can be used for practice-based learning, retrospective and prospective cohort analysis, insurance preauthorization and payment, and medical-legal documentation.
- We recommend working with a board-certified anesthesiologist who has completed additional specialization in pediatric anesthesia or has significant clinical experience with children and has expertise in ambulatory and office-based anesthesia.
 - Multimodal anesthesia has been shown to significantly decrease patient pain, need for intravenous opioids during recovery, and time to discharge from the postanesthesia care unit.⁷
- Patients must be treated in an accredited surgery facility, which can include a

hospital-based ambulatory surgery center and an office-based surgery facility.

- Control of airway is paramount, even with mild sedation; burn patients may have compromised airways from previous tracheostomy scars and/or prolonged intubation and mechanical ventilation.
- To maximize throughput with our practice, patients do not return until their next laser session, which is typically 6 to 8 weeks later.
- The next session serves as both the postoperative visit from the previous treatment and the preoperative visit for that day's session.
- At that time, we ask the patient for feedback about their symptoms and tailor the treatment for that day based on these observations, which can include changing the energy levels as well as type of laser used.

Positioning and Preparation

- Our burn patients usually receive a Propofol drip and boluses of fentanyl, ketamine, and midazolam as appropriate.
- The burn scar should be clean but sterile preparation is not necessary.
- Sterile drapes are not necessary.
- All operating room personnel must wear tinted eyewear for PDL or clear eyewear for CO₂ laser to protect against laser backscatter.
- The patient's eyes should be closed and covered with a saline-moistened towel.
- Fire prevention is of paramount concern for all laser cases, and patient safety protocols for reducing the potential for an oxygen-enriched environment must be followed.
 - This includes lower the inspired oxygen concentration to the lowest needed FIO₂, using room air only when discharging the laser in the head and neck region, avoiding towels or drapes that can serve as a reservoir for oxygen, and alerting all OR personnel when discharge of the laser commences.
- The lasers must be calibrated and tested on the back table, before treating the patient, to confirm that the appropriate amount of energy will be delivered.

TECHNIQUES

■ Pulsed Dye Laser



Video p8-c031_02

Anesthesia

- For small areas below the clavicles, as well as test areas, in adult patients only, no anesthesia is necessary, except for the cooling of the cryogen jet, which is administered milliseconds before the laser is discharged.
- All children, adults with large surface areas, and patients with hypertrophic scars on the face and neck require some type of anesthesia, which can range from oral anxiolytics and narcotics to TIVA (total intravenous anesthesia); general anesthesia with inhalation agents is rarely used, but patients will often benefit from a LMA (laryngeal mask airway) to control the tongue and epiglottis.
- Of note, most topical anesthetics constrict the capillary targets in the dermis, so we almost never utilize these agents, to ensure that the target receives and absorbs adequate energy for selective photothermolysis.

Laser Application

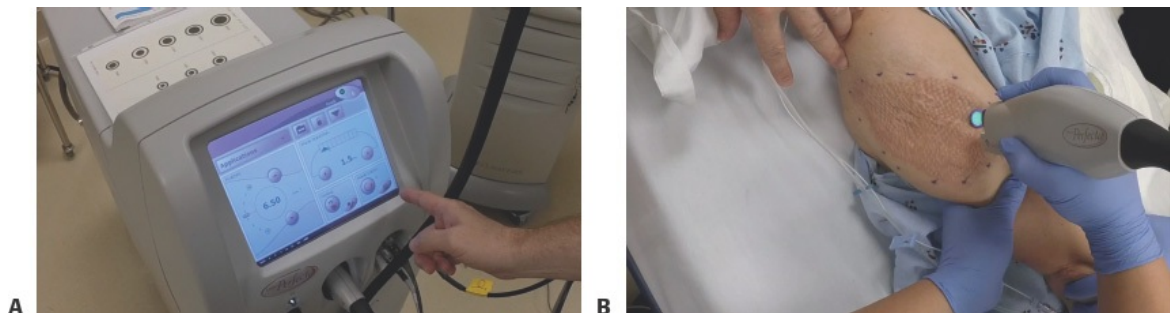
- We use a Candela V-Beam, 595-nm wavelength, PDL.
- The laser is set to 1-cm diameter circular spot size, cryogen mix of 30/20, and 1.5-ms pulse duration or pulse width (**TECH FIG 1A**).
- The energy or fluence setting is titrated to mild bruising without blistering. 6.5 J/cm^2 is a reasonable level for a patient's first session for Fitzpatrick class 1 and 2 patients. For patients with Fitzpatrick grade 3 and 4 pigmentation, acceptable starting energy settings are 4.5 to 5.0 J/cm^2 . Patients with Fitzpatrick class 5 and 6 skin types must be counseled that they are at high risk for mild blistering and hypopigmentation and should be treated with

minimal fluence, such as 3.5 J/cm².

- The energy setting for subsequent sessions is increased if the patient experiences minimal skin changes in the days following the procedure. Conversely, the energy setting is decreased if the patient experiences severe bruising, blistering, or epidermolysis in the days following the procedure.
- As the operator fires the laser sequentially over the burn scar, there should be mild overlap between successive bursts (**TECH FIG 1B**).
- Each laser burst can be expected to sting as if struck by a drawn rubber band.
- End points for titrating the fluence, in the OR, include slight ecchymosis of the skin. Immediate blistering or purpura indicates that too much energy has been applied and that reduction in fluence is required.

Wound Care

- We use topical antimicrobial ointment for several days, until bruising begins to resolve.
- Oral antibiotics and antiviral agents are almost never given, except in cases of recurrent cellulitis or frequent outbreaks of herpetic infection in the treated areas.



TECH FIG 1 • A. We typically use these settings for a patient's first PDL treatment session on our Candela V-Beam, 595 nm, PDL. The laser is set to 6.50-J/cm² fluence, 1-cm diameter spot size, cryogen mix of 30/20, and 1.5 ms pulse duration. **B.** The PDL handpiece is held so that the distance guide (*purple ring*) is flat at skin level. The treatment area of hyperemic autografted burn scar is encircled with marked *dots*. There should be mild overlap between

successive bursts.

■ Fractional CO₂ Laser



Video p8-c031_01

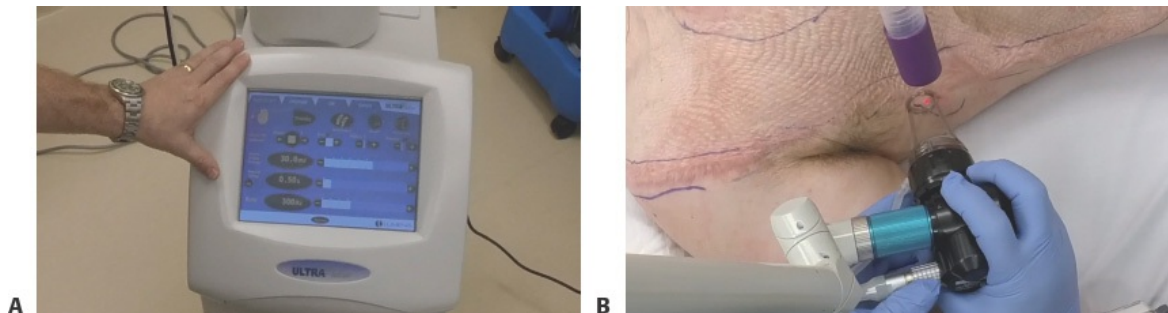
Anesthesia

- Fractional CO₂ laser ablation is extremely painful.
- For small areas below the clavicle, in adults who have minimal baseline neuropathic pain, topical anesthetics including lidocaine and bupivacaine mixtures can be applied for 20 to 30 minutes, to create enough anesthesia that the laser can be tolerated, when using 15 to 30 mJ/micropulse.
- However, most burn patients already have neuropathic symptoms from their hypertrophic scars, so most require at least intravenous sedation and analgesia, but total intravenous anesthesia is usually employed.

Laser Application

- We use a Lumenis UltraPulse fractional CO₂ laser at wavelength of 10 600 nm.
- The laser is set to 30 to 60 mJ/micropulse, 1- × 1-cm² square spot size, 250 to 300 Hz for the micropulses, 0.3- to 0.5-second delay between sequential firing, and 5% to 3% density in terms of tissue surface area (**TECH FIG 2**).
- Higher energies of 60 to 90 mJ/micropulse can be delivered safely, provided that density is dropped to 1%. We rarely use energy of this magnitude, expect

in very thick hypertrophic scars that require a greater depth of penetration, to yield fine, punctate, capillary bleeding. The efficacy of using such high energies has not been rigorously studied, and we cannot recommend using energy of this magnitude routinely.



TECH FIG 2 • A. On our Lumenis UltraPulse fractional CO₂ laser, initial settings consist of 30 to 60 mJ/micropulse, 1- × 1-cm² square spot size, 0.5-second delay between sequential spots, 300-Hz firing rate, and 5% density. **B.** The CO₂ laser handpiece is held so that the distance guide (translucent grey ring) is flat at skin level. The treatment area of indurated autografted burn scar is outlined by skin marker. There should be minimal or no overlap between successive bursts. An assistant suctions vaporized tissue smoke with the tip of the evacuator (purple end of plastic tubing) held a few centimeters from the laser spot to remove vaporized tissue smoke.

- While some surgeons use very high energies to treat keloids, we prefer to manage burn scar keloids by direct excision and fractionated, immediate postoperative radiation. In children, patients with keloids of the neck (where the thyroid and parathyroid glands could be in the field of irradiation), and patients with a history of XRT, we instead close the wound through complex repair, tissue rearrangement, or skin graft and then proceed with laser therapy to reduce the incidence of recurrence.
- The laser should be tested on a wooden tongue depressor, to confirm orderly and consistent ablation, evidenced by a regular pattern of burn marks on the

tongue depressor.

- As the operator fires the laser sequentially over the burn scar, there should be minimal or no overlap between successive bursts (**TECH FIG 2B**).
- An assistant should suction away vaporized tissue smoke, as this may be dense and irritating. Furthermore, the plume may contain viral particles that could theoretically infect members of the OR team. For that reason, the surgeon must wear a tight-fitting, filtered mask.
- The energy setting is titrated to pinpoint bleeding, indicative of penetration into the reticular dermis.
- Char is left in place.

Wound Care

- The treated areas are immediately dressed with a topical antibiotic ointment and cooled with ice packs.
- We routinely apply topical corticosteroids, dosed to patient weight, through vigorous massage into the fresh channels.
- Patients with a history of significant postoperative itching or pain are also treated with topical antihistamines and lidocaine, respectively.
- These pharmacologic agents are kept in contact with the treated areas with semiocclusive dressings, which are then gently and snugly wrapped with circumferential gauze, which is removed in 1 to 2 days.

PEARLS AND PITFALLS

Anesthesia

- All patients require a personalized plan, which can range from topical agents to general anesthesia, depending on patient age, location of burn scar, type of laser used, and energy applied. Almost all patients can be discharged on the day of surgery, except for those infrequent patients who may require monitoring of airway or who experience postoperative nausea and vomiting. It is critical to use only the amount of anesthesia necessary to produce the desired level of comfort.

End points

- PDL: slight bruising or reactive erythema.
- CO₂: fine punctate bleeding with reactive erythema.

	■ Diode and alexandrite: rupture of hair follicle with flash of light and audible crackle.
Complications	■ Blistering can occur with PDL, especially in patients with higher Fitzpatrick scores; this is very superficial and is treated with topical ointment until wound re-epithelializes. ■ Hypopigmentation is quite common. ■ Postinflammatory hyperpigmentation can occur with UV radiation exposure and should be treated with topical corticosteroids. ■ Allergy to topical antibiotics can occur after prolonged use of these agents and typically resolves with cessation of use. ■ Cellulitis is rare but does respond quickly to oral antibiotics, which include coverage of MRSA. ■ Wound breakdown and infarction is extremely uncommon and may be due to a combination of technical issues with too much energy delivered and superimposed infection.
Cessation of therapy	■ Most patients achieve maximum benefit after 4–6 sessions, but continued improvement can occur well beyond this series of treatments. We typically stop treatments when both the patient and provider agree that signs and symptoms have reached maximum improvement.

POSTOPERATIVE CARE

- The patient should be advised to expect reactive erythema, bruising, and occasional superficial blistering within 3 to 5 days.
- The patient should apply bacitracin ointment daily to the treated area.
- Patients must avoid sunlight to prevent UV radiation exposure.
- Postprocedure pain should be adequately covered by over-the-counter analgesics such as acetaminophen and NSAIDs.
- We do not routinely prescribe narcotic analgesics after PDL.
- The CO₂ laser is painful, and we routinely prescribe a small amount of narcotic analgesics for postprocedure pain.
- Dressings can be taken down by the family 1 to 3 days after treatment.
- Occupational and physical therapy can be started at that time.
- Compression garments can be worn when the scab formation occurs, typically 5 days after treatment.
- Children often go back to school, and adults return to work, within 1 to 2 days.

OUTCOMES

- Some degree of symptomatic improvement can be expected in all patients, though returns tend to diminish with each successive treatment (Clayton, Levi). We objectively measure improvement with the Vancouver Scar Score, in which the provider rates thickness, redness, color, texture, and pliability. Patients provide subjective feedback through the use of the UNC 4P scale, in which patients rate pain, paresthesias, pliability, and pruritus. Interestingly, patients often report continued subjective improvement, after the provider notes plateau in objective clinical findings.
- Patients who reach maximum improvement are re-evaluated in 2 to 3 months and then at yearly intervals thereafter. Children will often experience recurrence of symptoms during and after puberty and may benefit from an additional series of sessions, sometime many years later.
- One unexpected finding is that many burn patients with chronic neuropathic pain, whose hypertrophic scars have been treated with lasers, present with focal anatomic causes of their pain, such as nerve compression or neuroma formation. Laser therapies treat the generalized inflammatory and hypertrophic response, often unmasking surgically treatable causes of chronic neuropathic pain. Diagnosis of an anatomic cause can be made by clinical exam, with elicitation of a Tinel sign, as well as nerve block, which can be assisted with ultrasound guidance. If an anatomic cause is identified, then patients may undergo a combination of nerve decompression and transposition, neuroma resection with subfascial or intramuscular implantation, or fat grafting. In our experience, laser treatment of hypertrophic burn scars improves chronic neuropathic pain in 80% to 90% of patients, as defined by reduction of symptoms and de-escalation of pharmacologic regimen. In the remaining patients, 80% to 90% have an anatomic cause of neuropathic pain that is amenable to surgical intervention. One guiding observation is that over the past 10 years of treating hypertrophic burn scars with laser therapies, the more we look for discrete anatomic causes of neuropathic pain, the more likely we are to find abnormalities that respond to a combination of nerve decompression and neuroma resection. Fat grafting has also proven to be a highly successful form of treatment in refractory cases.

COMPLICATIONS

- Adverse events are minor and include hyperpigmentation, hypopigmentation, mild blistering, pain, rash, fever, and infection (Clayton).

- In our 10-year experience, involving 800 sessions per year, we have observed one case of herpetic whitlow, one case of wound breakdown with delayed healing, and two cases of postoperative pulmonary insufficiency, requiring intubation (one patient with aspiration at end of case, the other patient with myasthenia gravis).

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Fat Grafting for Nerve Entrapment Within Burn Scars

32

CHAPTER

C. Scott Hultman and Yuen-Jong Liu

DEFINITION

- Mortality from burn injury has markedly decreased in the second half of the 20th century as wound sepsis, wound coverage, kidney failure, and shock have been largely remedied.
- Patients who have undergone tangential excision of burn injuries, escharotomies, and autografting often develop symptomatic scars.
- Superficial sensory nerves may become entrapped in burn scars and cause debilitating paresthesias, such as burning pain, tingling, or hyperesthesia.
- Although nerve decompression and neurolysis are the primary treatments for entrapment, fat grafting is a low-risk adjunct procedure that can mitigate neuropathic symptoms by capitalizing on anti-inflammatory effects and physical cushioning by autologous fat.^{1–7}
- The principles of fat grafting for burn scars may also be applied to scars from other etiologies, such as chemical exposure, frostbite, abrasion, electrical injury, or a combination of injurious energy transfer to the skin and superficial soft tissues.

ANATOMY

- Nerve entrapment may occur at any location of the body where there are sequelae of burn injury.
- Superficial sensory nerves are affected, frequently in the extremities, such as the superficial radial nerve, the medial antebrachial cutaneous nerve, the saphenous nerve, the sural nerve, and lateral dorsal cutaneous nerve.

PATHOGENESIS

- Hypertrophic scarring and contractures develop in burn scars or in split-thickness skin grafts over excised burn scars.
- The fibrotic tissues constrict around superficial sensory nerves and cause a combination of pain, hyperesthesia, and paresthesia.
- Sensory receptors in the damaged skin may also receive aberrant innervation from sensory nerves, as the integument heals.

NATURAL HISTORY

- The neuropathic symptoms are a source of frustration for the patient, often preventing return to school and work.
- They require narcotic and non-narcotic analgesics and may become tolerant.
- Adjunct analgesics include gabapentin and pregabalin, which have adverse effects of varying severity.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Complete patient history should be elicited, focusing on the type of energy delivered: scald, electrical, flame, contact, chemical, cold, friction, or abrasion.
- Previous treatments and their effects should be noted, including skin grafting, laser treatments, topical scar treatments, and medications.
- Complete physical exam should be performed, focusing on the burned area, noting whether it is a native burn scar or burn scar after skin grafting.
- Total body surface area of the burn injury should be observed, as this often dictates algorithms for treatment, that include medical therapy (compression, silicone), laser photothermolysis and ablation, nerve decompression, and fat grafting.
- Functional deficits should be noted, such as loss of range of motion or loss of sensation.
- Gentle percussion around the symptomatic area can elicit Tinel sign corresponding to the location of nerve tethering or entrapment.
- The Tinel sign can be followed to assess the effectiveness of treatment.

DIFFERENTIAL DIAGNOSIS

- Nerve compression amenable to decompression and possible transposition
- Discrete neuroma formation that may benefit from exploration, resection, and implantation of nerve below fascia or into muscle or even bone
- Persistent hyperemia of hypertrophic burn scar, which may respond to laser

resurfacing

IMAGING

- Imaging is not required, although ultrasound may be helpful in guiding diagnostic nerve blocks, to confirm diagnosis of entrapped nerve vs neuroma, and to provide temporary relief.

SURGICAL MANAGEMENT

- Fat grafting is a modality that can offer significant relief of neuropathic symptoms, after patients have been considered for or treated with laser resurfacing, nerve decompression, or neuroma resection.
- Fat grafting involves surgically controlled incisional release of the integument from the underlying subcutaneous tissues and fascia.
- The grafted fat contains adipocytes and possibly stem cells, which are thought to have anti-inflammatory effects on the entrapped nerves and scar tissue.
- The grafted volume provides mechanical padding that decreases nerve sensitivity by effectively burying afferent end fibers, deeper and away from direct contact.
- Other reasonable surgical options include scar subcision and open neurolysis.
- LipiVage is the preferred system for small volume grafting, and Puregraft is preferred for large volume, structural fat grafting.

Preoperative Planning

- Overall, fat grafting is indicated for patients with any of the following criteria:
 - Require significant pharmacologic therapy for neuropathic pain
 - Have previously undergone laser therapies for hypertrophic burn scars
 - Have multiple areas of dysesthesias not necessarily corresponding to the anatomic distribution a sensory nerve
 - Have already undergone major peripheral nerve decompression, neurolysis, and neuroma resection
- The senior author prefers to use fat grafting as “rescue” therapy for patients with chronic, neuropathic burn scar pain, who have undergone other modalities with documented success in the literature, such as laser resurfacing and peripheral nerve decompression.
- Patients with large burn scar surface areas, who are on medications for neuropathic pain, should first undergo laser treatments with pulsed dye laser to reduce hyperemia, fractional CO₂ laser resurfacing to improve pliability of

burn scar, and laser-assisted drug delivery (usually kenalog) to reduce inflammatory component.

- Patients with a discrete Tinel sign, suggestive of neuroma or entrapment, as well as those with motor dysfunction, should first undergo surgical exploration, nerve decompression, and possibly neuroma resection.
- Patients who have multiple Tinel sign, who have undergone other modalities such as laser resurfacing, and who have previously had peripheral nerve surgery, can be considered optimal candidates for fat grafting.
- Another indication for fat grafting is the patient who is on an aggressive pharmacologic regimen for chronic neuropathic pain and who wants or needs to de-escalate medications, which often lose efficacy and cause side effects of decreased level of alertness, poor sleep hygiene, and peripheral swelling.
- The role for early fat grafting, within the first 6 to 12 months after wound closure, is unknown and would benefit from prospective clinical studies.
- The role for fat grafting in prepubertal children is also not known and requires prospective clinical trials.

Positioning

- Supine, to access fat from anterior abdominal wall and lateral trunk
- Shoulders abducted at 85 degrees for upper extremity surgery, with pressure points padded
- Lower extremities prepped such that ankles, knees, and hips can be mobile

Approach

- Fat grafting is often performed in multiple sessions, as there is a limit to how much fat can be grafted into and below a burn scar, especially when there is a paucity of subcutaneous tissue present.
- The authors plan harvest and use 0.5 to 1.0 cc of fat for every cm² of surface area grafted.
- Regular liposuction or power-assisted liposuction may be used to harvest the fat.

TECHNIQUES

■ Port Creation and Cannula Use



Video p8-c032_01

- The port sites of the donor and recipient sites are first injected with a wheel of local anesthetic, typically 1% lidocaine with epinephrine, to minimize bleeding at locations.
- Donor sites ports typically include the inferior umbilicus, the flanks near the anterosuperior iliac crest, or previous surgical scars on the abdomen.
- The donor sites are tumesced with approximately 200 mL, targeting above and below the superficial fascial system using a solution of 1 L lactated Ringer's containing 1 mL of 1:100 000 epinephrine and 50 mL of 1% lidocaine.
- Tumescent is allowed to diffuse for 10 minutes.
- Port sites, of 1 to 2 mm, are made with stab incisions, proximal to the symptomatic burn scar. At least two port sites are made, to allow for a radial, fanning, cross-hatched matrix, with overlapping tunneling and at different levels in the burn scar.
- A subcision cannula is tunneled antegrade, from proximal to distal, to decrease risk of avulsing nerve branches (**TECH FIG 1**).
- Rigotomy is performed with advancement of the cannula. Usually, a blunt-tipped or semi-blunt-tipped cannula can be advanced through the scar, but occasionally, a sharp pickle-fork cannula is needed to perform discrete rigotomies.
- Fat is injected on withdrawal of the cannula, in aliquots of 0.1 to 0.2 cc, up

to 0.5 mL with the bevel up and another 0.5 mL with the bevel down, over a distance of 2 to 6 cm.

- Additional passes of the subcision cannula are repeated in a fanning fashion through each fat grafting port, centering on the focus of nerve entrapment. Care is taken to stay superficial, directly under the burn scar, to avoid disruption of the deeper afferent neural plexus.



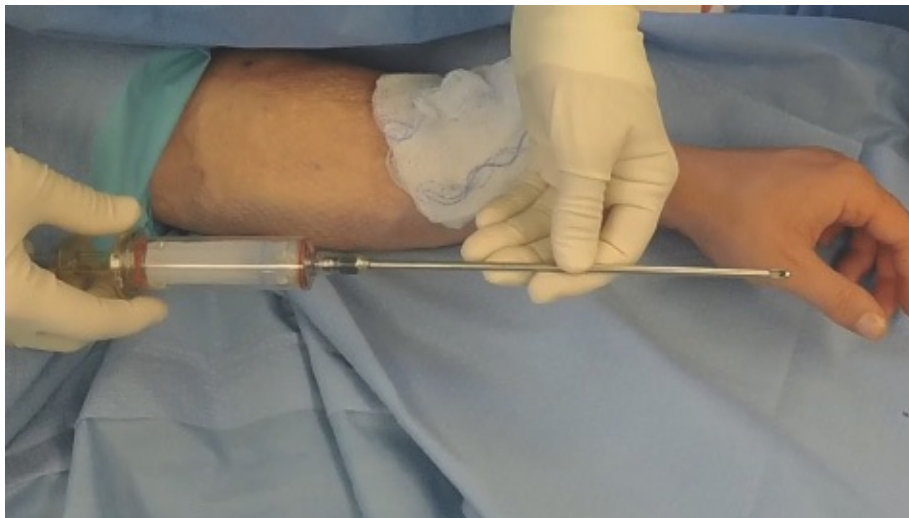
TECH FIG 1 • A subcision cannula is tunneled anterograde, from proximal to distal, to decrease risk of avulsing nerve branches.

LipiVage

- The tubing set attached to the LipiVage Harvester is connected to an aspirator and the vacuum level is set to approximately 60% of its capacity, ensuring a gentle vacuum (**TECH FIG 2**).
- The transfer adapter is removed, and the recommended aspiration cannula is attached. The senior author prefers to use a serrated, 1 to 2 mm cannula with multiple side ports, which is helpful for extracting fat during repeat harvests.
- Fat is harvested for approximately one minute, and then fluids are drained for a few seconds, from the trap mechanism with the LipiVage system.
- The nearly bloodless lipoaspirate is then washed with normal saline, within the closed system, before processing on the back table. Fat is then transferred into 3 cc injection syringes using the transfer adapter supplied. Harvesting

steps are repeated for additional fat if needed.

- The filter is simply rinsed for a few seconds, and the plunger tip is used to wipe the inner walls of the filter clean in between harvests.
- Fat cells collect in the filter chamber suspended within the harvester body.
- Fat cells are gently pulled toward the inner walls of the filter and collect along the length of the front of the blue plunger tip, while fluids wash through.
- Once inside, the fat is gently cleaned by the accompanying tumescent fluid.
- Fluid and oils pass through the fat and the filter walls and are then carried to the waste receptacle via the tubing set.
- Due to the low vacuum levels, there is very little oil present to begin with because fewer fat cells are damaged during harvesting.
- After fluids are drained, the concentrated and cleaned fat is immediately ready for injection.
- The unique LipiVage plunger tip design gently wipes the fat from the inner filter walls and transfers the fat as the plunger is pushed forward gradually.
- The processed fat grafts are allowed to settle on the back table for at least 10 minutes, with the 3 cc syringes upside down, so that any additional tumescent fluid and oil can separate and be discarded, prior to fat grafting.



TECH FIG 2 • Attaching tubing set to the LipiVage Harvester.

■ Puregraft



Video p8-c032_02

- Fat is aspirated into a syringe.
- The lipoaspirate is injected into a Puregraft drain bag (**TECH FIG 3**).
- The lipoaspirate is washed lactated Ringer's solution.
- The filtered fat is aspirated from Puregraft drain bag into small syringes for grafting.



TECH FIG 3 • The lipoaspirate is injected into a Puregraft drain bag.

PEARLS AND PITFALLS

Port sites: harvest

- Usually, all of the lipoaspirate needed for fat grafting can be obtained through an infraumbilical incision.
- If multiple rounds of fat grafting are anticipated, we usually harvest fat from the right and left lower quadrants first, followed by the central infraumbilical fat second, and possibly the flank on repeat harvests. This is done to yield a desirable, symmetric abdominal wall contour.
- We always avoid harvesting fat from the right and left upper abdominal wall quadrants, to avoid injury to the liver or spleen, in case an aberrant pass is deflected deeper from the costal margin and into the peritoneal cavity.
- Recipient sites are closed with 4.0 plain gut and a Steri-Strip.

Port sites: recipient

- Port sites are almost always placed proximal to area of concern, so that the rigotomy can be done from proximal to distal, parallel to the topical distribution of the cutaneous nerves.
- Several port sites enable a cross-hatched matrix, which increases the amount of fat that can be transferred and should survive.
- Recipient sites are closed with 4.0 plain gut and a Steri-Strip.

Fat harvest

- We recommend against energy-assisted liposuction, such as laser or ultrasound, as this may decrease the viability of the grafted fat.
- The LipiVage system is used most of the time, as this allows for efficient harvest of the small volumes required for fat grafting. Structural fat grafting, which requires larger volumes to replace deficient tissue, is better served by the Puregraft system.

Engraftment

- For burn scars in the extremities, no tourniquet is used.
- After the cannula is advanced from proximal to distal, effecting a rigotomy, fat is injected in 0.1 to 0.2 cc aliquots, from distal to proximal.
- Pre-tunneling is not performed in order to decrease the risk of hematoma.
- We use 3 mL syringes for injecting fat during grafting, as the small size gives adequate control over delivering 0.2 mL aliquots without having to change syringes often.
- Our formula for volume of final processed and purified fat needed for grafting is 0.5 to 1.0 cc of fat for every cm² of surface area treated. Of note, we typically harvest lipoaspirate 2–3 times the

volume needed for fat grafting ultimately needed, discarding tumescent fluid and oil as these elements separate.

POSTOPERATIVE CARE

- Acute postoperative pain from donor sites and at fat grafting sites lasts no more than 2 weeks. Typically, the patient experiences more pain in the donor site than the recipient site.
- Patients are kept on their neuropathic pain regimen but do require additional narcotics, especially for the donor-site pain.
- One dose of IV antibiotics is given at induction of anesthesia, and 5 days of oral antibiotics are given in the immediate postoperative period.
- The donor site is wrapped with gentle compression for 4 weeks to minimize the risk of seroma and hematoma. For abdominal donor sites, an abdominal binder is recommended at all times except when showering.
- The patient is advised against strenuous physical activity and heavy lifting (greater than ten pounds) for 4 weeks.
- The recipient site is dressed in clean, dry, gauze to absorb any drainage from the injection ports, and the initial postoperative may be removed on the 2nd day and reapplied as needed.
- The recipient site is treated with moderate compression during early engraftment, to prevent significant edema or hematoma. We believe that similar to the principle of needing a bolster to immobilize a skin graft, during the imbibition and inosculation phases, this compression helps with engraftment of the fat, in recipient sites, which may have less than optimal vascularity. The patient is advised to avoid direct pressure on the recipient site for 4 weeks, to prevent fat liquefaction or fat necrosis.

OUTCOMES

- Fat grafting reduces neuropathic pain, in approximately 90% of patients, permitting reduction in medication regimens.
- Fat grafting reduces scar symptoms such as pruritus, hyperesthesia, paresthesia, and tethering to deep structures.
- Fat grafting can improve tendon gliding in the hand and foot.
- Fat grafting improves scar pliability, texture, and color.

COMPLICATIONS

- Complications at the donor site are essentially complications from liposuction,

which are rare, but include seroma, hematoma, and infection at the donor site.

- Complications at the recipient site have not been reported but may include infection and graft loss. Infections are exceedingly rare. In the author's practice, postoperative cellulitis occurs less than 2% of the time and can successfully be treated with oral antibiotics, continued compression, and extremity elevation.
- A small subset of patients report no improvement in neuropathic symptoms after fat grafting, but the overwhelming majority of patients report relief, measured by reduction of pain and/or reduction in need for medications. In fact, relief from neuropathic symptoms can be dramatic, suggesting that rigotomy may be the primary mechanism of early improvement. Maintenance of relief argues toward the mechanical cushioning effects of the fat graft, or possibly the ability of the adipocyte stem cells to stabilize fibrotic recipient sites or even regenerate normal afferent innervation.

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Section VIII: Ear Reconstruction

Auricular Reconstruction for Microtia and Post-Traumatic Deformities

33
CHAPTER

Charles H. Thorne

DEFINITION

- Microtia literally means small ear but is used to refer to a spectrum of auricular anomalies (**FIG 1**) that are almost always associated with aural atresia (absence of the external auditory canal).
- From a practical point of view, any congenital deformity of the auricle that requires insertion of a complete or near-complete cartilage or synthetic framework is an example of microtia.
- As discussed below, the principles for reconstruction of other auricular deformities such as post-traumatic deformities are similar.

ANATOMY

- As depicted in **FIG 1**, the anomalies that constitute microtia vary from almost complete anotia to cases that demonstrate an almost normal lower 2/3 of the auricle. Microtia has been classified in various ways, but the most useful is the classification of Nagata: lobular microtia, small concha microtia, and large concha microtia. Complete anotia is almost never seen.
- Patients with microtia almost always have absence of the external auditory canal (aural atresia) with complete bony separation of the auricular remnant and the middle ear structures (**FIG 2**).

- The middle ear is underdeveloped and also presents variable abnormalities. If an apparent external auditory canal is present, it is almost always blind or stenotic. Patients with microtia, therefore, almost always have total conductive hearing loss on the affected side.
- Microtia is more common on the right side; 90% of cases are unilateral, and those patients usually have normal hearing in the contralateral ear.



FIG 1 • Variable presentation of microtia. The term microtia refers to a wide variety of presentations. **A.** Small conchal-type microtia. **B.** Lobular-type microtia. **C.** Almost complete anotia. **D.** Atypical microtia with hemifacial microsomia.

- In the 10% with bilateral involvement of microtia and aural atresia, the patients are functionally deaf and require bone conductive hearing aids on an urgent basis in order to develop speech.
- There are several anatomic differences between microtia and post-traumatic deformities:
 - The skin quality in post-traumatic cases may present problems because of scarring around the remnant.
 - Post-traumatic auricular remnants almost always contain a canal and a tragus, making reconstruction of near-normal auricle more likely.
 - Post-traumatic remnants may be distorted by scar but are almost always in the correct position, as opposed to microtic remnants that are often malpositioned.

PATHOGENESIS

- The auricle and the middle ear develop together from the first and second branchial arches, explaining the concomitant anomalies of those two structures.

- The inner ear is almost always normal in microtia patients because it arises separately in embryonic development and is not a branchial arch derivative.
- Microtia is the second most common congenital deformity affecting the head and neck (after cleft lip and palate) and is more common in patients of Southeast Asian descent.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Microtia and aural atresia fall within the larger spectrum of craniofacial microsomia or first and second branchial arch syndrome. Craniofacial microsomia can present with either unilateral (ie, hemifacial microsomia) or bilateral involvement.

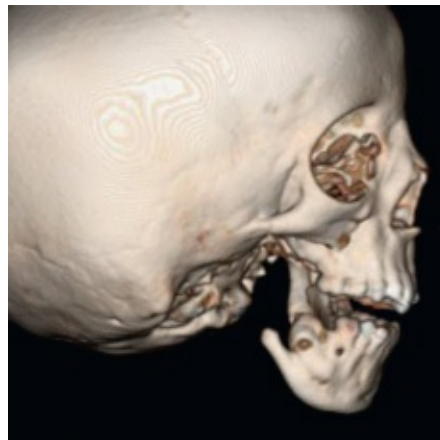


FIG 2 • Aural atresia. Microtia is almost always accompanied by aural atresia. Note the absence of an external auditory canal and, in this case, an extremely hypoplastic mandibular ramus.

- Most patients with microtia have symmetrical or nearly symmetrical faces, but radiographs usually show some asymmetry of the ipsilateral mandibular condyle indicating that microtia is part of the craniofacial microsomia spectrum.
- A minority have more obvious underdevelopment of the tissues of the face including mandible, soft tissue, facial nerve, and auricle.

SURGICAL MANAGEMENT

- The autogenous method of auricular reconstruction is the technique with which this author is most familiar.¹⁻³ If the reader is interested in a technique

using synthetic frameworks, the publications of John Reinisch are recommended.⁴

- The ideal age to perform reconstruction of a missing auricle is age 10 years.
 - At this age, the contralateral ear has reached adult size, and the rib cartilages are large enough to create an adult size ear framework. In a patient who is small for his/her age, delaying surgery until the patient is approximately the size of an average 10-year-old is recommended.
- Prior to age 10, the focus of patient management is on the hearing.
 - As mentioned, a patient with unilateral microtia has a total conductive hearing loss on the affected side but normal hearing in the unaffected ear. These patients can hear normally in quiet environments, but the lack of binaural input causes difficulty with localizing sound and in discriminating sounds in noisy environments. For example, a unilateral patient will have difficulty playing football when his/her name is yelled. The patient may have trouble immediately determining the direction of the sound and may look in the incorrect direction initially. In addition, in a room with multiple voices, it is more difficult for a microtia patient to screen out the background noise to focus on a conversation. These patients benefit from a bone conduction hearing aid (**FIG 3**).
 - Patients with bilateral microtia, on the other hand, absolutely require conduction aids because they are functionally deaf and will not develop normal speech without appropriate aids.
- Hearing can be restored either surgically or by use of a bone-anchored hearing aid (BAHA).
 - Reconstruction of the external auditory canal and ossicles can be surgically performed in approximately half the cases of aural atresia. In the other 50% of cases, the anatomy is too deranged for surgical repair.



FIG 3 • BAHA soft band. Infants with unilateral microtia benefit from the BAHA soft band, which will provide binaural hearing. Patients with bilateral aural atresia must have a bone conduction aid in order to hear and to develop normal speech.

- BAHAs are so effective, however, and less prone to complications when compared to canalplasty, that they are more commonly employed than surgical reconstruction of the canal (**FIG 4**).

Preoperative Planning

- When planning the auricular reconstruction, a tracing of the contralateral ear is made (**FIG 5**) that can be sterilized for intraoperative use. From that tracing, the surgeon then makes a drawing of the framework that would be required to produce that size auricle.
- Because the skin has a certain thickness (approximately 2 mm), the framework must be at least 4 mm shorter than the desired auricle (or shorter depending on how deep in the native lobule the framework will be placed).
- In addition, each of the convexities of the auricle must be much thinner and the concavities wider than the desired thickness on the ultimate auricle because the skin will make any raised portion of the framework (such as the helical rim) much thicker.
- Once the drawing of the framework has been made, separate drawings of each component can be made.
- At the time of surgery, only two markings must be made on the affected side prior to the induction of anesthesia:

- The lowest point on the unaffected side must be transferred to the affected side so the craniocaudal position of the ear is accurate. If this is not performed, then the lobules (and earrings) will not be in symmetrical positions.
- The angle that the ear makes with the vertical: Most auricles are approximately 15 degrees off vertical and slightly less angulated than the line created by the dorsum of the nose. There is some variability, however, and the correct angle should be marked.



FIG 4 • A bone-anchored hearing aid is secured by a magnet that is attached to a titanium implant in the skull.



FIG 5 • Templates. Tracings are made from the contralateral ear and sterilized for intraoperative use.

- The remaining measurements and drawings can be made after the patient is under anesthesia.
- Because some patients with microtia have more severe forms of facial asymmetry and may have airway issues, it is important to discuss airway management with the anesthesiologist. These patients may require more sophisticated intubation techniques or even, in the case of Treacher Collins patients, tracheostomy.

TECHNIQUES

■ Stage One

Markings and Anesthesia

- Once the patient has been intubated and prepping and draping has occurred, the plastic templates that were made preoperatively are used to draw the precise location, size, and orientation of the new auricle.
- A decision is made about the skin incision, which most commonly involves either rotation of the vertically malpositioned lobule or an incision that will allow dissection of the pocket and placement of the framework without rotation of the lobule.
- If an appropriate lobule is present and rotation will result in its being in the correct position at the caudal aspect of the new auricle, rotation is performed.
 - If on the other hand, there is an inadequate lobule or one that is located such that rotation into the correct position is impossible, then an incision without lobule rotation is performed.
 - Local anesthesia with epinephrine is injected and attention is directed to the chest.

Graft Harvest

- An incision is made over the caudal aspect of the ipsilateral rib cage, and the muscles are divided to expose the rib cartilages.
- Using the sterile, plastic templates, decisions are made about which cartilages to harvest.
- If an entire framework is required, two free floating ribs are usually required for the helical rim and the antihelix.

- The synchondrosis of two ribs is needed for the base of the framework, and sufficient additional cartilage is harvested to create the tragus-antitragus piece, small additional pieces to provide stabilization and projection, and a piece to be “banked” in the chest for the second stage of the procedure.

Pocket Dissection

- The operative field then shifts back to the temporal scalp.
- The incision is planned, with or without rotation of the lobule, and the pocket is dissected for placement of the framework. Hemostasis is obtained within the pocket.
 - The dissection of the pocket is tedious but extremely important. More complications occur from soft tissue management than from management of the cartilage or an imperfect framework.
- When the pocket is created, the congenital cartilaginous remnant, which varies tremendously, is removed.
 - Care is taken not to injure the skin in the process of removing that cartilage.

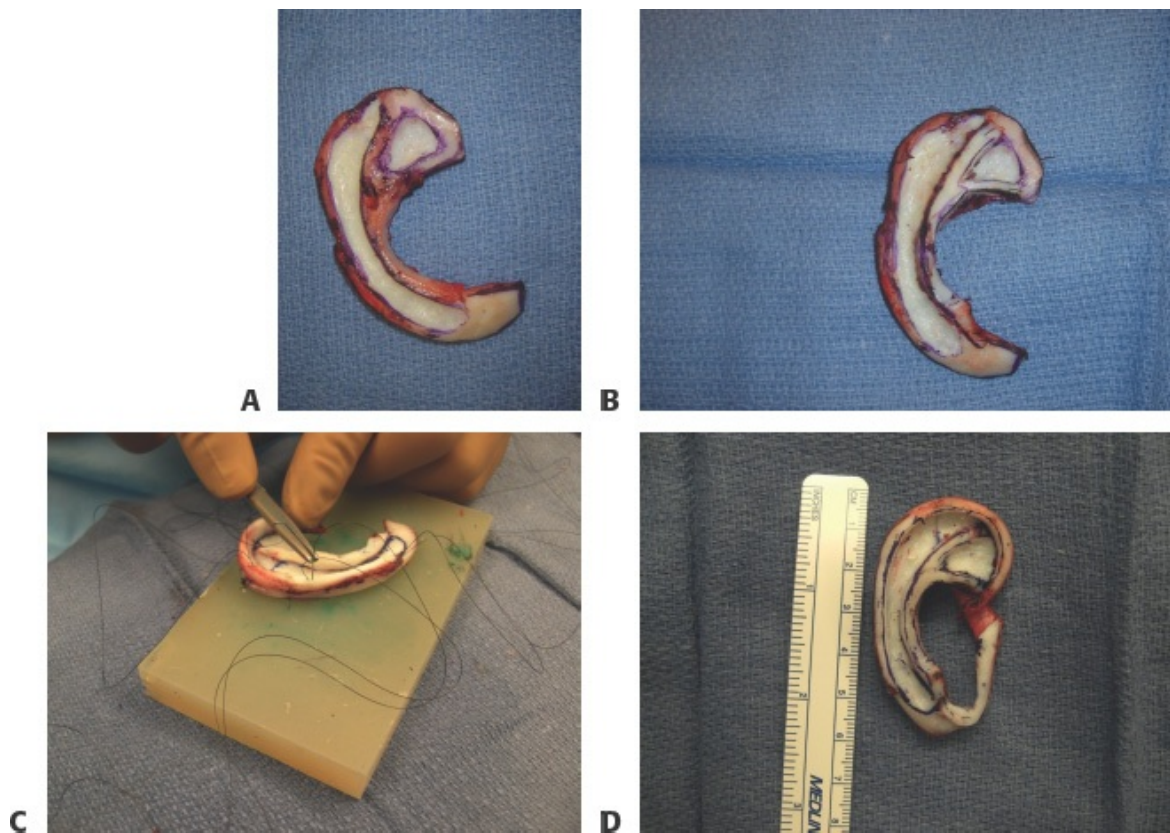
Auricle Framework Construction

- On a sterile back table, the framework is assembled (**TECH FIG 1A,B**).
- The base is carved to match the template, and the details of the scapha and triangular fossa are created using sterilized gouges.
- The antihelix is attached as an onlay graft using nylon sutures on short, thin straight needles (**TECH FIG 1C**).
 - Some surgeons prefer wire sutures.
 - Creating a good framework is extremely difficult without these specialized sutures.
- The helical rim is then attached with another series of sutures of nylon or wire.
- The last piece of the main framework to be added is the tragus-antitragus piece with the intervening incisura, an important component of the aesthetically pleasing auricle (**TECH FIG 1D**).
- Additional small pieces are frequently attached to the deep surface of the framework for stabilization and projection.
 - The most important of these extends from the base to the tragus, fixing the latter in the correct position and adding to its projection. The tragus is a thin, floppy piece of cartilage, and it is important to keep it in precisely the

correct position.

Insertion of the Framework and Wound Closure

- The framework is then inserted into the pocket along with two suction drains (**TECH FIG 2**).
- The author prefers Axiom Petite Wound Drains (REF 201AT), which are silicone drains with perforations at one end and a 19G needle at the other end for insertion into the suction tubing or Vacutainer tubes.



TECH FIG 1 • Construction of the framework. **A.** The base is carved from the synchondrosis of two rib cartilages. **B.** The antihelix and crura of the triangular fossa are attached as a single additional piece. **C.** Attachment of the helical rim. **D.** The completed framework after attachment of the tragus/antitragus piece.

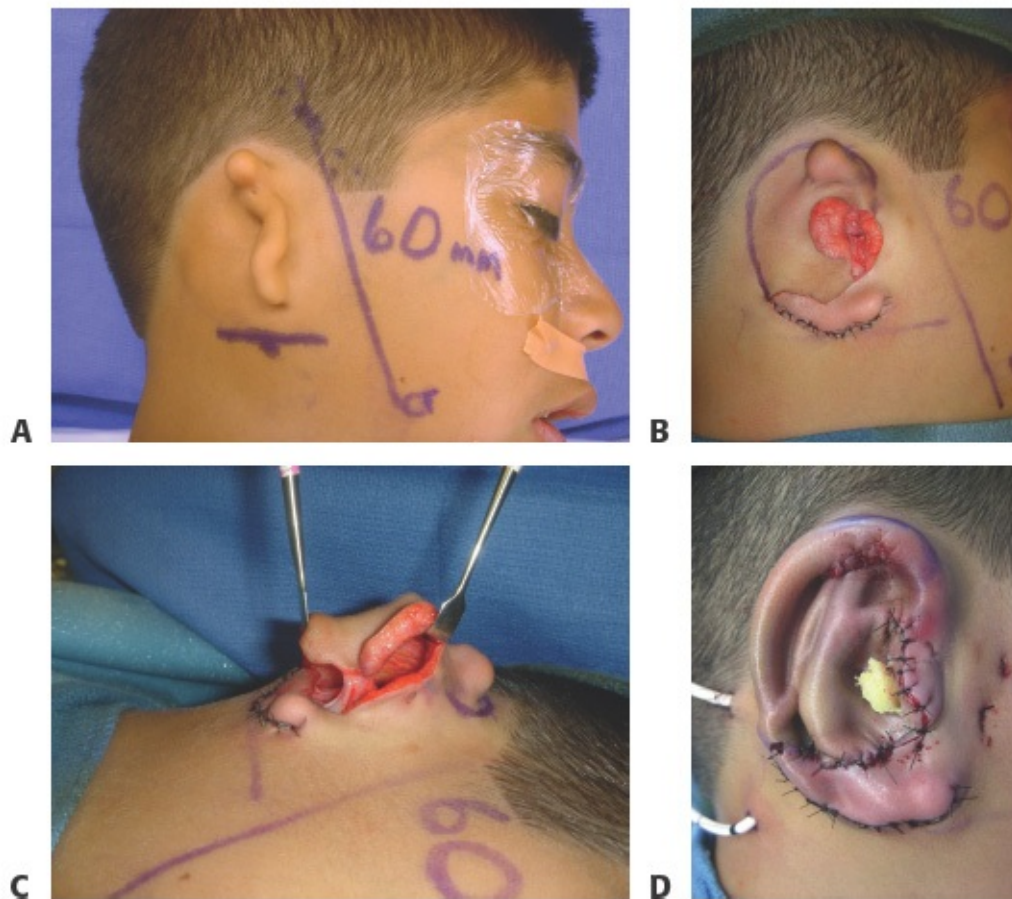
- The drains are then attached to wall suction, and the overlying skin is sucked

into the interstices of the framework.

- Only at this point can one decide which excess skin to excise.
- Excision of skin prior to the application of suction may result in over-resection of skin.
- The incisions are closed with interrupted nylon sutures.
- No dressing is placed.

Chest Wound Closure and Patient Transfer

- The chest incision is closed.
- Any holes in the parietal pleura are left alone without repair, and no chest tube or suctioning of the air in the pleural space is required.
- Positive pressure ventilation pushes the air out with each breath, and if a small rim of pneumothorax remains, it is of no consequence.



TECH FIG 2 • Dissection of the pocket. A. Preoperative markings. **B.** The lobule is rotated and the pocket is dissected. **C.** The pocket. **D.** After framework insertion and attachment of the drains to wall suction.

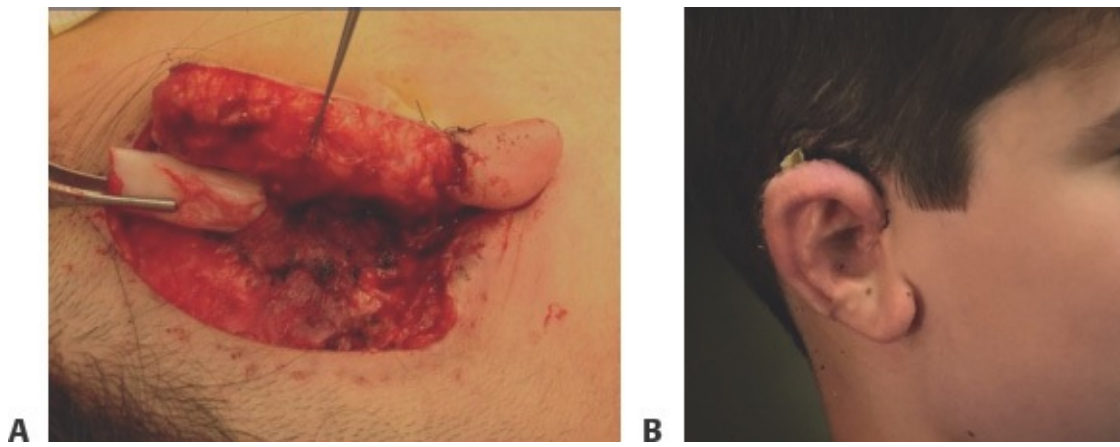
- The cartilage chips that remain after the carving of the framework are wrapped in an absorbable mesh and used to create a “rib” to replace the caudal margin of the rib cage.
- The wound is closed in layers, and the piece of cartilage mentioned above is placed in a subdermal pocket so that it can easily be found and removed at the second stage.
- The suction drains are left attached to the tubing, which is in turn attached to wall suction.
- The recovery room is informed of the patient’s imminent arrival, the suction tubing is temporarily disconnected from the wall, the patient is transported to the recovery room, and the tubing is reattached to wall suction.
 - Most wall suction units have a range for low, intermediate, and high suction.
 - The nurses are instructed to keep the suction exactly on the line that separates low from intermediate suction.

■ Stage Two

- Approximately 6 months later, the second stage is performed (**TECH FIG 3**).
- An incision is made around the posterior 180 degrees of the framework.
- The framework is elevated as far as the antihelix at the level of the temporalis fascia.
- A tunnel is created within the soft tissue, deep to the antihelix.
- The cartilage that had been left in the chest at the first stage is removed, shaped, and placed in the pocket, deep to the framework, to provide projection.
- The retroauricular skin is undermined and advanced into the sulcus.
- A full-thickness graft is taken from the inguinal crease and used to resurface

the medial surface of the elevated framework.

- Because the cartilage graft is in a soft tissue tunnel, the skin graft has an appropriate bed.
- The alternative is to cover the graft with a temporoparietal fascial flap, but the author prefers to keep that option available in case of a complication with cartilage exposure. With that in mind, the dissection of the original skin pocket and the undermining at the second stage must avoid the superficial temporal artery pedicle.



TECH FIG 3 • Second stage with elevation of the auricle. **A.** A cartilage graft that had been banked in a subdermal pocket below the original chest incision is inserted into a fascial pocket for projection of the auricle. **B.** Example after elevation. Xeroform is packed into the sulcus for 2 weeks after bolster removal.

PEARLS AND PITFALLS

Planning

- Make sure the new auricle is in the best possible location and is the correct size and at the correct angle. A beautiful ear in the wrong place is ugly. The identification of the location is much more difficult in the patients with significant facial asymmetry where compromises may have to be made. Patients with microtia,

especially those with more overt asymmetry, often have low hairlines. The management of the hairline is major topic unto itself. One choice is to excise the hair-bearing skin, either at the time of the initial operation or secondarily, and cover the framework with a temporoparietal flap and skin graft. Another choice is to place the framework under the hair-bearing skin and secondarily remove the scalp, leaving a thin layer of tissue over the framework to support the skin graft. This latter approach is tricky and requires both meticulous dissection and close postoperative observation. If the graft does not survive, the framework must be covered with vascularized tissue on an urgent basis.

Soft tissue management

- More complications arise from errors in judgment regarding soft tissue management than from poor framework construction. Although tedious, the soft tissue dissection is a priority.

Cartilage framework

- The imperfections of the framework, although hidden initially by swelling, will eventually show through the thin skin coverage. There are materials such as Styrofoam that can be used to practice the framework construction before attempting on a patient.

Exposed cartilage

- Any skin necrosis/exposed cartilage requires immediate attention and coverage with a temporoparietal flap and skin graft.

POSTOPERATIVE CARE

- The two main issues with the postoperative care are pain management and making sure that suction is applied to the drains for the 1st day or so.
- Pain from the thoracotomy is severe and requires parenteral analgesics to be administered, at least for the first night. Pain pumps with agents such as bupivacaine have not proven to be helpful.
- The drains are left attached to wall suction until the following morning. At that point the wall suction is removed and the drains are attached to red top Vacutainer tubes (or bulb suction if preferred).
- Patients are discharged on postoperative day 2 with the drains in place.
- The drains are then changed every 24 hours by the parents or caregivers, but not much fluid comes out after the 1st day, and it may be unnecessary to leave the drains after discharge.
- The patient is seen in the office on postoperative day 5 and the drains are removed.
- The sutures in the reconstructed auricle are usually left 10 to 14 days.

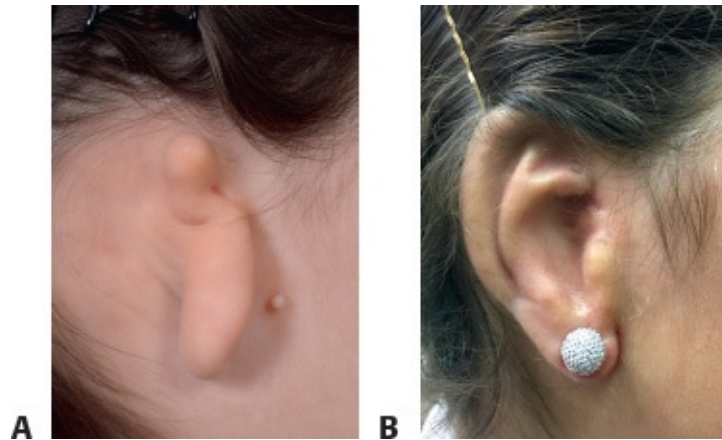


FIG 6 • Example of preoperative appearance (**A**) and postoperative result (**B**) after ear piercing.

OUTCOMES

- Examples of reconstruction for microtia and for post-traumatic deformities are shown in **FIGS 6** and **7**.

COMPLICATIONS

- By far the most significant and important complication is necrosis of the skin with exposure of the underlying framework (**FIG 8**).

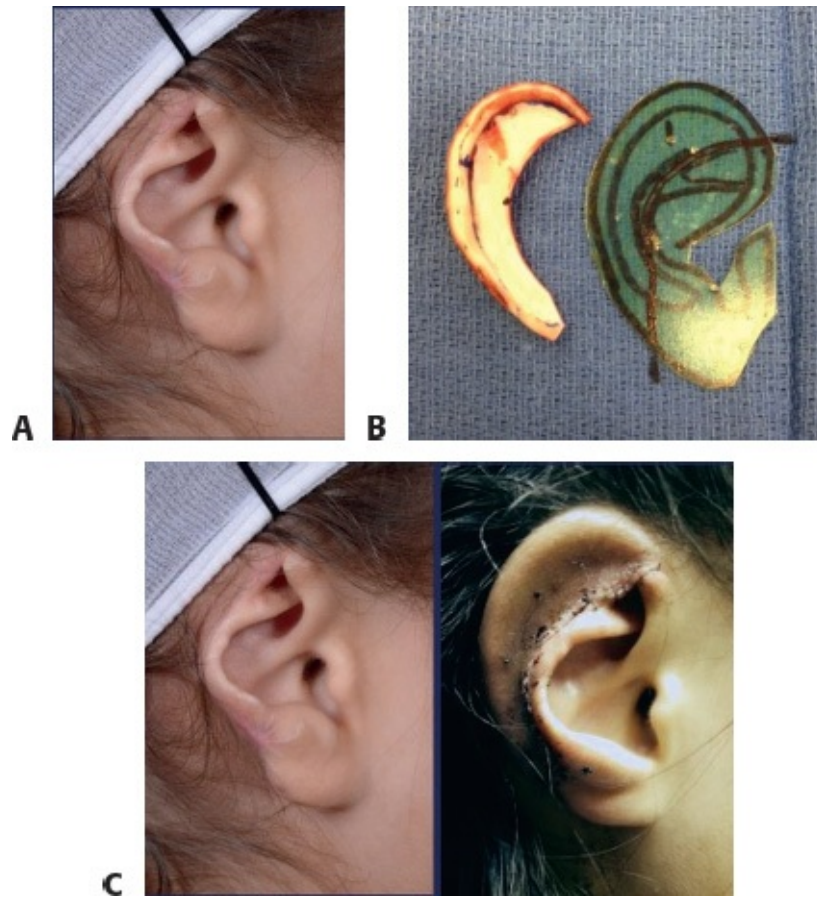


FIG 7 • A. Post-traumatic deformity. The remnant contains a normal concha, canal, and tragus, making an aesthetically pleasing result more likely. In this case, there was no scarring around the remnant as one might find in a burn patient or a victim of a motor vehicle accident. **B.** Framework constructed to replace the missing cartilage. **C.** Postoperative result.

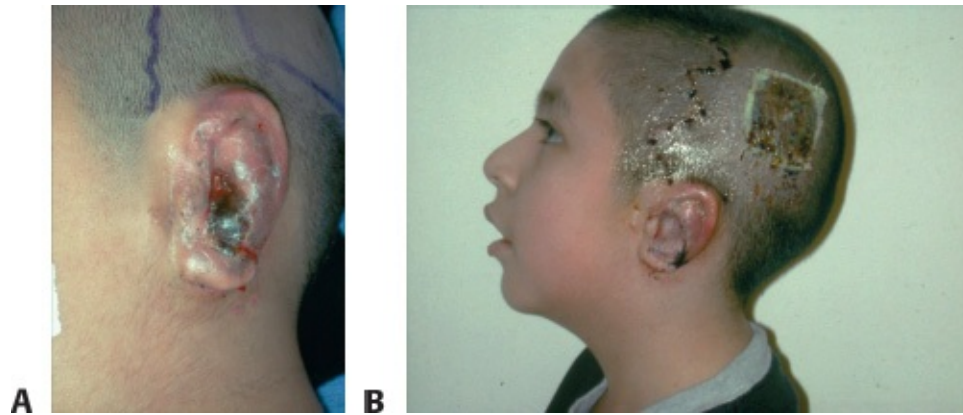


FIG 8 • A. The most common serious complication is necrosis of the overlying skin with impending exposure of framework. **B.** After salvage with temporoparietal flap and skin graft.

- Small areas of necrosis (5 mm or less) over concavities will heal with conservative management.
- Anything larger or any necrosis over a convexity of the framework such as the helical rim or the antihelix will not and must be treated early and aggressively.
- If the wound is left to heal and does not do so, the area will become contaminated or infected and will require a more significant debridement.
- The workhorse for closure is the temporoparietal fascial flap with a skin graft. The proximity of this tissue and its large size makes it possible to cover almost any area of necrosis.
- In patients with craniofacial microsomia who have had other surgery and may have had the superficial temporal vessels injured by a coronal incision or a free tissue transfer, the situation becomes much more difficult. The occipital fascia can be used but tends to be thicker, and the aesthetics of the reconstruction tend to suffer more from the use of this flap.
- In emergency situations, the exposed cartilage can be covered with a large scalping flap. The hair-bearing scalp is then returned to the scalp at a second stage, leaving skin-graftable tissue over the cartilage (crane principle).
- In the absence of local tissue coverage, one may also consider a free temporoparietal fascial flap harvested from the contralateral side.

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CHAPTER Stahl Ear

Akira Yamada and Arun Gosain

DEFINITION

- Stahl ear was first described by Binder in 1889.¹
- Stahl ear is a congenital auricular malformation in which an abnormal third crus traverses the scapha, resulting in posterosuperior deformation of the helix.

ANATOMY

- Type 1: Obtuse bifurcation of antihelix: Superior crus of antihelix is missing, and third crus is present. Therefore, the superior and inferior crura make an obtuse angle (**FIG 1A**).
- Type 2: Trifurcation of antihelix (extra crus); this is classic Stahl ear. The third crus extends across the scapha from the antihelix (**FIG 1B**).
- Type 3: Broad superior crus, broad third crus (protruded scapha fossa) (**FIG 1C**).

PATHOGENESIS

- Etiology is unknown.
- Abnormal course of an intrinsic transverse muscle may be associated with Stahl ear.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The third crus extends from the antihelix; the superior crus may or may not be present. The lower half of the auricle is usually normal.

NONOPERATIVE MANAGEMENT

- If the patient presents before 1 month of age, nonsurgical correction of the deformity with ear molding techniques may obviate the need for surgery.

- Ear molding techniques are most effective during the 1st month of life and are unlikely to work after the 2nd month of life.

SURGICAL MANAGEMENT

- There are three major types of normal helix-lobule curve (**FIG 2**). If the patient's helix-lobule curve falls into these three normal types, surgical correction of auricular shape may be directed toward deformities other than Stahl ear, such as prominent ear.

Preoperative Planning

- The possibility of ear molding is excluded if the patient presents after age 6 weeks. Ear shape analysis (especially helix type) is performed on the patient by applying an ear template for both auricles. Photographs are taken subsequent analysis. Based on photographic analysis, the patient shown has type A helix on both the normal (**FIG 3A**) and Stahl ear sides (**FIG 3B,C**).
- Two inflection points (abrupt change of the helix curve) are identified (**FIG 3D**), and the curve between the two inflection points is almost linear (**FIG 3E**).
- These two inflection points are the important landmark for wedge skin incision during surgery.

Positioning

- Supine position with slight head turn.
- Both auricles should be prepped in the sterile field, and the contralateral ear used as a reference in unilateral correction.

Approach

- Wedge excision is the simplest and most widely reported method.² Wedge excision is best indicated for type 2 Stahl ear. For type 1, excised cartilage may be transplanted to create the superior crus.³ Other options for type 1 are to make parallel three cartilage cuts⁴ or to place Mustarde sutures to accentuate the superior crus if there is adequate cartilage elasticity (**FIG 4A–D**).
- Cartilage turnover and rotation methods have been described but have mixed outcomes when used clinically.

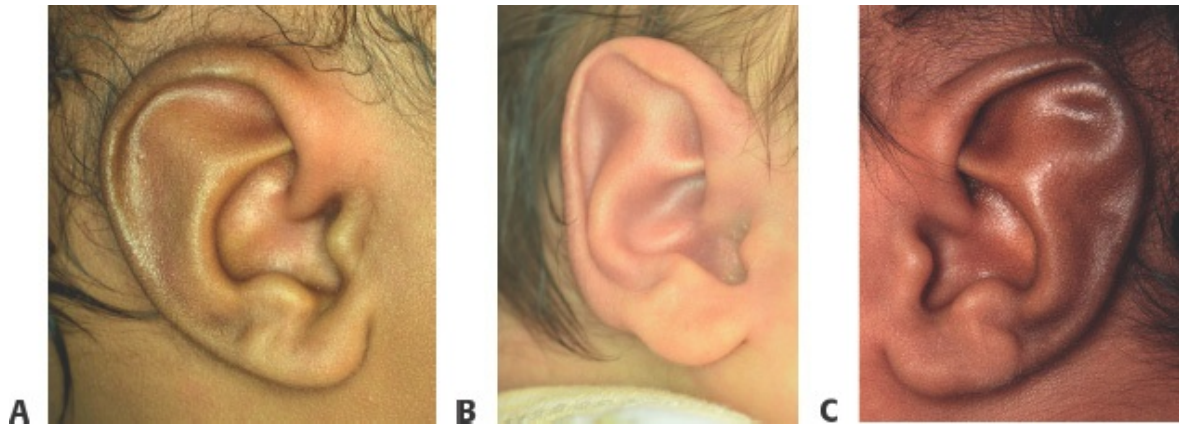


FIG 1 • **A.** Type 1 Stahl ear: Superior crus is missing. **B.** Type 2 Stahl ear: There are three crus (superior crus, inferior crus, and third crus). **C.** Type 3 Stahl ear: Wide third crus and protruded scapha fossa.

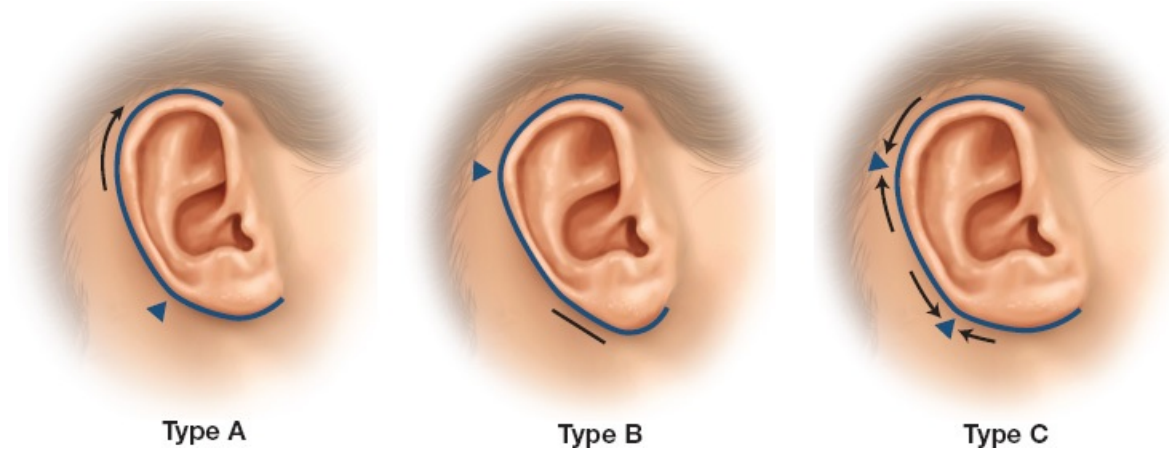


FIG 2 • The classification of helix-lobule curve.

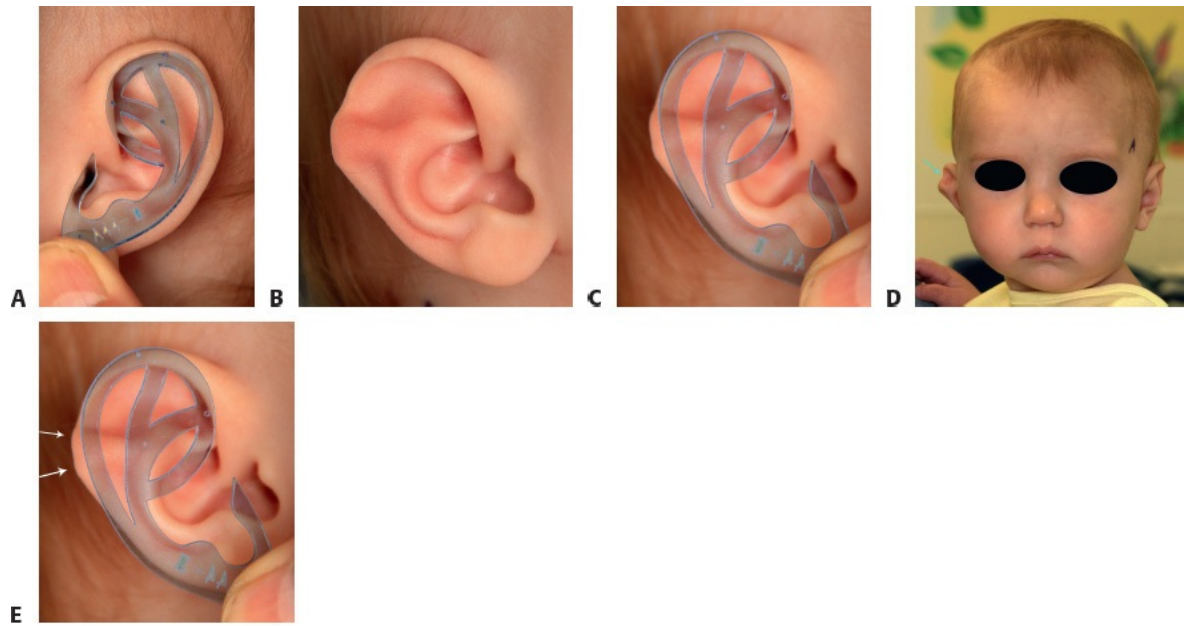
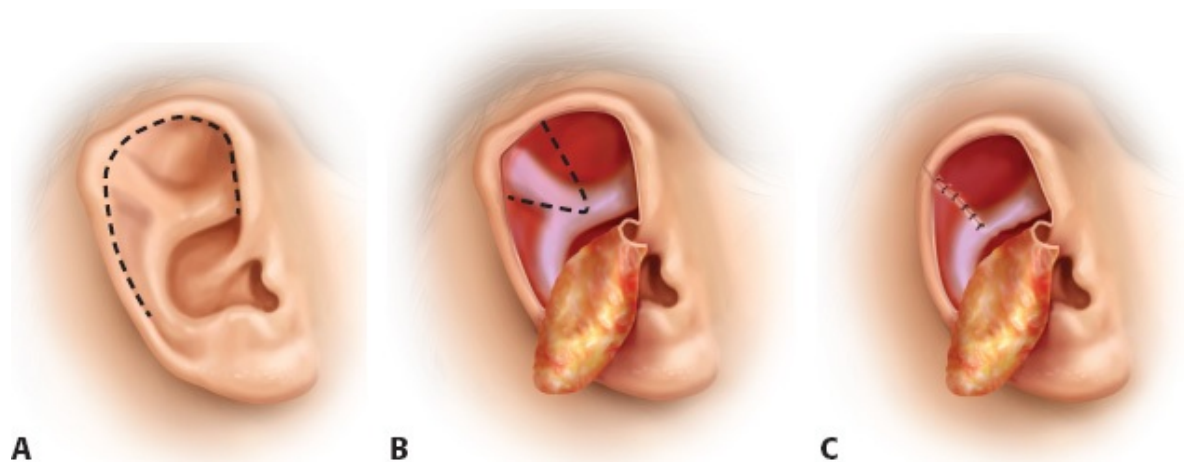


FIG 3 • Preoperative assessment of Stahl ear. **A.** The normal side ear has type A helix-lobule curve. **B.** The Stahl ear side: This is type 2 Stahl ear. **C.** Type A ear template is overlapped to assess the curve of Stahl ear. **D.** Frontal view of the patient helps to identify the change of the curve (*arrows*). **E.** Overall helix-lobule curve on Stahl ear is also type A, except around the third crus. Identification of two inflection points will determine the extent and shape of wedge excision.



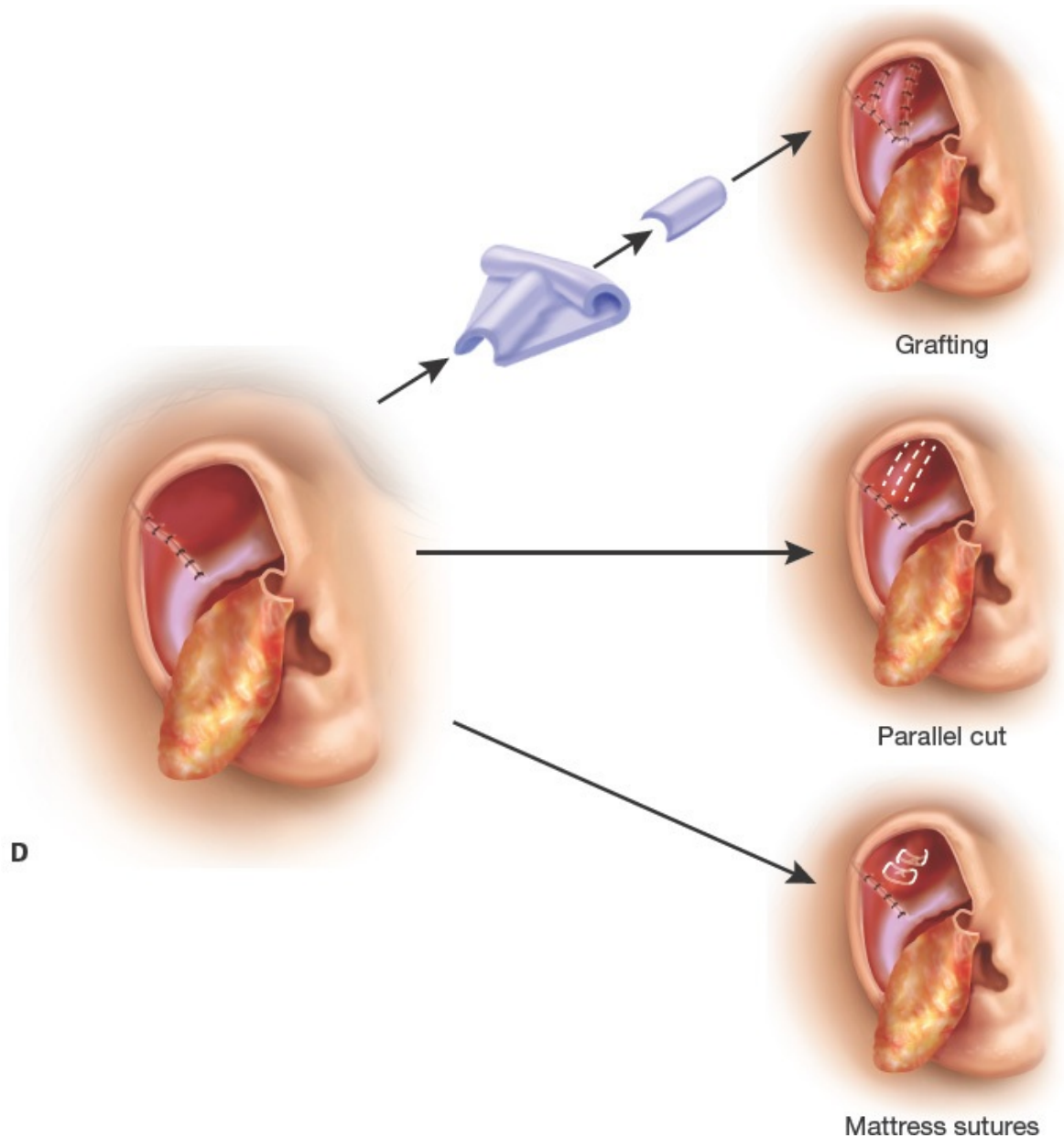
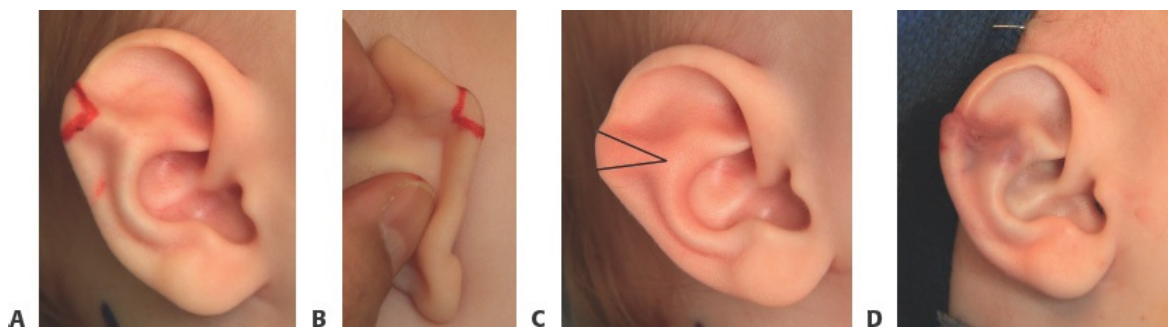


FIG 4 • Surgical approach for type 1 Stahl ear. **A.** Skin incision (*dotted line*) for type 1 Stahl ear. **B.** Wedge cartilage (third crus) is excised. **C.** Cartilage defect after wedge excision is closed primarily. **D.** There are three options to create the superior crus: cartilage grafting, parallel cartilage incision, or mattress sutures.

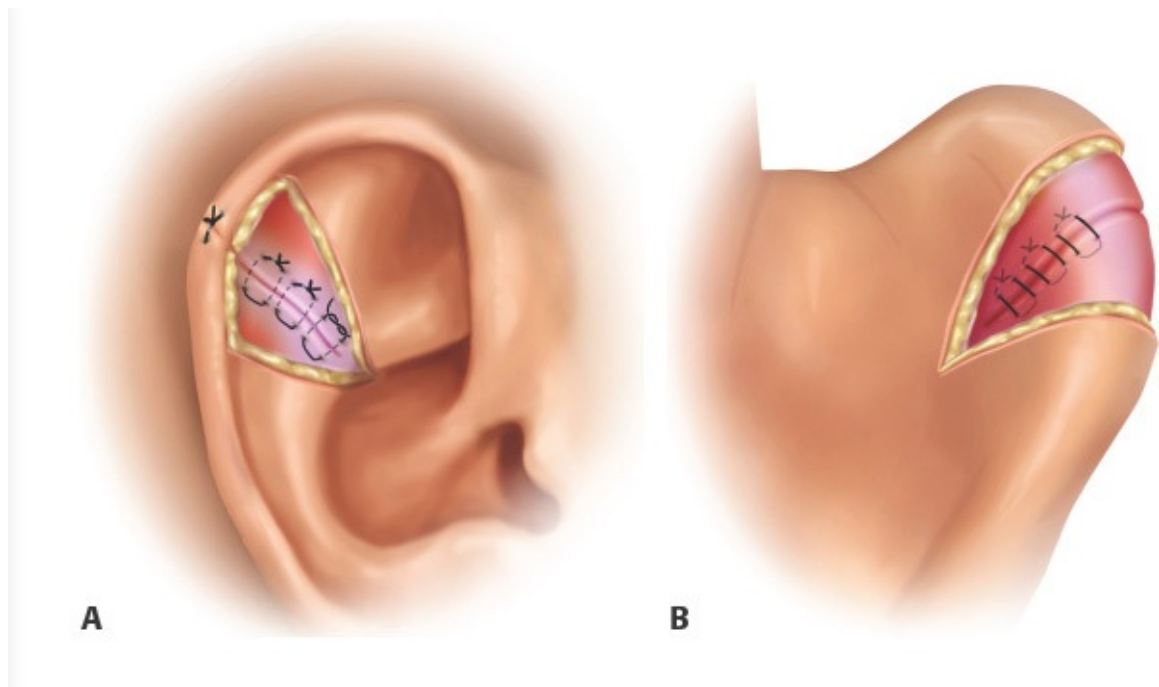
TECHNIQUES

■ Excision and Suturing

- Mark the wedge skin excision design between two inflection points (**TECH FIG 1A,B**).
- Cartilage (third crus) excision is expected to be longer than the skin wedge excision.
- Third crus excision is extended toward the antihelix, trying not to violate the antihelix (**TECH FIG 1C**).
- The cartilage is sutured together with 5-0 PDS (Ethicon Inc., Somerville, NJ). The focus is to align the curve of the helix (**TECH FIG 1D**).
- Suture the helix portion first and then move toward the antihelix (**TECH FIG 2A,B**).



TECH FIG 1 • The marking of the wedge skin excision. **A.** Anterior view. **B.** Posterior view. **C.** The marking for wedge cartilage excision. Note that cartilage excision is usually longer than the skin excision. Do not violate the antihelix. **D.** After wedge excision, the cartilage defect is closed primarily. The focus is to align the helix.



TECH FIG 2 • After aligning the cartilage of the helix, cartilage sutures are placed toward the antihelix. **A.** Anterior view. **B.** Posterior view.

■ Skin Closure

- Skin is closed in a single layer. Absorbable sutures can be used in children.
- We prefer 6-0 nylon suture for skin closure in adult patients, to be followed by suture removal in 2 weeks.

■ Bolster Sutures (TECH FIG 3)

- Bolster sutures are used to stabilize the helix and to prevent hematoma during the immediate post-op period.
- 4-0 Prolene is used to secure the bolster suture.
- Roll gauze is made with Xeroform plus Vaseline-based antibiotic ointments.
- Bolster sutures will be removed in 2 weeks. The wound is kept dry for 2 weeks.



TECH FIG 3 • Bolster sutures are in place. Tie has to be very gentle to prevent pressure injury.

PEARLS AND PITFALLS

Identify inflection points.

- This is the most important part of surgical planning. One must analyze the curve of the helix prior to surgery.

Photographic analysis

- A slight oblique photo is best to capture the shape of the helix for analysis. Analysis of the ear on a true lateral profile is less useful for planning.

Bolster sutures

- Tying very gently is the key. Even with a gentle tie, you will see tightness at the time of maximum swelling (48–72 h).
- Check underneath the bolster suture with bright LED light for pressure injuries, especially 2–3 days postoperatively.

Keep the wound dry for 2 weeks

- Avoid showering for 2 weeks postoperatively. The bolster must be kept clean to prevent infection.

POSTOPERATIVE CARE

- Periodic wound check for 2 weeks is mandatory to avoid complications.
- Keep the wound dry for 2 weeks to prevent infection. Showering may cause redness of the wound that may be difficult to differentiate from infection.

- Remove the bolster sutures in 2 weeks. During this time, periodic checks for pressure sore or tightness of the bolster sutures are important to prevent skin necrosis.

OUTCOMES

- Satisfactory outcomes are likely following the immediate wound healing process (**FIG 5**).

COMPLICATIONS

- Incomplete correction of helical deformities
- Infection
- Hematoma: Careful bolster suture helps to prevent hematoma and to stabilize the shape of the ear during the early wound healing process.



FIG 5 • Postoperative outcome.

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CHAPTER Constricted Ear

Akira Yamada and Julia Corcoran

DEFINITION AND ANATOMY

- The concept of constricted ear was proposed by Tanzer.¹ The helix and scapha are hooded, and the body and crura of the antihelix are flattened in varying degrees.
- Group 1 is the mildest form of constricted ear, often called lop ear, in which only the helix is involved (**FIG 1A**).
- Group 2 is a moderate form of constricted ear that involves helix and scapha.
 - Group 2 is divided into 2A and 2B: 2A has only cartilage deficiency (**FIG 1B**); 2B has both skin and cartilage deficiencies (**FIG 1C,D**).
- Group 3 is the most severe form of cupping and is characterized by a tubular structure (**FIG 1E**).
 - Differentiation between group 3 constricted ear and microtia can be difficult.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Constricted ear is congenital, and the etiology is unknown.
- Ear height² is significantly shorter than normal.
- The helix tends to be cupped.
- The upper portion of the antitragus (superior and inferior crus) is difficult to see.
- The shape of the lower half of the auricle is likely to be normal, especially in mild to moderate constricted ear (see **FIG 1C,D**).

NONOPERATIVE MANAGEMENT

- Nonsurgical manipulation of the ear cartilage in infancy does not work for the

constricted ear due to intrinsic deficiency of skin and/or cartilage.

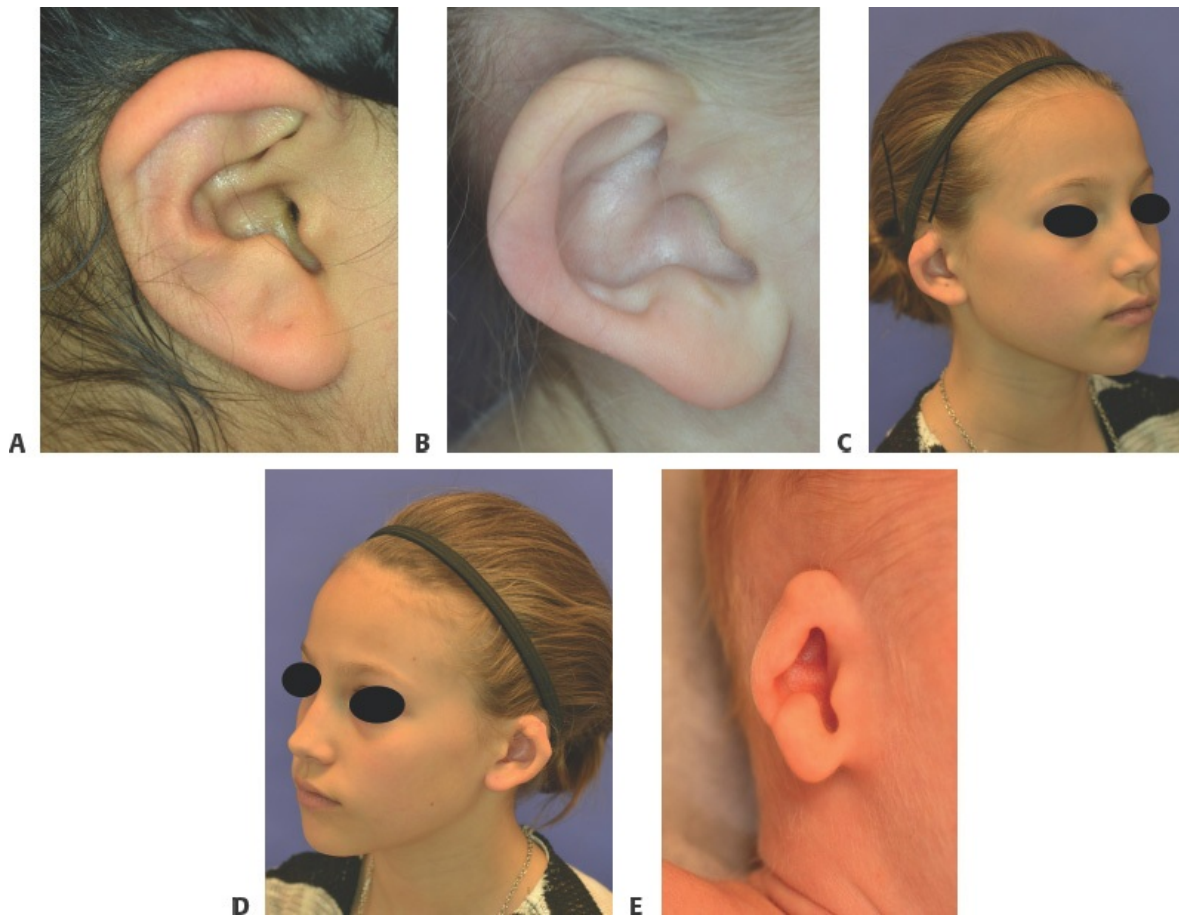


FIG 1 • Tanzer constricted ear classification. **A.** Group 1: Mild helix cartilage deformity without skin defect. **B.** Group 2A: Helix and scapha cartilage deformity without skin defect. **C,D.** Group 2B: Helix and scapha deformities with both cartilage and skin defects. **E.** Group 3: Most severe form of cupping; characterized by a tubular structure.

- Molding techniques in infancy may change the shape of the auricle but is unlikely to expand skin/cartilage.
- “Constricted” means there is cartilage and/or skin deficiencies that must be augmented by surgical procedures.

SURGICAL MANAGEMENT

Preoperative Planning

- Age-matched anthropometric data of ear dimension, especially vertical height, help to distinguish deviation of the patient's ear from norms (**FIG 2**).

Positioning

- Supine position with mild head turn. Both sides should be prepped, even with unilateral surgery, so that the contralateral ear can serve as a normal reference.

Approach

- If there is no skin defect and the cartilage defect is mild (Tanzer group 1), the Musgrave⁴ procedure alone is effective to correct the deformities. If there is moderate skin and cartilage defect (Tanzer group 2B), a local skin/fascia flap plus floating rib cartilage grafting⁵ is a good choice (presenting case).
- If the skin or cartilage defect is severe, microtia surgery⁶ may be indicated.
- Recommended surgical options for skin envelope augmentation, based on the severity:
 - Mild: Grotting skin flap

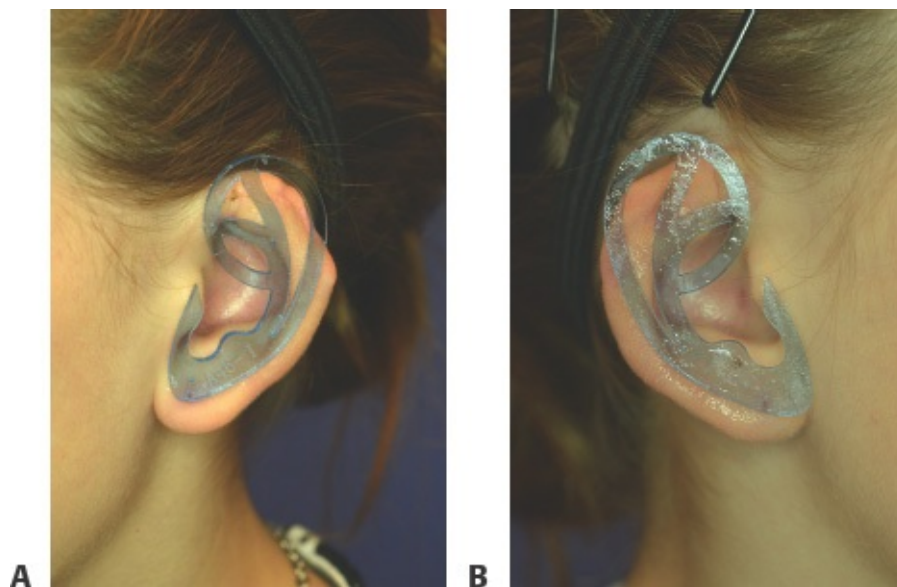


FIG 2 • A type A-2, 48-mm template is used to evaluate the degree of skin and cartilage defect of the upper half of the auricle of the left ear (**A**) and right ear (**B**).³

Although the left ear has more severe skin and cartilage defect, both auricles are diagnosed as Tanzer group 2B

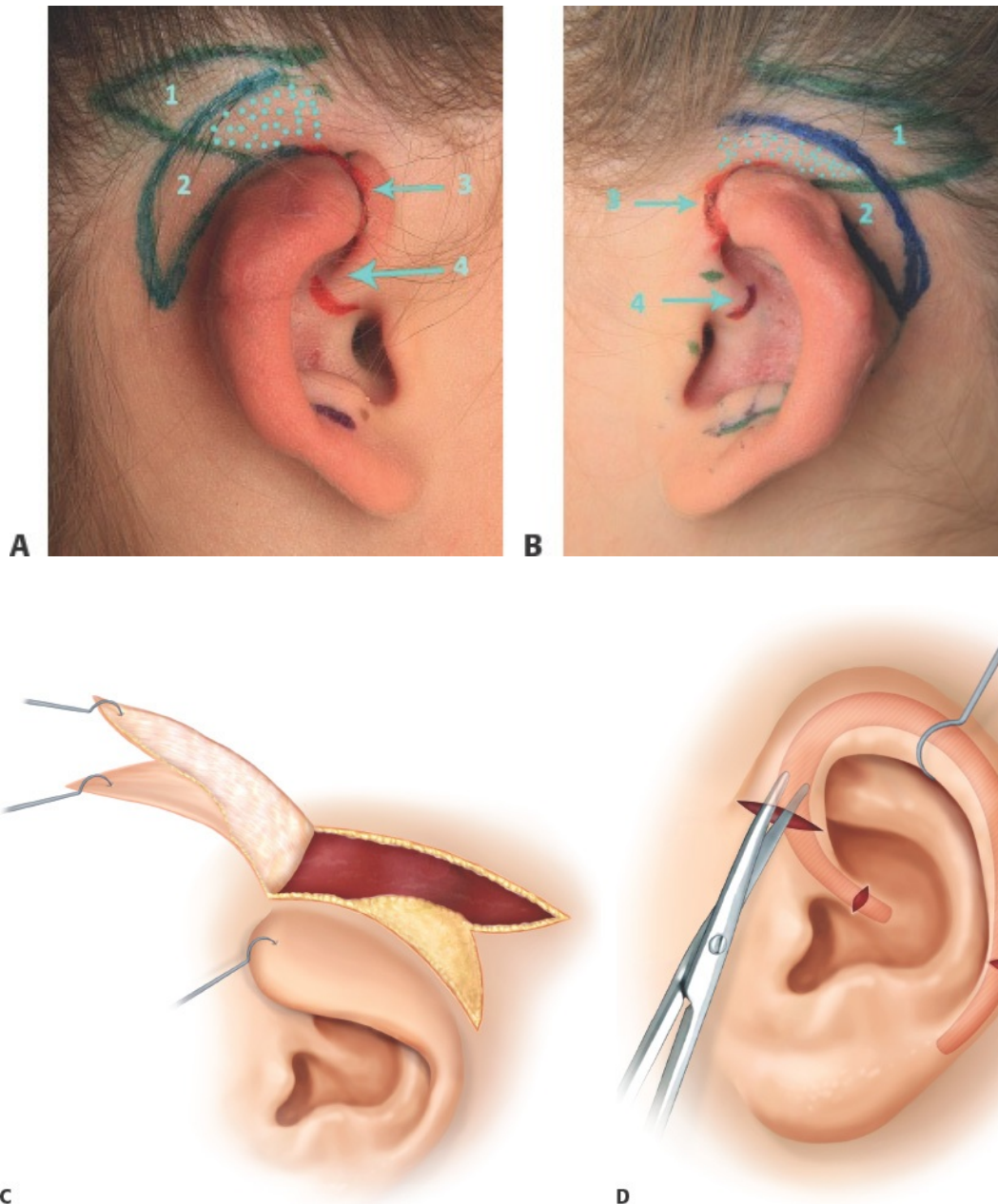
constricted ear.

- Moderate: Park procedure (Grotting skin flap plus fascia flap)
- Severe: Nagata microtia construction
- Recommended surgical options for cartilage defects, based on the severity:
 - Mild: Musgrave procedure
 - Moderate: floating rib (Park)
 - Severe: total framework (Nagata)

TECHNIQUES

■ Markings

- The Grotting skin flap⁷ measuring approximately 1.0 to 1.5 cm in width and 3.0 to 3.5 cm in length, is designed and elevated on the posterior surface of the superior auricle to drape the skin defects of the anterior and posterior helix and scapha.
- A bilobed flap is marked: the superior flap is a fascia flap, and the inferior flap is a Grotting skin flap. The fascia flap and the Grotting flap share a common base (**TECH FIG 1A,B**).
- A portion of the superficial temporal fascia will be attached beneath the proximal 1.5 cm of the Grotting flap to increase the vascularity of the Grotting flap (**TECH FIG 1C**).
- Three small, transverse skin incisions are marked at the helical crus, at or near the otobasion superius (the point of attachment of the superior helix to the temple), and at the descending helix (**TECH FIG 1D**).

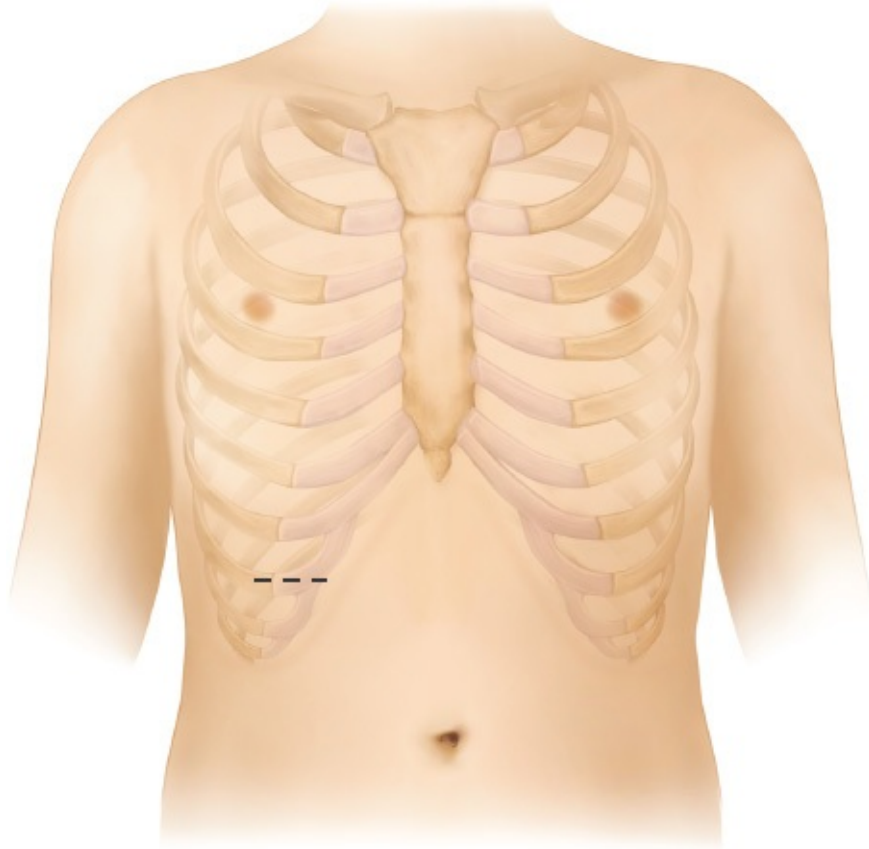


TECH FIG 1 • A,B. Design of the bilobed flaps. 1: Fascia flap. 2: Grotting skin flap. 3: Skin incision at otobasion. 4: Skin incision at crus helicus. *Dotted areas indicate shared pedicle.* **C.** The Grotting skin flap and the fascia flap are raised as a combined flap, sharing common pedicle at the base. **D.** Three small, transverse skin incisions are marked at the helical crus, at or near the otobasion superius (the point of

attachment of the superior helix to the temple), and at the descending helix.

■ Harvesting the 8th Rib Cartilage

- A 3-cm traverse skin incision is marked at the right lower costal margin (**TECH FIG 2**). After local epinephrine injection, the skin is incised.
- After identifying the fascia of the external oblique muscle, the fascia is incised transversely. The course of the external oblique muscle is examined, and the muscle fibers are split along the course of the fibers and retracted to identify the costal cartilage.
- Care is taken to identify any perforator vessels that emerge from intercostal spaces. These vessels are coagulated with bipolar cautery well above the intercostal space.
- Prior to incising the perichondrium, a small amount of local anesthetics (eg, 0.125%–0.25% bupivacaine) is injected in the intercostal space as a nerve block.
- The anterior perichondrium of the 8th rib cartilage is gently incised with a no. 15 blade in the midline, beginning at the bone-cartilage junction.
 - A 360-degree subperichondrial dissection is performed to completely dissect the cartilage from the perichondrium.
- After 8th rib cartilage is cut at the bone-cartilage junction and removed, saline irrigation of the wound is performed.
- Once homeostasis is confirmed, the perichondrium is closed with 4-0 Vicryl. The wound is then closed in layers.



TECH FIG 2 • A 3-cm transverse skin incision at lower costal margin for harvesting 8th rib cartilage.

■ Splitting the Rib Cartilage and Creating the Skin Tunnel

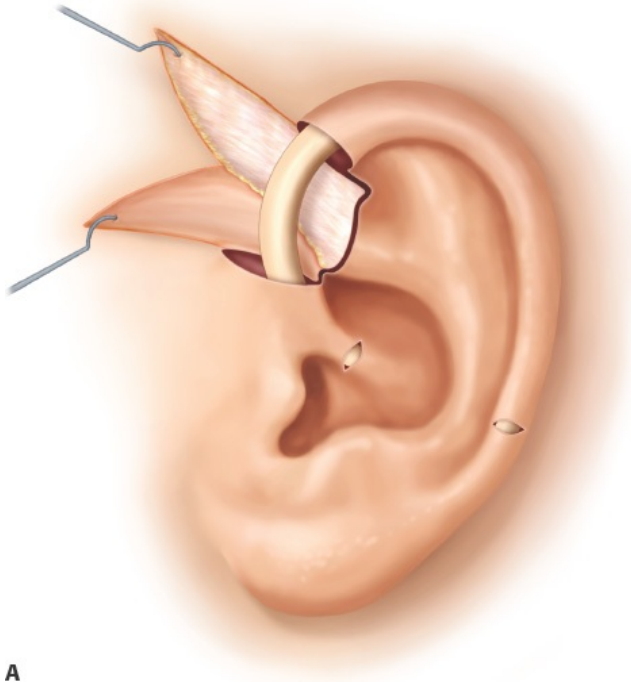
- The cartilage is split longitudinally into two pieces (**TECH FIG 3A,B**).
- Splitting must be precisely in the middle for simultaneous bilateral constricted ear reconstruction.
- Through the three small skin incisions described above, a skin tunnel is created above the existing helix (see **TECH FIG 1C**).
- The split cartilage is inserted into the helical tunnel through the skin incision site at or near the otobasion superius (**TECH FIG 3C**).



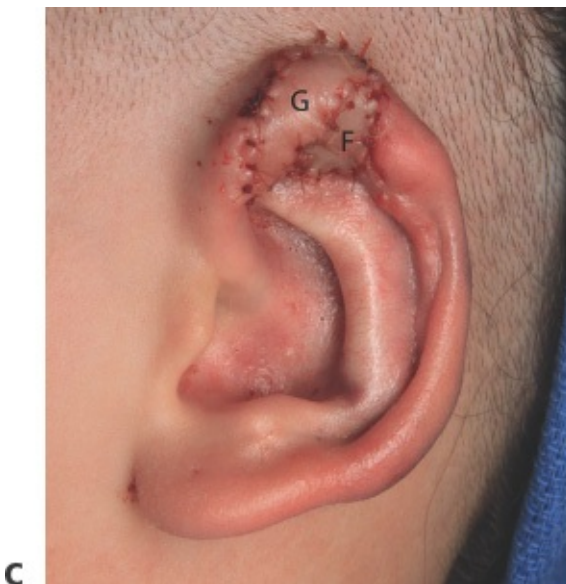
TECH FIG 3 • Split 8th rib cartilage for right (**A**) and left (**B**) ears is laid over a type A-2, 48-mm template.³ **C**. The split cartilage is inserted into the helical tunnel through the skin incision site at or near the otobasion superius.

■ Transpositioning the Fasciocutaneous Grotting Flap

- After helix expansion with newly inserted helical cartilage, the skin envelope defect at or near the otobasion superius will be identified (the point of attachment of the superior helix to the temple). A bilobed skin/fascia flap will be transposed to fill the defect (**TECH FIG 4A**).
- The size and location of the skin defect varies, depending on the severity and the nature of the constricted ear.
- In the example case, both skin flap and fascia flap are transposed to cover the anterior helix and scapha on the left side (**TECH FIG 4B,C**), and only skin flap is used to cover anterior helix and scapha on the right side (**TECH FIG 4D**).



TECH FIG 4 • A. A bilobed skin/fascia flap will be transposed to fill the defect. **B,C.** Both skin flap and fascia flap are transposed to cover the anterior helix and scapha on the left ear. G, Grotting skin flap; F, fascia flap plus skin graft. **D.** Immediate postoperative view of the right ear showing a Grotting skin flap (G).



■ Wound Closure and Bolster Sutures

- The skin incision is closed in a single layer.
- A small full-thickness skin graft is harvested from the back of the auricle and grafted above the fascia flap on the left side (see **TECH FIG 2**).
- Bolster sutures are used to stabilize the helix shape and to prevent hematoma during the immediate postoperative period (**TECH FIG 5**).
 - 4-0 Prolene (Ethicon, Somerville, NJ) is used to secure the bolster suture.
 - Roll gauze is made with Xeroform plus Vaseline-based antibiotic ointments.
- Bolster sutures will be removed in 2 weeks. The wound should be kept dry until removal of the bolsters.



TECH FIG 5 • Bolster sutures are used to stabilize the construction and to prevent hematoma.

PEARLS AND PITFALLS

Template ■ A sterilized ear template helps to maintain precision during surgery.

Planning ■ Preoperative planning to assess the defects of skin and cartilage is

	critical. The ear template facilitates this process.
Costal cartilage harvesting	■ Harvesting rib cartilage while leaving the perichondrium behind is safer than harvesting cartilage with perichondrium. This helps to prevent pneumothorax and to minimize chest wall deformities.
Bolster sutures	■ A very gentle tie is the key. Even with a gentle tie, one will see tightness at the time of maximum swelling (48–72 h). Check underneath the bolster suture with bright LED light for pressure sores, especially by 2 or 3 days postoperatively. ■ The authors recommend not shampooing for 2 weeks postoperatively. Keeping the bolster dressing clean and dry helps to prevent infection.

POSTOPERATIVE CARE

- Periodic wound check for 2 weeks is strongly recommended to avoid complications.
- It is recommended to keep the wound dry for 2 weeks to prevent infection. Shampoo may cause redness of the wound and make it difficult to differentiate from infection.
- The bolster sutures will be removed in 2 weeks. Until then, periodic checks for pressure sores or tightness of the bolster sutures are important to prevent skin necrosis.

OUTCOMES

- If a balanced augmentation of the skin envelope and cartilage is achieved to expand the helix, a stable outcome is likely (**FIG 3**).

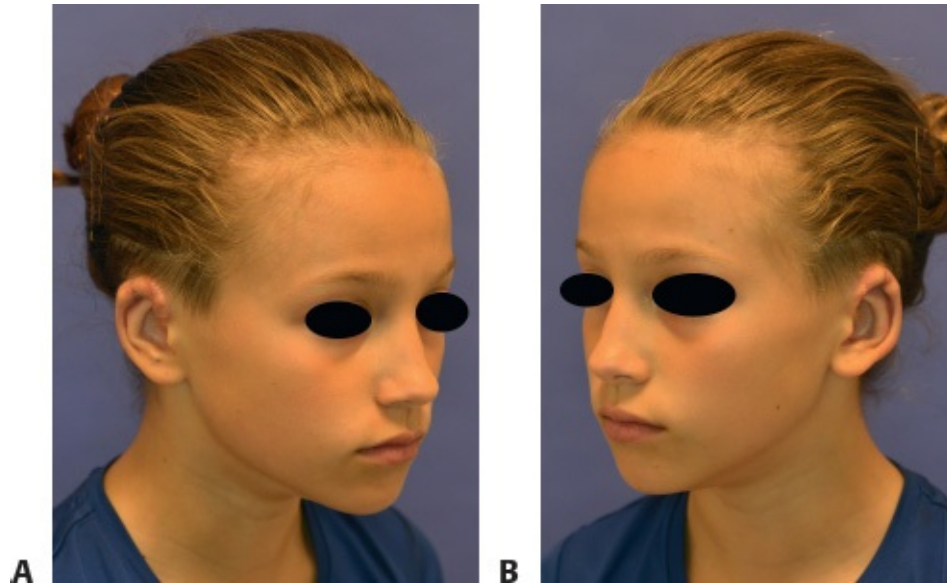


FIG 3 • Left (A) and right (B) ears are shown 3 months after surgery.

COMPLICATIONS

- Incomplete correction of the helix deformities
- Infection
- Hematoma: Careful bolster suture helps to prevent hematoma and to stabilize ear shape during the early wound healing process.

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CHAPTER Cryptotia

Akira Yamada and Arun K. Gosain

DEFINITION/ANATOMY

- Cryptotia is a relatively rare congenital ear deformity. The upper portion of the auricular cartilage is partially buried beneath the skin on the side of the head, hiding the upper portion of the ear. Cryptotia is often associated with helix-antihelix adhesion that results in a narrower helical arc in the upper pole. Cryptotia is also associated with upper helix deficiency that is a manifestation of constricted ear. Cryptotia is more frequent in Asian countries. In Japan, it has been reported in as many as 1 in 500 births.

PATHOGENESIS

- The cause of cryptotia is unknown. One theory is that cryptotia is the result of an anomaly of the intrinsic transverse and oblique auricular muscles.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- The upper portion of the helix is buried underneath the skin (**FIG 1**). If one pulls the existing helix, the upper portion of the helix comes out easily. On releasing the helix, the upper helix returns to its initial position buried beneath the temporal skin.



FIG 1 • Preoperative view of cryptotia; the upper pole of the helix is buried underneath the scalp.

DIFFERENTIAL DIAGNOSIS

- Helix-antihelix adhesion
- Constricted ear
- Microtia

NONOPERATIVE MANAGEMENT

- If the patient presents before 1 month of age, nonsurgical correction of the deformity with ear molding techniques may obviate the need for surgery.²
- Ear molding techniques are most effective during the first month of life and are unlikely to work after the 2nd month of life.
- Helix-antihelix adhesion associated with cryptotia or helix deficiency associated with constricted ear is less likely to resolve with molding techniques.

SURGICAL MANAGEMENT

Preoperative Planning

- It is important to check if the cryptotia is associated with other congenital anomalies, such as helix-antihelix adhesion or constricted ear. Pure cryptotia surgery will augment the skin deficiency but will not resolve helix-antihelix adhesion or cartilage defect of the helix associated with constricted ear.
- If cryptotia is not associated with cartilage deformities, surgery can be done in early childhood. However, if cryptotia is associated with helix deformities, the authors recommend delaying surgery until at least age 4 to 6 years because of

the possible need to harvest rib cartilage.

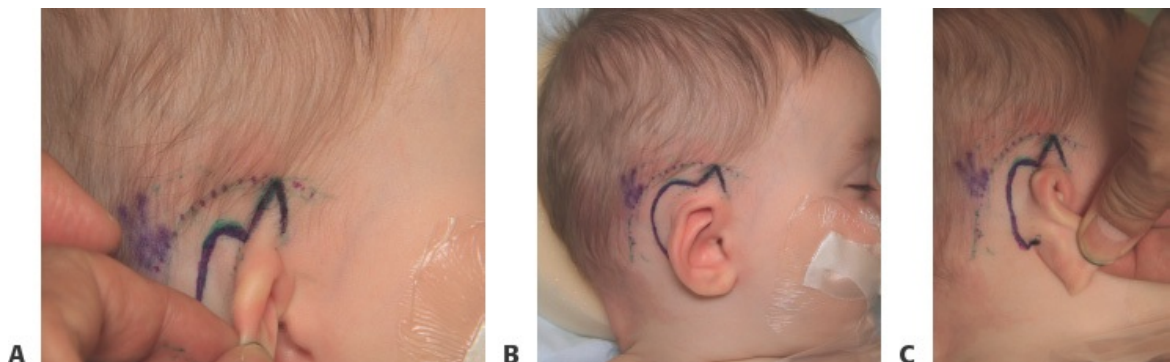
Positioning

- Supine position with both ears prepped, including the temporal hair near the ears

TECHNIQUES

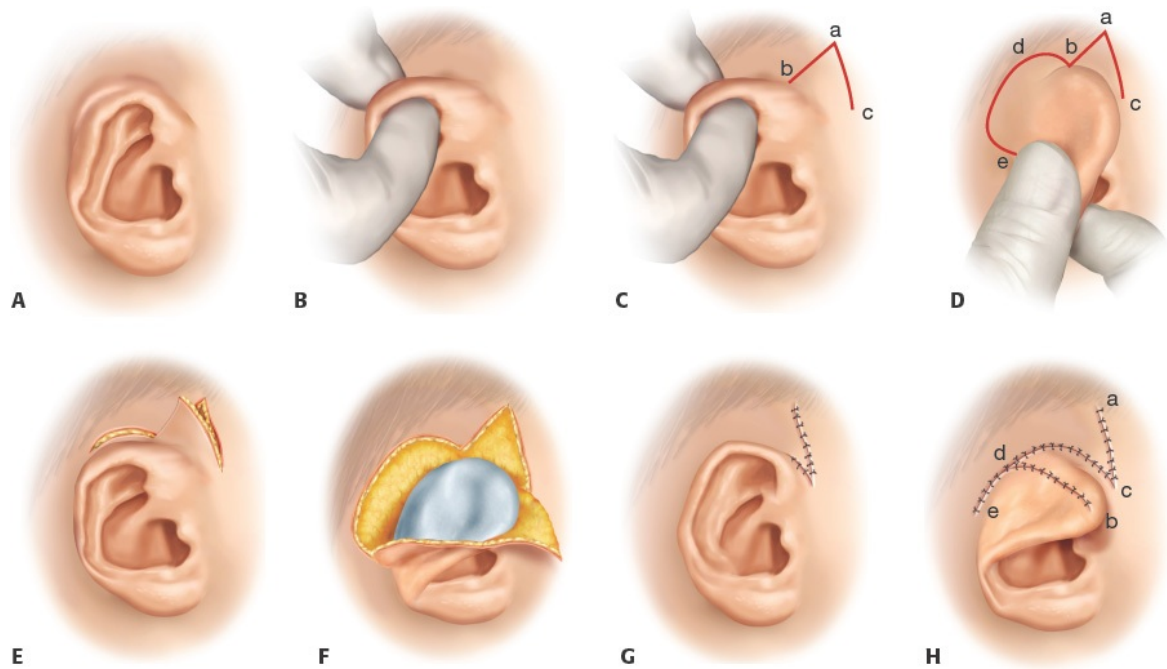
■ Marking of Z-plasty

- Z-plasty flaps are designed along the bandlike contracture above the auricle, while pulling outward away from head (**TECH FIG 1A**). The length of triangular flap depends on the degree of buried position of helix, but in this particular case, the tip of the triangular flap is located along the hairline margin (**TECH FIG 1B,C**).
- Usually, the length of Z-plasty limb is 1.5 to 2 cm³. The anterior limb of the Z (A–C) is usually placed 5 to 10 mm from the ascending margin of the helix. The posterior limb of Z-plasty (B–D) has a more obtuse angle than does the anterior limb, and the continuous extension of the skin incision is marked beyond the retroauricular sulcus (D–E). If more mobilization of the skin flap is needed, D–E can be extended further down, and a back cut may facilitate movement of the flap toward the skin deficiency behind the upper helix (**TECH FIG 2**).



TECH FIG 1 • **A.** Triangular flap is designed along the bandlike contracture above the auricle, while pulling outward from head. **B.** The tip of the triangular flap is

located along the hairline margin. **C.** If more mobilization of the skin flap is needed, the skin incision can be extended further down. A back cut may facilitate flap movement toward the skin deficiency behind the upper helix.



TECH FIG 2 • The diagram shows the basic design of the skin flaps, and the view after the wound closure. **A.** Preoperative view of cryptotia; upper helix is buried underneath the skin. **B.** The design of the skin incision is marked while buries portion of the upper helix is pulled out. **C.** AB lies along the line of traction. Point C must be located slightly anterior to the ascending margin of helix. **D.** CABD is a Z-plasty. The incision is extended further (as far as point E) in accordance with the requirement of cartilage plasty and the extent of skin advancement. 'de' curve is located posterior than intended retroauricular sulcus. **E.** Triangular skin flap 'cab' and skin flap 'bde' is raised. **F.** Upper ear cartilage is exposed with supra-perichondrial skin flap

dissection. **G.** Triangular skin flap is transposed posteriorly, and the wound is closed primarily: this maneuver eliminates the space for buried upper helix. **H.** Upper auricle is reflected anteriorly to demonstrate the completion of wound closure: Z-plasty plus advancement flap creates enough skin envelope for new helix.

■ Skin Flap Dissection and Ear Cartilage Exposure

- Dissection of the skin flap is performed just above perichondrium to see if any cartilage modification is needed. The temporal and mastoid skin is widely undermined to facilitate skin transposition so as to augment the posterior skin defect of the upper helix.

■ Skin Flap Transposition

- After skin flap preparation and careful hemostasis, the skin flaps are transposed toward the skin deficiency at the back of superior helix, filling residual defects.³

■ Wound Closure

- The skin is closed in single layer. In most cases, there is less skin tension after transposition of skin flaps to facilitate closure.

■ Bolster Sutures

- Bolster sutures (**TECH FIG 3**) are classic techniques, popularized by Tanzer more than 50 years ago. The bolster sutures have two purposes: (a) preventing hematoma formation and (b) to form an adhesion between the flap and cartilage. Nagata uses bolster sutures for almost all ear reconstruction. The key is to (a) use soft materials (eg, Xeroform gauze with additional soaking with ample Vaseline-based ointment) and (b) tie very gently to avoid any strain to the skin. The authors use 4-0 Prolene on a double-armed, SH

needle (Ethicon Inc., Somerville, NJ). Periodic check, especially 2 days post-op when the swelling is maximum, is mandatory to prevent a pressure sore underneath the bolster sutures.



TECH FIG 3 • The view after the bolster sutures are placed.

PEARLS AND PITFALLS

Timing of surgery	■ If you are unsure about helix deformities, delay the surgery until 4–6 years of age when a floating rib graft becomes an option.
Associated ear anomalies	■ Look for helix-antihelix adhesion, and helix deficiencies associated with a constricted ear.
Design of skin flaps	■ Mark the hairline before shaving so as not to obscure the margin of the hairless posterior auricular skin.
Bolster sutures	■ Tie very gently. Use soft materials for a gauze pillow such as Xeroform soaked in Vaseline-based ointment.
Skin flap dissection	■ Skin dissection should be at uniform thickness in a plane just above perichondrium.

POSTOPERATIVE CARE

- Patients/parents should be instructed to keep the wound dry for 2 weeks. Early shampoo prior to 2 weeks may cause redness of the wound. Although this may not indicate an infection, redness is confusing for both physicians and patients. If bolster sutures are used, periodic check underneath the bolster is mandatory to prevent pressure sore.

OUTCOMES

- **FIG 2** shows the immediate outcome of surgery. If surgery is performed in early childhood, it is important to explain to the family that the child/family may notice recurrent deformities of the helix later in childhood. Families should understand that a second surgery may be considered should helix deficiencies recur. Mild helix deformities can be addressed with the Musgrave procedure. For more severe helix deformities, floating rib graft (Park) may be indicated (see chapter on Constricted Ear).



FIG 2 • The view immediately after wound closure.

COMPLICATIONS

- Infection: Infection can be caused by a break in proper sterile surgical technique or dehiscence secondary to excessive tension during closure. It can also be an untoward sequela of prior hematoma evacuation. A history of atopic dermatitis (eczema) is a warning sign. The ear canal could also serve as a reservoir of bacteria, especially in swimmers. Careful preparation of hairs near the surgical site is important to prevent infection.
- Postoperative hematoma: Hematoma is heralded by the acute onset of severe,

persistent, and often unilateral pain. If there is evidence of ongoing bleeding, reoperation and exploration are mandatory. Meticulous postoperative dressing, including bolster sutures, helps to prevent hematoma.

- Skin necrosis: When raising skin flap, it is important to raise the skin flap in the same plane and thickness to avoid irregular thickness of the skin flap. Small blunt straight scissors may be better than popular curved scissors in this respect. The proper plane of elevation for prominent ear is just above the perichondrium. A thinner dissection plane may result in skin necrosis. When using bolster sutures, it is mandatory to check for possible pressure sore beneath the bolster regularly until sutures removal 2 weeks postoperatively.
- Chondritis: Chondritis is a surgical emergency, which, if left untreated, can result in permanent deformity. Therefore, prompt debridement of devitalized tissue is necessary.
- Late sequelae of helix deformities of ear: These are mainly caused by unrecognized helix-antihelix adhesion or helix deficiencies associated with cryptotia. In order to avoid these complications, it is important to recognize the associated congenital ear deformities associated with cryptotia.

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CHAPTER Prominent Ear

Akira Yamada and Arun K. Gosain

DEFINITION

- Prominent ears are a common abnormality, affecting about 5% of children. When observing other people's faces, the first thing we pay attention to is the facial triangle, eye–mouth–eye. The auricle is usually not the primary area of attention. However, if the auricle is projected more than 25 mm from the head, it tends to catch the attention of human eyes as “prominent.”

ANATOMY

- The main components of the prominent ear are (1) loss of antihelical fold, (2) concha scapha angle greater than 90 degrees, and (3) conchal cartilage excess (**FIG 1**).
- Understanding ear shape anatomy, aesthetics of the ear, ear shape dimensions, and proper anatomical location of the ear is essential to achieving a natural result for the correction of prominent ear deformity.^{1,2}

PATHOGENESIS

- The most common etiology of the prominent ear is effacement of the antihelical fold. Also a deep conchal bowl (greater than 1.5 cm) frequently contributes to the overall pathogenesis. Combination of these two is very common.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Five parameters should be assessed systematically to ensure that all components of the prominent ear deformity are recognized: (1) auriculocephalic angle, (2) scapha-conchal angle, (3) relationship of the antihelix to the helix, (4) horizontal distance from the most lateral aspect of the

helix to a point perpendicular to the skull, and (5) depth of the conchal bowl.

DIFFERENTIAL DIAGNOSIS

- Constricted ear
- Stahl ear
- Microtia

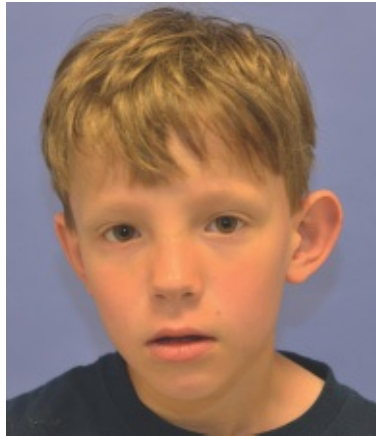


FIG 1 • Preoperative view of unilateral prominent ear (Case 2).

NONOPERATIVE MANAGEMENT

- If the patient presents in infancy, preferably less than 1 month of age, ear molding techniques may be indicated. Success of ear molding progressively diminishes after the first month of life, and after age 2 months, surgery is the only reliable option to correct the prominent ear.

SURGICAL MANAGEMENT

- If the distance from the head to the top of helix at any point is over 25 mm, it is considered to be a prominent ear.
- Because the prominent ear could be the target of bullying and ridicule during school age, the most popular timing of surgery is before the start of primary school.
- There seems to be a slightly different prominent ear concept among different cultures. Generally speaking, Asian countries are more tolerant to prominent ear, because the “big ear” is a good sign of luck and wealth.

Preoperative Planning

- Preoperative anthropometric measurement of the auricle is extremely important to achieve symmetry of the projection of the auricle postoperatively. The direct measurements also help to assess the nature of prominence. For example, if the patient has more prominence in the lower pole (25 to 30 mm), it is likely that conchal hypertrophy exists. To assess the degree of projection, the authors recommend measuring at least three points (eg, upper, middle, and lower) from the head to the top of helix. An otoplasty grid provides objective data of projection from the top to the tail of the helix (**FIG 2**). In case of unilateral prominent ear, otoplasty grid taken from normal data can be used as an intraoperative template to achieve symmetry (**FIG 3**).

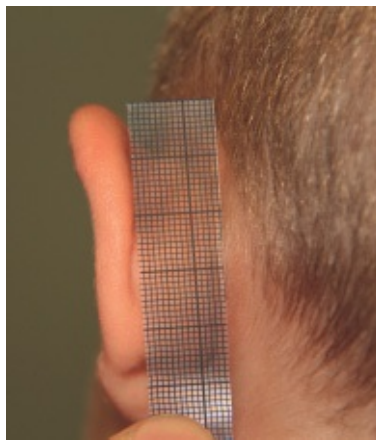


FIG 2 • Preoperative assessment of projection (Case 1).

Prediction of the Projection Reduction

- 20 mm distance from the mastoid to the peak of helix is acceptable projection, especially in Asian countries. In the United States, somewhere between 15 to 20 mm is the reasonable goal to achieve. The trend of ear projection in the patient's family is a good indicator for the targeted height of projection.

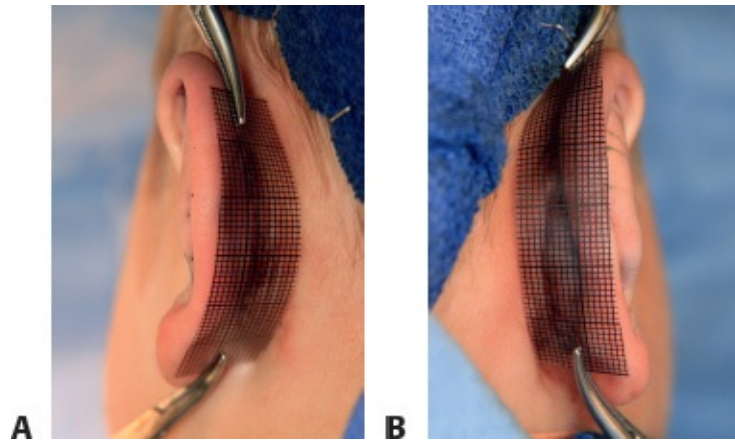


FIG 3 • Otoplasty grid is used to assess the postop helix-mastoid distance on the (A) left and (B) on the right.

Preoperative Quantification of Prominence by Otoplasty Grid

- After determining the goal of projection, the authors create a customized otoplasty grid for the patient, with a planned projection from the mastoid to the peak of the helix (15 mm in **FIG 2**). Upon placing the grid at the back of the auricle, one can visualize the amount of reduction needed for surgery.

Positioning

- Supine position with bilateral auricle preparation is recommended, even for the unilateral prominent ear, so as to check for symmetry (**FIGS 4** and **5**). One should also prepare the hair adjacent to the ears.

Approach

- Most cases need a combined approach to correct the deformities. Among numerous techniques reported in the literatures, Mustardé mattress sutures are the most commonly used method to create the antihelical fold.³
- Stenstrom-type anterior scoring⁴ can be applied to more rigid cartilage in older children and adults to facilitate folding of the antihelix. One must be aware that adult cartilage is also fragile, and overly aggressive scoring can cause secondary deformities with irregularity of the antihelix, which are aesthetically unfavorable.
- To prevent recurrence of the prominent ear deformity, posterior skin excision is an effective adjunct that can be combined with the Mustardé techniques (**FIG**

6). The postauricular sulcus should not be markedly decreased; thus, the amount of skin excision should be conservative. Excessive skin excision can cause tension in skin closure that may lead to hypertrophic scarring, especially in the dark-skinned population.



FIG 4 • The patient is placed in supine position to be able to assess bilateral projection.

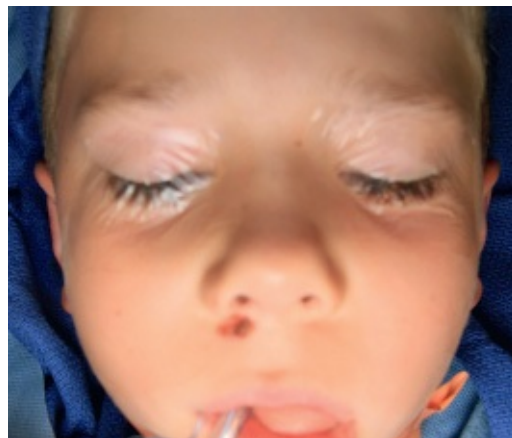


FIG 5 • Immediate postoperative view from the front. Symmetrical set back is achieved.

- If the patient has projection over 25 mm in the lower pole, conchal hypertrophy may exist and resection of conchal cartilage and/or conchal setback may be necessary. Conchal hypertrophy can cause two unwanted effects: (i) recurrence of projection, and (ii) unnatural bending with sharp angulation of the antihelix at the level of the antitragus.

- A prominent lobule not corrected by finger pressure on the helical rim will require an additional procedure.⁵ Fishtail-type skin excision and a suture from the dermis to the scalp periosteum, identifying the point of control,⁶ are techniques to address the prominent lobule (**FIG 7**).

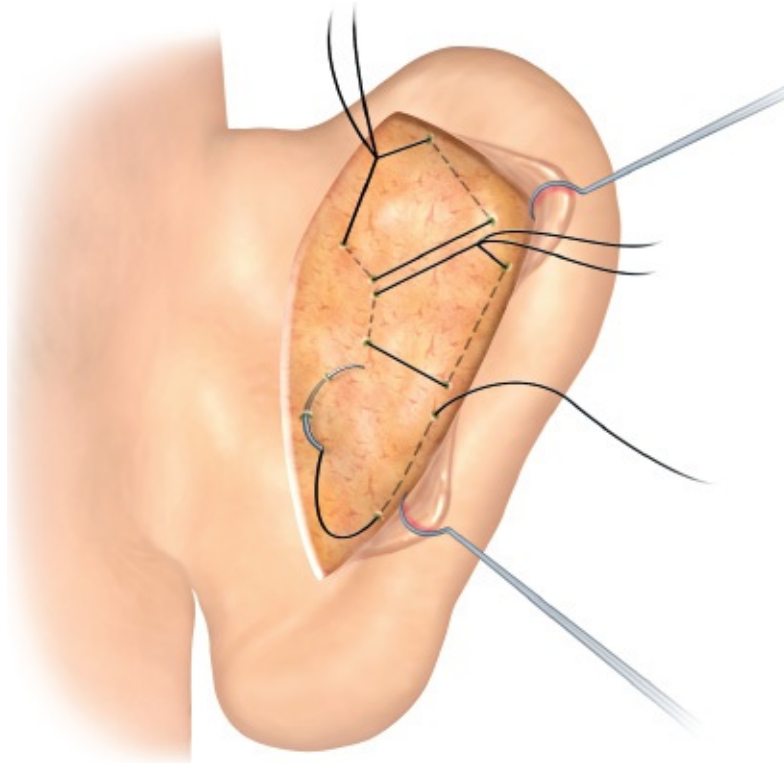


FIG 6 • Mustardé's radiated suture techniques are illustrated.

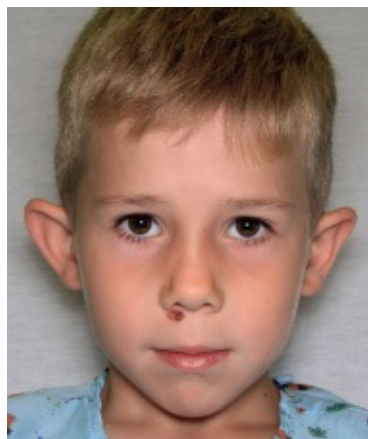


FIG 7 • Preoperative frontal view of Case 1 (bilateral)

prominent ears).

TECHNIQUES

■ Preoperative Marking After Intubation

- Visualizing the precise location to placing sutures: While using fingers to create ideal setback of the helix, the authors draw two curvilinear lines where the needle is planned to pass through the cartilage. Radiating direction of suture placement is also drawn (**TECH FIG 1**).



TECH FIG 1 • After intubation, curvilinear line (*red*) where sutures piercing cartilage and the direction of suture placement (*green*) are drawn on the anterior surface.

Deciding the Amount of Skin Incision

- Skin incision should be in the middle of posterior aspect of the auricle, so both helix and mastoid are accessible. The amount of skin excision should be conservative to preserve the postauricular sulcus. The skin closure should be tension free to prevent hypertrophic scarring (**TECH FIG 2**).



TECH FIG 2 • The amount of predicted skin excision is marked prior to preparation.

■ Local Injection

- 4 to 5 cc of half and half formula (mixture of 1% lidocaine with epinephrine, and 0.25% bupivacaine) is injected along the posterior skin incision, with pinpoint injection anteriorly where sutures are planned to penetrate cartilage. Injection is performed prior to skin prep to allow time for vasoconstriction.

■ Skin Flap Dissection

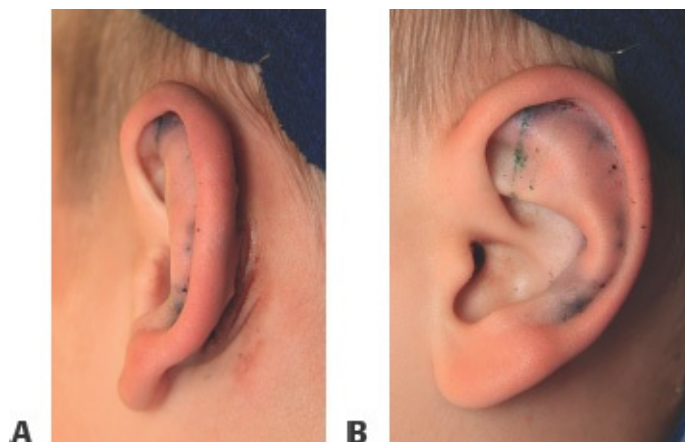
- The skin flap is dissected above the perichondrium. It is important to raise the skin flap in the same plane to create a skin flap of uniform thickness. The entire posterior cartilage surface can be exposed through this skin incision.

■ Identify the Two Curvilinear Lines and Draw Them on the Posterior Surface of the Auricle

- 25G needles are placed from the anterior surface through the posterior surface of the cartilage. These points are tattooed with blue ink (methylene blue). This maneuver is done for each point of insertion of the 25G needles, and the tattooed marks connected to create a curvilinear line on the posterior cartilage surface. Two curvilinear lines are drawn on the posterior surface.

■ Mattress Sutures Placement

- The authors use 4-0 double-armed needles (SH needle) for 4 points. A round needle is recommended because it is less likely to tear the cartilage. All four sutures are placed, but not tied, and held with mosquito forceps. The authors prefer to hand tie the sutures to visualize setback of the cartilage in creating the antihelix. The otoplasty grid helps to check the height of the helix from the skull (**TECH FIG 3A**). Sutures are tied sequentially from the top of the helix to the bottom. The lowest suture should be at the level of antitragus to avoid too much angulation or curve distortion of the antihelix due to the sutures. Care is taken to give a gentle curve to antihelix (**TECH FIG 3B**).



TECH FIG 3 • **A.** The view of projection immediately postoperatively on the left. **B.** The view of the anterior surface immediately after Mustardé suture placement.

■ Would Closure

- Two-layer skin closure is performed after confirmation of hemostasis and copious saline irrigation. The authors recommend lifting the helix very gently when closing the skin to minimize pull on the reshaped ear.

Bolster Sutures

- Use of bolster sutures (**TECH FIG 4**) is a classic technique popularized by Tanzer more than 50 years ago. Nagata also uses bolster sutures for most ear

reconstructions. The key is to (1) use soft materials (eg, Xeroform gauze) amply soaked in vaseline-based ointment and (2) tie very gently to avoid excess pressure on the skin. The authors use 4-0 Prolene, double-armed, SH needles for the bolster sutures. Periodic checks, especially 2 days postoperatively when the swelling is maximum, are mandatory to prevent pressure sores underneath the bolster sutures.



TECH FIG 4 • Bolster sutures are placed at the end.

PEARLS AND PITFALLS

Mustardé mattress sutures

- Try to keep the natural curve of the antihelix. Do not destroy the curve by sutures.

Two curvilinear lines

- Draw two curvilinear lines for suture placement on the posterior surface of the auricle before placing sutures.

Anterior cartilage surface scoring

- Do not abrade the cartilage too aggressively, as this may cause late cartilage deformities.

Measurement of the projection

- Check scalp-helix distance in at least three points bilaterally before and after surgery; the otoplasty grid can be used as a template.

Conchal

- If the angle of the antihelix in the vicinity of the antitragus is

hypertrophy

too acute, consider excising a small amount of concha.

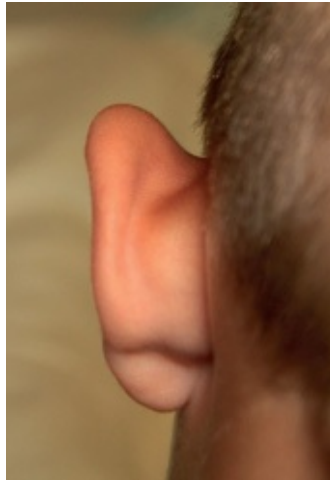


FIG 8 • Preoperative posterior left side view of Case 1 (bilateral prominent ears).

POSTOPERATIVE CARE

- The authors ask patients/parents to keep the wound dry for 2 weeks. Early shampoo prior to 2 weeks may cause redness; this does not necessarily indicate infection, but it may confuse both the physician and the patient. If one uses bolster sutures, periodic check underneath the bolster is mandatory to prevent pressure sores.

OUTCOMES

- Achieving symmetry is one of the key elements for the success of prominent ear correction (Case 1: **FIGS 8–10**). Measurement of the distance from mastoid to helix is a helpful guide. The authors use the otoplasty grid to help achieve symmetry. **FIG 11** shows the outcome of unilateral prominent ear correction (Case 2), for which the otoplasty grid was used as a guide to achieve symmetry.

COMPLICATIONS

- Recurrence of prominent ear: Combined approaches instead of a single technique are better to prevent recurrence of the prominent ear. The use of resorbable sutures for the Mustardé techniques can contribute to recurrence.
- Infection: Infection can be caused by a break in proper sterile surgical

technique or dehiscence secondary to excessive tension during skin closure. Infection can also be an untoward sequela of prior hematoma evacuation. History of eczema, such as atopic dermatitis, is a warning sign. The external auditory canal could serve as a reservoir for bacteria, particularly in swimmers. Prepping the hair near the surgical site is important to prevent infection.

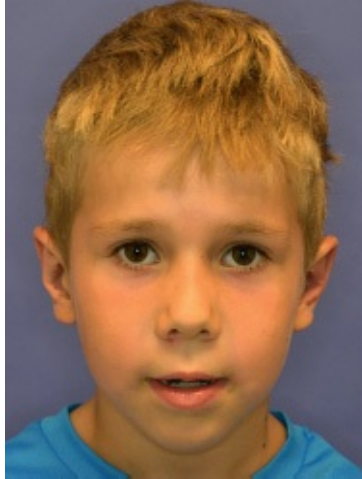


FIG 9 • Postoperative frontal view of Case 1 (bilateral prominent ears).



FIG 10 • Postoperative posterior view of Case 1 (bilateral prominent ears).

- Postoperative hematoma: Hematoma is a dreaded immediate postoperative complication. It is heralded by the acute onset of severe, persistent, and often unilateral pain. If there is evidence of ongoing bleeding, reoperation and

exploration are mandatory. Meticulous postoperative dressing is vital important to prevent hematoma. Compression dressings or bolster sutures are effective dressings and vary with surgeon preference.

- **Skin necrosis:** It is important to raise the skin flap in the same plane and thickness to avoid irregularity of the skin flap. Small blunt straight scissors may be better than curved scissors in this respect. The proper plane of elevation for prominent ear is just above the perichondrium. A thinner skin flap is prone to skin necrosis. When using bolster sutures, it is mandatory to check for pressure sores beneath the bolster on a regular basis until the bolster sutures are removed 2 weeks postoperatively.
- **Chondritis:** Chondritis is a surgical emergency. If left untreated, it can result in permanent deformity. Therefore, prompt debridement of devitalized tissue is necessary.
- **Dysesthesia:** Dysesthesia is an uncommon, or less recognized, complication. The best way to avoid this complication is to use a single skin incision rather than multiple skin incisions.
- **Suture granuloma and extrusion:** This is more common with permanent braided sutures.
- **Late sequelae of irregularities and deformities of the ear:** These are mainly caused by too aggressive surgical techniques to modify the ear cartilage. In order to avoid these complications, less traumatic techniques and gentle manipulation of the ear cartilages are recommended.

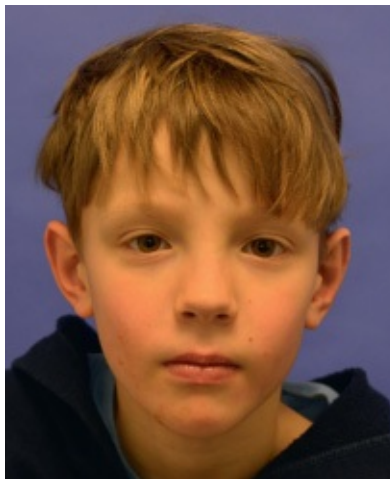


FIG 11 • Postoperative frontal view of Case 2 (unilateral prominent ear).

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Section IX: Eyelid Reconstruction

38

CHAPTER Eyelid Coloboma

Adam R. Sweeney and Christopher B. Chambers

DEFINITION

- Eyelid coloboma (plural: colobomata) is a congenital anomaly arising from developmental interruption of the eyelid folds causing an eyelid cleft in either the upper or lower eyelid.
- The defect may be isolated and incidental but is more commonly associated with craniofacial syndromes, ocular or periocular colobomata, or other facial clefts.^{1,2}

ANATOMY

- The classic description of an eyelid coloboma is a full-thickness defect of a segment or an entire eyelid including absence of the conjunctiva, tarsus, orbicularis muscle, and skin.
- The term “pseudocoloboma” may be used to refer to a partial-thickness defect of the lid, usually involving the deeper structures with intact superficial layers.
- There is considerable variability in involvement including only a slight lid indentation to complete lid absence with underlying ocular abnormalities.
- The majority are found in the medial third of the upper lid.
- Approximately 75% of cases are unilateral.^{2,3}

PATHOGENESIS

- The etiology of eyelid colobomata is not fully understood and likely varies.
- Variability in the formation of the eyelid folds early in embryogenesis vs later disruption of eyelid fusion/fissure may implicate the location of a coloboma

defect and any associated facial clefts.^{2,4}

- Attributed etiologies include intrauterine amniotic bands, abnormalities in vitamin A metabolism, intrauterine inflammation, decreased placental circulation, hamartomas, abnormal fetal vasculature, failure of eyelid fold fusion, or abnormal fetal migration of the neural crest cells.⁵⁻⁷
- Colobomata may occur in conjunction with Goldenhar syndrome (oculoauriculovertebral dysplasia),^{1,8} Treacher Collins syndrome (mandibulofacial dysostosis),³ frontonasal dysplasia, and Delleman syndrome.⁹ Goldenhar syndrome is associated with unilateral upper lid coloboma, whereas Treacher Collins is associated with lower eyelid coloboma or pseudocoloboma.²

NATURAL HISTORY

- Untreated, an eyelid coloboma may lead to neonatal exposure keratopathy with corneal ulceration and perforation.
- A small coloboma associated with the appropriate amount of superior rotation of the eye upon eye closure, known as a Bell reflex, may be asymptomatic requiring only cosmetic surgery later in life.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Careful physical examination should be performed to assess the thickness and extent of eyelid loss in both upper and lower eyelids of both eyes. Attention should be given to the degree of skin laxity for anticipated donor lids, integrity of anchor sites on the involved lid, and skin color/thickness.¹⁰
- Fornices of eyelids should be meticulously examined for adhesions (symblepharon) that may hint at underlying diagnosis of cryptophthalmos.
- Full ophthalmic examination with cycloplegic refraction, eye motility examination, external examination, slit-lamp examination and dilated fundus examination should be performed to identify other regions of adverse development.
- Both eyes should be closely examined.
- The most common finding is an upper eyelid medial full-thickness abnormality. The defect is typically a triangular or quadrangular lesion with the base toward the eyelid margin (**FIG 1**).^{1,6,11}
- The defect may vary in severity from a small indentation to the full eyelid length.
- If present in the lower eyelid, partial-thickness defects are more common.



FIG 1 • Left upper eyelid coloboma with loss of lashes, eyelid notch, and irregular upper eyelid contour.

DIFFERENTIAL DIAGNOSIS

- Associated syndromes:
 - Goldenhar syndrome (epibulbar dermoids, preauricular appendages, blind pretragal fistulae, hemifacial atrophy, vertebral anomalies)^{1,8}
 - Treacher Collins syndrome (lower eyelash irregularities, absence of lower puncta, iris coloboma, microphthalmos, midface hypoplasia, lateral downward slant of the palpebral fissures)³
 - Delleman syndrome (orbital cysts, intracranial cysts, skin appendages)⁹
 - Other facial clefting syndromes affecting the eyelids; as described by Tessier, facial clefts
- Eyelid trauma
- Entropion
- Cryptophthalmos

NONOPERATIVE MANAGEMENT

- A small eyelid coloboma with mild corneal exposure may be treated with lubrication, bandage contact lenses, or moisture chambers with surgery deferred until 6 months of age or later when pediatric eyelid tension has

relaxed.³

SURGICAL MANAGEMENT

- Surgical correction is the preferred method of treatment.
- Surgery is required and urgently indicated in cases where exposure keratopathy is present or imminent.

Preoperative Planning

- General anesthesia is recommended for pediatric cases.
- Review the facial photos and examination including size, location, and shape of the lid defect to help determine the appropriate technique.

Positioning

- The patient is positioned supine on a surgical table with an adjustable headrest lowered to give the surgeon the best access. The patient should be prepped and draped leaving the full face exposed.

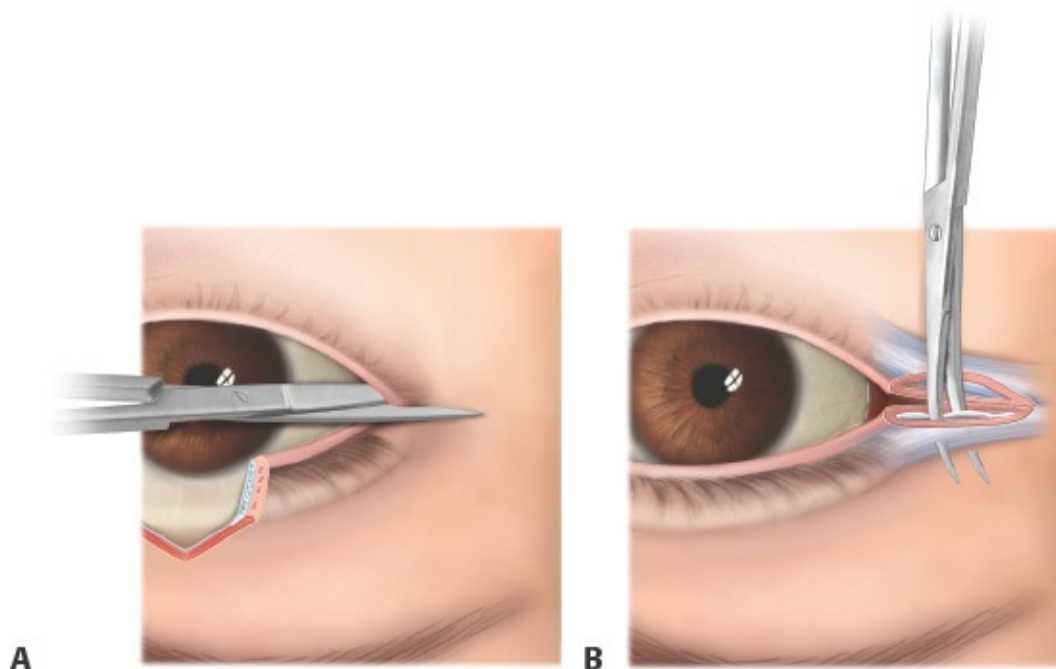
Approach

- Upper or lower eyelid lesions involving $\frac{1}{4}$ of the eyelid or less may be amenable to direct closure.
- Upper or lower eyelid lesions involving a quarter to half the eyelid are treated with Tenzel semicircular flap.
- Large lesions with significant tissue loss involving $\frac{1}{2}$ or more of the eyelid may be managed via a one-stage graft technique involving a tarsomarginal graft from the ipsilateral lower intact lid or from the contralateral intact upper eyelid.¹²
- For lesions with greater than $\frac{1}{2}$ eyelid tissue loss and not amenable to a one-stage closure, a two-stage lower lid rotation to the upper lid via a Cutler-Beard technique may be employed.¹³
- The vast majority of large colobomata involving greater than $\frac{1}{2}$ of the eyelid involve the upper eyelid; thus, techniques specifically addressing upper eyelid repair are described below. One-stage and two-stage grafting for lower eyelid closures are routinely performed and described for other conditions; however, these are out of the scope of this chapter.

TECHNIQUES

■ Direct Closure

- Place topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space around the lesion and the lateral canthus.
- Unscroll the underlying tissue of the eyelid margin to explore the full depth of the defect.

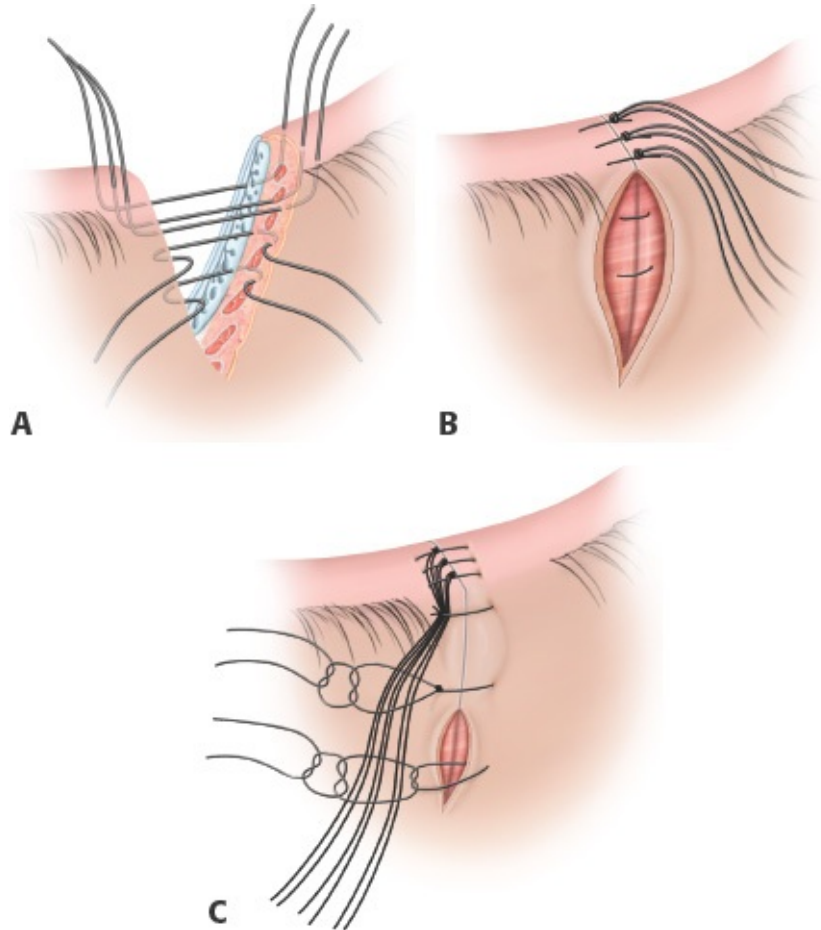


TECH FIG 1 • A,B. Upper eyelid coloboma with position of proposed canthotomy outlined in the *dotted line*.

- Using a no. 15 blade, trim the borders of the defect to prepare for a full-thickness, aligned graft site.
- Pull the defect edges together; if there is significant tension, consider a canthotomy and cantholysis (**TECH FIG 1**).
- Create a horizontal incision along the lid crease or intended lid crease from the border of the medial defect laterally along the lid crease. The extent of the lid crease incision should be lengthened to create the amount of laxity needed to approximate the lateral border of the defect to the medial border of the

defect without tension.

- Using a 6-0 Vicryl suture, make a single pass at the eyelid margin from tarsus to tarsus spanning the defect. Ensure equal depth (2 mm deep to the margin) and horizontal distance from the defect (2 mm from the defect border) to create a perfectly reapproximated closure. Apply tension to the ends of the suture to assess the alignment of the closure, but do not tie a knot.
- Using 6-0 Vicryl suture, reapproximate the deep tarsus using a buried interrupted pass. This pass should be repeated for every 2 mm of vertical tarsus absent. Do not tie the knot.
- Using another 6-0 Vicryl suture, reapproximate the eyelash line using a single pass.
- Using another 6-0 Vicryl suture, make a third eyelid margin pass reapproximating the gray line (**TECH FIG 2A**). Ensure attention is paid to the same techniques as used to reapproximate the tarsus at the margin.
- Tighten all the sutures. The eyelid margin should realign with a slight eversion. If the eyelid has perfect reapproximation, tie all the knots with a 3-1-1 knot. Leave the suture tails 3 to 5 mm long (**TECH FIG 2B**).
- Close the superficial skin using 7-0 fast gut interrupted sutures. Tie the knots of the sutures with the tails of the Vicryl suture under the knot to keep the eyelid margin suture tails from rubbing against the cornea (**TECH FIG 2C**).
- Close the relaxation incision with 7-0 fast gut sutures in an interrupted fashion.
- Apply erythromycin ointment over the wound.



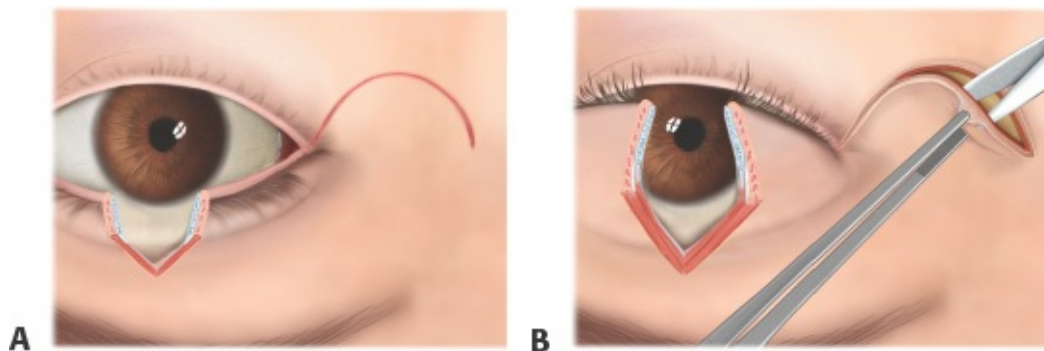
TECH FIG 2 • Margin involving defect closure. **A.** Simple closure of a small eyelid defect including three eyelid margin passes: one through the tarsus, one through the gray line, and one through the lash line. **B.** Deep nonmarginal tarsus passes are closed first in buried fashion. Tying of margin involving knots is then performed leaving suture tails 3 to 5 cm long. **C.** Close the superficial skin incorporating the marginal suture tails in the skin closure knots to detract the tails from the cornea.

■ Tenzel Semicircular Flap

- Place topical tetracaine on the conjunctival surface.
- Using a sterile marking pen, draw a semicircle at the lateral canthus

inferiorly oriented for upper lid repair or superiorly oriented for lower lid repair (**TECH FIG 3A**).

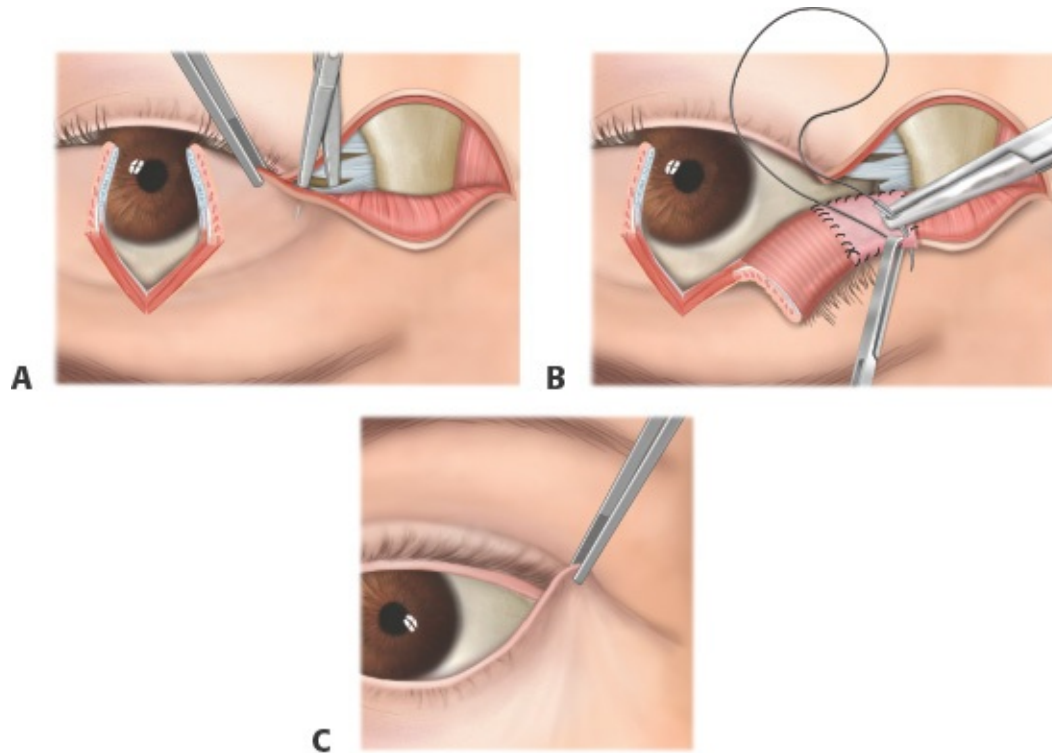
- Inject 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space around the defect extending to the frontozygomatic suture.
- Unscroll the underlying tissue of the eyelid margin to explore the full depth of the defect.
- Using a no. 15 blade, incise the skin and orbicularis tissue along the marked semicircle beginning at the lateral canthus.
- Undermine the musculocutaneous semicircular flap laterally using blunt dissection to create lid laxity (**TECH FIG 3B**).
- Complete a full-thickness canthotomy using Westcott scissors.



TECH FIG 3 • A,B. Diagram depicting inferiorly oriented semicircular orientation for large upper lid coloboma repair.

- Grasp the lateral aspect of the involved eyelid and gently apply anterior traction to expose the canthal tendon. For an upper eyelid coloboma, perform a superior arm cantholysis; and for lower eyelid coloboma, perform an inferior arm cantholysis (**TECH FIG 4A,B**).
- The cantholysis of the respective arm of the canthal tendon is performed by strumming the multiple attachments of the respective arm with closed scissors and then cutting each attachment, ensuring further laxity is felt with each cut (**TECH FIG 4B**). Avoid cutting conjunctiva by maintaining adequate visualization and hemostasis with handheld cautery.
- Full cantholysis is achieved when the respective eyelid can be distracted to reach the superior orbital rim for an inferior cantholysis or the inferior orbital rim for a superior cantholysis (**TECH FIG 4C**).

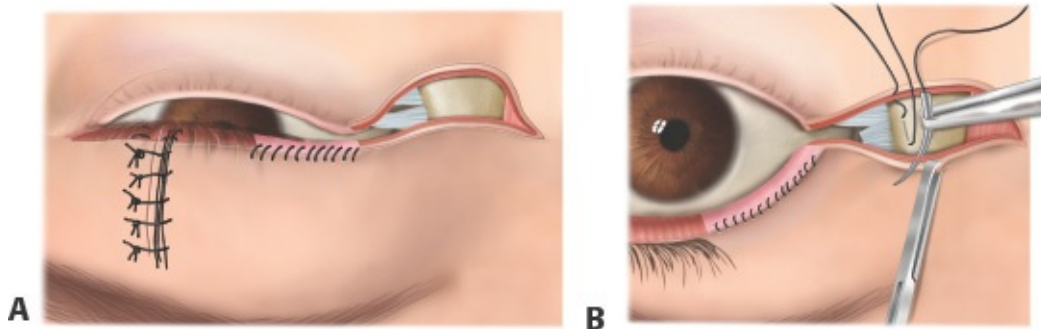
- Using a no. 15 blade, trim the borders of the defect to prepare a full-thickness, aligned graft site. This should be attempted to create a rectangle-shaped border to ensure easier closure.



TECH FIG 4 • Lateral canthotomy and cantholysis. A. Following canthotomy, a lateral cantholysis is performed by grasping the eyelid margin and brought anteriorly to expose the multiple canthal tendon arms. For upper lid repairs, a superior cantholysis is performed; for lower lid repairs, an inferior cantholysis is performed (**B**). **C.** Full lower lid cantholysis is achieved when the lower lid can be distracted superiorly to the superior orbital rim. Similarly, an upper lid cantholysis is achieved when the upper lid can be distracted to the inferior orbital rim.

- Using forceps, distract the loose eyelid margin to bring together the edges of the wound (**TECH FIG 5A**). Mark the temporal aspect of the distracted eyelid that aligns with the lateral canthus of the uninvolved/unaffected eyelid.

- Close the eyelid defect wound using the steps described in the “direct closure” technique above (**TECH FIG 3**).
- Using a single interrupted 5-0 Vicryl suture, make a pass through the deep tissues along the repaired eyelid where previously marked at the intended site of lateral canthus reconstitution. Secure this suture by passing it through the periosteum of the underlying lateral orbital rim exiting 1 to 2 mm superior to the entrance of the pass (**TECH FIG 5B**).
- Secure the lateral aspect of the flap using 5-0 Vicryl suture by making a single pass through the deep tissues of the flap, into the underlying prezygomatic fascia, and then out the deep tissue of the opposite side of the flap to create a buried suture adherent to the underlying fascia.
- Repeat this step with interrupted sutures to fully close the length of the flap.
- Reconstitute the lateral canthus by suturing the upper lid gray line to the lower lid gray line approximately 2 mm from the termination of the lateral gray line using 6-0 Vicryl suture.
- Close the superficial skin of the flap using 7-0 fast gut suture in an interrupted fashion.
- Apply erythromycin ointment over the wound.



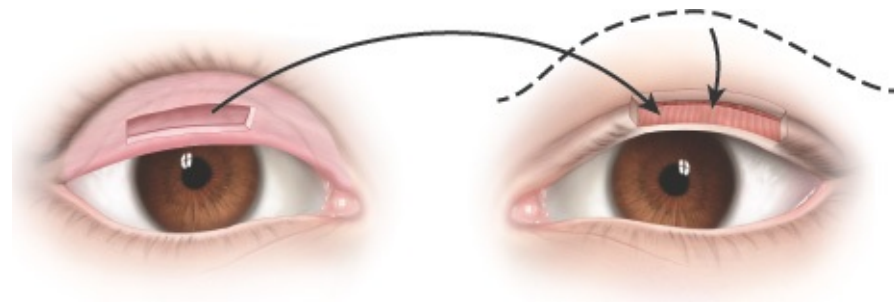
TECH FIG 5 • A. Align the tissue with minimal tension to the lateral canthus of the opposite eyelid. **B.** Secure the tissue with a 5.0 vicryl suture through the obicularis muscle to the orbital rim periosteum.

■ One-Stage Graft (Tarsomarginal Graft)

- Place topical tetracaine on the conjunctival surface.
- Using a sterile marking pen, draw an inferiorly oriented semicircle at the

lateral canthus.

- Inject 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space around the defect and the contralateral upper eyelid.
- Unscroll the underlying tissue of the eyelid margin to explore the full depth of the defect.
- Using a no. 15 blade, trim the borders of the defect for a full-thickness, aligned graft site.
- Using calipers, measure the dimensions of the missing underlying tarsus.
- Mark the contralateral (donor) upper eyelid with the calipers per the dimensions measured for the graft upper lid using an inferior border that is superior to the eyelid margin (**TECH FIG 6**).



TECH FIG 6 • Scheme depicting one-stage contralateral upper eyelid graft using donor conjunctival/tarsus to host eyelid. Host upper eyelid anterior lamella is placed over the graft after undermining superiorly and laterally.

- On the contralateral (donor) upper eyelid, use Westcott scissors to dissect a plane at the level of the orbicularis oculi, extending to the marked borders between the posterior lamella (conjunctiva and tarsus) and the anterior lamella (orbicularis muscle and skin).
- Using Westcott scissors, amputate the graft of tarsus and conjunctiva from the contralateral donor upper eyelid within the borders marked, sparing the eyelid margin.
- Bring the tarsomarginal graft into the donor site and suture the grafted tarsus to the host tarsus with two interrupted 6-0 Vicryl sutures per side leaving the eyelid margin free of suture. Ensure the knots are buried deep, avoiding potential conjunctival or corneal abrasion from posterior oriented knots.

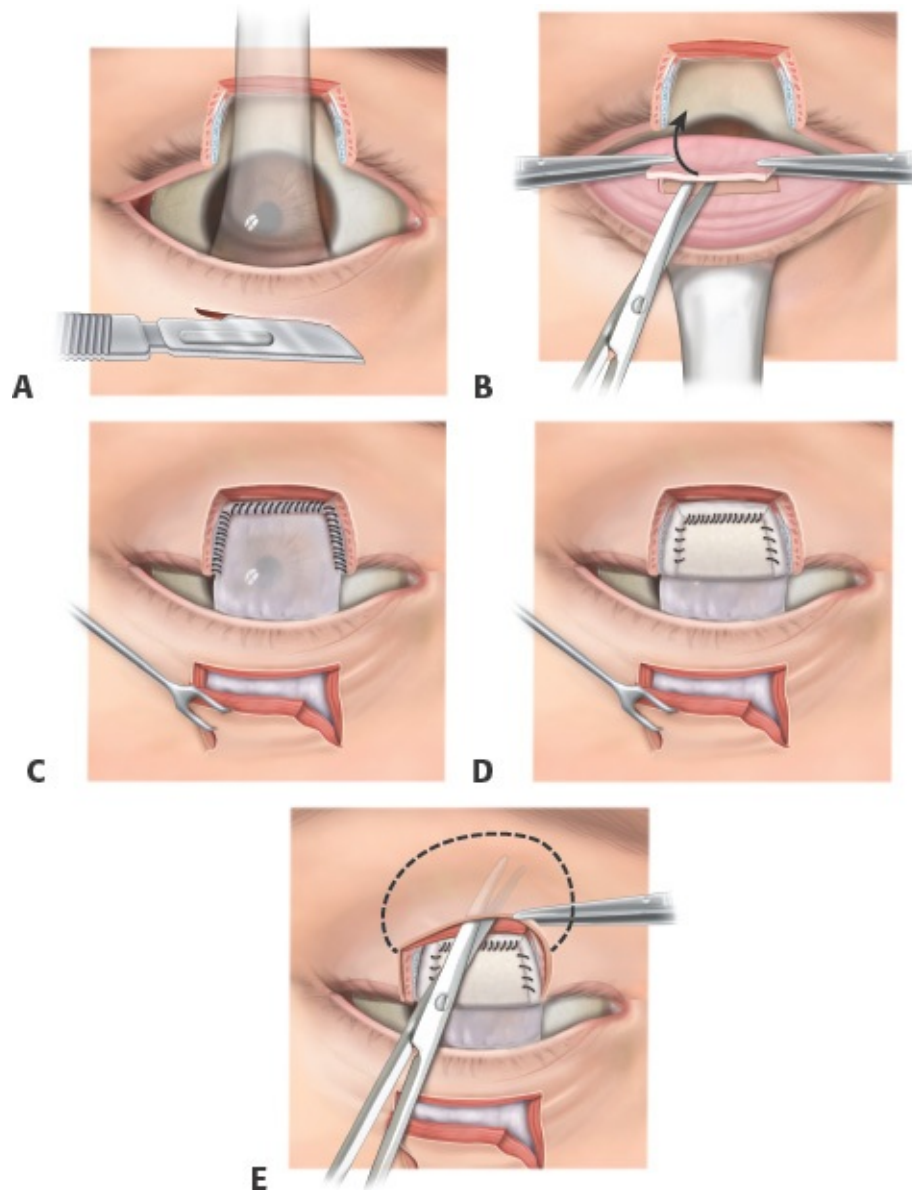
- Using Westcott scissors, reconstruct the donor upper lid anterior lamella by undermining deep to the patient's adjacent orbicularis muscle using Westcott scissors. Advance the adjacent anterior lamella over the graft tissue ensuring no vertical tension is created. Close this tissue with interrupted 7-0 gut passes.
 - Close the posterior lamella of the donor eyelid via the "direct closure" of deep horizontal eyelid lesion technique described above (**TECH FIG 3**).
 - Apply erythromycin ointment over both eyelids.
-

■ Two-Stage Graft (Cutler-Beard)

- Place topical tetracaine on the conjunctival surface.
- Inject 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space of the upper and lower eyelids.
- Unscroll the underlying tissue of the eyelid margin to explore the full depth of the defect.
- Using a no. 15 blade, trim the borders of the defect for a full-thickness, aligned graft site. This should be attempted to create a rectangle-shaped border to ensure easier closure.
- Using a sterile marking pen, make two vertical markings on the lower lid to outline the borders of the horizontal defect of the upper lid. Connect the vertical markings of the lower lid horizontal mark placed 4 mm inferior to the eyelid margin.
- Pass a 4-0 silk traction suture into the lower eyelid margin ensuring a tarsal bite is achieved.
- Using a no. 15 blade, incise the skin and orbicularis over the horizontal marking (**TECH FIG 7A**).
- Holding the silk suture by the tails, evert the lower lid over an eyelid retractor and make a horizontal conjunctival incision. This incision should be deep to the horizontal marking previously placed on the lower eyelid skin.
- Using Westcott scissors, incise through the conjunctival incision full thickness to connect to the anterior lamella incision.
- Using Westcott scissors, make deep orbicularis cuts through the vertical markings of the lower lid (**TECH FIG 7B**).
- With toothed forceps, grasp the superior edge of the flap created by the full-thickness horizontal incision already created. Bring this flap under the lower

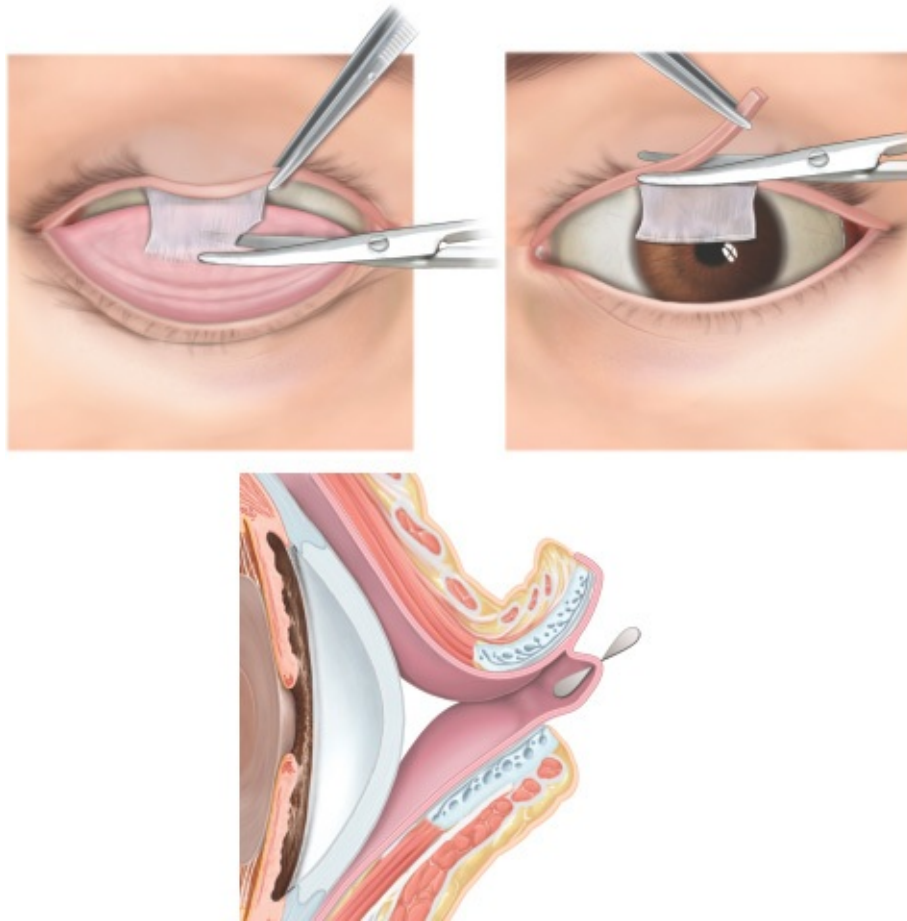
eyelid margin (through the blepharotomy) and place it into the region of the upper eyelid defect (**TECH FIG 7C**).

- Suture the lower lid grafted tarsus to the tarsus at the borders of the upper lid coloboma using 5-0 Vicryl suture with at least two passes per side ensuring anteriorly oriented knots to avoid conjunctival abrasion (**TECH FIG 7D**).
- Undermine around the lid defect until the anterior lamella is lax enough to close the anterior lamella directly and without tension using 5-0 Vicryl sutures (**TECH FIG 7E**).
- Close the superficial skin of the flap using 7-0 fast gut interrupted passes.
- Apply erythromycin ointment over the wound.
- The second stage is performed by releasing the flap with Westcott scissors at the intended eyelid margin. Excess conjunctiva and skin can be removed from the upper eyelid (**TECH FIG 8**).



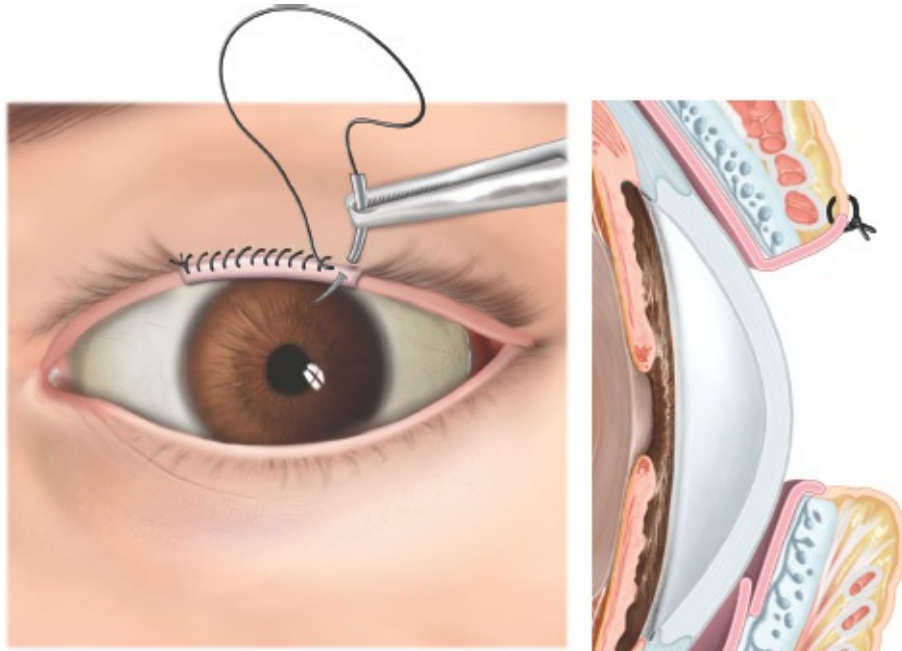
TECH FIG 7 • First stage of Cutler-Beard procedure. **A.** Incision is made through skin and orbicularis over the horizontal marking. **B.** Incision through the vertical markings is made revealing full tarsoconjunctival flap. This is dissected from the anterior lamellae. **C.** The flap is grasped and sutured into the graft position allowing laxity of tissue. **D.** The graft is sutured into position using 5-0 Vicryl suture ensuring anteriorly oriented knots. **E.** The anterior lamellae host tissue is

then sutured into position using 7-0 fast gut.



TECH FIG 8 • Second stage of Cutler-Beard procedure. **A.** Incise the graft tissue at the desired upper lid margin using a metal backing to protect the underlying cornea. **B.** Marginal and graft are then sutured ensuring no knots exposed to the cornea.

- The remaining conjunctiva is sutured into place to the anterior edge of the eyelid margin using 7-0 fast gut sutures with the knot placed away from the cornea (**TECH FIG 9**).
- In children between birth and 14 years old, the second stage is performed at 2 weeks, rather than the recommended 4 to 6 weeks, to minimize the risk of deprivation amblyopia.



TECH FIG 9 • Suture the excess conjunctiva over the anterior edge of the eyelid margin with a fast gut suture.

PEARLS AND PITFALLS

Choosing a technique

- Two-stage repairs for large colobomata incur a period of visual deprivation that can lead to amblyopia. Full consideration of one-stage technique, when applicable, is recommended.
- Skin laxity and eyelid graft development must be considered when choosing a graft. There is tendency to underestimate the tension and required modifications to adequately close pediatric eyelid defects.

Timing of surgery

- Children less than 3–6 months of age have less skin laxity, and when not contraindicated, postponement of surgery may achieve better outcomes. When early surgery is indicated, the lateral canthotomy and cantholysis described in the “direct closure” technique offers improved eyelid relaxation, decreasing horizontal tension.

POSTOPERATIVE CARE

- Prescribe topical application of antibiotic ointment over the wounds 3 times a

day for 1 to 2 weeks.

- Recommend sun tan lotion to improve scar results.
- Comanagement with pediatric ophthalmologist is recommended for regular refraction and monitoring for development of primary or secondary strabismus or corneal scarring.

OUTCOMES

- Surgical success is dependent on the degree of the coloboma and the procedure type selected.
- Irregular postoperative eyelid contour may occur if the lid defect is closed under too much tension.³

COMPLICATIONS

- Exposure keratopathy from unintended vertical traction
- Loss of lashes from the graft or trichiasis
- Entropion or ectropion
- Ptosis secondary to poor levator function or postoperative horizontal traction
- Poor appearance

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CHAPTER Congenital Ptosis

Adam R. Sweeney and Christopher B. Chambers

DEFINITION

- Blepharoptosis, commonly referred to as ptosis, is eyelid positioning inferior to normal posture. Often, ptosis is defined as asymmetry of 1 mm or more between the two upper eyelids or a marginal reflex distance of less than 2.5 mm.¹
- Congenital ptosis refers to cases presenting within the first year of life, as an isolated finding or as a manifestation of ophthalmic or systemic disorders.
- Typically, congenital ptosis results from fibrofatty degeneration of the levator complex.
- Congenital ptosis affects an estimated 1 in 842 births in the United States.¹

ANATOMY

- The anterior lamella is made up of the skin and the preseptal orbicularis (**FIG 1**).
- The posterior lamella is made up of the tarsus and the palpebral conjunctiva.
- The tarsus is a fibrous plate located in the eyelid. It is 9 to 10 mm in height in the upper eyelid and 4 mm in height in the lower lid. The length of the tarsus is approximately 22 to 25 mm.
- Posterior to the orbital septum lies the preaponeurotic fat pad, an important surgical landmark.
- The levator aponeurosis is the primary retractor of the upper eyelid and is located just posterior to the preaponeurotic fat.
- The levator palpebrae originates above the annulus of Zinn and attaches to Whitnall ligament, a transverse facial suspensory structure. This attachment allows the levator muscle's horizontal vector to be redirected to the vertical

vector created from its anterior extension, the levator aponeurosis, which terminates at the anterior tarsus.

- Muller muscle arises from the posterior layer of the levator muscle and inserts into the upper border of the tarsal plate.
- The lid crease is formed from levator aponeurosis fibers inserting into the fascicular bundles of the pretarsal orbicularis.
- In patients not of Asian descent, the lid crease is located between the upper border of the tarsus and the insertion of the orbital septum, which is approximately 3 to 5 mm superior to the upper border of the tarsus. The lid crease is approximately 9 to 11 mm and 8 to 9 mm superior to the eyelid margin in females and males, respectively.
- In Asians, the lid crease is much lower secondary to a more anterior preaponeurotic fat pad and low/absent attachment of the aponeurosis fibers to the fascicular bundles of the pretarsal orbicularis.

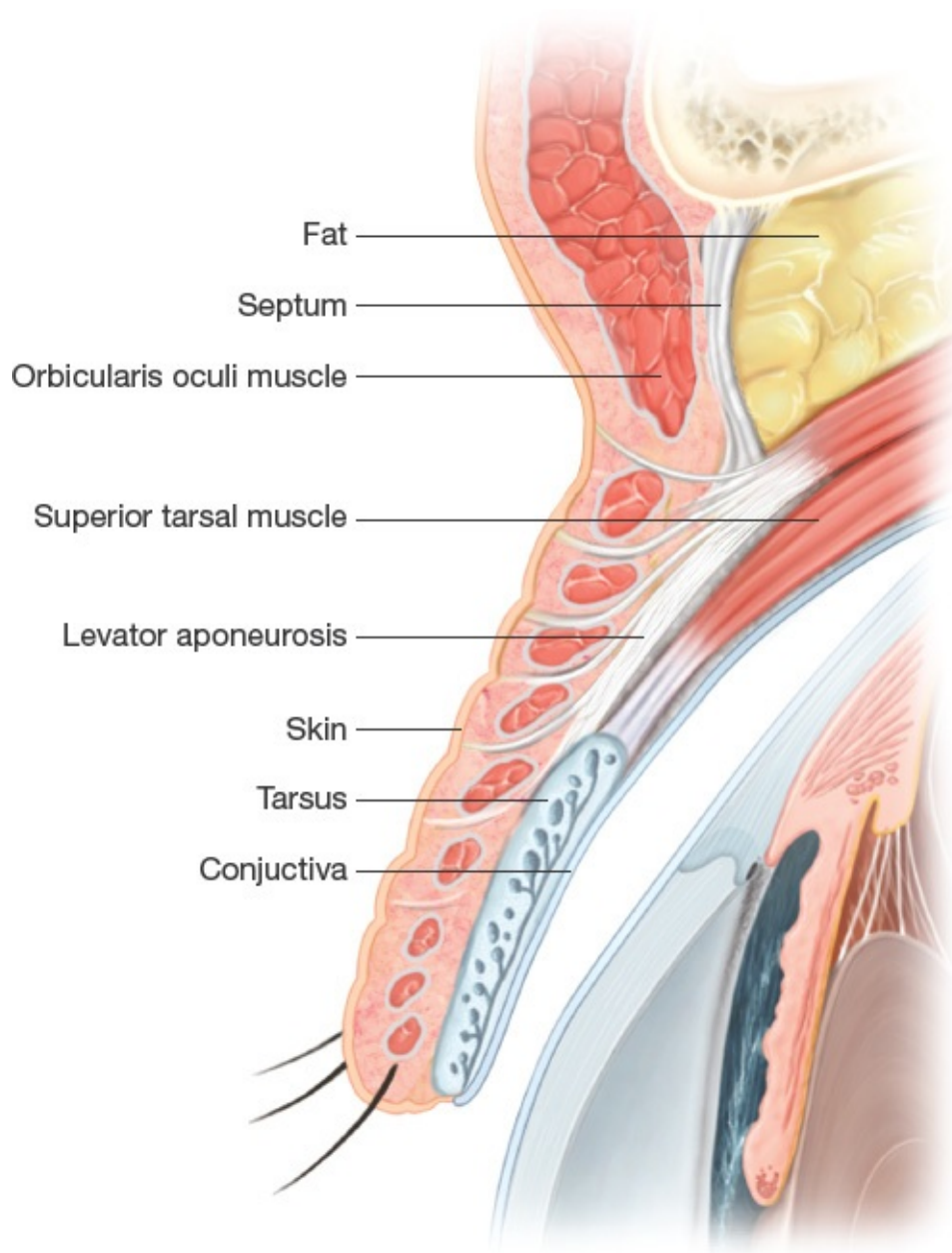


FIG 1 • Anatomy of the upper eyelid.

- The levator muscle is a striated muscle and is innervated by cranial nerve (CN) III, whereas Muller muscle is a smooth muscle innervated by the sympathetic chain.
- The frontalis muscle inserts into the orbicularis oculi at the inferior brow.

PATHOGENESIS

- There are multiple different etiologies of congenital ptosis.

- Approximately 80% of congenital ptosis arises from dysgenesis or fibrosis of the levator muscle with remaining integrity of the levator aponeurosis, termed myogenic ptosis or simple congenital ptosis.^{1,2}
- Myogenic ptosis is more common unilaterally than bilaterally.
- Neurogenic etiologies are much less common and arise from innervation abnormalities during development such as abnormal motor nerve connections of the levator muscle and branches of the trigeminal nerve innervating the external pterygoid muscle (Marcus Gunn jaw winking), interrupted sympathetic nervous chain (Horner syndrome), congenital cranial nerve III palsy, or congenital cranial dysinnervation disorders such as Duane retraction syndrome.
- Aponeurotic ptosis is caused by a defect in the tendon's ability to redirect the action supplied by the levator muscle. This is classically different from disinsertion of the aponeurosis from the levator muscle, as is commonly seen in advancing age or from trauma including childbirth.
- Mechanical ptosis is caused by a forced inferior excursion of the eyelid such as seen in tumor, eyelid inflammation/edema, cicatricial processes, or foreign body.
- Traumatic ptosis usually can be found to be inclusive in one of the above categories and may arise in utero or from trauma, such as during childbirth.

NATURAL HISTORY

- Congenital ptosis may be mild and benign with no impact on vision or function of the child.
- Severe congenital ptosis may cause amblyopia due to deprivation or astigmatism.
- Twenty to thirty percent with congenital ptosis have concurrent strabismus or astigmatism.^{3,4}
- Twenty-five percent of patients with congenital ptosis develop amblyopia of the involved eye.²

PATIENT HISTORY AND PHYSICAL FINDINGS

- Hallmark findings distinguishing congenital myogenic ptosis from acquired ptosis: absence or irregular upper eyelid crease, decreased levator function (particularly prominent in upward gaze), eyelid retraction in downward gaze, and presence of lagophthalmos (a common finding in congenital ptosis).
- Marcus Gunn jaw-winking ptosis involves elevations of the eyelid with

pterygoid muscle movement usually evident with sucking or chewing. Monitoring for association of lid height in various gazes and facial movements including jaw movement is important to rule out this condition.

- Horner syndrome classically manifests with ptosis, meiosis, and anhidrosis ipsilateral to the neurological defect. Ipsilateral lower lid inverse ptosis may also be seen. Heterochromia characterizes the congenital form from acquired Horner syndrome and necessitates systemic workup.
- Margin reflex distance (MRD) of the upper lid and vertical palpebral fissure height should be routinely assessed, when possible.
- MRD₁ in down gaze, evaluating chin, head, and brow position should be noted as compensatory mechanisms.
- Strength of Bell phenomenon (eye elevation and abduction on attempted lid closure) may indicate whether dysgenesis of the levator muscle includes the superior rectus muscle.
- Perform a pupil exam monitoring for symmetry.
- Test extraocular muscle movements assessing for partial CN III palsy or assessing for hypotropia-related pseudoptosis.
- Test the frontalis contribution by immobilizing the brow in primary position as children often will attempt to correct ptosis by recruiting the frontalis muscle.
- Assess corneal exposure issues with fluorescein staining.
- The phenylephrine test is performed by instilling one eye drop of 2.5% phenylephrine to the inferior cul-de-sac. This elevates the eyelids within 10 minutes via the sympathetic response on smooth muscles of the eyelid, principally Muller muscle. The MRD₁ should be assessed before and 10 minutes after instillation. Demonstration of adequate improvement of the ptosis after phenylephrine test may guide the surgical technique required, such as a Muller muscle resection. Unilateral phenylephrine dosing may reveal a contralateral ptosis masked by Hering law of equal bilateral innervation.
- Attaining visual acuity and fixation preferences may help detect amblyopia. Evaluation of these patients with a pediatric ophthalmologist is important.

IMAGING

- Quality full facial photographs should be obtained for preoperative planning and intraoperative reference.
- In older children or adults with congenital ptosis, visual field testing with taped and untaped eyelids should be performed.

- An A-scan may be performed if one is concerned about pseudoptosis, a term describing ptosislike appearance from pathology independent of the eyelid, such as microphthalmia or advanced hyperopia.
- Cycloplegic refraction or autorefraction may be performed to detect ptosis-induced astigmatism that may be amblyogenic.
- Congenital Horner syndrome should be evaluated with a tumor workup that may necessitate MRI investigation.

DIFFERENTIAL DIAGNOSIS

- Myogenic: myasthenia gravis, chronic progressive external ophthalmoplegia, muscular dystrophy, and oculopharyngeal dystrophy
- Myogenic etiology also seen in blepharophimosis-ptosis-epicanthus inversus syndrome (BPES), which also may have euryblepharon, telecanthus, ear deformities, and hypoplasia of the superior orbital rims and nasal bridge
- Neurogenic: Marcus Gunn jaw-winking ptosis, Horner syndrome, aberrant regeneration of the oculomotor nerve, Duane retraction syndrome
- Aponeurotic ptosis refers to slowly progressive ptosis from involutional changes in the levator aponeurosis with gradual stretching or dehiscence of this structure.
- Mechanical ptosis from excessive upper eyelid weight such as secondary to an eyelid mass, foreign body, or eyelid edema
- Pseudoptosis: Microphthalmia (underdevelopment of the orbit, lids, and socket) or advanced hyperopia with smaller anteroposterior globe length

NONOPERATIVE MANAGEMENT

- If ptosis is not cosmetically bothersome and does not appear to affect visual axis or lead to astigmatism, observation may be appropriate.

SURGICAL MANAGEMENT

- When potentially amblyogenic, prompt ptosis surgery is indicated.
- The timing of surgical correction in the absence of visually threatening ptosis is debated with many advocating for correction at approximately age 4 when structures are more defined and the child is more cooperative⁵; however, others suggest earlier treatment advocating ease of development and postoperative care.
- Consideration of the type of surgery should reflect the degree of ptosis, levator function, and emphasis on cosmetic outcomes.

- Surgeon preference often is considered when choosing a technique; however, surgeons should be comfortable with the major techniques including frontalis suspension, levator resection, and Muller muscle surgery.
- When levator function is less than 3 to 4 mm, frontalis suspension is typically preferred when possible.^{2,5}
- External levator resection or advancement may be employed for patients with moderate levator function and mild to moderate ptosis.^{2,5}
- A poor Bell phenomenon may require a temporary lower lid retraction suture, or Frost suture, to protect the cornea following ptosis surgery.
- Frontalis suspension may utilize a silicone, Mersilene mesh, Gore-Tex, Ptose-Up strips, or Supramid material. However, if the child is older than 3 or 4 years, autogenous fascia lata may be utilized, which some report yields better results.⁶

Preoperative Planning

- General anesthesia is recommended for pediatric cases.
- Review of the facial photos and exam including attention to the MRD₁, vertical fissure height, Bell phenomenon, and extraocular muscle
- For levator resection surgeries, the degree of levator function should be reviewed preoperatively. Unlike adult cases with intraoperative participation, pediatric cases under general anesthesia may require a preplanned amount of resection or intraoperative lid position. Berke offered guidelines for leaving the upper eyelid level 1 to 2 mm below the limbus if levator function is greater than 8 mm, at the limbus for levator function of 8 mm, and 1 to 2 mm above the limbus if levator function is less than 8 mm.⁷
- We recommend unilateral frontalis suspensions for unilateral congenital ptosis; however, some recommend bilateral surgery with extirpation of a functional levator muscle to offer improved symmetry.

Positioning

- Patient is positioned supine on a surgical table with an adjustable headrest lowered to give the surgeon the best access. The patient should be prepped and draped by leaving the full face exposed.

Approach

- Internal (posterior) approach: mullerectomy

- External (anterior) approach: levator resection
- Frontal approach: frontalis suspension

TECHNIQUES

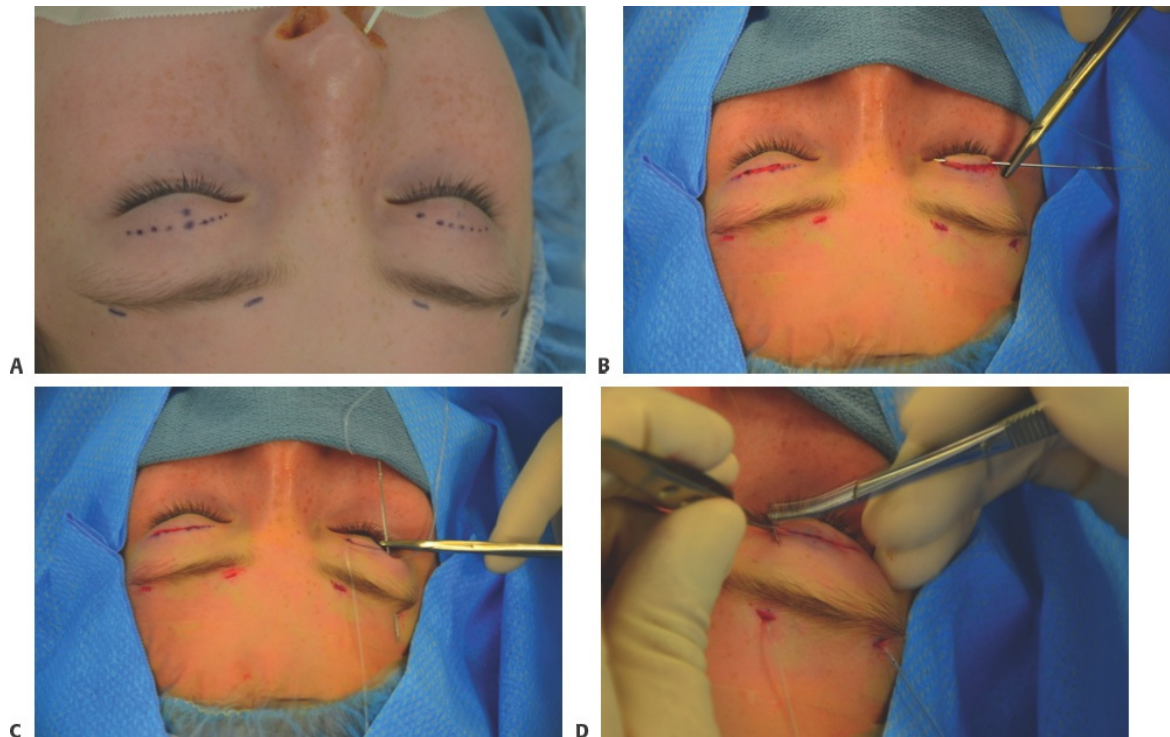
■ Frontalis Suspension

Markings and Eyelid Sutures

- Place topical tetracaine on the conjunctival surface.
- Mark the lid crease prior to injecting local anesthetic.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine subcutaneously inferior to the brow.
- Mark desired lid crease with a sterile marking pen. This is typically 8 and 10 mm above the eyelid margin in males and females, respectively.
- Mark one midpupillary point on the eyelid skin. Mark two points 4 mm medial and lateral to the marked “central point” superior to the brow (**TECH FIG 1A**).
- Make one stab incision at each of the marked stab sites above the brow with a no. 15 blade.
- Make an incision with a no. 15 blade along the previously marked eyelid crease.
- Attach a free needle to the sling material. The authors prefer Supramid (polyfilament, cable-type 3-0 suture). Pass this needle laterally to medially along the eyelid crease beneath the orbicularis muscle and just anterior to the tarsus (**TECH FIG 1B**). If the skin puckers while doing this, the needle is being passed too superficially.
- Check the eyelid contour to ensure the tarsus pass does not create squared off lid (too broad of a pass) or a peaked eyelid (too narrow of a pass).
- Both medial and lateral ends of the sling material are then passed just deep to the dermis to the stab incision sites immediately superior to the brow (**TECH FIG 1C**).
- Close the eyelid crease incision with 6-0 fast gut running sutures (**TECH FIG 1D**).

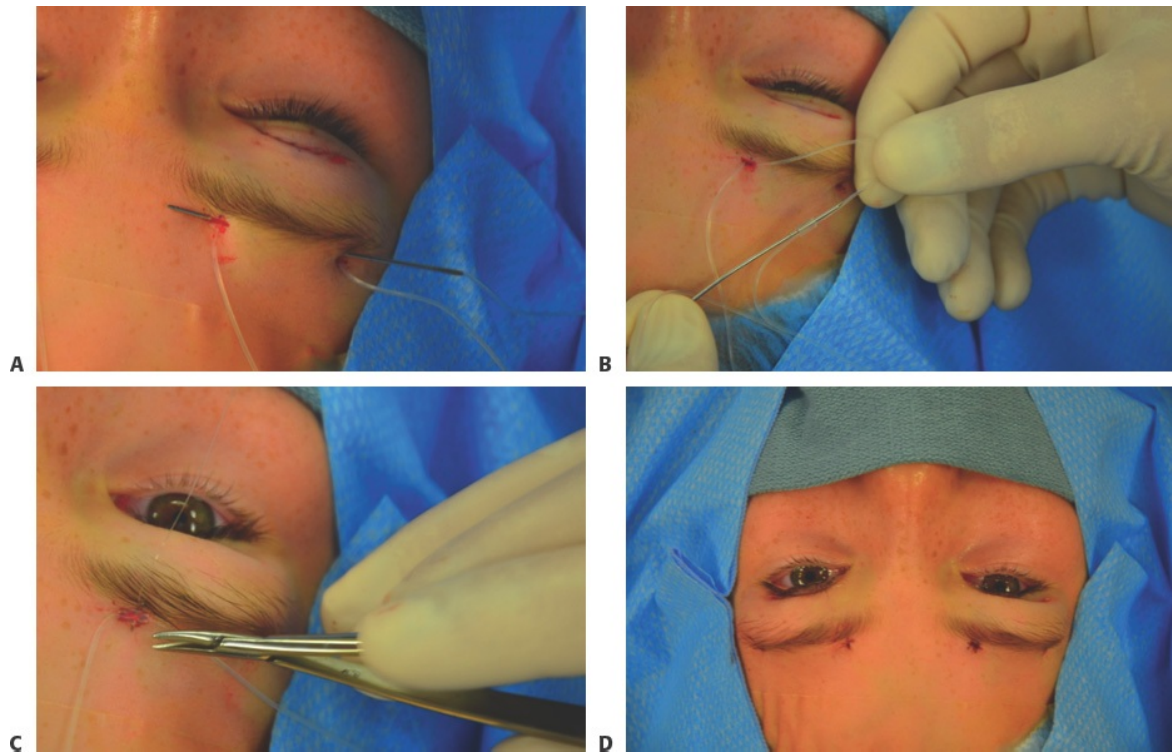
Brow Sutures

- Pass the needle from the lateral brow stab incision to the medial stab incision deep to the dermis (**TECH FIG 2A**).
- Tighten the sling material with care not to break the sling elevating the lid to the height of the superior limbus or 1 mm below the superior limbus. Assess eyelid contour.
- If using synthetic material, pass a cuff around both sling ends (**TECH FIG 2B**).
- Secure the sling with two square knots.
- Close the stab incisions with a deep pass using 5-0 Vicryl suture on a P-2 needle and finally closing the eyelid crease and superficial tissues of the stab incisions with 5-0 fast gut interrupted sutures (**TECH FIG 2C,D**).



TECH FIG 1 • Frontalis sling. **A.** Markings are made, importantly including one midpupillary point on the eyelid skin and two points 4 mm medial and lateral to the marked midpupillary point superior to the brow. **B.** A free needle attached to the sling material of choice is passed laterally to medially beneath the orbicularis and anterior to the tarsus. **C.** Both medial and lateral

ends of the sling material are passed just deep to the dermis to the stab incision sites superior to the brow.
D. The eyelid crease incision is closed in running fashion.



TECH FIG 2 • Frontalis sling. **A.** The sling needle is passed from the lateral brow stab incision to the medial stab incision deep to the dermis. **B.** Demonstration of passing a cuff around both ends of a silicone sling to be buried subcutaneously. **C.** Deep 5-0 Vicryl suture is placed underneath the sling prior to tying the sling. The Vicryl suture is then passed through subcutaneous tissue anterior to the enclosed sling. **D.** The stab incisions are closed with a deep pass using 5-0 Vicryl suture on a P-2 needle.

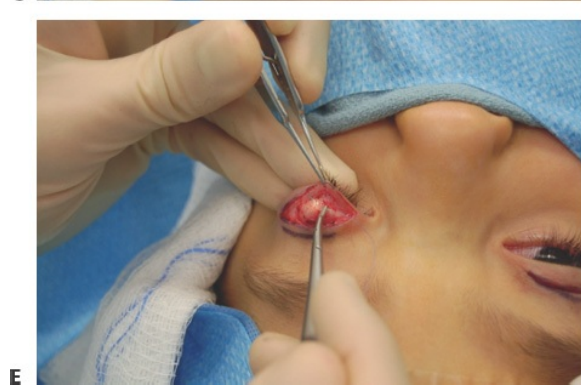
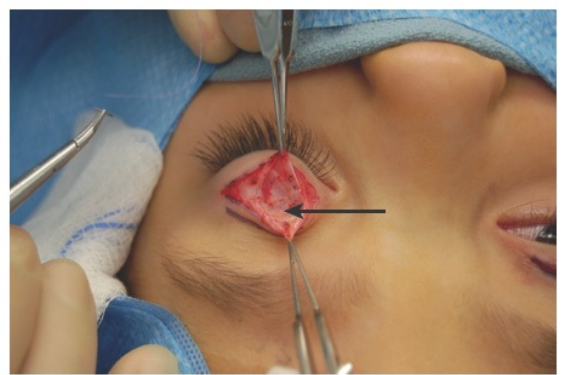
■ Levator Resection

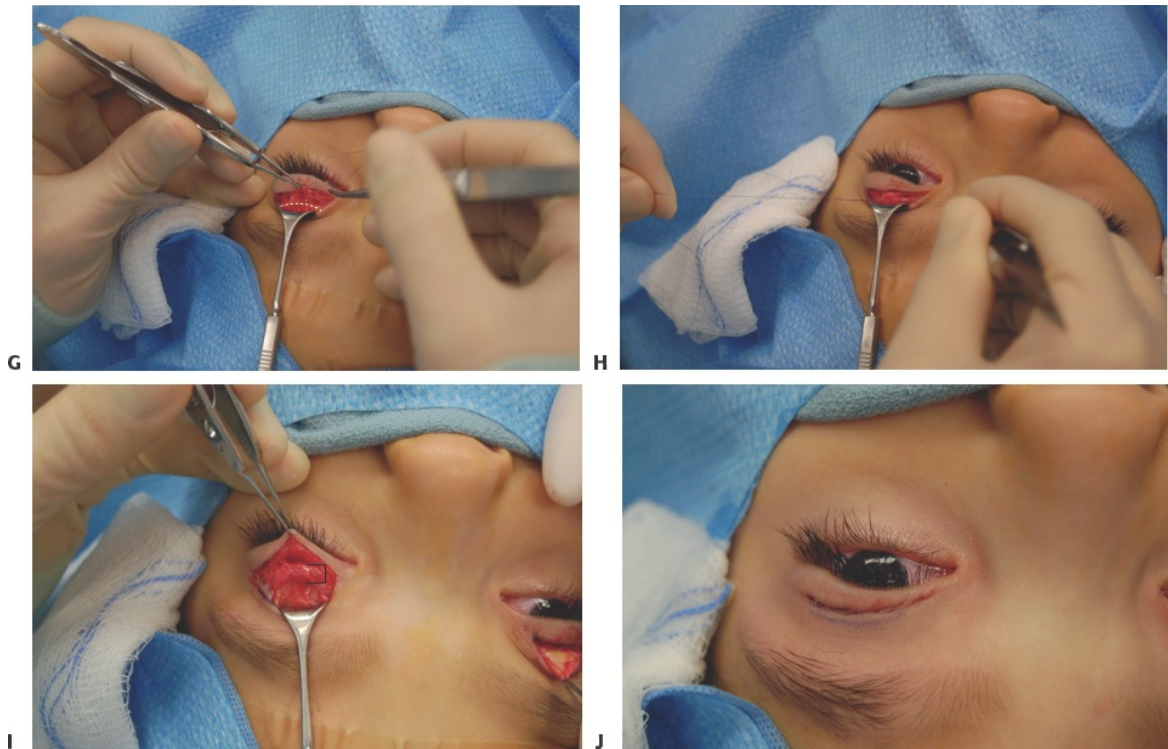
Markings and Dissection

- Place topical tetracaine on the conjunctival surface.
- Mark the desired lid crease (8 to 10 mm) with a sterile marking pen aligning symmetry with the fellow eye.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space adjacent and superior to the tarsus. Take care not to infiltrate the levator muscle with local anesthetic or add too much volume to the lids, distorting surgical landmarks.
- Use a no. 15 blade to incise the marked eyelid crease deepening the incision with scissors to the level of the tarsus (**TECH FIG 3A**).
- Using Westcott scissors, make short cuts along the inferior edge of the incision to dissect to the superior tarsus (**TECH FIG 3B,C**).
- Tent up the eyelid septum by holding and gently retracting the tarsus and the superior septum away from each other. Carefully cut shallowly to dissect through the septal plane revealing the levator aponeurosis (**TECH FIG 3D**).

Suturing and Closure

- Pass 2 double-armed 5-0 Vicryl sutures through the anterior upper tarsus border via partial-thickness passes (**TECH FIG 3E**). Take care to avoid making full-thickness passes, checking the palpebral conjunctiva for suture by flipping the eyelid after each pass (**TECH FIG 3F**).





TECH FIG 3 • Levator resection. **A.** An incision is made along the marked eyelid crease and deepened with Westcott scissors to the level of the tarsus. **B.** Careful sharp dissection is made to dissect to the superior tarsus. **C.** The tarsus is seen by glistening white tissue (*arrow*). **D.** The tarsus and superior septum are retracted to allow a dissection through this pocket to the levator aponeurosis (*arrow*). **E.** Two double-armed 5-0 Vicryl sutures are passed through the anterior upper tarsus border via partial-thickness passes. **F.** The eyelid is flipped using a blunt needle driver to ensure full-thickness passes have been avoided. **G.** Sutures are passed through the levator aponeurosis to the junction of Whitnall ligament, demarcated by a white linear band (*white dashes*). **H.** A temporary knot is tied, and the contour of the eyelid is checked. **I.** Excess levator aponeurosis (between *black brackets*) can be excised. **J.** The skin is closed

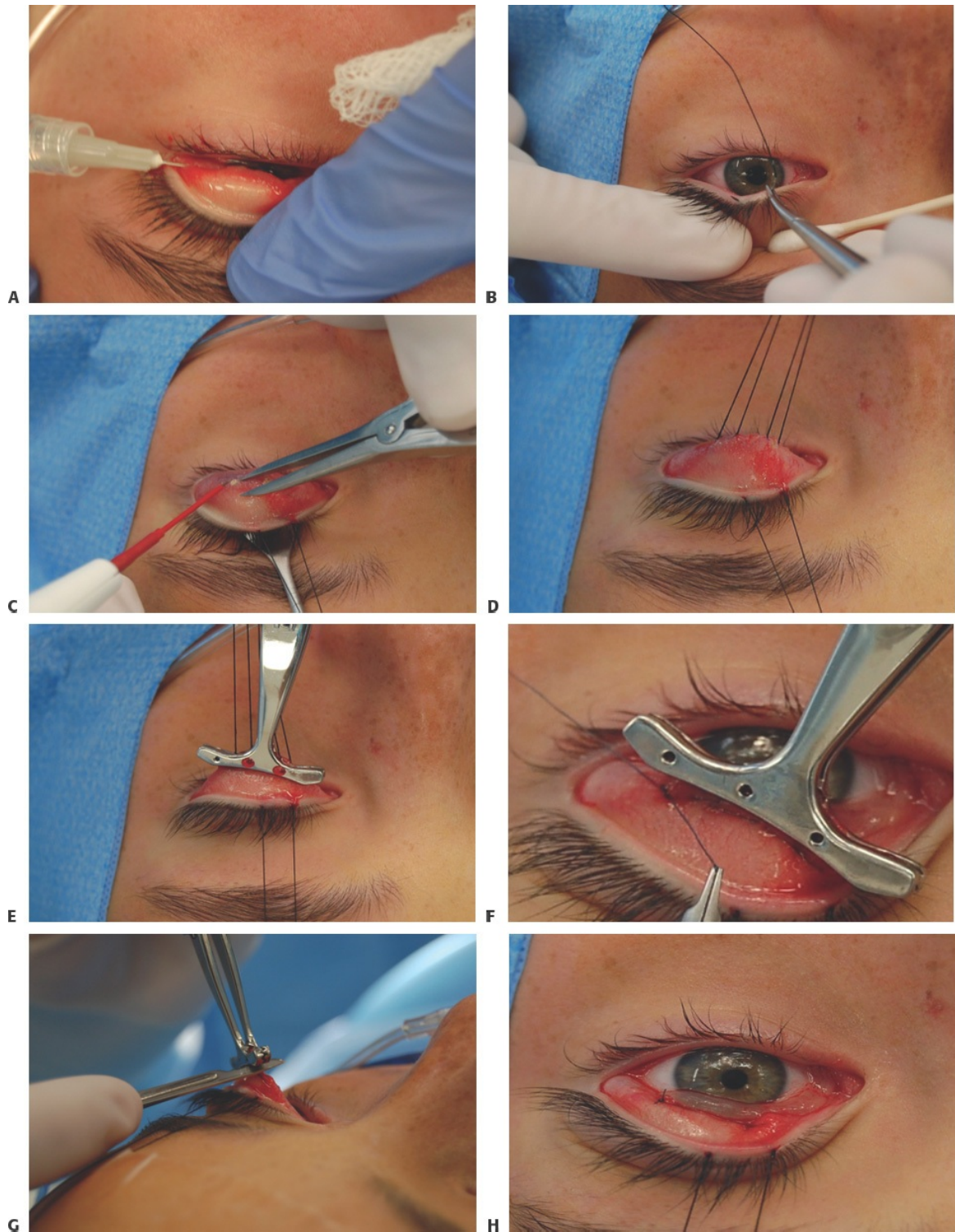
in running fashion.

- Per the graded resection anticipated prior to the procedure, each suture is then passed through the levator aponeurosis, near the junction of Whitnall ligament (**TECH FIG 3G**).
- A temporary knot is tied and the contour of the eyelid is checked (**TECH FIG 3H**). If appropriate lid height is achieved, the sutures can be permanently tied using a surgeon's knot.
- Excess levator aponeurosis (**TECH FIG 3I**) can be excised if needed.
- Close the skin with 6-0 fast gut in running fashion (**TECH FIG 3J**).
- If interested in recreating the eyelid crease, make a single pass of 6-0 gut suture through the inferior edge of skin, orbicularis, passing partial thickness through the levator aponeurosis, and exiting via the superior orbicularis and skin. This effectively attaches it to the levator aponeurosis to recreate the skin crease.

■ Conjunctivomullerectomy

- Place topical tetracaine on the conjunctival surface.
- Place a subcutaneous eyelid block below the brow using 2 cc 2% lidocaine with 1:100 000 epinephrine. Evert the eyelid and inject 1 cc lidocaine into the superior tarsal border deep to the conjunctiva (**TECH FIG 4A**).
- Pass a 4-0 silk suture deeply through the gray line to serve as traction sutures (**TECH FIG 4B**).
- Evert the eyelid using a Desmarres retractor.
- Using a caliper, measure the amount of Muller muscle to resect and mark inside the lateral borders of the tarsus with handheld cautery (**TECH FIG 4C**).
- Pass a two 4-0 silk sutures through the conjunctiva and Muller muscle at the marked sites (**TECH FIG 4D**).
- Elevate Muller muscle and the conjunctiva via the silk sutures into a mullerectomy clamp at the marked sites (**TECH FIG 4E**).
- Lock the clamp. Cut and remove the silk traction sutures from the Muller muscle.
- Hold the clamp in the nondominant hand between the middle and index finger leaving the thumb and index finger to load suture.

- Holding this position, run a 6-0 double-armed Vicryl suture in running horizontal mattress fashion along the entire end of the locked clamp. Repeat the running horizontal mattress passes with the second suture arm (**TECH FIG 4F**).
- Tie the two Vicryl suture arms with a surgeon's knot.
- With slight upward tension, use a no. 15 blade to incise the tissue held by the clamp with attention to incising as close to the metal clamp edge as possible keeping a metal-on-metal feel to ensure the suture is not cut (**TECH FIG 4G**).
- Remove the mullerectomy clamp and retraction sutures (**TECH FIG 4H**).



TECH FIG 4 • Conjunctivomullerectomy. **A.** Anesthetic is injected into the superior tarsal border deep to the conjunctiva. **B.** A 4-0 silk suture is passed deeply

through the gray line to serve as traction sutures. **C.** The predetermined amount of Muller muscle to resect is measured with calipers inside the lateral borders of the tarsus and marked with handheld cautery. **D.** Two 4-0 silk sutures are passed through conjunctiva and Muller muscle at the marked sites. **E.** Grasping the sutures, Muller muscle and the conjunctiva are elevated into a mullerectomy clamp at the marked sites. **F.** Running horizontal mattress sutures passed below the clamp. **G.** Incision of Muller muscle and conjunctiva held in the clamp ensuring sutures are not cut. **H.** Final appearance after removal of clamp.

PEARLS AND PITFALLS

Creating an eyelid crease

- Gently push superiorly on the upper eyelid lashes. This will manifest an eyelid crease that may be otherwise underrepresented.
- If a natural eyelid crease is not present and is surgically desired, create a crease with an incision 8–10 mm superior to the upper eyelid margin for males and 10–12 mm for females.

Undercorrection

- Utilize the results from the phenylephrine test to plan for the degree of expected correction for mullerectomy procedures.
- Adjustable sutures may be used for early postoperative adjustment.
- Err on the side of undercorrection, unless performing levator resection, in which case aim for 1 mm overcorrection.

Irregular eyelid contour

- Avoid closing or removing levator aponeurosis with the mullerectomy by grasping conjunctiva with Muller muscle from the more posterior structures.
- Place or adjust sutures where the deformity is greatest after applying tension under this region.

	■ Postoperatively, lid massage may be of benefit in mild to moderate cases.
Ectropion/entropion	■ Avoid suture tension at the inferior tarsus. ■ Avoid applying too much tension to sutures.
Postoperative lagophthalmos	■ Consider graded mullerectomy and tarsectomy in patients with significant preoperative lagophthalmos. ■ If frontal sling is needed in a setting of significant preoperative lagophthalmos, place a temporal tarsorrhaphy at the end of the procedure. ■ Place Frost sutures after levator resection procedures.

POSTOPERATIVE CARE

- Patients undergoing frontalis sling should be given an oral antibiotic for 7 days.
- Coordinate care with pediatric ophthalmologist to monitor for postoperative refractive error including induced amblyopia.
- Aggressive lubrication cannot be overstressed.
- If used, lower lid traction sutures should be removed at postoperative day 2.
- Topical antibiotic ointment should be applied 4 times a day for 1 week.
- If adjustable sutures are employed, the postoperative visit should be within 1 week.

OUTCOMES

- Overall, the reported successful outcome is 70% to 90% in pediatric ptosis cases with undercorrection accounting for the majority of poor results or failures.^{2,8}
- Frontalis sling procedures using synthetic material historically have had recurrence rates as high as 29% to 40%; however, autogenous fascia lata grafts and newer graft materials used in a sling procedure may offer superior results.^{5,6,9} Lee et al.² reported 5% to 10% poor outcomes with fascia lata grafts or Mersilene mesh.
- Anterior levator resection procedures result in poor outcomes in approximately 10% to 20%.^{2,7}
- Although not generally agreed upon, some surgeons find external levator resection to be associated with less reoperation rate.¹⁰
- An asymmetry of greater than 1 to 2 mm between eyelids may be as common

as 30% postoperatively.⁸

COMPLICATIONS

- Lagophthalmos
- Overcorrection
- Ectropion
- Exposure keratopathy
- Irregular eyelid contour or skin crease
- Implant infection or extrusion⁶
- Development or worsening of astigmatism postoperatively⁴
- Suture site granulomas over synthetic material

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CHAPTER Epiblepharon

Adam R. Sweeney and Christopher B. Chambers

DEFINITION

- Epiblepharon is a congenital eyelid anomaly in which inward rotation of the normal lash line toward the globe results in eyelash approximation to the cornea and/or conjunctiva.

ANATOMY

- A horizontal eyelid fold composed of skin and orbicularis is evident inferior to the eyelid margin. This is caused by the absence of the adhesion between the thin smooth muscle contributing to lower eyelid retraction and the soft tissue immediately deep to the lower eyelid skin.^{1,2}
- Often, the fold is more pronounced or isolated to the medial eyelid.
- The Asian lower eyelid has a higher attachment of the septum on the tarsus or inferior retractor. Additionally, there often is an absence or paucity of retractor septa attached to the overlying skin, similar to the Asian upper eyelid.¹
- The tarsus is not rolled in, nor is there rotation of the eyelid muscle, separating this condition from entropion.³

PATHOGENESIS

- Epiblepharon is one of the most common eyelid abnormalities among Asian children, with majority demonstrating spontaneous resolution throughout childhood.⁴
- Up to 95% of Asian children with epiblepharon will have it bilaterally.^{2,4,5}
- Epiblepharon much more commonly involves the lower eyelid than it does both upper and lower eyelids with a small minority of cases involving solely the upper eyelid.²

- There is no gender predilection.²
- Epiblepharon is less commonly seen in adults.
- Asian children with higher BMI are more likely to have epiblepharon.⁶
- Acquired epiblepharon is rare and often secondary to thyroid eye disease.⁷

NATURAL HISTORY

- The majority of patients will have spontaneous resolution with growth of the midface stretching and flattening the redundant fold.
- Patients with untreated epiblepharon may have a continuum of sequelae with some asymptomatic until development of thicker eyelashes, whereas others may develop conjunctival epithelial defects, corneal defects, recurrent corneal infections, and even corneal scarring.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients may be asymptomatic or have inciting surface irritation evident by rubbing of eyes, photophobia, persistent tearing, or discharge.
- Eyelashes may be vertically oriented and may touch the cornea. This often is exacerbated in down gaze.
- Fluorescein staining may reveal epithelial defects.
- Epiblepharon may be associated with astigmatism.
- Diagnosis is by physical exam with the eyelashes directed vertically in the setting of normal eyelid position (**FIG 1**). Additionally, an eyelid fold may be found to be mechanically corrected with downward pressure applied on the skin away from the eyelid involved.

IMAGING

- Preoperative quality external photos documenting resolution of the epiblepharon with eyelid fold excursion are recommended prior to undergoing surgery.

DIFFERENTIAL DIAGNOSIS

- Entropion with or without epiblepharon
- Trichiasis, or misdirected growth of eyelashes toward the eye
- Epicanthus tarsalis
- Dermatochalasis with lash ptosis
- Ptosis
- Discharge in nonverbal children may be a sign of backflow from the tear

drainage pathway, caused by nasolacrimal duct obstruction.



FIG 1 • Lower lid epiblepharon. Eyelashes are seen directed vertically with inferior eyelid fold.

NONOPERATIVE MANAGEMENT

- Monitoring is appropriate in asymptomatic cases without corneal eyelash apposition.
- Lubrication with scheduled artificial tears may suffice in asymptomatic cases with mild epiblepharon or conjunctival eyelash apposition.

SURGICAL MANAGEMENT

Preoperative Planning

- General anesthesia is recommended for pediatric cases.
- Surgical intervention is warranted in children whose lid abnormality causes keratopathy or conjunctivopathy, considerable irritation, or in cases where lubrication is not tolerated.
- Goals of surgical management are to achieve eyelid retractor tightening, removal of a strip of orbicularis and skin, and creation of a scar in a region between the preseptal and pretarsal orbicularis.
- In patients for whom a surgical eyelid crease is not desired, the standard

technique for epiblepharon is used. If a surgical eyelid crease is desired, the modified Hotz technique is used.

- A noninvasive everting suture technique may be offered. This modality may be appropriate for mild cases of epiblepharon, parents wishing to avoid creation of an eyelid crease/scar, or avoidance of general anesthesia.

Positioning

- The patient is positioned supine on a surgical table with an adjustable headrest lowered to give the surgeon the best access. The patient should be prepped and draped, leaving the full face exposed.

Approach

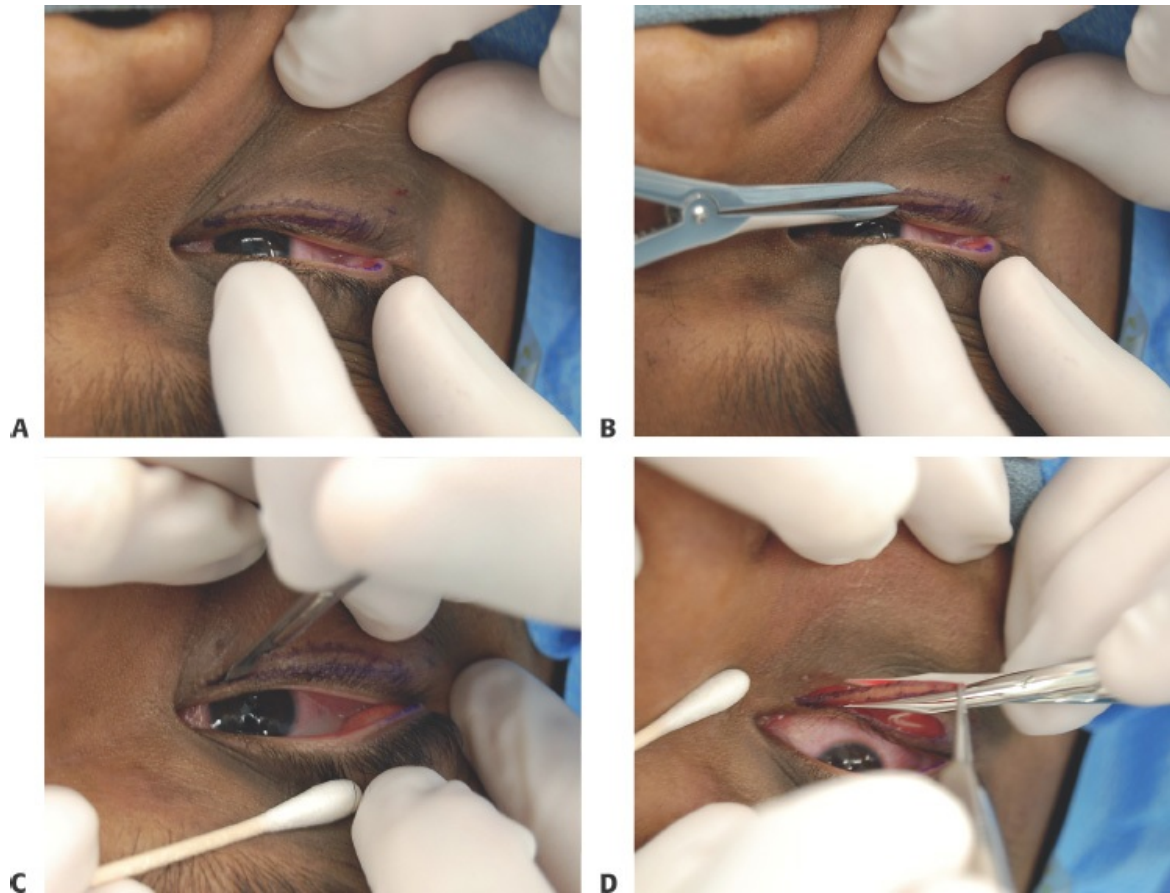
- An external approach to the lower lid tarsus and eyelid retractors is classically used. Alternatively, a noninvasive suture technique may also be used.

TECHNIQUES

■ Standard Technique

Markings and Incisions

- Place topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space adjacent to the eyelid margin of the lid involved.
- Using a sterile marking pen, outline the deficit nasally and temporally with a horizontal mark placed along the nonmarginal tarsus border (**TECH FIG 1A**).
- Use calipers to ensure the measured strip does not exceed 2 to 2.5 mm vertically (**TECH FIG 1B**).
- Use a no. 15 blade to incise a vertical semilunar-shaped strip of orbicularis and skin (**TECH FIG 1C**).
- Remove the incised skin using Westcott scissors (**TECH FIG 1D**).



TECH FIG 1 • **A.** Epiblepharon with outlining markings including a horizontal marking along the nonmarginal tarsus border. **B.** Calipers are used to confirm less than 2 mm of vertical tissue to be excised. **C.** The outlining incision is made. **D.** Westcott scissors are used to excise outlined skin.

Suturing

- Maintain hemostasis with monopolar cautery.
- Remove the incised orbicularis using handheld cautery (**TECH FIG 2A**).
- Using a 5-0 Vicryl suture, make a pass through the orbital septum and through the lower eyelid retractors (**TECH FIG 2B**).
- Continue this pass through the inferior edge of the tarsus, rotating the needle to pass out through the septum (**TECH FIG 2C**).
- Rotate the eyelid to ensure a full-thickness eyelid suture has not been placed and tie this knot using a surgeon's knot (**TECH FIG 2D**).

- Pass two identical sutures separated by approximately 2 to 3 mm closing the horizontal length of the strip (**TECH FIG 2E-G**).
- Using 5-0 Vicryl suture, close the superior and inferior edges of the incised orbicularis tissue in buried subcutaneous-interrupted passes.
- Close the skin with 6-0 fast gut running sutures (**TECH FIG 2H**).



A



B



C



D



E



F



G



H

TECH FIG 2 • A. Handheld cautery is used to remove underlying orbicularis within the previously marked region. **B.** Vicryl suture is passed through the orbital septum and lower eyelid retractors. **C.** The pass is continued through the inferior edge of the tarsus. **D.** A surgeon's knot is used to reapproximate the sutured tissues. **E.** The retractors are reapproximated to the tarsus. **F.** Suture tails are cut just above the knot. **G.** Eyelashes are checked for resolution of corneal apposition. **H.** Skin is closed using 6-0 fast gut in a running fashion.

■ Modified Hotz Technique

Markings and Incisions

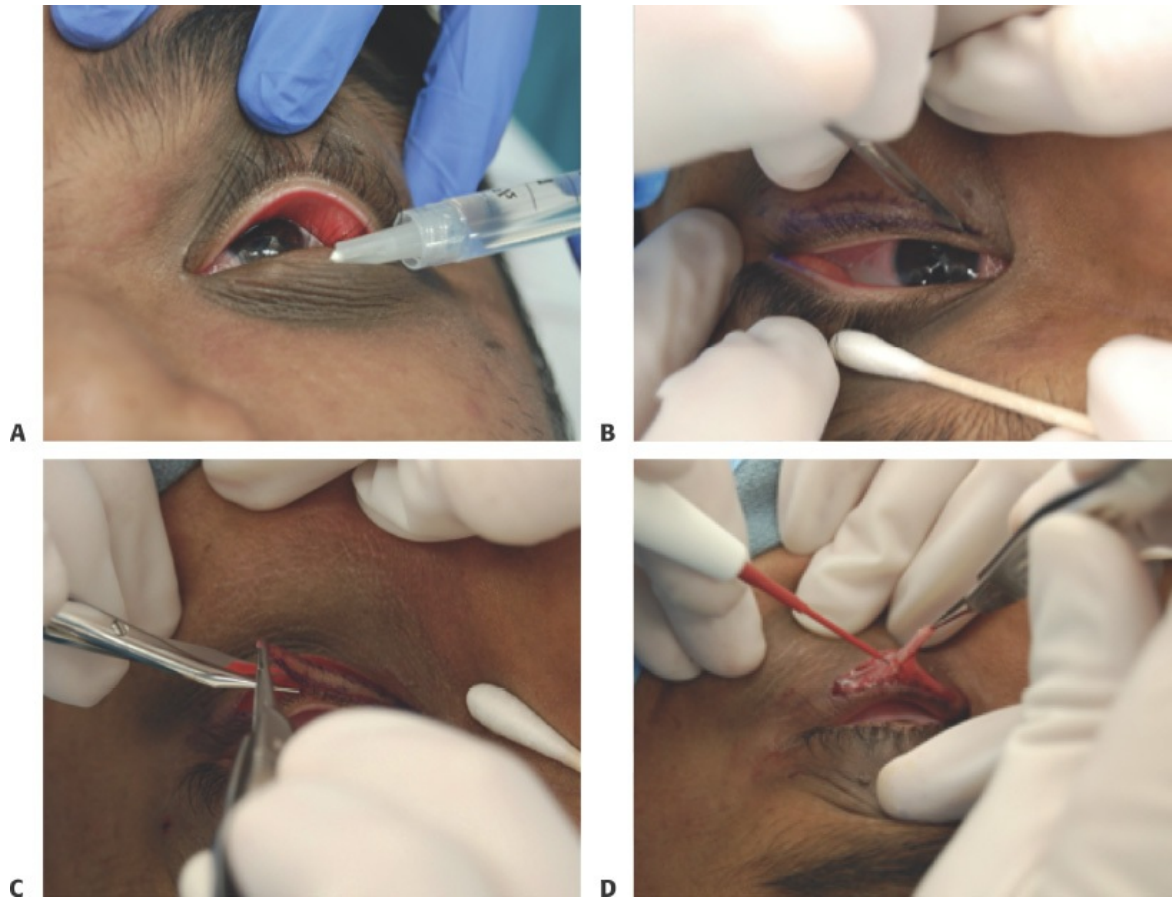
- Place topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space adjacent to the eyelid margin of the lid involved (**TECH FIG 3A**).
- Using a sterile marking pen, outline the eyelid crease prior to marking the epiblepharon deficit nasally and temporally with a horizontal mark placed along the nonmarginal tarsus border.
- Use a no. 15 blade to incise a 2- to 2.5-mm vertical semilunar-shaped strip of orbicularis and skin (**TECH FIG 3B**).
- Remove the incised skin using Westcott scissors (**TECH FIG 3C**).
- Maintain hemostasis with monopolar cautery.
- Remove the incised orbicularis using handheld cautery (**TECH FIG 3D**).

Suturing

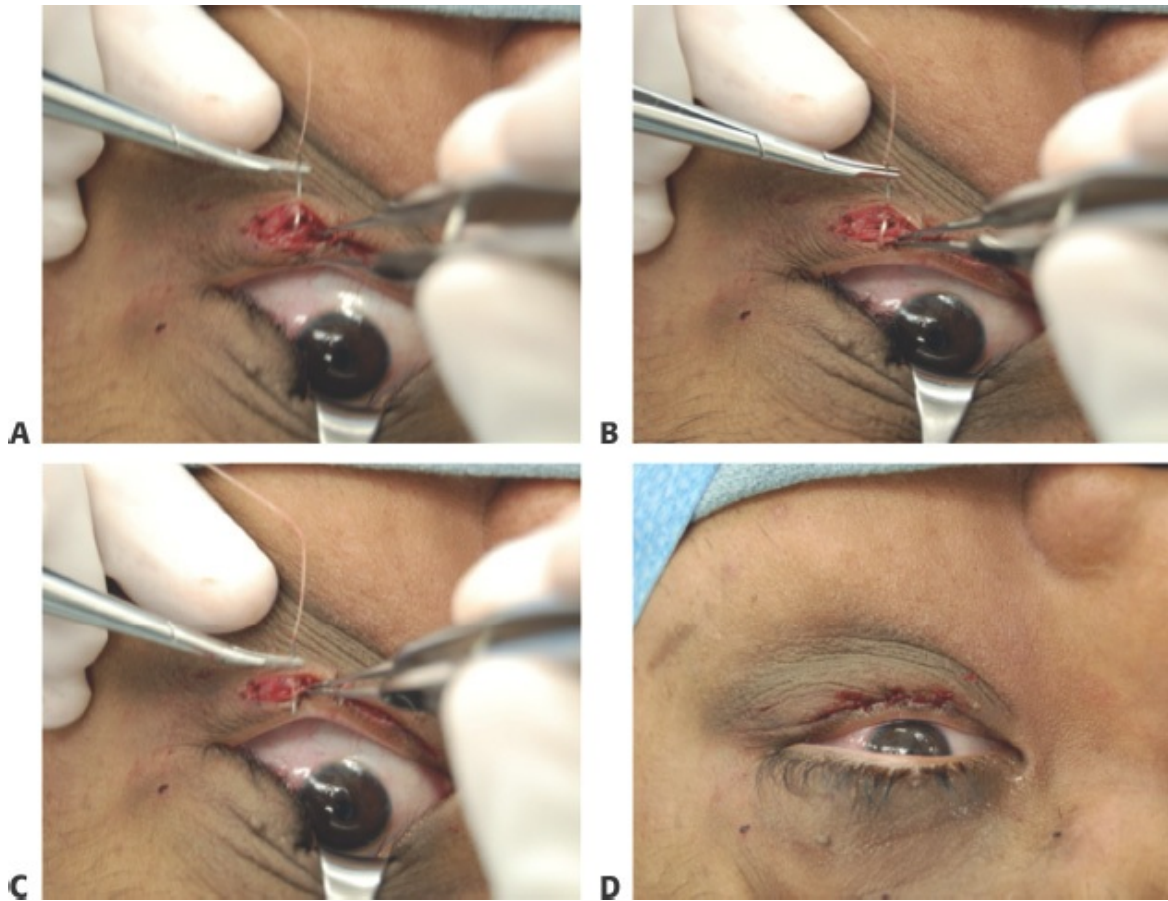
- Using a 5-0 Vicryl suture, pass the needle externally through the skin inferior to the incision, through the orbital septum, and through the lower eyelid retractors (**TECH FIG 4A**).
- Proceed by passing this needle through the inferior edge of the tarsus (**TECH FIG 4B**), rotating the needle to pass out through the septum, the

orbicularis, and the skin superior to the incision (**TECH FIG 4C**).

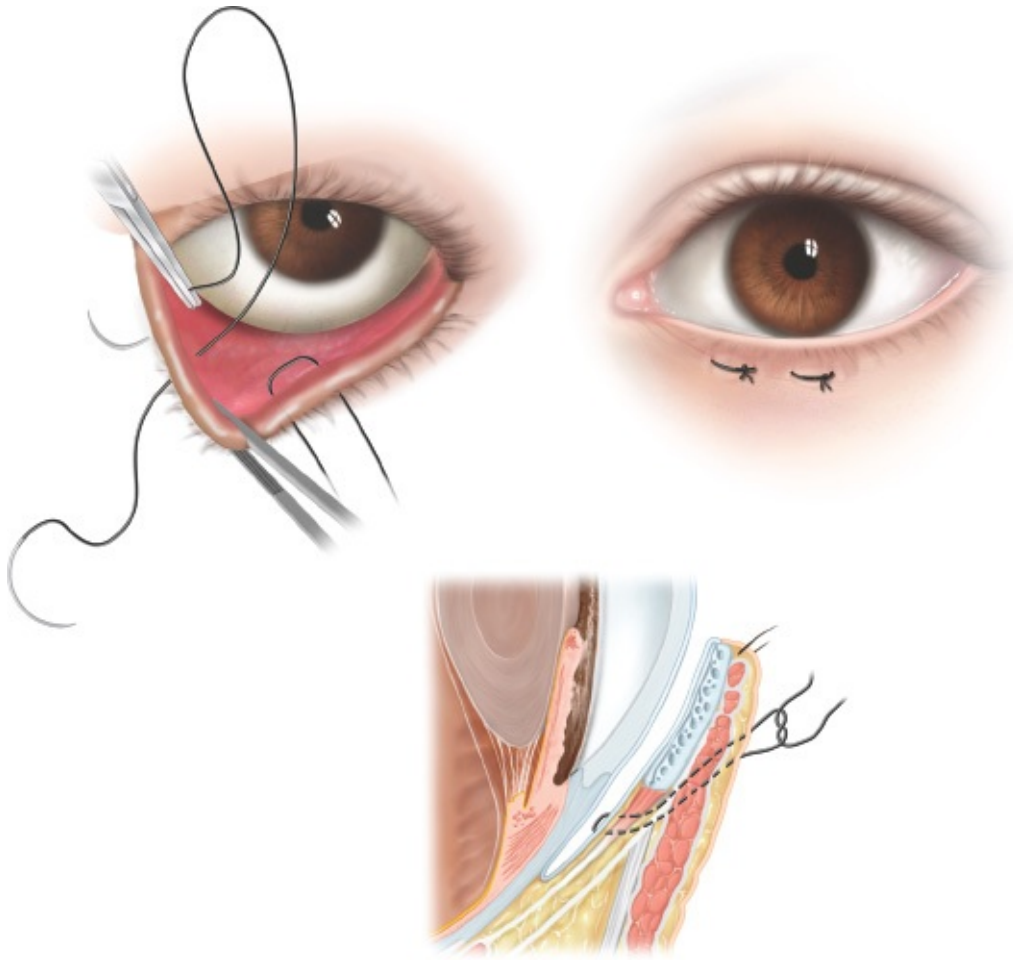
- Rotate the eyelid to ensure a full-thickness eyelid suture has not been placed.
- The suture can then be tied with an external surgeon's knot.
- Pass one identical suture both nasal and lateral to the central suture 2 mm from the nasal and lateral tarsal edge, respectively (**TECH FIG 4D**).



TECH FIG 3 • **A.** Anesthetic is injected into the subcutaneous space along the defect. **B.** The outlining incision is made. **C.** Westcott scissors are used to excise outlined skin. **D.** Handheld cautery is used to remove underlying orbicularis within the previously marked region.



TECH FIG 4 • A. 5-0 Vicryl suture is passed externally through the skin, through the orbital septum, and through the lower eyelid retractors. **B.** The pass is continued through the inferior edge of the tarsus and out through the skin. **C.** Eyelashes are checked for resolution of corneal apposition. **D.** The final outcome and appearance of the surgically created lid crease.



TECH FIG 5 • Illustration outlining the trajectory of the suture through the central cul-de-sac of the palpebral conjunctiva directed superiorly to exit 3 mm below the eyelid margin.

■ Everting Sutures/Buried Sutures Technique

- Place topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine into the subcutaneous space adjacent to the eyelid margin of the lid involved.
- Using a double-armed 3-0 silk suture, make a pass from the central cul-de-sac through the palpebral conjunctiva, orbicularis, and the eyelid skin (**TECH FIG 5**).
- The ideal exit of this suture is 3 mm below the eyelid margin for inferior epiblepharon repair and 3 to 4 mm above the eyelid margin for superior

epiblepharon repair.^{8,9}

- An identical suture is passed 2 to 3 mm medial to the central suture in the same fashion.
- The sutures are tied with long tails and the tails.
- Antibiotic ointment is applied over the suture site.
- The tails of the sutures are taped away from the eyelid margin.

PEARLS AND PITFALLS

Technique	■ In very large epiblepharon cases, a modified Z-epicanthoplasty to tighten the lower eyelid to the medial canthus may be performed prior to the standard or modified Hotz procedure. ¹⁰
Inadequate postoperative eversion	■ Overcorrect the eversion slightly to adjust for postoperative scarring.
Asymmetry	■ More orbicularis/skin may be taken medially to avoid recurrence and asymmetry.
Scar	■ Avoid tension on the skin. ■ Lubricate and protect the incision site from sun exposure postoperatively.

POSTOPERATIVE CARE

- Apply antibiotic eye ointment to the operative site 4 times a day for 1 week.
- Remove everting nonabsorbable sutures at 1-week follow-up, allowing for orbicularis scarring.

OUTCOMES

- Following incisional epiblepharon repair, 80% to 90% of patients are either asymptomatic or anatomically repaired.^{2,5}
- The everting sutures/buried sutures technique may be associated with up to a 23% recurrence rate.⁹
- There is no agreed-upon interval between surgical correction and possible recurrence.

COMPLICATIONS

- Suture abscesses
- Wound dehiscence
- Lid retraction, ectropion
- Canalicular trauma
- Lagophthalmos

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CHAPTER Canthopexy

Adam R. Sweeney and Christopher B. Chambers

DEFINITION

- Canthopexy is a resuspension of the canthus to the bony orbit used to treat eyelid laxity, ectropion, or misalignment.
- A common surgery in adult facial rejuvenation, canthopexy is an indispensable tool for treating children with eyelid positioning defects or deformities.

ANATOMY

- The canthal tendons maintain the shape of the palpebral fissure and also maintain lid apposition to the globe, important for proper corneal lubrication and tear drainage.
- The medial canthus has origins at the anterior and posterior lacrimal crests that *fuse temporal* to the lacrimal sac, enveloping the lacrimal sac. The medial canthus then divides into upper and lower segments that attach to the tarsus of the upper and lower lid.
- The medial canthus is involved in the lacrimal pump mechanism and intimately associated with the lacrimal sac.
- The lateral canthal tendon originates at the lateral orbital tubercle 4 to 5 mm posterior to the lateral orbital rim. This provides a posterior vector opposing the lid to the globe. The lateral canthal tendon then splits into superior and inferior segments that attach to the tarsal plates (**FIG 1**).
- The lateral canthal tendon inserts approximately 2 mm higher than does the medial canthal tendon. This creates a superior tilt to the palpebral fissure moving laterally.
- The orbital septum overlies the lateral canthus as it approaches the orbital rim and acts as a “superficial lateral canthus,” which can be used for suspension in

mild cosmetic defects.¹

PATHOGENESIS

- Common conditions that may cause eyelid laxity or malposition including congenital facial clefting (ie, Tessier 2 to 12 clefts), amniotic band syndrome, congenital eyelid malposition, or deformities resulting from other etiologies including trauma and cancer resection or from craniofacial manipulation (iatrogenic)

NATURAL HISTORY

- Eyelid laxity is both a cosmetic and a functional problem.
- Uncorrected, lower lid laxity may cause exposure keratopathy, epiphora, or problems with the lacrimal pump mechanism.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Lower eyelid laxity
- Canthal dystopia

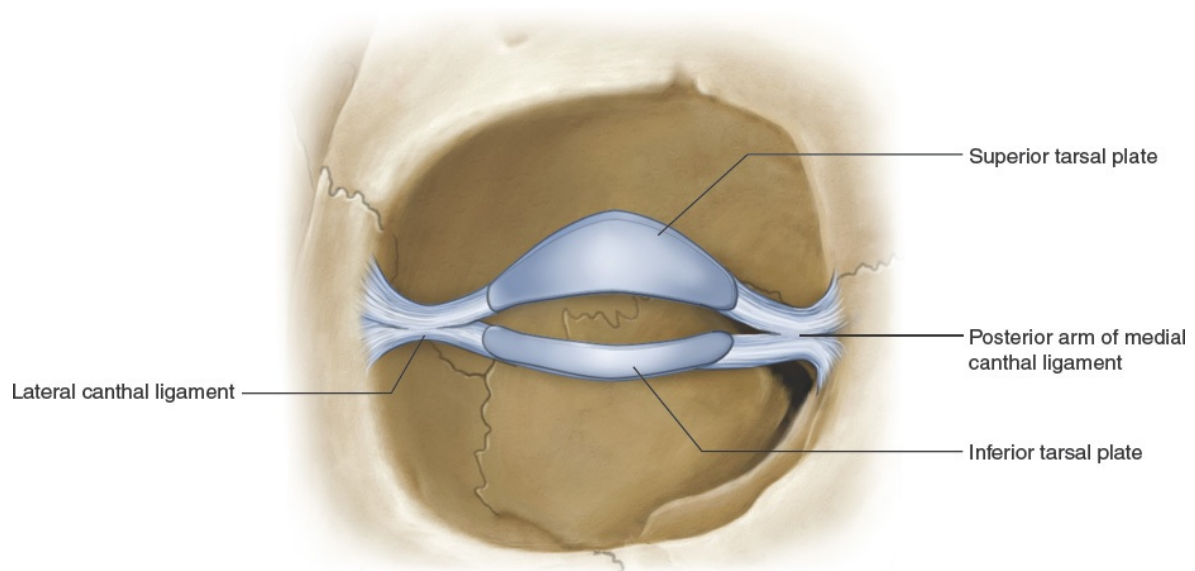


FIG 1 • Anatomy of the medial and lateral canthal tendons.

- Poor eyelid snap back test: This test refers to evaluating the time for the eyelid to return to normal position after pulling the lower lid down and away from the globe. It is graded from 0 (brisk snap back) to IV (severe laxity).

- Eyelid distraction—5 mm of eyelid distraction often considered excessively lax.
- Dry eye including exposure keratopathy or punctate epithelial erosions
 - Punctual stenosis from keratinization of the lid margin in medial ectropion²

IMAGING

- CT imaging of the face is appropriate in the evaluation of congenital craniofacial abnormalities. In the setting of orbital trauma, CT imaging is useful to assess for naso-orbital-ethmoid fractures.

NONOPERATIVE MANAGEMENT

- In patients not bothered by the cosmetic defect, scheduled application of lubricant artificial tears may provide the necessary corneal protection to defer or prevent surgery in mild cases.
- Careful attention must be made to prevent deprivation amblyopia by constant application of ointments, taping the eyelid shut, or patching of the eye.

SURGICAL MANAGEMENT

- If the cosmetic defect is bothersome or the patient is symptomatic, canthopexy, canthoplasty, or both may be performed to correct the eyelid abnormality.
- Medial canthopexy in the absence of nasal fractures may be performed either with or without wiring as adapted from Mustarde³ and Callahan,⁴ respectively.

Preoperative Planning

- General anesthesia is recommended for pediatric cases.
- Preoperative photos should be reviewed assessing the degree of malpositioning and marking of the face at the desired canthi position to create the proper slight superolateral contour of the eyelid with appropriate eyelid tightening achieved.

Positioning

- Patients should be positioned supine in an operating bed with adjustable head positioning. The contralateral eyelid may be temporarily taped shut or lubricated rather than covered to serve as a reference point during surgery.

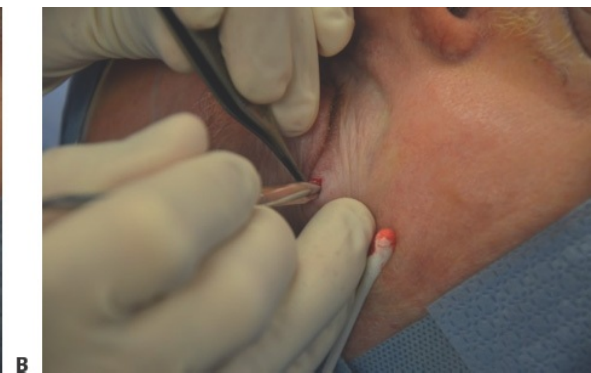
Approach

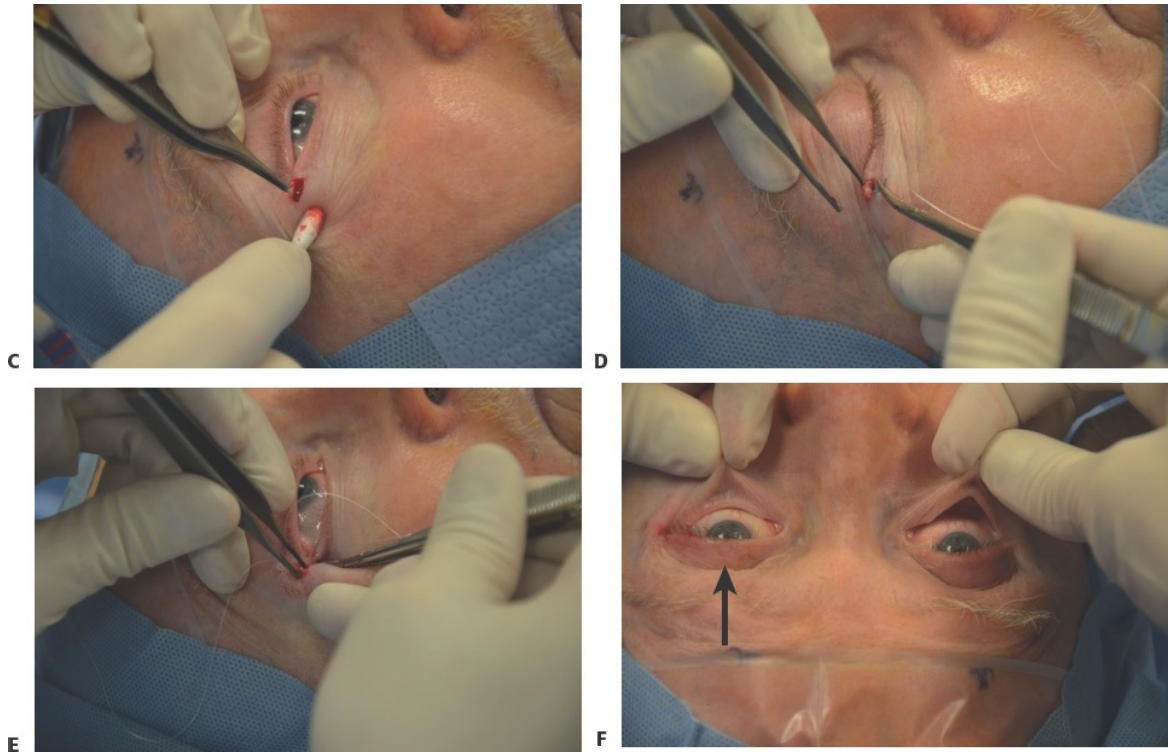
- Medial, lateral, or a combination of approaches may be performed depending on the location of the lid abnormality or the desired results.

TECHNIQUES

■ Lateral Canthopexy

- The lateral canthopexy procedure tightens the canthal tendon with sutured reconstruction of the canthal tendon. This effectively tightens the eyelid.
- Place 2 drops of topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine subcutaneously above and below the lateral canthus.
- Using a no. 15 blade, make a 1-cm horizontal subciliary incision at the lateral canthal angle (**TECH FIG 1A**).
- Retract the skin with skin hooks and bluntly dissect down to the periosteum using blunt-tipped scissors.
- Undermine and dissect in this plane to the lateral canthal tendon under the orbital septum (**TECH FIG 1B**).
- The lateral canthal tendon is identified by tension and the ability to “strum” if manipulated by closed blunt-tipped scissors. Grasping the lateral canthal tendon, vertically transect the lateral canthal tendon at its lateral insertion taking care to avoid the levator aponeurosis (**TECH FIG 1C**).
- Pass a double-armed 4-0 Vicryl suture on a P-2 needle (Ethicon, Somerville, NJ) entering anteriorly through the lateral canthus at its transected superior and inferior attachment points (**TECH FIG 1D**).





TECH FIG 1 • Lateral canthopexy. **A.** A 1-cm horizontal subciliary incision is made at the lateral canthal angle. **B.** Blunt-tipped scissors are used to dissect down to the periosteum. **C.** The lateral canthal tendon is grasped following undermining to assist in further dissection. **D.** A double-armed 4-0 Vicryl suture on a P-2 needle is used to make two passes from anterior to posterior through the lateral canthal tendon. **E.** Deep suture placement ensuring a bite of periosteum is achieved at the (medial) aspect of the lateral orbital rim. **F.** The eyelid laxity in the operative eye (*arrow*) is assessed for appropriate tension.

- Pass each suture through the periosteum of the inner (medial) aspect of the lateral orbital rim approximately 1 cm superior to the medial canthus (**TECH FIG 1E**). Ensure tension is achieved with a strong bite.
- Check the tension of the eyelid to ensure slightly exaggerated tension, anticipating slight laxity after postoperative healing (**TECH FIG 1F**).

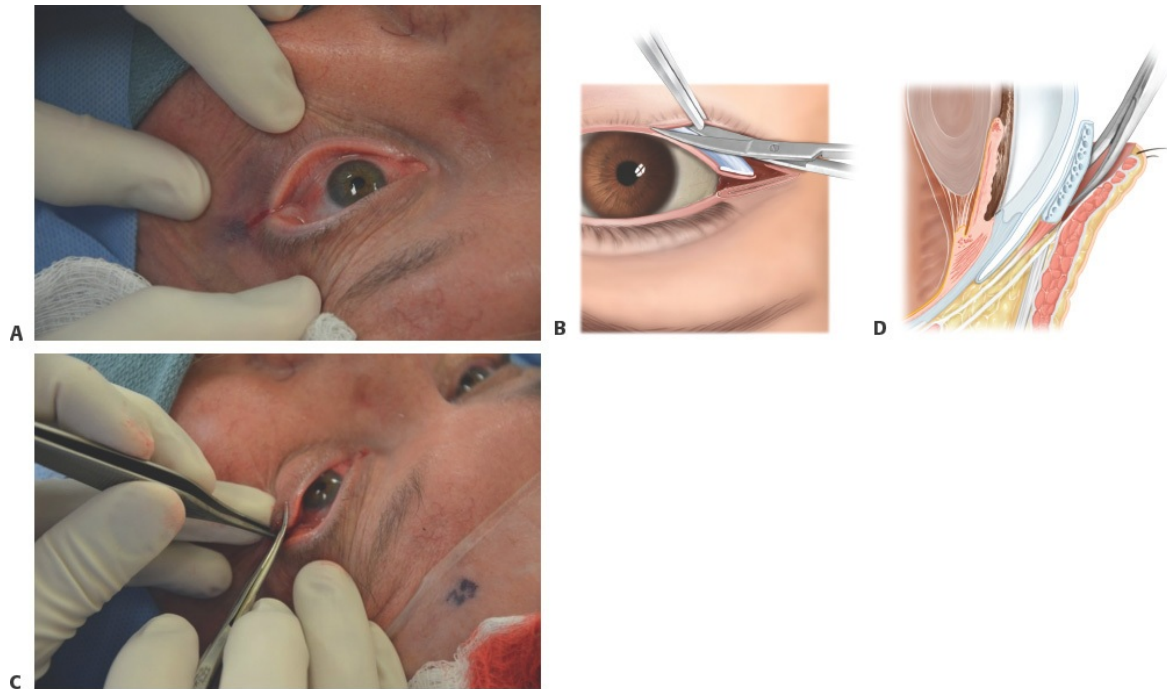
- Close with 2 deep passes to approximate soft tissues including the periosteum and orbicularis using 4-0 Vicryl suture.
- Close the skin with 6-0 fast gut suture.

■ Lateral Canthoplasty (Lateral Tarsal Strip)

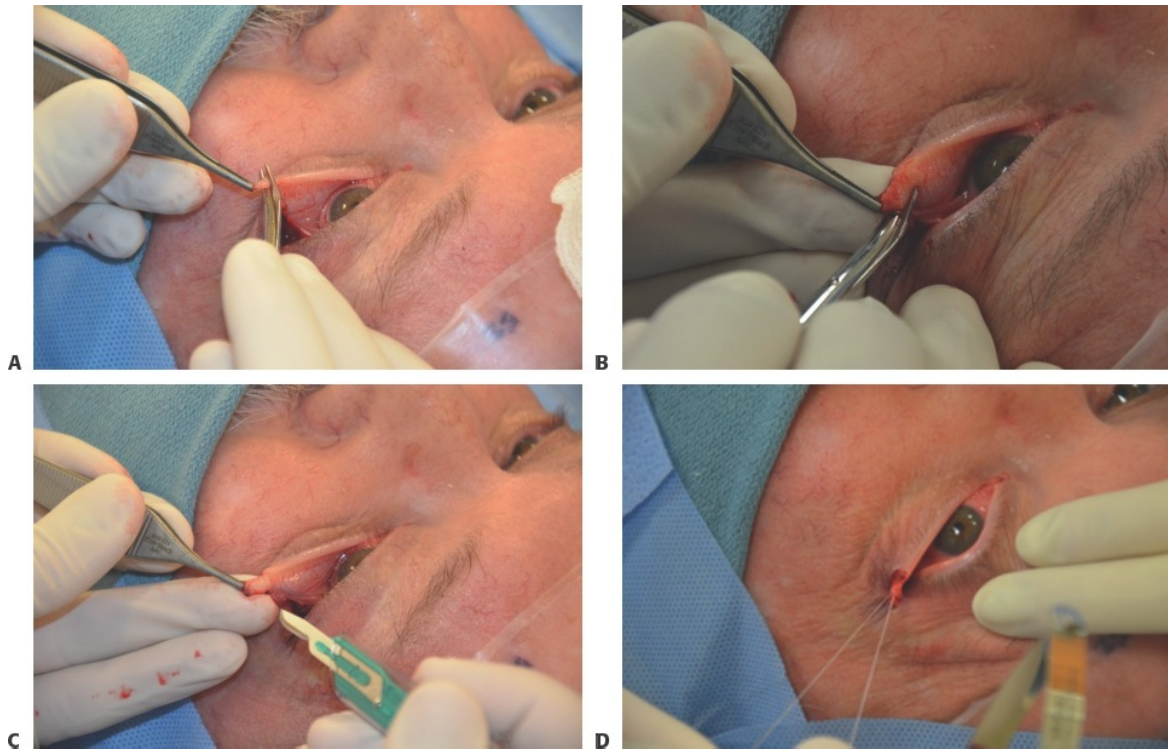
- The terms lateral canthoplasty and lateral tarsal strip are interchangeable. This procedure involves reconstruction of the lateral canthal tendon with lysis and reattachment of the tendon.
- Place 2 drops of topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine subcutaneously above and below the lateral canthus.
- Using a no. 15 blade, make a 2-cm partial-thickness skin incision at the lateral canthus (**TECH FIG 2A**).
- Use Westcott scissors to make a full-thickness cut at the site of the prior incision.
- Disinsert the inferior arm of the lateral canthus from the periosteum at the lateral incision site using Westcott scissors, strumming the canthal attachment points with closed scissors to find remaining canthal tendon arms that need to be released (**TECH FIG 2B**).
- The lower eyelid should be freely mobile to the superior orbital rim once all canthal attachments have been cut.
- Grasping the lateral tarsus at the lateral most point with toothed forceps, use Westcott scissors to separate the anterior and posterior lamellae (**TECH FIG 2C,D**).

Creating the Lateral Tarsal Strip

- Remove the mucocutaneous junction prior along the length of the desired lateral tarsal strip (**TECH FIG 3A**).
- Using Westcott scissors, cut the grasped tissue inferior to the inferior border of the tarsus, 5 mm inferior to the lid margin (**TECH FIG 3B**).
- De-epithelialize the skin and conjunctiva off the strip using a scraping technique with a no. 15 blade (**TECH FIG 3C**).



TECH FIG 2 • Lateral tarsal strip (lateral canthoplasty). **A.** Lateral canthotomy is performed. **B.** Cantholysis is performed using Westcott scissors. There may be multiple arms of the tendon that need to be cut. **C,D.** Westcott scissors are used to separate the anterior and posterior lamellae.



TECH FIG 3 • Lateral tarsal strip (lateral canthoplasty).

A. The mucocutaneous junction is removed from the eyelid margin. **B.** Grasping the lateral canthus, the lateral tarsal strip is fashioned by cutting the inferior border of the tarsus 5 mm inferior to the lid margin. **C.** An ideal strip is created by de-epithelializing the skin and conjunctiva off the strip using a scraping technique with a no. 15 blade. **D.** Both arms of a double-armed suture are passed from posterior to anterior through the lateral end of the tarsal strip.

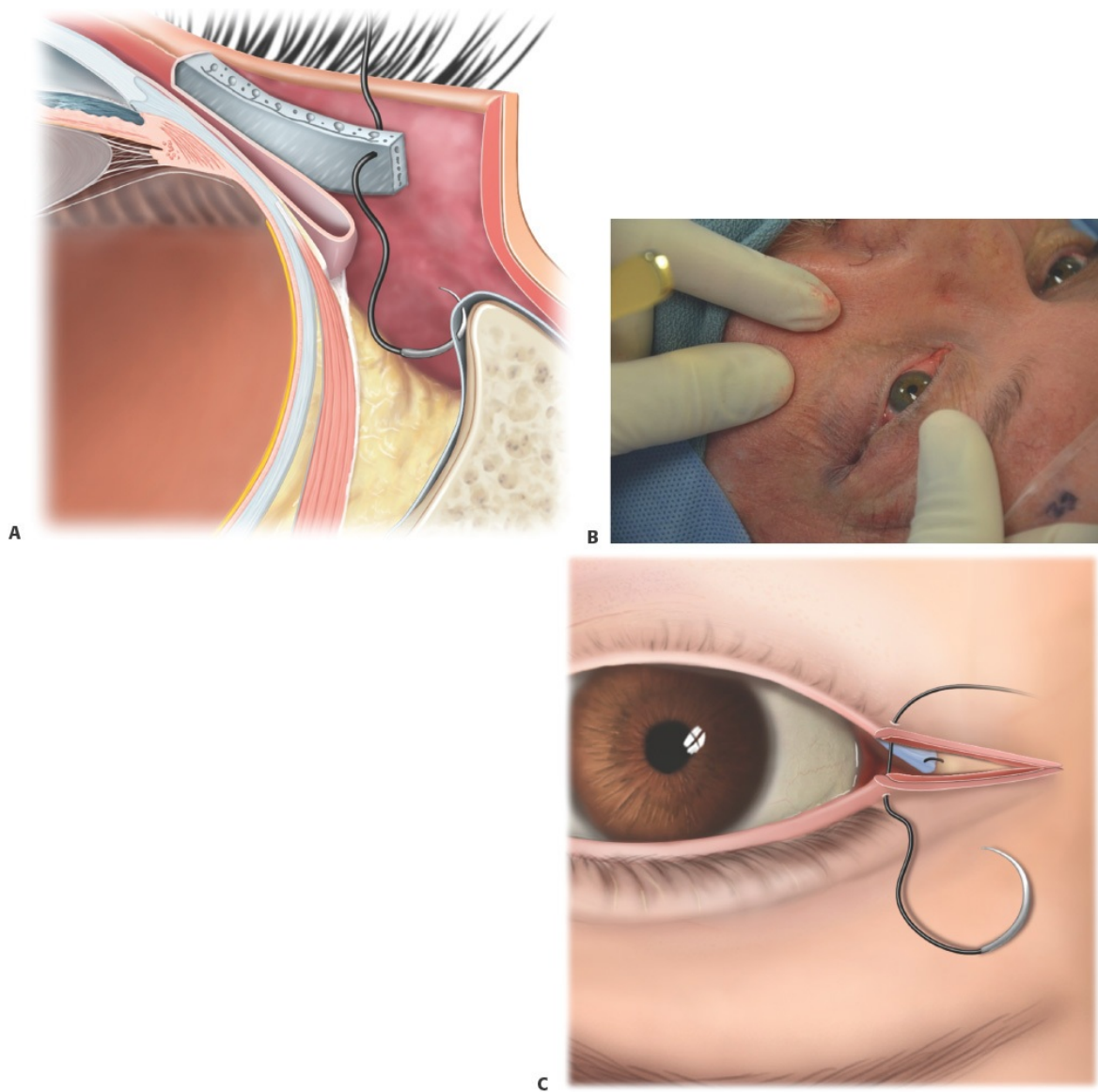
- Pass both arms of a double-armed 4-0 Vicryl suture on a P-2 needle from posterior to anterior through the lateral end of the tarsal strip, with one arm passing superiorly and one arm passing inferiorly (**TECH FIG 3D**).
- Pull the inferior lateral canthus superiorly into the desired position, generally 1 cm superior to the medial canthus.

Suturing

- Secure both arms of the suture by passing the needles deeply into the medial

periosteum of the lateral orbital rim (**TECH FIG 4A**).

- Check the tension of the eyelid to ensure slightly exaggerated tension, anticipating slight laxity after postoperative healing (**TECH FIG 4B**).
- Using 6-0 fast gut suture, reform the lateral canthal angle with a circular stitch entering from the inferolateral wound, out the gray line of the lower lid, through the gray line of the upper lid, and out the superolateral wound (**TECH FIG 4C**).
- Close the skin using 6-0 fast gut suture.

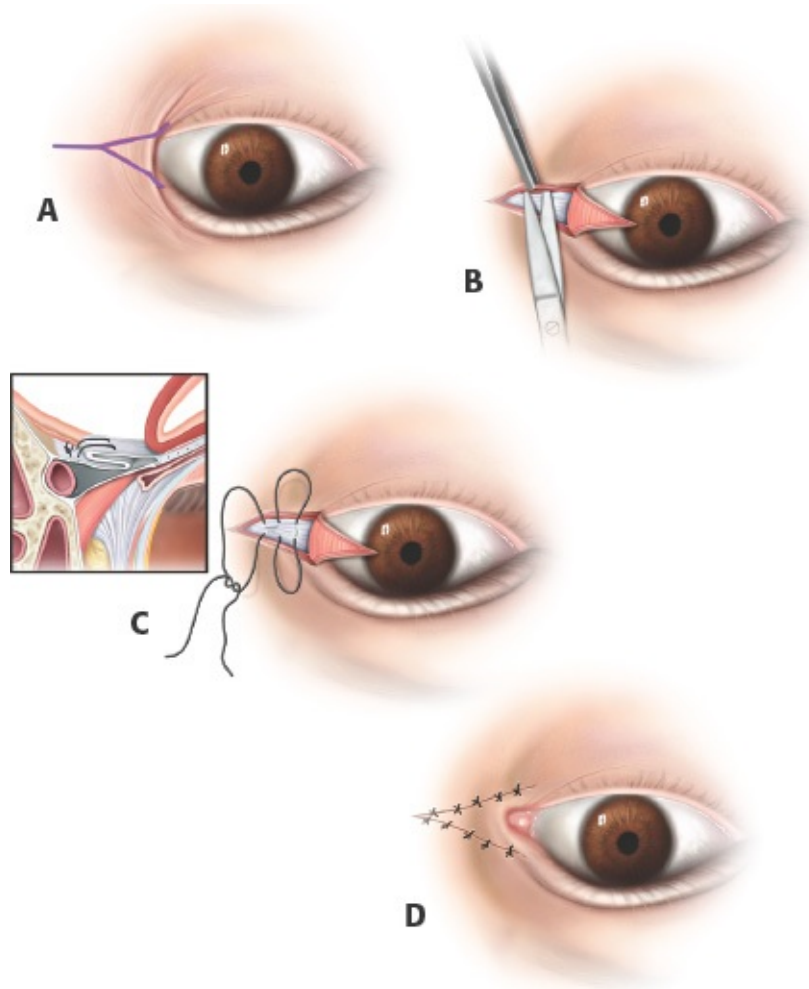


TECH FIG 4 • Lateral tarsal strip (lateral canthoplasty).

A. Both arms of the suture are secured deeply in the medial aspect of the lateral orbital rim periosteum. **B.** Tension of the eyelid is checked. **C.** The lateral canthal angle is reformed with a circular stitch entering from the inferolateral wound, out the *gray line* of the lower lid, through the *gray line* of the upper lid, and out the superolateral wound.

■ Y-V Medial Canthopexy

- Place 2 drops of topical tetracaine on the conjunctival surface.
- Inject 1 to 2 cc 2% lidocaine with 1:100 000 epinephrine subcutaneously above and below the medial canthus.
- With a sterile marking pen, draw a horizontal V terminating 5 mm medial to the medial canthal angle. Extend the marking with a 3-mm line horizontally from the tip of the V (**TECH FIG 5A**).
- Incise the skin and orbicularis using a no. 15 blade over the markings.
- Using Westcott scissors, bluntly dissect through the orbicularis and septum to the depth of the medial canthus ensuring to stay anterior to the nasolacrimal system (**TECH FIG 5B**).
- Pass both arms of a 4-0 double-armed silk suture underneath the lateral aspect of the medial canthus exiting anteriorly through the medial canthus. With each suture arm, make an additional pass through the medial canthus extending medially. Pull the suture arms to plicate the medial canthus (**TECH FIG 5C**).
- Tie the two suture arms with a surgeon's knot.
- Close the soft tissues using 6-0 Vicryl sutures in interrupted fashion and close the skin with 6-0 fast gut suture (**TECH FIG 5D**).



TECH FIG 5 • Y-V medial canthopexy. **A.** Markings of the V-Y with the point of the V terminating 5 mm medial to the medial canthal angle with a 3-mm horizontal extending line that is parallel to the palpebral fissure. **B.** Blunt dissection to the level of the medial canthus. **C.** Plication of the medial canthus with two throws of a double-armed suture extending medially. **D.** Soft tissue and overlying skin closed separately in interrupted fashion.

Technique	■ In children expected to have multiple facial surgeries, avoid a large amount of canthal tendon resection as this may render further procedures on these structures more difficult.
Inadequate postoperative suspension	■ Overcorrect the anatomic lateral canthopexy position slightly aiming for 1 cm superior to the medial canthus to allow for postsurgical laxity. ■ In procedures requiring a pass through periosteum, ensure the periosteum has indeed been grasped by applying a moderate amount of anterior tension on the suture after the pass. The tension felt on the suture should be firm. ■ When making a pass through the periosteum, aim to create a posterior vector to ensure the eyelid is approximated to the globes laterally.
Scar	■ Avoid tension on the skin. ■ Push on the inferior eyelashes to exaggerate the subciliary fold for accuracy of marking.

POSTOPERATIVE CARE

- If used, nonabsorbable sutures should be removed at 5 to 7 days postoperatively.
- Apply antibiotic eye ointment to the operative site until the suture absorbs.
- Sunscreen and lotion should be liberally applied over the operative region.

OUTCOMES

- Lateral canthoplasty is associated with an 83% reduction in discomfort by subjective grading scales and near universal improvement in objective eyelid position.⁵

COMPLICATIONS

- Improper positioning of fixation arm
- Loosening of the canthus
- Persistent pain lasting up to 3 months
- Eyelid contour abnormalities including rounding of the canthus
- Chemosis
- Eyelid imbrication can be seen if the inferior crus of the lateral canthal tendon is preferentially tightened or positioned too far cephalad.
- Epithelial inclusion cysts may occur in the lateral tarsal strip procedure if the tarsus is not denuded of epithelium prior to insertion.

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Nasolacrimal Duct Obstruction

CHAPTER

Emily M. Zepeda, Sarah M. Jacobs, and Christopher B. Chambers

DEFINITION

- Nasolacrimal duct obstruction (NLDO) is an obstruction that occurs within the duct of the nasolacrimal system, such that tears and mucus that have passed through the lacrimal sac are unable to appropriately drain into the nose.
- NLDO results in varying degrees of epiphora (tearing) and is often associated with mucopurulent discharge, swelling, and pain.

ANATOMY (LACRIMAL SYSTEM)

- The nasolacrimal duct is a part of the lacrimal drainage system that conveys tears from the ocular surface to drain into the nose (**FIG 1**).
- It is about 15 mm long, starting at the terminus of the nasolacrimal sac.
- The nasolacrimal duct passes inferiorly, posteriorly, and laterally within the canal formed by the maxillary and lacrimal bones. It travels into the inferior meatus and opens under the inferior turbinate. Its outflow is partially covered by the valve of Hasner.

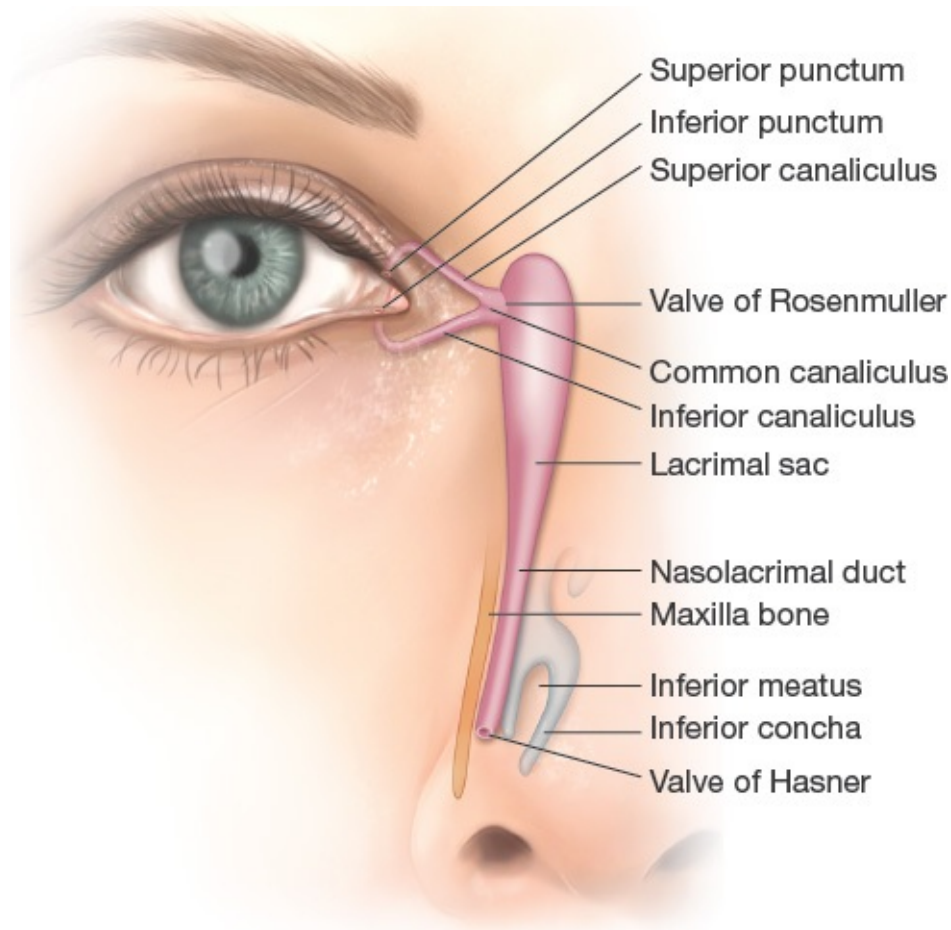


FIG 1 • Anatomy of the nasolacrimal system, which allows tears from the eye to pass through the puncta, canaliculi, and lacrimal sac, through the nasolacrimal duct to drain into the nasal cavity.

PATHOGENESIS

- NLDO can occur secondary to congenital or acquired disease.
- Congenital NLDO is usually secondary to a membrane blocking the valve of Hasner at the nasal end of the NLD.
- Obstructions become clinically evident in only 2% to 6% of full-term infants at 3 to 4 weeks of age.
- Conservative management options of congenital NLDO consist of observation, lacrimal sac massage, and topical/oral antibiotics. It is estimated that 90% of symptomatic congenital NLDO resolves in the first year of life with conservative management.

- For the remaining 10% of these cases, probing of the NLD can be curative by creating an opening through the imperforate valve of Hasner.¹
- Infants with craniofacial deformity or Down syndrome are also at higher risk of congenital NLDO. Dacryocystoceles can also create an obstructive process, leading to enlargement and potentially abscess of the lacrimal sac.
- Acquired NLDO may arise from numerous causes such as facial trauma, sinus disease, chronic allergy and inflammation, radiation treatment to the midface, toxicity from chemotherapeutic agents or radioactive iodine, or following sinonasal surgery. Involutional stenosis is the most common cause of NLDO in adults.
- Regardless of whether NLDO is congenital or acquired, any obstruction of the nasolacrimal outflow is capable of causing stagnation of bacteria leading to infection of the lacrimal sac known as dacryocystitis.

PATIENT HISTORY AND PHYSICAL FINDINGS

- In both congenital and acquired NLDO, the primary symptom is epiphora as a result of backflow of tears due to blockage of the duct.
 - At times, enough tear and mucous volume is accumulated within the lacrimal sac that there is a palpable or visible enlargement of the sac. Light pressure over the area of the lacrimal sac can often cause mucopurulent discharge to reflux through the lacrimal drainage system and out the puncta.
- Evaluation of a patient who presents with epiphora should focus on determining the underlying etiology of tearing, assessing for nonobstructive causes (eg, ectropion, reflex tearing, conjunctival infection or inflammation) and nonbenign entities (eg, nasolacrimal malignancy, granulomatosis with polyangiitis). Elements of the history and exam with this focus in mind include the following:
 - A history including duration since tearing onset, percentage of the day it occurs, how it interferes with activities of daily living, and whether any particular activities provoke it (eg, cold, heat, wind, visual tasks such as computers or reading). Any history of facial trauma, prior episodes of dacryocystitis, radiation, or chemotherapy should be elicited. The patient should also be asked about bloody tears, which would be a concerning sign for underlying malignancy.
 - Prior to instilling any eye drops, the tear meniscus height should be noted, and the tear breakup time should be measured, as a cue to whether dry eye–related reflex tearing is contributing to the patient’s epiphora.

- Eyelid structures and position in relation to the globe should be assessed for concurrent disease states such as ectropion, entropion, and trichiasis. The upper and lower puncta should be examined for patency and position relative to the globe. Lower lid tone should be evaluated for degree of laxity.
- A dye disappearance test can be performed on patients of any age. A fluorescein eye drop is instilled in each eye. Normal nasolacrimal drainage will allow the dye to flow through the punctum, such that the yellow dye disappears from the ocular surface in a matter of minutes. Patients with nasolacrimal outflow obstruction show delayed clearance of fluorescein.
- In adults, the lacrimal system should be probed and irrigated. Passage of saline into the nose and throat with ease and no reflux signifies a patent system. Reflux of irrigant signifies obstruction, and the pattern of reflux can reveal where the obstruction is located within the system. Reflux from the same punctum that is being irrigated indicates obstruction within the canaliculus. Reflux from the opposite punctum without mucus indicates obstruction at the common canaliculus. Reflux from the opposite punctum with mucus indicates obstruction in the nasolacrimal sac or duct.
- Periocular skin may show erythema, edema, and breakdown of superficial tissues when the discharge or tearing is profuse and constant.
- Finally, nasal evaluation should be performed. This may reveal deviated septum, polyposis, or tumors as a cause of obstruction. Nasal mucosa may also show erythema and edema indicating chronic sinus inflammation.

DIFFERENTIAL DIAGNOSIS

- Congenital glaucoma: When the only symptom is epiphora in a child, one must always rule out congenital glaucoma. The classic triad for congenital glaucoma is blepharospasm (involuntary squeezing of the eyelids closed), photophobia (uncomfortable sensitivity to light), and epiphora. Other findings suggestive of glaucoma include buphthalmos (enlarged globe and corneal diameter) and Haab striae (breaks in the innermost layer of the cornea, leading to corneal haze). If concern for congenital glaucoma exists, the child should be referred to pediatric ophthalmology.
- Dry eye: Epiphora due to dry eye will typically occur when the patient is engaged in a visual task such as reading or computer usage, which decreases their blink rate and exacerbates the dryness of the ocular surface. The patient experiences blurring, burning or foreign body sensation, and then tear flow. Symptoms are worse in hot, dry, or windy conditions.

- Trichiasis: Growth of eyelashes from malrotated lash follicles or metaplastic Meibomian oil gland orifices results in lashes rubbing and irritating the ocular surface, which provokes tearing. Penlight exam can locate these lashes, which can be treated with epilation or more permanent methods such as cryotherapy or radiofrequency ablation.
- Conjunctivitis: Infection or inflammation of the conjunctiva can cause epiphora and ocular discharge. On examination, patients with conjunctivitis will show injection and papillae or follicles, which appear as fine bumps on the normally smooth conjunctival surface.
- Eyelid ectropion or entropion: Poor eyelid position or lax lower eyelid tone can lead to epiphora. An eyelid with normal tone smoothly sweeps the tears across the ocular surface with each blink, pumping them down the punctal drains into the lacrimal sac. Lax eyelids that are rotated outward (ectropion) or inward (entropion) cannot serve this function effectively, so the unpumped tears spill over the lid margin onto the cheeks.

IMAGING

- The diagnosis of NLDO is based on patient history, elevated tear meniscus, and obstruction observed when the system is probed and irrigated. Imaging is not often needed for diagnosis.
- In select cases, maxillofacial computed tomography (CT) and magnetic resonance (MRI) scans are helpful to evaluate the anatomy after craniofacial injury, in patients with significant sinus or nasal disease, or to evaluate for neoplasia.
- Less commonly, two methods for specific mapping of the lacrimal drainage system itself can be employed:
- In contrast, dacryocystography, in which dye is injected into the punctum and CT or MRI imaging, is used to define the anatomic details of the lacrimal drainage system outlined by the contrast agent, allowing precise location of the obstructed site(s).
- Dacryoscintigraphy uses radionuclide eye drops to follow tear flow as a gamma camera takes multiple pictures of the outflow system.

SURGICAL MANAGEMENT

- As mentioned, most congenital NLDO resolves with nonsurgical management.
 - Approximately 10% of children with congenital NLDO require probing of the duct. A small subset of those may require repeat probing with balloon

dilation of the duct, infraction of the inferior turbinate, and/or placement of silicone stents within the nasolacrimal system to relieve their obstruction.

- Because of the high success rate with these methods, dacryocystorhinostomy (DCR) is rarely needed in the pediatric population. It is reserved for children who have persistent tearing following intubation, recurrent dacryocystitis, or craniofacial abnormalities with bony obstruction of the duct.
- In adults, however, DCR is the preferred primary surgery for NLDO after the other causes of tearing have been eliminated or addressed.

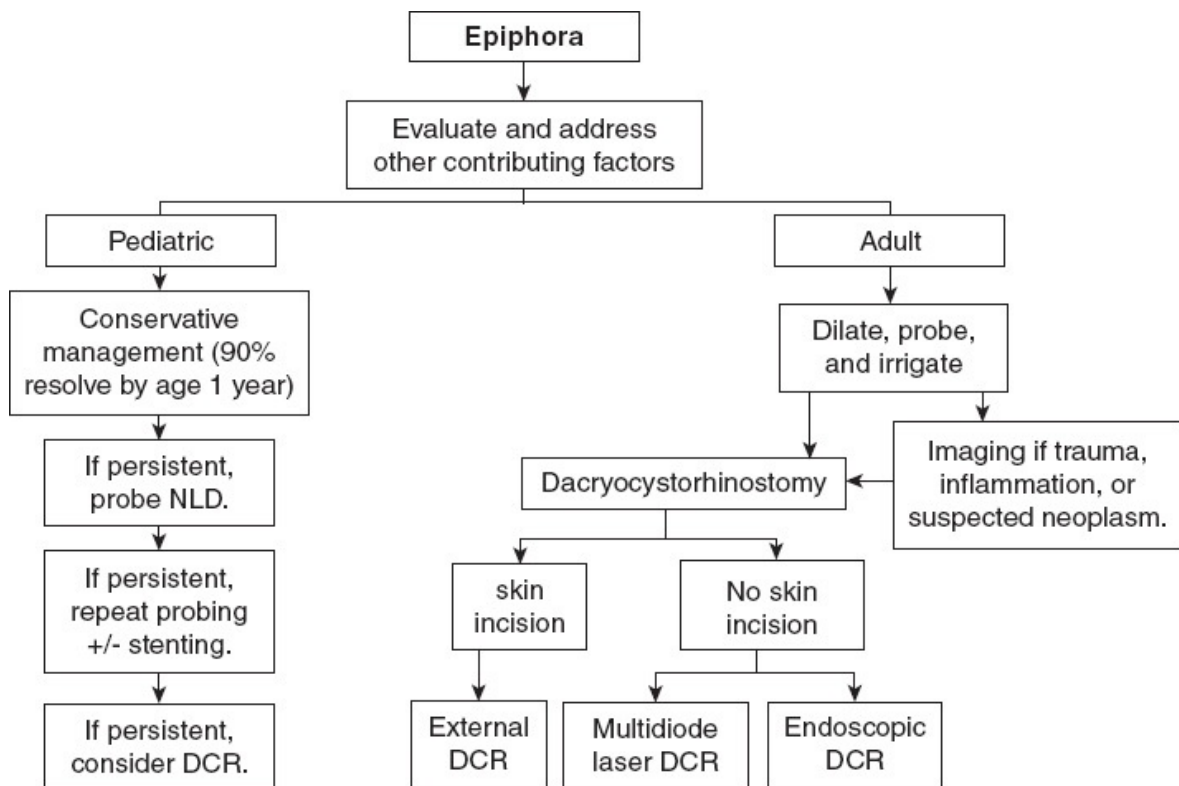


FIG 2 • Algorithm for management of epiphora due to nasolacrimal duct obstruction.

- The DCR operation can be performed in three ways (**FIG 2**):²⁻⁴
- External DCR: An incision is made through the skin overlying the lacrimal sac, allowing external access to the lacrimal sac fossa for bone removal, sac opening, and stent placement under direct visualization without the need for endoscopic camera equipment.
- Literature reports a slightly higher success rate with the external approach in certain studies. When appropriately placed, the incision heals with a very

subtle and cosmetically acceptable scar.

- Internal DCR (also known as endonasal or endoscopic DCR): Attention is brought to the middle meatus, which allows the most direct access to the lacrimal sac fossa so that the nasolacrimal duct can be bypassed. The middle meatus is visualized from within the nasal cavity, allowing removal of the nasal mucosa and the bone encasing the lacrimal sac from the inside, following by opening of the sac and retrieval of the stents.
- The reported advantages of the internal approach include the lack of a visible incision, less discomfort, faster recovery, and lower risk of compromising the lacrimal pump mechanism.
- Transcanalicular diode laser: A diode laser probe is passed through the canaliculus with its tip resting within the lacrimal sac. The laser is used to ablate the tissue of the lacrimal sac, bone of the lacrimal fossa, and a localized zone of the underlying nasal mucosa. Silicone stents are then passed through these laser-cut openings and retrieved within the nose.
- This method has no skin incision, and it enables a significantly faster operating time but reports a lower overall success rate.

Preoperative Planning

- For patients with dacryocystitis, active infection should be treated before DCR.⁵ If concern is high for significant nasal septal deviation or other nasal abnormalities, which may need to be addressed intraoperatively, ENT evaluation should be considered prior to surgery. The risk of bleeding can be proactively addressed by ensuring perioperative blood pressure control and withholding anticoagulants if allowed by the patient's primary care physician or prescribing cardiologist.
- In the preoperative area, the patient is given oxymetazoline nasal spray to help vasoconstrict and decongest the nasal mucosa. For example, the spray is administered starting about 30 minutes prior to the procedure, with one dose every 5 minutes for a total of three doses.
- In the operating room after anesthesia induction, the middle meatus is injected with lidocaine with epinephrine, then packed with pledgets soaked in oxymetazoline to provide additional anesthesia and local vasoconstriction at the site.
- Moderate sedation or general anesthesia may be used for the procedure. The decision is based on surgeon and patient preference. General anesthesia is

recommended for all pediatric cases and most adult cases.

Positioning

- The patient is positioned supine on a surgical table with an adjustable headrest. The headrest is lowered to extend the neck slightly which gives the surgeon the best access. The patient should be prepped and draped leaving adequate exposure of the eyelids and nose.

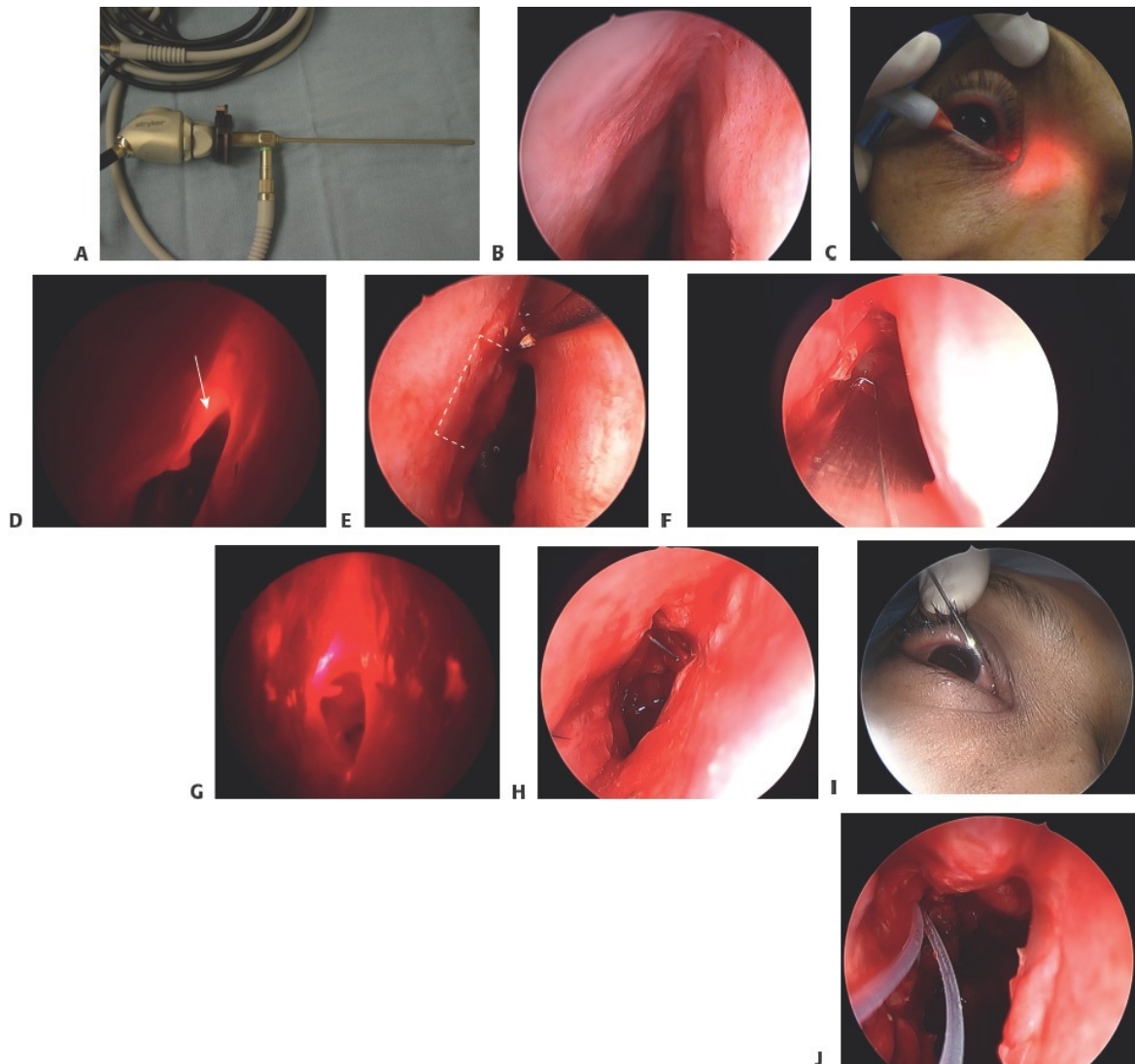
TECHNIQUES

■ Internal/Endoscopic DCR

- The surgical site is accessed through the nose, using an endoscope for visualization of the middle meatus along the lateral sidewall of the nasal passage beneath the middle turbinate (**TECH FIG 1A,B**).
- If desired, a 23-gauge light pipe can be passed through the canaliculus, bringing the lit tip to rest in the lacrimal sac. This light pipe provides a point of illumination through the tissue to help localize the lacrimal fossa (**TECH FIG 1C,D**).
- A crescent blade is used to create a three-sided flap incision through the nasal mucosa down to the bone, starting just anterior to the uncinate process and extending inferiorly the height of the turbinate (**TECH FIG 1E**). A periosteal elevator is then used to push the mucosa and periosteum away, exposing bare bone.
- Rongeurs (typically 2- and 3-mm up-biting Kerrison punches) are used to remove the bone of the lacrimal fossa and the anterior process of the maxilla (**TECH FIG 1F**) to expose the entire lacrimal sac. If necessary, a DCR drill can be employed to bur away any bone that cannot be removed with the rongeurs.
- When bone removal is complete, the light pipe and/or a Bowman probe can be passed through the canalicular system to visibly put the lacrimal sac on stretch. A sickle blade is then used to open the lacrimal sac vertically from its superior to inferior pole, allowing the probe to pass freely into the nasal cavity (**TECH FIG 1G,H**). A ball-tipped seeker probe can be used to break any adhesions within the sac, which are commonly present in patients with a

history of dacryocystitis. An antimetabolite such as mitomycin C can be applied to the sac to decrease the potential formation of scar adhesions.⁶

- Nasolacrimal stents, such as the silicone Crawford bicanalicular stent, are then passed through the upper and lower puncta and retrieved in the nose (**TECH FIG 1,I,J**). The stents remain in place for several weeks postoperatively to maintain patency of the openings during the healing process.



TECH FIG 1 • A,B. An endoscopic camera is introduced into the nasal cavity, allowing visualization of the middle meatus. **C,D.** A light pipe introduced through the punctum into the lacrimal sac can be used

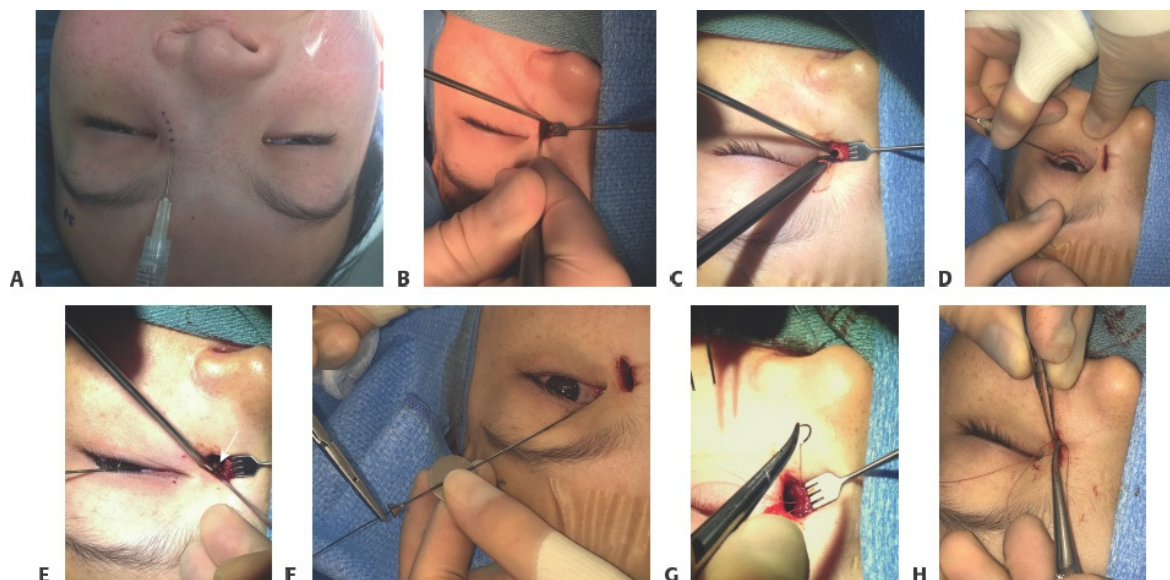
to help with internal visualization of the site where osteotomy should be placed. **E.** Incision is made through the mucosa down to bone along the *white dotted line*. **F.** Kerrison rongeurs are used to remove bone from the site to create the osteotomy. **G,H.** The site is confirmed with a light pipe, then the sac is incised open, and a Bowman probe is passed. **I,J.** Silicone stent tubes are passed through the upper and lower puncta and then visualized and within the nose.

■ External DCR

- A local anesthetic is injected, then the skin incision is made 3 to 4 mm from the medial canthus, starting 2 to 3 mm above the medial canthal tendon and extending over the lacrimal sac, following the direction of the nasojugal fold (**TECH FIG 2A**).
- A hemostat is used to bluntly spread the subcutaneous tissue apart, taking care to visualize the angular artery and cauterize it if necessary. Blunt dissection is carried down to the periosteum, which is scored with a blade or Bovie cautery needle. A periosteal elevator is then used to reflect the periosteum away from the bare bone, working in a posterolateral direction to access the bone of the lacrimal sac fossa (**TECH FIG 2B**).
- The periosteal elevator or hemostats are used to break through the lacrimal bone into the nose, and then the osteotomy is enlarged with rongeurs (typically 2 mm and 3 mm up-biting Kerrison punches) (**TECH FIG 2C**). Care is taken to punch through the bone cleanly, rather than rocking the pieces to break them away. This helps avoid propagating cracks along the skull base, which can result in cerebrospinal fluid (CSF) leak. An opening of 1 to 1.5 cm should be created through the bone, spanning the entire vertical height of the lacrimal sac.
- A Bowman probe is passed through the canaliculus, and its tip is used to tent the lacrimal sac (**TECH FIG 2D,E**). While holding the sac on stretch with the probe, a sickle blade is used to open the lacrimal sac vertically from its superior to inferior pole and then to make a horizontal cutback at the superior and inferior ends of the sac incision to create an anteriorly based lacrimal sac

flap. A corresponding anteriorly based flap is then opened through the nasal mucosa using Bovie or a blade. A ball-tipped seeker probe can be used to break any adhesions within the sac, which are commonly present in patients with a history of dacryocystitis. An antimetabolite such as mitomycin C can be applied to the sac and the nasal mucosa to decrease the potential formation of scar adhesions.⁶

- Nasolacrimal stents, such as the silicone Ritleng monocanalicular stent, are then passed through the upper and lower puncta, through the opened sac, and across through the opening in the nasal mucosa and retrieved in the nose (**TECH FIG 2F**). The stents remain in place for several weeks postoperatively to maintain patency of the openings during the healing process.
- The anterior flap of the lacrimal sac is sutured to the nasal mucosal flap with interrupted absorbable sutures (eg, 5-0 polyglactin), to hold both tissues tented above the stents (**TECH FIG 2G**). The skin incision is closed with buried absorbable sutures within the orbicularis muscle (**TECH FIG 2H**) and skin sutures of choice (eg, 6-0 fast gut, skin adhesive, or 6-0 nylon to be removed at 1 week).



TECH FIG 2 • A. External DCR incision marking and injection of local anesthetic. **B.** Incision is retracted open, allowing use of a periosteal elevator to lift the lacrimal sac from its fossa. **C.** An osteotomy is created

with Kerrison rongeurs. **D,E.** A Bowman probe is advanced through the canaliculus into the sac, resulting in tenting of the lacrimal sac (*white arrow*). **F.** A monocanalicular stent is placed. **G,H.** The lacrimal sac flap is sutured to nasal mucosa with absorbable sutures, and then the skin incision is closed.

PEARLS AND PITFALLS

Internal vs external approach

- Most patients have good outcomes with either approach, determined by patient and surgeon preference.
- External approach is recommended for reoperations, patients with inflammatory disease, tight internal anatomy (eg, deviated septum toward the operative side), and patients with bleeding disorders or blood thinners that cannot be stopped.

Intraoperative bleeding

- External DCR: visualize and cauterize the angular artery if it crossed the incision site, prior to opening the osteotomy.
- Internal DCR: epinephrine-soaked pledget packing helps slow intraoperative bleeding. Suction Bovie cautery is also of use, but take care to avoid too much heat exposure to the internal site, as overlying skin burns can result.

Stent duration

- Classically, stents are kept in place for 12 wk after surgery. If two monocanalicular stents are used, one can be removed at 6 wk and the other retained until 12 wk. This gives the patient earlier relief from epiphora during the recovery phase.

POSTOPERATIVE CARE

DCR is an outpatient surgery. Once the patient is deemed stable postoperatively, he/she may be discharged home with a responsible adult. Postoperative instructions should include the following:

- Avoid straining, bending, heavy lifting, or strenuous activity for at least 1 week.
- Ice pack or cold compresses can be used for the first 1 to 2 days to limit swelling and bruising.

- Nose blowing should be avoided for the first week to decrease the risk of bleeding. To reduce the risk of nose bleed from nasal vasodilation, hot drinks and food should be avoided for the first 1 to 2 days.
- At the 1 week postoperative visit, the surgical site is evaluated for any signs of impaired healing or infection, and any nonabsorbable sutures may be removed. At 6 to 12 weeks after surgery, the silicone stent is removed in the clinic, and the lacrimal drainage system is irrigated to confirm patency.

OUTCOMES

The DCR surgery is considered successful when the patient experiences total or near-total relief from epiphora. Patients often still experience tearing under circumstances in which reflex tears are normally expected (ie, emotion, ocular surface irritation, etc.), as would any eye, which is not considered a surgical failure. Surgeries fail for a variety of reasons, most relating to formation of adhesions that block the drainage tract and prevent tears from flowing freely into the nose.⁷

- The reported success rates for external DCR range from 90% to 95%. The success rate is improved by ensuring a large enough osteotomy, suturing the lacrimal and nasal mucosal flaps to keep them from obstructing the healing tract, and keeping the stents in place for several weeks postoperatively.
- There is a wider range of reported success rates for endonasal (internal) DCR. In the hands of an experienced surgeon, the success rate has been shown to be statistically equivalent to the external approach. The success rate is improved by ensuring a large enough osteotomy, avoiding excessive soft tissue maceration of the nasal mucosa and lacrimal sac, limiting thermal injury with cautery, and keeping the stents in place for several weeks postoperatively.

Intraoperative usage of the antimetabolite mitomycin-C has been shown to decrease scar formation and thereby increase success rate of the surgery, regardless of whether an external or endoscopic approach is used.^{6,8} Postoperative mitomycin C eye drops have also been tried but with less compelling effects.⁹

COMPLICATIONS

Intraoperative

- Hemorrhage. To decrease this risk, hold blood thinners preoperatively, utilize a block that contains epinephrine, and carefully visualize the anatomy to protect major vascular structures.
- Canalicular injury. Improper probing of the canaliculi can create a false passage and damage the common canaliculus when opening the sac. This risk can be decreased by using blunt probes and only advancing them along the existing canalicular lumen where there is minimal resistance.
- Orbital tissue injury. The use of drills and rongeurs can damage the structures of the orbit. Care must be taken to establish the anatomic location of the instrument with certainty prior to engaging it for bone removal. If fat is encountered in the surgical field, that is an indication that the orbit has been entered inadvertently.
- Skull base fracture and CSF leak. This risk can be decreased by carefully studying the preoperative imaging and taking note of the skull base contours across the ethmoid sinuses. Endoscopic DCR surgeons must avoid bone removal too far superiorly, to avoid breaching the fovea ethmoidalis or breaking the cribriform plate. External DCR surgeons must avoid rocking or twisting the rongeurs during bone removal, so that the skull base does not crack. The operative site should be inspected for leakage of CSF, which will be a clear fluid slightly more viscous than saline, which tests positive for beta-2-transferrin. Appropriate postoperative neuroimaging and consultation with neurology should be pursued if there is concern that a CSF leak has occurred.

Postoperative

- Bleeding can occur postoperatively, typically from the nasal mucosal vessels. Following the postoperative care instructions outlined earlier in the chapter decreases this risk. Most postoperative bleeding is self-limited and can be stopped by holding pressure against the nose for 5 to 10 minutes. For severe or persistent bleeding, patients should be seen emergently.
- Infection. It is rare to have postoperative infection after DCR, occurring only about 1% of the time even without the use of systemic antibiotics.¹⁰ If an infection does occur, the patient should be given a course of oral antibiotics with broad coverage of typical skin and mucosal flora.
- Extrusion/loss of the silicone stent tubing. The patient should be instructed not to pick or pull at the tubing within the nose or at the eyelid puncta. If it partially extrudes, it can sometimes be carefully advanced back into place. If it fully extrudes, most surgeons advise allowing the patient to heal without the

tubing rather than returning to the operating room to place a new stent.

- Lacrimal sump syndrome. Despite a patent osteotomy and normal results on probing and irrigation, patients with sump syndrome continue to experience tearing and mucous discharge due to an intact inferior pole of the lacrimal sac, which collects a pool of drainage. The chance of this complication can be decreased by creating a large osteotomy (at least 1 cm in diameter), ensuring the bone is opened all the way down to the level of the nasolacrimal duct entrance, and fully opening the lacrimal sac down to its inferior pole so that no pocket remains to collect fluid.
- Scarring of the ostium. After DCR, the bone or soft tissue can grow closed over the osteotomy site. When this occurs, the patient's epiphora returns and surgical revision is necessary to reopen the drainage tract. The risk of this complication can be decreased by creating a large enough osteotomy, clearing away soft tissue around the lumen, and applying mitomycin C to the tissue intraoperatively.

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43 Management of the Microphthalmic or Anophthalmic Orbit

CHAPTER

Sarah M. Jacobs and Christopher B. Chambers

DEFINITION

A spectrum exists ranging from small eyes to complete absence of any ocular tissue:

- Nanophthalmos is defined as a small eye with otherwise normal internal structures. The axial length of the eye is ≥ 2 standard deviations shorter than average.
- Microphthalmos is an eye with axial length less than 20 mm and additional structural abnormalities.¹
- Clinical anophthalmos describes some cases of microphthalmia in which the eye is so small that the patient appears anophthalmic. However, histopathologic examination of the tissue does identify products of optic vesicle formation.
- True anophthalmos involves the complete failure of primary optic vesicle outgrowth resulting in the absence of any detectable eye tissue.^{1,2}

ANATOMY

- Nanophthalmos: In addition to short axial length, the sclera is thickened relative to the eye, the anterior chamber angles are narrow, and the refractive error is highly hyperopic. The small eye may or may not result in a hypoplastic orbit.^{3,4}
- Microphthalmos: In addition to short axial length, the internal structures of the eye are abnormal. Microphthalmic eyes can be associated with coloboma of the uvea and/or lens, persistent fetal vasculature, Peters anomaly, glaucoma, and anterior polar cataracts. An uncommon variant, microphthalmia with cyst results from failure of the ocular embryonic fissure to close, leading to a small

rudimentary eye joined to a larger cystic cavity along the colobomatous inferonasal sclera.⁵ The orbit on the affected side is hypoplastic.

- Anophthalmos: There is complete absence of any ocular tissue. The eyelids have a small palpebral fissure, and beneath the lids a rudimentary conjunctival membrane is present covering the hypoplastic orbit.

PATHOGENESIS

- Embryologic failure of the optic vesicle to develop normally from the cerebral vesicle during the 4th to 8th week of gestation can lead to congenital absence or malformation of one or both eyes.
- Because the globe influences orbital growth, these ocular anomalies can result in orbital and facial maldevelopment as well.
- Nanophthalmos is typically sporadic, but autosomal recessive or autosomal dominant forms have been described (NNO1 on chromosome 11p and NNO3 on chromosome 2q). It can occur as an isolated disorder, or as part of a syndrome such as oculo-digital-dental syndrome (ODD), or autosomal dominant vitreoretinopathopathy with nanophthalmos (ADVIRC).⁶
- Microphthalmos occurs in approximately 10 per 100 000 live births. It can occur sporadically, with some suspected association to fetal alcohol syndrome or maternal infections during gestation, especially rubella, cytomegalovirus, and herpes simplex virus. It is estimated that over half of cases occur in conjunction with systemic abnormalities, including those occurring in the setting of chromosomal anomalies, including Trisomy 13 (Patau syndrome), Trisomy 18 (Edwards syndrome), or Wolf-Hirschhorn syndrome.⁷ In inherited cases, mutations of the SOX2 gene on chromosome 3q are frequently encountered.⁷ This condition can be associated with CHARGE syndrome (Coloboma, Heart defect, Atresia choanae, Retarded growth, Genital abnormality, and Ear abnormality), and PHACE syndrome (Posterior fossa anomalies, Hemangioma, Arterial lesions, Cardiac abnormalities, and Eye anomalies).
- Anophthalmos occurs approximately 2 per 100 000 live births. It is most often sporadic but can be associated with autosomal dominant defects of the SOX2 or RBP4 genes. Maternal deficiency of vitamin A during pregnancy can also pose a risk of anophthalmia.

NATURAL HISTORY

- Ocular volume drives the growth of the eyelids, fornices, and bony orbit. In

turn, hemifacial development parallels orbital development. Thus, a small or absent eye leads to a hypoplastic orbit that can result in deformity of the hemifacial skeleton (**FIG 1**).

- At birth, the normal newborn eye is approximately 70% of its adult size. In contrast, the newborn face is only 40% of its adult size. Rapid growth of the facial skeleton and soft tissues occurs during early childhood, with the face reaching 70% adult size by 2 years and 90% adult size by 5.5 years.⁸ The degree of orbital and facial maldevelopment is different for each microphthalmic child, depending on the amount of ocular tissue present and the trophic influence that tissue exerts.

PATIENT HISTORY AND PHYSICAL EXAMINATION

As part of the initial assessment, the following questions should be considered as they will guide further management throughout childhood:

- Is the eye present or absent?
- Is this a seeing eye?

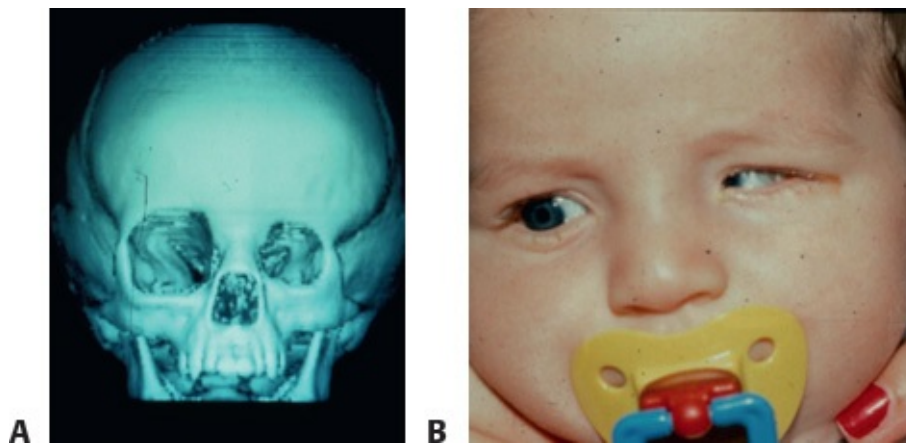


FIG 1 • A,B. Hypoplastic orbit and hemiface secondary to left microphthalmia.

- Is the other eye present? If so, is it normal?
- Are the orbits symmetric and appropriate in size?
- Are the periocular and facial soft tissues symmetric and appropriate in size?

A coordinated multidisciplinary approach is needed for evaluation of the microphthalmic or anophthalmic child, as approximately 50%

have associated systemic abnormalities and 25% have defined systemic syndromes. This approach should include:

- Comprehensive assessment by a pediatrician is needed, with particular attention to the face, ears, and palate; feeding difficulties, which can indicate neurologic or esophageal abnormalities; the cardiac system and genital anatomy (due to association with CHARGE); and metabolic disturbances, which may indicate pituitary dysfunction due to midline brain abnormalities.
- Referral to subspecialists such as neurologist, cardiologist, endocrinologist, nephrologist, and audiologist should be arranged if indicated.
- In cases with systemic findings or a syndromic diagnosis, evaluation and counseling by a pediatric geneticist is also recommended.

Ophthalmologic exam is recommended as soon as possible within the first 2 to 3 weeks of life. This should involve:

- Complete anterior and posterior assessment of both eyes to assess orbital and ocular anatomy as well as visual function. In unilateral cases, the fellow eye may have subtle findings such as coloboma, cataract, retinal dystrophy, or optic nerve hypoplasia.⁹
- Full cycloplegic refraction should be prescribed to maximize visual acuity of seeing eyes. Eyeglasses with polycarbonate lenses should be used in order to protect the globes from trauma.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Preferential gaze testing (eg, Teller cards) or pattern visual evoked potential (pattern VEP) can assess basic visual acuity in preverbal patients.
- Flash visual evoked potential (VEP) testing can evaluate for any visual-cortical function in patients with severe microphthalmia or apparent anophthalmia.⁹
- Facial photographs should be taken, including a ruler in the photo for scale.
- Imaging with ultrasound of the eye and orbit to evaluate its structure and detect ocular remnants or cysts.
- MRI for detailed assessment of the soft tissues of the orbit and brain
- Maxillofacial CT for assessment of the orbital and facial bones

NONOPERATIVE MANAGEMENT

- Management focuses on utilizing the remaining vision in one or both eyes, promoting appropriate growth of the orbit and face, and optimizing ocular appearance.
- **FIG 2** outlines a treatment algorithm to accomplish these goals according to varying degrees of severity. Parents should be counseled that a series of procedures and/or devices will be needed over time to help the orbit expand in parallel to the growth of the rest of the face.
- Certain cases can be managed nonoperatively with placement of progressively larger conformers:
 - Children with useful vision in the affected eye(s) should be fitted with a series of clear conformers to progressively expand the lids, fornices, and orbit while still allowing the eye to see through the device so that visual development can occur (**FIG 3**).
- Blind eyes measuring greater than 16 mm in length can be fitted with a series of ocular prostheses to maintain the socket while also improving the appearance of the eye.
- If an eye is unable to tolerate wearing a prosthetic shell due to mechanical irritation of the corneal surface, a graft can be placed to cover the cornea (**FIG 4**).

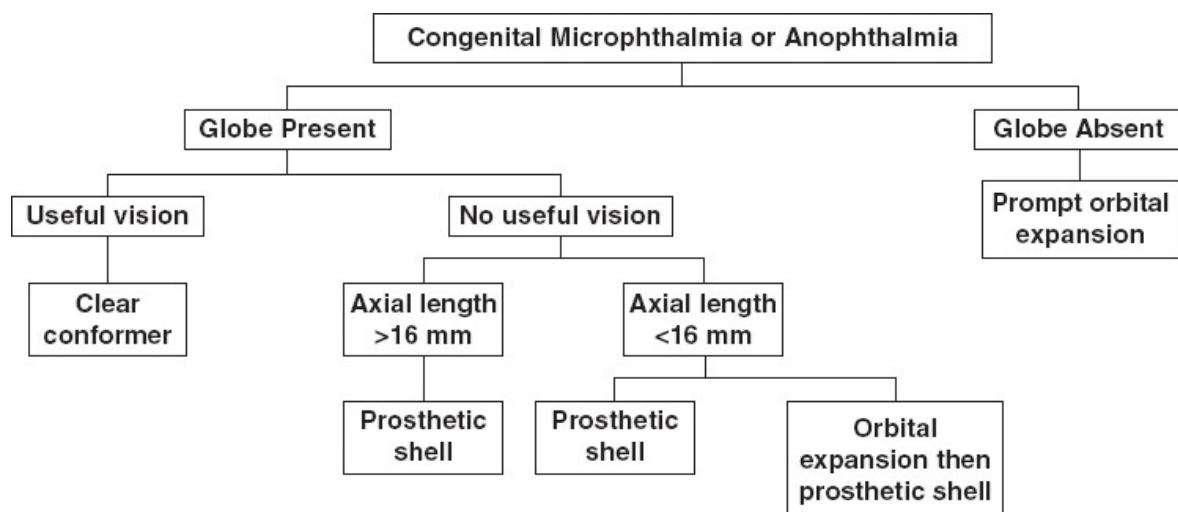


FIG 2 • Management framework for the microphthalmic or anophthalmic orbit.

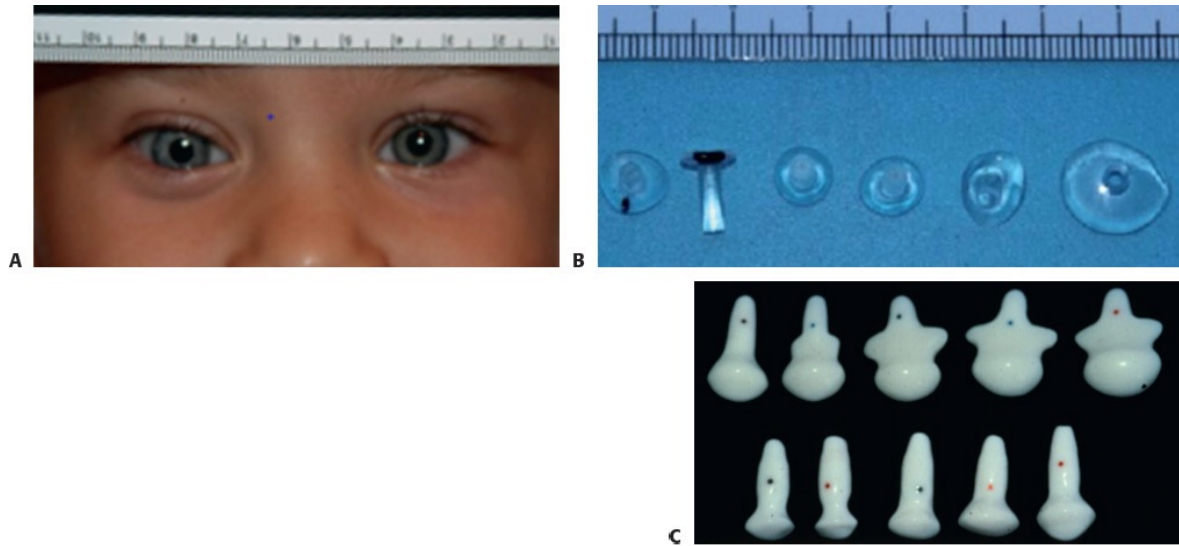


FIG 3 • A–C. A series of progressively larger conformers can be made to maintain the socket, exerting pressure to help the orbit expand and promote appropriate facial growth. For eyes with meaningful vision, clear material is used in order to avoid deprivational amblyopia.

- More severe cases can be managed with expandable devices placed into the conjunctival sac that are then inflated or exchanged for larger devices over time:
- Inflatable chambers. A flexible chamber with an anterior port that is nonsurgically seated into the conjunctival sac (**FIG 5**). A conformer holds the implant in place. Every 2 to 3 weeks in the clinic, additional saline volume is injected through the port into the chamber.
- Self-expanding hydrogels. Hydrophilic osmotic expanders (polymethyl methacrylate/polyvinylpyrrolidone), absorb up to 2000% their weight in water, resulting in expansion of 8 to 10 times the original volume (**FIG 6**).¹⁰ Hydrogel hemispheres or spheres are placed beneath the eyelids onto the conjunctival surface and secured in place with a temporary tarsorrhaphy.^{10–12} The gel is removed and exchanged for a larger-volume insert every 2 to 3 months, usually requiring a series of 2 to 4 hydrogels over the course of 4 to 12 months for adequate expansion depending on the initial size of the orbit (**FIG 7**).

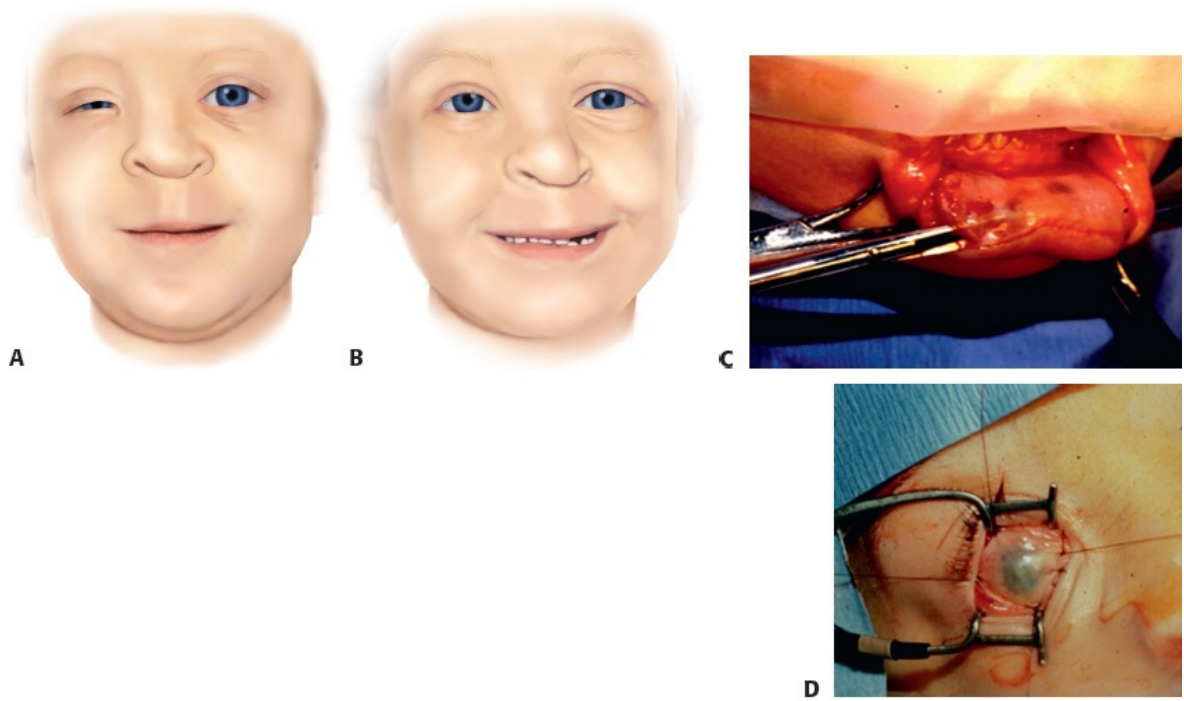


FIG 4 • A–D. To improve tolerance of the scleral shell prosthesis over the microphthalmic right eye, a mucous membrane graft is harvested from the lower lip and placed onto the ocular surface to protect the cornea.

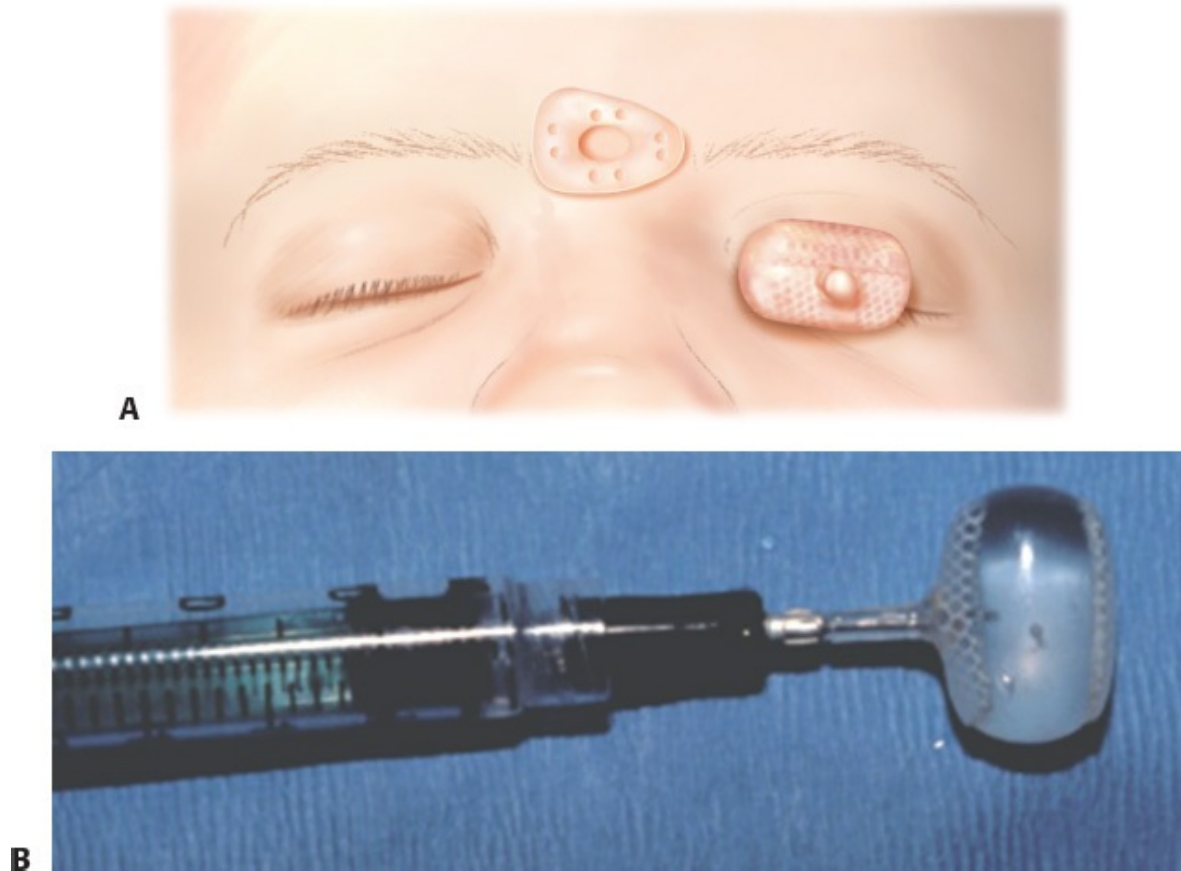


FIG 5 • A,B. A noninvasive inflatable orbital expander. The flexible chamber is seated into the conjunctival sac with its port facing anteriorly. A conformer (shown here resting on the glabella prior to insertion) is inserted over the chamber to maintain it in place. The port can be accessed with a needle and syringe to inject saline for progressive expansion of the chamber volume.

SURGICAL MANAGEMENT

- Most cases of microphthalmia or anophthalmia require surgical management for orbital expansion. There are four goals of orbital expansion:
- Stretch the periocular soft tissue to reduce the phimosis of the palpebral fissure and enlarge the fornices. This stretching makes it possible to wear a more appropriately sized conformer or prosthesis.¹³
- Stimulate orbital bone growth. Animal models and human cases repeatedly demonstrate that anophthalmic orbital volume does not increase at a normal

growth rate.¹⁴ Placing a device that exerts pressure within the orbit is effective in stimulating expansion of the bony orbital walls.

- Promote symmetric facial growth because the craniofacial skeleton is cued by the bony orbit.¹⁵
- Create space for a more permanent orbital implant. Having a larger orbital implant enables wearing of a smaller-volume prosthetic, which often improves the comfort and appearance for the patient.

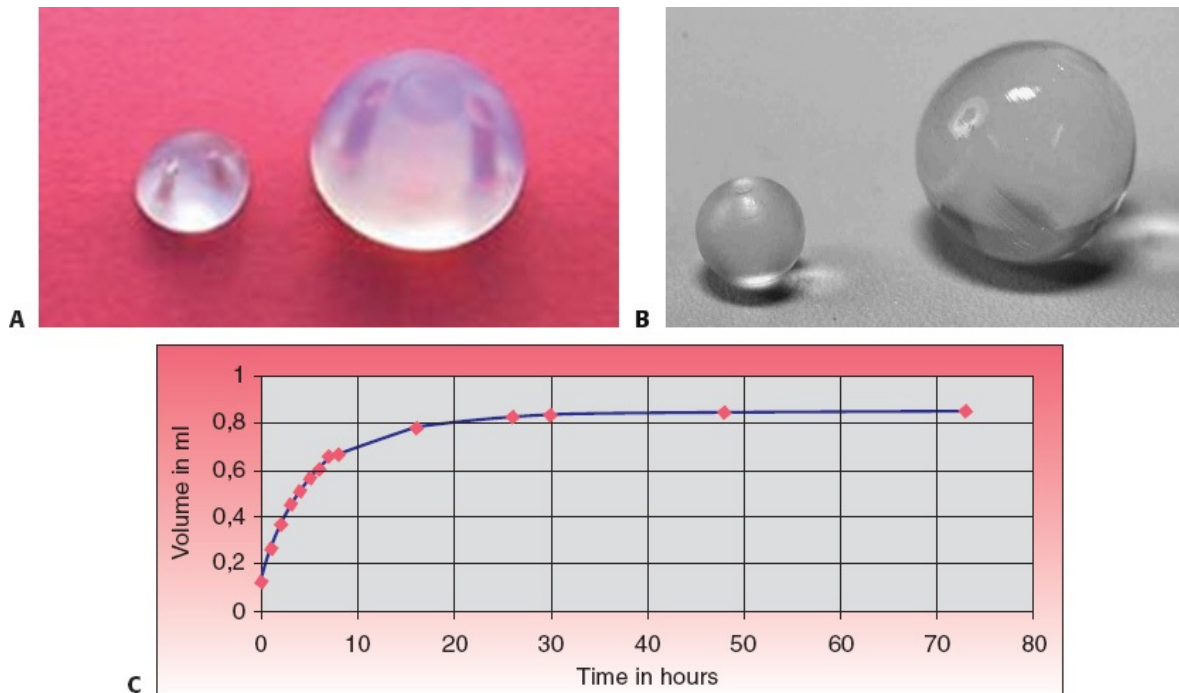


FIG 6 • A–C. Hemispheric or spherical hydrogel expanders increase in volume as they absorb water, with the potential to reach full volume within about 30 hours after implantation.



FIG 7 • A–I. Orbital growth and improved symmetry with a series of hydrogels. An infant diagnosed with bilateral anophthalmia had placement of 0.9 mL hydrogel spheres at 21 days of age. Progressive expansion of the orbit can be seen in photos from 3 to 5 months of age. At 5 months, the hydrogel was exchanged for a 1.5 mL volume. At 9 months, it was exchanged for a 2 mL volume. By 14 months of age, the orbital expansion was sufficient for placement of a dermis fat graft and subsequent fitting with ocular prostheses. Ongoing symmetric orbital and facial growth can be appreciated at 2 years of age.

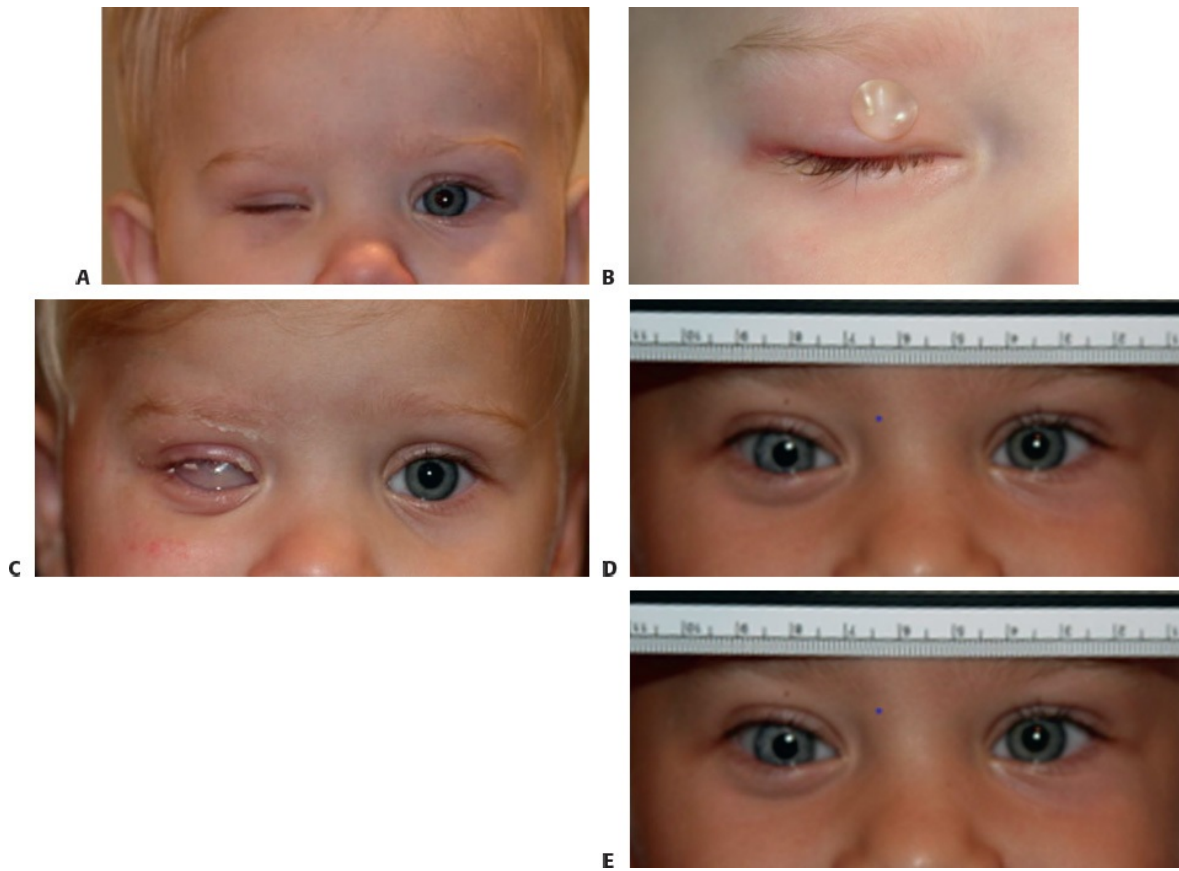


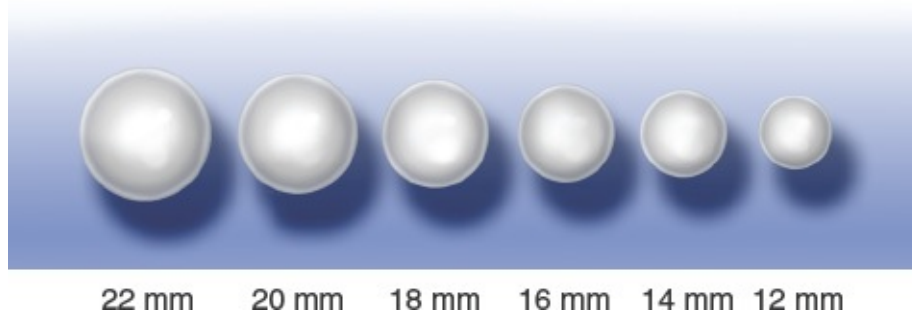
FIG 8 • A–E. A young boy with right microphthalmia is treated with hydrogel expanders in the office. A 0.9-mL hemisphere is placed onto the conjunctival surface. Cyanoacrylate glue is used for temporary tarsorrhaphy of the lids to hold it in place. When the hydrogel has expanded to full volume, it is exchanged for progressively larger hemispheres (1.5 mL, 2 mL) until the desired orbital volume is achieved. A well-matched prosthetic shell can then be worn.

TECHNIQUES

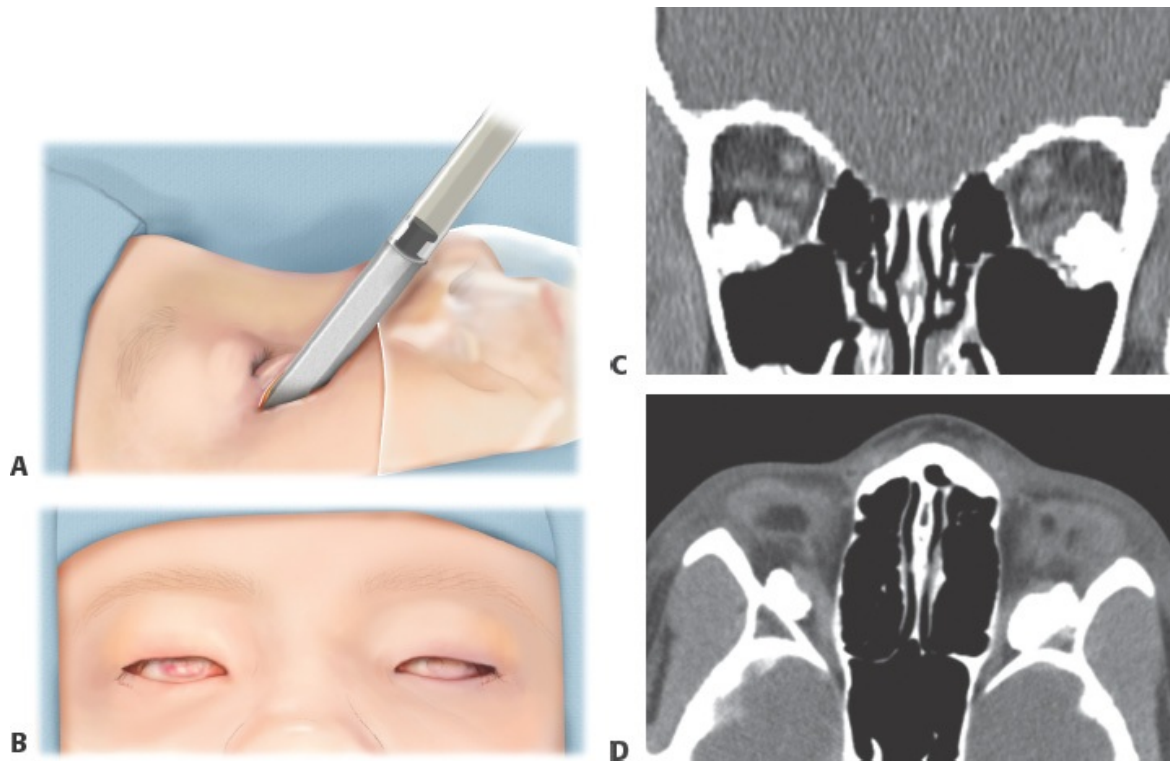
- There are multiple surgical methods for achieving expansion:
 - Rigid spherical implants within the orbit. Although these have the advantage of creating direct pressure within the deep orbit to stimulate growth, they are limited by the need for multiple surgeries to place serially

larger implants to promote progressive orbital growth (**TECH FIG 1**)

- Injectable fillers. These substances allow placement of added volume into the retrobulbar orbit without significant violation of the conjunctiva. Hydroxyapatite (HA) fillers are commercially available and long-lasting, making them a viable option for socket augmentation.¹⁶ An infraciliary skin incision is made, the filler cannula is introduced and advanced to the retrobulbar space and HA is then injected along the inferolateral orbital wall. The cannula is withdrawn, and the incision is closed with absorbable suture (**TECH FIG 2**). Serial injections can be performed to add more volume as the child grows.
- Hydrogel pellets can be injected into the retrobulbar orbit (**TECH FIG 3**).¹⁷

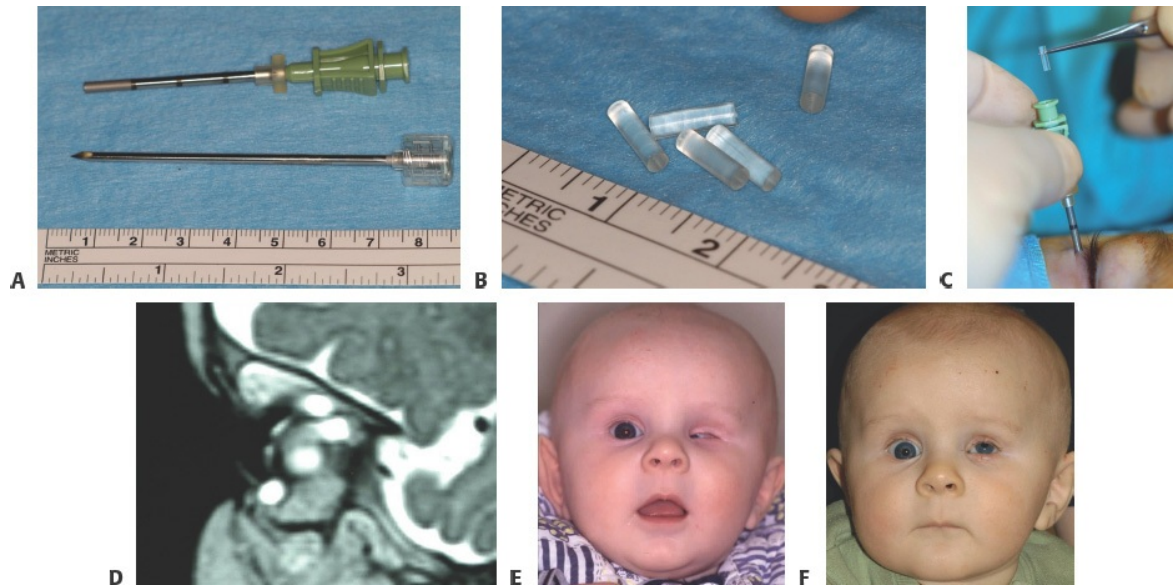


TECH FIG 1 • Rigid spherical orbital implants—shown here in silicone, ranging 12 to 22 mm in diameter—can be placed in the anophthalmic orbit to maintain space and promote volume expansion. The implants must be surgically exchanged for progressively larger sizes to keep pace with facial growth as the child grows.

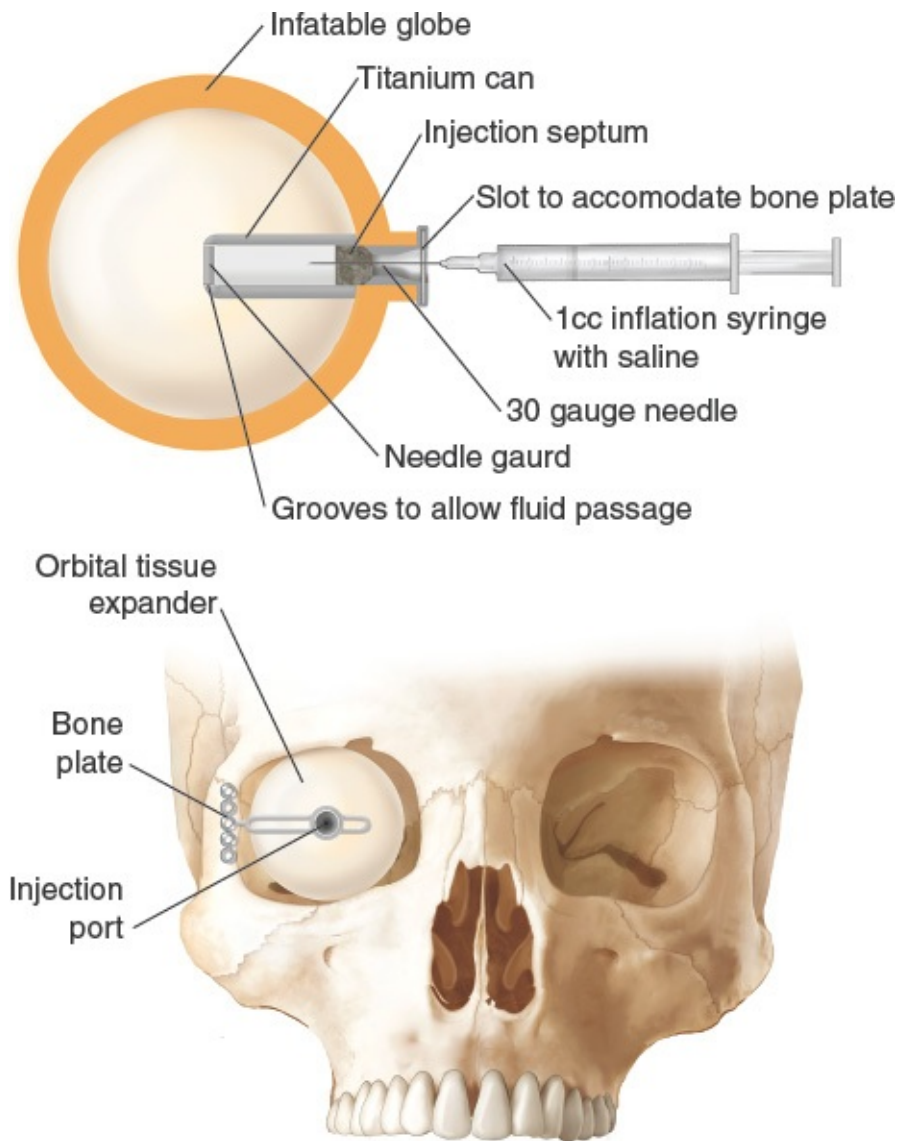


TECH FIG 2 • A–D. Retrobulbar injection of hydroxyapatite granules for orbital volume expansion through an infraciliary incision. Postprocedural CT scan demonstrates the radio-opaque filler along the inferolateral deep orbit.

- Inflatable orbital expanders. These devices are implanted into the orbit and then accessed through an external port to progressively add volume over time, thereby avoiding the need for serially exchanged conformers or implants. Early designs had a port placed beneath the scalp connected to an inflatable chamber in the orbit.¹⁸ A later design for an integrated orbital expander design involved a globe-shaped chamber with an anterior injection port implanted into the orbit and secured to the lateral orbital rim via screw-fixated titanium plate (**TECH FIG 4**). Saline injections through the anterior port inflate the chamber to accomplish gradual orbital expansion.^{15,19}



TECH FIG 3 • A–F. Hydrogel pellets are injected into the retrobulbar space under anesthesia. Sagittal CT scan shows their location and expansion. Clinical photos demonstrate orbital growth and improved hemifacial symmetry.

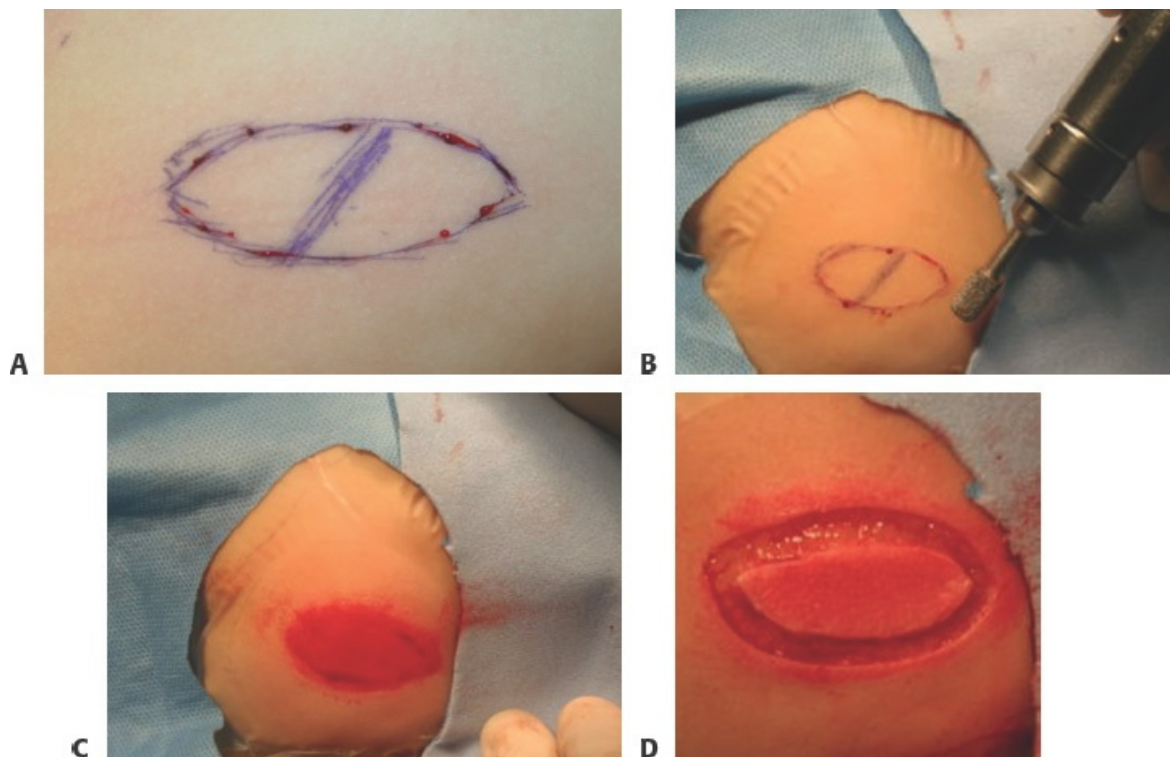


TECH FIG 4 • The integrated orbital expander is an inflatable globe placed as an orbital implant, screw-fixed with a bone plate to the lateral orbital rim. Serial injections with saline through the anterior port inflate the globe to promote orbital expansion.

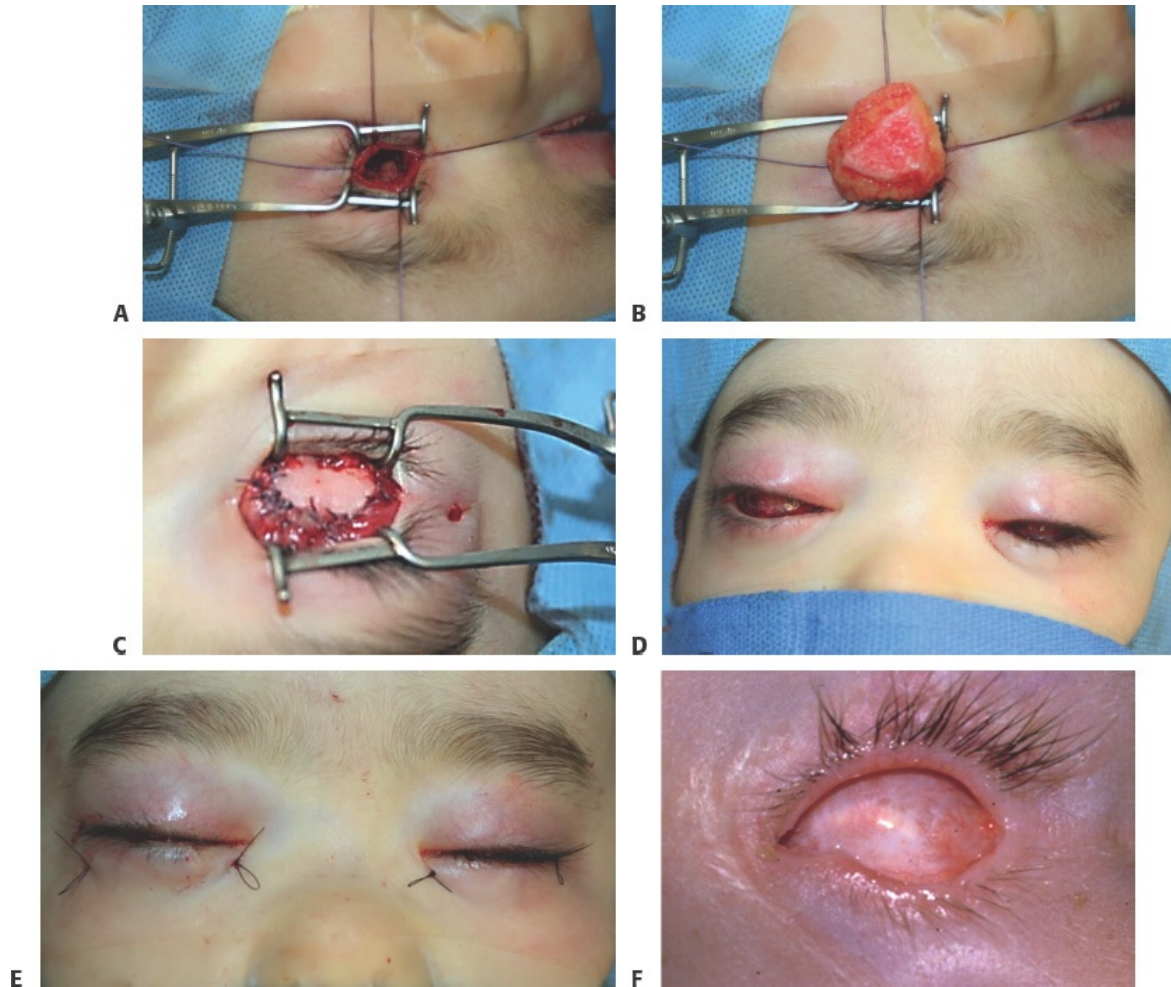
- The device is surgically removed when sufficient volume has been achieved.
- When sufficient orbital expansion has been achieved by one of the above methods, a dermis fat graft (DFG) should be placed as an autologous long-term orbital expander.²⁰
- In infants and young children, the graft is harvested from the buttock (**TECH**

FIG 5).

- An ellipse is outlined on the skin, first with ink and then reinforced with stab incisions. The marked area should correspond to the surface area of the socket where it will be implanted.
- Dermabrasion is performed to remove the epithelium down to the level where punctate bleeding is observed from the dermal vessels.
- The graft perimeter is then incised with a scalpel. Dissection is carried down through the fat in a wide cone, such that the harvested fat area is broader than the dermal surface.
- Hemostasis is obtained with bipolar cautery and then the incision is closed in 3 layers (fat, dermis, skin) with absorbable sutures.
- The orbit is prepared with an orbitotomy incision, typically oriented horizontally aligning with the palpebral fissure.
- The DFG is tucked into the orbit through this incision and then the dermis is sutured edge to edge with the conjunctiva using absorbable sutures (**TECH FIG 6**).
- After the graft is secured along its entire perimeter, a conformer is placed and the lids are closed with temporary tarsorrhaphy.



TECH FIG 5 • A–D. Dermis fat graft harvest. Buttock is marked with an ellipse. The outline is reinforced with stab incisions and then dermabrasion is performed to remove epithelium. The dermis is incised with a blade and then broader dissection is carried down through fat.



TECH FIG 6 • A–F. Dermis fat graft implantation. An orbitotomy is made through the conjunctiva, allowing insertion of the dermis graft into the orbit. The graft is secured edge to edge with conjunctiva to reform the socket surface. A conformer is placed over the graft and then the lid is closed with a temporary

tarsorrhaphy. The dermis conjunctivalizes as it heals, creating a stable surface for prosthetic wear.

PEARLS AND PITFALLS

Multidisciplinary approach	■ Ophthalmology, pediatrics, and relevant subspecialties (genetics, neurology, ENT) work together to optimize care outcomes.
Minimize surgical encounters	■ Repeated transconjunctival surgery creates traumatic conjunctival scarring, which impedes good results. ■ The risks of repeated general anesthesia to the neurocognitive development of young children are still uncertain.^{21,22}
Retaining hydrogels	■ Conjunctival hydrogel placement can be performed in the office with topical anesthesia, using cyanoacrylate glue rather than sutures to tarsorrhaphize the lids (FIG 8).
Dermis fat grafts	■ For bilateral cases, a single larger ellipse can be harvested then divided in two. ■ As the fat volume can be unwieldy during graft placement, placing the sutures systematically at the cardinal points first (12 o'clock and 6 o'clock and followed by 3 o'clock and 9 o'clock) helps retain the graft in the orbit during insertion. ■ In contrast to DFG in adults, fat atrophy does not occur to a significant degree in pediatric dermis fat grafts.
Trends in treatment	■ Management of the microphthalmic or anophthalmic orbit is moving toward goals of fewer invasive procedures, less exposure to anesthesia, and maximum symmetric growth. ■ At present these goals are best accomplished via serially larger conjunctival hydrogels, followed by dermis fat graft after sufficient expansion is achieved.

OUTCOMES

- Expansion of the bony orbit by surgical or nonsurgical means can enable near-normal facial growth, thereby improving cosmesis.
- Expansion of the eyelids and conjunctival fornices can enable wearing of an ocular prosthesis, which further improves cosmesis.

- Serial conformer therapy only directly expands the anterior orbital soft tissues, but the pressure created does induce some secondary expansion of the bony orbit. In one series of 61 microphthalmic eyes in 44 children, satisfactory symmetry was achieved in 21 cases with conformer therapy alone.¹³
- The sequence and timing of treatments must be tailored to each child to achieve the best outcome.

COMPLICATIONS

- Inadequate expansion, with residual hemifacial hypoplasia.
- Contracted conjunctival fornices, with inability to wear prosthesis.
- Infection, exposure, or extrusion of orbital implant.
- Secondary hypertrophy of dermis fat graft, requiring later debulking.

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Section X: Nasal Reconstruction

44

CHAPTER Nasal Tip Hemangioma

T. Kwan-Wong and Jugpal S. Arneja

DEFINITION

- Infantile hemangiomas is a benign, proliferative, vascular tumor of infancy that has a defined, although unpredictable natural history.
- Infantile hemangiomas is the most common pediatric benign tumor, affecting between 4% and 10% of children in their 1st year of life.¹
- Approximately 60% of infantile hemangiomas involve the head and neck regions,² and of these, a small percentage affect the nose.
- Nasal tip hemangioma can cause significant deformity, affecting the psychological and emotional well-being of the patient and the family.

ANATOMY

- Nasal contour is determined by draping of the nasal skin over a framework formed by the nasal bones in the cephalic third, by the upper lateral cartilages in the middle third, and by the paired lower lateral cartilages and the caudal septum in the caudal third.
- Nasal tip hemangioma usually resides in a subcutaneous plane—although cutaneous manifestations are not uncommon—and can extend between the medial crura of the lower lateral cartilages and occasionally into the columellar region as well.^{3,4}
- Hemangioma extending between the lower lateral cartilages tends to splay the medial and middle crura of the lower lateral cartilages from each other and can occasionally dislocate the lower lateral cartilages, by displacing the cephalic edge of the cartilage into the nasal passage.

PATHOGENESIS

- Infantile hemangiomas is histologically characterized by proliferating endothelial cells with varying luminal sizes, which tend to be smaller during the proliferative phase, becoming larger during the involutional phase.
- Involution is reflected by slowing of endothelial proliferation, apoptosis of existing endothelial cells, and replacement of vascular tissue with adipocytes and connective tissue.

NATURAL HISTORY

- Infantile hemangiomas is not present at birth but becomes apparent within the first few weeks of life.
 - The initial presentation of an infantile hemangioma may manifest as a localized telangiectasia, blanched spot, or area of ecchymosis.^{1,2,5,6}
- The natural course of infantile hemangioma is relatively predictable:
 - The proliferative phase (0 to 1 year) is characterized by rapid growth.
 - The involutional phase (until 7 to 10 years) when the hemangioma shrinks and fades
 - Complete involution in 50% of children at 5 years of age, 70% by 7 years^{5,7}
 - Nasal tip hemangiomas is slower to regress than those in other parts of the body.
 - Involutional phase (greater than 10 years) when the involutional process has completed
 - Even after involution, there are often residual stigmata such as residual fibrofatty tissue, atrophic/redundant/telangiectatic skin, and persistent deformity of nasal cartilage in about 50% of patients.³⁻⁷

PATIENT HISTORY AND PHYSICAL FINDINGS

- A thorough history should be obtained, including information about onset, progression, prior treatments, and symptoms of the nasal tip hemangioma.
- Physical examination (**FIG 1**)
 - Local—size, location, distortion of nasal cartilages, involvement of nasal vault, skin quality, presence of any scars, signs of active infection, ulceration.

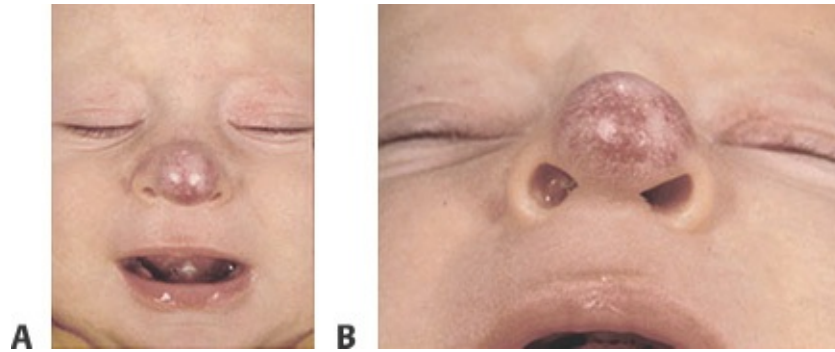


FIG 1 • A,B. A bulbous, pigmented hemangioma is evident at 6 months of age. (Reprinted from Arneja JS, Chim H, Drolet B, Gosain AK. The “Cyrano nose”: refinements in surgical technique and treatment approach to hemangiomas of the nasal tip. *Plast Reconstr Surg.* 2010;126:1291, with permission.)

- Regional—determine presence of any other lesions. Assess for any airway, visual, or auditory involvement that may necessitate earlier intervention.
- Systemic—rare with isolated infantile hemangioma of the nasal tip
 - Beardlike distribution may indicate airway involvement.
 - Large plaquelike distributions may suggest PHACES syndrome.

IMAGING

- Imaging is usually not required.
- Ultrasound may be useful to delineate flow within and the depth of the lesion.
- MRI may be used to delineate the extent of the hemangioma and its relation to the underlying nasal framework.

DIFFERENTIAL DIAGNOSIS

- Hemangioma
- Vascular malformation (lymphatic, venous, arteriovenous)
- Dermoid cyst

NONOPERATIVE MANAGEMENT

- Nonoperative options are usually considered as adjunctive rather than definitive treatments.
- Mainstay of nonoperative management is propranolol and corticosteroid

therapy.^{1-3,8}

- Propranolol is first-line medical therapy, and many practitioners feel this medication to be superior to oral corticosteroid treatment alone.
 - Dosing—1 to 3 mg/kg/d divided into TID dosing
 - Rare complications include hypoglycemia and limb cyanosis, while almost never bronchospasm and hypotension.
- Oral or intralesional steroid therapy ideally is used during proliferative phase (**FIG 2**). Steroid therapy can be administered for up to three treatment cycles.



FIG 2 • A,B. After completion of treatment with intralesional steroids and pulsed dye laser therapy, the lesion has decreased in size and cutaneous manifestations have resolved in the patient in FIG 1, shown here at age 3 years. (Reprinted from Arneja JS, Chim H, Drolet B, Gosain AK. The “Cyrano nose”: refinements in surgical technique and treatment approach to hemangiomas of the nasal tip. *Plast Reconstr Surg.* 2010;126:1291, with permission.)

- Can slow and sometimes arrest growth, but has little effect on regression. Response is usually seen within 1 week of initiating treatment.
- Oral corticosteroid—2 to 3 mg/kg/d of prednisolone for 8 weeks
- Intralesional corticosteroid—20 mg of triamcinolone directly into the lesion

SURGICAL MANAGEMENT

- Although precise timing of surgery is controversial, several principles exist:
 - Children begin experiencing psychosocial stigma from their peers around the

age of 5 to 7 years. Consequently, surgical correction is usually timed prior to school age.^{3,4,6,7}

- Surgical correction is usually preceded by adjuvant medical therapy to reduce the size.
- Surgery is usually not undertaken prior to the involutional phase unless the hemangioma causes significant airway obstruction and normal skin quality is important (see **FIG 1 & 2**).¹

Preoperative Planning

- Type of approach is determined based on the location of the lesion to be debulked or resected and orientation of the skin redundancy to be resected.
- Determine if any lower lateral cartilage or columellar reorientation or reconstruction is needed.

Positioning

- The patient is positioned supine on the operating table with a shoulder roll and neck hyperextension. Limbs and pressure points are adequately padded and protected.

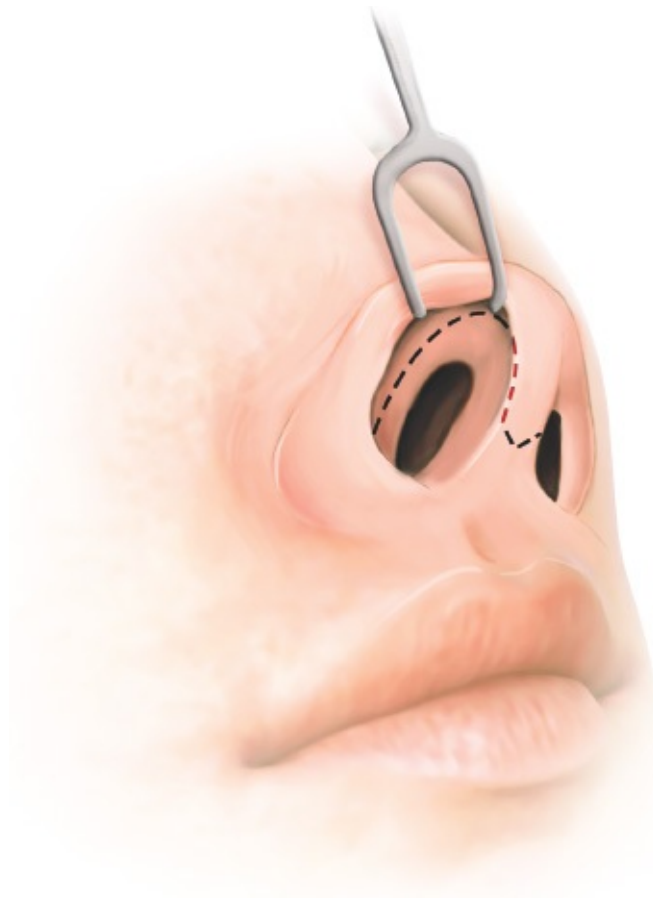
Approach

- Techniques differ principally with respects to scar placement and ability to control transverse and vertical skin excess.
- The open tip rhinoplasty is the generally preferred technique because it permits good visualization of the entire nasal tip, as well as excellent control of both horizontal and vertical dimensions.
- The nasal subunit approach attempts to hide the incisions within the junctions of the nasal subunits, providing good control of horizontal skin redundancy but with limited vertical control.
- The Rotterdam (extended L rhinotomy) trades more extensive scarring for excellent access to the nasal tip and dorsum and is useful in controlling extreme cutaneous redundancy.
- Epinephrine containing local anesthetics should be used prior to skin incision. It provides hydrodissection, hemostasis, and postoperative analgesia.

TECHNIQUES

■ Open Tip Rhinoplasty Approach

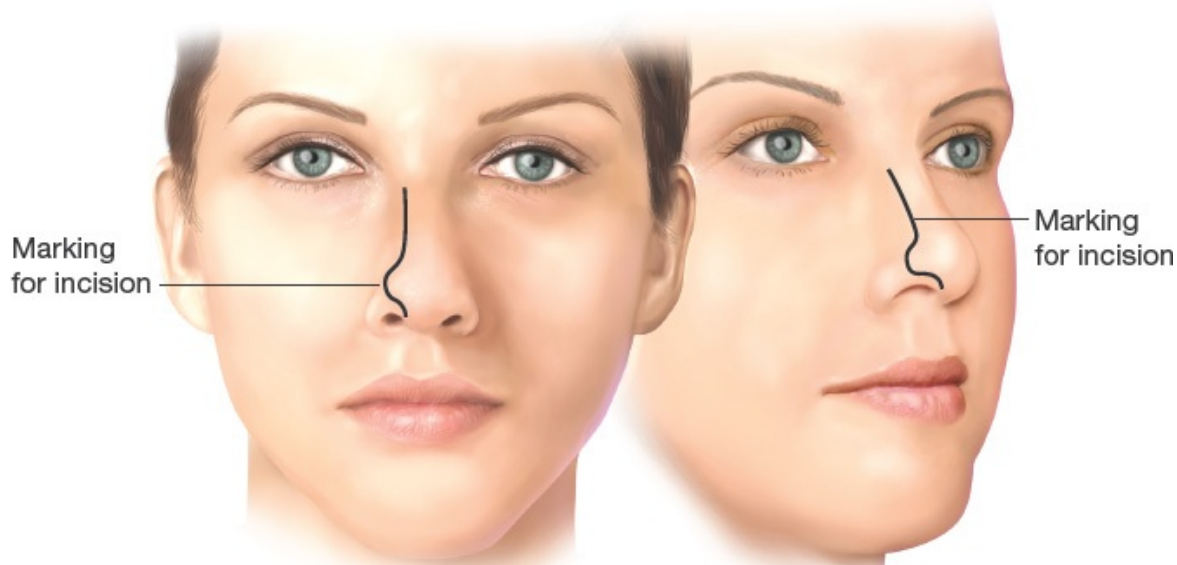
- A transverse transcolumellar incision is made at the junction of the middle and distal thirds of the columella (**TECH FIG 1**).
 - This incision may be adjusted proximally toward the columellar-lip junction if the hemangioma extends into the columella.
- Extended rim incisions are made, connecting to the columellar incision medially and proceeding along the length of the alar rim laterally.
 - The rim incision should be kept close to the nasal skin of the alar rim to avoid resection of vestibular lining, which can cause rim retraction.



TECH FIG 1 • Markings for an open tip rhinoplasty approach. The transcolumellar incision is connected to alar rim incisions to provide access to the nasal tip and dorsum.

■ Nasal Subunit Approach

- An incision is planned along the lateral aspect of the nasal dorsum, curving around the junction between the nasal tip and ala before proceeding medially and inferiorly around the medial aspect of the soft tissue triangle and into the lateral columellar region (**TECH FIG 2**).
- Depending on the size and location of the hemangioma, it may not be necessary to use the full length of the incision.

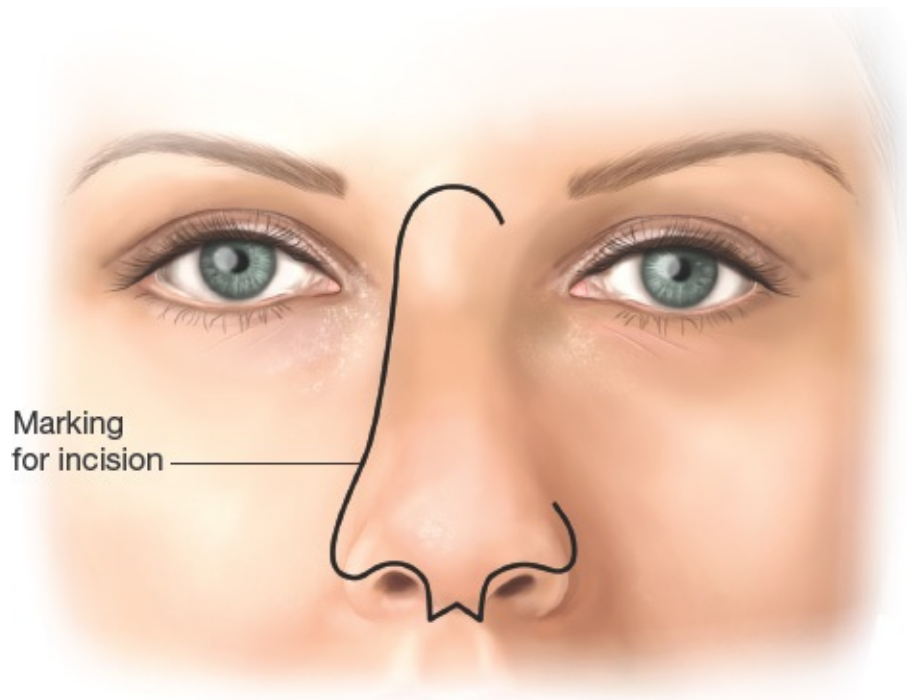


TECH FIG 2 • Markings for the nasal subunit approach. The full incision may not be needed depending on what areas of the nose need to be accessed.

■ Rotterdam/Extended L Rhinotomy Approach

- Markings are made for an inferior rhinotomy. Starting from the alar-cheek sulcus, the proposed incision follows the alar rim before traversing the columella and across the contralateral alar rim and then cranially along the alar-cheek sulcus.
- The extended L component is then marked by connecting the inferior rhinotomy markings with a line that courses cephalically along the

nasomaxillary junction before curving medially across the nasion (**TECH FIG 3**).



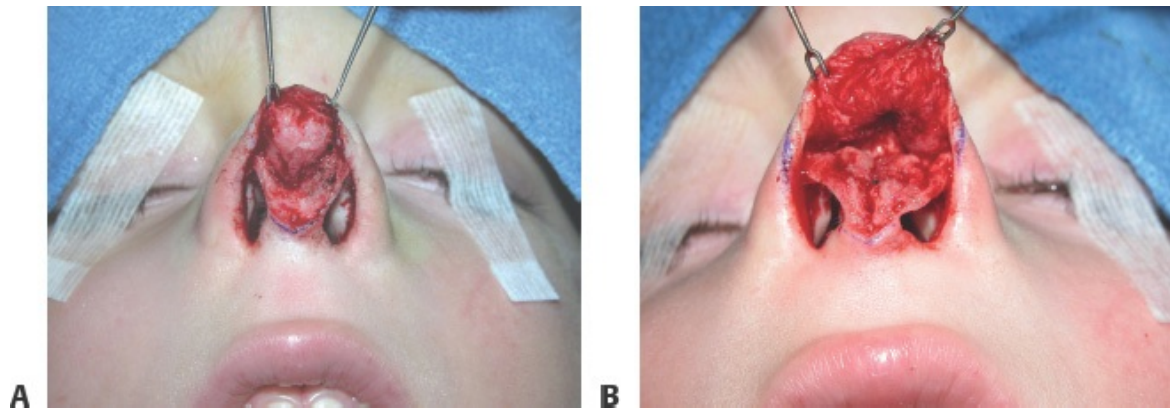
TECH FIG 3 • Markings for the Rotterdam/extended L rhinotomy.

■ Elevation and Resection of the Hemangioma (Open Tip Rhinoplasty Approach)

- Using tenotomy or sharp-tipped scissors, the hemangioma with its overlying skin is dissected free from the lower lateral cartilages (**TECH FIG 4A**).
 - If the hemangioma invades the nasal columella, dissection should proceed between the medial crura of the lower lateral cartilages.
- Using sharp scissors or a no. 15 blade scalpel, hemangioma and fibrofatty tissue is sharply resected from the nasal skin in a subdermal plane (**TECH FIG 4B**).
 - Caution should be taken throughout to ensure that sufficient thickness of nasal skin remains for flap perfusion and to avoid inadvertently “button holing” through the skin.
 - A finger may be placed on the superficial surface of the nasal skin to

provide constant tactile feedback regarding the depth of resection.

- If the hemangioma involves vestibular lining, it is preferable to allow it to naturally involute to avoid alar rim retraction, which can result from overaggressive resection in this area.



TECH FIG 4 • A. Dissection of the hemangioma begins in a plane between the hemangioma and nasal cartilage. **B.** Sharp excision of the hemangioma from the overlying nasal skin, ensuring uniform and adequate skin flap thickness, with lower lateral cartilage reconstruction.

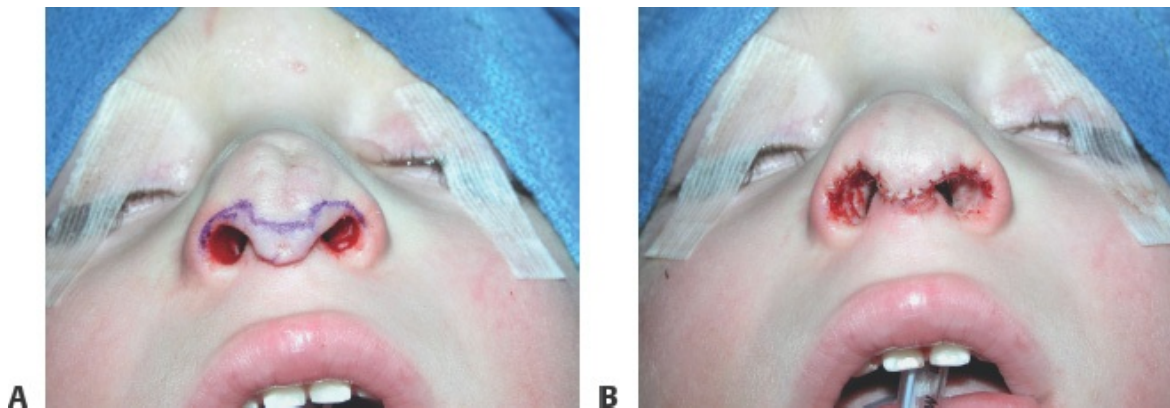
■ Lower Lateral Cartilage Reconstruction

- The shape and position of the lower lateral cartilages are assessed.
- If the lower lateral cartilage has been dislocated by the hemangioma, it should be resuspended to the upper lateral cartilage using sutures.⁵
- Interdomal sutures using 6-0 polydioxanone (PDS) are placed to reapproximate the medial and middle crura of the lower lateral cartilages if they have been splayed apart by the hemangioma (**TECH FIG 4A**).
- Transdomal sutures are placed using 6-0 PDS to restore domal projection if the intercrural angle has been flattened by mass effect of the hemangioma (**TECH FIG 4B**).

■ Skin Resection and Closure (Open Tip Rhinoplasty)

Approach)

- The nasal skin is redraped over the cartilaginous framework, and the redundant skin is marked out and sharply trimmed (**TECH FIG 5A**).
 - Skin resection should be conservative to avoid undue tension, which can produce nasal distortion, blunting of the nasal tip, or alar rim retraction.
 - With the open rhinoplasty approach, vertical skin excess can be corrected by adjusting the resection at the tip of the columellar flap, whereas horizontal skin excess can be controlled by adjusting the margin of resection at the columellar-rim flap.⁵
- The skin is approximated using rapid absorbing 5-0 polyglactin 910 (Vicryl Rapide), and if alar rim incisions were used for access, the vestibular lining is closed using 5-0 polyglactin 910 (Vicryl) (**TECH FIG 5B**).
 - If alar rim incisions were used, a silicone-conforming stent is inserted into the nares and secured using tape.



TECH FIG 5 • A. The nasal skin is loosely redraped over the nasal framework, and the skin excision is marked. Markings should err toward being more conservative to avoid undue tension during closure, which can cause nasal distortion. **B.** The final result after hemangioma excision, reconstruction of the lower lateral cartilages, and excision of resultant skin excess. Following this, Silastic-conforming stents are inserted and secured with tape.

PEARLS AND PITFALLS

Timing	■ Surgery should be delayed until involution is completed and/or cutaneous manifestations are resolved, unless there is airway/visual axis obstruction or life-threatening symptoms. ■ Surgery should be completed prior to school age to minimize the psychosocial impact experienced by the patient and parents.
Nonsurgical therapies	■ Propranolol should be considered for first-line medical therapy. Reduction in volume and color is often seen within 24–48 hours of initiating therapy. ■ Adjunctive corticosteroid therapy may be used in an intralesional or oral fashion. ■ Pulsed dye laser can be used to treat telangiectatic skin changes.
Surgical access	■ Location of the hemangioma and the vectors of skin excess will help determine the type of incision used. The authors prefer the open tip rhinoplasty approach for its exposure and ability to control both horizontal and vertical skin excess. ■ Use of local anesthetic with epinephrine provides hemostatic, analgesic, and hydrodissective benefits.
Hemangioma resection	■ If the hemangioma involves vestibular lining, it is preferable to leave residual hemangioma in these areas and to allow it to involute naturally. ■ Overaggressive resection of tumor can cause nasal tip blunting, nostril-tip disproportion, or a “skeletonization” appearance of the lower lateral cartilages.
Lower lateral cartilage reconstruction	■ Reconstruction and reapproximation of the lower lateral cartilages using domal creation and/or interdomal sutures may be necessary, especially if the hemangioma is large and/or involves the columellar region.
Minimize risk of alar rim retraction	■ If alar rim incisions are to be used, stay close to the cutaneous rim to avoid resecting vestibular lining. ■ Skin resection should be conservative, with closure being done under virtually no tension. ■ Silicone intranasal conforming stents should be used for 3 months post-operatively.

POSTOPERATIVE CARE

- If alar rim incisions are made, silicone intranasal stents should be placed

intraoperatively and left in place for at least 3 months to minimize the effects of scar contraction.

- Sutures should not be used to hold the stent in due to the risk of inadvertent columellar trauma if the suture is pulled through.
- Parents should be taught how to remove the stents for cleaning of the surgical site and how to replace and resecure the stents using tape.
- Scar massage may be started approximately 4 weeks following surgery.

OUTCOMES

- Good cosmetic results with high patient and parental satisfaction can be expected following resection of nasal tip hemangiomas (**FIG 3**).^{3,4,7}
- There is rarely a risk of recurrence if the resection is performed after the proliferative phase has passed.
- Families should be prepared for the possibility of secondary procedures such as repeat resection, scar revision, and laser therapy for cutaneous sequelae or secondary rhinoplasty.

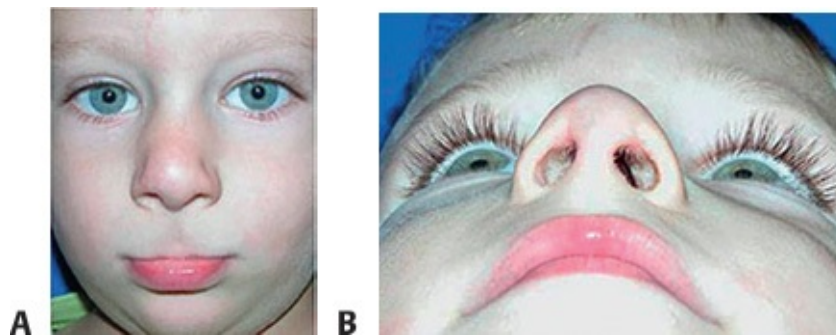


FIG 3 • Surgical correction was performed on the patient in FIGS 1 and 2 at 5 years of age and served to “sculpt” the final appearance of the nose. **A,B.** The postoperative result is shown 1 year later. Combined medical and surgical management resulted in an optimal aesthetic result in this patient. (Reprinted from Arneja JS, Chim H, Drolet B, Gosain AK. The “Cyrano nose”: refinements in surgical technique and treatment approach to hemangiomas of the nasal tip. *Plast Reconstr Surg*. 2010;126:1291, with permission.)

COMPLICATIONS

- Infection
- Hematoma
- Necrosis of skin flap margins
- Alar rim retraction and/or stenosis
- Poor nasal tip definition
- Nasal tip distortion
- Hypertrophic/keloid scarring

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CHAPTER Nasal Septal Hematoma

Whitney L. Quong and Jugpal S. Arneja

DEFINITION

- Hematoma of the nasal septum is a relatively rare, yet potentially serious consequence of trauma to the nose where blood accumulates between the cartilaginous/bony portion of the septum, and its overlying mucoperichondrium/mucoperiosteum. Any degree of craniofacial trauma should urge evaluation for the condition.
- Without prompt recognition and intervention, a septal hematoma may precipitate future cosmetic distortion, including secondary infection, resulting in septal abscess and/or ultimately a saddle nose deformity.
- Incision and drainage is the mainstay of treatment, but immediate reconstruction with autograft or homograft is an option if there is structural defect in the nasal septum.

ANATOMY

- The nasal septum comprises cartilaginous, membranous, and bony components (perpendicular plate of the ethmoid, vomer, premaxilla, maxillary crest, and palatine crest) covered by mucoperichondrium and mucoperiosteum layers (**FIG 1**). The septum is typically 2 to 4 mm thick.
- The blood supply of the nasal septum is derived from the sphenopalatine and the anterior and posterior ethmoid arteries, along with contributions from the superior labial artery (anteriorly) and the greater palatine artery (posteriorly). These vessels travel in the overlying mucous membrane and penetrate the mucoperichondrium through vascular canals. It is through diffusion that the cartilaginous septum receives its blood supply. The Kiesselbach plexus (Little area) is a region where the chief blood supplies to the internal nose converge

and is found in the anteroinferior third of the nasal septum.

- Bleeding into the potential space between the cartilage and its overlying mucoperichondrium leads to a septal hematoma (**FIG 2**), whereas external bleeding from Kiesselbach plexus results in epistaxis.

PATHOGENESIS

- Nasal septal hematoma typically results from trauma to the nasal complex, with even minor trauma causing the condition. Rarely, chronic irritation of the septum by nasogastric tube has also been found to precipitate the condition.¹
- Children are particularly prone to developing septal hematomas, as the pediatric cartilage is soft and prone to buckling,² and the mucoperichondrium is only loosely adherent to the underlying cartilage.¹
- The precise mechanism for development of nasal septal hematoma has not been defined, but has been proposed to occur when mechanical force to the nasal cartilage precipitates leakage or rupture of the mucoperichondrial vessels in the septum.
- If the mucosa remains intact, extravasated blood strips the mucoperichondrium and/or mucoperiosteum from cartilage/bone as it accumulates within a closed space.
- Where vessel compromise is coincident with fracture of the septal cartilage or bony components, blood may dissect through the fracture and form a hematoma.

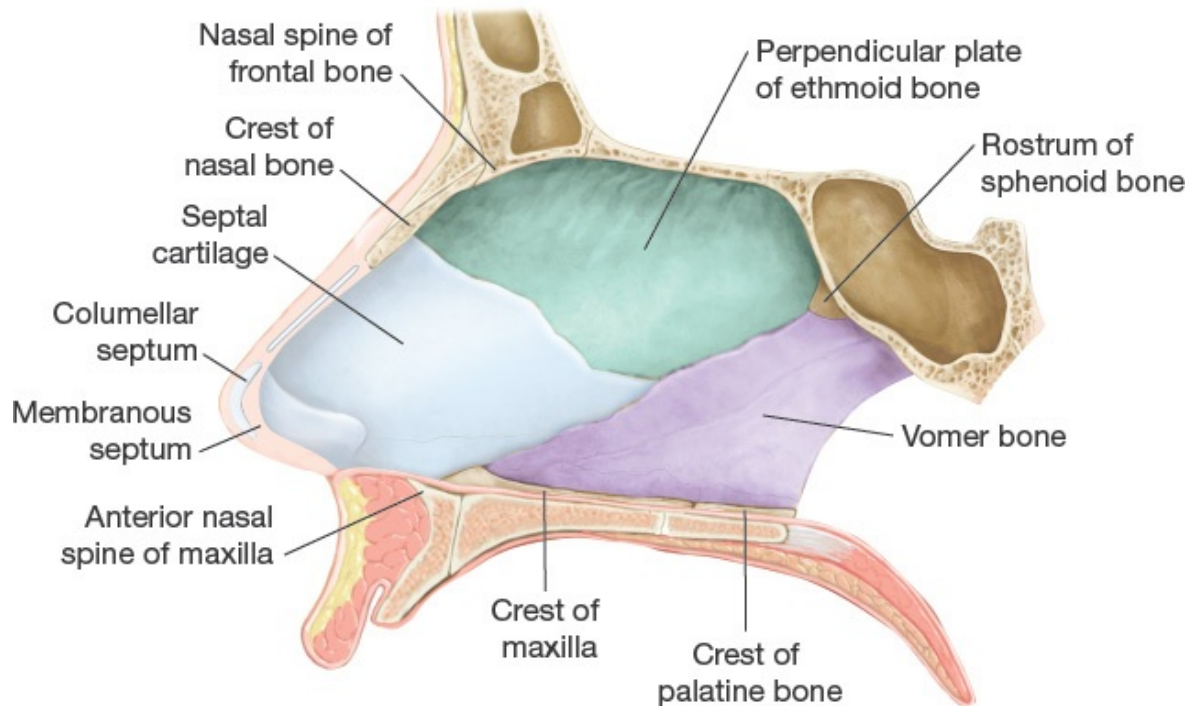


FIG 1 • The nasal septum is formed by cartilaginous, membranous, and bony components.

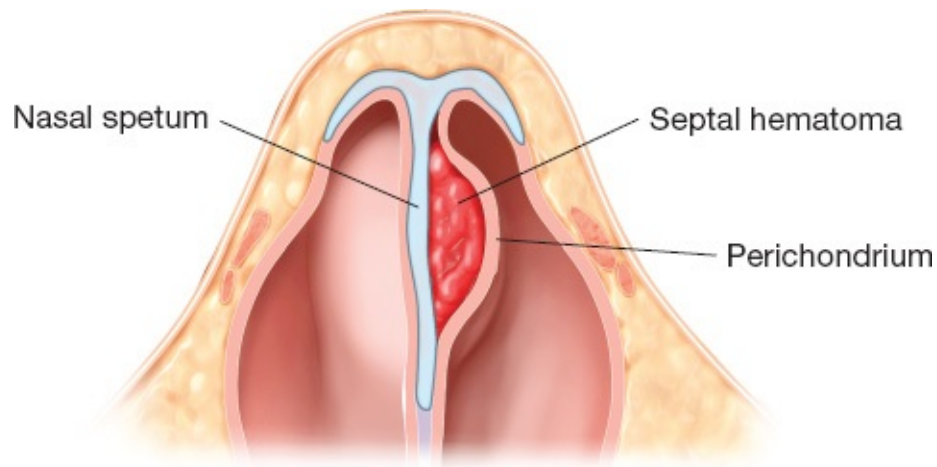


FIG 2 • A septal hematoma is formed when there is accumulation of blood into the potential space between the cartilaginous septum and the overlying mucoperichondrium.

NATURAL HISTORY

- When not promptly recognized, extravasated blood continues to expand between the perichondrium and cartilage. Eventually, the increased pressure causes collapse of the vessels supplying the septal cartilage. Pressure-induced ischemia, avascular necrosis, and liquefaction can result rapidly within 24 to 72 hours.
- Where there is significant necrosis and destruction of the septal cartilage, the structural integrity of the septum is compromised, and a saddle nose deformity may be the end result.
- Necrosed tissue may also act as a nidus for infection and abscess development. Bacteria isolated from septal abscesses are predominantly those species of the normal nasal flora, which include *Staphylococcus aureus*, *Streptococcus pneumoniae*, group A β -hemolytic streptococcus, and *Haemophilus influenzae*.³ Collagenases produced by these bacteria serve to accelerate cartilage liquefaction.
- Meningitis, cerebral abscess, subarachnoid empyema, and cavernous sinus thrombosis have also been reported as complications of septal hematomas.³
- Because the development of septal hematoma may be delayed up to 48 to 72 hours from initial trauma,¹ sequential evaluation is recommended.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Though relatively rare—occurring as a consequence to only 0.8% to 1.6% of nasal traumas¹—one should be suspicious for septal hematoma when there is any history of craniofacial trauma.
- A full head and neck examination should be performed to evaluate for any coincident injuries. In children, the possibility of abuse must be explored.
- On history, progressive nasal obstruction is the most commonly reported symptom. Report of facial pain/headache, epistaxis, and fever are also common symptoms. Clinical features elucidated on physical examination that increase the pretest probability include hyperemia of the nasal mucosa, enlargement of the septum, swelling/ecchymoses of the nasal dorsum, external nasal deformity, and purulent rhinorrhea.¹ Presence of any of these features should prompt further history about preceding nasal trauma, upper respiratory tract infections, or dental procedures.
- With nasal septal hematoma on the differential diagnosis, focused intranasal examination of the nasal septum is required. Direct anterior rhinoscopy to evaluate the nasal septum may be performed with nasal specula. In addition to the septum, the inferior turbinate, a portion of the middle turbinate, and

possibly the nasopharynx should be visualized. Both sides of the nasal septum must be evaluated.

- The nasal mucosa is normally pink, without ulcerations, crusting, or bleeding. The septal hematoma is visualized as a lateral bulging (unilateral, or bilateral), with purple/dusky fluctuance. Palpation of the septum, by inserting a gloved finger into the nostril, may aid identification of a fluctuance. If such fullness persists even after topical administration of a vasoconstrictive agent such as oxymetazoline, the diagnosis of septal hematoma is highly likely.

IMAGING

- If the diagnosis is an isolated nasal septal hematoma, without other indication, no further imaging studies are required.
- If the septal hematoma has further developed into a nasal septal abscess, computed tomography scanning of the head and neck region with contrast enhancement should be considered to evaluate for intracranial extension. Particularly, where there is extensive facial cellulitis, focal neurologic defects, altered consciousness, meningismus, severe headache, failure to improve with treatment, delay in diagnosis and treatment, or isolation of an unusual/virulent microorganism, further radiologic imaging is recommended.⁴

DIFFERENTIAL DIAGNOSIS

- Nasal septal abscess
- Deviated nasal septum
- Nasal septal polyp
- Nasal fracture

NONOPERATIVE MANAGEMENT

- In a cooperative patient presenting soon after injury and where necrosis and infection are not suspected, the hematoma may be evacuated in the clinic or emergency department. Under local anesthetic, a simple aspiration with needle (**FIG 3**) and syringe can be performed, and the nose subsequently packed and reassessed 48 to 72 hours later.

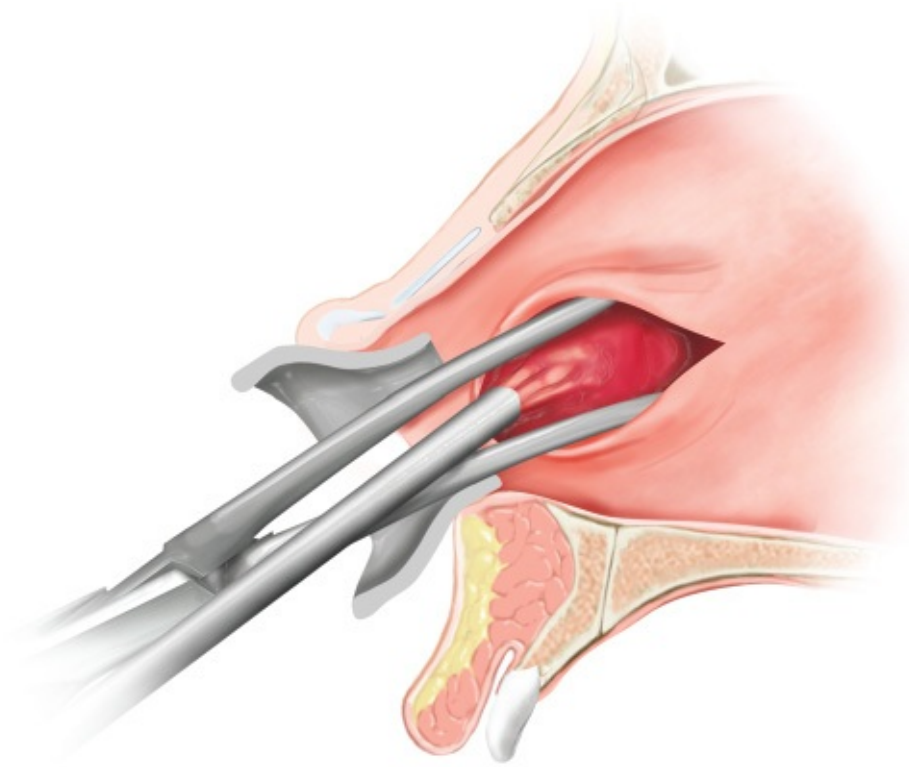


FIG 3 • A needle and syringe can be used to enter the hematoma and evacuate the accumulated clot.

- For a more organized hematoma, incision and drainage in the operating room is suggested.
- In a pediatric patient, if significant necrosis is suspected, or if immediate reconstruction is likely to be required, management in the operating room with incision and drainage under general anesthetic is recommended.

SURGICAL MANAGEMENT

- Antibiotics should be administered upon identification of a septal hematoma. Coverage should include the common upper respiratory tract microorganisms, with amoxicillin-clavulanate recommended for uncomplicated cases, and clindamycin used where abscess is suspected or known.
- If there is compromise to the structural integrity of the nasal septum, as is commonly seen with delayed identification of a hematoma or abscess, immediate reconstruction can be considered. This is particularly supported in the pediatric population, for whom loss of portions of the cartilaginous septum may ultimately have a long-term effect on the growth of the facial skeleton.⁵

Preoperative Planning

- To anesthetize the septum, pledgets soaked in an equal part mixture of 4% lidocaine and 0.05% oxymetazoline should be packed into the nares. Adequate contact of the pledgets with the septum should be ensured. After 10 minutes, a small amount of 1% or 2% lidocaine with epinephrine can be injected into the septum.

Positioning

- Place the patient supine, ensuring adequate access, visualization, and lighting of the nasal septum.

Approach

- After the septum is anesthetized, thorough examination of septum should be permissible. With a nasal speculum, the full extent of the hematoma should be evaluated, and both sides of the septum visualized.

TECHNIQUES

■ Aspiration

- With a needle attached to a syringe, pierce the hematoma and aspirate the cavity. Blood should be amenable to being withdrawn with little force. If there is concern regarding infection, send the aspirate for culture and sensitivity. This step may also be performed in the clinic/emergency department if the diagnosis is unclear, or as a temporizing measure prior to operative management.

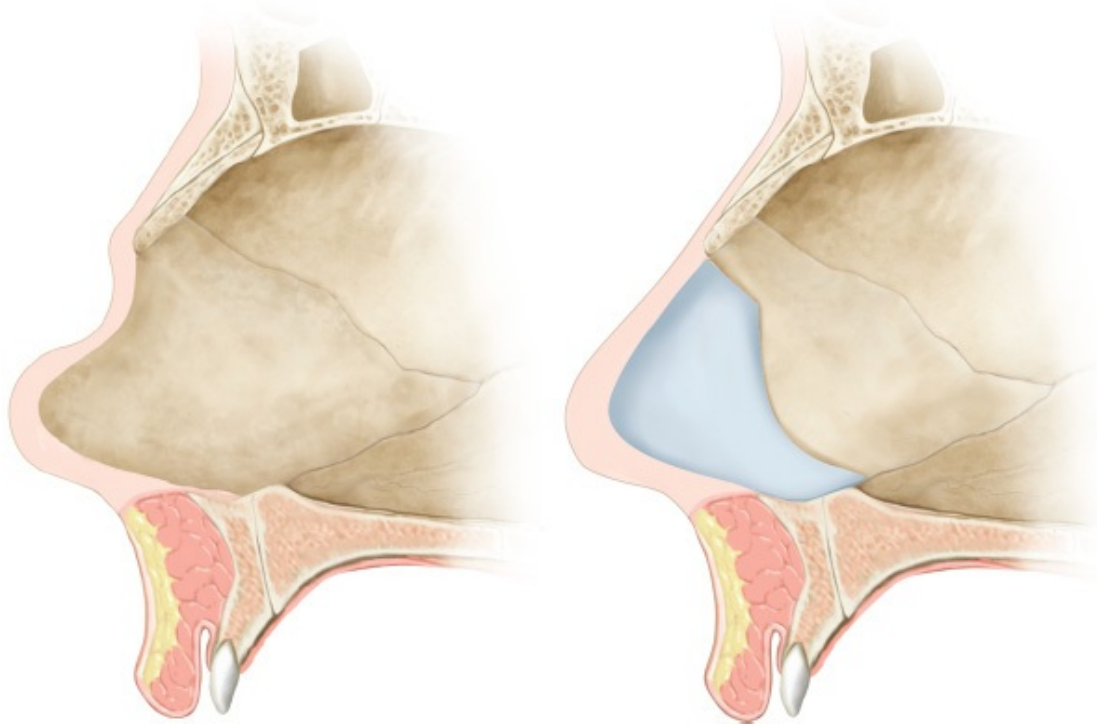
■ Hemitransfixion Incision

- A hemitransfixion incision is made at the junction of the membranous septum and the lower border of the nasal septal cartilage to further explore and evacuate the hematoma. Residual clot should be suctioned, and the cavity irrigated with saline. Necrotic cartilage should also be debrided. Subsequently, any defect in the cartilage can be assessed, and the need for reconstruction considered.

■ Septum Reconstruction

- Defect in the septal cartilage following debridement of the necrotic tissue can be reconstructed immediately. In this case, the surgeon may consider converting to an open tip approach for direct access to the nasal base and septum; the precise amount of the cartilage defect can be evaluated, and approach for reconstruction considered.
- Three principal methods of cartilage reconstruction are advocated: the “exchange technique” using posterior septal components to reconstruct the anterior defect, a “mosaicplasty” piecing together residual cartilage with fibrin glue, and reconstruction with a cartilage autograft or homograft.⁷
- An “exchange technique” is suitable where larger pieces of cartilaginous/bony septum remain in the posterior septum.
 - From the dorsal portion of the septum, a portion of the cartilage can be harvested and implanted into the defect as an autogenous septal graft.
 - Guide sutures may be used to position the graft into anatomic position, and transverse mattress sutures used for fixation.
 - If a defect still exists, and there is insufficient cartilage, a graft from the osseous septum may also be taken.
 - This exchange technique is not recommended in children, however, because disruption of the posterior septum may ultimately affect septal and midface growth.
- For multiple small cartilaginous septal components underlying the hematoma—that is the septum has fractured but not necrosed—a “mosaicplasty” can be performed. In this technique, the septal fragments are held together with fibrin glue and used to patch the defect. Although relatively simple, it has been suggested that this technique may not be the most effective in preventing or treating a saddle nose deformity.⁶
- A cartilage autograft or homograft is possibly the most preferred method of reconstruction. Cartilage is typically consistent, appropriately elastic, amenable to shaping, and typically heals uneventfully. There is debate as to its ideal source, with conchal, tragal, costal, or preserved donor cartilage being options.
 - When using preserved donor cartilage, there is typically not as significant limitation in size or volume as in comparison to employment of an autograft. Although different constructions including the “L-shaped” and

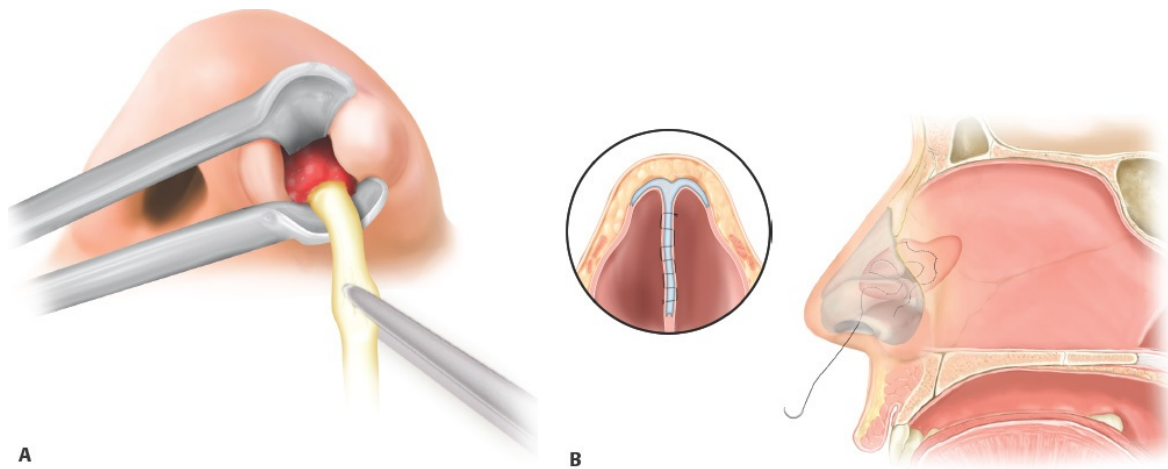
“angular-shaped” types have been described, possibly the “boomerang-shaped” (**TECH FIG 1**) design is the most preferred. The boomerang shape is proposed to best resist mechanical stress, as it provides supports to both the Little area, as well as the anterior nasal spine.⁶ Ultimately, if a graft is used, it should be fit to the size of the defect and provide support to the nose.



TECH FIG 1 • The boomerang-shaped cartilage graft provides support to the anterior spine and Kiesselbach plexus area and is resistant to mechanical stress.

■ Preventing Reaccumulation: Drain, Wick, or Quilt

- A few different measures are available to prevent reaccumulation of the hematoma. Into the hemitransfixion incision, an iodoform wick can be inserted, or a penrose drain may be stitched in place (**TECH FIG 2A**). Alternatively, and preferred, a quilting stitch (with an absorbable suture) can be performed, which runs back and forth across the septum in a random pattern to firmly press the mucoperichondrium against the cartilage and eliminate dead space (**TECH FIG 2B**).



TECH FIG 2 • To prevent reaccumulation of the hematoma, **(A)** a penrose drain may be stitched into place temporarily, or **(B)** a quilting stitch (with an absorbable suture) can be performed to firmly press the mucoperichondrium against the cartilage and eliminate dead space.

■ Nasal Packing

- Vaseline gauze packing is placed with or without suturing of the mucosa to the septum.

PEARLS AND PITFALLS

Bilateral hematoma incisions

- For bilateral septal hematomas, the hemitransfixion incisions should be staggered/nonopposing, as to avoid a through-and-through perforation of the septum.

Securing the cartilage graft

- To further secure the cartilage graft into the defect in an effort to avoid migration, silicone sheets can be placed on the mucosa, and mattress sutures used through the silicone sheet, mucosa, perichondrium, and cartilage graft. The sheets may be kept in place for up to 10 days.

POSTOPERATIVE CARE

- If infection was present, the patient should be monitored for fever, worsening facial cellulitis, increasing pain, and changes in mentation in the immediate postoperative period. Emergence of any of these features should prompt re-exploration of the hematoma and drainage of fluid, alteration on the antibiotic regimen, or CT scan to evaluate for intracranial involvement as necessary.
- The head of the bed should remain elevated to reduce edema and pain.
- For noninfected patients, the nasal packing and drain/wick should be kept in place for 72 hours before removal. At that time, re-evaluation is recommended to ensure no recurrence of the hematoma.
- Follow-up at 1 year is recommended to evaluate for saddle nose deformity. In children, ongoing follow-up may be necessary to assess growth of the nose.

OUTCOMES

- Large outcome studies of nasal septal hematoma treatment are not available. However, the data seem to suggest a significant rate of long-term complications.
- One study of 16 pediatric patients (7 with nasal septal hematoma, 9 with nasal septal abscess) with a mean follow-up period of 3 years found minor sequelae in 6 patients (minor cosmetic deformity, minor septal/vault alterations without airway compromise), and major sequelae in 10 patients (dorsum/tip/pyramid deformation with important cosmetic impairment, deviation of the septum with nasal obstruction, swelling of the septal cartilage, functional vault deformity, septal perforation).⁷ Another study using this classification system found a long-term complication rate of 63% patients with nasal septal hematoma and 89% in patients with septal abscess.¹
- One review of 8 articles discussing outcomes of early nasal septal reconstruction in the management of nasal septal abscess reported sequelae in 11 of the total 28 patients.⁵ These complications included underdevelopment of the nasal tip and premaxilla in one patient undergoing homologous reconstruction, minimal saddle deformity in one patient with homologous reconstruction, nonobstructing deviation of the nasal septum in four patients with homologous/exchange reconstruction, columellar retraction in one patient with autologous reconstruction, and three patients with over-rotation of the nasolabial angle after autologous reconstruction. One patient also developed saddle nose deformity, upward displacement of the anterior maxilla,

diminished vertical development of the nasal cavity, and a retrognathically positioned maxilla after reconstruction with homologous tissue.

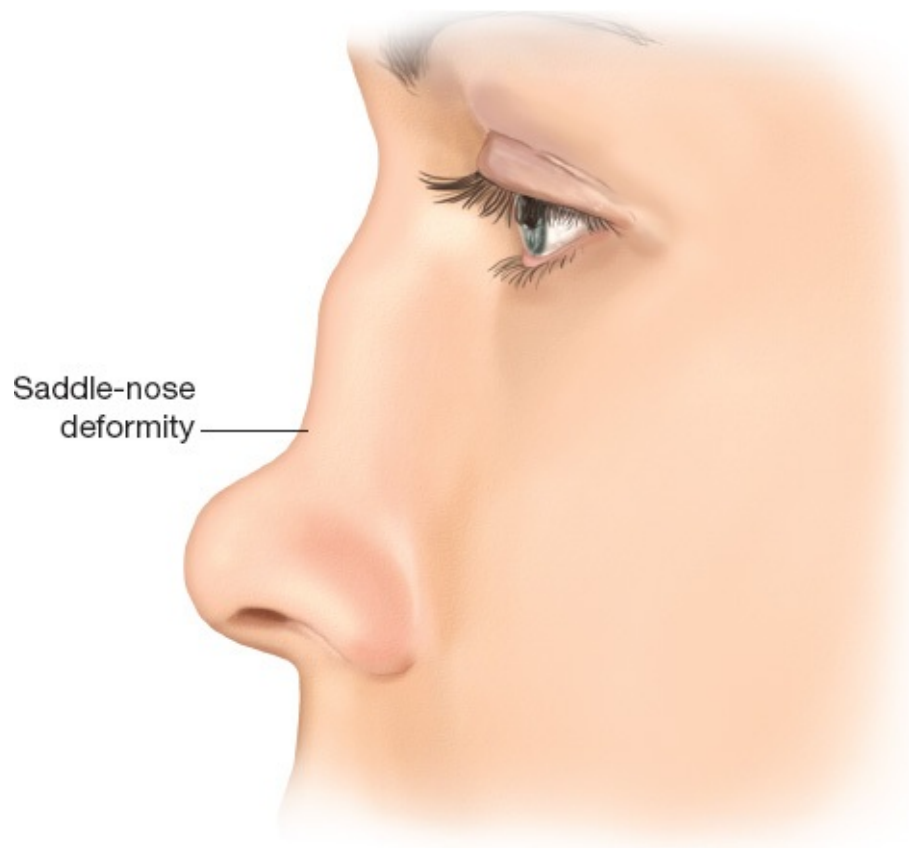


FIG 4 • The saddle nose deformity is one long-term cosmetic complication of cartilage collapse post-untreated septal hematoma.

COMPLICATIONS

- Nasal septal abscess, leading to meningitis, orbital cellulitis, intracranial abscess, cavernous sinus thrombosis, or oronasal fistula
- External deformity of the nose: saddle-nose type (**FIG 4**), tip over-rotation
- Growth inhibition of the midface in children, leading to underdevelopment of the nose and maxilla, midface retroposition, or retracted columella
- Nasal obstruction
- Septal deviation
- Septal perforation

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Section XI: Pediatric Neck Masses

46 Branchial Cleft Sinuses and Cysts

CHAPTER

Mark Felton, Jugpal S. Arneja, and Neil K. Chadha

DEFINITION

- Spectrum of congenital sinuses and cysts due to developmental anomalies in the branchial system.^{1,2}
- Account for up to 17% of cervical neck masses.³

ANATOMY

- Branchial arches are akin to ancient gill apparatus (**FIG 1**).
- Humans have five branchial/pharyngeal arches, 1 to 4 and 6 (there is no 5th branchial arch), which form craniocaudally from week 4.
- Membrane ectoderm externally and endoderm internally covers the arches.
- Cleft externally separates each arch.
- Pouch internally separates each arch.
- Each arch forms an artery, cartilaginous structure, nerve and muscle.
- Arches 1 and 3 mainly form the face, and arches 3, 4, and 6 form the neck, with 4 and 6 fusing.
- Ectodermal clefts obliterate except for the 1st branchial cleft, which forms the external auditory canal with outer side of the tympanic membrane forming the medial limit.
- Branchial pouches form various head and neck organs (Tables 1 and 2).

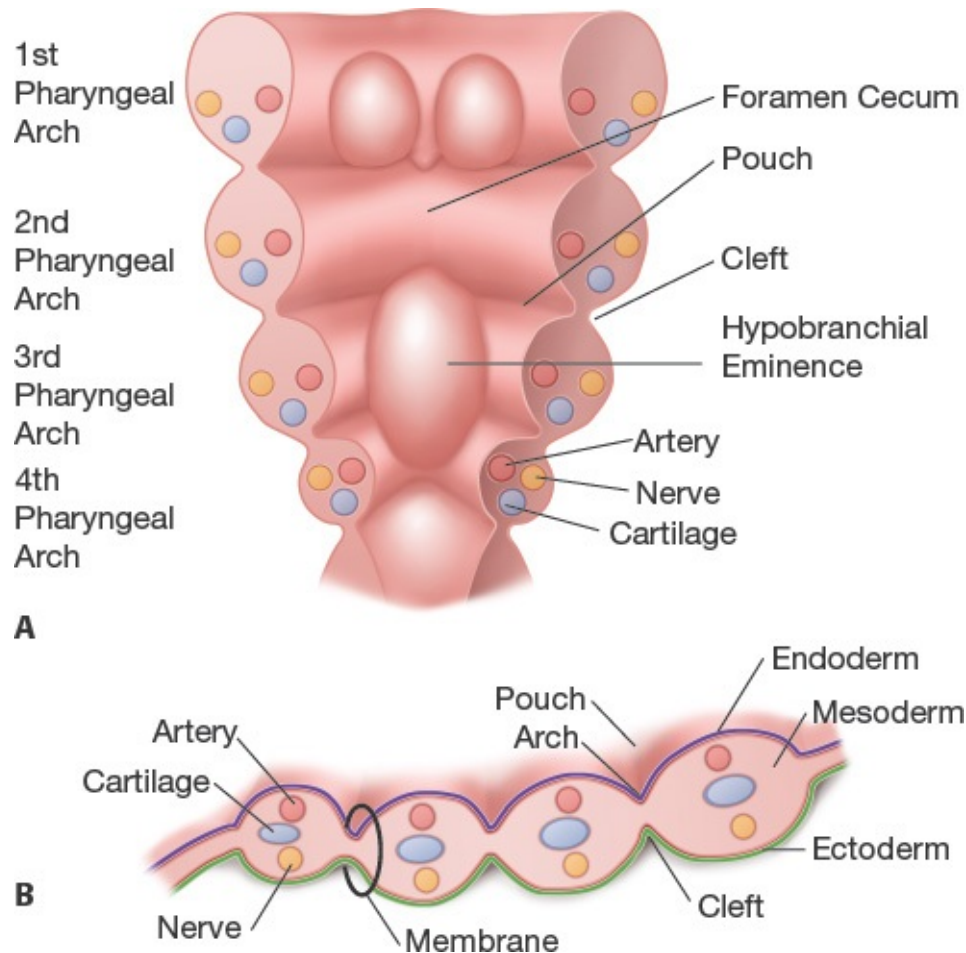


FIG 1 • Branchial arch and pouches.

PATHOGENESIS

- Failure of branchial pouch or cleft to obliterate during embryonic development can lead to fistula, sinus, or cyst formation:
 - A cyst is an epithelial-lined fluid-filled sac.
 - A sinus is a blind-ended epithelial lined tract opening on to skin or mucosa.
 - A fistula is an epithelial-lined tract connecting two surfaces (skin/mucosa).
- The resultant anomaly from failure of this process relates to the specific arch, pouch or cleft derivatives.
- The main branchial anomalies associated with sinuses and fistulae are 1st and 2nd cleft anomalies and 3rd and 4th pouch anomalies.
- Type 1 branchial anomalies are rare anomalies resulting in duplication of the external ear canal and are classified as Work's type 1 or 2.
- Branchial cleft cysts are regarded as 2nd branchial anomalies. Several theories

exist as to their origin including³:

- Lymph node inclusion theory—cystic transformation of lymph nodes
- Branchial cleft remnant theory—remnant of branchial cleft/pouch
- Thymopharyngeal duct theory—remnant of the connection between the thymus and 3rd pouch
- Cervical sinus of His theory—cyst is formed by remains of the cervical sinus.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Branchial sinuses and fistulas may present as a discharging neck punctum +/- neck swelling.
- Type 1 branchial anomaly is rare.
 - Often a late diagnosis
 - May present with a mass in parotid or submandibular region
 - Discharging neck punctum or discharging ear
- Type 2 branchial anomalies are the most common branchial anomaly.
 - Often present at or just after birth
 - External opening in the skin (punctum) along anterior border sternocleidomastoid muscle +/- discharge
- Type 3 and 4 branchial sinus
 - Neonates—lateral neck cyst/abscess +/- airway obstruction
 - Child/young adult—thyroiditis/recurrent neck abscess
 - Most commonly diagnosed in childhood (delayed diagnosis)
- Branchial cysts
 - May present as a cystic neck swelling +/- infection/abscess

Table 1 Branchial Arch and Pouch Derivatives

	Arch Derivatives				Pouch Derivatives
	Artery	Cartilage	Cranial Nerve	Muscle	
1	Part of terminal branches maxillary artery	Meckel cartilage: malleus and incus, anterior malleolar ligament, mandible template,	V—trigeminal	Muscles of mastication, mylohyoid, tensor tympani, anterior belly digastric	Tubo-tympanic recess, tympanic cavity, mastoid antrum, Eustachian tube

		maxilla, zygomatic bone and squamous temporal bone, mandible			
2	Stapedial arteries	Reichert cartilage: stapes, styloid process, stylohyoid ligament, lesser cornu, and superior body of hyoid	VII—facial	Muscles of facial expression, stapedius, stylohyoid, posterior belly digastric	Tonsils
3	Common carotid arteries, internal carotid arteries	Greater cornu and inferior part of hyoid	IX— glossopharyngeal	Stylopharyngeus	Inferior parathyroid glands and thymus
4	Left forms part of aortic arch, right forms part right subclavian artery	Laryngeal	X—vagus, superior laryngeal	Cricothyroid, pharynx constrictors	Superior parathyroid glands and possibly the calcitonin- producing cells of thyroid
6	Pulmonary arteries, ductus arteriosus	Laryngeal	X—vagus, recurrent laryngeal	Intrinsic muscles of larynx	

■ Peak age 3rd decade

- Most are located anterior to the upper part of the sternocleidomastoid muscle
- Branchio-oto-renal syndrome is an autosomal dominant syndrome with a prevalence of 1 in 40 000 people. It is caused by mutations in the *EYA1*, *SIX1*, and *SIX5* genes.⁴
- Children born with this typically have branchial anomalies, ear abnormalities (including pits, tags, atresia, hearing loss) and kidney abnormalities (including hypoplastic/absent kidneys). If suspected, these children require audiometry, an ultrasound of the renal tract, and genetic counseling.

IMAGING

- Imaging varies depending on the branchial anomaly.
- Cysts—ultrasound (USS) is obtained usually, but an MRI may be helpful when the diagnosis is not clear on USS.
- Type 1—CT to image middle ear and MRI for soft tissues and course of sinus/fistula (**FIG 2A**).
- Type 2—clinical diagnosis; usually no imaging required.
- Types 3 and 4—barium swallow/and direct laryngoscopy to assess for sinus/fistula entrance at the pyriform fossa; USS +/- MRI to assess thyroid involvement and any cystic component (**FIG 2B**).

Table 2 Pathophysiology and Sinus/Fistula Course

	1st Branchial Anomaly (Work's Type 1)	1st Branchial Anomaly (Work's Type 2)	2nd Branchial Anomaly	3rd Branchial Anomaly	4th Branchial Anomaly
Pathogenesis	1st cleft anomaly, derived from ectoderm	1st cleft anomaly, derived from ectoderm and mesoderm (cartilage and adnexal features).	2nd cleft anomaly	3rd pouch anomaly, persistence of thymobronchial canal	4th pouch anomaly, persistence of pharyngeal canal, v connection pharynx ultimobranchial body and parathyroid gland
Course	Tract runs	Tract runs from lower	Fistula, sinus or	Tract runs through the	Tract runs through the cricoid

	parallel to external auditory canal, opening medial, inferior or posterior to conchal cartilage and pinna.	more anterior in the neck than type 1, is always superior to hyoid bone, coursing over the angle of the mandible, through the parotid gland, terminating at or near the bony cartilaginous junction of the EAC, and often entering the middle ear. Has a close relationship to the facial nerve.	cyst along SCM anterior border, pass superiorly between ICA and ECA, over the hypoglossal nerve (3rd Arch) and open into the posterior pillar of tonsillar fossa (2nd pouch)	thyrohyoid membrane and above superior laryngeal nerve Opens in upper/lateral wall piriform fossa	membr: the sup larynge Opens apex of fossa
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SCM, sternocleidomastoid muscle; ICA, internal carotid artery; ECA, external carotid artery; PT, parathyroid; EAC, external auditory canal.

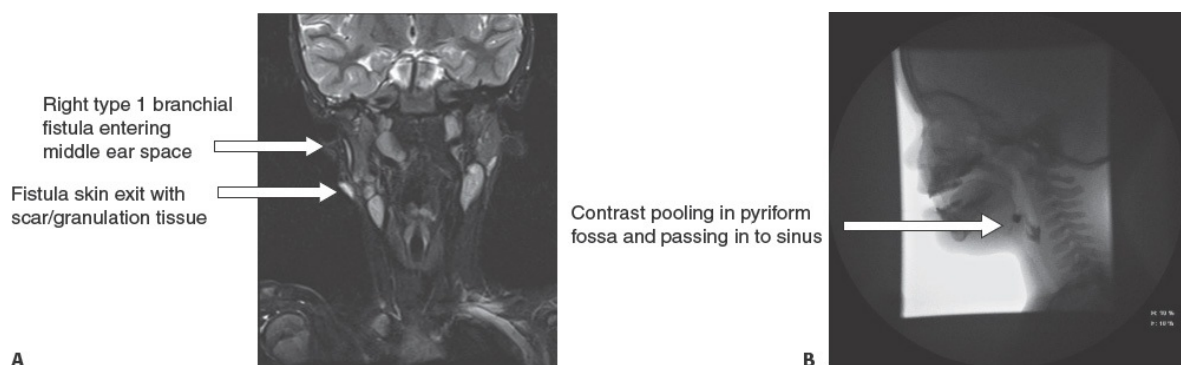


FIG 2 • A. MRI of type 1 branchial fistula. **B.** Sinogram of type 3 branchial sinus.

DIFFERENTIAL DIAGNOSIS

- Type 1 anomaly—parotitis, parotid tumor.
- For an infected/discharging type I branchial fistula, atypical mycobacterium is a differential to be considered.
- For neck swelling associated with type 3/4 branchial anomaly—lymphatic malformation, thyroiditis, abscess, lymph nodes.
- Branchial cysts—lymph nodes, abscess, lymphatic malformation, dermoid.

NONOPERATIVE MANAGEMENT

- Watchful approach may be opted for initially in very young children and those who are asymptomatic or have only minor symptoms.
- Treat any infections with antibiotics and avoid incision and drainage because this may lead to a persistent discharging fistula and/or make future surgical excision more challenging due to scarring.
- The majority will require surgical treatment.

SURGICAL MANAGEMENT

Preoperative Planning

- Review relevant imaging.
- Examine the patient preoperatively to check if the swelling/sinus/fistula is still present.
- Antibiotics are not routinely required for noninfected cases.
- Facial nerve monitoring should be used for type 1 branchial anomaly excisions.

Positioning

- Supine on head ring, with shoulder roll to extend neck
- Table in reverse Trendelenburg for hemostasis (head 30 degrees above feet)

Approach

- For branchial fistulas, type 2 branchial sinuses, and branchial cysts, the treatment of choice is open excision.
- Type 1 fistulas should be removed by a superficial parotidectomy approach. Type 1 branchial cleft fistulas may enter the middle ear or external auditory canal and therefore should be managed in conjunction with an otolaryngologist.

- For types 3 and 4 sinuses with a piriform sinus opening, the mainstay of treatment is now endoscopic sinus ablation via suspension laryngoscopy, usually performed by an otolaryngologist.⁵ If initial endoscopic treatment fails, open resection with possible hemithyroidectomy may be required.

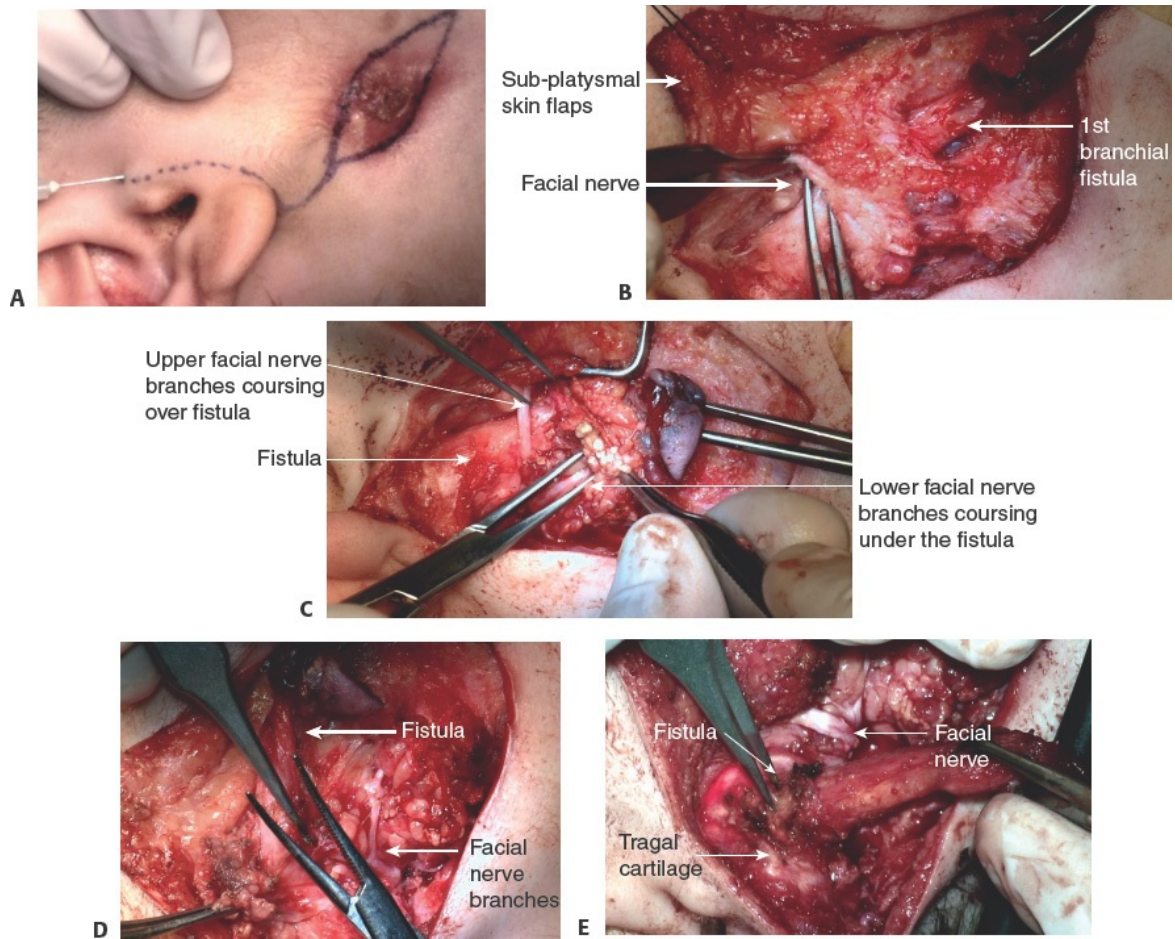
TECHNIQUES

■ Excision of Type 1 Branchial Fistula

- The facial nerve monitor is used throughout the procedure.
- Rotate the neck away from the lesion.
- The neck is prepped with aqueous Betadine. Drape the patient, leaving the ear, angle of mandible, and operated side of face exposed. The temple and side of mouth should be left exposed so as to see the facial muscles twitch, and a clear sterile drape can be used to cover the face.
- A modified parotidectomy incision (cervico-mastoid-facial incision) is marked out, descending from the anterior to the tragus, around the earlobe, continuing down the neck toward the fistula site and finishing by making an ellipse around the fistula punctum/wound.
- The incision site is infiltrated with 1% lidocaine with 1 in 100 000 epinephrine (**TECH FIG 1A**).
- The skin is then incised with a no. 15 blade, and the ellipse of the skin around the punctum is removed.
- Subplatysmal flaps are raised inferiorly and superiorly and retracted using silk stay sutures. A further stay suture is also used retract the earlobe back (**TECH FIG 1B**).
- Dissect around the fistula punctum and any inflamed tissue to reveal a fistula tract.
- Using a fine artery clip, carefully dissect the parotid gland from the tragal cartilage and mastoid tip, exposing the tympanomastoid suture.
- Next attention should be turned to finding the facial nerve by dissecting with an artery clip and microbipolar forceps over the tragal cartilage toward the tragal pointer. The fascia over the sternocleidomastoid muscle is also freed and the posterior belly of the digastric muscle is found deep to the sternocleidomastoid muscle. When dissecting over the upper 1/3 of the

sternocleidomastoid muscle, the greater auricular nerve will be encountered and the posterior branch of this nerve may need to be sacrificed (**TECH FIG 1C,D**).

- Note that the facial nerve may be displaced inferiorly and medially by the fistula. Use the facial nerve stimulator to aid in finding the facial nerve. The nerve is usually found:
 - 5 mm deep to the tympanomastoid suture
 - 1 cm deep and inferior to the tragal pointer
 - At the level of the posterior belly of digastric muscle
- This main branch of the facial nerve is traced to the bifurcation of upper and lower branches, using a fine artery clip and microbipolar forceps (or a blade) to remove the tissue superficial to the nerve. The artery clip is advanced along the nerve with blades open when dividing parotid tissue above the nerve for good visualization of the nerve. The upper and lower branches of the nerve are traced in same manor to free them from the fistula tract as required. The fistula tract will run in close proximity to the nerve, with the possibility of branches going both lateral and medial to the fistula.
- If it is difficult to find the facial nerve trunk, retrograde dissection may be performed, initially by tracing the fistula tract from the punctum and finding the nerves overlying the tract and then tracing them back to the main trunk in a retrograde fashion.
- Once facial nerve branches are dissected from both above and below the fistula, the surgery progresses to removing the fistula tract, slowly elevating the tract from over the inferior branches of the facial nerve and carefully sliding the tract from beneath any overlying branches.
- The fistula tract is dissected from surrounding tissue using microbipolar forceps and traced to its origin, which may be into tragal cartilage, the cartilaginous part of the outer external auditory canal, the bony part of the external ear canal, middle ear, or a combination of these (**TECH FIG 1E**).
- If the fistula ends at the tragus or cartilaginous canal, it can be separated from the cartilage and the area allowed to heal by secondary intention.
- If the fistula enters the bony ear canal and middle ear, which will be evident on CT scanning and preoperative examination, the case should be performed with someone skilled in Otologic surgery. Middle ear exploration, tympanoplasty, and possible bony canalplasty may need to be performed to fully remove the tract.



TECH FIG 1 • Excision of type 1 branchial fistula. **A.** Incision planned to excise scar/granulation tissue around the fistula; the skin is infiltrated with 1% lidocaine with 1 in 100 000 epinephrine. **B.** Subplatysmal skin flaps are raised, and then the priority is to locate the main trunk of the facial nerve and follow its branches. **C.** Facial nerve branches are seen coursing both over and under the fistula and are traced and freed from the fistula. **D.** The fistula is dissected from lower facial nerve branches on its undersurface. **E.** Once free from the facial nerve, the fistula is traced to its origin at the tragal cartilage and external ear canal/middle ear. The neck component of the fistula is excised prior to removing the

middle/external ear component of the fistula.

- Once the fistula is fully removed, the wound is closed. Exposed facial nerve may be covered by loosely apposing parotid tissue with 4/0 Vicryl sutures. Platysmal muscle edges are also apposed with interrupted buried 4/0 Vicryl sutures. No drain is required.
- The skin can be closed with a continuous running subcuticular 5-0 Prolene suture. Both ends of the Prolene suture should be left 1 to 2 cm long outside of the skin to facilitate removal. ¼ in. 3M Steri-Strips (St. Paul, MN) are applied to the wound with the cut ends of the suture hidden beneath.
- The patient can be discharged the same day once they are eating and drinking.
- No postoperative antibiotics are required.

■ **Excision of Type 2 Branchial Sinus/Fistula (TECH FIG 2)**

- The neck is prepared with aqueous Betadine.
- Drape the neck so as to square off the operative site, leaving the neck exposed from below the punctum to the mentum and lateral to the sternocleidomastoid muscle.
- Mark a small horizontal ellipse around the punctum.
- Inject 1% lidocaine with 1 in 100 000 epinephrine around the incision site.
- Use a lacrimal probe placed gently through the punctum to identify the sinus/fistula tract and confirm that it runs upward in the classic pattern toward the tonsillar fossa.
- Incise an ellipse of the skin around the punctum and dissect on to the tract using the microbipolar forceps. The lacrimal probe can be left in the tract to help follow the tract. Dissect along the tract superiorly using the microbipolar forceps. Keep close to the tract as it may course over the hypoglossal nerve and between the internal and external carotid arteries. If access is restricted, an endoscope or further separate superior “step-ladder” incision may be used to improve visualization of the tract.
- The tract is traced through the defect in the mylohyoid muscle. An artery clip and a 3-0 Vicryl tie are applied above the level of mylohyoid; the tract is

then cut and sent for histology.

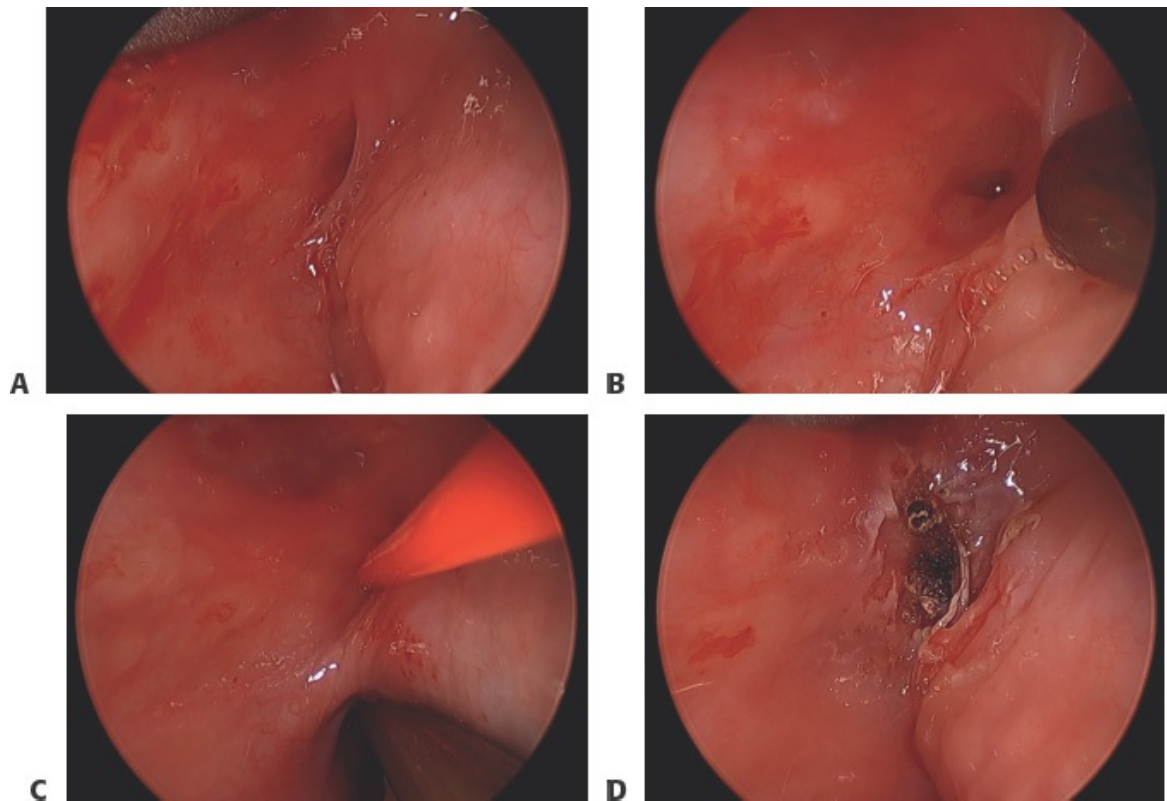
- The skin can be closed with a continuous running subcuticular 5-0 Prolene suture. Both ends of the Prolene suture should be left 1 to 2 cm long outside of the skin to facilitate removal. ¼ in. 3M Steri-Strips (St. Paul, MN) are applied to the wound with the cut ends of the suture hidden beneath.
- The patient can be discharged the same day once they are eating and drinking.
- No postoperative antibiotics are required.



TECH FIG 2 • Excision of type 2 branchial anomaly.

■ Endoscopic Management of Type 3/4 Branchial Sinuses

- The patient is intubated.
- Suspension laryngoscopy is performed using an age-appropriate Parsons laryngoscope. The laryngoscope is positioned to visualize the pyriform fossa (**TECH FIG 3A,B**).
- If a sinus is identified then a flexible bugbee monopolar cautery needle (size 4/5 French) is placed into the sinus and used to ablate the tract (set at 4–6 watts). Two to three passes of the cautery tip are usually required (**TECH FIG 3C,D**).
- The laryngoscope is then removed and the surgery complete.
- The patient is observed for any signs of airway compromise on the day unit and discharged once they are eating and drinking.
- If endoscopic ablation fails initially, it may be repeated. If revision endoscopic surgery fails, the patient will typically require open excision of the cyst/sinus/fistula with possible hemithyroidectomy.



TECH FIG 3 • Endoscopic ablation of type 3 branchial anomaly. **A,B.** Endoscopic photograph of the left pyriform fossa showing start of type 3 sinus tract. **C,D.** Ablation of the tract with Bugbee cautery (4–6 watts).

■ Excision of Branchial Cyst

- Rotate the neck away from the side of the cyst.
- The neck is prepared with aqueous Betadine.
- Drape the neck so as to square off the operative site, leaving the neck exposed from below the supraclavicular notch to the angle of the mandible and lateral to the sternocleidomastoid muscle.
- Mark a horizontal incision over the swelling but at least 2 cm below the angle of the mandible. This will avoid damage to the marginal mandibular nerve as it runs superficially.
- Inject 1% lidocaine with 1 in 100 000 epinephrine around the incision site.
- Incise the skin, through platysma and raise upper and lower subplatysmal flaps. The flaps are retracted back using either a self-retaining retractor or

silk sutures.

- Identify the anterior edge of the sternocleidomastoid muscle and instruct your assistant to retract this posteriorly.
- You should then identify the cyst. Dissect the cyst from the surrounding tissue using microbipolar forceps, being careful not to damage or puncture the cyst wall. The hypoglossal nerve, accessory nerve, jugular vein and carotid arteries may be in close proximity to the cyst and therefore dissecting on the cyst wall will avoid damage to these structures.
- Once all edges of the cyst are freed the cyst can be removed. Bipolar cautery should be used for hemostasis.
- The platysmal muscle edges are apposed with interrupted buried 4-0 Vicryl sutures. No drain is required.
- The skin can be closed with a continuous running subcuticular 5-0 Prolene suture. Both ends of the Prolene suture should be left 1 to 2 cm long outside of the skin to facilitate removal. ¼ in. 3M Steri-Strips (St. Paul, MN) are applied to the wound with the cut ends of the suture hidden beneath.
- The patient can be discharged the same day once they are eating and drinking.
- No postoperative antibiotics are required.

PEARLS AND PITFALLS

Diagnosis	■ Given the number of differential diagnoses for and complex surgical anatomy of branchial anomalies, a combination of imaging methods may be required to formulate a diagnosis. ■ The standard for diagnosing a type 3 or 4 branchial anomaly is direct laryngoscopy of the pyriform fossa under general anesthetic.
Incision	■ For type 1 fistulas use a modified cervico-mastoid-facial incision, excising the skin punctum and surrounding inflamed tissue in the same incision. ■ Place incisions parallel to or over skin creases where possible.
Hemostasis	■ Use of microbipolar forceps for cutting tissues allows accurate dissection with effective hemostasis. ■ Prior to skin closure, place patient in Trendelenburg position and ask anesthetist to perform a Valsalva maneuver on the patient to raise

	venous pressure and assist identification of any potential bleeding sites.
Dissection	■ In performing open branchial sinus/fistula or cyst excisions, stay close to and dissect on the cyst/tract to minimize damage to surrounding structures.
Closure	■ Closing the final skin layer with interrupted subcuticular 5-0 Prolene and 3M Steri-Strips (St. Paul, MN) removed at 10–14 days after surgery minimizes tissue reaction seen through use of absorbable skin sutures.

POSTOPERATIVE CARE

- Surgery is performed as outpatient surgery with discharge on the same day.
- Advice to keep wound dry.
- Postoperative antibiotics are not usually required, unless there is active infection at the time of surgical excision.
- Review with patient at 10 to 14 days with histology results and for removal of subcuticular Prolene skin suture and 3M Steri-Strips (St. Paul, MN).
- Follow up as an outpatient 3 months postoperatively.

OUTCOMES

- Recurrence rates:
 - Type 1—less than 2% although greater for middle ear involvement
 - Type 2—less than 2%
 - Type 3—The success rate for endoscopic management of pyriform fossa sinus tracts was 89.3% overall in a recent review (90.5% in primary cases and 85.7% in revision cases).⁵

COMPLICATIONS

- General—bleeding, infection
- Type 1—risk of injury to facial nerve (temporary/permanent) and potential complications from middle ear exploration (perforation tympanic membrane, hearing loss, temporary altered taste due to damage to chorda tympani nerve)
- Type 2—risk of injury to hypoglossal nerve, accessory nerve, lingual nerve
- Type 3—risk of injury to recurrent laryngeal nerve (endoscopic or open); external laryngeal nerve, parathyroid injury, hypothyroidism (open)
- Branchial cyst—vascular injury, nerve damage; marginal mandibular, vagus, hypoglossal, accessory, greater auricular

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CHAPTER Thyroglossal Duct Cysts

Mark Felton, Jugpal S. Arneja, and Neil K. Chadha

DEFINITION

- The most common congenital midline neck cyst¹
- Caused by embryological remnants of thyroid gland formation

ANATOMY

- These cysts can exist anywhere from the base of tongue to the level of the thyroid gland as they form in remnants of the thyroglossal duct (**FIG 1**).
- 75% are at the level of the hyoid bone.

PATHOGENESIS

- During week 4 of embryological development, the thyroid develops between the 1st and 2nd pharyngeal pouches from floor of the pharynx at the level of the foramen cecum (posterior 1/3 tongue) (**FIG 2**).
- This becomes a bilobed diverticulum and descends through the neck to reach final position anterior to the tracheal cartilages. As it descends through the neck, it leaves a tract.
- The tract usually atrophies after 5 to 10 weeks.
- Caudal attachment of the tract may remain as the pyramidal lobe of the thyroid.
- Failure of the tract to obliterate can lead to cyst formation at any point throughout the tract length (**FIG 3**).

NATURAL HISTORY

- Thyroglossal duct cysts are present at birth but may not be clinically apparent until enlarged secondary to infection.

- They present as a midline neck swelling most commonly in childhood and adolescents.
- 90% present as midline neck swellings only, but infection and formation of a secondary discharging sinus are possible (10%).

PATIENT HISTORY AND PHYSICAL FINDINGS

- Midline neck cyst.
- May elevate on swallowing and tongue protrusion.
- With a history of infection, there may be signs of an abscess or sinus formation with discharge.

IMAGING

- Ultrasonography of the neck and thyroid to evaluate the swelling and confirm a normal thyroid is present (**FIG 4**).
- In the absence of a thyroid gland, a thyroglossal duct cyst (TGDC) may contain the only functioning thyroid tissue.
- Nuclear imaging in the form of radioactive iodine scan can be used if there is doubt regarding normal functioning thyroid.
- Thyroid function blood tests are only required if presence of normal thyroid tissue is in question.

DIFFERENTIAL DIAGNOSIS

- Midline dermoid cyst
- Sebaceous cyst
- Midline branchial cleft cyst
- Lymph node
- Ectopic thyroid tissue
- Laryngocele
- Thyroid carcinoma within TGDC

NONOPERATIVE MANAGEMENT

- Conservative watchful waiting in children until over age 12 months
- Advise there is a risk of infection with possible sinus formation if conservative approach is taken.
- Antibiotics with possible aspiration if the cyst becomes infected and forms an abscess. It is not recommended to incise and drain an infected TGDC because this risks sinus formation with chronic discharge.

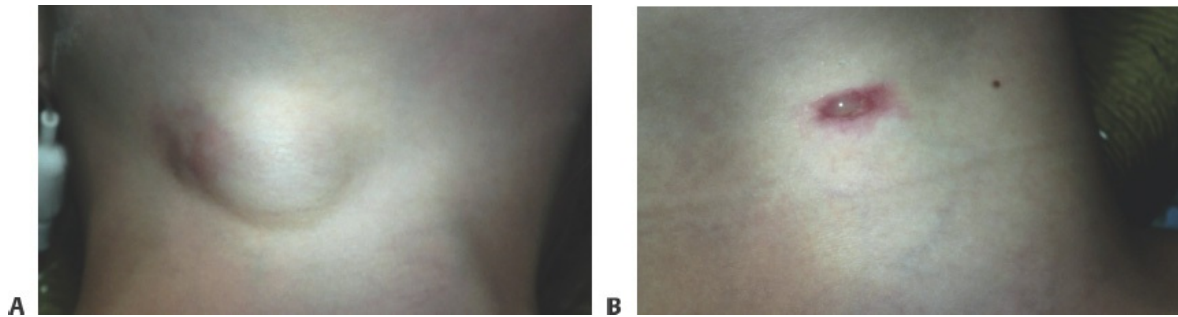


FIG 1 • Clinical photographs of anterior neck showing TGDC. **A.** Scar tissue is from previous site of infection with skin breakdown. **B.** TGDC with central discharging sinus.

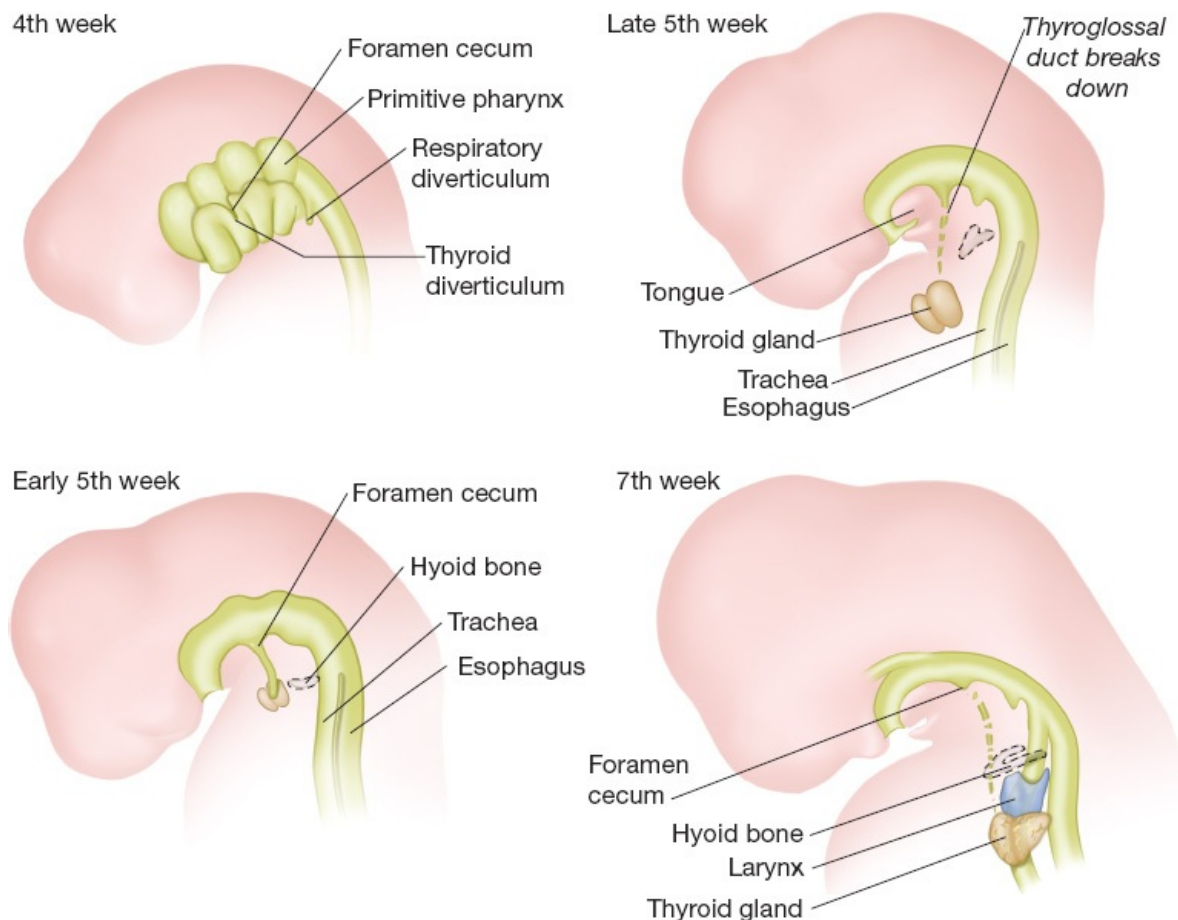


FIG 2 • Thyroid development.

- Uncommonly infection and inflammation may actually lead to closure of the residual duct and resolution of symptoms.

- Theoretical risk of malignant change of thyroid tissue within TGDC if left indefinitely, with less than 1% of excised TGDCs having a primary carcinoma on histology.²

SURGICAL MANAGEMENT

Preoperative Planning

- Review ultrasound scan result to confirm that normal thyroid tissue is present in the usual location.

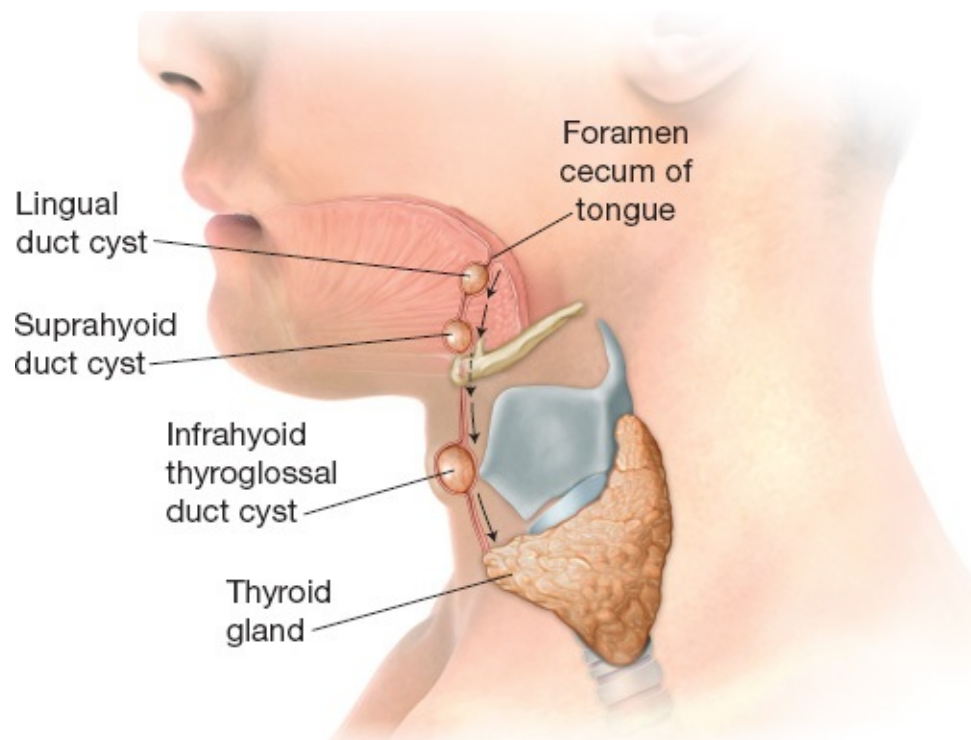


FIG 3 • Pathogenesis of TGDC development.

- Examine preoperatively to check that swelling is still present.
- Assess ideal level for placement of a transverse incision that will provide exposure from the level of the suprahyoid muscles to the superior border of the thyroid gland for removal of the TGDC (typically approximately midway between the palpable landmarks of the hyoid and upper thyroid notch).

Positioning

- Supine on head ring, with shoulder roll for neck extension
- Table in reverse Trendelenburg for hemostasis (head 30 degrees above feet)

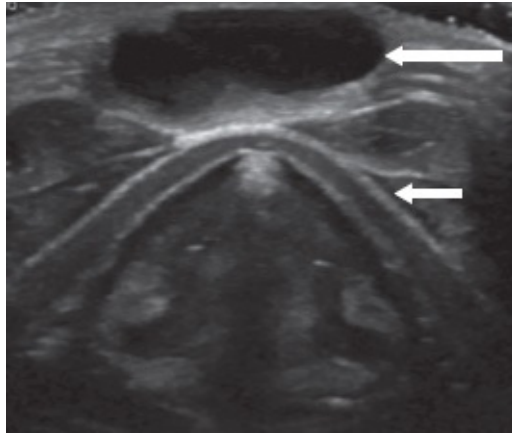


FIG 4 • Ultrasound scan of TGDC (*long arrow*) overlying thyroid cartilage (*short arrow*).

TECHNIQUES

■ Modified Sistrunk Procedure

Preparation of the Neck and Wound Incision

- Antibiotics are not indicated for routine noninfected cases.
- The neck is prepared with aqueous Betadine.
- Drape the neck so as to square off the operative site, leaving the neck exposed from the mentum to below the sternoclavicular notch and the sternocleidomastoid muscles laterally.
- Mark the site of horizontal incision over the cyst, ideally midpoint between the hyoid and thyroid notch so as to allow adequate access to both the suprahyoid muscles and the pyramidal lobe of the thyroid. Initially, plan to incise skin to incorporate the width of the cyst only in case it is identified to be a dermoid cyst, in which case following a tract superiorly and inferiorly is not required and cystectomy is adequate (**TECH FIG 1A,B**)
- Inject 1% lidocaine with 1 in 100 000 epinephrine around the incision site.
- An incision is made through the skin and subcutaneous tissue. Subplatysmal flaps are elevated both superiorly to above the level of the hyoid and inferiorly to below the level of the cricoid cartilage (**TECH FIG 1C**). Take care with this step as the cyst can be superficial, making it easy to puncture, which is more likely if the cyst is large and under pressure. If a cyst is

punctured, the dissection can continue with a clip on the cyst capsule at the puncture site.

Exposure of Thyroglossal Cyst and Tract

- Once the cyst is exposed, if clinically it is a dermoid and there is no obvious tract or surrounding attachments, the cyst can be removed and skin closed. Otherwise, the cyst can be left alone and dissection of the tract performed next, with widening the skin incision for better access if required (**TECH FIG 2A**).
- Identify the infrahyoid strap muscles, usually below the cyst. Identify the midline and carefully separate the right and left strap muscles, the more superficial muscle being sternohyoid and deeper muscle being sternothyroid (**TECH FIG 2B,C**).
- Carefully dissect along the medial edge of the sternohyoid and sternothyroid muscles if necessary, separating them from the cyst. Carefully expose the medial border of the length of the infrahyoid strap muscles from their hyoid attachment superiorly as far inferiorly as the superior border of the thyroid gland. Any tissue between the infrahyoid strap muscles will be removed in continuity with the cyst and will contain the inferior tract if present.
- Look for an inferior component of the thyroglossal duct extending inferiorly from the cyst, which extends to the pyramidal lobe of the thyroid gland. If the duct extends down to the thyroid gland, remove a small cuff of pyramidal lobe with the specimen. Even if the tract is not clearly visible, it will be safely removed by removing all the tissue between the strap muscles from the cyst down to the pyramidal thyroid lobe inferiorly.

Hyoid and Tongue Base Dissection, With Specimen Excision

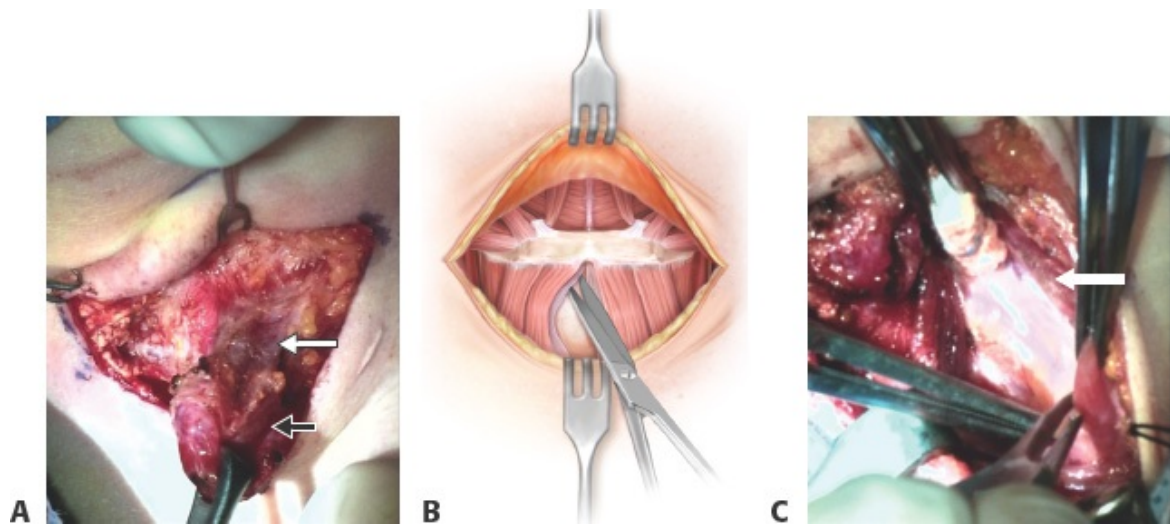
- After completion of this inferior dissection, ensure that the medial borders of the infrahyoid strap muscles are identified and exposed up to their attachments to the hyoid bone. The infrahyoid strap muscles are often adherent to the cyst just inferior to the hyoid bone. When there has been previous infection, a small portion of infrahyoid strap muscle may need to be left attached to the cyst and removed with the cyst and specimen. A tract arising from the superior aspect of the cyst may be seen passing into the hyoid bone, although the whole cyst may be adherent to the hyoid mid-portion.
- The superior muscular attachments of the hyoid bone (predominantly the

mylohyoid and geniohyoid) are then detached from the midportion of the hyoid bone superiorly, using the medial borders of the infrahyoid strap muscle attachments as a guide to how far to laterally dissect superiorly, thereby avoiding the hyoid lesser horns and the hypoglossal nerve.

- The central portion third of the hyoid bone is resected by cutting through the hyoid. It is imperative that this cut is precisely vertical and level with the medial borders of the infrahyoid strap muscles, lateral to the cyst or cyst tract if identified. An Allis forceps holding the central portion of the hyoid bone can help stabilize the bone. In small children, bipolar forceps are often sufficient to cut through the noncalcified hyoid, but in older children/adolescents/adults, straight Mayo scissors or even bone cutting forceps may be required cut through the hyoid bone. Cautery and bone wax can be used to stop any bleeding from the cut edges of the hyoid (**TECH FIG 3A,B**).

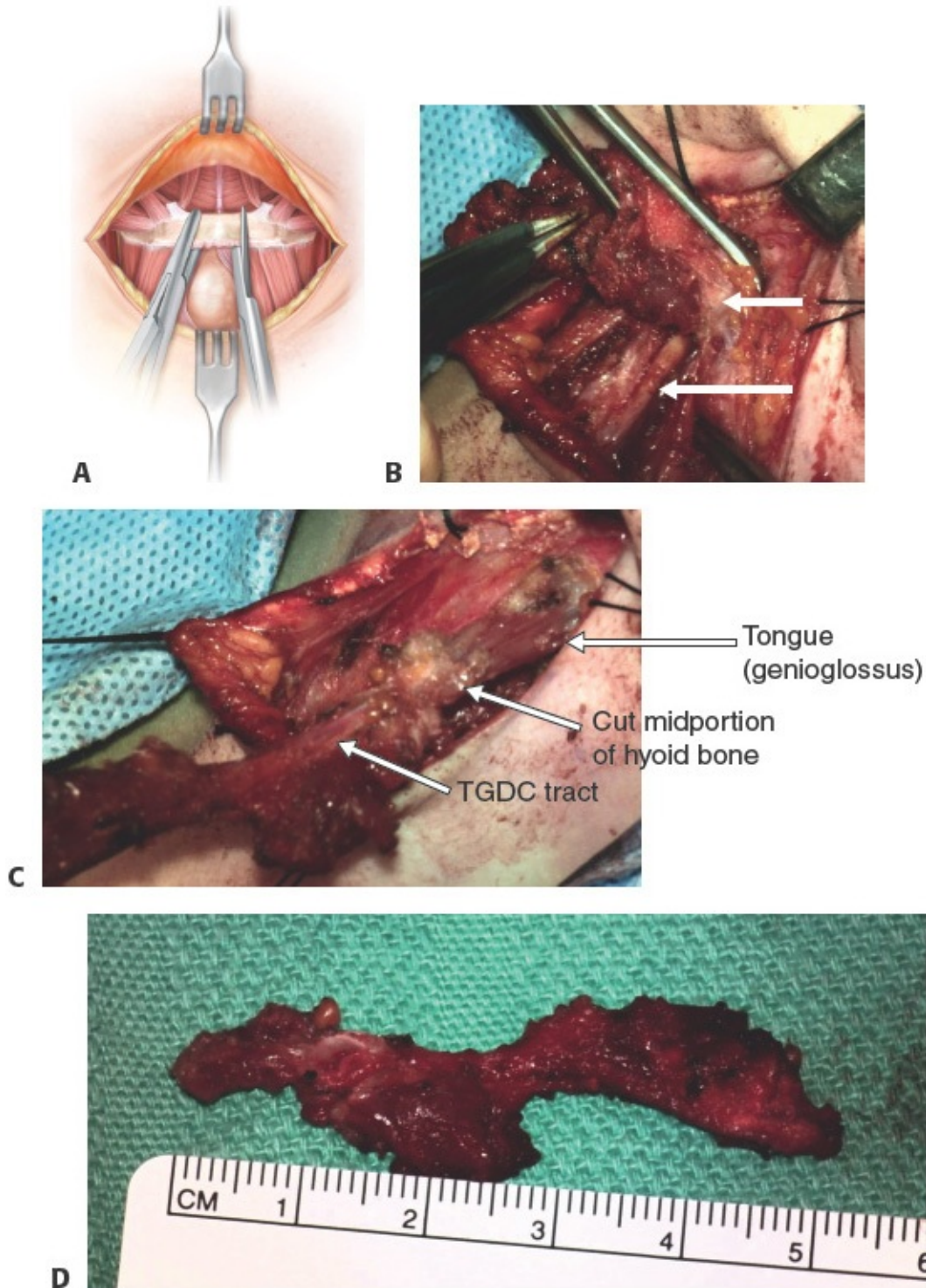


TECH FIG 1 • **A.** Position of TGDC, relations of the duct and position for surgical incision (midline collar incision), with the duct running through the hyoid bone and ending at pyramidal lobe of thyroid. **B.** Midline collar skin crease incision. **C.** Subplatysmal skin flaps are raised.



TECH FIG 2 • **A.** Midline dissection on the TGDC (*black arrow*) and tract (*white arrow*). **B.** Dissecting out the TGDC. **C.** The strap muscles are separated in the midline. *Arrow* indicates sternohyoid muscle.

- Now the inferior tract, cyst, and hyoid bone are free of the surrounding tissue; a superior tract arising from the superior and posterior aspect of the hyoid may be seen running into the tongue base. If present, the tract should be dissected from the surrounding tissue and followed up to the tongue base. A cuff of tongue muscle (genioglossus muscle) should always be taken with the midportion of the hyoid and the specimen to complete the excision and minimize risk of a residual superior tract. There is no need to excise tongue muscle in complete thickness through to the oropharynx, as originally described by Sistrunk (**TECH FIG 3C,D**).



TECH FIG 3 • A. Division of mid third of hyoid bone. **B.** The tract is traced to the hyoid and the hyoid (*short arrow*) is cut either side of tract in line with the medial edge of the thyrohyoid muscles (*long arrow*). **C.** A cuff

of tongue muscle is taken with the specimen. **D.**
Specimen.

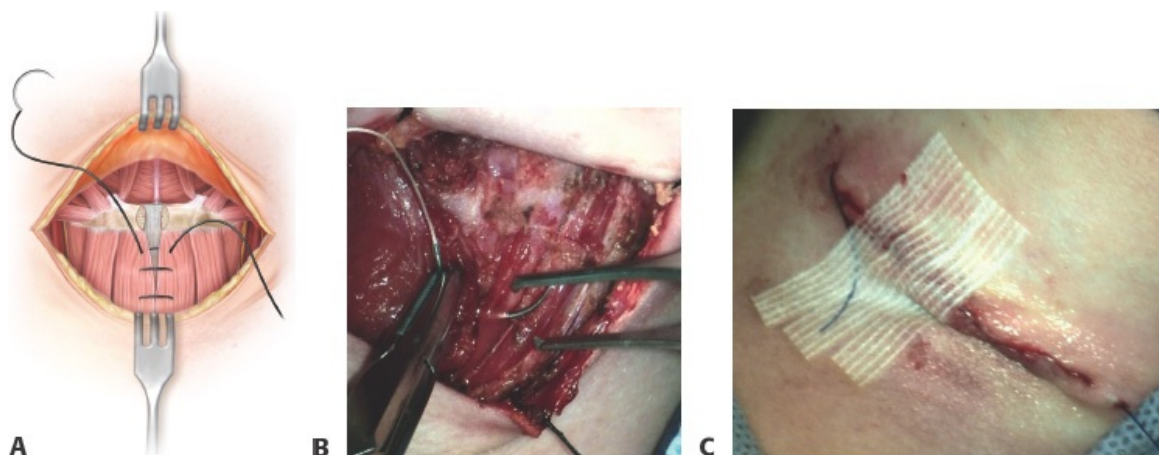
- Attention should then be focused on ensuring meticulous hemostasis. The patient should be placed in the Trendelenburg position (30 degrees head down) and saline wash poured in to the wound. A prolonged Valsalva maneuver by the anesthetist will reveal any further bleeding points for cauterization.

Wound Closure

- The operating table is then placed in a neutral position for wound closure.
- The strap muscles are apposed with 4-0 Vicryl and the skin flaps closed with interrupted buried 4-0 Vicryl sutures. No drain is required (**TECH FIG 4A,B**).
- The skin can be closed with a continuous running subcuticular 5-0 Prolene suture. Both ends of the Prolene suture should be left 1 to 2 cm long outside of the skin to facilitate removal. ¼ in. Steri-Strips are applied to the wound with the cut ends of the suture hidden beneath (**TECH FIG 4C**).
- The patient can be discharged the same day once they are eating and drinking.
- No postoperative antibiotics are required.

Modifications of the Procedure

- Skin sinus tract—A skin ellipse around the sinus and ellipse of tissue around the sinus tract is taken, which should be taken in continuation with the rest of the dissection of the thyroglossal cyst. This may lead to the horizontal incision site being more superior than ideal, and the incision therefore is lengthened to facilitate the inferior access.
- Recurrent cysts—En-bloc wide local of excision around the recurrent cyst, taking a core of strap muscle on either side down to pretracheal fascia.



TECH FIG 4 • A. Suturing of infrahyoid muscles. **B.** Strap muscles reapproximated with 4-0 Vicryl sutures. **C.** Skin is closed with 5-0 Prolene and Steri-Strips.

PEARLS AND PITFALLS

Incision	Initially only make your incision the width of the swelling until the diagnosis is confirmed in case it is a dermoid cyst, for which a smaller incision will suffice. Once a dermoid cyst is excluded, the incision can be widened.
Hemostasis	- Use of microbipolar forceps for cutting tissues allows accurate dissection with effective hemostasis. - Prior to skin closure, place patient in Trendelenburg position and ask anesthetist to perform a Valsalva on the patient to raise vascular pressure and assist identification of any potential bleeding sites. Bone wax can help oozing from edges of cut hyoid bone.
Dissection	- Actively look for any extension of the cyst/duct toward the pyramidal lobe and remove a cuff of the pyramidal lobe if the duct is in continuation. - Dissect along the medial aspect of strap muscles on to the hyoid bone. Remove the hyoid at the level of the medial aspects of the strap muscles to avoid damage to the hypoglossal nerve. - Look for a tract extending from the hyoid to the tongue base, dissect along this, and remove a cuff of tongue base with the specimen.
Closure	Closing final skin layer with interrupted subcuticular 5-0 Prolene and

Steri-Strips removed at 10–14 days after surgery minimizes tissue reaction seen through use of absorbable skin sutures

POSTOPERATIVE CARE

- Day case surgery
- Advice to keep wound dry
- Review 10 to 14 days with histology and for removal of Prolene skin suture and Steri-Strips
- Follow up outpatients 3 months

OUTCOMES

- Recurrence rate of 0% to 3% for modified Sistrunk as described above may be much higher with other techniques such as cystectomy only.^{1,3}

COMPLICATIONS

- Bleeding, infection, hypertrophic/keloid scar
- Accidental pharyngostomy
- Hypoglossal nerve injury
- Recurrence—treat with en-bloc wide local excision

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Section XII: Facial Reanimation

48

CHAPTER Sural Nerve Harvest

Andre P. Marshall, Jeffrey R. Marcus, and Michael R. Zenn

DEFINITION

- The sural nerve is a lower limb sensory nerve that provides sensation to the lateral and posterior distal third of the leg, lateral calcaneal region, lateral foot, and small toe.¹
- The sural nerve is easily accessible, has several large fascicles, and is the donor nerve most commonly used in peripheral nerve reconstructive surgery.^{2,3}
- Unilateral sural nerve harvests can provide up to 40 cm of autogenous nerve graft.

ANATOMY

- The sural nerve is a sensory nerve that begins in the lateral aspect of the foot and coalesces from branches between the Achilles tendon and lateral malleolus.
- The nerve splits into the medial and lateral cutaneous nerves of the leg along the posterior leg.
- The larger contributor, the medial sural cutaneous nerve, arises from the tibial nerve in the popliteal fossa between the medial and lateral heads of the gastrocnemius.⁴
- The sural nerve runs deep to the investing fascia down the posterior calf between the two heads of the gastrocnemius muscle and then subcutaneously in the distal third of the leg.
- It can be found close to, but deep to, the lesser saphenous vein to the ankle.
- It is consistently found in the space between the lateral malleolus and the calcaneus tendon.²⁻⁵

PATIENT HISTORY AND PHYSICAL FINDINGS

- Any history of prior lower extremity operation, either open or endoscopic, should be elicited from the patient.
- Physical exam should note any scars or prior incisions on the lower extremities, or numbness or paresthesias in the distribution of the sural nerve.

IMAGING

- Prior to sural nerve harvesting, no imaging of the lower extremities is necessary.

SURGICAL MANAGEMENT

Preoperative Planning

- Preoperatively, a comprehensive history and physical exam should be performed. It is imperative to note any prior lower extremity trauma, fractures, or previous operations.
- Patients should be counseled on the expected postoperative outcomes of cutaneous sensory loss in the sural nerve distribution.

Positioning

- The donor limb is placed in flexion at the knee.
- A bump, sandbag, or roll under the ipsilateral buttocks provides additional access to the posterior leg.
- In children, prone positioning is usually preferred and well tolerated.

Approach

- Open
- Endoscopically assisted

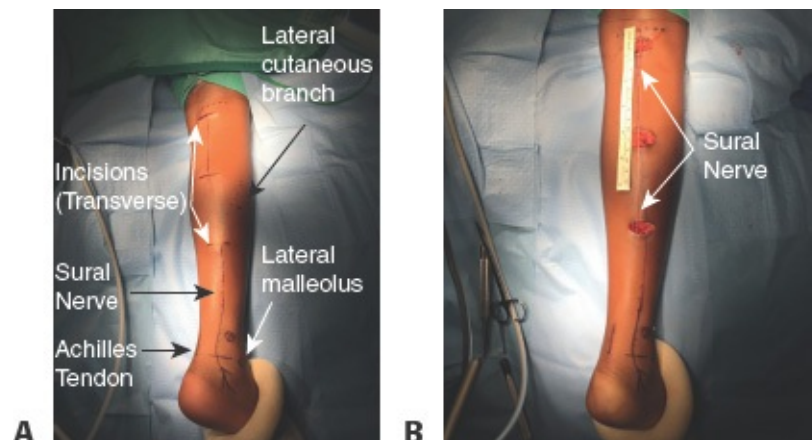
TECHNIQUES

■ Stair-Step Incisions



Video p8-c048

- The patient is placed in supine or prone position (**TECH FIG 1A**).
- An endoscope can be used to facilitate dissection.⁶
- A pneumatic tourniquet (optional) is placed around the thigh and the leg exsanguinated in the usual fashion prior to incision.
- A 2- to 3-cm transverse or vertical incision is made in the groove made by the lateral border of the Achilles tendon at the level of the lateral malleolus.
- The lesser saphenous vein is seen, retracted, and preserved.
- Blunt dissection is used to identify the nerve.
- The nerve is dissected of all surrounding tissue moving superior along the posterior calf.



TECH FIG 1 • **A.** Preoperative markings and an outline of the sural nerve and its lateral cutaneous

branch are shown. The proposed transverse incisions are shown in addition to the Achilles tendon and lateral malleolus. **B.** The sural nerve is shown following harvest along the transverse incisions.

- At approximately 10 cm, an additional 2- to 3-cm transverse incision is made more proximally along the course of the nerve.
- Proximal and distal dissection of the nerve is made through each incision.
- Up to two additional transverse incisions are made along the course of the nerve until adequate length is obtained.
- The nerve is transected at the popliteal fossa and removed from the leg (**TECH FIG 1B**).
- Incisions are closed in standard fashion, in a minimum of two layers with absorbable sutures.
- No drain tubes are necessary.

■ Harvest With a Tendon Stripper^{4,7}

- A pneumatic tourniquet is placed around the thigh and the leg exsanguinated in the usual fashion.
 - A 2- to 3-cm transverse or vertical incisions is made in the groove made by the lateral border of the Achilles tendon at the level of the lateral malleolus.
 - The lesser saphenous vein is seen, retracted, and preserved.
 - Blunt dissection is used to identify the nerve, and then transecting it up to 5 cm distal to the incision to gain additional length.
 - The cut end of the nerve is passed through a tendon stripper.
 - Mild traction is placed on the nerve, and the tendon stripper is passed proximally until its tip can be felt in the subcutaneous tissues near the popliteal fossa.
 - The stripper is twisted and counter-pressed until the nerve is felt to give way and able to slide out of the ankle wound.
 - Optionally, the leading edge of the tendon stripper is tented against the skin, a stab incision is made, across the end of the stripper to divide the nerve.
-

PEARLS AND PITFALLS

Anatomy	■ The sural nerve has many variations during its course. ■ The surgeon must be aware of the variable sural anatomy, particularly the branches of the medial and lateral cutaneous nerves.
Positioning	■ Sural nerve harvest can be done in either supine or prone position. In children, prone positioning is well tolerated and can better facilitate exposure and shorten harvest time.
Dissection	■ Avoid excessive circumferential dissection, which may place the nerve at greater risk of injury. ■ Superficial dissection is usually adequate to facilitate release from the overlying subcutaneous tissues.
Graft processing	■ In most cases, the graft is used intact. ■ Splitting of the graft into multiple grafts and preserving fascicles longitudinally has been described but is not practiced in our unit.

POSTOPERATIVE CARE

- Elastic bandages from the foot to the knee are placed and used to provide compression and help decrease hematoma formation. They are left in place for 48 hours and used thereafter for control of swelling as needed.
- Patients are encouraged to begin ambulation on postoperative day 1 to help reduce the risk of deep venous thrombosis. Full activity restrictions are kept in place for 2 weeks or dictated by the concurrent grafting procedure at the recipient site.
- Pain is minimal and managed with a combination of narcotic and non-narcotic analgesic medications.

OUTCOMES

- Scars should be expected at the donor site and are permanent. Regular scar management is recommended.
- The area of paresthesia and numbness in the ankle and foot is likely permanent but may decrease in size over time due to contributions from surrounding intact nerves.¹

COMPLICATIONS

- Postoperative complications are infrequent but include proximal neuroma formation, hematoma, and deep venous thrombosis. We have not seen cellulitis

in our patient cohort, but it is possible.

- The iatrogenic sensory nerve deficit along the lateral foot should be expected and is not considered a complication. It is generally well tolerated by patients and should be discussed preoperatively.

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Cross Face Nerve Graft

CHAPTER

Michael J. A. Klebuc

DEFINITION

- Cross face nerve graft—interposition nerve graft utilized to transmit facial nerve motor axons from a neurologically intact to a paralyzed/paretic, contralateral hemiface.
- Utilized to restore motor innervation to denervated muscles of facial expression and to neurotized free, functional muscle flaps, also can be employed for sensory restoration.
- Frequently utilized sources of nerve graft (sural nerve, saphenous nerve, medial antebrachial cutaneous nerve).
- Approximately 50% of a facial nerve's zygomatic and buccal branches can be selectively transected and their function redirected to the paralyzed hemiface without producing significant donor weakness (functional reserve).
- The facial nerve is the only donor nerve that can consistently restore spontaneous, emotionally mediated facial motion.

ANATOMY

- Facial nerve (somatic motor efferent component)—innervates the muscles of facial expression, auricular muscles, occipitalis, posterior belly digastric, stylohyoid, and stapedius.
- The facial nerve main trunk emerges from the skull base via the stylomastoid foramen where it can be identified coursing 1 cm deep to the tragal pointer and medial to the posterior belly of the digastric muscle.¹
- Within the parotid gland, the facial nerve divides into a temporofacial and cervicofacial trunk.
- Distal branches exit the parotid on its anteromedial surface.

- The following branches innervate the corresponding muscles of facial expression²:
 - Frontal branch—frontalis muscle
 - Zygomatic branches—orbicularis oculi, zygomaticus major, zygomaticus minor, levator labii superioris, levator labii superioris alaeque nasi, corrugator supercilii, procerus
 - Buccal branches—buccinator, risorius, orbicularis oris
 - Marginal mandibular branches—depressor anguli oris, depressor labii inferioris, mentalis
 - Cervical branches—platysma
- Muscles of facial expression are innervated on their deep surface with the exception of the levator anguli oris, buccinator, and mentalis.
- Zuker point describes the approximate location of the facial nerve branch supplying the zygomaticus major (**FIG 1**):
 - Midway point of a line drawn from the root of the helix to the lateral commissure.
 - Preferentially divided and coapted to a cross facial nerve graft (CFNG) as the first step in a two-staged free, functional muscle flap reconstruction.³

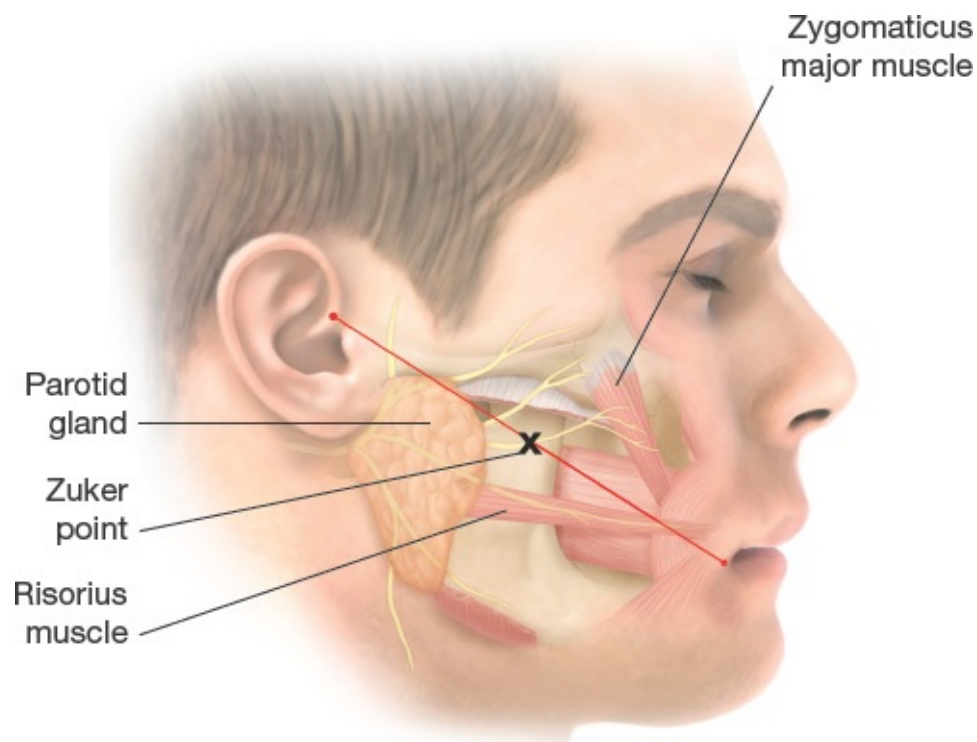


FIG 1 • The facial nerve branch supplying the zygomatic

major is typically found at a point halfway between the root of the helix and the commissure (Zuker point).

- Pitanguy line describes the course of the frontal branch of the facial nerve. The line extending 0.5 cm below the tragus to 1.5 above the lateral brow with the nerve running on the undersurface of the temporoparietal fascia.⁴
- The marginal mandibular branches—consistently lie on top of the facial artery and vein 1 to 3 cm below the mandibular border.⁵

NATURAL HISTORY

- Axonal growth through the cross face graft proceeds at approximately 1 mm/d.
- Ten to twelve months is typically required for the axons to traverse the graft.
- After 18 months of denervation, mimetic muscles undergo significant atrophy and poor functional outcomes are associated with nerve grafting.
- A narrow time window is present for the use of cross face nerve grafts as an isolated procedure to restore innervation to the paralyzed muscles of facial expression.
- The therapeutic window of CFNG is enhanced by the addition of a nerve “babysitter.”⁶
 - Transfer of an adjacent cranial nerve to the injured facial nerve to achieve rapid reinnervation and motor end plate preservation.
 - Partial hypoglossal-to-facial nerve transfer with an interposition jump graft and secondary selective facial nerve branch transection and distal end-to-end repair to CFNG.
 - Masseter-to-facial nerve transfer with immediate CFNG and distal end-to-end and/or end-to-side coaptation.⁷

PATIENT HISTORY AND PHYSICAL FINDINGS

- Etiology of the facial paralysis:
 - Developmental
 - Traumatic
 - Post-tumor extirpation
 - Bell palsy
 - Ramsay Hunt syndrome
- Duration of paralysis:
 - Denervation periods greater than 18 months are associated with poor

functional recovery (irreversible muscle atrophy) without utilization of a muscle flap.

■ Patient age:

- Peripheral nerve regeneration declines with advanced age.
- There is no definitive age cut off for cross face nerve grafting; however, after the age of 50 to 55 years, the ipsilateral motor nerve branch to masseter or other adjacent cranial nerves often provide a more reliable source of innervation to free muscle flaps with more powerful muscle flap contraction.

■ Comorbidities impairing nerve regeneration:

- Smoking—higher risk of skin flap necrosis
- Diabetes
- Vascular disease
- Previous radiation
- Neurologic disorders

■ History of hypercoagulable state:

- Patient or family history of pulmonary emboli or deep venous thrombosis signal the need for a hematologic workup if a subsequent free, functional muscle flap is planned.

■ Physical Examination

- A strong smile, normal blink, forceful eye closure, good lip pucker, and depression without synkinesis should be present on the donor hemiface.
- Perform a complete cranial nerve exam to look for additional deficits.
- Examine the eye on the paralyzed side for signs of exposure keratitis.
- Look for previous incisions that could compromise perfusion to the cheek flaps elevated during facial nerve exploration.
- Palpate and Doppler the superficial temporal and facial artery and veins on the paralyzed hemiface if a subsequent free, functional muscle flap is planned.
- Palpate lower extremity pulses if sural or saphenous nerve grafts are to be harvested to rule out peripheral vascular disease.
- The progressive growth of axons through the CFNG can be monitored by eliciting a Tinel sign.
- An active Tinel sign at the distal end of the cross face nerve graft suggests signals readiness for the next phase of the reconstruction.

IMAGING

■ MRI of brain and facial nerve

- High-resolution multiplanar T1 and T2 images, gadolinium-enhanced, fat-

suppressed, and internal auditory canal (IAC) protocol

- Used to evaluate injury to the facial nerve (ie, Bell palsy, tumors, stroke)
- Computed tomography
 - 0.625-mm or thinner axial images, reconstructions in coronal plane
 - Valuable for imaging temporal bone fractures
- CT angiogram
 - Useful for evaluating possible sites for microvascular anastomosis in patients with multiple head-neck surgeries or developmental differences including hemifacial microsomia.
- EMG of the facial nerve
 - Look for signs of early facial nerve recovery.
 - Look for signs of reversible muscle atrophy.

SURGICAL MANAGEMENT

Preoperative Planning

- Facial nerve EMG is obtained to evaluate for irreversible mimetic muscle atrophy.
- Facial nerve imaging as guided by the etiology of the paralysis (MRI, CT, CT angiogram).
- Determine the number of cross face nerve grafts to be utilized and evaluate the potential nerve graft donor sites.
- Discontinue smoking and nicotine products.
- Discontinue anticoagulants.

Positioning

- Supine on the operating table with narrow head extension.
- Head on foam or gel-filled headrest.
- Nasotracheal intubation with endotracheal tube sutured to nasal columella and supported on the hair-bearing scalp with foam, silk tape and staples (**FIG 2**) or an Oral RAE tube secured to the lower dentition with a 2-0 silk Ivy loop suture.
- Oral cavity cleansed with chlorhexidine gluconate mouth wash.
- Sterile tourniquet applied to the thighs.
- Sterile calf sequential compression devices.

Approach

- Preauricular approach is most frequently employed.
 - Aesthetically favorable access incision especially in children and young adults
 - Permits dissection of all facial nerve branches facilitating nerve stimulation, creating of a functional map and optimal donor nerve selection
 - Allows retrograde dissection of selected facial nerve branches into the parotid gland to enhance axonal concentration
- The nasolabial fold approach is infrequently used.
 - Unaesthetic scarring in children and young adults.
 - Limited ability to select the optimal donor nerve branch.
 - Access to only distal nerve branches with more limited axon counts.



FIG 2 • Nasotracheal intubation with head positioned on a narrow head-rest. Endotracheal tube sutured to columella and supported with foam to prevent pressure on the nasal alae.

TECHNIQUES

■ Exposure and Flap Elevation

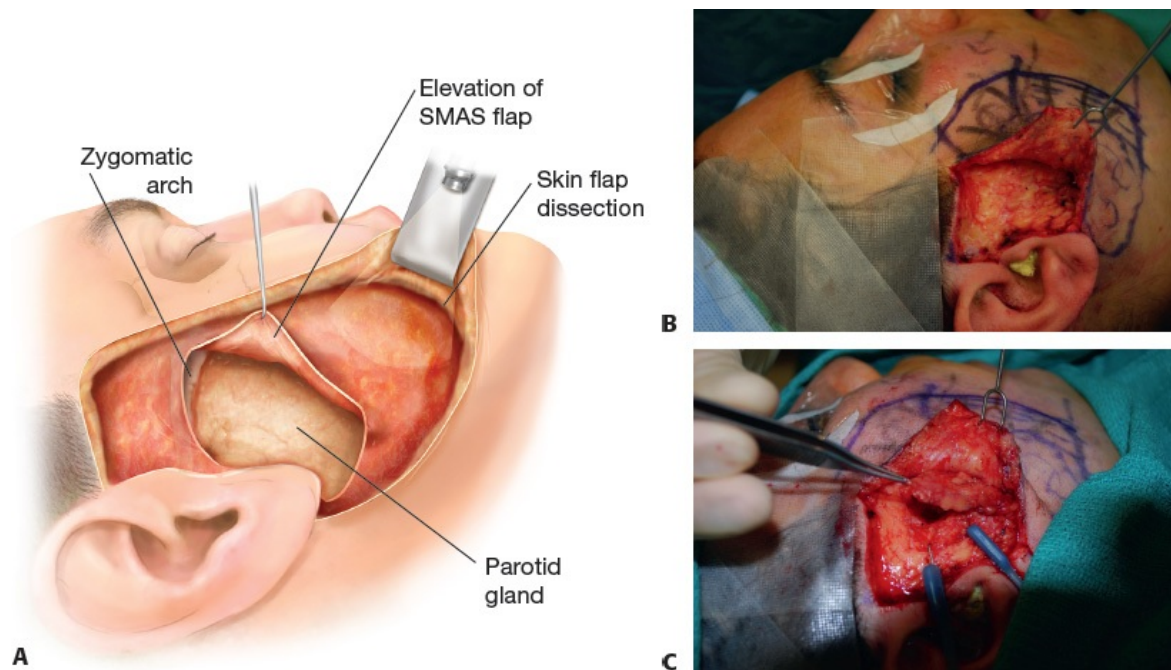
- The anterior border of the masseter muscle is palpated and marked.
- A pretragal, incision with an extension into the sideburn is now marked with a surgical pen.
- An additional point is marked half way between the root of the helix and the

commissure to indicate the general location of the facial nerve branch to the zygomaticus major muscle (Zuker point) (**TECH FIG 1**).³

- A petrolatum gauze dressing is used to occlude the external auditory canal.
- The subcutaneous tissues in the preauricular, zygomatic, and buccal regions are infiltrated with a 1:100 000 epinephrine, hemostatic solution (local anesthetics should be avoided).
- The preauricular incision with the sideburn extension is made and a skin and subcutaneous tissue flap is elevated in the preauricular, zygomatic, and buccal regions caring the medial aspect of the dissection approximated 3 cm past the medial border of the masseter muscle.
- An SMAS flap is now elevated with scissor dissection and bipolar cautery.
 - The flap is mobilized to the anteromedial border of the parotid gland where the zygomatic and buccal branches of the facial nerve are identified.
 - The SMAS flap is released transversely along the inferior zygomatic border and reflected to facilitate exposure (**TECH FIG 2**).



TECH FIG 1 • Operative markings. **A.** Preauricular incision with a possible submandibular extension (X) marks Zuker point and the *dashed lines* represent the region of skin flap elevation. **B.** Markings shown on the patient in the sample case.

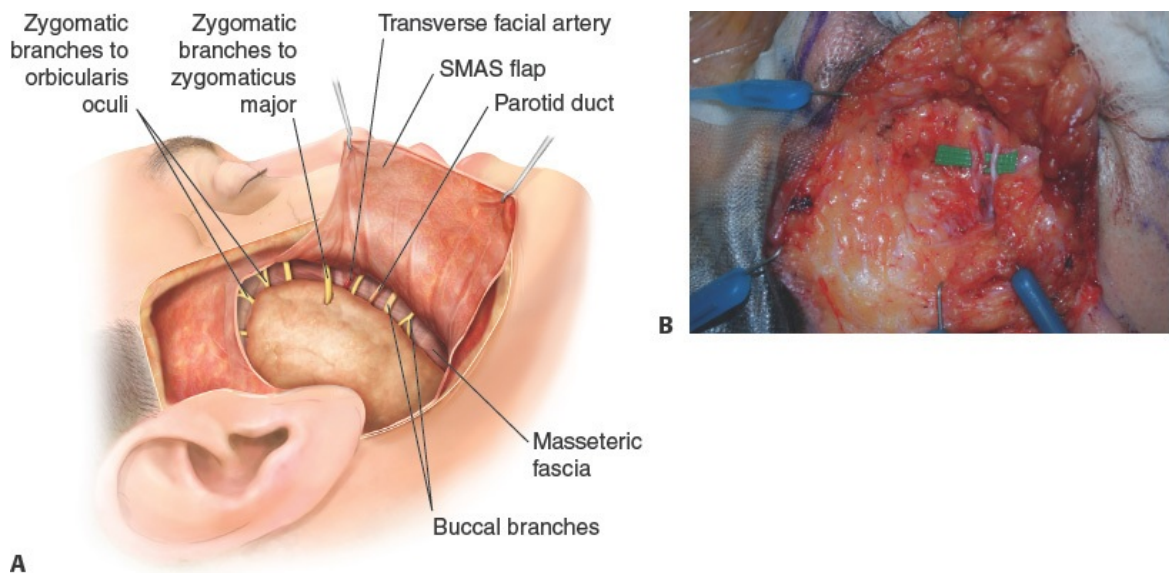


TECH FIG 2 • A,B. Extent of the skin-subcutaneous flap elevation and initial SMAS flap dissection. **C.** SMAS flap elevation.

■ Nerve Mobilization and Graft Harvest

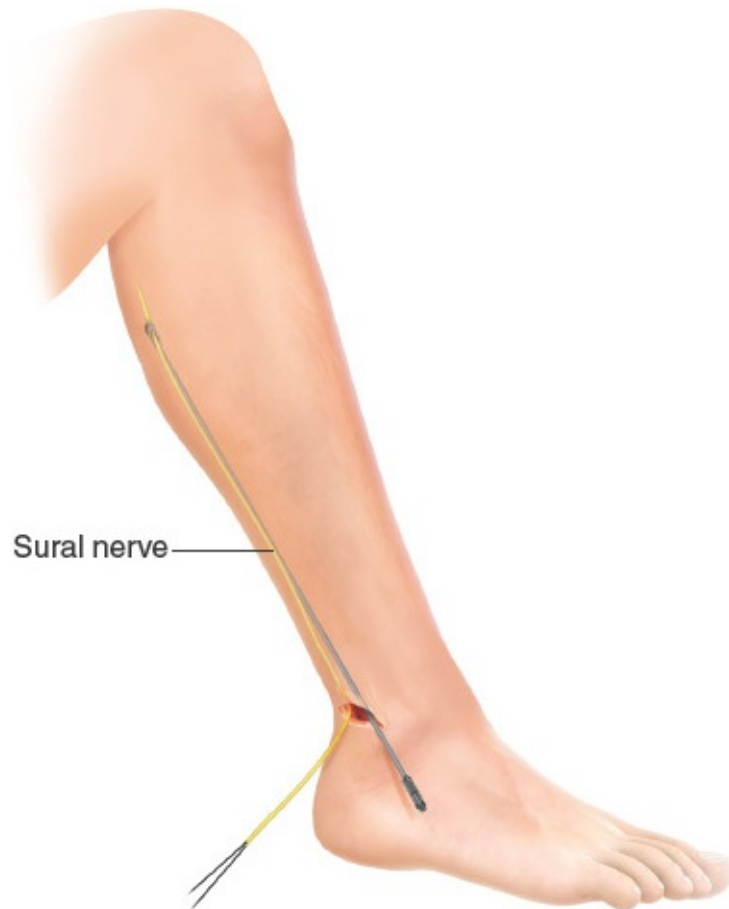
- The operating microscope is brought onto the field to enhance visualization and microsurgical dissection is used to further explore and mobilized the facial nerve branches.
- During the dissection, the transverse facial artery is often encountered. This is a useful landmark as the zygomatic branches above and below this structure often produce an excellent smile with little activation of the orbicularis oculi.
- The facial nerve branches are encircled with thin segments of microvascular background to facilitate later identification.
- Electrical stimulation is now performed. The facial nerve branches are stimulated at 0.5 to 1 mA at 40 Hz and a functional map of their activity is created.
- The largest and most powerful zygomatic branch that produces activation of the zygomatic major and levator anguli oris muscles without associated eye closure is identified.

- It is traced in a retrograde fashion into the parotid gland to maximizing its caliber (**TECH FIG 3**).
- Selective nerve branch transection at this site will be performed later in the case for smile restoration.
- If the surgical goals include restoration of eye closure, pucker and lip depression, then approximately 50% of the facial nerve branches to the orbicularis oculi, orbicularis oris, and depressor anguli oris and depressor labii inferioris are selected for eventual transection.⁸
- A submandibular extension of the initial access incision may be required to reach the marginal mandibular branches.
- Gowns and gloves are changed and new instruments are used to harvest the nerve grafts under tourniquet control.
- The sural nerve is approached via a limited access incision approximately 2 cm posterior to the lateral malleolus (**TECH FIG 4**).
- The sural nerve is separated for the lesser saphenous vein, ligated with 4-0 silk ties, and divided. A nerve stripping device (Aesculap TEK784, Aesculap Inc., Center Valley, PA) is used with a gentle back and forth twisting motion to mobilize the nerve from distal to proximal. If significant resistance is encountered, an additional counter incision is made and the tethering side branch released. Grafts measuring 25 to 30 cm are reliable harvested.



TECH FIG 3 • A. The facial nerve branches bordering the transverse facial artery are frequently selected for

transfer as they often produce an isolated smile with little or no activation of the orbicularis oculi or orbicularis oris. **B.** Isolation of zygomatic facial nerve branches.



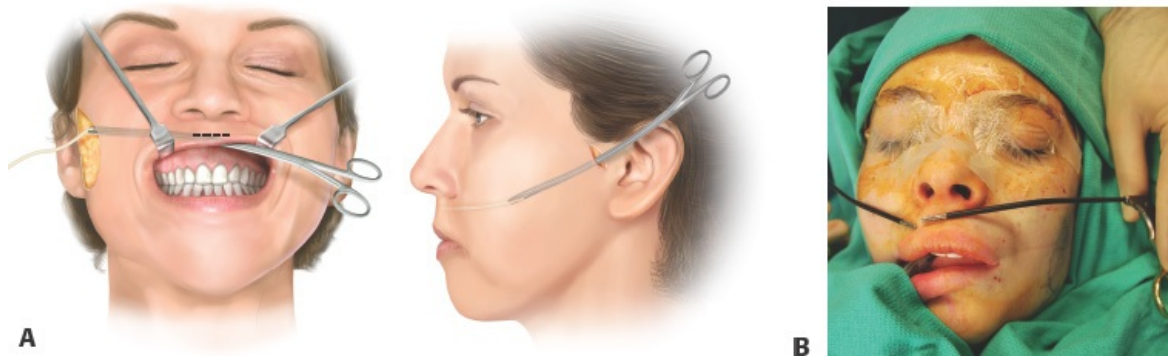
TECH FIG 4 • Sural nerve harvested via a limited access incision utilizing a nerve-stripping device.

■ Graft Passage and Completion

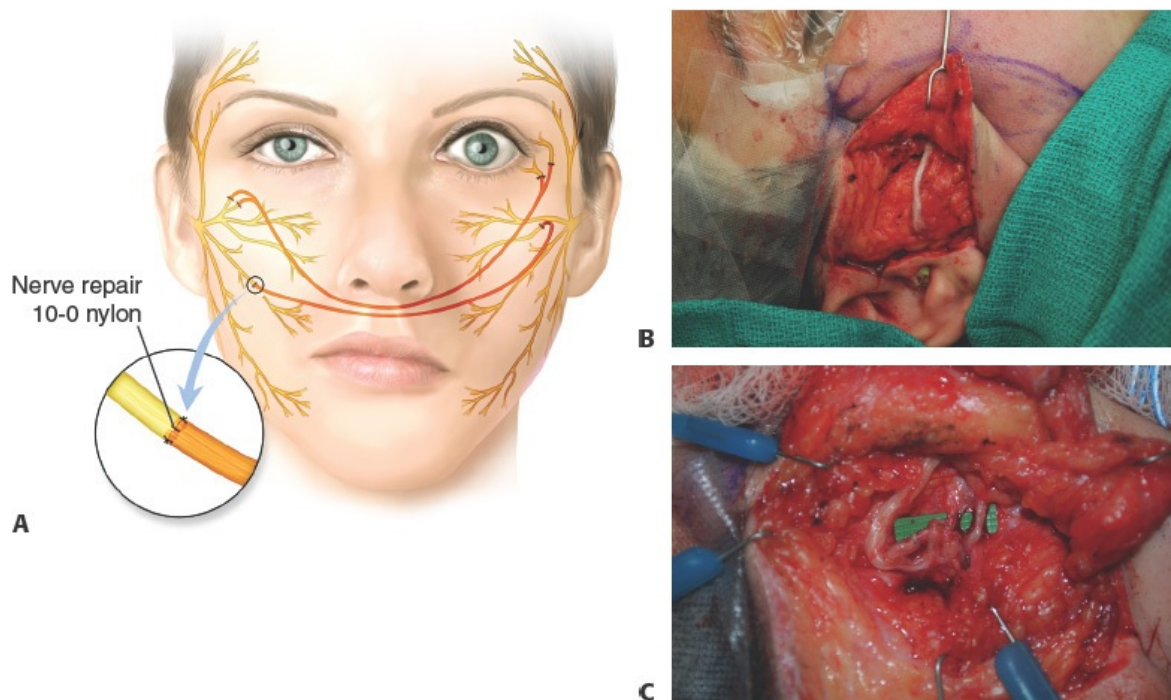
- If more than one nerve graft is to be passed through an adjacent tunnel, they are marked in increments with different colored sutures to facilitate identification.
- An alligator, tendon passing clamp is inserted through limited incision in the contralateral hairline and preauricular region. The clamp is now tunneled

through either the subcutaneous or deep supraperiosteal plane, traversing the upper lip, lower lip, and submental region as determined by the number of cross face nerve grafts (**TECH FIG 5**).

- Small access incisions may be required in the upper and lower lip to successfully create the tunnels.
- These incisions can be used to identify branches of the infraorbital and mental nerves that can be selectively transected and eventually coapted to the cross face nerve graft (end-to-side) if desired in an effort to enhance axonal growth.⁹
- The nerve grafts are reversed and the proximal nerve end is ligated with a colored 4-0 nonabsorbable, monofilament suture (facilitates delayed identification).
- The tendon passing clamps are used to gently draw the graft across the face.
- The donor facial nerve branches are selectively divided, and an end-to-end nerve repair is made between the facial nerve branch and corresponding nerve graft with 10-0 nylon suture in an interrupted, epineurial fashion (**TECH FIG 6**).
- The SMAS flap is returned to its native position and secured with 4-0 absorbable suture.
- The subcutaneous pocket is treated with spray thrombin or fibrin glue, and the incision is repaired over a closed suction drain.
- The nerve graft donor site access incisions in the extremities are closed in layers with absorbable, monofilament suture and covered with cyanoacrylate tissue adhesive. The incisions are covered with ABD pads and elastic bandages are utilized to support the feet and calves.
- Antibiotic ointment is applied to the head and neck incisions and no dressings are applied.
- A deep, atraumatic, extubation is then coordinated with the anesthesiologist.
- Foot sequential compression devices are applied for deep venous thrombosis prophylaxis.



TECH FIG 5 • Creating of subcutaneous tunnels with alligator clamps for passage of cross face nerve grafts.



TECH FIG 6 • **A.** Cross face nerve grafts for restoration of eye closure and smile with proximal and distal end-to-end nerve repairs. **B.** Cross face nerve graft in situ. **C.** End-to-end nerve repair between sural cross face nerve graft and a zygomatic branch of the facial nerve.

PEARLS AND PITFALLS

Facial nerve branch selection

- For smile restoration, select the largest facial nerve branch that produces isolated activation of the zygomaticus major without associated eye closure.
- Trace the nerve branch into the parotid gland to increase the axon density.

Nerve graft injury

- If significant resistance is met when harvesting the graft with a nerve-stripping device, an additional incision should be created.
- The obstructing side branch is then transected to prevent accidental nerve graft avulsion.
- Failure to do this may result in a graft of inadequate length with disruption of the internal architecture.

Hemostatic solutions

- Avoid local anesthetics that contain epinephrine as they will impair nerve conduction and the ability to create a functional map.
- A solution of 1:100 000 epinephrine will achieve good vasoconstriction without impairing nerve conduction.

Avoid aesthetic complications

- Short-acting muscle relaxants are only permitted on induction, if essential.
- The need to avoid muscle paralysis must be communicated during changes of anesthesia providers.
- Deep, atraumatic, extubation without compressive, face mask ventilation.

POSTOPERATIVE CARE

- Patient is maintained a clear liquid diet for 48 hours followed by a soft diet for 4 weeks.
- The oral cavity is rinsed with chlorhexidine gluconate mouth wash twice a day for 7 days, after which an electric tooth brush is utilized for oral hygiene.
- Pressure on the cheeks is strictly avoided.
- Incentive spirometry is avoided and patients are encouraged to deep breathe. A pinwheel can be used to encourage pediatric patients to breathe deeply.
- Ambulation with assistance is usually initiated on the first postoperative day and pedal sequential compression devices are utilized while in bed.
- Anticoagulation is generally avoided due to the potential increased risk of facial hematoma.

- No strenuous exercise or heavy lifting for 6 to 8 weeks following surgery.
- Elastic bandaging of the lower extremities is employed for 2 to 3 weeks to reduce edema and improve patient comfort.

OUTCOMES

- The ability of cross face nerve grafts to successfully innervate free, functional, muscle flaps for smile restoration has been demonstrated in multiple publications over the past two decades.⁷
- Although the reconstructed smile is spontaneous, it is frequently weaker than that achieved with a muscle flap innervated by the motor nerve to masseter.¹⁰
- The ability of CFNGs to deliver an adequate axonal load decreases with age, and alternate strategies are often employed for individuals in the sixth and seventh decades of life.
- Cross face nerve grafting as an isolated technique rarely produces adequate strength to achieve symmetric facial motion.
- Cross face nerve grafts can be used with a distal end-to-side coaptation to enhance the power of paretic muscles of facial expression.¹¹

COMPLICATIONS

- Potential weakening of the unaffected hemiface following selective transection of facial nerve branches.
- Hematoma formation requiring evacuation and potential disruption of the nerve grafts.
- Cheek skin flap necrosis (patients should be counseled on smoking cessation and avoiding nicotine).
- Neuroma formation at the nerve graft donor site.
- Failure of adequate nerve regeneration.
- Sialocele, salivary fistula, and parotitis.
- Otitis external resulting from blood collecting in the external auditory canal.
- Compartment syndrome after sural nerve graft harvest.

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50 Motor Branch of Masseter for Innervation of Free Muscle Flap

CHAPTER

Michael J. A. Klebuc

DEFINITION

- The descending branch of the motor nerve to the masseter muscle (CN V) can be selectively divided and employed to innervate free muscle flaps, utilized for smile restoration.

ANATOMY

- The masseter nerve branches from the mandibular nerve and passes above the lateral pterygoid muscle where it runs through the mandibular notch to enter the substance of the masseter muscle.
- Along its intramuscular path, the main trunk liberates a series of small proximal branches and terminates in a long descending branch that courses obliquely in posteroanterior, proximal-distal trajectory.
- The main trunk of the masseter nerve can be identified at a point 3 cm in front of the tragus, 1 cm below the zygomatic arch, and 1.5 cm deep to the SMAS (**FIG 1**).¹
- The masseter muscle has three lobes (superficial, middle, and deep).
- The motor nerve to the masseter (CN V) lies on the superficial surface of the deep lobe.²
- The main trunk and descending branches contain approximately 2700 and 1550 myelinated motor fibers, respectively.^{1,3}

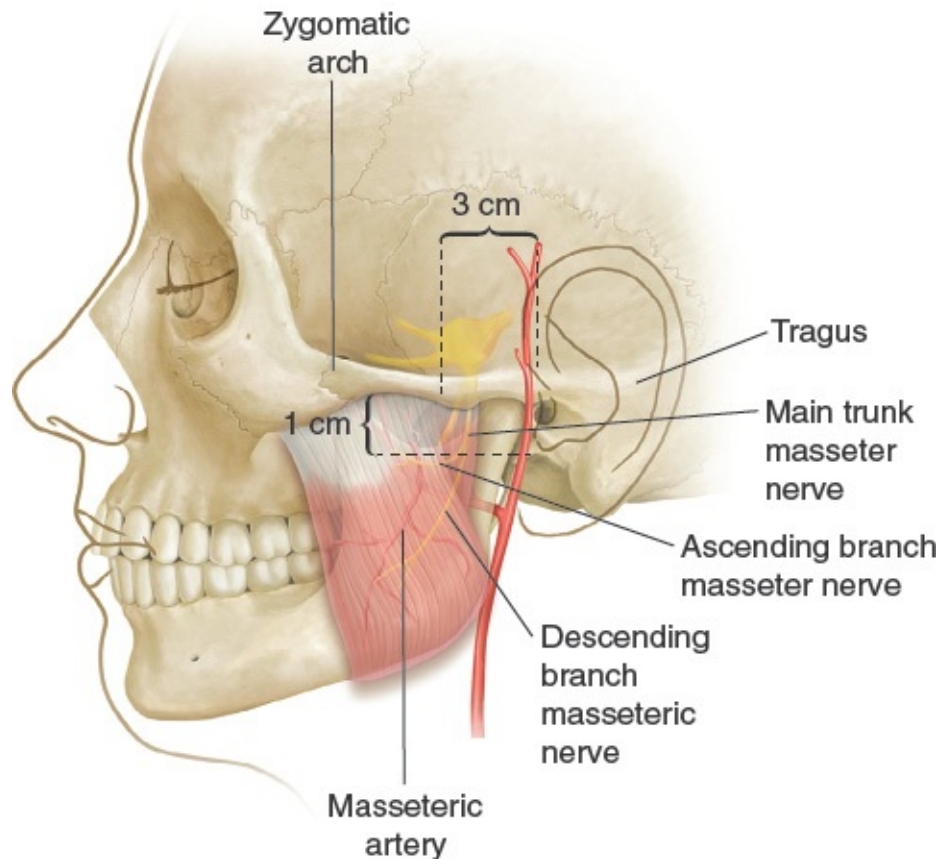


FIG 1 • Topographic landmarks for masseter nerve isolation. Main nerve trunk located 3 cm in front of the tragus, 1 cm below the zygomatic arch, and 1.5 cm deep to the SMAS.

- The descending branch of the masseter nerve is usually selectively transected and employed to innervate free muscle flaps utilized for facial reanimation.

PATHOGENESIS

- The masseter nerve is frequently selected as a source of innervation in cases of bilateral facial paralysis and when the facial nerve is unavailable as a donor (ie, Moebius syndrome, Lyme disease, bilateral temporal bone fractures, brainstem cavernous malformation, Guillain-Barré).⁴
- Often selected over cross face nerve grafts in older patients where the potential for nerve regeneration is diminished.⁵

PATIENT HISTORY AND PHYSICAL FINDINGS

- Etiology of the facial paralysis:

- Developmental
- Traumatic
- Post-tumor extirpation
- Bell palsy
- Ramsay Hunt syndrome
- Patient age:
 - Peripheral nerve regeneration declines with advanced age.
 - There is no definitive age cutoff for cross face nerve grafting; however, after the age of 50 to 55 years, the ipsilateral motor nerve branch to masseter or other adjacent cranial nerves often provide a more reliable source of innervation to free muscle flaps with more powerful muscle flap contraction.
- Comorbidities impairing nerve regeneration:
 - Smoking—higher risk of skin flap necrosis
 - Diabetes
 - Vascular disease
 - Previous radiation
 - Neurologic disorders
- History of hypercoagulable state:
 - Patient or family history of pulmonary emboli or deep venous thrombosis signals the need for a hematologic workup prior to free, functional muscle flap reconstruction.
- The patient's level of motivation and willingness to comply with postoperative physical therapy is also important to ascertain.
- History of temporomandibular joint dysfunction—consider alternative technique.

Physical Examination

- Active, forceful, contraction of the masseter and temporalis muscles is confirmed by palpation.
- The face is examined for previous access incisions and signs of trauma or injury to the muscles of facial expression.
- Dental occlusion and mouth opening are evaluated to rule out temporomandibular joint dysfunction.
- A cranial nerve examination is performed to identify additional neurologic deficits.
- Palpate and Doppler the superficial temporal and facial artery and veins on the

paralyzed hemiface to verify patency.

IMAGING

- Imaging studies are seldom required in the presence of a normal physical examination.

SURGICAL MANAGEMENT

Preoperative Planning

- Smoking cessation and avoidance of nicotine
- Discontinuation of oral anticoagulants
- EMG
 - Concomitant activation of the masseter muscle with attempted smiling (may predict development of an effortless smile)⁶
- Mark the nasolabial folds and smile vectors prior to entering the operating room.

Positioning

- Supine on the operating table with arms tucked
- Narrow head extension with foam- or gel-filled headrest.
- Nasotracheal intubation with nasal ray endotracheal tube sutured to the columella and supported on the hair-bearing scalp with foam, silk tape, and staples (**FIG 2**)



FIG 2 • Nasotracheal intubation with head positioned on a narrow headrest. Endotracheal tube sutured to columella and supported with foam to prevent pressure

on the nasal alae.

- Oral cavity cleansed with chlorhexidine gluconate mouthwash
- Preoperative intravenous antibiotic coverage for oral flora (ie, clindamycin)
- Contralateral lower extremity prepped if a free gracilis muscle flap will be utilized
- Sequential compression devices (sterile SCD on the donor leg)
- Foley catheter

Approach

- In the standard approach, the masseter nerve is explored via a preauricular incision after elevation of a cheek skin flap.
- When a limited preauricular approach is used, the neurorrhaphy is performed prior to the microvascular anastomosis to facilitate exposure.

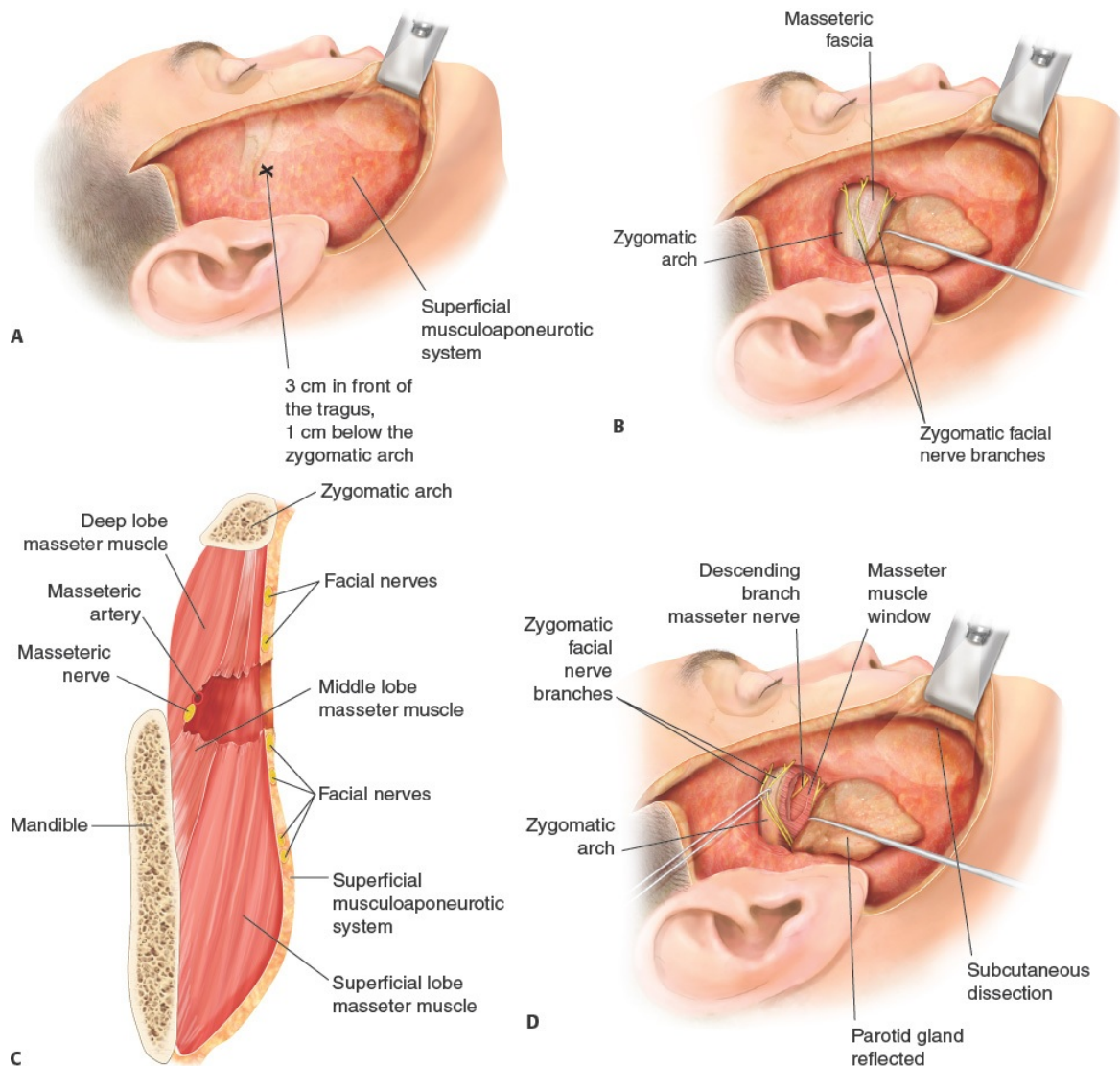
TECHNIQUES

■ Standard Preauricular Approach

- The external auditory canal is occluded with a petrolatum gauze dressing.
- A preauricular incision with a sideburn extension is made if the superficial temporal artery and vein will be used as recipient vessels. A submandibular extension is incorporated if the facial vessel will be used.
- A skin and subcutaneous tissue flap is elevated in the preauricular, zygomatic, and buccal regions, extending the medial aspect of the dissection to the lateral border of the orbicularis oris muscle.
- A point is marked on the SMAS, 3 cm in front of the tragus and 1 cm below the zygomatic arch. This landmark reliably corresponds to the general location of the underlying masseter nerve (**TECH FIG 1A**).¹
- The operating microscope is brought onto the field to enhance visualization and microsurgical dissection is utilized to identify zygomatic branches of the facial nerve that traverse this site.
- In cases of incomplete facial paralysis, these facial nerve branches are mobilized and gently retracted to provide access to the deeper tissues. Facial nerve branches are often absent in cases of developmental paralysis. This

significantly simplifies the dissection (**TECH FIG 1B**).

- With the aid of bipolar cautery, the cephalic border of the parotid is released from its attachments to the zygomatic arch and the gland is reflected inferiorly exposing the masseteric fascia.
- A window of the masseteric fascia is excised below the zygomatic arch exposing the superficial lobe of the masseter muscle.
- A right angle clamp and bipolar cautery are now utilized to release the muscle in layers by propagating the dissection through the superficial and middle lobes of the masseter muscle (**TECH FIG 1C**).
- In the deeper portion of the dissection, an electrical stimulator set at 0.5 to 1 mA at 40 Hz is employed to help identify the masseter nerve that usually resides in the zone of maximal muscle contraction.
- Small branches of the masseter nerve are frequently encountered and can be traced in a retrograde fashion back to the main trunk.
- The main nerve trunk is usually identified resting on the superficial surface of the deep lobe of the masseter muscle approximately 1.5 cm deep to the SMAS. Once identified, the main trunk of the masseter nerve is encircled with a vessel loop and the descending branch is further mobilized with microsurgical dissection (**TECH FIG 1D**).



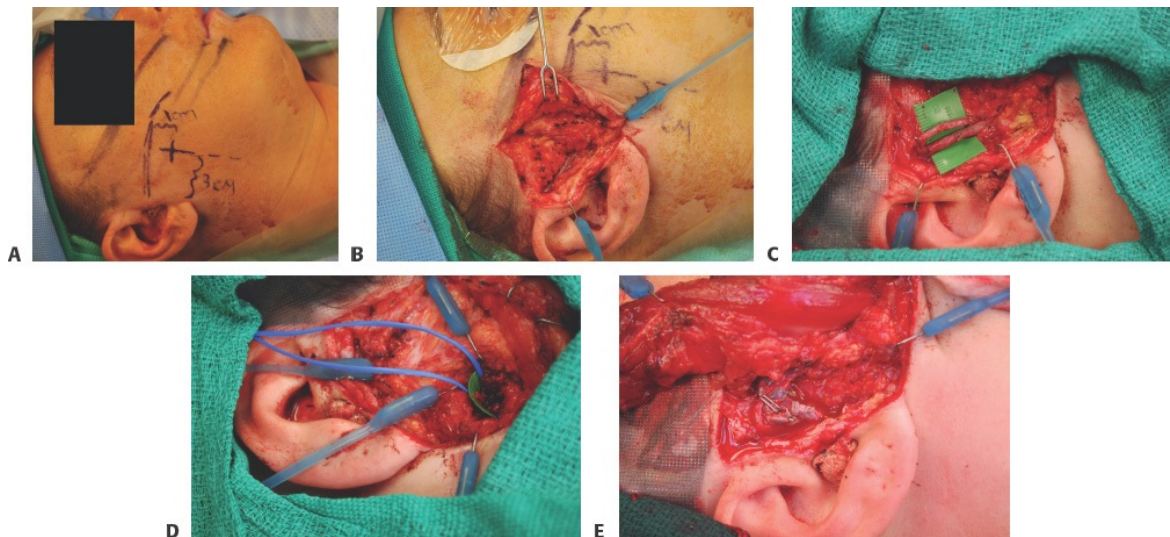
TECH FIG 1 • A. Skin flap elevated and location of the masseter nerve marked 3 cm in front of the tragus and 1 cm below the zygomatic arch. **B.** Regional zygomatic facial nerve branches mobilized and reflected. May be absent in cases of developmental paralysis. **C.** Cross-sectional view of masseter nerve dissection with the main nerve trunk resting on the superficial surface of the deep muscular lobe. **D.** Masseter nerve identified within the muscle. The descending branch will be mobilized and selectively transected. The ascending branch will be preserved to

prevent atrophy.

- The masseter nerve is accompanied by a sizable artery, and microvascular clips can prove beneficial in achieving hemostasis and avoiding frustrating hemorrhaging that impaired visualization.
- Once the maximal length of the descending branch has been dissected, it is selectively transected and transposed into a more superficial plane to facilitate later nerve repair. It is important to preserve the integrity of the proximal branches to prevent muscle atrophy and the development of a cosmetic deformity.
- With the aid of the operating microscope, an end-to-end microsurgical nerve repair is made in an interrupted, epineurial fashion with 10-0 nylon between the masseter nerve and the motor nerve of the free muscle flap.

■ Limited Preauricular Approach

- When a limited preauricular approach is used, the neurorrhaphy is performed prior to the microvascular anastomosis to facilitate exposure (**TECH FIG 2A**).
- **TECH FIG 3** shows an extended submandibular dissection to access the facial artery and vein for recipient vessels.



TECH FIG 2 • **A.** Preoperative markings. **B.** Skin flap elevation for limited, preauricular approach. **C.**

Superficial temporal vessels isolated. **D.** Descending masseter nerve branch isolated and transected. **E.** Nerve repair followed by microvascular anastomosis to facilitate exposure.



TECH FIG 3 • Extended submandibular dissection to access the facial artery and vein for recipient vessels.

PEARLS AND PITFALLS

Selective masseter nerve transection

- The descending branch is frequently divided and used to innervate free muscle flaps. Proximal branches are left intact to prevent muscle atrophy and development of a cosmetic deformity.

Excessive power

- Small muscle flaps should be utilized to avoid excessively powerful muscle contraction and exaggerated commissure excursion. The decreased bulk in the midface enhances the cosmetic result.

Inadequate resting tone

- Free muscle flaps innervated by the masseter nerve often produce inadequate facial tone to achieve symmetry in repose. Consider additional static support with fascia and or tendon grafts.

Patient motivation

- Selection of well motivated patients with a strong commitment to postoperative physical therapy is essential.

Facial

- Some individuals may notice significant facial motion with

motion with mastication

chewing. This is often improved by favoring the contralateral cheek region when eating.

Single-stage procedure

- Facial reanimation can be achieved in a single operative setting.

POSTOPERATIVE CARE

- The patients are maintained on a clear liquid diet for 48 hours and then transitioned to a soft mechanical diet for 4 weeks.
- Please refer to Chapter 52 for additional postoperative care after free muscle flap facial reanimation.

OUTCOMES

- Single-stage procedure
- Produces greater commissure excursion than cross face nerve grafts⁷
- More reliable motion in the older patient, as compared to cross face nerve grafts⁸
- Dense innervation permits the use of small muscle flaps with less midface bulk.
- Potential for cerebral adaptation⁹
- In longer-term follow-up, greater than 80% can make a smile without clenching and more than 50% develop an effortless smile.¹⁰

COMPLICATIONS

- Thrombosis and flap loss (rare)
- Excess commissure excursion if a large muscle flap is utilized
- Masseter muscle atrophy if the main nerve trunk is divided with development of a sharp mandibular angle
- Separation of the muscle flap from orbicularis oris with retraction into the midcheek
- Adhesion of the muscle flap to the dermis if excessively thin skin flaps are elevated
- Asymmetry in repose if additional static support is not provided
- Unwanted facial motion with mastication

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51 Masseter-to-Facial Nerve Transfer

CHAPTER

Michael J. A. Klebuc

DEFINITION

- The descending branch of the masseter nerve can be transferred to selected zygomatic-buccal branches of the facial nerve (V–VII) to restore motion in the midface and perioral region.
- The V to VII nerve transfer is utilized when intracranial and/or intratemporal segments of the facial nerve are irreversibly damaged in the presence of intact distal facial nerve branches and viable muscles of facial expression.

ANATOMY

- The masseter nerve branches from the mandibular nerve and passes above the lateral pterygoid muscle where it runs through the mandibular notch to enter the substance of the masseter muscle.
- Along its intramuscular path, the main trunk liberates a series of small proximal branches and terminates in a long descending branch that courses obliquely in a posterior-anterior, proximal-distal trajectory.
- The main trunk of the masseter nerve can be identified at a point 3 cm in front of the tragus, 1 cm below the zygomatic arch, and 1.5 cm deep to the SMAS (**FIG 1**).¹
- The masseter muscle has three lobes (superficial, middle, and deep).
- The motor nerve to masseter (CN V) lies on the superficial surface of the deep lobe.²

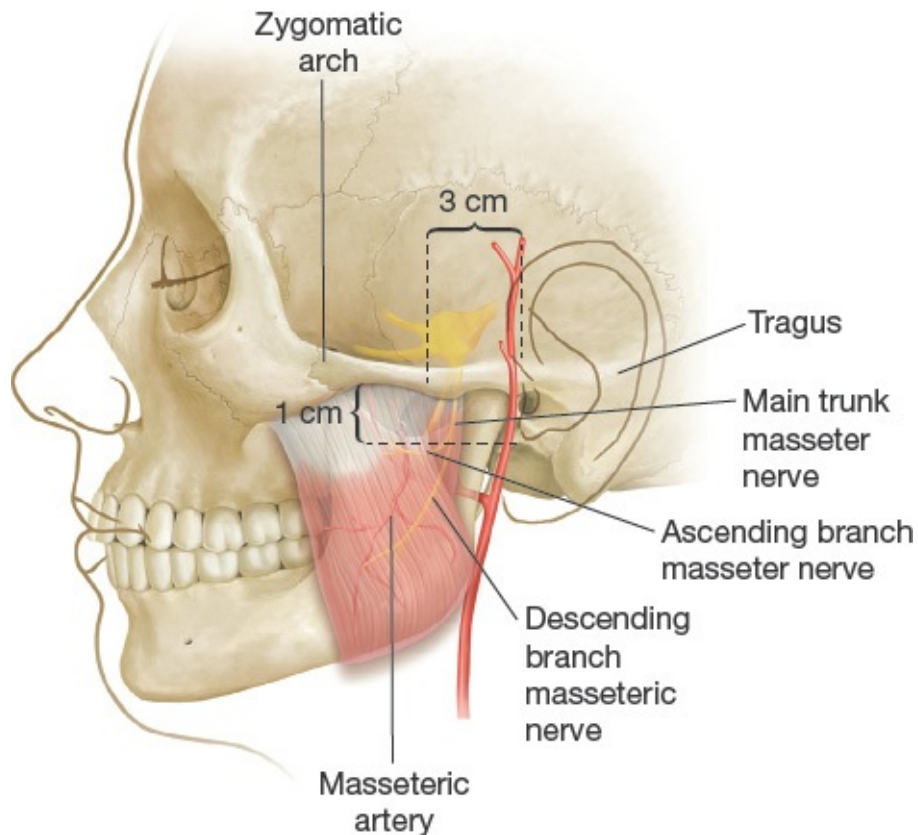


FIG 1 • Topographic landmarks for isolation of the motor nerve branch to masseter. The main trunk is identified 3 cm in front of the tragus, 1 cm below the zygomatic arch, and 1.5 cm deep to the SMAS.

- The main trunk and descending branches contain approximately 2700 and 1550 myelinated motor fibers, respectively.^{1,3}
- The descending branch of the masseter nerve is usually selected for the V to VII transfer.
- Facial nerve (somatic motor efferent component) innervates the muscles of facial expression, auricular muscles, occipitalis, posterior belly digastric, stylohyoid, and stapedius.
- The facial nerve main trunk emerges from the skull base via the stylomastoid foramen where it can be identified coursing 1 cm deep to the tragal pointer and medial to the posterior belly of the digastric muscle.⁴
- Within the parotid gland, the facial nerve divides into a temporofacial and cervicofacial trunk.

- Distal branches exit the parotid along its anteromedial border.
- The following branches innervate the corresponding muscles of facial expression⁵:
 - Frontal branch—frontalis muscle
 - Zygomatic branches—orbicularis oculi, zygomaticus major, zygomaticus minor, levator labii superioris, levator labii superioris alaeque nasi, corrugator supercilii, procerus
 - Buccal branches—buccinator, risorius, orbicularis oris
 - Marginal mandibular branches—depressor anguli oris, depressor labii inferioris, mentalis
 - Cervical branches—platysma
- Zuker point—midway point of a line drawn from the root of the helix to the lateral commissure (**FIG 2**)⁶:

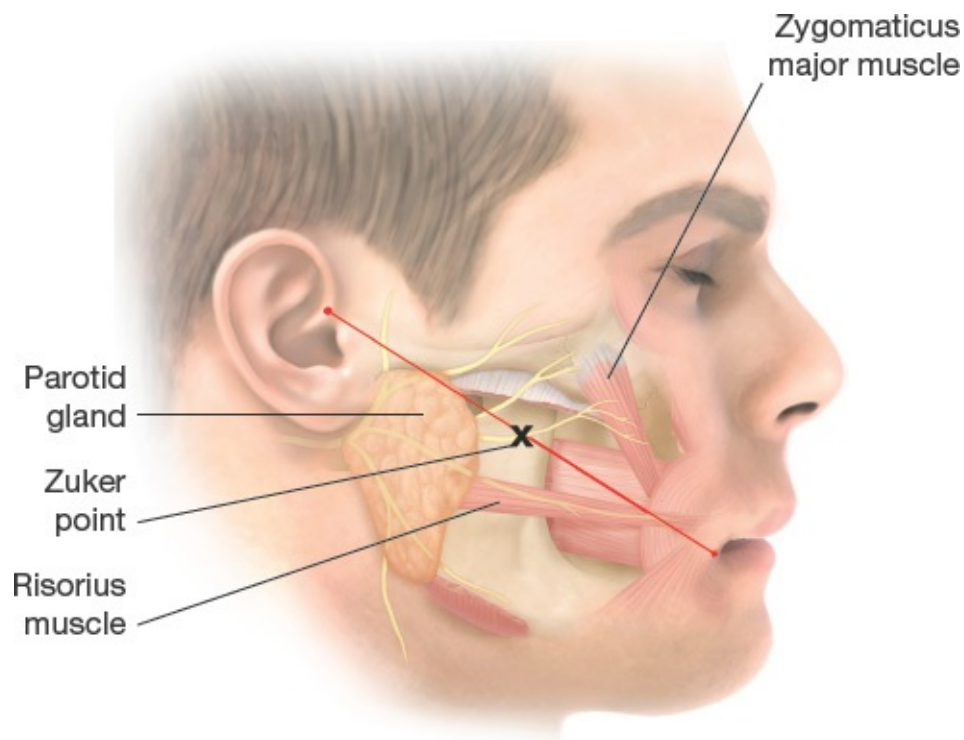


FIG 2 • The facial nerve branch supplying the zygomatic major is typically found at a point half way between the root of the helix and the lateral commissure.

- Describes the approximate location of the facial nerve branch supplying the zygomaticus major muscle.

- At this location, the zygomatic facial nerve branches coursing above and below the transverse facial artery are often selected for the V to VII transfer.

PATHOGENESIS

- Employed when intracranial and/or intratemporal segments of the facial nerve are irreversibly damaged in the presence of intact distal facial nerve branches and viable mimetic muscles.
- Commonly utilized after ablative oncologic surgery or trauma involving the brainstem and skull base.
- Etiology of facial nerve injury includes resection of acoustic neuroma, facial nerve schwannoma, cerebellopontine angle tumors, AVM, cholesteatoma, and skull base tumors. Unrecovered Bell palsy, mastoiditis, and skull base fractures are other common causes of facial nerve injury.⁷

PATIENT HISTORY AND PHYSICAL FINDINGS

- The duration of the paralysis is one of the most important pieces of information garnered from the patient's history, as the masseter-to-facial nerve transfer must be performed before the muscles of facial expression have undergone irreversible atrophy.
- The V to VII transfer is optimally employed immediately at the time of tumor extirpation yet remains a viable option up to 18 months after the onset of the paralysis.
- The patient's age is also of consequence in surgical planning. Generally, in the older patient population (greater than 55 years), the V to VII transfer is used in isolation with fascia lata grafts for additional static support. In younger patients, the V to VII transfer is often combined with cross face nerve grafts (CFNG) in a single operative setting. This is performed in an effort to create a marriage of power (V–VII) and spontaneity (CFNG).^{8,9}
- A history of diabetes, coronary artery disease, chronic obstructive pulmonary disease, smoking, underlying neurologic disorders, previous head-neck radiation, and temporal mandibular joint dysfunction should be noted and accounted.
- The patient's level of motivation and willingness to comply with postoperative physical therapy is also important to ascertain.
- On physical examination, active, forceful contraction of the masseter and temporalis muscles is confirmed by palpation.
- The face is examined for previous access incisions and signs of trauma or

injury to the muscles of facial expression.

- Dental occlusion and mouth opening are evaluated to rule out temporomandibular joint dysfunction.
- A cranial nerve examination is performed to identify additional neurologic deficits.
- The eye is examined for signs of exposure keratitis as adjunctive eye procedures may be performed with the V to VII transfer to maintain corneal health.
- A vascular examination of the lower extremities is undertaken to rule out significant peripheral vascular disease if fascia lata or sural nerve grafts are to be harvested.

IMAGING

- MRI of the brain and facial nerve
 - High-resolution multiplanar T1 and T2 images, gadolinium enhanced, fat suppressed, and internal auditory canal (IAC) protocol
 - Used to evaluate injury to the facial nerve (ie, Bell palsy, tumors, stroke)
- Computed tomography
 - 0.625 mm or thinner axial images, reconstructions in coronal plane
 - Valuable for imaging temporal bone fractures
- EMG of the masseter muscle and mimetic muscles innervated by the facial nerve
 - Look for signs of early facial nerve recovery.
 - Look for signs of reversible muscle atrophy.
 - Look for signs of coordinated activity between the mimetic muscles and the masseter.

SURGICAL MANAGEMENT

Preoperative Planning

- Smoking cessation and avoidance of nicotine
- Discontinuation of oral anticoagulants
- Facial nerve imaging as guided by the etiology of the paralysis (MRI, CT)
- EMG
 - Presence of muscle fibrillation (suggests potential, positive response to reinnervation)
 - Concomitant activation of the masseter muscle with smiling (may predict

development of an effortless smile)

Positioning

- Supine on the operating table with arms tucked
- Narrow head extension with foam or gel-filled headrest
- Nasotracheal intubation with nasal RAE endotracheal tube sutured to the columella and supported on the hair-bearing scalp with foam, silk tape, and staples (**FIG 3**)
- Oral cavity cleansed with chlorhexidine gluconate mouthwash
- Lower extremities prepped if nerve or fascia grafts are to be utilized



FIG 3 • Nasotracheal intubation with head positioned on a narrow headrest. Endotracheal tube sutured to columella and supported with foam to prevent pressure on the nasal alae.

- Sterile calf sequential compression devices
- Foley catheter

Approaches

- V to VII retrograde approach with adjacent branch preservation

- V to VII anterograde approach with distal, selective, facial nerve branch transection
- V to VII with fascia lata static suspension
- V to VII with CFNG

TECHNIQUES

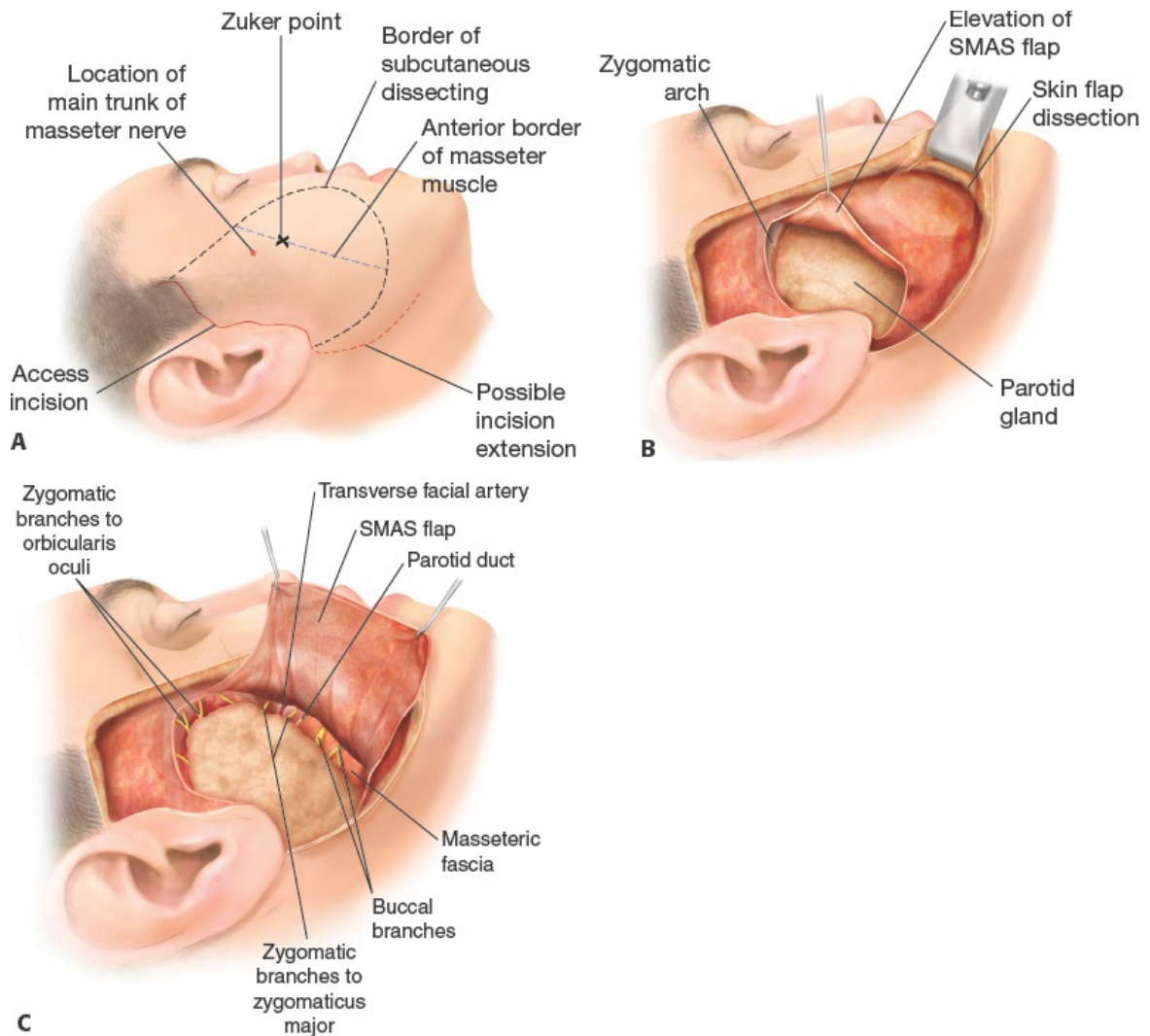
■ Retrograde Masseter-to-Facial Nerve Transfer

- The anterior border of the masseter muscle is palpated and marked.
- A pretragal incision with an extension into the sideburn is now marked with a surgical pen.
- An additional point is marked half way between the root of the helix and the commissure to indicate the general location of the facial nerve branch to the zygomaticus major muscle (Zuker point).⁶
- The topographic location of the masseter nerve is also marked 3 cm in front of the tragus and 1 cm below the zygomatic arch (**TECH FIG 1A**).
- A petrolatum gauze dressing is utilized to occlude the external auditory canal.
- The subcutaneous tissues in the preauricular, zygomatic, and buccal regions are infiltrated with a 1:100 000 epinephrine, hemostatic solution (**local anesthetics should be avoided to preserve nerve stimulation**).
- The preauricular incision with the sideburn extension is made, and a skin and subcutaneous tissue flap is elevated in the preauricular, zygomatic, and buccal regions extending the medial aspect of the dissection approximated 3 cm past the medial border of the masseter muscle (**TECH FIG 1B**).
- A SMAS flap is now elevated with scissor dissection and bipolar cautery. The flap is mobilized to the anteromedial border of the parotid gland where the inferior zygomatic and buccal branches of the facial nerve are identified. The SMAS flap is released transversely along the zygomatic border and reflected to facilitate exposure.



Video p8-c051

- The operating microscope is brought onto the field to enhance visualization, and microsurgical dissection is utilized to further explore and mobilize the facial nerve branches.
- During the dissection, the transverse facial artery is often encountered. This is a useful landmark, as the zygomatic branches above and below this structure often produce an excellent smile with little activation of the orbicularis oculi (**TECH FIG 1C**).

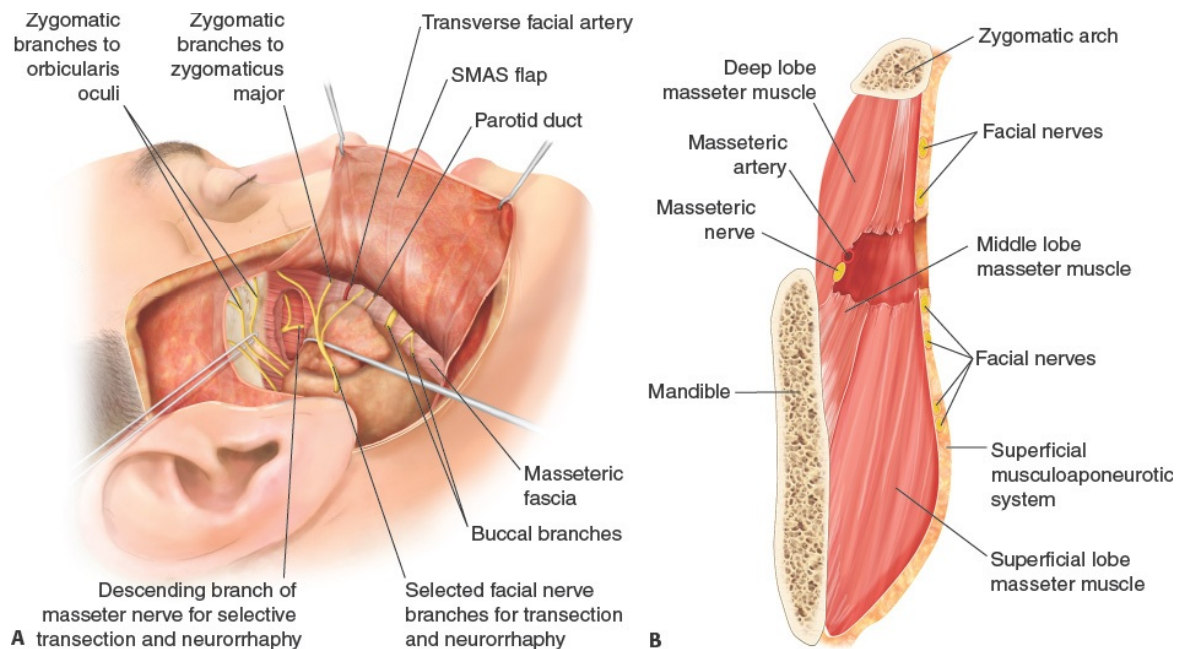


TECH FIG 1 • A. Operative markings: preauricular incision with a possible submandibular extension (X) marks Zuker point and (asterisk) identifies the general location of the motor nerve branch to masseter. The *dashed lines* represent the anterior border of the masseter muscle and the region of skin flap elevation. **B.** Demonstrates the extent of the skin-subcutaneous flap elevation and initial SMAS flap dissection. **C.** The facial nerve branches bordering the transverse facial artery are frequently selected for transfer as they often produce an isolated smile with little or no activation of the orbicularis oculi or orbicularis oris.

- These facial nerve branches often merge into a larger common branch. This is dissected in a retrograde fashion through the parotid gland until it dives into a deep plane in the preauricular region. At this point, adequate nerve length is usually present to achieve a primary nerve repair. However, the facial nerve is left undivided until this can be confirmed.
- Once the selected facial nerves have been mobilized, attention is focused on identifying the motor nerve branch to the masseter.

Identifying the Motor Nerve Branch

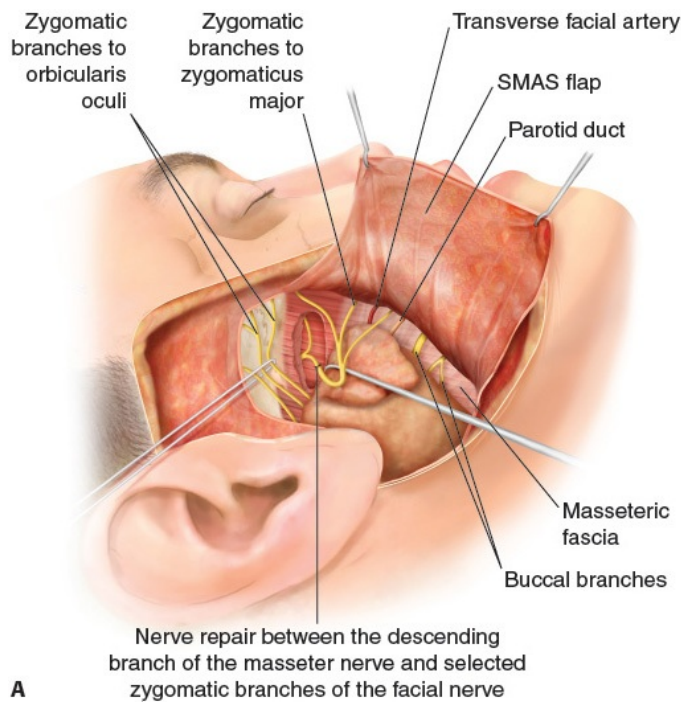
- A point 3 cm in front of the tragus and 1 cm below the zygomatic arch is again marked. The masseter fascia is released from the inferior border of the zygomatic arch with the bipolar cautery exposing the superficial surface of the masseter muscle.
- A right-angle clamp and bipolar cautery are now utilized to release the muscle in layers, propagating the dissection through the superficial and middle lobes of the masseter muscle (**TECH FIG 2A**).
- In the deeper portion of the dissection, an electrical stimulator set at 0.5 to 1 mA at 40 Hz is employed to help identify the masseter nerve that usually resides in the zone of maximal muscle contraction.
- Small branches of the masseter nerve are frequently encountered and can be traced in a retrograde fashion back to the main trunk (**TECH FIG 2B**).
- Once identified, the main trunk of the masseter nerve is encircled with a vessel loop, and the descending branch is further mobilized.
- The masseter nerve is accompanied by a sizable artery, and microvascular clips can prove beneficial in achieving hemostasis and avoiding frustrating hemorrhaging and impaired visualization.
- Once the maximal length of the descending branch has been dissected, it is selectively transected and transposed into a more superficial plane to facilitate later nerve repair. It is important to preserve the integrity of the proximal branches to prevent muscle atrophy and the development of a cosmetic deformity.



TECH FIG 2 • A. The main trunk, proximal ascending branches, and descending branch of the masseter nerve are identified via an intramuscular window. **B.** Cross-sectional view of masseter nerve dissection with the main nerve trunk resting on the superficial surface of the deep muscular lobe.

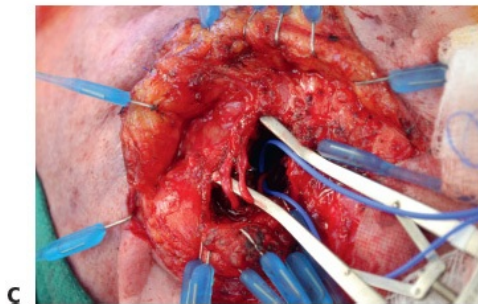
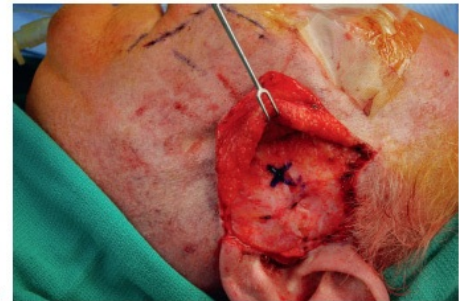
Dividing the Nerve Branch

- After verifying adequate length, the previously mobilized facial nerve branch is divided. With the aid of the operating microscope, an end-to-end microsurgical nerve repair is made in an interrupted, epineurial fashion with 10-0 nylon (**TECH FIG 3**).
- The SMAS flap is now returned to its native location and secured with absorbable monofilament sutures.
- The plane of subcutaneous dissection is treated with fibrin glue, and a 10-French closed suction drain is inserted.
- A layered closure of the access incisions is now performed, and the incisions are covered with antibiotic ointment. Stickers cautioning the need to avoid pressure are applied to the cheek.
- A deep, atraumatic extubation is then coordinated with the anesthesia provider.



A

B



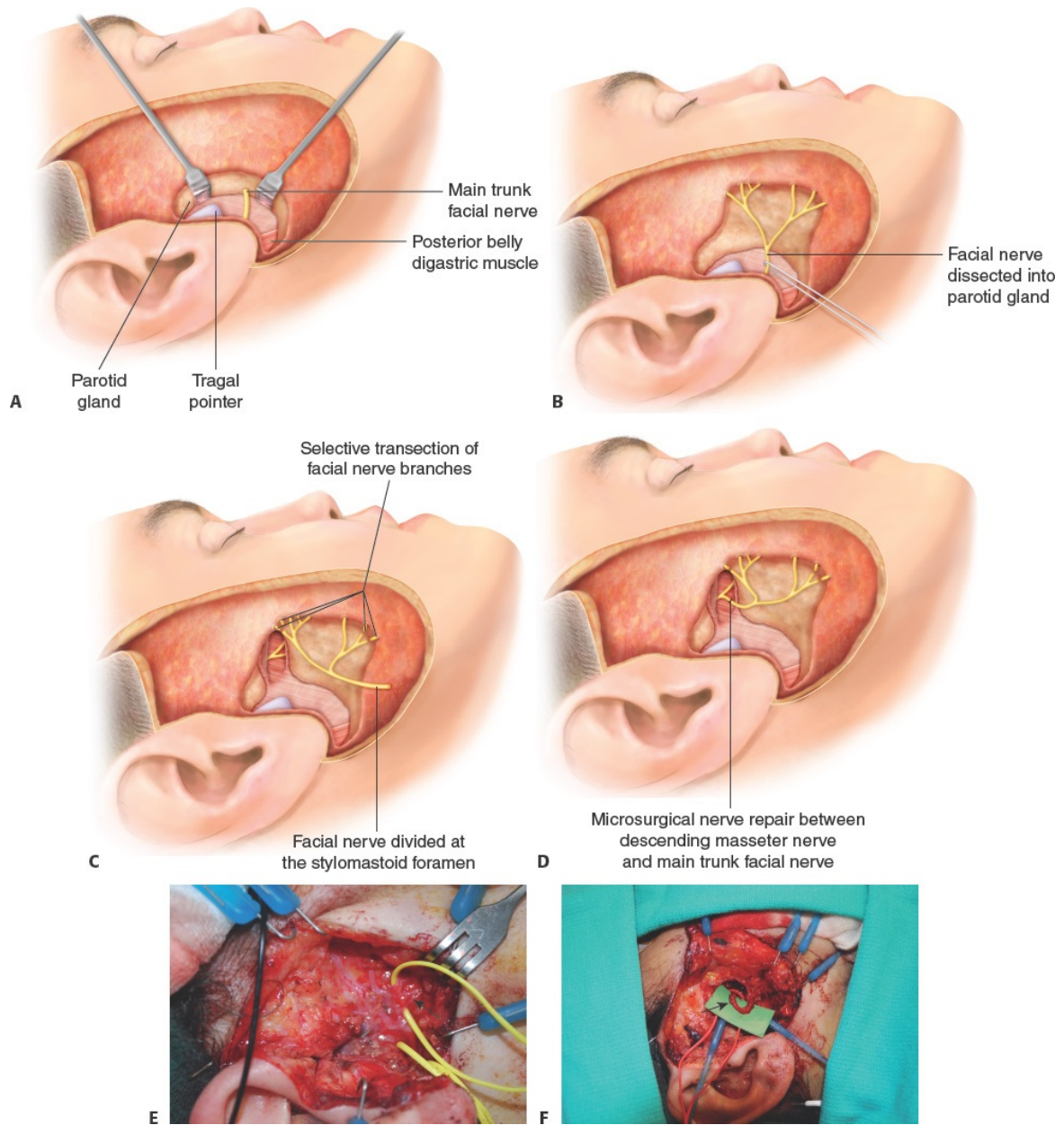
C

TECH FIG 3 • **A.** Microsurgical neurorrhaphy between the descending branch of the masseter nerve and selected zygomatic branches of the facial nerve. **B.** Masseter nerve location marked on SMAS 3 cm in front of the tragus and 1 cm below the zygomatic arch. **C.** Zygomatic facial nerve branches and the descending branch of the masseter nerve isolated for transfer.

■ Antegrade Masseter-to-Facial Nerve Transfer With Distal, Selective, Facial Nerve Branch Transection

- A preauricular incision with a subsideburn extension is created, and a broad based skin flap is elevated carrying the dissection 2 to 3 cm past the anterior border of the parotid gland. If additional exposure is required, a submandibular extension can be added to the original incision.
- The relatively avascular interval between the posterior border of the parotid gland and tragal cartilage (cartilaginous portion of the external auditory canal) is dissected with the aid of bipolar cautery and self-retaining Weitlaner retractors.
- The dissection is propagated deeply into the mastoid and retromandibular region. The main trunk of the facial nerve is identified exiting the skull base via the stylomastoid foramen approximately 1 cm deep to the tragal pointer and medial to the posterior belly of the digastric muscle.⁴ The main trunk of the facial nerve emerges from the skull base approximately 5 cm from the skin surface (**TECH FIG 4**). The depth of this structure is significant, and a submandibular extension of the access incision can be made to facilitate exposure, although it detracts from the overall aesthetics of the result.
- The main trunk of the facial nerve is encircled with a vessel loop and electrically stimulated to verify the absence of function. Blunt dissection with a fine right-angle clamp and bipolar cautery is then utilized to trace the nerve into the substance of the parotid gland. The nerve often transitions rapidly into a vertical course before separating into two divisions (temporofacial and cervicofacial) at the pes anserinus. The facial nerve branches are now dissected in an antegrade manner in a fashion akin to a superficial parotidectomy. The facial nerve branch mobilization is terminated approximately 1 to 2 cm from the anterior border of the parotid (**TECH FIG 4B**).
- In cases of complete facial paralysis, the main trunk of the facial nerve is transected at the stylomastoid foramen and transposed anteriorly to provide unobstructed access for the masseter nerve dissection (**TECH FIG 4C**).
- In cases of incomplete paralysis, isolation of the masseter nerve is significantly more complicated, as the main trunk of the facial nerve is left intact and the dissection must be propagated between the zygomatic branches to the eye, without injuring these structures.
- In cases of complete paralysis, the frontal branch, zygomatic branches innervating the orbicularis oculi, and the cervical branches are selectively transected to prevent development of synkinesis.

- The descending branch of the masseter nerve is now mobilized and selectively transected (as described above in the retrograde approach). An end-to-end neurorrhaphy is now created with the aid of the operating microscope and 10-0 nylon (**TECH FIG 4D-F**).
- The parotid fascia is repaired with absorbable monofilament sutures, the region of subcutaneous dissection is treated with fibrin glue, and the access incision is closed over a 10-French closed suction drain.
- “No pressure” stickers are applied to the cheek, and an atraumatic extubation is coordinated with the anesthesia provider.



TECH FIG 4 • A. Facial nerve trunk identified exiting the stylomastoid foramen approximately 1 cm below the tragal pointer. **B.** The intraparotid portion of the facial nerve dissected in a fashion analogous to a superficial parotidectomy. **C.** Facial nerve trunk selectively transected to enhance exposure and frontal, selected zygomatic, marginal mandibular and cervical branches of the facial nerve divided to prevent

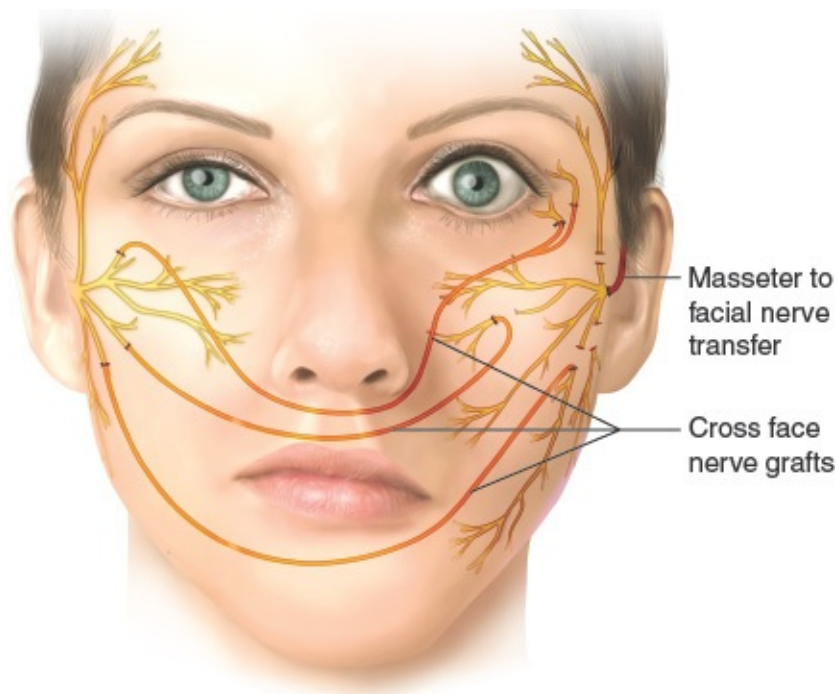
synkinesis. Masseter nerve identified resting on the deep lobe of the masseter muscle. **D.** Microsurgical neurorrhaphy between the masseter and facial nerve in an end-to-end fashion utilizing the operating microscope. **E.** Clinical example of the facial nerve mobilized within the parotid gland. *Arrow* and vessel loop identify the facial nerve branches to zygomaticus major and levator anguli oris. **F.** *Arrow* identifies the descending branch of the masseter nerve coapted to facial nerve trunk with 10-0 nylon in an interrupted epineurial fashion.

■ Masseter-to-Facial Nerve Transfer With Fascia Lata Grafts

- Isolated V to VII transfers in adult patients often lack adequate resting tone.
- In elderly patients, the V to VII transfer is often combined with fascia lata grafts for provision of additional, static support.
- The fascia lata graft is harvested from a proximal, lateral thigh incision with the aid of a lighted retractor. A graft measuring approximately 15 to 17 cm in length and 3 cm in width is obtained, and the fascial defect repaired with 0 polydioxanone suture. A layered closure is performed over a 15-French closed suction drain, as the donor site is prone to seroma formation.
- The graft is frequently divided into three segments that can be used independently to support the upper lip, commissure, and lower lip.
- The grafts can be positioned in the subcutaneous plane or delivered through Bichat-fat pad via a retrozygomatic tunnel.
- Only mild overcorrection is required as the reinnervated muscles of facial expression will provide additional support, and limited stretching of the fascia lata graft will develop.

■ Masseter-to-Facial Nerve Transfer With Cross Face Nerve Grafts

- In the younger patient population, the V to VII transfer is frequently combined with cross face nerve grafts (single-stage operation) in an effort to enhance spontaneity and resting tone.⁹
- The cross face nerve grafts are performed as described in Chapter 49 and the V to VII transfer as described above.
- Electrical stimulation of the unaffected, contralateral facial nerve branches is utilized to create a functional map, and the information is extrapolated to the “electrically silent” side to guide the distal nerve repairs.
- Typically, three to four cross face nerve grafts are combined with the V to VII transfer and target the orbicularis oculi, zygomatics major, orbicularis oris, and lower lip depressors (**TECH FIG 5**).



TECH FIG 5 • Three to four cross face nerve grafts are combined with the V to VII transfer and target the orbicularis oculi, zygomatics major, orbicularis oris, and lower lip depressors.

Proximal nerve branch preservation	■ Only the descending branch of the masseter nerve should be transferred. Proximal branches are left intact to prevent irreversible atrophy and a cosmetic deformity.
Static support	■ Fascia lata grafts are frequently required in older patients as the V to VII may not create adequate resting tone.
Sialocele	■ When extensive intraparotid dissection is performed, salivary collections can develop. This is reduced with the application of fibrin glue in the subcutaneous plain and usually responds to glycopyrrolate.
Patient motivation	■ These techniques are best suited to highly motivated individuals who are strongly committed to participate in postoperative therapy.
TMJ dysfunction	■ There is a potential for exacerbation of TMJ dysfunction, and therefore one should consider an alternate technique.

POSTOPERATIVE CARE

- No surgical dressings employed; apply antibiotic ointment to incisions for 48 to 72 hours.
- Avoid pressure on the surgical site (only one thin pillow under the head).
- Avoid incentive spirometry, and encourage deep breathing.
- IV antibiotic coverage for skin organisms and anaerobic oral flora (ie, clindamycin)
- Sequential Compression Devices (SCDs) and early mobilization
- Chlorhexidine mouthwash for 5 to 7 days and then electric toothbrush
- Soft mechanical diet for 4 weeks
- Once motion develops, the patient must practice smiling in front of a mirror (visual feedback) for a minimum of 30 min/d.

OUTCOMES

- Facial tone usually starts to develop at 3 to 4 months and facial motion at 5 to 6 months.^{7,10}
- In longer-term follow-up (greater than 2 years), 75% of patients can create a smile without clenching their teeth.
- Average commissure excursion achieved is 90% of the normal side.

- Many patients fail to develop adequate resting tone. Static suspension and cross face nerve grafts are frequently employed to counteract this problem.
- Donor site problems are rare due to the duplication of function between the masseter and temporalis muscles and the selective transection of only the descending branch of the masseter nerve.¹¹

COMPLICATIONS

- Sialocele formation that usually responds to glycopyrrolate
- Otitis externa from collection of sanguineous material in the external auditory canal
- Masseter muscle atrophy and development of a sharp mandibular angle if the entire masseter nerve is transected
- Oral-ocular, synkinetic dysfunction that usually responds favorably to botulinum toxin injections and is preferable to paralytic ectropion

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Pediatric Facial Reanimation Using a Functional Gracilis Muscle Transfer

52

CHAPTER

Brad M. Gandolfi, Jeffrey R. Marcus, and Michael R. Zenn

DEFINITION

- *Facial paralysis* does not describe a disease but instead the sequelae of denervation resulting from a spectrum of diseases, congenital defects, and acquired defects with a similar effect on the facial musculature.
- Facial nerve paralysis can involve the entire facial nerve distribution or only certain branches of the facial nerve. The facial nerve may be affected symmetrically or asymmetrically. The extent of the paralysis may be complete or incomplete relative to residual motor capacity.
- The pathogenesis of facial paralysis is complex and dependent on the etiology of the disease.^{1,2} That discussion is beyond the scope of this chapter but briefly can be divided into congenital and acquired facial paralysis (Table 1). An accurate diagnosis is crucial to selecting the proper surgical (or nonsurgical) intervention.
- *Facial reanimation* is a general term to describe restoration of facial movement. There are two main distinctions based on the status of native facial muscles:
 - Nerve transfers—When the denervating event is such that existing native facial musculature can be amenable to reinnervation with a functioning nerve, a nerve transfer is warranted. In this setting, the goal may be to restore multiple facial nerve targets—ie, multiple separate but coordinated movements.
 - Functional muscle transfer—In long-standing or congenital facial paralysis,

native muscles are not present to perform the function. Therefore, a transfer of functioning muscle provides reanimation. In such cases, only one facial movement, rather than multiple, is the goal of the procedure. One muscle provides one movement.

- This chapter focuses on free muscle transfer for restoration of smile in the pediatric population.

ANATOMY

Facial Nerve

- The facial nerve exits the stylomastoid foramen and enters the posterior parotid gland, dividing the gland into superficial and deep components.
- The facial nerve divides into two main branches within the parotid gland: the frontozygomatic and the cervicofacial trunks. These branches further divide before exiting the parotid gland.
- Five branches are classically described as exiting the parotid (frontal/temporal, zygomatic, buccal, marginal mandibular, and cervical). However, the branching pattern for each individual is unique, and many of the abovenamed nerves exist in multiples.³ The average number of branches exiting the parotid is 7 (**FIG 1**).
- Buccal and zygomatic branches begin to arborize and cross within and beyond the parotid, resulting in redundancy in the functional territory of these buccal-zygomatic branches.^{3,4} It is difficult to separate the activity of these branches as purely buccal or zygomatic because stimulation often results in a mixed response. Due to mixed nerve function, sacrifice of one nerve for end-to-end coaptation does not result in functional loss.
- The target for reanimation of smile is a buccal or zygomatic branch, selected based on targeted muscle stimulation. Stimulation should ideally identify a branch that produces vertical and horizontal movement of the commissure and upper lip consistent with the patient's natural smile, with minimal extraneous movement.
- Zuker point describes a relatively consistent buccal-zygomatic branch that meets the needs for facial reanimation.⁴ It is found at the center of a line drawn from the oral commissure to the helical root.

Nerve to the Masseter

- The nerve to the masseter arises as a branch of the trigeminal nerve (V3),

passing posterior to the temporalis muscle en route to the deep surface of the masseter (**FIG 2**).^{5,6}

Table 1 Causes of Facial Paralysis						
Congenital		Acquired				
Syndromic	Nonsyndromic	Traumatic	Tumor	Inflammatory	Neurodegenerative	Infectious
Developmental	Developmental	Intracranial	Benign	Bacterial	Bacterial	Bacterial
Genetic	Genetic	Extracranial	Malignant	Viral	Viral	Viral
Intrapartum	Intrapartum			Toxic	Toxic	Toxic
Idiopathic	Idiopathic			Genetic predisposition	Genetic predisposition	Genetic predisposition

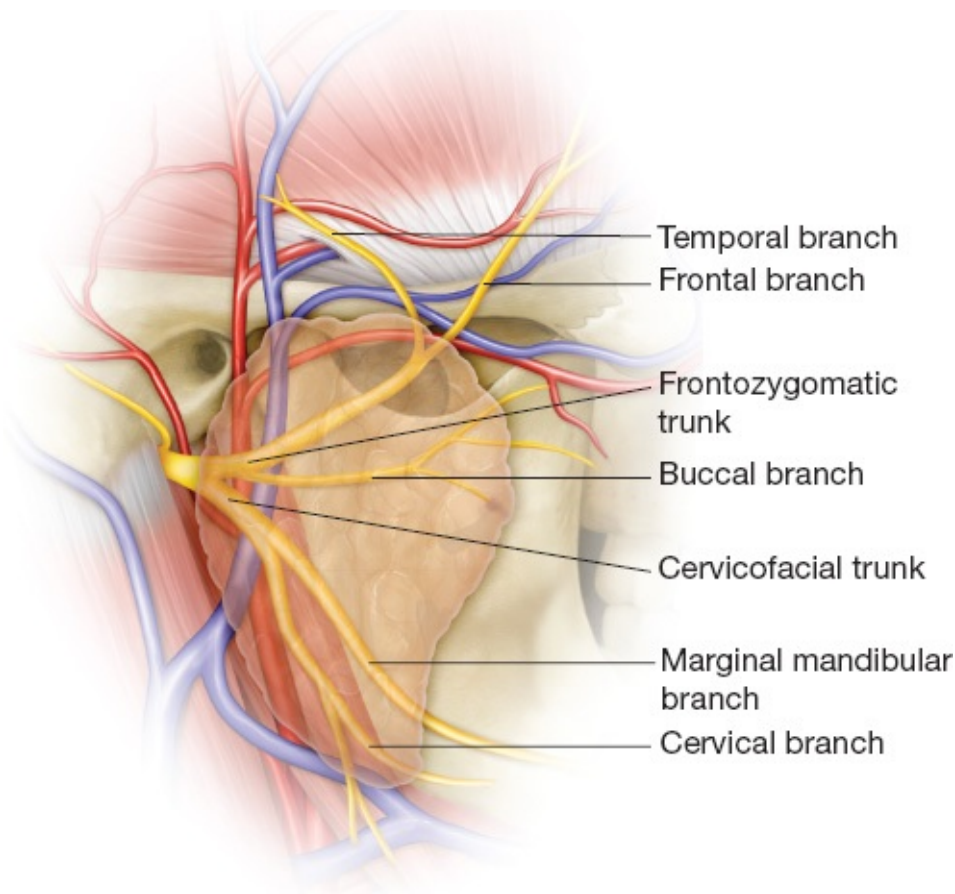


FIG 1 • The anatomy of the facial nerve.

- The nerve is reliably found 3 cm anterior to the tragus, 1 cm inferior to the zygomatic arch, and 1.5 mm deep to the SMAS.^{5,6}

Gracilis Muscle

- The gracilis muscle originates along the body and inferior ramus of the pubis, just below the pubic tubercle.⁷ It runs along the medial thigh and inserts into the medial tibial condyle, immediately deep to the sartorius muscle (**FIG 3A**).
- The gracilis lies immediately posterior to the much larger adductor longus, which is easily palpated on most patients.

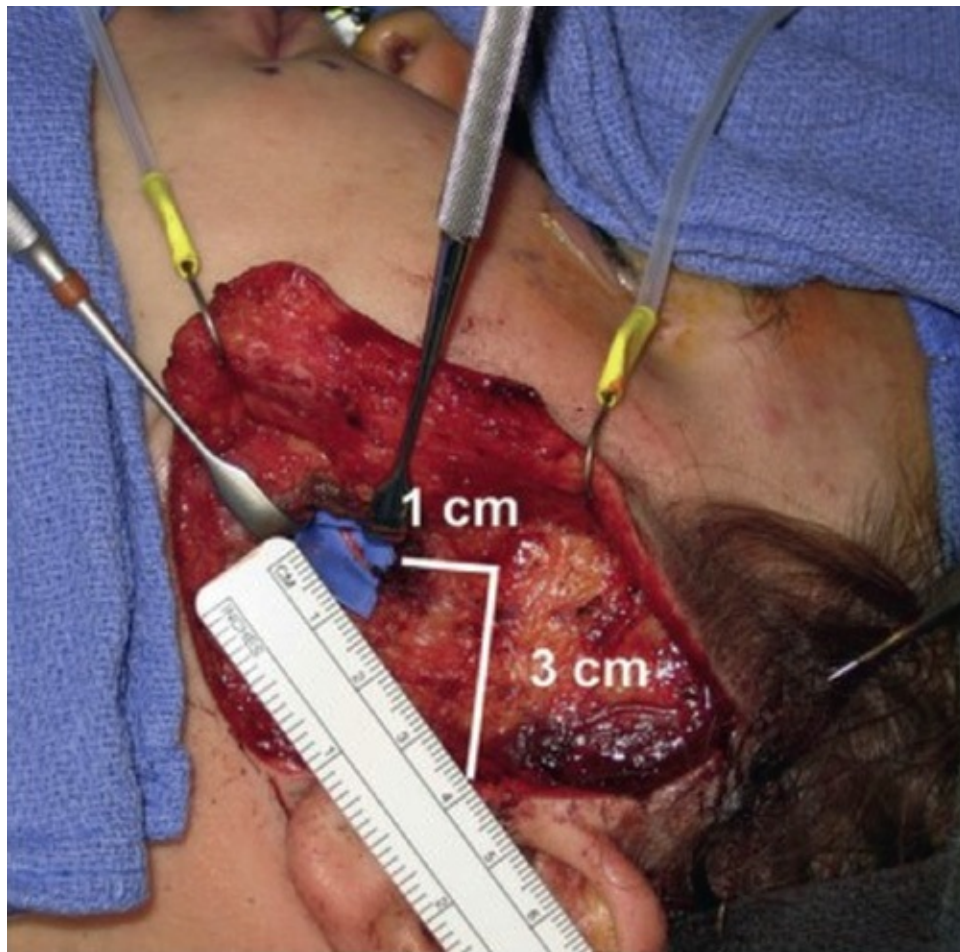


FIG 2 • The nerve to the masseter is found by splitting the temporalis and masseter muscles, under the zygoma. Reprinted from Borschel GH, et al. The motor nerve to the masseter muscle: an anatomic and histomorphometric study to facilitate its use in facial

reanimation. *J Plast Reconstr Aesthet Surg.*
2012;65(3):363-366, with permission from Elsevier.

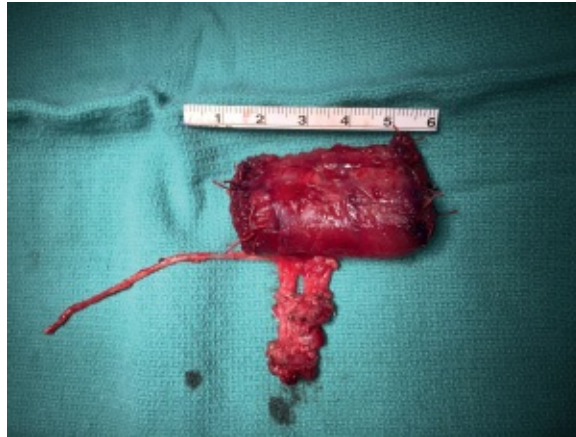


FIG 3 • Gracilis muscle with the pedicle ex vivo. Note the length of obturator nerve (left side of image).

- The muscle is supplied by the medial circumflex femoral artery, a branch of the deep femoral artery. The pedicle runs underneath the adductor longus en route to the gracilis.
- The artery enters the muscle 5 to 12 cm inferior to the pubic tubercle. It is generally 1 to 2 mm in diameter and may have two or three branches at the level of the muscle (**FIG 3B**).
- The artery is accompanied by two vena comitantes.
- The artery and the accompanying vein are 5 to 6 cm when dissected to the deep femoral vessels.
- The muscle has a minor pedicle at its distal aspect that is not appropriate for microvascular transfer.
- A branch of the obturator nerve supplies the gracilis muscle. It splits from the anterior branch of the obturator behind the pectineus and runs with the branch to the adductor longus. The nerve joins the muscle from its lateral aspect, generally at a 45-degree angle to the vascular pedicle. The nerve pierces the muscle and arborizes within it.
- The gracilis muscle has a tendinous origin from the pubis, which can be included with the flap. The muscle can be 3 to 4 cm wide at the level of the pedicle, requiring some muscle splitting to avoid bulky reconstructions.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The most important initial distinction in the preoperative evaluation of pediatric patients with facial paralysis is whether the condition is congenital or acquired. For those with congenital paralysis, the condition may have been apparent at birth or recognized shortly thereafter (**FIG 4**). For those with acquired paralysis, the circumstances and details of the inciting event(s) should be carefully noted. The timing of functional loss is the most critical detail.



FIG 4 • Photo taken shortly after birth, depicting a left-side congenital facial nerve paralysis.

- Functional impairment, including the following, should be noted:
 - Excessive tearing and/or dryness requiring frequent use of lubricating drops
 - Inability to close the eyes fully at night requiring the use of viscous eye lubricant
 - Oral incompetence (drooling) or speech articulation difficulties
 - Presence and extent of dental caries, which are predisposed on the affected side
- Any prior treatments should be noted as well as any progression or improvement in the condition.
- Prior medical, neurologic, or surgical history that would potentially be associated with the condition or the potential surgical treatments that may be considered should be noted.
- A focused examination of the function of the facial nerve is performed, taking care to document both static and dynamic deficiencies. The motor territory associated with each branch should be graded relative to the completeness of the paralysis. We prefer the Toronto Facial Grading System to track our progress.² If etiology of paralysis is unclear, level of injury can be elucidated using the Schirmer test, stapedius reflex test, salivary flow test, and taste examination.
- Photographs and video of the following should be included in the initial evaluation:
 - Repose
 - Brow elevation

- Eye closure (gentle)
- Eye closure (strong)
- Smile (lips together)
- Smile (natural dental display)
- Full dental display
- Pucker
- The ability to close the eyelids such that the cornea is protected must be assessed. Those who are unable to close fully and require viscous lubrication should be identified early and treated with priority ahead of smile reanimation.
- Amblyopia may be seen in as many as 50% of patients with facial nerve palsies, and thus a thorough ophthalmologic examination is warranted.¹ The eye examination should also assess for corneal pathology due to exposure.
- The presence of the facial artery should be confirmed. It is palpable in most patients regardless of age.
- The temporalis and masseter muscles should be palpated, particularly if considering the motor nerve to the masseter as a potential donor nerve. Normal strength and mass should be present.
- Syndromic associations can be seen in congenital facial paralysis and can include hemifacial microsomia, Mobius syndrome, and Poland syndrome among others. Therefore, the examination should include an evaluation of the facial bones (orbits, zygoma, maxilla, and mandible), soft tissues, and ear. Mobius syndrome includes the presence of a cranial nerve VI deficit and can also be associated with a Poland deformity and congenital hand anomalies. Thus, cranial nerves VI, VII, IX, X, and XII should be evaluated for disability.

IMAGING

- For candidate patients with long-standing or congenital paralysis, a radiographic workup is generally unnecessary. For those with associated congenital anomalies, such as craniofacial microsomia, craniofacial CT may be valuable for the comprehensive workup.
- In cases of recently acquired facial paralysis, an EMG may be useful to establish a baseline, demonstrate improvement, or predict recovery. In congenital or long-standing cases, EMG does not provide information that contributes to treatment planning and therefore is not necessary.

NONOPERATIVE MANAGEMENT

- Nonoperative management plays an important role in partial paralysis. A facial

rehabilitation specialist may be able to obtain a more symmetric smile by strengthening weaker muscles and de-emphasizing stronger, more active muscles. Such treatment requires participation of the child.

- In certain instances of incomplete paralysis, neurotoxins can be used on the unaffected side as an adjunct to obtain symmetry.
- Long-standing, complete, and near-complete paralysis in the pediatric population generally requires surgical management.

SURGICAL MANAGEMENT

- For the pediatric patient with congenital or long-standing complete paralysis affecting smile, our preferred treatment is microvascular free functional gracilis transfer. Using the gracilis, we can obtain satisfactory, and often outstanding, static and dynamic symmetry of smile.
- For unilateral facial paralysis, we prefer to use a branch of the facial nerve from the contralateral (functional) side to power the gracilis by way of a cross face nerve graft (CFNG). This allows a spontaneous, emotion-driven smile.
- In cases of bilateral facial paralysis, the nerve to the masseter is coapted to the obturator nerve, powering the functional gracilis. This nerve is powerful, is located in the field of dissection, and does not cause a functional deficit. Although jaw clenching (masseter activation) is required to stimulate activity in the transferred muscle, with postoperative psychomotor training, the patient can learn to use this muscle spontaneously. However, in contrast to CN VII (CFNG), the masseter nerve—which arises from CN V—lacks baseline tone. Therefore, even a strong smile powered by the masseter nerve will lack baseline tone in repose and therefore will potentially still be associated with repose asymmetry including facial shift.

Preoperative Planning

- As with any operation, the patient and parents should be thoroughly informed of risks, benefits, and expected outcomes of the procedure. Free flaps in any population may be lengthy in duration and carry a rare but present risk for early failure. Even when technically successful, achievement of a long-term symmetric smile cannot be guaranteed.
- Families must be briefed on the nature of nerve coaptations, timing of functional results, and postoperative care necessary. In general, the timing of nerve regeneration is as follows:
 - Two-stage repair:

- Cross face nerve graft: 6 to 9 months
 - In older children, a Tinel sign may be followed. In younger children, it may not be elicited.
- Free gracilis transfer: 6 to 12 months
- Nerve to masseter: 2 to 4 months
- Lack of activity (visible or palpable) beyond the later time limits suggests a poor prognosis relative to success of the procedure.
- Preoperatively, the patient is asked to smile, and the vectors of commissure and upper lip elevation are marked on the normal side (if present). These will be used to guide the reconstruction. It is important to do this with the patient in the upright position. Care must be taken not to wash these marks off during the procedure.
- In cases of bilateral paralysis, two sequential single-stage procedures using the nerve to masseter are performed. The vectors of desired pull to obtain a smile are also marked in these patients, guided by the typical appearance and location of the nasolabial fold.
- Given the substantial recovery process required, it is helpful to schedule the muscle transfer in the summer for school-aged children.
- As noted, a Tinel sign may or may not be present over the distal aspect of the CFNG. In the event that the Tinel sign cannot be elicited, intraoperative frozen section of the CFNG may confirm a normal fascicular pattern, thus confirming nerve regeneration and readiness for free muscle transfer.
- The functional muscle transfer of the gracilis is best accomplished with two surgical teams, minimizing anesthetic time and allowing the procedure to be accomplished in a safe and efficient manner. One team focuses on the recipient site preparation, whereas the other harvests the gracilis muscle and prepares it for transfer.

Positioning

- Stage 1 of two-stage procedure (CFNG):
 - A discussion with anesthesia team is important. The following needs must be conveyed:
 - No paralytic agents after induction
 - Choice of endotracheal tube and method of stabilization should not distort facial features or interfere with assessment of stimulation during surgery. The authors prefer nasal or oral RAE for stage 1 procedures.

- The bed is turned 90 degrees to allow all surgeons access to the field. The circuit must be long enough to accommodate the positioning.
- Corneal protection and lubrication must be provided and accommodated at each step of the operation.
- The surgery starts in the prone position, with harvest of the sural nerve.
- Once the nerve is harvested and the leg incisions closed, the patient is turned supine for the facial nerve dissection and nerve coaptation.
- Stage 2 of two-stage procedure or single-stage gracilis transfer (CNV masseter):
 - The patient is placed in the supine position.
 - The bed is positioned so the anesthesiologist is at the ipsilateral hip (turned 90 degrees), which allows both teams to operate freely.
 - For gracilis harvest, the legs are placed in a frog-leg position, with the hips and knees gently flexed. The ipsilateral gracilis is used for the following reasons:
 - The direction of the nerve and vascular pedicle are appropriate to allow muscle to be positioned in line with the facial artery and nerve and with maximal available obturator nerve length.
 - Two teams may operate simultaneously without interference.

Approach

- First stage (CFNG):
 - The sural nerve is harvested first. We prefer stair-step incisions (3) with a lighted retractor and direct visualization of the nerve during dissection. The proximal portion of the sural nerve is preferred due to size match and limited branching.
 - The facial nerve exploration is accomplished through a preauricular (face-lift) incision with a 3- to 5-cm extension along the mandibular angle to facilitate exposure (**FIG 5A**).
- The gracilis harvest is accomplished through a 10-cm incision placed over the medial aspect of the upper thigh.
 - The incision is placed on a line drawn from the inferior ramus of the pubis to the medial tibial condyle, centered approximately 10 cm below the pubic tubercle (**FIG 5B**).
- Recipient site (paralyzed face) and nerve to masseter
 - Similar to first-stage CFNG, the incision follows a preauricular face-lift

design with an extension 3 to 5 cm along the angle of the mandible.

- The incision stops 2 cm anterior to the palpable facial artery, which limits the length of incision while providing adequate microsurgery exposure.

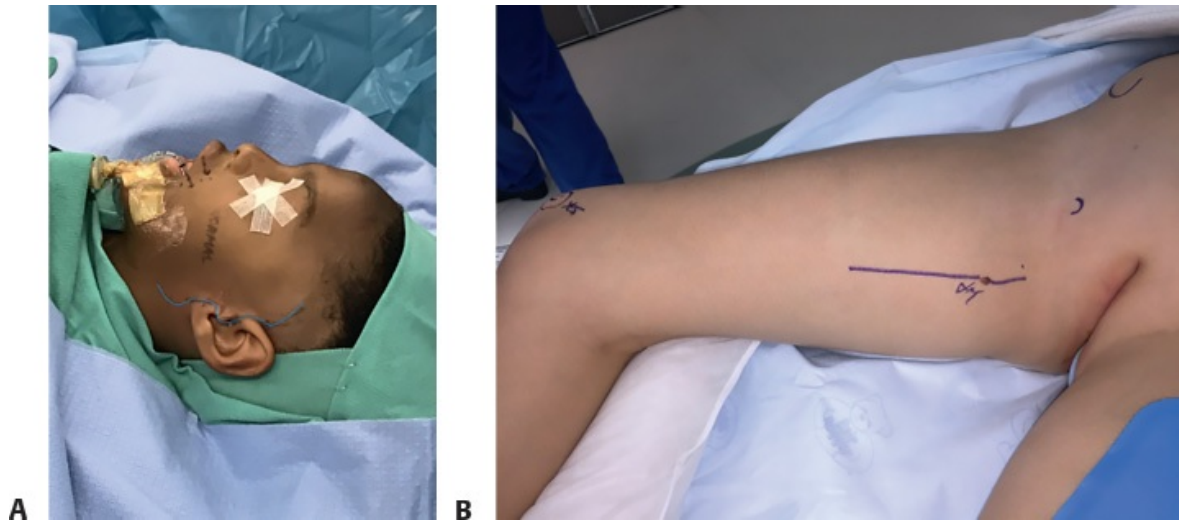


FIG 5 • **A.** Incision pattern for a first-stage cross face nerve graft. **B.** The incision for the gracilis is centered on the presumed location of the pedicle on the medial thigh.

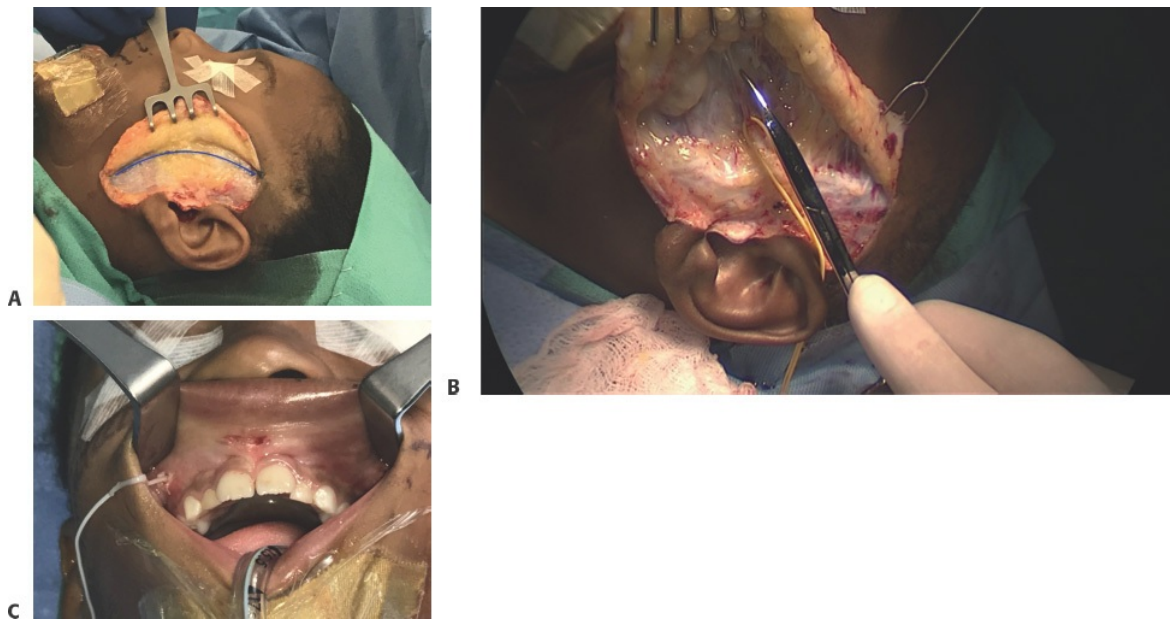
TECHNIQUES



Video p8-c052

■ Cross Face Nerve Graft

- The field is copiously infiltrated with a dilute solution of epinephrine (without any local anesthetic). This decreases blood loss, enhancing visibility, and facilitates the skin flap elevation.
- A modified face-lift–style incision is made on the normal (nonparalyzed) side as described above (see **FIG 5A**).
- Sharp dissection proceeds in a superficial plane until the border of the parotid is reached. Skin hooks are used for retraction.
- Once the border of the parotid is reached, the SMAS is incised, and the dissection continues in the sub-SMAS plane (**TECH FIG 1A**).
- The branches of the facial nerve are identified exiting the parotid with the help of a nerve stimulator (**TECH FIG 1B**).
- A proper donor nerve is identified. The donor nerve should supply the zygomaticus muscles and the levator labii. Nerves that simultaneously supply portions of the orbicularis should be avoided, if possible. The goal is to find a nerve that produces the patient's natural smile in relative isolation. The candidate nerves are then followed distally. Stimulation of two or three candidate branches ensures that enough redundancy exists to preclude functional loss with sacrifice of the ideal donor selection.



TECH FIG 1 • **A.** Incision of SMAS to enable donor nerve dissection. **B.** Nerve branches are identified on

the nonparalyzed side. **C.** The sural nerve is passed through a preperiosteal tunnel across the maxilla using stepped incisions. Tunneling is facilitated by securing the end of the nerve to a vessel loupe and sliding the loupe through the tunnel.

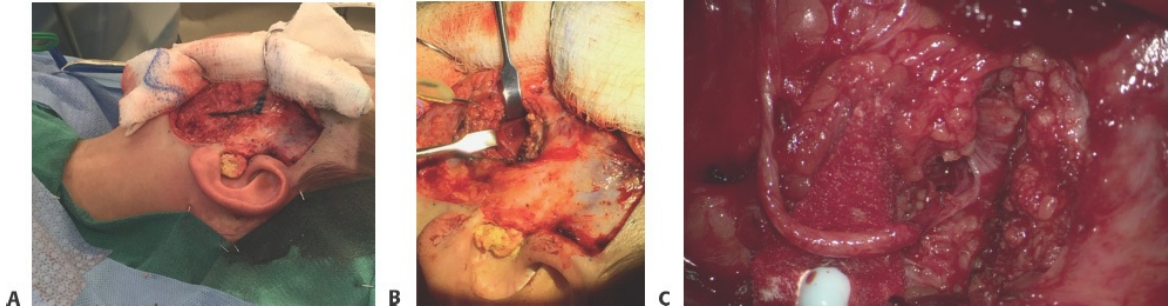
- A preperiosteal tunnel is then created from the medial extent of the dissection plane to the superior buccal sulcus. A small incision is made at the level of the contralateral canine to aide in the dissection.
- A vessel loop is then passed from the buccal sulcus incision into the edge of the face-lift dissection site (**TECH FIG 1C**).
- The sural nerve is harvested at this time.
- The nerve graft is reversed and then secured to the end of the vessel loop. The vessel loop is then pulled back through the subcutaneous tunnel, delivering the distal end of the nerve graft to the upper buccal sulcus atraumatically.
- The distal end of the graft is tagged with a hemoclip and secured to the periosteum lateral to the canine with a 4-0 nylon suture. This aids in identification at the second stage.
- The upper buccal sulcus incision is then closed.
- The proximal nerve graft is coapted to the donor facial nerve end to end under the surgical microscope.
- The cheek flap is then closed using 4-0 Vicryl dermal sutures, followed by 4-0 nylon skin suture. A short Penrose drain segment is placed for 24 hours.
- No compressive dressings or head wraps are used.

■ Identification of Nerve to Masseter

- The nerve to the masseter is identified after cheek flap elevation (described below in the gracilis muscle inset).
- An incision is made in the SMAS anterior to the temporomandibular joint, parallel to the zygomatic arch and just below the arch (**TECH FIG 2A**).
- Dissection proceeds through the superficial and intermediate muscle bellies of the masseter, and a nerve crossing obliquely from zygomatic arch to commissure is sought. The nerve can be found 3 cm anterior to the helical

root and 1 cm below the arch. A nerve stimulator may be used to help identify the nerve (**TECH FIG 2B**).

- The nerve is traced to its entrance into the undersurface of the masseter, where it is transected and transposed superficially (**TECH FIG 2C**).
- Any excess obturator nerve is trimmed prior to coaptation to the masseteric nerve to decrease reinnervation time.



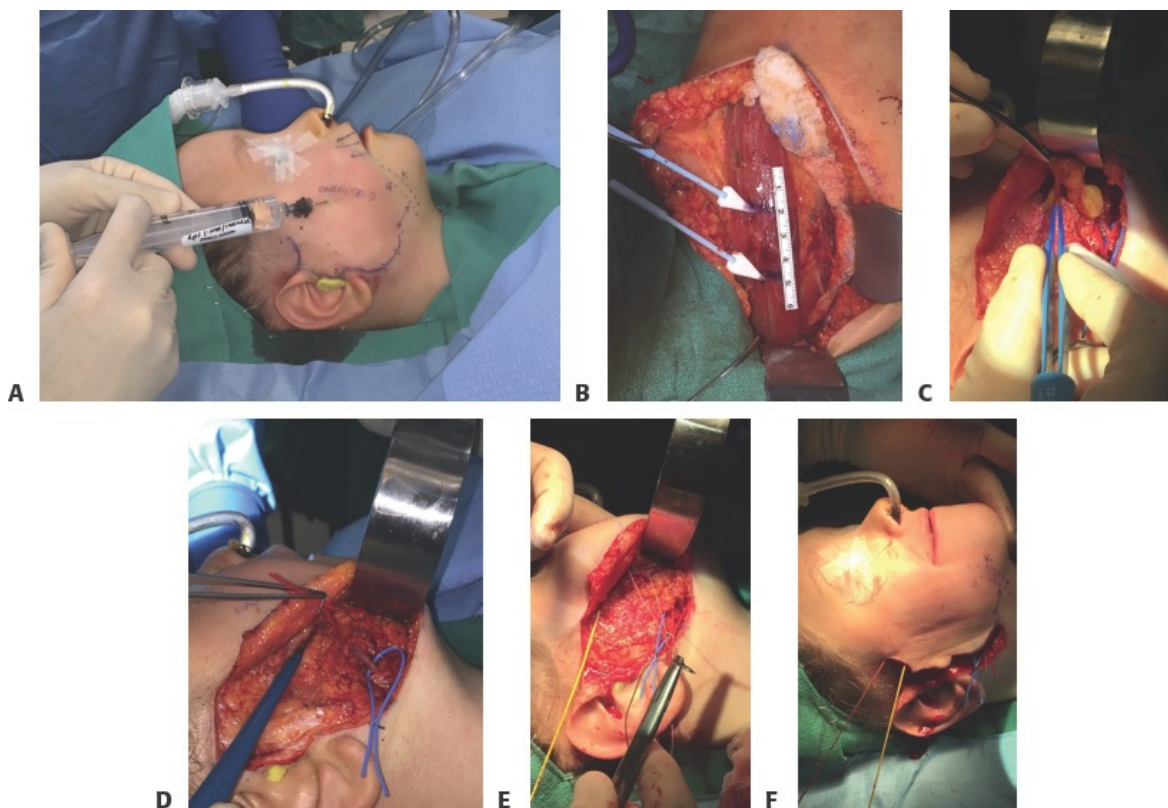
TECH FIG 2 • A. The incision to find the nerve to the masseter is anterior to the TMJ, just below the arch. **B.** The nerve to the masseter is identified. **C.** The nerve is superficially translocated and coapted to the obturator nerve.

■ Recipient Site Preparation

- The field is copiously infiltrated with a dilute solution of epinephrine (without any local anesthetic). This decreases blood loss, enhancing visibility, and facilitates the skin flap elevation (**TECH FIG 3A**).
- A pretrichial, retrotragal incision is made on the paralyzed face. The incision follows the pattern of a basic face-lift incision with an extension inferiorly that allows access to the facial vessels (**TECH FIG 3B**).
- The area from the zygomatic arch to the mandible is elevated in a sub-SMAS plane toward the oral commissure.
- The buccal fat pad is resected to decrease cheek bulk in anticipation of muscle placement (**TECH FIG 3C**). Additionally, deep fat of the cheek is excised as necessary or available.
- The facial vessels are identified and isolated. The vessels are dissected to the level of the commissure to provide length and different diameter choices for

anastomosis (**TECH FIG 3D**).

- Using preoperative vector marks as guides, three to four no. 2 Vicryl inset sutures are placed internally in the upper lip, commissure, and occasionally at the lower lip. One suture is always placed at the commissure.
- Generally, two sutures are placed for the upper lip.
- Depth of suture placement is key, as too shallow a bite will cause lip eversion and too deep lip inversion.
- If orbicularis muscle is present, sutures can be placed through the muscle. In many cases, no muscle is present, and sutures are placed in the submucosa (**TECH FIG 3E**).
- As sutures are placed, traction is placed on the suture to replicate smile. Suture placement is modified until the vectors of pull and the nasolabial fold mimics the anticipated smile (**TECH FIG 3F**).



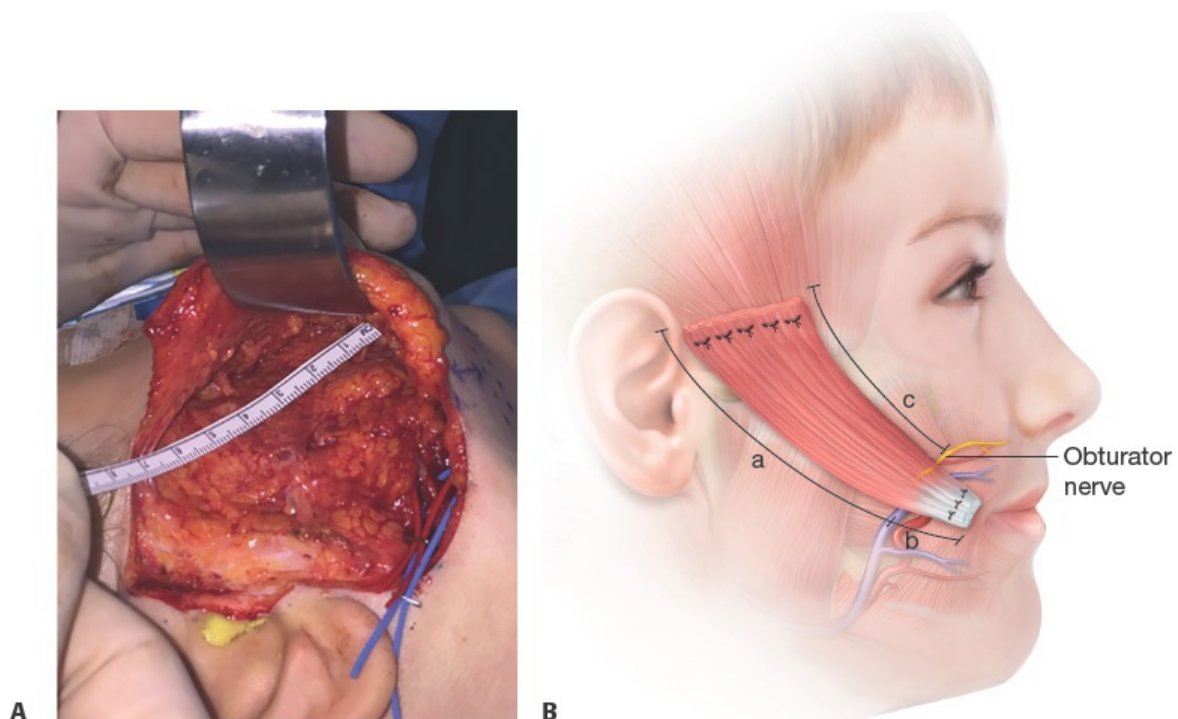
TECH FIG 3 • A. The dissection plane is copiously injected with dilute epinephrine. The incision for the gracilis recipient site on the face mimics a face-lift with an inferomedial extension along the mandible to

access the facial vessels. **B.** The gracilis muscle is measured for size and cut to length in situ. **C.** The ipsilateral buccal fat pad is resected to decrease the bulk deformity of the gracilis muscle. **D.** The facial vessels are identified at the border of the mandible. **E.** A series of sutures are placed at commissure in preparation for securing the muscle. **F.** The location of the commissure sutures is checked by placing traction on them and assessing the smile produced.

Determination of the Length of Muscle Needed for the Reconstruction

- This is done with slight traction applied to the inset sutures such that a slight smile is created.
- For purposes of semantics, we refer to the distal inset at the commissure as the insertion and the proximal inset along the zygoma as the origin.
- The muscle is positioned along the proposed vector of the smile—a reflection of the same vector estimated and drawn on the normal side.
- The distances from the commissure to the proposed medial and lateral points of origin along the zygoma are determined (**TECH FIG 4A**).
 - The distance along the medial point of origin is shorter than that to the lateral point of origin (**TECH FIG 4B**).
- The muscle is taken at the greater length, with an additional 2 cm of length added (1 cm per side) to accommodate a row of sutures at each end. These help prevent pull-through of the subsequent inset sutures. The muscle is then cut on a bias at the proximal end to account for the medial/lateral length discrepancy.
- If pedicle position and required muscle length are ideal, the proximal tendinous portion of the gracilis may be used at the inset origin.
- Once the segmental length is determined, it must be properly centered over the pedicle.
- Three measurements must be made:
 - Total length of muscle (described above, generally around 8 cm)
 - Length of muscle proximal to the facial vessels (approximately 5 cm)
 - Length of muscle distal to the facial vessels (approximately 3 cm)

- In this way, the dimensions can be transferred to the donor site.
- The dimensions are conveyed to the donor site surgical team.

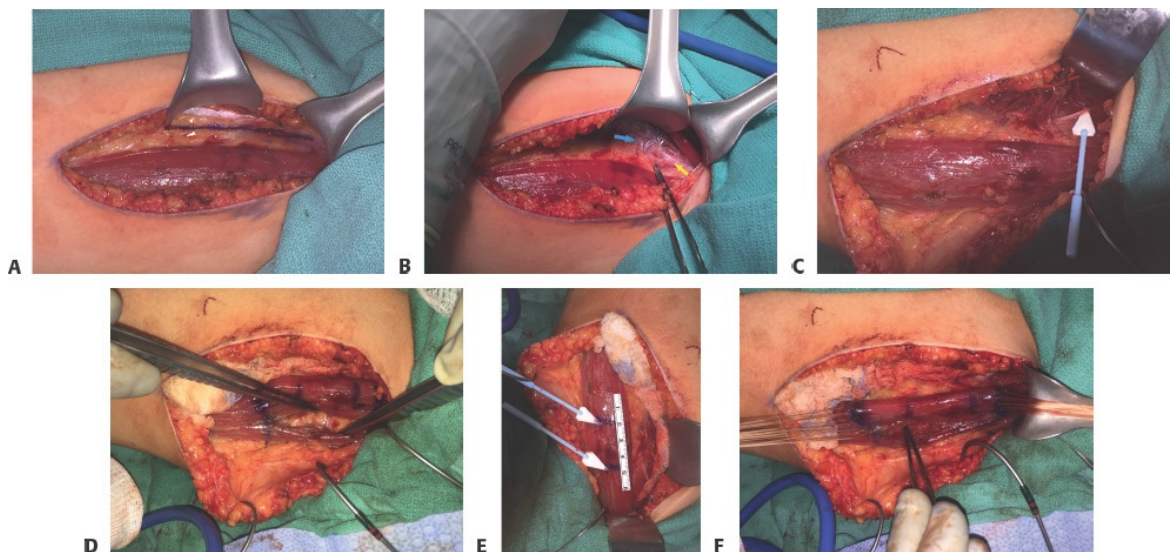


TECH FIG 4 • A. Measurements are taken from the proposed origin to the insertion of the gracilis in preparation for harvest. **B.** The gracilis muscle measurements are measured precisely using the proposed origins and insertions and their relation to the facial vessels. Most times, the anterior border of the muscle (measurement *c* in the diagram) will be shorter than the posterior border of the muscle (measurement *a*) because the origin is secured parallel to the zygoma. Measurement *b* is the length of the gracilis caudal to the vessel insertion.

■ Gracilis Muscle Harvest

- The patient is placed in the supine position. The hip and knees are slightly flexed (frog-leg position).

- The course of the gracilis muscle is marked out on the patient using anatomic landmarks as guides, and an incision is made above the course of the gracilis as described above (see **FIG 5B**).
- The incision is taken straight down toward the adductor longus. The saphenous vein will be encountered and preserved if possible.
- The adductor longus fascia is incised (**TECH FIG 5A**).
- The pedicle is identified approximately 5 to 10 cm below the pubic tubercle. It can be identified by its course: it travels below the adductor longus, entering the muscle at a 90-degree angle, at the posterolateral aspect of the muscle (**TECH FIG 5B**).
- The obturator nerve is identified as the pedicle enters the muscle, at a 45-degree angle to the muscle belly.
- The pedicle and nerve are traced under the adductor longus muscle to obtain the most length and size possible. A lighted retractor facilitates this dissection.
- A neurolysis is done to obtain greater length on the nerve pedicle. This can be taken back to the anterior and posterior division of the obturator nerve (**TECH FIG 5C**).
- Distal minor pedicles of the gracilis are ligated, and the muscle is isolated on all sides.



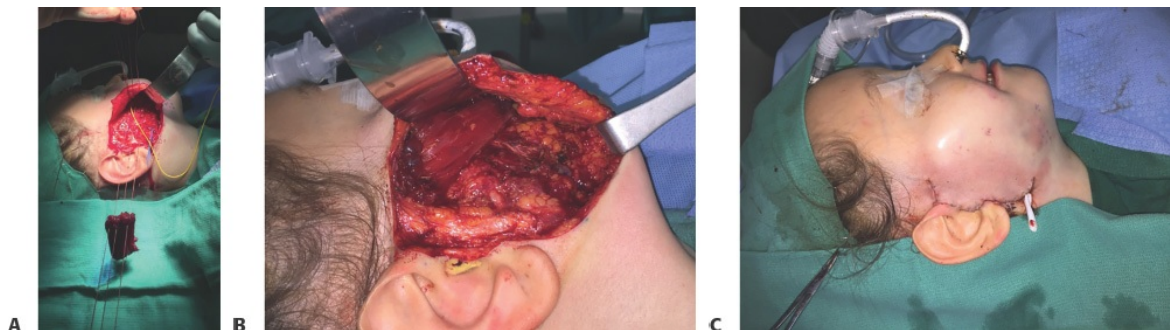
TECH FIG 5 • A. The adductor longus fascia (marked in *blue*) is incised to reveal the gracilis pedicle. **B.** The gracilis pedicle (*blue arrow*) and obturator nerve

(*yellow arrow*) in situ below the adductor longus. **C.** The dissection of the obturator nerve (seen over the WECK-CEL) extends under the adductor longus to its branch point. **D.** The gracilis muscle is split longitudinally to decrease bulk. **E.** The length of gracilis to be used is measured, while the muscle is still in situ. **F.** Mattress sutures are placed on the edges of the gracilis to prevent suture pull-through.

- Once isolated, a nerve stimulator is used to assess the contractile units of the muscle. The gracilis can usually be split into medial and lateral components (**TECH FIG 5D**).
 - This split occurs along a natural cleavage plane. Spanning vessels between the muscle segments should be preserved until nerve contraction has been tested.
 - The nerve is stimulated, and the best contractile segment is prepared for transfer.
 - In general, no more than one-third to one-half of the muscle is required for transfer, depending on the size of the child and muscle. Any muscle not harvested is left in situ.
- The length of the gracilis needed is then determined using measurements obtained from the recipient site (described above).
 - A total length measurement (a + b), length proximal to the pedicle (a), and length distal to the pedicle (b) will be relayed.
 - An additional 1 cm is added to each side to allow for a layer of bolster sutures to be placed at either end (**TECH FIG 5E**).
- A row of mattress sutures of 0-0 Vicryl are placed 1 cm from each end of the muscle to prevent suture pull-through (**TECH FIG 5F**).
- The proximal and distal muscle bellies are severed using bipolar electrocautery.
- Once the recipient site is ready, a heparin bolus is given. After 10 minutes, the vascular pedicle is clipped, and the muscle is transferred to the face.

■ Gracilis Muscle Inset

- The orientation of the muscle is then determined with consideration of microvascular anastomosis and the nerve coaptation.
- The previously placed inset sutures are then placed in the gracilis, just central on the gracilis to the row of mattress sutures. The muscle is then parachuted into position at the commissure (**TECH FIG 6A**).
- The obturator nerve is then passed through a previously created tunnel to the upper lip (if using a CFNG) or placed in position to coapt to the nerve to the masseter.
- The muscle is then temporarily placed and secured in its final inset position in preparation for a tension-free anastomosis that will not change after the final muscle inset.
- The microvascular anastomosis is then performed, generally vein before artery.
- The epineural nerve coaptation is performed. The buccal sulcus incision is closed at this time.
- The inset origin of the muscle is secured to the deep tissues and periosteum of the zygoma using mattress sutures of no. 1 Vicryl again behind the row of mattress sutures on the gracilis. The muscle should be spread over the inset origin to prevent excess bulk (**TECH FIG 6B**).
- When the muscle is inset, proper tension must be set. If the measurements have been properly made, the resting position will appear as a slight (20%–30% of max) smile.
- A Penrose drain is placed behind the ear by way of a separate stab wound.
- The cheek flap is closed using 4-0 Vicryl sutures in the dermis and a 5-0 Monocryl plus skin closure (**TECH FIG 6C**).



TECH FIG 6 • **A.** The gracilis muscle is parachuted into position at the commissure. **B.** The gracilis in the

final position. **C.** The skin is closed and the area drained with a Penrose drain.

PEARLS AND PITFALLS

Donor nerve evaluation

- Selection of an appropriate donor nerve for the CFNG is crucial to the overall success of the operation.
- The donor nerve should supply the zygomaticus muscles and the levator anguli oris, with minimal (if any) contributions to the orbicularis oris.
- The donor nerve branch taken must have redundancy with other nearby branches and therefore can (and should) be divided relatively proximally. This should be determined with a nerve stimulator to avoid any donor-site weakness.

Muscle inset

- An incorrectly inset muscle is nearly impossible to correct. Unfortunately, this may not be noticed until the muscle starts to function, months after the initial procedure. Care must be taken to avoid potential issues by concentrating on the following:
- Determine the desired vector of pull, and focus on adequate vertical orientation during inset.
- Use a row of mattress sutures to prevent pull-through.
- Avoid excess bulk by splitting the muscle in situ before transfer and by removing buccal fat.
- The muscle should be inset with tension to simulate 20%–30% of a natural smile.
- Avoid excess bulk by coursing the muscle posterior to the malar eminence and fanning the muscle out in the temple area.

Inset insertion suture placement

- Preoperative smile vector analysis is key to creating a pleasing smile and should be done in the upright position in the holding area.
- Time and care should be taken to place each suture in the appropriate position on the upper lip and commissure, avoiding inversion, eversion, and dimpling.
- A symmetric nasolabial fold should be created.

Gracilis harvest

- Identification of the gracilis is best done by visualizing the obturator nerve and the medial femoral circumflex vessels traversing underneath the adductor longus muscle en route to the medial aspect of the

gracilis.

- The pedicle size can be small but can be followed below the adductor longus to its origin on the profunda for additional length and diameter.
- The pedicle is best found by scoring the fascia of the adductor longus exposing the space below the adductor that contains the medial femoral vessels and obturator nerve.
- Donor site seromas are less common in facial reanimation than when the gracilis is used in breast reconstruction but still warrant placement of a drain.
- Lidocaine should not be used as a vasodilator during this portion of the procedure to avoid any effects on nerve stimulation. Papaverine is preferred.

POSTOPERATIVE CARE

- Free muscle transfers are monitored via implantable Doppler probes. Postoperative flap checks are performed on an hourly basis for 2 days, followed by every 4 hours for the next 2 days.
- Our postoperative management follows a gradual increase in activity:
 - Bed rest for 1 day
 - Gradual and slow mobilization thereafter
- No pressure on the operated side of the face for 6 weeks
- Perioperative antibiotics are given.
- Signs of reinnervation are followed in the clinic and can generally be expected at 2 to 4 months when the nerve to the masseter is used and 6 to 12 months when a CFNG is used.
- Once reinnervation is noted on examination, therapy is started. Patients work with therapists specifically trained in facial reanimation rehabilitation. We believe this to be critical to success.
- Exercises done in front of a mirror are useful to provide a feedback mechanism and improve symmetry. This should be done 2 or 3 times a day for 4 to 5 minutes at a time.
- Therapy should be continued for a period of 6 months.

OUTCOMES

- The goal of a functional gracilis transfer is smile recreation using a single vector pull of the muscle. Thus, limitations exist. A pure symmetric smile is a lofty goal, but with attention to detail and therapy, dramatic results can be

obtained (**FIG 6**).

- Studies have shown improved speech outcomes in patients with Mobius syndrome after undergoing bilateral gracilis transfers.

COMPLICATIONS

- Garcia et al. in a pooled data analysis reported a complication rate of 9.6%.⁷
- Complications included the following:
 - Postoperative hematoma (3.6%)
 - Infection (3.5%)
 - Vascular compromise (1.4%)
 - Salivary leak (1%)
 - Seroma (0.4%)
- Long-term failure of the muscle to reinnervate was reported at 1.8%



FIG 6 • Preoperative and 2-year postoperative pictures of the patient in **FIG 4**, who underwent a two-stage free gracilis transfer for a congenital facial nerve palsy.

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DEFINITION

- Neurotrophic keratopathy is a degenerative corneal disease caused by impairment of corneal innervation.¹
- Corneal neurotization involves using functioning sensory nerves from elsewhere on the face as donor nerves to reinnervate the cornea and restore corneal sensation and improve ocular surface health.

ANATOMY

- The cornea is the most densely innervated part of the body.^{1,2}
- Corneal innervation derives from the ophthalmic branch (V1) of the trigeminal nerve (CN V).³
- Lesions may occur anywhere along the course of the corneal innervation pathway including the pons, the trigeminal (gasserian) ganglion, the ophthalmic branch, the nasociliary nerves, and the long ciliary nerves.
- Despite corneal nerve density, the cornea is supplied by relatively few trigeminal neurons as a single neuron may support hundreds of individual nerve endings.⁴⁻⁶
- The corneal innervation is divided into three networks: stromal, sub-basal, and epithelial.^{7,8}

PATHOGENESIS

- Corneal sensation is a necessary component of reflexive tearing and blinking, which prevent corneal injury.
- Pain ordinarily would prompt patients to seek appropriate treatment after corneal injuries; however, an insensate cornea leaves patients unaware of their

corneal injury.

- Repetitive corneal epithelial injury and ulceration cause corneal scarring and vision loss.^{9–11}
- Corneal nerves also contain neuromediators that promote corneal epithelial maintenance and repair.^{3,11}
- Immediately following corneal denervation, animal models show decreases in epithelial cell vitality and mitosis, resulting in thinning, breakdown, and ulceration of the corneal epithelium.^{12–15}

NATURAL HISTORY

- Neurotrophic keratopathy is one of the most difficult ocular diseases to treat.¹
- Prognosis is dependent on the severity of corneal hypoesthesia and the presence of other concomitant ocular disorders such as dry eye disease, exposure keratopathy, and corneal limbal stem cell deficiency.
- Patients require lifelong treatment and even with optimal management many develop vision loss and blindness in the affected eye.
- Inflammation and repeated corneal injury may also result in neovascularization of the cornea, further impeding vision.

PATIENT HISTORY AND FINDINGS

- Patients typically present with persistent asymptomatic corneal epithelial defects.
- Neurotrophic keratopathy is classified into three stages depending on clinical findings based on the Mackie classification¹:
 - Stage 1: epithelial irregularity with punctate keratopathy and minimal stromal scarring.
 - Stage 2: epithelial ulceration surrounded by a rim of loose epithelium +/- stromal swelling.
 - Stage 3: corneal ulceration involving the stroma with risk of corneal perforation.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Diagnosis is based on clinical findings and a patient history of corneal hypoesthesia or anesthesia with delayed healing and persistence of corneal epithelial defects.^{16,17}
- Slit lamp: identifies corneal epithelial abnormalities, including diffuse staining with fluorescein, epithelial sloughing, and stromal neovascularization.

- Corneal esthesiometry: measures corneal sensation. This can be performed with a Cochet-Bonnet aesthesiometer (Luneau, France) by a skilled ophthalmologist.
- Schirmer test: used to diagnose concomitant dry eye disease, when needed.
- In vivo corneal confocal microscopy (IVCCM): documents the absence of corneal nerve fibers.

DIFFERENTIAL DIAGNOSIS

- Hallmark for diagnosis is the presence of a corneal ulcer and the absence of corneal sensation.
- Possible etiologies of corneal anesthesia and hypoesthesia are as follows:^{9,16}
 - Viral infection (herpes simplex and zoster keratoconjunctivitis)
 - Chemical burns
 - Physical injury to the trigeminal innervation (such as intracranial surgery)
 - Corneal surgery
 - Diabetes
 - Leprosy
 - Topical anesthetic abuse
 - Congenital (such as trigeminal agenesis, cerebellar hypoplasia, brainstem hypoplasia)
- Certain disease may also exacerbate neurotrophic keratopathy:
 - Dry eye disease
 - Exposure keratopathy; facial nerve paralysis
 - Corneal limbal stem cell deficiency

NONOPERATIVE MANAGEMENT

- The goals of treatment are to prevent corneal ulceration and promote epithelial healing when ulcerations occur.^{1,16,17}
 - Preservative-free topical artificial tears
 - Punctal occlusion
 - Therapeutic contact lenses (eg, the “Boston lens”)
 - Topical antimicrobials
 - Protective tarsorrhaphy
- If a corneal perforation is suspected, then cyanoacrylate glue or keratoplasty (cornea transplant) may be indicated.
- Exacerbating conditions, such as exposure keratopathy and limbal stem cell deficiency, should be treated.

- Experimental treatments for persistent ulcerations include topical IGF-1, substance P, or nerve growth factor (NGF).^{18–21}

SURGICAL MANAGEMENT

- Surgical management to restore corneal sensation in patients with corneal anesthesia or hypoesthesia has been described.^{22–24}
- Samii first described a surgical technique to reinnervate the cornea using an intracranial approach through an osteoplastic frontal craniotomy to guide regenerating axons directly into the ophthalmic nerve using a long sural nerve graft and the occipital nerve as donor.
- Avoiding an intracranial approach, Terzis²² described a technique using the peripheral nervous system to reinnervate the cornea by directly transferring the supraorbital and supratrochlear nerves to neurotize the cornea.
 - This technique necessitates a coronal incision and extensive dissection to access the supratrochlear and supraorbital nerves distally.
- This technique was then modified by Borschel, Ali, and Zuker,^{23,24} who were able to avoid a coronal incision by guiding axons from the proximal supratrochlear nerve into the anesthetic cornea via a sural nerve graft.
 - This technique uses two small supraorbital incisions.
 - This approach is described in detail in this chapter.

Preoperative Planning

- Thorough facial sensory nerve examination and mapping must be done in order to identify potential donor nerves for reconstruction. The authors use an occupational therapist and Semmes-Weinstein monofilaments to document facial sensation.
- All patients should be evaluated by an ophthalmologist to document visual acuity, overall ocular health, and corneal sensation using Cochet-Bonnet aesthesiometry.

Positioning

- The patient is placed in the supine position on the operating table, and the entire face is prepped and draped (**FIG 1**).
- The leg to be used for sural nerve harvest is also prepped and draped.



FIG 1 • We prefer to operate from the head of the bed with the patient in the supine position. Even with a thorough sensory examination documenting normal sensation in the contralateral face, we have found the donor supratrochlear or supraorbital nerves to be insufficiently large enough for coaptation on occasion. For this reason, we prep the patient's entire face in case we use the infraorbital nerve as a donor.

TECHNIQUES

■ Sural Nerve Harvest

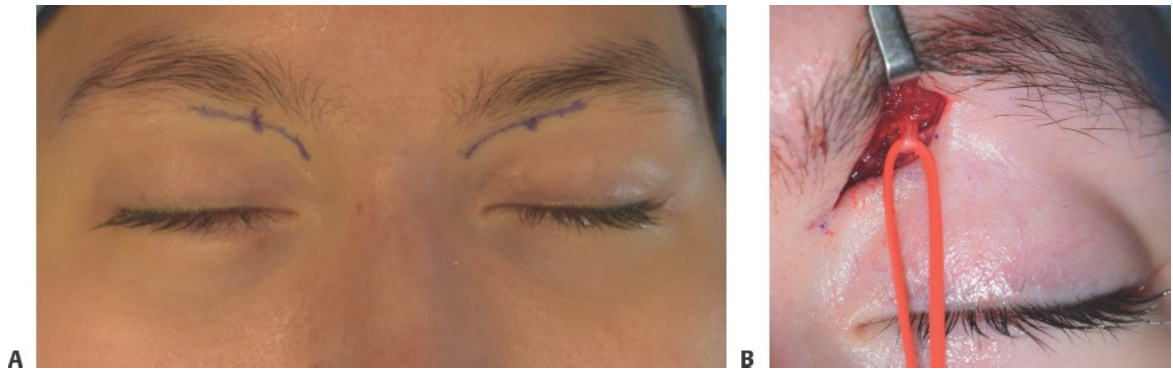
- This can be performed using the surgeon's preference. We prefer using a nerve stripper device that permits harvesting of the proximal tibial component of the sural nerve, which usually provides a branch-free graft of sufficient length.

Identification of the Contralateral Supratrochlear Nerve

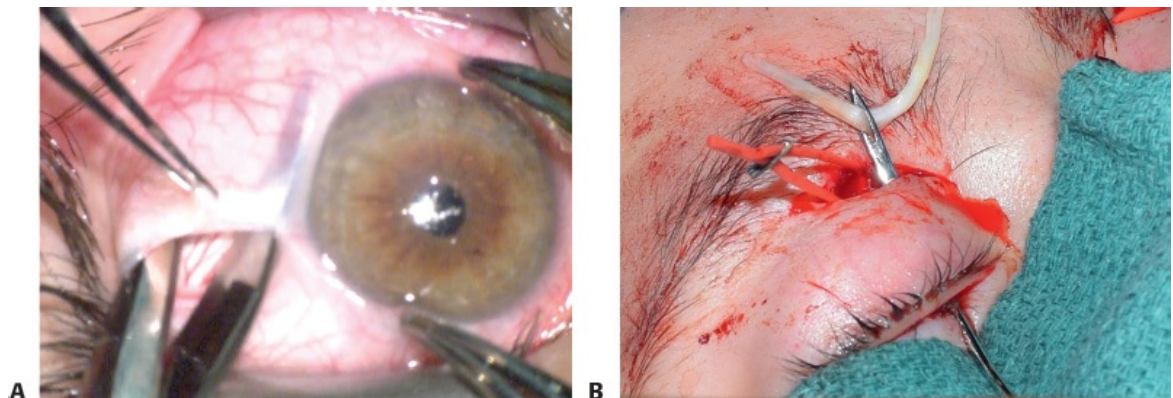
- Any functioning sensory nerve in the face can be used for corneal neurotization.
- Many patients have hemifacial sensory deficits associated with neurotrophic keratopathy. Our preferred technique is to use the contralateral supratrochlear nerve as a donor. If the ipsilateral supratrochlear or supraorbital nerves are normal and available, they may be used instead of the contralateral nerves.
- Two- to three-centimeter supraorbital incisions are made on the medial lower border of the eyebrows over each eye (**TECH FIG 1A**).
- The donor supratrochlear or supraorbital nerve is then identified through this incision on the donor side (**TECH FIG 1B**).
- The supratrochlear nerve is identified deep to the origin of the frontalis muscle, on the surface of the corrugator supercilii muscle traveling cephalad from the supratrochlear notch.
- The supratrochlear notch can often be palpated to guide dissection.
- Some supratrochlear nerves divide distal to the notch. Both branches can be incorporated as donors.

Tunneling of the Sural Nerve Graft to the Affected Cornea

- Once the supratrochlear or supraorbital nerve has been identified, the contralateral incision over the affected eye is deepened to the level of the subcutaneous tissue.
- A fine hemostat is used to bluntly dissect a subcutaneous plane between the two incisions to provide a passage for the sural nerve graft.
- With the distal portion of the hemostat through the incision on the affected eyelid, the distal end of the sural nerve graft is grasped and pulled through the subcutaneous pocket so that the nerve graft is traversing the incisions, reversing the direction of the nerve graft for coaptation.
- A superonasal perilimbal incision is made in the conjunctiva using blunt scissors, and a small pocket is made in the potential space between the sclera and Tenon capsule (**TECH FIG 2A**).



TECH FIG 1 • A. We palpate the supratrochlear notch to mark two incisions over the ipsilateral and contralateral supratrochlear nerves. As most patients with corneal anesthesia have hemifacial sensory abnormalities, we most frequently use the contralateral supratrochlear nerve as a donor sensory nerve for corneal neurotization. **B.** The supratrochlear nerve is identified below the level of the frontalis muscle at the location of the supratrochlear notch and is secured with vessel loop.



TECH FIG 2 • A. Once the sural nerve graft has been tunneled to the ipsilateral supraorbital incision, an incision is made into the perilimbal conjunctiva and a potential space is expanded between the conjunctiva and sclera. This permits the Wright needle to be passed from the perilimbal conjunctiva to the

ipsilateral supraorbital skin incision. **B.** The Wright needle is passed from the perilimbal conjunctival incision into the ipsilateral supraorbital skin incision. The sural nerve graft is then placed within the eye of the needle, tunneling the sural nerve graft into the orbit as the needle is withdrawn through the perilimbal conjunctival incision.

- A Wright needle (curved ophthalmologic trocar with eyelet) is then used to pass the sural nerve graft from the supraorbital incision over the affected eye, below the conjunctiva and Tenon capsule, to be delivered to the perilimbal incision (**TECH FIG 2B**).

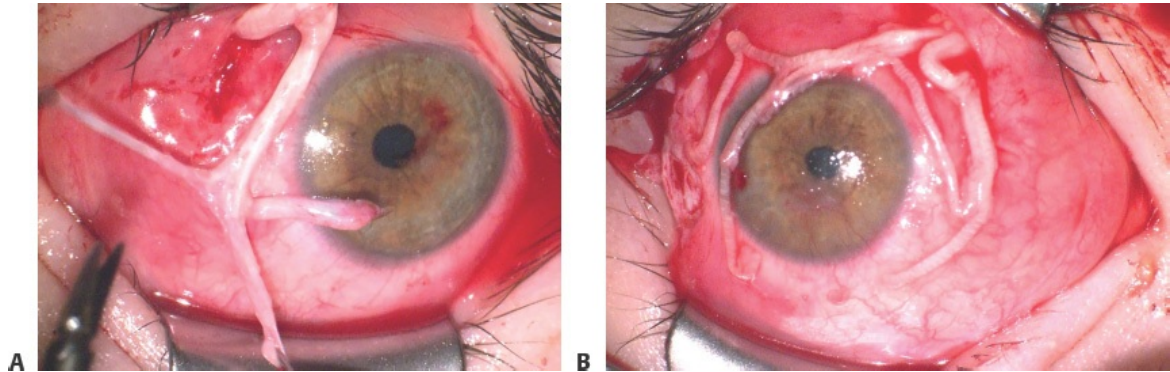
Dissection of the Sural Nerve Fascicles

- Under the operating microscope and on the surface of the affected eye, the sural nerve graft is divided into separate fascicles so that they may be evenly distributed around the eye to reinnervate the cornea (**TECH FIG 3A**).
- We aim to produce three to four fascicles from the sural nerve graft; however, in many patients, we have used only two fascicles, with good results.
- The fascicles are then distributed around the cornea to evenly distribute the location of regenerating axons into the cornea (**TECH FIG 3B**).

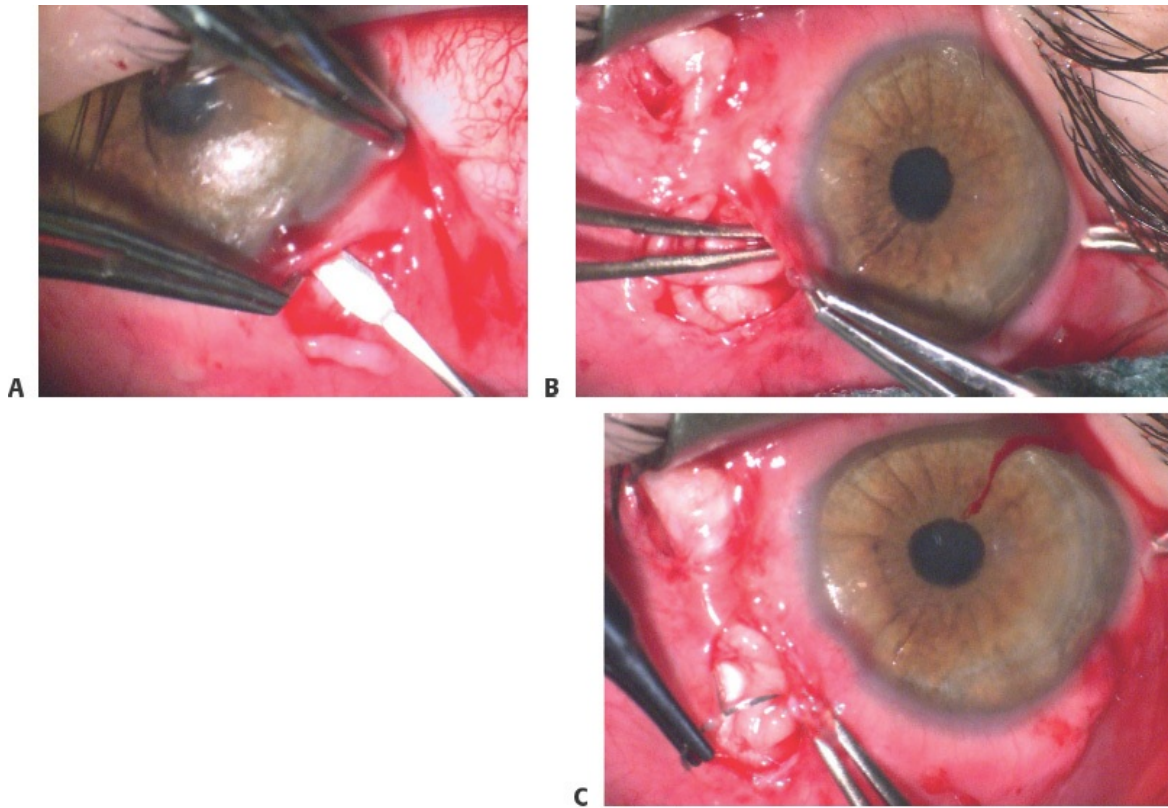
Tunneling of Fascicles Into the Corneal Stroma

- Separate perilimbal incisions are then made for each of the fascicles, and again a small perilimbal pocket is made between the sclera and Tenon capsule. Each fascicle is then tunneled below the conjunctiva into these incisions to lie adjacent to the cornea.
- A corneal scalpel blade is used to make a small scleral tunnel incision 1.0 to 1.5 mm from the limbus and approximately 1.5 mm wide (about twice the width of the fascicle) into the clear peripheral cornea so that each fascicle can be tunneled directly into the cornea (**TECH FIG 4A**).
- The nerve graft fascicle is then gently placed directly into the stromal pocket (**TECH FIG 4B**), and 10-0 absorbable (Vicryl) stitch is placed through the sclera and the epineurium of the fascicle to keep the fascicle in place.
- This is then done for each of the fascicles individually.

- Each of the perilimbal conjunctival incisions are then closed with 10-0 absorbable stitch (**TECH FIG 4C**) being careful to avoid any exposure of the fascicles.



TECH FIG 3 • A. Once overlaying the cornea, the sural nerve graft is dissected into separate fascicles. **B.** Once divided into separate fascicles, these are distributed evenly around the cornea. In our experience, there are a variable number of fascicles in the sural nerve. We aim to have at least two fascicles, with a maximum of four when available. Each fascicle is then tunneled below the level of the conjunctiva through perilimbal incisions to surround the eye.



TECH FIG 4 • A. Through each perlimbal incision, an ophthalmic scalpel is used to make a pocket within the corneal stroma. **B.** Once the stromal pocket has been made, the fascicle is tunneled directly into the corneal stroma using forceps. In the image, the distal portion of the sural nerve graft can be seen protruding into the corneal stroma. Each fascicle is sutured into place proximal to the stromal pocket using 10-0 absorbable sutures. **C.** After the sural nerve fascicle has been tunneled into the corneal stroma and secured to the sclera with a 10-0 stitch, the perlimbal conjunctival incision is sutured closed.

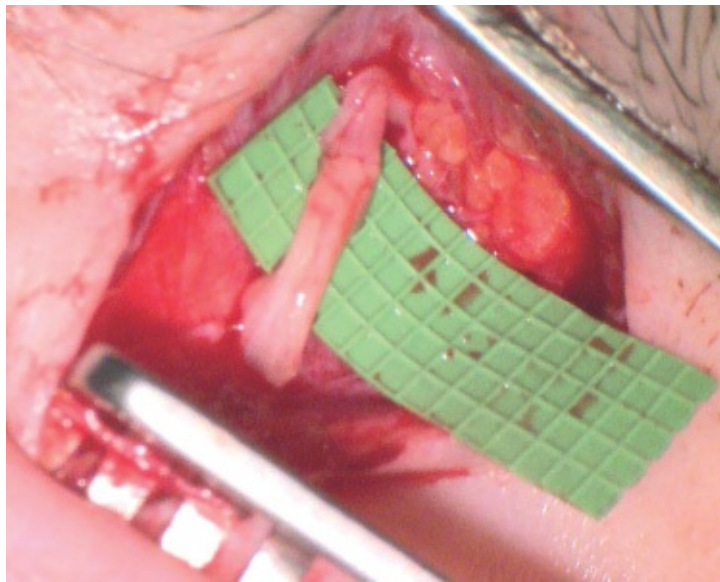
- A limbal incision and tunneling the nerve fascicles directly into the corneal stroma may significantly improve nerve regrowth as the limbus may act as a barrier to corneal nerve ingrowth.
- The affected eye is then closed with a temporary central tarsorrhaphy suture

to protect the corneal surface after surgery, and this is left in place for 1 to 2 weeks.

- If a permanent lateral tarsorrhaphy has not been performed previously, it can be done at this step.

Nerve Coaptation

- As the final step, the distal portion of the sural nerve graft is coapted to the supratrochlear nerve in an end-to-end fashion with 10-0 nylon suture or fibrin glue (**TECH FIG 5**) or both glue and sutures, depending on surgeon preference.
- The supraorbital incisions are closed with a 6-0 subcuticular Monocryl stitch.



TECH FIG 5 • Once all conjunctival incisions have been closed, the distal portion of the sural nerve graft is coapted to the proximal stump of the transected supratrochlear nerve. We have also done side-to-end repair; however, we prefer this technique as we have found the donor site morbidity to be minimal and end-to-end repair recruits a greater number of donor sensory axons.

PEARLS AND PITFALLS

Preoperative considerations

- A thorough sensory examination is necessary prior to the operation to identify normal functioning donor nerves.

Acquired vs congenital cases

- Acquired cases usually have straightforward neuroanatomy.
- Congenital cases often have aberrant anatomy.
 - These cases may have complete absence of any supratrochlear or supraorbital nerves despite intact glabellar sensation.
 - We have also used the ipsilateral infraorbital nerve to reconstruct corneal sensation.

Nerve harvest

- The tibial contribution to sural nerve is usually sufficient length. This can be harvested through a popliteal incision and a small counter incision in the midcalf.

Postoperative considerations

- Keep postoperative patients out of sports or vigorous activities for 6 weeks.
- Patients may experience pain once innervation occurs; this is actually a positive sign, but they should be warned in advance.

POSTOPERATIVE CARE

- Patients should be under the care of an ophthalmologist pre-, intra-, and postoperatively.
- The intraoperative tarsorrhaphy suture is left in place for 1 week.
- Patients are provided with postoperative topical medication:
 - Topical tobramycin and dexamethasone ointment until the tarsorrhaphy is removed
 - Topical moxifloxacin and prednisolone eyedrops
 - Preservative-free lubricating eyedrops
- Sensory and vision outcomes are monitored regularly by the ophthalmologist.

OUTCOMES

- To date, there have been only two series published describing outcomes in patients with corneal neurotization by Terzis²² and Borschel^{23,24} and a case report by Samii.
- In Terzis' series, all 6 patients were followed for an average of 16.3 ± 2.42 years and demonstrated significant improvements in corneal sensibility with no further deterioration of visual acuity or overall corneal health.²²

- In Borschel and Ali's series, using the described surgical technique for corneal neurotization, all patients demonstrated significant improvements in corneal sensation with some patients developing sensation indistinguishable from normal with Cochet-Bonnet esthesiometry; however, follow-up had not been carried out far enough to definitively determine vision outcomes.²³

COMPLICATIONS

- Axon regrowth through the nerve graft and into the cornea may take several months with this sural nerve grafting technique.
- Using the contralateral supratrochlear nerve results in minimal sensory loss on the donor side.
- Inability to regain protective sensation after corneal neurotization may be caused by unrecognized insufficiency of the donor nerve.
- Loss of sensation on the lateral ankle and foot after sural nerve harvest is of minimal functional consequence.

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Section XIII: Brachial Plexus (Obstetrical Injury)

Primary Treatment of Neonatal Brachial Plexus Palsy

54
CHAPTER

Bryce R. Bell, Ji-Geng Yan, and Hani Matloub

DEFINITION

- Injury to the nerves supplying the upper extremity (C5-T1) during the birth process
- Epidemiology¹
 - Incidence can vary greatly by institution.
 - The most recent nationwide study shows 1.51 per 1000 live births in the USA.
- Risk factors¹⁻³
 - Shoulder dystocia
 - Macrosomia (greater than 4–4.5 kg)
 - Instrumented delivery
 - Prior delivery with brachial plexus injury
 - Prolonged labor resulting in hypotonia
 - Tachysystole during labor
 - Use of oxytocin
 - Studies have consistently shown that more than half of patients with neonatal brachial plexus palsy (NBPP) have no identifiable risk factor.

ANATOMY

- Normally, the brachial plexus has contributions from C5 to T1.
- Can have prefixed or postfixed cords with contributions from C4 (22%) and T2 (1%), respectively
- Roots combine to form upper (C5/C6), middle (C7), and lower trunks (C8/T1).
- Near the level of the clavicle, these trunks give off anterior and posterior divisions to form lateral, medial, and posterior cords, so named for their relation to the axillary artery. The lateral cord is formed from the confluence of the anterior divisions of the upper and middle trunks. The posterior cord is formed from the posterior divisions of all three trunks. Finally, the medial cord consists of only the anterior division of the lower trunk.
- Cords then divide into terminal branches (musculocutaneous, axillary, radial, median, and ulnar).
- Smaller branches originate from various levels in the brachial plexus and are important in localizing the level of injury by clinical examination (**FIG 1**).
- The sympathetic chain runs along the ventral aspect of the exiting roots and is often disrupted in root avulsions from the spinal cord. This accounts for the findings seen in Horner syndrome.

PATHOGENESIS

- Mechanism of injury
 - Most commonly a downward force on the shoulder causes deviation of the neck away from the involved extremity. This typically involves at least the C5-C6 roots but can result in complete plexus injury.
 - More rarely, injury can occur due to extreme cranial traction on the extremity with neck extension during breech delivery. These injuries often involve the lower roots.
 - Traditionally, injury was thought to be caused by traction during delivery by the obstetrician, by either manual or instrumented delivery.
 - However, given that more than half of children with brachial plexus injuries do not have an identifiable risk factor, some debate exists on the presence of an intrauterine mechanism of injury that is more difficult to identify. One study estimated uterine contractions exert up to 9 times greater force on the shoulder than that applied by the obstetrician.⁴
 - In addition, Walsh et al. showed no significant decrease in incidence of NBPP despite structured training on management of shoulder dystocia and a rising cesarean section rate.⁵
 - These injuries result in varying degrees of weakness in the ipsilateral

extremity, ranging from subtle weakness to flaccid paralysis.

- Classifications of Seddon and Sunderland

- Seddon divided nerve injuries into three categories: neurapraxia, axonotmesis, and neurotmesis.⁶

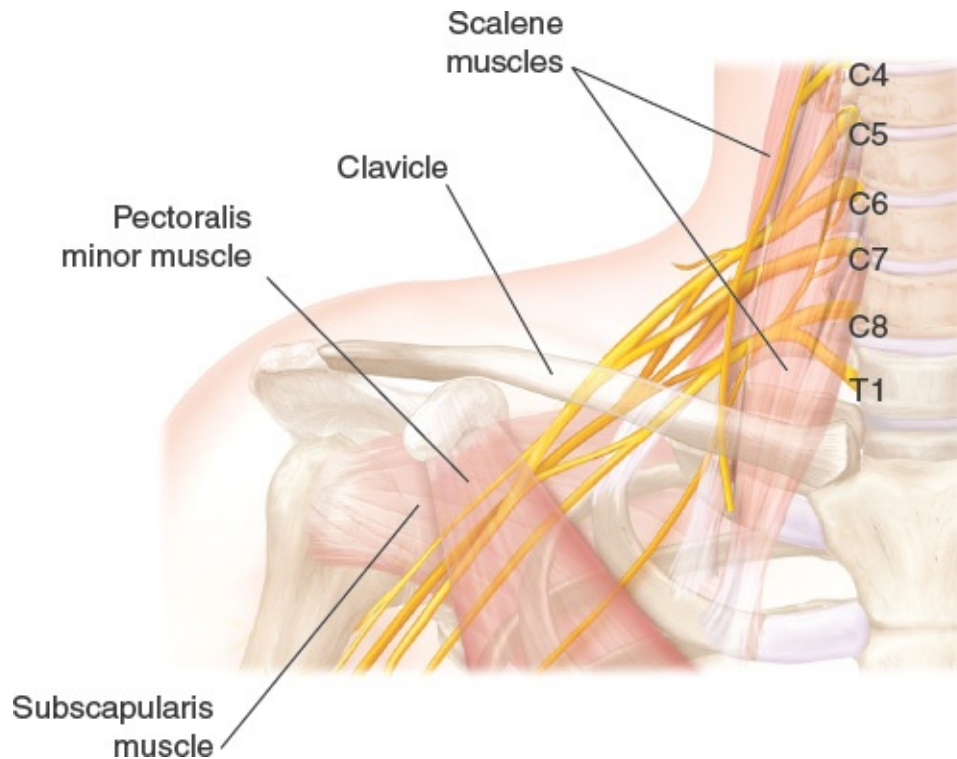


FIG 1 • The most common anatomy of the brachial plexus. The branching of the brachial plexus can be highly variable, and a thorough understanding of the most common variants is crucial prior to proceeding with brachial plexus exploration.

- Neurapraxic injuries have a transient loss of conduction, but do not undergo wallerian degeneration. In axonotmesis, the nerve is still externally in continuity but undergoes wallerian degeneration due to axonal disruption. Neurotmesis indicates a complete division of a nerve.
- Sunderland classified neurapraxia as type I and neurotmesis as type V. The axonotmesis category is divided into three separate categories, types II to IV, based on degree of internal injury short of complete division of the nerve.⁷ MacKinnon and Dellon later added a type VI injury, indicating multiple

degrees of injury in a single cross-sectional area of a nerve.⁸ This has been termed a neuroma-in-continuity.

- Wallerian degeneration occurs in axonotmetic and neurotmetic lesions due to axonal disruption. While there is some chance of recovery in axonotmetic lesions depending on the degree of internal injury, neurotmetic lesions will not recover without surgical repair or grafting.
- Contractures
 - Denervation leads to a progressive joint contracture due to muscle paralysis. This joint contracture was generally believed to be caused by muscle imbalance and fibrosis of denervated muscle groups. However, animal studies have shown that muscle contracture precedes fibrosis, indicating a separate, yet to be determined mechanism.⁹
 - Two types of joint contractures are seen in NBPP patients. The first is due to overpowering of affected muscles by their antagonists, as is seen with the internal rotation contracture at the shoulder in Erb palsy. The second is due to muscle contracture and shortening, as seen in the glenohumeral abduction contracture caused by the paralyzed deltoid or the elbow flexion contracture caused by the brachialis in Erb palsy.
 - Global shoulder dysfunction and glenohumeral deformity develop as early as 3 months due to unbalanced forces on the shoulder and may require open or arthroscopic reduction and tendon transfers for treatment.
 - It has also been shown that each segment of the upper extremity exhibits decreased length and girth compared to the unaffected extremity.¹⁰

NATURAL HISTORY

- In the past, full recovery had been reported to be as high as 95.7%.¹¹ However, more recent reports claim less optimistic spontaneous recovery rates in the 60% to 70% range.^{12,13}
- Upon closer analysis, it is clear that location and severity of injury, as well as the degree of spontaneous recovery by 3 to 6 months, can all dramatically change the prognosis for a given patient. Assessing these factors is essential to recommending a plan of care to the patient's parents.
- In patients with only mild weakness and rapid recovery within weeks, complete neurologic recovery is highly likely without surgical intervention.
- However, in patients with a flaccid upper extremity and Horner syndrome (indicating a complete brachial plexus injury with avulsion), acceptable recovery is extremely unlikely, and early surgical intervention at about 3

months is recommended. Even in the case where there is some degree of proximal muscle improvement, if the hand is still paralyzed at 3 months, one should proceed with surgical intervention to reinnervate the hand, as these patients are unlikely to recover meaningful hand function on their own.

- The remainder of neonatal brachial plexus patients fall between these two extremes, and the decision on the appropriate timing for intervention, if any, is still controversial.

PATIENT HISTORY AND PHYSICAL FINDINGS

- History should include a detailed maternal gestational history as well as patient birth history. The physician should seek specific information on the course of delivery, shoulder dystocia, instrumented delivery, respiratory distress or signs of hypoxia, and Apgar scores. This information can be helpful in ruling out other causes of apparent limb weakness or paralysis (ie, cerebral palsy, infection, fracture of the involved limb).
- Careful, systematic examination is crucial for making treatment decisions and comparisons over time. Given the importance of examination over time and the negative effects of delayed treatment, early referral to a multidisciplinary brachial plexus clinic is recommended. This will not only facilitate early surgical intervention when necessary but also ensure that patients receive prompt physical and occupational therapy to mitigate joint contracture formation while awaiting recovery.
- Physical examination should be performed with the child naked from the waist up to assess the entire upper extremity as well as the neck, chest, back, scapula, and abdomen. In the infant, physical examination relies heavily on observance of limb posture, spontaneous motion, neonatal reflexes, and passive motion.
- Certain postures have traditionally been associated with different levels of injury. The “waiter’s tip” posture describes a patient with the shoulder internally rotated, elbow extended, and wrist flexed. This posture would be suggestive of an upper plexus injury. Inversely, a patient with a lower plexus injury may have near normal shoulder and elbow function with a flaccid hand. A totally flaccid extremity indicates a complete brachial plexus injury.
- Horner syndrome describes a patient with ipsilateral ptosis, meiosis, and anhidrosis. This is indicative of a preganglionic avulsion from the spinal cord.
- There are many assessment tools and classification systems that can help synthesize information from the physical examination and assist in treatment decision-making. The most commonly used scores include the modified Mallet

scale, the Active Movement Scale, and the Toronto Test Score. All three of these scores have been assessed for inter- and intrarater reliability.

- The modified Mallet scale is a widely used measure of global shoulder function and does not grade specific muscles. It requires that the patient is mature enough to follow directions.
- The Active Movement Scale (AMS) is a detailed scoring of 15 different movements on a scale of 1 to 7. It was developed to quantify motor function in infants with NBPP and evaluate recovery over time. It can be used as early as 2 to 3 weeks of age by eliciting neonatal reflexes to assess specific joint movements.¹⁵
- The Toronto Test Score was developed to help predict recovery in children with NBPP. It can be used in young children who are unable to follow directions and tests five specific motions: elbow flexion, elbow extension, wrist extension, thumb extension, and finger extension.¹⁴

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Although the decision to proceed with primary nerve surgery for NBPP is a clinical one, further diagnostic testing can provide useful information in development of a surgical plan.
- Electrodiagnostic testing can be useful in determining preganglionic vs postganglionic lesions because avulsions will show normal sensory nerve action potential with no motor nerve conduction at the same level. However, these studies tend to overestimate the degree of recovery in NBPP and thus are not routinely used in surgical decision-making.
- Computed tomography (CT) myelography can also be useful in determining the presence of root avulsions preoperatively. One study showed 98% specificity, but only 37% sensitivity for CT myelography in diagnosing root avulsions if no rootlets are seen traversing the pseudomeningocele.¹⁶
- Another study compared CT myelography to MR myelography and found similar results for CT myelography to prior studies. However, MR myelography on a 3T magnet showed equivalent sensitivity and specificity without the need for lumbar puncture, intrathecal contrast injection, or ionizing radiation. Therefore, with improvements in technology, many now favor MR over CT myelography.¹⁷
- Other imaging modalities that some find useful are ultrasound to assess diaphragmatic motion and chest radiography to look for an elevated hemidiaphragm. Abnormal findings would indicate phrenic nerve injury. This

is particularly important if one is considering using the phrenic or intercostal nerves for plexus reconstruction.

DIFFERENTIAL DIAGNOSIS

- Spinal cord injury
- Pseudoparalysis
 - Septic joint
 - Upper extremity fracture
- Cerebral palsy

NONOPERATIVE MANAGEMENT

- Patients should be referred early to an occupational therapist with experience in neonatal brachial plexus injuries. Ideally, this therapist will see the patient at the same time as the surgeon to facilitate communication.
- Therapy should focus stretching and range of motion of the entire upper extremity to prevent contractures and maladaptive motions. It is particularly important to stabilize the scapula during shoulder range of motion and stretching to make sure motion is truly glenohumeral and not scapulothoracic.

SURGICAL MANAGEMENT

- The decision to proceed with microsurgical repair or reconstruction of the brachial plexus is perhaps the most controversial topic in management of neonatal brachial plexus injuries.
- As discussed earlier, most surgeons agree that infants with a flaccid extremity, Horner syndrome, or other signs of a preganglionic avulsion warrant early exploration and microsurgical intervention.
- Gilbert and Tassin popularized the absence of biceps function at 3 months as an indication to proceed with microsurgery.³ However, another study showed that when biceps function alone was used in decision-making, it would have incorrectly predicted recovery in 12.8% of cases.¹⁴
- The Hospital for Sick Children reports using AMS for initial evaluation of infants with NBPP. At 3 months, a conversion is made for scores of elbow flexion and elbow, wrist, thumb, and finger extension. The converted scores are then summed. If the score is above 3.5, then observation is continued and the patient re-evaluated every 3 months for continued improvement. If the patient fails to improve at each visit or fails the “cookie test” at 9 months, then microsurgery is scheduled.¹⁸

- After assessing the outcomes of patients managed by observation, microsurgery, and/or secondary orthopedic procedures (tendon transfer or external rotation osteotomy), Waters concluded that he would operate on infants with no return of biceps function by 5 months or a flail arm and Horner syndrome at 3 months.¹⁹
- We prefer to use the absence of any biceps function at 4 months as a trigger to proceed with surgery, re-evaluating monthly for continued improvement in those with some biceps function present at 4 months. Our center has performed surgery at up to a year for those that present late to our clinic for initial evaluation without biceps function. In these cases, we are likely to perform a bypass graft around the neuroma rather than neuroma resection and grafting, to avoid resecting any regenerated axons.

PREOPERATIVE PLANNING

- Once the clinical decision is made to proceed with surgery, develop a carefully considered operative plan that incorporates information from physical examination, imaging, and electrodiagnostic testing, if obtained.
- Review the results of the physical examination and imaging to estimate the number of roots involved and if they are ruptures or avulsions. The former are often amenable to neuroma resection and grafting, whereas the latter require neurotization from other levels or extraplexal nerves. If several levels are involved, prepare for transfer of nerves from outside the plexus to innervate critical targets for upper extremity function. This may require further workup with diaphragmatic ultrasound or chest radiographs to determine if the phrenic nerve or intercostal nerves are a suitable option for extraplexal neurotization.
- Consider what portion of the plexus is injured in a proximal to distal direction. Though most injuries are supraclavicular, more distal involvement may require a clavicular osteotomy and/or extension of the incision to expose the deltopectoral interval.
- In the case that the entire plexus is involved, the lower roots are usually avulsed, and options are limited for reinnervation. Although priority is usually given to elbow flexion and shoulder stability in adults, in NBPP, some advocate that priority should be given to grafting nerve roots supplying the hand because it is a shorter distance to regenerate than in adults, a greater capacity for healing, and more neural plasticity in the brain. In addition, there are proven extraplexal nerve transfer options for shoulder and elbow function.
- Failure to plan for all potential scenarios and their solutions not only prolongs

surgical time but may compromise the ultimate outcome for the patient if inappropriate decisions are made intraoperatively.

- The surgeon should request avoidance of muscle paralysis after induction of anesthesia to allow for assessment of signal transmission across neuromas via nerve stimulation.
- In some centers, pathology service is consulted to perform fresh frozen specimens for evaluation of neuromas to confirm resection to healthy axons before grafting.
- Neurology may be consulted for intraoperative evaluation of somatosensory evoked potentials (SSEPs). This can be extremely helpful when trying to distinguish between an intact root, an intraforaminal rupture, and an avulsion from the spinal cord. However, this requires special training on the part of the interpreting neurologist and is only available in a limited number of centers.

Positioning

- Some centers begin with the patient positioned in the prone position and perform bilateral sural nerve harvest prior to exploration. We prefer to begin in the supine position and perform the brachial plexus exploration prior to harvest, as this may avoid unnecessary nerve harvest if bilateral sural nerve grafts are not needed.
- For plexus exploration and reconstruction, the patient should be positioned supine with a small, transversely oriented roll placed at the level of the scapulae to extend the neck and to rotate to the contralateral side of the injury by improving access to the injured plexus.
- We also recommend placing the patient's head at the most proximal extent of the bed and the ipsilateral shoulder near the edge of the bed to improve positioning and access for the surgeon and assistants (**FIG 2**).
- It is crucial to assure that all bony prominences are well padded, as the procedure can last up to 12 hours. A Foley catheter with a temperature probe is also placed for urine output monitoring, fluid management, and avoidance of hypothermia.
- The patient should be prepped and draped from the level of the mandible proximally to just below the nipple on the ipsilateral chest and the ipsilateral extremity draped free (**FIG 3**).
- If considering use of the contralateral C7 nerve root, it will be necessary to prep and drape the contralateral chest and neck as well. In addition, both legs

should have a tourniquet placed on the thigh and be prepped and draped for a possible sural nerve harvest.



FIG 2 • The patient is positioned with the head at the most proximal extent of the bed and the ipsilateral shoulder near the edge of the bed to improve positioning and access for the surgeon and assistants. A transverse roll should be placed posteriorly at the level of the scapulae to allow neck extension and rotation away from the injured side.

Approach

- Although some surgeons use a straight incision paralleling the upper border of the clavicle for exposure, we prefer the use of an L-shaped incision.
- The proximal limb follows the posterior border of the sternocleidomastoid (SCM) muscle, and the transverse limb follows the superior border of the clavicle.
- We believe this improves access to the neural foramina to assess for proximal rupture vs avulsion from the spinal cord during initial exploration or end-to-side neurotization into the phrenic nerve, if necessary.



FIG 3 • The patient is prepped and draped from the level of the mandible proximally to just below the nipple on the ipsilateral chest, with the ipsilateral arm draped free. The incision is marked along the posterior border of the sternocleidomastoid (SCM) with the transverse limb following the superior border of the clavicle.

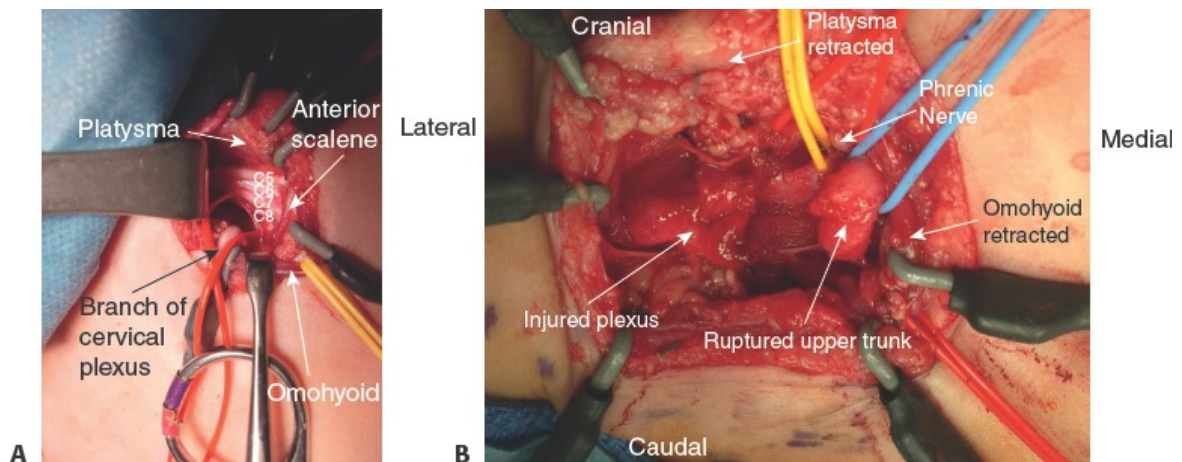
TECHNIQUES

■ Exposure

- The expected incision should be marked out clearly and hashed for correct closure at the conclusion of the case (see **FIG 3**). Formerly, our center injected the line of the incision with epinephrine diluted 1 to 400 000 to minimize blood loss during initial dissection. However, we have found that with careful dissection using electrocautery, epinephrine infusion is not necessary and eliminates a potential source of error in appropriate dilution.
- Dissection is taken down through the platysma with meticulous care to coagulate superficial vessels, attempting to minimize blood loss during the case. The flap is raised in the plane just below the platysma and reflected superolaterally to expose the posterior triangle. This is tied back with suture for retraction throughout the case.

- At this point, it may be necessary to reflect the clavicular head of the SCM and ligate the nearby external jugular vein to improve exposure of the anterior and middle scalene muscles and the more proximal nerve roots. The clavicular head of the SCM should be tagged and repaired at the conclusion of the case.
- Moving laterally, the omohyoid is either divided at its tendinous portion or tagged and retracted. The omohyoid is a consistent marker for the level of the suprascapular notch.
- During this exposure, the branches of the cervical plexus extending across the clavicle to the upper chest will be encountered and divided. With careful dissection, these can be traced proximally to identify the C4 root and then excised and used as additional nerve graft.
- There will be a fat pad at the level deep to the omohyoid that should be released from the clavicle, tagged, and reflected superolaterally. This should be repaired back to the clavicle during closure.
- Additionally, the transverse cervical vessels will cross the surgical field and may need to be ligated and cut to facilitate access to the supraclavicular brachial plexus.
- After this, the upper and middle trunks are often visible exiting between the anterior and middle scalene muscles. The junction of the C5 and C6 roots is the most common site for neuroma formation and is often visible now (**TECH FIG 1A**).
- Identify the phrenic nerve running in a cranial-to-caudal direction along the lateral border of the anterior scalene, and trace this proximally to its contribution from the C4 nerve root. Frequently the phrenic nerve gives off a contribution to the C5 nerve root. The identity of the phrenic nerve can be confirmed using a nerve stimulator and watching for contraction of the diaphragm. One should notify the anesthesia team to hold respiration during phrenic nerve stimulation to avoid confusion.
- This should give two markers confirming the levels of the brachial plexus. In many cases, the phrenic nerve is entrapped in scar tissue as it passes over the involved plexus, and care should be taken not to injure or excise it during dissection or neuroma resection.
- Often the anterior and middle scalene muscles are also included in the scar around the brachial plexus, and careful dissection is required to separate them and adequately expose the roots and the neural foramina (**TECH FIG 1B**).

- Once the levels have been appropriately identified, begin dissecting the C5 nerve root proximally to determine continuity all the way to the spinal cord. The branch to the long thoracic nerve should be identified during dissection of C5-C7 and protected initially. However, some or all of these branches may need to be sacrificed later during neuroma resection and grafting in the case of very proximal injuries.
- Carry out the same dissection proximally for C6-T1, inspecting closely for intraforaminal rupture or avulsion from the spinal cord. Again, the scalene muscles must be dissected free from the neuroma to allow enough retraction to inspect the more caudal C8 and T1 roots. In addition, caudal to C7, the subclavian vein and clavicle will need to be retracted to improve exposure. Take care to avoid violating the pleura just distal to T1.
- If there is uncertainty regarding whether or not a preganglionic avulsion exists, either a specimen can be sent for pathologic assessment to evaluate for involvement of the dorsal root ganglion or SSEPs can be evaluated if neurology service is available.



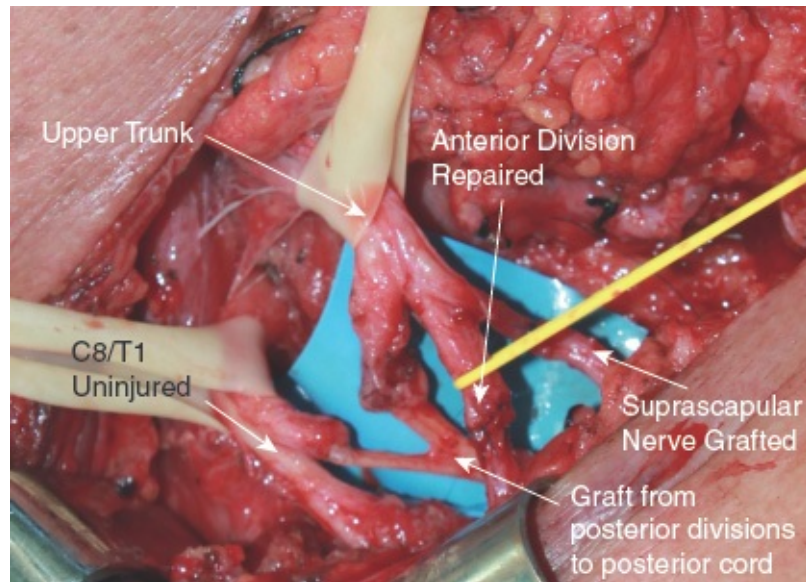
TECH FIG 1 • A. With the superficial dissection complete, the upper and middle trunks are often visible exiting between the anterior and middle scalene muscles. The junction of the C5 and C6 roots is the most common site for neuroma formation, and the neuroma is often visible now. **B.** In more severely scarred cases, accurate identification of individual roots and determining which levels are intact,

ruptured, or avulsed is often difficult. A nerve stimulator and intraoperative electrodiagnostic testing can be helpful.

- Next, dissect from proximal to distal along the cranial border of the C5 root and upper trunk to locate the suprascapular nerve exiting posteriorly toward the suprascapular notch. It is classically described as branching from the upper trunk. However, recent cadaver studies have shown that it often branches at or after the split of the anterior and posterior divisions of the upper trunk (most often from the posterior division) and can even have contributions from both the anterior and posterior divisions of the upper trunk.²⁰
- Continue laterally to identify the anterior division of the upper trunk and potentially the lateral pectoral nerve depending on its level of branching. This is traditionally described as branching from the lateral cord. However, it most often originates from the anterior division of the upper trunk rather than the lateral cord proper.²⁰
- Next dissect from the C7 root distally to identify the middle trunk with its anterior and posterior divisions. Continue this dissection distally until nerves are free of neuroma.
- Carry out the same dissection of the lower trunk distally to its anterior and posterior divisions and, if necessary, to the medial cord. Identify its branches as you dissect distally. It will be necessary to carefully dissect and retract the clavicle and subclavian vein during this portion of the dissection.
- Once all components of the plexus are identified, a nerve stimulator should be used to determine which portions of the brachial plexus are transmitting sufficient signals distally. Catalogue this information clearly and carefully to avoid neglecting essential functions during reconstruction.
- If infraclavicular access is also needed, this incision can be joined laterally with a standard deltopectoral incision near the coracoid process.
- Once the conjoined tendon is identified, the tendon can be tagged, cut, and reflected to expose the lateral, posterior, and medial cords as well as their terminal branches. This will be repaired at the conclusion of the case.

■ Neuroma Resection With Nerve Grafting

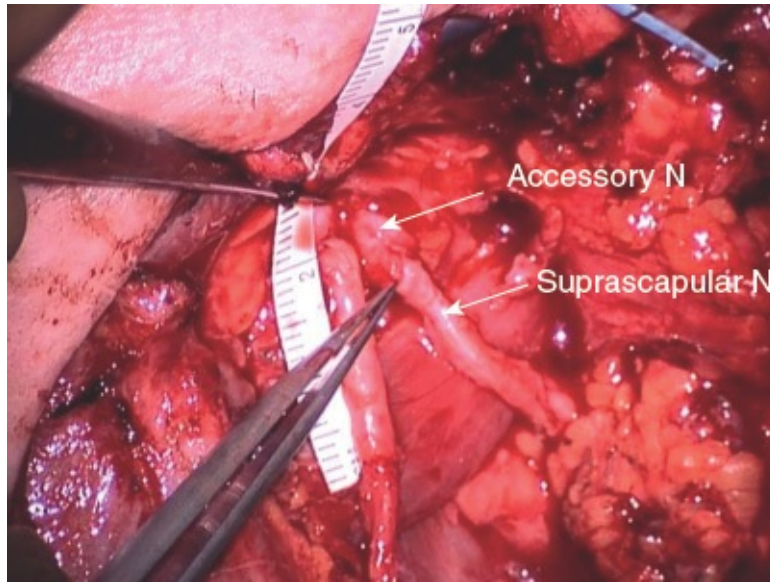
- Although neurolysis alone of a neuroma-in-continuity was performed in the past, it is no longer recommended due to inferior outcomes when compared to neuroma resection and grafting.²¹ Therefore, if it is determined that there is insufficient signal transmission across a neuroma, then resection and grafting should be performed.
- As mentioned in the prior section, careful dissection should be performed proximal and distal to the site of injury to ensure that there is a complete understanding of the injured structures. Do not presume a normal appearing nerve root proximal to a neuroma is not avulsed based solely on visual appearance. It is possible to have a two-level injury with avulsion from the spinal cord and a neuroma distally.
- Begin by sectioning the midportion of the neuroma and then at what appears to be normal nerve proximally and distally. Many centers will tag these specimens for orientation and send them for frozen section by the pathology department to determine whether the proximal and distal extent of the resection is free of fibrosis. Alternatively, perform an initial resection under loupe magnification, and then under the operating microscope, inspect the fascicular pattern to assess the adequacy of resection. Regardless, grafting to healthy stumps proximally and distally is important to assure fibrosis does not impair axon regeneration.
- Next, assess the length of nerve graft necessary to bridge each defect. This number will need to be multiplied by the number of cables necessary to match the size of the nerves being grafted. After a determination of the total length of graft needed, sural nerve harvest can be performed on one or both legs. This can be done open or endoscopically depending on surgeon preference and training. These techniques are described elsewhere in this text.
- If avulsions make grafting impossible at some levels, existing roots should be preferentially grafted to the medial and then posterior cords to restore hand function. Extraplexal nerve transfers can be used to reliably restore shoulder and elbow function in these cases, as will be described below.
- Coaptation of the nerves can be carried out using 9-0 or 10-0 nylon suture or fibrin glue depending on surgeon preference (**TECH FIG 2**).



TECH FIG 2 • After confirming intact roots and adequate neuroma resection, use the available graft material to reinnervate as many priority targets as possible.

■ Accessory (CN XI) to Suprascapular Nerve Transfer

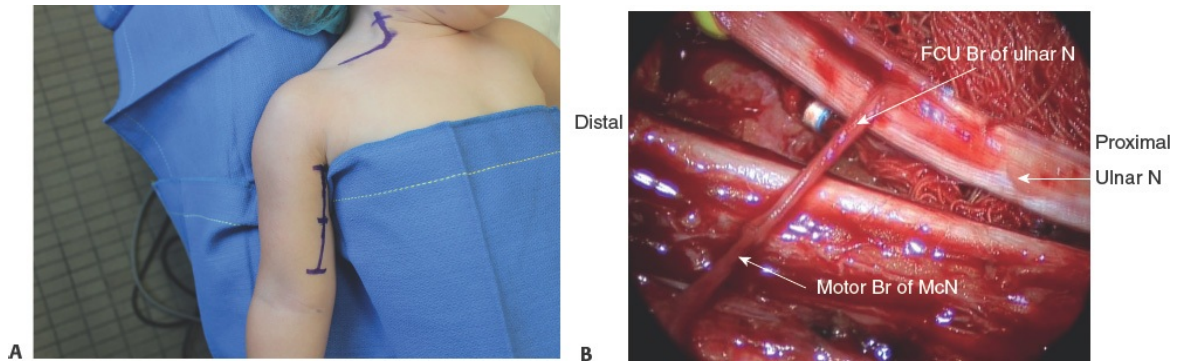
- If you cannot graft directly to the suprascapular nerve from the upper trunk or the C5/C6 root, either because of avulsion of the upper roots or the need to divert those roots to other targets, external rotation of the shoulder can be restored through transfer of CN XI.
- Trace the transverse cervical artery posteriorly to where it enters the trapezius muscle. Localize the accessory nerve using a nerve stimulator.
- Next, trace the accessory nerve distally, past its innervation of the upper and middle portions of the trapezius. Mobilize and then cut the nerve, making sure there is sufficient length to reach the stump of the suprascapular nerve. The stump of the suprascapular nerve should be prepared such that it is as close as possible to its origin while still resecting to healthy axons.
- Transpose the accessory nerve over to the suprascapular nerve stump, and coapt the two using either nylon suture or fibrin glue, depending on surgeon preference (**TECH FIG 3**).



TECH FIG 3 • The spinal accessory nerve is followed caudally to the branch to lower trapezius, where it is transected and rotated laterally to innervate the suprascapular nerve.

■ Ulnar to Musculocutaneous Nerve Transfer

- If the lower trunk and medial cord are intact and the patient has demonstrated full ulnar nerve function preoperatively, a portion of the ulnar nerve can be used to reanimate the biceps muscle.
- Beginning at the inferior border of the pectoralis major tendon, make a longitudinal incision on the medial arm about 8 cm long. Dissect down to the biceps fascia, and separate it from coracobrachialis (**TECH FIG 4A**).
- Identify the motor branch to the biceps, which is about 13 cm distal to the acromion.²² Dissect this as far proximally into the musculocutaneous nerve as possible, and then transect it for transfer to the ulnar nerve.



TECH FIG 4 • A. The incision is marked beginning at the inferior border of the pectoralis major tendon and extended distally along the medial border of the biceps tendon. **B.** After isolating the fascicles of the ulnar nerve to FCU as distally as possible, transect the motor branch to biceps as proximally as possible to assure there is no tension on the repair.

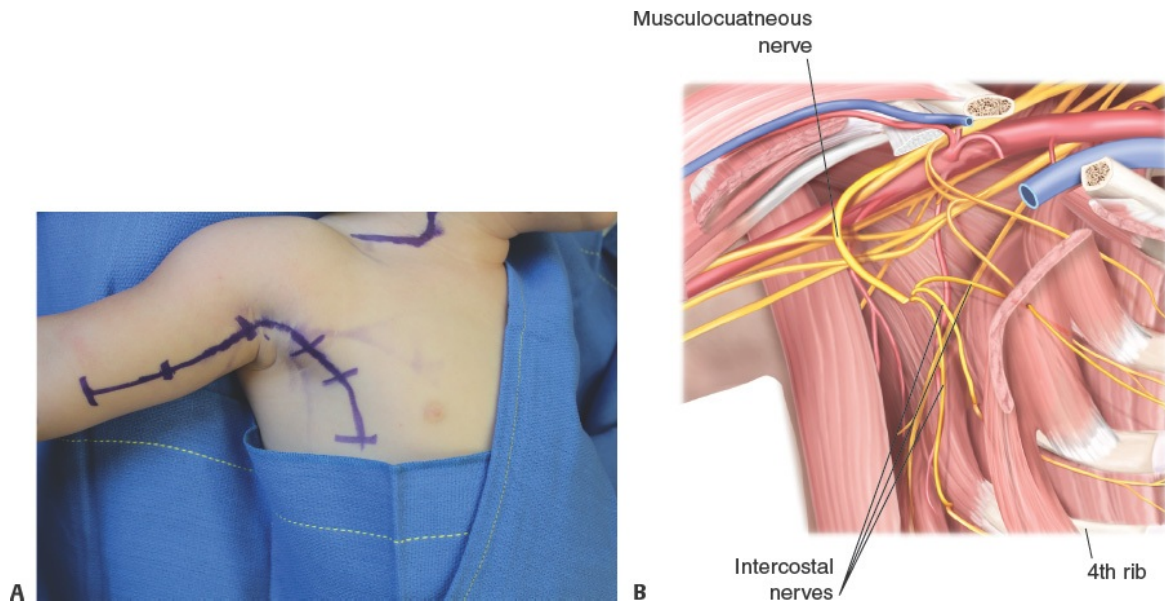
- Dissect posteriorly to locate the median and then ulnar nerves. If there is any confusion, a nerve stimulator can be used to differentiate the two.
- Using the microscope, make an epineurotomy in the ulnar nerve, and harvest two fascicles from the ulnar nerve. Use the nerve stimulator to confirm that they contain motor fibers, and section them distally enough that they can be transposed anteriorly to meet the biceps motor branch without tension.
- Coapt the ulnar nerve fascicles to the biceps motor branch under the microscope using either nylon suture or fibrin glue (**TECH FIG 4B**). Some surgeons will perform a similar transfer of median fascicles to the FCR flexor carpi radialis (FCR) to the motor branch to the brachialis in conjunction with this procedure for added elbow flexion strength.

■ Intercostal to Musculocutaneous Nerve Transfer

- If the ulnar nerve is not an option for restoration of elbow flexion, two to three intercostal nerves can be transferred in a similar manner.
- If you have already made the incision in the deltopectoral groove to expose the infraclavicular plexus, then you can extend this inferomedially across the chest. If not, then make an anterior axillary incision and extend your incision

inferomedially, perpendicular to the ribs down to the level just inferior to the nipple. Retract the pectoralis major tendon superiorly to expose the musculocutaneous nerve at its take off from the lateral cord. It should be sectioned here and mobilized for later coaptation with the cables from the intercostal nerves (**TECH FIG 5A**).

- Limit resection of the fat and the associated lymph nodes in the axillary fossa. However, dissect sufficiently to expose the involved structures and a more direct line for coaptation of the intercostal and musculocutaneous nerves.
- Dissect down to the ribs. It may be necessary to release portions of the origin of the pectoralis major and serratus anterior muscles. These should be tagged for repair at the conclusion of the case.
- Expose the second, third, and fourth ribs subperiosteally. The intercostal nerves from roots T2 to T4 are inferior to their respective ribs after dissecting through the external and internal intercostal muscles.
- Carefully dissect the intercostal nerves anteriorly to the mammary line and posteriorly to the point where they will be transposed toward the musculocutaneous nerve.
- Cut the intercostal nerves about 1 cm medial to the mammary line, and carefully mobilize each nerve posteriorly such that there is sufficient length to reach the musculocutaneous nerve in the axilla.
- Coapt the intercostal nerves as a cable graft to the musculocutaneous nerve as far distal as possible without tension or kinking, to minimize the distance for regeneration. Coaptation can be performed with nylon suture or fibrin glue, per surgeon preference (**TECH FIG 5B**).
- Make sure that there is no tension on the nerve coaptation site with the arm in 90 degrees of abduction and 90 degrees of external rotation.

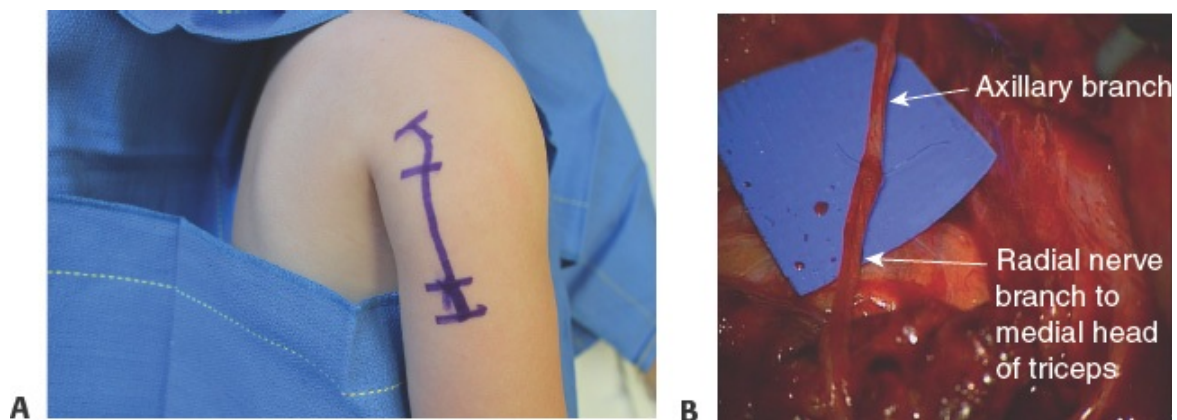


TECH FIG 5 • A. Mark out an anterior axillary incision, and extend your incision inferomedially, perpendicular to the ribs down to the level just inferior to the nipple. **B.** Cut the intercostal nerves about 1 cm medial to the mammary line, and carefully mobilize each nerve posteriorly such that there is sufficient length to reach the musculocutaneous nerve in the axilla. These will be transferred to the musculocutaneous nerve as a cable.

■ Radial to Axillary Nerve Transfer

- For this procedure, we prefer the patient to be flipped prone with the involved extremity prepped into the field and forearm either at the side or resting on the lower back. As mentioned before, paralysis should be avoided after induction of anesthesia to allow for use of the nerve stimulator.
- Make a J-shaped incision from the lateral border of the scapula, following the posterior border of the deltoid and extending down the posterior aspect of the upper arm (**TECH FIG 6A**).
- Dissect down to the fascia overlying the triceps and deltoid, watching for the lateral cutaneous branch of the axillary nerve. This can be used to trace proximally to the axillary nerve as it passes through the quadrangular space.

- Transect the axillary nerve just proximal to the teres minor motor branch, and transpose the nerve distally.
- Find the radial nerve as it passes through the triangular space, and trace it as distally to locate the motor branch the medial head of the triceps muscle. Transect the nerve as distally as possible such that there is sufficient length for tension-free repair.
- Transpose the triceps nerve branch proximally. Remove the lateral cutaneous nerve from the axillary nerve.
- Under the microscope, coapt the triceps motor branch to the axillary stump using nylon suture or fibrin glue. 8-0 or 9-0 suture is appropriate. Intercalary grafts are usually not needed (**TECH FIG 6B**).
- Abduct and rotate the arm to make sure that there is no tension on the repair with shoulder motion.



TECH FIG 6 • A. A J-shaped incision is marked from the lateral border of the scapula, following the posterior border of the deltoid and extending down the posterior aspect of the upper arm allowing exposure of the axillary nerve in the quadrangular space and the radial branch to the medial head of the triceps distally. **B,C.** The branch to the medial head of the triceps is transected as distally as possible and transposed proximally to meet the motor branch of the deltoid. A branch to the lateral or long head of the triceps could also be used if better for coaptation. No branch has been shown to be functionally superior to the others.

PEARLS AND PITFALLS

Preoperative planning

- Develop a complete understanding of the injury prior to surgery, as well as a plan with multiple alternatives. This facilitates efficiency during a long procedure and minimizes the chance of overlooking important targets for reinnervation.

Exploration

- It is crucial to fully explore each involved nerve root to its insertion in the spinal cord, even if it is involved in neuroma distally. Grafting from an avulsed nerve root assures complete failure of the surgery at that level.

Neuroma resection

- Use available resources to confirm adequate neuroma resection as grafting to a fibrotic nerve ending will limit or completely block nerve regeneration.

Reconstruction

- When there are limited intact nerve roots for grafting, preferentially graft to the lower trunk and medial cord as there are no proven extraplexal transfers for animating the hand but multiple options for extraplexal transfers for the shoulder and elbow.

Therapy

- Appropriate therapy before and after surgery is at least as important as a technically excellent repair or reconstruction. Maintaining full passive motion of all involved joints gives the recovering neuromuscular units the best chance to succeed. A strong relationship with a trusted occupational therapist, experienced in brachial plexus injury, is crucial for success.

POSTOPERATIVE CARE

■ Acute phase (0–4 weeks)

- Place the patient in cervical collar and shoulder immobilization dressing for 3 weeks in order to protect repairs. We perform weekly dressing changes in our therapy clinic to monitor the incisions as well as for skin breakdown in the axilla and between the forearm and abdomen.
- After 3 weeks of immobilization, begin gentle active and passive range-of-motion exercises for the neck, scapula, shoulder, elbow, and hand. We recommend two formal therapy visits per week initially.

■ Subacute phase (4 weeks to 2 years)

- Monitor active and passive range of motion and return of muscle function.
- Review and adjust home therapy program to emphasize the importance of consistency in performing exercises at home and to address any developing contractures early.

OUTCOMES

- Outcomes in brachial plexus surgery can be highly variable depending on the number of levels involved, the number of avulsion injuries, and the willingness or ability of the patient's family to participate in therapy.
- In patients undergoing nerve transfer or grafting, it may take 6 to 9 months to see any function in the involved muscle groups. Continued improvement can be seen for 2 to 4 years as patients continue to make gains in strength and coordination.
- It should be emphasized repeatedly to parents that therapy must continue at home until the child reaches skeletal maturity. Excellent early outcomes can be lost if therapy is neglected for any period of time, especially during a growth spurt.

COMPLICATIONS

- Injury to major vessels of the neck and upper extremity
- Failure to recover function after plexus reconstruction
- Pneumothorax
- Seroma formation
 - After axillary dissection during nerve transfers
 - With thoracic duct injury when exploring the left brachial plexus

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55 Secondary Neonatal Brachial Plexus Palsy Reconstruction

CHAPTER

Joshua M. Adkinson

DEFINITION

- Neonatal brachial plexus palsy (NBPP) results from injury to any brachial plexus nerve root (C₅-T₁) during a difficult delivery.^{1,2}
- Persistent paralysis and progressive spasticity, contractures, joint instability, and bony deformities of the upper extremity may occur in children with incomplete recovery of nerve function.
- The type, severity, and manifestations of NBPP vary greatly between patients and surgical options for treatment must be individualized.

ANATOMY

- Most commonly, the C₅C₆ roots are involved (Erb palsy), leading to deficits of shoulder abduction and external rotation (supraspinatus, infraspinatus, and deltoid), elbow flexion (biceps brachii, brachialis), and forearm supination (supinator).
- C₇ involvement causes paralysis of the subscapularis, teres major (TM), clavicular head of the pectoralis major (PM), brachioradialis (BR), extensor carpi radialis longus (ECRL) and brevis (ECRB), and possibly extensor carpi ulnaris and extensor digitorum communis (EDC). This leads to the classic “waiter tip” posture,³ with deficits of wrist and finger extension.
- Rarely, the C₈T₁ roots alone are affected (Klumpke palsy), leading to weakness/paralysis in the wrist/finger flexors and hand intrinsic muscles.
- Complete plexus involvement (C₅-T₁) leads to a flail extremity.

PATHOGENESIS

- Between 50% and 92% of patients with NBPP experience complete recovery of function without primary nerve reconstruction.^{1,4–8} In those with persistent deficits, the clinical findings will vary over time.
- Secondary deformities are impacted by the severity of the initial nerve injury, extent of muscle recovery, patient age at presentation, and previous treatments.
- In addition to paresis/paralysis of affected muscles, co-contraction of antagonistic muscles can occur in patients with partial recovery.⁹ This may lead to contracture and/or joint deformity.
- The most common posture in children with NBPP is internal rotation of the shoulder, flexion of the elbow, supination of the forearm, and ulnar deviation of the wrist, with variable involvement of the fingers.¹⁰ Many children also develop a limb-length discrepancy.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The preoperative evaluation of children with secondary NBPP deformities includes a detailed history, an assessment of functional limitations, and measurements of active and passive range of motion.
- Grading function
 - No grading systems are universally recommended for assessment of elbow, forearm, wrist, and hand function in patients with NBPP.
- Physical Examination
 - Function is observed, active and passive ranges of motion are documented, and muscle strength is assessed with and without gravity.
- Elbow
 - Co-contraction of the elbow flexors and extensors are assessed. Dislocation of the radial head and proximal ulna are noted.
- Forearm
 - Long-standing supination or pronation deformities may lead to fixed contracture of the interosseous membrane (IOM). Continued growth can then lead to bowing of the radius and ulna, dorsal dislocation of the distal ulna, and/or posterior dislocation of the radial head.
- Wrist
 - Ulnar deviation is common because of paralysis of the ECRL and ECRB.
- Hand
 - Limited metacarpophalangeal (MCP) joint extension is common, as is thumb instability.¹¹

IMAGING

- Anteroposterior and lateral radiographs of the elbow or wrist may be obtained to evaluate for joint subluxation/dislocation or articular deformities (**FIG 1**).

NONOPERATIVE MANAGEMENT

- All patients should undergo physical therapy, with the goal of muscle strengthening and full passive range of motion of the elbow, forearm, wrist, and fingers.
- Orthoses are used to maintain anatomic joint alignment and to prevent contracture.
- Botox injection into spastic musculature is effective for temporary (3–6 months) muscle weakening.

SURGICAL MANAGEMENT

- Surgical options include tendon transfers, arthrodeses, osteotomies, muscle/tendon releases, and functioning muscle transfers.
- Secondary reconstruction of the elbow, forearm, wrist, and hand is considered in children older than 4 years with incomplete recovery of upper extremity function after primary reconstruction or in those who present after the optimal window for nerve reconstruction.^{10,12–15}



FIG 1 • Right radial head dislocation (*arrow*) in long-

standing brachial plexus palsy.

- Restoration of elbow flexion is the priority, followed by wrist extension, thumb/finger flexion, wrist flexion, thumb/finger extension, and intrinsic hand reconstruction.
- Elbow flexion contractures greater than 40 degrees are an indication for surgical release. Less significant contractures can be released, but this may cause clinically significant elbow flexion weakness.
- Weak elbow flexion (less than MRC grade 3) may be addressed via Steindler flexorplasty or transfer of the latissimus dorsi (LD), PM, or triceps.
- The surgical approach to the forearm depends upon the underlying deformity. Supination contractures are best treated by a biceps rerouting. If there is minimal passive range of motion, IOM release or pronation osteotomy of the radius is recommended.
- Pronation deformities are treated by pronator teres (PT) release or rerouting. One must ensure good passive supination prior to PT rerouting.
- Weak wrist extension can be managed by transfer of the flexor carpi ulnaris (FCU) to the ECRB or ECRL (to counterbalance an ulnar deviation force). Weak finger extension can be managed with a combination of palmaris longus/flexor digitorum superficialis (FDS)_{middle} or FDS_{middle}FDS_{ring} transfer to the extensor pollicis longus (EPL) and EDC tendons, respectively.
- In patients with a total (pan-plexus) palsy, free functioning muscle transfers (eg, contralateral LD, gracilis, rectus femoris) are the procedure of choice.

Preoperative Planning

- Radiographs of the affected extremity should be reviewed, if relevant.

Positioning

- The patient is positioned supine on the operating room table with the affected extremity on a hand table. A well-padded tourniquet is placed high on the arm for procedures distal to and including the elbow.
- For pedicled LD muscle transfer, the patient is placed in the lateral decubitus position.
- The gracilis muscle harvest requires a frog leg position.

Approach

- Elbow approach: The muscles causing an elbow flexion contracture (brachialis, biceps brachii, and BR) are approached via an antecubital incision.
 - Procedures to restore elbow flexion require a technique-specific approach.
- Forearm approach: The biceps tendon is approached through an antecubital fossa incision. The entire length of the tendon and portion of the radius under which the tendon is rerouted must be visualized.
- Wrist/fingers approach: Procedures to restore wrist and finger function require a technique-specific approach. The FCU tendon may be approached through a single longitudinal incision or several stepcut incisions.
 - Free functioning muscle transfers to restore finger flexion require an extensile approach from the anterior upper arm across the acromion and lateral clavicle. This provides full visualization of the proposed site of origin of the transferred muscle as well the adjacent neurovascular structures to be protected and/or used for vascular anastomoses and nerve coaptation.

ELBOW RECONSTRUCTION

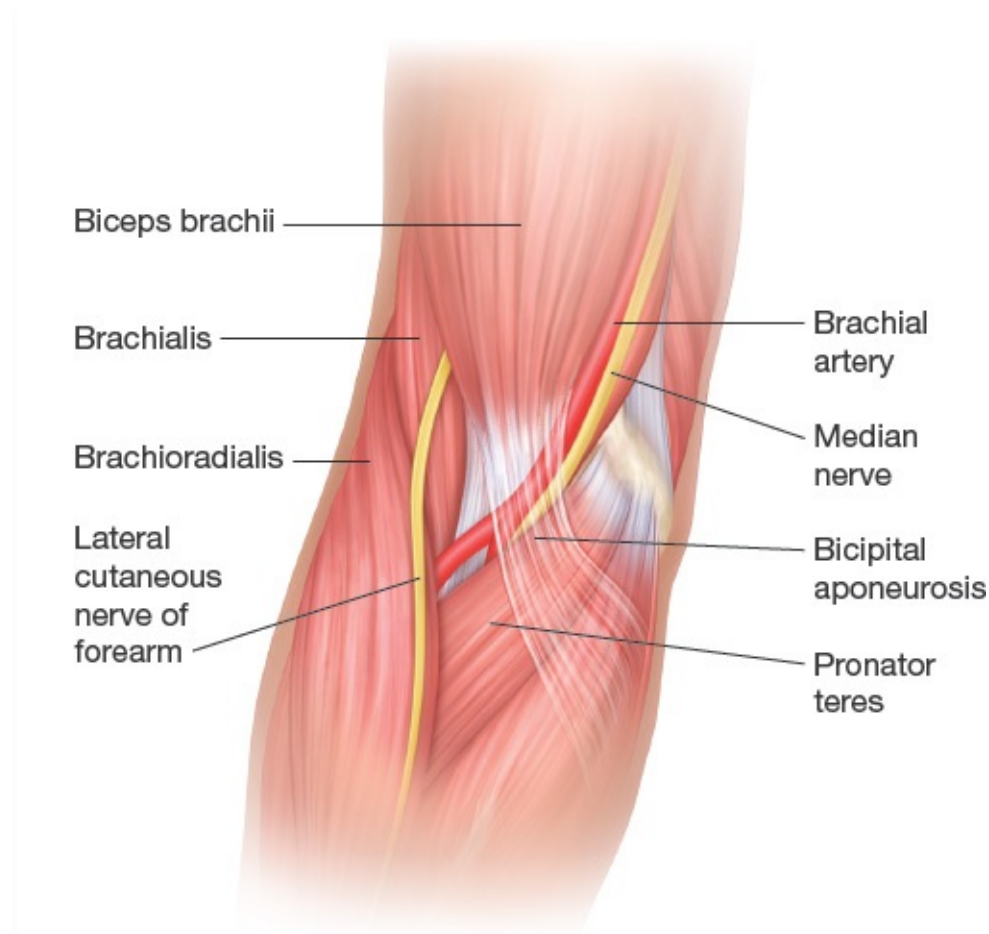
TECHNIQUES

■ Elbow Release

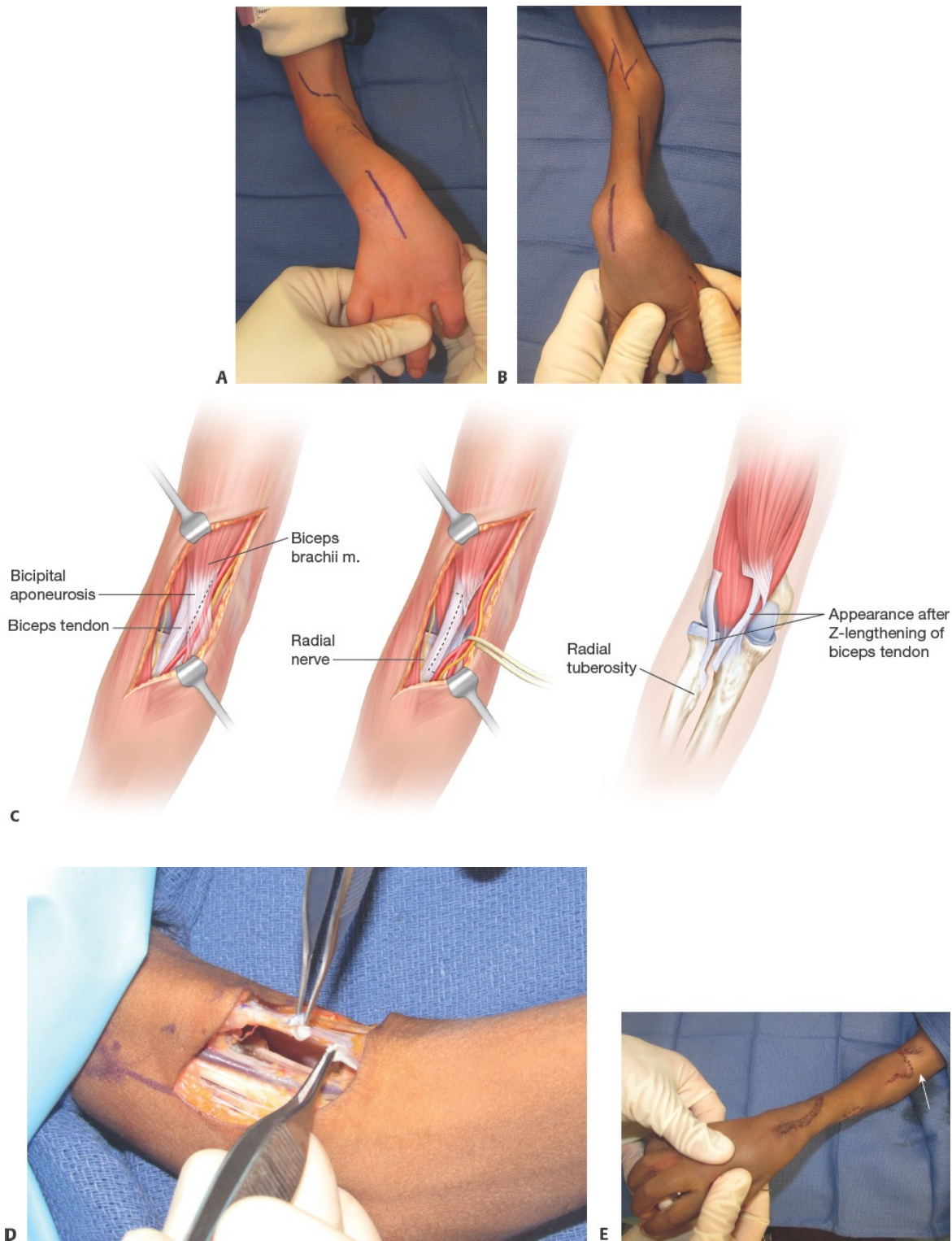
- Landmarks: median nerve, radial nerve, lateral antebrachial cutaneous nerve (LABC), brachial artery, brachialis muscle, biceps brachii muscle, BR (**TECH FIG 1**)
- Depending on the severity of the contracture, a curvilinear or Z-plasty incision is made and the lacertus fibrosus is identified and divided (**TECH FIG 2A,B**).
- The median nerve/brachial artery is identified and retracted medially and the LABC is retracted laterally.
- If fractional lengthening is indicated, then two incisions 1 cm apart are made with electrocautery at the musculotendinous junction of the brachialis. The anterior half of the BR is elevated from the humerus while protecting the radial nerve. The medial half of the biceps tendon is incised distally and the

lateral half proximally to provide lengthening. The release is reinforced with 3-0 braided suture, as needed.

- If a full release is indicated, then the biceps tendon is Z-lengthened¹⁶ (**TECH FIG 2C**), the brachialis is divided, and the BR is completely elevated from the humerus while protecting the radial nerve. The anterior elbow capsule is incised, if necessary. In long-standing contractures, foreshortened neurovascular structures will limit full passive elbow extension.
- The biceps tendon is reapproximated using 3-0 braided suture with the elbow in 30 degrees of flexion (**TECH FIG 2D**).
- The skin is closed in layers (**TECH FIG 2E**).



TECH FIG 1 • Structures crossing the elbow.



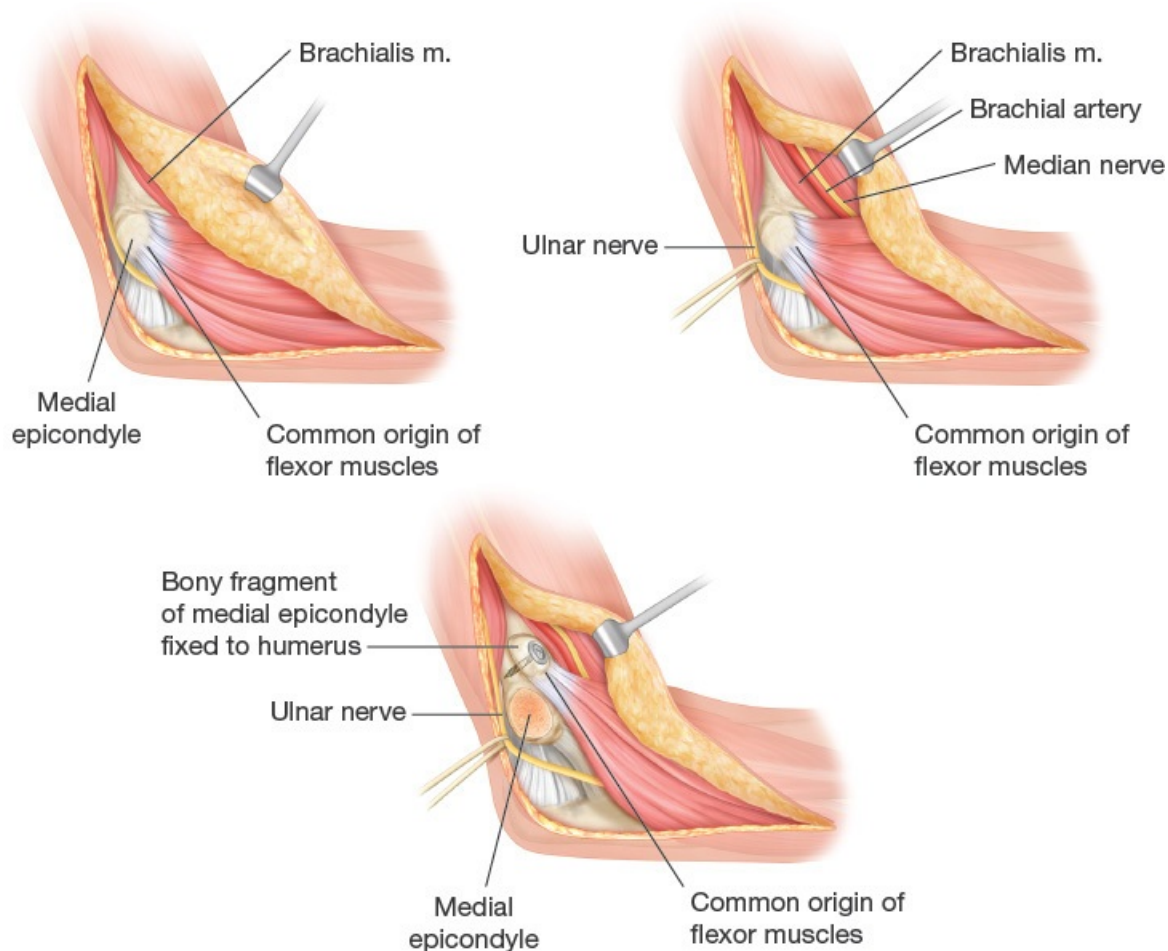
TECH FIG 2 • Approaches to elbow release. **A.** Curvilinear approach to the elbow. **B.** Z-plasty approach to the elbow. **C.** Steps in a biceps Z-

lengthening. **D.** Z-lengthened biceps tendon prior to reapproximation. **E.** Wound closure with a Z-plasty at the elbow (*arrow*).

■ Restoration of Elbow Flexion

Steindler Flexorplasty (**TECH FIG 3**)

- Landmarks: medial epicondyle, median nerve, ulnar nerve, brachial artery, humerus, biceps brachii muscle, brachialis muscle
- Fifteen-centimeter medial elbow curvilinear incision is made, and the skin flaps are elevated above the fascia while protecting the medial antebrachial cutaneous nerve.
- The ulnar nerve is retracted medially and the median nerve and brachial artery are retracted laterally.
- The flexor-pronator mass is freed from osseous attachments distally. Using an osteotome, the flexor-pronator origin at the medial epicondyle is elevated with a 2-cm segment of bone.
- The humerus is exposed deep to the brachialis. Approximately 5 to 7 cm proximal to the elbow joint, a bur is used to create a cortical window in the humerus.¹⁷
- With the elbow in 130 degrees of flexion, the medial epicondyle/flexor-pronator mass is secured to the humeral corticotomy using a 3.5-mm compression screw over a washer.



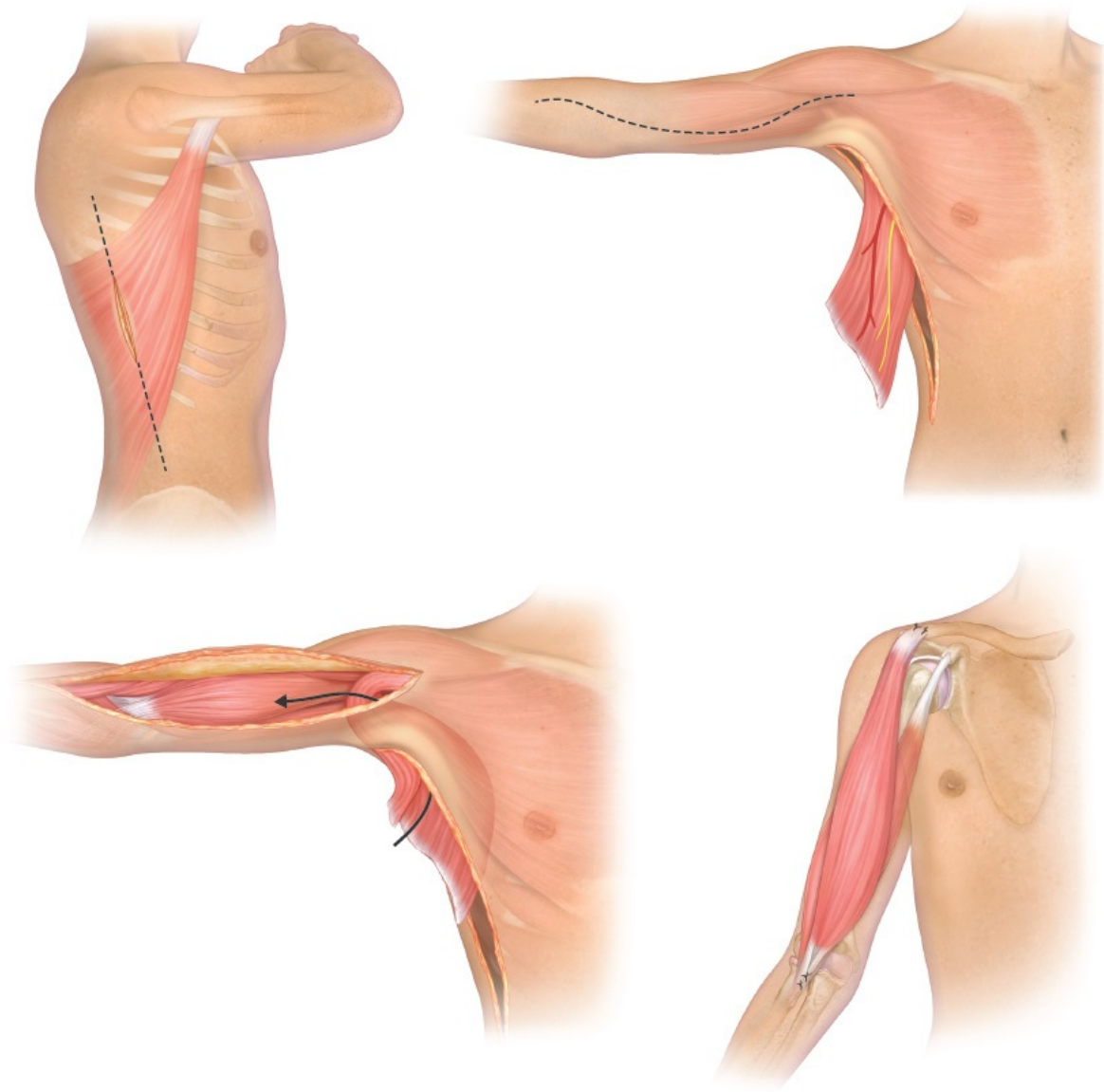
TECH FIG 3 • Steps in a Steindler flexorplasty.

- The ulnar nerve is transposed anteriorly to prevent tethering and the muscle is closed over the exposed osteotomy site using absorbable suture.
- The skin is closed in layers.

Latissimus dorsi Transfer (Pedicled) (**TECH FIG 4**)

- Landmarks: thoracodorsal neurovascular bundle, rhomboid muscle, teres major and minor muscles, acromion, clavicle, biceps brachii tendon
- Bipolar (moving the muscular origin and insertion) transfer is preferred because it increases the mechanical efficiency of the transfer and decreases the chance of vessel twisting/kinking.¹⁸
- Harvest—5-cm wide elliptically oriented skin paddle (8 cm distal to the axilla) is designed over the midaxis of the muscle and incised with superolateral and inferomedial extensions.

- The skin flaps are elevated off of the muscle and the arm is fully abducted and flexed.
- The muscle is marked at resting tension using 3-0 silk sutures placed at 5-cm intervals.
- The origin of the muscle is released and the muscle is elevated toward the axilla.
- The thoracodorsal neurovascular pedicle is identified on the deep surface of the muscle and dissected to its origin from the axillary artery. All adventitia is freed from the vessel to prevent tethering during transfer.
- The LD insertion is released from the bicipital groove of the humerus using electrocautery.
- Inset—a curvilinear longitudinal incision is made over the anterior upper arm with a transverse extension over the acromion and lateral clavicle.
- The skin flaps are elevated, and a deltopectoral window is created through which the muscle flap is passed, origin first. Confirmation of the neurovascular pedicle orientation is mandatory at this juncture.
- The insertion of the muscle is secured to the acromion and clavicle using two previously placed suture anchors.
- With the elbow in 100 degrees of flexion and full supination, the distal muscle is tubularized and secured to the distal biceps tendon with 2-0 braided suture or with suture anchors to the radial tuberosity.



TECH FIG 4 • Steps in a latissimus dorsi transfer for elbow flexion.

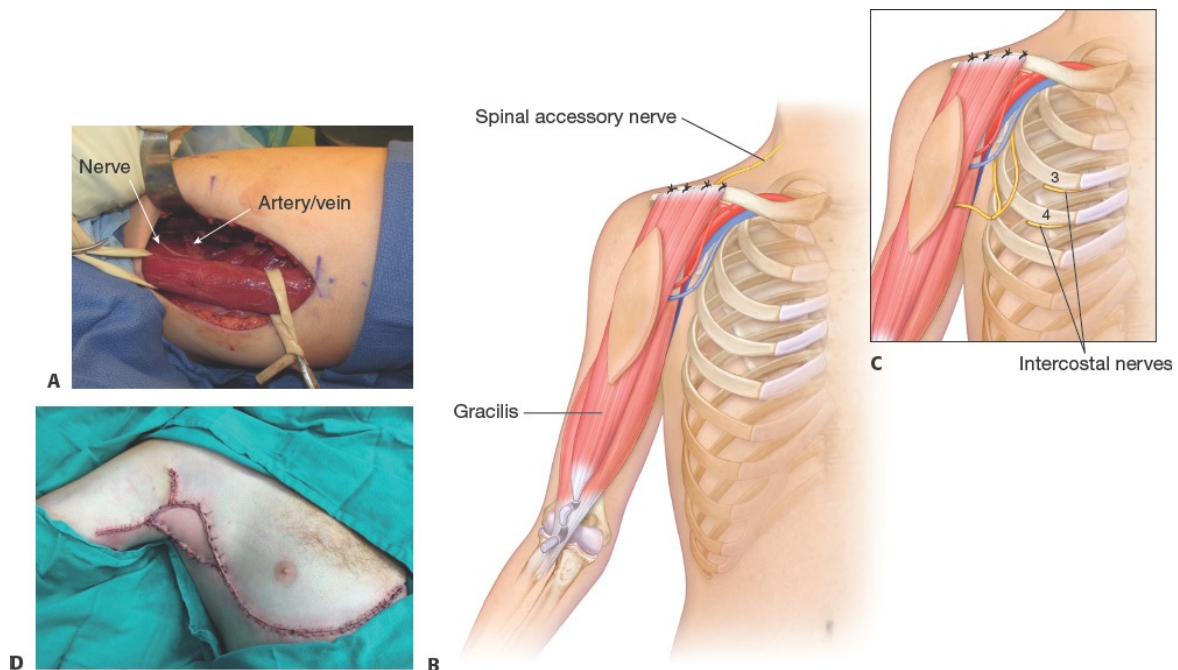
- Two drains are placed in the donor site and all wounds are closed in layers.
- The skin paddle is used for postoperative muscle flap perfusion monitoring.

Free Functioning Gracilis Transfer

- Landmarks: thoracoacromial artery, acromion, clavicle, biceps brachii tendon, PM, intercostal muscles, adductor magnus, adductor longus
- Harvest—a longitudinal incision is made 2 cm posterior to the palpable adductor longus tendon on the medial upper thigh. The gracilis muscle is

identified and freed from surrounding soft tissues.

- The obturator nerve is identified and dissected proximally toward the adductor hiatus where it is divided sharply.
- The medial circumflex femoral artery and vein are dissected to their origin on the deep femoral vessels between the adductor longus and magnus. Branches to the adductor longus must be carefully ligated and divided (**TECH FIG 5A**).
- The muscle is marked at resting tension using 3-0 silk sutures placed at 5-cm intervals.
- A 4-cm longitudinal incision is made overlying the medial proximal tibia. The sartorius fascia is divided and the distal gracilis tendon (the most superior structure of the pes anserinus) is identified and sharply release from the tibia.
- Inset—a curvilinear longitudinal incision is made over the anterior upper arm with a transverse extension 2 cm above the acromion and lateral clavicle. The distal biceps tendon is exposed while protecting the neurovascular structures.
- The thoracoacromial artery (or brachial artery) and cephalic vein are prepared and the spinal accessory nerve is dissected free from the deep surface of the anterior trapezius muscle, ensuring maximum length for transfer (**TECH FIG 5B,C**). The intercostal nerves are an alternative donor for motor reinnervation.¹⁹
- The medial circumflex vessels are ligated and the muscle is transferred to the arm.
- The muscle position is evaluated relative to the anticipated neurovascular repairs and the muscle is secured to the acromion and clavicle using two previously placed suture anchors.
- The vessel anastomoses and nerve coaptations are performed with 9-0 and 10-0 nylon suture, respectively.
- With the muscle at resting tension and the elbow flexed to 100 degrees, the gracilis tendon is woven into the distal biceps tendon with 2-0 braided suture or secured to the radial tuberosity with suture anchors.
- The wounds are closed in layers (**TECH FIG 5D**).
- An implantable venous Doppler is used to monitor perfusion in combination with clinical examination.
- The patient is placed on 81 mg of aspirin daily for 4 weeks.



TECH FIG 5 • **A.** Free functioning gracilis muscle transfer harvest. **B.** Free functioning gracilis transfer with spinal accessory motor nerve. **C.** Free functioning gracilis transfer with intercostal motor nerves. **D.** Free functioning gracilis muscle transfer inset and closure.

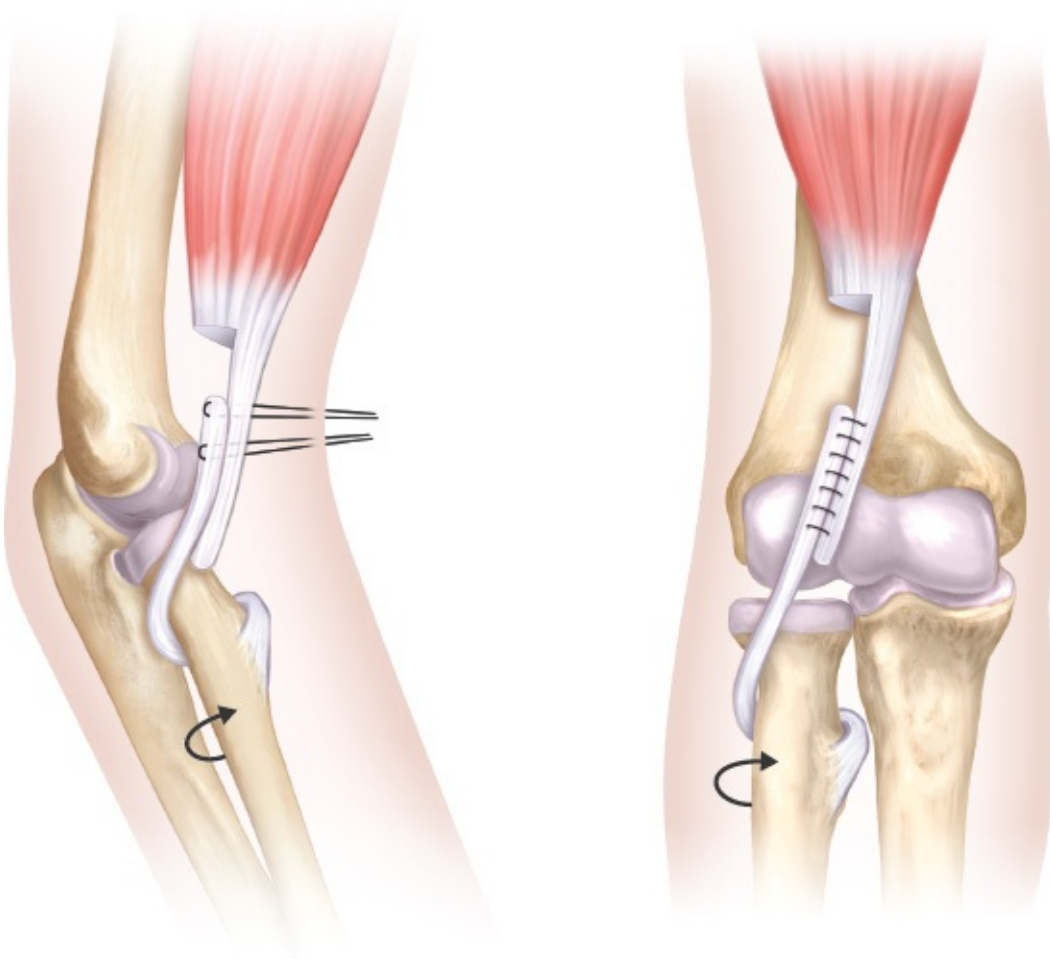
FOREARM RECONSTRUCTION

■ Biceps Rerouting

- Landmarks: biceps muscle, brachialis muscle, BR muscle, lacertus fibrosus, brachial artery and branches, recurrent radial artery, median nerve, radial nerve, LABC
- A curvilinear incision is made over the antecubital fossa and the LABC is identified and protected.
- The radial nerve is identified between the brachialis and BR and protected. The brachial artery and median nerve are also identified and gently retracted for protection. The radial recurrent artery is ligated, if necessary.
- The lacertus fibrosus is divided and the biceps tendon is traced to the interval

between the BR and PT such that the biceps insertion into the radius is visualized.

- The biceps tendon is then divided with a Z-lengthening technique.²⁰
- The distal biceps tendon is rerouted dorsolaterally around the radial neck using a curved clamp. The rerouted tendon is then secured to the proximal biceps tendon in a side-to-side fashion using 3-0 braided with the elbow in 90 degrees of flexion and the forearm in full pronation (**TECH FIG 6**).



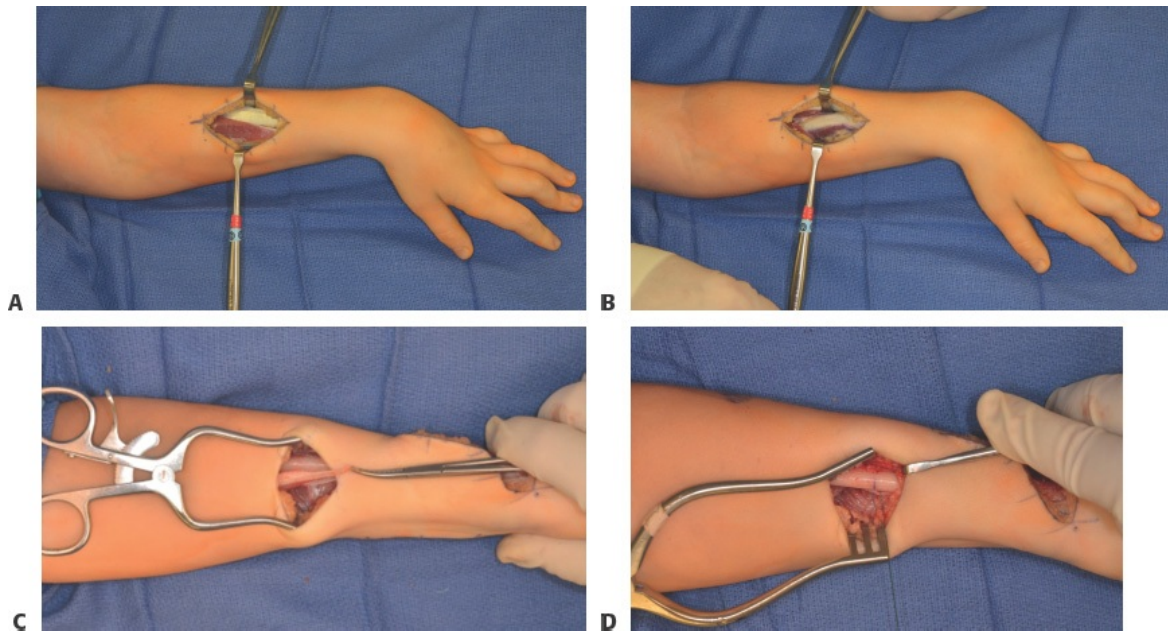
TECH FIG 6 • Biceps tendon rerouting.

■ PT Release/Rerouting



Video p8-c053_02

- Landmarks: BR, ECRL, ECRB, radius, radial artery, superficial radial nerve
- Six-centimeter skin incision at the volar radial aspect of the midforearm (**TECH FIG 7A**).
- The forearm fascia is divided and the BR and ECRL are retracted dorsally (**TECH FIG 7B**).
 - The superficial radial nerve lies under the BR and should be protected.
- The PT is detached from the insertion on the radius (the release is complete at this step). If rerouting is planned, then a 3-cm sleeve of the periosteum is taken with the PT to ensure adequate length for rerouting (**TECH FIG 7C**).
- The PT is mobilized proximally to allow for easy excursion.
- The IOM is released at the site of reinsertion and the PT is passed from volar to dorsal through a window in the IOM.
- The forearm is supinated and the PT is reinserted into the radius. In children, a 3-0 braided is woven into the PT tendon and passed through two transosseous drill holes to secure the PT to the radius (**TECH FIG 7D**). This is facilitated with the use of a Hewson suture passer.
 - In adults, a suture anchor may be used to secure the PT to the radius.
- The tourniquet is deflated, hemostasis is ensured, and the incision is closed in layers.



TECH FIG 7 • **A.** Approach for pronator teres exposure. **B.** Exposure of pronator teres insertion on the radius. **C.** Pronator teres elevation with a strip of the periosteum. **D.** Transosseous suture placement and docking of pronator teres onto dorsal radial shaft.

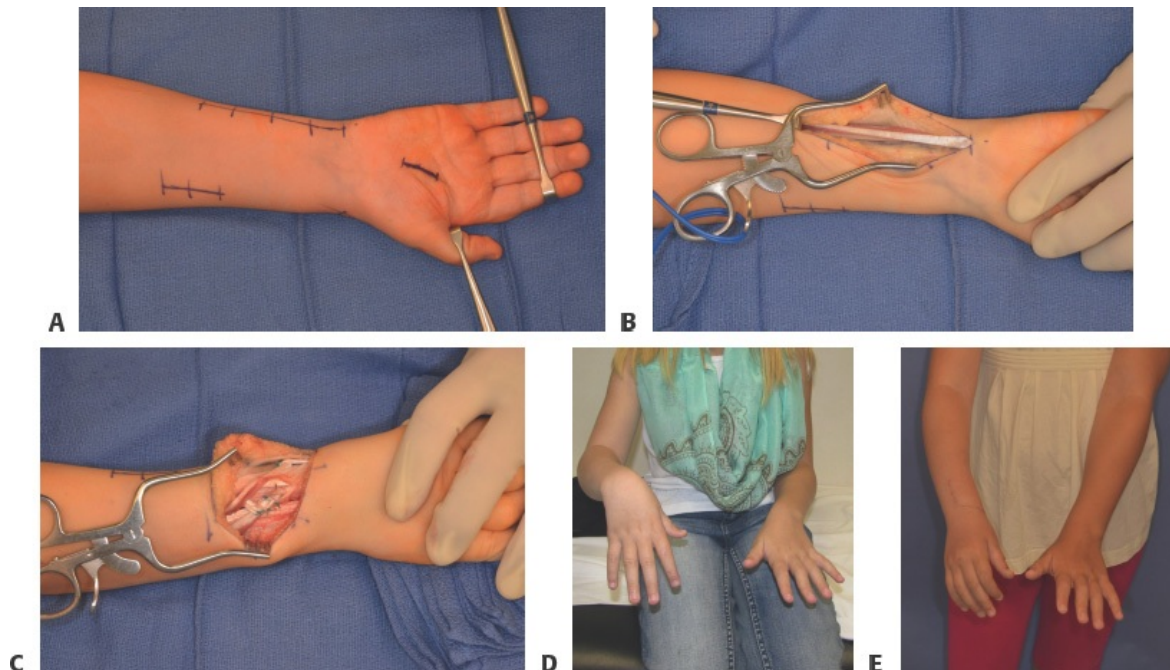
WRIST/FINGERS RECONSTRUCTION

■ FCU to ECRB Tendon Transfer for Wrist Extension



Video p8-c053_01

- Landmarks: FCU tendon, ulnar artery, ulnar nerve, ECRB tendon, ECRL tendon, EDC tendons
- A 10-cm incision made over the palpable FCU tendon extending proximally from the pisiform (**TECH FIG 8A**).
- The FCU is released from the pisiform, and the muscle/tendon unit is elevated while protecting the ulnar artery and nerve (**TECH FIG 8B**).
- A 6-cm incision is made over the distal dorsal forearm in line with the middle finger ray. The second extensor compartment is opened sharply, and the ECRB tendon is identified.



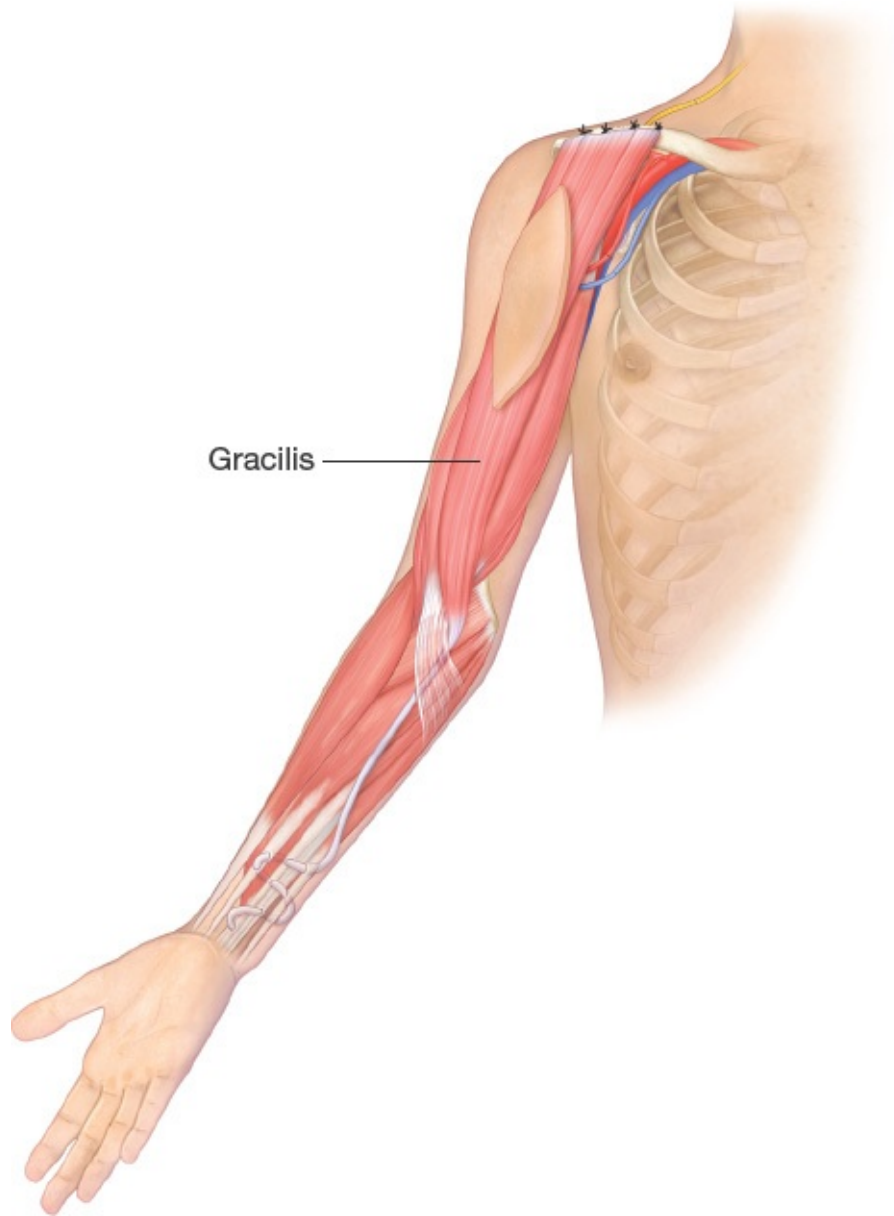
TECH FIG 8 • **A.** Markings for FCU to ECRB transfer, pronator rerouting, and thumb adductor release. **B.** FCU muscle/tendon exposure. Ulnar neurovascular bundle sits just deep to the tendon. **C.** The FCU to ECRB transfer was performed in combination with EPL rerouting. **D.** Preoperative right wrist extension. **E.** Postoperative right wrist extension.

- A wide subcutaneous tunnel is created to directly connect the FCU muscle to the proposed intersection with the ECRB tendon.¹¹ In the setting of ulnar wrist deviation, the FCU is instead woven into the ECRL to achieve radial balance.
- With the wrist in 30 degrees of extension, the FCU tendon is interwoven into the ECRB tendon using an end-to-side Pulvertaft weave with 3-0 braided suture (**TECH FIG 8C**).
- Hemostasis is ensured, and the incisions are closed in layers.
- The preoperative and postoperative posture of the right wrist is shown in **TECH FIG 8D,E**.

■ Free Functioning Gracilis Transfer for Finger

Flexion

- Landmarks: thoracoacromial artery, acromion, clavicle, intercostal muscles, adductor magnus, adductor longus, FPL, and FDP tendons
- See Restoration of Elbow Flexion technique, earlier, for harvest and proximal inset details. The muscle may also be directly attached to the humerus via suture anchors if additional distal length is necessary.
- A pulley is created at the elbow using either the PT or the FCU to optimize gracilis muscle excursion.²¹
- With the muscle tension set at resting length, the elbow at 90 degrees of flexion, and the MCP joints at 45 degrees of flexion, the gracilis tendon is woven obliquely through the FDP and FPL tendons in the distal third of the forearm and secured using 3-0 Ethibond suture. The FPL tendon junction with the FDP tendons is performed to ensure that the thumb does not flex prior to the digits (**TECH FIG 9**).
- Hemostasis is ensured and the incisions are closed in layers.
- An implantable venous Doppler is used to monitor perfusion in combination with clinical examination.
- The patient is placed on 81 mg of aspirin daily for 4 weeks.



TECH FIG 9 • Free functioning gracilis muscle for finger flexion.

PEARLS AND PITFALLS

ELBOW RECONSTRUCTION

Elbow release

- Electrocautery should be used to decrease bleeding during myotomy.
- Identify and protect the radial nerve during BR elevation.
- In long-standing contractures, the neurovascular structures will shorten and prevent full passive extension.
- Z-lengthening of the biceps tendon should be performed over as long a stretch of the tendon substance as possible.
- Extreme care should be taken when handling the thin biceps tendon during repair.
- Patients with weak flexion may have a functional loss of elbow flexion power after full release.

Steindler flexorplasty

- Small nerve branches to the flexor-pronator muscles and the medial collateral ligament of the elbow must be protected.
- Ensure good wrist extension power to counteract the possible development of a wrist flexion contracture. If active wrist extension is poor, simultaneous wrist arthrodesis can be performed.
- Concomitant ulnar nerve transposition is recommended to prevent traction on the nerve after muscle transposition.
- Ensure that the median nerve and brachial artery are free from compression or traction prior to securely fixing the transposed medial epicondyle/flexor-pronator mass.

LD transfer

- High brachial plexus lesions may preclude use of this transfer.
- Inclusion of a skin island will simplify recipient site closure.
- The muscle can be debulked to accommodate the upper arm soft tissue pocket.
- The neurovascular structures should be assessed repeatedly during transfer in an effort to avoid kinking/twisting.

Free functioning gracilis transfer

- Avoid nerve grafts, if at all possible.
- If normal (unaffected by the NBPP), the LD transfer results in better elbow flexion strength than the free gracilis transfer.
- Delay revision surgery for at least 1 year or after skeletal maturity.

FOREARM RECONSTRUCTION

Biceps rerouting

- Overtensioning of the transfer may lead to an elbow flexion contracture.
- The tendon may be fragile, and care should be taken to prevent fraying during handling.
- It is essential to Z-lengthen the entirety of the tendon to ensure

	adequate length for rerouting. ■ The posterior interosseous nerve is at risk during rerouting because it lies directly on the radius. ■ A concomitant IOM release is recommended if there is no passive pronation. ■ A BR rerouting in the forearm is recommended in patients without adequate triceps function, because biceps rerouting will impart an unopposed flexion force across the elbow.
PT release/rerouting	■ The superficial radial nerve and radial artery must be protected throughout the procedure. ■ The periosteal sleeve must be carefully elevated from the radius to provide adequate length for rerouting and reinsertion into the radius.
WRIST/FINGERS RECONSTRUCTION	
FCU to ECRB tendon transfer	■ If passive flexion of the wrist to 20 degrees is not possible, the tension is too great and the muscle weave must be loosened. ■ Avoid lifting the tendons from the wound when performing the weave because this will result in a lax repair. ■ Ensure that the subcutaneous tunnel through which the tendon is passed is wide and straight. ■ Wrist arthrodesis is a better option in children with weak wrist flexors.
Free functioning gracilis transfer	■ Delay revision or adjunctive procedures for at least 1 year or after skeletal maturity. ■ In children with weak or absent wrist extension, wrist arthrodesis may be considered in the future to direct the full force of flexion to the finger flexors.

POSTOPERATIVE CARE

Elbow Reconstruction

- Elbow release
 - No immobilization is necessary after a fractional lengthening of the elbow flexors. Immediate active and passive range of motion is initiated.
 - A full elbow release requires a long-arm orthosis for 4 weeks with initiation of active and passive range of motion. A nighttime extension orthosis is worn for 3 months.
- Steindler flexorplasty

- The elbow is immobilized in a long-arm orthosis for 6 weeks.
- After 6 weeks, gentle elbow extension and flexion are initiated under guidance of a hand therapist.
- Resistance exercises are introduced at 12 weeks.
- LD transfer
 - The elbow is immobilized at 100 degrees of flexion in a sling for 6 to 8 weeks. At 4 weeks, the patient is instructed to begin muscle contraction exercises.
 - At 8 to 10 weeks, active elbow extension and flexion are initiated under guidance of a hand therapist; re-education of the transferred muscle is often necessary.
 - Resistance exercises are introduced at 12 weeks.
- Free functioning gracilis transfer
 - The elbow is immobilized for 6 weeks in a position of 100 degrees of elbow flexion and the forearm in neutral.
 - Passive range of motion is initiated at 6 weeks, but passive flexion is restricted beyond 30 degrees for 12 weeks.
 - Re-education of the transferred muscle is necessary and EMG biofeedback is helpful.²²
- Contraction of the transferred muscle typically begins around 4-6 months postoperatively.

Forearm Reconstruction

- Biceps rerouting
 - The arm is immobilized in a long-arm cast with the elbow in 30 degrees of flexion and maximal pronation.
 - At 4 weeks, passive range-of-motion exercises are initiated and the patient is transitioned to a long-arm orthosis.
 - At 6 weeks, active elbow extension and flexion are initiated under guidance of a hand therapist.
 - The orthosis is discontinued at 8 weeks and resistance exercises are introduced at 10 weeks.
- PT release/rerouting
 - The forearm is placed in full supination using an above elbow orthosis for 6 weeks.
 - The patient is then allowed unrestricted motion under the supervision of a

hand therapist.

Wrist/Fingers Reconstruction

- FCU to ECRB tendon transfer
 - The wrist is immobilized in 30 degrees of extension for 4 weeks.
 - After 4 weeks, gentle range-of-motion exercises are begun and an orthosis is worn for an additional 4 weeks.
- Free functioning gracilis transfer
 - The arm is immobilized for 4 weeks with the elbow at 90 degrees of flexion, the wrist in neutral, and the fingers in at least 45 degrees of flexion at the MCP joints and interphalangeal joints.
 - At 4 weeks, a custom orthosis is created and a passive stretching program is initiated under the guidance of a hand therapist.
 - Upon spontaneous muscle contraction, the patient is directed to attempt active flexion of the fingers.
 - Therapy should continue for up to 1 year.
 - Re-education of the transferred muscle is necessary and EMG biofeedback is helpful.²²
 - Contraction of the transferred muscle typically begins around 4-6 months postoperatively.

OUTCOMES

Elbow Reconstruction

- Elbow release: fractional lengthening will increase elbow extension by 40 to 60 degrees, with minimal loss of elbow flexion power.²³⁻²⁵
 - A full elbow release will increase elbow extension by 50 degrees but leads to a 19-degree loss of active flexion.²⁵ Many patients are able to accomplish tasks that were difficult before surgery.
- Steindler flexorplasty: Al-Qattan²⁶ reports that patients can expect 110 degrees of active elbow flexion against resistance, with a mean postoperative elbow flexion contracture of 35 degrees.
- LD transfer: Most patients will achieve M4 elbow flexion strength after transfer, with a mean arc of flexion of 90 to 140 degrees.^{18,27}
- Free functioning gracilis transfer: El-Gammal et al. report an average arc of elbow flexion of 104 degrees. Elbow flexion power increased an average of 3.8 grades,²⁸ and 79% of patients achieve at least M4 elbow strength.²⁹ Average

passive elbow range of motion significantly decreased from 147 to 117 degrees.²⁸

Forearm Reconstruction

- Biceps rerouting: Rühmann and Hierner reported an average increase in pronation of 87 degrees (range 70 to 100 degrees). Active pronation to neutral was achieved in 91% of patients and 46% were able to pronate 30 degrees or more.³⁰ Results are less favorable in those with limited preoperative passive supination³¹ or active pronation.
- PT release/rerouting: PT release results in approximately 50 degrees of decreased forearm pronation.³² PT rerouting results in an improvement of active supination between 45 and 90 degrees.^{23,33} Over time, there may be attenuation at the insertion site, leading to loss of supination.³⁴

Wrist/Fingers Reconstruction

- FCU to ECRB tendon transfer: Transfer results in an average gain in wrist extension of approximately 47 degrees.³⁵ Al-Qattan¹⁴ reported that average wrist extension muscle strength increased from 0 to 4 on a modified MRC system for motor grading. All patients, regardless of gains in wrist extension, discontinued use of a wrist orthosis.³⁵
- Free functioning gracilis transfer: Terzis and Kostopoulos reported a postoperative mean MRC grade of 3.17 and 4.00 when innervated by the intercostal or spinal accessory nerve, respectively.³⁶ In a series by Chim et al.,²¹ the youngest patients in their series (ages 6 and 8) developed elbow joint flexion contractures. Many patients require secondary procedures to optimize finger flexion and hand function.

COMPLICATIONS

Elbow Reconstruction

- Elbow release: neurovascular injury, weakening of elbow flexion, recurrent contracture
- Steindler flexorplasty: neurovascular injury, nonunion of fusion site, elbow flexion contracture, wrist flexion contracture
- LD transfer: hematoma/seroma, muscle nonfunction or ischemic failure, loss of muscle tension, clavicle fracture, elbow flexion contracture, compartment syndrome

- Free functioning gracilis transfer: neurovascular injury, muscle nonfunction or ischemic failure, clavicle fracture, elbow flexion contracture

Forearm Reconstruction

- Biceps rerouting: neurovascular injury, persistent supination or pronation contracture, tendon rupture
- PT release/rerouting: neurovascular injury, persistent pronation or supination contracture, attenuation of the reinsertion site

Wrist/Fingers Reconstruction

- FCU to ECRB tendon transfer: neurovascular injury, attenuation of the transfer, limited finger release resulting from weak finger extensors or tight finger flexors.
- Free functioning gracilis transfer: neurovascular injury, muscle nonfunction or ischemic failure, adhesions, bowstringing across the elbow, elbow flexion contracture

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Section XIV: Lower Extremity

56 Rotationplasty of the Lower Extremity

CHAPTER

Samer Attar, Robert J. Steffner, and Terrance D. Peabody

DEFINITION

- Rotationplasty of the lower extremity is a reliable and durable reconstructive option in the setting of bone loss in the lower extremity due to tumor, infection, or trauma.
- With resection of the bone around the knee joint, the rotated tibia is attached to the remaining femur.
- With appropriate preoperative education and proper patient selection, it is a functional alternative to an above-knee amputation or endoprosthetic reconstruction—especially in the skeletally immature patient.

ANATOMY

- The distal limb is rotated 180 degrees. This technique permits the rotated ankle joint to function as a knee joint for prosthetic fitting (**FIG 1**).
- The stump can fit into a modified below-knee prosthesis that is end-bearing, as opposed to ischial-bearing prostheses for above-knee amputations.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Historically, rotationplasty has been described in the management of femoral bone loss from tuberculosis, proximal femoral focal deficiency, and sarcomas.^{1,2}
- Indications for rotationplasty

- Congenital bone loss or deficiency
- Sarcomas of the lower extremity
- Trauma
- Failed arthroplasty
- Skeletally immature patient or active adult patient
- Contraindications
 - Pre-existing nerve damage or ankle stiffness
 - Sciatic nerve involvement in tumor requiring its resection
- Physical examination
 - The soft tissues proximal and distal to the area of tumor must be intact and free of disease.
 - The ankle joint must be inspected for any contractures or limitations to motion.
 - The dorsalis pedis and posterior tibialis pulses must be inspected for flow.
 - Ankle extension, ankle flexion, and extensor hallucis longus motor strength must be documented.
 - A sensate foot with 5/5 motor strength and full ankle range of motion is ideal.

IMAGING

- Limb lengths of both lower extremities are obtained.
- Bone age should be approximated as the nonoperative limb will continue to grow.
- In malignant bone tumors about the knee undergoing resection, the distal femoral and proximal tibial growth plates are usually removed.
- When the patient reaches skeletal maturity, the rotated tibiotalar joint of the operative limb should be located at the center of rotation of the knee of the nonoperative limb.
- The projection of growth of the nonoperative limb must be taken into consideration at the time of surgery. Therefore, in a skeletally immature individual, the operative leg must be longer than the nonoperative femur.
- In the setting of sarcoma, magnetic resonance imaging determines where to resect the femur with an adequate margin, whether the joint is contaminated, and whether vascular structures are contaminated.
 - If there is joint invasion, an extra-articular resection should be performed.
 - If tumor infiltrates or encases vessels, vascular resection with anastomosis should be considered.

- The tibial and peroneal nerves should be intact and free of disease as they will be required to power ankle motion.



FIG 1 • Limb after rotationplasty, allowing the rotated ankle joint to function as a knee joint for prosthetic fitting.

SURGICAL MANAGEMENT

- Operative intervention must focus on the creation of appropriate flaps, wide resection of bone and soft tissue margins, and stable fixation of the remaining femur to the rotated tibia.

Preoperative Planning

- Extensive discussions with the patient and family are essential prior to performing a rotationplasty. The options of an amputation vs internal prosthesis

must be reviewed in addition to explaining their respective risks/benefits.

- Imaging is reviewed to determine levels of resection of the femur and tibia in order to:
 - Achieve a sound oncologic margin
 - Account for a projected center of rotation of the rotated tibiotalar joint to be at the same level of the nonoperative knee when the patient reaches skeletal maturity

Positioning

- The patient is placed supine on a radiolucent table.
- The entire lower extremity from the pelvis to the foot must be prepped and draped.
- This setup provides vascular access and enables internal fixation to the level of the hip joint if needed.
- Intraoperative fluoroscopy is recommended in order to aid placement of hardware.

Approach

- The skin incision must be planned to accommodate the disproportion between thigh and calf circumference.
- Circumferential incisions are commonly made at acute angles to each other to account for this thigh/calf discrepancy (**FIG 2**).
- A longitudinal incision is then drawn to connect the proximal and distal circumferential flaps. This line is placed ideally to expose a plane for tumor resection and neurovascular dissection.³⁻⁶

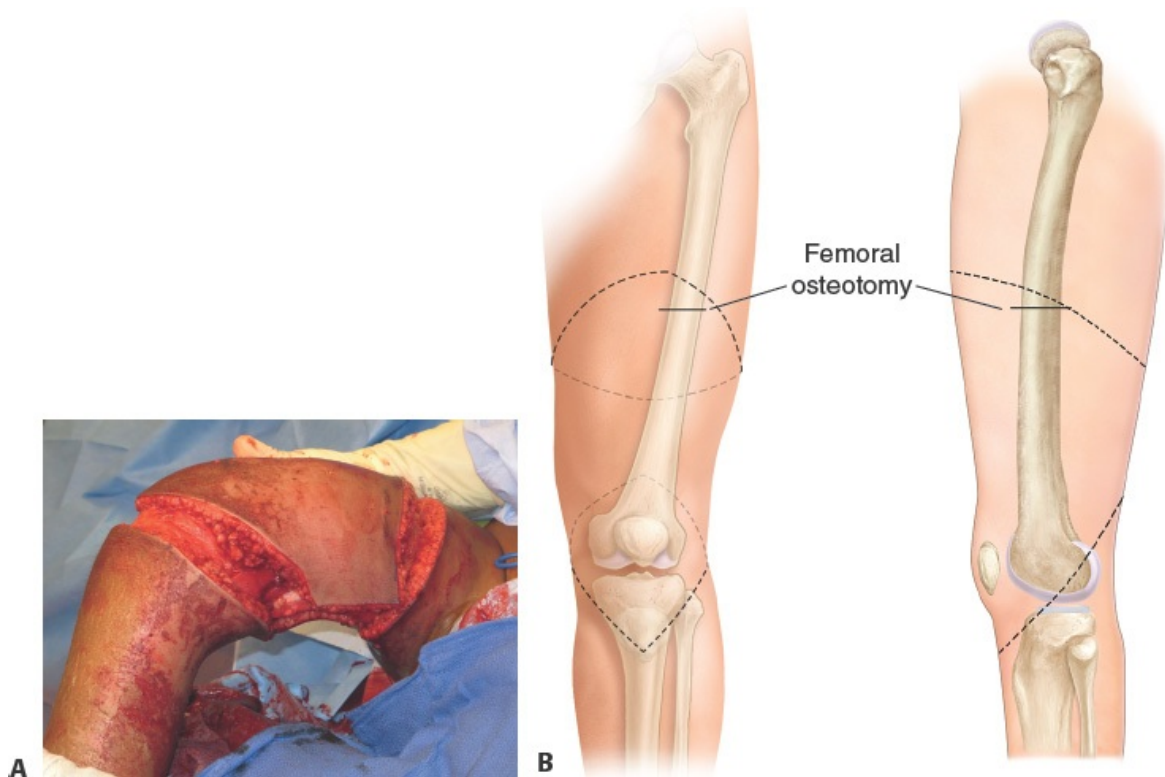


FIG 2 • Intraoperative outline of incision in the right lower extremity of a pediatric patient with a distal femur osteosarcoma.

TECHNIQUES

■ Incision

- Skin and subcutaneous tissues are incised and raised as flaps along the circumferential thigh and calf tissues and the longitudinal line connecting them (**TECH FIG 1A,B**).



TECH FIG 1 • **A.** Incision with thick skin flaps. Note the circumferential incisions placed at oblique angles in order to accommodate the difference in thigh and calf diameter during rotation and closure of the wounds. **B.** The rhomboid incision should have an

anterior axis that is about 5 to 10 cm longer than the intended length of the bone resection. The bone resection itself should be located at the proximal and middle thirds of the more proximal incision.

■ Nerves

- The peroneal nerve is identified deep to the biceps tendon coursing laterally around the proximal fibula. It is dissected free of the surrounding soft tissue and followed proximally into the posterior thigh until its bifurcation with the tibial nerve (**TECH FIG 2A**).
- The tibial nerve is traced distally through the popliteal space and distal to the proposed osteotomy site. It is also dissected proximally until the sciatic nerve is identified and traced above the level of the proposed femoral osteotomy.
- Alternatively, the sciatic nerve may be identified proximally and traced distally through its bifurcation into the tibial and peroneal nerves (**TECH FIG 2B**).

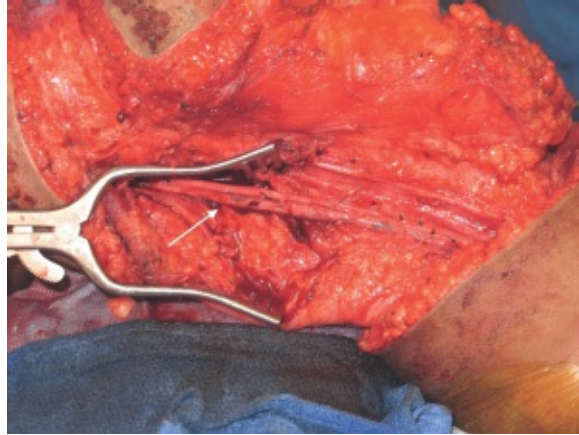


TECH FIG 2 • A. The peroneal nerve is dissected more proximally to the location where it joins the tibial nerve at the bifurcation. The tibial nerve can then be dissected distally into the popliteal space. **B.** Sciatic nerve (*arrow*) dissected from surrounding soft tissues.

■ Vessels

- Transection of the pes anserinus and medial gastrocnemius tendons reveals the popliteal artery and vein. They are traced distally to the trifurcation. Proximally, they are delivered posteriorly away from the femur, and the dissection should stop proximal to the proposed femoral osteotomy site.⁷
- The vessels must be free and untethered from all surrounding soft tissues from proximal to distal to prevent kinking and tension when the tibiotalar joint is rotated (**TECH FIG 3**).

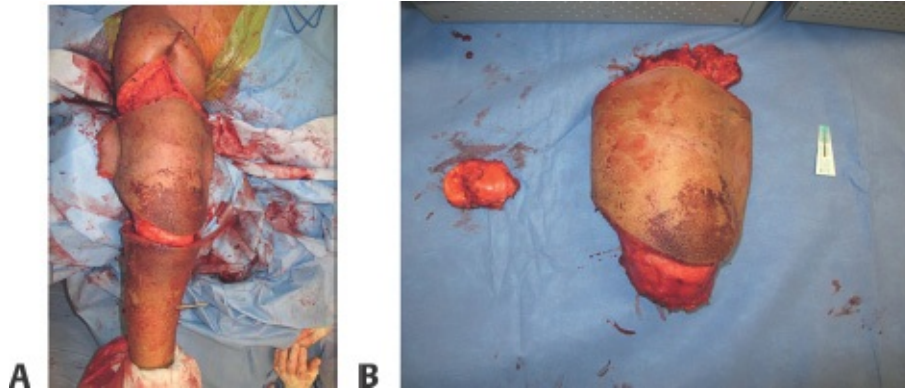
- In the setting of vascular involvement with tumor, the vessels can be resected and the remnants anastomosed. However, this technique possesses a higher risk and higher potential for complications.



TECH FIG 3 • Femoral vessels (*arrow*) dissected from surrounding soft tissues.

■ Osteotomies

- Once the neurovascular structures are dissected and freed, attention should be turned to the femoral and tibial osteotomies.
- Steinmann pins can aid in rotation of the limb (**TECH FIG 4A**).
 - Proximal to the level of bone resection, a pin can be placed anterior to posterior with the patella directed straight anteriorly.
 - Distal to the tibial resection, a second pin is placed in the medial tibia perpendicular to the femoral pin.
- The surrounding soft tissues are then incised down to the proposed osteotomy sites.
 - Distally, the patellar tendon, the cruciate and collateral ligaments, the knee menisci, and the posterior knee capsule are incised and released at the level of the tibial insertion.
 - Proximally, the quadriceps, hamstring, and adductor musculature are incised down to the level of the femoral osteotomy site.

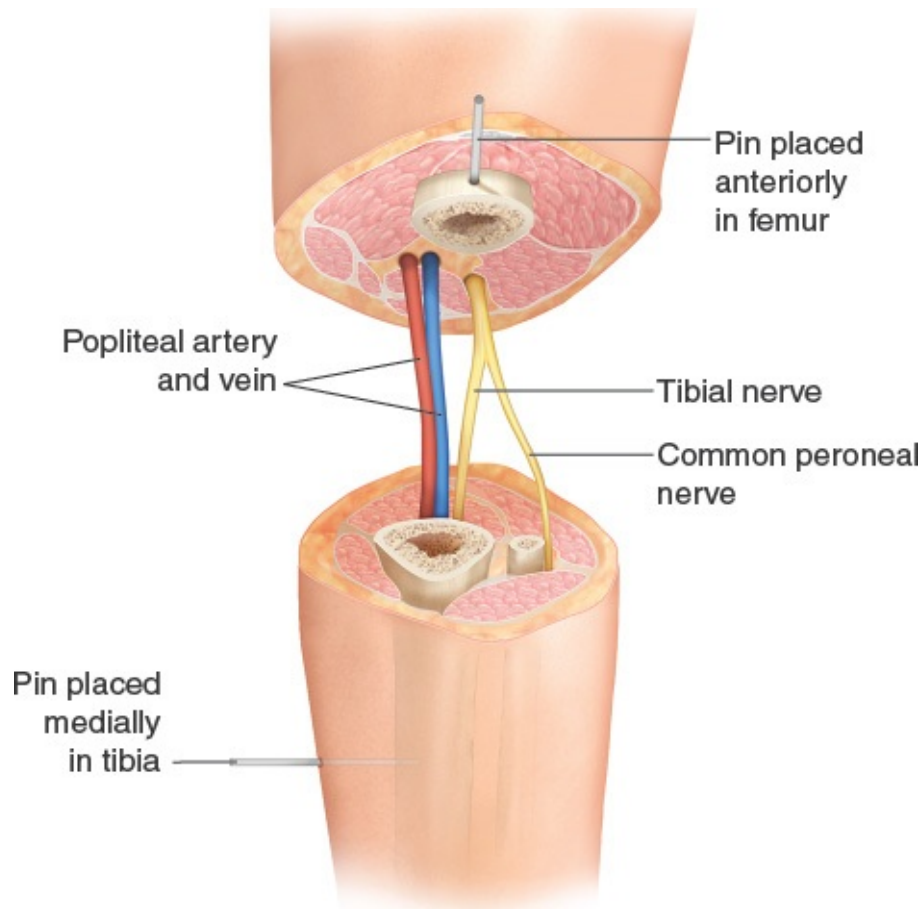


TECH FIG 4 • A. Steinman pin placed anterior to posterior in the proximal femur and medial to lateral in the distal tibia. **B.** Intercalary specimen with resected proximal tibia.

- Attention must always be paid to maintaining tumor margin and protecting neurovascular structures during these steps.
- The femur and tibia can then be osteotomized with an oscillating saw, and the specimen is passed off the field (**TECH FIG 4B**).

■ Marrow Margin

- A femoral bone marrow margin should be sent to pathology for a frozen section. It should be confirmed that this margin is negative prior to proceeding with reconstruction.
- During this wait time, the wound can be irrigated. The continuity of the vessels and nerves should be examined and should be tension-free (**TECH FIG 5**).



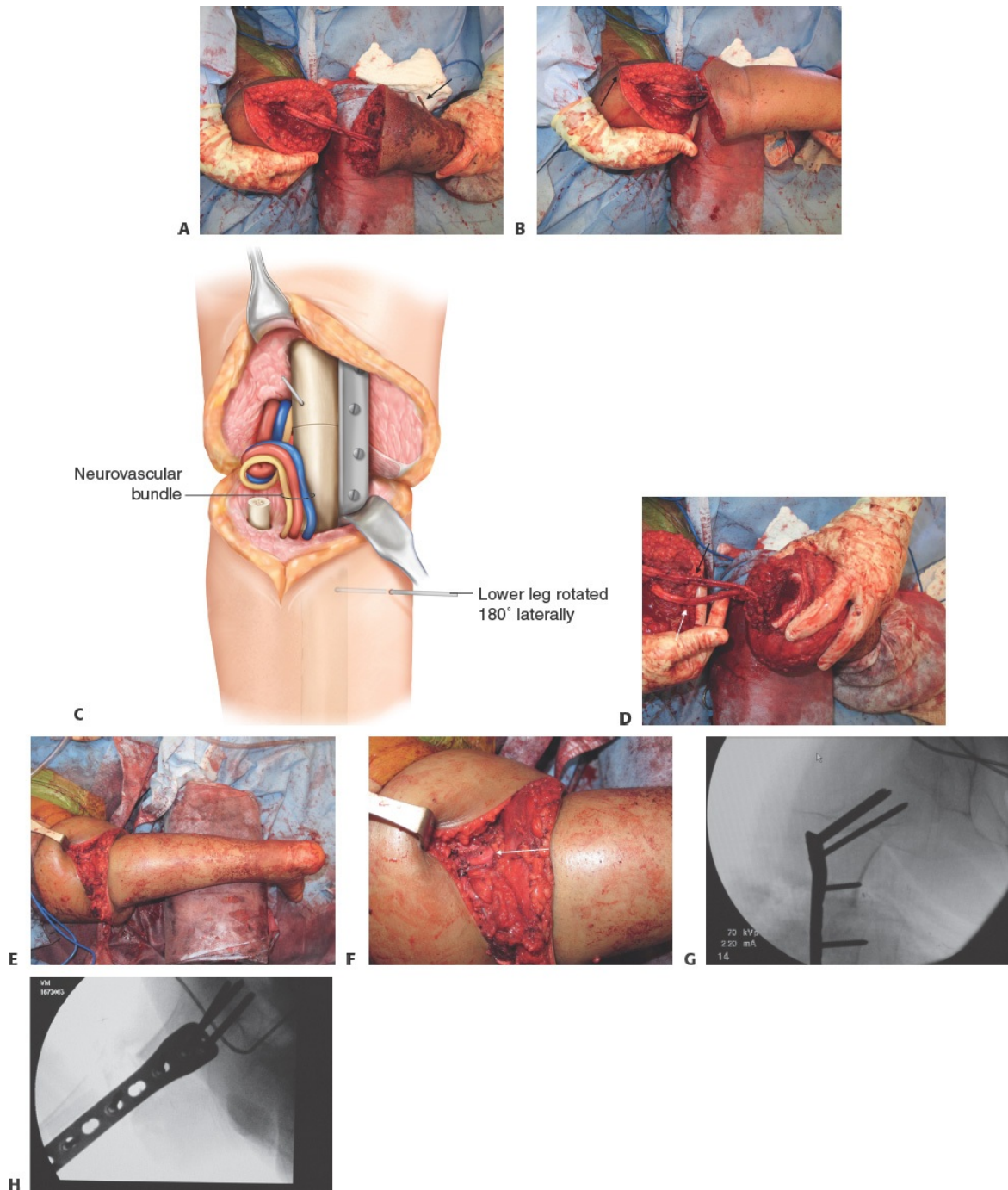
TECH FIG 5 • Depiction of the limb after extra-articular resection of the distal femur before rotation of the limb.

■ Rotation/Reconstruction

- Reconstruction involves external rotation of the tibia by 180 degrees. If a medial tibial pin was placed, it should be perpendicular to the femoral pin from the lateral direction once rotation is complete (**TECH FIG 6A–C**).
- The vessels and nerves should coil in a relaxed fashion with no excessive tension. Any kinking or tension of neurovascular structures suggests adherent soft tissues that should be released (**TECH FIG 6D–F**).
- The lateral aspect of the femur and medial aspect of the tibia are then exposed to permit compression plating fixation of the femoral-tibial junction. Fixation of six to eight cortices on either side of the junction is ideal if the remaining bone allows. Alternative methods of fixation are intramedullary

rods or external fixators.

- Intraoperative fluoroscopy aids final images documenting limb alignment and positioning of hardware (**TECH FIG 6G,H**).
- Flow to the foot must be documented prior to closure by palpation and/or Doppler ultrasound of the dorsalis pedis and posterior tibialis pulses.



TECH FIG 6 • **A.** Rotation of the distal limb. **B.** Tibial pin (*arrow*) is medial, and the foot is anterior. **C.** When the tibia has been rotated externally, the pin extends from lateral to medial, exactly 180 degrees from its original position. The osteotomy is fixed with a compression plate and screws. The vessels coil

medially. **D.** The neurovascular structures should be relaxed and tension-free. Continuity of the sciatic nerve (*white arrow*) and femoral vessels (*black arrow*). **E.** View of the lower extremity after rotation. **F.** Close-up view of the coiled vessels and nerves (*arrow*). **G.** Intraoperative fluoroscopic radiographs of compression plate fixation between the remaining proximal femur and rotated distal tibia. **H.** AP view. Lateral view.

■ Closure

- Drains are placed per surgeon discretion.
- A layered closure is then performed. The quadriceps fascia is usually sutured to the gastrocnemius musculature and deep fascia of the calf. The hamstring fascia is sutured to the pretibial fascia (**TECH FIG 7**).
- A bulky dressing is ideal to maximize padding and minimize swelling. The internal fixation should be rigid, so no cast is usually needed.



TECH FIG 7 • Extremity after closure and before dressing applied.

Indications	■ Indicated in skeletally immature or active individuals. Preoperative education of the patient and family with literature, photos, and communication with patients who have undergone rotationplasty is beneficial.
Preoperative planning	■ Plan the length of the operative limb so that at skeletal maturity, the rotated tibiotalar joint of the operative limb should be located at the center of rotation of the knee of the nonoperative limb.
Approach	■ Angle circumferential incisions to account for discrepancies in thigh and calf circumference.
Technique	■ Vessels and nerves should be coiled in a relaxed fashion with no tension. ■ Use landmarks or pins to approximate rotation of the tibiotalar joint to 180 degrees. ■ Confirm vascular flow after rotation and fixation.

POSTOPERATIVE CARE

- The status of the limb must be followed closely with frequent neurovascular and compartment checks.
- Mobilization out of bed with assistive devices is encouraged as soon as possible. Active motion of the hip and ankle should be promoted as well.
- If there is a nerve palsy, an ankle-foot orthosis may be placed, and the foot and ankle should be passively ranged to prevent a contracture until motor function returns.
- Adequate wound healing usually occurs in 2 to 6 weeks. At that point, provisional prosthetic fitting may begin. However, no weight bearing through the prosthesis should be allowed until clinical and radiographic healing is evident at the femoral-tibial junction (**FIG 3**).
- Once healing has occurred, activities as tolerated are allowed with a prosthesis.

OUTCOMES

- Rotationplasty provides local recurrence rates comparable to other forms of wide resection such as limb salvage and amputation.
- Gait velocity and the energy cost for mobility are improved compared to a transfemoral amputation.

- Rotationplasty permits participation in recreational and sports activities due to an end-bearing prosthesis, whereas endoprosthetic reconstruction has limitations due to concerns over prosthetic wear and loosening.
- Psychosocial problems due to the cosmetic appearance of a rotated limb are not usually reported.
- Psychosocial issues can be avoided through preoperative education of the patient and family with literature, photographs, and interactions with patients who have had rotationplasties.

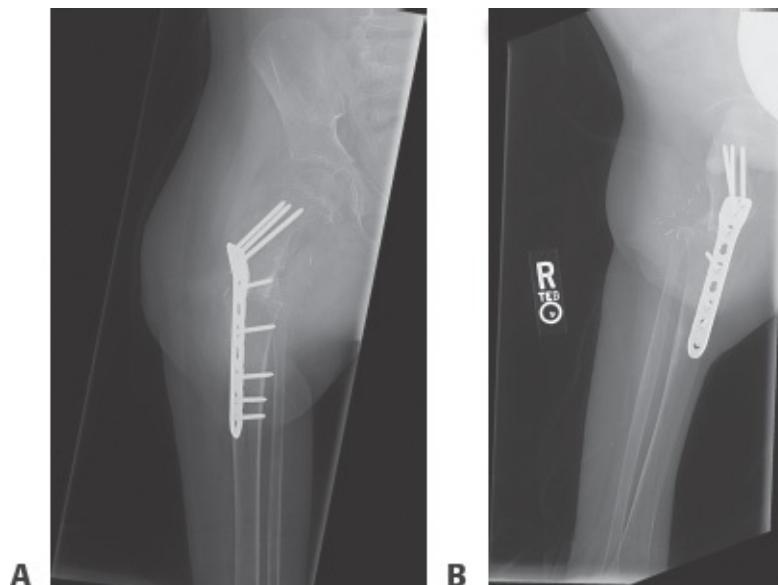


FIG 3 • Radiographs of the hip at 6 months postop. **A.** AP view. **B.** Lateral view.

- No adverse events have been reported with regard to the ability to pursue an education or career or develop and maintain relationships.
- There are no phantom pains or neuromas reported due to nerve continuity unlike in amputations.
- Rotationplasty is a reliable, predictable, and durable reconstructive option in the active or skeletally immature patient with a malignant bone tumor about the knee. Functionally, it can be equivalent or better than a transfemoral amputation, and it has comparable oncologic outcomes.^{8–16}

COMPLICATIONS

- Ischemia and vascular compromise can occur—especially in the setting of

vascular resection with anastomosis.

- Transient or permanent nerve palsy can lead to soft tissue contractures or a delay in rehabilitation with a prosthesis.
- Delayed or incomplete wound healing may require debridement with soft tissue coverage.
- Infection.
- Fracture nonunion.
- Hardware failure.
- Compartment syndrome.
- Rotational malalignment.

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CHAPTER Poland Syndrome

Patrick J. Buchanan and Paul S. Cederna

DEFINITION

- Poland syndrome is a developmental defect characterized by varying degrees of unilateral pectoralis major aplasia, thoracic skeletal defects, breast hypoplasia or aplasia, and ipsilateral syndactyly.^{1,2}
- A congenital unilateral absence of the sternocostal head of the pectoralis major muscle is pathognomonic for this congenital anomaly.

ANATOMY

- There are two predominant variations of Poland syndrome: simple form (mild) and complex form (severe).
- The simple form is the most common and is characterized by the absence of the sternocostal head of the pectoralis major muscle and effacement of the ipsilateral axillary fold.
 - The clavicular head of the pectoralis major muscle remains as a thin triangular muscle bundle that attaches the humerus to the inferomedial third of the clavicle.
 - The ipsilateral breast is hypoplastic or aplastic.
 - The ipsilateral nipple-areolar complex is typically smaller in diameter and displaced laterally and superiorly toward the axilla (**FIG 1**).
- The complex form is characterized by the absence of the sternocostal head of the pectoralis major muscle, ipsilateral rib and/or sternal hypoplasia or absence, and other ipsilateral muscular abnormalities (**FIG 2**).
 - The clavicular head of the pectoralis major muscle may be diminutive.
 - The ipsilateral latissimus dorsi, trapezius, pectoralis minor, serratus anterior, external oblique, and/or rectus abdominis muscles may be abnormal.

- The pectoralis minor muscle is commonly hypertrophic.
- Absence of the serratus anterior muscle results in a winged scapula.

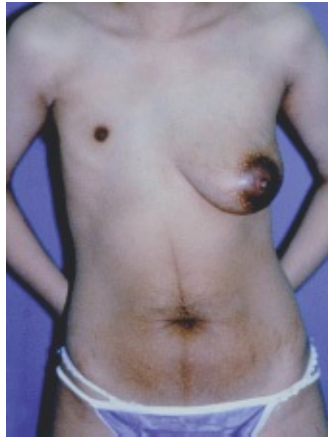


FIG 1 • Simple form of Poland syndrome depicting an ipsilateral breast anomaly with a smaller and superolaterally displaced nipple-areolar complex.

- Insertion of the ipsilateral rectus abdominis muscle is displaced cranially.
- The sternum is foreshortened and bifid with a pectus excavatum appearance.
- The ipsilateral scapula is small and cranially displaced, causing an internal shoulder rotation when compared to the contralateral side.
- The ipsilateral anterior second through fifth ribs are thin, short, and devoid of their superolateral cartilage.

PATHOGENESIS

- To date, no definitive cause of Poland syndrome has been elucidated.
- However, there are theories identifying developmental and familial causes.
 - Developmentally, in the 6th week of gestation, there is an interruption of the subclavicular arterial branches causing maldevelopment of the tissues supplied by these vascular pedicles
 - Currently, geneticists believe Poland syndrome is rarely inherited; however, there is documentation of a 1% inheritance pattern from affected individuals.

NATURAL HISTORY

- The true incidence and etiology of Poland syndrome still remains unknown; however, it tends to occur more on the right side, 2 to 3:1, is more common in

males, 2:1, and is estimated to occur 1 in 20 000 to 30 000 live births.³

- The most common presentation is that of a patient with a unilateral absence of the sternocostal head of the pectoralis major muscle with hypoplastic or absent breast parenchyma.¹



FIG 2 • Complex form of Poland syndrome showing ipsilateral axillary webbing, ipsilateral rib and sternal hypoplasia, ipsilateral trapezius, serratus anterior, rectus abdominis, and external oblique muscle abnormalities.

- The vast majority of patients with Poland syndrome present with concerns about the shape and appearance of their chest or abnormal breast development.¹

PATIENT HISTORY AND PHYSICAL FINDINGS

- The surgeon must be acutely aware of the social impact of Poland syndrome on the patient and their parents.
- Patients with the simple form of Poland syndrome may be aware of their abnormality earlier than their family, as it can remain unannounced until early adolescence, as muscle and breast development occur.
 - Early in childhood, parents may notice a slight chest asymmetry.
 - Adolescent children with Poland syndrome spend an inordinate amount of time trying to conceal their asymmetry from their parents and others.
- The severe form, on the contrary, is readily known during infancy by the parents, as the chest wall is grossly asymmetric.

- In all patients, there will be a noticeable soft tissue deficiency of the affected side of the chest due to volume loss from the partial or complete absence of the pectoralis musculature.
- The noticeable asymmetry often leads to adverse psychosocial sequelae.
- Patients often report an adverse impact on their social functioning, emotional well-being, and psychological health.

IMAGING

- Diagnostic imaging is available but usually not necessary in cases other than the most severe variants.
- Ultrasonography will show an absence of a portion of the pectoralis major muscle and asymmetry of the rib cage.⁴
- Mammography is typically not used as an imaging modality for Poland syndrome; however, absence of the pectoralis major muscle can be incidentally discovered on the mediolateral oblique view of a hypoplastic breast.⁴
- A CT scan can be used for presurgical planning to confirm the presence of the latissimus dorsi muscle and to better define the structural chest wall deformity.⁵
- MRI may be useful to better define the patient's anatomy as it offers a multiplanar view without the ionizing radiation of a CT scan.⁵
- Both color-coded duplex sonography and contrast-enhanced magnetic resonance angiography allow for the evaluation of selected arteries and vessels.⁵

DIFFERENTIAL DIAGNOSIS

- Unilateral accentuated thelarche
- Unilateral amazia
- Unilateral amastia

NONOPERATIVE MANAGEMENT

- Because reconstruction is rarely ever performed to restore a severe functional deficit, providing reassurance to the patient and their family is an important aspect of care that should not be overlooked by the surgeon.
- Removable external breast prostheses help correct the appearance of a female patient's chest and breast in clothing.

SURGICAL MANAGEMENT

- The reconstructive options for patients presenting with chest wall deformities from Poland syndrome depend on several key factors, including anatomical severity, gender, patient preferences, and associated anomalies.
- The timing and number of reconstructive stages is also of paramount importance.
 - A tissue expander can be placed early to gradually expand the affected side to decrease the amount of noticeable asymmetry as the contralateral breast developmentally matures.
 - Fat grafting can be initiated early to camouflage the asymmetry until the definitive reconstructive procedures are performed.
- Tissue expander-based reconstruction is ideal for the female patient with a hypoplastic and fibrotic breast or a patient with an aplastic breast.
- The latissimus dorsi muscle transfer can be used with any of the reconstructive approaches.
 - It is the best method to reconstruct the anterior axillary fold.
 - It can be performed on any patients, male or female, with a robust latissimus dorsi muscle.
 - The surgeon should discuss with the patients that harvesting of the latissimus dorsi muscle can create asymmetry in their back.
- Customized chest wall implants may be adjunctively needed in women and are often the treatment of choice in men.⁶
 - Author preference is for a custom silicone chest wall prosthesis.
 - The advantages of the customized chest wall implant reside in its ease of fabrication and insertion.
 - There is a relatively low morbidity for this technique compared to flap reconstruction.⁶
 - Disadvantages include implant migration, contour irregularities, patient reported discomfort, and potentially palpable or visible edges.⁶
- The endoscopic approach is typically performed in two stages when using a tissue expander and latissimus dorsi muscle transfer

Preoperative Planning

- Documenting the presence or absence of the serratus anterior and latissimus dorsi muscles is necessary, because this may affect desired reconstruction.
- The degree of pectoralis major muscle hypoplasia is also critical to determining the most appropriate reconstructive option for the patient.

- The sternal notch-to-acromion, acromion-to-olecranon, and olecranon-to-ulnar styloid distances are measured and compared to the contralateral side, in cases of notable skeletal abnormality.
- In women, the size of the breast and position of the nipple complex are assessed, particularly in regard to the contralateral, normal side.
- In the occasional male who seeks muscular strength improvement due to absence of the pectoralis musculature, objective testing of strength of the upper extremity via comparison to the contralateral side is needed.¹
- Male patients often lift weights in an attempt to increase the bulk of their affected chest.
- Weight lifting typically causes the pectoralis minor and the clavicular head of the pectoralis major muscle to become more hypertrophic (**FIG 3**).

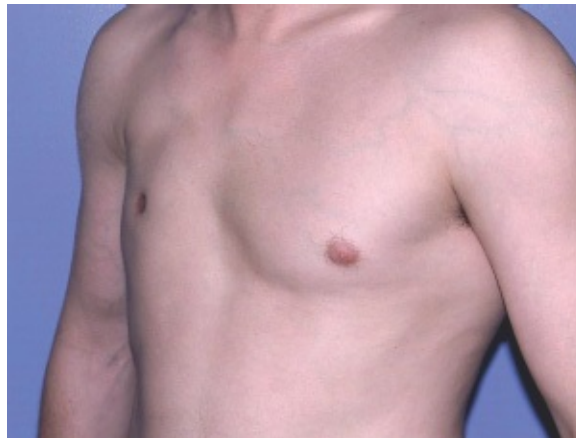


FIG 3 • Male patient with Poland syndrome showing hypertrophy of the ipsilateral pectoralis minor and clavicular head of the pectoralis major muscles.

Positioning

- The traditional latissimus dorsi muscle transfer harvest is performed by positioning the patient in a semilateral decubitus position with the ipsilateral arm elevated on an arm sling.
- **TECH FIG 1A** shows the intraoperative positioning for muscle harvest.
- **TECH FIG 1B** depicts the large incisional scar that can be expected from this traditional approach.
- Alternatively, the latissimus dorsi muscle harvest and implant placement can be performed via a single axillary incision with the patient's ipsilateral arm

extended cranially.

Approach

- Reconstructive options include the use of tissue expansion with implants, latissimus dorsi muscle transfers, customized chest wall implants, fat grafting, and rarely, free tissue transfers.^{1,7–10}
- Frequently, contralateral procedures are performed after definitive reconstruction of the affected side to achieve better symmetry.
- Symmetry procedures include, but are not limited to, contralateral breast reduction, mastopexy, repositioning of the nipple-areolar complex (NAC), and reducing the size of the NAC.
- Both implant-based and latissimus dorsi muscle transfer reconstructions can be performed with an endoscopic approach to minimize scarring.⁷

TECHNIQUES

■ Tissue Expansion with Implants

- The fibrotic breast tissue requires radial scoring prior to tissue expander placement to allow for adequate expansion.¹¹
- The degree of muscle coverage of the expander is dependent on the extent of pectoralis major muscle absence.
 - Partial superior coverage will be achievable in some patients.
 - Subglandular or subcutaneous placement is necessary when the pectoralis major muscle is notably hypoplastic or fully absent.
- Expansion is performed as necessary, followed by permanent implant placement, similar to breast reconstruction.
 - This technique can be performed in stages separated by many years.
 - The tissue expander can be placed early to allow for gradual expansion as the contralateral breast grows, prior to permanent implant placement.

■ Latissimus Dorsi Muscle Transfer

- Most often, a skin paddle is not required and, as such, a single incision can be used.

- A dorsal incision above the lateral border of the latissimus dorsi muscle, approximately 6 to 10 cm long, is one option to gain access to the muscle^{12,13} (see **TECH FIG 1A,B**).
- An endoscope can also be used to gain access to the muscle with a single, 5- to 6-cm incision placed within the axilla⁷ (**TECH FIG 1C**).
- The skin/soft tissue is elevated off of the fascia overlying the latissimus muscle to expose the borders of the entire muscle. The muscle is divided distally and the fascial and muscular attachments to the chest wall are divided, elevating the muscle toward the axilla^{12,13} (see **TECH FIG 1**).



TECH FIG 1 • **A.** Traditional open approach to latissimus dorsi muscle harvest with the patient positioned in a lateral decubitus with the ipsilateral arm extended at 90 degrees on an operative armrest. **B.** Surgical scar created after a traditional, open harvest of the latissimus dorsi muscle for Poland syndrome reconstruction. **C.** Endoscopic approach with the patient in a supine position and the ipsilateral arm extended at 90 degrees allowing for a 5- to 6-cm incision placed within the apex of the axilla.

- The ipsilateral chest skin is undermined through the axillary incision or through a periareolar approach.
- The chest and previous axillary dissection planes are then joined.
- The mobilized latissimus dorsi muscle is then transferred.
- Release the insertion of the latissimus dorsi muscle and suture it anteriorly near the bicipital groove, on the humerus, to recreate the anterior axillary fold.
- The origin, lumbosacral fascia, is affixed to the lateral border of the sternum.

- Care must be taken to preserve the innervation to minimize the amount of muscle atrophy over time.

■ Customized Chest Wall Implants

- The entire operation, with implantation, can be performed through a single 4-cm incision.
- A malleable custom silicone chest wall prosthesis is positioned using endoscopic techniques (**TECH FIG 2**).



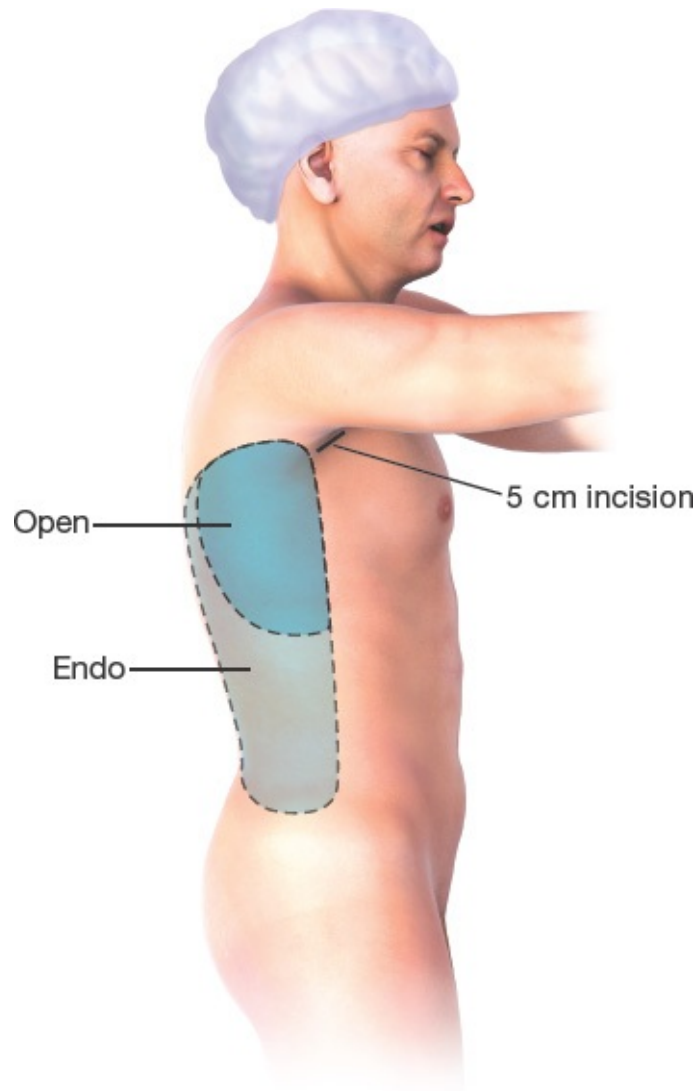
TECH FIG 2 • Customized chest wall implant insertion using the endoscopic approach with a single 4-cm incision.

■ Endoscopic Approach

- First stage⁷:
 - The patient is positioned supine, and a 5- to 6-cm incision is placed in the apex of the axilla (see **TECH FIG 1C**).
 - The dissection is performed in the subcutaneous plane to expose the border of the clavicular head of the pectoralis major muscle.
 - A 10-mm, 30-degree endoscope is attached to an endoretractor and placed within the dissected pocket to extend it medially to the sternum and inferiorly to the proposed inframammary fold.
 - Once this pocket is developed, a tissue expander is then placed.
- Second stage occurs once the tissue expander is expanded to its desired

volume and the patient has reached his or her full developmental maturity.⁷

- Performed in the lateral decubitus position.
- The same 5- to 6-cm incision is used for the harvest of the latissimus dorsi muscle.
- The 10-mm, 30-degree endoscope is inserted to complete the superficial and deep dissection of the latissimus dorsi muscle as previously described (**TECH FIG 3**).
- With the thoracodorsal neurovascular pedicle directly visualized, the origin and insertion of the muscle are divided.
- The patient is then repositioned supine, and the anterior dissection is performed to regain access to the tissue expander.
- The tissue expander is removed and the latissimus dorsi muscle is transferred into the anterior pocket and sutured into place.
 - The lumbosacral fascia is affixed to the sternum and along the new position of the inframammary fold.
 - The former lateral border of the latissimus dorsi muscle is secured to the inferior border of the clavicular head of the pectoralis major muscle.



TECH FIG 3 • Two-stage endoscopic approach using a 5-cm axillary incision. The initial dissection is performed under direct, open, visualization. The subsequent dissection is performed under endoscopic visualization for muscle harvest.

- The insertion of the latissimus dorsi muscle is attached anteriorly to the bicipital groove of the humerus.
 - A breast implant can then be positioned deep to the latissimus dorsi muscle.
-

PEARLS AND PITFALLS

Hemostasis	■ Maintain adequate hemostasis to avoid hematomas that may subsequently become infected causing removal of implants.
Latissimus dorsi muscle transfer	■ Avoid dissecting under the teres major at the inferior angle of the scapula. ■ Maintain visualization of the thoracodorsal pedicle during the endoscopic harvest of the latissimus dorsi muscle to avoid injury to the pedicle. ■ Perform dissection of the vascular pedicle under direct visualization in the axilla to permit safe mobilization of the latissimus dorsi muscle.
Tissue expander and implant	■ Score the deep surface of the breast parenchyma to allow complete expansion of the breast.
Customized chest implants	■ Paying special attention to “feathering” of the implant’s border during design and fabrication of the implant can hide visible, palpable edges (FIG 4). ■ Fat grafting during implantation can also help reduce visible and palpable edges. ■ Fat grafting can also be done secondarily to correct visible and palpable edges noted postimplantation.
Secondary procedures	■ Often contralateral mammoplasty is needed to maintain symmetry. ■ Nipple-areolar complex reconstruction is occasionally needed. ■ Translocation of the nipple-areolar complex to create symmetry with the contralateral side may be indicated.

POSTOPERATIVE CARE

- Following Poland syndrome reconstruction, standard incisional postoperative care is required.
- For patients who require an implant-based reconstruction, postoperative protocols apply.
 - Perioperative oral antibiotics are commonly given.
 - Closed-suction drains, when placed, are not removed until the output from each drain is less than 30 cc for 2 consecutive days.

OUTCOMES

- The goals for reconstruction of the female patient are to achieve breast symmetry, recreate the anterior axillary fold, and provide adequate infraclavicular fullness.
- These goals are successfully achieved with any of the aforementioned reconstructive options.
- To optimize breast symmetry, female patients most often request a contralateral mastopexy and/or reduction.
- Seyfer et al.¹⁴ performed 57 operations on 29 women and incurred no revision operations when they performed the latissimus dorsi transfer in conjunction with breast implant. Most complications seen were due to the breast implant itself. Capsular contractures were revised using open capsulotomies.¹⁴
- The general goal for reconstruction of the male patient is to achieve symmetric chest wall contour (**FIG 4**).
- As in their female counterpart, the latissimus dorsi transfer had better overall outcomes.³
- When performed as an isolated procedure, the latissimus dorsi muscle transfer is prone to undercorrect the deformity; however, fat grafting can be used as an adjunctive procedure to improve symmetry over time.
- The reconstructive results for Poland syndrome tend to be long-lasting, accompanied by high patient satisfaction.³

COMPLICATIONS

- Complications of Poland syndrome reconstruction include seroma, hematoma, infection, scar, delayed wound healing, and pain/paresthesias.
- Seroma formation was most often seen after the removal of the closed-suction drains in the latissimus dorsi transfer donor site.¹⁴
- However, as in the Seyfer et al.¹⁴ study, these seromas are typically small and treated conservatively until they resolve on their own.
- Long-term complications can occur with implant-based reconstruction and are manifested predominantly by capsular contracture and implant rupture.^{3,14}
- Progressive asymmetries can also become apparent over time due to discordant amount of breast tissue and differences in the skin envelope.
- Implant infection and malposition may also occur.

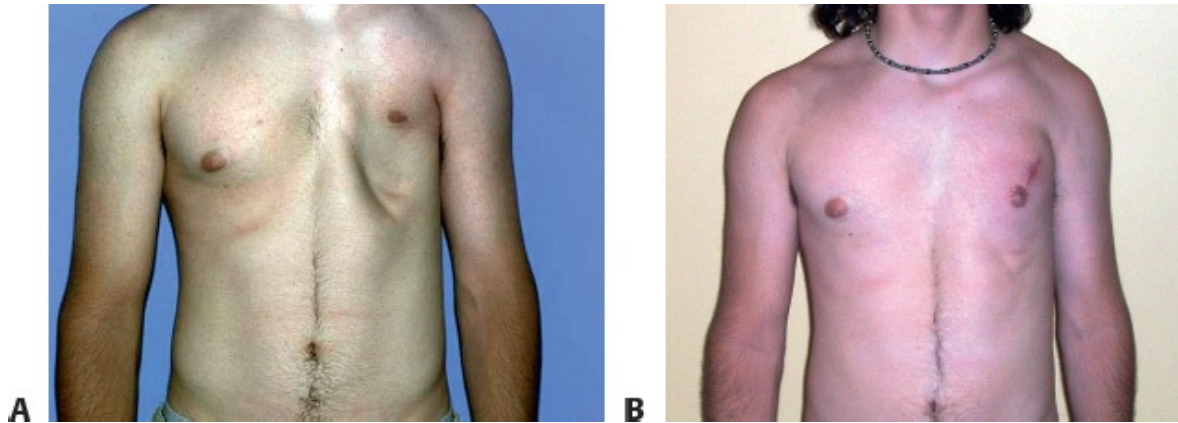


FIG 4 • Left Poland Syndrome. **A.** Preoperative. **B.** Four years postoperative using a customized chest wall implant reconstruction with a “feathering” technique to camouflage the edges of the implant.

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CHAPTER Gynecomastia

Dennis Hammond and Eric Yu Kit Li

DEFINITION

- Gynecomastia involves the abnormal proliferation of glandular breast tissue in men, resulting in breast enlargement.^{1,2}
- It is distinguished from pseudogynecomastia or lipomastia, which is characterized by fatty deposition without glandular development.

ANATOMY

- In healthy patients, the male breast resembles that of a prepubescent female.
- Fat is the predominant tissue and lobules are absent, in contrast to ductal and lobular development in females (**FIG 1**).
- The ideal male breast is also flat, to accentuate the contour of the underlying pectoralis major muscle.
- The arterial supply, venous drainage, lymphatic drainage, and sensory supply mimic those of the female breast.
- Although there is general consensus on the ideal size, shape, and location of the nipple-areolar complex (NAC) in women, this subject has been less extensively studied in men.
- Various authors have published equations to calculate the ideal NAC on the male torso, often as a function of measurements such as patient height and chest circumference.³⁻⁸
- Some general themes exist among the various formulas, in that the ideal male NAC is
 - Slightly oval (horizontal greater than vertical)
 - Smaller (with diameter lesser than 3 cm)

- Positioned around the 4th or 5th intercostal space
- Recent studies have characterized the shape of gynecomastia specimens as having a head, body, and tail^{9,10} (**FIG 2**).
 - The head is semicircular in shape and extends toward the midline.
 - The body is located directly underneath the NAC and intimately attached to it.
 - The tail tapers off and extends toward the axilla.
 - Awareness of this shape may help guide intraoperative dissection.

PATHOGENESIS

- Gynecomastia occurs due to a hormonal imbalance between the level or action of estrogens and androgens.^{1,2}
 - Estrogens stimulate breast development, whereas androgens inhibit it.
- Causes of this imbalance may be idiopathic, physiologic, pharmacologic, or pathologic.¹¹

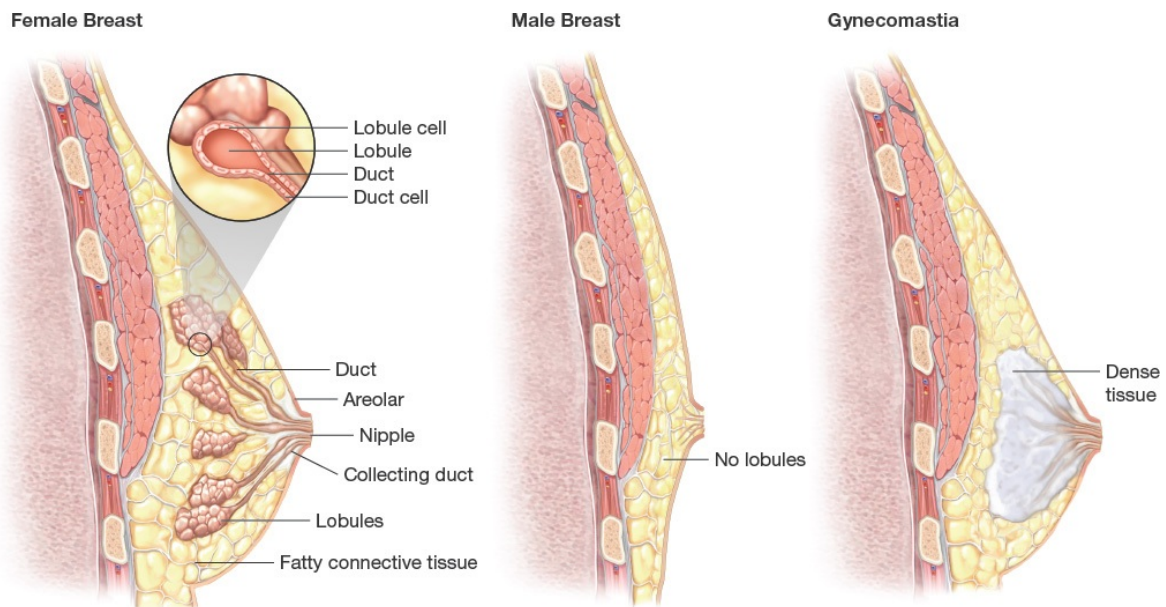


FIG 1 • In the normal male breast, fat is the predominant tissue and lobules are absent. This is in contrast to the developed female breast, which features lobules and ducts.

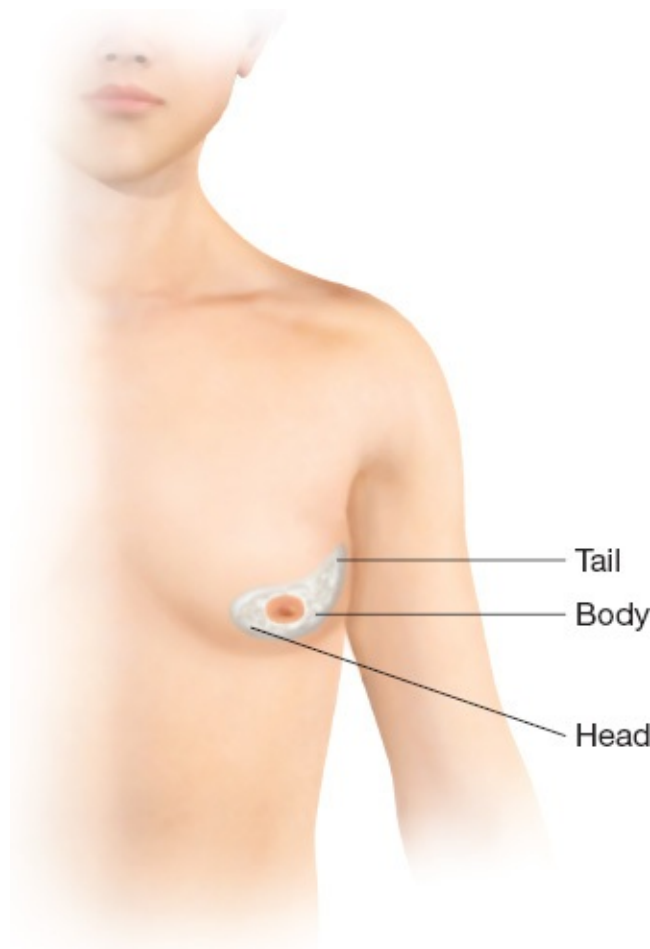


FIG 2 • A typical gynecomastia specimen with head, body, and tail sections.

- Obesity is also strongly associated with gynecomastia, due to increased levels of circulating estrogens from peripheral aromatization of androgens in adipose tissue.¹
- Histopathologically, early-stage gynecomastia is characterized by ductal proliferation with loose stromal tissue (florid type).¹²
- Over time, generally over the course of a year, the stromal tissue undergoes fibrosis (fibrotic type).¹²
- Gynecomastia that has undergone fibrosis is unlikely to be responsive to medical treatment.

NATURAL HISTORY^{1,2}

- Physiologic gynecomastia (**FIG 3A–C**)

- Often seen in newborns, adolescents, and older men
- Adolescent gynecomastia:
 - May begin as early as age 12
 - Can occur in up to 65% of adolescent boys¹³
 - Breast enlargement typically lasts 6 to 12 months.
 - Ninety percent of cases spontaneously resolve without treatment.¹⁴
 - Generally, presents as a subareolar, firm, concentric, fibrous mass with surrounding fibrofatty tissue that is proportional to the body habitus of the patient
- Senescent gynecomastia (**FIG 3D**):
 - Can occur in up to 65% of men over 65 years of age¹⁵
 - Generally presents as diffuse fibrofatty tissue that gradually enlarges over time
- Pathologic gynecomastia
 - Can occur at any age, related to a tumor or medical condition (eg, liver or kidney disease)
 - There may be a history of rapid eccentric growth, nipple discharge, skin changes, or constitutional symptoms.¹²
- Pharmacologic gynecomastia
 - Can occur at any age, related to a drug exposure.
 - Generally presents as a subareolar, firm, concentric, mass.
 - If the mass is not fibrotic, stopping the offending medication may resolve the condition.
 - If the mass is fibrotic, stopping the offending medication may halt progression of gynecomastia, but it is unlikely to reduce the breast enlargement already present.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with the suspected diagnosis should be evaluated for both signs and symptoms related to the abnormal breast growth.
- A detailed history should inquire about:
 - The onset and velocity of breast growth
 - The onset of puberty and ongoing pubertal development (if applicable)
 - Any tendency for spontaneous resolution of the breast hypertrophy
 - Associated symptoms, including pain, tenderness, weight loss, night sweats, and general malaise

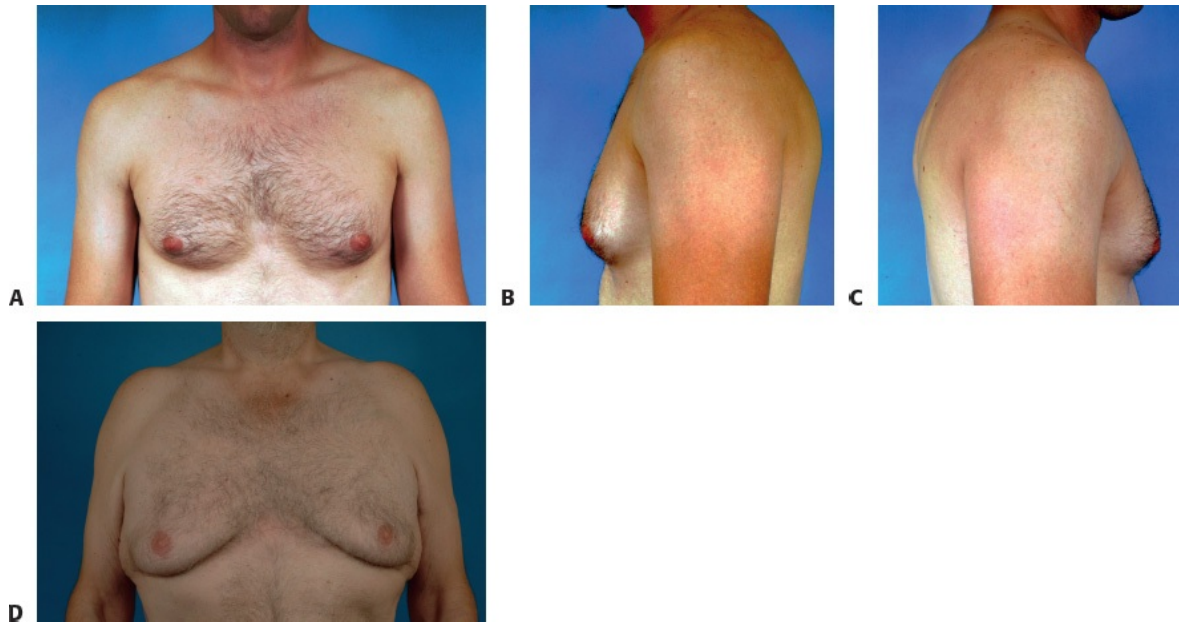


FIG 3 • A–C. Frontal and lateral views of a 24-year-old man who presented with bilateral physiologic gynecomastia. Both sides were characterized by a subareolar fibrous mass and surrounding fibrofatty tissues. **D.** Frontal view of a 52-year-old man who presented with bilateral senescent gynecomastia with skin excess and NAC ptosis. Both sides were characterized by diffuse fibrofatty tissues.

- Any social, vocational, or avocational dysfunction due to the breast enlargement
- The effect of the breasts on the patient's psychological well-being and self-esteem
- Any personal or family history of breast cancer or disorders
- Medication history, especially recreational and off-the-counter drugs (eg, marijuana and exogenous steroids)
- Symptoms suggestive of underlying thyroid, liver, or kidney disease
- A detailed physical should examine
 - The patient's height, weight, and body mass index
 - For the development of secondary sexual characteristics (if applicable)
 - For the presence of a subareolar mass and its area of involvement
 - For the presence of fibrofatty tissue and its area of involvement

- For other masses, irregularities, or deformities involving the breasts or chest wall
- Overall breast aesthetics, including the shape, size, and symmetry of the breasts and NACs, the degree of ptosis, excess skin, and the position and symmetry of the inframammary folds (IMFs)
- Standard breast measurements to highlight asymmetries, including the sternal notch to nipple, midclavicular to nipple, nipple to midline, and nipple to IMF distances
- The patient's neck, abdomen, and testicles for any masses or irregularities

IMAGING

- Imaging is not typically required if the history and physical examination are consistent with physiologic gynecomastia.
- In suspected cases of pathologic gynecomastia, appropriate imaging (mammogram, ultrasound, etc.) should be carried out based on the identified or suspected abnormalities.

DIFFERENTIAL DIAGNOSIS

- Idiopathic gynecomastia
- Physiologic gynecomastia
- Pseudogynecomastia or lipomastia
- Benign breast tumors (eg, fibroadenoma, giant fibroadenoma, phyllodes tumor, lipoma, or cysts)
- Malignant breast tumors (eg, ductal or lobular carcinoma, lymphoma, or metastases)

NONOPERATIVE MANAGEMENT

- Patient reassurance is the foremost treatment in adolescent gynecomastia.
 - About 90% of adolescent cases spontaneously resolve, so no treatment may be needed at all.¹⁴
 - Treatment is indicated when gynecomastia has persisted for more than 2 years, or if there are overriding functional, medical, or psychosocial concerns that warrant earlier intervention.¹⁶
- In gynecomastia related to reversible etiologies, the offending medication should be stopped or the underlying condition treated as soon as possible.
- Weight loss through dietary restriction and exercise are important first-line treatments in any gynecomastia related to obesity.

- Pharmacologic therapies, including danazol, tamoxifen, and anastrozole, may be effective in preventing or treating early-stage gynecomastia but are less effective once breast tissues undergo fibrosis.²
 - Of these medications, tamoxifen is most widely used, but there are no clear guidelines on the ideal dose or duration.
 - All medications also have unfavorable side effects that must be considered.
- If pathologic gynecomastia is suspected, patients should be urgently referred to the appropriate specialist(s).

SURGICAL MANAGEMENT

- Surgical treatment is indicated when gynecomastia is persistent or causes functional or aesthetic concerns.
- Options include liposuction, excision of the subareolar fibrous tissue, or a combination of the two.
- In patients with significant breast enlargement with skin excess and ptosis, mastopexy may be incorporated as well.
- Although weight loss should be the first-line strategy in any obese patient with gynecomastia, it is still reasonable to proceed with surgery in obese patients since normalizing the chest wall contour may allow the patient to lead a more active lifestyle.¹⁶
- Whether resected gynecomastia tissues should be routinely sent for histopathological examination is debatable.
 - The likely risk of finding occult malignancy in gynecomastia specimens is less than 0.01%.^{12,17}
 - Of note, the College of American Pathologists does not specifically require the use of cancer protocols for gynecomastia, nor do they offer any formal guidelines for the examination of gynecomastia tissue.

Preoperative Planning

- The patient is seen preoperatively 1 to 3 days before surgery to achieve several objectives:
 - To review the procedure in detail, and revisit goals and expectations of surgery with the patient
 - To complete all perioperative paperwork, including orders, prescriptions, and instruction sheets
 - To mark the patient in an unrushed, quiet, and controlled environment
 - To obtain preoperative photographs of the marked patient

- For all procedures, the patient is marked in a standing position with arms at the sides.
 - Preoperative markings are done with a variety of colored markers.
- A laser leveler can be used to confirm the horizontal plane across the chest.
- Preoperative photographs serve several functions:
 - They document the surgical plan electronically.
 - They can be brought to the operating room to guide intraoperative decision-making.
 - They can be compared to postoperative photographs to critically appraise surgical technique and final results.
 - They can be used to educate patients in the preoperative and postoperative settings.
- Photographs, at the minimum, should capture three standard views of the breasts including the front and each side.
 - Supplemental views, including ¾s, hands over head, and with breasts lifted by the patient, can also be taken.
 - Patients should be framed from the top of the shoulders to midway between the breast and umbilicus, with the width extending just outside the arms.

Positioning

- The patient is positioned supine on an operating room table that is capable of sitting up 90 degrees.
 - This positioning will allow the patient to be placed upright intraoperatively and the chest to be evaluated in the sitting position, which may guide intraoperative decision-making.
- The patient's head is positioned at the top of the table, supported by a foam headrest.
- The patient's arms are placed on arm boards and secured to allow safe upright positioning of the patient.
 - Arm boards are placed at the shoulder level.
 - Foam pads are placed between the arm and arm boards.
 - The arm is then secured to both with a soft towel followed by a gentle circumferential wrap of gauze, which runs from the axilla to the hand to provide a uniform layer of support.
- The patient's knees are elevated with a pillow to relieve pressure on the back while the patient is upright, and the patient's heels are supported with foam

pads.

- A heated air-warming device is placed on the lower body.
- The area from the top of the shoulders to midway between the inferior pole of the breast and umbilicus is prepped and draped to allow full visualization of the shoulders, chest, and breasts during surgery.

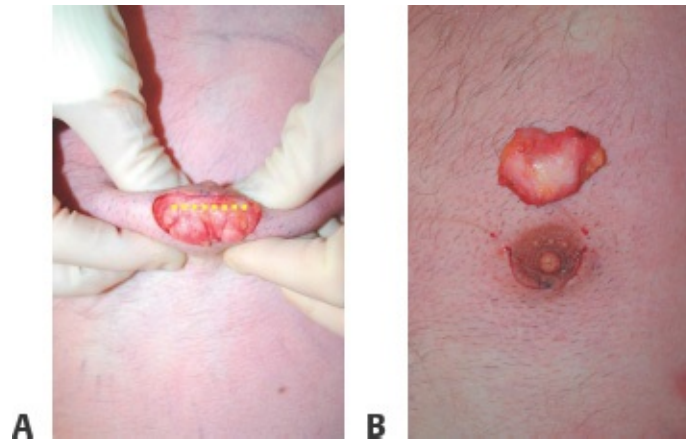
Approach

- All surgical techniques can be performed under local anesthesia, intravenous sedation, or general anesthesia.
- Development of a surgical plan is based on the need to address two issues.¹⁶
 - How to best remove the excess volume
 - When and how to best remove the excess skin
- Volume reduction techniques:
 - Direct glandular excision is performed when gynecomastia presents as an isolated subareolar fibrous mass.
 - Liposuction is performed when gynecomastia presents largely as a diffuse accumulation of fibrofatty tissue.
 - When both a subareolar fibrous mass and diffuse fibrofatty tissue are present, both direct excision and liposuction techniques are used to effectively recontour the chest wall.
- Skin reduction techniques:
 - In general, most patients do not require skin envelope excision after volume reduction, because the propensity of the chest wall skin to retract is significant, especially in younger patients.
 - Only in cases of significant skin excess or laxity is a skin-reducing procedure required.
 - Small localized areas of skin excess can be directly treated with skin excision.
 - Small reductions in the skin envelope or ptotic NACs can be treated with periareolar mastopexies.
 - Large reductions in the skin envelope or extremely ptotic NACs can be treated with circumvertical mastopexies.

TECHNIQUES

■ Direct Excision

- Landmarks:
 - The patient is marked in a standing position with arms at the sides.
 - The subareolar mass underneath the NAC is palpated and outlined with a surgical marker.
 - The planned incision on the inferior areolar border is marked.
- The planned incision on the inferior areolar border is first infiltrated with local anesthetic.
- Local anesthetic is also injected deep to the NAC and in the subcutaneous tissues overlying the fibrous mass.
 - In this fashion, the plane between the subcutaneous and glandular tissues is intentionally hydrodissected to facilitate later dissection with cautery.
- Using a no. 15 blade, the periareolar incision is made through the deep dermis.
- A Senn retractor is then placed on the dermal edge, upward traction is applied, and the plane between the deep dermis and glandular tissue is carefully dissected with monopolar cautery (**TECH FIG 1A**).
- The dissection is performed both medial and lateral to the area underneath the nipple first (where a true plane exists) and then joined in the middle transecting the ducts (where no true plane exists).
 - Care is taken to ensure that the NAC maintains a uniform thickness of 5 to 10 mm.
- Once beyond the boundaries of the NAC, the dissection is continued with monopolar cautery in the plane between the subcutaneous and glandular tissues, peripherally in all directions.
 - It is important to stay in this plane to preserve the overlying subcutaneous fat and maintain an even contour to the breast skin flaps.
- Once the fibrous mass is freed to its peripheral margins, it is elevated from the pectoralis major fascia.
 - Extra care is taken to avoid violating the fascia.
 - If possible, leave a bed of fat above the fascia to avoid a “saucer” contour deformity deep to the NAC.



TECH FIG 1 • A. The plane between the dermis and glandular tissues. **B.** The completed inferior areolar closure. The gynecomastia specimen is shown above.

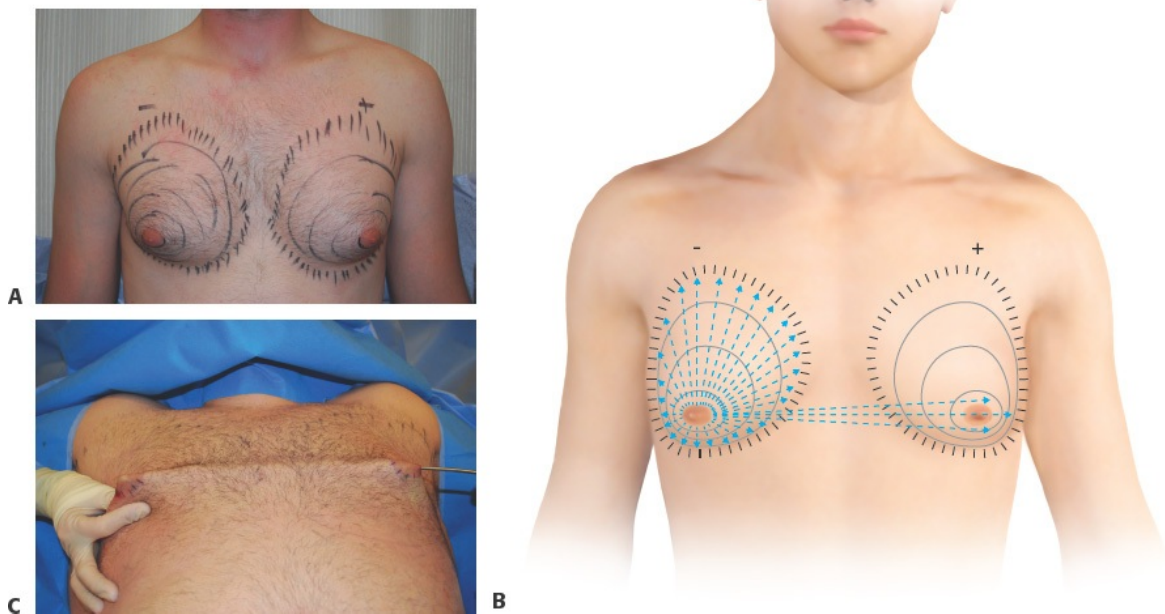
- After the fibrous tissue is removed, the chest wall is carefully palpated and inspected for any remaining contour irregularities.
 - Further scissor dissection or cautery excision can be done at this point to feather the peripheral contours and excise any remaining glandular tissue.
- The dissected space is irrigated with normal saline and hemostasis checked.
- The wound layers are closed with 4-0 Monocryl (Ethicon Inc., Somerville, NJ, USA) or equivalent absorbable monofilament dermal interrupted suture, followed by a 3-0 Stratafix (Ethicon Inc., Somerville, NJ, USA) or equivalent absorbable barbed subcuticular suture (**TECH FIG 1B**).
- Dermabond (Ethicon Inc., Somerville, NJ, USA) is lastly applied to the skin incision.

■ Liposuction

- Landmarks:
 - The patient is marked in a standing position with arms at the sides.
 - The fibrofatty issues surrounding the breast are palpated and outlined for liposuction (**TECH FIG 2A**).
 - The planned access incisions for liposuction are marked at the lower border of the NAC and/or along the lateral aspect of the IMF.
 - The planned incisions are infiltrated with local anesthetic.
 - Wetting solution is next infiltrated deep to the NAC and in the surrounding

areas of fibrofatty tissue.

- Typical wetting solution consists of 40 to 60 mL of 1% lidocaine with 1 amp of Epi added to 1 L of NS.
- Fluid is added to each breast until the tissue consistency is firm.
- After allowing time for the wetting solution to take effect, standard liposuction is performed (**TECH FIG 2B**).
- A 3- to 4-mm cannula is used by the author.
- Care is taken to feather the boundaries of the marked areas.
- In bilateral cases, the access incision on the opposite NAC can be used and the cannula passed across the midline to liposuction the subareolar area (**TECH FIG 2C**).
- Underneath the NAC, external pinching compression with the opposite hand is used to drive the dense subareolar fat into the cannula.
- In breasts with a well-defined IMF, the cannula can be used to discontinuously undermine it and soften it.
- All wounds are closed with dermal 4-0 Monocryl (Ethicon Inc., Somerville, NJ, USA) or equivalent absorbable monofilament dermal interrupted suture, and Dermabond (Ethicon Inc., Somerville, NJ, USA) is applied to the skin.



TECH FIG 2 • A. Preoperative markings of the

fibrofatty tissue surrounding the breast and the planned area of liposuction. **B.** The path of the liposuction cannula to reach all areas of the breast. In bilateral cases, the NAC access incision can be used to pass the cannula across the midline to liposuction the opposite subareolar area. **C.** The liposuction cannula is shown passing through the NAC access incision and across the midline to reach the opposite subareolar area.

■ Combination Technique

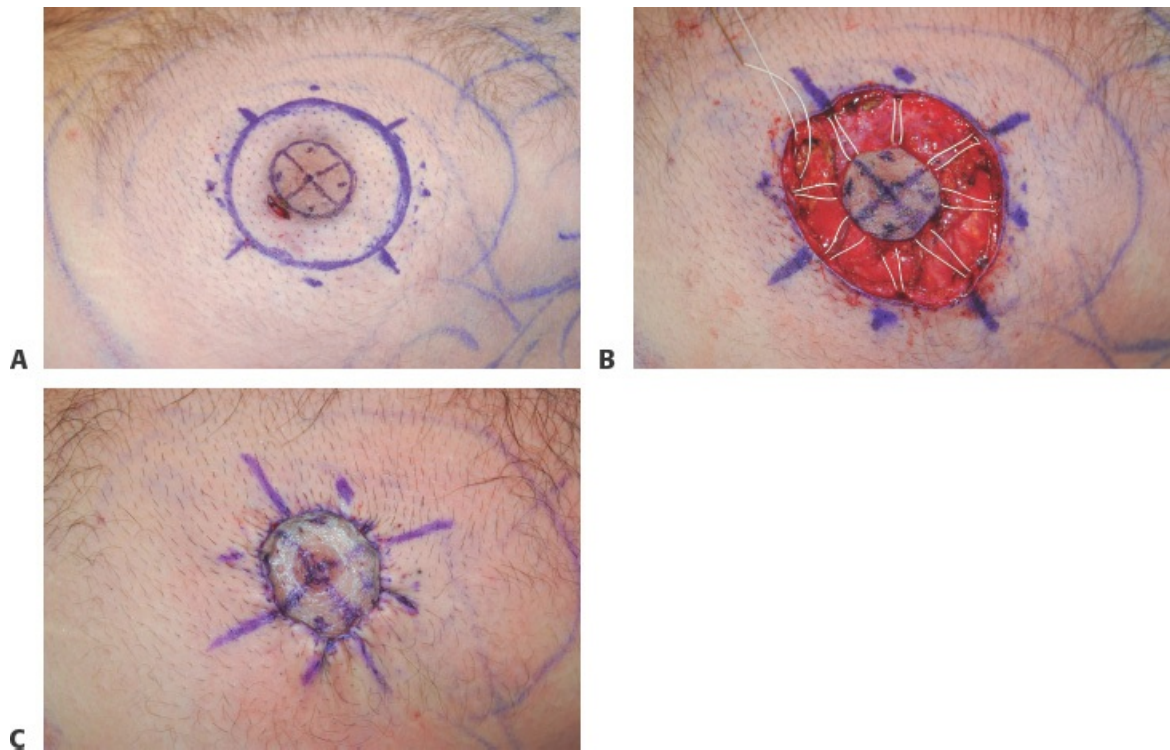
- Landmarks:
 - The patient is marked in a standing position with arms at the sides.
 - The subareolar mass underneath the NAC is palpated and outlined with a surgical marker.
 - The fibrofatty issues surrounding the breast are palpated and outlined for liposuction.
 - The planned incisions on the inferior areolar border and/or the lateral aspect of the IMF are marked.
- The planned incisions on the inferior areolar border and lateral IMF are first infiltrated with local anesthetic.
- Local anesthetic is also injected deep to the NAC and in the subcutaneous tissue overlying the fibrous mass.
- Wetting solution is then infiltrated into the surrounding areas of the fibrofatty tissue until the breast is firm.
- After allowing time for the wetting solution to take effect, liposuction is then performed using a 3- to 4-mm cannula, as described above.
- Once no further liposuction can be performed, the mass effect of the remaining fibrous portion is assessed.
- If there remains a persistent and protuberant fibrous mass, the inferior areolar border is incised and the glandular tissue excised via direct excision, based on the technique as described above.

■ Periareolar Skin Reduction

■ Landmarks:

- The patient is marked in a standing position with arms at the sides.
- The midsternal line, IMF, and lateral breast contour are marked.
- The top of the periareolar incision is drawn, and symmetry on both sides is confirmed with a laser leveler.
 - The author typically positions the new NAC 2 to 3 cm above the existing IMF.
- A circular pattern is next drawn around the NAC (**TECH FIG 3A**).
- Under maximum stretch, the NAC is outlined with a nipple marker with a maximum diameter of 3 cm.
- Local anesthetic is injected in the deep dermis of the periareolar pattern.
- Wetting solution is also infiltrated deep to the NAC and in the surrounding areas of fibrofatty tissue.
- Liposuction and/or direct excision is first carried out, as described above.
- The breast is accessed through an incision on the caudal portion of the periareolar pattern.
- The NAC is incised to the deep dermis, and the previously marked periareolar pattern preliminarily stapled.
- The patient is then placed upright to visualize the resultant breast shape, and the staple line is adjusted as needed to create the desired chest contour and NAC elevation.
- After the staple line is deemed satisfactory, the patient is returned supine.
- The staple line is marked with a surgical marker, and the staples are removed.
- The intervening skin within the periareolar pattern is then de-epithelialized.
- Typically, the periareolar dermis is minimally incised or not incised at all to maintain the subdermal plexus that supplies the NAC.
- The dermis may be incised, however, in staged scenarios in which the NAC has secondarily revascularized via its wound base.
- The periareolar defect is lastly closed using a periareolar purse-string technique.¹⁸
 - Eight evenly spaced cardinal points are marked on the areola and periareolar incision.
- A 2-0 Cytoplast (Surgiform Technologies Ltd., Columbia, SC, USA) or

equivalent polytetrafluoroethylene (PTFE) suture on a straight needle is selected.



TECH FIG 3 • A. A circular pattern is drawn around the NAC to outline the periareolar pattern. **B.** Appearance of the periareolar pattern after weaving of the purse-string suture. **C.** The completed periareolar closure.

- The suture is then passed, from deep to superficial, starting on the medial dermal shelf of the periareolar incision, through the corresponding cardinal point on the dermis of the areola, inserted back into the outer dermal shelf, and then passed through the periareolar dermis to the next cardinal point.
- This weaving is continued until the suture has weaved completely around the periareolar defect, culminating in the appearance of a wagon wheel (**TECH FIG 3B**).
- The free suture ends are then tightened to cinch the periareolar incision down to match the diameter of the areola, followed by placement of 8 to 10 square knots to secure the suture.

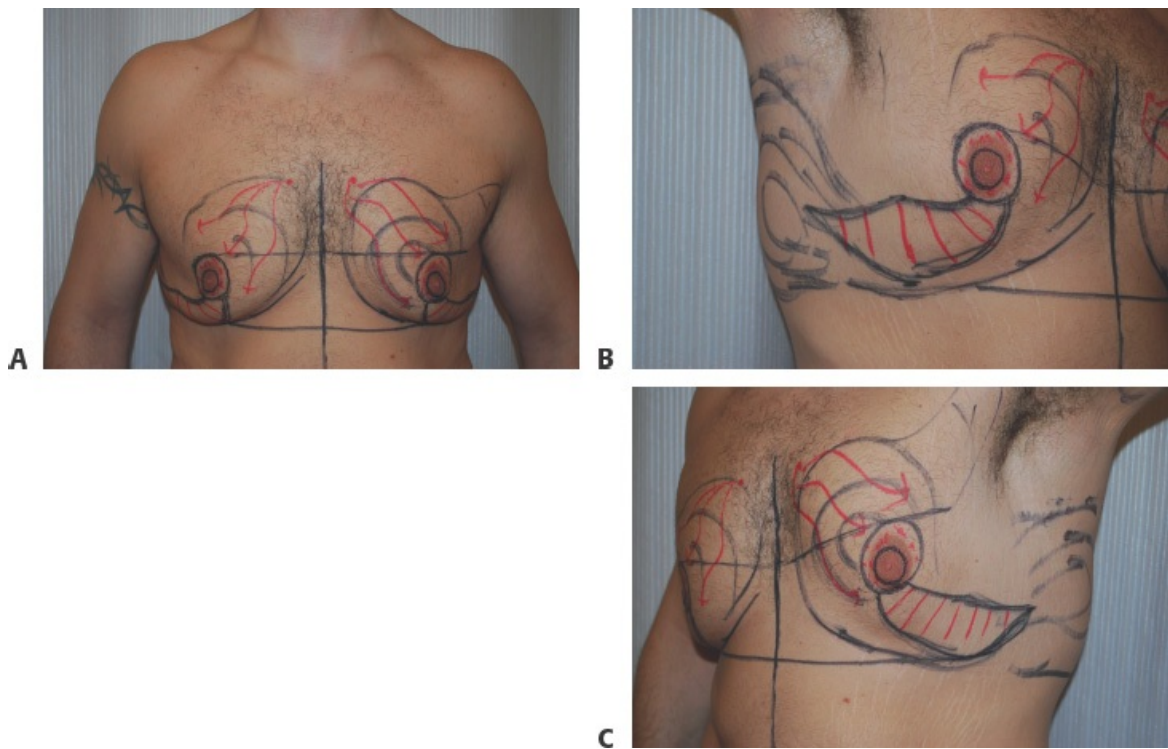
- The knot complex is placed underneath the medial dermal shelf, and the periareolar closure is completed with 3-0 Stratafix or equivalent absorbable barbed suture (Ethicon Inc., Somerville, NJ, USA) (**TECH FIG 3C**).

■ Circumvertical Skin Reduction

- Landmarks:
 - The patient is marked in a standing position with arms at the sides.
 - The midsternal line, IMF, and lateral breast contour are marked.
 - The top of the periareolar incision is drawn, and symmetry on both sides is confirmed with a laser leveler.
 - The author typically positions the new NAC 2 to 3 cm above the existing IMF.
 - A circular pattern is next drawn around the NAC, followed by a vertical pattern below the NAC extending in a curvilinear fashion toward the IMF (**TECH FIG 4**).
 - Under maximum stretch, the NAC is outlined with a nipple marker with a maximum diameter of 3 cm.
- Local anesthetic is injected in the deep dermis of the periareolar pattern.
- Wetting solution is also infiltrated deep to the NAC and in the surrounding areas of fibrofatty tissue.
- Liposuction and/or direct excision is first carried out, as described above.
 - The breast is accessed through an incision on the caudal portion of the periareolar pattern.
- The NAC is incised to the deep dermis, and the previously marked circumvertical pattern preliminarily stapled.
- The patient is then placed upright to visualize the resultant breast shape, and the staple line is adjusted as needed to create the desired chest contour and NAC elevation.
- After the staple line is deemed satisfactory, the patient is returned supine.
- The staple line is marked with a surgical marker, and the staples are removed.
- The intervening skin within the periareolar pattern is de-epithelialized, while the intervening skin within the vertical pattern may be de-epithelialized or removed altogether.
 - Typically, the periareolar dermis is minimally incised or not incised at all

to maintain the subdermal plexus that supplies the NAC, but the dermis of the vertical pattern may be incised to gain further access to the breast and/or facilitate flap advancement and closure.¹⁶

- The vertical pattern is closed with 4-0 Monocryl (Ethicon Inc., Somerville, NJ, USA) or equivalent interrupted deep dermal sutures followed by subcuticular closure with 3-0 Stratafix (Ethicon Inc., Somerville, NJ, USA) or equivalent absorbable barbed suture.
- The periareolar defect is closed using the periareolar purse-string technique,¹⁸ as described earlier.



TECH FIG 4 • A-C. Preoperative markings of the planned circumvertical pattern skin reduction.

PEARLS AND PITFALLS

Landmarks

- The top of the NAC is typically positioned 2 to 3 cm above the IMF by the authors. Although other techniques can be used to

calculate the ideal position of the NAC,³⁻⁸ it is ultimately the surgeon's artistic judgment that should prevail. To this end, sitting the patient up intraoperatively and tailor-tacking the periareolar or circumvertical patterns will preview the desired result and NAC position before irreversible incisions are made.

Technique

- Patients with hairy chests are advised to shave preoperatively. This will save time the day of surgery and also allow easier identification of the inferior areolar border for incision placement.
- If there is any doubt whether skin resection is required after volume reduction techniques, stage the mastopexy. Even when skin retraction is insufficient and a second-stage procedure is required, the amount of skin reduction required is usually less than originally thought, and it may be possible to reduce the amount of cutaneous scarring.¹⁶
- In cases of delayed skin envelope reduction, no additional internal dissection is required. As well, the dermal edges of the periareolar and circumvertical patterns can be safely incised at this point to facilitate tension-free closure since the NAC will have adequate secondary revascularization from its wound base.¹⁶
- A common area for persistent skin excess and fatty accumulation, particularly in obese patients, is under the arm along the lateral chest wall. The extra skin in this area can be directly excised to achieve the appropriate chest contour (**FIG 4**).
- In breasts with significant fibrofatty tissue, liposuctioning the breast tissue via various access incisions can be of mechanical advantage and help achieve a more uniform reduction in breast volume. In bilateral cases, it is helpful to use the contralateral breast incisions to liposuction the ipsilateral subareolar area (see **TECH FIG 2C**).
- When elevating the fibrous mass off the chest wall, avoid violating the pectoralis major fascia to minimize postoperative pain, bleeding, and scar tethering deep to the NAC. If possible, leave a thin layer of fat above the fascia to maintain a natural gliding plane and to avoid a “saucer” concave deformity involving the NAC.
- In patients presenting for revision gynecomastia surgery, use small liposuction cannulas to carefully control the amount of liposuction performed and avoid contour irregularities. Particularly in patients who have had only liposuction performed as the primary procedure, it is wise to perform direct excision in revision surgery to eliminate any residual breast bud and avoid further patient dissatisfaction.

Postoperative care

- It may be difficult to find compression dressings designed specifically for men. In our practice, we recommend that patients purchase a sports compression shirt that is a size smaller than the patient's normal size. If the shirt is too uncomfortable for the patient for prolonged use, the arms and bottom portion of the shirt may be trimmed so that the compression is isolated to the chest.

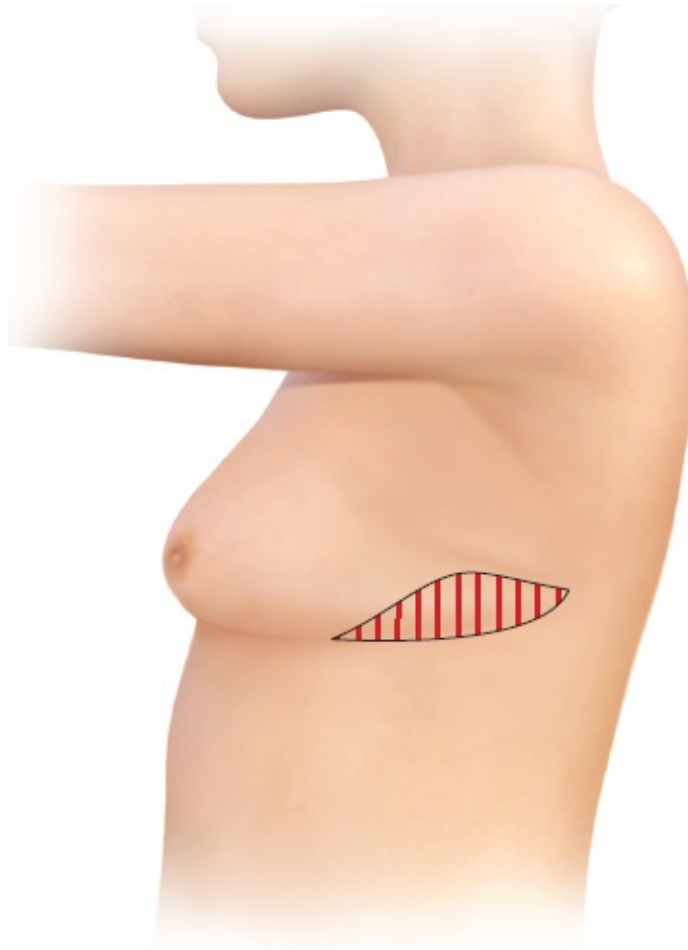


FIG 4 • A common area for persistent skin excess and fatty accumulation is the lateral chest wall.

POSTOPERATIVE CARE

- All incisions are covered with Dermabond; no additional external dressings are required.
- Patients are typically discharged the same day after surgery.
- Drains are usually unnecessary but, if placed, are typically removed at the first

follow-up visit.

- Routine follow-up visits are scheduled at 1 week, 6 weeks, 6 months, and yearly thereafter.
- A sports compression shirt is worn for the first 2 weeks.
- Patient may resume full activities generally 4 to 6 weeks after surgery.

OUTCOMES

- Gynecomastia surgery is generally well tolerated with patient satisfaction rates over 90%^{19–21} (**FIG 5**).
- Most patients benefit from improved emotional comfort, functional capacity, and social acceptance.^{22,23}
- Overall surgical complication rates vary from 5% to 30%, depending on the technique used.^{11,20,23–26}
- Recurrence is possible in incomplete resections or if the offending medication(s) is continued after surgery.
- Recurrence is also more likely in patients with glandular vs fibrofatty gynecomastia.²¹

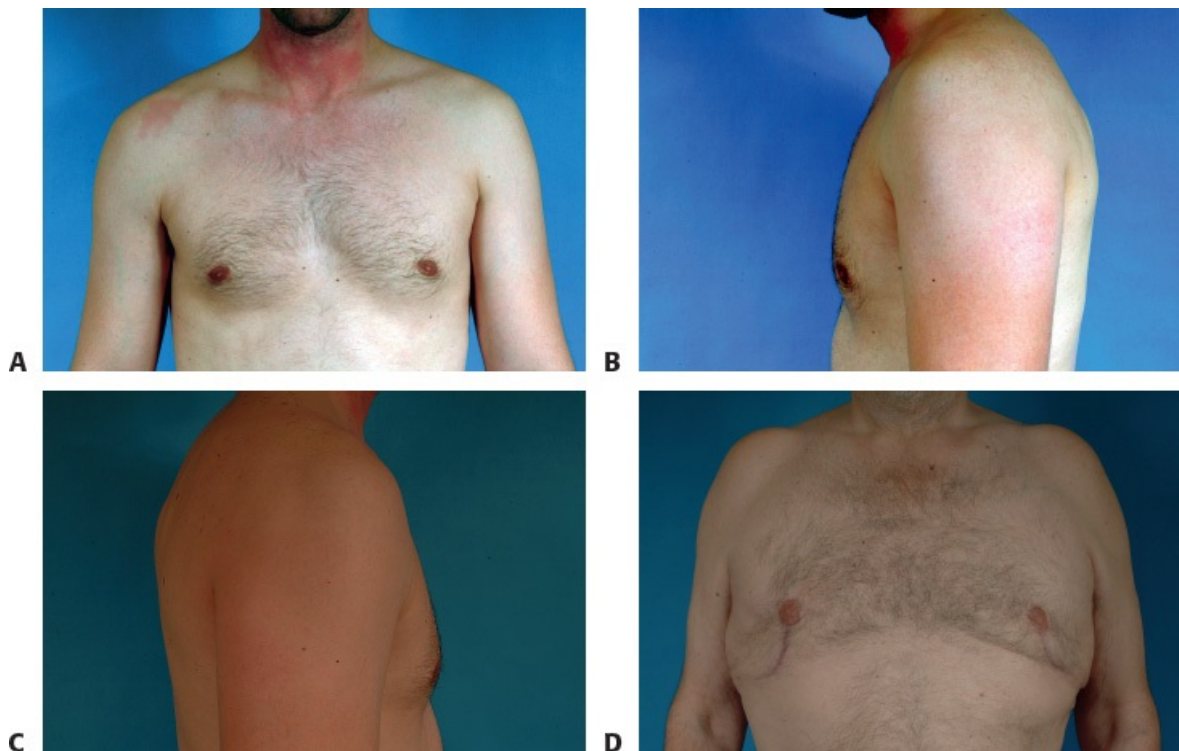


FIG 5 • A–C. 1 year postoperative frontal and lateral

views of the patient in **FIG 3A–C** after combined approach with direct excision and liposuction techniques. Note the improved and more masculine chest contour after surgery, as well as the natural reduction in the size of the NACs after removal of the underlying subareolar masses. **D.** 1 year postoperative frontal view of the patient in **FIG 3D** after liposuction for volume reduction and circumvertical mastopexy for skin reduction. Note the elevated position of the NAC and improved and more masculine chest contour after surgery.

COMPLICATIONS

- Early
 - Hematoma
 - Seroma
 - Infection
 - Delayed wound healing or wound dehiscence
 - NAC necrosis
- Late
 - Adverse scarring
 - Shape change
 - Loss of nipple-areolar complex function (sensation or lactation)
 - Fat necrosis
 - “Saucer” contour deformity to the NAC

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CHAPTER Juvenile Hypertrophy

Dennis Hammond and Eric Yu Kit Li

DEFINITION

- Juvenile or virginal breast hypertrophy is a rare condition characterized by atypical and pronounced breast growth during puberty in the absence of a discrete mass or nodularity.^{1,2}
- The term gigantomastia may be used to describe extreme cases.¹

ANATOMY

- At thelarche, the breast develops into glandular tissue composed of lobules and ducts and supporting stromal tissue.
- Breast development continues until the age of 18 to 20, at which point growth is complete.
- The arterial supply of the breast is derived from numerous sources, including perforators from the internal thoracic, external thoracic, thoracoacromial, and anterior and posterior branches of intercostal arteries.
 - The internal thoracic artery is the dominant source.
 - The blood supply to the nipple-areolar complex (NAC), in particular, is augmented by a rich vascular arcade that travels in a distinct fascial septum known as *Wuringer septum*³ (**FIG 1A**).
 - The arcade takes origin from the thoracoacromial, external thoracic, and intercostal arteries.
 - The septum arises approximately at the level of the 5th rib, dividing the breast into a superior two-thirds and inferior one-third, and courses from the pectoralis major fascia to the NAC (**FIG 1B,C**).
 - Preservation of the septum and its vascular arcade is key to maintaining a robust NAC during pedicle dissection in breast surgery.

- The venous drainage of the breast parallels the arterial supply.
- The lymphatic drainage of the breast is generally to the axillary and internal mammary lymph nodes.
- A variety of sensory nerves innervate the breast, including the anterior and lateral branches of the 2nd through 6th intercostal nerves and supraclavicular nerves.
 - The NAC is predominantly innervated by the lateral branch of the 4th intercostal nerve.
- The breast is enveloped by the Scarpa fascia, which forms anterior and posterior lamellae.
- Cooper ligaments are intraparenchymal fibers, which span both lamellae and confer structural support to the breast.
- The inframammary fold (IMF) is the foundation of the breast and is the point of convergence of the Scarpa fascia of the abdomen inferiorly with the anterior and posterior lamellae of the breast superiorly.⁴
 - The fat layer above the Scarpa fascia is thicker, denser, and more compact than the fat layer below it.
 - Avoidance of downward deforming pressures on the subscapal fatty layer/space, whether by an implant or parenchyma, is key to preventing “bottoming out” of the breast and undesired lowering of the IMF.

PATHOGENESIS

- The exact cause of juvenile hypertrophy is unknown.^{1,2}
- Theories include either increased end-organ sensitivity to normal levels of gonadal hormones or increased levels of gonadal hormones, although previous studies have identified normal hormone levels in juveniles diagnosed with this disease.

NATURAL HISTORY

- Juvenile hypertrophy is characterized by rapid and atypical breast growth during puberty.
- Initial growth over the first 6 months may be extreme, followed by a longer period of slower growth.
- Disease onset can be anytime during puberty, but in most cases, it is shortly after thelarche (ages 9 to 13).
- Involvement can be either unilateral, which is more common, or bilateral.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Juveniles with the suspected diagnosis should be evaluated for both signs and symptoms related to rapid breast growth.
- A detailed history should inquire about:
 - The onset and velocity of breast growth
 - The onset of puberty and ongoing pubertal development
 - Associated symptoms, including headaches; neck, shoulder, or back pain; shoulder grooving from brassiere straps; and skin irritation or intertrigo along the IMF
 - Any social, vocational, or avocational dysfunction due to the hypertrophied breasts
 - The effect of the breasts on the patient's psychological well-being and self-esteem
 - Any personal or family history of breast cancer or disorders
- A detailed physical should examine
 - The patient's height, weight, and body mass index
 - For signs related to hypertrophied breasts, including skin striae or hyperemia, peau d'orange skin, dilated subcutaneous veins, or, in severe cases, tissue necrosis involving the breast
 - For specific masses, irregularities, or deformities involving the breasts or chest wall

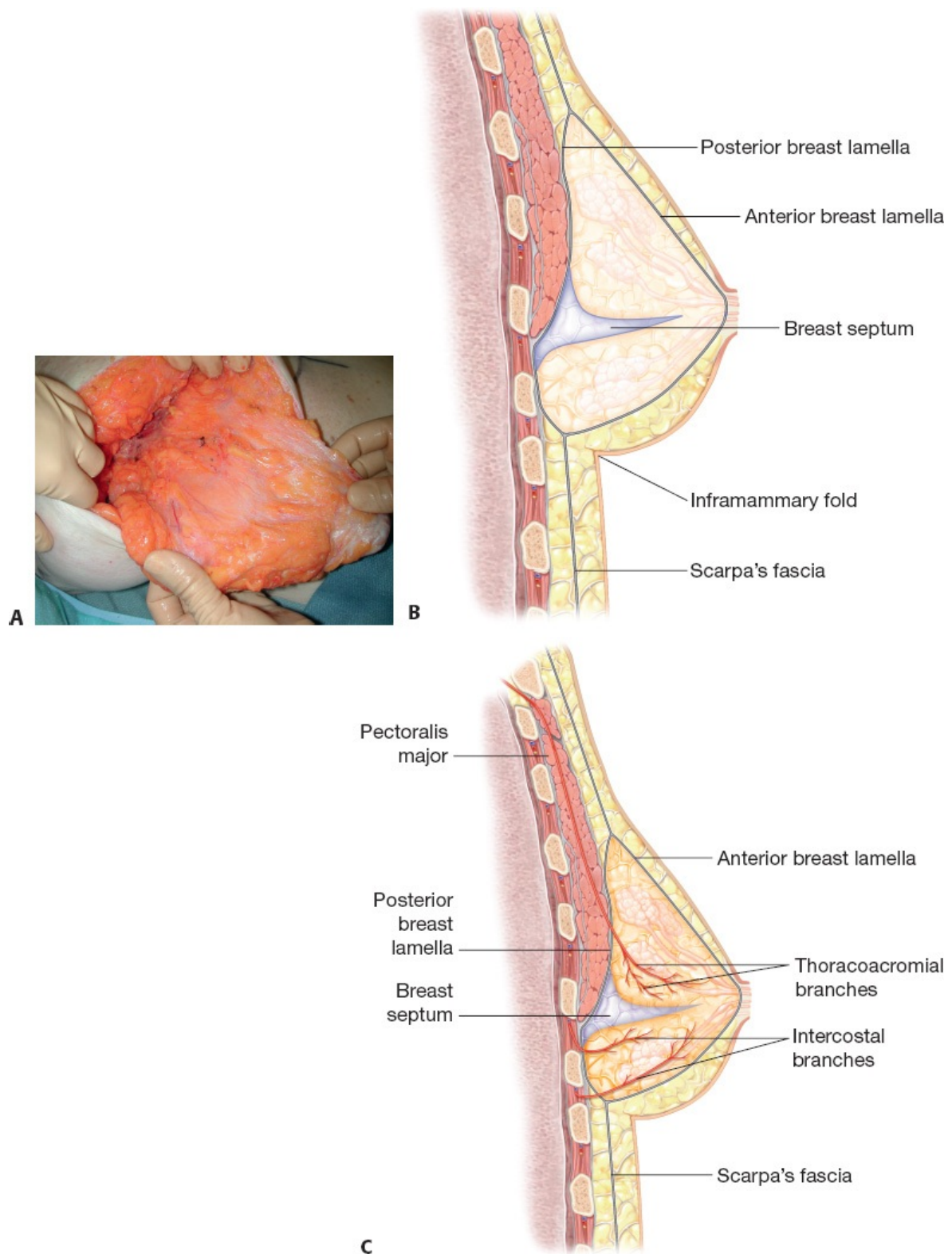


FIG 1 • A. Intraoperative appearance of the Wuringer septum, which is seen as a distinct white fascial layer

during pedicle dissection. **B.** The Wuringer septum is a horizontally oriented fascial condensation that spans from the pectoralis major fascia, at the level of the 5th rib, to the nipple-areolar complex. The septum contains a rich vascular arcade, which receives contributions from thoracoacromial, external thoracic, and intercostal arteries. The septum divides the breast into a superior 2/3rd and inferior 1/3rd. **C.** The IMF is the point of convergence of the Scarpa fascia of the abdomen inferiorly with the anterior and posterior lamellae of the breast superiorly. Wuringer septum is illustrated in the middle of the breast.

- Overall breast aesthetics, including the shape and size of the breasts and NACs, the degree of ptosis, and the position and symmetry of the IMFs
- Standard breast measurements to highlight asymmetries, including the sternal notch to nipple, midclavicular to nipple, nipple to midline, and nipple to IMF distances

IMAGING

- Mammography tends to be of limited value because of the density of the breast tissues in juvenile hypertrophy.
- Ultrasonography or magnetic resonance imaging may be useful in select situations, especially if masses or irregularities are identified on examination and the diagnosis is in question.
- Ultimately, diagnosis of juvenile hypertrophy is often clinical and based on history and examination.²

DIFFERENTIAL DIAGNOSIS⁵

- Physiologic breast hypertrophy (including normal growth or pregnancy-related growth)
- Benign breast tumors (eg, fibroadenoma, giant fibroadenoma, phyllodes tumor, or cysts)
- Malignant breast tumors (eg, ductal or lobular carcinoma, lymphoma, or metastases)

NONOPERATIVE MANAGEMENT

- Pharmacologic therapies, including tamoxifen, dydrogesterone, danazol, and bromocriptine, have been used as both primary treatment options or in combination with surgery, in either a neoadjuvant or adjuvant fashion.⁶
- The safety and efficacy of these therapies are not well established, however, due to the scarcity of reported cases.

SURGICAL MANAGEMENT

- Surgical treatment of juvenile hypertrophy is reduction mammoplasty.
- Surgery is ideally performed once breast size has stabilized for 6 to 12 months, but earlier intervention may be necessary if there are overriding functional, medical, or psychosocial concerns.^{2,7}
- All resected breast tissues should be sent for histopathological examination to rule out breast pathologies.
- Reduction mammoplasties are completed using the short scar periareolar inferior pedicle (SPAIR) technique.^{8,9}
- The SPAIR technique is advantageous over other techniques for numerous reasons:
 - It is versatile and can be used for breast reductions of varying size.
 - Most plastic surgeons have been trained and are comfortable using the inferior pedicle.
 - The circumvertical skin resection pattern minimizes scar burden, creates a more rounded breast shape, and improves breast projection while avoiding wound healing difficulties at the T junction or vertical segments associated with other breast reduction techniques.
 - Lessening the scar burden is a significant priority in young female patients.
 - The breast can be actively shaped with various intraoperative maneuvers to achieve the final desired contour.
 - The IMF is preserved, thus minimizing the risk of long-term “bottoming out” of the breast.

Preoperative Planning

- The patient should be seen preoperatively 1 to 3 days before surgery to achieve several objectives:
 - To review the procedure in detail and revisit goals and expectations of surgery with the patient

- To complete all perioperative paperwork, including orders, prescriptions, and instruction sheets
- To mark the patient in an unrushed, quiet, and controlled environment
- To obtain preoperative photographs of the marked patient
- Preoperative markings can be done with a variety of colored markers, each representing a specific surgical step.
 - The patient is marked in a standing position with arms at the sides.
 - A laser leveler can be used to confirm the horizontal plane across the chest.
 - The midsternal line, IMF, lateral breast contour, and breast meridian are first marked (**FIG 2A**).
 - The IMF is drawn across the chest so that it can be visualized with the breasts at rest (**FIG 2B**).
 - The periareolar pattern is outlined next:
 - The top point is the intersection of a line 2 to 4 cm above the IMF with the breast meridian (**FIG 2C**).
 - The bottom points are the top points of a rectangle, which is drawn 8 cm wide, centered on the breast meridian and arising from the IMF, with a height of 8 to 10 cm (**FIG 2D**).
 - The lateral and medial points are identified by lifting the breast up and outward and up and inward with just enough tension to create a rounded contour and transposing the breast meridian onto the breast (**FIG 2E,F**).
 - The above points are then joined together to create an elongated oval, which outlines the periareolar pattern (**FIG 2G**).
 - The superior aspect of the inferior pedicle is outlined last within the periareolar pattern:
 - The top points of the rectangle are joined with a curved line skirting the areola by 2 cm (**FIG 2H**).
 - The final design of the inferior pedicle thus comprises the area encompassed by the rectangle and the curved line.

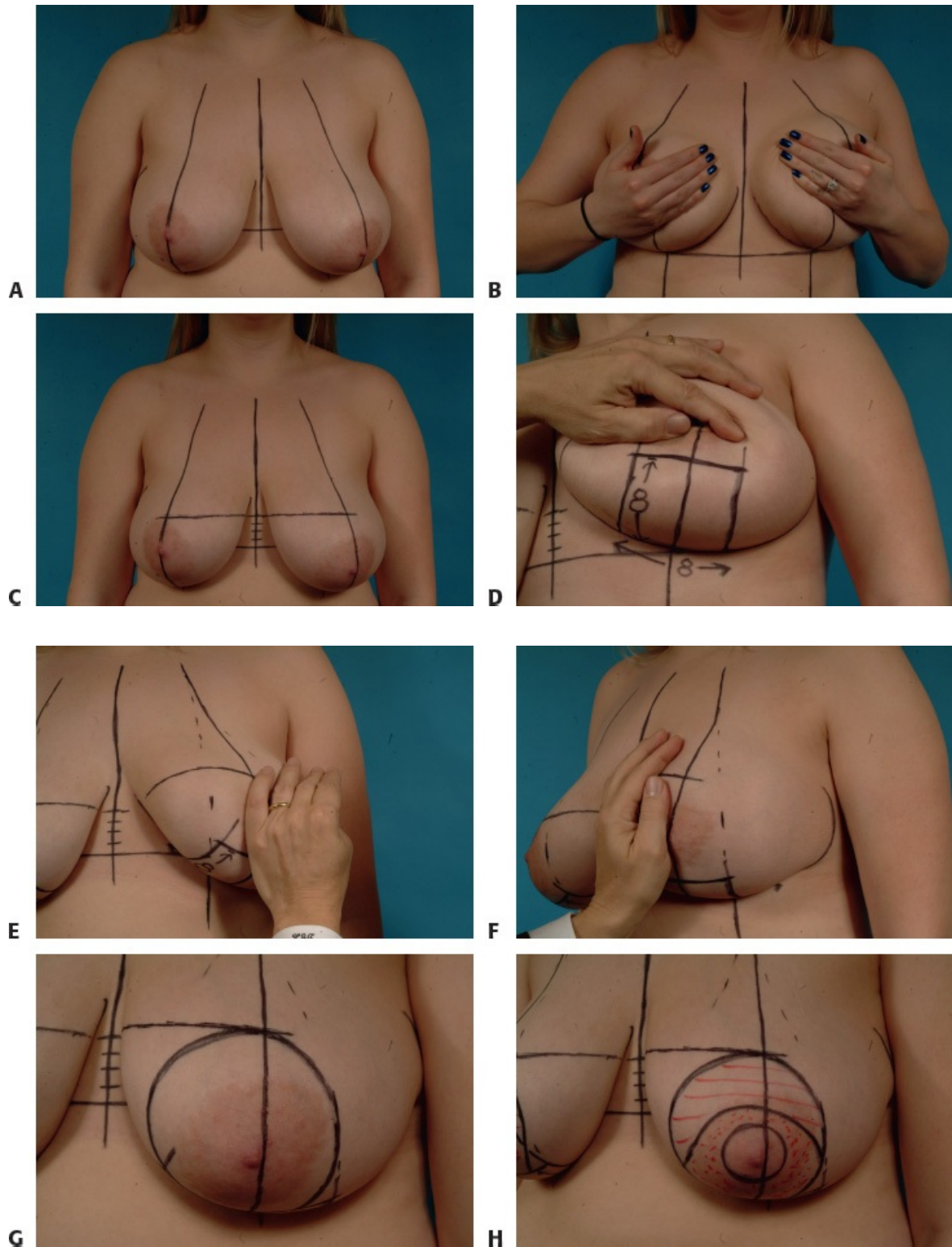


FIG 2 • A. The midsternal line, IMF, lateral breast contour, and breast meridian are marked. **B.** The IMF is drawn across the chest. **C.** The top point is the

intersection of a line 2 to 4 cm above the IMF with the breast meridian. **D.** The bottom points are the top points of an 8- × 8- to 8- × 10-cm rectangle, centered on the breast meridian, arising from the IMF. **E,F.** The lateral and medial points are identified by manipulating the breast and transposing the breast meridian. **G.** The periareolar pattern is outlined. **H.** The top points of the rectangle are joined with a curved line skirting the areola by 2 cm.

- Preoperative photographs serve several functions:
 - They document the surgical plan electronically.
 - They can be brought to the operating room to guide intraoperative decision-making.
 - They can be compared to postoperative photographs to critically appraise surgical technique and final results.
 - They can be used to educate patients at both the pre- and postoperative settings.
- Photographs, at the minimum, should capture three standard views of the breasts including the front and each side.
 - Supplemental views, including ¾s, hands over head, and with breasts lifted by the patient, can also be taken.
 - Patients should be framed from the top of the shoulders to midway between the breast and umbilicus, with the width extending just outside the arms.

Positioning

- The SPAIR technique is performed under general anesthesia.
- The patient is positioned supine, on an operating room table that is capable of sitting up 90 degrees.
 - This will allow the patient to be placed upright intraoperatively and the breasts to be evaluated in the sitting position, which may guide intraoperative decision-making.
- The patient's head is positioned at the top of the table, supported by a foam headrest (**FIG 3A**).
- The patient's arms are placed on arm boards and secured to allow safe upright

positioning of the patient.

- Arm boards are placed at the shoulder level.
- Foam pads are placed between the arm and arm boards (**FIG 3B**).

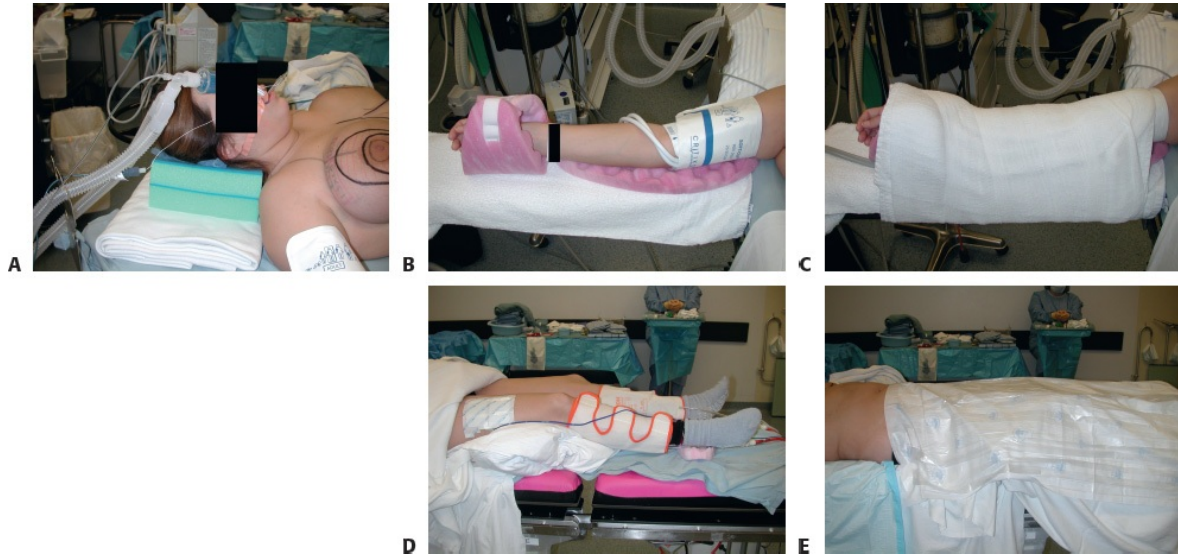


FIG 3 • **A.** The patient's head is positioned at the top of the table, supported by a foam headrest. **B.** Foam pads are placed between the arm and arm boards. **C.** The arm is secured with a soft towel followed by a gentle circumferential wrap of gauze. **D.** The patient's knees are elevated with a pillow, and the patient's heels are supported with foam pads. **E.** A heated air-warming device is placed on the lower body.

- The arm is then secured to both with a soft towel followed by a gentle circumferential wrap of gauze, which runs from the axilla to the hand to provide a uniform layer of support (**FIG 3C**).
- The patient's knees are elevated with a pillow to relieve pressure on the back while the patient is upright, and the patient's heels are supported with foam pads (**FIG 3D**).
- A heated air-warming device is placed on the lower body (**FIG 3E**).
- The area from the top of the shoulders to midway between the inferior pole of the breast and umbilicus is prepped and draped to allow full visualization of the shoulders, chest, and breasts during surgery.

TECHNIQUES

■ Short Scar Periareolar Inferior Pedicle (SPAIR) Technique^{8,9}

Incisions

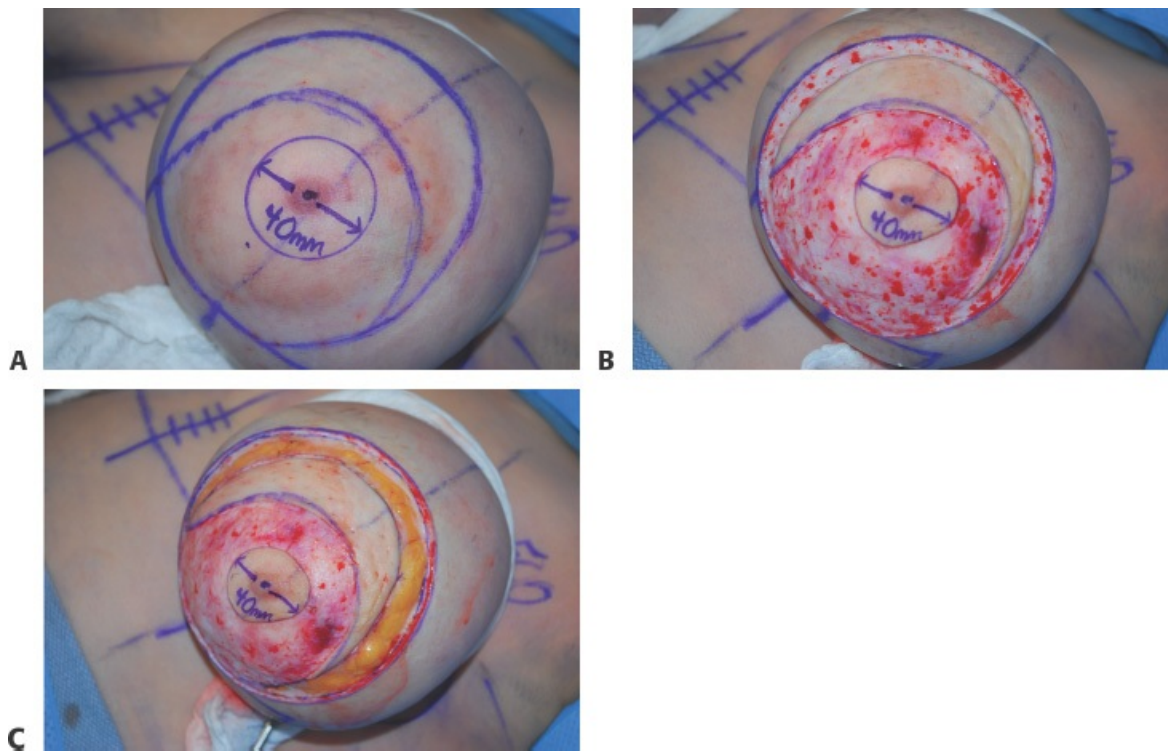
- With the breast under stretch using a tourniquet, a 40- to 52-mm areolar mark is made on the breast (**TECH FIG 1A**).
- Local anesthetic is injected into all the planned incisional areas and in the dermis of the area encompassed by the inferior pedicle.
- The areolar and periareolar incisions are made to the deep dermis, and the periareolar area de-epithelialized, except in the planned crescentric resection area above the NAC (**TECH FIG 1B**).
- The periareolar area is incised through the dermis leaving a 5-mm dermal cuff from the skin edge (**TECH FIG 1C**).
 - This dermal edge will be used ultimately for placement of the periareolar purse-string suture.

Flap Creation

- Breast flaps are then developed medially, superiorly, and laterally from the periareolar incision (**TECH FIG 2A,B**).
 - The medial and superior breast flaps are dissected thicker, aiming for 4 to 6 cm thickness (**TECH FIG 2C,D**).
 - The lateral breast flap is dissected thinner, along the plane of the outer lamina (**TECH FIG 2E**).
 - At the base of the superior breast flap dissection, the cephalic aspect of the breast septum is identified and preserved, while medially and laterally the septum is incised/released (**TECH FIG 2F**).
- The curved line skirting the areola is incised. and dissection proceeds to the pectoralis fascia to define the segment of breast tissue to be removed and free the inferior pedicle.
 - The final specimen resembles a horseshoe, with the lateral segment being larger (**TECH FIG 2G**).
 - Care is taken to avoid inadvertent undermining of the pedicle and preserve the septum.

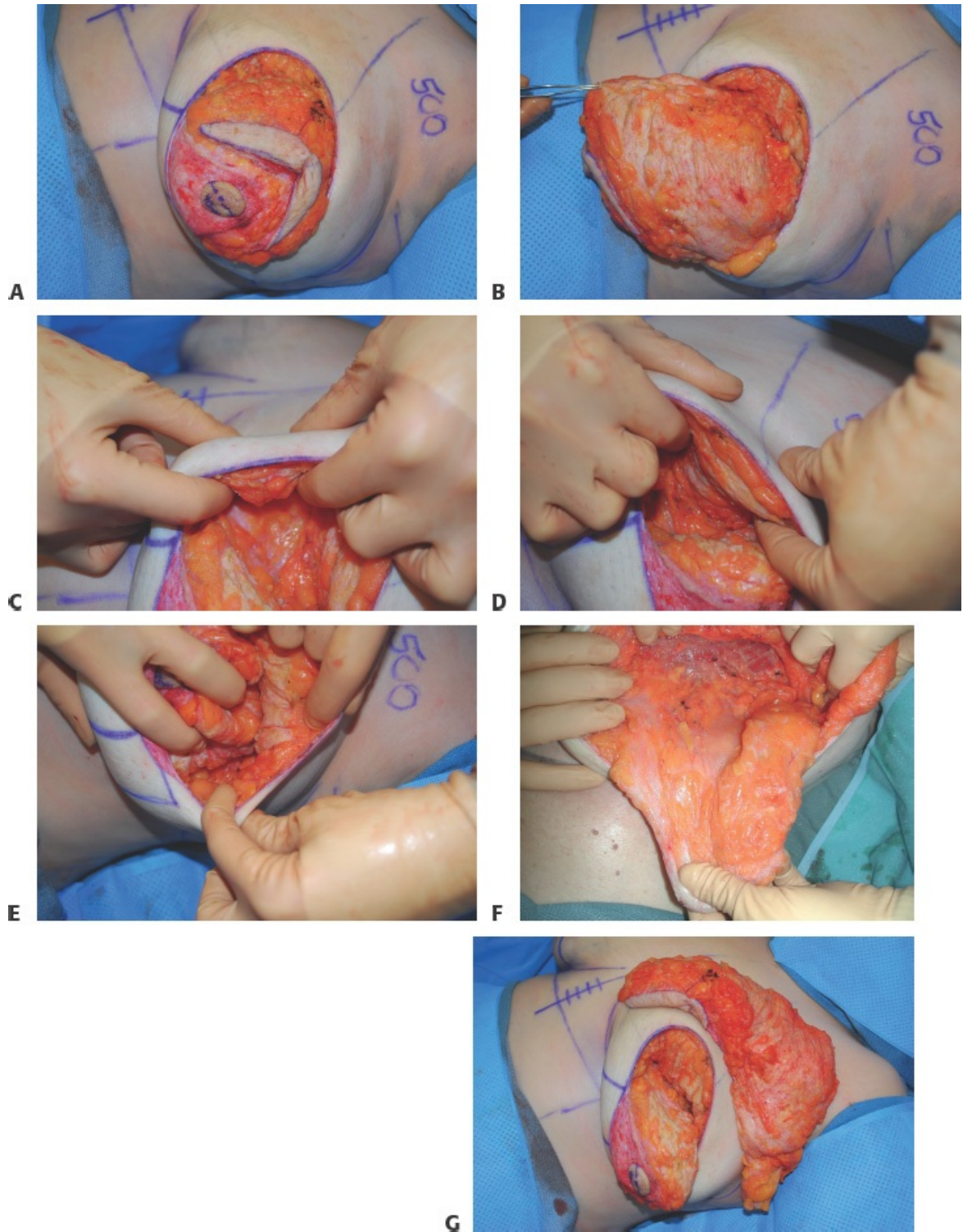
Shaping

- Various maneuvers are now used to further shape the breast as needed.
- If the upper pole is concave, the leading edge of the superior breast flap can be advanced superiorly and fixated to the pectoralis fascia using 3-0 PDS (Ethicon Inc., Somerville, NJ, USA) or equivalent absorbable interrupted sutures to autoaugment the upper pole (**TECH FIG 3A,B**).
- If the medial pole is deficient, the medial breast flap can be imbricated upon itself on its deep surface using 3-0 PDS (Ethicon Inc., Somerville, NJ, USA) or equivalent absorbable interrupted sutures to create a more rounded contour (**TECH FIG 3C,D**).
- If either contour is excessive, the breast flaps can be further debulked as needed.
- To centralize the pedicle, the superior aspect of the inferior pedicle is sutured to the pectoralis fascia (**TECH FIG 3E,F**).



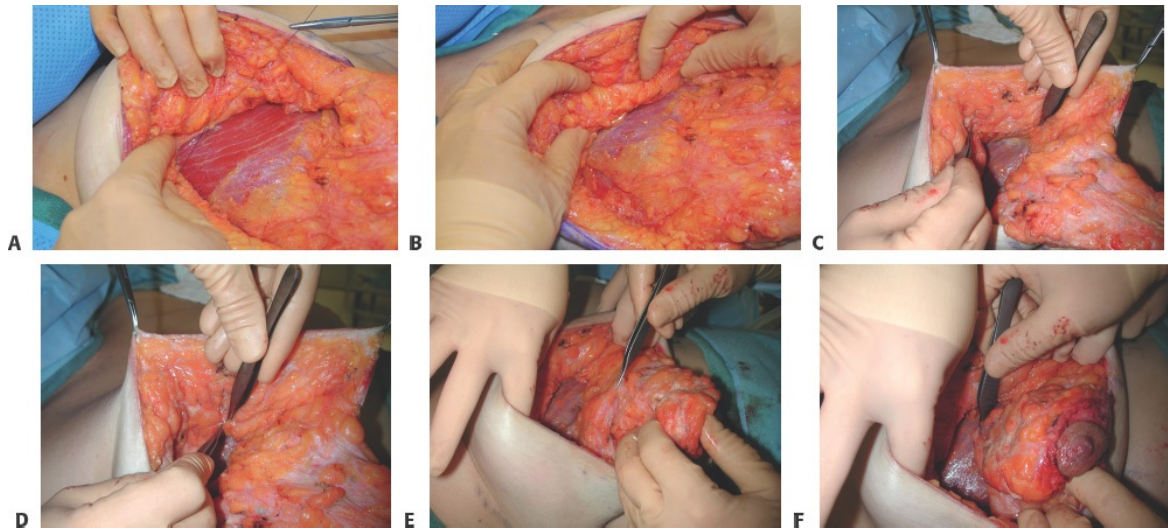
TECH FIG 1 • A. A 40- to 52-mm areolar mark is made on the breast. **B.** The areolar and periareolar incisions are made to the deep dermis, and the periareolar area de-epithelialized. **C.** The periareolar area is incised

through the dermis, leaving a 5-mm dermal cuff.

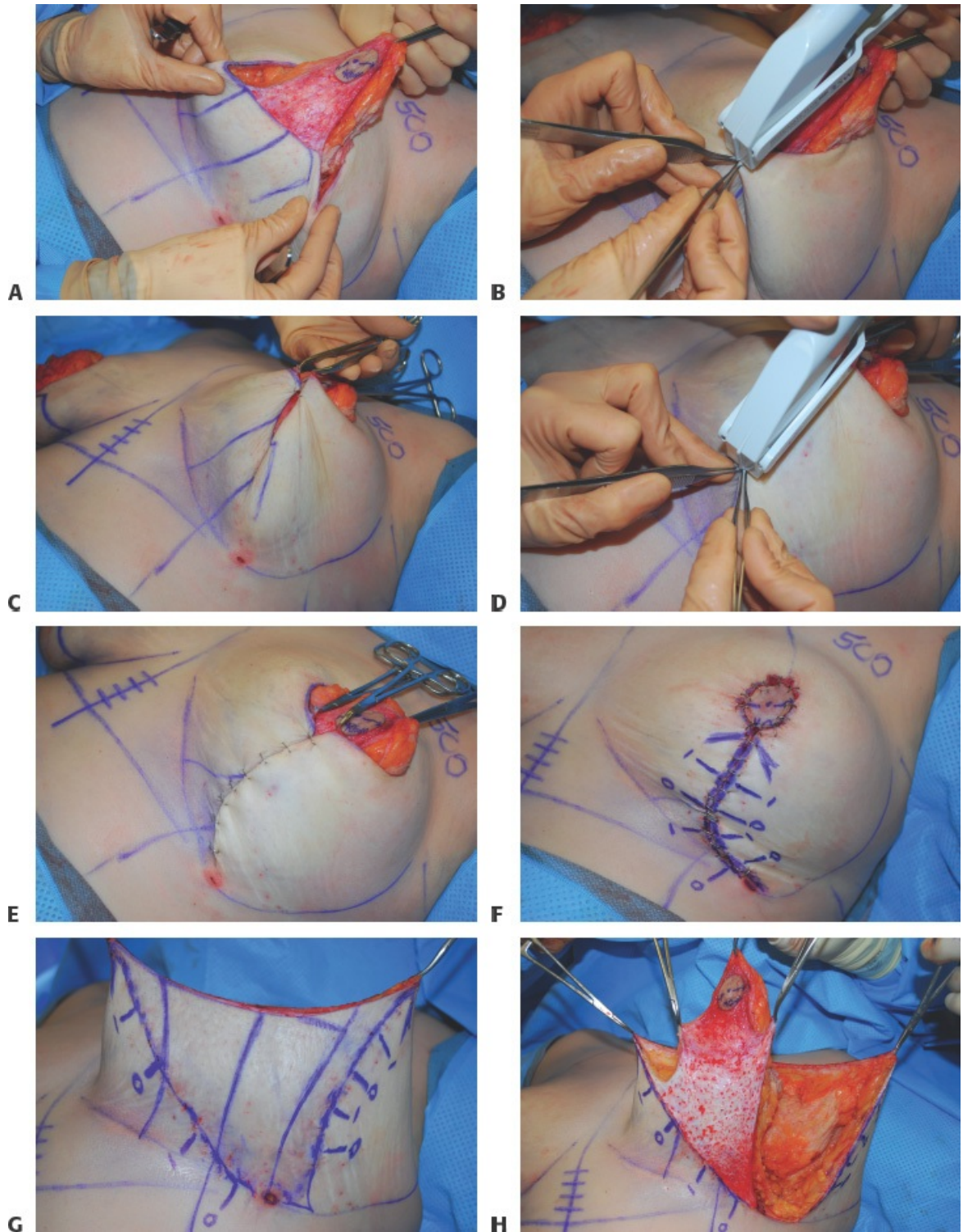


TECH FIG 2 • A,B. Breast flaps are developed from the periareolar incision. **C.** Medial breast flap. **D.** Superior breast flap. **E.** Lateral breast flap. **F.** The

cephalic aspect of the breast septum, after dissection of the superior breast flap. **G.** The horseshoe-shaped breast reduction specimen.



TECH FIG 3 • A,B. Autoaugmentation of the upper pole with sutures. **C,D.** Autoaugmentation of the medial pole with sutures. **E,F.** Suture suspension of the inferior pedicle to the pectoralis fascia.



TECH FIG 4 • A,B. Two lateral buckle points are identified, which are the starting points of the inferior pole skin plication. **C–E.** The inferior pole skin is

progressively stapled from superior to inferior, curving inferolaterally toward the IMF. **F,G**. The plication line is marked with a surgical marker. **H**. The outlined resection area is de-epithelialized, and the redundant medial and lateral wedges of tissue are removed.

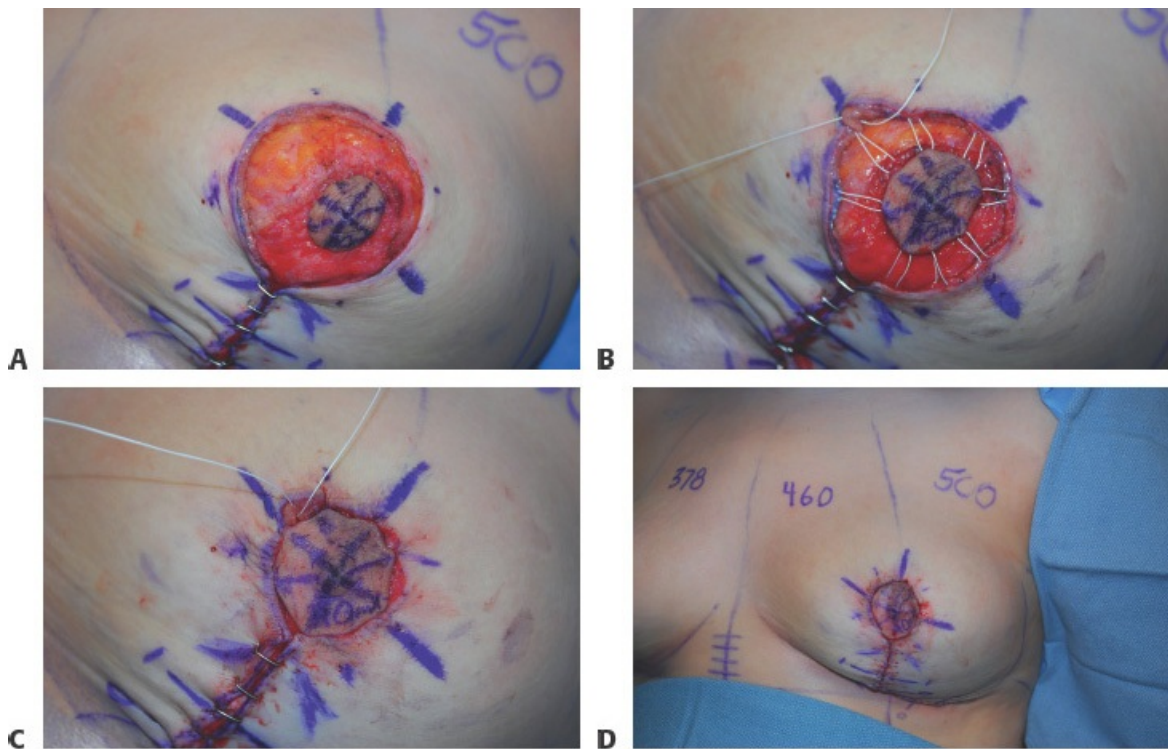
Skin Plication

- The vertical pattern to manage the excessive skin enveloped is next created.
- A hemostat is applied to the superior pedicle and cephalic traction applied in line with the breast meridian to reveal two lateral buckle points, which are stapled together and represent the starting point of the inferior pole skin plication (**TECH FIG 4A,B**).
- With two hemostats applied to the dermal edge of the buckle points and upward traction (away from patient) in line with the breast meridian, the inferior pole skin is progressively stapled from superior to inferior, curving inferolaterally toward the IMF to achieve a smooth and contoured breast shape (**TECH FIG 4C-E**).
- After preliminary staple closure, the patient is placed upright to visualize the resultant breast shape and make adjustments to the staple line as needed.
- After the staple line is deemed satisfactory, the patient is returned supine, the plication line is marked with a surgical marker with hash marks to guide closure, and the staples are removed (**TECH FIG 4F,G**).
- The outlined resection area, which typically resembles a “slanted V,” is de-epithelialized, and the redundant medial and lateral wedges of tissue adjacent to the pedicle are removed en bloc (**TECH FIG 4H**).

Closure

- A drain is placed as desired, coursing around the pedicle, and brought out through the lateral breast.
- The vertical incision is closed with 4-0 Monocryl (Ethicon Inc., Somerville, NJ) or equivalent interrupted deep dermal sutures followed by subcuticular closure with 3-0 Stratafix (Ethicon Inc., Somerville, NJ) or equivalent absorbable barbed suture.
- The periareolar defect is closed last using the periareolar purse-string technique.¹⁰

- Eight evenly spaced cardinal points are marked on the areola and periareolar incision (**TECH FIG 5A**).
- A 2-0 Cytoplast (Surgiform Technologies Ltd., Columbia, SC) or equivalent PTFE suture on a straight needle is selected.
- The suture is then passed, from deep to superficial, starting on the medial dermal shelf of the periareolar incision, through the corresponding cardinal point on the dermis of the areola, inserted back into the outer dermal shelf, and then passed through the periareolar dermis to the next cardinal point.
- This weaving is continued until the suture has weaved completely around the periareolar defect, culminating in the appearance of a wagon wheel (**TECH FIG 5B**).
- The free suture ends are then tightened to cinch the periareolar incision down to match the diameter of the areola (**TECH FIG 5C**), followed by placement of 8 to 10 square knots to secure the suture.
- The knot complex is placed underneath the medial dermal shelf, and the periareolar closure is completed with 3-0 Stratafix or equivalent absorbable barbed suture (Ethicon Inc., Somerville, NJ, USA) (**TECH FIG 5D**).



TECH FIG 5 • A. Eight evenly spaced cardinal points are marked on the areola and periareolar incision. **B.**

Intraoperative appearance of the periareolar pattern after weaving of the purse-string suture. **C.** The periareolar incision is cinched down to match the size of the areola. **D.** Completed periareolar closure.

PEARLS AND PITFALLS

Landmarks

- Place the top of the periareolar pattern 4 cm above the IMF for smaller reductions and 2 cm above the IMF for larger reductions because the vertical skin resection is more significant in larger breasts, which tends to create a more pronounced lifting effect.
- Draw the rectangle below the periareolar pattern with a height of 8 cm for smaller breasts and 10 cm for larger breasts to preserve more breast skin for redraping in larger reductions.
- Push the breasts medially after all markings are completed to confirm symmetry (**FIG 4A**).
- To ensure that there is sufficient skin medially to allow tension-free redraping of the breast, the distance from the midsternal line to the medial mark of the periareolar pattern should be at least 12 cm (**FIG 4B**).

Technique

- Periareolar patterns greater than 20 cm and reductions greater than 1000 g tend to be more difficult; they require more tedious dissection and greater operator skill and culminate in more pleating and scalloping around the periareolar closure.
- The thickness of the superior and medial breast flaps can be directly controlled by adjusting the path of dissection toward the chest wall; bevel inward for lesser thickness and vice versa.
- With upward traction of the two hemostats applied to the dermal edge of the buckle points, and gentle inward pressure on the inferior pedicle along the breast meridian, the inferior breast tissues will imbricate and reveal a curvilinear path toward the IMF, which guides preliminary staple closure of the breast.
- Instead of being resected, the medial wedge of tissue adjacent to the pedicle may be de-epithelialized and preserved for more medial fullness to the reduced breast.
- If the nipple to IMF distance of the inferior pedicle is long, plication sutures can be placed on the dermis of the pedicle to

shorten the distance and improve the lower pole contour of the pedicle (**FIG 5A,B**).

- If the resultant periareolar defect after closure of the vertical segment is not circular, it can be resected again and de-epithelialized to create a circular defect that matches the areola; this will better approximate the wound edges using the periareolar purse-string technique (**FIG 5C**).

Postoperative care

- If there is any concern about the vascularity of the NAC, especially in cases in which the inferior pedicle is long, a support bra should not be worn postoperatively to avoid compression on the pedicle, and patients should be specifically educated about this to avoid unnecessary anxiety about not wearing a bra.

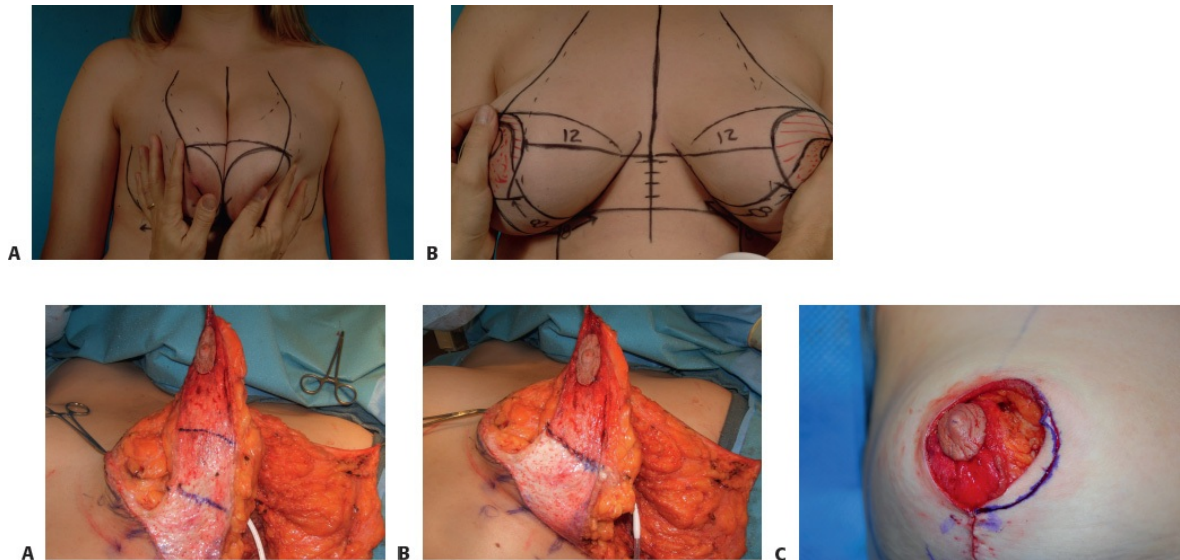


FIG 4 • A. The breasts are pushed medially to check that the markings are symmetrical. **B.** The minimum distance from the midsternal line to the medial periareolar pattern is 12 cm.

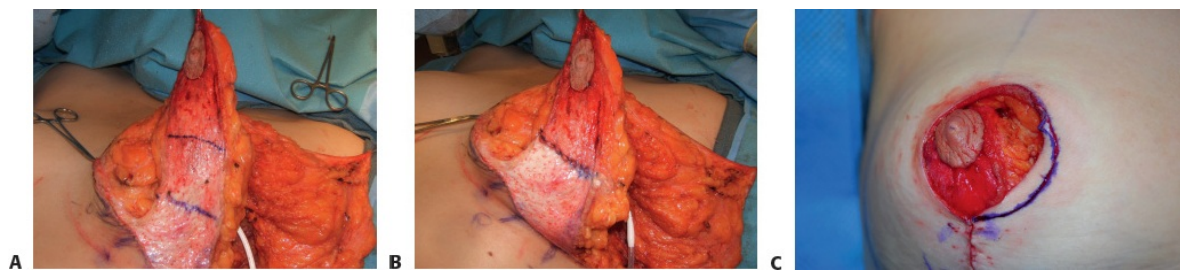


FIG 5 • A,B. Suture plication of the inferior pedicle to improve its contour. **C.** Planned re-resection of the periareolar pattern to create a more circular defect.

POSTOPERATIVE CARE

- All incisions are covered with Steri-Strips and Tegaderm dressings, and a support bra is worn.
- Patients are typically discharged the same day after surgery.
- Dressings remain in place for 7 to 10 days and are removed at the time of the first follow-up visit.
- Drains, if placed, are removed when their daily output is less than 30 mL.
- Routine follow-up visits are scheduled at 1 week, 6 weeks, 6 months, and yearly thereafter.
- Paper tape is applied to the healing wounds for the first 6 weeks and is changed as needed.
- A support bra is worn for the first 6 weeks.
- Patient may resume full activities, except vigorous running and weight lifting, generally 2 weeks after surgery.

OUTCOMES

- Reduction mammoplasty is generally well tolerated by adolescents from a physical and psychological perspective.⁷
- Approximately 60% of women are able to breastfeed after breast reduction.¹¹
- Approximately 2% of women lose sensation to the nipple-areolar complex after breast reduction.¹¹
- Recurrent hypertrophy is possible, especially if the reduction mammoplasty is performed during breast growth.

COMPLICATIONS

- Early
 - Hematoma
 - Seroma
 - Infection
 - Delayed wound healing or wound dehiscence
 - Nipple-areolar complex necrosis

- Late
 - Adverse scarring
 - Shape change
 - Loss of nipple-areolar complex function (sensation or lactation)
 - Fat necrosis

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60 Pectus Excavatum and Pectus Carinatum

CHAPTER

Jamie C. Harris and Fizan Abdullah

DEFINITION

- Pectus excavatum is the most common chest wall deformity that involves a concave deflection of the sternum posteriorly, with a wide range of severity from slight depression to almost reaching the level of the vertebrae. This abnormality can be present at birth but more frequently becomes apparent during puberty when rapid growth occurs.
- It occurs more frequently in males than females (3:1 ratio).
- Indications for repair include symptomatic relief, improved appearance, or to alleviate psychosocial anxiety due to the defect.
- Pectus carinatum is a congenital chest wall anomaly sometimes referred to as “pigeon chest,” less common than excavatum, which is associated with a convex deformity of the sternum, leading to protrusion of the chest wall.
- Two general types are described: chondrogladiolar, which is symmetric protrusion of the body of the sternum and cartilage, and chondromanubrial, which is protrusion of the manubrium sternum with inward depression of the inferior portion. This generally presents during adolescence and has a male predominance.¹

DIFFERENTIAL DIAGNOSIS

- Pectus carinatum vs excavatum
- Poland syndrome: absence of pectoris major and minor muscles, missing ribs, and chest wall depression
- Scoliosis: abnormal curvature of the spine that can make the chest wall appear deformed

PATIENT HISTORY AND PHYSICAL FINDINGS

- As with any patient, the first approach is a thorough history. The time course of presentation is important to identify, as it can vary from infancy to adolescence.
- The progression of the deformity is important to note. For example, during puberty the deformity can rapidly become much more prominent.
- Symptoms associated with pectus excavatum (PE) are rare but can include dyspnea or exercise intolerance. However, the majority of patients will not report symptoms.
- Often, the presenting complaint is poor appearance due to the enlarging deformity at puberty.
- Clear documentation of dyspnea, exercise intolerance, or worsening dyspnea is important to facilitate insurance coverage.
- Family history regarding chest wall deformities should be obtained; there is a 25% rate of positive family history.
- Cardiopulmonary sequela has long been investigated; however, definitive results are still lacking. It has been shown that patients have normal spirometry preoperatively but can report subjective improvement in breathing postoperatively.
- On physical exam, symmetry of the chest should be examined. Often, asymmetry can occur, most frequently favoring the right side. Calipers can be used to determine the depth and width of the deformity; however, computed tomography (CT) scan has become a more standardized way to categorize defects.
- Chest wall inspection includes observing chest wall symmetry or asymmetry, as well as the type of deformity present.
- Auscultation can reveal displaced cardiac sounds. Additionally, a systolic ejection murmur can sometime be appreciated due to the proximity of the chest wall to the pulmonary artery. Mitral regurgitation can also be present.
- Examination of the rest of the body, looking for stigmata of Marfan syndrome including long digits or history of bruising. If present, a full evaluation for Marfan syndrome should be done.

IMAGING AND OTHER DIAGNOSIS STUDIES

- Computed tomography of the chest has now become important for diagnosing severity of the PE. The Haller index is calculated from the axial images using the ratio of the transverse diameter from the inner ribs to the length of the

greatest point on defect between the posterior sternum and anterior vertebrae. A ratio greater than 3.2 is considered a severe defect.²

- Plain chest radiograph, posteroanterior (PA) and lateral views, has been described to calculate the Haller index as well and in some studies has been found to be equivalent for predicting severity.³ However, most patients will generally still have CT scan for evaluation.
- Pulmonary function tests in patients with pectus excavatum have been shown to have 10% to 20% less of the expected lung volume on spirometry. Additionally, the forced expiratory volume has been shown to be less than 80% of the predicted value for patients of similar age without pectus abnormalities.⁴
- Echocardiogram for cardiac evaluation is very important in this group of patients. There is a higher prevalence of cardiac abnormalities including right ventricular compression, mitral valve prolapse and arrhythmias. An echocardiogram is important to evaluate if cardiac structure is abnormal to allow for proper operative planning if identified.⁴

SURGICAL MANAGEMENT

Preoperative Planning

Pectus Excavatum

- In general, it is preferred to time repair during the pubertal growth phase, usually from ages 10 to 15.⁵ This is because the rapid growth phase can worsen pectus and therefore cause a previously repaired defect to recur. However, for children with severe exercise intolerance, earlier repair can be considered.
- Indications for operative correction include Haller index greater than 3.2, progression of severity of disease, pulmonary function tests (PFTs) demonstrating obstructive or restrictive lung patterns, or cardiac abnormalities such as displacement, arrhythmias, or murmurs.⁶
- There are two different types of repair: open (or Ravitch procedure) and the minimally invasive procedure (Nuss). There are a few important considerations to make when deciding which approach is appropriate. In patients with severe asymmetry, the open approach is often favored. Additionally, in patients presenting with a failed Nuss procedure, the open procedure should be considered for the second repair. However, overall, the Nuss procedure tends to be the procedure of choice for consideration in lower postoperative pain as well as improved appearance from its minimally invasive nature.

- If pursuing noninvasive repair with a Nuss bar, it is crucial to determine if the patient has allergies to metal, or a family history of metal allergy. If a family history is present, subsequent skin testing for metal allergy is necessary before proceeding. If an allergy is present, a titanium bar should be used instead of the standard stainless steel.
- The bar length for the Nuss procedure should be 2.5 cm shorter than the distance from the right to left midaxillary line.⁷
- General anesthesia should be achieved prior to beginning the operation, and a secure airway must be obtained at the beginning of the case.

Pectus Carinatum

- In general, most children with pectus carinatum will not require surgery. For children that are younger and have not yet completed puberty, orthotic bracing regimens are attempted to mold the chest into the correct position. Up to 75% of patients will achieve significant or complete correction of the pectus carinatum deformity using bracing alone.⁸
- The most common reason for incomplete or failed correction is patient noncompliance with bracing regimen. Noncompliance often results from failure to wear the brace often enough or in time periods long enough to correct the deformity.
- If the defect fails to improve, surgical correction can then be pursued.

TECHNIQUES

■ **Nuss Procedure: Minimally Invasive Approach for Pectus Excavatum**

Positioning and Incision

- Patient is supine with arms extended.
- The operating surgeon is on the right and assistant surgeon on the left.
- The initial incisions should be at the transverse midaxillary line at the level of the deepest depression of the sternum, 4 cm in length on each side.

Endoscopic Bar Placement

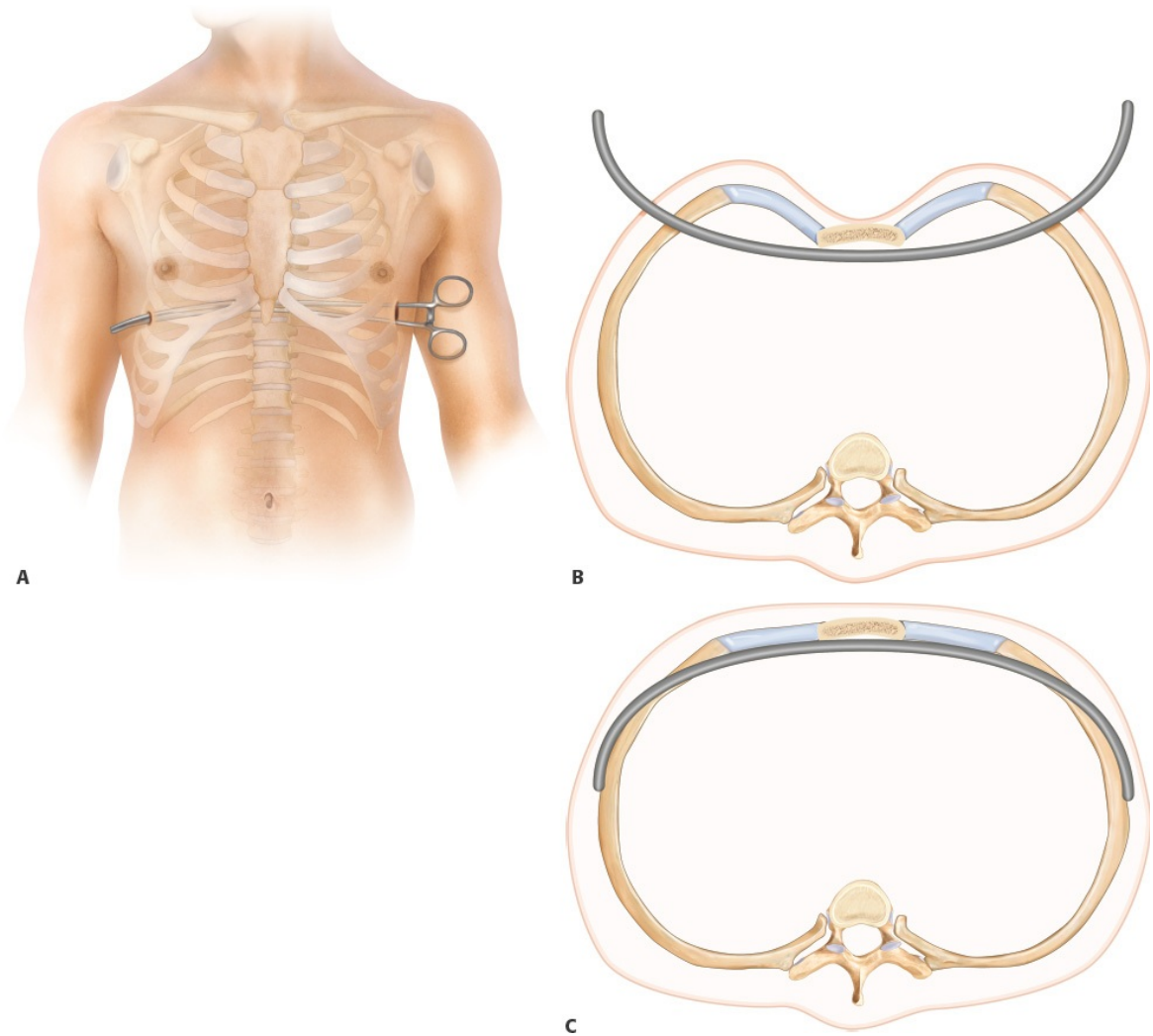
- Once the incisions are made, carry the right-sided incision down to the

pleura, entering under direct vision.

- A 5-mm thoracoscope is inserted in two rib spaces caudal to the right-sided incision to allow for direct vision of passage of the introducer.
- Deep subcutaneous tunnels are made on both the left and right sides, staying superficial to the muscle layer.
- Next, the introducer is inserted on the right, at the level just lateral to the beginning of the indentation. The introducer is passed through the intercostal muscles.
- Under direct visualization, the introducer is passed just posterior to the sternum, using extreme caution to avoid injury to the heart (**TECH FIG 1A**).
- Upon crossing the midline, the introducer is then passed through the left-sided intercostal muscles just lateral to the edge of the depression and taken out the skin incision.
- Next, umbilical tape is tied to the introducer on the left side of the chest, pulled through the tract, and removed on the right side.
- The preformed bar is then attached to the umbilical tape, and it is then pulled through the track, with the apex of the bar angled away from the sternum (**TECH FIG 1B**).
- The bar is then rotated 180 degrees, such that the convex portion of the bar is against the sternum (**TECH FIG 1C**).
- This is secured in place using bar stabilizers on both sides. Either wire of heavy PDS suture is passed around the stabilizers and the rib to avoid bar displacement.
- For patients that have severe deformity, a second bar can be used. This is placed in the same manner, slightly inferior to the original bar.

Closure

- A 16-French red rubber catheter is placed in the tract of the camera port. A positive end expiratory pressure of 5 mm Hg is given, and a Valsalva is done by anesthesia to evacuate any residual air within the thoracic cavity. Alternatively, Valsalva without a red rubber catheter can also be used to evacuate residual air.
- The lateral incisions are then closed in layers using an absorbable suture
- The skin is closed with a running subcuticular suture
- Rarely, a chest tube is required for this procedure.



TECH FIG 1 • A. The minimally invasive approach to pectus excavatum, the Nuss procedure, inserts the bar at the level of the deepest depression. **B.** The bar is inserted with the bend away from the chest wall. **C.** The bar is then rotated 180 degrees, correcting the deformity.

■ Open Ravitch Procedure for Pectus Excavatum

Positioning and Incisions

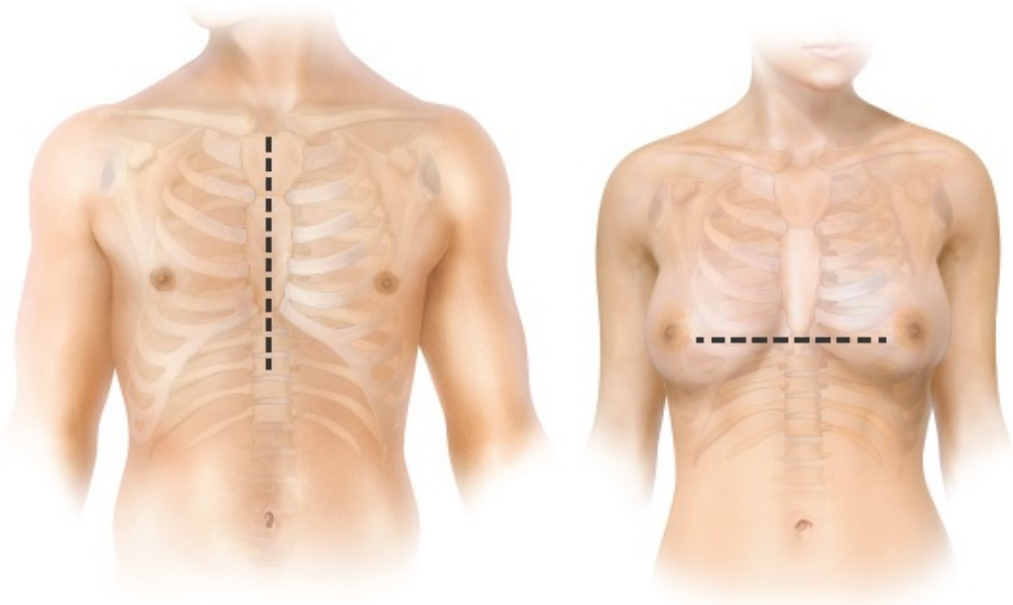
- The patient should be in the supine position with their arms out to the side on the operating room table.
- Both the chest and abdomen should be prepped and draped into the sterile

field.

- The operating surgeon will be positioned on the patient's right, the assisting surgeon on the patient's left, and the anesthesiologist at the head of the bed.
- Two incisions can be used depending on the cosmetic outcomes. A sternal incision or transverse incision at the fourth intercostal space is used in males.
- In females, better cosmetic outcomes can be achieved using a transverse incision instead of a sternal incision. Care should be taken to make this incision within the projected inframammary crease to prevent injury to the breast bud (**TECH FIG 2**).

Exposure and Resection of the Abnormal Ribs

- Continue the incision creating skin flaps that are centered at the sternum. The skin flap should extend cephalad to the angle of Louis, the manubriosternal junction, and caudally to the xiphoid, allowing for adequate visualization of sternum and costal cartilage.
- Next, the pectoralis major muscle flaps should be elevated; passing an empty knife anterior to the costal cartilage insures the correct plane. This is continued cephalad until the highest abnormal cartilage is seen.
- Next, the rectus abdominis is mobilized off of the inferior border of the sternum.
- The perichondrium is excised anteriorly to expose the bony rib up to the sternum, exposing the cartilage at its insertion site on the sternum
- Using a Haight elevator to protect the mediastinum, the deformed cartilage is cut from the sternum using a knife. The deformed cartilage is then removed and cut at the costal cartilage junction, leaving a 5-mm margin.



TECH FIG 2 • Open repair, Ravitch procedure, is used for both pectus excavatum and carinatum. Incision is made either midline for males or inframammary in females.



TECH FIG 3 • **A.** Skin flaps are made, and the periosteum is cleared from both sides of the sternum. The deformed cartilage is cut from the sternum using a knife and removed. **B.** The sternum is then either flattened with a wedge osteotomy (for carinatum) or elevated with a transverse osteotomy (for excavatum).

- This is continued until all deformed cartilage has been resected. Then, a sternal wedge osteotomy is made just cranial to the final resected cartilage (**TECH FIG 3**).

Sternal Closure

- At the level of the osteotomy, the sternum is fractured and lifted into a flat orientation.
- Although not necessary in all cases, a sternal bar can be inserted posterior to

the sternum at this point. This is secured to the adjacent ribs for greater stabilization.

- If a bar is not used, heavy silk suture is used to close the sternal ostomy, fixing the sternum at the corrected position.
- Perichondrial sheaths are then reapproximated if necessary.

Closure

- A Hemovac drain is inserted through the inferior skin flap and placed along the sternal edge of the cut cartilage.
- The pectoralis muscle is then closed in the midline and secured to the sternum.
- The rectus muscles are then closed in the midline using an absorbable suture and reattached to the sternum.
- Layered closure of the subcutaneous tissues is done, and the skin is closed using a subcuticular stitch.

■ Open Ravitch Procedure for Pectus Carinatum

- The initial steps of the carinatum repair mirror that of the Ravitch procedure for pectus excavatum.
- The difference in technique from excavatum begins when the sternal osteotomy is made. Unlike in pectus excavatum in which a wedge osteotomy is made, a transverse linear osteotomy is made for correction of pectus carinatum at the point where the superficial deflection begins.
- The xiphoid process is detached from the sternum to allow for better sternal mobilization. The sternum is then flattened posteriorly to create a flat surface. The xiphoid process is then reattached once the sternum is in correct position.⁹
- Closure is the same as for Ravitch procedure for pectus excavatum.

PEARLS AND PITFALLS

Pectus excavatum

- Most patients with symmetric pectus excavatum are well suited for a Nuss procedure.

- Most patients who require redo surgery for pectus excavatum may benefit from a Ravitch procedure or a combined Ravitch and Nuss procedure.

Pectus carinatum

- Nonoperative treatment is the mainstay of treatment for carinatum; however, asymmetric lesions tend to require surgery more often. For symmetric deformities, bracing is first-line treatment.
- In some hands, the combination of postoperative antibiotics with sterile operative techniques has resulted in almost no wound infections in patients with pectus carinatum¹⁰

POSTOPERATIVE CARE

Pectus Excavatum

- Chest radiograph should be performed in the recovery room. This should confirm appropriate placement of the bar and also evaluate for pneumothoraces. It is not uncommon to have very small bilateral pneumothoraces that can be monitored; these usually do not require tube thoracostomy.
- Pain can be significant in the postoperative period for both procedures. Additionally, for some patients, pain can continue during the entire time the Nuss bar is in place. This pain can be managed generally with physical therapy and medications. Rarely, the bar is removed for severe pain.
- For the initial 6 weeks postoperatively, patients must refrain from any sports.
- Patients are forbidden from participating in any heavy contact sports, such as wrestling, football, and hockey for the entire duration that the Nuss bar is in place. Aerobic activities, such as running or soccer, are allowed after the initial 6 weeks.
- The Nuss bar must remain in place for at least 2 years. Timing of removal is based upon patient growth; for older patients in their rapid growth phase, removal is usually closer to 2 years. For younger patients who have not yet reached puberty, the bar can remain in place for up to 4 years.

Pectus Carinatum

- Postoperative pain is initially managed with intravenous analgesia and then transitioned to oral pain medication.
- Generally, patients are discharged within 2 to 3 days postoperatively.
- Intravenous antibiotics can be considered for 48 hours postoperatively, and

oral antibiotics are continued for another 4 days.

OUTCOMES

- No difference in length of stay between open and Nuss procedures has been demonstrated. Procedure length was slightly increased with open operation.
- The Nuss procedure is associated with higher rates of reoperation, pneumothorax, and hemothorax.¹¹
- Postoperative seroma formation is the most common complication in the open procedure. Due to this, a drain is left in the potential space within the skin flaps.
- Patient satisfaction scores have not been found to differ significantly between Nuss and open procedures, with 93.3% and 92% reported overall improved cosmetic outcomes, respectively. Symptomatic relief was also reported by both groups of patients.¹²
- Overall recurrence rates vary among studies but have been quoted between 2% and 10% in both open and Nuss procedures.¹³

COMPLICATIONS

Pectus Excavatum

- Cardiac perforation: this is an exceedingly rare intraoperative complication; however, if it does occur, it has an extremely high rate of mortality. Immediate sternotomy with cardiac repair should be done. This complication is more often associated with the Nuss procedure.
- Pneumothorax: in general, asymptomatic pneumothorax can be observed. Rarely, this may be symptomatic and require insertion of a chest tube.
- Bar dislodgement in the Nuss procedure can occur in up to 5% of patients; this can happen through the immediate or late postoperative period. If early, it can lead to immediate recurrence, and reoperation is required.
- Allergic reaction to the metal bar, ranging from rash to anaphylaxis.
- Prolonged pain, requiring bar removal in some cases.
- Recurrence has been documented after bar removal.

Pectus Carinatum

- Fortunately, complications are rare following repair of pectus carinatum.¹⁰
- Pneumothorax has been quoted at rate of 2% after repair^{10,14} but were less than 10% of total lung volume.

- Wound infection is a risk with any surgery and occurs at a very low rate.
- Recurrence/continued exercise intolerance: almost all patients report an improvement in exercise tolerance 3 to 4 months post procedure, and only 2.8% did not report an excellent result.

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Section XVI: Thorax and Back

61 Myelomeningocele: Postnatal Repair

CHAPTER

Gregory G. Heuer and Jesse A. Taylor

DEFINITION

- Myelomeningocele (MMC) is a congenital malformation of the spinal cord in the family of neural tube defects and spina bifida.¹
- MMC develops from a failure of neurulation of the spinal cord during the fourth week of gestation. The exposure of the spinal cord results in dysfunction of neural tissue as a result of the malformation itself and damage to the exposed neural tissue.
- MMCs occur in roughly 1 in 1000 live births and lead to significant morbidity including bowel and bladder dysfunction, gait disturbances, and even paralysis. Importantly, lack of sensation caudal to the MMC may result in significant decubital wound issues.

ANATOMY

- The MMC results from failure of neurulation, which results in an “open book” of distinct elements that are normally closed over the spinal cord² (**FIG 1**).
- The placode, the exposed flat spinal cord tissue, is present in the center, with nerve roots running ventrally and exiting through the spine foramen. Atrophic nerve roots can often be seen exiting the placode and running to the skin and soft tissue. These are nonfunctional elements.
- The zona epitheliosa surrounds the placode and contains cerebrospinal fluid (CSF). This is part of the sac or “bubble” seen on imaging studies.

- The dura of the meninges is open and reflected and covers the fascia and muscle.
- The skin is located laterally to the lesion. Some of this tissue is extremely thin and atrophic. The quality of the skin needs to be taken into account, as it impacts surgical closure.

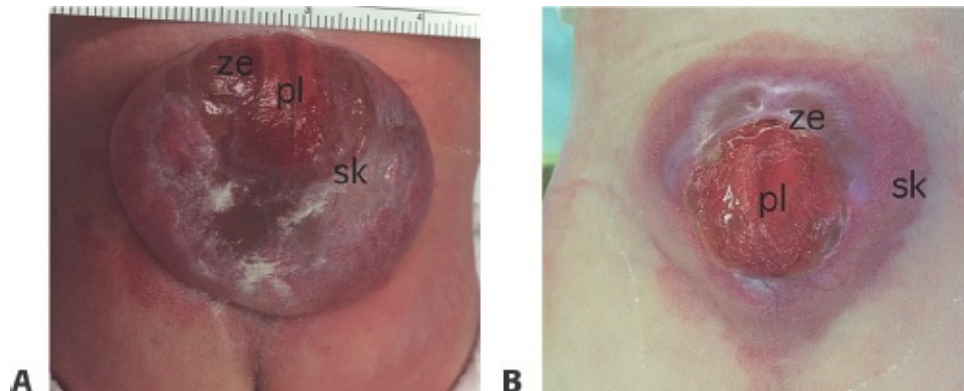


FIG 1 • Appearance of an MMC defect. The neural placode (*pl*) is seen at the center. This is surrounded by the zona epitheliosa (*ze*) and the skin (*sk*). The myofascial layer can often be seen through the translucent portion of the arachnoid surrounding the *ze*.

- Elements of the posterior vertebral body—the spinous process and lamina—are absent, and the spinal column is open dorsally. The open spinal column can be seen laterally as the bifida bone elements.
- In some cases, a sac is not present, and the placode is flat and in the spinal elements. This condition is known as myeloschisis and is managed in the same way as a MMC.

PATHOGENESIS

- During neurulation, normally the neural tube undergoes an ordered process of formation and closure. During this process, the neural folds meet and fuse, followed by closure of the layers around the spinal cord—including the dura, bone, muscle, and skin.¹
- MMC results from a failure of the neural tube to close at the caudal end, resulting in the exposure of the spinal cord—the placode—to the external environment.

- Most cases are idiopathic, though risk factors include genetic susceptibility and environmental risks such as toxins or medication exposure.
- Risk factors include genetic susceptibility and environmental risks such as toxins or medication exposure. In most cases, there is not an identifiable cause and is thus idiopathic.
- In some populations, the use of high-dose folic acid supplementation prior to conception can reduce the risk of neural tube defects, as folate is a known cofactor in many of the folding processes involved in neurulation.

NATURAL HISTORY

- MMC leads to irreversible loss of nerve function at the level of the exposed spinal cord.
- This loss of function occurs from³:
 - Abnormal development of the spinal cord
 - Direct damage to the exposed spinal cord from trauma and toxic injury

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with MMC are typically identified prior to birth.
- Ultrasound examination is performed for three reasons:
 - To define the MMC defect and its spinal level
 - To look at associated abnormalities of the central nervous system
 - To analyze the fetus for other structural abnormalities
- Patients with known MMC lesions are typically delivered via cesarean section.
- Newborn MMC patients are cared for in a systematic fashion (<http://www.chop.edu/clinical-pathway/myelomeningocele-myeloschisis-neonatal-clinical-pathway>).
 - General neonatal care must be the first priority, assuring that the newborn is stable and healthy and avoiding the temptation to focus solely on the MMC lesion.
 - In the presence of a MMC, the patient is generally positioned prone to avoid undue pressure on the exposed spinal elements. A sterile gauze is placed on the MMC lesion, and this is kept moist with a constant drip of sterile saline from a bag suspended above the patient.
 - The patient is placed on antibiotics (ampicillin and amoxicillin) as prophylaxis against bacterial seeding of the spinal elements.
 - Consults are obtained including the physical therapy, neurosurgery, orthopedics, plastic surgery, urology, and spina bifida team.

- An ultrasound of the head is obtained to establish a baseline of the ventricular system.
- A physical exam is performed on the infant.
 - The infant is examined for signs of hydrocephalus such as a full fontanelle, large head circumference, or splayed sutures.
 - In most instances, newborn MMC patients do not show clinical signs of hydrocephalus until after the MMC closure is performed.
 - The anatomy of the MMC defect is similar (see **FIG 1**) even if the overall appearance of the lesion may be grossly variable (**FIG 2**).
 - The size of the MMC lesion is noted as well as the quality of the skin. These factors are important to anticipate the need for specialized closure techniques such as rotational flaps, allograft patches, or skin grafts.
 - A neurologic exam is performed to assess the clinical level of function. The clinical exam is very difficult to interrupt in a newborn and should be done by a trained clinician and followed over time for any changes. Movement secondary to direct stimulation that is not clinically significant can be present below the level of the lesion and should not be confused with volitional movement.⁴
 - The infant should be examined for orthopedic deformities, such as talipes or hip contractures. These are important to note prior to the MMC closure as they may affect patient positioning both before and after surgery.
- Surgical closure of the MMC is typically performed within the first 48 hours after birth.
 - However, this can be delayed if the patient is not clinically stable as long as the positioning, wound care, and prophylactic antibiotics are administered. The risks of delaying surgery must be carefully weighed against the risks of infection and further neurological deterioration. If the surgery is delayed for weeks to months, the granulation tissue that develops can increase the technical difficulty of the closure.
- MMC closure is performed in a stepwise fashion to close the layers over the spinal cord that should be present.

SURGICAL MANAGEMENT

- The overall goal of the surgical closure is to obtain a multilayer closure of all three layers of the back—dura, muscle, skin—that is watertight.

Positioning

- The infant is placed prone with the abdomen suspended to promote venous return and reduce bleeding during surgery (**FIG 3**).
- The back is widely prepped on the table with Betadine. The back must be prepped in a wide fashion to allow for skin rotational procedures.

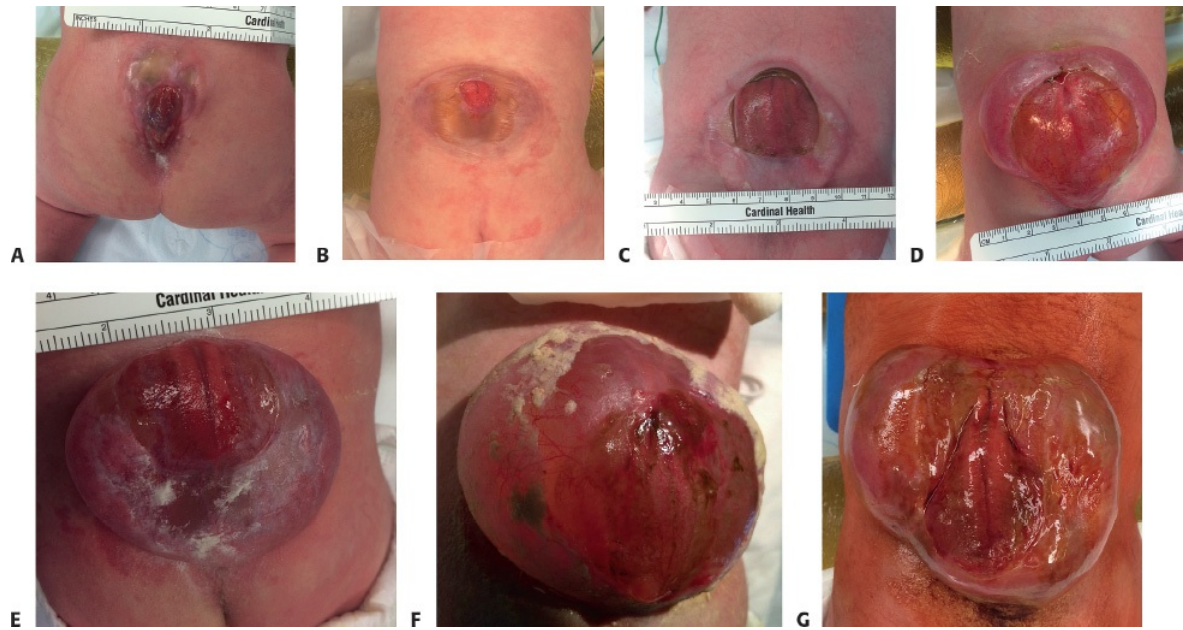


FIG 2 • Various MMC lesions. Note the variability in the size and appearance of the lesions.



FIG 3 • Intraoperative positioning of an MMC patient.

TECHNIQUES

- **Release of the Placode**

- The tissue just lateral to the placode is sharply incised, releasing the placode to float ventrally into the spinal column (**TECH FIG 1A**).
- It is often necessary to make this incision further from the placode and the residual tissue should be dissected from the placode.
- The placode can be rolled back into a tubular structure by placing sutures in the pial layer. This is often accomplished with 6-0 Prolene interrupted sutures (**TECH FIG 1B**).



TECH FIG 1 • A. Dissection of the placode from the surrounding tissue. **B.** The released placode is brought into a tubular shape with fine sutures.

■ Skin Release and Mobilization

- The skin is then released from the underlying fascia and muscle (**TECH FIG 2**).
- The skin is undermined widely, resulting in greater exposure of the underlying fascia and freeing up soft tissues that can be more easily rotated over the fascia during the skin closure.
- Care needs to be taken to stay in the proper plane and avoid tearing the skin and soft tissues during this undermining process.
- The edges of the skin are then trimmed back to the tissue that will support dermal and skin sutures.



TECH FIG 2 • The skin is extensively undermined.

■ Dura, Myofascial, and Skin Closure

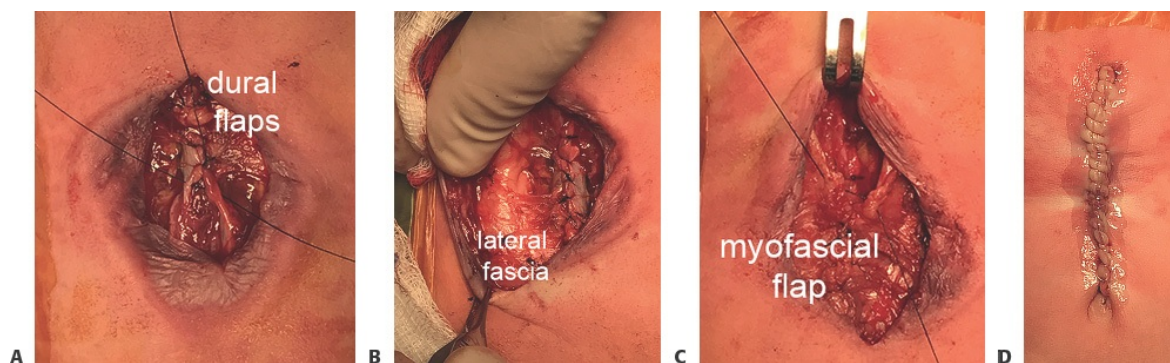
- The next step is closure of the lateral tissue over the placode. The goal of the closure is a watertight closure over the placode.
- The skin is held with a retractor, exposing the lateral dura and fascia.
- An incision is made in the lateral tissue. This tissue is normally the dura that

is present over the top of the muscle and fascia.

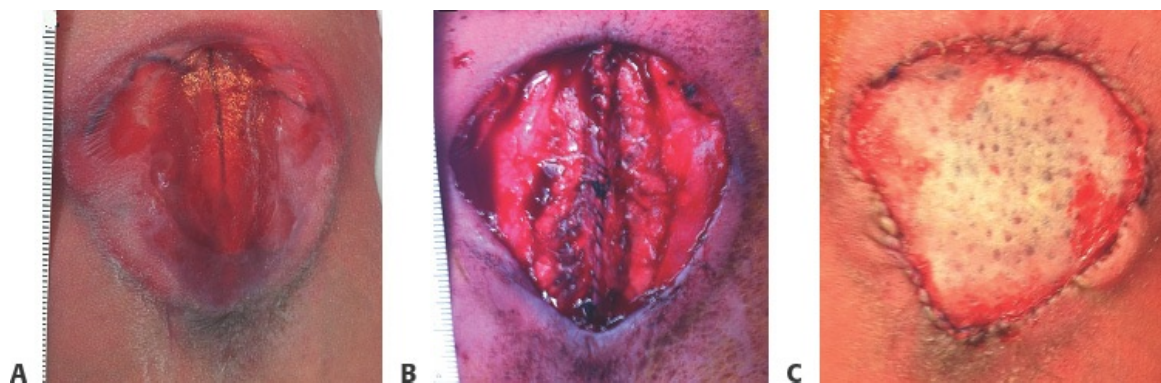
- This is carefully mobilized over the underlying tissue and rotated over the placode (**TECH FIG 3A**).
- The dura may be thin or absent in the sacral portion of the MMC.
- The next layer is the myofascial layer (**TECH FIG 3B**).
 - An incision is made in the fascial layer. This needs to be several centimeters away from the opening to allow it to be rotated over the dural closure without tension. Mobilization of the layer can be assisted by releasing this layer from the opening spina bifida elements.
 - This layer is rotated to the midline and closed (**TECH FIG 3C**).
- After closure of the myofascial flaps, the skin is further undermined. Additionally, extension of the superior and inferior skin edges can increase the mobilization of the skin flap.
- The skin flaps are then rotated to the midline and closed in two layers (**TECH FIG 3D**).

Additional Maneuvers

- If the skin cannot be mobilized, additional maneuvers are sometimes needed.
- This can include placing an AlloDerm patch (LifeCell, Branchburg, NJ) (**TECH FIG 4**), relaxing incisions in the posterior axillary line, or Z-plasty extensions.



TECH FIG 3 • **A.** The dural flaps are rotated over the placode and closed in the midline. **B.** Exposure of the lateral myofascia. **C.** Rotation and closure of the myofascial flaps. **D.** Appearance of the skin after closure.



TECH FIG 4 • Appearance of a large MMC preoperatively (**A**), which resulted in a skin wound (**B**) that required an AlloDerm patch (**C**).

PEARLS AND PITFALLS

Closure

- A multilayer watertight closure is essential to prevent wound breakdown and protect the placode from further damage or infection.
- If fluid collections form that are consistent with pseudomeningoceles, this needs to be treated, normally with CSF diversion.
- It is important to be aware of the vascular supply to skin flaps to prevent necrosis of the skin when performing Z-plasty or relaxing incisions.

Intraoperative care

- The patient needs to be positioned to take pressure off the abdomen and other pressure points; this will promote venous return, reduce bleeding, and prevent pressure sores.
- The patient should be prepped and draped widely to allow multiple options for skin closure.

POSTOPERATIVE CARE

- The patient is cared for in the neonatal ICU. Close observation for bladder dysfunction, pressure points, and orthopedic issues is paramount.
- Special attention should be paid to the examination of the wound. Wound care is very important as the wound is in the lumbosacral area and is prone to

contamination with stool or urine. A drape separating the anal region from the MMC closure should be placed to divert stool, but local wound care must be maximal to prevent infection.

- The child needs to be monitored for the development of hydrocephalus. In patients with a full fontanelle, enlarging pseudomeningoceles, or other clinical signs of hydrocephalus, they should be treated with CSF diversion, either with a ventriculoperitoneal shunt or an external ventricular catheter.

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62 Myelomeningocele, Prenatal (Fetal) Repair

CHAPTER

Gregory G. Heuer and Scott N. Adzick

DEFINITION

- Myelomeningocele (MMC) is a congenital malformation of the spinal cord in the family of neural tube defects and spina bifida as described in the previous chapter (Myelomeningocele, Postnatal Closure).
- Prenatal surgery was first attempted in the 1990s. A randomized controlled trial, the Management of Myelomeningocele Study (MOMS), demonstrated that closure during the prenatal period could be performed relatively safely and can result in significant benefit to the child.¹

ANATOMY

- The MMC results from failure of neurulation resulting in an “open book” of distinct elements that are normally closed over the spinal cord (**FIG 1**) as described in the Myelomeningocele, Postnatal Closure chapter.

PATHOGENESIS

- During neurulation, normally the neural tube undergoes an ordered process of formation and closure as described in the Myelomeningocele, Postnatal Closure chapter.

NATURAL HISTORY

- MMC leads to irreversible loss of nerve function at the level of the exposed spinal cord as described in the previous chapter (Myelomeningocele, Postnatal Closure).
- In addition, a fetus with MMC will progressively develop two associated conditions as the result of the continued cerebrospinal fluid (CSF) leak, a Chiari malformation with hindbrain herniation and hydrocephalus.²

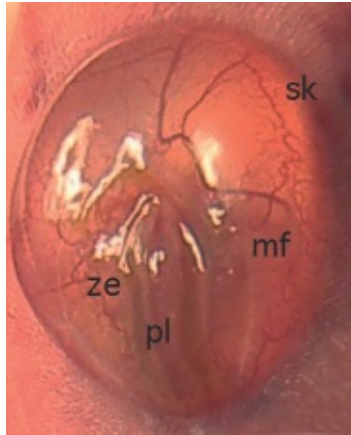


FIG 1 • Appearance of an exposed MMC defect during a fetal repair. The neural placode (*pl*) is seen at the center. This is surrounded by the zona epitheliosa (*ze*) and the skin (*sk*). The myofascial layer (*mf*) covered by dura can be seen through the translucent arachnoid.

PRENATAL EVALUATION

- Expectant mothers receive extensive prenatal testing to determine if they are candidates for prenatal surgery. The inclusion and exclusion criteria in the MOMS trial are still used by most fetal therapy centers (Table 1).³
- Ultrasound (US) examination is performed for three reasons: to define the MMC defect and its spinal level, look at associated CNS abnormalities, and evaluate the fetus for other structural abnormalities.
- With regard to the MMC defect and CNS-associated conditions, US is used specifically:
 - To define the level of bone and skin opening
 - To analyze the posterior fossa, specifically to look for the presence of hindbrain herniation (must be present as it confirms an open neural tube defect)
 - To determine the size of the lateral ventricles and degree of ventriculomegaly
 - To look for any associated abnormalities such as a spinal cord syrinx, a split cord malformation, or a significant kyphosis that may affect the eligibility of the patient for fetal MMC repair.
- Patients also receive a fetal magnetic resonance imaging (MRI) scan. These scans provide a more detailed anatomic evaluation of the MMC defect and associated abnormalities, particularly the presence of hindbrain herniation.

- In addition to imaging, the fetus undergoes an analysis for genetic or chromosomal abnormalities. Also, amniotic fluid analysis is performed to confirm an open neural tube defect.
- A detailed medical history for the mother is obtained, specifically looking for significant maternal health issues and risk factors associated with premature delivery.

SURGICAL MANAGEMENT

- The overall goal of the surgical repair is to obtain a multilayer closure that is watertight. To provide the greatest possible benefit to the fetus, the closure needs to protect the neural structures from direct trauma, prevent the leakage of CSF, and prevent the exposure of the neural structures to amniotic fluid. Additionally, the closure needs to be done in a manner that is safe for the fetus and the mother, as extreme premature birth can erase all potential gains of the surgical procedure. There are some modifications of the general technique outlined below, but the principles above should not be compromised.

Preoperative Planning³

- A preoperative US is obtained to confirm the location of the fetus and the placenta.

Table 1 MOMS Trial Inclusion and Exclusion Criteria

Inclusion	Singleton pregnancy
	Lesion level T1-S1
	Evidence of hindbrain herniation
	Gestational age of 19.0–25.9 weeks
	Normal karyotype
	U.S. residency
	Maternal age of 18 years or older
Exclusion	Fetal anomaly unrelated to myelomeningocele
	Severe kyphosis greater than or equal to 30 degrees
	Multiple gestation
	Previous spontaneous preterm birth less than 37 weeks
	Short cervix less than 20 mm
	Placental abruption or abnormal placentation (placenta previa)

	Obesity defined as BMI > 35
	Maternal medical condition that would place an additional risk to maternal health/surgical risk or the pregnancy (insulin-dependent diabetes, poorly controlled hypertension)
	Documented history of incompetent cervix or planned/current cerclage
	Maternal-fetal Rh isoimmunization, Kell sensitization, or a history of neonatal alloimmune thrombocytopenia
	Maternal HIV, hepatitis B or hepatitis C positivity
	Uterine anomaly such as multiple fibroids or müllerian duct abnormality; previous hysterotomy in the active segment of the uterus
	Patient does not have a support person
	Inability to comply with the travel and follow-up requirements
	Patient does not meet other psychosocial criteria to handle the implications of the trial
	Participation in another study that influences maternal and fetal morbidity and mortality or participation in this trial in a previous pregnancy

- The mothers receive an epidural catheter for delivery for intraoperative and postoperative pain control.
- Antibiotics and indomethacin are given.

Positioning and Anesthetic Concerns³

- The mother is placed supine on the operating room table with a bump placed under the right side to avoid inferior vena cava compression by the gravid uterus and compromise of venous return.
- The surgery is performed under deep general anesthesia, with the goal to achieve maximum uterine relaxation. In addition to maternal anesthetic, the fetus receives a direct dose of intramuscular anesthesia (vecuronium and fentanyl).
- The cardiac function of the fetus is continually monitored by fetal echocardiography. If a decrease in cardiac function is seen, the anesthetic to the mother is adjusted or the fetus is examined for signs of umbilical cord or

placental compression.⁴

- An arterial line is placed in the mother.

Approach

- The uterus is approached via a low transverse maternal laparotomy. Of note, the uterus is opened in the upper muscular portion and not the lower segment used for typical cesarean sections (**TECH FIG 1A**).
- The site of the placenta is mapped out on the surface of the uterus. If the placenta is anterior, the uterus is rotated out of the abdomen to gain access to the fundus and posterior uterine wall. The goal is to open the uterus at least 6 cm away from the placental edge. In addition to the placenta, the location of the fetus is noted so that the hysterotomy is made directly over the MMC defect to minimize the need for manipulation of the fetus. In some cases, the fetus is moved prior to opening the uterus to aid in this exposure.
- The uterus is opened under continuous sonographic visualization.
 - Two monofilament traction sutures are placed through the full thickness of the uterus.
 - A Bovie cautery is then used between the sutures and the uterus opened.
 - An atraumatic clamp is placed through this opening to compress the uterine tissue and to facilitate the firing of a specialized uterine stapling device that is only partially inserted. This device places a row of absorbable polyglycolic acid staples across the uterine wall and fetal membranes. This device cuts the uterine wall at the same time it places the staples, holding the layers together in a normal anatomic position and occluding crossing blood vessels. This is then repeated in the opposite direction to create the 6-cm hysterotomy.
 - An infusion of body temperature lactated Ringers with a level I infusion device is used to maintain the uterine volume and keep the fetus warm and buoyant.
 - The fetus is then held in the hysterotomy incision so that the back and MMC defect are in the opening.
- After the MMC repair the uterus and then the maternal laparotomy are closed in a layered fashion.
 - Full-thickness stay suture is placed first, followed by a running full-thickness layer that incorporates the absorbable staples. During this closure the uterus is filled with the lactated Ringers solution to reconstitute the amniotic fluid volume, and intra-amniotic antibiotics are added.
 - The running layer suture is tied followed by tying of the individual stay

sutures.

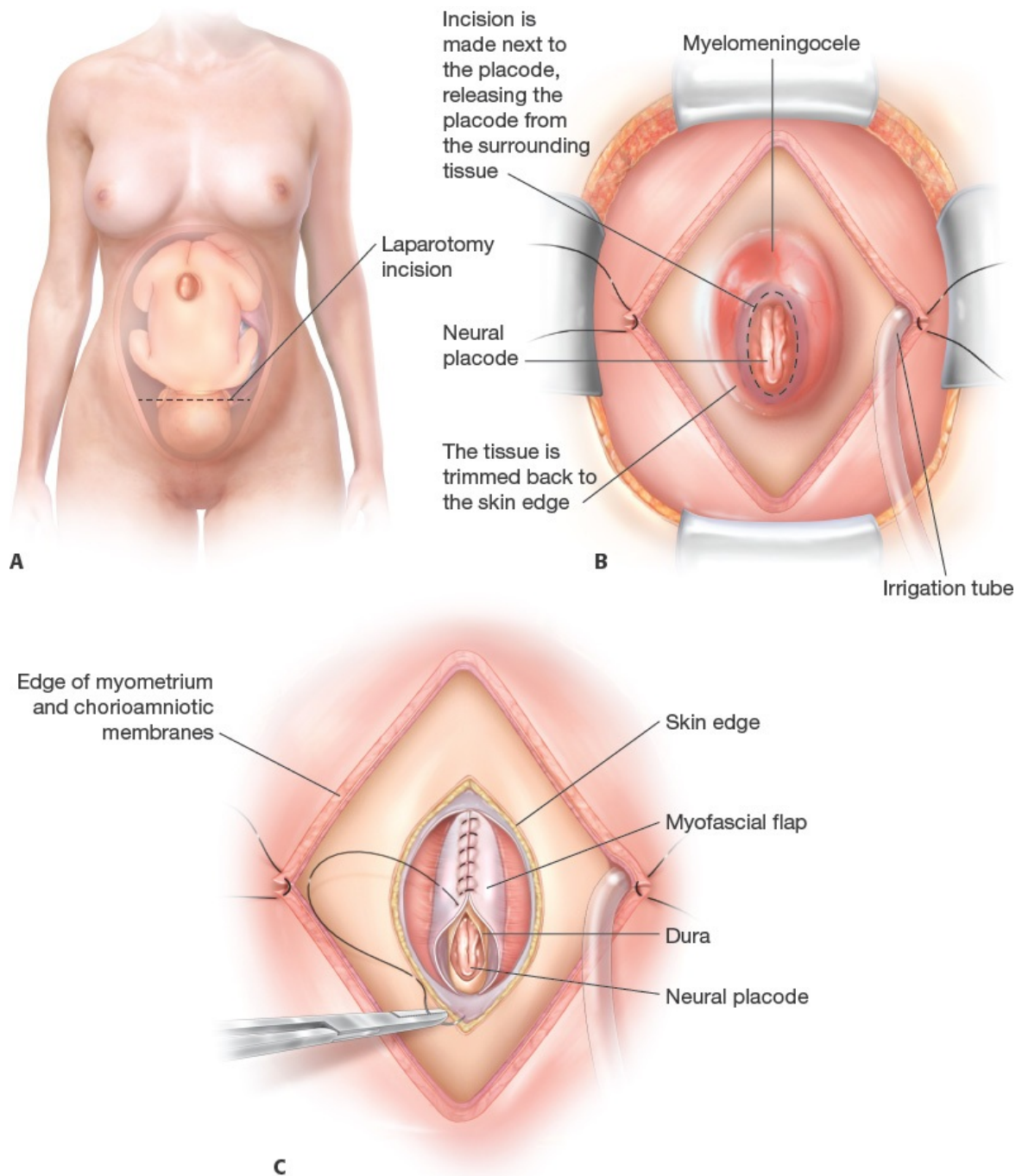
- The uterine closure is then covered with an omental patch to help seal it and provide blood supply.
- The laparotomy wound and skin are then closed.

TECHNIQUES

- Fetal MMC repair is performed in the same manner as postnatal repair. There are three important differences to the prenatal repair compared to the postnatal repair.⁵
 - First, one advantage of fetal MMC closure is the chance to maintain spinal function, and therefore, even greater care is needed in the fetal patient to minimize any trauma to the placode and neural tissue.
 - Second, the fetal tissue is more delicate than in a newborn, and therefore it may tear with even minor manipulation.
 - Lastly, maneuvers, such as pulling the skin tightly, that may be tolerated in a newborn may lead to cardiac depression in the fetus and are therefore avoided.

■ Release of the Placode

- The tissue just lateral to the placode is sharply incised, releasing the placode to float ventrally into the spinal column (**TECH FIG 1B**).



TECH FIG 1 • The laparotomy incision is shown in **A**. The incision in the uterus is performed in the upper segment. **B**. The exposed MMC defect. The fetus is positioned to allow access to the MMC defect and monitor the fetal cardiac function. **C**. The exposed MMC defect is then repaired.

- It is often necessary to make this incision further from the placode than desired to avoid damaging the spinal cord or exiting nerve roots. In these cases, the residual tissue should be dissected from the placode to reduce the risk of subsequent inclusion cyst formation.
-

■ Skin Release and Mobilization

- The skin is then released from the underlying fascia and muscle.
 - The skin is undermined using scissors in an elliptical fashion for several centimeters.
 - Undermining of the skin allows the skin to be mobilized, resulting in greater exposure of the underlying fascia and skin that can be more easily rotated over the fascia during the skin closure.
 - Care needs to be taken to stay in the proper plane and avoid tearing the skin during this undermining process.
-

■ Dura and Myofascial Closure

- The next step is closure of the lateral tissue over the placode.
- The goal of the closure is a watertight closure over the placode.
 - The skin is held with a retractor, exposing the lateral dura and fascia. The skin opening can be extended superiorly and inferiorly to aid in the exposure of the fascia.
 - An incision is made in the lateral tissue and this tissue is then rotated over the released placode. Some authors close only the dural layer, but we prefer a thick myofascial flap with the dural layer on the mesial surface to ensure watertight closure and direct contact between the delicate dural layer and the neural placode.
 - The myofascial flaps are then closed with a running suture such as a 4-0 polydioxanone (PDS). When this thick layer is closed in the midline, care is taken to approximate the dural surfaces and to protect the placode. This protection can be assisted with placement of a freer retractor over the placode during the suturing (**TECH FIG 1C**).

Skin Closure

- After closure of the myofascial flaps, the skin is further undermined.
- The skin flaps are then rotated to the midline; an assessment is then made if

flaps can be rotated to the midline without tearing the tissue significantly or leading to tension-related cardiac depression.

- A running monofilament, such as 4-0 PDS, is placed. The suture should be placed loosely; once the suture has been placed across the opening, the suture is pulled tight after each stitch in a stepwise fashion until the skin edges meet. This “lacing” technique allows the tension to be spread across the incision and reduces tearing. Additionally, to reduce the chance for tearing the suture through the skin, the suture should be placed away from the skin edge and in the thicker portion of the skin flaps.
- If the skin cannot be closed, a graft is then sized to the opening. This graft is normally constructed with AlloDerm (LifeCell, Branchburg, NJ) and is elliptical in shape. It is sutured with two running monofilament sutures.
- Other groups have described the use of relaxing incisions in the flank to aid in mobilization. However, these are generally not used because they are at risk to fail from devascularization after skin mobilization.

PEARLS AND PITFALLS

Selection	■ A detailed study of the mother and fetus is necessary for proper patient selection, confirming the presence of an open neural tube defect and no other associated fetal or maternal abnormalities that will prevent a good outcome.
Closure	■ A multilayer watertight closure is essential for maximal benefit to the fetus. ■ The goal of the surgery is to release the neural tissue and then rotate and close the layers over the placode, consisting of the dura, muscle, and skin.
Intraoperative Care	■ A dedicated fetal team is essential for a good outcome. This team should include fetal surgery, experienced anesthesia, obstetrics, and fetal cardiology.
Outcome	■ Fetal MMC repair can result in significant benefits for motor function, reversal of hindbrain herniation, and reduction in hydrocephalus.

POSTOPERATIVE CARE

- Postoperative care is focused on maintaining the pregnancy.
- During the operative procedure, the mother is given a bolus of magnesium sulfate and started on an infusion. This reduces uterine contractions and the risk for premature delivery. This infusion is continued for the first 18 to 24 hours.
- The mother is started on oral nifedipine after the magnesium sulfate infusion.
- The mother is given indomethacin prior to surgery, and this is continued for 48 hours postoperatively.
- The mother is observed as an inpatient for an average of 4 days and then is discharged to modified bed rest. The mother is followed closely for signs of premature labor or amniotic fluid leakage.
- Delivery is performed via an elective cesarean section prior to the development of labor and contractions, as this could lead to uterine rupture. The goal is to deliver at 37 weeks, but often the delivery is performed earlier than this time.

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CHAPTER Sacrococcygeal Teratoma

Nicholas J. Ahn and William H. Peranteau

DEFINITION

- Usually benign extragonadal germ cell tumor that develops prenatally, involving the coccyx with various degrees of pelvic and intra-abdominal involvement.
- It is the most common congenital neoplasm found in fetuses and neonates.
- Between 11% and 35% of the tumors may contain malignant elements such as yolk sac tumor or embryonal carcinoma.¹
- Large or solid tumors may lead to poor clinical outcomes due to high-output cardiac failure, hydrops fetalis, tumor rupture, or internal hemorrhage.²
- Surgical resection is the mainstay of treatment but has associated morbidities such as problems with micturition, defecation, or cosmetic dissatisfaction up to 40% to 50%.³ Large tumors with significant pelvic/intra-abdominal involvement have the most significant risk for urologic and anorectal complications.⁴

ANATOMY

- All sacrococcygeal teratomas (SCTs) involve the coccyx but are classified into four categories according to the location and extent of the tumor—the Altman Classification Scheme.⁵
 - Type I: primarily external with a small presacral component
 - Type II: external with intrapelvic extension
 - Type III: primarily pelvic and intra-abdominal with external component
 - Type IV: completely intrapelvic with no external component

PATHOGENESIS

- SCTs are thought to originate from the primitive knot (also known as Hensen node), where the three germ cell layers start to form.
- SCTs may be cystic, solid, or a mix of both. Solid tumors tend to be more vascular and are associated with an increased risk of high-output cardiac failure, hydrops fetalis, tumor rupture, hemorrhage, and fetal demise.

PATIENT HISTORY AND PHYSICAL FINDINGS

- The majority of the lesions are now diagnosed by the time of birth as early as 18 to 19 weeks of gestation due to advancement in antenatal imaging.
- Type I to III lesions that are not diagnosed prenatally are identified at birth by an obvious protruding mass originating from the sacral region.
- A rectal exam must be performed to assess the degree of intrapelvic extension of the tumor, especially for tumors that were diagnosed postnatally.
- Rarely, some type IV lesions can go undiagnosed until the child is up to 4 years of age and present with compressive symptoms of the bladder or rectum, such as urinary retention, obstruction, or constipation.

IMAGING

- Most SCTs are diagnosed prenatally at the time of approximately 20-week gestation fetal anatomy ultrasound. If diagnosed, the mother and fetuses should be referred to a high-volume multidisciplinary fetal diagnosis and treatment center where a high-resolution fetal ultrasound will be performed to assess the anatomical extension of the tumor and the characteristics of the mass (solid, cystic, vascularity) (**FIG 1A**).
- Ultrafast fetal MRI is used as an adjunct to ultrasonography to better assess the SCT, including the pelvic or abdominal extension of the tumor and its involvement with surrounding structures such as the colon, urinary tract, vagina, hip, and especially the spine (**FIG 1B**).
- After birth, hemodynamically stable infants may undergo a CT scan or MRI to assess the extent of the tumor for preoperative planning (**FIG 2**).

DIFFERENTIAL DIAGNOSIS

- Meningocele
- Lymphangioma
- Enteric duplication cyst
- Dermoid cyst
- Retrorectal hamartoma

- Meconium pseudocyst
- Tail remnant
- Lipoma

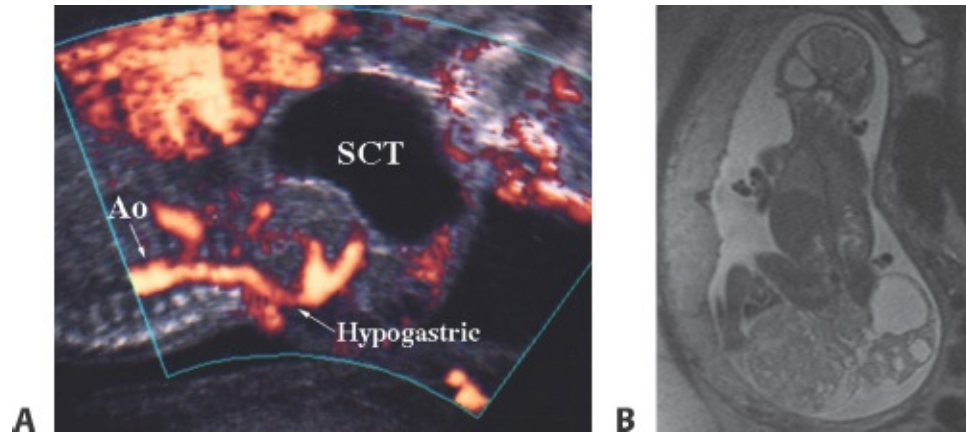


FIG 1 • Prenatal SCT imaging. **A.** High-resolution fetal ultrasound demonstrating a predominantly cystic type I SCT with blood supply originating from the hypogastric vessel. **B.** Ultrafast fetal MRI demonstrating a large type I SCT that has solid and cystic components.

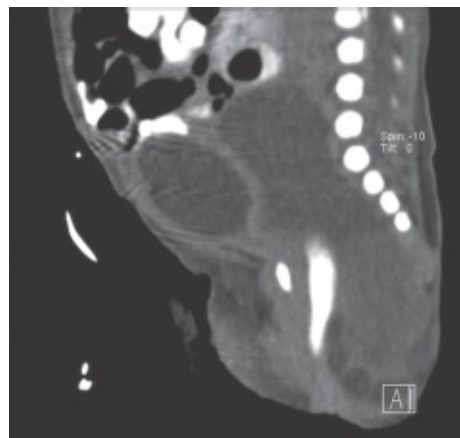


FIG 2 • Postnatal SCT imaging. Postnatal CT scan demonstrating a predominantly type II SCT.

SURGICAL MANAGEMENT

Preoperative Planning

- Fetuses with external tumors that are larger than 5 cm, predominantly solid, or have a significant vascular supply should be delivered by cesarean delivery to decrease the risk of catastrophic bleeding or tumor rupture.
- If the patient is stable, the tumor can be resected within the first week of life.
- CBC, type and screen, and cross-match must be performed in anticipation of surgery.
- Alpha-fetoprotein (AFP) and β -HCG levels should be obtained prior to surgery.
- CT scan or MRI of the abdomen and pelvis with contrast should be performed as discussed above in stable patients.

Positioning

- Most type I and type II lesions can be resected with the patient in prone jackknife position and completely resected from the posterior approach (**FIG 3**).



FIG 3 • Positioning. Prone position of newborn with large type I SCT.

- Lesions with significant intra-abdominal components often require an anterior (laparotomy) as well as posterior approach for complete resection and thus should be positioned supine for the anterior approach initially.
- Towel rolls or gel pads should be used to support the patient's shoulder and

pelvis from underneath when in the prone position.

- If uncertain regarding possible laparotomy, the patient should be sterilely prepped from the chest to the toes to allow for free intraoperative repositioning without repreparation and draping.

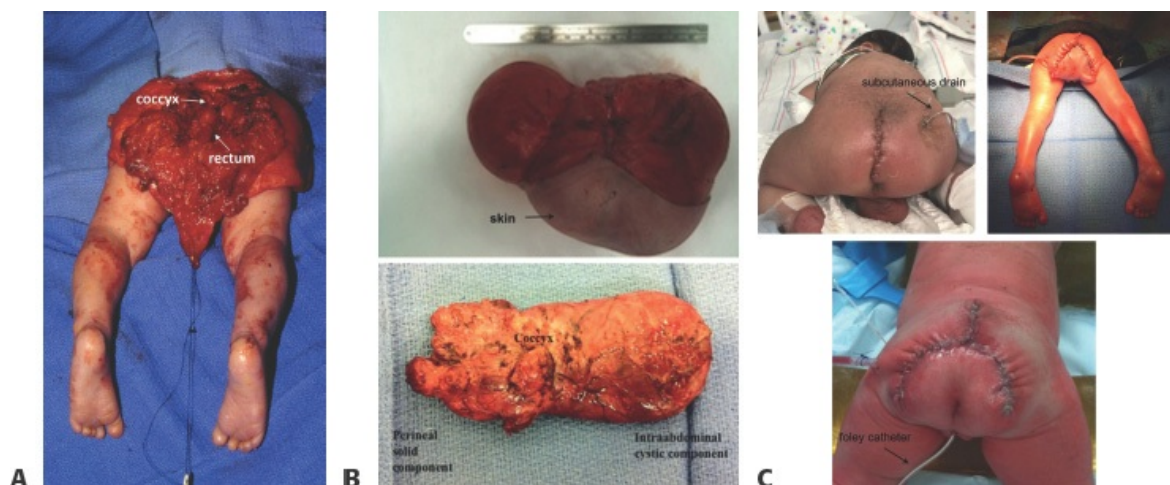
Approach

- Most type I and II lesions can be completely resected from the posterior approach.
- Lesions with large intra-abdominal components (some type III and type IV) require a combined anterior approach via a laparotomy and a posterior approach.

TECHNIQUES

■ Posterior Approach (TECH FIG 1)

- Landmarks: gluteal crease, sacrococcygeal junction, anal orifice
- A Foley catheter is placed prior to placing the patient in the prone jackknife position.
- The incision is made over the external component of the tumor in an orientation that allows for the development of large skin flaps. This often involves a transverse incision in an inverted V shape that starts at the sacrococcygeal junction.



TECH FIG 1 • Posterior approach for postnatal SCT resection. **A.** Most type I and II SCTs can be approached from the posterior approach. Care must be taken to identify the anus/rectum to avoid injuring it. The coccyx is identified and resected with the specimen. The surgeon must also try to save the attenuated muscle fibers to reconstruct the pelvic floor following tumor resection. **B.** Resected specimen. Ideally the tumor and coccyx are resected as a single specimen. Often thin, extra skin is resected with the tumor specimen as there is frequently redundant skin available for appropriate skin closure. **C.** Skin closure following SCT resection.

- The incision is carried down to the tumor capsule, which, in many cases, is very superficial.
- Being cognizant to stay on the tumor capsule to preserve attenuated muscle fibers that will later be used to reconstruct the pelvic floor, the tumor is circumferentially dissected out as skin/muscle flaps are raised.
- Identify and always be cognizant of the position of the anus and rectum, which are often displaced and closely opposed by the SCT. Placement of a Hegar dilator or large red rubber catheter in the anal opening helps the surgeon identify and avoid injury to the anus/rectum.
 - For tumors with a large intrapelvic component, similar attention should be paid to the ureters.
- Dissection of the tumor along its posterior superior border will lead the surgeon to the coccyx, which must be identified and resected.
 - The sacrococcygeal junction is identified and circumferentially dissected out.
 - Care is taken to stay on the anterior surface of the sacrococcygeal junction during dissection to avoid injury to the vascular supply to the tumor that usually originates from the middle sacral artery or branches from the hypogastric.
 - With an instrument on the anterior surface of the coccyx to protect underlying vessels, the sacrococcygeal junction is transected with a Bovie.

- Ligate the vascular supply to the tumor after the coccyx is transected at the sacrococcygeal joint.
 - The tumor and coccyx are ideally resected as a single specimen (**TECH FIG 1B**).
 - The muscles of the pelvic floor and anorectal sphincter are reconstructed.
 - Excess skin is removed to allow for the best appearance.
 - The skin is often closed in a “Mercedes” sign but can be closed in a vertical incision (often following complete resection after an initial debulking, see below) if more cosmetically appropriate (**TECH FIG 1C**).
 - If large skin flaps are raised, the skin is closed over a small drain.
-

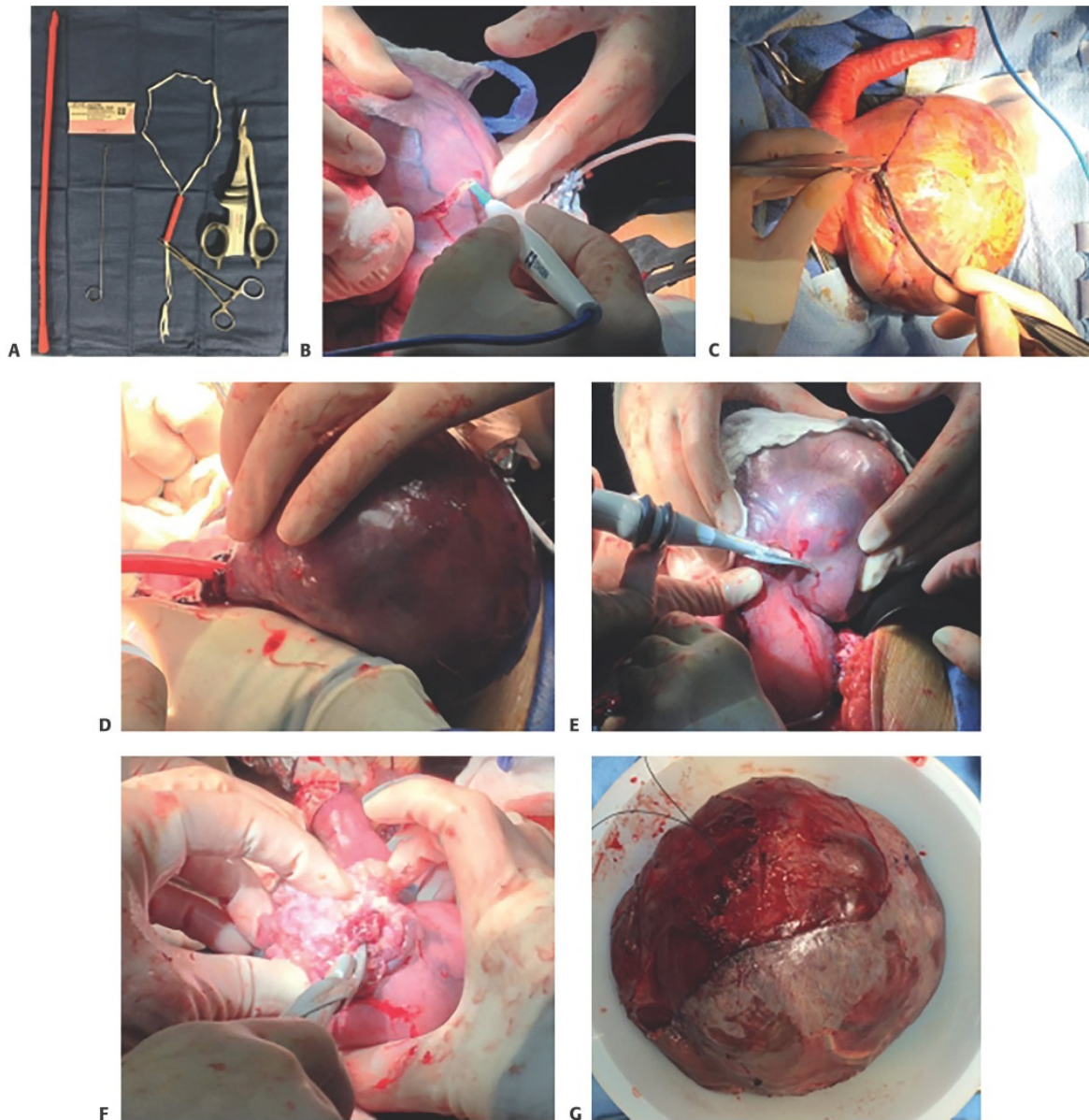
■ Anterior Approach

- Tumors with large intra-abdominal/intrapelvic components often require a laparotomy via an anterior approach in combination with the above posterior approach.
 - The anterior approach is done initially with the goal of identifying and controlling the vascular supply to the tumor prior to significant dissection of the tumor.
 - Large intra-abdominal/intrapelvic tumors may be closely associated with the colon, intestinal mesentery, and the ureters all of which should be identified and preserved.
 - The laparotomy is performed via a transverse incision between the umbilicus and pubic symphysis or, in cases with a very large intra-abdominal component, may be approached via a midline incision.
 - After controlling the vascular supply to the tumor and dissecting out the intra-abdominal component of the tumor, the patient is flipped to the prone position and the remainder of the tumor and coccyx resected.
-

■ Special Considerations—Debulking (**TECH FIG 2**)

- Large, predominantly solid lesions often have increased tumor vascularity and may be associated with high-output cardiac failure prenatally or immediately after birth. Fetuses with these lesions require close prenatal follow-up with assessment by high-resolution ultrasound often twice a week to monitor combined cardiac output and for signs of hydrops fetalis.

- If the SCT has a significant solid external component and there are signs of hydrops or early heart failure, the fetuses may be a candidate for debulking of the external component of the SCT. Depending on the gestational age of the fetus, this may occur as a cesarean delivery with immediate debulking after birth or open fetal surgery.^{2,6}
- The techniques of open fetal surgery are beyond the scope of this chapter.
- Surgical debulking includes the following:
 - A posterior approach to the tumor
 - The anus is identified and a Hegar dilator or red rubber catheter placed to assess the tract of the rectum.
 - The skin at the base of the external component of the SCT is scored with a Bovie.
 - A tourniquet consisting of an umbilical tie, and a cut large red rubber catheter is placed at the base of the SCT where the skin had been scored.
 - The tourniquet is tightened, and a harmonic scalpel is used to transect the tumor above the level of (distal to) the tourniquet.
 - The tourniquet is slowly released, and hemostasis is obtained by oversewing bleeding vessels with a 5-0 Prolene.
 - The skin is reapproximated and sutured over the cut edge of the tumor.
 - The infant is then resuscitated and cared for in the neonatal intensive care unit.
- All patients undergoing surgical debulking will require a second operation to complete the resection of the tumor, including the coccyx, once the infant is stable and well recovered (usually greater than 6 weeks after debulking).



TECH FIG 2 • SCT debulking. Large type I SCTs that threaten hemodynamic stability may require debulking prior to or immediately after birth. Some of the main instruments required for debulking (**A**). The skin of the tumor is scored with a Bovie near the base of the SCT (**B,C**). A tourniquet constructed from an umbilical tie, and a cut large red rubber catheter is placed around the base where the skin was scored (**D**). A harmonic scalpel is used to transect the tumor above the

tourniquet **(E,F)**. The tourniquet is released and bleeding vessels oversewn. Note, unlike formal resection of an SCT, debulking does not remove the coccyx or intrapelvic/intra-abdominal tumor components **(G)**. These components will be resected after recovery and stabilization from debulking.

PEARLS AND PITFALLS

Positioning and prep

- If uncertain of need for laparotomy, prep the patient from lower chest to toes to allow for repositioning during the case without the need for new prep and drapes.

Technique

- A Hegar dilator can be used to identify the rectum and avoid damage.

Complete resection

- The coccyx must be resected to lower the risk of recurrence.

POSTOPERATIVE CARE

■ Immediate postoperative care

- The patient should be positioned to avoid pressure on the wound as much as possible.
- The wound should be monitored for bleeding, dehiscence, or infection.
- If the tumor had a significant intrapelvic extension, urinary retention may occur, requiring a Foley catheter or intermittent catheterization.

■ Follow-up

- Final pathology should be followed up to rule out malignancy.
 - Benign lesions may be managed with surgical resection and observation alone.
 - If malignant elements are noted on histology, a consultation with oncology may be needed.
- All patients should be followed long term with rectal examinations and AFP levels every 3 to 6 months until the age of 3.

- The AFP level should return to normal by 9 months.
- If still elevated after 9 months or a mass is palpated on rectal exam, an MRI or CT scan must be performed in suspicion of a recurrence.

■ Recurrence

- Tumor spillage, incomplete resection, and malignant or immature histology are risk factors for recurrence.
- If recurrence is noted, a full metastatic workup including a CT chest, abdomen, pelvis, and laboratory studies are required.
- Management of recurrence requires re-excision with or without chemotherapy.

OUTCOMES

- The survival rate is greater than 90% if SCT is diagnosed on routine prenatal ultrasound.
- If the indication for the ultrasound examination was due to another complication of pregnancy, the mortality rate increases to 60%.
- If hydrops or placentomegaly is present, the mortality almost reaches 100%^{2,7} if no intervention performed.
- Recurrence after resection occurs in about 10% to 15% of all patients with SCT, as early as 1 month to as far out as 59 months post-op (median 10–16 months).
- Survival rate is decreased with recurrence: 90% without recurrence and 65% with recurrence.

COMPLICATIONS

- Prevalence of anorectal morbidities including severe constipation and fecal incontinence ranges from 6% to 60% of the patients.
- Urologic bladder, vesicoureteral reflux, and urinary incontinence can manifest in 5% to 45% of the patients.
- Large intrapelvic extension of the tumor is associated with these morbidities.⁴

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Section XVII: Abdomen

64

CHAPTER Prune Belly

Jamie C. Harris and Fizan Abdullah

DEFINITION^{1,2}

- Prune belly is an extremely rare disease, occurring in 1/35 000 live births. The majority of patients are male (**FIG 1**).
- It is characterized by three components: abdominal wall flaccidity, bilateral undescended testes, and urologic anomalies.
 - Abdominal wall laxity is associated with increased rates of respiratory infections, due to a poor cough mechanism, as well as increased incidence of lordosis.
 - Urinary tract anomalies lead to increased rates of infectious complications as well as ureteral obstruction; 81% of patients have megaureter.
 - Urinary tract abnormalities can include renal dysplasia and ureteral enlargement.
 - Additionally, both testes are intra-abdominal in the majority of patients.
- Overall outcome of the children is variable, with some not surviving past the neonatal period due to complications to some with minimal disease complications.

DIFFERENTIAL DIAGNOSIS

- Prune bellylike variant: abdominal flaccidity. However, unlike in prune belly, the rectus muscles are not involved.

Patient History and Physical Findings³

- Prenatal history is often unremarkable. However, oligohydramnios may be present.
- Physical examination

- A wrinkled abdomen with more laxity noted in the medial and inferior regions. This is a distinctive feature of prune belly. There will be redundant skin over the abdomen.



FIG 1 • This demonstrates the laxity in the abdominal wall of prune belly.

- As the children age, the abdomen will look more protuberant and less wrinkled.
- If portions of the urinary system are massively dilated, these can sometimes be palpated on abdominal exam.⁴
- Scrotal exam will reveal bilateral absence of testes in the majority of cases.
- Cardiac anomalies can be associated with prune belly; a cardiopulmonary exam should be included to listen for murmurs.
- Close monitoring of urine output is important to identify any obstructive uropathy that may be present. If present, nephrostomy tubes can be considered for urinary decompression.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Prenatal ultrasound
 - Hydroureteronephrosis, bladder distension, oligohydramnios, and cryptorchidism can be seen on prenatal ultrasound.⁵
- Postnatal urinary tract evaluation
 - Serum creatinine measurements

- This will identify any worsening renal function.
- Baseline measurements should be obtained at birth and trended to determine changes in function, creatinine greater than 0.7 mg/dL has a higher rate of developing renal failure.⁶
- Kidney Ureter Bladder radiograph (KUB):
 - Evaluation of the bowel for dilatation can be done using a KUB. Bowel will extend over the lateral edge of the abdominal wall, which is diagnostic of prune belly.
 - Due to the lack of abdominal wall structure, intestinal malrotation can occur due to poor fixation to the abdominal wall.⁴
- Renal and bladder ultrasound⁴:
 - An ultrasound will demonstrate atresia or absent kidney, hydronephrosis, megaureter, tortuous ureters, or megabladder.⁷
- Voiding cystourethrogram (VCUG):
 - This is used for evaluation of the urethra. It can evaluate for vesicoureteral reflux. If identified, prophylactic antibiotics are indicated.
- Evaluation for associated anomalies:
 - Echocardiogram: should be considered if murmur is appreciated on physical exam.
 - Chest radiograph: if signs of respiratory distress are present, a chest radiograph can identify pneumothorax or pulmonary hypoplasia.

SURGICAL MANAGEMENT^{3,8}

Preoperative Planning

- Respiratory status should be optimized prior to abdominal reconstruction.
- Urinalysis without evidence of infection should be done prior to surgery.
- Nasogastric tube placed prior to operation to decompress intestinal contents.

Positioning

- The patient is placed in the supine position.
- The abdomen is prepped with antiseptic.

Approach

- Two main open exposures have been described for umbilical preservation, described by Ehrlich and Monfort.

- The Ehrlich approach⁸:
 - A midline vertical incision is made from xiphoid to pubis; an inferior transverse incision is made at the lower end of the incision. The umbilicus is left on a vascular pedicle.
 - The midline incision is carried down to the peritoneum.
 - If a urologic repair is to be performed in the same operation, this will now take place.
- The Monfort approach⁹ (**FIG 2**):
 - An elliptical incision is used to remove redundant abdominal wall skin from xiphoid to pubis.
 - The umbilicus is preserved from the full-thickness skin excision with a second incision to preserve its original location.
 - The skin and subcutaneous tissue is dissected away from the underlying fascia, exposing the lateral abdominal wall.

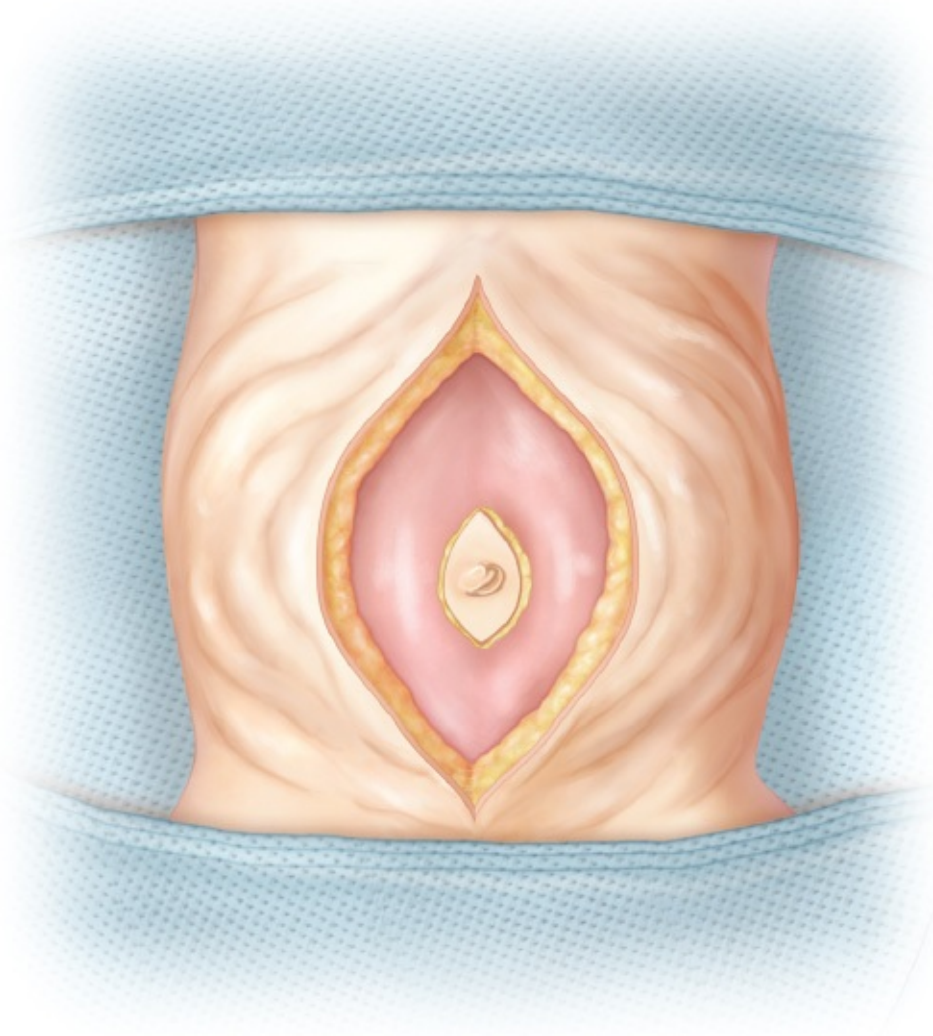


FIG 2 • The area of laxity where the skin will approximate is identified and excised.

TECHNIQUES

■ Ehrlich Approach

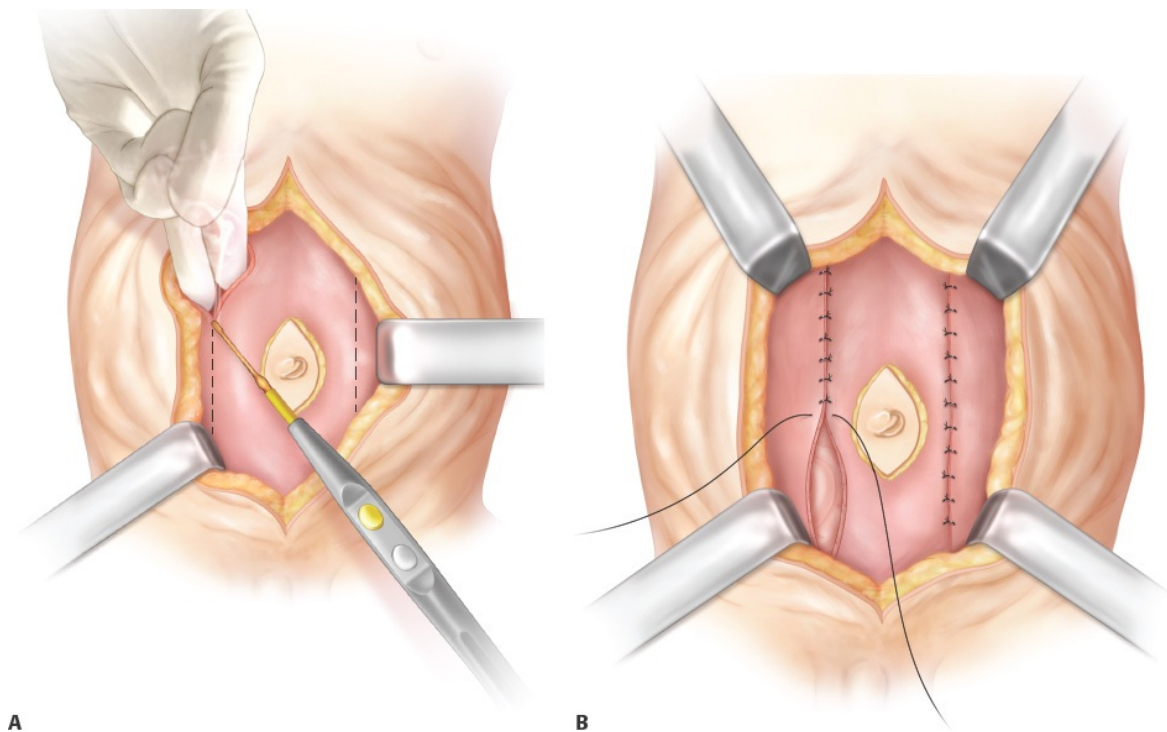
- Skin flaps are created from the midline incision laterally until the level of the midaxillary line, separating the abdominal musculature from the skin and subcutaneous tissue.⁸
- Fascial advancement is then done bilaterally until the two sides are aligned

in the midline.

- If umbilical sparing abdominoplasty is being done, the side with the umbilicus should be anterior.
- Horizontal mattress sutures are used to align the fascia.
- At this time, excess skin is excised bilaterally.

■ Monfort Approach

- Access to the abdomen is created using two fascial incisions to the epigastric arteries.⁹ If urological correction is to be done concurrently, these incisions expose the genitourinary system (**TECH FIG 1A**).
- Once the intra-abdominal portion is completed, the lateral fascia is closed by overlapping the central remaining fascia to decrease abdominal wall laxity bilaterally (**TECH FIG 1B**).

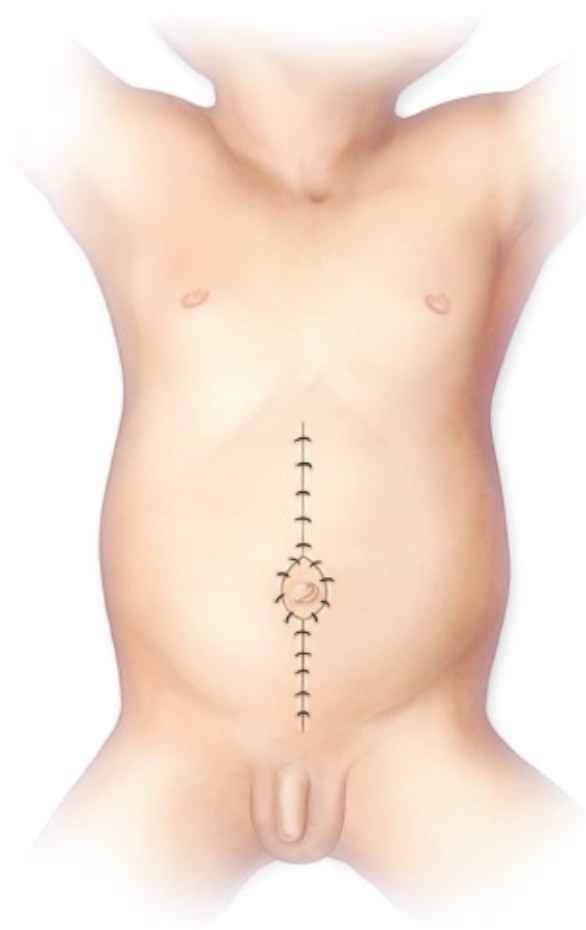


TECH FIG 1 • A. Lateral fascial incisions are made in the Monfort repair, which provides access to the abdominal cavity if urologic corrections are needed. **B.** The lateral fascia is closed by overlapping the central remaining fascia to decrease abdominal wall laxity

bilaterally.

■ Closure

- The skin and subcutaneous tissues are closed in two layers (**TECH FIG 2**).
- A drain is placed in the subcutaneous tissue and maintained to suction to prevent formation of seromas.
- The nasogastric tube is removed prior to extubation.



TECH FIG 2 • The skin is finally reapproximated in the midline, and closed in two layers.

Intraoperative monitoring

- It is important to monitor airway pressures during abdominal wall reconstruction to identify abdominal compartment syndrome.

Laparoscopy

- Laparoscopic abdominoplasty has been described and has been proposed to result in decreased rates of intra-abdominal adhesion formation. The fascia at the level of the anterior rectus muscle is plicated intra-abdominally, and then tacked to the medial fascial wall to reduce laxity.¹⁰

POSTOPERATIVE CARE

- Pain control, initially with intravenous analgesia.
- Subcutaneous drains are maintained to suction until drain output decreases, thereby minimizing the risk of seroma formation.
- An abdominal binder should be worn for 8 to 10 weeks postoperatively.
- Close monitoring of respiratory status is needed, as patients can develop respiratory distress in the postoperative period and may require intubation.

COMPLICATIONS³

- Continued abdominal wall laxity.
- Necrosis of skin flaps; close attention to blood supply of the flaps should be done to maintain adequate perfusion.
- Long-term complications can be related to urological complications.
- Overall mortality of prune belly is about 20% and is usually related to renal complications.

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65 Gastroschisis and CHAPTER Omphalocele

Jamie C. Harris and Fizan Abdullah

DEFINITION

Gastroschisis

- Gastroschisis is the most common congenital abdominal wall defect in the newborn period. This results from failure of the intestines to return back into the abdomen during development around week 10 of gestation.
- The abdominal wall defect is usually less than 4 cm in diameter and is more commonly located to the right of midline.

Omphalocele

- Omphalocele is the second most common abdominal wall defect, 1/5000 live births.
- This is characterized by a large defect, greater than 4 cm, and is covered by a membrane of peritoneum.
- This can contain intestines, as well as liver, spleen, and gonads. Unlike gastroschisis, omphalocele has a high rate of associated anomalies, including chromosomal abnormalities and cardiac defects.

DIFFERENTIAL DIAGNOSIS

- Ruptured omphalocele can be distinguished from gastroschisis based on the size of the defect (greater than 4 cm), as well as contents other than intestines in the defect.
- An umbilical cord hernia will be smaller than omphalocele, and does not contain abdominal organs.
- Pentalogy of Cantrell is a rare constellation of ectopia cordis, omphalocele,

sternal cleft, anterior diaphragmatic hernia, and intracardiac defect.

- In ectopia cordis, the defect is located at the midline of the sternum and contains the heart.

Patient History and Physical Findings

- Prenatal history
 - Often, abdominal wall defects are diagnosed on prenatal screening. Maternal serum and amniotic fluid demonstrates elevated alpha fetoprotein (AFP).
 - Amniotic fluid demonstrates elevated acetylcholinesterase.
 - There is a higher specificity of elevated AFP for gastroschisis compared to omphalocele.
- Postnatal history and physical (**FIG 1**)
 - For both defects, birth history as well as patient stabilization from a cardiopulmonary standpoint should be completed first.
 - Initial inspection should be done to determine:
 - The presence of a covering membrane (indicating omphalocele) (**FIG 1A**).
 - The viability of the intestines, evidence of necrosis, atresias, or perforation.
 - Contents in the defect, including liver, gonads, and other intra-abdominal organs.
 - If these are seen without a covering membrane, ruptured omphalocele should be considered.
 - Full cardiopulmonary exam should be done to determine if there are audible murmurs appreciated, which suggest an underlying cardiac defect.
 - Examination of the rest of the body to examine for any associated anomalies should be done.
 - Omphalocele is associated with multiple different syndromes including Beckwith-Wiedemann (omphalocele, macroglossia, and gigantism), and trisomy 13, 18, and 21.¹

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Prenatal ultrasound
 - Gastroschisis
 - Prenatal ultrasound will demonstrate intestines within the amniotic fluid, outside of the abdomen.
 - This is most commonly seen around 20 weeks of gestation.²
 - Anomalies, most commonly intestinal atresias, can also be identified on

prenatal ultrasound. Bowel dilatation greater than 14 mm is predictive of atresias.¹

■ Omphalocele

- Intestinal contents will be seen outside of the abdomen.
- The sac can be visualized on ultrasound, helping distinguish from gastroschisis.
- Additionally, liver can be visualized in the defect.
- This is seen around 18 weeks of gestation.
- Evaluations of other associated anomalies, including cardiac, can be done on prenatal ultrasound as well.

■ Postnatal echocardiogram

- The rate of cardiac anomalies in omphalocele is higher (14%–47%) than in gastroschisis (3%–33%).³
- Common cardiac anomalies that are seen are ventricular septal defect, atrial septal defect, and tricuspid atresia. A complete cardiac evaluation for omphalocele should be done in the perinatal period.

SURGICAL MANAGEMENT

Preoperative Planning

■ Gastroschisis

- There are two management strategies for gastroschisis:
 - Delayed closure with silo placement, allowing for reduction of the abdominal contents over the following days
 - Immediate reduction with closure at birth

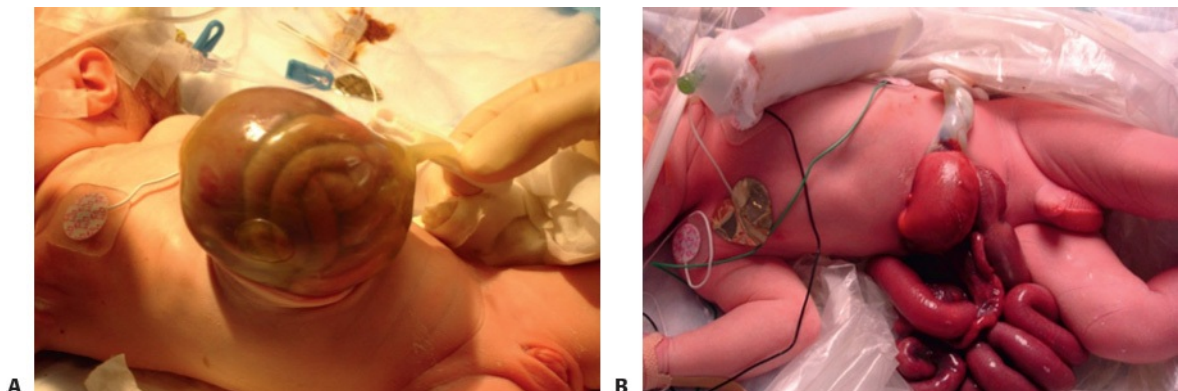


FIG 1 • A. Omphalocele presents with a membrane

covering and the umbilicus originating from this membrane. **B. Gastroschisis** presents with a defect in the abdominal wall without a membrane covering the extruded intestines.

- Many studies monitor intra-abdominal pressures for signs of abdominal compartment syndrome to guide decisions on immediate vs delayed closure.^{3,4}
- When the diagnosis is known prenatally, delivery should be done at a hospital in which pediatric surgeons can be present.
- The current guidelines have shown no difference in outcomes between vaginal delivery and cesarean section for gastroschisis. Delivery modality should be at the discretion of the obstetrician. Additionally, older gestational age is associated with less complications, where 37 weeks is considered term.⁵
- Immediately after birth, the intestines should be covered with sterile moist towels to minimize fluid losses. Intravenous access should be started to replace losses.
- Assessment of the viability of the bowel should be done.
 - If any atresias are noted, this should be documented. These are generally repaired 4 to 6 weeks after birth to allow the intestinal inflammation gastroschisis to decrease.
 - Atretic segments of intestine, if not compromised, are reduced into the abdomen.
- If necrotic or perforated intestines are encountered, termed complex gastroschisis, these are resected and enterostomies are created.
- An orogastric tube should be placed at birth to aid in bowel decompression to facilitate reduction into the abdominal cavity.
- **Omphalocele**
 - When the diagnosis is known prenatally, delivery should be done at a hospital in which pediatric surgeons can be present.
 - Surgical repair is dependent upon the size of the omphalocele. For giant omphaloceles with loss of abdominal domain, primary closure is generally not attempted. These are often complex and require a level of creativity to close. Closure methods that are used include promoting sac granulation by treating with topical agents such as diluted betadine, xeroform, or bacitracin to allow

the peritoneal sac to become firmer and more durable.

- Skin flaps and grafts, such as Gore-Tex mesh, can be used to cover the sac, and negative pressure wound VAC used to promote granulation.
- If the omphalocele is not a giant omphalocele, primary closure of the small omphalocele can be done.

Positioning

■ Gastroschisis

- The patient is positioned in the supine position, with the arms at the patient's side.
- The abdomen should be prepped and draped into the operative field.
- The surgeon is positioned on the right of the patient, while the assistant is on the left.

■ Omphalocele

- The patient is positioned in the supine position, with the arms at their sides.
- Antiseptic prep is used and should include the entire abdomen up to the chest.
- Reduction of the sac contents into the abdomen is performed at this point.

TECHNIQUES

■ Repair of Gastroschisis

Immediate Reduction

- If primary closure is feasible at the time of birth, the umbilical cord can be used to elevate the abdominal cavity to reduce the intestines within the cavity.
- Once the intestines are returned to the abdominal cavity, closure of the defect can be managed in a similar fashion with both methods.

Delayed Closure With Silo Placement

- The infant is placed supine⁶ (**TECH FIG 1**).
- The silo bag can either be spring loaded, which is placed below the fascia, or sutured to the fascia.
- The intestines are maintained in the silo.

- It is important to maintain upward traction on the silo to maintain bowel orientation and minimize any twisting or kinking of the mesentery to minimize the risk of ischemia.
- Once secured, serial reduction of the intestine within the silo is done, and complete reduction is usually accomplished within 2 to 3 days of life.
- Often, the silo can be placed with light sedation to minimize the need for general anesthesia in an infant.

Closure

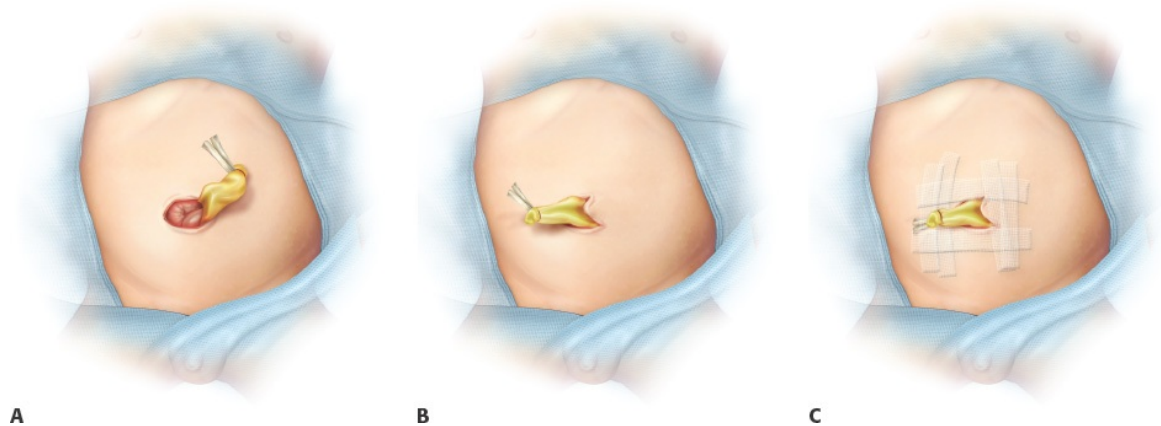
- Sutured closure of the defect is done after the intestines are reduced to the abdomen.
 - The fascia is then closed using either a purse-string or interrupted suture closure.
 - The skin is closed using a running subcuticular stitch.
- Alternatively, sutureless closure has been demonstrated to be a viable option for closure^{7,8} (**TECH FIG 2**).
 - The umbilical cord remnant is cut to fit over the fascial defect.
 - The remnant is then secured in place using Tegaderm or adhesive tape to reinforce the defect.
 - Tegaderm or tape is maintained for 3 days postoperatively and is then removed.
 - The defect closes circumferentially around the umbilical cord.



TECH FIG 1 • Initial management of gastroschisis involves placing a spring-loaded silo below the fascia and the intestines are suspended. This is serially reduced over the next few days until the abdominal contents are completely reduced and closure can be completed.

Primary Closure of Omphalocele

- The sac is incised circumferentially at the level of the skin.
- Any remaining herniated intestinal contents are completely reduced into the abdomen, monitoring airway pressures as they are reduced.
- After reduction, the sac is excised and the fascia is closed primarily.
- The fascia can be closed with either interrupted fascial sutures or running fascial closure.
- If the defect is large, primary fascial closure is not feasible and temporary closures or mesh closures can be considered.⁹
- Once the fascia is closed, the subcutaneous tissue is closed in layers.
- A running subcuticular suture is used to close the skin.
- Generally, drains are not used following skin closure.



TECH FIG 2 • Sutureless closure. **A.** The intestines are reduced completely into the abdominal cavity. **B.** The umbilical cord remnant is then placed over the defect and **(C)** secured in place with Tegaderm.

PEARLS AND PITFALLS

- | | |
|----------------------|--|
| Gastroschisis | <ul style="list-style-type: none">■ 5%–8% of gastroschisis patients have intestinal atresia; therefore, careful running of the bowel should be done whenever feasible.■ Gastroschisis defects placed in a silo bag can typically be reduced over 24–72 hours. |
| Omphalocele | <ul style="list-style-type: none">■ For patients with omphalocele, maintaining the membrane and not allowing it to rupture is paramount, as the membrane provides significantly more tissue to adequately cover the defect.■ Surgical options for closure and/or temporary surgical silo are used only if it is not possible to preserve the peritoneal sac in omphalocele, or if the sac ruptures. |

POSTOPERATIVE CARE

- **Gastroschisis**
 - During intestinal reduction, observation for signs of abdominal compartment syndrome including elevated airway or bladder pressures, as well as decreasing urine output should be monitored.
 - Return of bowel function is very slow in gastroschisis, and postoperative parenteral nutrition is necessary to support the infant until oral intake can be instated.
 - If atresias are present, resection and primary anastomosis can be completed once intestinal inflammation has decreased. This usually takes place 4 to 6 days after birth.
- **Omphalocele**
 - Airway pressures as well as bladder pressures should be monitored for signs of abdominal compartment syndrome.
 - If granulation of the sac is the initial method of closure, close inspection of defects within the sac should be done regularly.
 - Management of associated anomalies should continue to be done, as these are what cause the largest morbidity in this group.

COMPLICATIONS

- Most often, complications associated with gastroschisis have to do with prematurity rather than the surgical repair.²

- Similarly, complications associated with omphalocele are most often related to the associated anomalies.
- Gastroschisis has a high rate of necrotizing enterocolitis (NEC), and the surgeon should be cognizant of this if bloody stools or abdominal distention occur in the perioperative period.
- Overall survival rates in gastroschisis are 90%; overall survival rates in omphalocele are 70% to 95%.

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66 Management of the Open Abdomen

CHAPTER

Alexander F. Mericli and Charles E. Butler

DEFINITION

- The phrase “open abdomen” is used to describe a defect in the abdominal wall that exposes the viscera.
- There are several challenging clinical scenarios that can necessitate leaving the abdominal cavity opened or that can result in an open abdomen (**FIG 1**):
 - Damage control laparotomy after trauma
 - Excessive visceral edema as seen in severe abdominal sepsis
 - Following a decompressive laparotomy for management of abdominal compartment syndrome
 - Strategies involving a planned relaparotomy (second look for intestinal ischemia)
 - Staged abdominal wall reconstruction after fascial dehiscence and evisceration
- The central tenant of open abdomen management is the construction of a temporary abdominal closure until definitive abdominal wall reconstruction can be performed.
- When one is confronted with a clinical situation that requires an open abdomen or results in an opened abdomen, there is a number of reasons why it may be prudent to stage the abdominal reconstruction with a temporary abdominal closure:
 - Decreases tension on the musculofascial abdominal wall and prevents abdominal compartment syndrome
 - Reduces risk of evisceration
 - Facilitates regaining access to the abdominal cavity
 - Reduces lateral retraction of the skin, subcutaneous tissue, muscle and fascia

- Ideally, it facilitates a delayed primary abdominal wall closure.

ANATOMY

- The abdominal wall is a layered structure consisting of muscle and fascia.

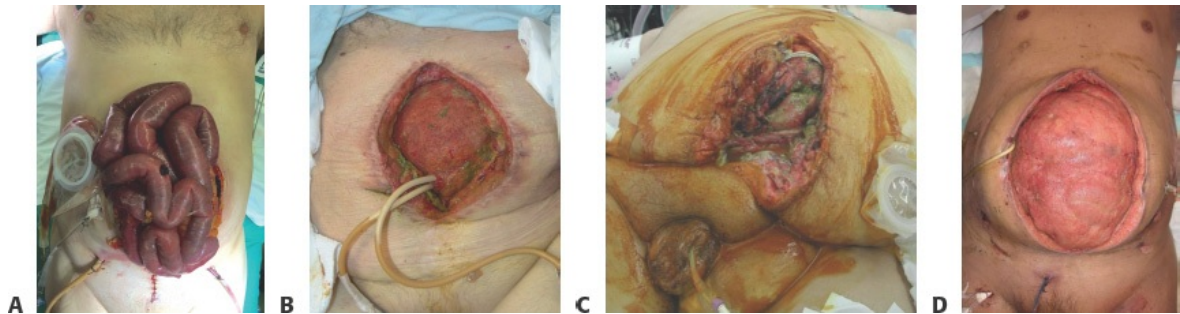


FIG 1 • Various clinical scenarios commonly managed using the technique of temporary open abdomen. From left to right: open abdomen after postsurgical evisceration; multiple enterocutaneous fistulae; open abdomen associated with abdominal sepsis; open abdomen after damage control laparotomy. © Charles E. Butler, MD.

- The paired rectus abdominis muscles comprise the central portion, ensheathed in the fascia of the anterior and posterior rectus sheaths.
- The rectus muscles are flanked on either side by the oblique family of muscles: the external oblique, followed by the internal oblique, followed by the transversus abdominis.
- Above the arcuate line (approximately at the level of the anterior superior iliac spine), the anterior rectus sheath is made up by contributions from the external oblique aponeurosis and internal oblique; the posterior rectus sheath is made up by the internal oblique, transversus, and transversalis fascia.
- Below the arcuate line, there is no posterior sheath, only transversalis fascia is below the rectus muscle (**FIG 2**).

PATHOGENESIS

- The scientific rationale for the creation and maintenance of an open abdomen is centered on the phenomenon of intestinal edema and decreasing the impact of the inflammatory cascade.

- The intestine is a highly vascularized structure with a rich network of arteries, veins, capillaries, and lymphatic vessels. In pathologic states, such as after an abdominal trauma, after abdominal surgery, or in abdominal sepsis, a decrease in clearance of fluid from the extracellular space can result in swelling of the intestinal wall several times the normal diameter, potentially interfering with perfusion of the bowel.
- Multiple inflammatory cells are present within the bowel wall and peritoneal membrane.
- In the postsurgical abdomen, the trauma abdomen, and in abdominal sepsis, there is a profound local inflammatory response, which quickly progresses to systemic inflammatory response syndrome (SIRS), which can easily contribute to multiple organ dysfunction syndrome (MODS).

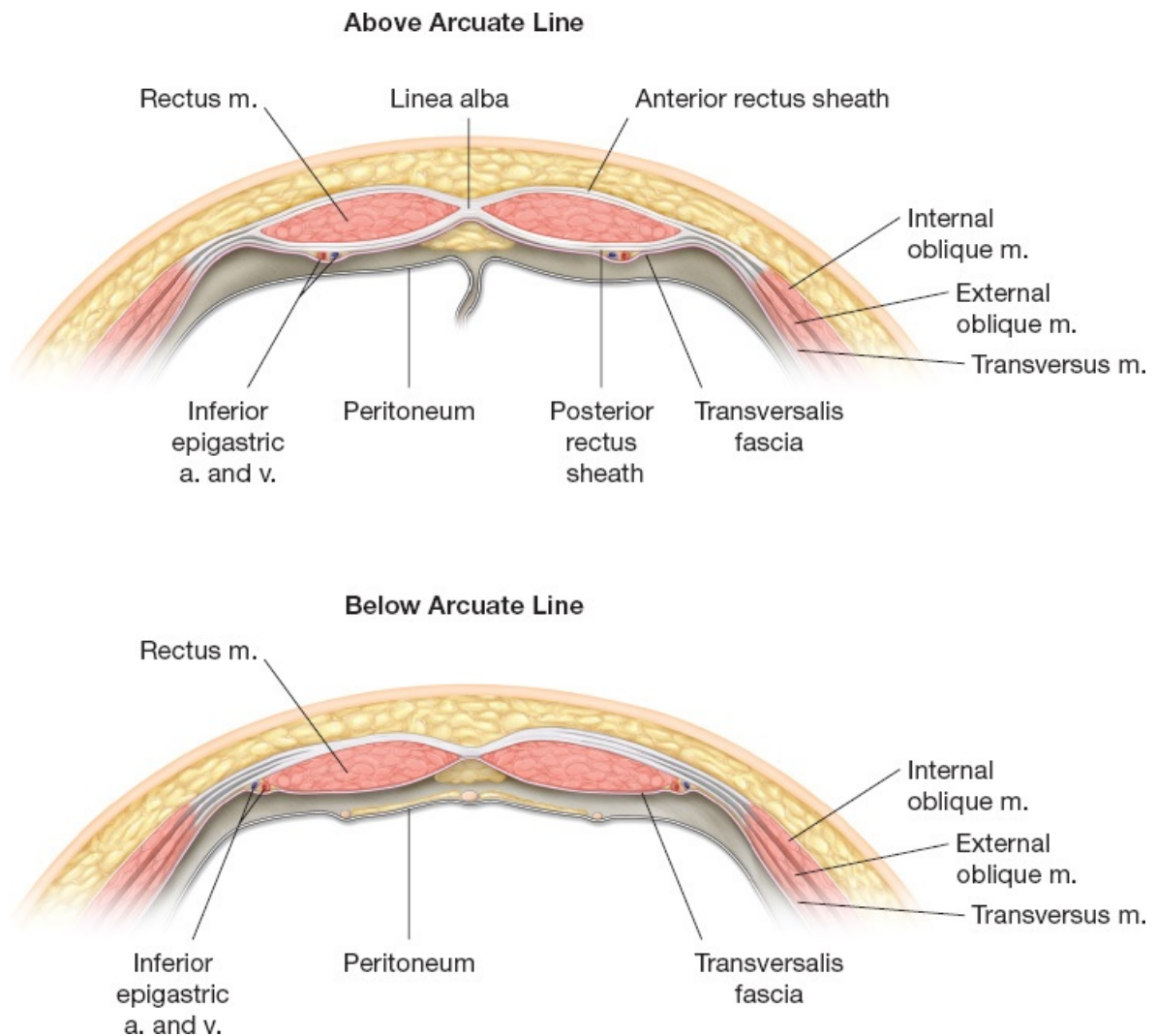


FIG 2 • Cross-sectional anatomy of the abdominal wall superior and inferior to the arcuate line.

- Premature closure of the abdomen can exacerbate the inflammatory response and accelerate these syndromes as well as contribute to abdominal compartment syndrome.¹
- Utilizing the open abdomen technique is associated with survival rates up to 80% after abdominal trauma, severe intra-abdominal sepsis, and acute evisceration.²⁻⁵

Abdominal Compartment Syndrome

- Abdominal compartment syndrome is a syndrome of uncontrolled intra-abdominal hypertension. Any factor that raises intra-abdominal pressure can contribute to abdominal compartment syndrome, including free blood and clots, bowel edema, vascular congestion, excessive crystalloid resuscitation, intraperitoneal packing, and nonsurgical bleeding, acidosis, hypothermia, and postoperative ileus.
- Normal intra-abdominal pressure is 0 to 5 mm Hg and can easily be quantified by measuring bladder pressure.
- Abdominal compartment syndrome is defined as a sustained bladder pressure of 20 mmHg or greater with dysfunction of 1 or more organ systems (ie, heart, lungs, kidneys, neurologic, etc.) OR a sustained bladder pressure of greater than 25 mmHg without organ dysfunction.
- Once diagnosed, emergent abdominal decompression is indicated. Typically, organ function returns to normal after decompression, but a mortality rate of 50% has been recorded, secondary to ongoing MODS.⁶

NATURAL HISTORY

- There are numerous physiologic changes that accompany an open abdomen. These changes are not insignificant and can contribute to substantial morbidity; however, the potential for morbidity of an intentional open abdomen is outweighed by the possible complications that could ensue, should the abdomen be closed prematurely.
- Fluid balance
 - A significant amount of peritoneal fluid is lost through an open abdomen, typically 1 L/h for a 70 kg person.

- If a closed suction system is used as part of the temporary abdominal closure, such as negative pressure therapy, then this fluid loss can be quantified and therefore accurately replaced.
- Maintenance of normothermia
 - The large cutaneous defect oftentimes present with an open abdomen impairs the body's thermoregulatory system.
 - The loss of peritoneal fluid exacerbates heat loss through convection.
 - Frequent temperature monitoring, forced air warming blankets, and a warmed room are all techniques that can be employed to counteract this effect.
- Protein loss
 - Peritoneal fluid is protein rich, with 2 g protein/L.⁷ This must be replaced through diet or enteral feeds in order to maintain nitrogen balance.
- Fistula
 - With the open abdomen, the bowel is at risk for injury. Patients with a fresh bowel anastomosis are at greatest risk.⁸
 - Whenever possible, the viscera should be covered by the omentum for an additional layer of protection.

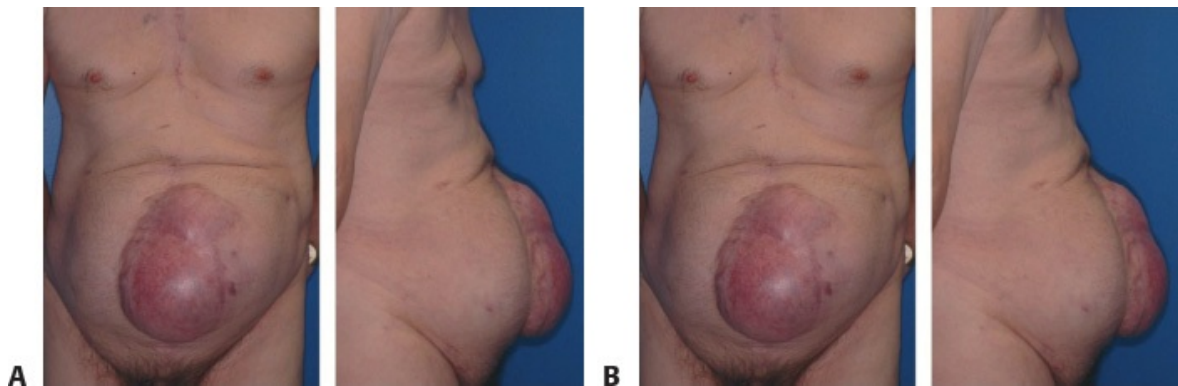


FIG 3 • Anterior and lateral views of a patient with abdominal loss of domain. The rectus and oblique muscles have retracted laterally overtime. The exposed viscera is skin grafted in anticipation of delayed abdominal wall reconstruction. © Charles E. Butler, MD.

- Loss of domain
 - The creation of an open abdomen places the patient at risk for losing

abdominal domain as the musculofascial abdominal wall retracts laterally over time (**FIG 3**).

- Methods of temporary abdominal closure are designed to prevent this situation by keeping the fascia as medial as possible.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Although it is most commonly the decision of the general or trauma surgeon, it is helpful for the plastic surgeon to understand the factors that are involved in deciding whether a patient should be managed with an open abdomen.
- Trauma/damage control
 - Preoperative predictors: penetrating torso trauma with hypotension, need for resuscitative thoracotomy, blunt abdominal trauma with intraperitoneal hemorrhage, and hypotension
 - Intraoperative predictors: development of a coagulopathy, intraoperative exsanguination requiring greater than 10 units of packed red blood cells, pH less than 7.2, base deficit greater than -6 in patients older than 55 years or greater than -15 in patients younger than 55 years, temperature less than 34°C , and/or estimated blood loss greater than 4 L^2 .
- Abdominal compartment syndrome
 - Patients with sustained intra-abdominal pressure greater than 20 mm Hg with onset of new organ dysfunction
 - Patients with acutely increased intra-abdominal pressures greater than 25 mm Hg without acute organ dysfunction should be considered for prophylactic decompression.
 - Patients at high risk for development of abdominal compartment syndrome: those requiring greater than 15 L crystalloid or 10 units of packed red blood cells, patients with increased peak inspiratory pressures greater than 40 mm Hg upon fascial closure.²
- Planned relaparotomy
 - Management of intestinal ischemia potentially requiring repeat bowel resections
 - Severe abdominal sepsis necessitating repeated debridements, such as in pancreatic necrosis or intra-abdominal abscesses
- Acute postoperative evisceration
 - Fascial dehiscence in the acute or subacute postoperative period can result in evisceration. Given that this often occurs during the inflammatory stage of wound healing, visceral edema and friable, inflamed abdominal wall soft

tissue may preclude immediate fascial reapproximation.

IMAGING

- Computed tomographic imaging of the abdomen and pelvis are imperative for surgical planning and preoperative evaluation. **FIG 4** demonstrates images from a patient with an open abdomen and associated lateral musculofascial retraction (loss of domain) (left) as well as a patient with an incisional ventral hernia after laparotomy (right).

SURGICAL MANAGEMENT

- A variety of surgical techniques for temporary abdominal closure are available, ranging from a skin-only closure to the more sophisticated ABThera System (KCI, San Antonio, TX).
- The ideal temporary closure contains the viscera, minimizes skin maceration and damage to the underlying bowel or fascia, and facilitates durable fascial reapproximation. Although there are advantages and disadvantages to each technique (Table 1), the method of temporary abdominal closure is largely dependent upon surgeon preference.

Preoperative Planning

- Preoperatively, a full history should be obtained and physical exam should be performed.
- A basic laboratory panel should be obtained and preoperative CT scan should be performed.

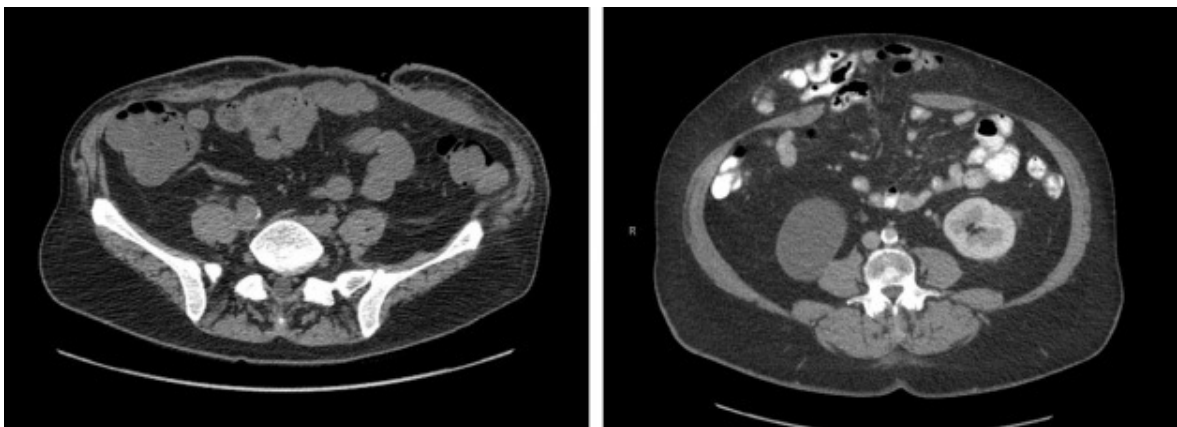


FIG 4 • Computed tomography images from a patient with an open abdomen and associated lateral

musculofascial retraction (loss of domain) (*left*) as well as a patient with an incisional ventral hernia after laparotomy (*right*).

Table 1 Temporary Abdominal Closure Techniques

	Materials/Technique	Advantages	Disadvantages
Skin-only closure	Suture; staples	Inexpensive; fast; minimizes fluid and heat loss	100% hernia rate; high risk of evisceration; risk of abdominal compartment syndrome
Silo technique	“Bogota” bag; 3 L IV bag; suture; drains; bag secured to edges of fascia to contain viscera within “silo”	Inexpensive; visualization of intra-abdominal contents; minimizes fluid and heat loss	Risk of evisceration; loss of domain; poor fluid management
Absorbable synthetic mesh	Polyglactin 910 mesh, suture; mesh placed as bridge between fascial edges	Absorbable, can apply skin graft once granulation tissue forms over mesh	100% ventral hernia rate; risk of enterocutaneous fistula and evisceration
Bioprosthetic mesh	Acellular dermal matrix; mesh placed as bridge between fascial edges	Incorporates; low risk of infection or extrusion in contaminated settings; can be skin grafted once granulation tissue forms	Expensive; extremely high ventral hernia rate at 5 years if used in bridging format
Nonabsorbable synthetic mesh	Polypropylene; polytetrafluoroethylene patch; patch anchored to fascia laterally and serial plication of the	Extends the life span of the temporary abdominal closure;	Fascial trauma; adhesions; enterocutaneous fistula formation; compartment

	patch at the midline progressively medializes the fascial edges	inexpensive; limits loss of domain	syndrome possible if plication too aggressive
Patch	Wittmann patch (Starsurgical, Inc., Burlington, WI); two pieces of mesh approximated to lateral fascial edges, two pieces latch onto each other similar to Velcro; mesh is sequentially tightened	Limits loss of domain; high rate of primary fascial approximation; allows for extended open abdomen	Requires multiple fascial manipulations; requires special equipment; adhesions can occur to undersurface of mesh
Vacuum pack closure	Nonadherent sheet placed over bowel, followed by surgical towels, drains, and iodoform-impregnated occlusive dressing; wall suction	Inexpensive; ability to monitor fluid losses; temperature control	Poor control of domain; theoretical potential for massive exsanguination. Enterocutaneous fistula formation
Commercial negative pressure system	V.A.C. Therapy (KCI, San Antonio, TX)	Plastic-encased sponge designed to be placed in contact with the viscera; prevents adhesions; fluid management; temperature control; minimizes visceral edema; high rate of success with primary fascial reapproximation if used in	Theoretical potential for massive exsanguination. Enterocutaneous fistula formation; expensive

		conjunction with fascial retention sutures	
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TECHNIQUES

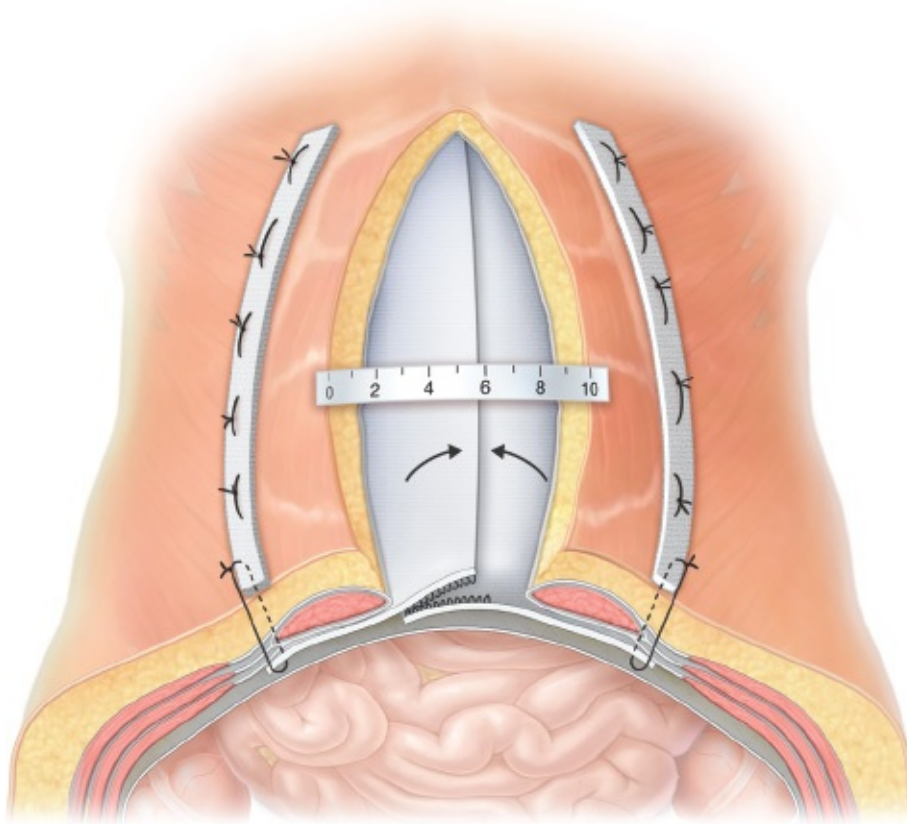
■ Fascial Closure Techniques

- Fascial closure techniques use an interposition graft material sutured to the abdominal fascia to bridge the laparotomy defect.
- These techniques can utilize *absorbable synthetic* materials such as polyglactin 910 mesh, *bioprosthetic mesh* such as Strattice (Acelity, Inc.), Surgimend (TEI biosciences, Inc.), or *nonabsorbable synthetic* materials such as the Wittmann Patch (Starsurgical, Inc.), expanded polytetrafluoroethylene, or polypropylene mesh.
- Initially, the mesh material should be loose in order to allow for visceral edema.
- As the edema resolves, the mesh is either serially excised, plicated, or advanced (Wittmann patch) to facilitate fascial approximation during reexploration.
- Typically, the patient is taken to the operating room every 48 hours for repeated washouts, reexplorations, and mesh tightening until the fascia can be reapproximated primarily.
- These techniques provide a mechanism to limit or reverse the loss of domain that occurs with an open abdomen. Therefore, fascial closure techniques should be considered when the open abdomen is likely to be prolonged greater than 1 week.
- Fascial closure techniques do require suturing to the abdominal fascia, which may increase the risk of fascial injury.

Fascial Approximation Anticipated During Present Hospital Admission

- Fascial closure technique if the possibility of fascial approximation is anticipated during hospital admission: Wittmann Patch (Starsurgical, Inc.)
 - Intraperitoneal drains are placed.

- Patch sutured to fascial edges on either side of laparotomy.
- Material has hooks and eyes similar to Velcro, which facilitates repeated openings and reclosures (**TECH FIG 1**).



TECH FIG 1 • Artistic rendition of the Wittmann patch for management of the temporary open abdomen in situations where fascial approximation is anticipated during present hospital admission. Note the hooks and loops on the opposing pieces of mesh allowing sequential fascial medialization.

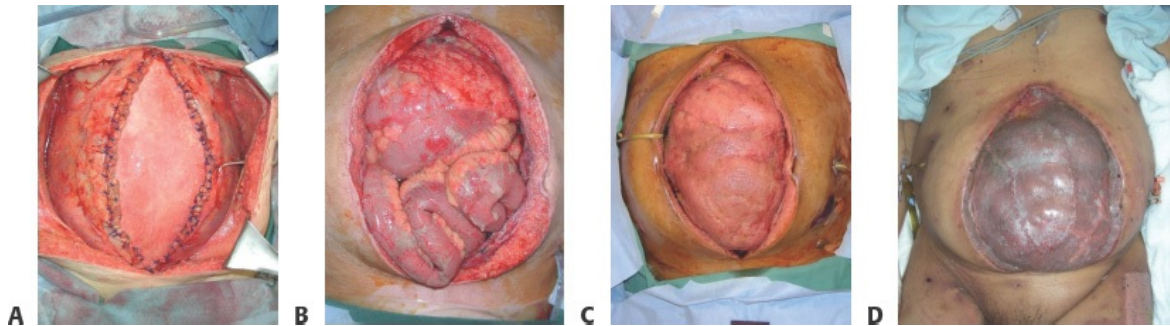
- The rate of primary closure for this method is 78% to 100%.⁹
- The rate of fistula is 2%.⁹

Delayed Fascial Approximation Anticipated

- Fascial closure technique if fascial approximation is likely not possible during initial hospital admission: bridged polyglactin 910 mesh or bridged

bioprosthetic mesh

- Intraperitoneal drains are placed.
- Mesh is fixed to the fascial using polydioxanone sutures, bridging the fascial defect (**TECH FIG 2A**).
- The mesh is covered with a moist dressing and changed twice daily.
- The mesh is evaluated for redundancy on a daily basis; if redundancy is present, the pleating is plicated in the midline at the bedside with running absorbable suture.
- If the fascial edges are able to be approximated to within 2 to 4 cm of each other before the formation of granulation tissue overlying the mesh, then the patient is returned to the OR for delayed primary fascial reapproximation.



TECH FIG 2 • A. Abdominal wall closure with bilateral component separation and bridged bioprosthetic mesh. **B–D.** Series of photographs demonstrating temporary abdominal closure with a split-thickness skin graft. From left to right: Due to visceral edema, fascial approximation is not possible. A bridging mesh is placed and granulation tissue forms over the mesh. Skin grafts are placed over the mesh and granulation tissue. © Charles E. Butler, MD.

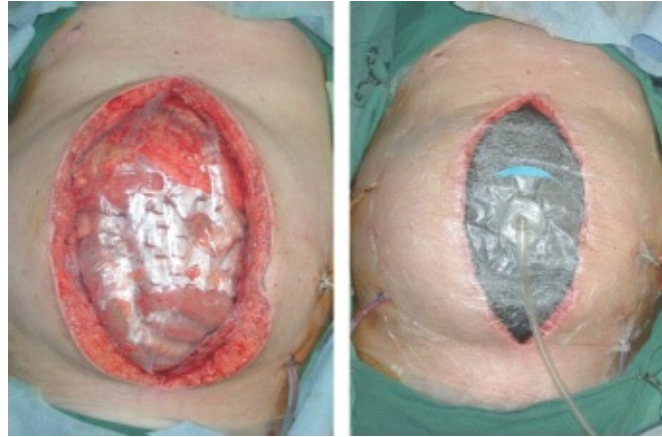
- If granulation tissue forms over the mesh before fascial reapproximation is possible, then a skin graft is applied and delayed reconstruction is planned for 6 to 12 months following the injury (**TECH FIG 2B–D**).
- In this scenario, bioprosthetic mesh may have several advantages over polyglactin 910, including a greater tensile strength and structural support

of the abdominal wall comparatively. The disadvantages include expense and difficulty to plicate at the bedside. Therefore, if a biologic is used, it should be inset with sufficient tension. Similarly, it too can be skin grafted once granulation tissue has formed.

Negative Pressure Wound Therapy for Temporary Abdominal Closure

- Negative pressure stimulates cell division, angiogenesis, and cell proliferation.^{10,11}
- Negative pressure for temporary abdominal closure was first described by Barker and colleagues.¹² They described a system in which a fenestrated plastic draped was placed in contact with the viscera, followed by surgical towels and drains; this middle layer was then covered by a bioocclusive adhesive sheet (Ioban). The drains were then connected to the wall suction at -150 mm Hg. Using this system, the authors achieved a primary fascial reapproximation rate of 55.4%. Fistula rate was 4.5%. The authors describe that within 7 to 10 days, the bowel would adhere to the abdominal wall, preventing primary reapproximation. Therefore, if definitive abdominal wall closure could not be achieved within 7 to 10, then the bowel should be skin grafted and definitive closure planned for 6 to 12 months.
- There are now several commercially available options for negative pressure management of the open abdomen. The most studied and popular system is the VAC System by KCI, Inc. (San Antonio, TX).
- The VAC System consists of an inner plastic-encased sponge designed to be in direct contact with the viscera. The plastic interface protects the bowel, prevents adhesion formation, and is perforated to allow drainage of peritoneal fluid.
- Next, a macroporous polyurethane sponge is then applied over the inner layer and is in direct contact with the overlying fascia and subcutaneous tissues.
- Fascial retention sutures can then be placed, if desired, to further medialize the fascial edges.
- The entire construct is then covered with an occlusive dressing and the machine is set to -125 mm Hg (**TECH FIG 3**).
- The patient is returned to the operative room every 2 to 3 days for irrigation, debridement, negative pressure dressing change, and further fascial medialization.

- Primary fascial closure rates using this system average 67%⁹ but can achieve 100% with the adjunctive use of fascial retention sutures.¹³
- Fistula rate is 2.9%.



TECH FIG 3 • Negative pressure therapy for management of the open abdomen. A sterile fenestrated plastic drape is placed over the exposed viscera, followed by a macroporous sponge, and covered with an occlusive plastic dressing. © Charles E. Butler, MD.

PEARLS AND PITFALLS

Physiologic rationale for temporary abdominal closure?

- Premature closure of the abdomen can exacerbate the inflammatory response and accelerate SIRS and MODS as well as contribute to abdominal compartment syndrome
- Utilizing the open abdomen technique is associated with survival rates up to 80% after abdominal trauma, severe intra-abdominal sepsis, and acute evisceration

When to consider temporary abdominal closure?

- Laparotomy for intra-abdominal trauma
- Abdominal compartment syndrome
- Abdominal sepsis
- Planned relaparotomy

	■ Acute evisceration
What are the two main methods of temporary abdominal closure?	■ Progressive fascial closure techniques ■ Negative pressure wound therapy
Postoperative care	■ Intensive fluid management due to insensible losses associated with open abdomen ■ Nutrition and protein intake ■ Return to the operating room every other day for repeat debridement, dressing change, and integral fascial advancement

POSTOPERATIVE CARE

- Because of the physiologic derangement that is associated with the clinical conditions necessitating an open abdomen, these patients often require intensive care.
- Postoperatively, the focus should be on resuscitation, fluid and electrolyte management, and nutrition. There is a multitude of information available on these topics, a review of which is outside the scope of this chapter.
- Time interval for repeated debridements
 - Regardless of the technique of temporary abdominal closure, the patient is typically returned to the operating room every 2 or 3 days.
 - There are no data to support a specific interval, and every clinical situation is different.
 - A shorter interval between episodes of general anesthesia may be physiologically challenging for the patient, whereas a longer period will allow for the formation of intestinal adhesions, increasing the risk for enteral injury.
- Nutrition
 - Assuming there are no contraindications (enteral anastomosis, ileus), enteral nutrition can and should continue during the period of open abdomen and temporary abdominal closure.
 - Because of the necessary repeated trips to the operating room, it can be difficult to meet nutritional requirements; therefore, a combination of both enteral and parenteral nutrition is prudent.
- Neuromuscular blockade

- A short course of neuromuscular blockade may decrease fascial edge retraction and be a useful adjunct to negative pressure devices.
- In one study, 192 open abdomen patients were divided into two groups: one receiving a continuous infusion of a neuromuscular blocker for greater than 24 hours and one receiving standard care.
- The patients receiving the neuromuscular blockade were more likely to achieve primary fascial closure by 7 days (93% vs 83% $P < .024$) and had no increase in pneumonia.¹⁴
- Antibiotics
 - There is no evidence for prophylactic administration of antibiotics in patients with open abdomens other than the typical perioperative prophylactic antibiotic dosing.
 - Antibiotic use and duration should be determined by the treatment appropriate for the primary abdominal pathology (ie, abdominal sepsis, abscess, etc.).
- Sedation and analgesia
 - There are no studies regarding optimal pain control or sedation in patients with an open abdomen.
 - Epidural anesthesia has been shown to reduce intra-abdominal pressure and pain control in patients with open abdomen due to abdominal compartment syndrome.¹⁵

OUTCOMES

- Once the indication for open abdomen has resolved, a delayed primary abdominal wall reconstruction should be performed as soon as possible.
- Delayed primary closure of the abdominal wall is most possible if performed within 8 days of initial open abdomen.^{16,17} A recent study of the damage control population demonstrated that delayed primary abdominal closure is only possible in 65% of patients.⁹
- If negative pressure temporary closure is combined with fascial retention sutures, a 100% primary repair rate can be achieved.¹³
- In situations where delayed primary abdominal closure cannot be obtained, a bridged biologic or synthetic absorbable mesh repair is performed, followed by skin grafting over the mesh once granulation tissue has formed. This controlled ventral hernia is then repaired 6 to 12 months later.¹⁸
- In certain clinical scenarios, the iatrogenic creation of a ventral hernia with

skin graft coverage is not in the patient's best interest. For instance, in the oncologic population, a durable soft tissue reconstruction must be established expeditiously so that the patient can proceed with adjuvant radiation and chemotherapy.

- In these situations, adjunctive abdominal wall reconstruction techniques can oftentimes be employed to achieve primary fascial reapproximation in the acute setting.
- These techniques are covered in other chapters and include component separation, the use of inlay mesh, and various autologous flaps.

COMPLICATIONS

- The open abdomen leads to fluid and electrolyte derangements that must be actively monitored and corrected. The prolonged open abdomen, bowel fistulization, and loss of abdominal domain can complicate management. The main goal of temporary abdominal closure is fluid management and minimizing the loss of domain.
- Methods of temporary abdominal closure are associated with a bowel fistulization rate of 2% to 4.5%. Factors that increase the likelihood of fistula are abdominal sepsis, bowel anastomosis, and negative pressure therapy in direct continuity with a new bowel anastomosis.
- If using a "fascial closure technique," primary fascial approximation should be achieved within 7 to 12 days; otherwise, the formation of intestinal adhesions may necessitate a delayed closure approach at a later date.
- If using a modern negative pressure technique, such as the ABThera System, primary fascial approximation can be achieved over a longer period of time, up to 30 days.
- Temporary abdominal closure techniques result in primary fascial approximation in 65% to 100% of patients. In the 35% of patients where primary fascial approximation is not possible, then either a delayed closure approach is taken (skin grafting followed by abdominal closure at a later date after the resolution of inflammation), an adjunctive abdominal reconstruction technique is utilized (component separation, flap), or some combination of both.

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CHAPTER Umbilicoplasty

Sergey Y. Turin, Chad A. Purnell, and Gregory A. Dumanian

DEFINITION

- Reconstruction of the umbilicus is an essential part of restoring the natural aesthetic of the abdomen.
- It is the focal point of the anterior abdominal wall, helps define the middle abdominal sulcus and if absent or malformed, will draw attention to the abdomen.¹
- We present two simple techniques for creation of a neoumbilicus.
 - One is to be used for patients with vertical midline incisions.
 - The other is for patients undergoing abdominoplasty when the umbilical stalk cannot be maintained.
- Umbilicoplasty for a scarred umbilicus after a standard abdominoplasty will also be discussed.

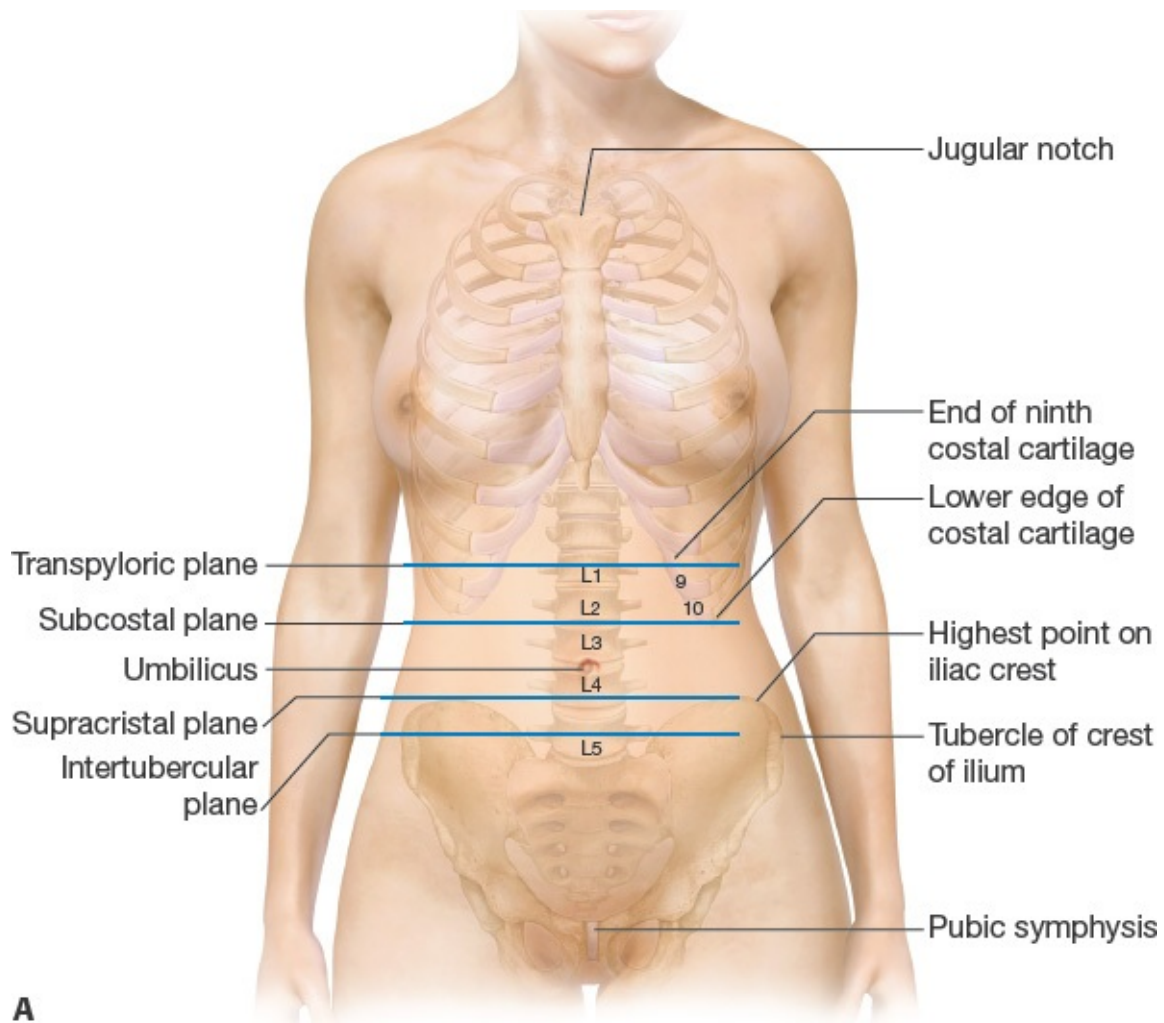
ANATOMY

- The umbilicus is generally described as a depressed circular indentation approximately 1.5 to 2 cm in diameter positioned in the midline of the abdomen at the level of the superior iliac crests² (**FIG 1A**).
- The vertical position has also been variably described as 30% to 47% of the way up between the symphysis pubis and the xiphoid.^{3,4}
- The aesthetic ideal of the female umbilicus has been described as T or vertical in shape with a superior hood or shelf.¹ Protrusion, transverse orientation, or excessive size are rated as less attractive. There is a linear depression running from the xiphoid to the umbilicus, and this compares to the smooth contour of skin without a depression from the umbilicus to the symphysis pubis. Surrounding the umbilicus is a zone of decreased fat approximately 3 cm in

diameter total, and this fat thickens to its maximum dimension for the ventral abdomen over the anterior rectus fascia.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Past surgical history, including prior transection of the umbilical stalk at the time of an umbilical hernia repair, must be obtained. Prior laparoscopy umbilical portal sites can be the cause of incisional hernias and scar formation around the umbilicus.
- A reversed sit-up maneuver should be done for evaluation of rectus diastasis.
- Significant abdominal hirsutism should be appreciated preoperatively and is a relative contraindication to umbilicoplasty, as hair-bearing skin is placed deep against the abdominal wall and could create an iatrogenic pilonidal cyst.



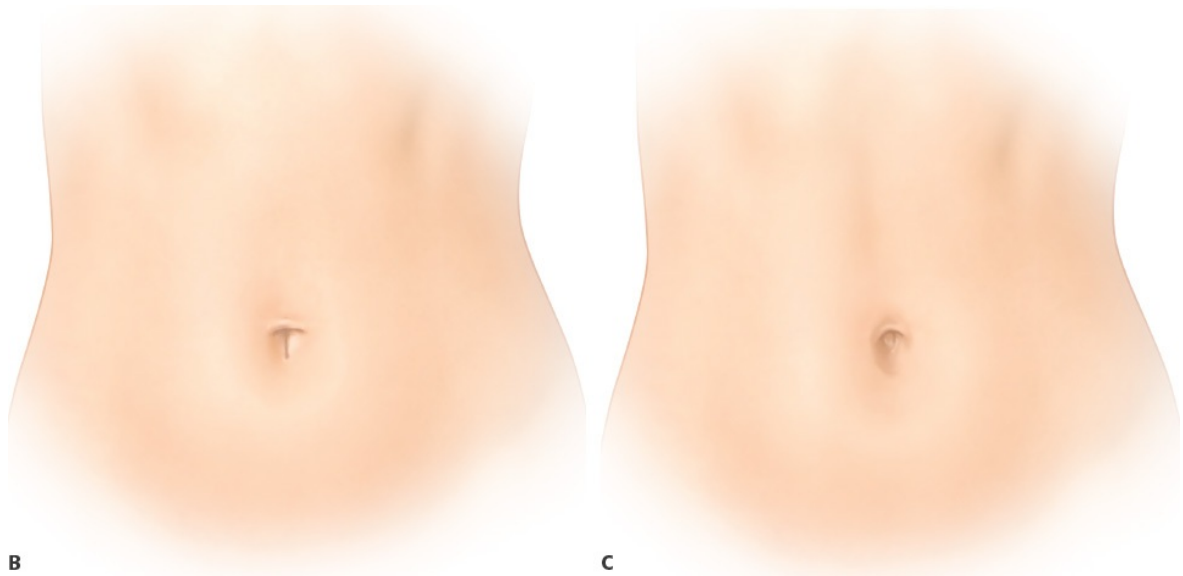


FIG 1 • **A.** Location of umbilicus. **B.** T-shaped umbilicus. **C.** Aesthetic abdominal contour with supraumbilical depression.

SURGICAL MANAGEMENT

Preoperative Planning

- The decision-making process for umbilicoplasty begins in the operating room after repair of the rectus muscles in the midline. The critical issue is whether or not the umbilical stalk remains vascularized and attached to the abdominal wall. For midline laparotomies, there is typically skin excess, and we find it easier to discard a marginal umbilical stalk and simply reconstruct it with pumpkin-teeth flaps.
- Patients undergoing an abdominoplasty where the stalk will not remain viable will need to be counseled that the reconstructed umbilicus with local flaps is not as aesthetic as the umbilical stalk that they currently have.

Positioning

- The patient is positioned in the usual supine position. The entire abdomen from xiphoid to pubis should be prepped to allow accurate determination of the midline and landmarks for appropriate umbilicus positioning.

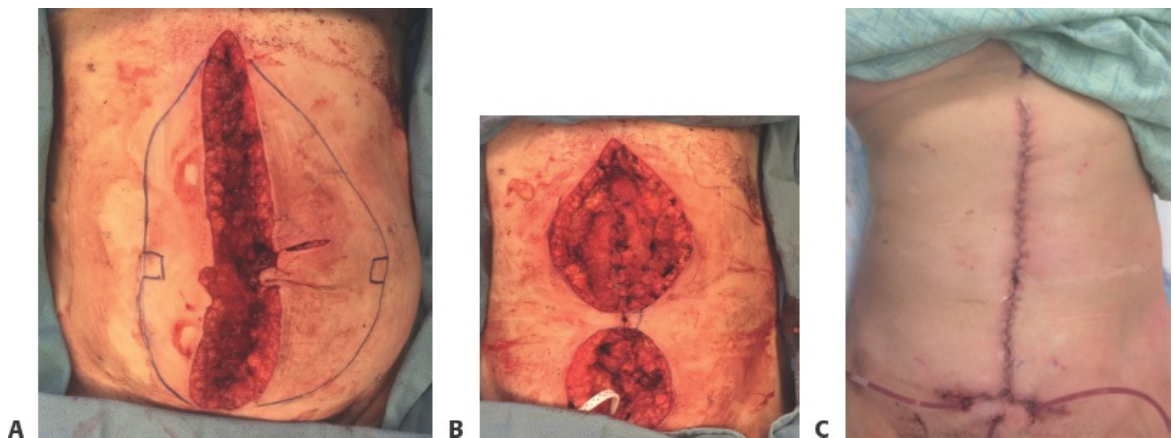
TECHNIQUES

■ Umbilicoplasty in the Setting of a Midline Incision



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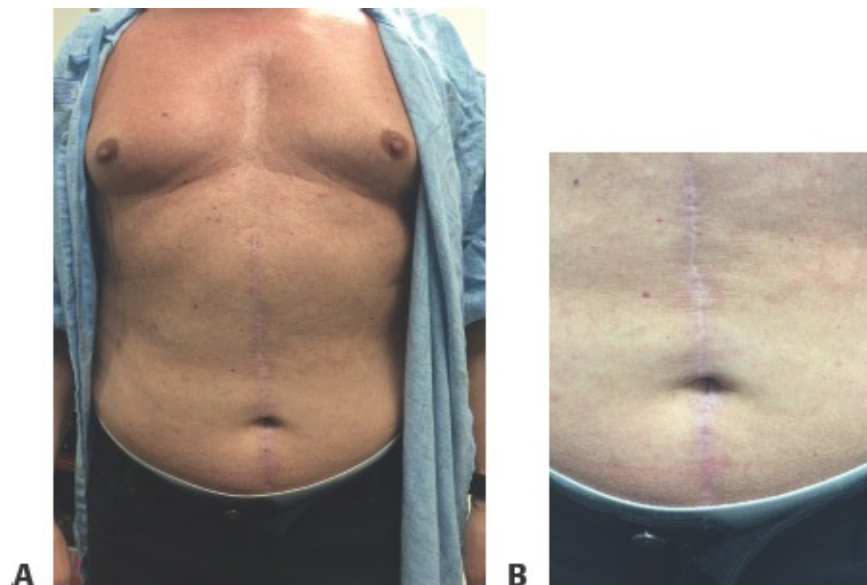
- Once the abdominal wall is reapproximated in the midline, we assess the amount of skin redundancy and if the umbilical stalk is still connected to the abdominal wall. In the majority of abdominal wall reconstructions, the skin is redundant and requires removal to decrease dead space and improve healing. The markings for what we term “pumpkin-teeth” flaps are made at the time of this vertically oriented skin excision (**TECH FIG 1A–C**).



TECH FIG 1 • Markings for “pumpkin-teeth” flaps as

final step in abdominal wall reconstruction.

- Vertical lines from the xiphoid to the pubis are drawn to outline the midline skin to be excised. Rectangular flaps 2 cm in height and 2 cm wide are drawn and preserved in the desired location of the neoumbilicus. The flaps are excised fairly thinly, with minimal dermal fat remaining attached. After incising these pumpkin teeth, the full-thickness vertical incision for the length of the abdominal skin closure is then completed.
- We also perform a small amount of excision lipectomy just superior to the site of the neoumbilicus to allow for a depression in that area—this provides an aesthetically pleasing contour to the umbilicus.
- As the closure progresses, two 3-way sutures between the edges of the flaps and the final planned position of the neoumbilicus on the abdominal wall are placed and then tied using a 3-0 polydioxanone suture. The remaining dermal sutures are then placed in standard fashion, “folding in” these pumpkin-teeth skin flaps as the neoumbilicus (**TECH FIG 2**).

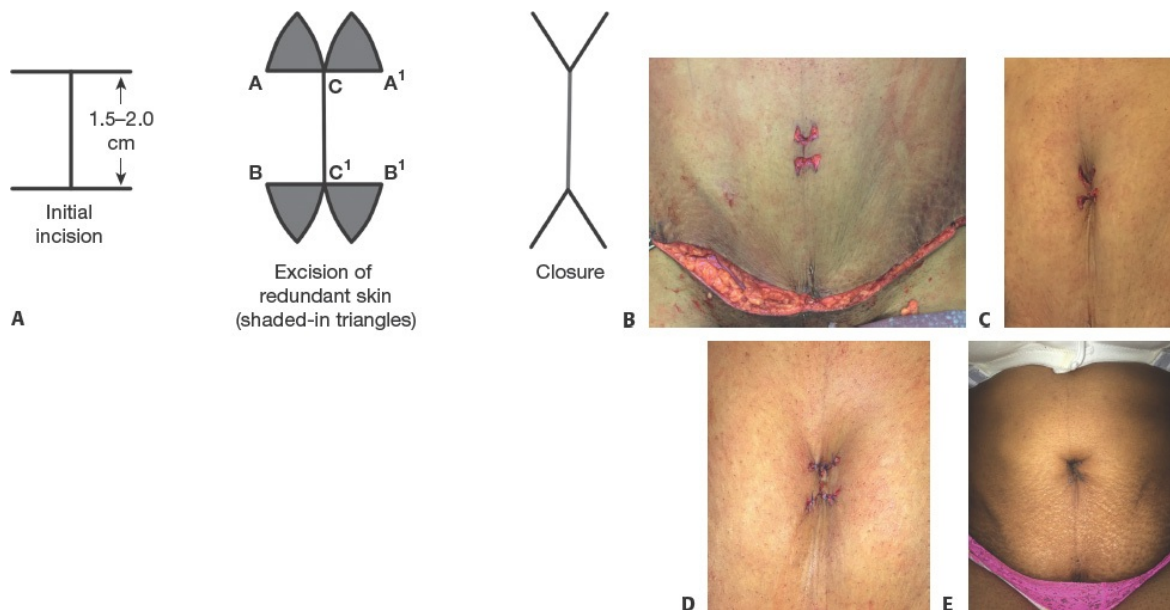


TECH FIG 2 • Postoperative result for “pumpkin-teeth” flaps.

■ De Novo Umbilicoplasty Without a Midline

Incision

- For situations when the native umbilicus is removed and there is no vertical midline incision but still some laxity in the transverse plane, we present a variation on the technique described above (**TECH FIG 3A**).
- Two laterally based rectangular flaps are incised, and the fat deep to this entire area for a diameter of 3 cm is excised. These rectangular flaps are then sewn down to the abdominal wall with 3-0 polydioxanone sutures.
- For closure of the donor site, again A is brought to A prime, and B is brought to B prime. This creates excessive tissue above and below the neoumbilicus, which is handled as two separate W-plasties. The hashed triangles are excised, and point C and C prime are sewn down to the abdominal wall to create a circular depression (**TECH FIG 3B–E**).



TECH FIG 3 • A. Umbilicoplasty design showing the initial H-shaped incision; excision of the redundant triangles of skin (shaded in); final closure design. **B.** Skin incised and approximated in midline, excess skin excised as W-plasties. **C.** Skin flaps tacked down to abdominal wall. **D.** Result at the end of the surgical procedure. **E.** Postoperative result.

■ Umbilical Stenosis After Abdominoplasty

- The goal of this umbilicoplasty is to bring the abdominal skin down to healthy umbilical stalk remnants (**TECH FIG 4**).
- In the office, the pinhole umbilicus opening is probed to ensure that a viable umbilicus stalk exists deep. The area around the scarred pinhole umbilicus opening is injected with 10 cc of xylocaine with epinephrine.
- The circular umbilical scar is excised.
- A 3-cm ring of fat is excised, especially superiorly, both to assist in local closure as well as to better identify the viable umbilicus stalk.
- The stalk is freed of scar tethering it to the abdominal wall and is mobilized superficially. The inferior aspect of stalk is opened in the Heineke Mikulicz fashion to enlarge the circular suture line.
- The closure is performed in one layer with 5-0 polypropylene sutures to the abdominal skin.



TECH FIG 4 • Umbilical stenosis after full abdominoplasty.

PEARLS AND PITFALLS

Patient selection

- Umbilicoplasty is not to be performed in hirsute skin, as this will bring hair-bearing skin deeply and create an iatrogenic pilonidal sinus.

Technical considerations	■ These procedures require a transverse excess of skin. If the skin is tight transversely, the umbilicoplasty will be pulled open. ■ Umbilicoplasties tend to drain for 1–2 weeks after creation. ■ Optimal appearance will include a depression of fat in the midline from the umbilicus to the xiphoid (see FIG 1C).
Scarred umbilicus	■ Treatment of a scarred umbilicus after abdominoplasty will require pressure on the circular scar with a marble or equivalent daily to stretch and maintain patency of the stalk.
Stenosis of the neoumbilicus	■ This may occur after inseting the umbilicus in an abdominoplasty or with a de novo umbilicus. Stenting is the first-line management options and can be accomplished with daily use of a Vaseline-impregnated gauze bolster or even a firm noise-reducing ear plug for the 1–2 months following reconstruction.⁵
Umbilicus malposition in sagittal or coronal planes	■ This occurs especially when skin is extremely redundant as in cases of massive weight loss. Preoperative placement of staples 10 cm from the midline aids in having the final skin closure in the midline.

POSTOPERATIVE CARE

- We encourage the patients to gently wash these closures with soap and water twice daily and to cover them with a dry gauze for cleanliness.

OUTCOMES

- Creation of a neoumbilicus at the time of a midline hernia repair is reliable and significantly improves appearance. Pumpkin-teeth flaps tack the skin down to the abdominal wall as an ultimate “quilting” suture to help limit seroma formation. The only complications have been excessive hair growth in males, and one female patient where the umbilicus lost its depth due to a lack of transverse skin laxity.

COMPLICATIONS

- Drainage has on occasion lasted for several weeks after umbilicoplasty. Although difficult to quantify, on occasion, there has been restenosis of the scarred umbilicus after umbilicoplasty.

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Section XVIII: Perineum

68

CHAPTER Hypospadias Repair

Christopher D. Morrison and Earl Y. Cheng

DEFINITION

- Hypospadias is defined as a ventrally located meatus proximal to its expected orthotopic location.
- Hypospadias is often associated with chordee, an abnormal ventral curvature of the penis.
- The prevalence of hypospadias is estimated at 1 per 200 to 300 live births, and the prevalence appears to be increasing.^{1,2}

ANATOMY

- The hypospadiac meatus can be located anywhere along the course of the urethra:
 - Posterior/proximal: perineal, scrotal, penoscrotal
 - Middle: along the shaft of the penis
 - Distal/anterior: subcoronal, glandular
- In general, a more proximal hypospadiac meatus is associated with a more significant degree of chordee.
- The glans can vary in size, and the urethral plate can range from grooved to completely flat.
- In most cases, the prepuce does not extend ventrally, resulting in a noncircumferential dorsal hooded foreskin.
- The skin overlying the ventral aspect of the urethra can be dysplastic or insufficient, leading to ventral tethering of the penis.
- The corpus spongiosum diverges laterally or is completely atretic, which can result in a urethra that is only covered by a very thin layer of ventral skin.

PATHOGENESIS

- Hypospadias results from the incomplete development of the penis and urethra between 8 and 14 weeks gestation.
- Tubularization of the urethra is thought to be androgen mediated, and disruption of this process results in a hypospadiac meatus.³
- Both genetic and environmental factors have been associated with hypospadias.⁴
 - Hypospadias is heritable and can be associated with several syndromes (less than 10% of cases).
 - Over 20 genes have been implicated in the pathogenesis of hypospadias.
 - Environmental factors such as maternal medication/drug use, maternal age, maternal obesity, and placental insufficiency have been associated with hypospadias and may account for the rising prevalence of hypospadias.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Hypospadias is typically recognized at the time of birth during newborn examination.
- Newborn circumcision (if desired) is contraindicated in the setting of hypospadias because the foreskin may be needed for surgical repair of the hypospadias.
- History
 - A complete prenatal and family history should be performed to identify possible contributing factors.
 - If possible, ask the parents about the direction and strength of the patient's urinary stream, as well as the curvature of the penis with erections. A downward deflected urinary stream or significant curvature of the penis may affect the patient's urinary and sexual function later in life.
- Exam
 - Penile exam:
 - Location and appearance of the meatus
 - Quality and depth of urethral plate
 - Size and configuration of the glans
 - Degree of chordee
 - Integrity of the ventral skin
 - Amount of dorsal hooded foreskin available
 - A careful scrotal and inguinal exam should be performed to look for other

abnormalities such as cryptorchidism, hydrocele, or hernia.⁵

- If a patient also has undescended testicles (unilateral or bilateral), it is important to consider the possibility of a disorder of sex development (DSD).
 - If undiagnosed, a DSD condition such as congenital adrenal hyperplasia (CAH) can be life threatening.
 - These patients should undergo an endocrine workup and karyotype.
 - Approximately 20% to 30% of patients with hypospadias and cryptorchidism will have a karyotype abnormality.³
 - The most common DSD seen in patients with hypospadias and cryptorchidism is mixed gonadal dysgenesis.

IMAGING

- Proximal hypospadias can be associated with renal anomalies. However, routine imaging is not performed in most cases of hypospadias. If the patient has a severe proximal hypospadias, one could consider obtaining a renal ultrasound.

NONOPERATIVE MANAGEMENT

- For patients with distal/anterior hypospadias in which the urinary stream is relatively straight and there is no significant chordee, surgical correction is generally considered optional and is usually performed more for appearance and psychosocial reasons rather than for correction of a functional need.
- There is controversy among some urologists as to whether correction of distal hypospadias confers long-term benefits for patients.
- A 1995 study of 500 men found great variability in the meatal location. Thirteen percent of these men had anterior hypospadias with no functional compromise, and two-thirds of these patients were unaware of their hypospadiac condition.⁵
- In contrast, a 2014 study examined the self-reported outcomes for patients who had uncorrected hypospadias and found that these patients were more likely to have worse voiding symptoms, more penile curvature making sexual intercourse difficult, and worse satisfaction with the appearance of their penis.⁶

SURGICAL MANAGEMENT

- Multiple different surgical techniques have been described for distal hypospadias, including the MAGPI and the Mathieu repair. However, the

tubularized incised plate (TIP) urethroplasty, as described by Snodgrass, is the technique that is now most commonly performed by hypospadias surgeons. It is suitable for patients with a sufficiently healthy and wide (greater than 7 mm) urethral plate and less than 30-degree chordee.

- Midshaft hypospadias is often approached similarly to distal hypospadias; however, it tends to be associated with more significant chordee.
 - If there is less than 30-degree chordee and the urethral plate is sufficiently healthy and wide, a TIP urethroplasty can be performed.
 - If there is less than 30-degree chordee but the urethral plate is too narrow, hypospadias repair can be performed using a transverse preputial island flap or an inner preputial inlay graft.
- Proximal hypospadias repair presents a greater challenge for several reasons:
 - There is a longer length of urethra that must be tubularized.
 - The urethral plate may be narrow, fibrotic, or even nonexistent.
 - There tends to be a more significant degree of chordee.

Preoperative Planning

- If diagnosed at the time of birth, most urologists will delay treatment until the child is 6 months of age to decrease potential anesthetic risks.
 - Ideally, the surgery should be performed prior to the child being old enough to remember the surgery.
 - Many advocate hypospadias repair between 6 and 12 months of life.⁷
- Historically, hormonal stimulation with testosterone, dihydrotestosterone, or human chorionic gonadotropin was given preoperatively to increase penile length, glans circumference, and vascularity as this was thought to aid in surgical correction.
 - However, there is now concern that hormonal stimulation may affect normal wound healing and may lead to an increased risk of postoperative complications.⁸
 - Nevertheless, hormone stimulation is still felt to be beneficial in more severe cases of hypospadias.

Positioning

- After the induction of general anesthesia, if possible, a caudal anesthetic block is recommended for perioperative pain control.
- The patient is positioned supine for the surgery.

Approach

- The operative approach varies based on the following:
 - Location of the hypospadiac meatus
 - Severity of chordee
 - Characteristics (width, depth, and health) of urethral plate
 - Quality of penile shaft and dorsal hood skin
 - Surgeon preference/experience
- The main components of a hypospadias repair consist of the following:
 - Evaluation and correction of chordee
 - Urethroplasty
 - Glanuloplasty
 - Skin coverage
- Hypospadias repair is typically performed with the use of 2.5 times surgical loupes or with an operating microscope.
- Hypospadias repair can be either a one- or two-staged repair. The decision to perform a one- or two-stage repair depends primarily on the degree of chordee and the health of the urethral plate.
 - If the chordee can be corrected with dorsal plication and the urethral plate is healthy and wide, a TIP urethroplasty should be performed.
 - If the chordee can be corrected with dorsal plication but the urethral plate is NOT healthy and wide, the surgeon can perform either a one-staged preputial onlay island flap urethroplasty or a two-staged inner preputial inlay graft with subsequent tubularization.
 - If division of the urethral plate is required for correction of chordee, this should be performed during the initial stage. The urethroplasty should be performed in a second stage at least 6 months later.
- An algorithm for intraoperative decision-making during hypospadias repair is presented in **FIG 1**.

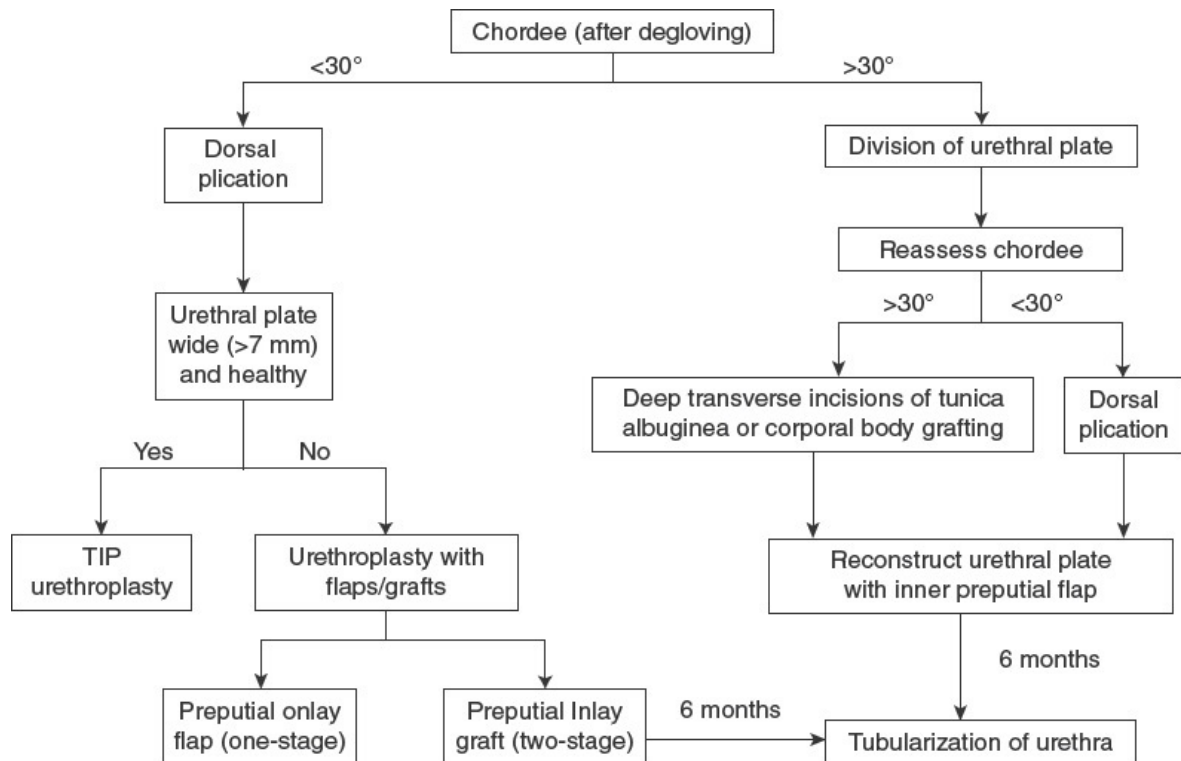


FIG 1 • Algorithm for hypospadias repair.

TECHNIQUES

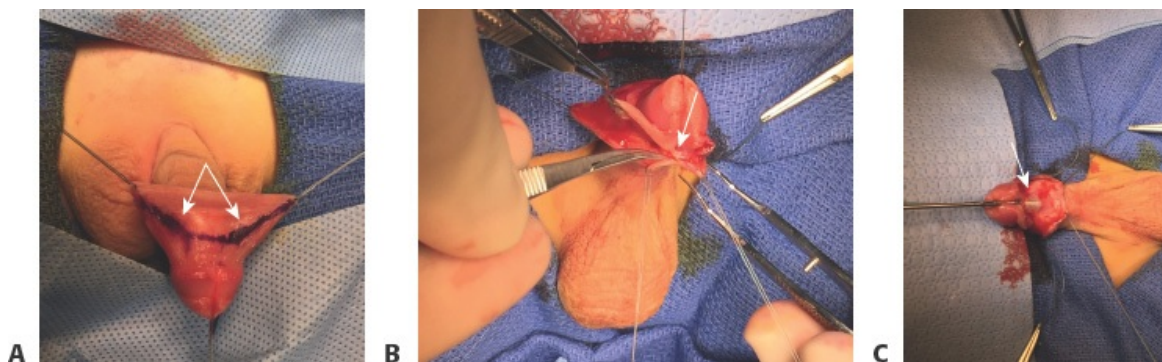
■ Tubularized Incised Plate Urethroplasty for Distal Hypospadias Repair

■ Examination Under Anesthesia

- Prior to beginning the surgery, examine the anatomy.
- Visually inspect the meatus.
- Calibrate the meatus with bougies and examine the ventral penile skin overlying the urethra.
- If the urethra and overlying skin is too thin, it may be necessary to perform a cutback procedure to healthier tissue and perform a more proximal hypospadias repair.
- Examine the urethral plate for width, depth, and overall health.

■ Initial Approach (TECH FIG 1)

- Place a 4-0 Ethibond suture longitudinally at the tip of the glans for retraction purposes.
- Make a reverse chevron incision on the dorsum of the penis to preserve the mucosal collar flaps.
- Working laterally to medially, carefully elevate the ventral skin off of the urethra. (Avoid incising into the urethra. If necessary, it is better to buttonhole the overlying skin than to incise into the native urethra.)
- Deglove the penis down to the penopubic and penoscrotal junction.
- Induce an artificial erection and evaluate degree of chordee by constricting the corpora cavernosa at the base of the penis with a tourniquet device (ie, rubber band, dental roll, and hemostat) and injecting saline through a small-gauge butterfly needle into the corpora cavernosa.

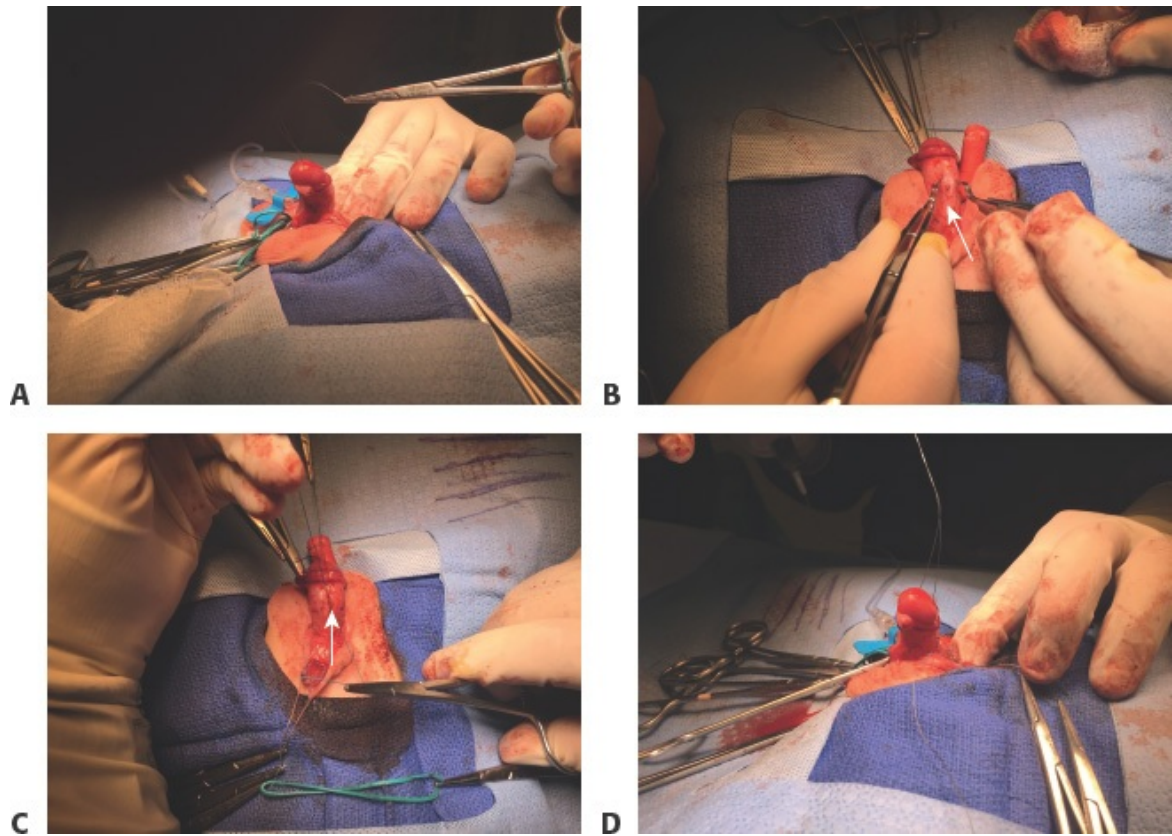


TECH FIG 1 • Initial incisions. **A.** Reverse chevron incision to preserve mucosal collars (*arrows*). **B.** Elevation of skin off of urethra behind hypospadiac meatus (*arrow*). **C.** Example of thin ventral urethra (*arrow*) that will require cut back.

■ Correction of Chordee With Dorsal Plication

- In most cases of distal hypospadias, degloving of the penis alone will adequately straighten the penis.
- In cases in which residual chordee remains that is less than 30 degrees, this can be corrected with dorsal plication (**TECH FIG 2**).

- Dorsal plication will shorten the penis and should be avoided in patients with a small phallus.

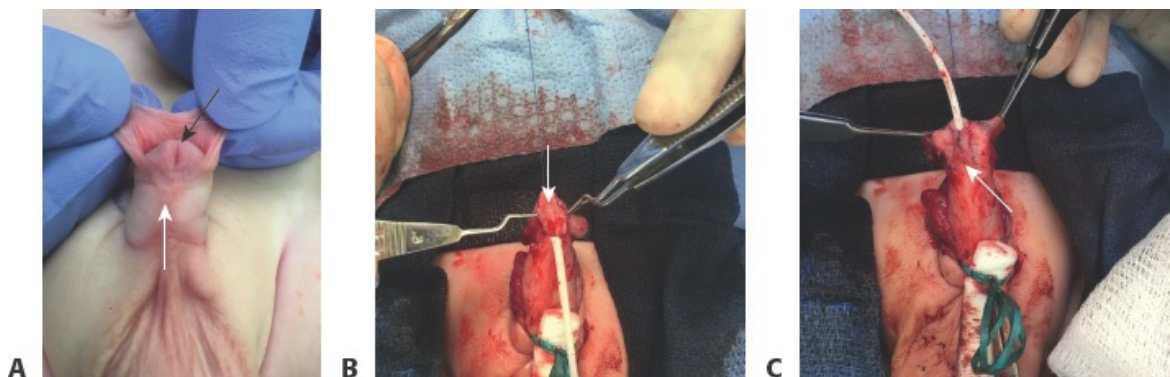


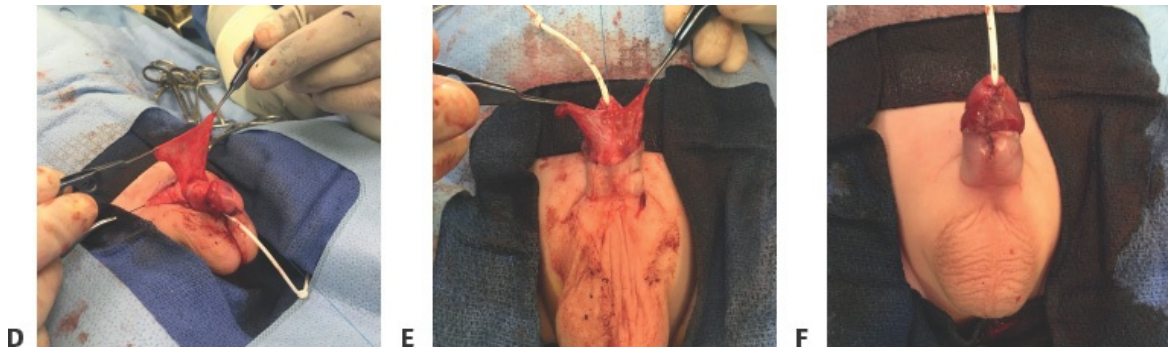
TECH FIG 2 • Dorsal plication. **A.** Artificial erection to assess chordee (less than 30 degrees). **B.** Dorsal incision at 12 o'clock (*arrow*; between neurovascular bundles). **C.** Plication suture (*arrow*) with 3-0 Ethibond suture. **D.** Corrected chordee following dorsal plication.

- Make an incision in Buck fascia at the 12 o'clock position over the dorsal vasculature.
- Place a 3-0 or 4-0 Ethibond suture (Ethicon Inc., Somerville, NJ) parallel to the shaft, ensuring not to injure the neurovascular bundles laterally.
- Imbricate Buck fascia over the plication suture using interrupted 6-0 PDS.

■ TIP Urethroplasty (TECH FIG 3)

- Elevate the spongiosum and create glans wings.
 - Often, the corpora spongiosum can be identified diverging lateral to the urethral plate.
 - If easily identified, elevate the divergent spongiosal tissue off the corporal bodies.
 - The corpus spongiosum can be used as an additional layer of closure over the urethral repair.
 - To create glans wings, incise along the lateral borders of the urethral plate to the top of the glans.
 - Dissect down to the corporal bodies.
 - Ensure that the glans wings are sufficiently wide to allow midline approximation without tension.
- Incise the urethral plate and tubularize the urethra (TECH FIG 3B,C).
 - Make a longitudinal incision at the base to deepen the groove.
 - Place a urethral stent (size varies based on urethral diameter, usually 6–8 French).
 - Close the urethra in two layers with a 7-0 PDS suture in a running subcuticular fashion with careful attention to turn in the epithelial edges.
 - Take care to not make the neomeatus too tight.
 - If the divergent spongiosal tissue was identified and easily mobilized, reapproximate over the urethral repair using interrupted 7-0 Vicryl sutures.





TECH FIG 3 • Distal hypospadias repair with TIP urethroplasty. **A.** Preoperative examination reveals coronal hypospadiac meatus (*white arrow*) and blind urethral dimple (*black arrow*). **B.** Incision of urethral plate (*arrow*). **C.** Urethroplasty repair (*arrow*). **D.** Harvesting of dartos flap. **E.** Overlying urethral repair with dartos flap. **F.** Hypospadias closure.

- The dartos flap is used as an additional layer of coverage over the urethral repair and can be harvested from either the ventral or dorsal penis, but typically, the dorsal dartos is more supple and better vascularized (**TECH FIG 3D,E**).
- Rotate the dartos flap over the urethral repair and suture in place using 7-0 Vicryl sutures.
- Close the glans in two layers. Use 6-0 PDS (Ethicon, Somerville, NJ) to close the deep layer and 7-0 Vicryl (Ethicon, Somerville, NJ) to close the superficial layers.
- For skin closure, transpose the mucosal collar flaps ventrally, excise the redundant tissue, and suture together with 7-0 Vicryl (**TECH FIG 3F**).
- If there is inadequate ventral skin for closure, mobilize flaps from the excessive dorsal preputial skin, transpose the flaps ventrally, and suture in place with 7-0 Vicryl.
- Secure the stent to the glans with two 6-0 Vicryl sutures.

■ Midshaft Hypospadias Repair

■ Transverse Preputial Island Flap (TPIF)

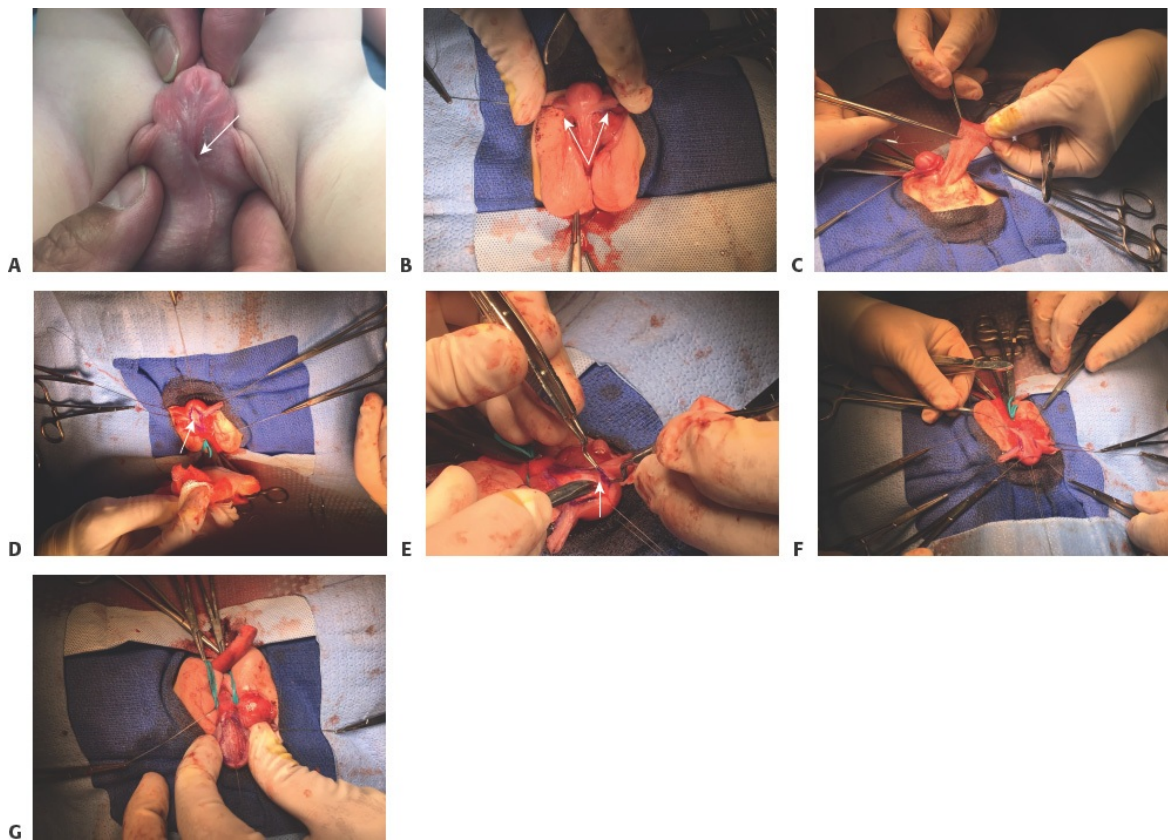
- Performed in a single-stage repair.
 - The urethral plate is preserved as the posterior urethral wall and a TPIF is used to make up the anterior wall of the neourethra.
 - Harvest a strip of skin from the inner preputial skin along its native blood supply.
 - Rotate the flap ventrally and position over the urethral plate to form the anterior urethral wall.
 - Suture the skin flap to the lateral edges of the urethral plate using a running 7-0 Vicryl suture.
 - Complete hypospadias repair as previously discussed (glanuloplasty, skin coverage, etc.).
-

■ Inner Preputial Inlay Graft (TECH FIG 4)

- An inner preputial graft is used to augment the urethral plate by placement of the graft into the defect that results following incision of the urethral plate.
- Measure the dimensions of the existing urethral plate to assess the length and width of an inlay graft needed for tubularization.
- Harvest an inner preputial graft of appropriate size.
- Defat the graft.
- Apply the tourniquet to reduce bleeding.
- Make a deep incision within the native urethral plate from the hypospadiac meatus to the tip of the penis.
- Elevate the urethral plate off the underlying corporal bodies.
- Place the inner preputial graft along the vascular bed and quilt it with 7-0 Vicryl sutures.
- Mature the graft to the surrounding urethral plate tissue with interrupted 7-0 Vicryl sutures.
- Fenestrate the graft with a micro knife to prevent hematoma formation beneath the graft.
- Following placement of the graft, one can perform a single-stage repair in which the lateral aspect of the urethral plate on each side of the graft is tubularized. Alternatively, one can perform a two-stage repair in which tubularization is delayed for 6 months later to allow maturation and

neovascularization of the graft prior to creation of the neourethra. At our institution, we generally favor a two-stage approach in this setting.

- Rotate the mucosal collar flaps ventrally alongside the urethral plate and suture with 7-0 Vicryl sutures.
- The graft is allowed to heal for 6 months and then is tubularized during the second stage.
- If there is greater than 30-degree chordee such that dorsal plication is insufficient to correct the curvature, the hypospadias repair should be approached similarly to that of a proximal hypospadias.



TECH FIG 4 • Proximal hypospadias repair with inner preputial graft (first stage). **A.** Proximal hypospadiac meatus (*arrow*), narrow unhealthy urethral plate, moderate depth of glans groove. **B.** Degloving penis while preserving mucosal collars (*arrows*). **C.** Harvesting inner preputial graft. **D.** Deep incision of urethral plate (*arrow*). **E.** Elevation of lateral urethral

plate (*arrow*) off the corporal bodies. **F.** Preputial graft overlying incised urethral plate. **G.** Graft sutured into place.

■ Proximal Hypospadias Repair

- Both one- and two-stage repairs for proximal hypospadias have been described.
- In most cases, there is significant (greater than 30 degrees) chordee that cannot be corrected with dorsal plication. Consequently, a two-stage repair is most often needed for proximal hypospadias repair.
- One-stage repair is reserved for the rare cases in which there is minimal chordee that can be corrected with dorsal plication.
- If the urethral plate is healthy and sufficiently wide (greater than 7 mm), a TIP urethroplasty can be performed.
- If the urethral plate is healthy but too narrow to tubularize, a one-stage repair can be performed with a transverse preputial island flap or an inner preputial inlay flap, as described for midshaft hypospadias repair.
- Two-stage repair is recommended for patient with significant chordee and/or an unhealthy urethral plate.
 - The goal of the first stage is to correct the chordee and/or augment the urethral plate for tubularization at the second stage.

■ Stage 1: Correction of Chordee

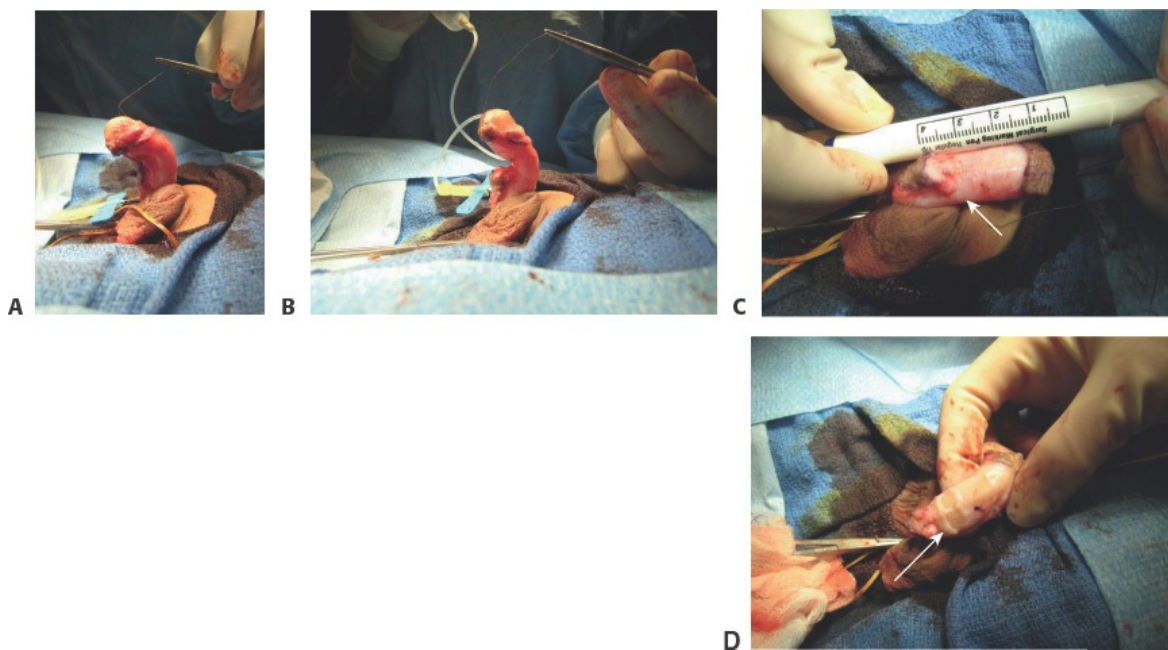
- If there is greater than 30-degree chordee, dorsal plication is usually insufficient and the following techniques should be used to correct the curvature.

Division of Urethral Plate

- Make a transverse incision in the urethral plate at the level of the maximal curvature.
- Elevate the urethra off the corporal bodies.
- Excise dysgenetic tissue away from the corporal bodies.
- Repeat artificial erection. If chordee is now less than 30 degrees, proceed with dorsal plication.

Deep Transverse Incisions of Tunica Albuginea (DTITA)

- If significant chordee still remains that is more than 30 degree despite division of the urethral plate, the next step is to make multiple nearly full-thickness incisions in the tunica albuginea at the level of the maximal curvature.
- No full-thickness incisions into the erectile tissue should be made and thus should not affect future erectile function.
- For severe chordee, DTITA is often insufficient and corporal body grafting is necessary.



TECH FIG 5 • Division of urethral plate with corporal body grafting. **A.** Significant chordee after degloving. **B.** Chordee persists despite division of urethral plate. **C.** Corporal body incision (*arrow*) with subsequent defect. **D.** SIS grafting (*arrow*) of corporal body defect.

Corporal Body Grafting (**TECH FIG 5**)

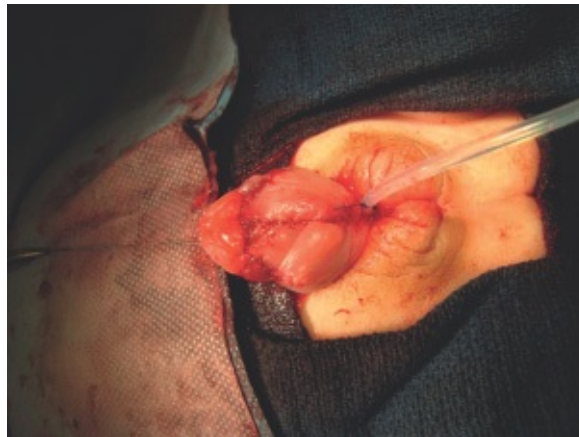
- Make a full-thickness ventral incision through the tunica albuginea at the area of greatest curvature and extend to the lateral borders of the neurovascular bundles.
- Elevate the corporal wall off of the underlying erectile tissue to create a

diamond-shaped defect.

- Graft the defect with either a dermal graft (harvested from the inguinal area) or small intestine submucosal (SIS) (off-the-shelf xenograft material).
- Suture the graft in place with a running 6-0 PDS.

Bridging of Urethral Plate Defect

- Following division of the urethral plate and correction of chordee, it is necessary to bridge the gap between the proximal and distal native urethral plates.
- Traditionally, this is performed utilizing Byars flaps. However, at our institution, we favor an inner preputial skin flap.
- Byars flaps (**TECH FIG 6**)
 - Make a midline dorsal incision in the preputial skin.
 - Rotate each preputial skin flap (Byars flap) ventrally along with their respective dartos vascular pedicles.

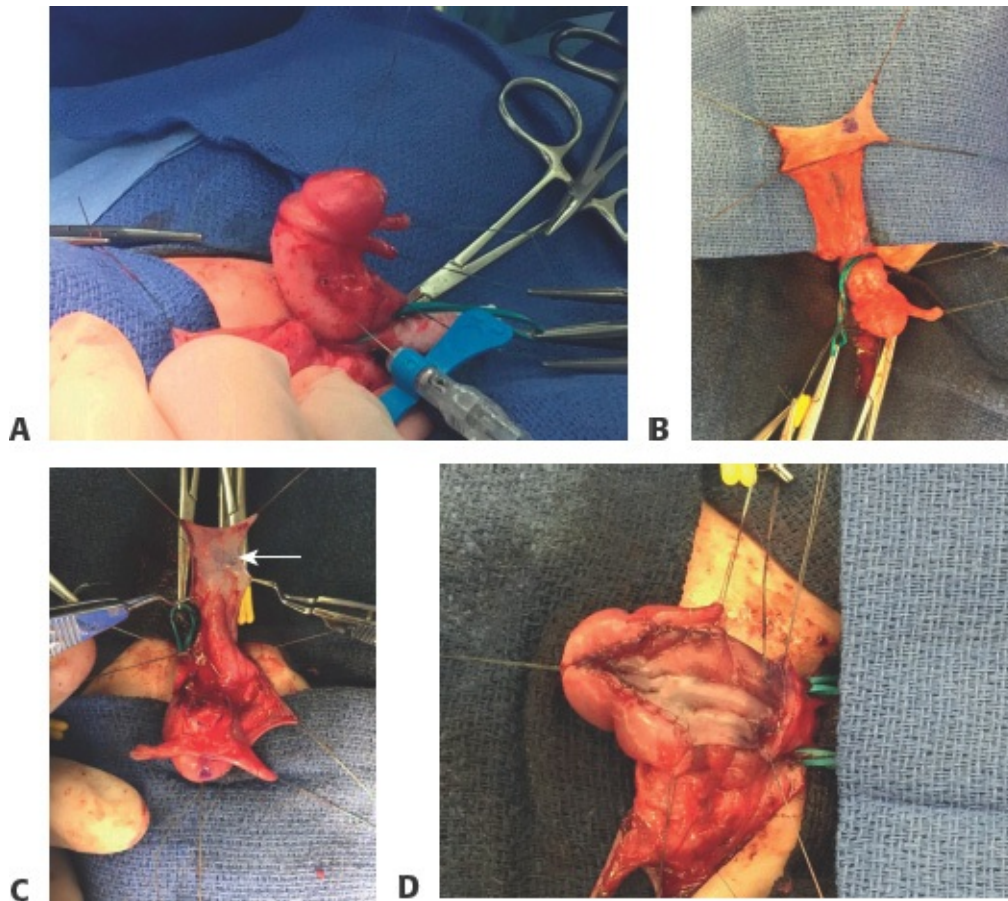


TECH FIG 6 • Byars flaps using ventrally rotated preputial flaps.

- Bring the flaps together in the midline and interpose the combined Byars flaps between the proximal and distal urethral plate. If the urethral plate in the glans is flat and insufficient, the plate can be incised and the Byars flaps can be placed into the defect with extension of the flaps out to the tip of glans.
- Suture the flaps in place utilizing 7-0 interrupted Vicryl sutures.
- At the time of the second stage, the Byars flaps are tubularized to form the

urethra.

- Because of the nature of the preputial skin used for Byars flaps, the resultant tubularized urethra can be more prone to be hypermobile or difficult to catheterize. Furthermore, in our experience, the patient is more prone to urethral diverticula formation. Thus, we have favored use of an inner preputial skin flap for bridging of the urethral defect.
- Inner preputial skin flap (**TECH FIG 7**)
 - Harvest an appropriate-sized flap from the dorsal inner preputial skin while preserving the blood supply from the dartos fascia.
 - Defat the distal one-third of the flap while maintaining the blood supply to the proximal two-thirds.
 - Incise the glans urethral plate.
 - Inlay the defatted distal one-third of the flap into the incised distal urethra.
 - The proximal two-thirds of the flap is positioned along the shaft of the penis.
 - The flap is quilted to the tunica albuginea utilizing interrupted 7-0 Vicryl sutures.
 - Fenestrate the flap to reduce subcutaneous hematoma formation.
 - The urethra is tubularized at the time of the second-stage repair.



TECH FIG 7 • Division of urethral plate with preputial inlay flap. **A.** This curvature of more than 30 degrees required division of the urethral plate. **B.** Harvested preputial inlay flap. **C.** Defatted distal third of preputial flap (*arrow*). **D.** Preputial inlay flap quilted to tunica albuginea.

■ Stage 2: Tubularization of the Urethra and Glanuloplasty

- Tubularization
- Deglove the penis.
- Induce artificial erection and ensure that any previous significant chordee has been corrected.
- Make parallel incisions along the inlay graft and residual urethral plate from

the level of the hypospadiac meatus to the distal aspect of the glans.

- Tubularize the urethral plate over a 6 or 8 French stent and close in two layers, with interrupted 7-0 PDS for the first layer and a running subcuticular 7-0 PDS for the second layer.
- If available, harvest a vascularized dartos flap from the dorsum and transpose over the repair with interrupted 7-0 PDS.

Tunica Vaginalis Flap

- If a vascularized dartos flap is insufficient, harvest a tunica vaginalis flap.
- Make a transverse scrotal incision over either the left or right scrotum.
- Create a subdartos pouch.
- Deliver the testicle.
- Harvest a rectangular tunica vaginalis flap large enough to completely cover the length of the repair, ensuring not to disrupt its proximal blood supply along the cord structures.
- Create a tunnel between the scrotal incision and the penoscrotal junction.
- Deliver the tunica vaginalis flap and cover the entire repair.
- Suture the tunica vaginalis flap in place with interrupted 7-0 Vicryl sutures.
- Place the testicle into the developed subdartos pouch, and pexy it in place with interrupted 4-0 chromic sutures at the 3 o'clock and 9 o'clock positions.

Completion

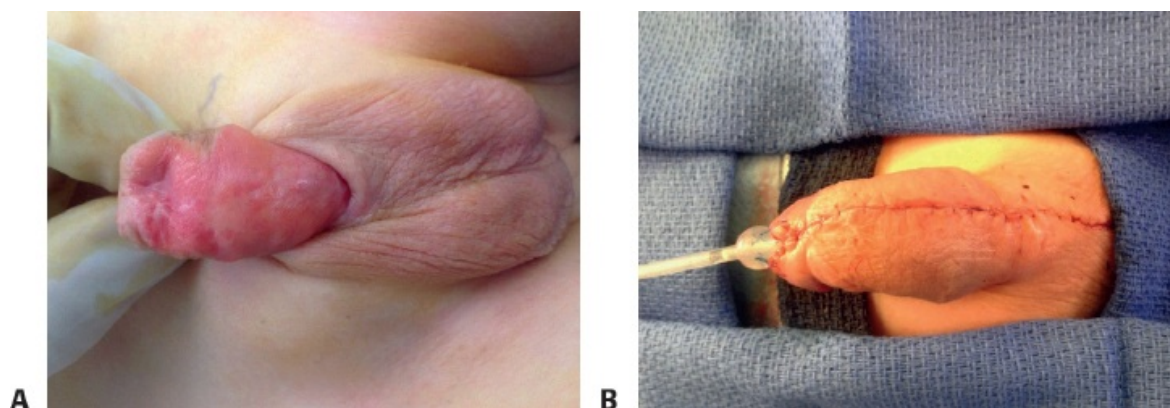
- Perform glanuloplasty.
- Close in two layers. Use 7-0 PDS to close the deep layer and 7-0 Vicryl to close the superficial layers.
- Mobilize and transpose the mucosal collar flaps ventrally and suture with 7-0 Vicryl sutures.
- Mobilize skin flaps as necessary for skin closure.
- Place a catheter into the bladder for drainage purposes.

■ Buccal Mucosa Graft for Redo Hypospadias Repair

- Unfortunately, not all primary hypospadias repairs are successful. As a result, some patients may require a redo hypospadias repair.
- In instances of a redo hypospadias repair, the urethral plate is often no longer

healthy and requires excision.

- In addition, inner preputial skin is typically not available for redo hypospadias repairs.
- As a result, a hypospadias repair using a buccal mucosa graft is required.
- Harvest a buccal mucosa graft from either cheek or the upper/lower lip.
- Mark out the edges of the desired graft.
- Infiltrate the edges of the graft with 1% lidocaine with epinephrine.
- Harvest the graft using scissors while preserving the underlying fatty tissue (avoid dissecting too deep as this will risk injuring the underlying muscles/nerves).
- Control bleeding from the graft site using bipolar cautery.
- Defat the graft.
- Excise the scarred urethra and surrounding scar tissue to create a healthy vascular bed along the surface of the corporal bodies. Make the buccal graft as wide as possible.
- Tack down the buccal mucosal graft to the location of the urethral plate with 7-0 Vicryl sutures in a quilted fashion.
- Fenestrate the graft with a micro knife to prevent hematoma formation beneath the graft.
- Allow at least 6 months for the buccal graft to mature.
- In a second stage, the buccal mucosa graft is tubularized and the hypospadias repair is completed (**TECH FIG 8**).



TECH FIG 8 • Second stage of proximal hypospadias repair with buccal mucosa. **A.** Healed first-stage repair with buccal mucosa. **B.** Tubularization and closure of

buccal mucosa urethral plate.

PEARLS AND PITFALLS

Indications	■ Proximal and middle hypospadias should be repaired to improve urinary and sexual function. ■ Distal hypospadias typically will not impact overall function but correction can be performed to improve the appearance.
Approach	■ The approach for each hypospadias repair should be dictated by the intraoperative assessment of the chordee and the urethral plate. ■ Counsel the patient and/or parents preoperatively regarding the possibility of needing a staged repair.
Technique	■ Know the limitations of the tissue available for repair. Attempting to do too much in a single stage may result in failure of the repair and increased morbidity for the patient. ■ Use all available tissue to cover the urethral repair to reduce the risk of urethrocutaneous fistula.
Complications	■ If a urethrocutaneous fistula or urethral diverticulum forms, the distal urethra and meatus must be interrogated. If a stricture or meatal stenosis is present, correction of the fistula or diverticulum without addressing the distal obstruction will inevitably lead to recurrence.

POSTOPERATIVE CARE

■ Dressing

- At the conclusion of the surgery, a slightly compressive dressing is typically placed around the penis to reduce swelling and promote hemostasis.
- At our institution, we place a benzoin-soaked Owen gauze around the incisions followed by Coban gauze secured with plastic tape.
- Care should be taken to ensure that the dressing is not too tight as this can decrease blood flow to the glans.
- The dressing is removed by a physician or nurse 4 to 5 days postoperatively.
- After removal of the dressing, a topical antibiotic ointment should be applied to the incisions routinely for 1 to 2 weeks as the incisions continue to heal.

■ Urinary diversion

- As mentioned previously, a urethral stent is sutured in place at the end of the surgery.
- Urinary diversion with a urethral stent allows for proper urethral healing and prevents postoperative urinary retention.
- Some physicians utilize suprapubic tubes for urinary diversion as these may limit bladder spasms. In patients with a history of severe bladder spasms, a suprapubic tube should be considered as strong bladder spasms can expel the urethral catheter.
- The urethral stent is typically removed 1 to 2 weeks postoperatively.
- **Postoperative antibiotics**
 - Historically, postoperative antibiotics were routinely prescribed while the urethral stent was in place.⁹ However, it is currently unclear whether postoperative antibiotics confer a benefit.
 - While awaiting more conclusive studies, we routinely prescribe postoperative antibiotics (ie, Bactrim, Keflex) while the urethral stent is in place.
- **Postoperative evaluation**
 - Take a thorough history of the patient's urinary stream (direction, force, urethral bulging during urination, leakage of urine from along the repair, etc.).
 - Carefully examine the repair and look for evidence of urethrocutaneous fistula (early signs consist of erythema or inflammation along the urethra proximal to the meatus).
 - Examine the meatus for evidence of meatal stenosis.
 - If concern for meatal stenosis or urethral stricture, uroflowmetry can help gauge the strength of the stream.

OUTCOMES

- A successful hypospadias repair should meet the following primary goals:
 - Patent urethra with a good functional urinary stream
 - Intact sexual function (ie, erections, ejaculation)
 - Good appearance
 - Patient satisfaction
- Success of a hypospadias repair is directly correlated with the severity of the hypospadias. Patients with a history of a proximal hypospadias and/or significant chordee requiring a multistaged repair with multiple grafts are more likely to have diminished function or worse appearance.
- Patients with a history of more proximal hypospadias are more likely to have a

shorter phallus, more voiding dysfunction, and lower maximum urinary flow compared to matched controls.¹⁰ Patients are also more likely to report erectile dysfunction and decreased sexual quality of life as adults.¹¹

- However, a study of patient-reported outcomes found that patients with a history of a successful hypospadias repair were more satisfied with the appearance of their phallus and fewer voiding symptoms than compared to patients who had uncorrected hypospadias.¹²

COMPLICATIONS

- Complication rates following hypospadias repair are also directly related to the severity of the hypospadias and the complexity of the repair.¹³
- In expert hands, distal hypospadias using the TIP urethroplasty can be performed with few complications.¹⁴ Most series quote a less than 10% incidence of complications for distal hypospadias repair.
- Short-term complications
 - Glans dehiscence is the most common acute postoperative complication seen following urethroplasty repair and is typically due to closure of the glans under too much tension or by too much ventral pressure from the urethral stent. If the patient has a functional urinary flow and direction, the decision to correct the glans dehiscence typically depends on the patient's or parents' concern for appearance.
 - Hematoma formation and infection are other potential short-term complications.
- Long-term complications
 - Urethrocutaneous fistula formation is the most commonly seen long-term complication and typically presents within 1 year of repair.¹⁵
 - Rates of urethrocutaneous fistula formation with proximal hypospadias repairs have been reported as high as 30% to 50%.^{16,17}
 - The patient or parents typically notices urine leaking from a site proximal to the meatus.
 - Often, there is an associated area of inflammation or wound breakdown.
 - A fistula is unlikely to close on its own with conservative management and reoperation is typically necessary.
 - In general, it is recommended to wait 6 to 12 months prior to reoperation to allow inflammation and edema to resolve.
 - Options for repair include primary closure vs redo urethroplasty.

- For primary closure, the fistula tract is excised and the urethra is closed with multiple layers of well-vascularized tissue. For primary closures, it is essential to calibrate the distal urethra to ensure no obstruction that will increase risk of recurrence.

■ Meatal stenosis

- The rates of meatal stenosis range from 0% to 17%.¹⁸
- Obstruction created by meatal stenosis will increase the risk of urethrocutaneous fistula and urethral diverticula formation.
- At follow-up appointments, it is important to query the patient and/or his family regarding urine stream and to closely examine the meatus.
- If evidence of meatal stenosis, a simple meatotomy performed in the operating room is typically sufficient.

■ Recurrent chordee

- If the patient develops recurrent significant ventral curvature of the penis, the patient may require reoperation if there is concern that it will affect urinary or sexual function in the future.
- For minor recurrent chordee (less than 30 degrees), dorsal plication is usually sufficient.
- For significant chordee (≥ 30 degrees), repeat hypospadias repair may be necessary (although this is uncommon).

■ Urethral diverticulum

- Patients with a urethral diverticulum typically describe a bulging of the ventral aspect of the penis during urination. At completion of urination, compression of the bulge will cause the expulsion of more urine.
- Urethral diverticula typically warrant correct. At the time of repair, excision of the excess urethra is typically sufficient. However, it is crucial to evaluate the distal urethra as there is likely an obstruction, which contributed to the initial diverticulum formation.

■ Urethral stricture

- Patients who present with urethral strictures often complain of a long, slow stream or having to strain to empty their bladder.
- Diagnosis is typically performed by cystourethroscopy.
- For mild, thin strictures, endoscopic management with direct visual incision of the urethra (DVIU) can be attempted; however, in many instances, the stricture will recur.

- For denser strictures or strictures that have failed endoscopic management, reoperation is indicated.

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69 Vaginal and Vulvar Reconstruction

CHAPTER

Elizabeth B. Yerkes and Julia Corcoran

DEFINITION

- Neovaginal creation or augmentation of the vaginal canal may be requested in several congenital conditions and in acquired vaginal stenosis. This chapter will address vaginal and vulvar reconstruction in emerging and young adults. It does not include vaginoplasty or labioplasty techniques that may be applied in reconstruction of urogenital sinus in cases of ambiguous genitalia, intersex states, and differences of sex development.
- Vaginal agenesis or congenital vaginal atresia (Mayer-Rokitansky-Küster-Hauser syndrome)
- Vaginal agenesis or insufficiency in the setting of complete androgen insensitivity and intersex/differences of sex development
- Classic bladder exstrophy or cloacal exstrophy
- Vaginal stenosis after early childhood surgery (congenital adrenal hyperplasia, intersex/differences of sex development, or persistent cloaca)
- Secondary changes after pelvic malignancy or graft versus host disease (GVHD)
- Vulvar reconstruction in the form of monsplasty and labioplasty may be requested to align the laterally displaced or offset mons tissue and pubic hair and to reconfigure and stabilize the labia minora after pubertal development in congenital conditions such as exstrophy-epispadias and its covered variants.
- Reduction labioplasty may be requested to address physically bothersome bulk of the labia minora.

ANATOMY

- The paired Müllerian (paramesonephric) bodies fuse in the midline and contact

the urogenital sinus. The sinovaginal bulb is induced and the vaginal plate is formed.

- Müllerian development occurs within first 10 weeks of gestation.
- The labia minora are formed from the urogenital folds and the labia majora and mons from the labioscrotal folds (**FIG 1**).

PATHOGENESIS

- Absent or incomplete development of the Müllerian bodies results in absence or atresia of the female genital tract.
 - Ovaries have a different embryologic development and are spared.
- Failure of the fusion of the Müllerian bodies results in duplication of the vagina or unilateral obstruction or atresia.
- Anomalous descent of the urorectal septum in dividing the cloaca, as in anorectal malformations, may interfere with fusion of the Müllerian bodies.
- Renal development and a portion of skeletal development occur at a similar time to Müllerian development, so anomalies may coexist.
- Pelvic diastasis associated with abdominal wall defects such as bladder exstrophy and cloacal exstrophy also results in nonfusion of the labial and mons tissues. Bifid clitoris also occurs in these conditions.
- Thickening of the labia minora with puberty results in extensive variation in size and shape. Sufficient hypertrophy may occur that some clothing and physical activity are physically bothersome.
 - Hygiene and tissue health may be a concern in young women with limited mobility or ability for self-care.

NATURAL HISTORY

- Vaginal agenesis or atresia does not resolve over time, but maturation of the vulvar tissues and proximal vaginal segment, if present, may facilitate the reconstruction.
- If a uterus and proximal vagina are present, judiciously allowing the vagina to distend with menstrual products may bring it closer to perineum or expand to create more tissue for pull-through reconstruction.
 - Local tissue flaps or nongenital grafts can be used to bridge the distance to the perineum.
 - Surgical benefits of this natural resource must be balanced against pain and the potential for retrograde menstrual flow and peritoneal irritation and deposits that could compromise future fertility.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patient age and autonomy as well as family values and motivations will impact discussions about goals and surgical options.
- General discussions may have already involved the parent due to the professional relationship from infancy.
- Once ready to discuss interventions, private discussions with the patient are essential but the parent must also be included for surgical discussions in minors.
- Patient readiness and goals for long-term results must be ascertained.
- Readiness to undertake daily vaginal dilations for indefinite period.
 - Goal may be simply unobstructed menstrual flow or use of tampon.
 - Understanding of need for progressive dilations, and potential additional procedures, thereafter for functional canal
- Readiness or anticipated timeline for intimate sexual contact.

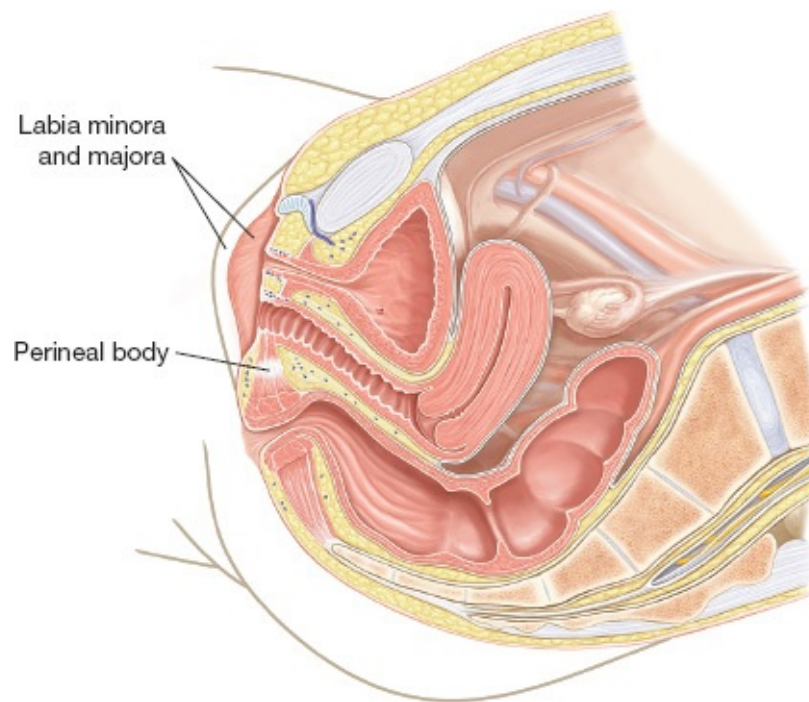


FIG 1 • Sagittal view of pelvic anatomy depicting relationship of urethra, vagina, and rectum in typical development.

- Maturity level to be able to discuss with partner

- Desire for heterosexual penetrative intercourse vs nonpenetrative sexual activities
- Anticipated life events (graduation, prom, marriage) that could be complicated by surgical recovery or complications
- Conflicts between family values/guarantor values and patient's desire for surgery
- Anatomical and patient factors that may inform management
 - Quality of distal UG sinus/vaginal pouch and vulvar skin
 - Presence of functional uterus and proximal vaginal segment
 - Degree of estrogenization and maturation of tissues
 - Location of hair bearing tissues
 - Prior pelvic or genital surgery
 - Prior abdominal, urinary, or rectal surgical procedures
 - Prior chemotherapy or regional radiation therapy in setting of pelvic malignancy
 - Inflammatory bowel disease
 - Dermatologic conditions
 - Continence status for urine and stool
- Patient factors that may impact perioperative care and success
 - Resilience
 - Willingness to ask for and accept support in the perioperative period
 - Compliance
 - Lack of privacy to complete required care (college dorm)
- Timing relative to next expected menstrual period
- History of hypercoagulable state or bleeding diathesis
 - Increased surgical risk in terms of bleeding after deep dissection or from graft donor site
 - Increased risk of perioperative thromboembolic complications after pelvic surgery and prolonged bed rest
- Gastrointestinal or dermatologic conditions
- Continence status for urine and stool

IMAGING

- Imaging is not specifically required for surgical planning, although pelvic ultrasound or MRI is often obtained in the course of establishing certain diagnoses and individual anatomy.

NONOPERATIVE MANAGEMENT

- Daily serial dilation program can achieve a functional vaginal canal in properly selected and motivated candidates.
 - Preferred initial therapy in vaginal agenesis, CAIS, and other intersex/differences of sex development with a vaginal pit or pouch to guide positioning of dilator.
 - May be used to progressively dilate vaginal stenosis.
 - Tissue health and surgical scarring may limit success.
- Assess maturity and commitment to goals of program
 - Program is voluntary and timing should be dictated by patient.
- Ongoing office support is important to verify technique and to enhance success.
- Daily or twice daily dilation for 10 to 20 minutes
 - Goal is to achieve and maintain vaginal depth while increasing caliber.
 - Dilations may cease when consistently sexually active but may otherwise need maintenance dilations.

SURGICAL MANAGEMENT

- Vaginoplasty
 - The individual anatomic situation will dictate whether neovagina construction or augmentation of the caliber of the vaginal canal is required.
 - Skin or mucosal grafts, nongenital pedicled flaps (bowel), and local tissue flaps may be incorporated in the vaginal reconstruction.
 - Choice of donor tissue may be based upon surgeon experience, patient expectations and preferences, donor tissue availability, harvest site morbidity and scarring, and donor tissue properties.
- Monsplasty and labioplasty
 - Inferomedial rotation of mons tissue in bladder exstrophy or cloacal exstrophy
 - Addresses soft tissue asymmetry
 - Allows for concomitant midline abdominal scar revision, with or without umbilicoplasty if desired, and removal of non-hair-bearing midline tissue
 - Melds with labia majora to create greater privacy for the clitoris, labia minora, and vaginal vestibule
 - Supports concomitant revision of asymmetric or mobile labia minora tissue and/or vaginoplasty

- Mobilization of tissue flaps to allow cosmetic and functional coverage of glans clitoris if overexposed after prior feminizing genitoplasty
- Reduction labioplasty
 - Excision or reconfiguration of physically bothersome hypertrophic labia minora

Preoperative Planning

- Review of prior operative notes in individuals with prior pelvic reconstructive procedures.
- A thorough pelvic examination with or without cystoscopy and vaginoscopy is often helpful in surgical planning and patient preparation and counseling.
 - Offer anesthesia or sedation due to the invasive and physically or emotionally uncomfortable nature of the examination.
- Schedule one or more detailed consultations with patient to review all surgical options in the context of individual anatomy and goals.
- Surgical scheduling with consideration of menstrual cycle
 - Avoid menses on day of surgery and for first postoperative week when vaginal stent or mold is used.
 - Continuous menstrual suppression may be considered perioperatively if cycles predictably unpredictable.
- Mechanical bowel preparation in patients with anorectal anomaly and in those who will have bowel vaginoplasty. Enema advised in other vaginal cases.

Positioning

- Sequential compression devices in place prior to positioning
- Position in dorsal lithotomy with all pressure points carefully padded (**FIG 2**).
 - Adequate padding on bed and/or protective barrier on sacral bony prominence, if present
 - Gentle support of atypical lumbosacral anatomy, if present
 - Attention to limited range of motion at hip or lower extremity with some diagnoses
- Standard to low dorsal lithotomy is preferred.
 - Minimizes stress on the spine and nerves in those with pre-existing pathology.



FIG 2 • Dorsal lithotomy positioning. This depicts the highest and widest positioning recommended. Position should accommodate either two surgeons between legs or one surgeon assisting patient's hip. Functional status and hip joint flexibility need to be considered for some diagnoses.

- Acute neurologic change may occur with more exaggerated or prolonged lithotomy.
- Allows participation of cosurgeon from step stool at patient's hip.

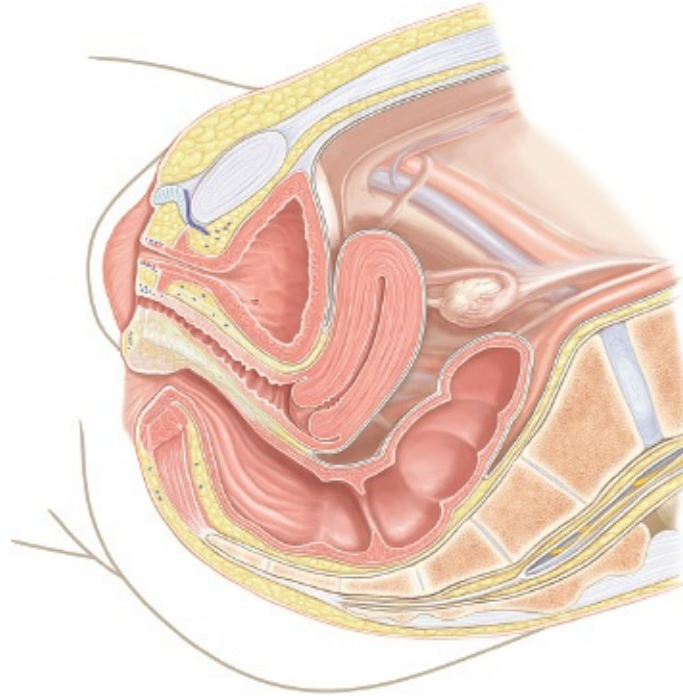
TECHNIQUES

■ Augmentation of Caliber of Vaginal Canal: Vaginoplasty and Introitoplasty

- This technique is not neovagina or vaginal replacement but rather augmentation of the existing vaginal canal caliber or circumference (**TECH FIG 1**).
 - Introital, distal, or mid vaginal stenosis
 - Globally narrow but patent vaginal canal
 - Angulation of vaginal canal at introitus
 - Anteriorly positioned and narrow introitus relative to axis of vaginal canal after having undergone exstrophy repair techniques without deep

mobilization of the urogenital complex

- Laterally positioned and angulated introitus in vaginal duplication of cloacal exstrophy



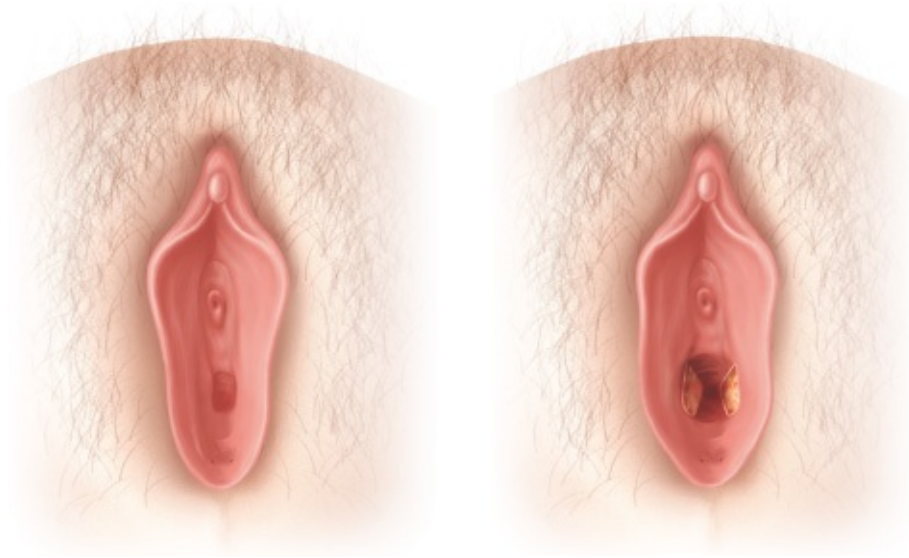
TECH FIG 1 • Narrow vaginal caliber can be augmented with graft techniques. The relationship between the posterior vaginal wall and rectum may be closer than natural relationship in setting of prior reconstruction.

- Remarkably increases vaginal caliber but cannot increase vaginal length due to presence of uterus.
- Relevant to exstrophy where cervix may sit more distally even when well supported.

Enlargement of the Vaginal Canal Caliber

- Radial incisions made at 3:00 and 9:00 with electrocautery (**TECH FIG 2**).
- Lateral location of incisions least likely to injure urethra, bladder base, or rectum.
- Incisions sequentially deepened to expand vaginal caliber without compromising support.

- Desired caliber for penetrative intercourse: two fingers, spread to 2.5 to 3 fingerbreadths.
- For tight stenosis or atresia or with anterior introitus/angulated canal, the authors prefer oral (buccal) mucosa free graft.

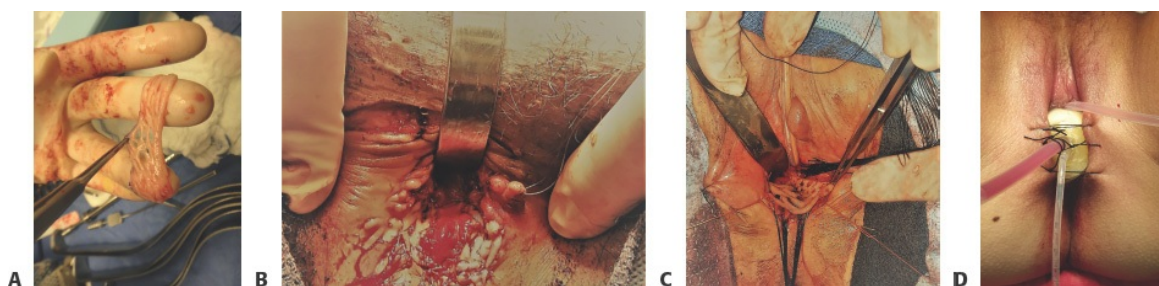


TECH FIG 2 • Perineal approach to augmentation procedures. Incisions at 3 and 9 o'clock minimize risk of injury to urethra and rectum, more of a concern in complex anomalies. The incisions are extended cranially into healthy proximal vagina so that even and adequate caliber established.

- For isolated introital stenosis, a local perineal skin flap can be utilized, alone or in combination with free graft, if it does not deform or compromise surrounding anatomy.

Resurfacing With Native Tissues: Buccal Mucosa

- Grafts are harvested from one or both cheeks, depending upon amount of substrate required.
- Graft is defatted and meshed by hand with strokes of scalpel. Alternatively, it may be intermittently temporarily folded and incised with fine scissors (**TECH FIG 3A**).
- Triangular defects will be created bilaterally by the radial incisions.



TECH FIG 3 • **A.** Harvested buccal tissue has been defatted and hand meshed to cover wider defect. For use in bilateral defects, it is divided obliquely into two triangular grafts to advance into defect. **B,C.** Two uses of buccal for augmentation procedures. **B.** Triangular grafts quilted in place bilaterally. Note that native vaginal mucosa remains along posterior wall. **C.** Young adult with deferred repair of urogenital sinus. The vagina was mobilized toward the perineum and spatulated. Buccal mucosa is being inset to bridge to gap and to improve introital caliber. **D.** Vaginal mold carefully inserted. Labia sutured across to prevent expulsion.

- The rectangular meshed buccal graft is cut obliquely into two triangles.
- 4-0 Vicryl suture is preplaced in apex of graft and advanced to apex of the triangular incision.
- The meshed graft is expanded to fill the defect and quilted into the dissected bed with resorbable suture (**TECH FIG 3B,C**). With the introitus and labia at rest, vagina appears normal, not gaping.
- Insert vaginal mold (**TECH FIG 3D**).
- An inflatable vaginal mold with central drainage port is not currently commercially available, but the concept elements are ideally applied to employed substitute.
 - Graft stability without undue pressure on urethra; sterile; impermeable; central drainage port for mucus and blood

■ Neovagina Construction

Perineal Dissection

- Perineal dissection of rectovesical space to create adequate vaginal vault.
- In the expected region of a vaginal opening, there may be a short pouch of supple tissue or flat, firm granular tissue.
- Selection of skin incisions allows the vestibular tissue to be incorporated as local flaps to minimize risk of introital stenosis (**TECH FIG 4**).



TECH FIG 4 • Vaginal agenesis. Incisions avoid infringing upon adjacent anatomy and can preserve tissue to advance into the neovagina. Tissue in this region is not uniformly good quality, however.

- After elevation of flaps and initial electrocautery, the remainder of the dissection occurs bluntly with judicious use of cautery.
 - Care is taken to maintain awareness of urinary tract and rectum during dissection.
- Desired caliber for penetrative intercourse: two fingers, spread to 2.5 to 3 fingerbreadths and at least 8 cm depth. Deep dissection will push peritoneum away but not enter it.

Graft Substrates and Techniques

- After the neovaginal bed has been dissected to allow adequate depth and caliber and a natural axis, the skin or mucosal graft is harvested and prepared.
- Historically, the McIndoe skin graft vaginoplasty was the preferred

approach.

- Harvest classically is a split-thickness graft from the buttocks, although full-thickness grafts have been described.
- Graft is sewn over a vaginal mold with dermal side facing outward. The mold and form are inserted into the neovaginal cavity and held in place for 1 week to allow graft to take.
- Contracture, lack of natural lubrication, and visible harvest site are the primary liabilities.



TECH FIG 5 • Healed buccal mucosa neovagina in case of vaginal agenesis. Note the pliable but not lax introitus and nice match to surrounding tissues.

- Oral (buccal) mucosa free graft is a newer concept for neovagina.
 - It has excellent take and histologic characteristics more similar to vaginal mucosa than skin¹ (**TECH FIG 5**).
 - Neovagina creation and more extensive defects will require maximal harvest from both cheeks.²
 - Graft is inset to line the cavity with interrupted resorbable sutures.
 - Vaginal mold carefully inserted and secured by sutures across labia.
 - Oral care: Chlorhexidine mouthwash and frequent cheek exercises to prevent harvest site contracture during secondary healing.
 - Strict bed rest with log rolling and HOB less than 30 degrees for 6 to 7 days with vaginal mold in place, along with Foley catheter.
- Peritoneal flap neovagina
 - Laparoscopic Davydov procedure³ involves multiple peritoneal flaps

mobilized and pulled through to the perineum to create a neovaginal scaffold.

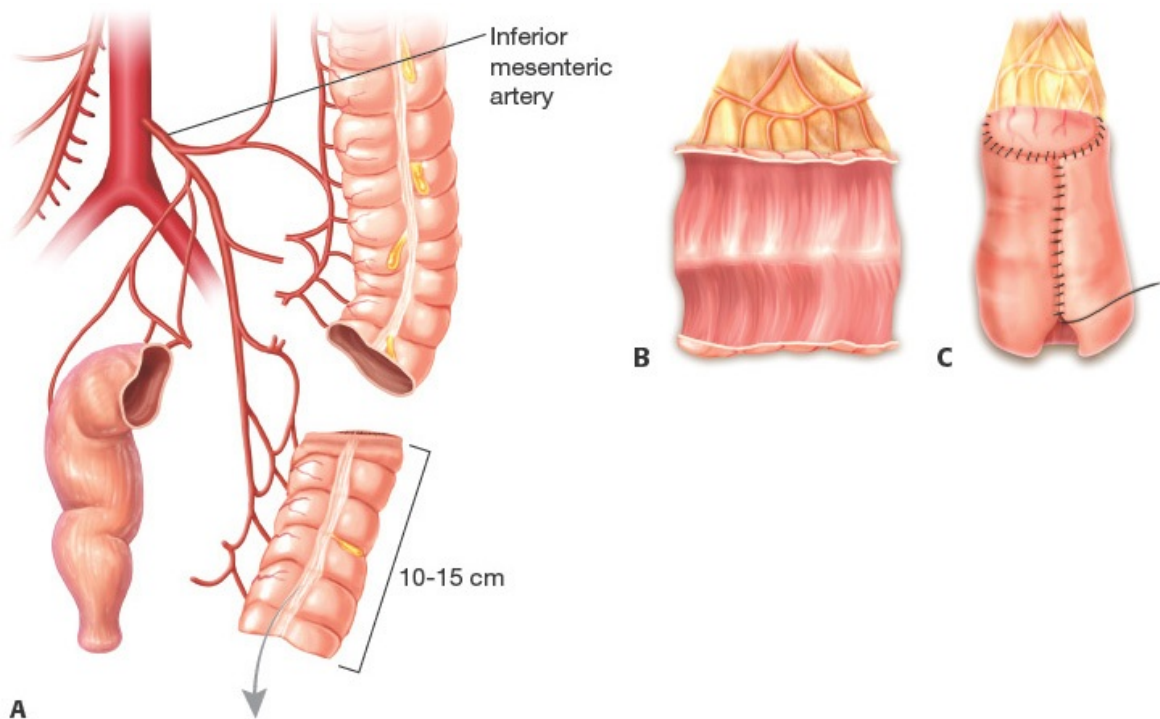
- Subsequent epithelialization by squamous metaplasia to have vaginal properties.
- Single peritoneal flap modification⁴ involves laparoscopically raising a 10 × 10 cm suprapubic peritoneal flap, leaving an intact pedicle infraumbilically.
 - The flap is pulled through to the perineum and tubularized over a mold.
 - The apex of the neovagina is created laparoscopically with a purse-string suture.
 - The pelvic peritoneum is run closed transversely.
 - Stenting is required continually for 3 months until epithelialized, and then nightly until consistently having penetrative intercourse.

Pedicled Flap Techniques

Sigmoid Colon and Ileum

- Bowel vaginoplasty principles
 - Segment of small or large bowel is harvested on its mesentery and pulled through the dissected rectovesical space for anastomosis at the perineum.
- A 12- to 15-cm segment of sigmoid colon is isolated on a branch of the inferior mesenteric artery via open or laparoscopic abdominal approach. The distal most branches may be ligated to allow more mobility of the mesentery and sigmoid segment⁵ (**TECH FIG 6A**).
- The segment is maintained isoperistaltic. The sigmoid is reconstituted.
- The segment is pulled through to the perineum and secured with interrupted anastomosis of resorbable sutures.
- The apex of the neovagina is oversewn in two layers and fixed to the sacral promontory to minimize prolapse.
- Monti principle
 - Described in small series, with limited follow-up, for sigmoid and ileum.
 - Bowel segment is isolated and opened and retubularized longitudinally.
 - Sigmoid Monti: An 8- to 10-cm segment of ileum is opened near anterior mesentery, such that mesentery forms a cap at apex. This configuration most favorable to allow vagina to reach perineum and to support apex of neovagina⁶ (**TECH FIG 6B,C**).
 - Ileal Monti: 12-cm segment of ileum opened on antimesenteric border.

Two segments may be combined end to end.⁷



TECH FIG 6 • A. Harvest of sigmoid colon for vaginoplasty. Knowledge of vascular supply to colon is essential. Maintaining isoperistaltic orientation may support mucus efflux. Support of the apex minimizes global prolapse, but redundancy may also result in prolapse. **B.** In sigmoid Monti construction, the isolated 8- to 10-cm segment of sigmoid is unfurled to its longest by opening close to the mesenteric border. **C.** The sigmoid is then retubularized in the opposite plane to create the neovagina. The neovagina is then pulled down through the neovaginal bed created via perineal and abdominal dissection.

- Neovagina caliber based upon length of bowel segment harvested. Length of neovagina determined by circumference of bowel segment. Sigmoid has advantage in that regard.
- Advantages over nonreconfigured sigmoid or ileum are the length of

segment required and the more mobile and less obtrusive mesentery.

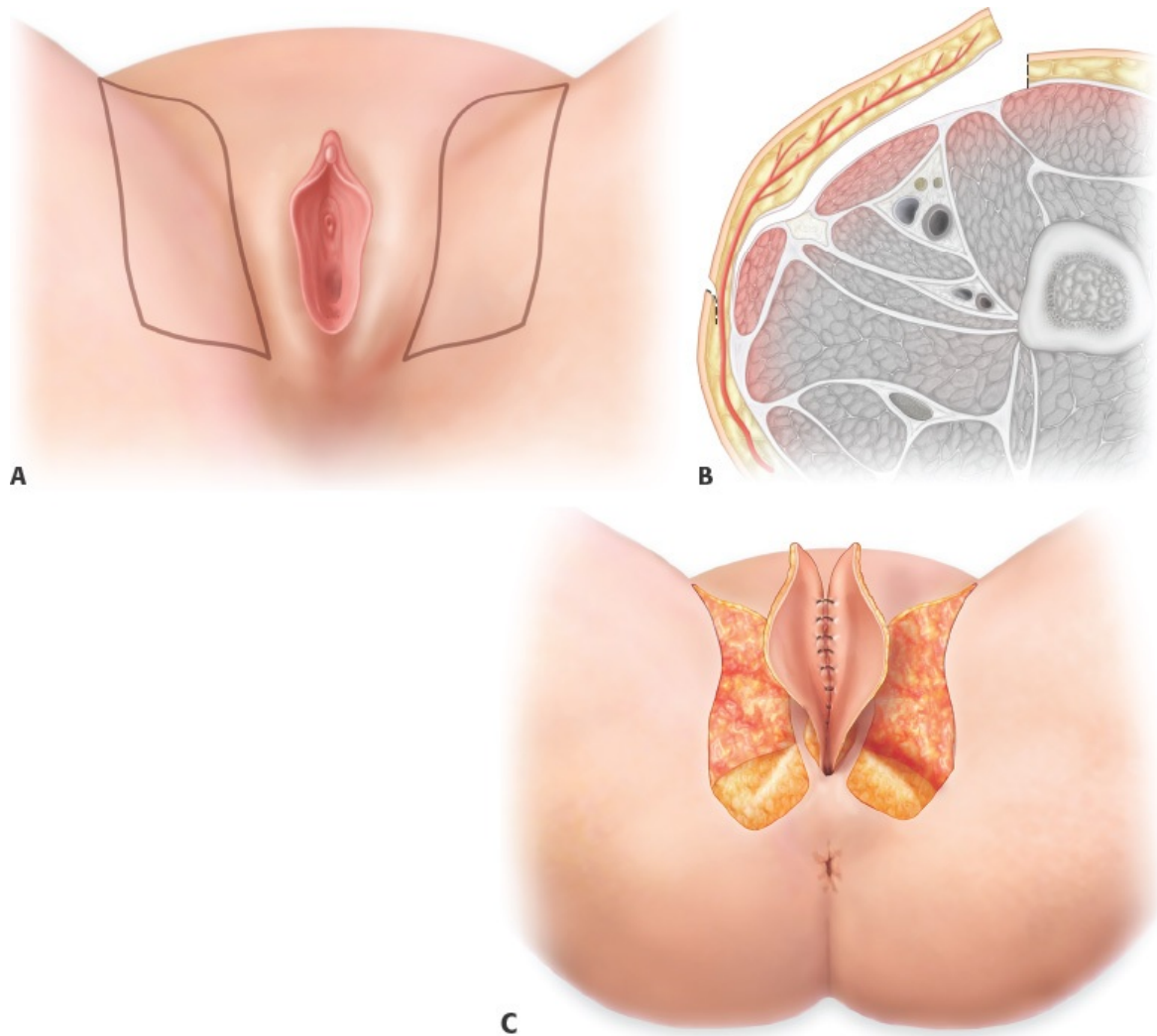
- Postoperative stenting is recommended with ileal Monti to maintain caliber while the neovaginal cavity heals.⁷ A dilation program then ensues.
- A petroleum jelly gauze roll splint may be left for 24 to 48 hours after sigmoid neovagina. Longer-term stenting is not required with sigmoid neovagina, likely due to bulk of the tissue and natural interior caliber, but dilation of the introitus may be advantageous to prevent stenosis.
- Both segments provide self-lubrication, but the mucus from colonic neovagina may be more problematic in terms of quantity and odor, particularly if redundant segment or introital stenosis.
- Prolapse is uncommon if the bowel segment is designed to limit redundancy and if well supported. Redundant tissue may be excised, and dilations are advisable while healing.
- Diversion colitis related to isolation of the colonic segment from the remainder of the GI tract may result in pain, bleeding, and discharge. Primary gastrointestinal conditions, including malignancy, may also afflict the segment.

Pudendal Thigh (Singapore) Flaps

- This is a fasciocutaneous axial sensate flap based on posterior labial vessels and terminal branches of the pudendal nerve^{8,9} (**TECH FIG 7A,B**).
- Donor area usually has not been involved in previous urogenital and lower abdominal wall reconstructions.
- Donor site closes in a primary manner and hides parallel to the labia majora in the groin/leg sulcus.
- Does not need postoperative stenting or routine dilation.
- Sensation is from the local neural plexus.
- Vagina will be lined with epithelium. Desquamation leads to secretion of sebaceous material. When used to create a total neovagina, lubrication is required for penetrative sexual activity.
- Flap is designed lateral to the labia majora, raised distal to proximal including the deep fascia.
 - Rotation into an expanded vaginal canal or introitus occurs most naturally at the 4 and 8 o'clock positions (rather than 3 and 9 o'clock vaginal incisions) with minimal tension on the point of rotation (**TECH FIG 7C**).
 - Inset with resorbable suture.
 - Close donor in layers, also with resorbable suture material. No need for

drains.

- For total vaginal reconstruction, bilateral flaps can be raised, 15×6 cm, and sewn to each other with epithelial side lining the tube, which becomes the neovaginal canal. The neovagina is then situated into the dissected space between bladder and rectum and suspended well to the most superior point to maintain length and prevent prolapse. Drainage is recommended in this situation.



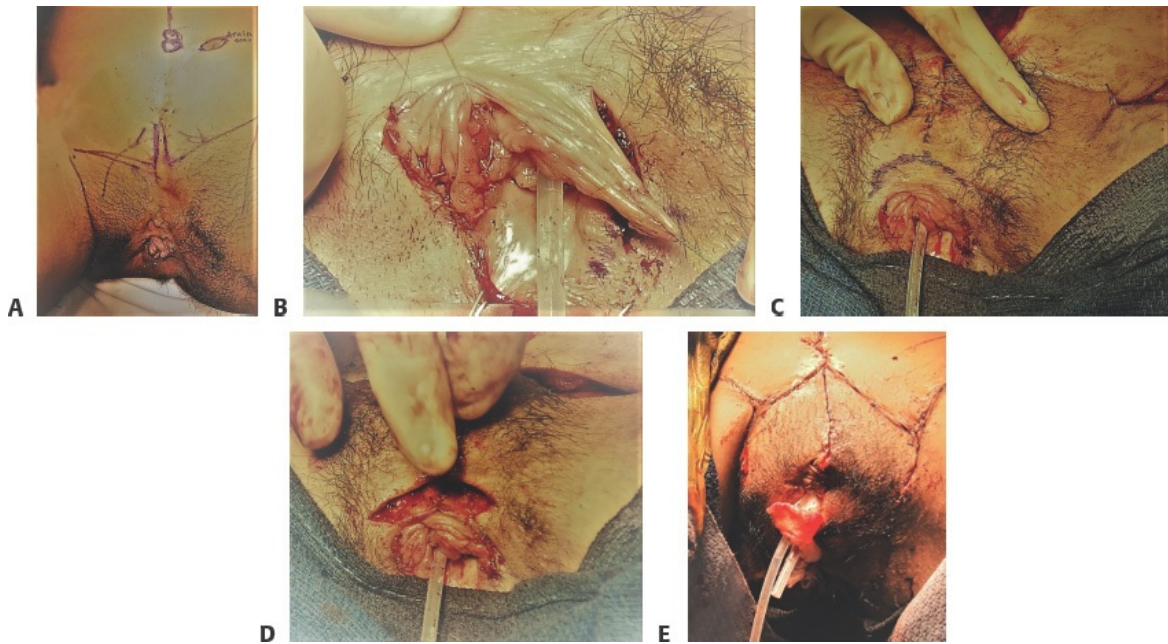
TECH FIG 7 • A. The fasciocutaneous pudendal thigh flap is based on posterior labial vessels and branches of the pudendal nerve. **B.** The plane of dissection for harvest of the flap, as well as the posterior cutaneous relaxing incision that allows tunneling of the graft. **C.**

Tunneling and union of the paired pudendal thigh flaps in complete vaginal replacement. The flaps must be well anchored to the apex of the prepared neovaginal bed to maintain length and decrease risk of prolapse.

■ Monsplasty and Labioplasty

- Surgeon must determine well in advance of planned procedure whether the mons tissue is adequate for rotational flaps or whether tissue expansion is required.
- Goals:
 - Remove midline shiny hairless skin, revising adjacent midline surgical scar
 - Rotate hair-bearing tissue to midline
 - Create a natural contour of mons and labia majora to allow the clitoris, labia minora and vaginal vestibule to enjoy less overt exposure.
 - Interestingly, the inferomedial rotation to cover the genitalia in females is opposite of the goal in males of evening up the pubic hairline and tissue while visually increasing penile stature through upward rotation of tissues.
- Pubic hair can be clipped but not shaved prior to marking the hair-bearing rotational flaps.
- If vaginoplasty will be performed as well, it will be completed prior to the monsplasty and labioplasty.
- Rotation flaps are marked with relaxing incisions (**TECH FIG 8A**). Midline scar excision and umbilicoplasty incisions are planned as well, if part of the requested procedure.
- The labia minora may require advancement or partial excision for improved cosmesis or patient comfort/hygiene (**TECH FIG 8B**).
 - Planning occurs along with the monsplasty but the actual labial work is easier to visualize prior to recreating the mons.
- A semilunar incision creates a non-hair-bearing skin flap just cranial to the labial complex. This is previously operated tissue (**TECH FIG 8C**).
 - Resultant flap will be turned down to become the underside of the mons-labial confluence and will form part of a hood for clitoral unit.
- The semilunar flap is turned down and rolled to deepen the “hood” or to line the anterior fusion of the labia majora and mons (**TECH FIG 8D**).

- The hair-bearing mons flaps are rotated toward the midline and sutured to each other in layers with resorbable sutures. The inferior or caudal edge of the flaps is sutured to the “hood”/ledge with resorbable suture (**TECH FIG 8E**).
- Expanded flaps require postoperative drains for 4 to 6 days until the flap is well seated.

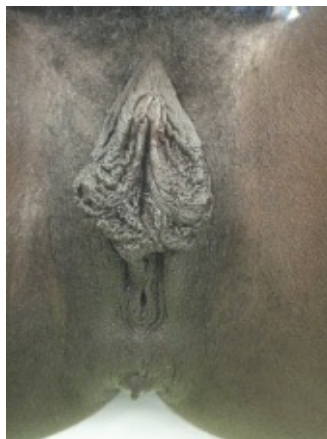


TECH FIG 8 • The surgical steps are depicted from two different patients. **A.** Exposed urethra and genital tissues to be better concealed with monsplasty. Rotational flaps are marked in preparation for monsplasty. **B.** Advancement of mobile or anteriorly mounded labia minora for improved concealment of clitoris and urethra after childhood repair of exstrophy. **C.** Semilunar incision is raised from previously operated midline hairless tissue. Tissue expanders have been removed and midline closure preplanned with staples. This hairless flap will be turned down to conceal the more intimate anatomy and to line the underside of the monsplasty. **D.** Semilunar flap turned down. Note that the flap has been trimmed in the

midline and closed vertically to conceal the upper labia minora. **E.** Final appearance after monsplasty flaps rotated and approximated. Scar revision, umbilicoplasty and vaginoplasty were also completed in this patient.

■ Reduction Labioplasty

- Goal is to restore comfort rather than to address cosmetic misgivings (**TECH FIG 9**). Reassurance regarding wide spectrum of “normal” is central.
- Defer any intervention until adequate time for adjustments has occurred, as well as development one or more years beyond menses. Potential to “regrow” bulk if development incomplete.
- For whichever is used of the three techniques described below, adhere to the following:
 - Place traction sutures in the tips of the labia minora to gauge tissue to be excised.
 - Mark inner and outer surface of labia minora.
 - Mark both sides for symmetry prior to revising either labia.
 - Perform a two-layer closure.



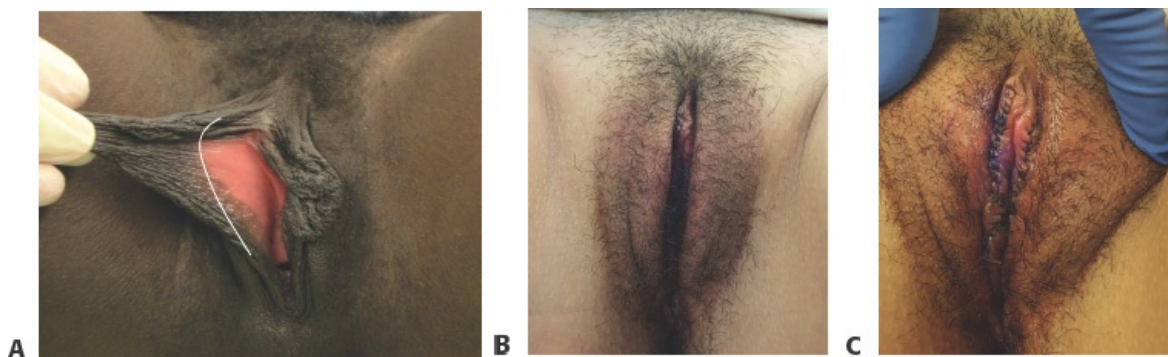
TECH FIG 9 • Marked, physically bothersome hypertrophy of the labia minora is seen with the labia at rest.

Simple Excision and Closure

- This method offers easiest recovery and least chance to redevelop bulk. There is no potential for flap dehiscence.
 - Greater risk of exposing clitoris or creating irregularity anteriorly, due to more difficulty blending into the naturally folded clitoral hood contour (**TECH FIG 10A**).
- Skin is incised sharply and dartos divided with electrocautery.
- Dartos is run longitudinally with resorbable suture.
- Skin is also closed with continuous resorbable suture.
- Suture line is anterior and may result in more friction during healing but this is not generally symptomatic (**TECH FIG 10B,C**).

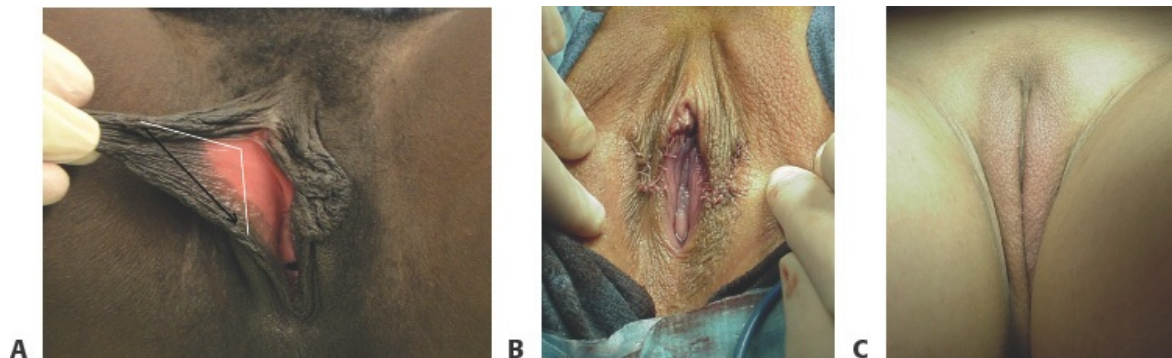
Wedge Excision With Advancement

- This method is more prone to postoperative edema and discomfort, more prone to redevelop bulk, and more prone to dehiscence without layered closure.
- Wedge excision and advancement is a full-thickness resection of the central portion of the hypertrophied labia.
- The apex of the flap will advance to the bottom of the wedge incision (**TECH FIG 11A**).
- First layer closure with running resorbable suture begins in corner of wedge incision, gradually anchoring the flap.
- Skin closure is hidden on lateral and medial surfaces of the labia minora. Longer lasting resorbable suture is used on the cutaneous layer at the apex of the flap (**TECH FIG 11B,C**).



TECH FIG 10 • **A.** Retracted labia marked for simple excision. Care must be taken to taper onto the clitoral

hood to avoid cranial irregularity and to avoid exposing glans clitoris. **B.** Labia at rest after simple excision. **C.** Immediate postoperative appearance with labia spread. The anterior suture line is not typically irritating, as it is concealed by the labia majora.



TECH FIG 11 • A. Retracted labia marked for wedge resection and advancement. The running closure of the dartos begins in the apex and progresses down to the tip of the flap. Longer lasting resorbable sutures are recommended at the tip. **B.** Postoperative appearance in a different patient. Note that the suture line is anterior with simple excision but here is hidden in the inner and outer labial surfaces. **C.** The appearance is similar at rest to simple excision.

Hybrid Approach

- Useful in cases in which the labia minora are globally enlarged with posterior insertion.
- Offers benefits of hidden suture line and natural blending with clitoral hood, with a less extensive flap recession than the wedge excision (**TECH FIG 12**).
- Rationale for two-layer closure, regardless of technique:
 - Finlike rather than flat contour of labia
 - Hemostasis, decreased risk of hematoma. Insurance against dehiscence in advancement cases.



TECH FIG 12 • Retracted labia marked for hybrid excision with partial advancement and partial simple closure. Again, the running closure of the dartos begins in the apex and progresses down to the tip of the flap. In this approach, the flap is shorter so the posterior aspect of the closure will be simple two-layer closure.

PEARLS AND PITFALLS

Patient readiness

- Older teens may profess readiness for vaginal reconstruction with immediate goal of ease of tampon use and desire to prepare for future sexual activity, but they may primarily desire to “get it over with.”
- Unless imminently prepared for sexual activity and willing to accept support, they may lack the emotional maturity for the procedure and to adhere to a postoperative dilation program.

Operative preparation

- A strong understanding of pelvic anatomy and potential congenital or postsurgical variations is relevant when dissecting space for neovagina or widening the vaginal canal.
- Injury to the urethra, bladder, or rectum significantly changes the operative experience and potentially long-term functionality.

Hemostasis

- Address vault bleeding with packing rather than blind coagulation in deep cavity.
- Remain alert to adjacent pelvic structures.

Progression of postoperative therapies	■ Even with a highly motivated and mature patient, frequent office visits are recommended early postoperatively. ■ Provider reinforces or redirects patient regarding adequacy of axis and depth of daily use of dilators.
Patient selection for reduction labioplasty	■ Reduction of prominent labia minora for cosmetic purposes is strongly discouraged. ■ Reassure about normal variations in prominence of labia minora in girls and women. ■ For physical bother due to bulky tissue and friction/irritation from clothing: ■ Instruct in trial of manually tucking redundant tissue in after bathing and toileting. ■ Instruct in application of bland ointment nightly to manage irritation. Ointment in daytime may increase bother. ■ Defer surgical management until estrogenization and maturation of tissues is secure. ■ Surprising “regrowth” of tissues may occur if maturation in early evolution.
Labioplasty and perineal care	■ Dehiscence of labial flaps can result in prolonged healing, unfavorable cosmetic result, or asymmetry. ■ Two-layer closure of the labioplasty, particularly at the tip of the labia, reduces risk of separation. ■ Moist perineal environment and oral or topical antibiotic use increase risk of candidal infection and healing concerns. Nystatin powder to groin creases may be protective.

POSTOPERATIVE CARE

- Vaginal packing and vaginal stents/molds
 - Inflatable and solid forms have been utilized. None currently commercially available.
 - Not required for pudendal thigh flaps.
 - Required for approximately 7 days for graft take with skin or oral mucosa.
 - Required all day and night for 3 months in peritoneal flaps due to requirement of squamous metaplasia.
- Mouth care after buccal mucosa harvest
 - Donor site heals by secondary intention and forms fibrinoid plaque within 2 days.
 - Chlorhexidine mouthwash rinses several times daily.

- Mouth exercises minimize likelihood of function-limiting donor contraction. Open wide. Puff check. Mindful manual massage of site by tongue.
- Home dilation program: as described above for each technique. Frequent visits to reinforce technique and improve compliance.
- Activity restrictions
 - Avoid lifting, straddle stance or activity, squatting, or kneeling with perineal pressure for 3 to 4 weeks. Driving restrictions based upon approach.
 - No tampon use or sexual activity until adequate healing determined by surgeon.

OUTCOMES

- A paucity of data exists regarding objective short- and long-term surgical outcomes as well as validated patient-reported outcomes.
- Female Sexual Function Inventory scores compared favorably to controls in large peritoneal flap series.⁴
- Long-term results after sigmoid vaginoplasty report high level of success and patient satisfaction.^{5,10}
 - However, decreased sexual function with abnormal depression indices may occur highlighting importance of pre- and postoperative counseling and support.¹¹
- Tissue quality and match and adequacy of vaginal caliber are very good after buccal mucosa vaginoplasty.^{1,2}
- Sexual activity is allowed by successful maintenance dilations. If pregnancy is achieved, consultation with maternal fetal medicine and caesarean delivery is recommended in neovagina, regardless of type.

COMPLICATIONS

- Injury to surrounding structures: urethra, bladder base/ureter, or rectum may occur with dissection of the neovaginal cavity
- Vaginal contracture or stricture
- Introital stenosis
- Prolapse of pedicled tissues
- Bothersome discharge (sigmoid)
- Secondary changes within donor substrate (eg, chronic inflammation, inflammatory bowel, malignancy)
- Unsatisfactory cosmetic or functional result

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CHAPTER Ambiguous Genitalia

Deborah L. Jacobson and Elizabeth B. Yerkes

DEFINITION

- Individuals born with ambiguous genitalia have external genitalia that are not fully typical male or female in appearance. Others have developmental differences that are not externally apparent but may impact future function or well-being. These groups have some degree of discordance between genetic, gonadal, and phenotypic sexual characteristics.
- Medical nomenclature used over the decades was well intentioned but has been viewed as pejorative. Accordingly, nomenclature with multiple subterminologies has evolved with the goal of correcting this situation.
- Hermaphroditism, pseudohermaphroditism, intersex state/disorder, and disorders of sex development (DSD) have been used to describe the state of having ambiguous or nontypical genitalia with or without chromosomal or gonadal anomaly.
- Even the most recent nomenclature, which originated from a consensus of experts, affected individuals, and advocates, is not uniformly accepted by the community. “Disorder” is not widely embraced as a desired description.
- Whereas genital ambiguity and differences of sex development have historically been considered pathologic and in need of surgical correction, contemporary viewpoints acknowledge many phenotypic variations on the continuum of human genital development.
- The authors understand that surgical reconstruction of ambiguous genitalia is a controversial topic and do not presuppose that surgical intervention is necessary for, or would be preferred by, any given individual.
- This chapter will cover the technical aspects of genital reconstruction; however, surgical management should only be undertaken after extensive

counseling and shared decision-making. Longitudinal multidisciplinary care for the individual and family is strongly encouraged.

- This chapter will focus on feminizing genital procedures and the diagnoses that could involve decision-making for these types of procedures.

ANATOMY

■ Clitoris

- The corpora cavernosa (erectile bodies) of the clitoris originate proximally as paired crura, swell medially to form the clitoral bulbs, and unite distally.
- The paired cavernosa support a glans covered by a prepuce of labia minora. MRI imaging studies performed by O'Connell et al demonstrate that the glans lies caudal to the corporal bodies, leading to a natural hairpin curve.¹
- Autonomic input is via the paired cavernous nerves, which originate from the vaginal plexus at the 10 and 2 o'clock positions along the vagina and course dorsally along the proximal urethra.² The nerves travel with the cavernous arteries and enter the clitoral bodies under the pubic arch.
- Somatic supply is via the paired dorsal nerves of the clitoris, which originate from the pudendal nerves, run dorsolaterally along the crura and ischiopubic rami at approximately the 11 and 1 o'clock positions, and enter the glans at the corona. The nerves branch, fanning out along the clitoral bodies dorsally and laterally. Nerves are absent in the dorsal midline and deficient ventrally.
- The cavernous arteries originate from the internal pudendal artery, travel with the cavernous nerves, and enter the clitoral body under the pubic arch. Dissection between the crura at the pubic arch should be avoided.
- Variations from typical clitoral anatomy should be expected in patients with virilization of female genital tissue.

■ Labia

- The labia majora embryologically correspond to the male scrotum. They are separated by the vulvar cleft, which contains the labia minora and clitoris. Together the structures conceal the vestibule.
- The labia minora and urethral plate correspond to the male anterior urethra. The labia join superiorly to frame the glans clitoris as the clitoral hood.

■ Vagina

- The vagina consists of a rugated mucous membrane fixed to a bilayered muscular invagination. It is suspended from the levator ani ventrally, the rectovaginal septum dorsally, and the cervix apically.
- Arterial supply is via uterine, vaginal, and internal pudendal branches

coursing along the anterolateral surface of the vagina.

- Innervation originates anterolaterally via autonomic branches of the uterovaginal plexus and somatic branches of the pudendal nerve.
- The ureters pass adjacent to the lateral margins of the vagina and insert into the base of the urinary bladder.

PATHOGENESIS

- Cloacal development
 - The cloacal membrane folds with differential embryonic growth beginning in week 4, and the cloaca partitioned into anterior (urogenital sinus—UG sinus) and posterior (hindgut) compartments with the descent of the urorectal septum.
 - Disruption of normal cloacal development can lead to persistent cloaca or UG sinus anomalies.
- Development of the external genitalia
 - Fetal androgenization leads to elongation of the genital tubercle, fusion of the urethral folds, and fusion of the labioscrotal folds.
- Development of the abdominal wall
 - Failure of mesodermal ingrowth or premature rupture of the cloacal membrane leads to bladder or cloacal exstrophy.
- Development of the UG sinus
 - Caudal paramesonephric (Müllerian) duct deficiencies may lead to agenesis of the proximal vagina and variable anatomy of the uterus/fallopian tubes (Mayer-Rokitansky-Küster-Hauser syndrome).
 - Lateral paramesonephric (Müllerian) fusion anomalies may lead to uterus didelphys, bicornuate uterus, or unicornuate uterus.
 - Deficiency of the distal UG sinus may lead to vaginal atresia.
 - Incomplete vaginal canalization may lead to an imperforate hymen or transverse vaginal septum.

NATURAL HISTORY

- The natural history of an individual in this population, or the population as a whole, is not entirely known.
- For androgenized individuals, it is unclear what the prenatal hormonal milieu (both in terms of absolute androgen levels and the response of developing genital/nervous tissues) portends for future gender identity or sexuality.
- For virilized females (such as patients with congenital adrenal hyperplasia) in

whom medical control is irregular, continued irreversible changes may occur in the genital tissues.

- The psychosocial outcomes of early vs delayed surgery remain unclear, as does the definition and likelihood of surgical success.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Antenatal course: complications, history of prematurity, and other anomalies
- Evidence of maternal exposure to endogenous or exogenous androgen
 - Severe acne, abnormal hair growth, clitoral enlargement, or Cushingoid appearance
 - Drugs, virilizing tumors, or adrenal disorders
- Family history:
 - Known chromosomal anomalies
 - Fetal/neonatal demise
 - Genital ambiguity or urologic anomalies
 - Infertility or consanguinity
- Physical examination
 - General: overall appearance, dysmorphic features, and general infant well-being
 - Spine: gross deformity or neurocutaneous marks
 - Anomalous findings may indicate genetic syndromes or fetal exposures.
 - Tethered cord or occult spinal cord anomalies are common with select diagnoses.
 - Abdomen: marked distention, hernias, suprapubic masses, and wall abnormalities
 - May indicate bladder outlet obstruction, hydrometrocolpos, or urinary ascites
 - Perineum
 - Labioscrotal folds: prominence, rugation, pigmentation, and presence of gonads
 - Clitorophallic structure: dorsal stretched length, glans width, and corporal consistency
 - Perineal orifices: number, location, and patency
 - Gonads: presence by palpation, location, and consistency
 - Palpable gonadal tissue suggests presence of at least some ipsilateral testicular tissue

IMAGING AND SPECIALIZED EXAMINATION

- Modalities are employed selectively based upon clinical findings and the active differential diagnosis.
- Ultrasonography: Evaluation of the adrenals, kidneys, ureters, bladder, Müllerian structures, and gonads
 - Dilation of genital ducts or duplications or unclear anatomy may lead to additional radiographic or operative investigations.
- Genitography: Delineation of internal genitourinary anatomy
 - A Foley catheter or occlusive nipple is used to occlude the UG sinus orifice.
 - Retrograde administration of contrast material defines the proximal anatomy including sinus length and level of confluence.
 - The vaginal confluence may be missed if the system is not well distended.
- Voiding cystourethrography (VCUG)
 - The catheter may be advanced for VCUG after genitogram if indicated or if the sinus is not opacified. Vesicoureteral reflux and bladder anatomy is assessed during filling, at bladder capacity, during voiding, and after voiding is complete.
 - VCUG alone may not opacify the vagina, so it is less useful study for assessing the UG sinus.
- Endoscopy: Direct visualization of patient anatomy
 - Because general anesthesia is required, endoscopy may be performed at the time of definitive reconstruction unless additional anatomic evaluation is required for surgical decision-making.
- MRI: Delineation of pelvic anatomy and associated spinal anomalies
 - MRI often requires anesthesia in young children and would therefore be considered when other imaging studies are inconclusive.
- Diagnostic laparoscopy: very selectively used in infancy if additional information required
 - Laparoscopy is utilized to clarify internal anatomy and gonadal characteristics.
 - Gonadal biopsy may be necessary in select cases.

DIFFERENTIAL DIAGNOSIS

This list includes only conditions in which patients could potentially be candidates for feminizing procedures.

- Differences in gonadal differentiation

- Pure gonadal dysgenesis
- Mixed gonadal dysgenesis
- Ovotesticular DSD (previously “true hermaphroditism”)
- Differences in androgenization
 - Adrenal sources
 - Congenital adrenal hyperplasia (in 46 XX patients)
 - 21-Hydroxylase deficiency
 - 11 β -Hydroxylase deficiency
 - 3 β -Hydroxysteroid dehydrogenase deficiency
 - 17 β -Hydroxysteroid dehydrogenase deficiency (late virilization in 46 XY phenotypic female)
 - Androgen-secreting tumor
 - Maternal sources
 - Drugs
 - Androgen-secreting tumor
 - Placental sources
 - Placental aromatase deficiency
 - Androgen receptor dysfunction
 - Variations in activity of androgen receptor in various tissues (46 XY patients)
 - Complete androgen insensitivity syndrome (external genitalia phenotypically female, lacking Müllerian structures due to intact MIS)
 - Partial androgen insensitivity (diverse external phenotype, degree of virilization at puberty and innate gender identity not predictable)
- Differences in embryonic development
 - Persistent cloaca
 - Exstrophy-epispadias and cloacal exstrophy
 - Müllerian anomalies
 - Müllerian agenesis (Mayer-Rokitansky-Küster-Hauser syndrome)
 - Vaginal atresia
 - Fusion anomalies
 - Vaginal duplication
 - Uterine duplication
 - Vaginal septum variations

- Urogenital sinus anomalies
 - High vaginal confluence
 - Low vaginal confluence

NONOPERATIVE MANAGEMENT

- Create a multidisciplinary team incorporating experienced pediatric urologists/pediatric surgeons/pediatric gynecologists, endocrinologists, psychiatrists/psychologists, geneticists, and nurses/social support members to work with the parents and child to guide patient care. Consider formal ethics consultations when appropriate.
- There is a broad spectrum of “normal” female external genitalia. Referring providers, parents, and patients may be reassured by education on range of “normal.” Appearance and future functionality are important to consider in the pediatric patient if surgery is requested.
- The timing and indications for feminizing genital reconstruction are currently controversial, and there may be long-term consequences of both action and inaction in this arena.
- Performing feminizing surgery in prepubertal children precludes autonomous self-determination in surgical decision-making and may lead to regret.
- Consider the psychosocial consequences of genital ambiguity, and provide appropriate counseling for patient and parent.
- Patients deserve long-term psychological support, with or without surgical intervention.
- Extended support networks may be found both within the hospital and in the patient’s own community.
- Discuss patient reproductive potential, optimizing patient sexual development and fertility when possible. Administration of androgens or estrogens may be recommended in longer term, depending on the underlying anatomy and function.
- Consider the potential for gonadal malignancy, which varies significantly with gonadal histology and patient pathophysiology. Whenever possible, gonadal preservation should be considered.

SURGICAL MANAGEMENT

Preoperative Planning

- Diagnostic laboratory evaluation may include karyotype, serum electrolytes,

17-hydroxyprogesterone, testosterone, luteinizing hormone, and follicle-stimulating hormone levels. Additional adrenal and sex hormone testing is used more selectively but is essential to make a diagnosis in some cases.

- A thorough examination under anesthesia should be completed, including inspection of external genitalia, palpation for gonads, cystoscopy, vaginoscopy (if applicable), and genitography.
- Consider the need for gonadal biopsy or gonadectomy at the time of intervention, along with possible gonad cryopreservation.
- Patients undergoing vaginoplasty require bowel preparation (enema vs polyethylene glycol solution) prior to surgical intervention.

Positioning

- Isolated genitoplasty with or without repair of a low UG sinus is generally performed in frog-leg (infants, young children) or dorsal lithotomy (older patients) position with padding of all pressure points.
- For reconstruction of a high UG sinus, most patients will require both prone and supine positioning, so total lower body preparation is utilized. This preparation may be advantageous in infants and young children for sterility of the field, whether high or low confluence.
- Ensure there are no IVs in lower extremities.
- A single-shot caudal block is reasonable in eligible patients, but a continuous caudal catheter is not utilized intraoperatively.
- After endoscopy and catheter placement, keep the catheters sterile and move the patient up the table for second prep. Prep the lower body circumferentially from the xiphoid to the toes.
- Place feet and legs in a stockinette.
- Drape to allow for lower body repositioning from supine to prone within the drape (**FIG 1**).
- Position the patient with stacked towels under the pelvis. Initial prone vs supine positioning will depend upon the planned procedures.

Approach

- Primary components of the feminizing genitoplasty include the following:
 - Clitoral degloving
 - Elevation of the urethral plate and mobilization of the common UG sinus
 - Clitoral reduction
 - Urogenital sinus reconstruction and vaginoplasty

- Creation of a clitoral hood and labioplasty



FIG 1 • Prone view of circumferential body preparation from the xyphoid to the toes. The child is toweled out and “passed through” a drape to allow transitions from supine to prone within the drape. The hips will be elevated on stacked towels.

- Several clitoral reduction techniques are utilized in contemporary feminizing genitoplasty.
 - Each is performed with attention to clitoral nerve sparing.
- The timing of reconstruction elements is controversial.
 - “Early” single-stage reconstruction of the genitalia and UG sinus is performed with the goal of no additional procedures and no memory of the recovery. Additionally, the excess UG sinus tissue and genital skin can be redistributed as needed if the procedure is completed in a single stage. Despite these potential advantages, the smaller caliber of the infant vagina may increase the risk of vaginal stenosis and the likelihood of secondary procedures. Routine postoperative vaginal dilations are not recommended in this age group.
 - “Late” reconstruction preserves autonomous self-determination and allows the full advantage of virgin planes and tissues.
 - There may be limited options for positioning older patients.
 - Vaginal dilations will be required postoperatively, whether by medical grade dilators or sexual activity, so emotional maturity and commitment to outcomes are essential.

- A staged reconstruction, by deferring either genitoplasty or vaginoplasty, precommits to two operative events and limits the redistribution of healthy tissues. The second stage may involve previously operated tissues.
- The operative approach varies based on:
 - The surgical components to be included
 - The level of vaginal confluence in the UG sinus (“high” vs “low”)
 - The degree of virilization

TECHNIQUES

■ Feminizing Genitoplasty: Examination

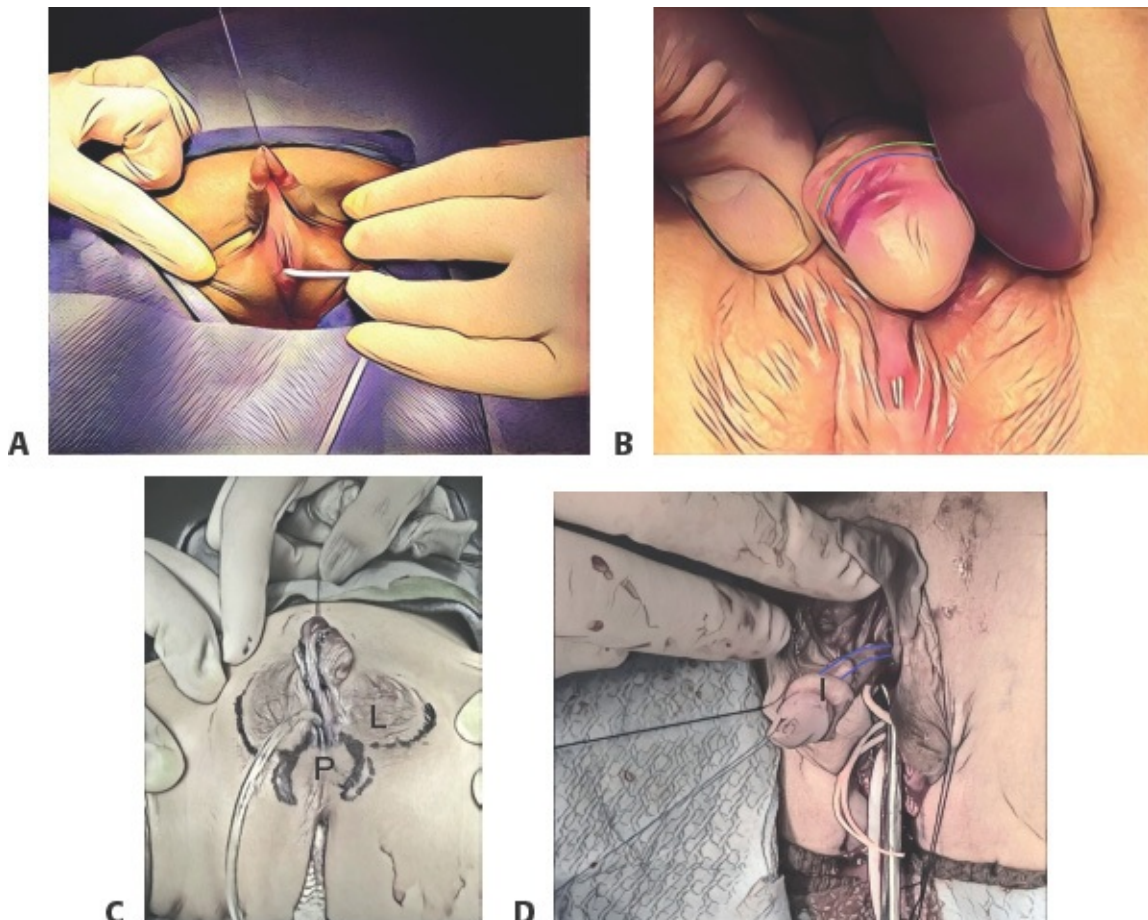
- If repair of the UG sinus (urethroplasty and vaginoplasty) will occur:
 - Examination under anesthesia and endoscopy is performed in the dorsal lithotomy position to define UG sinus anatomy and denote the relative positions of the urethra and vagina.
 - A Fogarty catheter is inserted into the vagina and clamped. A Foley catheter is inserted into the bladder and periodically drained.
 - Alternatively, a Councill tip Foley catheter may be introduced into the vagina over a wire after emptying the bladder. Once the confluence of urethra and vagina is identified surgically, the catheter is redirected to the bladder.
 - A sponge may be placed into the rectum to allow for intraoperative palpation of the anterior rectal wall.
- If repair of the UG sinus will *not* occur:
 - Examination under anesthesia is performed.
 - A Foley catheter is inserted into the bladder and periodically drained.

■ Contemporary Nerve Sparing Clitoral Degloving

- Blunt lysis of adhesions between the glans clitoris and inner prepuce is performed.
- A retraction suture is placed through the dorsal midline of the glans (**TECH FIG 1A**).
- The skin is retracted to expose the inner prepuce. A dorsal degloving

incision is made more proximally than a standard circumcising incision to preserve preputial tissue for glans coverage as the inner layer of the clitoral hood (**TECH FIG 1B**).

- Placement of the ventral degloving incision varies with the degree of virilization and intended procedure.
 - When the UG sinus meatus is found on the glans clitoris, the ventral degloving incision is immediately beneath the corona.
 - When the UG sinus meatus is located proximal to the glans clitoris, the ventral degloving incision begins immediately proximal to the orifice and extends distally to flank the urethral plate (**TECH FIG 1C**).
- The clitoris is sharply degloved to the base, preserving the dartos with the skin and leaving Buck fascia and the underlying neurovascular bundle undisturbed (**TECH FIG 1D**).
 - The suspensory ligament will be encountered dorsally and should be left in situ proximally to support the proximal clitoral body and the glans after clitoral reduction.

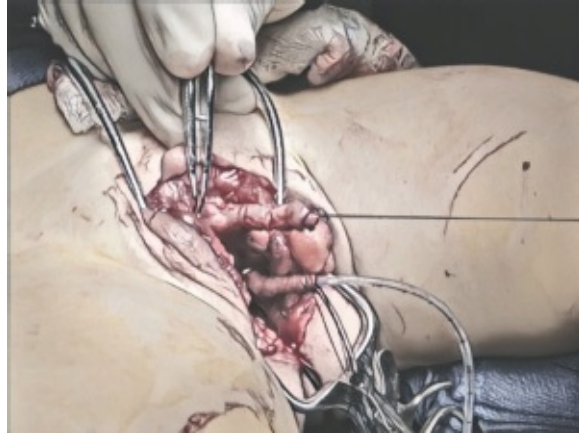


TECH FIG 1 • A. A traction suture placed through the dorsum of the glans clitoris facilitates visualization of the urethral plate. **B.** The clitoral degloving incision is more proximal than is typical for circumcision to allow for creation of the inner layer of a clitoral hood. The *blue line* delineates the typical circumcising incision, and the *green line* delineates the preferred degloving incision. **C.** When the urethra is proximal, the ventral degloving incision flanks the urethral plate. A posteriorly based omega-shaped perineal flap is created on the perineum at the time of the dorsal and ventral degloving incisions. The labia majora will ultimately be moved posteriorly to flank the perineal flap after it has been advanced into the vagina. “P” denotes a posteriorly based flap and “L” denotes the labia majora. **D.** Preservation of the paired dorsal neurovascular bundles beneath Buck fascia. “I” represents the inner prepuce, which becomes the inner layer of the clitoral hood. The dorsal overlaid lines represent the neurovascular tissue.

■ Elevation of the Urethral Plate and Mobilization of the Common UG Sinus

- Terminology: If the orifice of the UG sinus is on the clitoral body, a “urethral plate” consisting of a mucosal strip and its underlying spongiosum extends along the ventral clitoral body from the UG sinus orifice to the glans. “UG sinus” refers to the intact common channel.
- The urethral plate/common UG sinus is elevated off the ventrum of the clitoral body, leaving the tunica albuginea intact.
- The point of distal division varies based on the degree of virilization and whether reconstruction of the UG sinus is planned.
 - If UG sinus reconstruction is planned, the urethral plate or common UG

sinus is divided along the distal clitoral body and fully mobilized (**TECH FIG 2**). If the UG sinus orifice is in the glans, the UG sinus is transected distally rather than dissected out of the glans.



TECH FIG 2 • The prepuce is fully mobilized away from the clitoral body. Note that the inner layer of the clitoral hood is partially covering the glans in this photograph. The UG sinus is also mobilized. A catheter is in place, and multiple traction sutures assist with mobilization.

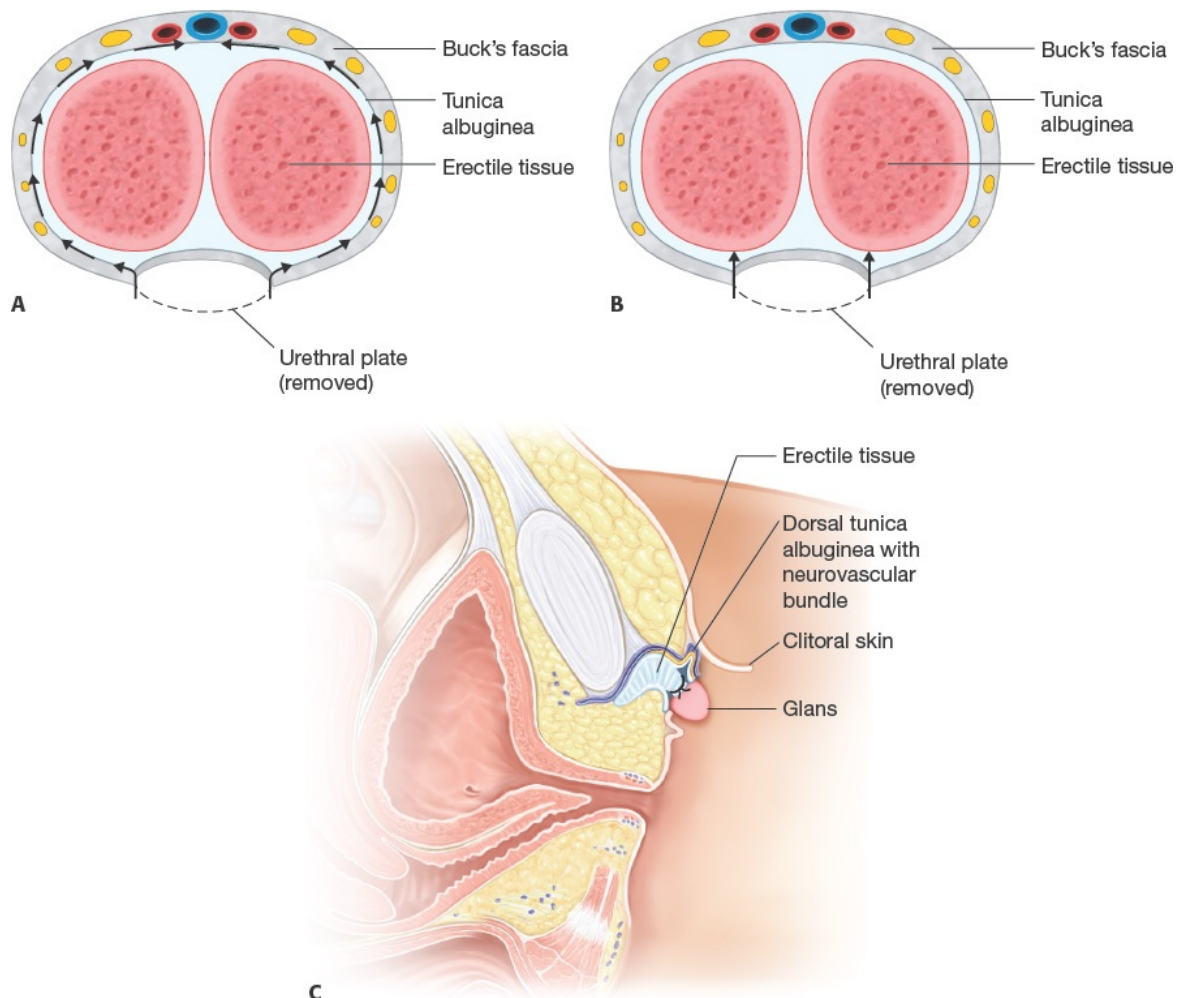
- If UG sinus reconstruction is deferred, the urethral plate is elevated and ultimately partially resected to allow recession of the glans.

■ Clitoral Reduction

- Historical feminizing genitoplasty procedures included clitorrectomy and clitoral recession procedures, each of which resulted in dysfunction. Contemporary approaches emphasize both cosmesis and function. The dorsal neurovascular tissue is preserved in each approach.
- Conservation of clitoral tissue and its neural innervation is of paramount importance for the preservation of genital sensitivity.³
- Two main techniques allow debulking of the hypertrophied corpora cavernosa with preservation of the glans clitoris on its neurovascular pedicle.
- In both techniques, Buck fascia is incised ventrally, exposing the tunica albuginea.

- In the description coined nerve-sparing ventral clitoroplasty (NSVC),³ the dorsal neurovascular bundle is elevated off the tunica albuginea along the length of the clitoral body and left in continuity with the glans (**TECH FIG 3A**). Use of papaverine minimizes vascular spasm that may compromise the glans clitoris.
 - The erectile bodies are dismembered from the glans and transected 1.5 to 2 cm from the bifurcation.
 - The tunica albuginea is oversewn to allow for clitoral erection.
 - The glans is resected with care to avoid kinking of the neurovascular bundle.
 - Glans support and proximal engorgement are afforded.
- The alternative nerve-sparing approach, as preferred by the authors, differs in that the dorsal tunica albuginea is preserved along with the neurovascular bundle (**TECH FIG 3B**).
 - The intact tunica albuginea protects the neurovascular tissue without adding problematic bulk.
 - Parallel incisions are created along the ventrum of the clitoral body and the erectile tissue.
 - The erectile tissue is bluntly dissected and ligated proximally, preserving the shell of tunica albuginea dorsally and laterally.
 - The glans is approximated to the corporal stump. The intact dorsal tissue gently bows into the subcutaneous tissue⁴ (**TECH FIG 3C**).
- Corporal-sparing clitoroplasty has been proposed as a means of preserving the corporal bodies to allow for potential reversal of feminizing procedures and phalloplasty in the future.⁵
 - After the clitoris is degloved, the glans and neurovascular tissue are elevated off the clitoral body as a unit.
 - The plane between the corpora is sharply dissected, allowing separation of the hemicorpora.
 - The tunica albuginea of each hemicorpora is oversewn with absorbable sutures to create independent bodies.
 - The hemicorpora are now rotated inferolaterally into dartos pouches fashioned within the labia majora.
- The glans clitoris is rarely reduced in size. Concealment can be accomplished without glans reduction.
- If reduction is deemed necessary, wedge resection from the ventrum is

avored. Innervation is denser dorsally.⁶



TECH FIG 3 • A. Buck fascia and the neurovascular tissue are mobilized off the clitoral bodies and preserved. Full-thickness resection of the clitoral bodies is performed. **B.** Dissection proceeds ventrally into the corpora. Spongy erectile tissue is excised and ligated proximally, but the shell of tunica albuginea and the neurovascular tissue are both preserved. **C.** Sagittal view of the glans clitoris seated on debulked clitoral bodies. Note that the neurovascular tissue is preserved and not kinked.

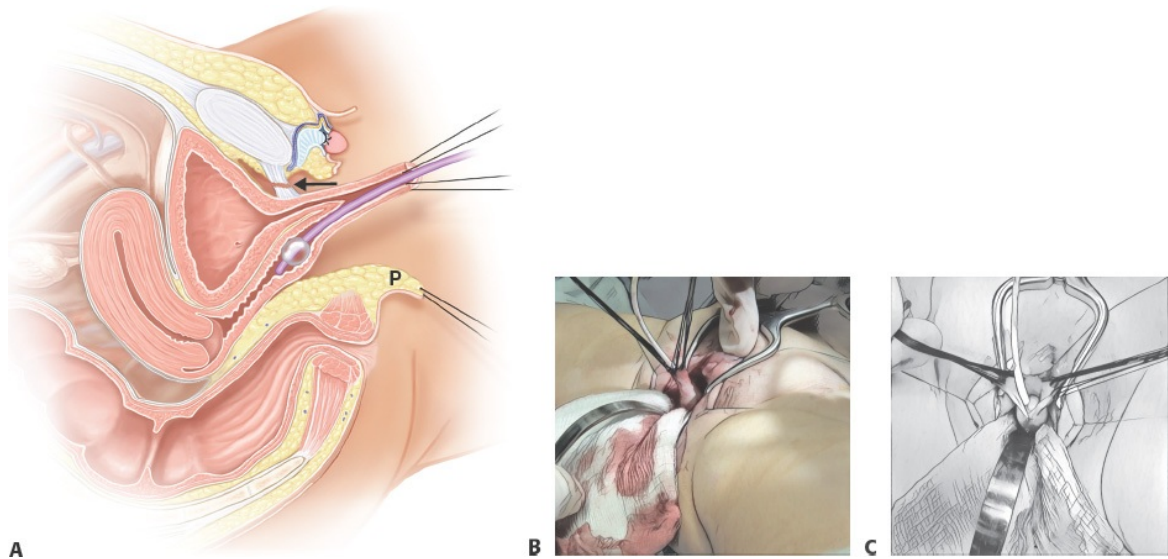
■ Urogenital Sinus Reconstruction and Vaginoplasty

Creation of a Perineal Flap

- If UG sinus mobilization is planned for urethroplasty and vaginoplasty, a posteriorly based omega-shaped perineal flap is created on the perineum at the time of the dorsal and ventral degloving incisions (see **TECH FIG 1C**).
- Raising a perineal flap exposes the bulbar portion of the UG sinus and allows dissection between the UG sinus and rectum.
- The flap will ultimately be advanced into the vagina to increase the distal vaginal caliber. Advancing the flap reduces the risk of stenosis.
- Flap vaginoplasty without partial mobilization of the UG sinus enlarges the UG sinus, but the urethral meatus remains recessed, or hypospadiac.
- Overzealous advancement of the perineal flap may result in dehiscence, ischemia, or an unnatural slope of the perineal body. Additionally, this tissue will typically be hair-bearing and lacks mucosal properties.

Total and Partial Urogenital Mobilization (TUM and PUM) (**TECH FIG 4A**)

- Mobilization of the common UG sinus brings the genitourinary complex toward the perineum,^{7,8} facilitating either flap vaginoplasty or pull-through vaginoplasty.
- Multiple stay sutures are placed around the common UG sinus orifice to facilitate a traumatic retraction. The common UG sinus is dissected as a unit proximally, including partial dissection under the pubis (**TECH FIG 4B**).



TECH FIG 4 • Urogenital mobilization, sagittal view. A posteriorly based perineal flap (*P*) has been mobilized to facilitate posterior exposure and for incorporation to vagina, if needed. **A.** In total urogenital mobilization (TUM), the UG sinus is mobilized as a unit both between the vagina and rectum and anteriorly under the pubis. The supportive pubourethral ligament (*black arrow*) are taken down for this extensive mobilization. In partial urogenital mobilization (PUM), the anterior dissection stops short of dividing the pubourethral ligaments. **B.** A catheter is in place in the UG sinus and multiple traction sutures facilitate dissection. **C.** The vagina has reached the perineum and is spatulated posteriorly to allow advancement of a perineal flap.

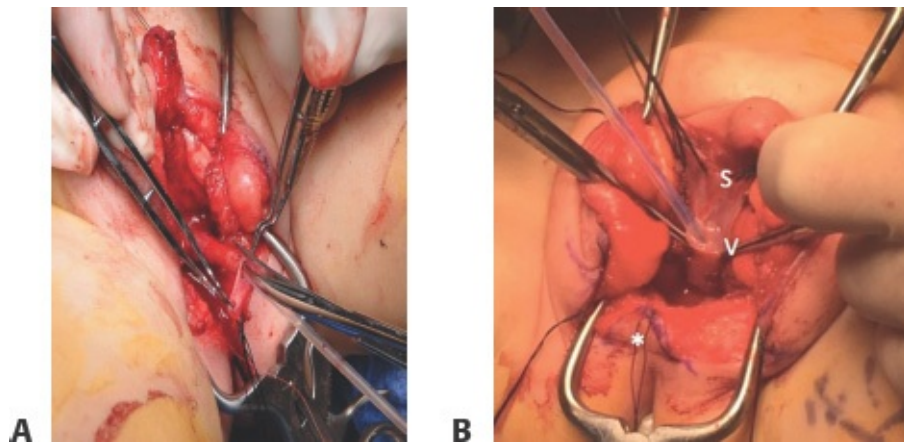
- The posterior perineal attachments are sharply divided, dropping the rectum away from the bulbar section of the UG sinus. As posterior dissection continues, the peritoneum is bluntly pushed away from the posterior wall of the UG sinus.
- If this degree of anterior and posterior mobilization is not sufficient to access the confluence, additional dissection occurs anteriorly, dividing the

pubourethral ligament. This step differentiates PUM from TUM.⁸ TUM bears the potential risk of disturbing pelvic support and continence mechanisms.

- The sinus is further mobilized toward the perineum, and the vaginal balloon catheter is palpated.
- If the confluence is still high, the patient is placed prone and the vagina is separated from the common UG sinus.
 - The common UG sinus is opened over the distal vagina near the confluence, where the vagina is relatively underdeveloped. The posterior wall incision can be extended proximally and distally until the urethral meatus is seen. If a Councill tip Foley was placed into the vagina, the catheter is redirected up the urethra into the bladder.
 - Meticulous sharp dissection creates a plane between the anterior wall of the vagina and the urethra and bladder base. Multiple traction sutures are placed on the vagina (**TECH FIG 4C**).
 - Following adequate vaginal mobilization, the common UG sinus becomes the urethra with a running closure of absorbable suture over the Foley catheter.

Use of the Excess Mobilized Common UG Sinus

- Best use determined by the distance for the vagina to reach the perineum.



TECH FIG 5 • The mobilized UG sinus may be opened anteriorly (**A**) so that the excess sinus may be incorporated into the vagina. Patient A had an ASTRA. If the sinus is opened posteriorly (**B**), the excess sinus creates a mucosa-lined vestibule. Patient B had partial

urogenital mobilization. Note the open sinus (S), the frondular hymenlike tissue at the vaginal opening (V) and the posteriorly based perineal flap. The vagina will be spatulated further posteriorly to reach normal caliber. The flap will be advanced to complete the posterior wall of vagina.

- If the vagina remains high, the urogenital sinus can be used to complete the vaginal wall.
 - The common UG sinus can be incised anteriorly and the tissue is everted and advanced to become the anterior vaginal wall as a Passerini-type flap⁹ (**TECH FIG 5A**).
 - The excess UG sinus tissue can be used in a variety of ways to augment the vagina.^{9,10}
 - The patient is then turned supine and the perineal flap is advanced posteriorly if needed.
- If the vagina has reached the perineum, the patient is turned supine.
 - The common UG sinus is incised posteriorly, and the redundant sinus tissue is used to line the vaginal vestibule (**TECH FIG 5B**).
 - The posterior vaginal wall is spatulated to accept the perineal flap.
- Labioplasty is completed.

Comparison of Surgical Options for Vaginoplasty Based on Level of Confluence

Low Vaginal Confluence (**TECH FIG 6**)

- If a low vaginal confluence is present, partial urogenital mobilization (PUM) is completed (see above).
- The mobilized sinus is opened posteriorly to expose the urethra and vagina.



TECH FIG 6 • Completion of vaginoplasty after PUM. Note separate urethral (U) and vaginal (V) openings. The posteriorly based perineal flap (*asterisk*) allows a wider vaginal caliber. Silk traction sutures are holding the excess UG sinus, which will line the vestibule with a robust mucosa. The labia majora will be advanced posteriorly to flank the perineal flap.

- The vagina is incised posteriorly to increase the caliber, and the perineal flap is advanced into the vagina with interrupted absorbable sutures.
- Labioplasty is completed.

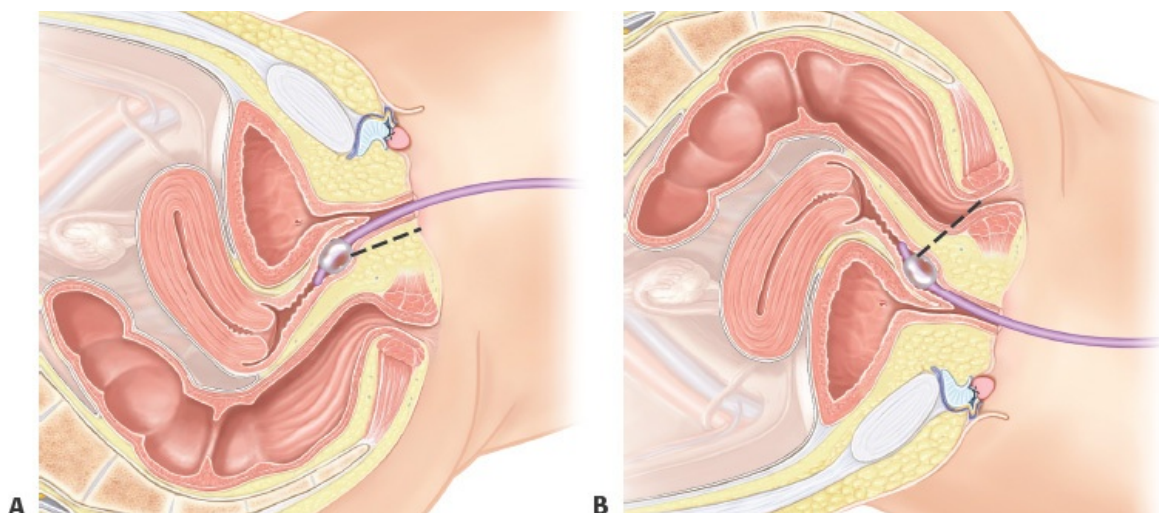
High Vaginal Confluence

- If a high vaginal confluence is present, prone positioning will optimize visualization for a vaginal pull-through procedure.
- Either a classic pull-through or TUM with pull-through may be used.
 - In the classic pull-through, the UG sinus is not mobilized. It is opened posteriorly in the midline, extending the incision into the normal-caliber vagina. The vagina is dissected off the urethra or bladder base and mobilized toward the perineum.
 - In TUM, the UG sinus has been fully mobilized (see above), and if the vagina has not reached the perineum, the UG sinus is opened over the confluence to expose the vaginal lumen and proximal urethra. Keeping the UG sinus tissue intact allows more flexibility for use of excess tissue.^{9,10}
- Stay sutures are placed along the incised margin of the vagina to facilitate retraction.

- A malleable retractor is placed and elevated toward the rectum to optimize exposure.
- The investing structures are dissected off the vagina along the posterior and lateral walls.
- Once the posterior wall is exposed, the retractor is placed in the vaginal lumen to facilitate exposure of the junction of the vagina with the common UG sinus.
- The mucosa of the anterior vagina is incised transversely and additional traction sutures are placed.
- The anterior plane is dissected sharply; it is very thin distally and care must be taken to avoid entering the urethra or urinary bladder. Dissection continues anteriorly and posteriorly until the vagina can reach the perineum with or without local flaps.
- Following adequate vaginal mobilization, the common UG sinus is reconstituted as the urethra via multilayer closure over the Foley catheter.
- Regional flaps can be mobilized to help the vagina reach the perineum.
 - If TUM was employed, the excess common UG sinus may be incised anteriorly to allow eversion of the flap and incorporation as the anterior vaginal wall (Passerini-type flap).
 - The patient is rotated supine and the perineal flap is affixed to the vagina with interrupted absorbable sutures.
- One can imagine how the advantages provided by alternating between the posterior prone approach and the supine anterior view are unrealistic in teens and adults. Even if the urogenital sinus work can be completed prone, clitoroplasty and labioplasty should only be attempted supine or in lithotomy.

Anterior Sagittal Transrectal Approach

- Anterior sagittal transrectal approach (ASTRA) is a newer alternative approach for pull-through vaginoplasty in the setting of a high confluence.¹¹
- Aside from the transrectal exposure of the UG sinus, the dissection of the vagina off the common UG sinus and subsequent urethroplasty is similar to a TUM.



TECH FIG 7 • Comparison of the approach to the vagina for urogenital mobilization (perineal; **A**) vs ASTRA (transanorectal; **B**).

- Exposure of the posterior wall of the vagina is afforded by a full-thickness sagittal incision of the anterior wall of the anus and rectum; the surgeon's view and the access to the vagina are thereby more direct. There is a tradeoff between this enhanced exposure and the potential morbidity of opening the rectum. The procedure can be safely completed without colostomy, but some opine that this additional risk is not justified (**TECH FIG 7**).
- Suitability for the ASTRA approach is determined at the time catheter placement by transrectal palpation of the vaginal catheter balloon (greater than 3 cm from the anus).
- Perioperative preparation includes the following:
 - Preoperative mechanical bowel preparation.
 - Triple antibiotic therapy or equivalent for 72 hours.
 - Diet held until evidence of bowel function.
- The procedure begins in prone position, and the rectum is opened (**TECH FIG 8A**).
- Clitoroplasty and dissection of the distal UG sinus are deferred.
- Without otherwise mobilizing the UG sinus first, the vagina is opened posteriorly (**TECH FIG 8B**) and dissected off the common UG sinus, similar to that described for TUM, and the UG sinus is closed as the urethra.



TECH FIG 8 • A. Full-thickness incision of the anterior anus and rectal wall. Nasal speculum in rectum. **B.** UG sinus opened to expose vaginal catheter. Catheter will be redirected to urethra. **C.** Skin is being incised in the midline toward the UG sinus meatus. Note that there is no midline posteriorly based perineal flap.

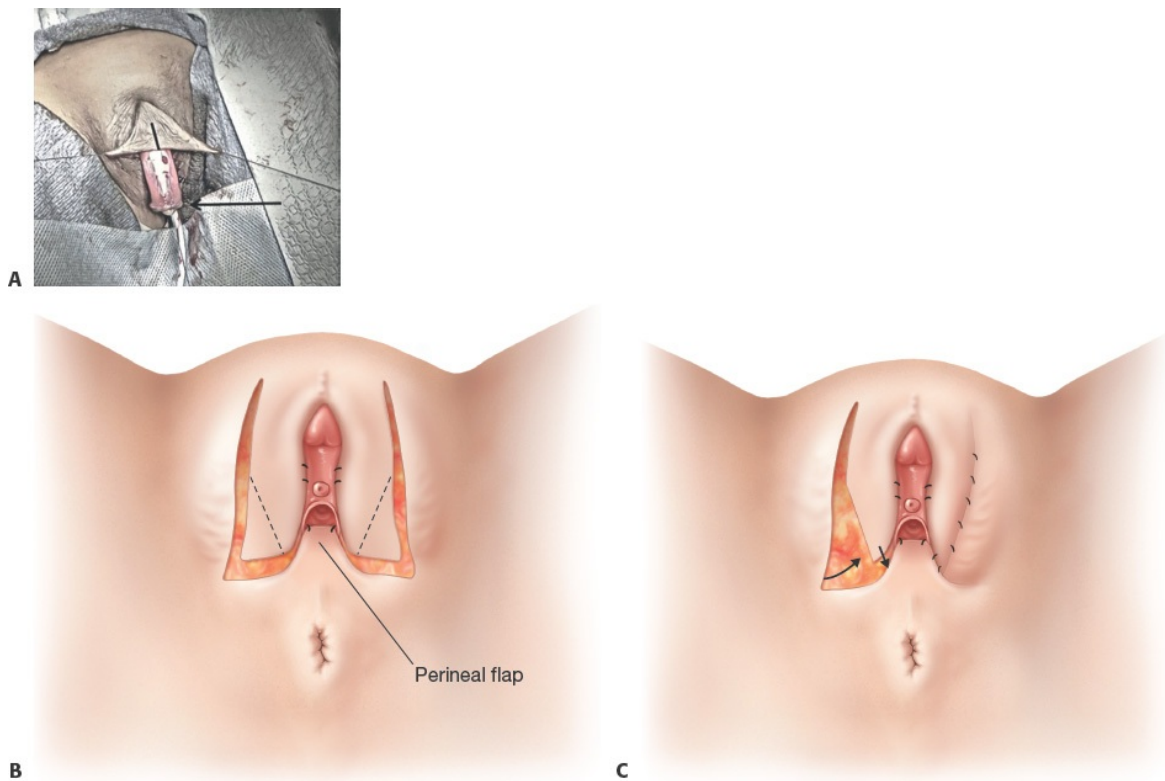
- The perineal skin is then incised to the level of the UG sinus orifice, and the posterior wall of the UG sinus is dissected (**TECH FIG 8C**).
- The procedure otherwise differs from TUM in that the anterior wall of the UG sinus is only mobilized under the pubis if additional sinus tissue will be needed to complete the vaginal wall.
- Otherwise the posterior wall of the sinus is opened, exposing healthy mucosa to line the vestibule.
- The rectum is closed and the anterior sphincter complex is reconstituted. The perineal body is closed in layers and sutured directly to the spatulated posterior vaginal wall.
- The patient is rotated prone for clitoroplasty and labioplasty.
- Because the cutaneous incision extends from anus to common UG sinus orifice, there is no midline posteriorly based flap.
 - This has not generally been required, but a flap could be raised from each side if necessary.
 - In either case, closure of the deep perineal tissues and a two-layer skin closure are recommended.

■ Creation of a Clitoral Hood and Labioplasty

- The remaining dorsal clitoral skin is incised in the midline to approximately 1.5 cm from the base, creating the Byars flaps that will be fashioned into the

clitoral hood and labia minora (**TECH FIG 9A**).

- The intact 1.5 cm of clitoral skin is plicated with interrupted absorbable dermal sutures to provide contour to the clitoral hood.
- This outer layer of the clitoral hood is sutured to the inner layer of the hood reserved at the time of initial clitoral degloving.
- The paired Byars flaps are tapered and tucked next to the urethral plate, creating a fin of tissue similar to labia minora. The medial border of each flap is sutured to the urethral plate or mucosa-lined vestibule with interrupted absorbable sutures.



TECH FIG 9 • A. Fashioning clitoral hood and labia minora from clitoral skin. The clitoral skin is incised to create Byars flaps (*black line*). The incision stops about 1.5 cm short of the base to create the outer hood. Note that the initial clitoral skin incision allowed sufficient skin to form the inner layer of the hood (*black arrow*). **B.** Byars flaps are draped around the glans clitoris as the clitoral hood and labia minora.

Dermal sutures provide contour to the outer layer of the clitoral hood. The labia minora are trimmed (*dotted lines*) for labial configuration and sutured to vestibular tissue. Dog ears of clitoral body skin are trimmed anteriorly to allow provide a grooved contour between the labia minora and majora. Two-layer closure of the inferior apices will minimize the risk of labial dehiscence. **C.** Completion of labioplasty after clitoral reduction and vaginoplasty with a posteriorly based perineal flap. Full-thickness debulking at the apices of the labia majora may be undertaken to reduce the loose skin folds. Rugation will persist to some degree. The labia majora are advanced posteriorly to flank the perineal flap, with a two-layer closure at the apices.

- If UG sinus reconstruction with vaginoplasty has been completed, the labia majora will also be addressed (**TECH FIG 9B,C**).
 - If the labia majora are anteriorly positioned, they are mobilized and advanced posteriorly to flank the perineal flap (if used).
 - Full-thickness debulking at the apex may improve appearance, although rugations of the androgenized tissue may persist. Care should be taken with fibrofatty debulking, as this may result in devascularization or asymmetry.
- A cleft is preserved between the labia minora and the labia majora by excising a dog-ear of skin anteriorly. Closure is via interrupted absorbable sutures.
- A two-layer closure at the apex of each labium will minimize the risk of dehiscence.

PEARLS AND PITFALLS

Preoperative decision-making

- Multidisciplinary guidance is essential prior to performing irreversible genital surgery, and operative interventions should only be undertaken after extensive counseling.

	■ The impact of deferring intervention until the age of consent is not fully understood.
Positioning	■ Coordinate with the anesthesia team to ensure upper body IV access, avoidance of continuous caudal catheterization in setting of total lower body preparation, and communication regarding multiple anticipated position changes. ■ Create a broad sterile field with total lower body preparation and strategic use of surgical drapes to facilitate genitoplasty and UG sinus reconstruction in younger children. ■ Adolescents and young adults should be placed in dorsal lithotomy position. The exposure for high dorsal dissection is much more limited in this population.
Labioplasty	■ Two-layer closure of the apices of Byars and labia majora flaps will minimize the risk of labial dehiscence as postoperative edema ensues.
Inadequate surgical preparation	■ Inadequate familiarity with patient anatomy can lead to rectal injury during posterior dissection of the UG sinus or can lead to neurovascular injuries of the clitoris and urinary tract. ■ A collaborative mentality is strongly recommended when complex anatomy may place patients beyond an individual surgeon's expertise.

POSTOPERATIVE CARE

- A Penrose drain is placed in the vagina after vaginoplasty and removed in 24 to 48 hours.
- An indwelling urethral catheter is left to drainage for several days postoperatively. Catheters may be left in place for up to 2 weeks depending on the nature of the UGS, the degree of urethral reconstruction, or other patient factors.
 - Care should be taken to secure the catheter so it does not compromise the integrity of the labial flaps.
- Ointment and bulky fluff compression dressings are applied to the perineum and left in place for 2 or 3 days. Dressings are removed prior to discharge.
- Perineal mobility is minimized in the early postoperative period.
 - In infants, a mermaid wrap around the knees is appropriate. Foam or a thick gauze roll between knees and ankles prevents pressure damage.
 - Older individuals should be instructed to avoid straddling, squatting, kneeling, or Valsalva to minimize perineal engorgement.

- Short-duration, plain water tub soaks are begun approximately 3 days postoperatively, except in ASTRA.
- Bacitracin ointment is applied to the perineum for 3 days postoperatively, after which use of bland ointment is recommended.
- Care is taken to avoid moisture trapping beneath the ointment with consequent skin maceration or dehiscence.

OUTCOMES

- Historic outcomes evaluations revealed substantial patient dissatisfaction with genital appearance and the need for repeated surgical intervention.^{12,13}
- Creation of an adult-caliber vaginal introitus in infancy is neither feasible nor desired.
- Under ideal circumstances, creation of a supple introitus during infant vaginoplasty will allow for passive or active vaginal dilations at the age of sexual maturity. There is a reasonable probability of introital revision, and this should be emphasized in preoperative counseling.
- Retrospective cohort studies have described impairment in clitoral sensitivity among patients undergoing feminizing genitoplasty^{13,14} and demonstrated a linear correlation between diminished sensation and sexual dysfunction.¹⁵
- As surgical technique has improved, prospective cohort studies reveal more favorable cosmetic outcomes following feminizing genital surgery^{5,16,17} (**FIG 2**).
- Retrospective evaluation of clitoral sensation and perfusion reveals improvement in functional outcomes following nerve-sparing clitoroplasty¹⁸; however, prospective assessments of clitoral sensation and overall sexual function are lacking.
- Further prospective studies are also needed to assess surgical and psychosocial outcomes among this population.
- If surgery is done during infancy, there is a significant lag time between surgery and sexual maturity. Educated modifications in technique are therefore challenging.

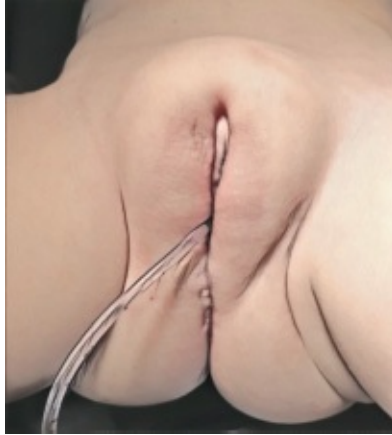


FIG 2 • Immediate postoperative result after a pull-through vaginoplasty via ASTRA in a child with completely fused labia majora and a high UG sinus. Creation of clitoral hood includes contouring dermal plication sutures. The labia majora did not require posterior mobilization in this child. Due to the ASTRA approach, there are perineal body sutures rather than a posteriorly based perineal flap.

COMPLICATIONS

- Clitoral ischemia with loss of tissue
- Dehiscence
- Vaginal stenosis
- Diminished clitoral sensation, impaired sexual function
- Unsatisfactory cosmetic outcome
- Patient regret

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Section XIX: Emergency Department Lacerations

Facial Laceration Emergency Room Closure Techniques

71
CHAPTER

Christina Pasick and Peter J. Taub

DEFINITION

- Facial soft tissue injuries are commonly encountered in the emergency room. Common etiologies are motor vehicle collisions, animal bites, sports and job-related injuries, and interpersonal violence.
- These injuries are often complex and may have significant impact on the patient's facial form and function.
- Plastic surgeons are often consulted by the emergency room physician or requested by the patients themselves for facial injuries ranging from simple lacerations to complex craniofacial trauma.

ANATOMY

- Facial aesthetic subunits should be considered when planning reconstruction so that incisions lie within or along the border of the involved subunit (**FIG 1**).
- Lacerations deep to the superficial musculoaponeurotic system (SMAS) risk injury to the facial nerve branches. See Table 1 for physical exam findings in injured facial nerve branches.
- Blunt injuries to the face may cause a temporary neuropraxia to the nerve that does not require immediate operative measures but instead should be observed for 3 weeks.

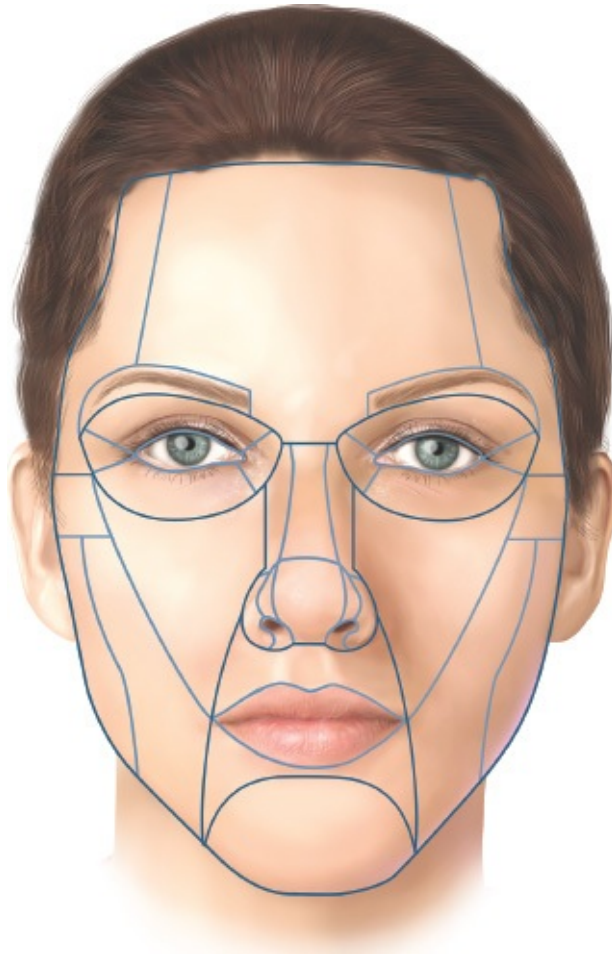


FIG 1 • The facial aesthetic subunits. Scars are more inconspicuous when planned within or along these lines.

- Extensive branching and cross-innervation of the branches of the facial nerve is present medial to the lateral canthus (**FIG 2**). As a general rule, lacerations of the nerve medial to the lateral canthus do not require repair. However, lacerations to the marginal mandibular nerve medial to the lateral canthus of the eye should be repaired, as there is not adequate crossover for functional recovery of the depressor muscles following medial injury to the marginal mandibular nerve. The temporal branch is another facial nerve branch with minimal crossover, but this nerve will most likely have innervated its target muscles (frontalis) should a laceration occur medial to the lateral canthus.
- The sensory nerves of the face can be utilized as guidelines for local anesthesia nerve blocks. Suspicion for nerve laceration should be elevated

when lacerations are present in these regions.

- Knowledge of the location of the major arteries of the face can raise suspicion for lacerated vessels in deep wounds in these locations (**FIG 3**).
- The parotid duct or Stensen duct lies in the line drawn between the tragus and the middle of the upper lip. Stensen duct empties into the mouth at the buccal mucosa overlying the second maxillary molar.

PATHOGENESIS

- The mechanism of injury (ie, motor vehicle collision) can help to gauge the force involved in creating the injury and help determine if additional radiographic studies are necessary.
 - Suspect a larger area of tissue injury when dealing with a crush wound as opposed to a simple laceration.
- Human bites should all be treated as contaminated wounds, and the need for careful irrigation and prophylactic antibiotics apply.

Table 1 The Physical Exam Findings Behind Injuries of the Facial Nerve Branches

Facial Nerve Branch Injured	Weakness Observed on Physical Exam
Temporal branch	Inability to elevate eyebrow
Zygomatic branch	Inability to close eye
Buccal branch	Inability to elevate upper lip
Marginal mandibular branch	Inability to evert lower lip
Cervical branch	Inability to activate platysma

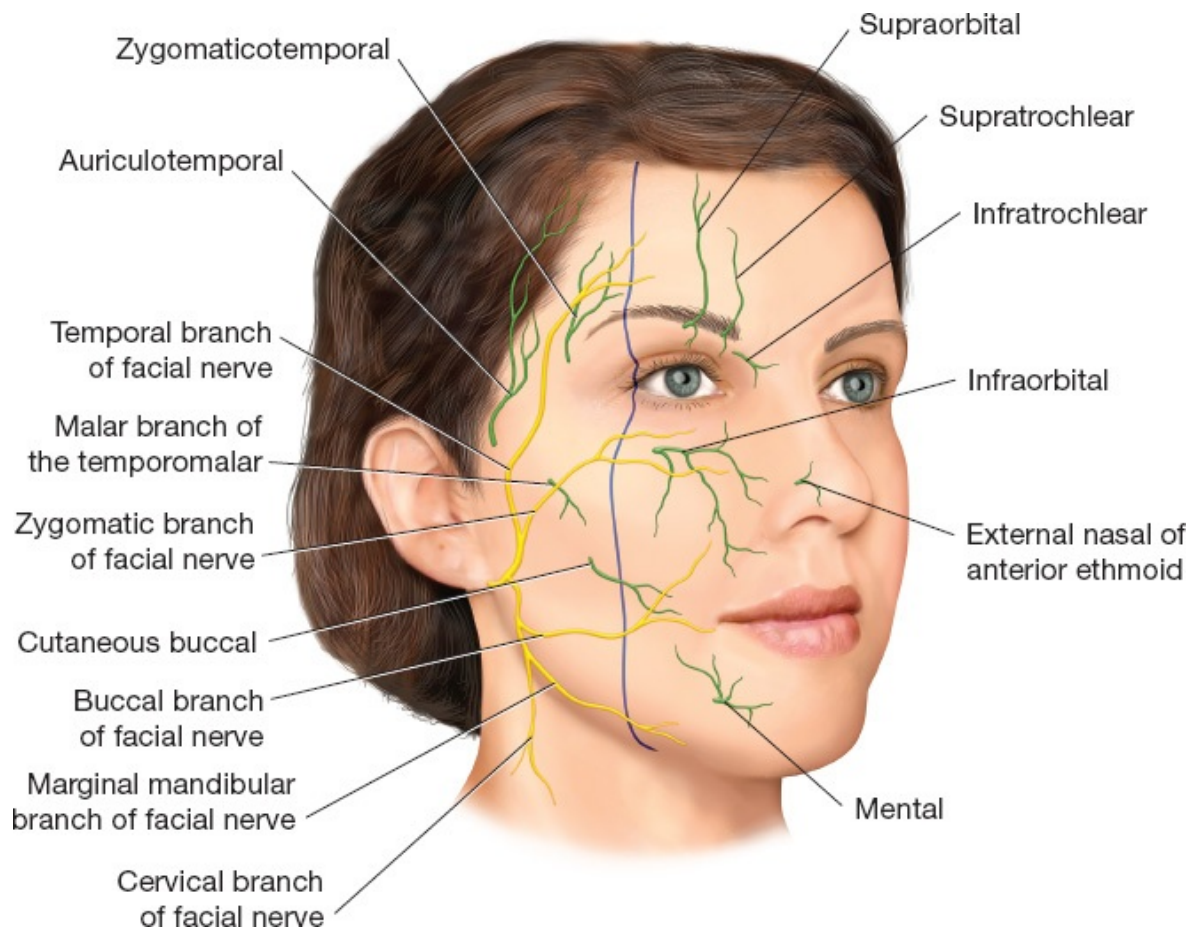


FIG 2 • The branches of the facial nerve: temporal, zygomatic, buccal, marginal mandibular, cervical. Extensive branching and cross-innervation is present medial to the lateral canthus (*marked line*). As a rule, lacerations of the nerve medial to the lateral canthus do not require repair.

- Organisms often found in human mouths include *Eikenella*, *Staphylococcus*, *Streptococcus viridans*, and *Bacteriodes*.¹
- If the initial injury is not treated and the patient presents with a developed infection, inpatient therapy with IV antibiotics is often warranted, with a low threshold for OR debridement and washout.
- Dog bites are the most common type of animal bite in the emergency room and are often contaminated with various bacteria, including *Pasteurella multocida*, *Bacteroides*, *S viridans*, and *Capnocytophaga*.¹

- Infection rates are not as high as seen in cat bites due to lower bacterial levels and the open avulsion-type injury seen in dog attacks rather than the deep puncture injury in cat bites that can trap bacteria. These open wounds facilitate irrigation.
- Crush component of dog bites often results in substance loss and requires debridement and reconstruction of avulsed tissue.²
- High incidence in the pediatric population.³
- Cat bites should always be considered heavily contaminated wounds, as the nature of the long and narrow cat teeth lead to deeply penetrating wounds with a very narrow orifice, resulting in seeding of bacteria into deep structures.
- Organisms often found include *Pasteurella multocida* and *Bartonella henselae*.

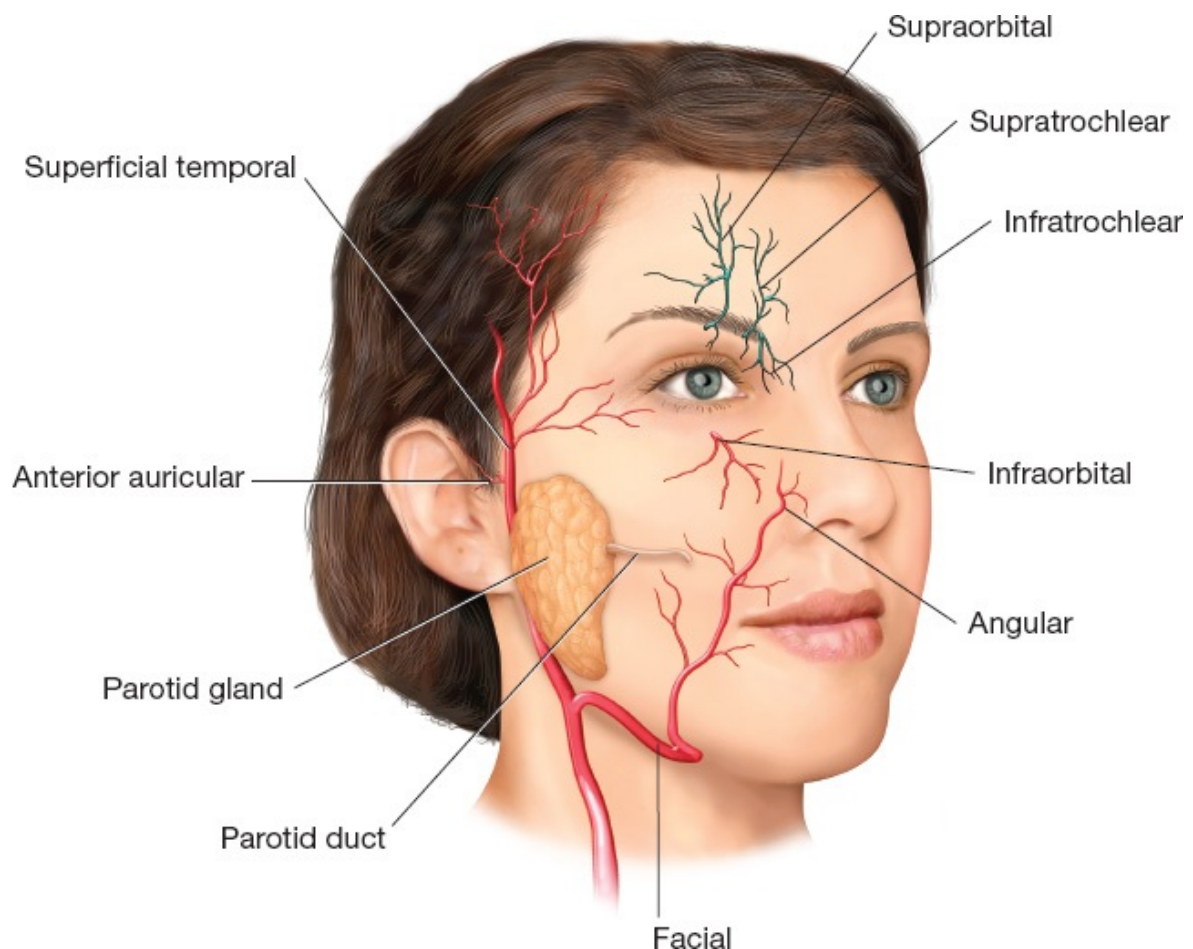


FIG 3 • The major arteries of the face. These arteries arise from the external carotid system (in red) and the

internal carotid system (in *green*). Path of the parotid duct or Stensen duct. Lacerations in this line should be evaluated for laceration of the parotid duct system.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Trauma patients require a primary trauma survey and secondary trauma evaluation immediately.
- The patient should be assessed for more serious intracranial, ophthalmologic, and cervical spine injuries.
- Suspect skull base fracture with the following signs: raccoon eyes (periorbital ecchymosis), battle sign (postauricular ecchymosis), otorrhea, or hemotympanum.
- Take a complete history.
 - The etiology and timing of the wound
 - Other medical problems that may put the patient at risk for wound healing difficulties
 - Medications that may make the patient a bleeding risk
 - Smoking status
 - Tetanus vaccination history
- Physical examination
 - Remove all clothing, jewelry, dried blood, and foreign material that may obscure the examination.
 - Use a systematic approach, inspecting for lacerations, avulsions, “road rash,” and areas of edema or ecchymosis.
 - Palpate wounds for bony step-offs to clue into underlying fracture.
 - To rule out Le Fort fracture, depress the maxilla bilaterally with your thumbs to feel for mobility. If mobile, proceed to grasp the maxillary teeth with one hand while holding the nasal spine in place with the other hand. Movement of the dental alveolus points toward a Le Fort I fracture, whereas movement of the nasal bridge points toward a Le Fort II or III fracture.
 - Check for involvement of deeper structures: muscle, nerve, artery, bone, joint.
 - Especially in bite wounds with fangs, the deeper structures may be injured.
 - Irrigation of the base of the wound provides more thorough visualization.
 - Sensory test for nerve involvement:

- V1 ophthalmic branch: provides sensation to the forehead
- V2 maxillary branch: provides sensation to the cheek
- V3 mandibular branch: provides sensation to the lower third of the face/chin
- Motor test for facial nerve involvement:
 - Test for weakness in the facial nerve (cranial nerve VII) quickly and effectively by asking the patient to raise the eyebrows, close eyes, smile, puff out cheeks, and evert lower lips.
- Assess for crepitus (subcutaneous emphysema) in bite wounds that would indicate an infection forming along the deeper fascial planes.
- Examine all wounds for foreign body contaminants.

IMAGING

- If facial fractures are suspected, a CT scan should be performed.
- Plain x-ray or CT scan is helpful in determining the presence and location of foreign bodies within the wound.
- Ultrasound may prove as a quick and reliable tool for locating foreign body without the side effects of radiation.

NONOPERATIVE MANAGEMENT

- Nonoperative, or nonsurgical, management may occur in cases with very superficial and noncontaminated lesions, where washout, debridement, and closure are not necessary.
- Small wounds may have a preferred aesthetic outcome when allowed to close secondarily.

SURGICAL MANAGEMENT

- It is important to emphasize to the patient that any full-thickness injury to the skin will result in a scar.
 - The type of scar that forms can be dependent on multiple factors and is largely based on genetic predisposition.
- To maximize the chance of forming a fine-lined scar:
 - Most wounds require irrigation and debridement and closure in layers.
 - An early and tension-free closure of lacerations is a main priority.
 - Aim to close the wound in the direction of Langer lines, the relaxed skin tension lines of the face (**FIG 4**).
 - Find Langer lines in younger patients by asking them to animate their faces; the resultant skin folds simulate Langer lines.

- Delaying closure beyond 8 hours may increase the risk of infection of the wound bed and compromise aesthetic results, as swelling obscures anatomical landmarks.⁴

Preoperative Planning

- Use emergency room anesthesia: create a comfortable environment for the surgeon and the patient.

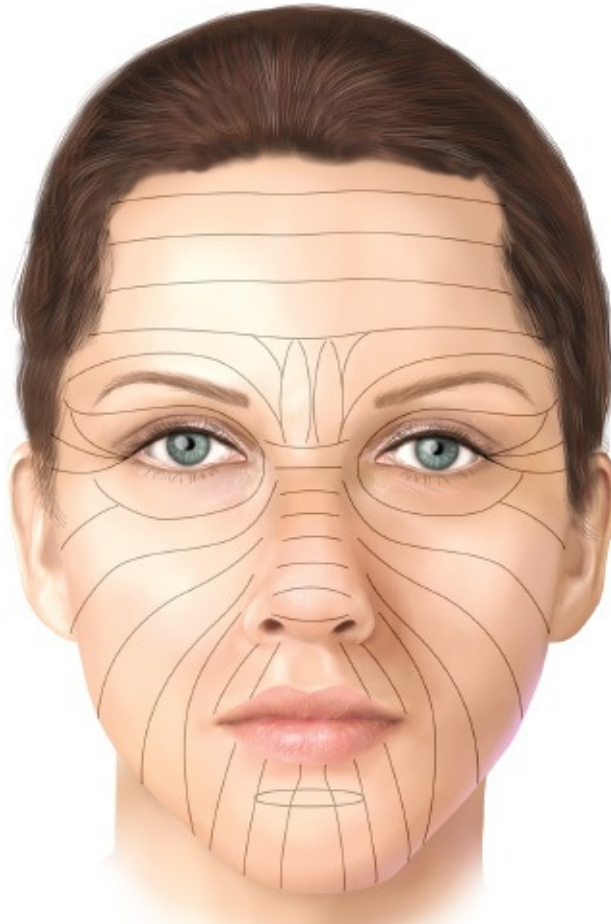


FIG 4 • Relaxed skin tension lines are ideal vectors for final scar placement.

- Topical anesthetic
 - Eutectic mixture of local anesthetics (EMLA) cream, composed of a mixture of 2.5% prilocaine and 2.5% lidocaine, is widely present in the emergency room—its effect is directly dependent on the time the cream has been on the skin.

- Place cream on skin and cover with a Tegaderm (3M, St. Paul, MN) or other occlusive dressing for at least 45 minutes.
- This often will need to be supplemented with local injected anesthesia but is a useful start for pediatric cases in which there is high anxiety associated with the local anesthesia.
- Local injected anesthetics
 - Lidocaine: most commonly used form of anesthesia in the ED. Maximum safe dose is 4.5 mg/kg. Effect usually lasts for 2 hours.
 - Epinephrine 1:100 000 may be added to the lidocaine solution to prolong the duration of its effect (to 4 hours) and reduce the amount of local anesthesia needed by reducing its diffusion away from the wound.
 - When epinephrine is added to lidocaine, the maximum safe dose is raised to 7 mg/kg.
 - Epinephrine takes about 7 to 15 minutes to take effect.
 - It was previously believed that epinephrine should not be used around end arteries such as the nose and stellate lacerations but is now accepted as safe practice.
 - Bicarbonate may be added to local anesthesia in the awake patient to reduce the burning pain on injection by raising the pH of the acidic lidocaine solution.
 - Bicarbonate also increases the effectiveness of the local anesthetic by favoring the nonionized form of the molecule, which passes through the cell membrane more easily.
 - Add 1 cc of 1 mEq/mL bicarbonate for every 9 cc of local anesthetic.
 - Bupivacaine: a longer-acting anesthetic, which may be added to the solution per the surgeon's discretion
 - Max safe dose: 2.5 mg/kg. Effect usually lasts 4 hours. When epinephrine is added, max safe dose is raised to 3 mg/kg, and the effect is prolonged to 8 hours.
 - Improve comfort on injection: warm the local anesthetic solution, use a higher-gauge (smaller caliber) needle, inject through wound instead of through skin
- Nerve blocks
 - For large lacerations in a single nerve distribution, nerve blocks can be effective and reduce the tissue distortion, which results when a large amount of local anesthetic is given as a field block.

■ Conscious sedation

- Beneficial for pediatric patients who are uncooperative, making repair of facial lacerations difficult.
- Helps to make the repair safer and reduces emotional trauma to the patient.⁵
- This requires continuous monitoring of vital signs, requiring a nurse to be present throughout.
- For pediatric cases, a combination of ketamine and versed are commonly used.
- Ketamine: analgesic and amnestic agent
 - Pediatric dosing: 6 to 10 mg/kg PO once, 30 minutes prior to procedure; or 0.5 to 2 mg/kg IV once at start of procedure
- Versed: sedative-hypnotic and amnestic agent
 - Pediatric dosing: 0.25 to 0.5 mg/kg PO or IM 15 minutes prior to procedure; or 0.05 to 0.1 mg/kg IV 3 minutes prior to procedure

■ Irrigation

- Thoroughly irrigate all wounds to remove blood, foreign body debris, and bacteria.
- Use of a pressured irrigation system is helpful if available in the ED.
- May use 1-L bottle of normal saline with holes punched in the lid with an 18-gauge needle as a make-shift pressurized system.

■ Debridement

- Trimming of jagged skin edges with a 15-blade for optimal cosmetic closure.
- Debridement of devitalized skin and tissue will reduce contamination and facilitate healing.
- Be mindful of the location of your debridement, as heavy debridement in the critical areas in the face (eyelid, nose) may lead to significant disfigurement.

■ Hemostasis

- Use pressure, suture ligation such as Vicryl 4-0 (Ethicon, Somerville, NJ), Surgicel (Ethicon, Somerville, NJ), silver nitrate, thrombin, or fibrin. Electrocautery is now often available in the ED.
- Because of extensive collateralization of vessels in the head and neck, even major vessels such as the facial artery may be ligated if bleeding is uncontrolled.
- If bleeding is significant, you may extend the laceration to achieve visualization of the bleeding vessel.
- Do not blindly clamp tissues as this risks injury to nearby nerves and other

structures.

- If the bleeding vessel cannot be clearly visualized, the wound should be packed, pressure applied, and the patient should be brought to the operating room promptly.

Positioning

- Prior to beginning any procedure in the emergency room, ensure you have a well-lit and adequate space.
- Head of bed should be elevated on a pillow for head and neck lacerations.
- Pediatric cases may require “papoosing” of the child by nursing staff and may require that a family member present throughout the procedure.

Approach

- Wounds may be closed with sutures, staples, skin tape, or wound adhesive.
- Suture choice:
 - Absorbable for all deeper layers and for mucosa and pediatric epidermis
 - Nonabsorbable for suture ligation of large vessels and for epidermal approximation
 - Nonbraided (monofilament) material best for contaminated wounds

Table 2 Appropriate Suture Choice for Specific Facial Laceration Locations

Location	Suture Material ^a	Suture Size	Suture Half-life	Removal
Scalp Galea Skin	Vicryl/PDS Prolene or staples Or chromic gut	2-0 3-0	2–3 wk/4 wk Permanent 2 wk	Absorbable 7–14 d Absorbable
General face Muscle Deep dermal Epidermis	Vicryl/PDS Monocryl Nylon or Prolene	3-0 or 4-0 4-0 or 5-0 5-0 or	2–3 wk/4 wk 1–2 wk Permanent	Absorbable Absorbable 5 d

		6-0		
Eyelids Orbicularis Skin	Vicryl Nylon	6-0 6-0	2–3 wk Permanent	Absorbable 3–5 d
Ear Cartilage/skin	Nylon or Prolene	5-0 or 6-0	Permanent	5 d
Nose Cartilage Skin	PDS/clear nylon Nylon or Prolene	4-0 5-0 or 6-0	4 wk/permanent Permanent	Absorbable/permar 3–5 d
Lip Muscle Mucosa Vermilion border	Vicryl/PDS Chronic gut Nylon or Prolene	3-0 or 4-0 3-0 or 4-0 6-0	2–3 wk/4 wk 2 wk Permanent	Absorbable Absorbable 5 d
Intraoral mucosa	Chronic or Vicryl Rapide	3-0 or 4-0	2 wk	Absorbable
Pediatric skin	Fast absorbing plain gut	6-0 or 6-0	5 d	Absorbable

^aAll suture materials refer to those supplied by Ethicon, Inc. (Somerville, NJ).

- Taper/round needle ideal for muscle, fascia, mucosa
- Cutting needle ideal for skin
- Common emergency department suture choices available are as follows:
 - Muscle: Vicryl 4-0, Monocryl 4-0, PDS 4-0 (Ethicon, Somerville, NJ)
 - Skin:
 - Buried deep dermal layer: Monocryl 4-0 or 5-0
 - Superficial subcuticular layer: nylon/Prolene 5-0 or 6-0 (Ethicon,

Somerville, NJ)

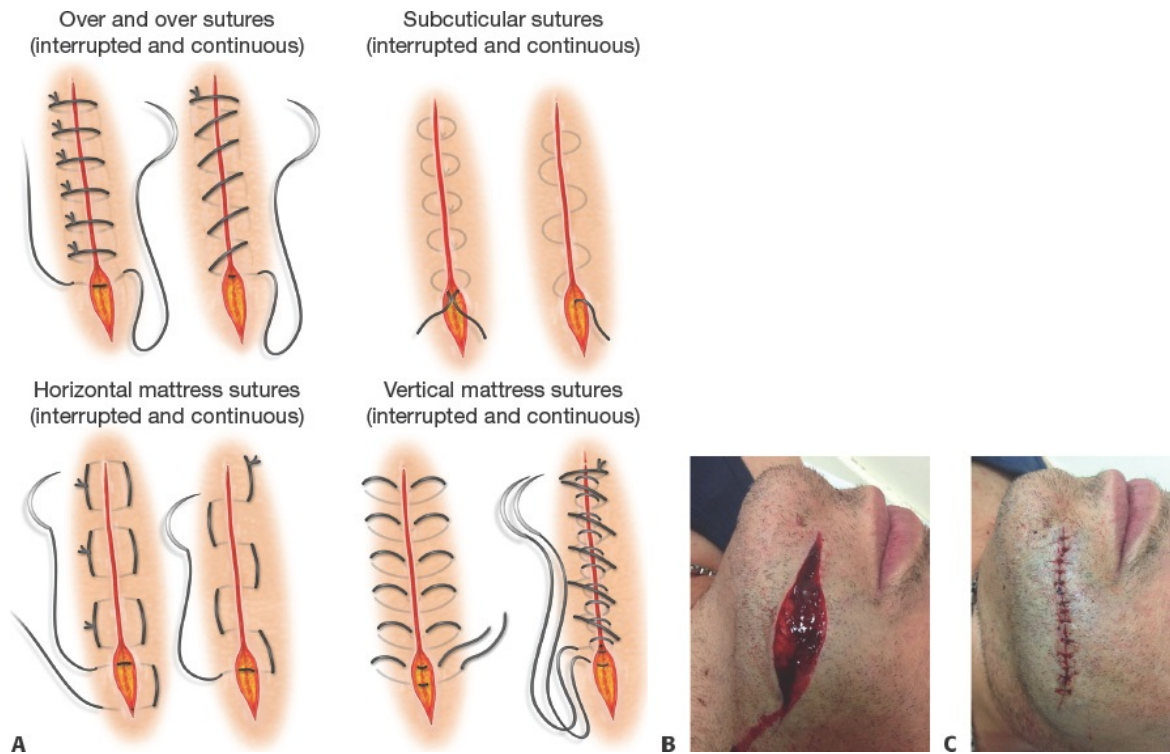
- Mucosa: simple chromic/Vicryl Rapide 3-0 or 4-0 (Ethicon, Somerville, NJ)
- Pediatrics: simple fast absorbing plain gut 5-0 or 6-0
- Proper suture choice for specific anatomic locations of the face is imperative for maximizing healing and minimizing scar formation (Table 2).

TECHNIQUES

■ General Laceration Closure Techniques

- Simple interrupted: standard for closing all layers. Allows for optimal tissue reapproximation, especially in wounds with uneven lengths. Recommended for buried deep dermal and epidermal closure (**TECH FIG 1A**).
- Simple running: quicker means of closing epidermis in wounds with long length. Optimal for use in wounds where both sides evenly line up and there is no apparent “dog ear.”
 - Disadvantages:
 - Not as precise as simple interrupted stitch
 - Unintentional breakage of the suture will lead to separation of the entire wound
 - Need to remove entire suture length if infection develops postrepair
- Vertical mattress: optimal for eversion of skin edges, yet is widely known as the most ischemic suture method and may result in skin ischemia if placed too tightly.
- Horizontal mattress: particularly useful in thick glabrous skin.
 - Similar to the vertical mattress counterpart in that it is effective in everting skin but risks development of skin ischemia.
- Staples: optimal for fast and effective closure of scalp wounds. May be used in very contaminated wounds that need to be closed loosely.
- Adhesive skin tape: beneficial for very superficial and small wounds closed with minimal tension^{6,7}
 - Brief and painless procedure
 - Difficult to exactly approximate edges and maintain eversion of epidermis
 - Resulting scar similar to suture repair^{7,8}
 - Best for upper third of the face as this area is of least skin tension

- Dermabond: may be used for clean wounds closed with minimal or no tension.



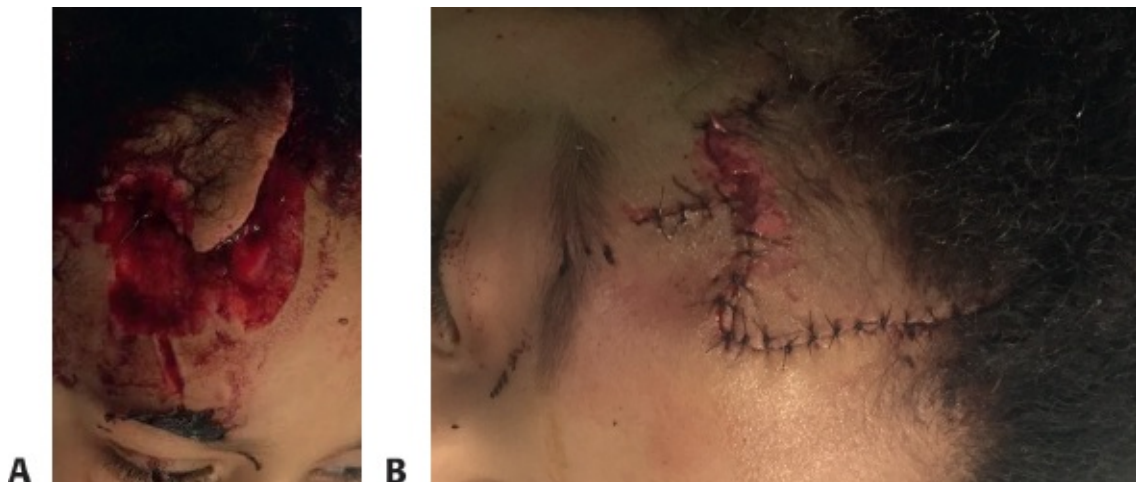
TECH FIG 1 • A. Suture closure techniques. **B,C.** Ideal closure for reapproximation of edges is simple interrupted suture.

- In crush injuries where the extent of the damage is unclear, tissues can be loosely reapproximated.
- If flap is avulsed, it should be tacked down where it lies, so that the closure is tension free. If there is undue tension on the flap, chance of necrosis is high.
- Epidermis should be everted at the edges, as eversion will flatten out to create a flat scar. Skin that is not everted at closure may produce a concave-shaped scar.
- Deeper wounds that cannot be closed can be packed with normal saline wet-to-dry dressings or iodoform gauze packing strips. Exposed bone or neurovascular structures can be covered first with Xeroform.
- Burns and abrasions can be treated with Adaptic gauze and bacitracin or

with silver sulfadiazine.

■ Scalp Lacerations

- Two-layered closure:
 - Galea layer: use 2-0 Vicryl or PDS (Ethicon, Somerville, NJ) for tension-bearing layer.
 - Skin: use full-thickness continuous suture with 3-0 Prolene (Ethicon, Somerville, NJ) or staples.
 - Alternatively, can use 3-0 chromic as this does not requires suture removal
- Scalp defects fewer than 3 cm can usually be closed primarily.
 - Galea scoring may be necessary to gain laxity for closure.
- Attempt to prevent hair from being entangled in the sutures.
- May use Penrose drainage for first 24 to 48 hours (**TECH FIG 2**).



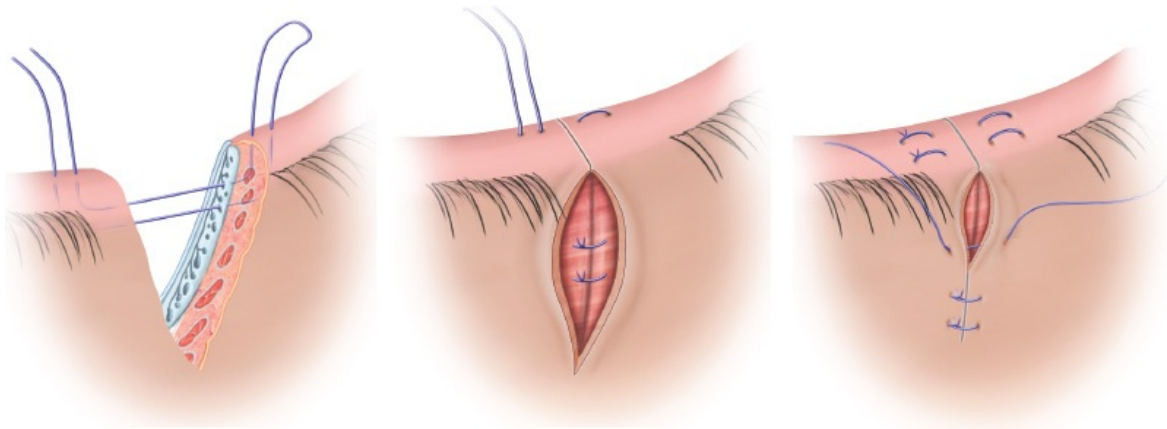
TECH FIG 2 • **A.** Laceration and partial avulsion of the forehead and anterior scalp. **B.** Galea layer reapproximated with Vicryl 2-0 (Ethicon, Somerville, NJ) and skin closed with interrupted nylon sutures.

■ Eyelid Lacerations

- First complete a full exam +/- ophthalmology consult to rule out ocular injury and lacrimal duct injury.
 - Jones I: instill fluorescein dye in the eye, wait 5 minutes, check for

drainage through ipsilateral nare.⁹

- Absence of fluorescein indicates nonfunctioning lacrimal system, and Jones II is performed.
- Jones II: irrigate residual fluorescein dye in the nasolacrimal system with saline and watch for reflux from the canaliculi or presence of fluorescein dye in the wound. Either finding indicates damage to lacrimal duct system.
- Proper alignment of all layers minimizes risk of lid notching, ectropion, and functional deficit.
- Three layered closure of conjunctiva, tarsus, and skin
- Orbicularis and tarsus: 6-0 Vicryl (Ethicon, Somerville, NJ).



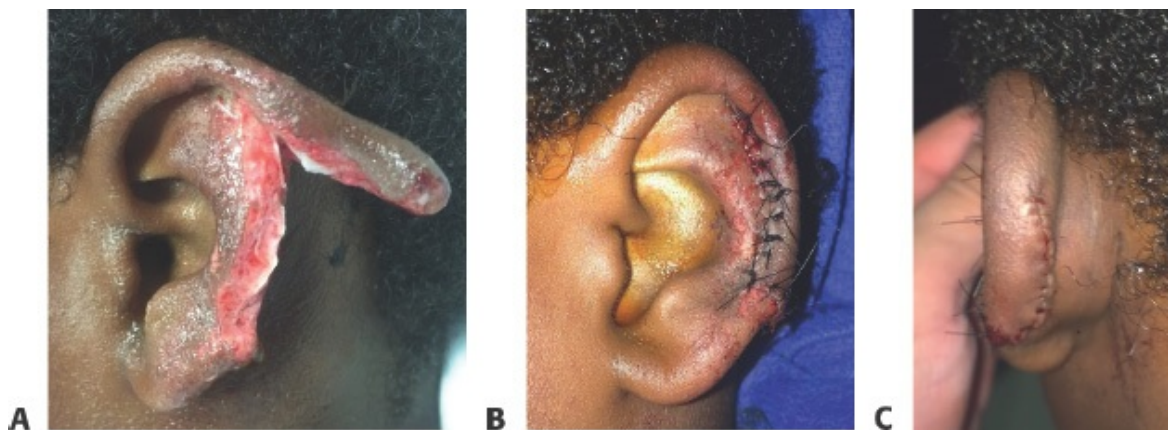
TECH FIG 3 • Laceration of the eyelid margin requires everting vertical mattress suture into the tarsus to realign lid margin and prevent notching of the eyelid. After the eyelid margin is realigned, the remainder of the laceration can be reapproximated.

- Skin: 6-0 fast absorbing gut suture or 6-0 nylon.
- Keep all knots directed away from the cornea.
- If lid margin is involved, approximate the gray line and tarsal plate with everting vertical mattress suture to prevent notching of the eyelid (**TECH FIG 3**).
- Depth of suture: through skin and half way through tarsus
- Partial-thickness defects involving less than 50% of eyelid length can be closed with local advancement flaps. Involvement greater than 50% requires a skin graft harvested from the contralateral eyelid for a tension-free closure.⁹

- Full-thickness defects involving less than 33% of the upper lid and 50% of the lower lid can be closed primarily.
- More significant eyelid defects require flaps for closure.

■ Ear Lacerations

- Irrigate ear lacerations thoroughly to prevent possible chondritis.
- Debride skin conservatively to avoid cartilage exposure after closure.
- As long as the skin is still adherent to the cartilage, approximating only the skin in suture bites is sufficient for realignment of the cartilage. Use 5-0 or 6-0 Prolene (Ethicon, Somerville, NJ).
- Large defects with exposed cartilage should be covered with Xeroform petrolatum gauze dressing (Covidien, Mansfield, MA) with frequent dressing changes until reconstruction is completed.
- Avulsion injuries: should be promptly debrided, and small avulsion fragments less than 1.5 cm in width can be reattached as a composite graft in the first 12 hours. Large avulsions/amputation may require intraoperative microvascular replantation.
 - Venous congestion is a common problem following microvascular arterial anastomosis; postoperative leech therapy is commonly employed.
- Dress ear laceration with Xeroform gauze (Covidien, Mansfield, MA) and fluffed gauze in a pressure dressing with circumferential head wrap to avoid hematoma formation (**TECH FIG 4**).



TECH FIG 4 • A. Laceration of the ear through cartilage, with partially avulsed helical rim flap. **B,C**

Irrigated and closed with interrupted nylon sutures anteriorly and interrupted chromic sutures posteriorly.

■ Nasal Lacerations

- Nasal hemostasis may need to be achieved with either anterior or posterior nasal packing layered cottonoid or Xeroform gauze (Covidien, Mansfield, MA).
 - Septal nasal hematomas must be ruled out. If visualization of the septum is not clear, slide your small finger into each nostril for palpation of a bulging hematoma.
 - If septal hematoma is present, this should be drained under direct vision with an no. 11 blade.
 - Unlike ear lacerations, reapproximating the skin does not necessarily reapproximate the underlying cartilages, and lacerations should be addressed separately.
 - Use 4-0 Vicryl (Ethicon, Somerville, NJ) or clear nylon suture for cartilage reapproximation.
 - Use nylon or 5-0 or 6-0 Prolene (Ethicon, Somerville, NJ) for skin closure.
 - The traditional view of resecting an entire subunit of the nose if greater than 50% is compromised has been challenged in favor of retaining all native healthy tissue.
 - Defects of tissue may be repaired in the operating room with local flaps such as the dorsal nasal, nasolabial, and paramedian forehead flap.¹⁰
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■ Lip Lacerations

- By taking care to align the “white roll” of the vermilion border, the outcome will be the most cosmetic. Differences in alignment of the white roll as small as 1 mm can be noticeable to the human eye at conversational distance.
- Align the white roll (vermillion-cutaneous junction), philtral columns, and cupid's bow before any injection with anesthetic to avoid distortion of these landmarks by the added volume of the anesthetic (**TECH FIG 5**).
 - You may mark these by tattooing with methylene blue.
- Primary closure can be accomplished when less than 30% of the lip is

involved in the defect.⁹

- Defects in the central upper lip may distort the anatomy of the philtral columns. The defect should be closed with the available lip tissue and may be corrected later.
- Closure of each layer of the laceration is necessary to maintain appropriate thickness of the lip throughout the laceration.



TECH FIG 5 • A demonstration of a lip laceration through the cutaneous-vermillion border. The first stitch for optimal reapproximation is at the level of the white roll (*white line*).

- Muscle: 3-0 or 4-0 Vicryl (Ethicon, Somerville, NJ)
- Epithelialized skin and white roll stitch: 6-0 nylon/Prolene (Ethicon, Somerville, NJ)
- Mucosa (lip surface): 3-0, 4-0 chromic suture

■ Facial Nerve Injury

- Any laceration in the path of the branches of the facial nerve should be explored for laceration of nerve (see **FIG 2**).
- Deep lacerations through the parotid gland are at high risk of nerve injury (**TECH FIG 6**).
- Repair of the lacerated nerve should take place as soon as possible and within 72 hours of injury.
- Repair delayed after 72 hours is difficult secondary to inability to stimulate

the distal end of the nerve due to depletion of neurotransmitters at the motor end plates and contraction of the cut segment of nerve.

- In the operating room and under magnification vision, the ends of the nerve should be trimmed and coapted tension free with 9-0 or 10-0 nylon epineural sutures.
- If repair cannot be completed without tension, consider nerve grafting or placement of a nerve conduit.



TECH FIG 6 • Laceration of preauricular region of the face, deep through parotid gland and lacerating the main trunk of the facial nerve as well as the parotid duct.

■ Parotid Duct Injury

- Evaluate a parotid duct injury by cannulating the intraoral segment with a 22-gauge Angiocath, and inject 1 cc of hydrogen peroxide, methylene blue, or milk into the duct. Blue dye (caution: messy!), milk, or foaming of hydrogen peroxide in the wound indicates a ductal injury.
- If the laceration appears to only involve gland tissue, the lacerated gland can be oversewn.
- Repair lacerated duct over a stent (red rubber catheter) using 7-0 nylon.
- Keep stent in place for 5 days with prophylactic antibiotics (**TECH FIG 7**).



TECH FIG 7 • A. Unrestrained child in motor vehicle collision with multiple significant lacerations and significant loss of tissue. Extensive debridement in the ED revealed multiple pieces of glass in the wound. **B.** After thorough irrigation, the wound was closed in layered interrupted fashion.

PEARLS AND PITFALLS

Preoperative planning

- Treat all bite wounds as contaminated wounds with thorough irrigation, debridement, and antibiotics.
- Small wounds may heal as well or better if left to heal secondarily.
- Always consider facial aesthetic lines when planning closure for optimal scar placement.
- Be aware that crush injuries can produce larger areas of damage than initially appreciated.

Irrigation

- Thoroughly irrigate all wounds; you can never overirrigate.

Debridement

- Debridement of devitalized skin will reduce contamination and improve healing.

Closure

- Be mindful of proper suture choice for each anatomic location.

- Alignment of skin edges is optimal with simple interrupted suture.
- Align critical regions (ie, the white roll of the vermillion border or the eyelid margin) first to minimize distortion of these regions.

Final outcome

- In addition to factors such as timing, technique, and suture material, healing has a large genetic component.

POSTOPERATIVE CARE

- One dose of IV antibiotics should be given in ED for all facial lacerations.
- If wound is grossly contaminated or patient is diabetic, send the patient home on an oral outpatient antibiotic regimen with MRSA coverage (clindamycin or Bactrim).
- Rarely, acute wounds will require IV antibiotic treatment.
- Subacute and severely contaminated wounds may require admission for IV antibiotics.
- Bite wounds should be treated as contaminated wounds in the acute setting and require anaerobic coverage.
 - First-line treatment for bite wound is Augmentin (875 mg PO bid × 7 days for adults, and 45 kg/d PO bid × 7 days for pediatric dosing).
 - IV therapy for bite wounds: first line is Unasyn (Pfizer, Inc., New York, NY) 1.5 g IV q6h.
- All wounds should be given care instructions for daily cleaning and bacitracin application TID until sutures are removed
- Tetanus prone wounds: greater than 6 hours old, contaminated or in contact with soil, puncture wounds, animal or human bites, largely devitalized, infected.³
 - Incompletely immunized or uncertain: full tetanus vaccine (if moderate- to high-risk wound, also give tetanus immunoglobulin)
 - Greater than 10 years since immunization: give tetanus toxoid (if high risk, give tetanus immunoglobulin)
 - Five to ten years since immunization: if moderate to high risk, give toxoid.
 - If less than 5 years since immunization: no need for booster

OUTCOMES

- In general, the high vascularity of the face results in good healing with a low infection and dehiscence rate.
- Final scar maturation is completed by 1 year postoperatively, and as aesthetic

appearance is always a concern to patients, maximizing aesthetic outcome should always be a priority

COMPLICATIONS

■ Infection

- Dog bite infection rates around 5% to 8% after ED washout^{3,11} (**FIG 5**).
- No change in incidence of dog bite infection rate between closure and nonclosure of wounds; therefore, approximation of tissues is recommended.¹²

■ Hematoma

- Auricular hematomas should be drained promptly through incisions in skin, and a compressive bolster dressing should be placed to prevent reaccumulation.



FIG 5 • Child presenting with cellulitis and abscess of the right cheek 48 hours after ED closure of dog bite wounds.

■ Sialoceles

- Unidentified laceration of the parotid gland or parotid duct may result in delayed accumulation of saliva, presenting as swelling and tenderness of one cheek. Treatment involves compressive dressing, and if drainage is required, perform I&D through intraoral route.

■ Chondritis

- Delayed onset of pain after ear laceration warrants prompt evaluation for chondritis. Cartilage is poorly vascularized, and infection requires IV

antibiotic therapy.

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Section XX: Craniofacial Prosthetics

72 Craniofacial Anaplastology: Prosthetic Osseointegration

CHAPTER

Chad A. Purnell, Rosemary Seelaus, and Pravin K. Patel

DEFINITION

- Anaplastology derives from the Greek *ana* to make again, anew, upon *plastos*—something made, formed, molded *logy*—the study of art and science of restoring a malformed or absent part of the human body through artificial means.
- Prosthetic derives from Greek *prósthesis*, addition, application, attachment as an artificial device that replaces a missing body part that may be lost through trauma, disease, or congenital conditions.
- Prosthetic and autologous reconstructive techniques are complementary, and in many circumstances, both are required to achieve an optimal aesthetic outcome in the reconstruction of craniofacial defects.¹ Prosthetic reconstruction can result in significantly improved quality of life for patients when conventional reconstruction reaches its limits.^{1,2}
- Although autologous techniques remain the standard for long-term stable nasal and ear reconstruction, it frequently requires multistage surgical procedures with difficulty in achieving consistency of outcome and patient acceptability. Though the prosthetic approach can achieve consistency in outcome with minimal surgical intervention, it requires a lifetime of maintenance^{4,5} (Table 1). Each approach must be considered by having the patient and family involved in the discussion. However, in some instances such as orbital exenteration, ocular and periorbital prosthesis is the only option for the patient as no

autogenous alternatives exist.³

- Facial prosthetics can be either adhesive retained or fixed to osseointegrated implants. Other means of retention have been described but are less ideal. Due to disadvantages of skin reactions and less secure fixation with adhesives, implant-retained prostheses are most commonly used and result in the higher patient satisfaction.^{1,4}

Table 1 Comparison of Autologous vs Prosthetic Techniques for Facial Reconstruction

Autologous	Prosthetic
Often complex, multistage surgery	Minimal surgery
Reconstruction requires minimal maintenance once complete	Significant, lifetime maintenance
Can be higher risk for comorbid patients	Safer in patients with comorbidities
Wide range of reconstructive outcomes	Typically provides near-exact replication of anatomic structure
Own tissues used, late complications rare	Creates prosthetic-tissue interface, late complications more common

- *Osseointegration* derives from the Greek *osteon*, bone, and the Latin *integrare*, to make whole. The term refers to the direct structural and functional connection between living bone and the surface of a load-bearing implant.⁵ Osseointegrated implants may retain a prosthesis through magnets or through a bar-and-clip mechanism (**FIG 1**).

ANATOMY

- The placement of osseointegrated implants into the craniofacial skeleton requires an understanding of the bony buttresses of the face (**FIG 2**). These areas of greater bony strength provide adequate bone stock for implant placement.
- The patient-specific anatomy for cranial bone thickness and the mastoid region must be taken into consideration for placement of temporal bone osseointegrated implants and implants for bone conducting hearing amplification.
- Orbital prostheses are retained by the thickened bony rim of the orbit. Nasal

prostheses are retained by the thickened bony rim of the pyriform aperture.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Because of the extensive deformity whether of congenital, traumatic, or from tumor ablation, a multidisciplinary team tailored to the patient's needs will help in achieving the patient's goals with an understanding of what can and what cannot be achieved by surgical autologous and prosthetic approaches. The team ideally consists of a craniofacial surgeon, an anaplastologist, a psychologist, and in the case of auricular reconstruction and bone anchored implants, an audiologist and otolaryngologist are included. The psychologist plays a critical role in providing the supportive voice for the patient during the decision-making process and in the accepting of the outcome with their own expectations, which may not be technically achievable. Communication and educating the patient and family is critical.
- A history of the patient should be collected, with particular focus on the area to be reconstructed. History of pathology leading to tissue loss, prior reconstructive attempts and donor sites, and pathology that contributes to wound healing should all be elicited. This importantly includes a history of tobacco use, corticosteroid use, and radiation therapy.
- This examination should fully assess soft tissue quality and vascularity of the area to be reconstructed. Areas targeted for placement of implants must have stable and adequate soft tissue coverage.



FIG 1 • Magnet (*left*) and bar-and-clip (*right*) attachment methods for prostheses.

- Bone in areas for potential osseointegrated implant placement should be assessed for quality and areas of potential bone loss. This assessment is best done through skeletal imaging.
- The patient should be evaluated to determine the appropriateness of practical prosthetic use. This includes an evaluation of manual dexterity (to don/doff prosthesis), general personal hygiene, social support, history of compliance with medical treatment, and access to anaplastology services.

IMAGING

- Conventional 2D photography and 3D soft tissue imaging is ideal not only for documentation but for virtual design and planning of prosthetic implants.



FIG 2 • The craniofacial buttresses (shown in color) are areas of increased bony strength in the facial skeleton, which are the safest locations for implant placement.

- For straightforward placement of osseointegrated implants in the temporal/mastoid region in patients with normal bony anatomy, imaging may not be necessary. However, imaging is frequently necessary for symmetrical anatomical restoration and for virtual planning of the implants. CT or CBCT imaging is essential to evaluate bone depth and density, which may be abnormal. Areas of prior bony resection or reconstruction are evaluated carefully for residual bone. Bone quality is of paramount importance after radiation therapy, and abnormal anatomy in craniofacial syndromes should be noted.
- Preoperative 3D planning software that integrates the soft tissue and the underlying skeletal anatomy allows the simulated placement of screws into bone to determine ideal vectors and locations of placement (**FIG 3**). These technologies can be merged with intraoperative stereotactic guidance for particularly challenging cases to ensure optimal placement.⁶ At our center, we prefer to use a computer-generated guide for precise implant placement⁷ (**FIG 4**).

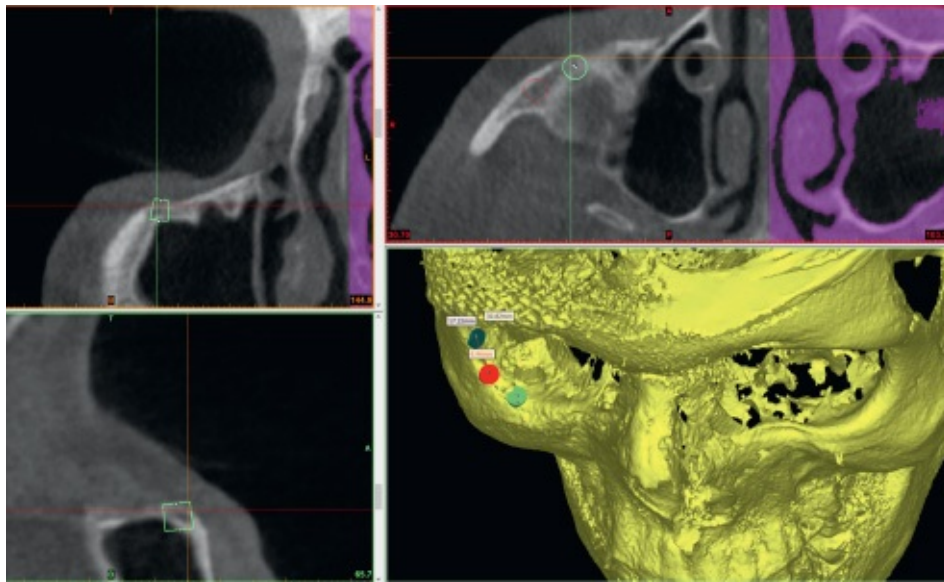


FIG 3 • Three-dimensional virtual planning for ideal implant placement.

SURGICAL MANAGEMENT

Preoperative Planning

- The number of implants to be placed should be decided with an anaplastologist to ensure adequate fixation. This decision will be affected by the location of the prosthesis as well as the type of fixation (magnet vs bar-and-clip). Magnet fixation may require additional implants to be placed.

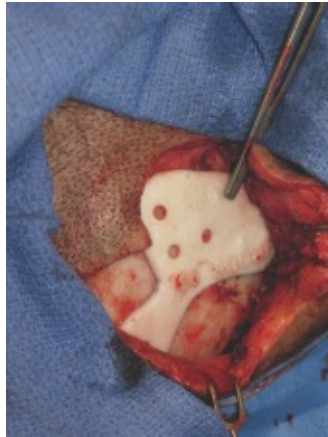


FIG 4 • Custom 3D printed drill guide for precise implant placement.

- The anaplastologist, with the craniofacial surgeon, will prepare a template of the area to be reconstructed with implant locations designated to guide surgical placement. In the case of the ear, this template is usually made from the position of the contralateral ear and centered around the external auditory meatus or tragus if present.
- The implant depth is often decided prior to implant placement but can be decided intraoperatively based on clinical assessment of bone depth and density. Most craniofacial implant systems come in 3 and 4 mm depths.

Positioning

- Standard supine positioning with a head drape and general endotracheal anesthesia is used for most implant placements. For uncomplicated implant placement, some surgeons may prefer local anesthesia with sedation.
- Hair in the operative area is trimmed in a limited fashion.
- If surgical drapes will obscure visualization of a contralateral normal structure, marking should be performed prior to draping to ensure symmetry.

Approach

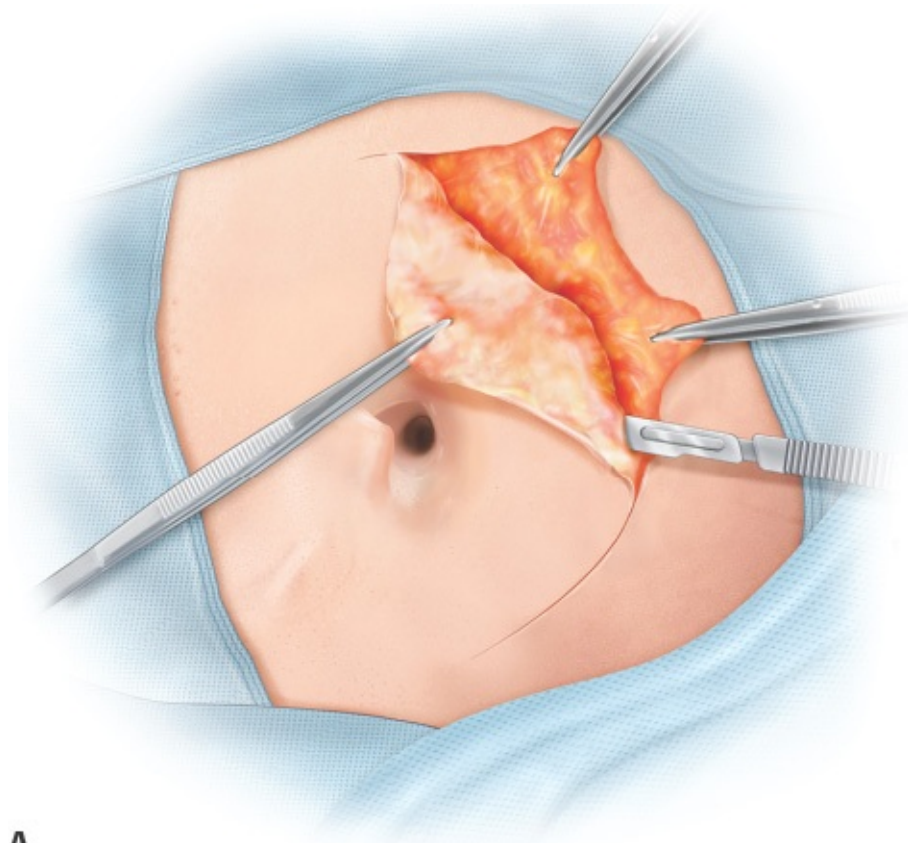
- A one- or two-stage technique can be utilized for implant placement. In a one-stage technique, the implant is positioned and an abutment is immediately placed through the skin. The one-stage approach is appropriate in a majority of scenarios.
- In a two-stage technique, skin is reclosed over implants capped with a cover screw. The implants are then allowed to integrate into bone (approximately 3 months). Exposure of implants and abutment placement occurs at a later stage. A two-stage approach is generally indicated if bone is irradiated or of poor quality, in children, or in the orbital or maxillary region.^{8,9} We typically favor a more conservative two-stage approach for many of our patients rather than early loading of the implant.

Osseointegration and healing time may range from 3 to 9 months depending on patient comorbidities and bone quality. This is typically based on intraoperative assessment.

TECHNIQUES

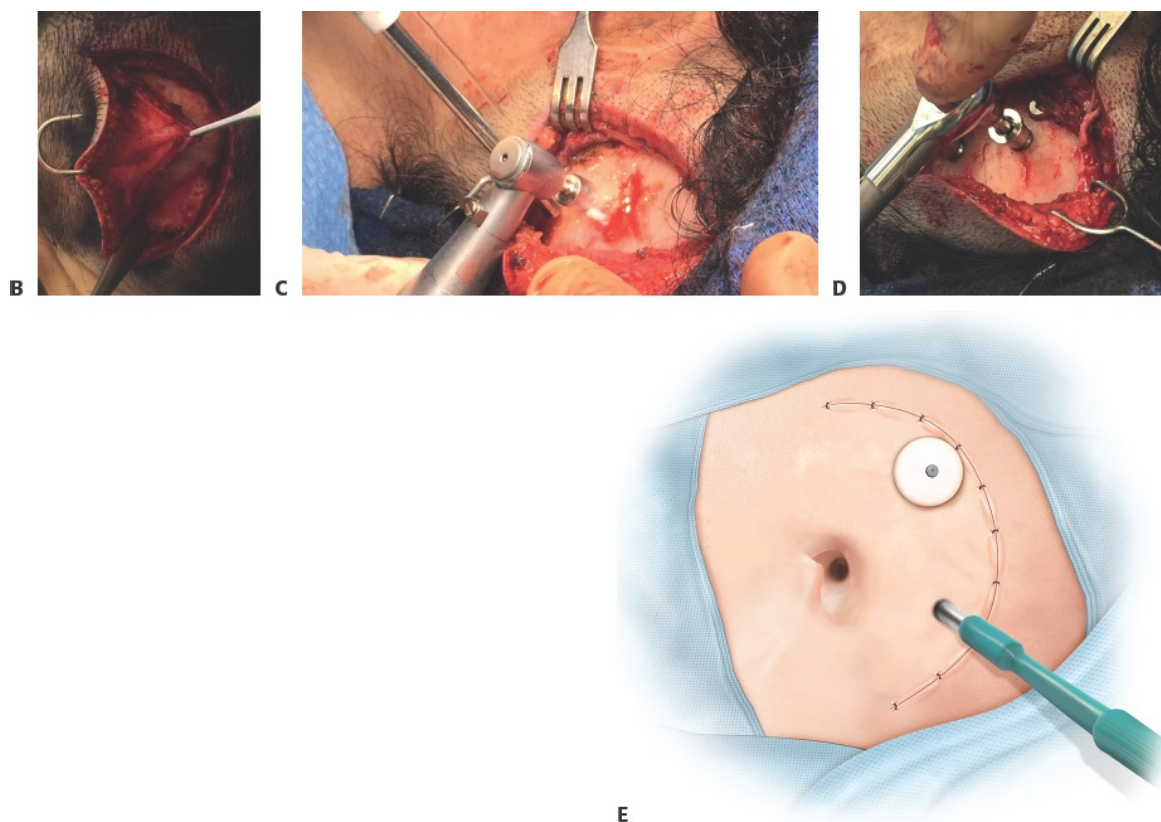
■ General Technique of Implant Placement

- Using the template created by anaplastology, the sites for implant placement are marked utilizing a needle dipped in methylene blue buried through skin and into bone.
- After a skin flap is raised (see specific anatomic areas for skin flap design), the skin is thinned to an ideal thickness of 2 to 3 mm (**TECH FIG 1A**). The skin flap is depilated through thinning or electrocautery of hair follicles or prior laser treatment. Periosteum is elevated (**TECH FIG 1B**).



A

- The sites for implant placement are identified. A guide drill with depth stop is used to drill a pilot hole in the correct vector (**TECH FIG 1C**). If the 3-mm depth stop results in complete drilling through bone, the 3-mm depth stop widening bit should be used and a 3-mm depth implant placed. If significant bone remains with the 3-mm depth stop, the 4-mm depth stop and implant can be used.
- A wider drill bit with countersink is used to widen and countersink the pilot hole at the appropriate depth.
- Outer table particulate bone is harvested and placed within the depth of the cranial bone at the dural interface when it is drilled full thickness.



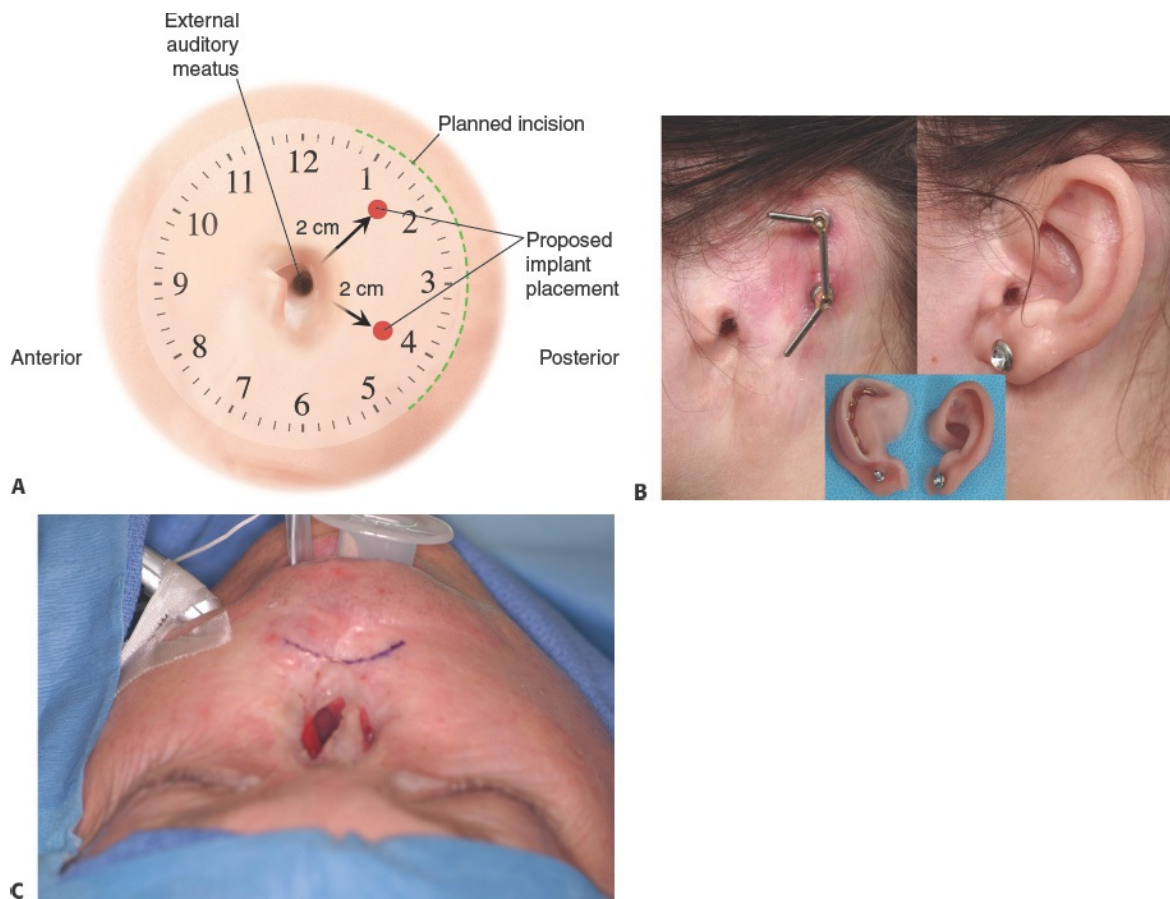
TECH FIG 1 • **A.** Skin flap is thinned to an ideal thickness of approximately 3 mm. **B.** Periosteum elevated. **C.** Drill with depth stop at predetermined implant locations. **D.** The implant is tightened with a torque wrench. **E.** Biopsy Punch used to perforate skin at location of implants in one-stage technique.

- Implants are placed into the holes with a handpiece set at slow speed of 2000 rpm at 25 N-cm handpiece. The torque of 25 N-cm can be increased depending on the density of the bone.
- Tighten implant with torque device by the hand to recommended torque level of the implant system (**TECH FIG 1D**).
- At this point, if a one-stage technique is planned, a biopsy punch is used to make skin holes directly over each implant (**TECH FIG 1E**).
- Healing or standard abutments are placed into each implant in the one-stage technique.
- If a two-stage technique is used, cover screws are placed over each implant and skin is closed.

- The skin incision is closed in layers, including the periosteum.

■ Implants for Auricular Prostheses

- A skin flap is designed in the proposed area of implant placement by avoiding pre-existing scars if possible. Typically, this is an anteriorly based single flap encompassing the area of all implants. Implants are ideally placed 2 cm from proposed or actual external auditory meatus, at least 1 cm apart from each other, with at least one implant above and one below the meatus. Incision is planned 1 to 2 cm posterior to the implants (**TECH FIG 2A**).
- Two implants are usually adequate for fixation of a bar-and-clip prosthesis. These are placed within the confines of the planned ear prosthesis, with positions above, below, and posterior to the external auditory meatus¹⁰ (**TECH FIG 2B,C**).
- If an anchor for a bone-anchored hearing aid is to be placed, this is placed posterior to the planned auricular prosthesis into the temporal bone. If a magnetic-type implant is planned, it is 30 mm in diameter and thus must be located further from the ear.



TECH FIG 2 • A. Skin flap design for auricular prosthesis. Incision planned 1 to 2 cm posterior to planned implants, which are placed 2 cm from external auditory meatus, at 2 and 4 o'clock position, or 8 and 10 o'clock position. **B.** Auricular prosthesis. (*Left*) Contralateral native ear. (*Right*) Prosthetic reconstruction. **C.** (*Left*) Bar-and-clip mechanism of implant attachment. (*Right*) Prosthetic in place. (*Inset*) Prosthesis showing clips for attachment.

■ Implants for Nasal Prostheses

- Ideally, at least three implants are utilized for fixation of a nasal prosthetic.
- Incisions are designed to be hidden by the eventual prosthesis, and flaps are raised anteriorly and posteriorly (**TECH FIG 3A**).
- Good-quality bone is limited around the nasal cavity. The frontal process of

the maxilla (medial buttress) or premaxilla are sources of reasonable bone for fixation. The radix can also be used (**TECH FIG 3B**).

- Correlation with dental anatomy is essential to avoid the maxillary tooth roots if placing implants into the premaxilla.



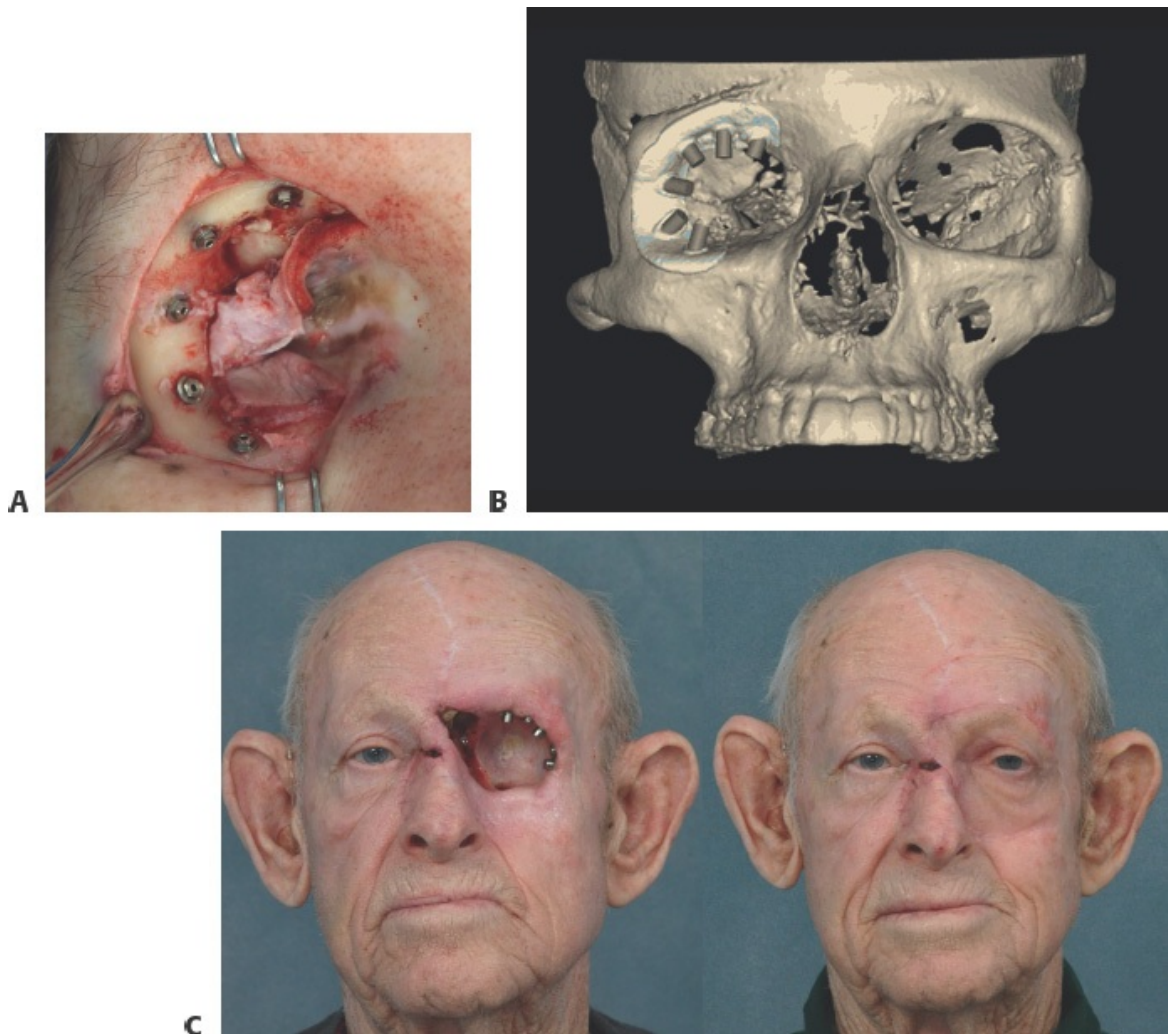
TECH FIG 3 • **A.** Curvilinear incision used to access premaxilla for nasal implant placement. This incision will be completely hidden by the prosthesis. **B.** Implant locations for nasal prosthesis. **C.** (Left) Implants in place for magnet-retained nasal prosthesis. (Right) Prosthesis in place.

■ Implants for Orbital Prostheses

- Typically, three to five implants are adequate for fixation of an orbital prosthesis. Extra implants are often placed as it is assumed that an implant will be lost at some point.
- Incision is made at the orbital rim, under the area of the planned prosthesis. Flaps are raised in both directions from the incision, with the majority of the dissection deep to the rim (**TECH FIG 4A**).
- Implant location is generally designed in the superolateral orbital rim, if present, due to thicker bone in this area and for consideration of prosthetic appearance. If the lateral orbital rim is unavailable, the inferior and superior

rims are selected for implant placement. The medial orbital bone is thin and of limited utility for fixation (**TECH FIG 4B**).

- Longer length implants should be used if possible given higher rates of implant loss in the orbit.



TECH FIG 4 • **A.** Orbital exposure for implant placement. Note rim incision and subperiosteal dissection into orbit. **B.** Surgical planning for orbital implant placement. Lateral orbital rim is the location for the majority of implants. Multiple implants placed due to higher instability of orbital implants. **C.** (*Left*) Orbital exenteration defect with implants in place. (*Right*) Defect with prosthesis in place.

PEARLS AND PITFALLS

Communication/education	■ Educating the patient and family is critical to a successful outcome for the patient and for the treating team. Patients need to understand of the details of the steps involved to achieving the desired outcome. Expectations are best managed from the beginning. The psychologist and nurse are critical to this dialogue.
Implant vector	■ Implants should be placed to full depth and ideally perpendicular to both bone and soft tissue. ■ The guide drill must be used completely down to the depth stop to ensure proper seating.
Soft tissue contour	■ Soft tissue should be thinned in a gentle taper around the implant area to avoid a step-off.
Hair at site of implants	■ If hair remains after surgery, this can be treated with a laser depilation at a later time.
Postoperative maintenance	■ It is critical that patients with the support of their family establish a daily routine for the management of the peri-implant soft tissue and care of the prosthesis. Failure to provide adequate care will lead to loss of implant.
Follow-up	■ Patients with prostheses should be followed frequently at a minimum of an annual visit to assess the peri-implant tissue and the quality of the prosthesis. It is important for the team to assess its own outcomes and understand the patient's satisfaction or dissatisfaction with the treatment.



FIG 5 • Head wrap dressing used postoperatively after auricular implant placement.

POSTOPERATIVE CARE

- The area of reconstruction is covered with a pressure dressing and then a head wrap dressing (**FIG 5**), which is left in place for a period of 2 to 3 days. After this point, abutment site care is initiated and showering is permitted.
- The abutment site is cleaned daily with mild soap and a soft bristle brush to prevent crusting or buildup. Peri-implant hair should be trimmed and ideally removed permanently.
- If a one-stage technique is utilized, healing abutments are left in place for 10 to 12 weeks until the final abutment is positioned. In a two-stage technique, a period of 12 or more weeks is allowed for osseointegration. Once the final abutment is in place, the prosthesis fabrication can begin.

OUTCOMES

- Craniofacial implant–anchored prosthetics are well tolerated and have a long history of success. A majority of patients are able to wear their prosthesis for greater than 12 hours/d.^{1,11,12} Implant anchoring tends to improve patient-reported quality of life overall.
- Implant failure rates are low in nonirradiated patients, with failure rates of 5% to 20% in nonirradiated sites in long-term studies.^{7,11,13,14}
- Failure rates are higher in irradiated patients.¹⁵ Large studies have shown failure rates of 23% to 54% over time in irradiated fields.^{7,13,14,16,17} Studies are mixed on whether high-dose radiation increases implant failure rates over low-dose radiation.

- The role of hyperbaric oxygen (HBO) on implant survival in irradiated fields is as of yet unclear.¹⁵ Some studies suggest that HBO used after implant placement may decrease failure in irradiated bone,^{13,17} whereas others have seen no differences in outcomes.¹⁶
- Prostheses themselves have a limited life. Many studies cite a 2- to 5-year life span.¹⁸ However, prostheses may last significantly less time depending on the patient's tolerance of discoloration or level of activity with prosthetics in place due to tearing or damage.¹⁹

COMPLICATIONS

- The most common complication with osseointegrated implants are soft tissue–related reactions due to inflammation.^{15,20,21} Reactions are typically graded on a scale of 1 to 4 (Holgers scale). One is slight local erythema. Two is erythematous and slightly moist, 3 is moist with granulation tissue, and 4 is infection.²¹ Rates of reactions overall range from 3% to 26%, with grade 1 reactions being by far the most common.^{9,14,21} Device removal due to infection is extremely rare. The vast majority of skin reactions can be treated with medication. In cases of exuberant granulation tissue, local tissue around the abutment can be removed surgically (**FIG 6**). Aggressive thinning of peri-implant soft tissues at the time of placement in order to eliminate skin mobility around the implant is the best way of limiting peri-implant soft tissue reaction.



FIG 6 • Exuberant granulation tissue reaction around abutments.

- Implant failure can occur early because of inadequate osseointegration with

poor bone quality and can occur late due to chronic soft tissue infection affecting the peri-implant bone interface.

- During drilling for auricular implants, occasionally the dura of the middle cranial fossa or the sigmoid sinus will be exposed or perforated. In these cases, if bone stock is good, the implant can be placed as normal and the leak will seal. If the bone stock is poor, the leak should be sealed with pericranial tissue followed by autogenous particulate bone harvested from the same operative field and packed densely into the defect with fibrin sealant. The implant should be relocated.

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Section XXI: Conjoined Twins

73

Conjoined Twin Separation

CHAPTER

Michael R. Bykowski, Joseph E. Losee, and Lorelei J. Grunwaldt

DEFINITION

- Conjoined twins are individuals who are physically connected by their anatomy and share one or more organs. The site of fusion and orientation of the twins characterize the different types of conjoined twins. Although some conjoined twins can live functional lives, surgical separation is often performed for religious beliefs, cultural beliefs, parental wishes, and/or to promote survival of one or both twins.
- Conjoined twin separation is the procedure of surgically dividing the conjoined twins, allocation and reconstruction of shared organs, and soft tissue coverage. The challenge of the complex anatomy and physiology requires comprehensive preoperative planning and coordination by a multidisciplinary team often lead by the plastic surgeon.
- Because there is great variability of fusion patterns of conjoined twins, surgical management cannot be reliably predicted and is not amendable to treatment within fixed protocols. As such, this chapter discusses the general key principles for planning and executing separation of conjoined twins.

ANATOMY

- The detailed anatomy of conjoined twins is dependent on each set of twins. In general, however, the larger the connecting bridge between twins, the more complex its contents.
- The tissues of conjoined twins are normal but the anatomy is not. The anatomy

is always abnormal but not in a reliably predictable manner. Nonetheless, there are general patterns to the anatomy based on the fusion type. The anatomical arrangements may be such that one twin may be incapable of independent existence.

- Classification is based on terminology according to the most prominent site of connection plus the suffix “pagus,” which is the Greek word meaning “that which is fixed”.¹ Some forms are described below:
 - Thoracopagus (40 cases; **FIG 1A**): junction primarily at the chest with varying amount of fusion of the heart, pericardium, and diaphragm.
 - Omphalopagus (34 cases; **FIG 1B**): joined at the abdomen and often have fusion of the liver and gastrointestinal (GI) tracts.
 - Pygopagus (18 cases; **FIG 1C**): connection at the sacrum/perineum and commonly face away from each other. May have fusion of the terminal spinal cord and associated meninges.
 - Ischiopagus (6 cases; **FIG 1D**): connected at the pelvic level. Each twin may have a normal leg and a common fused leg (ischiopagus tripus) or each has two normal legs (ischiopagus tetrapus). Often have fusion of distal small intestine/large intestine and genitourinary system.
 - Craniopagus (2 cases; **FIG 1E**): fusion of the skull and meninges. (The separation of craniopagus twins is often driven by the neurosurgical team and is not discussed in detail in this chapter.)

PATHOGENESIS

- Conjoined twins are monozygotic, monoamniotic, and monochorionic.
- There are two leading theories for the pathogenesis of conjoined twin formation.²
 - Failure of separation of the embryonic plate approximately 15 to 17 days of gestation
 - Union of two separate embryonic discs

NATURAL HISTORY

- Conjoined twinning occurs in 1.5 per 100 000 births.³
- Other congenital anomalies that are not related to conjoining frequently occur and impact survival with cardiac abnormalities occurring in greater than 60%.⁴

PATIENT HISTORY AND PHYSICAL FINDINGS

- The minimal diagnostic criterion is the fusion of some portion of monozygotic

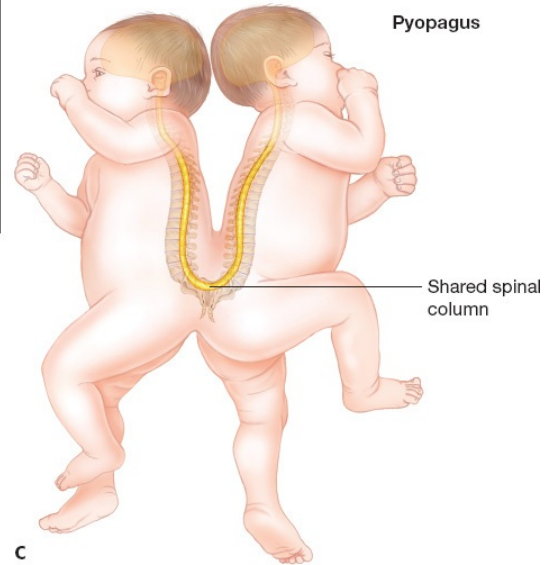
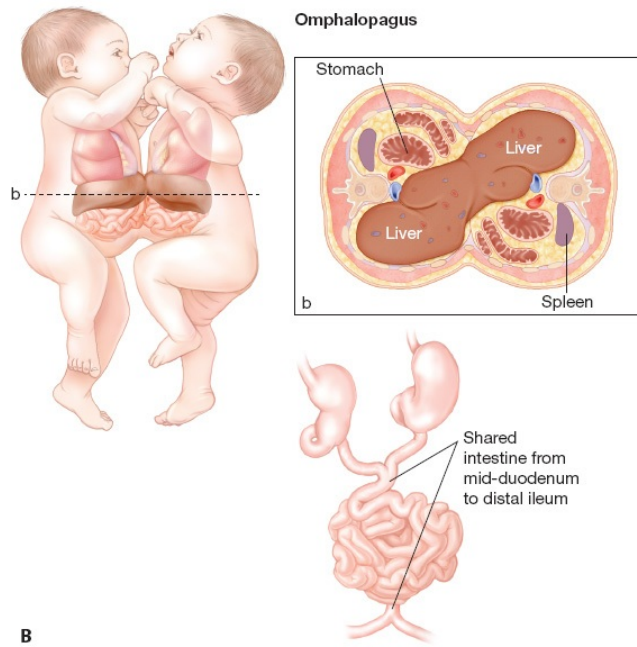
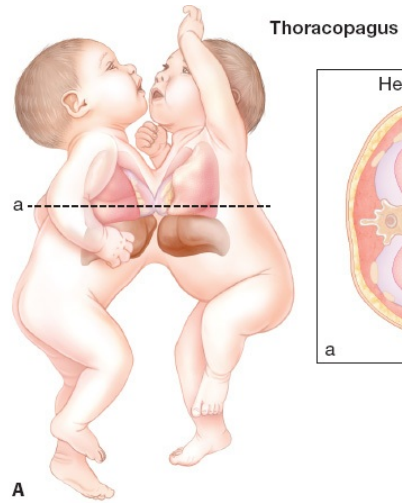
twins.

- The main physical finding—ie, the site at which the twins are connected—provides insight to the internal anatomy. Predictable patterns of fusion occur and are associated with shared organs and organ abnormalities (see **FIG 1**).

IMAGING

- From the time of prenatal diagnosis to the time of surgical separation, imaging is the most important aspect of conjoined twin management.
- Prenatal and postnatal imaging evaluations are critical for predicting prognosis, obstetrical planning, medical management, and ultimately surgical separation.
- Conjoined twins can be first diagnosed by prenatal ultrasound by the 12th week of gestation.⁵
 - Specific diagnostic ultrasound findings include fixed position of the twin bodies on repeated examinations over time, lack of a separating membrane between the twins, and an inability to visualize a separation between the fetal bodies and skin contours.
- Once the presence of conjoined twins is diagnosed prenatally, further imaging is crucial to delineate the anatomy and extent of shared organs; both of which are important for obstetrical purposes and prognosis.
- Due to the high incidence of cardiac abnormalities, fetal echocardiography is the most important prenatal evaluation.
 - All conjoined twins (irrespective of the site of connection, but especially for those with a ventral union pattern)⁴ should undergo fetal echocardiography.
 - The degree of cardiac fusion and the severity of associated cardiac anomalies can help predict the postnatal viability and thus provide information for parental counseling.
- Prenatal computed tomography (CT) is useful to delineate the anatomic arrangement of the twins, primarily bony anatomy.
- Magnetic resonance imaging (MRI) is the best modality to provide the most detailed imaging of the fetuses as well as their associated anomalies and extent of union.
 - Ultrafast T2-weighted MRI sequences eliminate the need for maternal sedation and allow precise anatomical assessment of fetal organs avoiding the artifact due to fetal movement.
- Once the fetuses are determined to be viable and subsequently survive birth

and the neonatal period, elective surgery can be planned with a team approach and with repeat postnatal imaging (discussed in detail below under “Preoperative Planning”).



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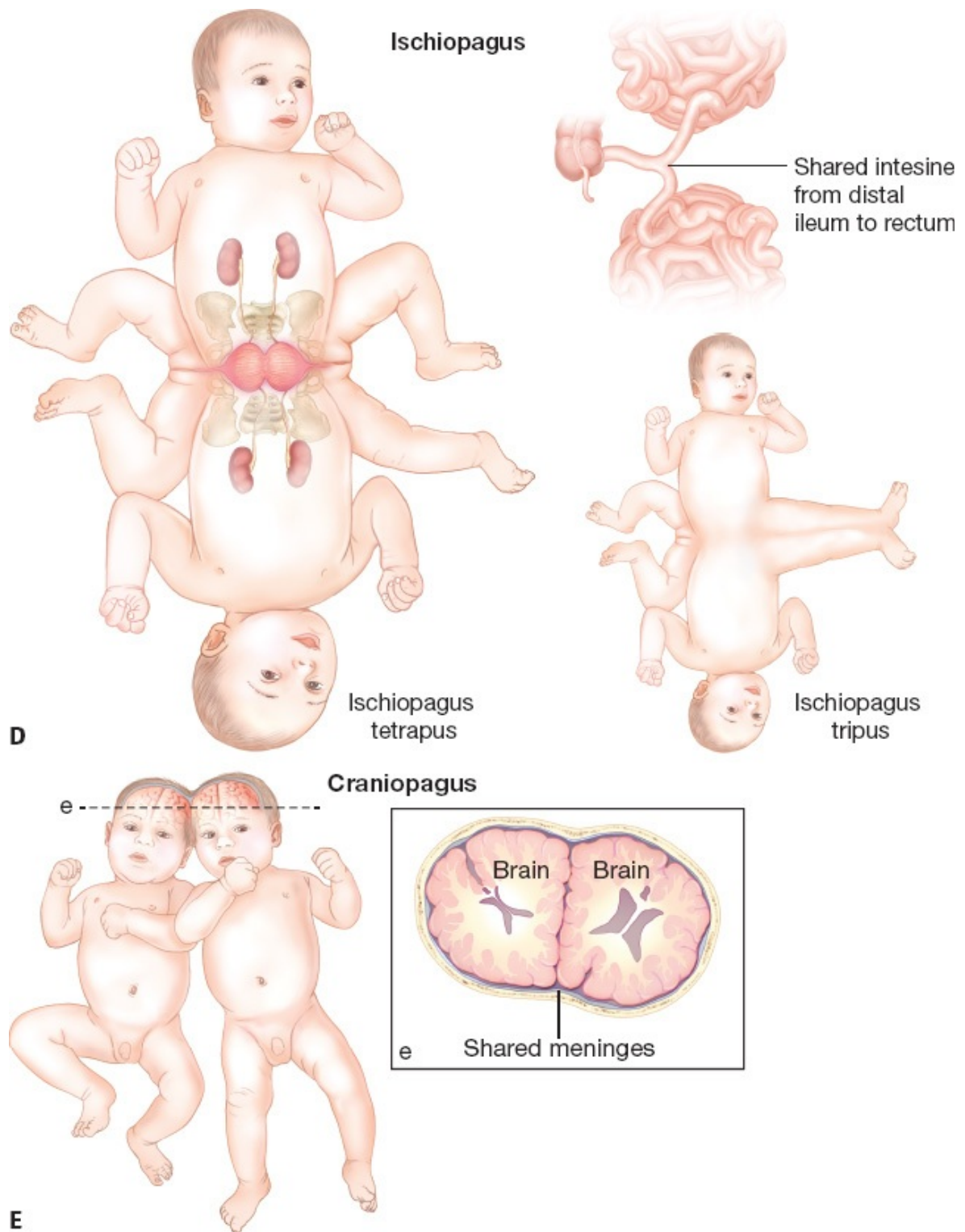


FIG 1 • Five most common classifications. **A.** Thoracopagus. **B.** Omphalopagus. **C.** Pygopagus. **D.** Ischiopagus. **E.** Craniopagus.

DIFFERENTIAL DIAGNOSIS

- Teratoma
- Lymphatic malformation

NONOPERATIVE MANAGEMENT

- In determining operative vs nonoperative management of conjoined twins, a pragmatic approach is necessary to balance:
 - What is technically feasible by the health care team.
 - The parental wishes.
 - The likely outcome for the children with or without separation. (The issue of parental consent is beyond the scope of this chapter.) The technical feasibility and prognosis are issues that depend on each other and are dictated by which organs are connected and the extent of their connections.
- An extreme example demonstrating successful nonoperative management of a set of conjoined twins is the famous Eng and Chang Bunker. These twins—born in Siam in 1811—gained notoriety while traveling with the Barnum & Bailey Circus under the exhibition name “Siamese Twins.” Despite their abdominal connection, Eng and Chang married sisters, fathered 22 children, and lived together for 63 years.
- Separation of conjoined twins is contraindicated in the following circumstances:
 - Thoracopagus twins with complex cardiac fusion
 - Craniopagus twins with extensive cerebral fusion
 - Separation that would result in physical disability, which is unacceptable to the parents. This is often associated with shared organ systems with compromise of one or both twins when the organ system is removed from one twin (often seen in parapagus, extensive ischiopagus, and craniopagus).

SURGICAL MANAGEMENT

- The discussion of this chapter focuses on elective separation, but the management of conjoined twins can be characterized as three distinct groups:
 - Nonoperative
 - Emergency separation
 - Elective separation
- The objective of the operation is to separate the conjoined twins while adequately allocating each individual with organs for survival and to obtain soft tissue coverage over the resulting defect. In general, the anatomy of the

junction and the shared organs and structures dictate the technical details of the procedure.

- A multidisciplinary approach is required along with frequent planning meetings, involving all of the staff necessary before, during, and after surgical separation.
- The staff should include nursing, neonatologists, pediatricians, critical care physicians, anesthesiologists, and a variety of surgical specialists. Because a critical factor in conjoined separation is soft tissue coverage, the plastic surgeon is often the team leader and coordinates all activity.
- Elective separation should be delayed until at least 2 months of age if possible.⁶ The timing of separation varies widely from 2 months to 2 years of age. The critical factor is to allow time for extensive preoperative planning and simultaneous medical optimization.
- Occasionally, conjoined twins require mechanical ventilation to preserve respiratory functioning toward the end of tissue expansion of the abdomen or thorax, as there may be decreased tidal volume from external compression.⁷
- Due to the varied anatomy of conjoined twins, it is usually not possible to follow a predetermined protocol for surgical separation. In general, the main steps of the procedure are as follows:
 - Exposure of shared organs
 - Division, allocation, and reconstruction of shared organs
 - Identification and ligation of cross-circulation
 - Abdominal wall reconstruction and wound closure with rotational flaps, previously expanded tissues, and skin substitute materials

Preoperative Planning

- Although the health care team is large and multidisciplinary, it must be clear that there is a lead surgeon who is in charge and makes the final decisions on preoperative evaluations and treatment.
- Conjoined twin separation is technically challenging due to the various organs that can be fused. The most important factor for successful separation is preoperative planning through postnatal multimodal imaging modalities.
- Postnatal imaging is the keystone of preoperative planning to, firstly, assess operability and, secondly, to understand the shared anatomy and help with surgical planning.
- Three features are key to determining survival and thus should be a focus of

preoperative planning:

- Major vascular connections
 - CT angiogram: this modality is necessary to visualize vascular connections.
- Management of the body wall closure: without adequate soft tissue coverage, the patient is at risk for exposure of viscera, evisceration, and sepsis. CT imaging allows sufficient assessment of the anticipated soft tissue deficiency and can help determine reconstructive options. If closure is too tight, cardiac and pulmonary functioning can be compromised. Therefore, additional soft tissue coverage needs to be created or temporizing measures must be employed.
 - Tissue expansion.
 - Mesh or dermal substitutes.
 - Rotational flaps can be used as an adjunct to tissue expansion and skin substitutes.
- Performance of both hearts after separation: cardiovascular performance after separation is not predictable given potential changes in cardiac functioning and changes in circulation.
- Even with extensive postnatal imaging, close monitoring and treatment in the intensive care unit is necessary.
- Because congenital anomalies (unrelated to conjoined twinning) are common,³ all patients regardless of the form of conjoined twin should undergo cranial ultrasound, abdominal ultrasound, CT, and MRI. Three-dimensional models can be created to aid in surgical planning.
- As stated above, each type of union is associated with specific structural abnormalities, so preoperative evaluation and planning will vary.
- Each organ system should be preoperatively evaluated in a systematic manner.
 - Cardiovascular system: due to the high rate of cardiac abnormalities in all forms of conjoined twins, all twins should undergo postnatal echocardiography to characterize cardiac anomalies. Thoracopagus twins should undergo electrocardiographic-gated cardiac CT or cardiac MRI for detailed assessment of cardiac anatomy.
 - Respiratory system: CT is performed to demonstrate the anatomy of the lungs and airways. Parapagus twins often have abnormalities of the tracheobronchial tree. Although the respiratory systems in thoracopagus and omphalopagus twins develop separately, there may be associated abnormalities (eg, hypoplastic lobes secondary to diaphragmatic hernia or

asymmetric chest union).

- **Hepatobiliary tree:** the number of gallbladders, liver, and pancreas should be known. Furthermore, liver vascularity and hepatic venous drainage for each twin must be ascertained. The liver is fused in all parapagus twins, most thoracopagus and omphalopagus twins, and less frequently in ischiopagus twins. Cross-sectional imaging will demonstrate the degree of fusion and visualize the intrahepatic vessels. MRI or CT scan with contrast injected into one twin can help to delineate the plane of liver separation. Overall, 25% of thoracopagus twins share a biliary system. Magnetic resonance cholangiopancreatography (MRCP) provides a detailed assessment of biliary anatomy.
- **GI system:** the length of the alimentary tract should be evaluated. Though laparoscopy or upper GI contrast studies have been used to evaluate bowel distribution, much of the anatomy can be determined and managed during the separation procedure by the general surgeons. The lower GI tract is shared most often in ischiopagus twins (70% of cases) and in 25% of pygopagus twins. Pygopagus twins often have varying degrees of rectal fusion and common anuses. Contrast enema along with MRI will demonstrate complex anorectal abnormalities.
- **Urinary tract:** imaging studies are performed to assess the number, reflux status, and anatomy of the kidneys, ureters, urinary bladders, and urethras. Cystograms can identify small fistulae not revealed by cross-sectional imaging. In 15% of pygopagus cases, the bladder is shared. Half of ischiopagus twins share pelvic organs.
- **Genital system:** in pygopagus and ischiopagus twins, vaginoscopy is mandatory to assess vaginal and cervical anatomy. MRI can demonstrate the number of uteri, ovaries, vaginas, and testes.



FIG 2 • Markings prior to chest and abdominal tissue expander placement and subsequent removal due to restrictive lung disease.

- Central nervous system: the nature and extent of spinal cord fusion is assessed in pygopagus, ischiopagus, and parapagus twins with spinal MRI.
- Integumentary system: the soft tissue deficiency that will occur following separation can be estimated with CT scan. This information can be used to plan for the number of and placement of tissue expanders. Vascular territories of the skin can be mapped by intravenous fluorescein dye.
- Musculoskeletal system: CT scan provides detailed assessment of bony anatomy, which is especially useful to determine pelvic and spinal bony anatomy in cases of caudal union. MR angiography can be used as an adjunct to determine blood supply when vascularized muscle flaps are planned—eg, when a shared limb will be used for wound closure.
- The primary goal of the plastic surgeon is to provide coverage overlying the newly created defect following separation.
- Tissue expanders have been placed intraperitoneally and in subcutaneous positions throughout the bodies of conjoined twins.
- The size of the defect following separation can be extensive and require multiple strategies in addition to tissue expanders, including meshes or dermal substitutes.
 - Tissue expansion overlying the abdomen/thorax can compress the compliant

chest wall and immature respiratory muscles of young children, leading to restrictive lung disease⁷ (**FIGS 2 and 3**). As such, tissue expanders should be minimized around the thorax (**FIG 4**).

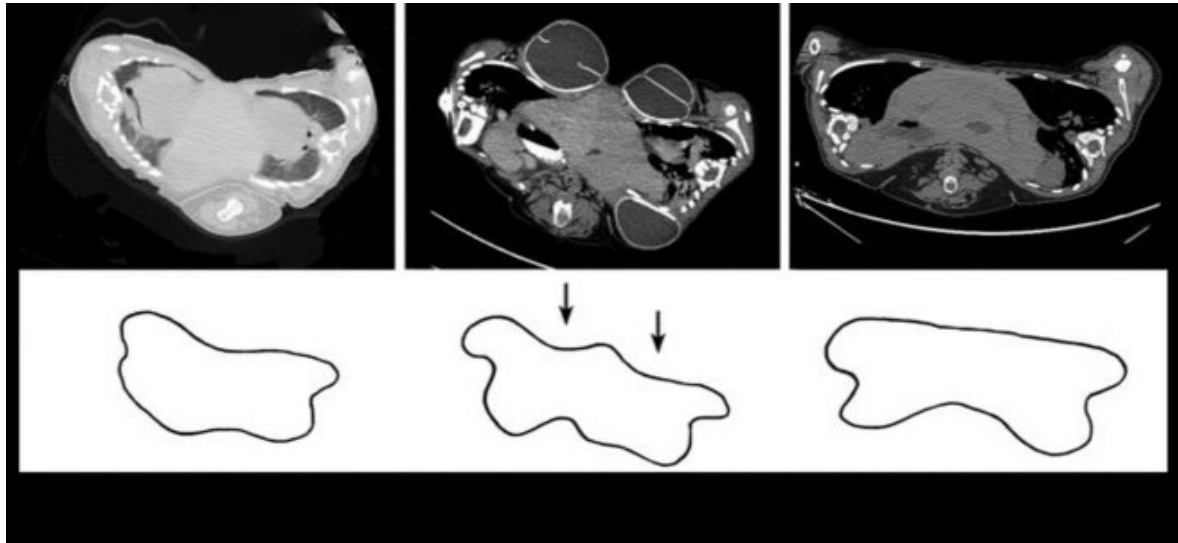


FIG 3 • Top row. CT cross-section view through ischiopagus twins with and without tissue expanders. **Bottom row.** Line drawing of chest cavity showing deformation of anterior chest wall with tissue expanders in place. (*Left*) Preoperative chest CT scan. (*Center*) Chest scan with tissue expanders inflated and resultant chest deformation. (*Right*) Chest scan 6 months after tissue expander removal and resolution of clinical respiratory symptoms.



FIG 4 • Tissue expanders removed for the chest of one twin but maintained in the other. A tissue expander is placed on the left extremity.

- When plausible, expanders should be placed near the pelvic ring so that counter pressure is provided to optimize tissue expansion. Caution must be taken to avoid expanding too rapidly to avoid skin ischemia and expander exposure.
- Due to the thin subcutaneous layer in infants, smooth wall tissue expanders are used. Textured implants tend to minimize capsule formation, which can promote thinning of the skin.
 - Distant ports are used rather than integrated ports. The reason is that the thin skin overlying the expander is more prone to breakdown from repeated injections during the expansion process.
- Tissue expansion using pneumoperitoneum is an alternative. Sterile air is injected (500–1500 cc) every 3 days to expand abdominal circumference.⁸ Ischiopagus tripus twins present with an accessory hip joint and lower extremity, giving a tripod, or “tripus” configuration. As discussed below in “Techniques,” the tripus (**FIG 5**) can provide additional coverage by filleting it open for maximal use of the skin, subcutaneous tissues, and muscle.

Positioning

- Positioning will depend on how the twins are conjoined. Due to the potential

for a long duration of surgery, the twins must be well padded to prevent the development of decubitus wounds.

- Positioning must allow adequate exposure to the planned line of separation.
- If a posterior approach is favored, position the patient supine initially. Once intubated and venous access secured, the twins can be turned prone. This maneuver can be cumbersome. Circumferential sterile surgical preparation is often required.



FIG 5 • Posterior view of the conjoined twins that demonstrates the tripus (after bones removed), which will be used for the abdominal wall reconstruction.

- An important consideration is that a separate room is prepared and staffed for once the separation is completed. One twin will be transferred from the initial operating room to the other room while final reconstruction and wound closure is performed for each. After separation, each individual should have its own anesthesia team, surgical team, surgical staff, and operating room.
- A staff member is assigned to communicate ongoing progress of the surgery and coordinates patient transfers.

Approach

- An anterior approach is most often performed.
- Depending on the conjoined twin anatomy, some surgeons favor a posterior

approach.

TECHNIQUES

■ Separation of Ischiopagus Conjoined Twins

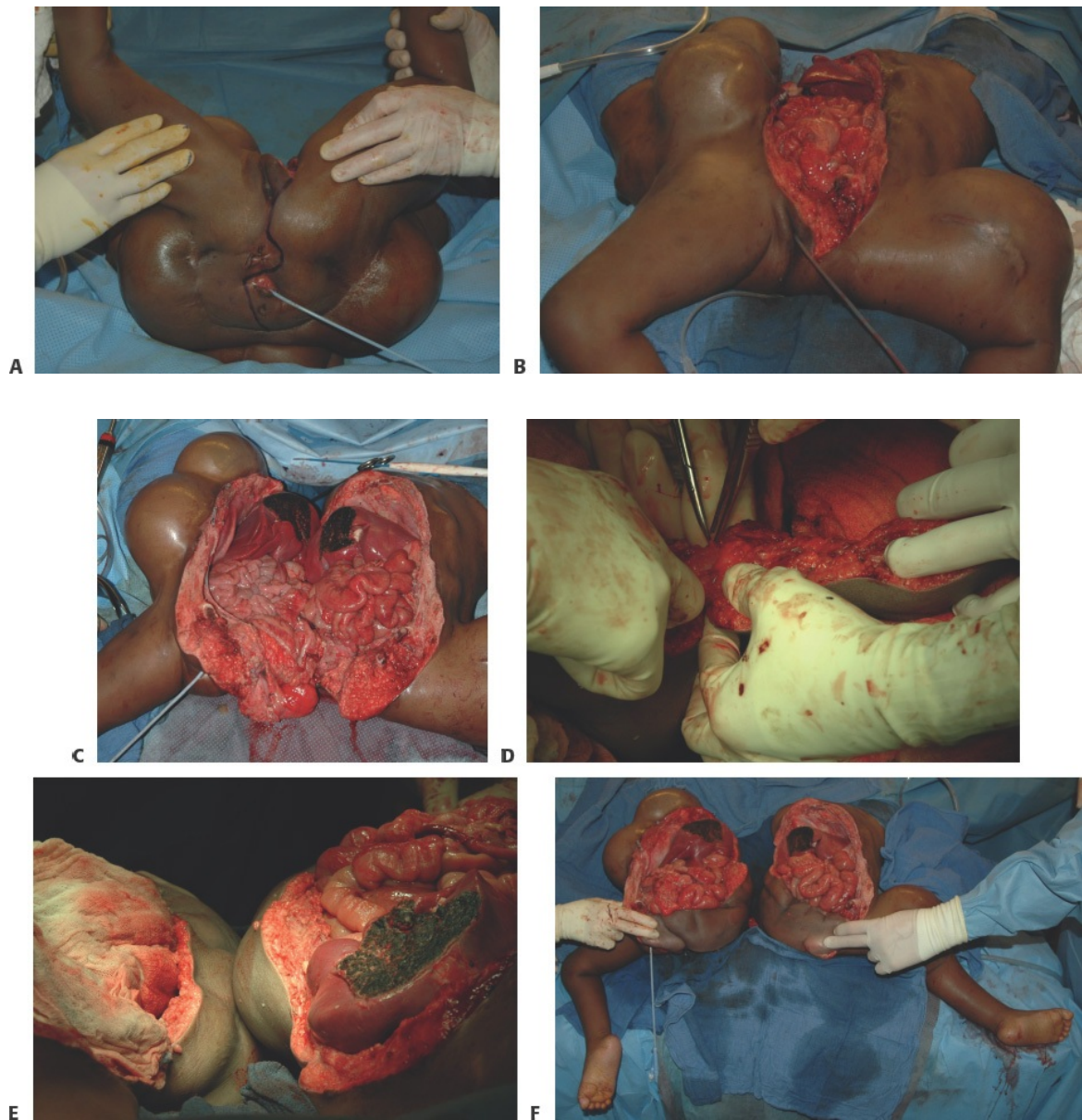
Outline and Order of Procedures

- Anterior incision extending from the chest to perineum.
- Anterior pelvic osteotomy and “booking open” of fused pelvic ring.
- Ligation and reimplantation of twin no. 1’s left ureter.
- Transabdominal liver separation.
- Separation of two ileums from the single channel into the colon.
- Posterior pelvic osteotomy with excision of the extranumerary hip joint of the tripus.
- Fillet of the tripus to create two musculocutaneous flaps.
- Repair of ventral abdominal wall and pelvic floor defects with allograft, tissue expanded advancement flaps, and musculocutaneous flaps for each twin.

Initial Steps

- Plan the skin incision to provide optimal exposure of the shared internal organs to facilitate equal allocation and reconstruction of organs. Special attention is paid to the pelvic region where the most complex connection occurs between the gastrointestinal and genitourinary tracts.
- Markings: while the twins are supine, mark the most cephalad point at the junction between the twins. Extend the marking inferiorly along the midline (in line with the umbilicus) toward the pelvis. The marking continues to the left of twin no. 1’s labia majora, which was preoperatively determined to go with twin no. 1 (**TECH FIG 1A**).
- Sharply incise the ventral surface along the midline through the skin between the tissue expanders (**TECH FIG 1B**).
- Continue the incision deep through subcutaneous tissue with electrocautery to enter the abdominal cavity. Continue dissection inferiorly to the pelvic region to directly expose the anterior aspect of the pelvic ring. Note: it is known from preoperative imaging that the pubic symphysis is near-normal

and midline.



TECH FIG 1 • **A.** Inferior view of the twins demonstrating the markings about the perineum. **B.** The ventral incision is performed along the midline to provide adequate exposure of internal anatomy. **C.** The conjoined livers are exposed and separated with electrocautery and ligation of small venous branches that traverse the isthmus. **D.** The small soft tissue

bridge is the only connection of the twins. **E.** These soft tissues are separated, and the twins are entirely separate. **F.** The tripus of each twin is rotated medially and laterally and tacked down to be used for pelvic reconstruction.

- The urologists dissect, identify, and retract the ureters and bladders to prepare for safe division of the anterior pelvic ring at the pubic symphysis.
- In conjunction with the orthopedic surgeon, the pubic symphysis is visualized and divided using a combination of electrocautery and an osteotome. This maneuver allows the pelvis to “book” open.
- With this exposure, dissection is carried posteriorly toward the rectum, which appears to have two blood supplies, one from each twin.
- With focus moved more proximally, it is ascertained that each twin has an entire length of small bowel to near the distal end where there is a common channel of small bowel that leads into a single colon.
- Attention is directed to the anterior chest where dissection is carried down deep between the chest cavities of both twins. Dissection is continued along this plane to the posterior aspect of the twins toward the operating table.
- The connected livers are now adequately exposed, which are fused at the midline for a broad segment encompassing an approximately 8-cm span. The shared liver is separated with electrocautery and ligation of small venous branches that traverse the isthmus with 3-0 Vicryl sutures (**TECH FIG 1C**).
- Once the liver is divided, each twin’s liver, stomach, and proximal small bowel can be easily retracted to the right and to the left to identify the four kidneys in the retroperitoneum.
- A Balfour retractor is placed to give adequate exposure.
- Attention is then turned to separate the small bowel. At the level of the Meckel diverticulum, an EndoGIA stapler is fired across twin no. 2’s small bowel who will later undergo creation of an end ileostomy.
- Twin no. 1’s small bowel, colon, and colonic mesentery are separated from twin no. 2’s small bowel. A bulldog clamp is used to assess the vascularity of the colon, which is determined to have two separate active blood supplies. The colonic blood supply of twin no. 2 is divided because she will not have a colonic conduit.

- Of note, because twin no. 1 had more of the perineum, it was preoperatively decided to leave the rectum with twin no. 1.
- The colon is retracted laterally to allow the urology team to proceed. The balloon in each bladder is palpated to determine its location in the shared pelvis. Twin no. 2's left ureter, which connects to the contralateral twin's bladder, is ligated with 3-0 Vicryl at the ureterovesical junction.
- Dissection is performed to create definition between the bladders.
- Dissection is continued to isolate the uterus, fallopian tubes, and ovaries of each twin with their respective pedicles. This dissection further delineates the plane of cleavage for the twins.
- The previously ligated ureter of twin no. 2 is tunneled through the mesentery, spatulated, and closed to the neohiatus of the bladder. Good efflux of urine is confirmed, and the bladder is irrigated easily.
- After genitourinary reconstruction, attention is turned to the bony pelvis as it is still connected at the posterior aspect along with the extranumerary hip joint of the tripus.
- From preoperative evaluation, the iliac vessels are known to feed the conjoined connection within the single nonfunctional tripus.
- Using an abdominal retractor, the organs of each twin are retracted laterally to provide access to their medial shared hip structures and components.
- The aortas are palpated, and the iliac vessels of each child are identified and followed, which lead to either side of the hip joint. With the help of the orthopedic surgeon, osteotomies are created on either side of the hip joint, which is then excised.
- The distal portion of the femur was previously removed in a separate procedure due to concerns with pressure necrosis on adjacent tissue expanded skin. The proximal femur is then directly visualized and is grabbed with a towel clip. The proximal femur is skeletonized with electrocautery and removed in continuity.
- After the removal of the hip joint and the proximal femur, further dissection of the iliac vessels is performed as they course into the tripus internally. The dissection of the iliac vessels is performed cautiously with a handheld Doppler device until each set of iliac vessels is traced into the tripus. The tripus is then split longitudinally to create two individual musculocutaneous axial pattern flaps.
- At this point, a small soft tissue bridge only connects the twins (**TECH FIG**

1D). These soft tissues are separated, and the twins are entirely separate (**TECH FIG 1E**).

- The tripus of each twin is rotated medially and laterally and tacked down to be used for pelvic reconstruction (**TECH FIG 1F**).
- A patient bed is brought into the operating room, and twin no. 2 is transferred to the adjacent operating room where further reconstruction is completed.

Twin no. 2

- The procedure begins with the inset of the tripus, which is on the posterolateral right side of her lower body. The hemitripus is reflected as a musculocutaneous flap from lateral to medial at the inferior aspect of her ventral wound recreating her pelvic floor. The hemitripus is inset into the inferior edge of the wound initially into layers closing the deep soft tissues with 2-0 Vicryl (Ethicon, Inc., Somerville, NJ) in interrupted buried fashion followed by a single closure utilizing 3-0 Monocryl (Ethicon, Inc., Somerville, NJ) in an interrupted buried deep dermal fashion.
- The left upper leg expander, left chest wall tissue expander, and right upper chest wall tissue expander are removed to create the left leg inferiorly based advancement flap. This flap is elevated in the subfascial plane while also harvesting the capsule. The composite tissues are advanced centrally toward the ventral defect.
- On the left lower lateral abdomen, a wide-based rotation flap is created from removal of its tissue expander, which is rotated medially. Similarly, on the right upper posterior chest, the tissue expander is removed to create a wide-based rotation flap, which is based superiorly and rotated centrally.
- A large sheath of extra thick AlloDerm is used to close the fascial defect of the ventral body. The AlloDerm is inset to the surrounding fascia and body wall utilizing 2-0 PDS (Ethicon, Inc., Somerville, NJ) in a horizontal mattress fashion.
- On the inferior aspect of the ventral defect, the tripus remnant is used to recreate the pelvic floor by suturing muscular elements of the tripus to the surrounding remnants of the muscular pelvic girdle.
- The advancement flaps are closed in layers utilizing 2-0 Vicryl in an interrupted buried fashion within the deep tissues followed by skin closure utilizing 4-0 plain gut in a simple running fashion.

- The ventral defect is decreased in size using a no. 1 Maxon (Ethicon, Inc., Somerville, NJ) suture along the periphery of the closure to create a purse-string effect.
- The general surgeons re-entered the case to create a left-sided ostomy by incising the AlloDerm. The end ileostomy is brought through the left abdominal wall.
- A negative suction-assisted closure device is placed on the skin defect area directly atop the AlloDerm.
- The patient is transferred to the intensive care unit. Over the oncoming weeks, the vacuum-assisted suction device is used to promote formation of granulation tissue (**TECH FIG 2**).

Twin no. 1

- As with twin no. 2, the split tripus is used as an axial-based musculocutaneous flap for pelvic floor reconstruction. A large piece of 16 × 20-cm AlloDerm is sewn across the abdominal wall to act as a barrier and also to act as a substitute for the anterior rectus sheath.
- The four tissue expanders were removed. The expanders from the anterior chest and the lateral chest wall are used as advancement flaps.



TECH FIG 2 • Postoperative photograph of twin no. 2 showing healing of soft tissue defect.

- Back cuts are made along the lateral abdominal wall into the right axilla and also into the left axilla in the left lateral chest wall. These flaps are advanced into the middle and are sutured to each other.
- A large central defect remains that measures 10 × 15 cm where the AlloDerm is exposed. A negative suction-assisted closure device is placed atop of the exposed AlloDerm.
- The patient is transferred to the intensive care unit. Over the oncoming weeks, the vacuum-assisted suction device is used to promote formation of granulation tissue (**TECH FIG 3**).



TECH FIG 3 • Postoperative photograph of twin no. 1 showing healing of soft tissue defect.

PEARLS AND PITFALLS

Preoperative imaging

- Images obtained without anesthesia can be suboptimal. CT scans under general anesthesia allow suspension of respiration to minimize artifact.
- An additional benefit is that the anesthesia team has an opportunity to assess how each twin behaves hemodynamically while under general anesthesia.

Abdominal closure	■ Primary closure of the abdomen should be completed under no tension, as tension can lead to cardiopulmonary insufficiency and death. ■ A combination of techniques should be used to obtain tension-free closure, including tissue expanders, pneumoperitoneum, dermal replacement materials, and/or meshes (as a temporary measure).
Abdominal tissue expansion	■ Use of tissue expanders overlying the abdomen can be used to achieve skin expansion and coverage of moderately sized soft tissue defects. However, additional measures are often required such as rotational flaps and/or dermal replacement materials. ■ Tissue expanders should be placed near the pelvic ring to provide counter pressure to optimize soft tissue expansion.
Thorax tissue expanders	■ Circumferential placement of thorax expanders can lead to restrictive lung disease. This problem is especially true in younger patients with more compliant chest walls and immature respiratory muscles. ■ Restriction of respiratory mechanics is more pronounced in twins who are joined at the chest, which results in compressive forces on three of the four sides of the chest wall.
Pressure relief	■ A pressure relieving bed is critical to reduce decubitus ulcer development. ■ Pressure relief is paramount, especially with use of posterior tissue expanders, to avoid soft tissue necrosis and expander exposure.
Tripus fillet procedure	■ The third leg in ischiopagus tripus twins is deformed and nonfunctional and can even induce pressure necrosis to adjacent soft tissues undergoing expansion. ■ The filleted tripus can be separated to create musculocutaneous flaps for each twin for abdominal and/or pelvic floor reconstruction.

POSTOPERATIVE CARE

- Planning of postoperative care occurs in the preoperative period. Meticulous supportive care in the intensive care unit is mandatory. The acute physiological changes occur after separation, especially when cardiac separation is performed and/or extensive cross-circulation is present prior to separation.
 - Cardiovascular instability should be anticipated.
- In most cases, elective paralysis and mechanical ventilation is necessary for 24 to 48 hours for cardiopulmonary stabilization.
- Aside from critical care support, attention should be focused to promote wound healing.

- Nutrition must continue to be optimized postoperatively.
 - Parenteral and enteral feeding should be considered.
- Focus should be to reduce the risk of health care–associated infection with the strict use of gowns and gloves to decrease exposure to hospital pathogens.
- Pressure-relieving beds are required for wound healing and to prevent development of decubitus ulcers.
- Extremity immobilization can promote flap healing and can prevent accidental trauma induced by the moving infants.

OUTCOMES

- Patient outcomes depend on the extent and complexity of the connection of the conjoined twins.^{9,10}
- Omphalopagus twins typically have the least extensive connection and have the highest survival rates.
- Due to complex cardiac connections and abnormalities, thoracopagus twins have the lowest survival rates, with the exception of craniofacial anomalies.¹⁰

COMPLICATIONS

- Tight closure of the abdomen or thoracic cavities can lead to cardiopulmonary insufficiency, which can lead to abdominal compartment syndrome, restrictive lung disease, or a cardiac low-output state.
- Wound healing complications are common postoperatively.
 - Tissue necrosis can occur with high-tension closure, especially due to unpredictable blood supply of soft tissues.
 - With inadequate soft tissue coverage or subsequent breakdown, abdominal viscera can be exposed.

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Index

Note: Page numbers followed by the letter “*f*” refer to figures; those followed by the letter “*t*” refer to tables; and those followed by the letter “*b*” refer to boxes.

A

- Abbe flap, 2652–2653, 2652*f*–2653*f*. *See also* Estlander flaps
 - anatomy, 1063
 - complications, 1067
 - definition, 1063
 - donor-site preparation, 1064, 1064*f*
 - imaging, 1063
 - merits and demerits, 1064*b*
 - pathogenesis, 1063
 - patient history and physical findings, 1063
 - placement and closure, 1066, 1066*f*
 - raising the flap, 1065, 1065*f*
 - recipient-site preparation, 1064, 1065*f*
 - surgical management
 - approach, 1064
 - patient positioning, 1064
 - preoperative planning, 1063–1064
- Abdominal compartment syndrome, 3031
- Abdominal oblique release, external, 1574–1575
- Abdominal panniculectomy
 - anatomy, 1602

- complications, 1607
- definition, 1602
- flap advancement and skin resection, 1606, 1606*f*–1607*f*
- imaging, 1603, 1603*f*
- merits and demerits, 1607*b*
- natural history, 1602
- nonoperative management, 1603
- outcomes, 1604*f*, 1607
- pathogenesis, 1602
- patient history and physical findings, 1602, 1603*f*
- postoperative care, 1607
- in super obese
 - anatomy, 1609
 - during closure, 1611, 1611*f*
 - complications, 1611
 - definition, 1609
 - diagnostic studies, 1609
 - imaging, 1609
 - merits and demerits, 1611*b*
 - nonoperative management, 1609
 - outcomes, 1611
 - pannus preparation and transection, 1610, 1610*f*
 - patient history and physical findings, 1609
 - postoperative care, 1611
- surgical management, 1603–1604, 1603*f*
 - patient position and anesthesia, 1603–1604
 - preoperative planning, 1603
- with umbilical transposition, 1605, 1605*f*
 - dissection, 1604, 1605*f*
 - markings and incision, 1604, 1604*f*
- Abdominal wall, 1556
 - anatomy, 1563, 3030, 3031*f*
 - complications, 3036

- definition, 3030, 3030*f*
- imaging, 3032, 3032*f*
- merits and demerits, 3035*b*
- natural history, 3031–3032, 3032*f*
- outcomes, 3036
- pathogenesis, 3030–3031
- patient history and physical findings, 3032
- postoperative care, 3035–3036
- surgical management, 3032, 3033*b*
- Abdominal wall defects
 - anatomy, 1588–1589
 - complications, 1595
 - imaging, 1589
 - merits and demerits, 1595*b*
 - pathogenesis, 1589
 - patient history and physical findings, 1589
 - postoperative care, 1595
 - surgical management
 - approach, 1590, 1591*f*–1592*f*
 - patient position, 1590
 - preoperative planning, 1589–1590, 1589*f*
- Abdominal wall reconstruction, rectus femoris flap for
 - anatomy, 1580, 1581*f*
 - complications, 1586
 - definition, 1580
 - imaging, 1580
 - merits and demerits, 1586*b*
 - outcomes, 1586, 1586*f*
 - patient history and physical findings, 1580
 - postoperative care, 1586
 - surgical management, 1580–1582
 - surgical markings, 1583, 1583*f*
- Abdominal-based flaps, for breast reconstruction

- anatomy, 1438–1439, 1438*f*–1439*f*
- complications, 1445
- decision-making algorithm, 1441*f*
- definition, 1438
- differential diagnosis, 1440
- imaging, 1440
- merits and demerits, 1442*b*, 1444*b*
- natural history, 1439
- outcomes, 1445
- pathogenesis, 1439
- patient history and physical findings, 1439
- postoperative care, 1444
- SIEA flap
 - anterior dissection, pedicle, 1442–1443, 1442*f*–1443*f*
 - donor site closure, 1444
 - flap inset, 1443–1444
 - harvest completion, 1443
 - incision and exposure, 1442, 1442*f*
 - recipient vessels and microanastomosis, 1443
- surgical management
 - approach, 1441
 - patient positioning, 1441
 - preoperative planning, 1440–1441
- Abdominoplasty
 - anatomy, 1596
 - closure and exteriorization of umbilicus, 1599, 1600*f*
 - complications, 1601
 - definition, 1596
 - flap inset, 1598–1599, 1599*f*
 - imaging, 1596
 - incisions and dissection, 1598, 1598*f*
 - markings, 1597
 - merits and demerits, 1600*b*

- mons pubis, conjunction with, 1642, 1642*f*
- narrower waistline, 1600, 1600*f*
- outcomes, 1598*f*, 1600–1601
- patient history and physical findings, 1596
- postoperative care, 1600
- surgical management, 1596–1597, 1597*f*
 - approach, 1597
 - patient position, 1597, 1597*f*
 - preoperative planning, 1596–1597
- umbilical stenosis after, 3040, 3040*f*
- Abductor digiti minimi (ADM), 1986–1987, 1986*f*, 2366
 - to abductor pollicis brevis, 2015, 2015*f*
 - opponensplasty, 2231–2232, 2232*f*
- Abductor pollicis (AP) brevis
 - abductor digiti minimi, 2015, 2015*f*
 - extensor indicis proprius tendon, 2015–2016, 2016*f*
 - flexor digitorum superficialis, 2013–2015, 2014*f*
 - palmaris longus to, 2013, 2014*f*
- Abductor pollicis longus suspensionplasty, 1965, 1965*f*–1967*f*
- ABI (ankle-brachial index), 2365, 2400, 2401*f*
- Ablative fractional resurfacing, 52*f*, 54
- Ablative nonfractional resurfacing, 54
- Above-knee amputation, 2549
- Above-knee popliteal exposure, 2403, 2403*f*
- Abscesses drainage, of lower leg and foot
 - anatomy, 2335, 2335*f*
 - approach, 2336
 - complications, 2337
 - definition, 2335
 - differential diagnosis, 2336
 - imaging, 2336
 - merits and demerits, 2336*b*
 - necrotic right lateral foot wound, 2336, 2337*f*

- nonoperative management, 2336
- patient history and physical findings, 2336
- postoperative care, 2337
- preoperative planning, 2336
- supine position, 2336
- ACB. *See* Amniotic constriction band (ACB) reconstruction
- Acellular dermal allograft, 2656, 2656*f*
- Acellular dermal matrix (ADM), 1221, 2698
 - direct-to-implant breast reconstruction, 1399–1400, 1400*f*, 1401*f*
- Acetaminophen, 2414
- Acetylsalicylic acid (ASA), 421
- ACG. *See* Alar contour graft (ACG)
- Achilles tendon reconstruction
 - anatomy, 2416, 2416*f*
 - complications, 2419
 - definition, 2416
 - differential diagnosis, 2417
 - flexor hallucis longus tendon, 2419, 2419*f*
 - imaging, 2416–2417, 2417*f*
 - natural history, 2416
 - open direct (end-to-end) suture repair, 2418, 2418*f*
 - pathogenesis, 2416
 - patient history, 2416
 - percutaneous repair, 2418, 2418*f*
 - physical findings, 2416
 - postoperative care, 2419
 - reconstruction with VY advancement, 2419
 - surgical management, 2417
 - approach, 2417
 - patient positioning, 2417, 2417*f*
 - preoperative planning, 2417
- Acne scarring, 55
- Acneform eruptions, 66

- Acquired ectropion, 1103–1104
- Active Movement Scale, 2949
- Acute infection, 2506
- Acute osteomyelitis, 2352–2353
- Acute traumatic injury, repair of, 2453
- Acute venous insufficiency, 2520
- Acute wound, sharp debridement of, 2428–2429, 2429*f*
- Adductor canal, 2524, 2525*f*
- Adductor canal blocks
 - anatomy, 2310
 - complications, 2313–2314
 - definition, 2310
 - imaging, 2310
 - merits and demerits, 2313*b*
 - outcomes, 2313
 - patient history and physical findings, 2310
 - postoperative care, 2313
 - surgical management, 2310–2311
 - approach, 2311
 - patient positioning, 2311
 - preoperative planning, 2311
 - ultrasound-guided technique, 2312*f*
- Adductor pollicis, 1986–1987, 1986*f*
- Adductor pollicis (AdP) with tendon graft
 - ECRB, 2037, 2038*f*–2039*f*
- Adenoid cystic carcinoma
 - facial nerve, 1256, 1256*f*
 - FOM, 1210
- Adequate septal cartilage, 299
- Adipofascial flaps, 2123
- Adjunctive hyperbaric oxygen treatment, 2408
- ADM. *See* Abductor digiti minimi (ADM)
- Adrenaline

- furrow palatoplasty, 2664
- hard palate incisions, 2676
- Advanced Trauma Life Support guidelines, 2467
- A secondary aneurysmal bone cyst of the talar body, 2343*f*
- Aesthetic chin projection assessment
 - in woman vs. men, 758, 758*f*
- Aesthetic subunits, 1122, 1122*f*
- Aggressive wound debridement, 2408
- AIA (anterior interosseous artery), 2126, 2128, 2132
- Airway assessment, 2618
- Airway compromise, 2682
- Airway contracture, 2766, 2766*f*–2767*f*
- Airway obstruction, 698, 2674, 2690, 2694
 - palatal fistula, 2704
 - two-flap palatoplasty, 2689
 - velopharyngeal insufficiency, 2713
- Alar base, 2629, 2631
 - anatomy, 2606
 - elevation, 2610
 - on lateral lip element, 2608*f*–2609*f*, 2609
 - managing, 321–322, 321*f*
 - repositioning of, 2612, 2613*f*
 - subunits, 1146, 1147*f*
- Alar cartilage, 2617
 - malposition, 289
 - resection, ethnic rhinoplasty, 291
- Alar collapse, 377
- Alar contour graft (ACG)
 - anatomy, 377
 - complications, 379
 - definition, 377, 377*f*
 - imaging, 377
 - lateral placement—open approach, 378

- merits and demerits, 379*b*
- open, medial placement, 378, 378*f*
- outcomes, 379
- patient history and physical findings, 377
- postoperative care, 379
- surgical management, 378
 - approach, 379
 - preoperative planning, 378
- Alar rim
 - grafts, 319–321
 - reconstruction, 1182
- Alar wedge resection, ethnic rhinoplasty, 292
- Allen test, 1173, 1987
- Allergic contact dermatitis, 973
- Allergy, local anesthesia, 973
- Allograft(s), 2431, 2436, 2769
 - cancellous chips, 2358
 - dermis, 358, 358*f*
 - reconstruction and femur resection, 2503, 2504*f*
- Alloplastic chin augmentation
 - anatomy, 758, 758*f*
 - chin implant styles, 758, 759*f*
 - complications, 760–761
 - definition, 758
 - differential diagnosis, 758
 - imaging, 758
 - implant placement and fixation, 760
 - merits and demerits, 759*b*
 - natural history, 758
 - nonoperative management, 758
 - outcomes, 760
 - pathogenesis, 758
 - patient history and physical findings, 758

- postoperative care, 760
- surgical management
 - approach, 759, 759*f*–760*f*
 - patient positioning, 759
 - preoperative planning, 759
- Alloplastic implants, 392
- Alloplastic reconstruction, calvarium
 - anatomy, 519
 - complications, 522
 - definition, 519
 - imaging studies, 519–520, 520*f*
 - intraoperative technique, 520, 521*f*
 - left parietal skull defect, 519, 520*f*
 - merits and demerits, 520*b*
 - natural history, 519
 - outcomes, 522
 - pathogenesis, 519
 - patient history and physical findings, 519
 - postoperative care, 522
 - resected calvarial tumor specimen, 519, 519*f*
 - surgical management
 - patient positioning, 520
 - preoperative planning, 520
- Alopecia, 990, 2803
- Alveolar bone, 2616
- Alveolar cleft defects
 - alveolar bone grafting of
 - anatomy, 643, 643*f*
 - complications, 649
 - definition, 643
 - dissection, 645–647, 645*f*, 646*f*, 647*f*
 - iliac crest bone graft harvest, 648, 648*f*
 - imaging studies, 644

- indications, 645
- merits and demerits, 645*b*
- natural history, 644
- nonoperative management, 644
- outcomes, 649
- pathogenesis, 643–644
- patient history and physical findings, 644
- postoperative care, 649
- surgical management, 645, 645*f*
- bone morphogenetic proteins
 - anatomy, 663, 663*f*–664*f*
 - gingivoperiosteoplasty with BMP-2, 666
 - imaging studies, 664
 - merits and demerits, 666*b*
 - natural history, 664
 - outcomes, 668
 - patient history and physical findings, 664
 - postoperative care, 668
 - secondary, 666
 - surgical management, 664, 665*f*
- Ambiguous genitalia
 - anatomy, 3062
 - complications, 3073
 - definition, 3062
 - differential diagnosis, 3063–3064
 - examination, 3063
 - imaging, 3063
 - merits and demerits, 3072*b*
 - natural history, 3063
 - nonoperative management, 3064
 - outcomes, 3066*f*, 3072
 - pathogenesis, 3062–3063
 - patient history and physical findings, 3063

- postoperative care, 3072
- surgical management
 - approach, 3064–3065
 - patient position, 3064, 3065*f*
 - preoperative planning, 3064
- The American Society of Regional Anesthesia (ASRA) guidelines, 2330
- Amino esters, 1759
- Aminoglycosides, 2466, 2471
- Amniotic constriction band (ACB) reconstruction
 - adipofascial advancement technique, 2260–2261, 2262*f*, 2263*f*
 - anatomy, 2259
 - complications, 2264–2265
 - definition, 2259
 - differential diagnosis, 2259
 - fenestrated syndactyly, release of, 2263, 2263*f*
 - imaging, 2259, 2261*f*
 - merits and demerits, 2264*b*
 - natural history, 2259
 - nonoperative management, 2260
 - outcomes, 2264, 2264*f*
 - pathogenesis, 2259
 - patient history and physical findings, 2259, 2260*f*
 - postoperative care, 2264
 - surgical management, 2260–2261
 - patient positioning, 2261
 - preoperative planning, 2261
- Amputation, 2372
 - absolute indications for, 2394
 - relative indications of, 2394
 - traumatic, fingertip, 1766–1770
- Anastomosis, 2394–2396, 2394*f*
 - flap and, 2526, 2526*f*

- Anatomic closing wedge osteotomies, 1035, 1036*f*
- Anatomic (shaped) implants
 - anatomy, 1319
 - complications, 1326
 - definition, 1319
 - imaging, 1320, 1320*f*
 - merits and demerits, 1324*t*, 1324*b*
 - outcomes, 1325
 - pathogenesis, 1319
 - patient history and physical findings, 1319–1320
 - postoperative care, 1325
 - surgical management
 - approach, 1321
 - patient positioning, 1321
 - preoperative planning, 1320–1321
- Anatomic templates, 1031, 1032*f*
- Ancillary procedures, 208
- Androgenetic alopecia, 416
- Anesthesia
 - complications, 1759
 - digital nerve block
 - dorsal transmetacarpal block, 1756–1757
 - transthecal digital block, 1757, 1757*f*
 - volar subcutaneous block, 1756, 1756*f*
 - hand injection volumes, 1755, 1756*f*
 - median nerve block
 - anatomy, 1754, 1754*f*–1755*f*
 - at wrist, 1758, 1758*f*
 - merits and demerits, 1759*b*
 - outcomes, 1759
 - postoperative care, 1759
 - superficial branch of radial nerve
 - anatomy, 1754

- at wrist, 1758
- surgical management, 1755
 - approach, 1755, 1756*f*
 - patient positioning, 1755
 - preoperative planning, 1755
- ulnar nerve block
 - neurovascular bundle anatomy, 1754
 - at wrist, 1758, 1758*f*
- wide-awake local anesthesia no tourniquet, 1754
 - definition, 1754
 - trigger finger release, 1758
- Aneurysmal bone cyst, 2423
- Angiography
 - peroneal nerve injury, 2411
 - posterior interosseous artery flap, 2127
 - ulnar artery perforator flap, 2121
- Angiosarcoma, 2421
- Angle fractures, open treatment of, 911–912, 911*f*–912*f*
- Angle occlusal classification, 697–698
- Angle's classification, 592, 592*f*–593*f*
- Animation deformity, 373
- Ankle
 - bone tumors of
 - anatomy, 2342
 - benign bone tumor of the talus, 2343, 2343*f*
 - complications, 2348
 - definition, 2342
 - differential diagnosis, 2342
 - imaging, 2342
 - malignant bone tumors, 2343–2347, 2344*f*, 2346*f*, 2347*f*
 - merits and demerits, 2343*b*
 - nonoperative management, 2342
 - outcomes, 2348

- patient history, 2342
- physical findings, 2342
- postoperative care, 2347–2348
- primary, 2342
- surgery, 2342
- surgical management, 2342
- soft tissue infections, debridement of, 2351, 2351*f*
 - anatomy, 2349–2350, 2349*f*
 - complications, 2351
 - definition, 2349
 - differential diagnosis, 2350
 - imaging, 2350
 - merits and demerits, 2351
 - nonoperative management, 2350
 - pathogenesis, 2350
 - patient history and physical findings, 2350
 - postoperative care, 2351
 - supine position, 2350
 - surgical management, 2350
- Ankle amputation, 2546
- Ankle block
 - anatomy, 2322
 - complications, 2325
 - deep peroneal nerve, 2323, 2323*f*
 - definition, 2322
 - general considerations, 2322
 - materials, 2322
 - patient positioning and preparation, 2322, 2322*f*
 - saphenous nerve, 2324, 2324*f*
 - superficial peroneal nerve, 2323, 2324*f*
 - sural nerve, 2324, 2324*f*
 - tibial nerve, 2323, 2323*f*
- Ankle hematoma, 2325

- Ankle reconstruction with free flap
 - anatomy, 2392, 2393*f*
 - anterolateral thigh, 2396
 - complications, 2398
 - definition, 2392
 - gracilis, 2397
 - imaging, 2392
 - latissimus dorsi, 2397–2398
 - merits and demerits, 2398*b*
 - non operative management, 2392
 - outcomes, 2398, 2398*f*
 - pathogenesis, 2392, 2393*f*
 - patient history, 2392
 - physical findings, 2392
 - postoperative care, 2398
 - rectus abdominis, 2397
 - surgical management, 2392–2395
 - approach, 2395
 - patient positioning, 2395
 - preoperative planning, 2394–2395, 2394*f*
 - vastus lateralis, 2392–2395, 2396*f*
- Ankle swelling, 2411
- Ankle-brachial index (ABI), 2365
- Ankle-foot orthotic (AFO), 1028
- Ankyloglossia, 2691
- Anophthalmia
 - anatomy, 555, 556*f*
 - complications, 560
 - definition, 555
 - differential diagnosis, 557
 - expander inflation and closure, 559
 - exposure and orbitotomy, 558, 559*f*
 - imaging studies, 556–557, 557*f*

- merits and demerits, 558*b*
- natural history, 555
- nonoperative management, 557
- orbital tissue expander and microport placement, 559, 559*f*
- outcomes, 560
- pathogenesis, 555
- patient history and physical findings, 556, 557*f*
- postoperative care, 560
- surgical management
 - approach, 558–560
 - patient positioning, 558
 - preoperative planning, 558, 558*f*
- Anophthalmic orbit. *See* Microphthalmia
- Anophthalmos, 2877
- ANS (anterior nasal spine), 328
- Antegrade masseter-to-facial nerve transfer, with distal, selective, facial nerve branch transection, 2928–2929, 2929*f*
- Antegrade posterior interosseous artery flap, 2132
- Anterior bullectomy, 805*f*
- Anterior cruciate ligament (ACL), 2465
- Anterior ethmoidectomy, 804, 805*f*
- Anterior hairline approach, 84–85, 84*f*, 85*f*
- Anterior hairline brow lift, 74
- Anterior interosseous nerve (AIN), ulnar nerve palsy
 - anatomy, 2043, 2043*f*–2044*f*
 - complications, 2047
 - definition, 2043
 - differential diagnosis, 2044
 - imaging, 2044
 - internal topography, 2043, 2043*f*–2044*f*
 - merits and demerits, 2047
 - outcomes, 2047
 - patient history and physical findings, 2044

- postoperative care, 2047
- proximal exposure, 2045, 2045*f*
- surgical management
 - approach, 2045, 2045*f*
 - patient positioning, 2045
 - preoperative planning, 2045
- Anterior knee, 2486
- Anterior lamella of skin, 1089
- Anterior limb, of medial canthal tendon, 831
- Anterior maxillary osteotomy, 574, 576*f*
- Anterior nasal spine (ANS), 328
- Anterior platysmaplasty and myotomy, 248, 248*f*–249*f*
- Anterior sagittal transrectal approach (ASTRA), 3069–3070
- Anterior superior iliac spine (ASIS), 1574, 1619, 1621
- Anterior tibial artery, 2338, 2395, 2400, 2420, 2423
- Anterior tibial artery exposure, 2404
- Anterior tibial-dorsalis pedis artery, 2378–2379, 2378*f*–2382*f*
- Anterior vault reconstruction, 550, 550*f*
- Anterolateral thigh (ALT) flap, 1116, 2383, 2396, 2440, 2487–2488, 2518
 - anatomy, 2144, 2144*f*
 - complication, 989, 2146
 - definition, 2144
 - design and identification of perforator, 2145, 2145*f*
 - donor-site closure, 2146
 - fasciocutaneous flap, 1221, 1225–1226, 1225*f*–1226*f*
 - flap harvest, 1204, 1204*f*
 - FOM
 - disadvantages, 1211
 - history, 1211
 - graft sources, 986*b*
 - harvest, 2145, 2145*f*
 - lateral femoral cutaneous nerve, 1204, 1204*f*

- lateral mandible defect, 1048
- merits and demerits, 2146*b*
- myocutaneous flap, 2488
- outcomes, 2146
- patient history and physical findings, 2144
- perforator flap, 1215
- pharyngeal reconstruction, 1230
- pharyngoesophageal reconstruction
 - anatomy, 1236
 - complications, 1241
 - definition, 1236
 - donor-site closure, 1240
 - flap harvest, 1237–1240, 1238*f*
 - imaging studies, 1237
 - merits and demerits, 1237*b*
 - neck skin reconstruction, 1239–1240
 - outcomes, 1241
 - partial vs. circumferential defects, 1239, 1239*f*
 - patient history and physical findings, 1236–1237
 - postoperative care, 1241
 - surgical management, 1237
- postoperative care, 2146
- with radial forearm free flap, 1074
- specific donor-site dissections, 986
- surgical management
 - approach, 2144
 - patient positioning, 2144
 - preoperative planning, 2144
- thinning, 2146
- Antia-Buch chondrocutaneous advancement techniques, 1133
- Antia-Buch flaps
 - anatomy, 1129
 - “classic” helix-only defect, 1130, 1130*f*

- complications, 1132
- definition, 1129
- helical-scapal defect, 1131, 1131*f*
- helical-scapal-antihelix defect, 1131, 1131*f*
- imaging, 1129
- merits and demerits, 1130*b*
- modifications, 1130
- nonoperative management, 1129
- outcomes, 1132
- patient history and physical exam, 1129
- postoperative care, 1132
- superior and inferior incisions, 1130
- surgical management, 1129
 - approach, 1129
 - patient positioning, 1129
 - preoperative planning, 1129
- V-Y advancement flap, 1130, 1130*f*, 1131*f*
- Antibiotic therapy, 2336, 2471
 - bone tumors of knee, 2464
 - femoral bone debridement, 2509
 - knee, bony and soft tissue debridement, 2466
 - osteomyelitis, 2353
- Anticoagulation, 988
- Antoni type B schwannoma, 2299
- AP brevis. *See* Abductor pollicis (AP) brevis
- APB tendon transfer, 2033*f*, 2036–2037
- Apert syndrome, 445, 465*f*
- Apgar score
- Apnea hypopnea index (AHI), 636
- Aponeurotic ptosis, 2850
- Aquaphor, 209
- Aquaplast splint, 863, 863*f*
- ARCA (anterior radial collateral arteries), 2134–2135, 2134*f*

- Arcade of Struthers, 1992, 1992*f*
- Arch bar, 959, 960*f*
 - maxillomandibular fixation, of mandible fractures, 904, 904*f*
- Arcus marginalis, 144, 152, 163, 1084, 1085*f*
 - fat grafting for periorbital rejuvenation, 166, 167*f*
- Argon beam coagulation, 2343
- Army-Navy retractor, 1449
- *Arnica montana*, 203
- Arterial blood supply
 - craniopagus twins, 523, 523*f*
 - of ear, 1129
 - laterally or medially based cervicofacial flap, 1103, 1103*f*–1104*f*
 - of nose, 1146
 - SCAIF flap, 1249
 - skin grafts, 1122, 1122*f*
- Arteriography, vascular reconstruction of lower extremity, foot, and ankle, 2400
- Arteriovenous malformations (AVM), 2275
- Artery repair, 2152, 2152*f*
- Arthritis
 - distal radioulnar joint, Darrach procedure for, 1969, 1970*f*
 - scaphoid nonunion advanced collapse, 1957
 - scapholunate advanced collapse, 1957
 - scaphotrapeziotrapezoid joint, 1957
 - thumb carpometacarpal joint, 1956
 - thumb trapeziometacarpal joint (*see* Trapeziometacarpal (TMC) joint, thumb)
- Arthrodesis
 - distal interphalangeal joints of fingers, 1959, 1959*f*
 - thumb carpometacarpal joint, 1958, 1967, 1968*f*–1969*f*
- ASA (acetylsalicylic acid), 421
- Asian blepharoplasty
 - anatomy, 127, 127*f*–128*f*

- complications, 131
- definition, 127
- exposure of fusion, 129, 129*f*
- merits and demerits, 130*b*
- outcomes, 130
- patient history and physical findings, 127–128
- postoperative care, 130
- skin-aponeurosis fixation technique, 129, 129*f*
- skin-tarsus fixation technique, 130, 130*f*
- surgical management, 128–129
 - anesthesia, 129
 - approach, 129
 - positioning, 129
 - preoperative planning, 128–129, 129*f*
- ASIS (anterior superior iliac spine), 2137, 2140, 2355, 2358, 2518
- Aspiration, 2895
- Aspirin, 140–141, 2444
- Asymmetric transverse distraction osteogenesis, 486–487, 487*f*
- Atherosclerosis, 2523
- Atrophic nonunion, 2506, 2509
- Atrophic surgical scarring, 55
- Atrophic/edentulous mandible fractures, 913
- Aural atresia, 2816*f*
- Auricular cartilage, 316–317, 316*f*
- Auricular prosthesis implants, 3087, 3088*f*
- Auriculotemporal nerve
 - anatomy, 966, 966*f*
 - scalp reconstruction with rotation flaps, 980
- Autogenous bone grafts, 510
- Autogenous rib graft
 - allograft materials, 510
 - alloplastic materials, 509
 - autogenous bone grafts, 510

- bone substitutes, 510
- bony defect, 511
- complications, 514
- cranial defect exposure, 511
- cranioplasty technique, 513
- definition, 509
- endochondral and intramembranous ossification, 509, 509*f*–510*f*
- floating ribs, 509
- imaging, 510
- merits and demerits, 511*b*
- nonoperative management, 510
- outcomes, 514
- pathogenesis, 509
- patient history and physical findings, 510
- postoperative care, 514
- rib harvest, 512, 512*f*
- scalp closure, 513
- split rib technique, 513, 513*f*
- surgical management
 - approach, 511
 - patient positioning, 511, 511*f*
 - preoperative planning, 510–511
- Autograft bone, 2355
- Autograft cancellous bone graft
- Autologous fat, 165
- Autologous gluteal augmentation flap, 1615–1617, 1616*f*–1617*f*
- Autospreader flaps, narrow midvault, 302, 302*f*
- Avulsed flaps with impaired venous outflow, 2429
- Axilla, keystone flap reconstruction, 2541, 2542*f*
- Axillary hyperhidrosis
 - anatomy, 1749, 1749*f*
 - complications, 1752
 - definition, 1749

- differential diagnosis, 1750
- imaging/diagnosis, 1750, 1750*f*
- natural history, 1749
- nonoperative management, 1750
- outcomes, 1752
- pathogenesis, 1749
- patient history and physical findings, 1749–1750
- postoperative care, 1752
- surgical management
 - positioning, 1750, 1751*f*
 - preoperative planning, 1750, 1750*f*
- Axonotmesis, 2410, 2451

B

- Babysitter nerves
 - complications, 1285
 - cross face nerve graft, 1282–1283, 1283*f*–1284*f*
 - definition, 1277
 - exposure, 1280–1281, 1280*f*–1281*f*
 - flowchart, 1279, 1279*f*
 - mandibular branch, 1277*f*, 1278
 - merits and demerits, 1280*b*
 - motor nerve to masseter, 1281–1282, 1282*f*
 - outcomes, 1285
 - pathogenesis, 1278
 - patient history and physical findings, 1278
 - postoperative care, 1284–1285
 - superficial muscle fibers, 1277–1278, 1277*f*
 - surgical management
 - approach, 1280
 - patient positioning, 1279–1280, 1279*f*
 - preoperative planning, 1279

- temporal branch, 1277*f*, 1278
- zygomatic division, 1277*f*, 1278
- Bacitracin ointment, 3072
- Back reconstruction, keystone flaps for, 1746, 1746*f*
- Bacterial osteomyelitis, 2509
- Bactroban, 203
- BALs (basal aesthetic lines), 334, 373
- Banner flaps
 - aesthetic subunits, 1146, 1147*f*
 - complications, 1153
 - definition, 1146
 - merits and demerits, 1148*b*
 - outcomes, 1152–1153
 - patient history and physical findings, 1146–1147
 - postoperative care, 1152
 - surgical management
 - approach, 1147
 - patient positioning, 1147
 - preoperative planning, 1147
 - technique, 1148, 1148*f*
- Barrel-stave technique, 456
- Basal aesthetic lines (BALs), 334, 373
- Basal cell carcinoma (BCC)
 - anatomy, 2303
 - complications, 2308
 - defect after Mohs resection, 1055, 1056*f*
 - definition, 2303
 - differential diagnosis, 2304
 - direct closure and lateral cantholysis, 1078
 - imaging, 2304
 - lower eyelid defects, 1085, 1085*f*, 1086*f*
 - merits and demerits, 2307*b*
 - nasolabial flap, 1070

- natural history, 2303
- nonoperative management, 2304–2305
- nostril sill and upper lip defect after excision, 1189*f*–1190*f*
- outcomes, 2308
- pathogenesis, 2303
- patient history and physical findings, 1084, 2303, 2304*f*
- postoperative care, 2308
- surgical management, 2305
- Basilic vein, 2123
- BCC. *See* Basal cell carcinoma (BCC)
- Beare-Stevenson syndrome, 616
- Bell phenomenon, 1094–1095
- Belotero Balance, 27
- Below-knee amputation, 2549
- Below-knee popliteal exposure, 2403, 2404*f*
- Belt lipectomy. *See* Lower body lift
- Benign bone tumors, 2342
- Benign tumors, 2421
- Bennett fracture
 - anatomy, 1810
 - closed reduction and pinning, 1812
 - complications, 1815
 - definition, 1810
 - Gedda classification for, 1810
 - imaging, 1811
 - merits and demerits, 1814*b*
 - natural history, 1810
 - open reduction and internal fixation, 1813
 - outcomes, 1815
 - pathogenesis, 1810
 - patient history and physical findings, 1810–1811
 - plain radiographs, 1810*f*
 - postoperative care, 1814–1815

- surgical management, 1811
 - patient positioning, 1811
 - preoperative planning in, 1811
- Wagner approach, 1811
- Bennett or Hohmann retractors, 2461
- Bergland Scale Score, 649
- Beta-blocker, 2406
- Beta-blockers, 2276
- Betadine, 861
- Bicarbonate, 3077
- Biceps and brachialis lengthening, 2193–2194, 2193*f*–2194*f*
- Biceps femoris tendon, 2413
- Biceps to triceps transfer, 2191–2192, 2192*f*
- Bicompartamental knee arthroplasty, 2470*f*
- Bicoronal synostosis
 - craniosynostosis, 531
 - natural history, 445
- Bier block anesthesia, 1979, 1979*f*
- Bilateral advancement flap, 1519, 1519*f*–1520*f*
- Bilateral cleft lip adhesion, 2633–2634
- Bilateral cleft lip and palate (BLCP), 567, 567*f*
- Bilateral cleft lip, nasal deformity, 2715*t*
- Bilateral cleft lip repair
 - anatomy, 2637
 - definition, 2637
 - diagnosis, 2638
 - imaging, 2638
 - incisions, 2640, 2640*f*–2641*f*
 - lip fusion, 2637
 - markings, 2639, 2639*f*
 - merits and demerits, 2642*b*
 - nonoperative management, 2638, 2638*f*
 - outcomes, 2642–2643

- pathogenesis, 2637
- patient history and physical findings, 2637, 2637*f*
- postoperative care, 2642
- reconstruction, 2640–2641
- surgical management, 2638
 - patient position, 2638, 2639*f*
 - variations in technique, 2641, 2642*f*
- Bilateral complete cleft palate, two-flap palatoplasty, 2688, 2688*f*
- Bilateral coronal synostosis
 - anatomy, 434
 - definition, 434
 - patient history and physical findings, 435
 - techniques, 442
- Bilateral maxillomandibular fixation screws, 585–586, 586*f*
- Bilateral nasal bone deviation, 326–327, 327*f*
- Bilateral sagittal split osteotomy (BSSO), for mandibular deficiency
 - anatomy, 697–698
 - angle occlusal classification, 697–698
 - completion process, 704
 - complications, 705
 - Dal Pont modification, 697
 - definition, 697
 - differential diagnosis, 698
 - exposure, 700, 700*f*–701*f*
 - Hunsuck modification, 697
 - imaging studies, 698
 - medial ramus, 701, 701*f*–702*f*
 - merits and demerits, 700*b*
 - nonoperative management, 699
 - occlusal correction and maxillomandibular fixation, 702, 702*f*–703*f*
 - outcomes, 705
 - pathogenesis, 698

- patient history and physical findings, 698
- postoperative care, 705
- rigid fixation, 703
- surgical management, 699–705
- Bilateral temporalis muscles, 461
- Bilateral transverse L-shaped maxillary osteotomy, 564, 565*f*
- Bilateral V-Y gluteal myocutaneous flaps, 2788, 2788*f*
- Bilobed flap(s), 2827, 2827*f*–2828*f*
 - aesthetic subunits, 1146, 1147*f*
 - complications, 1153
 - definition, 1146
 - merits and demerits, 1148*b*
 - outcomes, 1152–1153
 - patient history and physical findings, 1146–1147
 - postoperative care, 1152
 - surgical management
 - approach, 1147
 - patient positioning, 1147
 - preoperative planning, 1147
 - technique, 1148–1149, 1149*f*
- Bioabsorbable composites, 2469
- Biobrane double-layer dressing, 2769
- Bipolar diathermy, 2679
- Blast injuries, 2412
- Bleeding, 2674, 2689
 - NLDO, 2875
 - palatal fistula, 2704
 - velopharyngeal insufficiency, 2713
- Blepharochalasis, 138
- Blepharoplasty
 - Asian
 - anatomy, 127, 127*f*–128*f*
 - complications, 131

- definition, 127
- exposure of fusion, 129, 129*f*
- merits and demerits, 130*b*
- outcomes, 130
- patient history and physical findings, 127–128
- postoperative care, 130
- skin-aponeurosis fixation technique, 129, 129*f*
- skin-tarsus fixation technique, 130, 130*f*
- surgical management, 128–129
- lower (*see* Lower blepharoplasty)
- upper (*see* Upper blepharoplasty)
- Blepharoptosis, 114, 2849
- Blindness, 837
- Blood supply, lip, 1068, 1069*f*
- Blunt and penetrating traumas, 780
- Blunt cannula injection, 34
- Blunt dissection
 - condyle fractures, 919
 - orbital floor blow-out fractures, 812, 812*f*
- Blunt subgaleal dissection, medial orbit wall fractures, 835
- Blunt trauma, pediatric midface fractures, 950
- BMAC (bone marrow aspirate concentration), 2357, 2360–2361
- BMP-2, 2474
- Body fractures, open treatment of, 911
- BO-Fort procedure, 490
- Boies elevator, 860, 860*f*
- Bolster sutures
 - constricted ear, 2830, 2830*f*
 - cryptotia, 2834
 - prominent ears, 2839, 2839*f*
 - Stahl ear, 2824, 2824*f*
- Bone, 1710–1711, 1710*f*
- Bone canthopexy

- anatomy, 185, 185*f*–186*f*
- closure, 189
- complications, 189
- definition, 185
- drill holes and positioning of, 187–189
- figure-of-8 suture fixation of, 187, 187*f*
- imaging, 186
- operative approach, 186, 187*f*
- outcomes, 189
- pathogenesis, 186
- patient history and physical findings, 186
- postoperative care, 189
- preoperative preparation, 186
- surgical management, 186
- Bone fixation, 2151, 2151*f*
- Bone flap creation approach, 1811-1885
 - 4 + 5 extensor compartmental artery vascularized bone flap, 1881–1882, 1882*f*
 - 1,2-intercompartmental supraretinacular artery vascularized bone flap, 1882–1883, 1883*f*
 - medial femoral condyle microvascular flap, 1883–1885, 1884*f*
 - superficial palmar branch of radial artery vascularized bone flap, 1883, 1883*f*
- Bone grafting, for foot and ankle
 - anatomy, 2355
 - bone marrow aspirate concentrate, 2360–2361, 2361*f*
 - calcaneal autograft harvest, 2360, 2360*f*
 - complications, 2362
 - concentrated synthetic growth factors, 2361
 - definition, 2355
 - differential diagnosis, 2356
 - iliac crest autograft harvest, 2358, 2358*f*–2359*f*
 - iliac crest autograft harvest (cancellous), 2359, 2359*f*

- imaging, 2356
- indications, 2355
- merits and demerits, 2361*b*
- natural history, 2356
- nonoperative management, 2356
- outcomes, 2362
- pathogenesis, 2356
- patient history and physical findings, 2356
- postoperative care, 2362
- proximal tibia autograft harvest, 2359, 2360*f*
- surgical management, 2357–2358
 - approach, 2357–2358
 - patient positioning, 2357, 2358*f*
 - preoperative planning, 2357
- Bone harvest, 1041–1043, 1042*f*–1043*f*
- Bone marrow aspiration
 - cement spacer placement and internal fixation, 2475–2476, 2475*f*
 - completion of reaming, 2478
 - graft placement, 2478, 2479*f*
 - guidewire insertion, 2476–2477, 2477*f*
 - harvesting bone marrow, 2478, 2479*f*
 - reaming graft material, 2477–2478, 2478*f*
 - RIA preparation, 2477, 2477*f*
 - soft tissue coverage and monitoring, 2476, 2476*f*
 - spacer removal and bone preparation, 2476, 2476*f*
- Bone morphogenetic protein (BMP-2), 2361
- Bone morphogenetic proteins (BMPs), 2357
 - alveolar cleft defects
 - anatomy, 663, 663*f*–664*f*
 - gingivoperiosteoplasty with BMP-2, 666
 - imaging studies, 664
 - merits and demerits, 666*b*
 - natural history, 664

- outcomes, 668
- patient history and physical findings, 664
- postoperative care, 668
- secondary, 666
- surgical management, 664, 665*f*
- complications, 668–670
- cranial vault defects
 - anatomy, 663
 - imaging studies, 664
 - merits and demerits, 666*b*
 - natural history, 664
 - outcomes, 668
 - patient history and physical findings, 664
 - postoperative care, 668
 - surgical management, 665, 665*f*
 - surgical technique, 667
- mandibular defects
 - anatomy, 663
 - imaging studies, 664
 - merits and demerits, 666*b*
 - natural history, 664
 - outcomes, 668
 - patient history and physical findings, 664
 - postoperative care, 668
 - surgical management, 665, 665*f*
 - surgical technique, 667
- rare tessier clefts
 - anatomy, 663
 - imaging studies, 664
 - natural history, 664
 - outcomes, 668
 - patient history and physical findings, 664
 - surgical management, 665

- surgical technique, 667, 669*f*
- Bone reconstruction, of knee
 - anatomy, 2473
 - complication, 2481
 - definition, 2473
 - imaging, 2473–2474, 2474*f*
 - induced membrane with intramedullary autogenous bone grafting
 - cement spacer placement and internal fixation, 2475–2476, 2475*f*
 - completion of reaming, 2478
 - graft placement, 2478, 2479*f*
 - harvesting bone marrow, 2478, 2479*f*
 - inserting guidewire, 2476–2477, 2477*f*
 - reaming graft material, 2477–2478, 2478*f*
 - RIA preparation, 2477, 2477*f*
 - soft tissue coverage and monitoring, 2476, 2476*f*
 - spacer removal and bone preparation, 2476, 2476*f*
 - merits and demerits, 2480*b*, 2480*f*
 - natural history, 2473
 - outcomes, 2480–2481
 - pathogenesis, 2473
 - patient history and physical findings, 2473
 - postoperative care, 2480, 2480*f*
 - surgical management, 2474*f*
 - approach, 2475
 - patient positioning, 2475
 - preoperative planning, 2474–2475, 2475*f*
- Bone resorption, 391
- Bone transposition
 - anteroposterior transpositions, 458, 458*f*
 - inverse transpositions, 457, 457*f*
- Bone tumors
 - ankle and foot of

- anatomy, 2342
- benign bone tumor of the talus, 2343, 2343*f*
- complications, 2348
- differential diagnosis, 2342
- imaging, 2342
- malignant bone tumors, 2343–2347, 2344*f*, 2346*f*, 2347*f*
- merits and demerits, 2343*b*
- nonoperative management, 2342
- outcomes, 2348
- patient history, 2342
- physical findings, 2342
- postoperative care, 2347–2348
- surgical management, 2342
- definition, 2342
- of femur
 - anatomy, 2502
 - complications, 2505
 - definition, 2502
 - differential diagnosis for, 2502
 - femur resection and allograft reconstruction, 2503, 2504*f*
 - functional outcomes, 2505
 - imaging, 2502, 2503*f*
 - merits and demerits, 2504*b*
 - natural history, 2502
 - oncological outcomes, 2505
 - pathogenesis, 2502
 - patient history and physical findings, 2502
 - postoperative care, 2505
 - surgical management, 2502–2503
- of knee
 - anatomy, 2460
 - complications, 2464
 - definition, 2460

- differential diagnosis for, 2460
- distal femur resection, 2461, 2461*f*
- endoprosthetic reconstruction, 2461, 2461*f*
- endoprosthetic reconstruction of proximal tibia, 2463, 2463*f*
- estimated incidence of 3260, 2460
- imaging, 2460
- merits and demerits, 2464*b*
- natural history, 2460
- outcomes, 2464
- pathogenesis, 2460
- patient history and physical findings, 2460
- postoperative care, 2464
- reconstruction, 2462, 2462*f*
- surgical management, 2460–2461
- of lower leg
 - anatomy, 2423, 2423*f*
 - complications, 2426
 - definition, 2423
 - diaphyseal tibia tumor resection and reconstruction, 2424
 - differential diagnosis for, 2423
 - functional outcomes, 2426
 - imaging, 2423
 - merits and demerits, 2425*b*
 - natural history, 2423
 - oncological outcomes, 2426
 - pathogenesis, 2423
 - patient history, 2423
 - physical findings, 2423
 - postoperative care, 2426
 - surgical management, 2423–2424, 2424*f*
- primary, 2342
- Bone tunnels creation, 2495, 2495*f*
- Bone-anchored hearing aid (BAHA), 2816

- Bony abscess, 2466
- Bony damage, 2468
- Bony nasal pyramid and septum, reduction, 855, 855*f*
- Bony reconstruction of foot and ankle. *See* Bone grafting, for foot and ankle
- Botox, 3, 238
- Bottom-to-top approach, 938–939, 938*f*
- Bottom-to-top-to-middle approach, 940
- Botulinum toxin injection
 - depressor anguli oris, 15
 - anatomy, 14
 - approach, 15
 - complications, 16
 - definition, 14
 - imaging, 15
 - merits and demerits, 15*b*
 - outcomes, 15–16
 - patient history and physical findings, 14–15
 - positioning, 15
 - postoperative care, 15
 - preoperative planning, 15
 - surgical management, 15
 - to forehead
 - anatomy, 5, 5*f*
 - complications, 6
 - definition, 5
 - merits and demerits, 6*b*
 - nonoperative management, 5
 - outcome, 6, 6*f*
 - patient history and physical findings, 5
 - postoperative care, 6
 - to glabellar region
 - anatomy, 2

- complications, 4
- definition, 2
- merits and demerits, 4*b*
- outcomes, 4
- patient history and physical findings, 3
- postoperative care, 4
- surgical management, 3, 4*b*
- gummy smile, 10
 - anatomy, 9, 9*f*
 - approach, 9
 - complications, 10
 - definition, 9
 - merits and demerits, 10*b*
 - nonoperative management, 9
 - outcome, 10, 10*f*
 - patient history and physical findings, 9
 - positioning, 9
 - postoperative care, 10
- perioral rhytids
 - anatomy, 11, 11*f*
 - complications, 13
 - definition, 11
 - marionette lines, 12
 - merits and demerits, 13*b*
 - outcomes, 13, 13*f*
 - pathogenesis, 11
 - patient history and physical findings, 11
 - postprocedural care, 13
 - vertical rhytids, 12
- to platysma bands, 18, 18*f*
 - anatomy, 17, 17*f*
 - complications, 19
 - definition, 17

- merits and demerits, 18*b*
- outcomes, 19, 19*f*
- pathogenesis, 17
- patient history and physical findings, 17
- postprocedural care, 19
- preparation, 17
- to soften crow's feet
 - anatomy, 7
 - complications, 8
 - definition, 7, 7*f*
 - imaging, 7
 - merits and demerits, 8*b*
 - outcomes, 8
 - patient history and physical findings, 7
 - positioning, 7
 - postoperative care, 8
 - preoperative planning, 7
- Bouchard nodes, on PIPJs, 1956, 1957*f*
- Boutonniere deformities
 - finger, 1938, 1938*f*
 - ligament reconstruction to correct, 1948
 - Nalebuff classification of, 1940, 1941*t*
 - reconstructive surgery for, 1940
 - thumb, 1938
- Bouvier test, median and ulnar nerve injuries, 2034
- Box and U-shaped osteotomies
 - anatomy, 536, 536*f*
 - canthal and nasal reconstruction, 540
 - closure, 540
 - complications, 541
 - cranial, 538, 539*f*
 - definition, 536
 - facial, 538, 539*f*

- fixation, 540, 540*f*
- imaging studies, 536
- incision and exposure, 538, 538*f*
- merits and demerits, 538*b*
- orbital, 538, 539*f*
- outcomes, 541, 541*f*
- pathogenesis, 536
- patient history and physical findings, 536
- postoperative care, 541
- surgical management
 - patient positioning, 537
 - preoperative planning, 537, 537*f*
- translocation, 539
- Brachioradialis (BR), 2001*b*, 2001*f*, 2002*f*, 2114
 - to extensor carpi radialis brevis tendon transfer, 2198, 2198*f*–2199*f*
 - to flexor pollicis longus transfer, 2016, 2017*f*, 2207–2208, 2208*f*
- Bradycardia, 957
- Branchial cleft sinuses and cysts
 - anatomy, 2898, 2898*f*, 2900*b*
 - complications, 2904
 - definition, 2898
 - differential diagnosis, 2900
 - endoscopic management, 2902, 2903*f*
 - excision, 2903
 - imaging, 2899, 2900*f*
 - merits and demerits, 2904*b*
 - nonoperative management, 2900
 - outcomes, 2904
 - pathogenesis, 2898
 - patient history and physical findings, 2898–2899
 - postoperative care, 2904
 - surgical management

- approach, 2900
- patient position, 2900
- preoperative planning, 2900
- Branchio-oto-renal syndrome, 2899
- Breast amputation, with free nipple grafting
 - markings, 1358, 1358*f*
 - nipple grafting, 1359, 1359*f*
 - tissue excision, 1358–1359, 1359*f*
- Breast augmentation
 - anatomy, 1298–1300
 - chest wall prominence, 1302
 - complications, 1312–1313
 - deep pectoralis fascia, 1300
 - definition, 1297–1298
 - dual plane (*see* Dual plane augmentation)
 - female to male transition (*see* Transgender breast surgery)
 - with free nipple grafts, 1328
 - imaging, 1302
 - merits and demerits, 1312*b*
 - outcomes, 1312
 - patient history and physical findings, 1300–1302, 1301*f*
 - physical assessment, 1301–1302
 - Pinch test, 1301, 1301*f*
 - postoperative care, 1312
 - round (*see* Round implants)
 - subfascial implant (*see* Subfascial implant)
 - subglandular implant (*see* Subglandular implant)
 - submuscular implant (*see* Submuscular implant)
 - surgical management
 - approach, 1304, 1305*f*
 - incision placement, 1302–1303, 1304*f*
 - patient positioning, 1304, 1304*f*
 - pocket control, 1304

- preoperative planning, 1302–1304
- transaxillary (*see* Transaxillary breast augmentation)
- Breast cancer related upper limb lymphedema. *See* Lymphedema microsurgery
- Breast conservation therapy (BCT), 1367
- Breast contractures
 - definition, 2783
 - merits and demerits, 2784*b*
 - natural history, 2783
 - pathogenesis, 2783
 - patient history and physical findings, 2783
 - postoperative care, 2784
 - surgical management, 2783
 - approach, 2783, 2783*f*, 2784*f*
 - patient position, 2783
 - preoperative planning, 2783
- Breast reconstruction
 - abdominal-based flaps (*see* Abdominal-based flaps, for breast reconstruction)
 - with local tissue rearrangement (*see* Partial mastectomy, local tissue rearrangement)
 - superior gluteal artery perforator flap (*see* Superior gluteal artery perforator (SGAP) flap)
 - transverse upper gracilis flap (*see* Transverse upper gracilis (TUG) flap)
- Breast reduction with free nipple graft
 - anatomy, 1350
 - complications, 1353, 1354*f*
 - definition, 1350
 - imaging, 1350
 - merits and demerits, 1351*b*, 1352*b*
 - outcomes, 1353
 - patient history and physical findings, 1350

- postoperative care, 1353
- surgical management
 - approach, 1351
 - patient positioning, 1350
 - preoperative planning, 1350
- wise pattern skin excision markings, 1351, 1351*f*
- Brow, injectable fillers in, 20–22
- Brow lifting
 - anatomy, 69–70, 69*f*
 - motor nerves, 70
 - sensory nerves, 70
 - anterior hairline brow lift, 74
 - approach, 72
 - brow lowering procedure, 75, 75*f*
 - coronal brow lift, 72–74, 73*f*
 - definition, 69
 - merits and demerits, 76*b*
 - nonoperative management, 71
 - outcomes, 76
 - pathogenesis, 70–71, 71*f*
 - patient history and physical findings, 71
 - positioning, 72
 - postoperative care, 76
 - surgical management, 71–72, 71*f*
- Brow lowering procedure, 75, 75*f*
- Buccal branches, skin-only face and neck lifting, 196
- Buccal fat pad
 - anatomy, 254, 254*f*
 - complications, 256
 - definition, 254
 - excision techniques, 255*b*, 255*f*
 - imaging, 254
 - merits and demerits, 256*b*

- outcomes, 256, 256*f*
- patient history and physical findings, 254
- postoperative care, 256
- surgical management, 254
- Buccal fat pad flap, 1221
- Buccal fat pad pseudoherniation, 254
- Buccal fat transposition flap, 1220
- Buccal mucosa graft, for redo hypospadias repair, 3048–3049
- Buccal mucosal defects
 - acellular dermal matrix, 1221
 - anatomic borders, 1219, 1219*f*
 - anterolateral thigh fasciocutaneous flap, 1225–1226, 1225*f*–1226*f*
 - autogenous grafts, 1221
 - buccal fat pad flap, 1220–1221
 - buccal space, 1219
 - complications, 1227
 - cutaneous paddles of chimeric flaps, 1226
 - definition, 1219
 - external to internal layers, 1219, 1219*f*
 - FAMM flap, 1222–1223, 1223*f*
 - masseteric (or submasseteric) space, 1220
 - merits and demerits, 1221*b*
 - outcomes, 1227
 - pathogenesis, 1220
 - patient history and physical findings, 1220
 - pectoralis major myocutaneous flap, 1223
 - platysmal myocutaneous island flap, 1222
 - postoperative care, 1227
 - Pterygomandibular space, 1219
 - radial forearm fasciocutaneous free flap, 1224, 1224*f*
 - submental island flap, 1221–1222, 1222*f*
 - surgical management
 - approach, 1220–1221

- patient positioning, 1220
 - preoperative planning, 1220
- Buccal myomucosal flap, 2700–2701, 2700*f*
- Buccal nerve, anatomy of, 966, 966*f*
- Buccal sulcus
 - incision, 2631, 2633
 - of Le Fort I fractures, 890
- Bunnell Transfer, 2013–2015, 2014*f*
- Bupivacaine, 2329
 - emergency room anesthesia, 3077
 - furlow palatoplasty, 2664
- Buried sutures technique, 2861, 2861*f*
- Burn injury
 - anatomy, 2805
 - complications, 2809
 - definition, 2805
 - imaging, 2806
 - merits and demerits, 2808*b*
 - natural history, 2805–2806
 - outcomes, 2809
 - pathogenesis, 2805
 - patient history and physical findings, 2806
 - postoperative care, 2809
 - surgical management, 2806
- Burn scar contractures, 2767, 2767*f*
- Burned hand reconstruction
 - anatomy, 2772
 - complications, 2776
 - contracture release with full-thickness skin grafting, 2774–2775, 2775*f*
 - definition, 2772
 - imaging, 2772
 - merits and demerits, 2775*b*

- natural history, 2772
- pathogenesis, 2772
- patient history and physical findings, 2772
- postoperative care, 2776
- surgical management, 2772–2773
 - patient position, 2773
 - preoperative planning, 2773
- Burow flap advancement, 1056, 1056*f*–1057*f*
- Buttock lift
 - anatomy, 1612, 1613*f*
 - with autologous gluteal augmentation, 1615–1617, 1616*f*–1617*f*
 - complications, 1618
 - definition, 1612
 - merits and demerits, 1617*b*
 - pathogenesis, 1612
 - patient history and physical findings, 1612
 - postoperative care, 1617
 - surgical management
 - approach, 1614
 - patient position, 1613–1614, 1614*f*
 - preoperative planning, 1612–1613
- Byars flaps, 3047

C

- C flap
 - inset of, 2613
 - on medial lip element, 2608–2609, 2608*f*–2609*f*
- Calcaneal autograft harvest, 2360, 2360*f*
- Calcaneus, 2352*f*
- Calcium sulfate, 2469
- Calvarial reconstruction
 - with split calvarial grafts
 - anatomy, 997
 - complications, 1000
 - definition, 997
 - ex vivo, 998, 998*f*
 - imaging studies, 997
 - merits and demerits, 998*b*
 - outcomes, 1000
 - patient history and physical findings, 997
 - postoperative care, 1000
 - in situ, 999, 999*f*
 - surgical management, 997–998
 - thin split-thickness in situ, 999
 - with split rib grafts
 - complications, 996
 - definition, 994
 - harvest site and completion, 995, 996*f*
 - imaging studies, 994
 - merits and demerits, 995*b*
 - outcomes, 996
 - patient history and physical findings, 994
 - postoperative care, 996
 - rib graft harvest, 995, 995*f*

- rib/thoracic cage, 994, 994*f*
- surgical management, 994
- Calvarium, alloplastic reconstruction
 - anatomy, 519
 - complications, 522
 - definition, 519
 - imaging studies, 519–520, 520*f*
 - intraoperative technique, 520, 521*f*
 - left parietal skull defect, 519, 520*f*
 - merits and demerits, 520*b*
 - natural history, 519
 - outcomes, 522
 - pathogenesis, 519
 - patient history and physical findings, 519
 - postoperative care, 522
 - resected calvarial tumor specimen, 519, 519*f*
 - surgical management
 - patient positioning, 520
 - preoperative planning, 520
- CAM boots, 2372
- Camitz Transfer, 2013, 2014*f*
- Camouflage corrections, 887*b*
- Canalicular injury, 2875
- Canaliculi, lacrimal system, 830*f*, 831
- Cancellous fragments, 2468
- Cancerous lesions, 2365
- Cannula, 21
- Cannula use, 2811
- Canthal and nasal reconstruction, 540
- Canthal tilt, 158
- Canthopexy, 152, 154
 - anatomy, 2863, 2863*f*
 - complications, 2868

- definition, 2863
- imaging, 2864
- lateral canthal manipulation with
 - anatomy, 157, 158*f*–159*f*
 - complications, 161
 - definition, 157
 - inferior retinacular lateral canthopexy/canthoplasty, 159–160, 160*f*
 - merits and demerits, 160*b*
 - outcomes, 160, 161*f*
 - pathogenesis, 157–158
 - patient history and physical findings, 158–159
 - postoperative care, 160
- merits and demerits, 2868*b*
- natural history, 2863
- nonoperative management, 2864
- outcomes, 2868
- pathogenesis, 2863
- patient history and physical findings, 2863–2864
- postoperative care, 2868
- surgical management, 2864–2868
 - approach, 2864–2868
 - patient position, 2864
 - preoperative planning, 2864
- Canthoplasty
 - lateral canthal manipulation with
 - anatomy, 157, 158*f*–159*f*
 - complications, 161
 - definition, 157
 - inferior retinacular lateral canthopexy/canthoplasty, 159–160, 160*f*
 - outcomes, 160, 161*f*
 - pathogenesis, 157–158

- patient history and physical findings, 158–159
- pearls and pitfalls, 160*b*
- postoperative care, 160
- lateral tarsal strip
 - anatomy, 1103
 - complications
 - definition, 1103
 - imaging, 1104
 - markings and anesthesia, 1103*f*, 1105
 - merits and demerits, 1105*b*
 - natural history, 1104
 - nonoperative management, 1104
 - outcomes, 1107
 - pathogenesis, 1103–1104
 - patient history and physical findings, 1104
 - patient positioning, 1105–1106
 - postoperative care, 1107
 - preoperative planning, 1105
 - removal of, 1103*f*–1104*f*, 1105–1106
 - strip placement, 1107
- Canthotomy, 1081, 1081*f*–1082*f*
- Capanna method, 2512, 2514–2515, 2514*f*
- Capanna technique, 2424
- Caprini scale, 2444
- Capsular contracture, 390
- Capsulotomies, 1740
- Caput ulna, 1933, 1933*f*–1934*f*
- Carbon dioxide lasers, 2800
- Cardiovascular system, conjoined twins, 3095
- Carpal tunnel release, 1762–1763, 1763*f*
 - anatomy, 1977, 1978*f*
 - complications, 1985
 - definition, 1977

- diagnostic studies, 1979
- differential diagnosis, 1979
- endoscopic carpal tunnel release, 1981–1983, 1981*f*, 1982*f*, 1983*f*
- hypothenar fat flap, 1984, 1984*f*
- imaging, 1979
- merits and demerits, 1985*b*
- nonoperative management, 1979
- open carpal tunnel release, 1980, 1981*f*
- outcomes, 1985
- pathogenesis, 1977
- patient history and physical findings, 1977
- postoperative care, 1985
- surgical management, 1979–1980
 - approach, 1980, 1980*f*
 - patient positioning, 1979
 - preoperative planning, 1979, 1979*f*
- Carpal tunnel syndrome (CTS), 1930, 1933, 1936, 1977, 1979, 1984–1985
- Carpometacarpal (CMC) joint fracture-dislocations
 - anatomy
 - general, 1796
 - ligamentous, 1796, 1796*f*
 - skeleton, 1796
 - closed reduction and percutaneous pinning, 1798, 1798*f*–1799*f*
 - complication, 1800
 - definition, 1796
 - differential diagnosis, 1797
 - imaging, 1797, 1797*f*
 - merits and demerits, 1800*b*
 - natural history, 1797
 - nonoperative management, 1797
 - open reduction and internal fixation, 1799, 1800*f*
 - outcomes, 1800

- pathogenesis, 1796–1797
- patient history and physical findings, 1797
- postoperative care, 1800
- surgical management, 1797–1798
 - approach, 1798
 - patient positioning, 1798
- Carroll-Girard screw, 955
- Cartilage grafts, 314, 314*f*
- Cartilage turnover and rotation methods, Stahl ear, 2821
- Cartilaginous wedge resections
- Cat bites, 3075
- Caudal septal reduction, 335, 335*f*
- Caudal septum, 2632*f*
- Causalgia, 1930
- Cefazolin, 2466
- Cement spacer placement, 2475–2476, 2475*f*
- Central nervous system, conjoined twins, 3096
- Central wedge excision, 549
- Centrifugation, 180–181, 180*f*
- Cephalic vein, 2114
- Cephalosporins, 2466
- Cerebrospinal fluid leakage, 831
- Cervical branches, 196
- Cervical lipectomy, 245–246, 245*f*
- Cervical nerves, 966, 966*f*
- Champy technique, 941
- Charles procedure, 2568–2569, 2569*f*. *See also* Fasciocutaneous debulking of extremity lymphedema
- Cheek reconstruction
 - with laterally based cervicofacial flap
 - arterial blood supply, 1103, 1103*f*–1104*f*
 - complications, 1107
 - deep-plane elevation or tissue expansion, 1103

- definition, 1103, 1103*f*
- flap elevation, 1105, 1105*f*
- imaging studies, 1104
- markings, 1105, 1105*f*
- merits and demerits, 1105*b*
- outcomes, 1107, 1107*f*–1108*f*
- patient history and physical findings, 1103–1104
- postoperative care, 1107
- reconstructive zones, 1103
- surgical management, 1104
- medially based cervicofacial flap
 - arterial blood supply, 1103, 1103*f*–1104*f*
 - complications, 1107
 - deep-plane elevation or tissue expansion, 1103
 - definition, 1103, 1103*f*
 - desmoplastic melanoma, 1105, 1106*f*
 - dissection, 1105, 1106*f*
 - dog-ear excision, in inferomedial portion, 1106, 1106*f*
 - imaging studies, 1104
 - markings, 1105, 1106*f*
 - merits and demerits, 1105*b*
 - outcomes, 1107, 1107*f*–1108*f*
 - patient history and physical findings, 1103–1104
 - postoperative care, 1107
 - reconstructive zones, 1103
 - surgical management, 1104
- radial forearm flap
 - advantage, 1116
 - anatomy, 1116, 1117*f*
 - complications, 1121
 - definition, 1116
 - flap design, 1118, 1118*f*
 - flap dissection, 1118, 1118*f*

- flap inset, 1119–1120, 1120*f*
- imaging, 1116
- merits and demerits, 1118*b*
- outcomes, 1121
- patient history, 1116
- physical examination, 1116
- postoperative care, 1121
- subfascial dissection, 1119, 1119*f*
- surgical management, 1117
- skin grafts
 - arterial and venous anatomy, 1123*f*
 - buccomandibular, 1122, 1122*f*
 - definition, 1122
 - with full-thickness skin graft, 1125, 1125*f*
 - lymphatic drainage, 1122
 - merits and demerits, 1125*b*
 - nonoperative management, 1124
 - outcomes, 1126–1127
 - patch appearance, 1126
 - patient history and physical findings, 1122–1124
 - postoperative care, 1126
 - preauricular, 1122, 1122*f*
 - with split-thickness skin graft, 1126, 1127*f*–1128*f*
 - suborbital, 1122, 1122*f*
 - surgical management, 1124
- tissue expansion
 - anatomy, 1109
 - complications, 1115
 - definition, 1109
 - direct expansion and closure, 1110
 - expanded cervicofacial flap, 1110, 1112, 1113*f*
 - expanded flap elevation and inset, 1111, 1111*f*–1112*f*
 - flap incisions and tissue transposition, 1110

- incision placement, 1110
- insertion, 1111
- merits and demerits, 1111*b*
- neck expansion, 1113, 1113*f*
- outcomes, 1114, 1114*f*
- patient history and physical findings, 1109
- port placement, 1110
- postoperative care, 1114
- size, shape, and number, 1110
- surgical management, 1109–1110
- Cheilion, 2729
- Chemical peels, 60
- Chemosis, 147, 156
- Chemotherapy, 2456, 2497
- Cheng's grading and management for lymphedema, 1506*b*
- Chest wall deformity, 996
- Chest wall incision, 996
- Chest wall reconstruction
 - latissimus dorsi flap for
 - anatomy, 1543, 1543*f*
 - axillary tunnel dissection, 1545
 - complications, 1546
 - definition, 1543
 - flap elevation, 1544–1545, 1545*f*
 - merits and demerits, 1545*b*
 - outcomes, 1546
 - patient history and physical findings, 1543–1544
 - postoperative care, 1546
 - surgical management, 1544
 - pectoralis flap for
 - anatomy, 1514–1515, 1514*f*–1515*f*
 - complications, 1521
 - definition, 1514

- differential diagnosis, 1516
- imaging, 1516
- merits and demerits, 1517*b*
- natural history, 1515–1516
- nonoperative management, 1516
- pathogenesis, 1515
- patient history and physical findings, 1516, 1517*f*
- postoperative care, 1521
- surgical management, 1516–1517
- serratus anterior flap for
 - anatomy, 1547, 1548*f*–1551*f*
 - complications, 1555
 - definition, 1547
 - flap harvest, 1553–1554, 1553*f*–1554*f*
 - imaging, 1549
 - intrathoracic flap inseting, 1554, 1554*f*
 - merits and demerits, 1554*b*
 - outcomes, 1555
 - pathogenesis, 1547
 - patient history and physical findings, 1547–1549
 - postoperative care, 1554–1555
 - surgical management, 1549–1551
- Chest wound closure, microtia, auricular reconstruction for, 2818
- Chin augmentation
 - anatomy, 386, 387*f*–388*f*
 - complications, 390–391
 - definition, 386, 388*b*
 - external (submental) approach, 388–389, 388*f*, 389*f*
 - imaging, 387
 - implant selection, 387
 - intraoral approach, 390
 - merits and demerits, 390*b*
 - outcomes, 390, 391*f*

- pathogenesis, 386
- patient history and physical findings, 386–387
- postoperative care, 390
- surgical management, 387
- Chin deformities
 - osseous genioplasty
 - anatomy, 411
 - complications, 414–415
 - definition, 411
 - imaging, 412
 - merits and demerits, 413*b*
 - outcomes, 414, 414*f*–415*f*
 - patient history and physical findings, 411
 - postoperative care, 414
 - surgical management, 412–415
 - techniques, 412–413, 413*f*
 - variations, 413
- Chin pogonion projection, 411
- Chin ptosis, 757, 757*f*
- Chin reduction
 - anatomy, 406
 - complications, 410
 - definition, 406
 - genioplasty, 408–409, 408*f*, 409*f*
 - imaging, 406
 - mandible setback/chin setback, 407
 - mandibuloplasty, 407–408, 408*f*
 - merits and demerits, 410*b*
 - outcomes, 410
 - patient history and physical findings, 406
 - postoperative care, 410
 - surgical management, 406–407
 - approach, 407

- positioning, 407
- preoperative planning, 407
- Chlorhexidine mouthwash, 892
- Chloroprocaine, 2329
- Chondritis, 2835, 2840, 3083
- Chondroblastoma, 2423
- Chondrosarcoma, 2460
- Chopart amputation, 2546
- Chordee correction
 - bridging of urethral plate defect, 3047, 3047*f*–3048*f*
 - corporal body grafting, 3047, 3047*f*
 - deep transverse incisions of tunica albuginea, 3046
 - dorsal plication, 3044, 3044*f*
 - urethra and glanuloplasty tubularization, 3048
 - urethral plate division, 3046
- Chronic infection, 2365, 2506
- Chronic osteomyelitis, 2369*f*, 2433, 2469
- Chronic periprosthetic infection, 2470*f*
- Chronic right posterior ankle wound
- Chronic vascular disease, 2365
- Chronic wounds, 980, 2366, 2429
- Cicatricial alopecias, 417, 428
- Cicatricial ectropion, 815
- Cierny-Mader classification system, 2466
- Circular excision and purse-string closure, 2761–2762, 2761*f*
- Circumferential body lift. *See* Lower body lift
- Circumferential orbital osteotomies, 548, 548*f*
- Circumflex scapular artery (CSA), 1037
- Circumflex scapular pedicle (CSP), 687, 687*f*
- Circumflex scapular system, 1038
- Circumflex subscapular artery (CSA), 1037, 1037*f*
- Circum-mandibular wires, 959–962, 961*f*
- Circumvertical skin reduction, 2989, 2989*f*

- “Classic” helix-only defect, 1130, 1130*f*
- Classic V-Y flap, 1183–1184, 1184*f*
- Claudication, 2400
- Claw deformity of digits, 2020–2022
- Claw hand deformity, 2034, 2038*f*–2039*f*
- Clear cell sarcoma, 2421
- ClearVue boards, 426
- Cleft alveolus deformity, 656, 657*f*–658*f*
- Cleft lip
 - anatomy, 2596
 - complications, 2605
 - definition, 2596
 - differential diagnosis, 2596
 - dissection
 - lateral nasolabial element, 2603
 - medial lip element, 2602, 2602*f*
 - nasal structures, 2602–2603
 - etiology, 2596
 - lateral lip element elevation, 2599, 2600*f*
 - lateral nasolabial element
 - matching nasolabial lengths, 2600–2602, 2602*f*
 - nasal sill, 2600, 2601*f*
 - Nordhoff point, 2600, 2601*f*
 - lip closure
 - cutaneous approximation, 2604
 - muscle repair, 2603–2604, 2603*f*
 - medial nasolabial element
 - measurements and interpositional triangle, 2598, 2599*f*
 - vermilion, Cupid’s bow, and nose, 2597–2598, 2598*f*
 - merits and demerits, 2604*b*
 - outcomes, 2605, 2605*f*
 - pathogenesis, 2596
 - patient history and physical findings, 2596

- postoperative care, 2605
- surgical management, 2596–2597
 - approach, 2597
 - patient position, 2597
 - preoperative planning, 2597
- suture techniques, 2604
- Cleft lip adhesion
 - bilateral, 2633–2634
 - unilateral
 - completion, 2633, 2633*f*
 - incision and dissection, 2631, 2632*f*
 - markings, 2631, 2631*f*
 - suturing, 2631–2633, 2632*f*
- Cleft lip repair. *See* Bilateral cleft lip repair
- Cleft lip/nose deformity. *See* Salyer unilateral cleft lip/nose repair
- Cleft palate repair
 - Sommerlad palatoplasty (*see* Sommerlad palatoplasty)
 - two-flap palatoplasty (*see* Two-flap palatoplasty)
 - von Langenbeck palatoplasty (*see* Von Langenbeck palatoplasty)
- Clindamycin, 2336
- Clitoral degloving, 3065, 3066*f*
- Clitoral hood, creation of, 3071, 3071*f*
- Clitoral reduction, 3066–3067, 3067*f*
- Clitoris, 3062
- Cloacal membrane, 3062
- Clonidine, 203
- Closed Mallet fracture pinning, 2082
- Closed nasal fracture correction
 - anatomy, 853, 853*f*
 - bony nasal pyramid and septum, reduction, 855, 855*f*
 - complications, 856
 - definition, 853
 - imaging, 854

- local anesthetic, administration of, 854, 854*f*
- merits and demerits, 856*b*
- nasal airway assessment and splint application, 855, 856*f*
- nonoperative management, 854
- outcomes, 856
- pathogenesis, 853
- patient history and physical findings, 853
- postoperative care, 856
- surgical management, 854
 - approach, 854
 - positioning, 854
 - preoperative planning, 854
- Closed reduction and pinning
 - Bennett fracture
 - distal phalanx fractures, 1776–1777, 1776*f*–1777*f*
 - metacarpal neck fractures, 1788–1789, 1788*f*–1789*f*
 - metacarpal shaft fractures, 1791, 1791*f*
 - proximal phalanx fractures, 1782–1783, 1782*f*–1783*f*
 - Rolando fractures
- Closed rhinoplasty
 - anatomy, 263, 263*f*
 - complications, 268
 - controlling tip rotation in
 - anatomy, 283, 283*f*
 - complications, 287
 - definition, 283
 - elastic rotation, securing, 285, 285*f*
 - imaging, 283
 - long lateral crus, shortening, 286, 286*f*
 - long upper lateral, shortening, 286, 286*f*
 - merits and demerits, 286*b*
 - natural history, 283
 - nonoperative management, 283

- outcomes, 287, 287*f*
- pathogenesis, 283
- patient history and physical findings, 283
- postoperative care, 287
- projection, 286
- surgical management, 283–285, 284*f*
- definition, 263
- dorsal resection, 265, 266*f*, 267*f*
- imaging, 263–264
- increasing and decreasing tip projection in
 - anatomy, 276, 276*f*
 - complications, 282
 - definition, 276, 276*f*
 - imaging, 277, 277*f*
 - lobule projection, increasing, 279, 279*f*–280*f*
 - lobule projection, reducing, 278, 279*f*
 - merits and demerits, 281*b*
 - nostril apex projection, increasing, 280, 280*f*–281*f*
 - nostril apex projection, reducing, 278, 278*f*
 - outcomes, 282, 282*f*
 - pathogenesis, 276
 - patient history and physical findings, 276–277
 - postoperative care, 282
 - surgical management, 277
- merits and demerits, 267*b*
- narrow midvault in
 - anatomy, 269
 - complications, 275
 - definition, 269
 - endonasal access, 272, 272*f*
 - imaging, 271
 - merits and demerits, 274*b*
 - outcomes, 274, 275*f*

- pathogenesis and natural history, 269–270
- patient history and physical findings, 270–271
- postoperative care, 274
- septoplasty, 273–274, 273*f*
- spreader graft placement, 274
- spreader graft tunnels, 272*f*, 273
- surgical management, 271–272
- outcomes, 268
- pathogenesis, 263, 264*f*
- patient history and physical findings, 263
- postoperative care, 267
- surgical management, 264–268
 - approach, 264–268, 264*f*
 - preoperative planning, 264
- Closing wedge osteotomies, 1034–1035, 1034*f*
- Closure, 1679, 1679*f*, 1725, 1725*f*
- Cold compresses, 837
- Coleman technique, 2650
- Collagenase therapy, 2181, 2181*f*, 2430
- Coloboma, 2720
- Colorado needle, 133, 134*f*, 2622
- Colorado-tipped Bovie electrocautery, 939
- Columellar, 2606, 2617
 - animation deformity of, 375, 375*f*
 - base deformity, 376, 376*f*
- Columellar struts, 313, 313*f*
- Combination technique, 2988
- Combined median and ulnar nerve injuries
 - anatomy, 2032–2033
 - claw hand deformity, 2034, 2038*f*–2039*f*
 - complications, 2042
 - definition, 2032
 - high, 2040–2041

- imaging, 2034–2035
- low, 2036–2040
- merits and demerits, 2036*b*, 2041*b*
- nonoperative management, 2035
- outcomes, 2042
- pathogenesis, 2033
- patient history and physical findings, 2033–2034
- postoperative care, 2042
- sensory deficits, 2032, 2033*f*
- surgical management
 - approach, 2035
 - patient positioning, 2035
 - preoperative planning, 2035
- thermoplastic splints, 2035, 2035*f*
- Combined sensory index (CSI), 1979
- Comminuted fractures
 - angle and ramus fractures, 911–912, 911*f*–912*f*
 - body fractures, 911
 - symphysis/parasymphysis, 910
- Commissuroplasty, 2729, 2732, 2733*f*
- Common peroneal nerve
 - decompression, 2413, 2413*f*
 - traction injury, 2413
- Communication, 334
- Compartment syndrome, 2331, 2334
 - complications, 1765, 1765*f*
 - definition, 1760
 - diagnostic studies, 1760–1761
 - fasciotomy
 - dorsal forearm, 1764, 1764*f*
 - hand, 1762–1763, 1762*f*, 1763*f*
 - with two longitudinal incisions, 1764, 1764*f*
 - volar forearm with curvilinear incision, 1763, 1763*f*

- merits and demerits, 1765*b*
- natural history, 1760
- outcomes, 1765
- pathogenesis, 1760
- patient history and physical findings, 1760, 1761*f*
- postoperative care, 1765, 1765*f*
- surgical management
 - alternative forearm fasciotomy, 1762, 1762*f*
 - alternative parallel forearm incision approach, 1762, 1762*f*
 - dorsal forearm longitudinal approach, 1762, 1762*f*
 - patient positioning, 1761
 - preoperative planning, 1761
 - ulnar incision, 1762
 - volar forearm curvilinear approach, 1761, 1762*f*
- Volkmann ischemic contracture, 1765, 1765*f*
- Complete clefts, 2606, 2668
- Complex regional pain syndrome (CRPS), 2533
- Component dorsal hump reduction, 335, 335*f*
- Component separation technique
 - anatomy, 1563
 - complications, 1570–1571
 - definition, 1563
 - imaging, 1564
 - laparoscopic component separation, 1565, 1565*f*
 - merits and demerits, 1564*b*
 - minimally invasive component separation, 1566–1567, 1566*f*
 - open component separation, 1564–1565, 1564*f*
 - outcomes, 1568–1570, 1568*f*–1569*f*
 - pathogenesis, 1563
 - patient history and physical findings, 1563
 - periumbilical perforator-sparing technique, 1565–1566
 - posterior component separation, 1567, 1567*f*
 - postoperative care, 1568

- surgical management, 1564
- Composite grafts
 - alar rim reconstruction, 1182
 - complications, 1182
 - definition, 1180
 - graft placement, 1181, 1181*f*
 - merits and demerits, 1181*b*
 - patient history and physical findings, 1180
 - postoperative care, 1182
 - surgical management
 - approach, 1180
 - patient positioning, 1180
 - preoperative planning, 1180
- Computed tomographic angiography (CTA)
 - ankle reconstruction with free flap, 2392, 2394*f*
 - debridement of soft tissue infections of lower leg, 2427
 - free flap, reconstruction of heel and plantar defects, 2380, 2383
 - free flaps, 2487
 - medial plantar flap, 2374
 - microvascular free flap transfer, 2440, 2441*f*
 - open fractures, 2468
 - pedicled rectus flap, 2518
- Computed tomography (CT)
 - bone grafting for foot and ankle, 2356–2357
 - bone reconstruction of knee, 2473, 2474*f*
 - condyle fractures, 917
 - conjoined twins, 3093
 - crooked nose, 325, 325*f*
 - debridement of soft tissue infections of lower leg, 2427
 - enophthalmos, 848
 - femoral bone debridement, 2507
 - free flaps, soft tissue defects of thigh, 2522
 - Le Fort I fracture, 890, 890*f*

- malignant bone tumors of the foot and ankle, 2345
- mandible fractures, open treatment of, 908
- nonunion of mandible fracture, 927, 927*f*–928*f*
- open fractures, 2468
- orbital roof fractures, 840
- osteomyelitis, 2352, 2468
- panfacial fractures, 935
- pediatric mandible fractures, 958
- pediatric midface fractures, 951, 951*f*
- pediatric orbital fractures, 943
- short nose, 338
- zygomatic arch fractures, closed reduction and treatment, 872
- Computer-aided design (CAD) 3D model, 770, 770*f*–771*f*
- Computer-aided design/computer-aided modeling (CAD/CAM), in fibula free flap reconstruction
 - anatomy, 1022*f*, 1023
 - complications, 1029
 - definition, 1022
 - dental implants, 1027
 - fibula flap harvest, 1025–1026
 - fibula flap osteotomy, 1026–1027, 1026*f*
 - flap inset, 1027
 - imaging studies, 1023–1024, 1024*f*
 - mandibular osteotomy, 1026
 - merits and demerits, 1025*b*
 - microsurgical anastomosis, 1027
 - outcomes, 1029, 1029*f*
 - pathogenesis, 1023
 - patient history and physical findings, 1023
 - postoperative care, 1028–1029
 - surgical management, 1024–1025
- Concentrated synthetic growth factors, 2361
- Concha bullosa, 329

- Condylar fractures, 958
 - open treatment of, 908, 912–913, 912*f*
 - anatomy, 915–916, 915*f*–916*f*
 - complications, 922
 - definition, 915, 915*f*
 - imaging, 917, 917*f*
 - indications/contraindications, 918
 - merits and demerits, 921*b*
 - natural history, 916
 - nonoperative management, 918
 - outcomes, 922, 922*f*
 - pathogenesis, 916
 - patient history and physical findings, 917
 - postoperative care, 922
 - preauricular approach, 921
 - retromandibular approach, 919, 919*f*, 920*f*
 - Risdon (submandibular) approach, 920, 920*f*–921*f*
 - surgical management, 918
- Cone beam CT (CBCT), 958
- Congenital glaucoma, 2871
- Congenital melanocytic nevi (CMN)
 - complications, 2743
 - definition, 2735
 - dermabrasion and curettage, 2737
 - differential diagnosis, 2735–2736
 - classification, 2735–2736
 - nevus distribution, 2736, 2736*f*
 - imaging, 2735
 - laser, 2737
 - malignancy risk, 2735
 - natural history, 2735
 - nevus excision with expanded flap reconstruction
 - approach, 2740, 2740*f*

- closure, 2742, 2742*f*
- excision, 2741*f*, 2743*b*
- incision, 2740*b*, 2740*f*–2741*f*
- merits and demerits, 2743*t*
- patient position, 2739
- postoperative care, 2743
- preoperative planning, 2739
- suturing, 2742, 2742*f*
- nonoperative management, 2737
- outcomes, 2743
- pathogenesis, 2735
- patient history and physical findings, 2736–2737
- surgical management, 2737
- tissue expander placement
 - approach, 2738
 - merits and demerits, 2739*t*
 - patient position, 2738
 - postoperative care, 2739, 2739*f*
 - preoperative planning, 2737–2738
 - technique, 2738*b*
- Congenital midline nasal mass
 - anatomy, 2744, 2744*f*
 - complications, 2751
 - definition, 2744
 - differential diagnosis, 2746
 - endoscopic excision of intranasal glioma, 2750, 2750*f*
 - imaging, 2745, 2746*f*
 - medial orbit composite unit translocation, 2749–2750, 2749*f*
 - merits and demerits, 2747*b*
 - natural history, 2745
 - outcomes, 2751
 - pathogenesis, 2744–2745
 - patient history and physical findings, 2745, 2745*f*

- postoperative care, 2751
- surgical management
 - approach, 2746, 2747*f*
 - patient position, 2746
 - preoperative planning, 2746
- transcranial NDSC resection
 - bandeau/frontal bone repair, 2748
 - completion, 2748
 - cranial base repair and seal, 2748, 2749*f*
 - incisions, dissection, and craniotomy, 2747, 2748*f*
 - keystone osteotomy and dermal sinus excision, 2747–2748, 2748*f*
 - nasal approach/frozen biopsy, 2747–2748, 2747*f*
- Congenital ptosis, 2753
 - anatomy, 2849, 2849*f*
 - complications, 2856
 - definition, 2849
 - differential diagnosis, 2850
 - imaging, 2850
 - merits and demerits, 2856*b*
 - natural history, 2850
 - nonoperative management, 2850
 - outcomes, 2856
 - pathogenesis, 2849–2850
 - patient history and physical findings, 2850
 - postoperative care, 2856
 - surgical management, 2850–2856
 - approach, 2851–2856
 - patient position, 2851
 - preoperative planning, 2851
- Congenital vaginal atresia. *See* Vaginal agenesis
- Conjoined twin
 - anatomy, 3092, 3093*f*–3094*f*

- complications, 3101
- definition, 3092
- differential diagnosis, 3094
- imaging, 3092–3093
- merits and demerits, 3100*b*
- natural history, 3092
- nonoperative management, 3094
- outcomes, 3101
- pathogenesis, 3092
- patient history and physical findings, 3092
- postoperative care, 3100
- separation of ischiopagus, 3097–3100, 3097*f*–3098*f*
- surgical management, 3094–3097
 - approach, 3097
 - patient position, 3096–3097
 - preoperative planning, 3095–3096, 3096*f*–3097*f*
- Conjunctival scarring, 837
- Conjunctival-lateral canthotomy, 886, 886*f*
- Conjunctivitis, 2871
- Conjunctivomullerectomy, 2854, 2855*f*
- Constricted ear
 - anatomy, 2826
 - complications, 2831
 - definition, 2826, 2826*f*
 - markings, 2827, 2827*f*–2828*f*
 - merits and demerits, 2830*b*
 - nonoperative management, 2826–2827
 - outcomes, 2830, 2831*f*
 - patient history and physical findings, 2826
 - postoperative care, 2830
 - rib cartilage
 - harvest, 2828, 2828*f*
 - splitting, 2828, 2829*f*

- skin tunnel creation, 2828, 2829*f*
- surgical management
 - approach, 2827–2830
 - patient position, 2827
 - preoperative planning, 2827, 2827*f*
- Continuous catheter technique, 2315–2316
 - nerve stimulator, 2318
 - supplies for, 2316
 - ultrasound-guided, 2320
- Continuous epidural anesthesia, 2326
- Continuous positive airway pressure (CPAP), 500
- Contour irregularities, 200
- Contracture release, 2766
 - with full-thickness skin grafting, 2774–2775, 2775*f*
- Contralateral fibula flap, 1025, 2433*f*
- Contralateral flap, 1031
- Contralateral free fibula flap harvest, 2432
- Contralateral mucoperichondrial septal flap, 1165*f*
- Conventional angiographies, 2522
- Conventional x-rays, 2522
- CoolSculpting, 243
- Copeland test, 2416
- Cordeiro modification, skate flap
 - elevating and inseting, 1478–1479, 1478*f*–1479*f*
 - flap design, 1477, 1478*f*
- Corneal abrasion, 119
- Corneal injury, 837
- Corneal neurotization
 - anatomy, 2942
 - complications, 2946–2947
 - definition, 2942
 - diagnostic studies, 2942
 - differential diagnosis, 2942–2943

- imaging, 2942
- merits and demerits, 2946*b*
- natural history, 2942
- nonoperative management, 2943
- outcomes, 2946
- pathogenesis, 2942
- patient history and physical findings, 2942
- postoperative care, 2946
- surgical management, 2943
 - patient position, 2943
 - preoperative planning, 2943
- Corneal shields, 825
- Coronal approach, in orbital roof fractures, 843–845, 844*f*
- Coronal brow lift, 72–74, 73*f*
- Coronal synostosis, 531
- Coronoid fractures, 913
- Coronoidectomy, mandibular coronoid fractures, 925, 925*f*
- Corporal body graft, 3047, 3047*f*
- Corporal-sparing clitoroplasty, 3067
- Corpus cavernosa, resection of, 1690*f*, 1691
- Corrugator muscles
 - hypercontraction of, 3
 - transblepharoplasty excision of, 94, 94*f*
- Corrugator supercilii (CS), 2
 - medial head of, 2
 - originates, 2
 - removal, transpalpebral corrugator resection, 111, 111*f*
 - transpalpebral corrugator resection, 109
- Corticosteroids, 1860
- Costal cartilage graft, dorsal augmentation
 - anatomy, 343, 343*f*
 - complications, 349
 - definition, 343

- dorsal graft, preparing and affixing, 344–345, 345*f*–346*f*
- harvesting, 344, 344*f*
- merits and demerits, 348*b*
- outcomes, 349, 349*f*
- patient history and physical findings, 343
- postoperative care, 349
- surgical management, 343
- transosseous suture/K-wire, use of, 347–348, 347*f*–348*f*
- Costochondral graft
 - complications, 675
 - definition, 671
 - differential diagnosis, 673
 - glenoid fossa, 671
 - imaging studies, 673
 - mandible exposure and pocket creation, 673–674, 674*f*
 - mandibular anatomy, 671, 671*f*–672*f*
 - merits and demerits, 673*b*
 - natural history, 671
 - outcomes, 675
 - pathogenesis, 671
 - patient history and physical findings, 672–673, 672*f*
 - postoperative care, 675
 - rib harvest, 671*f*–672*f*, 673
 - rib osteocartilaginous junction, 671, 671*f*–672*f*
 - rib placement and fixation, 674, 674*f*
 - surgical management
 - patient positioning, 673
 - preoperative planning, 673
 - temporomandibular joint, 671, 671*f*–672*f*
- Cottle elevator, 862, 863*f*
- Cottle maneuver, 298
- Cotton tip applicator
 - on awake patient, 58

- on sedated patient, 57, 58*f*
- Cranial base repair and seal, 2748, 2749*f*
- Cranial index (CI), 453
- Cranial osteotomy, 538, 539*f*
- Cranial vault, 3D implant reconstruction
 - anatomy, 515
 - closure, 517
 - complications, 518
 - definition, 515
 - differential diagnosis, 515
 - free flap coverage, 516, 516*f*
 - imaging, 515, 515*f*
 - implant placement and fixation, 516, 517*f*
 - merits and demerits, 516*b*
 - natural history, 515
 - nonoperative management, 515
 - outcomes, 517, 518*f*
 - pathogenesis, 515
 - patient history and physical findings, 515
 - postoperative care, 517
 - surgical management
 - patient positioning, 516
 - preoperative planning, 516
- Cranial vault defects
 - anatomy, 663
 - imaging studies, 664
 - merits and demerits, 666*b*
 - natural history, 664
 - outcomes, 668
 - patient history and physical findings, 664
 - postoperative care, 668
 - surgical management, 665, 665*f*
 - surgical technique, 667

- Cranialization
 - anatomy, 779–780, 779*f*–780*f*
 - complications, 784–785, 785*f*
 - definition, 779
 - differential diagnosis, 781, 781*f*
 - imaging studies, 780, 781*f*
 - merits and demerits, 781*b*
 - natural history, 780
 - nonoperative management, 781
 - outcomes, 784
 - pathogenesis, 780
 - patient history and physical findings, 780, 780*f*
 - postoperative care, 784
 - preparation and exposure, 781–782, 782*f*
 - repair and closure, 782–784, 783*f*
 - in situ, 779*f*–780*f*
 - surgical management
 - approach, 781
 - patient positioning, 781
 - preoperative planning, 781
- Craniofacial
 - anatomy, 2752
 - disjunction, 897, 898*f*
- Craniofacial anaplastology
 - anatomy, 3084, 3085*f*
 - auricular prosthesis implants, 3087, 3088*f*
 - complications, 3090
 - definition, 3084
 - imaging
 - implant placement, 3086–3087, 3086*f*–3087*f*
 - merits and demerits, 3089*b*
 - nasal prosthesis implants, 3088, 3088*f*
 - orbital prosthesis implants, 3089, 3089*f*

- outcomes, 3090, 3090*f*
- patient history and physical findings, 3084–3085
- postoperative care, 3090, 3090*f*
- surgical management
 - approach, 3086
 - patient position, 3086
 - preoperative planning, 3085–3086
- Craniofacial dysostosis syndromes, 499
- Craniofacial fibrous dysplasia (CFD), 762
- Craniopagus, 3092, 3093*f*–3094*f*
- Craniopagus twins
 - bony and soft tissue reconstruction, 527, 528*f*
 - circumferential venous sinus, 523, 523*f*
 - classifications, 523, 523*f*
 - closure, 526*f*, 527
 - complications, 528
 - definition, 523
 - imaging studies, 524, 524*f*–525*f*
 - merits and demerits, 526*b*
 - neurovascular separation, 527
 - nonoperative management, 524
 - outcomes, 528
 - patient history and physical findings, 524
 - postoperative care, 528
 - reinforced silicone sheet, 526*f*, 527
 - scalp flaps retracted with access craniotomy, 526, 526*f*
 - surgical management
 - approach, 526
 - patient positioning, 526
 - preoperative planning, 524*f*–525*f*, 525
 - tissue expansion, 527, 527*f*
 - venous drainage, 523, 523*f*, 526*f*, 527
- Cranioplasty, 513

- Cranioplasty reconstruction, with autogenous rib graft
 - allograft materials, 510
 - alloplastic materials, 509
 - autogenous bone grafts, 510
 - bone substitutes, 510
 - bony defect, 511
 - complications, 514
 - cranial defect exposure, 511
 - cranioplasty technique, 513
 - definition, 509
 - endochondral and intramembranous ossification, 509, 509*f*–510*f*
 - floating ribs, 509
 - imaging, 510
 - merits and demerits, 511*b*
 - nonoperative management, 510
 - outcomes, 514
 - pathogenesis, 509
 - patient history and physical findings, 510
 - postoperative care, 514
 - rib harvest, 512, 512*f*
 - scalp closure, 513
 - split rib technique, 513, 513*f*
 - surgical management, 510–511
- Craniosynostosis
 - anatomy, 530, 530*f*
 - bicoronal synostosis, 531
 - closure, 534
 - complications, 535
 - coronal synostosis, 531
 - craniectomy, 533, 533*f*–534*f*
 - definition, 530
 - growth inhibition, 530
 - imaging, 531

- lambdoid synostosis, 531
- merits and demerits, 532*b*
- metopic synostosis, 531
- outcomes, 535
- patient history, 530
- physical examination, 530
- postoperative care, 535
- sagittal synostosis, 530, 532, 532*f*
- surgical management
 - approach, 531
 - patient positioning, 531
 - preoperative planning, 531
- Craniotomy, congenital midline nasal mass, 2747, 2748*f*
- Craniotomy incision, 981, 981*f*–982*f*
- C-reactive protein (CRP), 2467, 2471, 2474
- Critical limb ischemia, 2400, 2406
- Crooked nose
 - anatomy, 324
 - complications, 332
 - definition, 324
 - imaging, 325, 325*f*
 - local anesthesia, administration of, 326
 - lower lateral cartilage correction, 331
 - merits and demerits, 332*b*
 - nasal bone correction, 326–327, 327*f*
 - outcomes, 332
 - pathogenesis, 324
 - patient history and physical findings, 324–325
 - postoperative care, 332
 - septoplasty, 327–329, 328*f*–330*f*
 - upper lateral cartilage correction, 330, 330*f*
- Cross face nerve graft, 2936, 2936*f*
 - anatomy, 2913, 2913*f*

- complications, 2918
- definition, 2913
- imaging, 2914
- merits and demerits, 2918*b*
- natural history, 2913–2914
- outcomes, 2918
- patient history and physical findings, 2914
- postoperative care, 2918
- surgical management
 - approach, 2914
 - patient position, 2914, 2914*f*
 - preoperative planning, 2914
- Cross face nerve grafting (XFNG), 1256, 1277
- Cross-finger flap, 2099–2101, 2100*f*
- Cross-hatching injection technique, 44, 44*f*
- Crouzon syndrome, 445–446, 616
- Crow’s feet, botulinum toxin injection to
 - anatomy, 7
 - complications, 8
 - definition, 7, 7*f*
 - imaging, 7
 - merits and demerits, 8*b*
 - outcomes, 8
 - patient history and physical findings, 7
 - positioning, 7
 - postoperative care, 8
 - preoperative planning, 7
- Cruciate anastomosis, 1705
- Crush injury, nerve repair and graft, 2006
- Cryosurgery (liquid nitrogen), 2343
- Cryptotia
 - anatomy, 2832
 - complications, 2835

- definition, 2832
- differential diagnosis, 2832
- merits and demerits, 2834*b*
- nonoperative management, 2832
- outcomes, 2834–2835, 2835*f*
- pathogenesis, 2832
- patient history and physical findings, 2832, 2832*f*
- postoperative care, 2834
- surgical management
 - patient position, 2832–2834
 - preoperative planning, 2832
- C-shaped structure
 - lunotriquetral ligament, 1857, 1857*f*–1858*f*
 - scapholunate ligament, 1851, 1852*f*
- Cubital tunnel syndrome
 - anatomy, 1992, 1992*f*
 - complications, 1999
 - definition, 1992
 - differential diagnosis, 1993–1994
 - imaging, 1993
 - merits and demerits, 1994*b*
 - nonoperative management, 1994
 - outcomes, 1999
 - pathogenesis, 1992–1993
 - patient history and physical findings, 1993
 - postoperative care, 1999
 - in situ cubital tunnel decompression, 1994
 - surgical management
 - approach, 1994
 - patient positioning, 1994
 - preoperative planning, 1994
 - transposition of the ulnar nerve, 1995–1998, 1996*f*
- Cultured epithelial autograft (CEA), 2769

- Cultures, 2507
- Cupid's bow, 2597–2598, 2598*f*, 2603*f*
 - anatomy, 2606
 - deformities, 2645*b*, 2645*f*
 - asymmetry more than 2 mm high, 2647, 2647*f*
 - mismatch of 1 to 2 mm, 2646, 2646*f*
- Curved tip osteotomy, 623*f*, 626
- Customized chest wall implants, 2980, 2980*f*
- Cutaneous lip, 2596
- Cutaneous melanom
 - tenzel semicircular rotational flap, 1084
- Cutaneous paddles of chimeric flaps, 1226
- Cutaneous scar modifications, 2733, 2733*f*
- Cutler-beard, eyelid coloboma, 2846–2847, 2846*f*–2847*f*
- Cutler-Beard flap
 - anatomy, 1089, 1089*f*
 - anterior lamella, 1089
 - blood supply, 1090
 - external carotid, 1090
 - lower eyelid retractors, 1090
 - posterior lamella, 1089
 - upper eyelid retractors, 1090
 - complications, 1093
 - definition, 1089
 - flap creation, 1091–1092, 1092*f*
 - flap separation, 1092, 1092*f*
 - imaging, 1090
 - merits and demerits, 1090*b*
 - outcomes, 1093
 - patient history and physical findings, 1090
 - postoperative care, 1093
 - surgical management
 - patient positioning, 1090

- preoperative planning, 1090
- C-V flap, nipple reconstruction
 - anatomy, 1482
 - complications, 1484
 - definition, 1482
 - elevation and inseting, 1483, 1483*f*
 - flap design, 1483, 1483*f*
 - merits and demerits, 1484*b*
 - outcomes, 1484
 - patient history and physical findings, 1482
 - postoperative care, 1484
 - surgical management
 - patient positioning, 1482
 - preoperative planning, 1482, 1483*f*
- Cyst(s)
 - inclusion, 147
 - keratin-filled, 66
 - mucous
 - anatomy, 2281
 - complications, 2286
 - definition, 2280
 - differential diagnosis, 2282
 - imaging, 2282
 - merits and demerits, 2286*b*
 - natural history, 2281
 - nonoperative management, 2282
 - outcomes, 2286
 - pathogenesis, 2281
 - patient history and physical findings, 2282
 - postoperative care, 2286
 - surgical management, 2282
- Cysts. *See specific types*

D

- Dacryocystorhinostomy (DCR), 2871–2872
- Dacryoscintigraphy, 2871
- Dal Pont modification, 697
- DALs (dorsal aesthetic lines), 334
- DAO. *See* Depressor anguli oris (DAO)
- Darrach procedure, for distal radioulnar joint arthritis, 1969, 1970*f*
- DCFG (diced cartilage fascia graft), 366–367, 372
 - placement of, 370, 371*f*
- DCIA (deep circumflex iliac artery) flap, 928
- De Novo umbilicoplasty without midline incision, 3039, 3039*f*
- de Quervain syndrome
 - anatomy, 2093
 - complications, 2095
 - definition, 2093
 - differential diagnosis, 2093
 - imaging, 2093
 - merits and demerits, 2094*b*
 - nonoperative management, 2093
 - outcomes, 2095
 - pathogenesis, 2093
 - patient history and physical findings, 2093
 - postoperative care, 2095
 - surgical management
 - approach, 2093
 - patient positioning, 2093
- Debridement
 - of bone infection
 - anatomy, 2352
 - complications, 2354
 - definition, 2352

- differential diagnosis, 2353
- imaging, 2352–2353, 2352*f*
- medial malleolar chronic wound, 2353*f*
- merits and demerits, 2354*b*
- nonoperative management, 2353
- outcomes, 2354
- pathogenesis, 2352
- patient history, 2352
- patient positioning, 2353
- physical findings, 2352
- postoperative care, 2354
- preoperative planning, 2353
- surgical management, 2353, 2353*f*
- pressure injury, 2787*b*, 2792
- Debulking, sacrococcygeal teratoma, 3019, 3020*f*
- Dedifferentiated chondrosarcoma, 2502
- Deep circumflex iliac artery (DCIA) flap, 928
- Deep flexor-pronator aponeurosis, 1994
- Deep infection
 - bone tumors of femur, 2505
 - bone tumors of knee, 2464
- Deep inferior epigastric artery (DIEA), 1414
- Deep inferior epigastric perforator (DIEP) flap breast reconstruction
 - abdominal donor site closure, 1435*f*, 1436
 - anatomy, 1429–1430, 1429*f*
 - breast shaping, 1435, 1435*f*
 - complications, 1437
 - definition, 1429
 - footprint control, 1434–1435, 1435*f*
 - harvest, transfer and revascularization, 1435, 1435*f*
 - incision and flap elevation, 1432
 - internal mammary recipient vessels, exposure and preparation, 1433–1434, 1434*f*

- merits and demerits, 1431*b*, 1436*b*
- natural history, 1430
- nonoperative management, 1430
- outcomes, 1437
- pathogenesis, 1430
- patient history and physical exam, 1430
- perforator dissection, 1433
- perforator location and selection, 1432–1433
- postoperative care, 1437
- surgical management
 - patient positioning, 1431
 - preoperative markings, 1431
 - preoperative planning, 1430
- vessel dissection, 1433, 1433*f*
- Deep motor branch, 1989, 1990*f*
- Deep muscular fascia, 1649
- Deep neurovascular structures, 2486*f*–2487*f*, 2486
- Deep pars marginalis, 2616
- Deep peroneal nerve, 2323, 2323*f*, 2338
- Deep plane face-lift
 - anatomy, 231
 - complications, 237
 - definition, 231
 - merits and demerits, 236*b*
 - modified deep plane rhytidectomy, 232*b*, 233*f*
 - natural history, 231
 - nonoperative management, 231
 - outcomes, 236
 - patient history and physical findings, 231
 - postoperative care, 236
 - surgical management, 231–232
 - approach, 232
 - positioning, 232

- preoperative planning, 232
- Deep pyriform space, 32
- Deep sarcoma, 2499, 2499*f*, 2500*f*
- Deep sternal wound infections (DSWIs), 1522
- Deep temporal fascia (DTF), 872, 873*f*
- Deep temporal fascia harvest, 363, 363*f*
- Deep transverse incisions of tunica albuginea (DTITA), 3046
- Deep vein thrombosis (DVT), 1536, 2444
 - history, 1230
 - prophylaxis, 1121
- Deeper interdigastic fat, 242
- Deeper peels, 60
- Degloving injuries, 2429
- Dehiscence, 2635
- Delayed breast tissue expansion
 - anatomy, 1377, 1377*f*
 - capsule scar release, 1378
 - complications
 - bleeding/hematoma, 1379
 - infections, 1379
 - mastectomy skin necrosis, 1379
 - definition, 1377
 - mastectomy skin necrosis, 1379
 - merits and demerits, 1378*b*, 1379*b*
 - outcomes, 1379
 - patient history, 1377
 - physical findings, 1377
 - postoperative care, 1379
 - submuscular tissue expander pocket, 1378, 1378*f*
 - surgical management
 - approach, 1377
 - patient positioning, 1377
 - preoperative planning, 1377

- tissue expander insertion, 1378, 1378*f*
- wound closure, 1378
- Delayed enophthalmos repair, 817
- Delayed hard palate repair
 - anatomy, 2658
 - definition, 2658
 - hard palate repair, 2659–2660, 2660*f*
 - imaging and diagnosis, 2658
 - merits and demerits, 2661*b*
 - outcomes, 2661
 - pathogenesis, 2658
 - soft palate repair, 2659, 2659*f*
 - surgical management
 - patient position, 2658
- Delayed primary closure, 2366
- Delayed repair, with nonvascularized bone graft, 1038
- Delayed reverse sural artery flap, 2390
- Deltopectoral flap, 1230
- Demineralized bone matrix (DBM), 2360–2361
- Demyelination, 1977
- Dental compensation, 698
- Dental implants, 1027
- Dental model analysis, 592
- Deoxycholic acid (DOCA), 243
 - anatomy, 257
 - complications, 261–262
 - definition, 257
 - differential diagnosis, 257
 - imaging, 257
 - merits and demerits, 260*b*
 - nonsurgical management, 258
 - approach, 258
 - positioning, 258

- preoperative planning, 258
- outcomes, 260–261
- patient history and physical findings, 257
- postoperative care, 260
- surgical management, 257
- techniques, 258, 259*f*
- Depressor alae nasi, 2596
- Depressor anguli oris (DAO), 15
 - anatomy, 11, 11*f*, 14, 1073*f*
 - approach, 15
 - complications, 13, 16
 - definition, 11, 14
 - imaging, 15
 - merits and demerits, 15*b*
 - outcomes, 15–16
 - pathogenesis, 11
 - patient history and physical findings, 14–15
 - positioning, 15
 - postoperative care, 15
 - preoperative planning, 15
 - surgical management, 15
- Depressor labii inferioris (DLI), 14–16, 1073, 1073*f*
- Depressor septi nasi (DSN) muscle
 - anatomy, 373
 - columella, animation deformity of, 375, 375*f*
 - columellar base deformity, 376, 376*f*
 - complications, 376
 - definition, 373
 - imaging, 373
 - merits and demerits, 376*b*
 - outcomes, 376
 - patient history and physical findings, 373
 - postoperative care, 376

- short upper lip/transverse crease, 375, 375*f*
- surgical management, 373–374, 374*f*
- tip descent, 374, 374*f*
- tip descent illusion, 374, 375*f*
- Depressor supercillii
 - removal, transpalpebral corrugator resection, 111, 111*f*
 - transpalpebral corrugator resection, 109
- Dermabrasion
 - and curettage, 2737
 - to face
 - anatomy, 67
 - approach, 67
 - complications, 68
 - definition, 67
 - mechanical dermabrasion, 67, 68*f*
 - merits and demerits, 68*b*
 - outcomes, 68
 - patient history and physical findings, 67
 - positioning, 67
 - postoperative care, 68
 - preoperative planning, 67
 - surgical management, 67
- Dermal sinus excision, 2747–2748, 2748*f*
- Dermatochalasis, 138
- Dermoid cysts, 2745
- Descending genicular artery, approach to, 2488
- Desmoplastic melanoma, 1105, 1106*f*
- Deviated caudal dorsum correction, 329
- Dexamethasone, 1979
- Dextran, 2444
- Diabetes mellitus, 2365, 2373
- Diabetic foot ulcers
 - aggressive wound debridement, 2408

- anatomy, 2407
- definition, 2407
- differential diagnosis, 2408
- flaps and grafts, 2408
- imaging, 2408
- merits and demerits, 2408*b*
- natural history, 2407
- nonoperative management, 2408
- outcomes, 2409
- pathogenesis, 2407
- patient history and physical findings, 2407–2408
- surgical management, 2408
- Diabetic ulcers, 2365
- Diabetics, 2350
- Diagnostic laparoscopy, ambiguous genitalia, 3063
- Diaphyseal fractures, 2471
- Diaphyseal fragments, 2468
- Diaphyseal tibia tumor resection and reconstruction, 2424
- Diazepam, 2683
- Diced cartilage
 - fascia graft, for dorsal augmentation
 - anatomy, 362
 - complications, 365
 - deep temporal fascia harvest, 363, 363*f*
 - definition, 362
 - differential diagnosis, 362
 - imaging, 362
 - merits and demerits, 364*b*
 - nonoperative management, 362
 - pathogenesis, 362
 - patient history and physical findings, 362
 - postoperative care, 364
 - surgical management, 362–363, 363*f*

- techniques, 363, 364*f*
- in rhinoplasty
 - anatomy, 366
 - combined techniques, 371
 - complications, 372
 - DCFG, placement of, 370, 371*f*
 - definition, 366
 - fascial wrapping, 370, 370*f*
 - harvest, 368–369, 368*f*
 - imaging, 366
 - merits and demerits, 371*b*
 - nonoperative management, 367
 - outcomes, 372
 - patient history and physical findings, 366
 - postoperative care, 371–372
 - surgical management, 367–368, 372*f*–371*f*
 - techniques, 369, 369*f*
 - temporal fascia harvest, 369, 369*f*
- Diced cartilage fascia graft (DCFG), 366–367, 372
 - placement of, 370, 371*f*
- DIEA. *See* Deep inferior epigastric artery (DIEA)
- Dieffenbach technique, 1135
- DIEP (deep inferior epigastric artery perforator) flap, 2487–2488
- Diet, 2386, 2444
- Digit(s)
 - duplication (*see* Polydactyly)
 - revision amputation and shortening of
 - fingertip (*see* Fingertip)
- Digital artery sympathectomy
 - anatomy, 2156, 2156*f*
 - complications, 2159
 - definition, 2156
 - differential diagnosis, 2157

- exposure, 2157, 2158*f*
- imaging, 2156–2157
- merits and demerits, 2157*b*, 2158*b*
- natural history, 2156
- nonoperative management, 2157
- outcomes, 2159
- pathogenesis, 2156
- patient history and physical findings, 2156
- postoperative care, 2159
- surgical management
 - approach, 2157
 - patient positioning, 2157
 - preoperative planning, 2157
- Digital fascia, 2176
- Digital nerves
 - anatomy, 1754
 - definition, 1754
 - local anesthesia, 1755–1757, 1756*f*, 1757*f*
- DIO (dorsal interosseous), 2109
- DIPJs. *See* Distal interphalangeal joints (DIPJ) of hand
- Diplopia, 877, 951, 957
- Direct closure and lateral cantholysis
 - anatomy, 1078, 1079*f*
 - canthotomy, 1081, 1081*f*–1082*f*
 - complications, 1082
 - definition, 1078
 - merits and demerits, 1080*b*
 - natural history, 1078
 - nonoperative management, 1079
 - outcomes, 1082
 - pathogenesis, 1078
 - patient history and physical findings, 1078–1079
 - postoperative care, 1082

- primary wound closure, 1080, 1080*f*–1081*f*
- surgical management, 1079
- techniques, 1081
- wound preparation, 1080
- Direct-to-implant (DTI) breast reconstruction
 - anatomy, 1398
 - complications, 1403
 - definition, 1398
 - imaging, 1398
 - merits and demerits, 1401*b*
 - outcomes, 1402–1403
 - with partial muscle coverage and acellular dermal matrix, 1399–1400, 1400*f*, 1401*f*
 - patient history and physical findings, 1398
 - postoperative care, 1401–1402
 - surgical management
 - approach, 1399
 - patient positioning, 1399
 - preoperative planning, 1399, 1399*f*
- Disease-modifying antirheumatic drugs (DMARDs), 1939–1940
- Distal anterior interosseous nerve transfer
 - anatomy, 2043
 - complications, 2047
 - definition, 2043
 - differential diagnosis, 2044
 - imaging, 2044
 - internal topography, 2043, 2043*f*–2044*f*
 - merits and demerits, 2047
 - outcomes, 2047
 - patient history and physical findings, 2044
 - postoperative care, 2047
 - surgical management
 - approach, 2045, 2045*f*

- patient positioning, 2045
- preoperative planning, 2045
- Distal femur osteosarcoma, 2462*f*
- Distal fibula bone tumor, straight lateral approach for, 2344*f*
- Distal fibula resection, 2343–2344
- Distal flap necrosis, 2449
- Distal foot/toe amputation, 2322
- Distal hypospadias repair, tubularized incised plate urethroplasty for
 - anesthesia, 3043
 - initial approach, 3043, 3043*f*
- Distal interphalangeal joints (DIPJ) of hand
 - arthrodesis, 1959, 1959*f*
 - mucous cysts in (*see* Mucous cysts)
 - rheumatoid arthritis
 - arthrodesis of, 1947
 - boutonniere deformity, 1938, 1938*f*
 - dorsal tenodesis of, 1947
 - swan-neck deformities, 1937, 1938*t*
- Distal lower extremity autografts, 2357
- Distal osteotomy, 2435, 2514
- Distal phalanx fractures
 - anatomy, 1775
 - closed reduction and pinning, 1776–1777, 1776*f*–1777*f*
 - complications, 1779
 - definition, 1775
 - imaging, 1776
 - in mallet fingers, 1775
 - merits and demerits, 1778*b*
 - natural history, 1775
 - nonoperative management, 1776
 - open reduction and internal fixation, 1777
 - open seymour fractures (*see* Seymour fractures)
 - outcomes, 1779

- pathogenesis, 1775
- patient history and physical findings, 1776
- postoperative care, 1779
- surgical management, 1776
 - approach, 1776
 - patient positioning, 1776
- types of, 1775, 1775*f*
- Wehbe and Schneider classification, 1775
- Distal radioulnar joint (DRUJ) osteoarthritis
 - Darrach procedure for, 1969, 1970*f*
 - hemiresection arthroplasty, 1970, 1971*f*
 - provocative testing of, 1956
- Distal radius fractures (DRFs)
 - anatomy, 1913, 1913*f*–1914*f*
 - classification systems and eponyms, 1915, 1916*f*
 - complications, 1929–1930
 - definition, 1913
 - differential diagnosis, 1915
 - dorsal bridge plate fixation, 1917
 - additional fracture reduction and fixation, 1926
 - completion and closure, 1926
 - equipment, 1925
 - pertinent anatomy, 1925, 1925*f*
 - plate placement, 1925–1926, 1926*f*
 - postoperative care, 1926, 1927*f*
 - site preparation and exposure, 1925, 1925*f*
 - dorsal plate fixation of, 1923, 1923*f*, 1924*f*
 - external fixation, 1917
 - completion and closure, 1920
 - equipment for, 1919
 - fracture reduction, 1919, 1919*f*
 - pertinent anatomy, 1919, 1919*f*, 1920*f*
 - pin and external fixation frame placement, 1919–1920, 1920*f*

- postoperative care, 1920
- imaging, 1915, 1915*f*
- initial management, 1915–1916, 1916*f*
- merits and demerits, 1927*b*
- nonoperative management, 1916
- outcomes, 1929
- patient history and physical findings, 1913–1915, 1915*f*
- percutaneous pinning, 1917
 - equipment, 1917, 1917*f*
 - Kapandji intrafocal technique for, 1917, 1918*f*
 - Kirschner wire (K-wire) insertion, 1917–1918, 1918*f*
 - placement, 1918, 1918*f*
 - postoperative care, 1918–1919
- surgical management, 1916–1917
 - approach, 1917
 - patient positioning, 1917, 1917*f*
 - preoperative planning, 1916
- volar plating, 1917
 - completion and closure, 1922, 1922*f*
 - equipment for, 1921
 - exposure, 1921, 1921*f*
 - fracture reduction and plate fixation, 1921–1922, 1922*f*
 - pertinent anatomy, 1919*f*, 1921
 - postoperative care, 1922, 1922*f*
- wrist OA, 1957
- Distal thigh, 2317*f*
- Distal ulna, hemiresection arthroplasty of, 1970, 1971*f*
- Distal ulnar groove deepening, 2088
- Distally based medial hemisoleus flap, 2448–2449, 2448*f*
- Distraction osteogenesis (DO), 447
 - Le Fort II osteotomy
 - anatomy, 606, 607*f*
 - complications, 615

- definition, 606, 606*f*
- imaging studies, 606
- indications, 609*b*
- merits and demerits, 614*t*
- outcomes, 615
- postoperative care, 614–615
- pyramidal pattern, 609, 609*f*
- quadrangular osteotomy, 610–613, 610*f*–611*f*
- surgical management, 606–608
- zygomatic repositioning, 610, 610*f*
- temporomandibular joint
 - anatomy, 691
 - complications, 696
 - definition, 691
 - differential diagnosis, 692
 - imaging studies, 692
 - indications, 693
 - merits and demerits, 693*b*
 - natural history, 691–692
 - outcomes, 695–696
 - pathogenesis, 691
 - patient history and physical findings, 692
 - postoperative care, 695
 - reverse distraction, 693–695, 694*f*
 - surgical management
 - extraoral/submandibular approach, 693
 - intraoral approach, 693
 - patient positioning, 693
 - preoperative planning, 691*f*, 693
- DLI (depressor labii inferioris), 14–16
- Dog bites, 3075
- Dominant nutrient artery, 2432
- Donor and recipient nerves, mobilization and transection, 2052

- Donor site closure, 1658, 1658*f*, 1694–1695
- Donor strip harvest, hair transplantation, 424, 424*f*
- Donor-site defect, keystone flaps to close, 1747, 1747*f*
- Donor-site repair, flap advancement and final closure, 1087, 1087*f*
- Doppler Allen test, 2115
- Doppler probe, 2512, 2515, 2524
- Doppler sonography, 2134
- Doppler ultrasound, 2129
- Dorsal aesthetic lines (DALs), 334, 380
- Dorsal augmentation
 - diced cartilage, fascia graft for
 - anatomy, 362
 - complications, 365
 - deep temporal fascia harvest, 363, 363*f*
 - definition, 362
 - differential diagnosis, 362
 - imaging, 362
 - merits and demerits, 364*b*
 - nonoperative management, 362
 - pathogenesis, 362
 - patient history and physical findings, 362
 - postoperative care, 364
 - surgical management, 362–363, 363*f*
 - techniques, 363, 364*f*
 - using alloplastic material
 - anatomy, 350, 350*f*–351*f*
 - completion, 359, 359*f*
 - complications, 360, 360*f*
 - definition, 350
 - e-PTFE implant, pretreatment of, 356, 356*f*
 - implant carving, 353–354, 353*f*
 - implant deviation, correction of, 359, 359*f*
 - implant insertion, 356, 357*f*

- implant wrapped with temporal fascia/allograft dermis, 358, 358*f*
- incision, 354–355, 354*f*
- merits and demerits, 359*b*
- patient history and physical findings, 350
- pocket, dissection for, 355–356, 355*f*–356*f*
- postoperative care, 360
- supratip area, management of, 357, 357*f*–358*f*
- surgical management, 350–352, 351*f*, 352*f*
- using costal cartilage graft
 - anatomy, 343, 343*f*
 - complications, 349
 - definition, 343
 - dorsal graft, preparing and affixing, 344–345, 345*f*–346*f*
 - harvesting, 344, 344*f*
 - merits and demerits, 348*b*
 - outcomes, 349, 349*f*
 - patient history and physical findings, 343
 - postoperative care, 349
 - surgical management, 343
 - transosseous suture/K-wire, use of, 347–348, 347*f*–348*f*
- Dorsal foot arterial anatomy, 2168, 2168*f*–2169*f*
- Dorsal hand compartment release, 1762, 1762*f*
- Dorsal hump, open rhinoplasty with
 - anatomy, 294
 - complications, 296
 - correction of, 294, 295*f*
 - definition, 294
 - imaging, 294
 - merits and demerits, 296*b*
 - outcomes, 296
 - patient history and physical findings, 294
 - postoperative care, 296

- surgical management, 294
- Dorsal intercalated segmental instability (DISI), 1851, 1857, 1899
- Dorsal metatarsal artery flap, 2368*f*–2369*f*
- Dorsal plication, correction of chordee with, 3044, 3044*f*
- Dorsal rectangular flap, finger syndactyly release
 - anatomy, 2216, 2216*f*–2217*f*
 - complications, 2222
 - definition, 2216
 - dorsal markings, 2218, 2219*f*
 - dressings and immobilization, 2221–2222, 2222*f*
 - flap creation, 2219, 2221*f*
 - grafting, 2219–2221, 2221*f*
 - imaging, 2216–2217, 2217*f*
 - merits and demerits, 2218*b*, 2222*b*
 - natural history, 2216
 - outcomes, 2222
 - patient history and physical findings, 2216
 - postoperative care, 2222
 - surgical management
 - approach, 2218
 - patient positioning, 2218
 - preoperative planning, 2217–2218
 - volar markings, 2219, 2219*f*
- Dorsalis pedis artery, 2369, 2378–2379
- Dorsally displaced distal radius fractures, 1987
- Dorsoulnar fibers, 1986*f*
- Double barrel fibula technique, 2515, 2515*f*
- Double crush, 2412
- Double extended V-Y flap, 1183
- “Double Eyelid” surgery. *See* Asian blepharoplasty
- Double follicular units (DFU), 421
- Double-barrelled fibula technique, 2436, 2436*f*
- Double-injection method, 326

- Double-opposing postauricular and preauricular flaps, 1138–1140, 1139*f*
- Double-opposing Z-plasty
- Doyle stents, 332
- Drainage of abscesses. *See* Abscesses drainage, of lower leg and foot
- Drawbridge effect, 2676
- Drop piriform wires, 959–962, 961*f*
- DRUJ (distal radioulnar joint), 2126, 2128–2129
- Dry eye, 2871
- Dry liposuction, 2572–2573
- DSN muscle. *See* Depressor septi nasi (DSN) muscle
- DTF (deep temporal fascia), 872, 873*f*
- Dual plane augmentation
 - anatomy, 1314
 - complications, 1318
 - definition, 1314
 - imaging, 1314–1315, 1314*f*
 - merits and demerits, 1316*b*, 1317*b*
 - outcomes, 1318
 - pathogenesis, 1314
 - patient history and physical findings, 1314
 - postoperative care, 1318
 - surgical management
 - approach, 1315–1316, 1315*f*–1316*f*
 - patient positioning, 1315
 - preoperative planning, 1315, 1315*f*
- Duplex arteriogram, 2365
- Dupuytren disease
 - anatomy, 2176, 2176*f*–2177*f*
 - Checkrein ligament release, 2183, 2183*f*
 - complications, 2184
 - definition, 2176

- imaging, 2178
- merits and demerits, 2183*b*
- natural history, 2178
- nonoperative management, 2178
- outcomes, 2184
- pathogenesis, 2177–2178, 2177*f*
- patient history and physical findings, 2178
- postoperative care, 2184
- surgical management
 - approach, 2178–2179
 - patient positioning, 2178
 - preoperative planning, 2178
- Dura and myofascial closure, 3015
- Dura, myofascial, and skin closure, 3010, 3010*f*
- Durkan carpal compression test, 1977
- Dutasteride, 418
- Dynamic rhytids, 5
- Dynamic spacers, 2469
- Dynamic sphincter pharyngoplasty
 - dissection, 2709, 2710*f*
 - markings, 2709, 2710*f*
 - surgical management, 2707
- Dyschromia, 55
- Dysesthesia, prominent ears, 2840

E

- Ear cartilage exposure, cryptotia, 2834
- Ear lacerations, 3080, 3081*f*
- Ear lobe
 - anatomy, 1138
 - complications, 1141
 - definition, 1138

- double-opposing postauricular and preauricular flaps, 1138–1140, 1139*f*
- imaging, 1138
- with local flaps, 1138, 1139*f*
- longitudinally folded preauricular flap, 1140, 1140*f*
- merits and demerits, 1139*b*
- patient history and physical findings, 1138
- postoperative care, 1141
- surgical management, 1138–1139
- Ear lobules. *See* Ear lobe
- Ear reconstruction
 - antia-buch flaps
 - anatomy, 1129
 - “classic” helix-only defect, 1130, 1130*f*
 - complications, 1132
 - definition, 1129
 - helical-scapal defect, 1131, 1131*f*
 - helical-scapal-antihelix defect, 1131, 1131*f*
 - imaging, 1129
 - merits and demerits, 1130*b*
 - modifications, 1130
 - nonoperative management, 1129
 - outcomes, 1132
 - patient history and physical exam, 1129
 - postoperative care, 1132
 - superior and inferior incisions, 1130
 - surgical management, 1129
 - V-Y advancement flap, 1130, 1130*f*, 1131*f*
 - ear lobe
 - anatomy, 1138
 - complications, 1141
 - definition, 1138
 - double-opposing postauricular and preauricular flaps,

- 1138–1140, 1139*f*
 - imaging, 1138
 - with local flaps, 1138, 1139*f*
 - longitudinally folded preauricular flap, 1140, 1140*f*
 - merits and demerits, 1139*b*
 - patient history and physical findings, 1138
 - postoperative care, 1141
 - surgical management, 1138–1139
- postauricular flap
 - anastomotic network, 1133
 - anatomy, 1133, 1133*f*
 - complications, 1137
 - definition, 1133
 - imaging studies, 1134
 - marginal ear defects, 1134–1135, 1134*f*, 1135*f*
 - merits and demerits, 1135*b*
 - patient history and physical findings, 1134
 - postoperative care, 1136
 - surgical management, 1134
- Ear region, panfacial fractures, 934
- Early infection, 2469
- ECA (extensor compartmental artery) vascularized bone flap
- ECRL (extensor carpi radialis longus), 2001*b*, 2001*f*, 2002*f*
 - to flexor digitorum profundus transfer, 2212, 2212*f*
 - tenodesis, for scapholunate dissociation, 1903
- ECU (extensor carpi ulnaris), 2126, 2130–2132, 2131*f*
- ECU tendon subluxation. *See* Extensor carpi ulnaris (ECU) tendon subluxation
- EDC (extensor digitorum communis), 2109, 2131
- Edema
 - antia-buch flaps, 1132
 - prevention, 2453
- EDM (extensor digiti minimi), 2040, 2126, 2130–2132, 2131*f*

- Ehrlich approach, prune belly, 3023
- EIP (extensor indicis proprius), 2033*f*, 2036–2037, 2109
- Elbow extension procedures
 - anatomy, 2186
 - complications, 2195
 - definition, 2186
 - imaging, 2188
 - merits and demerits, 2190*b*, 2194*b*
 - nonoperative management, 2188
 - outcomes, 2195
 - patient history and physical findings, 2186–2188
 - postoperative care, 2195
 - surgical management
 - approach, 2189
 - patient positioning, 2189
 - preoperative planning, 2189
- Elbow flexion test, 1993
- Elbow reconstruction. *See also* Neonatal brachial plexus palsy (NBPP)
 - complications, 2968
 - elbow release, 2959–2960, 2960*f*
 - outcomes, 2968
 - postoperative care, 2967
 - restoration of elbow flexion
 - free functioning gracilis transfer, 2963, 2963*f*
 - latissimus dorsi transfer, 2962–2963, 2962*f*
 - steindler flexorplasty, 2961–2962, 2961*f*
- Elbow splints, 2635
- Electrocautery, 389*f*
- Electrodiagnostic studies
 - cubital tunnel syndrome, 1993
 - median and ulnar nerve injuries, 2035
 - ulnar tunnel syndrome, 1988

- Empty nose syndrome, 275
- Encephalocele, 2745
- Enchondroma
 - anatomy, 2295
 - complications, 2297
 - definition, 2295
 - differential diagnosis, 2295
 - excision and bone grafting, 2296, 2296*f*–2297*f*
 - imaging, 2295, 2295*f*
 - incidental, 2295
 - merits and demerits, 2297*b*
 - natural history, 2295
 - nonoperative management, 2295–2296
 - outcomes, 2297
 - pathogenesis, 2295
 - patient history and physical findings, 2295
 - postoperative care, 2297
 - radiograph of, 2295, 2295*f*
 - surgical management, 2296
 - approach, 2296
 - preoperative planning, 2296
- Endochondral and intramembranous ossification, 509, 509*f*–510*f*
- Endonasal access, 272, 272*f*
- Endonasal rhinoplasty, 272
- Endonasal spreader graft placement, 300–302
- Endoprosthesis, 2424, 2503
- Endoscopic brow lifting, 79–80, 79*f*
 - anatomy, 77, 78*f*
 - approach, 78
 - complications, 81
 - definition, 77
 - endoscopic brow lift, 79–80, 79*f*
 - imaging, 77

- merits and demerits, 81*b*
- nonoperative management, 77
- outcomes, 81
- pathogenesis, 77
- patient history and physical findings, 77
- patient positioning, 78
- postoperative care, 81
- preoperative planning, 78
- surgical management, 78, 78*f*
- suspension, 80–81, 80*f*
- Endoscopic endonasal marsupialization
 - anterior ethmoidectomy, 804, 805*f*
 - completion process, 806
 - frontal dissection, 805, 805*f*
 - maxillary antrostomy, 804, 805*f*
 - uncinectomy, 804*f*
- Endoscopy
 - ambiguous genitalia, 3063
 - Poland syndrome, 2980, 2980*f*
 - sagittal synostosis
 - incisions and endoscope insertion, 481, 481*f*
 - spring placement, 481, 482*f*
 - spring removal, 481
- End-to-end microanastomoses, 2490
- End-to-side anastomosis, 2442, 2526, 2526*f*
- End-to-side microanastomoses, 2490
- Enophthalmos, 809–810, 824, 951, 957
 - secondary correction of
 - anatomy, 847
 - complications, 851
 - definition, 847
 - imaging, 848
 - merits and demerits, 851*b*

- natural history, 848
- orbital floor repair, 851, 851*f*
- outcomes, 851
- pathogenesis, 847–848
- patient history and physical findings, 848, 849*f*
- periorbital repair, 849, 850*f*
- postoperative care, 851
- surgical management, 848–849
- zygoma repair, 850, 850*f*
- Enoxaparin, 2444
- Enzymatic debridement, 2430
- EPB (extensor pollicis brevis) tendon, 2112
- Epiblepharon
 - anatomy, 2857
 - complications, 2862
 - definition, 2857
 - merits and demerits, 2862*b*
 - nonoperative management, 2858
 - outcomes, 2862
 - with outlining markings, 2858*f*
 - pathogenesis, 2857
 - patient history and physical findings, 2857, 2857*f*
 - postoperative care, 2861–2862
 - surgical management
 - approach, 2858–2861
 - patient positioning, 2858
 - preoperative planning, 2858
- Epidural abscess, 2330
- Epidural analgesia, 2326
- Epidural anesthesia
 - anatomy, 2326, 2326*t*, 2328*b*
 - complications, 2330
 - contraindications to, 2327

- definition, 2326
- imaging, 2327
- merits and demerits, 2329*t*
- nonoperative management, 2327
- outcomes, 2330
- patient history, 2327
- physical findings, 2327
- postoperative care, 2329–2330
- surgical management, 2327
 - anesthetic administration, 2329
 - epidural placement, 2328, 2328*f*
 - lumbar and thoracic epidurals, approaches to, 2327
 - patient positioning, 2327, 2328*f*
 - preoperative planning, 2327
 - preparation, 2328
- Epidural hematoma, 2330
- Epidural injection, vertebral levels for, 2328*b*
- Epinephrine, 186, 2328–2329, 2631, 2633
 - bilateral cleft lip repair, 2638
 - emergency room anesthesia, 3077
 - eyelid coloboma, 2843
 - local anesthesia, 972
 - nasal tip hemangioma, 2888
 - neck contracture, 2781
 - secondary deformities, of lip and nose, 2645, 2648
- Epineurial repair, 2004, 2004*f*
- Epistaxis, open treatment of nasal fractures, 864
- Epitendinous repair with Silfverskiöld sutures, 2059, 2059*f*
- Epithelioid sarcoma, 2421
- e-PTFE (expanded polytetrafluoroethylene), 351, 356, 356*f*
- Erector spinae
 - anatomy, 1727
 - complications, 1729

- definition, 1727
- imaging, 1727
- muscle flap, 1728–1729, 1728*f*–1729*f*
- outcomes, 1729
- patient history and physical findings, 1727
- postoperative care, 1729
- surgical management
 - approach, 1727
 - patient positioning, 1727
 - preoperative planning, 1727
- Erythematous follicular popular, 66
- Erythrocyte sedimentation rate (ESR), 2467, 2471, 2474
- Estlander flaps
 - anatomy, 1055, 1055*f*
 - complications, 1058
 - definition, 1055
 - external landmarks, 1055
 - imaging, 1056
 - lower lip, 1057, 1057*f*
 - merits and demerits, 1058*b*
 - outcomes, 1058, 1058*f*
 - patient history and physical findings, 1055, 1056*f*
 - postoperative care, 1058
 - surgical management
 - approach, 1056
 - patient positioning, 1056
 - preoperative planning, 1056
 - upper lip, 1056, 1056*f*–1057*f*
- Ethmoid bone, medial orbit wall fractures, 829, 829*f*
- Ethnic rhinoplasty
 - alar cartilage resection, 291
 - alar wedge resection, 292
 - anatomy, 288–289

- complications, 293
- definition, 288
- dorsal resection, 290, 290*f*
- graft placement and wound closure, 291–292
- imaging, 289
- merits and demerits, 292*b*
- nasal spine–caudal septum, 290, 290*f*
- open approach, 317, 317*f*
 - anatomy, 315
 - definition, 315
 - grafting, harvesting cartilage for, 316–317, 316*f*
 - middle nasal vault, 318, 318*f*
 - nasal base, stabilizing, 319, 319*f*
 - nasal dorsum, managing, 317, 318*f*
 - nasal septum, exposing, 317, 317*f*
 - nasal tip, managing, 319–321, 320*f*
 - patient history and physical findings, 315–316, 316*f*
 - surgical management, 316
- osteotomy, 292, 292*f*
- outcomes, 293, 293*f*
- patient history and physical findings, 289
- postoperative care, 293
- septoplasty and spreader graft tunnels, 291
- skeletonization, 290
- surgical management, 289
 - approach, 289
 - patient positioning, 289
 - preoperative planning, 289
- turbinectomy, 291
- upper lateral cartilages and shortening the nose, 291, 291*f*
- Etidocaine, 2329
- European League Against Rheumatism (EULAR), 1931
- Eustachian tubes, 2658

- Eutectic mixture of local anesthetics (EMLA) cream, 3077
- Everting sutures, 2861, 2861*f*
- Ewing sarcoma, 2424*f*, 2460
- Excess lower lateral cartilages, long nose, 336, 336*f*
- Exchange of expander, permanent implant
 - complications, 1397
 - definition, 1393
 - implant pocket creation, 1394–1396, 1395*f*
 - implant selection and closure, 1396–1397, 1396*f*
 - merits and demerits, 1397*b*
 - outcomes, 1397
 - patient history and physical findings, 1393
 - postoperative care, 1397
 - surgical management
 - implant selection, 1393–1394
 - patient positioning, 1394
 - preoperative planning, 1393–1394
 - tissue expander removal, 1394, 1394*f*
- Excisional debridement, 1701, 1718
- Expanded polytetrafluoroethylene (e-PTFE), 351, 356, 356*f*
- Expander exchange, permanent implant
 - complications, 1397
 - definition, 1393
 - implant pocket creation, 1394–1396, 1395*f*
 - implant selection and closure, 1396–1397, 1396*f*
 - merits and demerits, 1397*b*
 - outcomes, 1397
 - patient history and physical findings, 1393
 - postoperative care, 1397
 - surgical management
 - implant selection, 1393–1394
 - patient positioning, 1394
 - preoperative planning, 1393–1394

- tissue expander removal, 1394, 1394*f*
- Extended skin paddle option, 1657, 1657*f*
- Extended SMAS facelift and necklift
 - anatomy, 211, 211*f*
 - complications, 214
 - definition, 211
 - merits and demerits, 214*b*
 - outcomes, 214, 214*f*
 - patient history and physical findings, 211
 - postoperative care, 214
 - surgical management, 211
 - approach, 211
 - patient positioning, 211
 - preoperative planning, 211
 - techniques, 212*b*
 - incisions and dissection, 212–213, 212*f*
 - redraping and fixation, 213, 213*f*
- Extended vertical rectus myocutaneous (eVRAM) flap, 2518*f*
- Extended vertical thigh lift, 1652–1653, 1652*f*–1653*f*
- Extended V-Y flap, 1183
- Extensive lateral mandible defect, 1048, 1049*f*
- Extensor carpi radialis brevis (ECRB), 2026, 2026*f*–2027*f*
 - to adductor pollicis, 2022, 2023*f*
 - to adductor pollicis with tendon graft, 2022, 2023*f*
 - to AdP tendon transfer, 2037
 - to AdP with tendon graft, 2037, 2038*f*–2039*f*
 - anatomy, 2196
 - to lateral bands with tendon graft, 2022, 2022*f*
 - tendon transfer, brachioradialis, 2198, 2198*f*–2199*f*
- Extensor carpi radialis longus (ECRL), 2001*b*, 2001*f*, 2002*f*
 - to flexor digitorum profundus transfer, 2212, 2212*f*
 - tenodesis, for scapholunate dissociation, 1903
- Extensor carpi ulnaris (ECU) tendon subluxation

- anatomy, 2085
- complications, 2089
- definition, 2085
- differential diagnosis, 2086
- exposure, 2087
- imaging, 2086
- merits and demerits, 2088*b*
- natural history, 2085
- nonoperative management, 2086
- outcomes, 2089
- pathogenesis, 2085
- patient history and physical findings, 2085–2086
- postoperative care, 2089
- surgical management
 - patient positioning, 2086
 - preoperative planning, 2086
- Extensor compartmental artery (ECA) vascularized bone flap, 1881–1882, 1882*f*
- Extensor digitorum communis
 - flexor carpi radialis, 2027, 2028*f*
 - flexor carpi ulnaris, 2027, 2028*f*
 - flexor digitorum superficialis, 2028–2029, 2029*f*
- Extensor digitorum longus (EDL) tendons, 2363
- Extensor hallucis longus (EHL) tendon, 2344, 2346, 2363
- Extensor indicis proprius (EIP), 2033*f*, 2036–2037
 - to abductor pollicis brevis, 2015–2016, 2016*f*
- Extensor pollicis longus (EPL) tendon, 2023, 2023*f*
 - palmaris longus, 2029, 2030*f*
- Extensor retinaculum, anterior approach to, 2494
- Extensor tendon injuries
 - anatomy, 2078–2079, 2078*f*–2079*f*
 - complications, 2084
 - definition, 2078

- differential diagnosis, 2080
- imaging, 2080
- merits and demerits, 2084*b*
- natural history, 2080
- nonoperative management, 2080–2081
- outcomes, 2084
- pathogenesis, 2079
- patient history and physical findings, 2080, 2080*f*
- postoperative care, 2084
- surgical management
 - approach, 2081
 - patient positioning, 2081
 - preoperative planning, 2081
- Extensor tendon rehabilitation, 2077
- Extensor tenolysis with/without dorsal capsular release, 2075, 2075*f*
- External auditory meatus, 1133
- External dacryocystorhinostomy, 2874, 2874*f*
- External distraction, Le Fort III osteotomy of
 - anatomy, 621
 - complications, 631, 632*f*
 - curved tip osteotomy, 623*f*, 626
 - definition, 621
 - device placement, 627, 627*f*–628*f*
 - exposure, 625–626, 625*f*
 - imaging, 622, 624*f*
 - lateral orbital wall osteotomy, 621*f*, 626, 628, 629*f*
 - merits and demerits, 625*b*
 - mobilization, 626, 626*f*
 - nasofrontal osteotomy, 621*f*, 626
 - outcomes, 630–631, 630*f*–631*f*
 - pathogenesis, 621
 - patient history and physical findings, 622, 623*f*
 - postoperative care, 630

- skull-cranial bones and facial bones, 621, 623*f*
- surgical management, 624
- traditional lines, 621, 621*f*
- External mandibular distraction
 - with pins
 - corticotomy, 725, 726*f*
 - exposure and dissection, 725, 725*f*
 - placement, 725–726, 726*f*
 - uniplanar or multiplanar distraction devices, 726, 727*f*
 - with rigid external device, 727–728, 728*f*–729*f*
- External nasal nerve, 966, 966*f*
- External nasal valve repair, nasal airway obstruction, 384, 384*f*
- External oblique aponeurotomy, 1557, 1557*f*, 1559, 1564, 1564*f*
- External oblique muscle, 1563
- External transfacial mandibular distraction
 - anatomy, 733
 - complications, 737, 738*f*
 - definition, 733
 - differential diagnosis, 733
 - exposure, 734, 735*f*
 - imaging, 733
 - merits and demerits, 734*b*
 - nonoperative management, 733–734
 - osteotomy and completion, 736, 736*f*
 - outcomes, 737
 - pathogenesis, 733
 - patient history and physical findings, 733
 - pin passage, 735, 735*f*–736*f*
 - postoperative care, 737, 737*f*
 - surgical management
 - patient positioning, 734–737
 - preoperative planning, 734
- External valve stenosis, 381

- Extramucosal internal stents, 332
- Extraoral approach, 602
- Extremity lymphedema, fasciocutaneous debulking of
 - anatomy, 2567
 - complications, 2570
 - definition, 2567
 - imaging, 2567
 - merits and demerits, 2568*b*, 2569*b*
 - outcomes, 2570
 - patient history and physical exam, 2567
 - postoperative care, 2570
 - radical debridement with split-thickness skin grafts, 2568–2569, 2569*f*
 - staged excision, 2569
 - surgical management
 - approach, 2568
 - patient positioning, 2568
 - preoperative planning, 2568
- Extubation, 2694
- Eye contracture, 2766, 2766*f*–2767*f*
- Eyebrow, position of, 3
- Eyelid(s)
 - anatomy, 2777
 - definition, 2777
 - merits and demerits, 2779*b*
 - nonoperative management, 2777
 - pathogenesis, 2777
 - patient history and physical findings, 2777
 - surgical management, 2777–2778
 - lower lid, 2777
 - patient positioning, 2778
 - preoperative planning, 2778
 - upper lid, 2777

- Eyelid coloboma
 - anatomy, 2842
 - complications, 2847
 - definition, 2842
 - differential diagnosis, 2843
 - merits and demerits, 2847*b*
 - natural history, 2842
 - nonoperative management, 2843
 - outcomes, 2847
 - pathogenesis, 2842
 - patient history and physical findings, 2842, 2842*f*
 - postoperative care, 2847
 - surgical management, 2843–2847
 - approach, 2843–2847
 - patient positioning, 2843
 - preoperative planning, 2843
- Eyelid defects
 - assessment, 1078
 - full-thickness, 1078, 1080*f*–1081*f*
 - incomplete closure, 1078
- Eyelid ectropion/entropion, 2871
- Eyelid lacerations, 3080, 3080*f*
- Eyelid reconstruction
 - Cutler-Beard flap (*see* Cutler-Beard flap)
 - direct closure and lateral cantholysis
 - anatomy, 1078, 1079*f*
 - canthotomy, 1081, 1081*f*–1082*f*
 - complications, 1082
 - definition, 1078
 - merits and demerits, 1080*b*
 - natural history, 1078
 - nonoperative management, 1079
 - outcomes, 1082

- pathogenesis, 1078
- patient history and physical findings, 1078–1079
- postoperative care, 1082
- primary wound closure, 1080, 1080*f*–1081*f*
- surgical management, 1079
- techniques, 1081
- wound preparation, 1080
- Hughes flap (*see* Hughes flap)
- lateral tarsal strip canthoplasty
 - anatomy, 1103
 - complications
 - definition, 1103
 - imaging, 1104
 - markings and anesthesia, 1103*f*, 1105
 - merits and demerits, 1105*b*
 - natural history, 1104
 - nonoperative management, 1104
 - outcomes, 1107
 - pathogenesis, 1103–1104
 - patient history and physical findings, 1104
 - postoperative care, 1107
 - removal of, 1103*f*–1104*f*, 1105–1106
 - strip placement, 1107
 - surgical management, 1104
- with palatal grafts
 - complications, 1098
 - definition, 1094
 - hard palate, 1095–1097, 1095*f*, 1097*f*
 - lamellar anatomy, 1094–1095, 1094*f*
 - merits and demerits, 1096*b*
 - patient history, 1095
 - physical examination, 1096
 - postoperative care, 1098

- surgical management, 1096
- tenzel semicircular rotational flap
 - anatomy, 1084
 - complications, 1088
 - definition, 1084
 - design and flap elevation, 1086, 1086*f*
 - donor-site repair, 1087, 1087*f*
 - flap inset, 1086*f*, 1087
 - merits and demerits, 1086*b*
 - nonoperative management, 1084
 - outcomes, 1088
 - patient history and physical findings, 1084
 - posterior lamellar flap, 1087
 - postoperative care, 1088
 - surgical management, 1085
 - tarsal edges, 1086, 1086*f*
- Eyelid retractors
 - lower, 1090
 - upper, 1090
- Eyelid-cheek junction, 50

F

• Face

- dermabrasion to
 - anatomy 67
 - approach, 67
 - complications, 68
 - definition, 67
 - mechanical dermabrasion, 67, 68*f*
 - merits and demerits, 68*b*
 - outcomes, 68
 - patient history and physical findings, 67
 - patient positioning, 67
 - postoperative care, 68
 - preoperative planning, 67
 - surgical management, 67
- laser resurfacing of
 - ablative fractional resurfacing, 52*f*, 54
 - ablative nonfractional resurfacing, 54
 - anatomy, 52, 52*f*
 - complications, 55–56
 - definition, 52
 - imaging, 54
 - nonablative fractional resurfacing, 52*f*, 54
 - outcomes, 55, 55*f*–56*f*
 - pathogenesis, 52
 - patient history and physical findings, 52, 54*b*
 - postoperative care, 55
 - surgical management, 54
- local anesthesia (*see* Local Anesthesia)
- sensory and motor nerve anatomy, 1123*f*
- TCA peel to

- anatomy, 57
- awake patient, cotton tip applicator on, 58
- complications, 58–59
- definition, 57
- merits and demerits, 58*b*
- outcomes, 58
- patient history and physical findings, 57
- postoperative care, 58
- sedated patient, cotton tip applicator on, 57, 58*f*
- surgical management, 57
- vital structures, 975, 975*f*
- Face-lifting and neck lifting techniques, 201
 - anatomy, 201
 - anterior neck treatment, 206–208, 207*f*
 - complications, 209–210, 210*f*
 - imaging, 201
 - incisions, 203, 204*f*
 - merits and demerits, 209*b*
 - outcomes, 209
 - patient history and physical findings, 201
 - postoperative care, 209
 - skin flap elevation, 204–205, 204*f*–205*f*
 - SMAS treatment options, 205–206, 206*f*
 - surgical management, 202–203
 - patient positioning, 203
 - patient preparation, 202–203
 - preoperative planning, 202
- Facial aging, 201
- Facial artery, 1122
 - dissection and exposure, 1176, 1176*f*
 - musculomucosal flap, 2701, 2701*f*, 2704
 - myomucosal flap, 1220
 - perforator flap

- arterial anatomy, 1188, 1188*f*
- basal cell carcinoma, 1189*f*–1190*f*
- complications, 1192
- definition, 1188
- imaging, 1189
- merits and demerits, 1190*b*
- outcomes, 1192
- patient history and physical findings, 1188–1189, 1189*f*–1190*f*
- postoperative care, 1192
- to repair perioral defect, 1190–1191, 1191*f*
- secondary revision surgery, 1191, 1191*f*
- small cell carcinoma
- surgical management, 1189
- venous, 1188, 1188*f*
- Facial artery musculomucosal (FAMM) flap
 - arterial anatomy, 1193
 - buccal mucosal defects, 1222–1223, 1223*f*
 - complications, 1197
 - definition, 1193
 - inferiorly based FAMM flap, 1194
 - intact upper jaw dentition vs. edentulous alveolar cleft deformities, 1194
 - merits and demerits, 1195*b*
 - outcomes, 1197
 - patient history and physical findings, 1194
 - postoperative care, 1197
 - superiorly based FAMM flap, 1194
 - surgical management
 - approach, 1195
 - patient positioning, 1195
 - preoperative planning, 1195
 - venous anatomy, 1193
- Facial bipartition

- anatomy, 542–543, 543*f*
- anterior vault reconstruction, 550, 550*f*
- central wedge excision, 549
- circumferential orbital osteotomies, 548, 548*f*
- complications, 553–554
- definition, 542, 542*f*
- differential diagnosis, 545
- downfracture, 549
- exposure, 547–548, 547*f*
- frontonasal osteotomies, 549
- hypertelorism, 543, 547*b*
- imaging, 545, 545*f*
- mechanisms of arrest, 543
- merits and demerits, 551*t*
- natural history, 544
- nonoperative management, 545
- outcomes, 552, 552*f*–553*f*
- patient history and physical findings, 544, 544*f*
- postoperative care, 552
- soft tissue reconstruction, 551, 551*f*
- surgical management
 - approach, 546
 - hypertelorism, 545
 - indications, 545
 - osteotomy, 545, 546*f*
 - patient positioning, 546
 - preoperative planning, 546, 547*f*
 - timing, 545
- two halves stabilization, 549, 550*f*
- zygomatic and maxillary osteotomies, 549
- Facial clefts
 - complications, 655
 - definition, 650

- differential diagnosis, 653
- imaging, 653
- merits and demerits, 655*t*
- nonoperative management, 653
- outcomes, 655
- pathogenesis, 650
- patient history and physical findings, 650–653
- postoperative care, 655
- surgical management
 - patient positioning, 653
 - preoperative planning, 653
 - Z-plasty approach, 653
- surgical technique, 654–655, 654*f*
- Tessier classification, 650, 650*f*, 654*b*
- Facial fat, 164
- Facial hair transplantation, 429
- Facial harmony, 338
- Facial laceration emergency room closure techniques, 3074–3083
- Facial laceration locations, 3078*t*
- Facial lacerations
 - anatomy, 975, 975*f*
 - definition, 975
 - differential diagnosis, 976
 - imaging, 976
 - natural history, 975–976
 - nonoperative management, 976
 - outcomes, 979
 - pathogenesis, 975
 - patient history, 976
 - physical findings, 976
 - postoperative care, 979
 - surgical management
 - approach, 977

- indications, 976
- patient positioning, 976–977
- preoperative planning, 976
- techniques
 - facial nerve injuries, 978
 - lacrimal system/eyelid injuries, 978
 - local anesthetic, administration of, 977, 977*f*
 - parotid duct injuries, 978
 - suture techniques, 978, 978*f*
 - wound irrigation, 977
 - wound preparation, 977
- Facial nerve
 - anatomy, 2932, 2933*f*
 - condyle fractures, 916
 - injury, 200, 978, 3081–3082, 3082*f*
 - skin-only face and neck lifting, 196
- Facial nerve blocks
 - infraorbital nerve block, 970, 970*f*
 - mental nerve block, 971, 971*f*
 - supraorbital and supratrochlear nerves, 970, 970*f*
- Facial osteotomy, 538, 539*f*
- Facial paralysis, 297
 - anatomy, 2933*f*
 - causes, 2936*b*
 - complications, 1271
 - definition, 1262, 2932
 - imaging, 1264
 - lengthening temporalis myoplasty
 - completion process, 1269
 - definition, 1262
 - elevation and advancement, 1269, 1270*f*
 - flap harvest, 1268–1269, 1268*f*–1269*f*
 - surgical management, 1264, 1264*f*

- merits and demerits, 1265*b*
- outcomes, 1271
- pathogenesis of, 2932
- patient history, 1262
- physical examination, 1262
- postoperative care, 1271
- smile assessment, 1263
- surgical management
 - approach, 1264
 - patient positioning, 1264
 - preoperative planning, 1264, 1265*f*
- temporalis muscle flap
 - definition, 1262
 - dissection, 1265, 1265*f*
 - flap elevation, 1265–1266, 1266*f*
 - flap inset and completion, 1267, 1267*f*
 - interposition graft, 1266–1267
 - neurovascular supply, 1262, 1263*f*
 - retrograde temporalis flap, 1264
 - superficial and deep layers, 1262, 1263*f*
 - surgical management, 1264
- Facial reanimation. *See also* Pediatric facial reanimation
 - anatomy, 1255–1256
 - Babysitter nerves
 - complications, 1285
 - cross face nerve graft, 1282–1283, 1283*f*–1284*f*
 - definition, 1277
 - exposure, 1280–1281, 1280*f*–1281*f*
 - flowchart, 1279, 1279*f*
 - mandibular branch, 1277*f*, 1278
 - merits and demerits, 1280*b*
 - motor nerve to masseter, 1281–1282, 1282*f*
 - outcomes, 1285

- pathogenesis, 1278
- patient history and physical findings, 1278
- postoperative care, 1284–1285
- superficial muscle fibers, 1277–1278, 1277*f*
- surgical management, 1279–1280
- temporal branch, 1277*f*, 1278
- zygomatic division, 1277*f*, 1278
- cross-face nerve grafts
 - donor nerve selection, 1259–1260
 - facial nerve exposure, 1259
 - tunnel creation and nerve reconstruction, 1260, 1260*f*
- definition, 1255
- dual minihypoglossal and masseteric nerve transfers, 1259, 1259*f*
- free flap defect repair, 1258, 1258*f*
- merits and demerits, 1257*b*
- nerve grafting, 1257–1258, 1257*f*
- nerve-to-masseter transfer, 1258–1259, 1258*f*
- outcomes, 1261, 1261*f*
- patient history and physical findings, 1256
- surgical management, 1256
- Facial reconstruction, autologous vs. prosthetic techniques for, 3086*b*
- Facial soft tissue injury
 - anatomy, 3074, 3074*f*–3075*f*, 3078*b*
 - complications, 3083, 3083*f*
 - definition, 3074
 - merits and demerits, 3082*b*
 - nonoperative management, 3076
 - outcomes, 3083
 - pathogenesis, 3074–3075
 - patient history and physical findings, 3076
 - postoperative care, 3083
 - surgical management, 3076–3078, 3076*f*

- approach, 3077–3078
- patient positioning, 3077
- preoperative planning, 3076–3077
- FAMM. *See* Facial artery musculomucosal (FAMM) flap
- Fascia graft
 - for dorsal augmentation
 - anatomy, 362
 - complications, 365
 - deep temporal fascia harvest, 363, 363*f*
 - definition, 362
 - differential diagnosis, 362
 - imaging, 362
 - merits and demerits, 364*b*
 - nonoperative management, 362
 - pathogenesis, 362
 - patient history and physical findings, 362
 - postoperative care, 364
 - surgical management, 362–363, 363*f*
 - techniques, 363, 364*f*
 - in rhinoplasty
 - anatomy, 366
 - combined techniques, 371
 - complications, 372
 - DCFG, placement of, 370, 371*f*
 - definition, 366
 - fascial wrapping, 370, 370*f*
 - harvest, 368–369, 368*f*
 - imaging, 366
 - merits and demerits, 371*b*
 - nonoperative management, 367
 - outcomes, 372
 - patient history and physical findings, 366
 - postoperative care, 371–372

- surgical management, 367–368, 372*f*–371*f*
- techniques, 369, 369*f*
- temporal fascia harvest, 369, 369*f*
- Fascial closure techniques, 3033–3035
 - delayed fascial approximation anticipated, 3034, 3034*f*
 - fascial approximation anticipated, 3033–3034, 3034*f*
 - negative pressure wound therapy, 3034–3035, 3035*f*
- Fascial sparing technique, 1418, 1418*f*
- Fascial wrapping, 366, 370, 370*f*
- Fasciocutaneous debulking of extremity lymphedema
 - anatomy, 2567
 - complications, 2570
 - definition, 2567
 - imaging, 2567
 - merits and demerits, 2568*b*, 2569*b*
 - outcomes, 2570
 - patient history and physical exam, 2567
 - postoperative care, 2570
 - radical debridement with split-thickness skin grafts, 2568–2569, 2569*f*
 - staged excision, 2569
 - surgical management
 - approach, 2568
 - patient positioning, 2568
 - preoperative planning, 2568
- Fasciocutaneous flap, 2381–2383, 2440
- Fasciocutaneous free flaps, 2394
- Fasciocutaneous grotting flap transposition, 2829, 2829*f*
- Fasciotomy
 - definition, 2331
 - foot, 2333, 2333*f*
 - central central compartment, 2331
 - deep central compartment, 2331

- intrinsic compartment, 2331
- lateral compartment, 2331
- medial compartment, 2331
- superficial central compartment, 2331
- forearm
 - dorsal, 1764, 1764*f*
 - with two longitudinal incisions, 1764, 1764*f*
 - volar forearm with curvilinear incision, 1763, 1763*f*
- hand, 1762–1763, 1762*f*, 1763*f*
- lower leg, 2332, 2333*f*
 - anterior, 2331
 - deep posterior compartment, 2331
 - diagnosis, 2331
 - lateral, 2331
 - superficial posterior, 2331
- merits and demerits, 2334*b*
- outcomes, 2334
- postoperative care, 2334
- thigh, 2332, 2332*f*
 - anterior, 2331
 - medial (adductor), 2331
 - posterior, 2331
- Fat aspirate processing, 1492
- Fat grafting
 - anatomy, 48, 2810
 - approach, 48
 - and closure, 111, 112*f*
 - complications, 51, 2813
 - definition, 48, 2810
 - differential diagnosis, 2810
 - imaging, 48, 2810
 - large-volume (*see* Large-volume fat grafting)
 - low-volume (*see* Low-volume fat grafting, contour correction)

- merits and demerits, 50*b*, 2813*b*
- natural history, 2810
- outcomes, 51, 51*f*, 2813
- pathogenesis, 2810
- patient history and physical findings, 48, 2810
- patient positioning, 48
- for periorbital rejuvenation
 - anatomy, 162–164, 162*f*–164*f*, 178
 - arcus marginalis release, 166, 167*f*
 - complications, 168, 184
 - definition, 162, 178
 - eye brow and temporal region, 165
 - fat harvest, 165, 180–183, 180*f*, 183*f*
 - imaging, 178
 - injection technique, 165
 - lower eyelid, 162, 166, 166*f*
 - malar fat grafting, 166, 166*f*
 - merits and demerits, 167*b*, 183*b*
 - nonoperative management, 164, 178
 - outcomes, 167, 184
 - patient history and physical findings, 164, 165*f*, 178
 - postoperative care, 167, 184
 - surgical management, 164, 178–180, 179*f*
 - upper eyelid, 162, 166
- postoperative care, 51, 2813
- preoperative planning, 48
- surgical management, 48, 2810–2811
 - approach, 2811
 - patient positioning, 2811
 - preoperative planning, 2811
- techniques, 49*b*, 49*f*, 50*f*
- Fat harvest
 - and injection technique, 165

- for periorbital rejuvenation, 180–183, 180*f*, 183*f*
- Fat injection
 - anatomy, 171
 - complications, 176, 177*f*
 - definition, 170
 - differential diagnosis, 172
 - merits and demerits, 176*b*
 - nonoperative management, 172
 - outcomes, 176
 - pathogenesis, 171–172
 - patient history and physical findings, 172, 172*f*
 - postoperative care, 176
 - surgical management, 172
- Fat-sensitive images
 - soft tissue tumors, knee, 2457
 - soft tissue tumors of thigh, 2498
- FCR (flexor carpi radialis), 1754, 2027, 2028*f*
 - to PIN, 2052
 - reverse radial forearm flap, 2114, 2114*f*, 2116, 2118
- FCU (flexor carpi ulnaris), 1203, 1992
 - digitorum communis, 2027, 2028*f*
 - ulnar artery perforator flap, 2120–2123
- FD. *See* Fibrous dysplasia (FD)
- FDB (flexor digitorum brevis), 2363, 2366
- FDL (flexor digitorum longus), 2363
- FDMA (first dorsal metacarpal artery) flap, 2105, 2107, 2109, 2110*f*–2111*f*, 2113
- FDP. *See* Flexor digitorum profundus (FDP)
- FDS. *See* Flexor digitorum superficialis (FDS)
- Free flap reconstruction, wound preparation for, 2441*f*
- Female pattern hair loss (FPHL), 416–417
- Feminizing genitoplasty, 3065
- Femoral artery, 2400, 2402, 2402*f*

- Femoral bone debridement
 - anatomy, 2506
 - chronic osteomyelitis of distal femur, 2508, 2508*f*
 - complications, 2509
 - definition, 2506
 - imaging, 2506–2507, 2506*f*–2507*f*
 - merits and demerits, 2509*b*
 - natural history, 2506
 - nonoperative management, 2507
 - outcomes, 2509
 - pathogenesis, 2506
 - patient history and physical findings, 2506
 - postoperative care, 2509
 - surgical management, 2507
 - approach, 2507, 2507*f*
 - patient positioning, 2507
 - preoperative planning, 2507
- Femoral bone marrow margin, 2973, 2973*f*
- Femoral nerve
 - anatomy, 2310, 2532*f*, 2533–2534
 - complications, 2313–2314
 - definition, 2310, 2533
 - imaging, 2310, 2310*f*–2311*f*, 2534
 - merits and demerits, 2313*b*
 - nerve stimulator technique, 2312, 2312*f*
 - nonoperative management, 2534
 - outcomes, 2313
 - pathogenesis, 2534
 - patient history and physical exam, 2310, 2534
 - postoperative care, 2313
 - surgical management, 2310–2311, 2534
 - approach, 2311
 - patient positioning, 2311

- preoperative planning, 2311
- ultrasound-guided technique, 2311–2312, 2311*f*
- Femoral vessels, 2972, 2972*f*
- Femoropopliteal bypass, 2402–2403, 2402*f*
 - above-knee popliteal exposure, 2403, 2403*f*
 - below-knee popliteal exposure, 2403, 2404*f*
 - femoral artery identification, 2402
 - longitudinal incision, 2402
- Femur, bone tumors of
 - anatomy, 2502
 - complications, 2505
 - definition, 2502
 - differential diagnosis for, 2502
 - femur resection and allograft reconstruction, 2503, 2504*f*
 - functional outcomes, 2505
 - imaging, 2502, 2503*f*
 - merits and demerits, 2504*b*
 - natural history, 2502
 - oncological outcomes, 2505
 - pathogenesis, 2502
 - patient history and physical findings, 2502
 - postoperative care, 2505
 - surgical management, 2502–2503
 - approach, 2503
 - patient positioning, 2503
 - preoperative planning, 2503
- Femur isthmus, intraoperative measurement of, 2477*f*
- Femur reconstruction
 - anatomy, 2510, 2511*f*
 - Capanna method, 2514–2515, 2514*f*
 - complications, 2516
 - definition, 2510
 - double barrel fibula technique, 2515, 2515*f*

- free fibula flap, 2513–2514, 2513*f*
- imaging, 2511, 2511*f*
- merits and demerits, 2515*b*
- outcomes, 2516
- patient history and physical findings, 2510
- postoperative care, 2515
- surgical management
 - approach, 2512
 - patient positioning, 2512, 2512*f*
 - preoperative planning, 2512, 2512*f*
- FFA (frontal fibrosing alopecia), 418, 418*f*
- Fiberoptic nasendoscopy, 2690
- Fibrous dysplasia (FD)
 - anatomy, 762, 762*f*
 - complications, 773
 - definition, 762
 - differential diagnosis, 764
 - imaging, 763–764, 764*f*
 - indications, 764
 - lower zone
 - exposure, 768, 768*f*
 - reconstruction, 769–771, 770*f*–771*f*
 - resection, 768–769, 769*f*
 - merits and demerits, 766*b*
 - natural history, 763
 - nonoperative management, 764
 - outcomes, 772, 772*f*
 - pathogenesis, 762
 - patient history, 763
 - physical examination, 763, 763*f*
 - postoperative care, 772
 - surgical management
 - approach, 766

- patient positioning, 766
- preoperative planning, 765–766
- timing of intervention, 765
- upper zone
 - exposure, 766–767, 767*f*
 - reconstruction, 767–768
 - resection, 767
- Fibula flap, 1116, 2433, 2512
 - elevation, 1032–1033
 - harvest
 - design, 1025
 - incisions and flap elevation, 1025–1026
 - reconstruction, 1053, 1053*f*
 - with templates
 - anatomy, 1030
 - closing wedge osteotomies, 1034–1035, 1034*f*
 - complications, 1036
 - creating anatomic templates, 1031, 1032*f*
 - definition, 1030
 - fibula flap elevation, 1032–1033
 - imaging, 1030
 - maintaining native condyle position and occlusion, 1031
 - merits and demerits, 1031*b*
 - outcomes, 1035, 1036*f*
 - patient history and physical findings, 1030
 - patient positioning, 1030
 - postoperative care, 1035
 - surgical management, 1030–1031
- Fibula flap osteotomy, 1026–1027, 1026*f*
- Fibula free flap reconstruction, with CAD/CAM techniques
 - anatomy, 1022*f*, 1023
 - complications, 1029
 - definition, 1022

- dental implants, 1027
- flap inset, 1027
- harvest, 1025–1026
- imaging, 1023–1024, 1024*f*
- mandibular osteotomy, 1026
- merits and demerits, 1025*b*
- microsurgical anastomosis, 1027
- osteotomy, 1026–1027, 1026*f*
- outcomes, 1029, 1029*f*
- pathogenesis, 1023
- patient history and physical findings, 1023
- postoperative care, 1028–1029
- surgical management, 1024–1025
- Fibular fracture, 2411
- Filler injection
 - anatomy, 37, 37*f*–38*f*
 - complications, 40
 - definition, 37
 - in glabella, forehead and brow, 21
 - anatomy, 20, 20*f*
 - approach, 20
 - complications, 22
 - definition, 20
 - merits and demerits, 21*b*
 - nonoperative management, 20
 - outcomes, 21
 - patient history and physical findings, 20
 - positioning, 20
 - postoperative care, 21
- malar region
 - anatomy, 26
 - complications, 28
 - definition, 26

- imaging, 27
- merits and demerits, 28*b*
- nonoperative management, 27
- outcomes, 27*f*, 28
- pathogenesis, 26–27
- patient history and physical findings, 27
- postoperative care, 27
- surgical management, 27
- techniques, 27*b*
- merits and demerits, 40*b*
- nonoperative management, 38
- to nose
 - anatomy, 42, 42*f*
 - complications, 46, 47*f*
 - definition, 42
 - imaging, 42
 - merits and demerits, 44*b*
 - nasal dorsum injection, 43, 43*f*
 - nasal sidewall injection, 44, 44*f*
 - nasal tip/ala injection, 44, 44*f*
 - outcomes, 43*f*, 44*f*, 45
 - patient history and physical findings, 42
 - postoperative care, 45
 - surgical management, 42–43
 - techniques, 43*b*
- outcomes, 40, 40*f*–41*f*
- patient history and physical findings, 37–38
- postoperative care, 40
- techniques, 38*b*
 - lips, 38–39
 - marionette lines, 39
 - oral commissures, 39
 - in prejowl area, 39

- upper periorbital area
 - anatomy, 23
 - approach, 23
 - complications, 25
 - definition, 23
 - merits and demerits, 24*b*
 - outcomes, 25
 - patient history and physical findings, 23, 23*f*
 - patient positioning, 23
 - postoperative care, 25
 - preoperative planning, 23
 - techniques, 24, 24*f*
- Finasteride, 418
- Finger clawing, low combined median and ulnar nerve palsy, 2038–2039
- Finger extension procedures, 2027–2029
 - anatomy, 2201, 2201*f*
 - complications, 2204–2205
 - definition, 2201
 - imaging, 2202
 - merits and demerits, 2202*b*, 2204*b*
 - outcomes, 2204
 - patient history and physical findings, 2201–2202, 2202*f*
 - postoperative care, 2204
 - surgical management
 - algorithm, 2203*f*
 - patient positioning, 2202
 - preoperative planning, 2202
- Finger flexion
 - combined median and ulnar nerve injury, 2038*f*, 2040
 - restoration, 2023
- Finger syndactyly release, dorsal rectangular flap
 - anatomy, 2216, 2216*f*–2217*f*

- complications, 2222
- definition, 2216
- dorsal markings, 2218, 2219*f*
- dressings and immobilization, 2221–2222, 2222*f*
- flap creation, 2219, 2221*f*
- grafting, 2219–2221, 2221*f*
- imaging, 2216–2217, 2217*f*
- merits and demerits, 2218*b*, 2222*b*
- natural history, 2216
- outcomes, 2222
- patient history and physical findings, 2216
- postoperative care, 2222
- surgical management
 - approach, 2218
 - patient positioning, 2218
 - preoperative planning, 2217–2218
- volar markings, 2219, 2219*f*
- **Fingertip**
 - amputations, 2149
 - anatomy, 1766, 1766*f*–1767*f*
 - complications, 1770
 - definition, 1766
 - imaging, 1767
 - merits and demerits, 1769*b*
 - nail ablation, 1768, 1769*f*
 - nonoperative management, 1767
 - outcomes, 1770
 - pathogenesis, 1766
 - patient history and physical findings, 1767
 - postoperative care, 1770
 - with primary closure, revision, 1767, 1768*f*
 - surgical management, 1767
 - injuries, flap coverage

- anatomy, 2096
- complications, 2103–2104
- definition, 2096
- imaging, 2097
- merits and demerits, 2102*b*
- nonoperative management, 2097
- outcomes, 2103
- pathogenesis, 2096
- patient history and physical findings, 2096–2097
- postoperative care, 2103
- surgical management, 2097*f*–2098*f*
- First dorsal compartment release, 2094, 2094*f*
- First dorsal metatarsal artery (FDMA) variants, 2168
- First metatarsal, 2344, 2344*f*–2345*f*, 2369*f*
- First plantar metatarsal artery, 2378–2379
- First plantar metatarsal vein
- First-generation cephalosporin, 284
- 1st DMTA (reverse first dorsal metatarsal artery) flap, 2368, 2368*f*–2369*f*
- Fistula, 2682, 2689, 2696. *See also* Palatal fistula
 - intentional, 2696
 - Pittsburgh fistula classification, 2696
 - unintentional, 2696
- Fixed plate position technique, 442
- Flank and lumbar defects
 - anatomy, 1721, 1721*f*
 - complications, 1726
 - definition, 1721
 - imaging, 1722
 - natural history, 1722
 - nonoperative management, 1722
 - outcomes, 1726
 - pathogenesis, 1722

- patient history and physical findings, 1722
- postoperative care, 1726
- surgical management
 - approach, 1723
 - patient positioning, 1722–1723
 - preoperative planning, 1722
- Flank defects, 1589
- Flankplasty, with lipoaugmentation, 1631, 1631*f*–1632*f*
- Flap coverage of thumb defects
 - anatomy, 2105
 - complications, 2113
 - definition, 2105
 - imaging, 2105
 - merits and demerits, 2112*b*
 - nonoperative management, 2105
 - outcomes, 2113, 2113*f*
 - patient history, 2105
 - physical findings, 2105
 - postoperative care, 2113
 - surgical management, 2105–2106, 2106*f*
 - approach, 2106
 - first dorsal metacarpal artery flap, 2109, 2110*f*–2111*f*
 - moberg flap, 2107–2109, 2108*f*
 - reverse dorsoradial homodigital flap, 2112
- Flap creation
 - Cutler-Beard flap, 1091–1092, 1092*f*
 - Hughes flap, 1090, 1091*f*
- Flap necrosis, 2674, 2689
- Flap separation
 - Cutler-Beard flap, 1092, 1092*f*
 - Hughes flap, 1091
- Flexor carpi radialis (FCR), 1754, 2027, 2028*f*
 - to PIN, 2052

- reverse radial forearm flap, 2114, 2114*f*, 2116, 2118
- Flexor carpi ulnaris (FCU), 1203, 1992
 - digitorum communis, 2027, 2028*f*
 - ulnar artery perforator flap, 2120–2123
- Flexor digiti minimi, 1986–1987, 1986*f*
- Flexor digitorum brevis (FDB), 2363, 2366
- Flexor digitorum longus (FDL), 2363
- Flexor digitorum profundus (FDP), 1935
 - index and long finger flexion reconstruction, 2016, 2016*f*
 - side-to-side transfer, 2023
 - tendon transfer for FPL rupture, 1942–1944, 1945*f*
 - transfer
 - extensor carpi radialis longus, 2212, 2212*f*
 - flexor digitorum superficialis, 2213, 2213*f*
- Flexor digitorum superficialis (FDS), 1203, 1935
 - to abductor pollicis brevis, 2013–2015, 2014*f*
 - to AdP tendon transfer, 2037, 2038*f*–2039*f*
 - to ECRB, 2052
 - to extensor digitorum communis, 2028–2029, 2029*f*, 2202, 2203*f*
 - to flexor digitorum profundus transfer, 2213, 2213*f*
 - lasso, 2020, 2021*f*
 - Stiles-Bunnell transfer, 2021–2022, 2021*f*
 - tendon transfer for ruptured FPL tendon reconstruction, 1942–1944, 1945*f*
 - tenodesis for correction of swan-neck deformity, 1945, 1946*f*
- Flexor hallucis longus (FHL), 1026, 2343, 2346, 2363, 2419, 2419*f*, 2432, 2510, 2514
- Flexor pollicis brevis, 1986–1987, 1986*f*
- Flexor tendon injury, 1930
- Flexor tendon reconstruction
 - anatomy, 2065
 - complications, 2072
 - definition, 2065

- differential diagnosis, 2066
- imaging, 2065
- merits and demerits, 2071*b*
- natural history, 2065
- nonoperative management, 2066
- outcomes, 2072
- pathogenesis, 2065
- patient history and physical findings, 2065
- postoperative care
 - stage 1, 2072
 - stage 2 (Modified Duran), 2072
- surgical management
 - approach, 2066
 - patient positioning, 2066
 - preoperative planning, 2066
- Flexor tendon rehabilitation, 2077
- Flexor tendon repair
 - anatomy, 2054–2055
 - complications, 2060
 - definition, 2054
 - differential diagnosis, 2055
 - imaging, 2055
 - merits and demerits, 2056*b*, 2059*b*
 - outcomes, 2060
 - pathogenesis, 2055
 - patient history and physical findings, 2055
 - postoperative care, 2059–2060
 - surgical management
 - approach, 2056
 - patient positioning, 2056
 - preoperative planning, 2056
 - zone I repair
 - primary suture, 2056, 2056*f*

- pull-through button, 2056–2057, 2057*f*
- zone II to V repair
 - locked cruciate, 2058, 2058*f*
 - modified Becker/Massachusetts General Hospital, 2058, 2058*f*
 - modified Kessler suture, 2058, 2058*f*
 - Tajima modification, 2057, 2057*f*
- Flexor tendon sheath
 - anatomy and, 1771, 1771*f*
 - closed irrigation of, 1772–1773, 1772*f*, 1773*f*
 - complications, 1774
 - definition, 1771
 - differential diagnosis, 1771–1772
 - imaging, 1771
 - merits and demerits, 1774*b*
 - natural history, 1771
 - nonoperative management, 1772
 - open debridement of, 1773–1774, 1773*f*, 1774*f*
 - outcomes, 1774
 - pathogenesis, 1771
 - patient history and physical findings, 1771, 1772*f*
 - postoperative care, 1774
 - surgical management, 1772
 - approach, 1772
 - patient positioning, 1772
 - preoperative planning, 1772
- Flexor tenolysis with/without volar capsular release, 2075, 2075*f*–2076*f*
- Floating ribs, 994, 994*f*
- Floor of mouth (FOM) reconstruction
 - anatomy, 1209, 1209*f*
 - complications, 1214
 - imaging, 1210
 - merits and demerits, 1211*b*

- pathogenesis, 1209–1210
- patient history, 1210
- physical examination, 1210
- postoperative care, 1214
- radial forearm free flap
 - flap dissection, 1212, 1212*f*
 - flap inset, 1212, 1213*f*
 - recipient site preparation, 1211–1212, 1211*f*
- soft tissue flaps
 - anterolateral thigh flap, 1211
 - medial sural artery perforator flap, 1211
 - pectoralis major musculocutaneous flap, 1211
 - radial forearm fasciocutaneous free flap, 1210
- Fluid-sensitive images
 - soft tissue tumors, knee, 2457
 - soft tissue tumors of thigh, 2498
- Fluoroscopy, 2424, 2477*f*, 2478, 2503
- Follicular unit extraction (FUE), 416, 421, 425–426
- Follicular unit transplantation (FUT), 416
- Follicular units (FUs), 416
- FOM reconstruction. *See* Floor of mouth (FOM) reconstruction
- Foot
 - abscesses drainage
 - anatomy, 2335, 2335*f*
 - approach, 2336
 - complications, 2337
 - differential diagnosis, 2336
 - imaging, 2336
 - merits and demerits, 2336*b*
 - necrotic right lateral foot wound, 2336, 2337*f*
 - nonoperative management, 2336
 - patient history and physical findings, 2336
 - postoperative care, 2337

- preoperative planning, 2336
- supine position, 2336
- bone tumors of
 - anatomy, 2342
 - benign bone tumor of the talus, 2343, 2343*f*
 - complications, 2348
 - definition, 2342
 - differential diagnosis, 2342
 - imaging, 2342
 - malignant bone tumors, 2343–2347, 2344*f*, 2346*f*, 2347*f*
 - merits and demerits, 2343*b*
 - nonoperative management, 2342
 - outcomes, 2348
 - patient history, 2342
 - patient positioning, 2342
 - physical findings, 2342
 - postoperative care, 2347–2348
 - preoperative planning, 2342
 - primary, 2342
 - surgery, 2342
 - surgical management, 2342
- soft tissue infections, debridement of, 2351, 2351*f*
 - anatomy, 2349–2350, 2349*f*
 - complications, 2351
 - definition, 2349
 - differential diagnosis, 2350
 - imaging, 2350
 - merits and demerits, 2351
 - nonoperative management, 2350
 - pathogenesis, 2350
 - patient history and physical findings, 2350
 - postoperative care, 2351
 - preoperative planning, 2350

- supine position, 2350
- surgical management, 2350
- Foot exposure and second toe harvest, 2170–2172, 2171*f*–2172*f*
- Foot fasciotomy, 2333, 2333*f*
 - central central compartment, 2331
 - deep central compartment, 2331
 - intrinsic compartment, 2331
 - lateral compartment, 2331
 - medial compartment, 2331
 - superficial central compartment, 2331
- Foot reconstruction, keystone flaps for, 1746, 1746*f*
- Forced duction test, 817, 817*f*
 - pediatric orbital fractures, 943
- Forearm pronation, combined median and ulnar nerve injury, 2040–2041
- Forearm reconstruction. *See also* Neonatal brachial plexus palsy (NBPP)
 - biceps rerouting, 2964, 2964*f*
 - compartment syndrome
 - anatomy, 1760, 1761*t*, 1761*f*
 - fasciotomy (*see* Fasciotomy)
 - complications, 2968
 - outcomes, 2968
 - postoperative care, 2967
 - PT release/rerouting, 2964, 2965*f*
- Forefoot reconstruction
 - anatomy, 2363–2364
 - bones, 2363
 - cutaneous sensation, 2363
 - digit extending muscles, 2363
 - dorsal forefoot sensation, 2363
 - extrinsic and intrinsic muscles, 2363
 - flexor digitorum brevis, 2363

- medial and lateral compartments, 2363
- plantar flexion, 2363
- plantar surface, 2363
- vascular supply, 2363
- complications, 2372
- definition, 2363
- differential diagnosis, 2365
- free flap
 - for distal skin defect, 2370, 2370*f*
 - latissimus, 2370–2371, 2371*f*
- free gracilis for osteomyelitis, 2369, 2369*f*
- imaging, 2365
- merits and demerits, 2371*b*
- natural history, 2365
- nonoperative management, 2365–2366
- outcomes, 2372
- pathogenesis, 2364–2365
- patient history and physical findings
 - forefoot wounds, evaluation of, 2365
 - gait cycle and biomechanics, 2365
- postoperative care, 2371–2372
- reverse fasciocutaneous flap, 2368, 2368*f*–2369*f*
- secondary healing using regenerative matrix, 2367, 2368*f*
- surgical management
 - approach, 2366–2367, 2367*f*
 - patient positioning, 2366
 - preoperative planning, 2366
- Forefoot wounds, evaluation of, 2365
- Forehead
 - botulinum toxin injection to
 - anatomy, 5, 5*f*
 - complications, 6
 - definition, 5

- merits and demerits, 6*b*
- nonoperative management, 5
- outcome, 6, 6*f*
- patient history and physical findings, 5
- postoperative care, 6
- injectable fillers in, 21
 - anatomy, 20, 20*f*
 - approach, 20
 - complications, 22
 - definition, 20
 - merits and demerits, 21*b*
 - nonoperative management, 20
 - outcomes, 21
 - patient history and physical findings, 20
 - patient positioning, 20
 - postoperative care, 21
- Foreign body sensation, 119
- Four-flap Z-plasty for first web space, 2228, 2228*f*
- Four-handed technique, 219, 219*f*
- FPHL (female pattern hair loss), 416–417
- FPL (flexor pollicis longus), 2105
- FPL (split flexor pollicis longus), 2023, 2023*f*
- Fractional CO₂ laser
 - anesthesia, 2807
 - application, 2807–2808, 2808*f*
 - wound care, 2808
- Fractional lengthening of flexor tendons, 2203, 2204*f*
- Fracture, naso-orbital-ethmoid
 - anatomy, 865, 866*f*
 - complications, 870
 - definition, 865
 - differential diagnosis, 865
 - imaging, 865, 867*f*

- merits and demerits, 870*b*
- natural history, 865, 866*f*
- nonoperative management, 865
- open reduction internal fixation, 868–869, 869*f*
- outcomes, 870
- pathogenesis, 865
- patient history and physical findings, 865, 866*f*
- postoperative care, 870
- surgical management, 865–867
- Free fibula flap, midface reconstruction, 2433–2435, 2434*f*, 2513–2514, 2513*f*
 - anatomy, 1001–1002, 1001*f*–1003*f*
 - anticipated secondary surgeries, 1008
 - classification, 1002
 - complications, 1010
 - customization, skeletal fixation, and inset, 1008, 1008*f*
 - definition, 1001
 - horizontal and vertical skeletal buttresses, 1002
 - imaging, 1002
 - lateral approach
 - completion process, 1008, 1008*f*
 - deep posterior compartment dissection, 1007, 1007*f*
 - distal osteotomy, 1007, 1007*f*
 - donor site markings, 1006, 1006*f*
 - incision and skin paddle dissection, 1006, 1006*f*
 - lateral and anterior compartment dissection, 1006–1007, 1007*f*
 - posterior compartment dissection, 1007, 1007*f*
 - proximal osteotomy, 1007, 1007*f*
 - merits and demerits, 1005*b*
 - midface defect, 1005
 - nonoperative management, 1004
 - outcomes, 1010
 - patient history and physical findings, 1002, 1004*f*

- postoperative care, 1009, 1009*f*
- surgical management
 - approach, 1005
 - patient positioning, 1005
 - preoperative planning, 1004–1005, 1005*f*
- Free flap reconstruction, 2115, 2126, 2366, 2518
 - ankle
 - anatomy, 2392, 2393*f*
 - anterolateral thigh, 2396
 - complications, 2398
 - definition, 2392
 - gracilis, 2397
 - imaging, 2392
 - latissimus dorsi, 2397–2398
 - merits and demerits, 2398*b*
 - non operative management, 2392
 - outcomes, 2398, 2398*f*
 - pathogenesis, 2392, 2393*f*
 - patient history, 2392
 - physical findings, 2392
 - postoperative care, 2398
 - rectus abdominis, 2397
 - surgical management, 2392–2395
 - vastus lateralis, 2392–2395, 2396*f*
 - choice, 2366
 - for distal skin defect, 2370, 2370*f*
 - heel and plantar defects, 2378–2380
 - anterior tibial-dorsalis pedis artery, 2378–2379, 2378*f*–2382*f*
 - assessment of defect, 2384
 - complications, 2387
 - definition, 2378
 - final inset, 2385, 2386*f*
 - flap harvest, 2384, 2385*f*

- imaging, 2380
- lateral plantar artery
- merits and demerits, 2386*b*
- microanastomosis with temporary inset, 2385, 2385*f*
- outcomes, 2387, 2387*f*
- patient history, 2380
- peroneal-lateral calcaneal artery, 2380
- physical findings, 2380
- posterior tibial-medial plantar artery, 2379–2380
- postoperative care, 2386–
- recipient vessel preparation, 2384, 2384*f*
- superficial venous system of foot
- surgical management, 2380–2383
- wound preparation, 2384, 2384*f*
- hemi-tongue
 - anatomy, 1198, 1198*f*
 - anterolateral thigh flap, 1204, 1204*f*
 - closure, 1206
 - complications, 1207
 - definition, 1198
 - flap inset, 1205–1206, 1205*f*
 - imaging, 1199
 - merits and demerits, 1200*b*
 - outcomes, 1207
 - pathogenesis, 1198–1199
 - patient history and physical findings, 1199
 - postoperative care, 1207
 - radial forearm free flap, 1201–1202, 1202*f*
 - sensory reinnervation, 1206, 1206*f*
 - surgical management, 1199–1200
 - ulnar artery perforator flaps, 1203, 1203*f*–1204*f*
- knee, soft tissue coverage of
 - anatomy, 2486, 2486*f*–2487*f*

- assessment of the defect, 2489
- benefits of, 2486
- complications, 2492, 2492*f*
- definition, 2486
- final inset, 2490, 2490*f*–2491*f*
- flap harvest, 2489, 2489*f*–2490*f*
- imaging, 2487
- merits and demerits, 2491*b*
- microanastomosis with temporary inset, 2490
- outcomes, 2492
- pathogenesis, 2487
- patient history and physical findings, 2487
- postoperative care, 2491–2492
- recipient vessel preparation, 2488–2489, 2488*f*
- surgical management, 2487–2488
- wound preparation, 2488, 2488*f*
- latissimus, 2370–2371, 2371*f*
- lower leg, soft tissue coverage of
 - anatomy, 2438
 - anterior tibial vessels for recipient vessel.
 - assessment of defect, 2442
 - complications, 2445
 - definition, 2438
 - distal third of leg, 2438
 - final inset, 2443, 2443*f*
 - flap harvest, 2442, 2442*f*
 - imaging, 2440
 - main arteries and veins, 2438*f*–2439*f*
 - medial sural vessels as recipient vessel, 2439*f*–2440*f*
 - merits and demerits, 2444*b*
 - microanastomosis with temporary inset, 2442–2443, 2443*f*
 - middle third of leg, 2438
 - outcomes, 2444, 2444*f*–2445*f*

- patient history and physical findings, 2440
- peroneal artery perforators for recipient vessel
- peroneal vessels for recipient vessel
- posterior tibial vessels for recipient vessel
- postoperative care, 2444
- recipient vessel preparation, 2441, 2441*f*
- surgical management, 2440–2441
- upper third of lower leg, 2438
- wound preparation, 2441, 2441*f*
- scalp
 - anatomy, 984
 - complications, 989
 - definition, 984
 - graft sources, 985, 986*b*
 - imaging, 984
 - merits and demerits, 988*t*
 - microsurgery, 987, 987*f*
 - outcomes, 988, 988*f*
 - pathogenesis, 984
 - patient history, 984
 - physical examination of, 984
 - postoperative care, 988
 - specific donor-site dissections, 986
 - superficial temporal artery preparation, 986
 - surgical management, 984–985
- thigh, soft tissue defects of
 - adductor canal, approach to, 2524, 2525*f*
 - anatomy, 2522
 - complications, 2528
 - definition, 2522
 - flap and anastomosis, 2526, 2526*f*
 - flap inset, skin grafting, 2526–2527, 2527*f*
 - groin, approach to, 2524, 2524*f*

- imaging, 2522–2523
- outcomes, 2527–2528
- patient history and physical findings, 2522
- patient positioning, 2523, 2523*f*
- pearls and pitfalls, 2527*b*
- postoperative care, 2527, 2528*f*
- preoperative planning, 2523
- saphenous vein, dissection of, 2525, 2525*f*
- surgical approach, 2523
- surgical management, 2523
- viability rates, 2372
- Free flap transposition, 1540
- Free flaps graft sources, 985, 986*b*
- Free floating orbital rim technique, 442
- Free gracilis for osteomyelitis, 2369, 2369*f*
- Free groin flap
 - anatomy, 2137–2138
 - flap size, 2138
 - lateral cutaneous branch, 2138
 - SCIA, 2137, 2137*f*–2138*f*
 - vascular and regional, 2137*f*–2138*f*
 - venous drainage, 2138
 - definition, 2137
 - design, 2142
 - harvest, 2142, 2142*f*
 - imaging, 2138
 - merits and demerits in, 2142*b*
 - outcomes, 2142–2143
 - patient history and physical findings, 2138, 2139*f*
 - postoperative care, 2142
 - surgical management, 2138–2139
 - approach, 2139
 - patient positioning, 2139

- preoperative planning, 2139
- Free lateral arm flap
 - anatomy, 2134, 2134*f*
 - complications, 2136, 2136*f*
 - definition, 2134
 - flap design, 2135, 2135*f*
 - flap harvest, 2135, 2135*f*
 - imaging, 2134
 - merits and demerits in, 2136*b*
 - outcomes, 2136
 - patient history, 2134
 - physical findings, 2134
 - postoperative care, 2136
 - surgical management, 2134
- Free medial plantar flap, 2373
- Free muscle flap, 2381–2383
- Free tissue transfer, palatal fistula, 2703, 2703*f*
- Free transverse rectus abdominis myocutaneous flap
 - abdominal closure, 1421, 1421*f*
 - anatomy, 1414
 - complications, 1422
 - definition, 1414
 - fascial dissection, 1418, 1418*f*
 - imaging, 1415
 - intramuscular dissection, 1419, 1419*f*
 - markings, 1416, 1416*f*–1417*f*
 - merits and demerits, 1421*b*
 - microsurgery and flap inset, 1420–1421, 1420*f*
 - outcomes, 1421
 - patient history and physical findings, 1414–1415
 - perforator identification, 1417, 1418*f*
 - postoperative care, 1421
 - recipient vessel dissection, 1419, 1420*f*

- surgical management
 - approach, 1416
 - patient positioning, 1416
 - preoperative planning, 1415–1416
- Fresh-frozen allografts, 2342–2343, 2346–2347
- Froment sign, 1987, 1993
- Frontal bone, medial orbit wall fractures, 829, 829*f*
- Frontal cephalogram, chin deformities, 412
- Frontal fibrosing alopecia (FFA), 418, 418*f*
- Frontal pneumatization patterns, 801–802, 802*f*
 - Agger nasi cell, 801, 802*f*
 - frontal bullar cell, 802
 - intersinus septal cell, 802
 - suprabullar cell, 802
 - supraorbital ethmoid cell, 802
- Frontal recess, 801
- Frontal region, panfacial fractures, 934
- Frontal sinus cranialization
 - anatomy, 779–780, 779*f*–780*f*
 - complications, 784–785, 785*f*
 - definition, 779
 - differential diagnosis, 781, 781*f*
 - imaging, 780, 781*f*
 - merits and demerits, 781*b*
 - natural history, 780
 - nonoperative management, 781
 - outcomes, 784
 - pathogenesis, 780
 - patient history and physical findings, 780, 780*f*
 - postoperative care, 784
 - preparation and exposure, 781–782, 782*f*
 - repair and closure, 782–784, 783*f*
 - in situ, 779*f*–780*f*

- surgical management
 - approach, 781
 - patient positioning, 781
 - preoperative planning, 781
- Frontal sinus drainage pathway (FSDP), 794*f*–795*f*
- Frontal sinus fractures
 - algorithm, 796, 797*f*
 - complications, 800
 - definition, 794
 - delayed endoscopic cranioplasty, 797
 - endoscopic correction
 - endoscopic reduction and internal fixation, 799
 - endoscopic repair, incisions, 798, 798*f*
 - mesh/polyethylene plate, 799, 799*f*
 - endoscopic cranioplasty and fixation techniques, 797
 - endoscopic endonasal sinus procedures, 797
 - frontal sinus drainage pathway, 794, 794*f*–795*f*
 - imaging, 796, 796*f*
 - merits and demerits, 798*b*
 - natural history, 795
 - outcomes, 800
 - pathogenesis, 795
 - patient history, 795
 - physical examination, 796
 - postoperative care, 800
 - supratrochlear and supraorbital neurovascular bundles, 794*f*–795*f*, 795
 - surgical management
 - approach, 798
 - patient positioning, 798
 - preoperative planning, 797, 797*f*
 - traditional open surgical techniques, 797
 - vertical and horizontal components, 794

- Frontal sinus mucocele
 - anatomy, 801
 - complications, 808
 - definition, 801
 - differential diagnosis, 803
 - endoscopic endonasal marsupialization
 - anterior ethmoidectomy, 804, 805*f*
 - completion process, 806
 - frontal dissection, 805, 805*f*
 - maxillary antrostomy, 804, 805*f*
 - uncinectomy, 804*f*
 - frontal sinus trephination, 806–807, 806*f*
 - imaging, 803, 803*f*
 - merits and demerits, 804*b*
 - natural history, 802
 - outcomes, 808
 - pathogenesis, 802
 - patient history and physical findings, 802–803
 - postoperative care, 808
 - surgical management
 - approach, 804
 - combined endonasal-external approach, 807
 - patient positioning, 804
 - preoperative planning, 803
- Frontal sinus obliteration
 - with fat
 - anatomy, 786, 786*f*
 - complications, 789
 - definition, 786
 - differential diagnosis, 787
 - imaging, 787, 787*f*
 - merits and demerits, 788*b*
 - nonoperative management, 787

- outcomes, 789
- pathogenesis, 786
- patient history and physical findings, 786–787
- postoperative care, 789
- surgical management, 787
- pericranial flap harvest
 - anatomy, 790
 - anteriorly based pericranial flap, 791, 791*f*–792*f*
 - complications, 793
 - definition, 790
 - imaging, 790
 - indications, 790
 - laterally based pericranial flap, 792
 - merits and demerits, 791*b*
 - outcomes, 792
 - pathogenesis, 790
 - patient history and physical findings, 790
 - postoperative care, 792
 - surgical management, 790
- Frontal sinus trephination, 806–807, 806*f*
- Frontalis, 71
- Frontalis muscle, transpalpebral corrugator resection, 109
- Frontalis suspension
 - brow sutures, 2851, 2852*f*
 - markings and eyelid sutures, 2851, 2852*f*
- Frontonasal osteotomies, 549
- Fronto-orbital advancement
 - advantages, 435
 - anatomy, 434
 - bilateral coronal synostosis
 - anatomy, 434
 - definition, 434
 - patient history and physical findings, 435

- techniques, 442
- bone manipulation and stabilities, 435
- complications, 443
- definition, 434
- disadvantages, 435–436
- “fixed plate” position technique, 442
- “free floating” orbital rim technique, 442
- imaging, 435, 436*f*
- merits and demerits, 437*b*
- metopic synostosis
 - anatomy, 434
 - definition, 434
 - orbital roof osteotomy, 441
 - patient history and physical findings, 434–435
 - resorbable plate, 441, 441*f*
- outcomes, 443
- pathogenesis, 434
- postoperative care, 443
- surgical management
 - approach, 437
 - patient positioning, 436
 - preoperative planning, 436
- Tilt procedure, 437, 437*f*–438*f*
- unilateral coronal synostosis
 - anatomy, 434
 - bony fixation, 440, 440*f*–441*f*
 - completion, 440
 - definition, 434
 - exposure and bur hole placement, 438, 438*f*
 - patient history and physical findings, 435
 - supraorbital rim osteotomy and advancement, 438–439, 439*f*
- Fronto-orbital distraction
 - anatomy, 445

- complications, 450
- craniosynostosis, 446
- definition, 445
- device application, 448
- differential diagnosis, 446
- epidemiology, 445
- imaging, 446, 446*f*
- merits and demerits, 447*b*
- metopic synostosis, 448–449, 449*f*
- natural history, 445–446
- outcomes, 450, 450*f*–451*f*
- pathogenesis, 445
- postoperative care, 450
- surgical management
 - approach, 447
 - patient positioning, 447
 - preoperative planning, 447
- unicoronal synostosis, 447, 448*f*
- Frontotemporal angle, 97
- Frozen biopsy, 2747–2748, 2747*f*
- FSDP (frontal sinus drainage pathway), 794*f*–795*f*
- FTSG (fullthickness skin graft), 2105, 2107, 2109, 2112
- Fiducials, CT scan with, 2345
- FUE (follicular unit extraction), 416, 421, 425–426
- Full scar brachioplasty-bicipital groove scar, 1646–1647, 1647*f*
- Full-thickness eyelid defects, 1078, 1080*f*–1081*f*
- Full-thickness skin grafting, contracture release with, 2774–2775, 2775*f*
- Full-thickness skin grafts, 2769
 - harvesting of, 2771
- Functional burn reconstruction
 - airway, eyes, and lips, 2766, 2766*f*–2767*f*
 - anatomy, 2765

- burn scar contractures, 2767, 2767*f*
- contracture release, 2766
- definition, 2765
- imaging, 2766
- merits and demerits, 2766*b*
- natural history, 2765
- nonoperative management, 2766
- pathogenesis, 2765
- patient history and physical findings, 2765
- surgical management, 2766
- Functional remodeling process, 691
- Furlow palatoplasty
 - anatomy, 2662
 - closure, 2666
 - complications, 2667
 - definition, 2662
 - hard palate, 2664
 - imaging, 2663
 - merits and demerits, 2664*b*
 - nasal layer, 2665
 - oral layer, 2664
 - outcomes, 2667
 - palatal fistula conversion by, 2699
 - patient history and physical findings, 2662–2663
 - postoperative care, 2667
 - surgical management
 - approach, 2663
 - patient positioning, 2663
 - preoperative planning, 2663
- velopharyngeal insufficiency
 - dissection, 2708, 2709*f*
 - markings, 2708, 2708*f*
 - surgical management, 2707

- Z-plasty with intravelar veloplasty
- FUs (follicular units), 416
- FUT (follicular unit transplantation), 416

G

- G' (G-prime), 26
- Gabapentin, peroneal nerve injury, 2414
- Gait, 2355, 2456
 - analysis, 2365
 - cycle and biomechanics, 2365
- Galea aponeurotica, 69–70, 97
- Galeotomies, hairline lowering, 103, 103*f*
- Gamekeeper deformity, 1938
- GAN (great auricular nerve), 198
- Ganglion cysts
 - anatomy, 2280, 2280*f*–2281*f*
 - complications, 2286
 - definition, 2280
 - differential diagnosis, 2282
 - dorsal wrist, 2281, 2282*f*, 2283, 2283*f*
 - imaging, 2282
 - merits and demerits, 2286*b*
 - natural history, 2281
 - nonoperative management, 2282
 - outcomes, 2286
 - pathogenesis, 2281
 - patient history and physical findings, 2281, 2282*f*
 - postoperative care, 2286
 - surgical management, 2282
 - volar wrist, 2281, 2282*f*, 2284, 2284*f*
- Gastrocnemius muscle flap, 2463
 - anatomy, 2482

- complications, 2485
- definition, 2482
- elevation of, 2483–2484, 2484*f*
- imaging, 2482
- merits and demerits, 2485*b*
- pathogenesis, 2482
- patient history and physical findings, 2482
- postoperative care, 2485, 2485*f*
- surgical management
 - approach, 2483
 - patient positioning, 2483
 - preoperative planning, 2483
- Gastroschisis
 - complications, 3029
 - definition, 3026
 - diagnostic studies, 3026
 - differential diagnosis, 3026
 - imaging, 3026
 - merits and demerits, 3029*b*
 - patient history and physical findings, 3026, 3027*f*
 - postoperative care, 3029
 - repair
 - closure, 3028, 3028*f*
 - delayed closure with silo placement, 3028, 3028*f*
 - immediate reduction, 3028
 - surgical management
 - patient positioning, 3027
 - preoperative planning, 3026–3027
- Gavello procedure, 1138
- Gender-affirming surgery
 - anatomy, 1687, 1688*f*–1689*f*
 - complications, 1697
 - definition, 1687

- imaging, 1689
- outcomes, 1696
- pathogenesis, 1687
- patient history and physical findings, 1687–1689
- penile inversion vaginoplasty
 - approach, 1689
 - patient positioning, 1689
 - preoperative planning, 1689
- postoperative care, 1696
- Genioplasty, chin reduction, 408–409, 408*f*, 409*f*
- Genital system, conjoined twins, 3095
- Genitography, 3063
- Gentamicin, 2471
- Giant cell tumors
 - anatomy, 2281
 - of bone, 2423
 - complications, 2286
 - definition, 2280
 - differential diagnosis, 2282
 - imaging, 2282
 - merits and demerits, 2286*b*
 - natural history, 2281
 - nonoperative management, 2282
 - outcomes, 2286
 - pathogenesis, 2281
 - patient history and physical findings, 2282
 - postoperative care, 2286
 - surgical management, 2282
- Gilles approach, 872–873, 873*f*
- Gillies incision, 955
- GILLS score, 2691
- Gingivobuccal sulcus, 395, 395*f*
 - incision, 2610

- Gingivoperiosteoplasty (GPOP)
 - anatomy, 656, 657*f*–658*f*
 - complications, 662
 - definition, 656
 - flap elevation, 659–660
 - imaging, 656
 - markings and incisions, 659, 659*f*
 - merits and demerits, 659*b*
 - nonoperative management, 657
 - outcomes, 662
 - patient history and physical findings, 656
 - postoperative care, 661
 - repositioning of elements, 660, 660*f*
 - Skoog's technique, 658
 - surgical management
 - approach, 658–659
 - patient positioning, 658, 658*f*
 - preoperative planning, 658, 658*f*
 - surgical management, patient positioning, 658
 - suturing and completion, 660, 660*f*–661*f*
- Glabella, injectable fillers in, 20–22
- Glabellar muscles, 93, 93*f*
- Glabellar region, botulinum toxin injection into
 - anatomy, 2
 - complications, 4
 - definition, 2
 - outcomes, 4
 - patient history and physical findings, 3
 - postoperative care, 4
 - surgical management
 - approach, 3
 - merits and demerits, 4*b*
 - patient positioning, 3

- preoperative planning, 3
- Glanuloplasty, 3048
- Glioma, 2745
- Glomus tumors of hand
 - anatomy, 2287
 - complications, 2290
 - definition, 2287
 - differential diagnosis, 2287
 - imaging, 2287, 2287*f*
 - lateral approach, 2289, 2290*f*
 - location based on palpation, 2288, 2288*f*
 - merits and demerits, 2290*b*
 - natural history, 2287
 - outcomes, 2290
 - pathogenesis, 2287
 - patient history and physical findings, 2287
 - postoperative care, 2290
 - surgical management, 2288, 2288*f*
 - patient positioning, 2288
 - preoperative planning, 2288
 - transungual approach, 2288, 2289*f*
 - zigzag incision, 2288, 2288*f*
- Glucose-6-phosphate dehydrogenase (G6PD) enzyme deficiency
 - EMLA, 967
- Gluteal augmentation
 - completion, 1629–1630, 1631*f*
 - island flap harvesting and placement, 1629, 1630*f*
- Gluteal autoaugmentation, lower body lift, 1621, 1622*f*
- Gluteal flaps, for sacral pressure injuries. *See* Sacral pressure injury
- Gluteal muscles, bilateral V-to-Y advancement of, 2788, 2788*f*
- Gluteal rotation flap, 1701, 1702*f*
- Gluteal thigh flap for perineal reconstruction. *See* Perineal reconstruction

- Gluteus maximus myocutaneous flap, 2788, 2788*f*
- Gout, 2456
- GPOP. *See* Gingivoperiosteoplasty (GPOP)
- Gracilis flap, 2397, 2518
 - perineal and vaginal reconstruction (*see* Perineal reconstruction)
- Gracilis muscle
 - anatomy, 1682, 1682*f*, 2933, 2933*f*
 - harvest, 2938–2939, 2939*f*
 - inset, 2939, 2940*f*
- Graf technique, 1336, 1336*f*
- Graft harvest, 2916
 - medial orbit wall fractures, 835
- Graft implantation, 429
- Graft passage and completion, 2917
- Graft, resorption of, 996
- Grafts, closed rhinoplasty, narrow midvault in, 275
- Granulomas, 147
- Grasp improvement procedures
 - anatomy, 2210
 - complications, 2215
 - definition, 2210
 - imaging, 2210
 - merits and demerits, 2212*b*, 2214*b*
 - nonoperative management, 2211
 - outcomes, 2215
 - patient history and physical findings, 2210
 - postoperative care, 2214
 - surgical management
 - approach, 2212
 - patient positioning, 2211
 - preoperative planning, 2211
- Great auricular nerve (GAN), 198, 215, 226*f*–227*f*
 - anatomy, 966*f*, 967

- of ear, 1129
- Greater arc injury, 1895–1896, 1895*f*, 1896*f*
- Greater occipital nerve, 97, 966*f*, 967
- Greater palatine artery, 2671
- Greater palatine vessels isolation, 2685–2686, 2686*f*
- Greenstick-type fractures, 908
- Groin, approach to, 2524, 2524*f*
- Grouped fascicular repair, 2004–2005, 2004*f*
- Gruss types NOE fractures, 867, 868*f*
- GSW (gunshot wounds), 934
- Gummy smile, botulinum toxin injection, 10
 - anatomy, 9, 9*f*
 - approach, 9
 - complications, 10
 - definition, 9
 - merits and demerits, 10*b*
 - nonoperative management, 9
 - outcome, 10, 10*f*
 - patient history and physical findings, 9
 - patient positioning, 9
 - postoperative care, 10
- Gunshot wounds (GSW), 934
- Gustilo classification system, 2466
- Guyon canal, 1986
- Gynecomastia
 - anatomy, 1355, 1355*f*, 1635, 2983, 2983*f*–2984*f*
 - complications, 1360, 1638–1639, 2991
 - definition, 1355, 1635, 2983
 - differential diagnosis, 1356, 2985
 - imaging, 1356, 1635, 2985
 - merits and demerits, 1357*b*, 1360*b*, 1638*b*, 2990*b*
 - natural history, 2984, 2984*f*
 - nonoperative management, 1356, 2985

- outcomes, 1360, 1636*f*–1637*f*, 1638, 2990, 2991*f*
- pathogenesis, 1355, 1635, 2983–2984
- patient history and physical findings, 1356, 1635, 2984–2985
- postoperative care, 1360, 1638, 2990
- surgical management, 1635, 2985–2986
 - approach, 1356–1357, 2986
 - patient positioning, 1356, 2986
- preoperative planning, 1356, 2985

H

- Hair restoration surgeons (HRS), 419
- Hair transplantation
 - anatomy, 416
 - cicatricial alopecia, trauma/postrhytidoplasty, 428
 - complications, 432
 - definition, 416
 - differential diagnosis, 418
 - donor site closure, 424–425, 425*f*
 - donor strip harvest, 424, 424*f*
 - facial hair transplantation, 429
 - FUE harvest, 425–426
 - graft preparation, 426–427, 427*f*
 - imaging, 418
 - implantation of grafts, 429
 - merits and demerits, 429*b*
 - natural history, 417, 418*f*
 - nonoperative management, 418–419, 419*f*
 - outcomes, 430–432
 - pathogenesis, 416–417
 - patient history and physical findings, 417–418
 - postoperative care, 430
 - recipient sites, creation of, 427–428, 428*f*
 - surgical management, 419–424, 420*f*, 421*f*, 424*b*
 - hairline design, 422–423, 422*f*–423*f*
 - patient positioning, 423–424
 - preoperative planning, 421–423, 421*f*
 - in women, 427*f*, 428
- Hairline lowering
 - anatomy, 97
 - complications, 105

- definition, 97, 98*f*
- flap elevation, 101, 102*f*
- galeotomies, 103, 103*f*
- incision and dissection, 101, 101*f*
- local anesthesia, 100, 100*f*
- merits and demerits, 105*b*
- outcomes, 105
- patient history and physical findings, 97
- postoperative care, 105
- preoperative planning and positioning, 98, 100*f*
- scalp advancement, 103, 103*f*–104*f*
- scalp fixation and wound closure, 104, 104*f*–105*f*
- surgical management, 97–98, 99*f*
- Halitosis, palatal fistula, 2704
- Hammer's key area, 847, 847*f*
- Hammond modification, skate flap, 1479–1480, 1479*f*, 1480*f*
- Hamstring muscle, 2465
- Hamstring V-Y flap, 1712, 1713*f*
- Hand
 - compartment syndrome
 - anatomy, 1760, 1760*f*, 1762*b*
 - fasciotomy of, 1762–1763, 1762*f*, 1763*f*
 - flexor tendon sheaths of, 1771, 1771*f*
 - lumps and bumps of (*see* Ganglion cysts; Giant cell tumors)
 - malignant skin tumors (*see* Skin tumors, malignant)
 - osteoarthritis (*see* Osteoarthritis (OA))
 - rheumatoid arthritis
 - boutonniere deformity (*see* Boutonniere deformities)
 - MCPJ and PIPJ arthritic changes, 1936, 1936*f*–1937*f*
 - MCPJ volar subluxation and ulnar deviation, 1936–1937, 1936*f*–1937*f*
 - sparing of DIPJ, 1936
 - swan-neck deformity (*see* Swan-neck deformity)

- Handlebar palsy, 1987
- Hard palate
 - harvest, 1096–1097, 1097*f*
 - mucosal graft, 190, 191*f*
 - posterior lamellar reconstruction, 1097, 1097*f*
 - repair, 2659–2660, 2660*f*
- Harvesting bone marrow, 2478, 2479*f*
- Hearing, 2618
- Heberden nodes, on DIPJs, 1956, 1957*f*
- Heel defect, 2376*f*–2377*f*
- Helical-scapal defect., 1131*f*
- Helical-scapal-antihelix defect, 1131, 1131*f*
- Helix defect, 1130, 1130*f*
- Hemangioma(s), 2759–2760
 - definition, 2291
 - of hand
 - cavernous, 2291
 - complications, 2294
 - congenital, 2291
 - differential diagnosis, 2292
 - excision, 2292–2293, 2293*f*
 - imaging, 2292
 - incision and dissection, 2292, 2292*f*–2293*f*
 - infantile, 2291
 - merits and demerits, 2294*b*
 - natural history, 2291
 - nonoperative management, 2292
 - outcomes, 2294
 - pathogenesis, 2291
 - patient history and physical findings, 2291, 2291*f*
 - postoperative care, 2294
 - surgical management, 2292
 - zigzag incision, 2292, 2292*f*–2293*f*

- natural history, 2275
- nonoperative management, 2276
- Hemangioma resection of, nasal tip hemangioma, 2890, 2890*f*
- Hematoma(s), 200, 1741, 1991, 2387, 2428, 2445, 2485, 2492
 - antia-buch flaps, 1132
 - auricular, 3083
 - deep plane face-lift, 237
 - face-lifting and neck lifting, 209
 - formation, 2321
 - orbital floor blow-out fractures, 815
 - to prevent reaccumulation of, 2896*f*
- Hemicortical resection, 2424
- Hemifacial microsomia (HFM), 671, 2729
- Hemiglossectomy
 - defects, 1199–1200, 1200*f*–1201*f*
 - indications, 1198
- Hemihamate arthroplasty (HHA), 1818
 - advantage, 1822
 - autograft harvest, 1826, 1827*f*
 - contraindications, 1824
 - definition, 1822
 - graft fixation and closure, 1827, 1828*f*
- Hemi-tongue reconstruction, free flap
 - anatomy, 1198, 1198*f*
 - closure, 1206
 - complications, 1207
 - definition, 1198
 - flap harvest
 - anterolateral thigh flap, 1204, 1204*f*
 - radial forearm free flap, 1201–1202, 1202*f*
 - ulnar artery perforator flaps, 1203, 1203*f*–1204*f*
 - flap inset, 1205–1206, 1205*f*
 - imaging, 1199

- merits and demerits, 1200*b*
- outcomes, 1207
- pathogenesis, 1198–1199
- patient history and physical findings, 1199
- postoperative care, 1207
- sensory reinnervation, 1206, 1206*f*
- surgical management
 - patient positioning, 1199–1200
 - preoperative planning, 1199
- Hemitransfixion incision, 2895
- Hemorrhage, Le Fort I fractures, 892
- Hemosiderin, 2428
- Hemostasis, 144, 1058, 1061, 1072, 2115, 2122
 - emergency room anesthesia, 3077
 - palatal grafts, 1098
 - partial auriculectomy defects, 1144
- Hemothorax, 996
- Heparin, 2444
- Hepatobiliary tree, conjoined twins, 3095
- Hernia, definition of, 1572
- Hernia repair
 - anatomy, 1556
 - anterior component separation
 - endoscopic, 1559, 1559*f*
 - minimally invasive, 1558
 - open, 1557–1558, 1557*f*
 - definition, 1556
 - imaging, 1556
 - merits and demerits, 1557*b*
 - outcomes, 1561
 - patient history and physical findings, 1556
 - postoperative care, 1561
 - surgical management

- approaches, 1557
- patient positioning, 1556
- preoperative planning, 1556
- transversus abdominis release, 1559–1560, 1560*f*
- Herniated orbital fat, lower eyelid
 - anatomy, 132, 132*f*
 - anesthesia and eye preparation, 133
 - complications, 137
 - definition, 132
 - excision of, 134, 135*f*
 - eyelid retractors, isolating, 133, 134*f*
 - merits and demerits, 136*b*
 - outcomes, 137, 137*f*
 - patient history and physical findings, 132
 - postoperative care, 136
 - repositioning, 135–136, 136*f*
 - surgical management, 132
- Hertel exophthalmometry, 848
- Heterotopic ossification (HO), 2481, 2765
- Hetinoblastoma gene mutation, 2338
- HFM (hemifacial microsomia), 671, 2729
- HHA. *See* Hemihamate arthroplasty (HHA)
- High combined median and ulnar nerve injuries
 - finger flexion, 2040
 - forearm pronation, 2040–2041
 - sensory nerve transfers, 2041
 - thumb flexion, 2040
- High radial nerve palsy
 - anatomy, 2048–2049
 - complications, 2053
 - definition, 2048
 - imaging, 2049
 - merits and demerits, 2050*b*, 2053*b*

- outcomes, 2053
- patient history and physical findings, 2049
- postoperative care, 2053
- surgical management
 - algorithm, 2050*f*
 - patient positioning, 2049
 - preoperative planning, 2049
- High-energy trauma, 2467
- High-frequency linear transducer, 2310–2311
- High-grade chondrosarcoma, 2423, 2503*f*
- High-grade osteosarcoma, 2502
- Hildreth's test, 2287
- Hip and buttock pathology, 2531
- HO (heterotopic ossification), 2481, 2765
- Hook of hamate fractures, 1987
- Horner syndrome, 2850, 2949
- HRS (hair restoration surgeons), 419
- Huber transfer, 2015, 2015*f*
- Hughes flap
 - anatomy
 - anterior lamella, 1089
 - blood supply, 1090
 - external carotid, 1090
 - lower eyelid retractors, 1090
 - posterior lamella, 1089
 - upper eyelid retractors, 1090
 - complications, 1093
 - definition, 1089
 - flap creation, 1090, 1091*f*
 - flap separation, 1091
 - imaging, 1090
 - merits and demerits, 1090*b*
 - outcomes, 1093

- patient history and physical findings, 1090
- postoperative care, 1093
- surgical management
 - patient positioning, 1090
 - preoperative Planning, 1090
- Human bites, 3074
- Hunsuck modification, 697
- Hyaluronic acid, 20–21, 37, 42
- Hyaluronic acid fillers, 164
- Hydrocephalus, with syndromic craniosynostosis, 446
- Hydrogen peroxide, 2471
- Hydrosurgery system, 2429, 2429*f*
- Hydroxyapatite, 2361
- Hyperbaric oxygen (HBO) treatment, 2366
- Hypercontraction, of corrugator muscles, 3
- Hyperdynamic glabellar musculature, 2
- Hyperfunctioning of muscles, 2
- Hypernasal speech, 2707
- Hyperparathyroidism, 2460
- Hypertelorism, 543, 547*b*, 2745
- Hypertrophic healing tendency, 210
- Hypertrophic hypothenar muscles, 1987
- Hypertrophic nonunion, 2506, 2509
- Hypertrophic scars, 66, 2765, 2806
- Hypervascularity, 2752
- Hypogastric plexiform tumor, 2755, 2756*f*
- Hypoglobus, 847
- Hypomastia., 1290, 1290*f*
- Hypomegakaryocytic thrombopenia, 2268
- Hypopigmentation, 66
- Hypoplasia, 2617
- Hypoplastic mandible, 672, 672*f*
- Hypoplastic medial/lateral lip element, 2650–2651

- Hypoplastic thumb reconstruction
 - anatomy, 2225
 - complications, 2233
 - definition, 2225
 - imaging, 2226
 - merits and demerits, 2233*b*
 - natural history, 2225
 - nonoperative management, 2226
 - outcomes, 2233
 - pathogenesis, 2225
 - patient history and physical findings, 2225–2226, 2226*f*
 - postoperative care, 2233
 - surgical management
 - approach, 2227
 - patient positioning, 2227
 - preoperative planning, 2227
- Hypospadias
 - anatomy, 3041
 - complications, 3050
 - definition, 3041
 - imaging, 3041
 - merits and demerits, 3049*b*
 - nonoperative management, 3042
 - outcomes, 3050
 - pathogenesis, 3041
 - patient history and physical findings, 3041
 - postoperative care, 3049–3050
 - prevalence of, 3041
 - repair, algorithm for, 3043*f*
 - surgical management, 3042
 - approach, 3042, 3043*f*
 - patient positioning, 3042
 - preoperative planning, 3042

- Hypothenar compartment release, 1762, 1763*f*
- Hypothenar fascia, 1986, 1986*f*, 1989, 1990*f*
- Hypothenar fat flap, carpal tunnel release, 1984, 1984*f*
- Hypothenar hammer syndrome, 1987, 2160
- HypoThermosol, 426

- IAN (inferior alveolar nerve), 398, 697, 907, 1047
- Iatrogenic airway obstruction, 275
- Iatrogenic injury, 1991, 2411
- ICAP flap, 1370, 1370*f*
- ICSRA (intercompartmental suprarretinacular artery) vascularized bone flap, 1882–1883, 1883*f*
- Iliac crest, 2355, 2360
- Iliac crest bone graft
 - harvesting, 648, 648*f*
 - cancellous, 2359, 2359*f*
 - tricortical structural, 2358, 2358*f*–2359*f*
 - nonunion of a mandible fracture, 929–930, 929*f*
- Iliac crest harvest site, 2358*f*
- Ilizarov technique, 2424
- ILO. *See* Inverted L osteotomy (ILO)
- IMA (internal mammary artery), 1515
- Imaging
 - free groin flap, 2138
 - free lateral arm flap, 2134
 - pedicled groin flaps, 2138
 - posterior interosseous artery flap, 2127
 - reverse radial forearm flap, 2115
 - soft tissue tumors, excision of, 2339
 - ulnar artery perforator flap, 2121
- IMAP (internal mammary artery perforator) flap, 1230

- Immediate tissue expander placement
 - and closure, 1390–1391, 1391*f*
 - complications, 1392
 - definition, 1385
 - implant pocket creation, 1386–1390, 1387*f*–1389*f*
 - merits and demerits, 1386*b*, 1391*b*
 - outcomes, 1392
 - patient history and physical findings, 1385
 - postoperative care, 1392
 - preparation of, 1390, 1390*f*
 - surgical management
 - implant selection, 1385–1386
 - patient positioning, 1386
 - preoperative planning, 1385–1386
 - wound assessment, 1386
- Impaired blood flow, 2392
- Impaired visual acuity, 140
- Implant(s)
 - chin augmentation with
 - anatomy, 386, 387*f*–388*f*
 - complications, 390–391
 - definition, 386, 388*b*
 - external (submental) approach, 388–389, 388*f*, 389*f*
 - imaging, 387
 - implant selection, 387
 - intraoral approach, 390
 - merits and demerits, 390*b*
 - outcomes, 390, 391*f*
 - pathogenesis, 386
 - patient history and physical findings, 386–387
 - postoperative care, 390
 - surgical management, 387
 - malar

- anatomy, 392, 392*f*
- complications, 396
- definition, 392
- imaging, 393
- intraoral approach, 395, 395*f*
- merits and demerits, 396*b*
- nonoperative management, 393
- outcomes, 396, 396*f*–397*f*
- pathogenesis, 392–393, 393*f*
- patient history and physical findings, 393
- periorbital approach, 394, 394*f*
- postoperative care, 396
- preoperative preparation, 394*b*
- surgical management, 393–394
- types of, 943–944
- Implant deviation, correction of, 359, 359*f*
- IMS (intermuscular septum), 2130
- In situ cubital tunnel decompression, 1994, 1995*f*
- Inadequate tip projection, 288
- Incisional hernias
 - abdominal wall closure, 1577–1578, 1577*f*
 - anatomy, 1572
 - complications, 1579
 - definition, 1572
 - external abdominal oblique release, 1574–1575
 - imaging, 1572
 - laparotomy, 1574, 1574*f*
 - merits and demerits, 1578*b*
 - mesh inset, 1576, 1576*f*–1577*f*
 - nonoperative management, 1573
 - outcomes, 1579
 - pathogenesis, 1572
 - patient history and physical findings, 1572

- postoperative care, 1578–1579
- surgical management
 - approach, 1574
 - positioning, 1574
 - preoperative planning, 1573–1574
- suture pull-through, 1572, 1573*f*
- Incisive nerve, 1047
- Inclusion cysts, 147
- Incomplete clefts, 2606
- Index finger abduction, 2037–2038
- Induced membrane, with intramedullary autogenous bone grafting, 2474–2475, 2475*f*
 - cement spacer placement and internal fixation, 2475–2476, 2475*f*
 - completion of reaming, 2478
 - graft placement, 2478, 2479*f*
 - harvesting bone marrow, 2478, 2479*f*
 - inserting guidewire, 2476–2477, 2477*f*
 - reaming graft material, 2477–2478, 2478*f*
 - RIA preparation, 2477, 2477*f*
 - soft tissue coverage and monitoring, 2476, 2476*f*
 - spacer removal and bone preparation, 2476, 2476*f*
- Infected lateral malleolar wound, 2351*f*
- Infection(s)
 - bone tumors of foot and ankle, 2348
 - closed rhinoplasty, narrow midvault in, 275
 - deep plane face-lift, 237
 - face-lifting and neck lifting, 209
 - Le Fort III fracture, 902
 - open treatment of nasal fractures, 864
- Inferior alveolar nerve (IAN), 398, 697, 907, 1047
- Inferior gluteal artery perforator flap breast reconstruction
 - anatomy, 1452–1454
 - approach, 1454

- complications, 1457
- definition, 1452
- flap design and markings, 1455, 1455*f*
- harvesting, 1455–1456, 1456*f*
- imaging, 1454
- merits and demerits, 1456*b*
- outcomes, 1457
- patient history and physical exam, 1454
- patient positioning, 1454
- postoperative care, 1457
- recipient vessel exposure, 1456
- surgical management, 1454
- Inferior labial artery, 1063, 1063*f*
- Inferior orbital fissure, 809
- Inferior pedicle
 - anatomy, 1345
 - complications, 1348–1349
 - definition, 1345
 - imaging, 1345
 - internal shaping sutures, 1347–1348, 1348*f*
 - merits and demerits, 1348*b*
 - nipple dissection, 1347, 1347*f*
 - nipple incision, 1346, 1346*f*
 - nipple resection, 1347, 1347*f*
 - outcomes, 1348
 - patient history and physical findings, 1345
 - postoperative care, 1348
 - surgical management
 - approach, 1346
 - patient positioning, 1346
 - preoperative planning, 1345–1346, 1346*f*
- Inferior retinacular lateral canthopexy/canthoplasty, 159–160, 160*f*
- Inferior retinaculum, 157

- Inferior turbinates, 380
- Inflamed deep peroneal nerve
- Inflatable orbital expanders, 2882
- Inframammary approach, breast augmentation plane
 - dual plane type II placement, 1316–1317, 1317*f*
 - Keller funnel, 1316–1317, 1317*f*
 - partial subpectoral placement, 1316–1317
 - partial subpectoral placement and dual plane creation
 - closure, 1323, 1324*f*
 - implant placement, 1323, 1323*f*
 - incision and dissection, 1322, 1322*f*
 - pocket creation, 1322–1323, 1323*f*
 - smooth round silicone implant, 1316–1317
 - with subfascial placement, 1324
- Infraorbital artery, 1122
- Infraorbital nerve, 392, 889, 2640
 - anatomy, 966, 966*f*
 - surgical management, intraoral approach, 970, 970*f*
- Infraorbital rim (IOR), 809, 878, 882, 2724*f*
- Infrapopliteal disease, 2400
- Infratrochlear nerve, 966, 966*f*
- Inguinal defects, 1589
- Inguinal vascularized lymph node harvest, 2563, 2563*f*
- Injection of fillers, in glabella, forehead and brow, 21
 - anatomy, 20, 20*f*
 - approach, 20
 - complications, 22
 - definition, 20
 - merits and demerits, 21*b*
 - nonoperative management, 20
 - outcomes, 21
 - patient history and physical findings, 20
 - positioning, 20

- postoperative care, 21
- Inner canthal distance (ICD), 542, 543*f*
- Inner preputial inlay graft, 3045, 3046*f*
- Inner preputial skin flap, 3047
- Innervated flap, 2383
- In-plane needle insertion approach, ultrasound-guided, 2316
 - imaging, 2318
 - needling, 2319
 - patients positioning, 2318
 - lateral decubitus position, 2318
 - prone position, 2318
 - supine position, 2318
- Insulated Desmarres retractor, 159
- Integumentary system, conjoined twins, 3096
- Intense pulsed light (IPL) device, 2802, 2802*f*
- Intercompartmental suprarretinacular artery (ICSRA) vascularized bone flap, 1882–1883, 1883*f*
- Interleukin-6 (IL-6), 1931
- Intermaxillary fixation. *See* Maxillomandibular fixation (MMF)
- Internal mammary artery (IMA), 1515
- Internal mammary artery perforator (IMAP) flap, 1230
- Internal mammary vessels, 1447, 1449, 1449*f*
- Internal mandibular distraction
 - anatomy, 718, 718*f*–719*f*
 - complications, 722
 - definition, 718
 - differential diagnosis, 719
 - imaging, 719
 - inverted “L” osteotomy, 720
 - merits and demerits, 720*b*
 - nonoperative management, 719
 - outcomes, 722
 - pathogenesis, 718

- patient history and physical findings, 718
- placement, 720
- postoperative care, 722
- removal, 721
- surgical management
 - patient positioning, 720
 - preoperative planning, 719
- Internal nasal valve, 269, 297, 380
 - repair, nasal airway obstruction, 383, 383*f*
- Internal/endoscopic dacryocystorhinostomy, 2873, 2873*f*
- International Classification for Surgery of the Hand in Tetraplegia (ICT), 2210
- Interorbital distance (IOD), 542, 543*f*
- Interossei, 1986–1987, 1986*f*
- Interosseous ligament complex, wrist. *See* Scapholunate interosseous ligament (SLIL) injury
- Interpositional genioplasty, 4
- Interpupillary distance (IPD), 542, 543*f*
- Intra-abdominal pressure, 1572
- Intralesional curettage, 2503
- Intramedullary autogenous bone grafting, 2475, 2475*f*
- Intranasal deformity, 380
- Intranasal glioma
 - endoscopic excision of, 2750, 2750*f*
 - pathogenesis, 2745
- Intraneural topography of median nerves, 2004, 2005*f*
- Intraoral approach, 603
 - alloplastic chin augmentation, 759
 - malar implants, 395, 395*f*
 - mandibular setback, 740–749
- Intraoral cheek surface, 1219, 1219*f*
- Intraoral vertical ramus osteotomy (IVRO)
 - inferior osteotomy, 715, 715*f*

- setback procedure, 714
- superior osteotomy, 715, 715*f*, 716*f*
- surgical management, mandible repositioning, 715, 716*f*
- Intravascular injection, 2325
- Intravelar veloplasty, Z-plasty with
- Intravenous antibiotics, 2469, 2471
- Intrinsic release, 2076
- Introitoplasty, 3054–3055, 3054*f*, 3055*f*
- Inverted L osteotomy (ILO)
 - anatomy, 706
 - combined extraoral-intraoral ILO, 709–710, 710*f*
 - complications, 711
 - definition, 706
 - differential diagnosis, 706
 - extraoral
 - exposure, 707–709, 708*f*
 - osteotomy, 707–709, 709*f*
 - imaging, 706
 - internal mandibular distraction, 720
 - intraoral, 710, 710*f*
 - merits and demerits, 707*b*
 - neonates and children, 706
 - postoperative care, 711
 - preoperative planning, 706
 - skeletally mature patients, 706
 - surgical management
 - approach, 707
 - patient positioning, 707, 707*f*
- Inverted V deformity, 270
- Inverted-T excision, 2655–2656, 2656*f*
- Involucrum, 2466
- IOM (interosseous membrane), 2126
- IOR (infraorbital rim), 809, 878, 882, 2724*f*

- Ipsilateral fibula flap, 1025
- Ipsilateral flap, 1031
- Ipsilateral mucoperichondrial septal _flap, 1165*f*
- Ipsilateral vein, 2404
- Ischemia
 - breast, plastic surgery of, 1412
 - free fibula flap for midface reconstruction, 1010
 - irreversible muscle damage, 1760
- Ischemic claudication, 2400
- Ischemic rest pain, 2400
- Ischial pressure injury, 2787, 2793, 2793*f*
 - debridement with gluteal rotation flap, 2788, 2788*f*
 - V-Y advancement flap for, 2787, 2787*f*
- Ischial ulcers, posterior thigh and hamstring flaps for
 - anatomy, 1705, 1706*f*–1707*f*
 - complications, 1714
 - definition, 1705
 - differential diagnosis, 1707
 - imaging and other diagnostic studies, 1707
 - natural history, 1706
 - nonoperative management, 1707–1708
 - outcomes, 1714
 - pathogenesis, 1705–1706
 - patient history and physical findings, 1706–1707
 - postoperative care, 1713–1714
 - surgical management
 - approach, 1708, 1710*b*
 - positioning, 1708
 - preoperative planning, 1708
- Ischiopagus conjoined twins, 3092, 3093*f*–3094*f*, 3097–3100. *See also* Conjoined twin
- I-shaped silicone implants, 351, 351*f*
- Island flap, 2107

- Islandized propeller flaps, 2592–2593, 2592*f*
- Isolated neck lift
 - anatomy, 238, 238*f*
 - complications, 240
 - definition, 238
 - imaging, 238
 - merits and demerits, 240*b*
 - outcomes, 240, 241*f*
 - patient history and physical findings, 238
 - postoperative care, 240
 - surgical management, 238–240
 - approach, 239–240
 - positioning, 239
 - preoperative planning, 238–239
 - techniques, 239*b*, 239*f*
- IVRO. *See* Intraoral vertical ramus osteotomy (IVRO)

J

- Jackson-Pratt drains, 1531
- Jackson-Weiss syndrome, 616
- Jahss technique, metacarpal neck, 1788, 1788*f*–1789*f*
- Jamshidi needle, 2361, 2361*f*
- Jeanne test, 1987, 1993
- Jejunum flap, for pharyngeal reconstruction
 - after laryngopharyngectomy, 1231, 1231*f*
 - anatomy, 1229, 1229*f*
 - complications, 1235
 - definition, 1229
 - donor-site closure, 1234
 - flap harvest, 1231, 1232*f*
 - flap inset, 1232–1233, 1233*f*
 - imaging, 1230
 - merits and demerits, 1231*b*
 - outcomes, 1235
 - patient history and physical findings, 1229–1230
 - postoperative care, 1234, 1235*f*
 - surgical management
 - open or a laparoscopic approach, 1230
 - patient positioning, 1230
 - preoperative planning, 1230
- Joint loss, 2473
- Joseph periosteal elevator, 327, 2699
- Jumping genioplasty, 413
- Juvederm, 42
- Juvederm Ultra XC, 27
- Juvederm Ultra/Juvederm Ultra Plus, 43
- Juvenile breast hypertrophy
 - anatomy, 2992, 2993*f*

- complications, 3000
- definition, 2992
- differential diagnosis, 2993
- imaging, 2993
- merits and demerits, 2999*b*
- natural history, 2992
- nonoperative management, 2994
- outcomes, 3000
- pathogenesis, 2992
- patient history and physical findings, 2992–2993
- postoperative care, 3000
- surgical management, 2994–2996
 - patient position, 2995–2996, 2995*f*
- preoperative planning, 2994–2995, 2994*f*–2995*f*

K

- Kaposiform hemangioendothelioma, 2759
- Karapandzic flaps
 - anatomy, 1059, 1059*f*
 - bilateral, large midline lower lip defect, 1060, 1060*f*–1061*f*
 - complications, 1061
 - definition, 1059
 - imaging, 1059
 - merits and demerits, 1061*b*
 - outcomes, 1061, 1061*f*
 - patient history and physical findings, 1059
 - postoperative care, 1061
 - surgical management
 - approach, 1060
 - patient positioning, 1060
- Keen-type approach
 - zygomatic arch fractures, closed reduction and treatment, 874,

874*f*

- zygomaticomaxillary complex, 887, 887*f*
- Keratin-filled cysts, 66
- Ketamine, 3077
- Keystone area, 857
- Keystone flaps
 - anatomy, 1738, 1743–1744, 1743*f*, 2537–2538
 - for back reconstruction, 1746, 1746*f*
 - to close donor-site defect, 1747, 1747*f*
 - complications, 1741, 1748, 2543
 - definition, 1738, 1743, 2537, 2537*f*–2538*f*
 - design, technique for, 1745, 1746*f*
 - for foot reconstruction, 1746, 1746*f*
 - history, 1744
 - imaging, 1738, 1744, 2539
 - merits and demerits, 2540*b*, 2542*b*
 - nonoperative management, 2539
 - outcomes, 1741, 1748, 2543
 - pathogenesis, 1738
 - patient history and physical findings, 1738, 1744, 2538–2539
 - postoperative care, 1741, 1748, 2543
 - surgical management, 1744, 1744*f*, 1745*f*
 - approach, 1738, 1745, 2539
 - patient positioning, 2539
 - positioning, 1738, 1745
 - preoperative planning, 1738, 1745, 2539
- Keystone osteotomy, 2747–2748, 2748*f*
- Kidney ureter bladder radiograph (KUB), 3022
- Kienbock disease, 1905, 1957
- Killian incision, 300–302, 301*f*
- Kirschner wire (K-wire)
 - fixation
 - distal phalanx fractures, 1776–1777

- into dorsal lunate and triquetrum, 1861, 1862*f*
- metacarpal neck fractures, 1788, 1788*f*–1789*f*
- thumb trapeziometacarpal joint, 1836
- uses of, 347–348, 347*f*–348*f*, 2271
- Knee
 - bone tumors of
 - anatomy, 2460
 - complications, 2464
 - definition, 2460
 - differential diagnosis for, 2460
 - distal femur resection, 2461, 2461*f*
 - endoprosthetic reconstruction, 2461, 2461*f*
 - endoprosthetic reconstruction of proximal tibia, 2463, 2463*f*
 - estimated incidence of 3260, 2460
 - imaging, 2460
 - merits and demerits, 2464*b*
 - natural history, 2460
 - outcomes, 2464
 - pathogenesis, 2460
 - patient history and physical findings, 2460
 - postoperative care, 2464
 - reconstruction, 2462, 2462*f*
 - surgical management, 2460–2461
 - disarticulation, 2461
 - dislocation, 2411, 2413
 - soft tissue tumors
 - anatomy, 2456
 - complications, 2458
 - definition, 2456
 - differential diagnosis, 2457
 - functional outcomes, 2458
 - imaging, 2456–2457, 2457*f*
 - knee sarcoma, wide resection of, 2457, 2458*f*

- merits and demerits, 2458*b*
- natural history, 2456
- oncological outcomes, 2458
- pathogenesis, 2456
- patient history, 2456
- physical findings, 2456
- postoperative care, 2458
- surgical management, 2457
- Knee, bony and soft tissue debridement
 - anatomy, 2465–2466
 - blood supply, 2465–2466
 - distal femur, 2465
 - dynamic stabilizers, 2465
 - extensor mechanism, 2465
 - femoral nerve, 2466
 - patellofemoral articulations, 2465
 - sciatic nerve, 2466
 - static stabilizers, 2465
 - superficial femoral artery, 2465
 - tibiofemoral articulation, 2465
 - bone infection management, 2470, 2470*f*
 - complications, 2472
 - definition, 2465
 - imaging
 - infection after TKA, 2468
 - open fractures, 2468
 - osteomyelitis, 2468
 - merits and demerits, 2471*b*
 - outcomes
 - infection after TKA, 2472
 - open fractures, 2472
 - osteomyelitis, 2472
 - pathogenesis, 2466–2467

- open fractures, 2466
- osteomyelitis, 2466
- total knee arthroplasty, infection after, 2466–2467
- patient history and physical findings
 - infection after TKA, 2467, 2467*f*
 - open fractures, 2467
 - osteomyelitis, 2467, 2467*f*
- postoperative care
 - infection after TKA, 2471
 - open fractures, 2471
 - osteomyelitis, 2471
- soft tissue infection management
 - hydrogen peroxide, 2471
 - irrigation and debridement, 2470, 2471*f*
 - local antibiotics, 2471
 - negative pressure wound therapy, 2471
- surgical management
 - medial parapatellar approach, 2469
 - open fractures, 2468
 - osteomyelitis, 2468–2469
 - patient positioning, 2469
 - total knee arthroplasty, infection after, 2469
- Krackow sutures, 2494, 2494*f*
- KUB (kidney ureter bladder radiograph), 3022
- Kybella, 238

L

- L flap
 - on lateral lip element, 2608*f*–2609*f*, 2609
 - suturing, 2610
- Labbé procedure
 - anatomy, 1272
 - definition, 1272
 - imaging, 1272
 - lengthening temporalis myoplasty
 - myeloplasty, 1274, 1274*f*–1275*f*
 - superficial aponeurosis, 1273, 1273*f*–1274*f*
 - zigzag Cairns approach, 1273, 1273*f*–1274*f*, 1276
 - local infection, 1276
 - merits and demerits, 1273*b*
 - nonoperative management, 1272
 - outcomes, 1276
 - patient history and physical findings, 1272
 - postoperative care, 1276
 - postoperative hematoma, 1276
 - surgical management, 1272–1276
 - nasogenial approach, 1276
 - patient positioning, 1273
 - preoperative planning, 1273
- LABC (lateral antebrachial cutaneous nerve), 2052, 2052*f*, 2115–2116, 2118–2119
- Labia, 3062
- Labial artery, 1055, 1055*f*
- Labial mucosal flap, palatal fistula, 2700, 2700*f*
- Labioplasty, 3053, 3058, 3058*f*, 3071, 3071*f*
- Laceration closure techniques, 3078–3079, 3079*f*
- Lacri-Lube, 814–815

- Lacrimal apparatus, 823, 823*f*
- Lacrimal bone, medial orbit wall fractures, 829, 829*f*
- Lacrimal caruncle, 830, 830*f*
- Lacrimal nerve, 966, 966*f*
- Lacrimal sac, lacrimal system, 830*f*, 831
- Lacrimal sump syndrome, 2876
- Lacrimal system
 - eyelid injuries, 978
 - of medial canthal tendon, 831
- Lambdoid synostosis
 - craniosynostosis, 531
 - natural history, 445
- Lamella, with palatal grafts, 1094, 1094*f*
 - anterior, 1094
 - middle, 1095
 - posterior, 1095
- Lamellar high SMAS face-lift
 - anatomy, 215, 226*f*–227*f*
 - complications, 225–227
 - definition, 215, 216*f*
 - imaging, 216
 - merits and demerits, 225*b*
 - outcomes, 225*f*–226*f*
 - patient history and physical findings, 215–216
 - postoperative care, 225
 - skin flap elevation, 219–220, 219*f*
 - skin flap repositioning, trimming, and closure, 223–224, 224*f*
 - SMAS dissection, 221–222, 221*f*
 - SMAS suspension, 222–223, 222*f*
 - surgical management, 216–227
 - approach, 218–227
 - positioning, 218
 - preoperative planning, 216–218

- temple dissection, 220, 220*f*
- Lamina papyracea, 829
- Laparoscopic component separation, 1565, 1565*f*
- Laparoscopic harvest of pedicled omental flap, 1669
- Laparotomy, incisional hernias, 1574, 1574*f*
- Large-volume fat grafting
 - anatomy, 1496
 - complications, 1501
 - definition, 1496
 - fat harvest, 1497
 - fat injection, 1498–1499, 1498*f*–1500*f*
 - fat processing, 1498, 1498*f*
 - imaging, 1496
 - merits and demerits, 1500*b*
 - outcomes, 1501
 - patient history and physical exam, 1496
 - postoperative care, 1501
 - surgical management
 - approach, 1497
 - patient positioning, 1497
 - preoperative planning, 1497
- Laryngeal mask airway (LMA), 3
- Laser burn scar revision. *See* Burn injury
- Laser handpiece, 2802*f*
- Laser resurfacing of face
 - ablative fractional resurfacing, 52*f*, 54
 - ablative nonfractional resurfacing, 54
 - anatomy, 52, 52*f*
 - complications, 55–56
 - definition, 52
 - imaging, 54
 - nonablative fractional resurfacing, 52*f*, 54
 - outcomes, 55, 55*f*–56*f*

- pathogenesis, 52
- patient history and physical findings, 52, 54*b*
- postoperative care, 55
- surgical management
 - approach, 54
 - positioning, 54
 - preoperative planning, 54
- Laser therapy
 - skin grafts, 1127
 - of vascular lesions, 2802, 2802*f*
- LAST (local anesthetic systemic toxicity), 973, 1759, 2314, 2330
- Late infections, 396, 1115, 2469
- Lateral arm flap, 1116
- Lateral brow approach, orbital roof fractures, 842–843, 842*f*
- Lateral calcaneal vessels, dissection of, 2384*f*
- Lateral canthal lines. *See* Crow's feet, botulinum toxin injection to
- Lateral canthal manipulation, with canthopexy/canthoplasty
 - anatomy, 157, 158*f*–159*f*
 - complications, 161
 - definition, 157
 - inferior retinacular lateral canthopexy/canthoplasty, 159–160, 160*f*
 - merits and demerits, 160*b*
 - outcomes, 160, 161*f*
 - pathogenesis, 157–158
 - patient history and physical findings, 158–159
 - postoperative care, 160
- Lateral canthal-orbital rim distance (LC-OR), 158–159
- Lateral canthopexy, 619*f*
- Lateral canthoplasty, 2864*f*–2865*f*, 2865–2867
 - creation, 2865–2867, 2866*f*
 - suturing, 2867, 2867*f*
- Lateral canthus
 - bone canthopexy, bridge of

- anatomy, 185, 185*f*–186*f*
- closure, 189
- complications, 189
- definition, 185
- drill holes and positioning of, 187–189
- figure-of-8 suture fixation of, 187, 187*f*
- imaging, 186
- operative approach, 186, 187*f*
- outcomes, 189
- pathogenesis, 186
- patient history and physical findings, 186
- postoperative care, 189
- preoperative preparation, 186
- surgical management, 186
- drill holes and positioning of, 187–189
- Lateral cephalogram, chin deformities, 412
- Lateral circumflex femoral artery (LCFA), 1715, 1718
- Lateral collateral ligament, 2473
- Lateral crural strut grafts, 312, 312*f*
- Lateral decubitus position with appropriate padding, 1717, 1717*f*
- Lateral femoral circumflex artery, 1580, 1581*f*
- Lateral forefoot defect, on dorsalis pedis artery
- Lateral key pinch reconstruction
 - anatomy, 2206, 2206*f*
 - complications, 2209
 - definition, 2206
 - imaging, 2206
 - merits and demerits, 2208*b*
 - outcomes, 2209
 - patient history and physical findings, 2206, 2207*f*
 - postoperative care, 2209
 - surgical management
 - approach, 2207

- patient positioning, 2207
- preoperative planning, 2207
- Lateral lip elements
 - anatomy, 2606
 - hypoplastic, 2650–2651
 - Millard/Mohler modifications
 - alar base and L flap, 2608, 2608*f*–2609*f*
 - dissection, 2609–2610, 2610*f*
 - markings, 2607, 2608*f*–2609*f*
- Lateral mandible reconstruction, with soft tissue flaps
 - anatomy, 1047
 - completion, 1051
 - complications, 1051
 - definition, 1047
 - horizontally oriented flaps, 1048, 1049*f*
 - imaging, 1048
 - indication, 1047
 - merits and demerits, 1048*b*
 - nonhorizontally oriented flaps, 1049, 1049*f*–1050*f*
 - outcomes, 1051
 - patient history and physical findings, 1047–1048
 - postoperative care, 1051
 - surgical management, 1048
- Lateral mucosa fullness, 2648, 2650*f*–2651*f*
- Lateral nasolabial element
 - matching nasolabial lengths, 2600–2602, 2602*f*
 - nasal sill, 2600, 2601*f*
 - Nordhoff point, 2600, 2601*f*
- Lateral orbital wall fractures
 - anatomy, 823, 823*f*
 - complications, 827
 - definition, 823
 - exposure, 825, 825*f*–826*f*

- fracture repair, 826, 826*f*
- imaging, 824
- lateral cantholysis and completion, 826–827, 827*f*
- markings, 825, 825*f*
- merits and demerits, 827*b*
- nonoperative management, 824
- outcomes, 827
- pathogenesis, 823
- patient history and physical findings, 823–824
- postoperative care, 827
- surgical management, 824
- Lateral orbital wall osteotomy, 621*f*, 626, 628, 629*f*
- Lateral osseous flap, 1039
- Lateral plantar midfoot defect
- Lateral sural cutaneous nerve, 2456
- Lateral tarsal strip. *See* Lateral canthoplasty
- Lateral tarsal strip canthoplasty
 - anatomy, 1103
 - complications
 - definition, 1103
 - imaging, 1104
 - markings and anesthesia, 1103*f*, 1105
 - merits and demerits, 1105*b*
 - natural history, 1104
 - nonoperative management, 1104
 - outcomes, 1107
 - pathogenesis, 1103–1104
 - patient history and physical findings, 1104
 - postoperative care, 1107
 - removal of, 1103*f*–1104*f*, 1105–1106
 - strip placement, 1107
 - surgical management
 - patient positioning, 1105–1106

- preoperative planning, 1105
- Lateral thigh-based flaps, 1589*f*
- Laterally based cervicofacial flap
 - arterial blood supply, 1103, 1103*f*–1104*f*
 - complications, 1107
 - deep-plane elevation or tissue expansion, 1103
 - definition, 1103, 1103*f*
 - flap elevation, 1105, 1105*f*
 - imaging, 1104
 - markings, 1105, 1105*f*
 - merits and demerits, 1105*b*
 - outcomes, 1107, 1107*f*–1108*f*
 - patient history and physical findings, 1103–1104
 - postoperative care, 1107
 - reconstructive zones, 1103
 - surgical management
 - approach, 1104
 - patient positioning, 1104
 - preoperative planning, 1104
- Latham device, 2630
- Latissimus dorsi, 2397–2398
- Latissimus dorsi flap (LDF), 1525
 - anatomy, 1543, 1543*f*
 - axillary tunnel dissection, 1545
 - complication, 989
 - complications, 1546
 - definition, 1543
 - flap elevation, 1544–1545, 1545*f*
 - graft sources, 986*b*
 - merits and demerits, 1545*b*
 - outcomes, 1546
 - patient history and physical findings, 1543–1544
 - postoperative care, 1546

- specific donor-site dissections, 986
- surgical management, 985
 - positioning, 1544
 - preoperative markings, 1544, 1544*f*
 - preoperative planning, 1544
- Latissimus dorsi muscle, 1041
 - mandibular defects, 1038
 - vascularized rib with blood supply, 1038
- Latissimus dorsi (LD) muscle
 - anatomy, 1543, 1543*f*
- Latissimus dorsi muscle transfer, 2979–2980, 2979*f*
- Latissimus dorsi musculocutaneous flap, 2487–2488
- Latissimus dorsi (LD) myocutaneous flap, 1405–1406, 1406*f*
 - anatomy, 1404, 1404*f*
 - complications, 1407
 - definition, 1404
 - imaging, 1404
 - merits and demerits, 1407*b*
 - nonoperative management, 1405
 - outcomes, 1407
 - pathogenesis, 1404
 - patient history and physical findings, 1404
 - postoperative care, 1407
 - surgical management
 - approach, 1405
 - patient positioning, 1405
 - preoperative planning, 1405
- Latissimus dorsi transfer, 2962–2963, 2962*f*
- LCFA (lateral circumflex femoral artery), 1715, 1718, 2395, 2488
- LC-OR (lateral canthal-orbital rim distance), 158–159
- LD myocutaneous flap, Latissimus dorsi (LD) myocutaneous flap
- LDF. *See* Latissimus dorsi flap (LDF)
- Le Fort fracture, 950

- Le Fort I distraction osteogenesis (DO)
 - anatomy, 584
 - bony release, 586, 587*f*–588*f*
 - complications, 590
 - definition, 584
 - imaging, 584
 - merits and demerits, 585*b*
 - outcomes, 590, 590*f*
 - patient history and physical findings, 584, 584*f*
 - postoperative care, 590
 - rigid external distraction, 589, 589*f*
 - rigid external distraction device, 588, 588*f*
 - soft tissue release, 585–586, 586*f*
 - surgical management
 - approach, 585–590
 - patient positioning, 585
 - preoperative planning, 585
- Le Fort I fractures, 952
 - anatomy, 889, 889*f*–890*f*
 - complications, 892
 - definition, 889
 - exposure and reduction, 891, 891*f*
 - imaging, 890
 - maxillomandibular fixation, 891, 891*f*
 - merits and demerits, 892*b*
 - open reduction internal fixation, pediatric midface fractures, 953, 953*f*
 - pathogenesis, 889
 - patient history and physical findings, 890
 - postoperative care, 892
 - surgical management, 890
 - approach, 890
 - positioning, 890

- preoperative planning, 890
- Le Fort I osteotomy
 - anatomy
 - muscular structures, 572
 - osseous structures, 571–572, 571*f*
 - vascular, 572
 - complications, 583
 - definition, 571
 - dental examination, 573
 - growth evaluation, 572
 - imaging, 573
 - merits and demerits, 574*b*
 - nonoperative management, 573
 - outcomes, 583
 - patient history, 572
 - postoperative care, 583
 - skeletal examination, 572
 - soft tissue examination, 573
 - surgical management
 - approach, 573
 - patient positioning, 573, 573*f*
 - preoperative planning, 573
 - surgical technique
 - vertical patient positioning of maxilla, 579*f*–580*f*, 579
 - surgical technique
 - fixation, occlusal check, and closure, 580, 581*f*–582*f*
 - incision and exposure, 574, 576*f*
 - lateral nasal wall osteotomies, 577, 577*f*
 - lateral osteotomies, 577, 577*f*
 - maxillary down-fracture and mobilization, 578, 578*f*
 - preparation and external reference, 574, 574*f*
 - Pterygoid plate separation, 576, 576*f*–577*f*
 - removal of interferences, 578, 579*f*

- septal osteotomy, 576, 576*f*–577*f*
- TMJ examination, 572
- Le Fort II advancement, with distraction osteogenesis
 - anatomy, 606, 607*f*
 - complications, 615
 - definition, 606, 606*f*
 - imaging, 606
 - indications, 609*b*
 - merits and demerits, 614*t*
 - outcomes, 615
 - postoperative care, 614–615
 - pyramidal pattern, 609, 609*f*
 - quadrangular osteotomy, 610–613, 610*f*–611*f*
 - surgical management, 606–608
 - zygomatic repositioning, 610, 610*f*
- Le Fort II fracture, 952
 - anatomy, 893, 893*f*
 - completion, 895
 - complications, 896
 - definition, 893
 - epidemiology, 893–894
 - fixation, 895, 895*f*
 - imaging, 893
 - merits and demerits, 896*b*
 - nonsurgical management, 894
 - open reduction internal fixation, pediatric midface fractures, 954, 954*f*
 - outcomes, 896
 - pathogenesis, 893
 - patient history and physical findings, 893
 - postoperative care, 896
 - reduction, 894, 894*f*
 - surgical management, 894, 894*f*

- Le Fort II osteotomy
 - complications, 605
 - definition, 602
 - differential diagnosis, 602
 - fixation, 603, 604*f*
 - high-step osteotomy, 604, 604*f*
 - imaging, 602
 - intraoral buccal sulcus incision, 602, 602*f*
 - merits and demerits, 603*b*
 - outcomes, 605
 - patient history and physical findings, 602
 - postoperative care, 605
 - single dorsal nasal incision, 602
 - surgical management
 - extraoral approach, 602
 - intraoral approach, 603
 - paranasal approach, 603, 603*f*
 - patient positioning, 602
 - preoperative planning, 602
- Le Fort III advancement
 - anatomy, 616
 - complications, 620
 - definition, 616, 616*f*–617*f*
 - exposure, 618–619, 618*f*, 619*f*
 - fracture pattern, 616, 616*f*–617*f*
 - imaging, 617, 617*f*
 - merits and demerits, 618*b*
 - natural history, 616
 - outcomes, 620
 - pathogenesis, 616
 - patient history and physical findings, 616–617
 - postoperative care, 620
 - surgical management

- approach, 617
- patient positioning, 617
- preoperative planning, 617
- Le Fort III fracture, 952
 - anatomy, 897, 898*f*
 - complications, 902
 - definition, 897, 898*f*
 - imaging, 898*f*, 899
 - merits and demerits, 901*b*
 - open reduction internal fixation, pediatric midface fractures, 954–955, 955*f*
 - outcomes, 902
 - pathogenesis, 897
 - patient history and physical findings, 897–898, 898*f*
 - postoperative care, 901–902
 - repair with coronal flap, miniplate fixation, and intermaxillary fixation, 899–900, 900*f*
 - surgical management, 899
- Le Fort III osteotomy
 - with external distraction
 - anatomy, 621
 - complications, 631, 632*f*
 - curved tip osteotome, 623*f*, 626
 - definition, 621
 - device placement, 627, 627*f*–628*f*
 - exposure, 625–626, 625*f*
 - imaging, 622, 624*f*
 - lateral orbital wall, 628, 629*f*
 - lateral orbital wall osteotomy, 621*f*, 626
 - merits and demerits, 625*b*
 - mobilization, 626, 626*f*
 - nasofrontal osteotomy, 621*f*, 626
 - outcomes, 630–631, 630*f*–631*f*

- pathogenesis, 621
- patient history and physical findings, 622, 623*f*
- postoperative care, 630
- preoperative planning, 624
- skull-cranial bones and facial bones, 621, 623*f*
- surgical management, 624
- traditional lines, 621, 621*f*
- midface hypoplasia
 - access, 636, 636*f*
 - anatomy, 634, 634*f*
 - definition, 634
 - differential diagnosis, 635
 - distraction protocol, 639
 - extended transconjunctival incision, 636–637, 636*f*, 637*f*
 - imaging, 635, 635*f*
 - lateral orbitotomy, 637, 638*f*
 - merits and demerits, 637*b*
 - nasofrontal osteotomy, 637, 638*f*
 - natural history, 634
 - nonoperative management, 635
 - outcomes, 640, 640*f*–641*f*
 - pathogenesis, 634
 - patient history and physical findings, 635
 - postoperative care, 640
 - preoperative planning, 635–636
 - pterygomaxillary osteotomy, 638, 638*f*
 - rigid external device placement, 638, 639*f*
 - surgical management, 635–636
- Le Fort III–type osteotomy, 490
- Le Fort osteotomy, 276
- Left gastroepiploic pedicle, omental flap harvest with, 1667, 1668*f*
- Leg elevation, 2371
- Leg length discrepancy, 2348

- Leg splint, 2443, 2490
- Leiomyosarcoma, 2421
- Lengthening temporalis myoplasty, 1264, 1264*f*
 - completion process, 1269
 - definition, 1262
 - elevation and advancement, 1269, 1270*f*
 - flap harvest, 1268–1269, 1268*f*–1269*f*
 - Labbé procedure
 - myeloplasty, 1274, 1274*f*–1275*f*
 - superficial aponeurosis, 1273, 1273*f*–1274*f*
 - zigzag Cairns approach, 1273, 1273*f*–1274*f*, 1276
 - surgical management, 1264, 1264*f*
- Lenticular excision and linear closure, 2760*b*
- Lesser occipital nerve, 97
- Lesser occipital nerves, 966*f*, 967
- Levator anguli oris muscle, 1073, 1073*f*
- Levator function (LF), 115
- Levator labii superioris, 32
- Levator labii superioris alaeque nasi, 9, 9*f*, 32
- Levator resection, congenital ptosis, 2853, 2853*f*–2854*f*
- Levator veli palatini (LVP), 2672, 2687
- Levobupivacaine
 - furrow palatoplasty, 2664
 - hard palate incisions, 2676
- LF (levator function), 115
- Lid crease height (LC), 115
- Lid-cheek junction. *See* Tear trough
- Lidocaine, 2328–2329, 2865, 3077
- Li-Fraumeni syndrome, 2338, 2460, 2497
- Limb Salvage Index, 2394
- Limb-threatening infection, 2408
- Limited fasciectomy, 2176, 2182*f*
- Limited maxillectomy defect, 1013, 1013*f*–1014*f*, 1015–1016

- Limited preauricular approach, 2921
- Linear threading injection technique, 43, 43*f*
- Lingual nerve transection, 1200, 1200*f*–1201*f*
- Lip(s)
 - closure
 - cutaneous approximation, 2604
 - Millard/Mohler modifications, 2612–2613, 2613*f*
 - muscle repair, 2603–2604, 2603*f*
 - commissure defects, with Estlander flaps
 - anatomy, 1055, 1055*f*
 - complications, 1058
 - definition, 1055
 - external landmarks, 1055
 - imaging, 1056
 - lower lip, 1057, 1057*f*
 - merits and demerits, 1058*b*
 - outcomes, 1058, 1058*f*
 - patient history and physical findings, 1055, 1056*f*
 - postoperative care, 1058
 - surgical management, 1056
 - upper lip, 1056, 1056*f*–1057*f*
 - contracture, 2766, 2766*f*–2767*f*
 - fat grafting at time of facelifting, 50
 - fillers injection
 - anatomy, 37, 37*f*–38*f*
 - complications, 40
 - definition, 37
 - merits and demerits, 40*b*
 - nonoperative management, 38
 - outcomes, 40, 40*f*–41*f*
 - patient history and physical findings, 37–38
 - postoperative care, 40
 - techniques, 38*b*

- reconstruction, with radial forearm free flap
 - anterolateral thigh flap, 1074
 - complications, 1077
 - definition, 1073
 - external anatomy, 1073, 1073*f*
 - full-thickness lower lip defects, 1074
 - imaging, 1074
 - innervation, 1074
 - internal anatomy, 1073, 1073*f*
 - large, full-thickness defects, 1074
 - larger partial-thickness defects, 1074
 - lateral arm flap, 1074
 - merits and demerits, 1075*b*
 - motor innervation, 1073
 - operative management, 1074
 - outcomes, 1077
 - parascapular flap, 1074
 - patient history and physical findings, 1074
 - postoperative care, 1077
 - recipient site preparation and inseting, 1075, 1076*f*
 - sensory innervation, 1073
 - skin graft closure, 1075, 1075*f*
 - surgical management, 1074
 - vascular supply, 1074
- Lip adhesion
 - anatomy, 2629
 - bilateral cleft lip adhesion, 2633–2634
 - complications, 2635
 - definition, 2629
 - merits and demerits, 2635*b*
 - nonoperative management, 2630
 - outcomes, 2635
 - patient history and physical findings, 2629–2630

- postoperative care, 2635
- premaxillary setback, 2634–2635, 2634*f*
- surgical management, 2630–2635
 - approach, 2630–2635
 - patient position, 2630
 - preoperative planning, 2630
- unilateral cleft lip adhesion
 - completion, 2633, 2633*f*
 - incision and dissection, 2631, 2632*f*
 - markings, 2631, 2631*f*
 - suturing, 2631–2633, 2632*f*
- Lip defect(s)
 - with Abbe flap
 - anatomy, 1063
 - complications, 1067
 - definition, 1063
 - donor-site preparation, 1064, 1064*f*
 - flap placement and closure, 1066, 1066*f*
 - imaging, 1063
 - merits and demerits, 1064*b*
 - pathogenesis, 1063
 - patient history and physical findings, 1063
 - raising the flap, 1065, 1065*f*
 - recipient-site preparation, 1064, 1065*f*
 - surgical management, 1063–1064
 - with Karapandzic flaps
 - anatomy, 1059, 1059*f*
 - bilateral, large midline lower lip defect, 1060, 1060*f*–1061*f*
 - complications, 1061
 - definition, 1059
 - imaging, 1059
 - merits and demerits, 1061*b*
 - outcomes, 1061, 1061*f*

- patient history and physical findings, 1059
- postoperative care, 1061
- surgical management, 1059–1060
- Lip element
 - lateral
 - alar base and L flap, 2608, 2608*f*–2609*f*
 - anatomy, 2606
 - dissection, 2609–2610, 2610*f*
 - markings, 2607, 2608*f*–2609*f*
 - medial
 - anatomy, 2606
 - C flap and M flap, 2608, 2608*f*–2609*f*
 - dissection, 2602, 2602*f*, 2609, 2610*f*
 - markings, 2607, 2608*f*–2609*f*
- Lip lacerations, 3081, 3081*f*
- Lip lengthening, skin flap for, 2623–2624, 2623*f*
- Lip pits, 2654–2656
 - acellular dermal allograft, 2656, 2656*f*
 - inverted-T excision, 2655–2656, 2656*f*
 - split lip advancement technique, 2655, 2655*f*
 - transverse elliptical excision, 2654, 2655*f*
 - vertical elliptical wedge excision, 2654, 2655*f*
- LipiVage, 2812, 2812*f*
- Lip-nose adhesion, 2631
- Lipodystrophy, 1596
- Lipoma, 2498
- Lipoma arborescens, 2457
- Liposarcoma, 2421
- Lipostructural fat grafting, 165
- Liposuction, 207, 1636, 1636*f*, 2987, 2987*f*
 - donor site autologous fat harvesting, 1491, 1492*f*
 - lymphedema
 - anesthesia, 2572

- complications, 2574
- compression garment application, 2573
- equipment, 2572
- follow-up, 2573–2574
- imaging, 2571
- irrigation, 2573
- merits and demerits, 2572*b*, 2573*b*
- outcomes, 2574
- patient history and physical exam, 2571
- patient position, 2572
- postoperative care, 2573
- surgical management, 2571–2572
- mons pubis, 1641, 1641*f*
- scar glandular resection with, 1636, 1636*f*
- Lisfranc amputation, 2546
- LLC. *See* Lower lateral cartilage (LLC)
- LMA (laryngeal mask airway), 3
- Lobule projection (LP), 276, 276*f*
 - increasing, 279, 279*f*–280*f*
 - reducing, 278, 279*f*
- Local anesthesia
 - additives, 972
 - agent selection, 968
 - anatomy, 966, 966*f*
 - behavioral and communication techniques, 972
 - complications, 973
 - definition, 966
 - facial nerve blocks
 - infraorbital nerve block, 970, 970*f*
 - mental nerve block, 971, 971*f*
 - supraorbital and supratrochlear nerves, 970, 970*f*
 - in-office procedures, 966
 - local infiltration, 969, 969*f*

- mechanisms of action, 967, 969*b*
- natural history, 967
- patient history, 967
- physical examination, 968
- postoperative care, 973
- relative contraindications, 967
- surgical management
 - infiltrative anesthesia, 969
 - injectable agents, 969
 - patient positioning, 968
 - preoperative planning, 968
 - smaller needle sizes, 969
 - topical agents, 968
- tumescent anesthesia, 971, 971*t*
- types, 966
- Local anesthetic systemic toxicity (LAST), 973, 1759, 2314, 2330
- Local anesthetic toxicity, 2321
- Local anesthetics, administration of, 977, 977*f*
- Local flaps, 2115
 - and grafts, 2408
 - partial breast reconstruction
 - anatomy, 1367
 - complications, 1375
 - definition, 1367
 - flap harvesting, 1372
 - merits and demerits, 1374*b*
 - oncological follow-up, 1375
 - outcomes, 1375
 - patient history and physical findings, 1367–1368
 - patient positioning, 1371
 - perforator mapping, 1371
 - postoperative care, 1375
 - preoperative planning, 1371

- prognosis, 1375
- types, 1368–1371
- Local infiltration, 967, 969, 969*b*, 969*f*
- Local random patterned flaps, 2366
- Locked cruciate suture repair, 2058, 2058*f*
- Long and ring finger revascularization, 2153, 2153*f*
- Long nose
 - adjuvant procedures, 336
 - anatomy, 333, 333*f*
 - caudal septal reduction, 335, 335*f*
 - complications, 337
 - component dorsal hump reduction, 335, 335*f*
 - definition, 333
 - excess lower lateral cartilages, 336, 336*f*
 - imaging, 334
 - merits and demerits, 337*b*
 - outcomes, 337
 - pathogenesis, 333
 - patient history and physical findings, 333–334
 - postoperative care, 337
 - surgical management, 334–337, 334*f*
 - tip support, optimizing, 336, 336*f*
- Loss-of-resistance technique, 2328
- Love's pin test, 2287
- Low combined median and ulnar nerve palsy
 - finger clawing, 2038–2039
 - index finger abduction, 2037–2038
 - small finger abduction, 2040
 - thumb adduction, 2037
 - thumb opposition, 2036–2037
- Low-energy trauma, 2467
- Lower abdominal defects, 1589
- Lower back/buttock, anatomic layers of, 1612

- Lower blepharoplasty
 - anatomy, 171
 - complications, 176, 177*f*
 - definition, 170
 - differential diagnosis, 172
 - merits and demerits, 176*b*
 - nonoperative management, 172
 - outcomes, 176
 - pathogenesis, 171–172
 - patient history and physical findings, 172, 172*f*
 - postoperative care, 176
 - surgical management, 172
 - techniques, 174, 174*f*
 - via subciliary incision
 - anatomy, 148, 149*f*–150*f*
 - complications, 155–156
 - definition, 148
 - imaging, 150
 - merits and demerits, 155*b*
 - nonoperative management, 151
 - outcomes, 155, 156*f*
 - patient history and physical findings, 148–150
 - postoperative care, 155
 - skin-muscle flap approach with orbicularis oculi resuspension, 152–153, 152*f*–153*f*
 - skin-only flap approach with reverse orbicularis oculi tightening, 153–154, 154*f*
 - surgical management, 151
- Lower body lift
 - anatomy, 1619, 1619*f*–1620*f*
 - complications, 1624
 - definition, 1619
 - with gluteal autoaugmentation flaps

- abdominal lift, 1621–1622, 1622*f*
- markings, 1621, 1621*f*
- imaging, 1620
- merits and demerits, 1623*b*
- outcomes, 1623
- patient history and physical findings, 1619
- postoperative care, 1623
- surgical management, 1620, 1620*f*
- without autoaugmentation, 1623, 1623*f*
- Lower extremity, 2365, 2374–2375
 - amputation
 - approach considerations, 2548
 - merits and demerits, 2550*b*
 - physical exam and arterial pressures, 2548, 2548*f*
 - postoperative care, 2550
 - preoperative planning, 2548
 - angiography, 1030
 - wound, 2429*f*
- Lower extremity reconstruction, reverse sural artery flap for
 - anatomy, 2388
 - complications, 2390
 - definition, 2388
 - delayed reverse sural artery flap, 2390
 - fasciocutaneous pedicle incised, flap dissection with, 2389*f*
 - imaging, 2388
 - merits and demerits, 2390*b*
 - outcomes, 2390
 - patient history and physical findings, 2388
 - postoperative care, 2390
 - supercharged reverse sural artery flap, 2390
 - surgical management, 2388*f*
 - patient positioning, 2389
 - patient positioning approach, 2389

- preoperative planning, 2388, 2388*f*
- Lower eyelid
 - blepharoplasty, 1104
 - consists of, 148, 149*f*–150*f*
 - fat grafting for periorbital rejuvenation, 162, 166, 166*f*
 - herniated orbital fat
 - anatomy, 132, 132*f*
 - anesthesia and eye preparation, 133
 - complications, 137
 - definition, 132
 - excision of, 134, 135*f*
 - eyelid retractors, isolating, 133, 134*f*
 - merits and demerits, 136*b*
 - outcomes, 137, 137*f*
 - patient history and physical findings, 132
 - postoperative care, 136
 - repositioning, 135–136, 136*f*
 - surgical management, 132
 - laxity, 1104
 - postseptal fat compartments in, 148, 149*f*–150*f*
- Lower eyelid(s)
 - skin pinch skin excision
 - anatomy, 138
 - complications, 139
 - definition, 138
 - excess eyelid skin removal, 138
 - imaging, 138
 - merits and demerits, 139*b*
 - outcomes, 139
 - patient history and physical findings, 138
 - postoperative care, 139
 - surgical management, 138
 - transconjunctival fat removal and redraping

- anatomy, 140, 140*f*–141*f*
- completion, 144
- complications, 146–147
- definition, 140
- exposure, 143, 143*f*
- fat pad resection, 144, 144*f*
- imaging, 142, 142*f*
- merits and demerits, 145*b*
- nonoperative management, 142
- outcomes, 146, 146*f*–147*f*
- patient history and physical findings, 140–142
- postoperative care, 146
- surgical management, 142–143
- Lower eyelid defects
 - basal cell carcinoma, 1085, 1085*f*, 1086*f*
 - tenzel semicircular rotational flap
 - design and flap elevation, 1086, 1086*f*
 - donor-site repair, 1087, 1087*f*
 - flap inset, 1086*f*, 1087
 - tarsal edges, 1086, 1086*f*
- Lower eyelid incision, pediatric orbital fractures, 948
- Lower eyelid reconstruction, with palatal grafts
 - complications, 1098
 - definition, 1094
 - hard palate, 1095–1097, 1095*f*, 1097*f*
 - lamellar anatomy, 1094–1095, 1094*f*
 - merits and demerits, 1096*b*
 - patient history, 1095
 - physical examination, 1096
 - postoperative care, 1098
 - surgical management, 1096
- Lower eyelid surgery, palatal spacer grafts, 193, 193*f*
- Lower lateral cartilage (LLC), 377, 2604, 2714

- correction, crooked nose, 331
- isolation of, 306, 306*f*–307*f*
- reconstruction, 2890
- separation of, 306
- Lower leg
 - abscesses drainage
 - anatomy, 2335, 2335*f*
 - approach, 2336
 - complications, 2337
 - differential diagnosis, 2336
 - imaging, 2336
 - merits and demerits, 2336*b*
 - necrotic right lateral foot wound, 2336, 2337*f*
 - nonoperative management, 2336
 - patient history and physical findings, 2336
 - postoperative care, 2337
 - preoperative planning, 2336
 - supine position, 2336
 - bone tumors of
 - anatomy, 2423, 2423*f*
 - complications, 2426
 - definition, 2423
 - diaphyseal tibia tumor resection and reconstruction, 2424
 - differential diagnosis for, 2423
 - functional outcomes, 2426
 - imaging, 2423
 - merits and demerits, 2425*b*
 - natural history, 2423
 - oncological outcomes, 2426
 - pathogenesis, 2423
 - patient history, 2423
 - physical findings, 2423
 - postoperative care, 2426

- surgical management, 2423–2424
- fasciotomy, 2332, 2333*f*
 - anterior, 2331
 - deep posterior compartment, 2331
 - diagnosis, 2331
 - lateral, 2331
 - superficial posterior, 2331
- keystone flap reconstruction, 2540–2541
 - flap viability and definitive hemostasis, 2541
 - islandization of, 2540, 2540*f*
 - markings, 2540, 2540*f*
 - strategic suturing, 2541, 2541*f*
- soft tissue infections, debridement of
 - anatomy, 2427
 - complications, 2430
 - debridement of the chronic wound, 2429
 - definition, 2427
 - enzymatic debridement, 2430
 - hydrosurgery system, 2429, 2429*f*
 - imaging, 2427
 - merits and demerits, 2430*b*
 - outcomes, 2430
 - pathogenesis, 2427
 - patient history and physical findings, 2427
 - postoperative care, 2430
 - sharp debridement of the acute wound, 2428–2429, 2429*f*
 - surgical management, 2427–2428
- soft tissue tumors, excision of
 - anatomy, 2338, 2338*f*–2339*f*
 - complications, 2341
 - definition, 2338
 - differential diagnosis, 2339
 - free tissue transfer, 2340

- imaging, 2339
- merits and demerits, 2341*b*
- natural history, 2338
- outcomes, 2341, 2341*f*
- pathogenesis, 2338
- patient history and physical findings, 2339
- patient positioning, 2339
- postoperative care, 2341
- preoperative planning, 2339, 2340*f*
- previous biopsy incision, excision of, 2340, 2340*f*
- surgical management, 2339
- tourniquet, 2340
- soft tissue tumors of, 2421, 2422*f*
 - anatomy, 2420, 2420*f*
 - complications, 2422
 - definition, 2420
 - differential diagnosis for, 2421
 - functional outcomes, 2422
 - imaging, 2421
 - merits and demerits, 2422*b*
 - natural history, 2420–2421
 - oncological outcomes, 2422
 - pathogenesis, 2420
 - patient history and physical findings, 2421
 - surgical management, 2421
 - tourniquet, 2421
- Lower lid malposition, 190, 191*f*
- Lower lid reconstruction, eyelids, 2778
- Lower lid retractors, 825
- Lower lip
 - cross-sectional anatomy, 1055, 1055*f*
 - defect, bilateral Karapandzic flaps, 1060, 1060*f*–1061*f*
 - reconstruction with nasolabial flap

- banner-shaped flap, 1071
- blood supply, 1068, 1069*f*
- complications, 1072
- definition, 1068
- differential diagnosis, 1070
- imaging, 1070
- lymphatic drainage, 1068, 1069*f*
- merits and demerits, 1071*b*
- motor and sensory innervation, 1068, 1069*f*
- musculature, 1068, 1069*f*
- nonoperative management, 1070
- outcomes, 1072
- pathogenesis, 1068
- patient history and physical findings, 1068–1070
- postoperative care, 1072
- surgical management, 1070–1071
- techniques, 1071, 1071*f*
- Lower posterior torso
 - anatomy, 1625–1626, 1625*f*
 - complications, 1634
 - definition, 1625
 - imaging, 1626
 - merits and demerits, 1634*b*
 - natural history, 1626
 - nonoperative management, 1626–1627
 - outcomes, 1634
 - patient history and physical findings, 1626
 - postoperative care, 1634
 - surgical management, 1627
- Low-grade chondrosarcoma, 2423, 2502
- Low-volume fat grafting, contour correction
 - anatomy, 1490
 - complications, 1495

- definition, 1490
- imaging, 1490
- merits and demerits, 1494*b*
- outcomes, 1494–1495
- patient history and physical findings, 1490
- postoperative care, 1494
- surgical management
 - approach, 1491
 - patient positioning, 1491
 - preoperative planning, 1490–1491
- wound closure, 1494
- LP. *See* Lobule projection (LP)
- L-shaped silicone implants, 351, 351*f*
- LT injuries. *See* Lunotriquetral (LT) ligament injuries
- Luer Lock plugged syringe, 49*f*
- Lumbar epidurals, 2327
- Lumbar spinal pathology, 2412
- Lumbar spine regions, anatomic features of, 2326*t*
- Lumenis UltraPulse fractional CO2 laser, 2808*f*
- Lunotriquetral ballottement test, 1858, 1859*f*
- Lunotriquetral compression test, 1858, 1859*f*
- Lunotriquetral (LT) ligament injuries
 - anatomy, 1857, 1857*f*–1858*f*
 - closure in, 1863
 - complications, 1864
 - differential diagnosis, 1859
 - ECU tendon grafting, 1862–1863, 1862*f*–1863*f*
 - exposure and tendon harvest, 1860, 1861*f*
 - imaging, 1858–1859, 1859*f*–1860*f*
 - lunate and triquetrum
 - bony preparation in, 1861, 1862*f*
 - K-wire fixation into, 1861, 1862*f*
 - merits and demerits, 1864*b*

- natural history, 1857
- nonoperative management, 1860
- outcomes, 1864
- pathogenesis, 1857, 1858*f*
- patient history and physical findings, 1857–1858, 1859*f*
- perilunat injuries, 1857, 1858*f*
- postoperative care, 1864, 1864*f*
- surgical management, 1860
 - approach, 1860, 1860*f*
 - patient positioning, 1860
 - preoperative planning, 1860
- LVP (levator veli palatini), 2672
- Lymphatic drainage
 - of ear, 1129
 - with nasolabial flap, 1068, 1069*f*
 - skin grafts, 1122
- Lymphatic malformations (LM), 2798–2799
- Lymphaticovenous anastomosis, 1506–1507, 1506*f*, 2553, 2553*f*–2555*f*
 - anatomy, 2551, 2551*f*
 - complications, 2555
 - definition, 2551
 - differential diagnosis, 2552
 - imaging, 2552
 - merits and demerits, 2553*b*, 2555*b*
 - natural history, 2552
 - nonoperative management, 2552
 - outcomes, 1509, 2555
 - pathogenesis, 2552
 - patient history and physical exam, 2552
 - postoperative care, 1509, 2555
 - surgical management
 - approach, 2553

- patient positioning, 2553
- preoperative planning, 2553
- Lymphedema
 - anatomy, 2557, 2571
 - complications, 2566
 - definition, 2557, 2571
 - differential diagnosis, 2559
 - donor sites, 2560*t*
 - imaging, 2558–2559
 - indocyanine green appearance, 2561*b*
 - liposuction
 - anesthesia, 2572
 - complications, 2574
 - compression garment application, 2573
 - equipment, 2572
 - follow-up, 2573–2574
 - imaging, 2571
 - irrigation, 2573
 - merits and demerits, 2572*b*, 2573*b*
 - outcomes, 2574
 - patient history and physical exam, 2571
 - patient position, 2572
 - postoperative care, 2573
 - surgical management, 2571–2572
 - merits and demerits, 2565*t*, 2565*b*
 - microsurgery (*see* Lymphedema microsurgery)
 - natural history, 2557–2558
 - nonoperative management, 2559
 - outcomes, 2566
 - pathogenesis, 2557, 2571
 - patient history and physical exam, 2558
 - postoperative care, 2565–2566
 - surgical management

- approach, 2560
- patient positioning, 2560
- preoperative planning, 2559–2560
- Lymphedema, fasciocutaneous debulking of
 - anatomy, 2567
 - complications, 2570
 - definition, 2567
 - imaging, 2567
 - merits and demerits, 2568*b*, 2569*b*
 - outcomes, 2570
 - patient history and physical exam, 2567
 - postoperative care, 2570
 - radical debridement with split-thickness skin grafts, 2568–2569, 2569*f*
 - staged excision, 2569
 - surgical management
 - approach, 2568
 - patient positioning, 2568
 - preoperative planning, 2568
- Lymphedema microsurgery
 - anatomy, 1502
 - complications, 1511
 - definition, 1502
 - differential diagnosis, 1503
 - donor sites of lymph node–carrying flaps, 1505*t*
 - imaging, 1503
 - merits and demerits, 1508*b*
 - natural history, 1502
 - nonoperative management, 1503
 - outcomes
 - lymphaticovenous anastomosis, 1509
 - quality of life, 1509–1511
 - vascularized lymph node transfer, 1509

- pathogenesis, 1502
- patient history and physical findings, 1502
- postoperative care
 - lymphaticovenous anastomosis, 1509
 - vascularized lymph node transfer, 1509
- surgical management
 - approach, 1504–1506
 - lymphaticovenous anastomosis, 1503
 - patient positioning, 1504
 - preoperative planning, 1504
- vascularized lymph node transfer, 1503

M

- M flap, on medial lip element, 2608–2609, 2608*f*–2609*f*
- MABC (medial antebrachial cutaneous nerve), 2122–2123, 2125
- MABC (medial antebrachial cutaneous) nerve, 1994
- Macrocytic lymphatic malformation, 2760, 2799
- Macrostomia, 2729
- Macrostomia repair, Tessier 7. *See* Tessier 7–macrostomia repair
- Magnetic resonance angiography, pedicled rectus flap, 2518
- Magnetic resonance imaging (MRI)
 - Achilles tendon reconstruction, 2417, 2417*f*
 - bone grafting for foot and ankle, 2356–2357
 - bone reconstruction of knee, 2473, 2474*f*
 - bone tumors
 - ankle and foot of, 2342
 - of knee, 2460
 - of lower leg, 2423
 - conjoined twins, 3093
 - debridement of soft tissue infections of lower leg, 2427
 - femoral bone debridement, 2507
 - forefoot reconstruction, 2365
 - free flaps, 2487
 - reconstruction of heel and plantar defects, 2380
 - soft tissue defects of thigh, 2522
 - medial plantar flap, 2374
 - open fractures, 2468
 - orbital roof fractures, 840, 840*f*
 - osteomyelitis, 2353, 2468
 - peroneal nerve injury, 2411
 - radial tunnel decompression, 2000
 - scapholunate instability, 1853
 - soft tissue tumors

- knee, 2457, 2457*f*
- lower leg, 2339, 2421
- thigh, 2498
- tibial nerve, 2452
- ulnar tunnel syndrome, 1988
- Magnetic resonance neurography, nerve repair and graft, 2006
- Malar fat grafting, fat grafting for periorbital rejuvenation, 162
- Malar implants
 - anatomy, 392, 392*f*
 - complications, 396
 - definition, 392
 - imaging, 393
 - intraoral approach, 395, 395*f*
 - merits and demerits, 396*b*
 - nonoperative management, 393
 - outcomes, 396, 396*f*–397*f*
 - pathogenesis, 392–393, 393*f*
 - patient history and physical findings, 393
 - periorbital approach, 394, 394*f*
 - postoperative care, 396
 - preoperative preparation, 394*b*
 - surgical management, 393–394
 - approach, 394
 - positioning, 394
 - preoperative planning, 393, 393*f*
- Malar region, filler injection in
 - anatomy, 26
 - complications, 28
 - definition, 26
 - imaging, 27
 - merits and demerits, 28*b*
 - nonoperative management, 27
 - outcomes, 27*f*, 28

- pathogenesis, 26–27
- patient history and physical findings, 27
- postoperative care, 27
- surgical management, 27
- techniques, 27*b*
- Male pattern baldness (MPB), 416–417
- Malignant bone tumors, of foot and ankle, 2342
 - calcaneus, 2345, 2346*f*
 - distal fibula resection, 2343–2344, 2344*f*
 - distal tibia, 2346–2347, 2347*f*
 - first metatarsal, 2344, 2344*f*–2345*f*
 - general principles, 2343
- Malignant melanoma, 2383, 2735
- Malignant peripheral nerve sheath tumors (MPNST), 2421, 2752–2753
- Malleable retractors, 834
- Mallet scale, 2949
- Malocclusion, Le Fort I fractures, 892
- Mandible
 - anatomy, 712, 712*f*
 - complications, 717
 - definition, 712
 - differential diagnosis, 713–714
 - exposure, 714, 714*f*
 - imaging, 713
 - implants
 - anatomy, 398, 399*f*
 - assessment and contour, 402
 - closure, 402, 402*f*
 - complications, 403–404
 - definition, 398
 - imaging, 398, 399*f*
 - incision, 400, 400*f*–401*f*

- merits and demerits, 402*b*
- nonoperative management, 398
- outcomes, 403, 403*f*–405*f*
- patient history and physical findings, 398
- positioning, 399
- positioning and fixation, 401, 401*f*–402*f*
- postoperative care, 403, 403*f*
- preoperative planning, 399
- preoperative preparation, 400
- intraoral osteotomies
 - inferior osteotomy, 715, 715*f*
 - mandible repositioning, 715, 716*f*
 - setback procedure, 714
 - superior osteotomy, 715, 715*f*, 716*f*
- merits and demerits, 714*b*
- nonoperative management, 714
- ostetomy, 727*f*
- outcomes, 717
- panfacial fractures, 934
- pathogenesis and natural history, 713
- patient history and physical findings, 713
- postoperative care, 717
- surgical management
 - patient positioning, 714–717
 - preoperative planning, 714
- Mandible fractures
 - maxillomandibular fixation of
 - anatomy, 903, 903*f*
 - arch bars, 904, 904*f*
 - complications, 906
 - definition, 903
 - edentulous patients, special considerations in, 905
 - imaging, 903

- merits and demerits, 905*b*
- pathogenesis, 903
- patient history and physical findings, 903
- postoperative care, 906
- rapid fixation hybrid MMF systems, 905
- screws, 905, 905*f*
- surgical management, 903–906
- open treatment of
 - anatomy, 907, 907*f*–908*f*
 - angle and ramus fractures, 911–912
 - atrophic/edentulous mandible, fractures of, 913
 - body fractures, 911
 - complications, 914
 - condylar and subcondylar fractures, 912–913, 912*f*
 - coronoid fractures, 913
 - definition, 907
 - exposure, 909, 909*f*
 - external fixation, 913, 913*f*
 - fracture reduction, initial approaches to, 910
 - imaging, 908
 - merits and demerits, 914*b*
 - nonoperative management, 908
 - pathogenesis, 907–908
 - patient history and physical findings, 908
 - plate application, 910, 910*f*
 - postoperative care, 914
 - surgical management, 908–909
 - symphysis/parasymphysis, 910
- Mandible fractures, open treatment of, 911–912, 911*f*–912*f*
- Mandible reconstruction
 - anatomy, 1022, 1022*f*
 - fibula flap with templates
 - anatomy, 1030

- closing wedge osteotomies, 1034–1035, 1034*f*
- complications, 1036
- creating anatomic templates, 1031, 1032*f*
- definition, 1030
- fibula flap elevation, 1032–1033
- imaging, 1030
- maintaining native condyle position and occlusion, 1031
- merits and demerits, 1031*b*
- outcomes, 1035, 1036*f*
- patient history and physical findings, 1030
- postoperative care, 1035
- surgical management, 1030–1031
- with fibula free flap, CAD/CAM techniques
 - anatomy, 1022*f*, 1023
 - complications, 1029
 - definition, 1022
 - dental implants, 1027
 - fibula flap harvest, 1025–1026
 - fibula flap osteotomy, 1026–1027, 1026*f*
 - flap inset, 1027
 - imaging, 1023–1024, 1024*f*
 - mandibular osteotomy, 1026
 - merits and demerits, 1025*b*
 - microsurgical anastomosis, 1027
 - outcomes, 1029, 1029*f*
 - pathogenesis, 1023
 - patient history and physical findings, 1023
 - postoperative care, 1028–1029
 - surgical management, 1024–1025
- with scapula flap
 - anatomy, 1037–1038
 - bone harvest, 1041–1043, 1042*f*–1043*f*
 - definition, 1037

- diagnostic studies, 1038
- flap variations, 1044, 1044*f*
- imaging, 1038
- latissimus dorsi muscle, 1041
- merits and demerits, 1040*b*
- outcomes, 1045
- patient history and physical findings, 1038
- postoperative care, 1045
- preparation and inset of the flap, 1043
- recipient site preparation, 1040
- skin flap harvest, 1040, 1041*f*
- surgical management, 1038–1040
- Mandibular asymmetry, 699
- Mandibular branches, skin-only face and neck lifting, 196
- Mandibular coronoid fractures
 - management of
 - anatomy, 923
 - approach, 923
 - complications, 926
 - coronoidectomy, 925, 925*f*
 - definition, 923
 - differential diagnosis, 923
 - imaging, 923, 924*f*
 - merits and demerits, 926*b*
 - nonoperative management, 923
 - outcomes, 926
 - pathogenesis, 923
 - patient history and physical findings, 923
 - positioning, 923
 - postoperative care, 926
 - preoperative planning, 923
 - surgical management, 923
 - ORIF via modified retromandibular approach, 924, 925*f*

- Mandibular defects
 - anatomy, 663
 - BSSO
 - anatomy, 697–698
 - angle occlusal classification, 697–698
 - completion process, 704
 - complications, 705
 - Dal Pont modification, 697
 - definition, 697
 - differential diagnosis, 698
 - exposure, 700, 700*f*–701*f*
 - Hunsuck modification, 697
 - imaging, 698
 - medial ramus, 701, 701*f*–702*f*
 - merits and demerits, 700*b*
 - nonoperative management, 699
 - occlusal correction and maxillomandibular fixation, 702, 702*f*–703*f*
 - outcomes, 705
 - pathogenesis, 698
 - patient history and physical findings, 698
 - postoperative care, 705
 - rigid fixation, 703
 - surgical management, 699–705, 700*f*
 - causes of, 1023, 1023*f*
 - delayed repair with nonvascularized bone graft, 1038
 - imaging, 664
 - latissimus dorsi muscle, 1038
 - merits and demerits, 666*b*
 - natural history, 664
 - osteocutaneous fibula flap, 1038
 - osteocutaneous radial forearm flap, 1038
 - osteocutaneous scapula flap, 1038

- outcomes, 668
- patient history and physical findings, 664
- pedicle or free myocutaneous flap, 1038
- postoperative care, 668
- surgical management, 665, 665*f*
- surgical technique, 667
- vascularized iliac crest flap, 1038
- vascularized medial femoral condyle corticoperiosteal flap, 1038
- Mandibular distraction osteogenesis (MDO), 723, 2691
- Mandibular foramen, 1022
- Mandibular hypoplasia, 672, 672*f*, 718
- Mandibular nerve, 966, 966*f*
- Mandibular reconstruction, osteocutaneous parascapular flap
 - anatomy, 683, 683*f*
 - bone flap creation, 686–687, 687*f*
 - complications, 690
 - definition, 683
 - facial atrophy, reconstruction, 688, 689*f*
 - flap contouring and inset, 687, 688*f*
 - flap design, 685–687, 685*f*
 - imaging, 683
 - merits and demerits, 685*b*
 - outcomes, 690
 - patient history and physical findings, 683
 - postoperative care, 690
 - soft tissue dissection, 685, 686*f*
 - surgical management, 683–690
 - vascular pedicle dissection, 687, 687*f*
- Mandibular setback
 - anatomy, 739
 - BSSO procedure, 740, 740*f*
 - chin reduction, 407, 407*f*
 - complications, 749, 749*f*

- definition, 739
- differential diagnosis, 740
- imaging, 740
- merits and demerits, 741*b*
- nonoperative management, 740
- outcomes, 749
- pathogenesis and natural history, 739
- patient history and physical findings, 739
- postoperative care, 749
- surgical management
 - intraoral approach, 740–749
 - patient positioning, 740, 740*f*
 - preoperative planning, 740
 - surgical technique
 - condylar patient positioning and rigid fixation, 747*f*, 746
- surgical technique
 - bony interference, removal, 746, 746*f*
 - completion process, 748
 - exposure, 741, 741*f*–742*f*
 - mandibular osteotomy and split, 743, 744*f*–745*f*
 - maxillomandibular fixation, 745, 745*f*
 - medial ramus osteotomy, 742, 742*f*–743*f*
 - occlusal correction, 745, 745*f*
- Mandibular surgery
 - anatomy, 706
 - combined extraoral-intraoral inverted L osteotomy, 709–710, 710*f*
 - complications, 711
 - definition, 706
 - differential diagnosis, 706
 - extraoral inverted L osteotomy
 - exposure, 707–709, 708*f*
 - osteotomy, 707–709, 709*f*
 - imaging, 706

- intraoral inverted L osteotomy, 710, 710*f*
- merits and demerits, 707*b*
- neonates and children, 706
- postoperative care, 711
- skeletally mature patients, 706
- surgical management
 - approach, 707
 - patient positioning, 707, 707*f*
 - preoperative planning, 706
- Mandibulo-maxillary fixation (MMF), 1031
- Mandibuloplasty, chin reduction, 407–408, 408*f*
- Mangled Extremity Severity Score (MESS), 2394
- Mannerfelt lesion, 1934
- Manson Classification of NOE fractures, 866–867, 867*f*
- Manson's classification, 951
- Marcaine, 186, 511, 995, 1322, 2698
- Marcus Gunn jaw-winking ptosis, 2850
- Margin reflex distance (MRD), 115, 2850
- Marginal ear defects, 1134–1135, 1134*f*, 1135*f*
- Marginal skin necrosis, deep plane face-lift, 237
- Marionette lines, fillers injection, 12
 - anatomy, 37, 37*f*–38*f*
 - complications, 40
 - definition, 37
 - merits and demerits, 40*b*
 - nonoperative management, 38
 - outcomes, 40, 40*f*–41*f*
 - patient history and physical findings, 37–38
 - postoperative care, 40
 - techniques, 38*b*
- Maryland Foot Score, 2455
- Masseter for innervation, of free muscle flap
 - anatomy, 2919, 2919*f*

- complications, 2923
- definition, 2919
- imaging, 2920
- merits and demerits, 2922*b*
- outcomes, 2922–2923
- pathogenesis, 2919
- patient history and physical findings, 2919–2920
- postoperative care, 2922
- surgical management
 - approach, 2920
 - patient position, 2920, 2920*f*
 - preoperative planning, 2920
- Masseteric cutaneous ligaments, 196, 206*f*, 215
- Masseter-to-facial nerve transfer
 - anatomy, 2924–2925
 - antegrade, with distal, selective, facial nerve branch transection, 2928–2929, 2929*f*
 - complications, 2931
 - with cross face nerve grafts, 2930, 2930*f*
 - definition, 2924
 - with fascia lata grafts, 2930
 - imaging, 2925
 - merits and demerits, 2930*b*
 - outcomes, 2931
 - pathogenesis, 2925
 - patient history and physical findings, 2925
 - postoperative care, 2930–2931
 - retrograde, 2926–2927, 2926*f*, 2927*f*, 2928*f*
 - surgical management
 - approach, 2926
 - patient position, 2925–2926, 2925*f*
 - preoperative planning, 2925
- Mastectomy

- skin necrosis, 1379
- with skin reduction after massive weight loss, 1637, 1637*f*
- Mastication, 398
- Mastisol, 314, 754, 754*f*, 863, 1348
- Mastopexy
 - anatomy, 1331
 - complications, 1338
 - definition, 1331, 1331*f*
 - differential diagnosis, 1332
 - imaging, 1332
 - merits and demerits, 1333*b*, 1337*b*
 - outcomes, 1338
 - pathogenesis, 1331
 - patient history and physical findings, 1331
 - postoperative care, 1338
 - surgical management
 - patient positioning, 1333
 - preoperative planning, 1332–1333, 1332*f*
- Mathes flap, 2369–2370
- Mattress sutures placement, in prominent ears, 2838, 2839*f*
- Maxilla
 - anatomy, osseous, 571, 571*f*
 - segmental Le Fort I advancement
 - closure, 599
 - down-fracture, 597
 - fixation, 599, 599*f*
 - Le Fort I osteotomy, 596–597, 597*f*
 - MMF and alar base width, 599
 - segmentation, 597–598, 598*f*
 - transverse expansion and advancement, 598
 - surgical management, vertical patient positioning, 579, 579*f*–580*f*
- Maxilla, anatomy, 2606, 2607*f*
- Maxillary antrostomy, 804, 805*f*

- Maxillary fractures, Le Fort III fracture, 897
- Maxillary hypoplasia, 584, 584*f*
- Maxillary nerve, 966, 966*f*
- Maxillary reconstruction, soft tissue flaps
 - anatomy, 1011–1012, 1011*f*–1012*f*
 - complications, 1021
 - definition, 1011
 - eyelids, 1019
 - imaging, 1012
 - merits and demerits, 1015*b*
 - nonoperative management, 1012–1013
 - nose, 1019
 - outcomes, 1020–1021
 - pathogenesis, 1012
 - patient history and physical findings, 1012
 - postoperative care, 1020
 - surgical management, 1013–1015
 - type I (limited maxillectomy) defect, 1013, 1013*f*–1014*f*, 1015–1016
 - type II (subtotal maxillectomy) defect, 1013, 1016
 - type III (total maxillectomy) defect, 1013, 1016–1019
 - type IV defect (orbitomaxillectomy), 1013, 1019
 - upper lip and oral commissure, 1019
- Maxillary region, panfacial fractures, 934
- Maxillary transverse deficiency, 562, 562*f*
- Maxillomandibular fixation (MMF)
 - anatomy, 1052
 - complications, 1054
 - definition, 1052
 - imaging, 1052, 1052*f*
 - Le Fort I fracture, 891, 891*f*
 - Le Fort II fracture, 894
 - of mandible fractures

- anatomy, 903, 903*f*
- arch bars, 904, 904*f*
- complications, 906
- definition, 903
- edentulous patients, special considerations in, 905
- imaging, 903
- merits and demerits, 905*b*
- pathogenesis, 903
- patient history and physical findings, 903
- postoperative care, 906
- rapid fixation hybrid MMF systems, 905
- screws, 905, 905*f*
- surgical management, 903–906
- merits and demerits, 1053*b*
- occlusion, 1052, 1052*f*
- outcomes, 1054
- patient history and physical finding, 1052
- pediatric mandible fractures, 958–959, 962–964
- postoperative care, 1053–1054, 1053*f*
- surgical management, 1052, 1052*f*
- techniques, 1053, 1053*f*
- Mayfield's stages, perilunate injuries, 1857, 1858*f*
- MCA (middle collateral artery), 2134
- McCoy facial trisquare, 885, 885*f*
- MCFA (medical crura footplate approximation), 373, 384
- MCL (medial collateral ligament), 2465, 2473
- MCP. *See* Metacarpophalangeal (MCP) joint
- MCP (metacarpophalangeal) joint, 2107
- MDO (mandibular distraction osteogenesis), 723, 2691
- Mechanical dermabrasion, 67, 68*f*
- Mechanical ectropions, 1104
- Mechanical ptosis, 2850
- Medial antebrachial cutaneous (MABC) nerve, 1994

- Medial canthal tendon, 830
- Medial epicondyle, 1992, 1992*f*
- Medial femoral condyle microvascular flap, 1883–1885, 1884*f*
- Medial gastrocnemius rotational flap, 2476*f*
- Medial hemisoleus muscle flap, 2446–2447, 2447*f*
 - distally based, 2448–2449, 2448*f*
 - proximally based, 2447, 2447*f*, 2449
- Medial inframalleolar perforator flap, 2794, 2795*f*
- Medial intermuscular septum, 1992, 1992*f*
- Medial knee soft tissue wound, 2484*f*
- Medial lip element
 - anatomy, 2606
 - dissection, 2600*f*, 2602
 - hypoplastic, 2650–2651
 - Millard/Mohler modifications
 - C flap and M flap, 2608, 2608*f*–2609*f*
 - dissection, 2609, 2610*f*
 - markings, 2607, 2608*f*–2609*f*
- Medial malleolar chronic wound, 2353*f*
- Medial nasolabial element
 - measurements and interpositional triangle, 2598, 2599*f*
 - vermilion, Cupid's bow, and nose, 2597–2598, 2598*f*
- Medial orbit composite unit translocation, 2749–2750, 2749*f*
- Medial orbit wall fractures
 - anatomy, 829–831
 - bony, 829–830, 829*f*
 - soft tissue, 830–831, 830*f*
 - complications, 837
 - definition, 829
 - differential diagnosis, 832
 - exposure, 833–834, 834*f*
 - fracture repair, 835, 835*f*
 - graft harvest, 835

- imaging, 831, 832*f*
- merits and demerits, 836*b*
- natural history and physical findings, 831
- nonoperative management, 832
- outcomes, 837
- pathogenesis, 831
- postoperative care, 837
- surgical management, 832–833, 833*t*, 833*b*
 - positioning, 833
 - preoperative planning, 832–833
- Medial osseous flap, 1039
- Medial parapatellar approach, 2469
- Medial plantar artery for recipient vessel
- Medial plantar flap
 - anatomy, 2373, 2373*f*–2374*f*
 - complications, 2377
 - definition, 2373
 - design of, 2373*f*–2374*f*
 - donor site closure, 2374, 2376*f*
 - harvest, 2375, 2375*f*
 - imaging, 2374
 - merits and demerits, 2376*b*
 - outcomes, 2376–2377
 - patient history, 2373–2374
 - patient positioning, 2374
 - physical findings, 2373–2374
 - postoperative care, 2376
 - surgical management
 - heel defect, 2374, 2376*f*–2377*f*
 - preoperative planning, 2374
- Medial rectus muscle, medial orbit wall fractures, 831
- Medial sural artery, approach to, 2488
- Medial sural artery perforator flap (MSAP), 1211

- Medial thighplasty, mons pubis, conjunction with, 1642, 1643*f*
- Medially based cervicofacial flap
 - arterial blood supply, 1103, 1103*f*–1104*f*
 - complications, 1107
 - deep-plane elevation or tissue expansion, 1103
 - definition, 1103, 1103*f*
 - desmoplastic melanoma, 1105, 1106*f*
 - dissection, 1105, 1106*f*
 - dog-ear excision, in inferomedial portion, 1106, 1106*f*
 - imaging, 1104
 - markings, 1105, 1106*f*
 - merits and demerits, 1105*b*
 - outcomes, 1107, 1107*f*–1108*f*
 - patient history and physical findings, 1103–1104
 - postoperative care, 1107
 - reconstructive zones, 1103
 - surgical management
 - approach, 1104
 - patient positioning, 1104
 - preoperative planning, 1104
- Median nerve
 - anatomy, 1754, 1754*f*–1755*f*
 - identification, decompression and dissection, 2048*f*, 2050
 - local anesthesia at wrist, 1758, 1758*f*
- Median nerve palsy
 - definition, 2012
 - tendon transfers
 - anatomy, 2012
 - approach, 2013
 - complications, 2017
 - differential diagnosis, 2013
 - imaging, 2013
 - merits and demerits, 2013*b*, 2017*b*

- natural history, 2012
- nonoperative management, 2013
- outcomes, 2017
- pathogenesis, 2012
- patient history and physical findings, 2012
- patient positioning, 2013
- postoperative care, 2017
- preoperative planning, 2013
- surgical management, 2013
- Medical crura footplate approximation (MCFA), 373, 384
- Medpor porous polyethylene malar implants, 393, 393*f*
- Melanoma
 - anatomy, 2303
 - complications, 2308
 - definition, 2303
 - desmoplastic, 1105, 1106*f*
 - differential diagnosis, 2304
 - imaging, 2304
 - on left heel, 2383
 - merits and demerits, 2307*b*
 - nasolabial flap, 1070
 - natural history, 2303
 - outcomes, 2308
 - pathogenesis, 2303
 - patient history and physical findings, 2304, 2304*f*
 - postoperative care, 2308
 - surgical management, 2305
- Meningocele, 2745
- Meningoencephalocele, 2745
- Mental nerve, 1047
 - anatomy, 966, 966*f*
 - neurofibromatosis, 2756, 2757*f*
 - surgical management, intraoral approach, 971, 971*f*

- Mentalis dysfunction, 391
- Mentalis muscle, 1073, 1073*f*
- Mepivacaine, 2329
- Mesh placement
 - determining plane of, 1724, 1724*f*
 - and muscle approximation, 1724, 1724*f*, 1725*f*
- Mesotherapy, 419
- Metacarpal capsulodesis, 2020, 2021*f*
- Metacarpal enchondroma. *See* Enchondroma
- Metacarpal fractures
 - anatomy and, 1787
 - base/CMC fracture, 1787
 - complications, 1795
 - definition, 1787
 - head fractures, 1787
 - imaging, 1787
 - merits and demerits, 1795*b*
 - neck fractures
 - closed reduction and pinning of, 1788–1789, 1788*f*–1789*f*
 - definition, 1787
 - Jahss technique, 1788, 1788*f*–1789*f*
 - natural history, 1787
 - nonoperative management, 1787–1788
 - open reduction and internal fixation headless compression screws, 1789, 1790*f*
 - pathogenesis, 1787
 - surgical management, 1788
 - outcomes, 1795
 - patient history and physical findings, 1792
 - postoperative care, 1795
 - shaft fractures
 - closed reduction and pinning, 1791, 1791*f*
 - nonoperative management, 1787–1788

- open reduction and internal fixation, 1792–1793, 1792*f*
- pathogenesis, 1787
- surgical management, 1788
- surgical management
 - approach, 1788
 - patient positioning, 1788
 - preoperative planning, 1788
- Metacarpophalangeal (MCP) joint
 - cross intrinsic transfer, 1950, 1950*f*
 - planned skin incision over, 1950, 1951*f*
 - rheumatoid deformities of (see Swan-neck deformity)
 - silicone arthroplasty, 1948, 1949*f*, 1953, 1954*f*
 - ulnar collateral ligament of thumb
 - acute repair, reconstruction of, 1804, 1804*f*
 - anatomy, 1802, 1802*f*
 - chronic repair, reconstruction of, 1805–1808, 1806*f*, 1807*f*, 1808*f*
 - complications, 1809
 - differential diagnosis, 1803
 - merits and demerits, 1809*b*
 - nonoperative management, 1803
 - postoperative care, 1809
 - provocative testing, 1803
- Metaphyseal fragments, 2468
- Methicillin-resistant *Staphylococcus aureus* (MRSA), 2336
- Methotrexate (MTX), 1939–1940
- Meticulous hemostasis, 812, 2443, 2774
- Metopic synostosis
 - anatomy, 434
 - craniosynostosis, 531
 - definition, 434
 - fronto-orbital distraction, 448–449, 449*f*
 - natural history, 445

- orbital roof osteotomy, 441
- patient history and physical findings, 434–435
- resorbable plate, 441, 441*f*
- Metzenbaum dissecting scissors, 1751
- MFUS. *See* Microfocused ultrasound (MFUS)
- Microanastomosis, with temporary inset, 2385, 2385*f*, 2490
- Microfat injections, upper and lower blepharoplasty with
 - anatomy, 171
 - complications, 176, 177*f*
 - definition, 170
 - differential diagnosis, 172
 - merits and demerits, 176*b*
 - nonoperative management, 172
 - outcomes, 176
 - pathogenesis, 171–172
 - patient history and physical findings, 172, 172*f*
 - postoperative care, 176
 - surgical management, 172
 - techniques, 174, 174*f*
- Microfocused ultrasound (MFUS)
 - anatomy, 257
 - complications, 261–262
 - definition, 257
 - differential diagnosis, 257
 - imaging, 257
 - merits and demerits, 260*b*
 - nonsurgical management, 258
 - approach, 258
 - positioning, 258
 - preoperative planning, 258
 - outcomes, 260–261
 - patient history and physical findings, 257
 - postoperative care, 260

- surgical management, 257
- techniques, 259
- Microform clefts, 2606
- Micrognathia
 - anatomy, 723, 723*f*
 - complications, 731, 732*f*
 - definition, 723
 - differential diagnosis, 724
 - external mandibular distraction
 - with pins, 725–726, 725*f*, 726*f*, 727*f*
 - with rigid external device, 727–728, 728*f*–729*f*
 - imaging, 724, 724*f*
 - merits and demerits, 725*b*
 - nonoperative management, 724
 - outcomes, 730–731, 731*f*
 - pathogenesis and natural history, 723
 - patient history and physical findings, 724
 - postoperative care, 730, 730*f*
 - surgical management
 - approach, 725
 - patient positioning, 725
 - preoperative planning, 724
- Microphthalmia
 - management
 - anatomy, 2877
 - complications, 2885
 - definition, 2877
 - diagnostic studies, 2878
 - imaging, 2878
 - merits and demerits, 2884*b*
 - natural history, 2877, 2878*f*
 - nonoperative management, 2878–2879, 2878*f*–2881*f*
 - outcomes, 2885

- pathogenesis, 2877
- patient history and physical findings, 2877–2878
- surgical management, 2880
- orbital expansion for
 - anatomy, 555, 556*f*
 - complications, 560
 - definition, 555
 - differential diagnosis, 557
 - expander inflation and closure, 559
 - exposure and orbitotomy, 558, 559*f*
 - imaging, 556–557, 557*f*
 - merits and demerits, 558*b*
 - natural history, 555
 - nonoperative management, 557
 - orbital tissue expander and microport placement, 559, 559*f*
 - outcomes, 560
 - pathogenesis, 555
 - patient history and physical findings, 556, 557*f*
 - postoperative care, 560
 - surgical management, 558–560, 558*f*
- Micropigmentation, 419
- Microsurgery, for scalp flaps, 987, 987*f*
- Microsurgical anastomosis, 1027
- Microtia, auricular reconstruction for
 - anatomy, 2815, 2815*f*, 2816*f*
 - anesthesia, 2817
 - complications, 2819*f*, 2820
 - definition, 2815
 - framework, 2815*f*, 2816*f*, 2817–2818
 - graft harvest, 2817
 - markings, 2817
 - merits and demerits, 2819*b*
 - outcomes, 2818*f*, 2820

- pathogenesis, 2815
- patient history and physical findings, 2815–2816
- patient transfer, 2818
- postoperative care, 2819
- second stage, 2819, 2819*f*
- surgical management, 2816–2817
 - preoperative planning, 2816–2817, 2817*f*
- variable presentation of, 2815*f*
- Microvascular anastomosis, 2165, 2166*f*, 2435, 2442–2443, 2443*f*, 2515
- Microvascular free flap, soft tissue coverage of lower leg, 2387
 - anatomy, 2438
 - anterior tibial vessels for recipient vessel.
 - assessment of defect, 2442
 - complications, 2445
 - definition, 2438
 - distal third of leg, 2438
 - final inset, 2443, 2443*f*
 - flap harvest, 2442, 2442*f*
 - imaging, 2440
 - main arteries and veins, 2438*f*–2439*f*
 - medial sural vessels as recipient vessel, 2439*f*–2440*f*
 - merits and demerits, 2444*b*
 - microanastomosis with temporary inset, 2442–2443, 2443*f*
 - middle third of leg, 2438
 - outcomes, 2444, 2444*f*–2445*f*
 - patient history and physical findings, 2440
 - peroneal artery perforators for recipient vessel
 - peroneal vessels for recipient vessel
 - posterior tibial vessels for recipient vessel
 - postoperative care, 2444
 - recipient vessel preparation, 2441, 2441*f*
 - surgical management, 2440–2441

- donor site morbidity, 2440
- flap thickness, 2440
- patient positioning, 2441, 2441*f*
- preoperative planning, 2440, 2441*f*
- upper third of lower leg, 2438
- wound preparation, 2441, 2441*f*
- MICS (minimally invasive component separation), 1566–1567, 1566*f*
- Midabdominal defects, 1589
- Midazolam, 2328
- Midcarpal injections, 1860
- Middle nasal vault, 318, 318*f*
- Middle temporal vein, 37*f*–38*f*
- Midface aging, 27
- Midface hypoplasia, Le Fort III osteotomy
 - access, 636, 636*f*
 - anatomy, 634, 634*f*
 - definition, 634
 - differential diagnosis, 635
 - distraction protocol, 639
 - extended transconjunctival incision, 636–637, 636*f*, 637*f*
 - imaging, 635, 635*f*
 - lateral orbitotomy, 637, 638*f*
 - merits and demerits, 637*b*
 - nasofrontal osteotomy, 637, 638*f*
 - natural history, 634
 - nonoperative management, 635
 - outcomes, 640, 640*f*–641*f*
 - pathogenesis, 634
 - patient history and physical findings, 635
 - postoperative care, 640
 - pterygomaxillary osteotomy, 638, 638*f*
 - rigid external device placement, 638, 639*f*

- surgical management, 635–636
- Midface reconstruction, free fibula flap
 - anterior and posterior compartments, 1001–1002, 1001*f*–1003*f*
 - anticipated secondary surgeries, 1008
 - classification, 1002
 - completion process, 1008, 1008*f*
 - complications, 1010
 - customization, skeletal fixation, and inset, 1008, 1008*f*
 - deep posterior compartment dissection, 1007, 1007*f*
 - definition, 1001
 - distal osteotomy, 1007, 1007*f*
 - donor site markings, 1006, 1006*f*
 - horizontal and vertical skeletal buttresses, 1002
 - imaging, 1002
 - incision and skin paddle dissection, 1006, 1006*f*
 - lateral and anterior compartment dissection, 1006–1007, 1007*f*
 - merits and demerits, 1005*b*
 - midface defect, 1005
 - nonoperative management, 1004
 - outcomes, 1010
 - patient history and physical findings, 1002, 1004*f*
 - posterior compartment dissection, 1007, 1007*f*
 - postoperative care, 1009, 1009*f*
 - proximal osteotomy, 1007, 1007*f*
 - surgical management, 1004–1005
- Midface regions, 28
- Midface rotation advancement, 2721
- Midface zones, 28
- Midfoot amputation
 - Chopart amputation, 2546
 - Lisfranc amputation, 2546
- Midline needle insertion technique, 2328*f*
- Midshaft hypospadias repair

- inner preputial inlay graft, 3045, 3046*f*
- transverse preputial island flap, 3045
- Midvault narrowing. *See* Narrow midvault
- Minimally invasive component separation (MICS), 1566–1567, 1566*f*
- Minor clefts, 2606
- Minoxidil, 418, 421
- Mitek anchor, 90
- Mixed dentation stage
- MMC. *See* Myelomeningocele (MMC)
- MMF. *See* Maxillomandibular fixation (MMF)
- Moberg flap, 2105, 2106*f*, 2107–2109, 2108*f*, 2113
- Modified Allen test
 - reverse flow radial forearm flap, 2115, 2115*f*
 - ulnar artery thrombosis, 2162
- Modified Becker/Massachusetts General Hospital (MGH) Repair, 2058, 2058*f*
- Modified Fasanella-Servat procedure, 116–117, 116*f*–117*f*
- Modified Hotz technique, markings and incisions, 2860, 2860*f*, 2861*f*
- Modified Kessler suture repair, 2058, 2058*f*
- Modified Sistrunk procedure
 - hyoid and tongue base dissection, 2907–2909, 2908*f*
 - modifications, 2909, 2909*f*
 - neck and wound incision preparation, 2907, 2907*f*
 - thyroglossal cyst and tract exposure, 2907, 2908*f*
 - wound closure, 2909, 2909*f*
- Mohler back cut, 2608–2609, 2608*f*–2609*f*
- Mohs micrographic surgery, 1122, 2305–2306
- Monfort approach, prune belly, 3023–3024, 3024*f*
- Monobloc distraction
 - anatomy, 499
 - complications, 503

- coronal (or bitemporal) zigzag incision, 500
- definition, 499
- differential diagnosis, 500
- due to maxillary hypoplasia, 500, 500*f*
- exposure, 501, 501*f*
- imaging, 499
- indications, 500
- merits and demerits, 501*b*
- natural history, 499
- nonoperative management, 500
- osteotomies and distractor placement, 501–502, 502*f*
- outcomes, 503
- pathogenesis, 499
- patient history and physical findings, 499
- postoperative care, 503
- removal of, 502
- surgical management
 - patient positioning, 500
 - preoperative planning, 500
- transoral (Keen) incision, 500
- Monobloc frontofacial advancement
 - BO-Fort procedure, 490
 - complications, 496, 498*f*
 - definition, 490
 - with facial bipartition, 495, 495*f*
 - grafting and fixation, 493, 494*f*–495*f*
 - imaging, 490
 - Le Fort III procedure, 490, 490*f*–492*f*
 - merits and demerits, 493*b*
 - normal facial features, 490
 - osteotomies and advancement, 493, 494*f*
 - outcomes, 496, 497*f*
 - patient history and physical findings, 490

- postoperative care, 496
- preparation and exposure, 493
- surgical management
 - approach, 491
 - patient positioning, 491
 - preoperative planning, 491
- Tessier sign, 493, 493*f*
- Monostotic fibrous dysplasia (MFD), 762
- Mons pubis
 - anatomy, 1640, 1640*f*
 - central wedge excision of, 1642, 1642*f*
 - complications, 1644
 - conjunction with abdominoplasty, 1642, 1642*f*
 - conjunction with medial thighplasty, 1642, 1643*f*
 - definition, 1640
 - horizontal excision with lipoplasty, 1642, 1642*f*
 - imaging, 1641
 - labia majora, lateral wedge excision, 1642, 1643*f*
 - liposuction, 1641, 1641*f*
 - merits and demerits, 1643*b*
 - outcomes, 1643
 - pathogenesis, 1640, 1641*f*
 - patient history and physical findings, 1640–1641
 - postoperative care, 1643
 - surgical management, 1641
- Monsplasty, 3053, 3058, 3058*f*
- Motor deficits, 1987
- Motor innervation, 1068, 1069*f*, 1073
- Motor nerve branch, 2927, 2927*f*
- Motor nerves, 70, 82
- Motor vehicle collisions (MVC), 934
- MPB (male pattern baldness), 416–417
- MRD (margin reflex distance), 115

- MRI. *See also* Magnetic resonance imaging (MRI)
 - cubital tunnel syndrome, 1993
 - radial nerve palsy, 2025
- MS-TRAM flap. *See* Muscle-sparing free transverse rectus abdominis myocutaneous (MS-TRAM) flap
- MTX (methotrexate), 1939–1940
- Mucoepidermoid carcinoma, FOM, 1210
- Mucoperichondrial perforation correction, 329
- Mucosa
 - closure, Millard/Mohler modifications, 2610–2611, 2611*f*–2612*f*
 - deformities, 2648–2652
 - repair, 2645
 - Z-plasty, 2651
- Mucosal flaps, 2659
- Mucous cysts
 - anatomy, 2281
 - complications, 2286
 - definition, 2280
 - differential diagnosis, 2282
 - imaging, 2282
 - merits and demerits, 2286*b*
 - natural history, 2281
 - nonoperative management, 2282
 - outcomes, 2286
 - pathogenesis, 2281
 - patient history and physical findings, 2282
 - postoperative care, 2286
 - surgical management, 2282
- Mucus-secreting respiratory mucosa, 779
- Muenke syndrome, 616
- Mulliken technique, 2639
- Multiple flexor tendon injury repair
 - anatomy, 2061

- complications, 2064
- definition, 2061
- imaging, 2061
- injured structures repair, 2063, 2063*f*
- merits and demerits, 2062*b*, 2063*b*
- outcomes, 2064
- pathogenesis, 2061
- patient history and physical findings, 2061
- postoperative care, 2064
- proximal structures, tagging, 2063, 2063*f*
- surgical management
 - patient positioning, 2062
 - preoperative planning, 2062
- wound presentation, exposed injuries, 2062, 2062*f*
- Multiple-digit artery sympathectomy incision, 2157, 2157*f*
- Multisuture synostosis, natural history, 445
- Muscle dissection, 2461
- Muscle flaps, 1728–1729, 1728*f*–1729*f*, 2394–2395, 2440, 2470, 2526–2527
- Muscle of Riolan, 1094–1095
- Muscle-chimeric perforator flap, 2383, 2440, 2489, 2490*f*–2491*f*
- Muscle-sparing free transverse rectus abdominis myocutaneous (MS-TRAM) flap
 - abdominal donor-site closure, 1426
 - anatomy, 1423
 - complications, 1428
 - definition, 1423
 - harvest, 1425, 1425*f*
 - imaging, 1424
 - inset, 1426
 - merits and demerits, 1425*b*, 1427*b*
 - outcomes, 1428
 - patient history and physical exam, 1423

- postoperative care, 1428
- recipient vessel dissection, 1425–1426, 1426*f*
- surgical management
 - approach, 1424
 - patient positioning, 1424
 - preoperative planning, 1424
- Muscular dehiscence, 2645
- Muscular flap, 2371
- Musculature, 1068, 1069*f*, 1073, 1073*f*
- Musculoperiosteal vessels, 2432, 2510
- Musculoskeletal system, conjoined twins, 3096
- Musculoskeletal Tumor Society functional score, 2341
- Mustardé's radiated suture techniques
- *Mycobacterium fortuitum*, 209
- Myelomeningocele (MMC)
 - postnatal repair
 - anatomy, 3007, 3007*f*
 - definition, 3007
 - merits and demerits, 3011*b*
 - natural history, 3007
 - pathogenesis, 3007
 - patient history and physical findings, 3007–3008, 3008*f*
 - postoperative care, 3011
 - surgical management, 3008, 3009*f*
 - prenatal (fetal) repair
 - anatomy, 3012, 3012*f*
 - definition, 3012
 - evaluation, 3012, 3014*b*
 - merits and demerits, 3015*b*
 - natural history, 3012
 - pathogenesis, 3012
 - postoperative care, 3016
 - surgical management, 3012–3013

- Myeloplasty, 1274, 1274*f*–1275*f*
- Myocutaneous flap, 2518
- Myocutaneous gracilis flap, 1683, 1683*f*–1684*f*
- Myofascial gracilis flap, 1684
- Myoplasty techniques. *See* Lengthening temporalis myoplasty
- Myotomy, 248, 248*f*–249*f*
- Myxofibrosarcoma, 2421

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[More information](#)



Q

- Quadrangular osteotomy
 - design and exposure, 610, 610*f*–611*f*
 - maxillary device placement, 611, 612*f*
 - osteotomy and completion, 611–613, 613*f*

R

- RA. *See* Rheumatoid arthritis (RA), hand and wrist
- Radial artery anatomy, 1171–1172, 1172*f*
- Radial forearm fasciocutaneous free flap, 1221
 - buccal mucosal defects, 1224, 1224*f*
 - FOM, 1210
- Radial forearm flap (RFF), 2440
 - advantage, 1116
 - anatomy, 1116, 1117*f*
 - complications, 1121
 - definition, 1116
 - flap design, 1118, 1118*f*
 - flap dissection, 1118, 1118*f*
 - flap inset, 1119–1120, 1120*f*
 - imaging, 1116
 - merits and demerits, 1118*b*
 - outcomes, 1121
 - patient history, 1116
 - physical examination, 1116
 - postoperative care, 1121
 - subfascial dissection, 1119, 1119*f*
 - surgical management, 1117
 - approach, 1117
 - patient positioning, 1117
 - preoperative planning, 1117

- Radial forearm free flap (RFFF)
 - anterolateral thigh flap, 1074
 - closure of forearm donor site, 1177, 1177*f*
 - complications, 1077, 1178–1179
 - definition, 1073, 1171
 - detached flap reader, 1176, 1176*f*
 - dissection and exposure, 1176, 1176*f*
 - external anatomy, 1073, 1073*f*
 - flap harvest, 1174–1175, 1175*f*
 - flap inset, 1176–1177, 1177*f*
 - FOM reconstruction
 - flap dissection, 1212, 1212*f*
 - flap inset, 1212, 1213*f*
 - recipient site preparation, 1211–1212, 1211*f*
 - full-thickness lower lip defects, 1074
 - hemi-tongue reconstruction, free flap, 1201–1202, 1202*f*
 - imaging studies, 1074, 1173
 - innervation, 1074
 - internal anatomy, 1073, 1073*f*
 - large, full-thickness defects, 1074
 - larger partial-thickness defects, 1074
 - lateral arm flap, 1074
 - merits and demerits, 1075*b*, 1174*b*
 - motor innervation, 1073
 - nerve supply, 1172–1173, 1172*f*
 - operative management, 1074
 - outcomes, 1077, 1178
 - parascapular flap, 1074
 - patient history and physical findings, 1074, 1173
 - postoperative care, 1077, 1178
 - radial artery, 1171–1172
 - recipient site preparation and inseting, 1075, 1076*f*
 - sensory innervation, 1073

- skin graft closure, 1075, 1075*f*
- surgical management
 - approach, 1074
 - patient positioning, 1074
 - preoperative planning, 1074, 1173
- templating and flap design, 1173, 1174*f*
- vascular anatomy, 1171, 1172*f*
- vascular supply, 1074
- Radial forearm phalloplasty
 - closure of donor site and dressings, 1694–1695
 - construction of neourethra, 1694
 - flap dissection, 1693–1694
 - flap transfer, vascular anastomoses, and nerve coaptation, 1694, 1695*f*
 - preparation of recipient site, 1694
- Radial longitudinal deficiency (RLD)
 - centralization/radialization, 2268, 2271, 2272*f*
 - classification system
 - Bayne and Klug, 2266
 - modification, 2267
 - complications, 2273
 - definition, 2266
 - differential diagnosis, 2268
 - imaging, 2268, 2268*f*
 - merits and demerits, 2272*b*
 - natural history, 2267
 - nonoperative management, 2268
 - outcomes, 2272–2273
 - pathogenesis, 2267
 - patient history and physical findings, 2267
 - postoperative care, 2272
 - soft tissue distraction
 - preoperative, 2268, 2270–2271

- surgical management, 2268–2269
 - approach, 2269
 - patient positioning, 2269
 - preoperative planning, 2269
- wrist and forearm anatomy in, 2266–2267, 2266*f*–2267*f*
- Radial nerve
 - identification, decompression and dissection, 2049*f*, 2051
 - palsy
 - anatomy, 2025
 - complications, 2030
 - definition, 2025
 - differential diagnosis, 2025
 - imaging, 2025
 - merits and demerits, 2026*b*, 2030*b*
 - natural history, 2025
 - nonoperative management, 2025
 - outcomes, 2030
 - pathogenesis, 2025
 - patient history and physical findings, 2025
 - postoperative care, 2030
 - surgical management, 2025–2026
 - superficial branch of, 1754
- Radial polydactyly repair
 - anatomy, 2234, 2234*f*
 - complications, 2241
 - definition, 2234
 - imaging, 2234–2235
 - Iowa classification of, 2234, 2234*f*
 - merits and demerits, 2241*b*
 - methods for, 2235–2236
 - acral transposition, 2236, 2236*f*
 - resection and reconstruction, 2235
 - sharing technique, 2235–2236, 2235*f*–2236*f*

- natural history, 2234
- outcomes, 2241
- pathogenesis, 2234
- patient history and physical findings, 2234
- postoperative care, 2241
- Rotterdam system classification, 2234
- surgical management, 2235–2236
 - approach, 2236
 - patient positioning, 2236
 - preoperative planning, 2236
- type IV
 - disarticulation, osteotomy, and fixation, 2237–2238, 2239f
 - flap creation, 2237, 2239f
 - markings and exposure, 2237, 2237f–2238f
 - reattachment and closure, 2240, 2241f
 - tendon correction, 2238–2240, 2240f
- Radial tunnel decompression. *See also* Radial tunnel syndrome (RTS)
 - exposure, 2001
 - release of entrapment, 2001–2002
- Radial tunnel syndrome (RTS)
 - anatomy, 2000
 - complications, 2003
 - definition, 2000
 - differential diagnosis, 2001
 - imaging, 2000–2001
 - nonoperative management, 2001
 - outcomes, 2003
 - pathogenesis, 2000
 - patient history and physical findings, 2000
 - postoperative care, 2003
 - surgical management, 2001
- Radial/ulnar forearm flaps, 1230

- Radiation therapy, 2523
 - nasolabial flap, 1070
 - osteoradionecrosis, 1023
- Radiesse, 42
- Radiocarpal joint with avascular proximal scaphoid pole and cartilage fragmentation, 1880
- Radiographic fistulograms, 2697
- Radiographs
 - bone reconstruction of knee, 2473, 2474*f*
 - posterior interosseous artery flap, 2127
- Radioscaphocapitate ligament, anatomy, 1905, 1905*f*
- Radiotherapy, 2456, 2458, 2460, 2497
- RAE (Ring-Adair-Elwyn) tube, 2638, 2639*f*
- “Ramirez-style” open anterior component separation, 1557–1558, 1557*f*
- Ramus fractures, mandible fractures, open treatment of, 911–912, 911*f*–912*f*
- Range of motion, 2456, 2482, 2498
- Range-of-motion (ROM) exercises, 2118, 2124, 2372
- Rapid fixation hybrid MMF systems, 905
- Rapid palatal expansion (RPE)
 - anatomy, 562
 - bilateral transverse L-shaped maxillary osteotomy, 564, 565*f*
 - complications, 566
 - definition, 562
 - differential diagnosis, 562, 563*f*
 - exposure, 563, 563*f*
 - imaging studies, 562, 562*f*
 - indications, 562
 - merits and demerits, 563*b*
 - nonoperative management, 562
 - osteotomies, 563, 564*f*
 - outcomes, 565–566

- patient history and physical findings, 562
- postoperative care, 565, 565*f*
- surgical management
 - patient positioning, 563
 - preoperative planning, 562, 562*f*
- Rare tesser clefts
 - anatomy, 663
 - imaging studies, 664
 - natural history, 664
 - outcomes, 668
 - patient history and physical findings, 664
 - surgical management, 665
 - surgical technique, 667, 669*f*
- Raynaud disease (RD). *See* Digital artery sympathectomy
- Raynaud phenomenon (RP). *See* Digital artery sympathectomy
- RCA (radial collateral artery), 2134
- RDI (respiratory distress index), 636
- Recipient site fat grafting, 1493–1494, 1493*f*
- Recipient site preparation, 1040, 2937–2938, 2937*f*
- Recipient site preparation and microanastomosis
 - advantages and disadvantages, 2564*t*
 - axilla, 2564
 - dorsal ankle, 2565
 - dorsal wrist, 2564–2565
 - groin, 2565
 - medial elbow, 2564
 - posterior knee, 2565
- Recipient vessel preparation, 2384, 2384*f*, 2488–2489, 2488*f*
 - descending genicular artery, approach to, 2488, 2488*f*
 - lateral circumflex femoral artery, approach to, 2488
 - medial sural artery, approach to, 2488, 2488*f*
 - recipient vein, selection of, 2489
 - superior medial and lateral genicular artery, approach to, 2489

- Recipient vessels for microsurgical breast reconstruction
 - anatomy
 - internal mammary vessels, 1447
 - thoracodorsal vessels, 1447
 - complications, 1451
 - definition, 1447
 - imaging, 1448
 - merits and demerits, 1450*b*
 - outcomes, 1451
 - patient history and physical findings, 1448
 - postoperative care, 1451
 - surgical management
 - approach, 1448–1449
 - patient positioning, 1448, 1448*f*
 - preoperative planning, 1448
- Rectus abdominis, 2397
- Rectus abdominis flap, 1116, 1525
 - anatomy, 1528
 - complications, 1531
 - definition, 1528
 - imaging, 1529
 - merits and demerits, 1531*b*
 - nonoperative management, 1529
 - outcomes, 1531
 - pathogenesis, 1528
 - patient history and physical findings, 1528
 - postoperative care, 1531
 - surgical management
 - approach, 1529–1530
 - positioning, 1529
 - preoperative planning, 1529
- Rectus abdominis muscle flap, 2487–2488
- Rectus abdominis musculocutaneous flap, 1529–1530, 1530*f*

- Rectus abdominis myocutaneous flaps
 - graft sources, 986*b*
 - specific donor-site dissections, 986
 - surgical management
 - patient positioning, 985
- Rectus diastasis, 1596
- Rectus elevation, 1678
- Rectus femoris, 2395
- Rectus femoris flap
 - anatomy, 1580, 1581*f*
 - complications, 1586
 - definition, 1580
 - imaging, 1580
 - merits and demerits, 1586*b*
 - outcomes, 1586, 1586*f*
 - patient history and physical findings, 1580
 - postoperative care, 1586
 - surgical management
 - positioning, 1582
 - preoperative planning, 1580–1582
 - surgical markings, 1583, 1583*f*
- Rectus femoris flap, for abdominal wall reconstruction
 - anatomy, 1580, 1581*f*
 - complications, 1586
 - definition, 1580
 - imaging, 1580
 - merits and demerits, 1586*b*
 - outcomes, 1586, 1586*f*
 - patient history and physical findings, 1580
 - postoperative care, 1586
 - surgical management, 1580–1582
 - surgical markings, 1583, 1583*f*
- Rectus femoris muscle, 1580, 1581*f*

- RED (rigid external device)
 - advantages, 729
 - disadvantages, 729
 - external mandibular distraction, 727–728, 728*f*–729*f*
- RED (rigid external distraction), 588, 588*f*
- Red lip, 2596
- Redo hypospadias repair, buccal mucosa graft for, 3048–3049
- Reduction labioplasty
 - hybrid approach, 3060, 3060*f*
 - simple excision and closure, 3059, 3059*f*
 - wedge excision with advancement, 3059, 3059*f*
- Reduction mammoplasty
 - anatomy, 1340, 1340*f*–1341*f*
 - central mound
 - completion, 1343, 1343*f*
 - excision of parenchyma, 1342–1343, 1343*f*
 - markings, 1342, 1342*f*
 - complications, 1344
 - definition, 1340
 - differential diagnosis, 1341
 - imaging, 1341
 - merits and demerits, 1342*b*, 1344*b*
 - natural history, 1340
 - nonoperative management, 1341
 - outcomes, 1344
 - pathogenesis, 1340
 - patient history and physical findings, 1340–1341
 - postoperative care, 1344
 - surgical management
 - approach, 1341
 - patient positioning, 1341
 - preoperative planning, 1341
- Redundant skin excision, 1358

- Reflex sympathetic dystrophy, 1930
- Regional flaps, 2114–2115
- Regional nerve blocks, local anesthetic, administration of, 977, 977*f*
- Regnault scale for breast ptosis, 1340
- Repetitive microtrauma, chronic, 1987
- Replantation of digits
 - anatomy, 2147–2148, 2148*f*
 - complications, 2155
 - definition, 2147, 2147*f*
 - imaging, 2149, 2150*f*
 - merits and demerits, 2151*b*, 2154*b*
 - midlateral incisions, 2151, 2151*f*
 - natural history, 2149
 - nonoperative management, 2149
 - outcomes, 2154–2155, 2154*f*
 - pathogenesis, 2148, 2148*f*
 - patient history and physical findings, 2149
 - postoperative care, 2154
 - skin closure, 2153, 2153*f*
 - surgical management
 - approach, 2150
 - patient positioning, 2150
 - preoperative planning, 2150
- Respiratory distress index (RDI), 636
- Respiratory system, conjoined twins, 3095
- Restylane, 43
- Restylane Lyft, 32
- Restylane Refyne, 27
- Restylane-L, 27
- Retinacular sling reconstruction, ECU subsheath, 2087, 2087*f*–2088*f*
- Retinoblastoma gene mutation, 2460
- Retrobulbar hematoma, orbital floor blow-out fractures, 810

- Retrograde masseter-to-facial nerve transfer, 2926–2927, 2926*f*, 2927*f*, 2928*f*
- Retrograde posterior interosseous artery flap, 2129–2132, 2129*f*
 - harvest with skin bridge, 2130–2131, 2131*f*
 - inset, 2131–2132, 2132*f*
 - island flap harvest, 2130, 2130*f*
- Retromandibular approach, condyle fractures, open treatment of, 919, 919*f*, 920*f*
- Retro-orbicularis oculi fat (ROOF), 70
- Retroperitoneal femoral nerve exposure, pelvic pathology, 2535
- Retrorectus space, 1575
 - mesh positioning in, 1576, 1576*f*–1577*f*
- Revascularization and replantation of digits. *See* Replantation of digits
- Reverse dorsalis pedis fasciocutaneous flap, 2366
- Reverse dorsoradial homodigital flap, 2112–2113
- Reverse fasciocutaneous flap, 2368, 2368*f*–2369*f*
- Reverse first dorsal metatarsal artery (1st DMTA) flap, 2368, 2368*f*–2369*f*
- Reverse medial plantar artery flap, 2366
- Reverse orbicularis oculi tightening (ROOT), 151
 - lower blepharoplasty via subciliary incision, 153–154, 154*f*
- Reverse radial forearm flap (RRFF)
 - anatomy, 2114–2115, 2114*f*
 - complications, 2119
 - definition, 2114
 - imaging, 2115
 - merits and demerits, 2118*b*
 - nonoperative management, 2115
 - outcomes, 2118–2119
 - patient history, 2115, 2115*f*
 - physical findings, 2115, 2115*f*
 - postoperative care, 2118

- reverse flow radial forearm flap, 2116–2118, 2117*f*
- reverse radial forearm flap
- surgical management, 2115–2116
 - approach, 2116
 - patient positioning, 2116
 - preoperative planning, 2115–2116, 2116*f*
- Reverse sural artery flap, lower extremity reconstruction
 - anatomy, 2388
 - complications, 2390
 - definition, 2388
 - delayed reverse sural artery flap, 2390
 - fasciocutaneous pedicle incised, flap dissection with, 2389*f*
 - imaging, 2388
 - merits and demerits, 2390*b*
 - outcomes, 2390
 - patient history and physical findings, 2388
 - postoperative care, 2390
 - supercharged reverse sural artery flap, 2390
 - surgical management, 2388*f*
 - patient positioning, 2389
 - patient positioning approach, 2389
 - preoperative planning, 2388, 2388*f*
- RFF. *See* Radial forearm flap (RFF)
- RFFF. *See* Radial forearm free flap (RFFF)
- Rhabdomyolysis, 1760, 1765
- Rhabdomyosarcoma, 2421
- Rheumatoid arthritis (RA), hand and wrist
 - ACR criteria for, 1931, 1942*b*
 - ACR/EULAR classification criteria for, 1931, 1932*t*
 - boutonniere deformities
 - finger, 1938, 1938*f*
 - ligament reconstruction to correct, 1948
 - Nalebuff classification of, 1940, 1941*t*

- reconstructive surgery for, 1940
- thumb, 1938
- carpal ligaments and TFCC, 1933, 1933*f*–1934*f*
- carpal tunnel syndrome, 1936
- definition, 1931
- diagnosis, 1931
- differential diagnosis, 1931–1932
- extensor tendons of
 - finger, 1936, 1936*f*–1937*f*
 - hands and wrist, 1933–1935, 1934*f*, 1935*t*–1936*t*, 1935*t*
- imaging, 1932, 1932*f*
- merits and demerits, 1952*b*
- nonoperative management, 1939–1940
- outcomes, 1953, 1954*f*
- pathogenesis, 1931
- patient history and physical findings, 1932–1939, 1933*f*
- postoperative care, 1945, 1948, 1950–1951
- radiographs of, 1932, 1932*f*
- surgical management, 1940–1941, 1941*f*
 - patient positioning, 1941
 - preoperative planning, 1940–1941
- swan-neck deformity (*see* Swan-neck deformity)
- tendon transfer for
 - extensor tendon ruptures, 1942, 1943*f*, 1944*f*
 - FPL rupture, 1942–1944, 1945*f*
 - options after, 1935, 1935*t*–1936*t*
 - tendon ruptures, 1942
- thumb deformity, 1938
- trigger fingers in, 1938–1939
- wrist joint, 1933
- Rheumatoid hand deformity, 2090–2091
- Rheumatoid nodules, 2421
- Rhinitis closed rhinoplasty, narrow midvault in, 275

- Rhinoplasty
 - anesthesia, controlling tip rotation in
 - anatomy, 283, 283*f*
 - complications, 287
 - definition, 283
 - elastic rotation, securing, 285, 285*f*
 - imaging, 283
 - long lateral crus, shortening, 286, 286*f*
 - long upper lateral, shortening, 286, 286*f*
 - merits and demerits, 286*b*
 - natural history, 283
 - nonoperative management, 283
 - outcomes, 287, 287*f*
 - pathogenesis, 283
 - patient history and physical findings, 283
 - postoperative care, 287
 - projection, 286
 - surgical management, 283–285, 284*f*
 - diced cartilage and fascia grafting in
 - anatomy, 366
 - combined techniques, 371
 - complications, 372
 - DCFG, placement of, 370, 371*f*
 - definition, 366
 - fascial wrapping, 370, 370*f*
 - harvest, 368–369, 368*f*
 - imaging, 366
 - merits and demerits, 371*b*
 - nonoperative management, 367
 - outcomes, 372
 - patient history and physical findings, 366
 - postoperative care, 371–372
 - surgical management, 367–368, 372*f*–371*f*

- techniques, 369, 369*f*
- temporal fascia harvest, 369, 369*f*
- fascia graft, dorsal augmentation
 - anatomy, 362
 - complications, 365
 - deep temporal fascia harvest, 363, 363*f*
 - definition, 362
 - differential diagnosis, 362
 - imaging, 362
 - merits and demerits, 364*b*
 - nonoperative management, 362
 - pathogenesis, 362
 - patient history and physical findings, 362
 - postoperative care, 364
 - surgical management, 362–363, 363*f*
 - techniques, 363, 364*f*
- secondary cleft (*see* Secondary cleft rhinoplasty)
- Rhytides, 55
- Rhytids
 - dynamic, 5
 - perioral
 - anatomy, 11, 11*f*
 - complications, 13
 - definition, 11
 - marionette lines, 12
 - merits and demerits, 13*b*
 - outcomes, 13, 13*f*
 - pathogenesis, 11
 - patient history and physical findings, 11
 - postprocedural care, 13
 - vertical rhytids, 12
 - static, 5
- RIA (reamer-irrigator-aspirator) system, 2474–2475, 2478*f*

- preparation, 2477, 2477*f*
- Rib graft harvest, 995, 995*f*
- Rib/thoracic cage, 994, 994*f*
- Right gastroepiploic pedicle, omental flap harvest with
 - dissection, 1665, 1665*f*
 - flap positioning, 1666, 1667*f*
 - ligation and division, 1665–1666, 1666*f*
- Right leg lymphedema, 2552*f*
- Rigid external device (RED)
 - advantages, 729
 - disadvantages, 729
 - external mandibular distraction, 727–728, 728*f*–729*f*
- Rigid external distraction (RED), 584, 588–589, 588*f*, 589*f*
- Rigid spherical orbital implants, 2881, 2881*f*–2884*f*
- Rigotomy, 2811
- Ring finger FDS, to APB tendon transfer, 2036
- Ring-Adair-Elwyn (RAE) tube, 2638, 2639*f*
- Risdon (submandibular) approach
 - condyle fractures, 918, 920, 920*f*–921*f*
 - nonunion of a mandible fracture, 930, 931*f*–932*f*
- RLD. *See* Radial longitudinal deficiency (RLD)
- Robin sequence, 2675
- Rolando fractures
 - anatomy
 - closed reduction and pinning of
 - complications
 - definition
 - imaging
 - merits and demerits
 - natural history
 - open reduction and internal fixation
 - outcomes
 - pathogenesis

- patient history and physical findings
- plain radiographs
- postoperative care
- surgical management
 - patient positioning
 - preoperative planning
- Wagner approach
- ROM (range-of-motion) exercises, 2118, 2124, 2372
- ROOF (retro-orbicularis oculi fat), 70
- ROOT (reverse orbicularis oculi tightening), 151
 - lower blepharoplasty via subciliary incision, 153–154, 154*f*
- Ropivacaine, 2329
- Rose-Thompson effect, 2598, 2599*f*
- Rotation advancement flap
 - harvest
 - approaching pedicle, 1518
 - blunt finger dissection, 1518, 1518*f*
 - humeral insertion, 1518
 - skin incision, 1517
 - submuscular dissection, 1517
 - scalp reconstruction, 981, 981*f*–982*f*
- Rotation flaps reconstruction
 - anatomy, 980
 - chronic wounds, 980
 - complications, 983
 - definition, 980
 - imaging, 981
 - merits and demerits, 981*b*
 - nonoperative management, 981
 - outcomes, 982
 - pathogenesis, 980
 - patient history, 980
 - physical examination, 980

- postoperative care, 982
- rotation advancement flap, 981, 981*f*–982*f*
- surgical management, 981
- Rotationplasty, of lower extremity
 - anatomy, 2970, 2970*f*
 - complications, 2976
 - definition, 2970
 - imaging, 2970
 - merits and demerits, 2975*b*
 - outcomes, 2975–2976
 - patient history and physical findings, 2970
 - postoperative care, 2975, 2975*f*
 - surgical management, 2971
 - approach, 2971, 2971*f*
 - patient position, 2971
 - preoperative planning, 2971
- Rotation/reconstruction, distal limb, 2973, 2974*f*
- Rotterdam/extended L rhinotomy approach, 2890
- Round implants
 - anatomy, 1319
 - complications, 1326
 - definition, 1319
 - imaging, 1320, 1320*f*
 - merits and demerits, 1324*b*
 - outcomes, 1325
 - pathogenesis, 1319
 - patient history and physical findings, 1319–1320
 - postoperative care, 1325
 - surgical management
 - approach, 1321
 - patient positioning, 1321
 - preoperative planning, 1320–1321
- Rowe disimpaction forceps, 891, 891*f*, 899, 900*f*–901*f*

- RPE. *See* Rapid palatal expansion (RPE)
- RRFF. *See* Reverse radial forearm flap (RRFF)
- RTS. *See* Radial tunnel syndrome (RTS)
- “Rule of nines” test, 2000

S

- SAAP flap, 1370
- Sacral and trochanteric pressure injury, 2793, 2793*f*
- Sacral pressure injury, 2787
 - anatomy, 1698, 1698*f*
 - complications, 1704
 - definition, 1698
 - differential diagnosis, 1700
 - history and physical findings, 1699–1700
 - imaging, 1700
 - natural history, 1699, 1699*f*
 - nonoperative management, 1700
 - outcomes, 1704
 - pathogenesis, 1698–1699
 - postoperative care, 1704
 - surgical management
 - approach, 1701
 - positioning, 1700, 1700*f*
 - preoperative planning, 1700
- Sacrococcygeal teratoma (SCT), 3019
 - anatomy, 3017
 - complications, 3021
 - debulking, 3019, 3020*f*
 - definition, 3017
 - differential diagnosis, 3017
 - imaging, 3017, 3017*f*–3018*f*
 - merits and demerits, 3021*b*
 - outcomes, 3021
 - pathogenesis, 3017
 - postoperative care, 3021
 - surgical management, 3018, 3018*f*

- Saethre-Chotzen syndrome, 445
- SAF. *See* Serratus anterior flap (SAF)
- Safe donor area (SDA), 419, 420*f*
- Sagittal craniosynostosis
 - anatomy, 485, 485*f*
 - asymmetric transverse distraction osteogenesis, 486–487, 487*f*
 - complications, 489
 - definition, 485
 - imaging studies, 486
 - merits and demerits, 486*b*
 - outcomes, 488
 - patient history, 485
 - physical examination, 485
 - postoperative care, 488
 - surgical management
 - patient positioning, 486, 486*f*
 - preoperative planning, 486
- Sagittal split osteotomy, 407, 407*f*
- Sagittal synostosis
 - anatomy, 477
 - complications, 483
 - cranial sutures, 477, 477*f*
 - craniosynostosis, 530, 532, 532*f*
 - definition, 477
 - differential diagnosis, 478
 - endoscopy-assisted technique
 - incisions and endoscope insertion, 481, 481*f*
 - spring placement, 481, 482*f*
 - spring removal, 481
 - family history, 478
 - imaging studies, 478
 - merits and demerits, 479*b*
 - natural history, 445, 478

- nonoperative management, 479
- open technique
 - exposure, 479, 480*f*
 - spring placement, 477, 480*f*
 - spring removal, 480, 480*f*–481*f*
- outcomes, 483
- pathogenesis, 477–478
- perinatal history, 478
- physical examination, 478
- postoperative care, 483
- surgical management
 - approach, 479
 - patient positioning, 479, 479*f*
 - preoperative planning, 479
- Salivary gland
 - carcinomas, hemiglossectomy, 1198
 - tumors, FOM, 1209
- Salyer unilateral cleft lip/nose repair
 - Abyholm closure of anterior palate, 2624, 2626*f*–2628*f*
 - anatomy
 - abnormal cleft lip/nose, 2616–2617
 - normal upper lip, 2616
 - complications, 2626
 - definition, 2616
 - differential diagnosis, 2618
 - imaging, 2618
 - lateral lip element elevation, 2621
 - marking, 2619–2621, 2620*f*–2623*f*
 - medial lip incision, 2621
 - merits and demerits, 2619*b*
 - muscle repair, 2618
 - natural history, 2617
 - nonoperative management, 2618

- Noordhoff's vermilion flap technique, 2624, 2624*f*
- nose repair, 2618
- outcomes, 2626
- pathogenesis, 2617
- patient history and physical findings, 2618
- postoperative care, 2626
- skin flap for lip lengthening, 2623–2624, 2623*f*
- surgical management, 2618–2619
 - approach, 2619
 - patient position, 2619
 - preoperative planning, 2618–2619
- Saphenous nerve, 2324, 2324*f*
- Saphenous vein, 2395
 - dissection of, 2525, 2525*f*
- Sarcoma
 - FOM, 1209
 - subtypes, 2339
- Sartorius, 2403
 - flap, 2518
 - muscle, 1583, 1583*f*
- SBRN (superficial branch of radial nerve)
 - anatomy, 1754
 - at wrist, 1758
- SCAIF. *See* Supraclavicular artery island flap (SCAIF)
- Scalp
 - advancement, hairline lowering, 103, 103*f*–104*f*
 - fixation and wound closure, hairline lowering, 104, 104*f*–105*f*
 - lacerations, 3079, 3079*f*
- Scalp reconstruction
 - with free flaps
 - anatomy, 984
 - complications, 989
 - definition, 984

- graft sources, 985, 986*b*
- imaging studies of, 984
- merits and demerits, 987*f*
- microsurgery, 987, 987*f*
- outcomes, 988, 988*f*
- pathogenesis of, 984
- patient history, 984
- physical examination of, 984
- postoperative care, 988
- specific donor-site dissections, 986
- superficial temporal artery preparation, 986
- surgical management of, 984–985
- with rotation flaps
 - anatomy, 980
 - chronic wounds, 980
 - complications, 983
 - definition, 980
 - imaging, 981
 - merits and demerits, 981*b*
 - nonoperative management, 981
 - outcomes, 982
 - pathogenesis, 980
 - patient history, 980
 - physical examination, 980
 - postoperative care, 982
 - rotation advancement flap, 981, 981*f*–982*f*
 - surgical management, 981
- with tissue expansion
 - advancement of flap, 992, 992*f*
 - anatomy, 990
 - base diameter, 990
 - complications, 993
 - definition, 990

- insertion, 991, 991*f*
- merits and demerits, 991*b*
- outcomes, 993, 993*f*
- pathogenesis, 990, 990*f*
- patient history, 990
- physical examination, 990
- postoperative care, 993
- shapes, 990
- surgical management, 990–991
- Scaphal cartilage, 1130
- Scaphocephaly, 477
- Scaphoid
 - fractures, 1957
 - normal orientation of, 1899, 1899*f*–1900*f*
- Scaphoid fracture nonunion
 - anatomy, 1880
 - complications, 1888
 - definition, 1880
 - imaging, 1881
 - merits and demerits, 1886*b*
 - outcomes, 1887–1888
 - patient history, 1880
 - postoperative care, 1886–1887
 - scaphoid preparation and fixation, 1885, 1885*f*
 - surgical management
 - contraindications, 1881
 - patient positioning, 1881
- Scaphoid fractures fixation
 - anatomy, 1865–1866, 1865*f*–1866*f*
 - complications, 1872
 - definition, 1865
 - differential diagnosis, 1867
 - imaging, 1866–1867

- merits and demerits, 1871*b*
- natural history, 1866
- nonoperative management, 1867
- open reduction and internal fixation
 - dorsal approach, 1868–1869
 - volar approach, 1870
- outcomes, 1871
- pathogenesis, 1866
- patient history and physical findings, 1866
- postoperative care, 1871
- surgical management
 - approach, 1868
 - patient positioning, 1868
 - preoperative planning, 1867–1868
- Scaphoid nonunion
 - anatomy, 1873
 - complications, 1879
 - definition, 1873, 1873*f*
 - dorsal approach
 - closure, 1877
 - scaphoid fixation, 1877
 - site exposure and preparation, 1876–1877, 1877*f*
 - imaging, 1873–1874
 - merits and demerits, 1874*b*, 1877*b*
 - outcomes, 1878–1879
 - patient history and physical findings, 1873
 - postoperative care, 1878
 - surgical management
 - approach, 1874
 - patient positioning, 1874
 - volar approach
 - bone graft, 1874–1875, 1875*f*
 - scaphoid fixation, 1875–1876, 1876*f*

- site exposure and preparation, 1874, 1875*f*
- site stabilization, 1875, 1876*f*
- Scaphoid nonunion advanced collapse (SNAC), 1887*f*–1888*f*, 1880, 1957
- Scapholunate advanced collapse (SLAC), 1899, 1957
- Scapholunate (SL) dissociation
 - anatomy and, 1899
 - complications, 1903
 - definition, 1899
 - dorsal capsulodesis for, 1899
 - advantage of, 1899
 - complications, 1903
 - disadvantage of, 1899
 - merits and demerits, 1903*b*
 - outcomes, 1903
 - postoperative care, 1903
 - using suture anchors, 1901, 1901*f*
 - extensor carpi radialis longus, 1899
 - closure, 1902
 - exposure and reduction, 1901–1902
 - outcomes, 1903
 - tendon transfer, 1899–1900, 1902
 - imaging studies, 1899
 - merits and demerits, 1903*b*
 - outcomes, 1903
 - patient history and physical findings, 1899
 - postoperative care, 1903
 - slider-crank model of wrist, 1899–1900
 - surgical management, 1899–1900, 1899*f*–1900*f*
 - approach, 1900, 1900*f*
 - patient positioning, 1900
 - preoperative planning, 1900
- Scapholunate instability, 1899. *See also* Scapholunate dissociation

- Scapholunate interosseous ligament (SLIL) injury
 - differential diagnosis, 1853
 - direct repair for, 1853
 - nonoperative management, 1853
 - pathogenesis, 1851
 - radiograph imaging of, 1852, 1852*f*
 - rupture of, 1851
 - scapholunate advanced collapse, 1851
- Scapholunate ligament reconstruction
 - anatomy, 1851, 1852*f*
 - ballottement test, 1851
 - capsulodesis in, 1853
 - complications, 1856
 - definition, 1851
 - differential diagnosis, 1853
 - exposure in, 1853, 1853*f*
 - fixed vs. reducible deformity in, 1851
 - imaging, 1852–1853, 1852*f*
 - merits and demerits, 1855*b*
 - natural history, 1851
 - nonoperative management, 1853
 - outcomes, 1855–1856, 1856*f*
 - pathogenesis, 1851
 - patient history and physical findings, 1851
 - postoperative care, 1855
 - scaphoid and lunate, reduction of
 - flexor carpi radialis graft, 1853–1854, 1854*f*, 1855*f*
 - K-wire placement, 1854, 1854*f*
 - static vs. dynamic instability, 1851
 - surgical management, 1853
 - approach, 1853
 - patient positioning, 1853
 - preoperative planning, 1853

- volvar and dorsal wrist incision, 1853, 1853*f*
- Watson scaphoid shift test, 1851, 1852*f*
- Scaphotrapeziotrapezoid (STT) joint arthritis, 1957
- Scapula flap, mandible reconstruction
 - anatomy, 1037–1038
 - bone harvest, 1041–1043, 1042*f*–1043*f*
 - definition, 1037
 - diagnostic studies, 1038
 - flap variations, 1044, 1044*f*
 - imaging studies, 1038
 - latissimus dorsi muscle, 1041
 - merits and demerits, 1040*b*
 - outcomes, 1045
 - patient history and physical findings, 1038
 - postoperative care, 1045
 - preparation and inset of the flap, 1043
 - recipient site preparation, 1040
 - skin flap harvest, 1040, 1041*f*
 - surgical management, 1038–1040
- Scapular fasciocutaneous flap, 1039
- Scapular flap, 1116
- Scapular osteocutaneous flaps, 1038
- Scar contracture
 - anatomy, 2580, 2580*f*–2581*f*
 - definition, 2580
 - imaging, 2581, 2582*f*
 - merits and demerits, 2582*b*, 2587*b*
 - outcomes, 2588, 2588*f*
 - patient history and physical exam, 2580, 2581*f*
 - postoperative care, 2588
 - surgical management
 - approach, 2582
 - indications, 2581

- patient positioning, 2581–2582
 - preoperative planning, 2581
- Scarpa fascia, 1649
- Scarring
 - of lip, 2635
 - of ostium, 2876
- SCC. *See* Squamous cell carcinoma/cancer (SCC)
- Schrudde angle rotation flap, 1109
- Schwannoma, 2456–2457, 2498
 - anatomy, 2299
 - complications, 2302
 - definition, 2299
 - differential diagnosis, 2300
 - enucleation, 2301, 2301*f*
 - imaging, 2300, 2300*f*
 - merits and demerits, 2302*b*
 - natural history, 2299
 - nonoperative management, 2300
 - outcomes, 2302
 - pathogenesis, 2299
 - patient history and physical findings, 2299, 2299*f*
 - postoperative care, 2302
 - surgical management, 2300
 - approach, 2300
 - patient positioning, 2300
 - preoperative planning, 2300
- SCIA. *See* Superficial circumflex iliac artery (SCIA)
- SCIA (superficial circumflex iliac artery), 2137–2138
 - free groin flap, 2142, 2142*f*
 - pedicled groin flap, 2140
- Sciatic nerve, 2315, 2318–2319, 2502, 2972
 - anatomy, 2529, 2529*f*–2530*f*
 - innervation/function, 2529

- mechanisms of injury, 2529
- complications, 2533
- definition, 2529
- imaging, 2530–2531, 2531*f*
- merits and demerits, 2531*b*, 2532*b*
- nonoperative management, 2531
- outcomes, 2533, 2533*t*
- patient history and physical exam, 2530
- postoperative care, 2533
- surgical management, 2531, 2531*f*
- Sciatic pathology, 2412
- SCIP (superficial circumflex iliac artery perforator) flap, 2487–2488
- Scleral show, 158
- Sclerotherapy, for vascular tumors of hand, 2276
- SCM (sternocleidomastoid), 212
- Scoliosis, 2752
- Scratch collapse test, 1993, 2411
 - tibial nerve, 2452
- SCT. *See* Sacrococcygeal teratoma (SCT)
- Sculptra, 42
- SDA (safe donor area), 419, 420*f*
- SEAP flaps, 1371
- Sebaceous cell carcinoma
 - direct closure and lateral cantholysis, 1078
 - tenzel semicircular rotational flap, 1084
- Second toe-to-thumb transfer
 - anatomy, 2250–2251, 2250*f*
 - angiography and, 2251
 - complications, 2258
 - definition, 2250
 - merits and demerits, 2257*b*
 - osteosynthesis, 2256, 2256*f*–2257*f*
 - outcomes, 2257–2258

- patient history and physical findings, 2251, 2251*f*
- plain radiographs of, 2251, 2251*f*
- postoperative care, 2257
- preparation of, 2255, 2255*f*–2256*f*
- second toe flap
 - artery and nerve dissection, 2254, 2254*f*
 - closure, 2255, 2255*f*
 - incision placement for, 2253, 2253*f*
 - metatarsal osteotomy and flap placement, 2255, 2255*f*
 - soft tissue dissection, 2253–2254, 2254*f*
- surgical management, 2251–2252
 - patient positioning, 2252
 - preoperative planning, 2252
- Secondary cleft rhinoplasty
 - anatomy, 2714
 - complications, 2718
 - definition, 2714
 - dorsal correction, 2717
 - imaging, 2715
 - merits and demerits, 2718*b*
 - nasal framework correction, 2717
 - nostril correction, 2717
 - open cleft lip rhinoplasty
 - incision and dissection, 2716, 2716*f*
 - shape correction, 2716–2717, 2716*f*
 - outcomes, 2718
 - patient history and physical findings, 2714–2715, 2715*t*, 2716*b*
 - postoperative care, 2718
 - surgical management, 2715
 - approach, 2715
 - patient position, 2715
 - preoperative planning, 2715
 - tip and ala, reshaping, 2717

- Secondary deformities, of lip and nose
 - Abbe flap, 2652–2653, 2652*f*–2653*f*
 - anatomy, 2644
 - complications, 2657
 - Cupid’s bow, 2645*b*, 2645*f*
 - asymmetry more than 2 mm high, 2647, 2647*f*
 - mismatch of 1 to 2 mm, 2646, 2646*f*
 - definition, 2644
 - lip pits, 2654–2656
 - acellular dermal allograft, 2656, 2656*f*
 - inverted-T excision, 2655–2656, 2656*f*
 - split lip advancement technique, 2655, 2655*f*
 - transverse elliptical excision, 2654, 2655*f*
 - vertical elliptical wedge excision, 2654, 2655*f*
 - merits and demerits, 2656*b*
 - outcomes, 2657
 - pathogenesis, 2644
 - patient history and physical findings, 2644
 - postoperative care, 2657
 - surgical management
 - approach, 2644–2645
 - patient position, 2644
 - preoperative planning, 2644
 - vermilion and mucosa, 2648–2652
 - hypoplastic medial/lateral lip element, 2650–2651
 - lateral mucosa fullness, 2648, 2650*f*–2651*f*
 - notch in free edge, 2651–2652
 - red line malalignment, 2648
- Secondary healing using regenerative matrix, 2367, 2368*f*
- Secondary hyperhidrosis, 1749
- Secondary infections, 2430
- Secondary patency, 2401
- Secondary pedicle technique, breast reconstruction, 1364

- Secondary post-traumatic enophthalmos, 847
- Segmental Le Fort I advancement
 - anatomy, 592–593
 - Angle’s classification, 592, 592*f*–593*f*
 - complications, 601
 - imaging studies, 594–595, 595*f*
 - incision and dissection, 596
 - of maxilla
 - closure, 599
 - down-fracture, 597
 - fixation, 599, 599*f*
 - Le Fort I osteotomy, 596–597, 597*f*
 - MMF and alar base width, 599
 - segmentation, 597–598, 598*f*
 - transverse expansion and advancement, 598
 - merits and demerits, 596*b*
 - natural history, 594
 - outcomes, 601
 - pathogenesis, 594
 - patient history and physical findings, 594, 594*f*
 - postoperative care, 600
 - surgical management
 - patient positioning, 595–596, 596*f*
 - preoperative planning, 595–596
 - three-piece segmental advancement, 592
 - two-piece segmental advancement, 592
- Semmes-Weinstein monofilament test, 2352, 2374, 2408
- Sensate flap, 2383
- Sensory distribution of leg, 2315*f*
- Sensory innervation, 1068, 1069*f*
 - buccal mucosa, 1219
 - of ear, 1129
 - FOM, 1211

- nose, 1154
- radial forearm free flap, 1073
- SCAIF flap, 1249
- skin grafts, 1122
- Sensory nerve, 70
 - subcutaneous lateral brow lifting, 82
 - transfers, combined median and ulnar nerve injury, 2041
- Septal cartilage, 326
- Septal collapse, closed rhinoplasty, narrow midvault in, 275
- Septal deformities, 957
- Septal extension graft, short nose, 338, 340*f*–341*f*
- Septal fractures/dislocations, 860
- Septal hematoma, open treatment of nasal fractures, 864
- Septal perforation, closed rhinoplasty, narrow midvault in, 275
- Septal resection, open rhinoplasty, controlling tip rotation in, 312, 312*f*
- Septal stents, 328–329
- Septal tilt correction, 328, 328*f*–330*f*
- Septoplasty, 273–274, 273*f*, 291
 - crooked nose, 327–329, 328*f*–330*f*
 - nasal airway obstruction, 383, 383*f*
- Septum, 2617
 - anatomy, 2606, 2607*f*
 - reconstruction, 2895–2896, 2896*f*
- Sequestrum, 2466
- Serial puncture injection technique, 44, 44*f*
- Seromas, 200, 1618, 1638, 1741
- Serratus anterior flap (SAF)
 - anatomy, 1547, 1548*f*–1551*f*
 - complications, 1555
 - definition, 1547
 - flap harvest, 1553–1554, 1553*f*–1554*f*
 - imaging, 1549

- intrathoracic flap inseting, 1554, 1554*f*
- merits and demerits, 1554, 1554*b*
- outcomes, 1555
- pathogenesis, 1547
- patient history and physical findings, 1547–1549
- postoperative care, 1554–1555
- surgical management
 - approaches, 1551
 - incision and initial dissection, 1552, 1552*f*
 - positioning, 1551
 - postdissection wound, 1552, 1552*f*
 - preoperative markings, 1552, 1552*f*
 - preoperative planning, 1549–1551
- Seymour fractures
 - complications, 1776
 - definition, 1775
 - indications for surgical management, 1776
 - merits and demerits, 1778
 - natural history, 1775
 - open debridement and pinning, 1776–1777, 1778*f*
 - outcomes, 1779
 - pathogenesis, 1775
- SFA (superficial femoral artery), 2400, 2402, 2497, 2502
- SFS (superficial fascial system), 1619
- SGAP flap. *See* Superior gluteal artery perforator (SGAP) flap
- Shaft fractures
 - closed reduction and pinning, 1791, 1791*f*
 - nonoperative management, 1787–1788
 - open reduction and internal fixation, 1792–1793, 1792*f*
 - pathogenesis, 1787
 - surgical management, 1788
- Sharp debridement of acute wound, 2428–2429, 2429*f*
- Sharp injury, nerve repair and graft, 2006

- Sheffield splint, 2417
- Shield-tip graft, short nose, 339–340, 339*f*
- Short nose
 - anatomy, 338
 - complications, 342
 - definition, 338
 - imaging, 338
 - merits and demerits, 342*b*
 - outcomes, 342
 - pathogenesis, 338
 - patient history and physical findings, 338
 - postoperative care, 342
 - septal extension graft, 338, 340*f*–341*f*
 - shield-tip graft, 339–340, 339*f*
 - surgical management, 338–339
 - approach, 339
 - positioning, 339
 - preoperative planning, 339
 - tongue-and-groove technique, 341–342, 341*f*
- Short scar periareolar inferior pedicle (SPAIR) technique, 2995
 - closure, 2998–2999, 2999*f*
 - flap creation, 2996, 2997*f*
 - incisions, 2996, 2996*f*
 - shaping, 2996, 2997*f*
 - skin plication, 2998, 2998*f*
- Short upper lip/transverse crease, 375, 375*f*
- Short-scar face-lift
 - anatomy, 251
 - complications, 253
 - definition, 251
 - merits and demerits, 252*b*
 - outcomes, 252, 252*f*
 - patient history and physical findings, 251

- postoperative care, 252
- surgical management, 251
- techniques, 251–252, 251*f*, 252*f*
- Sialoceles, 3083
- Sialoma, 200
- Siamese twins, 3094
- SIEA (superficial inferior epigastric artery), 2563
- Signet ring sign, 1852, 1852*f*
- Silicone metacarpophalangeal joint arthroplasty (SMPA), 1940, 1948, 1949*f*, 1953, 1954*f*
- Silicone soft elastomer intramuscular augmentation, of buttocks, 1632–1633, 1632*f*
- Silver sulfadiazine, 2351
- Simmonds/Thompson test, 2416
- Simple displaced fractures
 - angle and ramus fractures, 911–912, 911*f*–912*f*
 - body fractures, 911
 - symphysis/parasymphysis, 910
- Single injection technique, supplies for, 2316
- Single pedicle technique, breast reconstruction, 1364
- Single-digit sympathectomy, 2157
- Single-stage flexor tendon grafting, 2066–2068, 2067*f*
- Single-stage operation, nonunion of a mandible fracture, 929–930, 929*f*
- Skate flap for nipple reconstruction
 - anatomy, 1476, 1476*f*
 - complications, 1481
 - definition, 1476
 - merits and demerits, 1477*b*, 1480*b*
 - outcomes, 1481
 - patient history and physical findings, 1476
 - postoperative care, 1481
 - surgical management

- patient positioning, 1477
- preoperative planning, 1477, 1477*f*
- Skeletal deficiency, 398
- Skeletal malocclusion, definition, 592
- Skeleton, malar implants, 392, 392*f*
- Skeletonization ethnic rhinoplasty, 290
- Skin closure, 2891, 2891*f*
 - prune belly, 3024, 3024*f*
 - Stahl ear, 2824
- Skin flap
 - dissection
 - cryptotia, 2834
 - prominent ears, 2838
 - harvest, surgical management
 - lateral approach, 1040
 - medial approach, 1040, 1041*f*
 - necrosis, 1741
 - transposition, cryptotia, 2834
- Skin grafting
 - with acellular allodermal matrix, 2584, 2585*f*
 - harvesting, 2583, 2584*f*
 - placement and securing, 2583, 2584*f*
 - recipient site preparation, 2583, 2583*f*
- Skin grafts
 - anatomy, 1180
 - arterial and venous anatomy, 1123*f*
 - buccomandibular, 1122, 1122*f*
 - closure, with radial forearm free flap, 1075, 1075*f*
 - complications, 1182
 - definition, 1122, 1180
 - with full-thickness skin graft, 1125, 1125*f*
 - harvest
 - advantages, 2769

- anatomy, 2769
- definition, 2769
- full-thickness skin grafts, 2769, 2771
- merits and demerits, 2770*b*
- natural history, 2769
- postoperative care, 2771
- prognosis, 2769
- split-thickness skin grafts, 2769–2771, 2770*f*, 2771*f*
- surgical management, 2769
- lymphatic drainage, 1122
- merits and demerits, 1125*b*, 1181*b*
- nasal tip reconstruction, 1182
- nonoperative management, 1124
- outcomes, 1126–1127
- patch appearance, 1126
- patient history and physical findings, 1122–1124, 1180
- postoperative care, 1126, 1182
- preauricular, 1122, 1122*f*
- site preparation and graft harvest, 1181, 1181*f*
- with split-thickness skin graft, 1126, 1127*f*–1128*f*
- suborbital, 1122, 1122*f*
- surgical management, 1124
 - approach, 1124, 1180
 - patient positioning, 1124, 1180
 - preoperative planning, 1124, 1180
- Skin laxity, 2127
- Skin necrosis, 2835
- Skin paddle, 1590
 - debulking of, 988, 988*f*
 - de-epithelization and transposition of, 1678, 1678*f*
 - elevation of, 1678
- Skin pinch skin excision
 - anatomy, 138

- complications, 139
- definition, 138
- excess eyelid skin removal, 138
- imaging, 138
- merits and demerits, 139*b*
- outcomes, 139
- patient history and physical findings, 138
- postoperative care, 139
- surgical management, 138
- Skin release and mobilization, 3009, 3009*f*, 3015
- Skin resection, 2891, 2891*f*
- Skin substitutes, 2366–2367
- Skin tumors, malignant
 - basal cell carcinoma (see Basal cell carcinoma (BCC))
 - melanoma (see Melanoma)
 - Mohs micrographic surgery, 2305–2306, 2306*f*–2307*f*
 - squamous cell carcinoma (see Squamous cell carcinoma/cancer (SCC))
 - surgical management
 - approach, 2305, 2306*f*
 - patient positioning, 2305
 - preoperative planning, 2305
- Skin-aponeurosis fixation technique, 129, 129*f*
- Skin-muscle flap approach, lower blepharoplasty via subciliary incision, 152–153, 152*f*–153*f*
- Skin-only face and neck lifting
 - anatomy, 196
 - complications, 200
 - definition, 196
 - imaging, 197
 - merits and demerits, 199*b*
 - natural history, 196–197
 - nonoperative management, 197

- outcomes, 199, 199*f*–200*f*
- pathogenesis, 196
- patient history and physical findings, 197
- postoperative care, 199
- surgical management, 197–198, 197*f*
- techniques, 198*b*
- Skin-only flap approach, lower blepharoplasty via subciliary incision, 153–154, 154*f*
- Skin-tarsus fixation technique, 130, 130*f*
- Skoog's technique, 658
- Skull base fracture, 2875
- Skull defects
 - anatomy, 774
 - complications, 778
 - definition, 774
 - iliac crest bone graft, 776–777, 777*f*
 - imaging studies, 774, 775*f*
 - merits and demerits, 775*b*
 - outcomes, 778
 - patient history and physical findings, 774
 - postoperative care, 778
 - rib graft, 777, 777*f*
 - split parietal calvarium, 775–776, 776*f*
 - surgical management
 - approach, 774
 - patient positioning, 774
 - preoperative planning, 774
 - zigzag bicoronal incision, 775, 775*f*
- SL dissociation. *See* Scapholunate (SL) dissociation
- SLA (superior labial artery), 37
- SLAC (scapholunate advanced collapse), 1899
- SLAT (split lip advancement technique), 2655, 2655*f*
- Slider-crank model, 1899–1900

- Sliding gluteal flap, 1703, 1703*f*
- SLIL injury. *See* Scapholunate interosseous ligament (SLIL) injury
- Small cell carcinoma, of upper lip and nostril floor
- Small finger abduction
 - correction, 2040
 - low combined median and ulnar nerve palsy, 2040
- Small nerve gap repair, small caliber nerve, 2008, 2008*f*–2009*f*
- SMAS. *See* Superficial musculoaponeurotic system (SMAS)
- SMASectomy, 206, 206*f*
- SMASectomy face-lift
 - anatomy, 228, 228*f*
 - complications, 230
 - definition, 228
 - merits and demerits, 229*b*
 - outcomes, 230
 - patient history and physical findings, 228
 - postoperative care, 230
 - surgical management, 228–230
 - techniques, 229*b*, 229*f*
- SMG (submandibular gland), 242–243
 - reduction, 246–247, 246*f*–247*f*
- SMPA (silicone metacarpophalangeal joint arthroplasty), 1940, 1948, 1949*f*, 1953, 1954*f*
- SNAC (scaphoid nonunion advanced collapse), 1880, 1887*f*–1888*f*
- Snapback test, 158
- Sodium bicarbonate, local anesthesia, 972
- Soft palate repair, 2659, 2659*f*
- Soft tissue anatomy, 802
- Soft tissue debridement, 2467
- Soft tissue flaps, 2127
 - floor of mouth reconstruction
 - anterolateral thigh flap, 1211
 - medial sural artery perforator flap, 1211

- pectoralis major musculocutaneous flap, 1211
- radial forearm fasciocutaneous free flap, 1210
- lateral mandible reconstruction
 - anatomy, 1047
 - completion, 1051
 - complications, 1051
 - definition, 1047
 - horizontally oriented flaps, 1048, 1049*f*
 - imaging studies, 1048
 - indication, 1047
 - merits and demerits, 1048*b*
 - nonhorizontally oriented flaps, 1049, 1049*f*–1050*f*
 - outcomes, 1051
 - patient history and physical findings, 1047–1048
 - postoperative care, 1051
 - surgical management, 1048
- lateral mandible reconstruction with
 - anatomy, 1047
 - completion, 1051
 - complications, 1051
 - definition, 1047
 - horizontally oriented flaps, 1048, 1049*f*
 - imaging, 1048
 - indication, 1047
 - merits and demerits, 1048*b*
 - nonhorizontally oriented flaps, 1049, 1049*f*–1050*f*
 - outcomes, 1051
 - patient history and physical findings, 1047–1048
 - postoperative care, 1051
 - surgical management, 1048
- maxillary reconstruction
 - anatomy, 1011–1012, 1011*f*–1012*f*
 - complications, 1021

- definition, 1011
- eyelids, 1019
- imaging, 1012
- imaging studies, 1012
- merits and demerits, 1015*b*
- nonoperative management, 1012–1013
- nose, 1019
- outcomes, 1020–1021
- pathogenesis, 1012
- patient history and physical findings, 1012
- postoperative care, 1020
- surgical management, 1013–1015
- type I (limited maxillectomy) defect, 1013, 1013*f*–1014*f*, 1015–1016
- type II (subtotal maxillectomy) defect, 1013, 1016
- type III (total maxillectomy) defect, 1013, 1016–1019
- type IV defect (orbitomaxillectomy), 1013, 1019
- upper lip and oral commissure, 1019
- Soft tissue infections, debridement of
 - definition, 2349
 - of foot and ankle, 2351, 2351*f*
 - anatomy, 2349–2350, 2349*f*
 - complications, 2351
 - differential diagnosis, 2350
 - imaging, 2350
 - merits and demerits
 - nonoperative management, 2350
 - pathogenesis, 2350
 - patient history and physical findings, 2350
 - postoperative care, 2351
 - preoperative planning, 2350
 - supine position, 2350
 - surgical management, 2350

- Soft tissue masses, 2411
- Soft tissue sarcoma resection, 1592
- Soft tissue tumors, knee
 - anatomy, 2456
 - complications, 2458
 - definition, 2456
 - differential diagnosis, 2457
 - functional outcomes, 2458
 - imaging, 2456–2457, 2457*f*
 - knee sarcoma, wide resection of, 2457, 2458*f*
 - merits and demerits, 2458*b*
 - natural history, 2456
 - oncological outcomes, 2458
 - pathogenesis, 2456
 - patient history, 2456
 - physical findings, 2456
 - postoperative care, 2458
 - surgical management, 2457
 - approach, 2457
 - patient positioning, 2457
 - preoperative planning, 2457
- Soft tissue tumors, lower leg, 2421, 2422*f*
 - anatomy, 2338, 2338*f*–2339*f*, 2420, 2420*f*
 - complications, 2341, 2422
 - definition, 2420
 - definition, 2338
 - differential diagnosis, 2339
 - differential diagnosis for, 2421
 - free tissue transfer, 2340
 - functional outcomes, 2422
 - imaging, 2339, 2421
 - merits and demerits, 2341*b*, 2422*b*
 - natural history, 2338, 2420–2421

- oncological outcomes, 2422
- outcomes, 2341, 2341*f*
- pathogenesis, 2338, 2420
- patient history and physical findings, 2339, 2421
- patient positioning, 2339
- postoperative care, 2341
- preoperative planning, 2339, 2340*f*
- previous biopsy incision, excision of, 2340, 2340*f*
- surgical management, 2339, 2421
 - approach, 2421
 - biopsy incisions, 2421
 - patient positioning, 2421
 - preoperative planning, 2421
 - simple marginal excision, 2421
- tourniquet, 2340, 2421
- Soft tissue tumors of thigh
 - anatomy, 2497
 - completion, 2500
 - complications, 2501
 - deep sarcoma, 2499, 2499*f*, 2500*f*
 - definition, 2497–2501
 - differential diagnosis, 2498
 - functional outcomes, 2501
 - imaging, 2498, 2498*f*
 - incision and dissection, 2500, 2500*f*
 - merits and demerits, 2500*b*
 - natural history, 2497
 - oncological outcomes, 2501
 - pathogenesis, 2497
 - patient history and physical findings, 2497–2498
 - postoperative care, 2501
 - subcutaneous sarcoma, 2499, 2499*f*
 - surgical management, 2498

- approach, 2498
- patient positioning, 2498, 2498*f*
- preoperative planning, 2498, 2498*f*
- Soft tissue–only reconstruction defects, 1047
- Soleal sling, 2451, 2453, 2453*f*
 - release of, 2454
- Soleus flap, soft tissue coverage of lower leg
 - anatomy, 2446, 2446*f*
 - complications, 2449
 - definition, 2446
 - distally based medial hemisoleus flap, 2448–2449, 2448*f*
 - imaging, 2446
 - merits and demerits, 2448*b*
 - outcomes, 2449, 2449*f*–2450*f*
 - patient history, 2446
 - physical findings, 2446
 - postoperative care, 2449
 - proximally based medial hemisoleus flap, 2447, 2447*f*, 2449
 - surgical management, 2446–2447
 - approach, 2447
 - frog leg positioning, 2447, 2447*f*
 - preoperative planning, 2446–2447
- Sommerlad palatoplasty
 - anatomy, 2675
 - complications, 2682
 - definition, 2675
 - hard palate
 - incisions and dissection, 2676–2677, 2676*f*–2677*f*
 - nasal layer elevation, 2677–2678, 2677*f*
 - von Langenbeck incisions, 2678, 2678*f*
 - imaging, 2675
 - merits and demerits, 2676*b*
 - nasal layer, 2678, 2679*f*

- closure, 2681, 2681*f*
- muscle dissection, 2679, 2679*f*–2680*f*
- oral layer, 2678, 2678*f*
- outcomes, 2682
- patient history and physical findings, 2675
- postoperative care, 2682
- surgical management
 - approach, 2676, 2676*f*
 - patient position, 2676
 - preoperative planning, 2675–2676
- Space-occupying masses, 1987
- Spaghetti wrist
 - anatomy, 2061
 - complications, 2064
 - definition, 2061
 - imaging, 2061
 - injured structures repair, 2063, 2063*f*
 - merits and demerits, 2062*b*, 2063*b*
 - outcomes, 2064
 - pathogenesis, 2061
 - patient history and physical findings, 2061
 - postoperative care, 2064
 - proximal structures, tagging, 2063, 2063*f*
 - surgical management
 - patient positioning, 2062
 - preoperative planning, 2062
 - wound presentation, exposed injuries, 2062, 2062*f*
- SPAIR technique. *See* Short scar periareolar inferior pedicle (SPAIR) technique
- Speech problems, 2682
- Speech therapy, velopharyngeal insufficiency, 2707
- Sphenoid bone, medial orbit wall fractures, 830
- Sphenoid greater wing, 2752

- Sphincter pharyngoplasty, dynamic. *See* Dynamic sphincter pharyngoplasty
- Split calvarial bone graft harvest
 - age, 504
 - anatomy, 504, 504*f*
 - complications, 508
 - definition, 504
 - imaging studies, 505, 505*f*
 - merits and demerits, 506*b*
 - osteoconduction, 504
 - osteoinduction, 504
 - osteointegration, 504
 - outcomes, 508
 - outer table ex vivo split calvarial graft, 507, 507*f*
 - outer table in situ split calvarial graft, 506–507, 506*f*–507*f*
 - pathogenesis, 504
 - patient history and physical findings, 505
 - postoperative care, 508
 - shave graft, 506
 - surgical management
 - approach, 505
 - patient positioning, 505
 - preoperative planning, 505
- Split calvarial grafts
 - anatomy, 997
 - complications, 1000
 - definition, 997
 - ex vivo, 998, 998*f*
 - imaging studies, 997
 - in situ, 999, 999*f*
 - merits and demerits, 998*b*
 - outcomes, 1000
 - patient history and physical findings, 997

- postoperative care, 1000
- surgical management
 - approach, 998
 - patient positioning, 998
 - preoperative planning, 997–998
- thin split-thickness in situ, 999
- Split flexor pollicis longus (FPL), 2023, 2023*f*
- Split lip advancement technique (SLAT), 2655, 2655*f*
- Split rib grafts
 - complications, 996
 - definition, 994
 - harvest site and completion, 995, 996*f*
 - imaging studies, 994
 - merits and demerits, 995*b*
 - outcomes, 996
 - patient history and physical findings, 994
 - postoperative care, 996
 - rib graft harvest, 995, 995*f*
 - rib/thoracic cage, 994, 994*f*
 - surgical management
 - patient positioning, 994
 - preoperative planning, 994
- Split rib technique, 513, 513*f*
- Split-thickness skin graft (STSG), 2366, 2368*f*–2369*f*, 2371, 2375, 2376*f*, 2396–2398, 2463, 2523, 2526–2527, 2769
 - free lateral arm flap, 2136
 - harvesting of, 2770–2771, 2770*f*, 2771*f*
 - posterior interosseous artery (PIA) flap, 2126, 2129, 2132
 - reverse radial forearm flap, 2116, 2118–2119
 - ulnar artery perforator flap, 2121, 2123
 - to volar forearm, 1765, 1765*f*
- Sports-related injuries, 958
- Spreader graft tunnels, 272*f*, 273, 291

- Squamous cell carcinoma/cancer (SCC), 2128*f*
 - anatomy, 2303
 - buccal mucosal defects, 1220
 - complications, 2308
 - definition, 2303
 - differential diagnosis, 2304
 - direct closure and lateral cantholysis, 1078
 - excision reconstruction, 2305, 2305*f*
 - FOM, 1209
 - hemiglossectomy, 1198
 - imaging studies for, 2304
 - of the lateral mandible, 1049, 1049*f*–1050*f*
 - merits and demerits, 2307*b*
 - nasolabial flap, 1070
 - natural history, 2303
 - nonoperative management
 - outcomes, 2308
 - pathogenesis, 1068, 2303
 - patient history and physical findings, 2303, 2304*f*
 - of pharynx, 1244–1245, 1244*f*–1245*f*
 - postoperative care, 2308
 - on scalp, 984, 984*f*
 - surgical management, 2305, 2305*f*
 - tenzel semicircular rotational flap, 1084
 - wide local excision of, 2305, 2306*f*
- SRN (superficial radial nerve) injury, 1930
- SSA (subscapular artery), 1037, 1037*f*
- STA (superficial temporal artery), 37, 37*f*–38*f*
- Stahl ear
 - anatomy, 2821, 2821*f*
 - complications, 2825
 - definition, 2821
 - excision and suturing, 2823, 2823*f*–2824*f*

- merits and demerits, 2824*b*
- nonoperative management, 2821
- outcomes, 2825, 2825*f*
- pathogenesis, 2821
- patient history and physical findings, 2821
- postoperative care, 2825
- preoperative assessment, 2822*f*
- surgical management, 2821–2825, 2822*f*
 - approach, 2821–2825, 2822*f*–2823*f*
 - patient position, 2821
 - preoperative planning, 2821, 2822*f*
- Stair-step incisions, 2911–2912, 2911*f*
- Standard preauricular approach, 2920–2921, 2921*f*
- Standard technique
 - markings and incisions, 2858, 2858*f*
 - suturing, 2859, 2859*f*
- Standardized Way to Assess Grafts (SWAG), 649
- Stapedial artery, 2729
- *Staphylococcus aureus*, pyogenic flexor tenosynovitis, 1771
- Static rhytids, 5
- Static spacers, 2469
- Statin, 2406
- Steindler flexorplasty, 2961–2962, 2961*f*
- Stenosis tenosynovitis. *See* Trigger finger release
- Stenstrom-type anterior scoring, 2837
- Steri-Strips, 2635
- Sternal debridement
 - anatomy, 1522, 1523*f*
 - complications, 1526
 - definition, 1522
 - imaging, 1523, 1524*f*
 - merits and demerits, 1526*b*
 - natural history, 1523

- nonoperative management, 1523
- outcomes, 1526
- pathogenesis, 1522
- patient history and physical findings, 1523
- postoperative care, 1526
- surgical management
 - approach, 1524
 - positioning, 1524
 - preoperative planning, 1524
- Sternal fixation, 1525
- Sternal necrosis, 1522
- Sternal nonunion, 1522
- Sternocleidomastoid (SCM), 212
- Sternum, 1522, 1523*f*
- Steroids, 2276
- STF (superficial temporal fascia), 872, 873*f*
- Stiles-Bunnell transfer, of FDS to lateral bands, 2021–2022, 2021*f*
- Stimulating catheter, 2318
- Straightline cleft palate repair. *See* Sommerlad palatoplasty
- Strip suturectomy, 447
- Structural autograft, 2355, 2362
- Stryker-Leibinger, 2622
- STSG. *See* Split-thickness skin graft (STSG)
- STT (scaphotrapeziotrapezoid) joint arthritis, 1957
- Sturge-Weber syndrome (SWS), 2799
- Subciliary approach, pediatric orbital fractures, 946–947, 947*f*
- Subciliary incision
 - lower blepharoplasty via
 - anatomy, 148, 149*f*–150*f*
 - complications, 155–156
 - definition, 148
 - imaging, 150
 - merits and demerits, 155*b*

- nonoperative management, 151
- outcomes, 155, 156*f*
- patient history and physical findings, 148–150
- postoperative care, 155
- skin-muscle flap approach with orbicularis oculi resuspension, 152–153, 152*f*–153*f*
- skin-only flap approach with reverse orbicularis oculi tightening, 153–154, 154*f*
- surgical management, 151
- Subcision cannula, 2811, 2812*f*
- Subcondylar fracture, mandible fractures, open treatment of, 908, 912–913, 912*f*
- Subcutaneous fat, 2378
- Subcutaneous lateral brow lifting
 - anatomy, 82, 82*f*
 - approach, 83–84, 84*f*
 - complications, 87–88
 - definition, 82
 - direct eyebrow incision, 87
 - hairline approach
 - anterior, 84–85, 84*f*, 85*f*
 - posterior, 86, 86*f*
 - merits and demerits, 87*b*
 - nonoperative management, 83
 - outcomes, 87
 - pathogenesis, 82–83
 - patient history and physical findings, 83
 - positioning, 83
 - postoperative care, 87
 - preoperative planning, 83
 - surgical management, 83–84
 - transverse forehead line approach, 86–87, 86*f*
- Subcutaneous plane, 74

- Subcutaneous sarcoma, 2499, 2499*f*
- Subcutaneous tissue expander insertion into abdomen, 1739, 1739*f*
- Subfascial implant
 - definition, 1297–1298, 1298*f*
 - IMF incision, 1305, 1305*f*
 - implant placement, 1307–1308, 1308*f*
 - periareolar incision, 1306–1307, 1306*f*
 - pocket, 1307, 1307*f*
 - closure, 1308, 1308*f*–1309*f*
 - control, 1307
 - subcutaneous periareolar approach, 1307
 - transparenchymal periareolar approach, 1307
- Subglandular implant
 - definition, 1297, 1297*f*
 - IMF incision, 1305, 1305*f*
 - implant placement, 1307–1308, 1308*f*
 - periareolar incision, 1306–1307, 1306*f*
 - pocket
 - closure, 1308, 1308*f*–1309*f*
 - control, 1307
 - subcutaneous periareolar approach, 1306
 - subglandular pocket, 1306–1307, 1307*f*
 - transparenchymal periareolar approach, 1306
- Submandibular approach, 673–674, 674*f*
- Submandibular gland (SMG), 242–243
 - reduction, 246–247, 246*f*–247*f*
- Submental artery island flap, 1220
- Submental island flap, 1221–1222, 1222*f*
- Submental vascularized lymph node harvest, 2562
- Submucosal resection, 384, 384*f*
- Submucous cleft palate
 - velopharyngeal insufficiency, 2706
- Submuscular implant

- definition, 1298, 1298*f*
- IMF incision, 1305*f*, 1309
- implant placement, 1308*f*, 1311
- periareolar incision, 1306*f*, 1309–1310
- pocket closure, 1308*f*–1309*f*, 1311
- pocket dissection, 1310–1311, 1310*f*
- Suboptimal knee range of motion, 2492
- Subpectoral tissue expander placement, dermal allograft, 1381–1382, 1381*f*, 1382*f*
- Subperiosteal defect exposure, 517
- Subplatysmal fat, 242, 244, 245*f*
- Subplatysmal neck lifting
 - anatomy, 242
 - anterior platysmaplasty and myotomy, 248, 248*f*–249*f*
 - cervical lipectomy, 245–246, 245*f*
 - complications, 250
 - definition, 242, 242*f*–243*f*
 - imaging, 243
 - merits and demerits, 249*b*
 - nonoperative management, 243
 - outcomes, 249
 - patial digastric myectomy, 247, 248*f*
 - patient history and physical findings, 242–243, 243*f*–244*f*
 - postoperative care, 249
 - skin flap elevation, 245
 - submandibular gland reduction, 246–247, 246*f*–247*f*
 - surgical management, 243–244
 - approach, 244, 244*f*
 - positioning, 244
 - preoperative planning, 244
- Subscapular artery (SSA), 1037, 1037*f*
- Subscapular vascular system, 1037
- Subtalar joint, 2355

- Subtotal maxillectomy defect, 1013, 1016
- Supercharged reverse sural artery flap, 2390
- Supercilii muscle, removal, transpalpebral corrugator resection, 111
- Superficial aponeurosis, 1273, 1273*f*–1274*f*
- Superficial branch of radial nerve (SBRN)
 - anatomy, 1754
 - at wrist, 1758
- Superficial circumflex iliac artery (SCIA), 2137–2138
 - free groin flap, 2142, 2142*f*
 - pedicled groin flap, 2140
- Superficial circumflex iliac artery perforator (SCIP) flap, 2487–2488
- Superficial fascial system (SFS), 1619
- Superficial infections, 2362
- Superficial inferior epigastric artery (SIEA), 2563
- Superficial musculoaponeurotic system (SMAS), 201–202, 205–206, 206*f*, 231, 916, 1103, 1146
 - dissection, lamellar high SMAS face-lift, 221–222, 221*f*
 - flap, 205–206, 206*f*, 2915, 2926–2927
 - manipulation, 196
 - plication, 206
 - suspension, lamellar high SMAS face-lift, 222–223, 222*f*
- Superficial palmar branch of radial artery vascularized bone flap, 1883, 1883*f*
- Superficial peeling techniques, 60
- Superficial peroneal nerve, 2323, 2324*f*, 2410–2412, 2412*f*, 2414, 2420, 2423
 - compression release and/or neurectomy, 2413–2414
- Superficial radial nerve (SRN) injury, 1930
- Superficial sarcomas, 2421
- Superficial scar, 2429
- Superficial temporal artery (STA), 37, 37*f*–38*f*
- Superficial temporal fascia (STF), 872, 873*f*

- Superficial vein, 2395
- Superficial venous system of foot
- Superior gluteal artery flap, 1735, 1735*f*–1736*f*
 - anatomy, 1734, 1734*f*
 - complications, 1737
 - definition, 1734
 - imaging, 1734
 - outcomes, 1737
 - patient history and physical findings, 1734
 - postoperative care, 1737
 - surgical management
 - approach, 1735
 - positioning, 1734
 - preoperative planning, 1734
- Superior gluteal artery perforator (SGAP) flap, 1461, 1462*f*
 - anatomy, 1459–1460, 1459*f*–1460*f*
 - complications, 1463
 - definition, 1459
 - imaging, 1460
 - merits and demerits, 1462*b*
 - outcomes, 1462
 - patient history and physical exam, 1460
 - postoperative care, 1462
 - recipient vessel exposure, 1462
 - surgical management
 - approach, 1461
 - patient positioning, 1461
 - preoperative planning, 1460–1461
- Superior labial artery (SLA), 37
- Superwet liposuction, 2572
- Supraclavicular artery island flap (SCAIF)
 - advantages, 1249
 - anatomy, 1249–1250, 1249*f*

- complications
 - distal flap ischemia and necrosis, 1253
 - donor site wound dehiscence, 1254
 - hematoma, 1254
 - orocutaneous fistula formation, 1254
 - shoulder sensation and dysesthesia, 1254
 - strictures, 1254
 - venous insufficiency, 1254
- definition, 1249
- disadvantages, 1250
- flap harvest, 1251–1252, 1251*f*
- flap inset and completion, 1252–1253, 1252*f*
- imaging studies, 1250
- markings, 1251, 1251*f*
- merits and demerits, 1251*b*
- outcomes, 1253
- patient history and physical findings, 1250
- postoperative care, 1253, 1254*f*
- procedure, 1250
- surgical management
 - patient positioning, 1250
 - preoperative planning, 1250, 1250*f*
- Supraclavicular flap, 1230
- Supraclavicular vascularized lymph node harvest, 2561, 2561*f*
- Supraorbital artery, 20, 20*f*
- Supraorbital nerve, 20, 20*f*, 70
 - anatomy, 966, 966*f*
 - facial nerve blocks, 970, 970*f*
 - and supratrochlear nerve, scalp reconstruction with rotation flaps, 980
 - transpalpebral corrugator resection, 109
- Supratarsal approach, orbital roof fractures, 842*f*, 843
- Supratip area, management of, 357, 357*f*–358*f*

- Supratrochlear artery, 20, 20*f*
- Supratrochlear nerve, 70
 - anatomy, 966, 966*f*
 - facial nerve blocks, 970, 970*f*
 - transpalpebral corrugator resection, 109
- Sural flap, 2440
- Sural nerve, 2324, 2324*f*
- Sural nerve harvest
 - anatomy, 2911
 - coaptation, 2946, 2946*f*
 - complications, 2912
 - definition, 2911
 - dissection, 2945, 2945*f*
 - identification, 2944, 2944*f*
 - imaging, 2911
 - merits and demerits, 2912*b*
 - outcomes, 2912
 - patient history and physical findings, 2911
 - postoperative care, 2912
 - surgical management
 - approach, 2911
 - patient position, 2911
 - preoperative planning, 2911
 - technique, 2009
 - tunneling, 2944–2946, 2944*f*, 2945*f*
- Surgical management of semicircular rotational flap, 1085
- Suture closure techniques, 3079*f*
- Suture techniques, 978, 978*f*
- SWAG (Standardized Way to Assess Grafts), 649
- Swan-neck deformity, 1933
 - characteristics of, 1937, 1937*f*
 - correction of
 - FDS tenodesis for, 1945, 1946*f*

- lateral band mobilization, 1947, 1947*f*
- retinacular ligament reconstruction, 1945, 1946*f*
- step-cut (Z) central slip lengthening, 1947
- mechanism of, 1937, 1938*t*
- thumb, 1938
- SWS (Sturge-Weber syndrome), 2799
- Syme amputation, 2546
- Sympathectomy, 2158, 2158*f*
- Symphysis, mandible fractures, open treatment of, 908, 910
- Syndromic cleft palate, 2669
- Synovial osteochondromatosis, 2456
- Synovial sarcoma, 2421
- Syringe fascial sleeve wrapping, 370, 370*f*

T

- TA (tibialis anterior), 2363
- Tajima suture repair, 2057, 2057*f*
- Tangential excision and skin grafting, 2577–2578, 2577*f*, 2578*f*
 - anatomy, 2575
 - complications, 2579
 - contact ankle burn, 2577*f*
 - definition, 2575
 - merits and demerits, 2577*b*, 2578*b*
 - natural history, 2575
 - nonoperative management, 2575–2576
 - outcomes, 2579
 - pathogenesis, 2575
 - patient history and physical exam, 2575, 2575*f*–2576*f*
 - postoperative care, 2579
 - surgical management
 - patient positioning, 2577
 - preoperative planning, 2576, 2576*f*
- Tanzer constricted ear classification, 2826*f*
- TAR (transversus abdominis release), 1556, 1559–1560, 1560*f*
- TAR (thrombocytopenia-absent radius) syndrome, 2268
- Tarsal tunnel, 2451, 2452*f*, 2453, 2453*f*
 - release of, 2454–2455, 2454*f*
- Tarsoligamentous integrity, 158
- Tarsomarginal graft, eyelid coloboma, 2845–2846, 2845*f*
- Tarsometatarsal (TMT) joint, 2344
- TBIs (toe-brachial pressures), 2400
- TCA peel. *See* Trichloroacetic acid (TCA) peel
- TCL (transverse carpal ligament), 1977, 1978*f*, 1986*f*
- TCS (Treacher Collins syndrome), 723
- TDAP flap. *See* Thoracodorsal artery perforator (TDAP) flap

- Tear trough, 50, 162
 - fat grafting, 183
 - and lid-cheek junction
 - anatomy, 26
 - complications, 28
 - definition, 26
 - merits and demerits, 28*b*
 - outcomes, 28
 - pathogenesis, 26–27
 - patient history and physical findings, 27
 - postprocedural care, 28
 - preparation, 27, 27*f*, 28*f*
- Temporal crest line, 69, 69*f*
- Temporal fascia/allograft dermis, 358, 358*f*
- Temporal ligamentous adhesion, 69
- Temporal region
 - fillers injection, 39
 - anatomy, 37, 37*f*–38*f*
 - complications, 40
 - definition, 37
 - merits and demerits, 40*b*
 - nonoperative management, 38
 - outcomes, 40, 40*f*–41*f*
 - patient history and physical findings, 37–38
 - postoperative care, 40
 - techniques, 38*b*
- Temporalis muscle, 69, 440, 871, 873*f*, 944*f*
 - fascia, 222*f*
 - flap
 - definition, 1262
 - dissection, 1265, 1265*f*
 - elevation, 1265–1266, 1266*f*
 - inset and completion, 1267, 1267*f*

- interposition graft, 1266–1267
- neurovascular supply, 1262, 1263*f*
- retrograde temporalis flap, 1264
- superficial and deep layers, 1262, 1263*f*
- surgical management, 1264
- Temporary lateral tarsorrhaphy, 154
- Temporary nerve paralysis, 973
- Temporomandibular joint (TMJ), 915
 - anatomy, 676
 - complications, 682
 - definition, 676
 - differential diagnosis, 676
 - distraction osteogenesis
 - anatomy, 691
 - complications, 696
 - definition, 691
 - differential diagnosis, 692
 - imaging, 692
 - indications, 693
 - merits and demerits, 693*b*
 - natural history, 691–692
 - outcomes, 695–696
 - pathogenesis, 691
 - patient history and physical findings, 692
 - postoperative care, 695
 - reverse distraction, 693–695, 694*f*
 - surgical management, 693–695
 - imaging, 676, 676*f*
 - merits and demerits, 678*b*
 - nonoperative management, 677
 - outcomes, 682
 - patient history and physical findings, 676
 - postoperative care, 682

- reconstruction with stock/custom prosthesis
 - design, 681, 681*f*
 - markings, 678, 678*f*
 - maxillomandibular fixation and prosthesis insertion, 680, 680*f*
 - preauricular incision and discectomy, 678–679, 678*f*
 - submandibular incision and condylectomy, 679, 679*f*
- surgical management
 - patient positioning, 677, 677*f*
 - preauricular approach, 677
 - preoperative planning, 677, 677*f*
 - retromandibular approach, 678
 - submandibular approach, 678
- Temporoparietal fascia (TPF), 916
- Ten test, 2411, 2452
- Tendon graft
 - with ECRB to adductor pollicis, 2022, 2023*f*
 - with ECRB to lateral bands, 2022, 2022*f*
- Tendon repair, 2152, 2322
- Tendon sheath inflammation
 - anatomy, 2090
 - complications, 2092
 - definition, 2090
 - differential diagnosis, 2090
 - imaging, 2090
 - merits and demerits, 2092*b*
 - natural history, 2090
 - nonoperative management, 2090
 - outcomes, 2092
 - pathogenesis, 2090
 - patient history and physical findings, 2090
 - postoperative care, 2092
 - surgical management
 - approach, 2091

- patient positioning, 2091
- Tendon stripper, harvest with, 2912
- Tendon transfers
 - median nerve palsy
 - anatomy, 2012
 - approach, 2013
 - complications, 2017
 - definition, 2012
 - differential diagnosis, 2013
 - high median nerve injury, 2015–2016
 - imaging, 2013
 - low median nerve injury, 2013–2015
 - merits and demerits, 2013*b*, 2017*b*
 - natural history, 2012
 - nonoperative management, 2013
 - outcomes, 2017
 - pathogenesis, 2012
 - patient history and physical findings, 2012
 - patient positioning, 2013
 - postoperative care, 2017
 - preoperative planning, 2013
 - surgical management, 2013
 - thumb opposition, 2013–2015
 - of pronator teres to extensor carpi radialis brevis, 2052, 2052*f*
- Tenolysis of flexor tendons
 - anatomy, 2073
 - complications, 2077
 - definition, 2073
 - differential diagnosis, 2074
 - imaging, 2074
 - merits and demerits, 2076*b*
 - natural history, 2073
 - nonoperative management, 2074

- outcomes, 2077
- pathogenesis, 2073
- patient history and physical findings, 2073–2074
- postoperative care, 2077
- surgical management
 - approach, 2074
 - patient positioning, 2074
 - preoperative planning, 2074
- Tenosynovitis of first dorsal compartment. *See* de Quervain syndrome
- Tenotomy scissors, 1989
- Tenovaginitis. *See* Trigger finger release
- Tensor fascia lata (TFL)
 - flaps for trochanteric ulcers (*see* Trochanteric ulcers)
 - V-Y advancement flap, 1718–1719, 1719*f*
- Tensor fascia lata flap, 2487–2488, 2518
- Tensor veli palatini (TVP), 2687
- Tenzel semicircular flap, 1078
 - eyelid coloboma, 2844–2845, 2844*f*–2845*f*
- Tenzel semicircular rotational flap
 - anatomy, 1084
 - complications, 1088
 - definition, 1084
 - lower eyelid defects
 - design and flap elevation, 1086, 1086*f*
 - donor-site repair, 1087, 1087*f*
 - flap inset, 1086*f*, 1087
 - tarsal edges, 1086, 1086*f*
 - merits and demerits, 1086*b*
 - nonoperative management, 1084
 - outcomes, 1088
 - patient history and physical findings, 1084
 - posterior lamellar flap, 1087

- postoperative care, 1088
- preoperative planning, 1085, 1085*f*
- surgical management, 1085, 1085*f*
- Teratogen exposure, 2596
- Terry Thomas sign, 1852, 1852*f*
- Tessier 3 and 4 clefts
 - anatomy, 2719
 - complications, 2728
 - definition, 2719, 2719*f*
 - dissection and facial flap elevation, 2723–2724, 2723*f*–2724*f*
 - eyelid correction, 2724, 2724*f*
 - facial musculature repositioning, 2725, 2725*f*–2726*f*
 - imaging, 2720
 - incisions, 2722, 2722*f*
 - markings, 2722, 2722*f*
 - merits and demerits, 2722*b*
 - outcomes, 2726–2727
 - patient history and physical findings, 2719
 - postoperative care, 2726
 - surgical management, 2720–2721
 - approach, 2720
 - patient position, 2721
 - preoperative planning, 2721
- Tessier 7–macrostomia repair
 - anatomy, 2729, 2729*f*
 - complications, 2734
 - cutaneous scar modifications, 2733, 2733*f*
 - definition, 2729
 - imaging, 2730
 - merits and demerits, 2731*b*
 - natural history, 2729
 - outcomes, 2734
 - pathogenesis, 2729

- patient history and physical findings, 2729–2730
- postoperative care, 2734
- surgical management, 2730
 - approach, 2730
 - patient position, 2730
 - preoperative planning, 2730
- vermilion-shifted commissuroplasty with optional cutaneous Z-plasty
 - commissuroplasty and skin closure, 2732, 2733*f*
 - design, 2731, 2732*f*
 - dissection and orbicularis repair, 2731–2732, 2732*f*
 - markings, 2731, 2731*f*
- Tessier sign, 493, 493*f*
- Tetanus immunization, 976
- TFL. *See* Tensor fascia lata (TFL)
- TGDC. *See* Thyroglossal duct cysts (TGDC)
- Thenar compartment release, 1762, 1763*f*
- Thenar flap, 2101–2102, 2101*f*–2102*f*
- Thermoplast splint, 863, 863*f*
- Thigh fasciotomy, 2332, 2332*f*
 - anterior, 2331
 - medial (adductor), 2331
 - posterior, 2331
- Thigh pathology
 - lower femoral nerve exposure, 2535
 - lower sciatic exposure, 2529*f*–2530*f*, 2532
- Thigh, soft tissue tumors of
 - anatomy, 2497
 - approach, 2498
 - completion, 2500
 - complications, 2501
 - deep sarcoma, 2499, 2499*f*, 2500*f*
 - definition, 2497–2501

- differential diagnosis, 2498
- functional outcomes, 2501
- imaging, 2498, 2498*f*
- incision and dissection, 2500, 2500*f*
- merits and demerits, 2500*b*
- natural history, 2497
- oncological outcomes, 2501
- pathogenesis, 2497
- patient history and physical findings, 2497–2498
- patient positioning, 2498, 2498*f*
- postoperative care, 2501
- preoperative planning, 2498, 2498*f*
- subcutaneous sarcoma, 2499, 2499*f*
- surgical management, 2498
- Third and fourth lumbricals, 1986–1987, 1986*f*
- Third occipital (C3) nerves, 966*f*, 967
- Thoracic epidurals, 2327
 - anatomic features of, 2326*t*
 - approaches to, 2327
- Thoracic reconstruction
 - omental flap for
 - anatomy, 1532–1534, 1533*f*
 - complications, 1542
 - definition, 1532
 - differential diagnosis, 1535
 - flap inset, 1540, 1540*f*
 - free flap transposition, 1540
 - imaging, 1535
 - laparoscopic harvest, 1539, 1539*f*
 - merits and demerits, 1540*b*
 - natural history, 1534
 - nonoperative management, 1535
 - open harvest, 1537–1538, 1537*f*–1538*f*

- outcomes, 1541–1542, 1541*f*
- pathogenesis, 1534
- patient history and physical findings, 1534
- pedicle transposition, 1539–1540, 1539*f*
- postoperative care, 1541
- surgical management
 - approach, 1536–1537
 - positioning, 1536
 - preoperative planning, 1536*f*, 1535, 1535–1536
- rectus abdominis flap for
 - anatomy, 1528
 - complications, 1531
 - definition, 1528
 - imaging, 1529
 - merits and demerits, 1531*b*
 - nonoperative management, 1529
 - outcomes, 1531
 - pathogenesis, 1528
 - patient history and physical findings, 1528
 - postoperative care, 1531
 - surgical management
 - approach, 1529–1530
 - positioning, 1529
 - preoperative planning, 1529
- Thoracic vascularized lymph node harvest, 2562, 2562*f*
- Thoracoacromial artery, 1515
- Thoracoacromial pedicle, 1517, 1517*f*, 1519*f*
- Thoracodorsal artery, 1543
- Thoracodorsal artery perforator (TDAP) flap, 1368–1370, 1368*f*–1369*f*, 1544–1545, 1545*f*, 2381–2383, 2383*f*, 2387*f*, 2440, 2487–2488
 - flap design, 1372, 1373*f*
 - flap placement and completion, 1372–1373, 1373*f*–1374*f*

- harvesting, 1372, 1373*f*
- Thoracodorsal vessels, 1447, 1450
- Thoracopagus, 3092, 3093*f*–3094*f*
- Thorax, 1532
- Three-dimensional (3D) implant reconstruction, cranial vault
 - anatomy, 515
 - closure, 517
 - complications, 518
 - definition, 515
 - differential diagnosis, 515
 - free flap coverage, 516, 516*f*
 - imaging, 515, 515*f*
 - implant placement and fixation, 516, 517*f*
 - merits and demerits, 516*b*
 - natural history, 515
 - nonoperative management, 515
 - outcomes, 517, 518*f*
 - pathogenesis, 515
 - patient history and physical findings, 515
 - postoperative care, 517
 - surgical management, 515
- Three-dimensional osteotomy, 1035
- Three-dimensional (3D) reconstructions, 890, 890*f*
- Thrombocytopenia-absent radius (TAR) syndrome, 2268
- Through-knee amputation, 2549
- Thumb
 - adduction
 - low combined median and ulnar nerve palsy, 2037
 - restoration, 2022
 - boutonniere deformity, 1938
 - carpometacarpal joint, 1957
 - arthritis, 1956
 - arthrodesis of, 1958, 1967, 1968*f*–1969*f*

- Eaton classification of, 1958, 1959*b*
- fusion for osteoarthritis, 1962, 1962*f*
- reconstruction using FCR (Eaton-Littler procedure), 1963–1964, 1963*f*–1964*f*
- trapeziectomy and APL suspensionplasty, 1965, 1965*f*–1967*f*
- extension, 2029, 2030*f*
- flexion, 2037*f*, 2040
- opposition reconstruction, 2036–2037
 - high median nerve injury, 2015–2016
 - low median nerve injury, 2013–2015
 - surgical management, 2772–2773
 - Z-plasty, 2773–2774, 2773*f*–2774*f*
- stabilization, 2023
- swan-neck deformity, 1938
- Thumb defects, flap coverage of
 - anatomy, 2105
 - complications, 2113
 - definition, 2105
 - imaging, 2105
 - merits and demerits of, 2112*b*
 - nonoperative management, 2105
 - outcomes, 2113, 2113*f*
 - patient history, 2105
 - physical findings, 2105
 - postoperative care, 2113
 - surgical management, 2105–2106, 2106*f*
 - approach, 2106
 - first dorsal metacarpal artery flap, 2109, 2110*f*–2111*f*
 - moberg flap, 2107–2109, 2108*f*
 - reverse dorsoradial homodigital flap, 2112
- Thumb hypoplasia
 - anatomy, 2243
 - Blauth classification system, 2243

- definition, 2243
- differential diagnosis, 2243
- imaging, 2243
- index finger pollicization
 - completion, 2248, 2248*f*
 - complications, 2249
 - dorsal flap placement, 2247, 2247*f*
 - markings and dissection, 2244–2245, 2244*f*–2245*f*
 - merits and demerits, 2249*b*
 - metacarpal preparation and osteosynthesis, 2246–2247, 2246*f*
 - outcomes, 2249
 - postoperative care, 2249
 - tendon repair, 2247–2248, 2248*f*
- pathogenesis and natural history, 2243
- patient history and physical findings, 2243
- surgical management, 2244
 - approach, 2244
 - patient positioning, 2244
 - preoperative planning, 2244
- Thyroglossal duct cysts (TGDC)
 - anatomy, 2905, 2905*f*
 - complications, 2910
 - definition, 2905
 - differential diagnosis, 2905
 - exposure of, 2907, 2908*f*
 - imaging, 2905, 2906*f*
 - merits and demerits, 2909*b*
 - natural history, 2905
 - nonoperative management, 2905–2906
 - outcomes, 2910
 - pathogenesis, 2905
 - patient history and physical findings, 2905
 - postoperative care, 2910

- surgical management
 - patient position, 2906
 - preoperative planning, 2906
- Tibial invertors and plantar flexors (TIP), 2452
- Tibial nerve, 2323, 2323*f*, 2972
 - acute traumatic injury, repair of, 2453
 - anatomy, 2451–2452, 2451*f*
 - complications, 2455
 - differential diagnosis, 2453
 - imaging, 2452–2453
 - injuries, 2451–2455
 - merits and demerits, 2455*b*
 - nonoperative management, 2453
 - outcomes, 2455
 - pathogenesis, 2452
 - patient history, 2452
 - physical findings, 2452
 - postoperative care, 2455
 - soleal sling, release of, 2454
 - surgical management, 2453
 - approach, 2453, 2453*f*
 - patient positioning, 2453
 - preoperative planning, 2453
 - tarsal tunnel, release of, 2454, 2454*f*
 - tibial nerve traction injury, 2454–2455
 - traction injury, 2454–2455
- Tibial reconstruction
 - anatomy, 2431–2432, 2431*f*
 - complications, 2436–2437
 - definition, 2431
 - double-barrelled fibula technique, 2436, 2436*f*
 - free fibula flap, 2433–2435, 2434*f*
 - imaging, 2432, 2432*f*

- merits and demerits, 2436*b*
- outcomes, 2436
- patient history, 2432
- pedicled fibula graft, 2435–2436, 2435*f*
- physical findings, 2432
- surgical management
 - approach, 2433
 - patient positioning, 2432–2433, 2433*f*
 - preoperative planning, 2432
- Tibial stimulation, 2318
- Tibialis anterior (TA), 2363
- Tibialis posterior muscle, 2432, 2510
- Tibial-peroneal arterial occlusive disease, 2404–2405
 - anterior tibial artery exposure, 2404
 - conduit, selection of, 2404
 - indications, 2404
 - pedal artery exposure, 2405
 - peroneal artery exposure, 2405, 2405*f*
 - posterior tibial artery exposure, 2404–2405
- Tibiofemoral articulation, 2465
- Tinel sign, 1977
 - at elbow, 1993
 - tibial nerve, 2452
- Tinel test, 1987, 2411
- TIP (tibial inverts and plantar flexes), 2452
- Tip projection (TP), 276, 276*f*, 338
 - in open rhinoplasty
 - anatomy, 304
 - complications, 308–309
 - definition, 304, 304*f*
 - determination of, 307
 - imaging, 305
 - lower lateral cartilages, isolation of, 306, 306*f*–307*f*

- lower lateral cartilages, separation of, 306
- merits and demerits, 308*b*
- nonoperative management, 305
- nose, opening, 306
- outcomes, 308, 308*f*–309*f*
- pathogenesis, 304–305, 305*f*
- patient history and physical findings, 305
- postoperative care, 308
- resupporting, 307–308, 307*f*
- surgical management, 305–306
- Tip rotation, controlling in open rhinoplasty
 - anatomy, 310
 - cartilage grafts, 314, 314*f*
 - columellar struts, 313, 313*f*
 - complications, 314
 - definition, 310, 310*f*
 - imaging, 310
 - lateral crural strut grafts, 312, 312*f*
 - merits and demerits, 314*b*
 - outcomes, 314
 - patient history and physical findings, 310, 310*f*
 - postoperative care, 314
 - scroll area, division of, 311–312, 311*f*
 - septal resection, 312, 312*f*
 - skin undermining, 311
 - surgical management, 311
 - suture techniques, 313, 313*f*
 - tongue-and-groove technique, 313, 313*f*
- TIP urethroplasty, 3044–3045, 3044*f*–3045*f*
- Tissue expander exposure, 1741
- Tissue expander fill, 1740
- Tissue expander infection, 1741
- Tissue expander placement

- approach, 2738
- and closure, 1390–1391, 1391*f*
- complications, 1392
- definition, 1385
- implant pocket creation, 1386–1390, 1387*f*–1389*f*
- merits and demerits, 1386*b*, 1391*b*, 2739*t*
- outcomes, 1392
- patient history and physical findings, 1385
- patient position, 2738
- postoperative care, 1392, 2739, 2739*f*
- preoperative planning, 2737–2738
- preparation of, 1390, 1390*f*
- surgical management
 - implant selection, 1385–1386
 - patient positioning, 1386
 - preoperative planning, 1385–1386
- technique, 2738*b*
- wound assessment, 1386
- Tissue expander removal and flap advancement, 1740, 1740*f*
- Tissue expander with acellular dermal matrix
 - anatomy, 1380
 - complications, 1383
 - definition, 1380
 - with dermal allograft
 - prepectoral, 1382
 - subpectoral, 1381–1382
 - imaging, 1380
 - merits and demerits, 1383*b*
 - outcomes, 1383
 - pathogenesis, 1380
 - patient history and physical findings, 1380
 - postoperative care, 1383
 - surgical management

- approach, 1380
- patient positioning, 1380
- preoperative planning, 1380
- Tissue expansion, 2366
 - advancement of flap, 992, 992*f*
 - anatomy, 990, 1109
 - base diameter, 990
 - complications, 993, 1115
 - definition, 990, 1109
 - with implants, 2979
 - insertion, 991, 991*f*, 1111
 - merits and demerits, 991*b*, 1111*b*
 - neck expansion, 1113, 1113*f*
 - outcomes, 993, 993*f*, 1114, 1114*f*
 - pathogenesis, 990, 990*f*
 - patient history, 990, 1109
 - physical findings, 990
 - postoperative care, 993, 1114
 - shapes, 990
 - surgical management, 990–991, 1109–1110
 - approach, 991
 - direct expansion and closure, 1110
 - expanded cervicofacial flap, 1110, 1112, 1113*f*
 - expanded flap elevation and inset, 1111, 1111*f*–1112*f*
 - flap incisions and tissue transposition, 1110
 - incision placement, 1110
 - patient positioning, 991, 1110
 - port placement, 1110
 - preoperative antibiotics, 991
 - preoperative planning, 990–991, 1109–1110
 - risks, 991
 - size, shape, and number, 1110
 - temporary markings, 991

- Tissue necrosis, 46, 47*f*
- TKA. *See* Total knee arthroplasty (TKA)
- TMC. *See* Trapeziometacarpal (TMC) joint, thumb
- TMJ. *See* Temporomandibular joint (TMJ)
- Tobramycin, 2471
- Toe amputation, 2545
- Toe fillet flap, 2366
- Toe to thumb transfer
 - anatomy, 2168, 2168*f*–2169*f*
 - complications, 2175
 - definition, 2168
 - imaging, 2169
 - merits and demerits, 2170*b*, 2174*b*
 - outcomes, 2174–2175
 - patient history and physical findings, 2168–2169
 - postoperative care, 2174
 - recipient site preparation, 2172, 2172*f*–2173*f*
 - surgical management
 - approach, 2170
 - patient positioning, 2170
 - preoperative planning, 2170
 - thumb closure, 2173, 2173*f*
- Toe-brachial pressures (TBIs), 2400
- Tongue flap (anteriorly based), 2702, 2702*f*
- Tongue-and-groove technique
 - open rhinoplasty, controlling tip rotation in, 313, 313*f*
 - short nose, 341–342, 341*f*
- Tongue-lip adhesion. *See* Pierre Robin sequence (PRS)
- Topical antibiotics, 2803
- Topical liposomal lidocaine, 2800
- Topical tetracaine, 2843, 2846, 2858, 2861, 2865
- Topical timolol, 2800
- Toronto Test Score, 2949

- Total cranial vault remodeling
 - anatomy, 470, 470*f*
 - closure, 475
 - complications, 476
 - definition, 470
 - imaging, 470
 - merits and demerits, 471*b*
 - natural history, 470
 - new Bandeau and forehead
 - bone remodeling, 473, 473*f*
 - removal, 472, 472*f*
 - nonoperative management, 470
 - occipital bone, 474
 - outcomes, 476, 476*f*
 - pathogenesis, 470
 - patient history and physical findings, 470
 - pericranial flap dissection, 471, 472*f*
 - postoperative care, 476
 - replacement, 475, 475*f*
 - skull base, 474, 474*f*
 - surgical management
 - approach, 471
 - patient positioning, 471
 - preoperative planning, 470–471, 471*f*
 - zigzag skin incision, 471, 471*f*
- Total glossectomy defects
 - anatomy, 1215
 - anesthesia and assessment, 1216, 1216*f*
 - complications, 1218
 - definition, 1215
 - flap inset, 1217, 1217*f*
 - flap selection and harvest, 1216, 1216*f*
 - imaging, 1215

- merits and demerits, 1216*b*
- outcomes, 1218, 1218*f*
- pathogenesis, 1215
- patient history and physical findings, 1215
- postoperative care, 1218
- surgical management
 - patient positioning, 1215
 - preoperative planning, 1215
- Total knee arthroplasty (TKA), 2465–2467, 2467*f*
 - knee, bony and soft tissue debridement
 - imaging, 2468
 - outcomes, 2472
 - pathogenesis, 2466–2467
 - patient history and physical findings, 2467, 2467*f*
 - postoperative care, 2471
 - surgical management, 2469
- Total maxillectomy defect, 1013, 1016–1019
- Total urogenital mobilization (TUM), 3068, 3068*f*
- TP (tip projection), 276, 276*f*
- TPF (temporoparietal fascia), 916
- TPIF (transverse preputial island flap), 3045
- Traction injury, 2412
- TRAM flap. *See* Transverse rectus abdominis myocutaneous (TRAM) flap
- Transaxillary breast augmentation
 - anatomy, 1290
 - closure and dressings, 1295, 1295*f*
 - complications, 1296
 - definition, 1290
 - device placement, 1294, 1294*f*
 - incision and initial dissection, 1291
 - merits and demerits, 1295*b*
 - optical cavity, 1292, 1292*f*

- outcomes, 1296
- patient history and physical findings, 1290, 1291*f*
- pectoralis major muscle release, 1292–1294, 1293*f*
- postoperative care, 1295
- surgical management
 - approach, 1291
 - equipment, 1290, 1291*f*
 - patient positioning, 1290–1291, 1291*f*
 - preoperative planning, 1290
- Transcanalicular diode laser, 2872
- Transconjunctival approach
 - of malar implants, 394, 394*f*
 - pediatric orbital fractures, 948, 948*f*
- Transconjunctival fat, removal and redraping
 - anatomy, 140, 140*f*–141*f*
 - completion, 144
 - complications, 146–147
 - definition, 140
 - exposure, 143, 143*f*
 - fat pad resection, 144, 144*f*
 - imaging, 142, 142*f*
 - merits and demerits, 145*b*
 - nonoperative management, 142
 - outcomes, 146, 146*f*–147*f*
 - patient history and physical findings, 140–142
 - postoperative care, 146
 - surgical management, 142–143
- TransCyte double-layer dressing, 2769
- Transforming growth factor β (TGF β) mutations, 478
- Transgender breast surgery
 - anatomy, 1327
 - complications, 1329
 - definition, 1327

- imaging, 1327
- merits and demerits, 1328*b*
- nonoperative management, 1327
- outcomes, 1329, 1329*f*–1330*f*
- patient history and physical findings, 1327
- postoperative care, 1329
- surgical management
 - patient positioning, 1327, 1327*f*
 - preoperative planning, 1327
- Translaceration approach, 843
- Transmetatarsal amputation, 2545, 2545*f*
- Transosseous suture technique
 - bone tunnels creation, 2495, 2495*f*
 - completion and assessment of repair, 2495
 - extensor retinaculum, anterior approach to, 2494
 - suture passage and knot tying, 2495, 2495*f*
 - tendon preparation, 2494, 2494*f*
- Transpalpebral corrugator resection
 - anatomy, 93, 93*f*, 109
 - complications, 96, 113
 - corrugator and depressor supercilii muscle, removal of, 111, 111*f*
 - corrugator and procerus muscles, transblepharoplasty excision of, 94, 94*f*
 - definition, 93, 109
 - fat grafting and closure, 111, 112*f*
 - history, 109
 - imaging, 109
 - incision and dissection, 110, 110*f*
 - merits and demerits, 95*b*, 112*b*
 - nonoperative management, 93, 110
 - outcomes, 95, 95*f*, 112, 112*f*
 - pathogenesis, 109
 - patient history and physical findings, 93, 109

- postoperative care, 95, 112
- surgical management, 93–94, 110
 - approach, 94, 110
 - positioning, 94
 - preoperative planning, 94, 110
- Transparietal/transtemporal distraction, for sagittal craniosynostosis
 - anatomy, 485, 485*f*
 - asymmetric transverse distraction osteogenesis, 486–487, 487*f*
 - complications, 489
 - definition, 485
 - imaging, 486
 - merits and demerits, 486*b*
 - outcomes, 488
 - patient history, 485
 - physical examination, 485
 - postoperative care, 488
 - surgical management
 - patient positioning, 486, 486*f*
 - preoperative planning, 486
- Transportation of amputated digit, 2149
- Transposition of ulnar nerve, 1995–1998
 - anterior subcutaneous, 1997–1998, 1997*f*–1998*f*
 - submuscular, 1996–1997, 1996*f*
- Transverse carpal ligament (TCL), 1977, 1978*f*, 1986*f*
- Transverse corrugator supercilii, 70
- Transverse elliptical excision, lip pits, 2654, 2655*f*
- Transverse facial artery, 1122
- Transverse forehead line approach, 86–87, 86*f*
- Transverse mucosal resection and linear closure, 2762, 2762*f*
- Transverse osteotomy, 586, 587*f*–588*f*
- Transverse preputial island flap (TPIF), 3045
- Transverse rectus abdominis myocutaneous (TRAM) flap, 1528
 - anatomy, 1408, 1408*f*–1409*f*

- complications, 1412–1413
- definition, 1408
- dissection and flap elevation, 1410, 1411*f*
- free TRAM flap (*see* Free transverse rectus abdominis myocutaneous flap)
- imaging, 1409
- merits and demerits, 1412*b*
- muscle-sparing free flap (*see* Muscle-sparing free transverse rectus abdominis myocutaneous (MS-TRAM) flap)
- nonoperative management, 1409
- outcomes, 1412
- passing and inseting the flap, 1410–1411, 1411*f*
- pathogenesis, 1408
- patient history and physical findings, 1408–1409
- postoperative care, 1412
- preparation, 1410, 1410*f*
- surgical management
 - patient positioning, 1409
 - preoperative planning, 1409
- Transverse upper gracilis (TUG) flap, 1471–1472, 1472*f*
 - anatomy, 1469, 1470*f*
 - complications, 1474
 - definition, 1469, 1469*f*
 - harvesting
 - completion, 1472, 1473*f*
 - dissection, 1471, 1471*f*
 - flap elevation, 1471, 1472*f*
 - flap preparation and placement, 1472, 1472*f*–1473*f*
 - imaging, 1470
 - merits and demerits, 1473*b*
 - outcomes, 1474
 - patient history and physical exam, 1469–1470
 - postoperative care, 1474

- surgical management
 - approach, 1470
 - patient positioning, 1470
 - preoperative planning, 1470
- Transversus abdominis muscle, 1563
- Transversus abdominis release (TAR), 1556, 1559–1560, 1560*f*
- Trapdoor orbital fractures, 816, 877
- Trapeziometacarpal (TMC) joint, thumb
 - arthrodesis, dorsoradial approach to, 1832
 - with K-wire fixation, 1836
 - with plate and screw fixation, 1833–1836, 1833*f*, 1834*f*, 1835*f*
 - complications, 1837–1838
 - definition, 1831
 - differential diagnosis, 1832
 - imaging, 1831–1832
 - merits and demerits, 1836*b*
 - nonoperative management for, 1832
 - outcomes, 1836, 1837*f*
 - pathogenesis, 1831
 - patient history and physical findings, 1831
 - postoperative care, 1833*f*, 1836
 - surgical management, 1832
 - patient positioning, 1832
 - preoperative planning, 1832
- Trapezius muscle flap
 - anatomy, 1730, 1730*f*
 - based on DSA, 1731–1732, 1732*f*
 - based on transverse cervical, 1732, 1732*f*–1733*f*
 - complications, 1733
 - definition, 1730
 - imaging, 1731
 - outcomes, 1733
 - patient history and physical findings, 1730–1731

- postoperative care, 1733
- surgical management
 - approach, 1731
 - positioning, 1731
 - preoperative planning, 1731
- Traumatic nerve injuries
 - primary repair and graft
 - anatomy, 2004–2005
 - bruner/mid-lateral incisions, 2006
 - complications, 2010
 - definition, 2004
 - in elbow, 2004, 2007*f*–2008*f*
 - in forearm, 2004, 2005*f*
 - imaging, 2005–2006
 - larger nerve gaps/caliber nerve, 2009
 - merits and demerits, 2007*b*, 2010*b*
 - outcomes, 2010
 - patient history and physical findings, 2005
 - postoperative care, 2010
 - primary, 2007
 - small nerve gap, caliber nerve, 2008
 - stair-step sural nerve harvest, 2006, 2006*f*
 - surgical management
 - approach, 2006
 - patient positioning, 2006
 - preoperative planning, 2006
 - tenotomy scissors, 2006
 - at wrist level, 2004, 2004*f*
- Traumatic optic neuropathy, 951, 957
- Traumatic ptosis, 2850
- Traumatic superior orbital fissure syndrome, 824
- Treacher Collins syndrome (TCS), 723
- Triangular fibrocartilage complex (TFCC) tear, 1839

- Trichiasis, 2871
- Trichloroacetic acid (TCA) peel, 60
 - anatomy, 57
 - complications, 58–59
 - cotton tip applicator
 - on awake patient, 58
 - on sedated patient, 57, 58*f*
 - definition, 57
 - merits and demerits, 58*b*
 - outcomes, 58
 - patient history and physical findings, 57
 - postoperative care, 58
 - surgical management, 57
- Trigeminal nerve
 - anatomy, 966, 966*f*
 - components, 966, 966*f*
 - scalp reconstruction with rotation flaps, 980
- Trigger digit. *See* Trigger finger release
- Trigger finger, in rheumatoid arthritis, 1938–1939
- Trigger finger release
 - anatomy, 2090
 - complications, 2092
 - definition, 2090
 - differential diagnosis, 2090
 - imaging, 2090
 - merits and demerits, 2092*b*
 - natural history, 2090
 - nonoperative management, 2090
 - outcomes, 2092
 - pathogenesis, 2090
 - patient history and physical findings, 2090
 - postoperative care, 2092
 - surgical management

- approach, 2091
 - patient positioning, 2091
- Trim Doyle splints, 863, 863*f*
- Tripod concept, 331
- Trochanteric ulcers
 - anatomy, 1715, 1715*f*
 - complications, 1720
 - definition, 1715
 - differential diagnosis, 1717
 - imaging, 1717
 - natural history, 1716
 - nonoperative management, 1717
 - outcomes, 1720
 - pathogenesis, 1715–1716
 - pertinent history and physical findings, 1716–1717
 - postoperative care, 1720
 - surgical management
 - approach, 1717
 - positioning, 1717, 1717*f*
 - preoperative planning, 1717
- “Tube of toothpaste” maneuver, 1557, 1557*f*
- “Tube-in-a-tube” method, 1693
- Tubularization, 3048
- TUG flap. *See* Transverse upper gracilis (TUG) flap
- TUM (total urogenital mobilization), 3068, 3068*f*
- Tumescence analgesia fluid formula, 971, 971*t*
- Tumescence anesthesia, 971, 971*t*
- Tumescence infiltration of donor and recipient sites, fat grafting, 1491
- Tumor necrosis factor (TNF), 1931
- Tumors
 - definition, 2275
 - resection, 1363
- Tunica vaginis flap, 3048

- Turbinate reduction, 329
- Turbinectomy
 - ethnic rhinoplasty, 291
 - partial, 329
- Turbinoplasty, nasal airway obstruction, 384, 384*f*
- Turkish Delight, 366
- Turnover flap, 1518–1519, 1519*f*
- Two halves stabilization, 549, 550*f*
- Two-flap palatoplasty
 - anatomy, 2683
 - bilateral complete cleft palate, 2688, 2688*f*
 - complications, 2689
 - definition, 2683
 - differential diagnosis, 2683–2684
 - merits and demerits, 2685*b*
 - natural history, 2683
 - nonoperative management, 2684
 - outcomes, 2689
 - pathogenesis, 2683
 - patient history and physical findings, 2683
 - postoperative care, 2689
 - surgical management, 2684
 - approach, 2684
 - patient position, 2684
 - preoperative planning, 2684
 - for unilateral complete cleft palate
 - greater palatine vessels isolation, 2685–2686, 2686*f*
 - markings, 2685, 2685*f*
 - nasal closure, 2687
 - nasal mucoperiosteum dissection, 2686–2687, 2687*f*
 - oral closure, 2687–2688
 - oral mucoperiosteal flaps elevation, 2685, 2685*f*
 - velar musculature dissection and reconstruction, 2687

- Two-stage flexor tendon reconstruction, 2068–2069, 2068*f*–2069*f*
- Two-stage operation, nonunion of mandible fracture, 930–932, 930*f*
- Tyndall effect, 20, 33, 36
- Type 1 branchial sinus/fistula, 2900–2902, 2901*f*
- Type 2 branchial sinus/fistula, 2902, 2902*f*
- Type I (limited maxillectomy) defect, 1013, 1013*f*–1014*f*, 1015–1016
- Type II (subtotal maxillectomy) defect, 1013, 1016
- Type III (total maxillectomy) defect, 1013, 1016–1019
- Type IV defect (orbitomaxillectomy), 1013, 1019

U

- UCL reconstruction. *See* Ulnar collateral ligament, of thumb
- UCS. *See* Unilateral coronal synostosis (UCS)
- Ulcer, 1710–1711, 1710*f*
- Ulcer excision, 1708
- Ulcerations, 2387
- Ulcers, 2400
- ULCs (upper lateral cartilages), 269, 291, 291*f*, 380
 - correction, 330, 330*f*
- Ulnar artery perforator flap, 2122–2123
 - advantage, 2120
 - anatomy, 2120–2121
 - complications, 2125
 - definition, 2120
 - imaging, 2121
 - merits and demerits of, 2124*b*
 - nonoperative management, 2121
 - outcomes, 2124, 2124*f*
 - patient history, 2121
 - pedicled flap, 2122–2123
 - physical findings, 2121

- postoperative care, 2124
- propeller flap, 2123, 2123*f*–2124*f*
- surgical management, 2121–2122, 2122*f*
 - approach, 2122
 - patient positioning, 2122
 - preoperative planning, 2122
- Ulnar artery perforator flaps, hemi-tongue reconstruction, 1203, 1203*f*–1204*f*
- Ulnar artery thrombosis
 - anatomy, 2160, 2160*f*
 - complications, 2167
 - definition, 2160
 - differential diagnosis, 2163
 - dissection of, 2164, 2164*f*
 - donor grafts, 2163, 2164*b*
 - flow and closure, 2166
 - imaging, 2162–2163
 - merits and demerits, 2166*b*
 - natural history, 2161
 - nonoperative management, 2163
 - outcomes, 2167
 - pathogenesis, 2160–2161
 - patient history and physical findings, 2161–2162
 - postoperative care, 2167
 - segment resection and superficial arch, 2165, 2165*f*
 - signs of
 - surgical management
 - approach, 2164, 2164*f*
 - patient positioning, 2164
 - preoperative planning, 2163
 - vein graft harvesting, 2165, 2165*f*
- Ulnar collateral ligament, of thumb
 - acute reconstruction of

- incision for, 1804, 1804*f*
- suture placement and closure, 1804, 1805*f*
- anatomy, 1802, 1802*f*
- chronic tear reconstruction of
 - bone tunnel creation and tendon graft, 1807, 1807*f*
 - incision, 1805, 1806*f*
 - K-wire placement, 1807–1808, 1808*f*
 - palmaris autograft, 1808, 1808*f*
 - palmaris tendon harvest, 1806–1807, 1806*f*
 - suture anchor, 1807, 1808*f*
- complications, 1809
- definition, 1802
- differential diagnosis, 1803
- imaging, 1803
- indications, 1803
- merits and demerits, 1809*b*
- natural history, 1803
- nonoperative management, 1803
- outcomes, 1809
- pathogenesis, 1802, 1802*f*
- patient history and physical findings, 1803
- postoperative care, 1809
- Stener lesion, 1802, 1802*f*
- surgical management
 - approach, 1803
 - patient positioning, 1803
 - preoperative planning, 1803
- Ulnar nerve
 - decompression, 1989–1990, 1990*f*
 - local anesthesia at wrist, 1758, 1758*f*
 - neurovascular bundle anatomy, 1754
 - schwannoma, 2300*f*, 2301*f*
- Ulnar nerve injury

- anatomy, 2019
- complications, 2024
- definition, 2019
- differential diagnosis, 2020
- imaging, 2020
- merits and demerits, 2020*b*, 2024*b*
- natural history, 2019
- nonoperative management, 2020
- outcome studies, 2024
- pathogenesis, 2019
- patient history and physical findings, 2019
- postoperative care, 2024
- surgical management
 - approach, 2020
 - patient positioning, 2020
 - preoperative planning, 2020
- Ulnar nerve palsy
 - anterior interosseous nerve
 - anatomy, 2043
 - complications, 2047
 - definition, 2043
 - differential diagnosis, 2044
 - end-to-end neurorrhaphy, 2046, 2046*f*
 - imaging, 2044
 - internal topography, 2043, 2043*f*–2044*f*
 - merits and demerits, 2047
 - outcomes, 2047
 - patient history and physical findings, 2044
 - postoperative care, 2047
 - reverse end-to-side, 2046, 2046*f*
 - surgical management, 2044–2045, 2045*f*
 - low combined median and
 - finger clawing, 2038–2039

- index finger abduction, 2037–2038
- small finger abduction, 2040
- thumb adduction, 2037
- thumb opposition, 2036–2037
- motor component identification, 2045, 2045*f*
- Ulnar tunnel release, 1989–1990, 1989*f*
- Ulnar tunnel syndrome
 - anatomy, 1986–1987, 1986*f*
 - complications, 1991
 - definition, 1986
 - differential diagnosis, 1988
 - imaging, 1988
 - merits and demerits, 1990*b*
 - nonoperative management, 1988
 - outcomes, 1990–1991
 - pathogenesis, 1987
 - patient history and physical findings, 1987
 - postoperative care, 1990
 - surgical management, 1988
 - patient positioning, 1988
 - preoperative planning, 1988
 - volar approach, 1988
 - ulnar tunnel release and ulnar nerve decompression, 1989–1990, 1989*f*, 1990*f*
- Ultherapy, 238
- Ultrasound (US)
 - Achilles tendon reconstruction, 2417, 2417*f*
 - cubital tunnel syndrome, 1993
 - lumbar and thoracic spine for epidural placement, 2327, 2327*f*
 - nerve repair and graft, 2005
 - reverse radial forearm flap, 2115
 - ulnar tunnel syndrome, 1988
- Ultrasound-assisted liposuction

- depiction of liposuction technique, 1357*f*
- markings, 1357
- persistent tissue removal, 1357, 1358*f*
- Ultrasound-guided technique
 - adductor canal blocks, 2312*f*
 - continuous catheter technique, 2320
 - Deep peroneal nerve block, 2323, 2323*f*
 - femoral nerve blocks, 2311–2312, 2311*f*
 - in-plane needle insertion approach, 2316, 2318–2319
 - vs. nerve stimulation, 2316
 - out-of-plane needle insertion approaches, 2316, 2319–2320
 - saphenous nerve block, 2324, 2324*f*
 - superficial peroneal nerve block, 2323, 2324*f*
 - sural nerve block, 2324, 2324*f*
 - tibial nerve block, 2323
- Umbilical stenosis, after abdominoplasty, 3040, 3040*f*
- Umbilical transposition, 1592, 1604*f*, 1605, 1605*f*. *See also* Abdominal panniculectomy
- Umbilicoplasty
 - anatomy, 3037, 3037*f*–3038*f*
 - complications, 3040
 - definition, 3037
 - merits and demerits, 3040*b*
 - midline incision, 3038–3039, 3038*f*–3039*f*
 - outcomes, 3040
 - patient history and physical findings, 3037
 - postoperative care, 3040
 - surgical management, 3038
- Umbilicus, 3037
- Uncinectomy, 804*f*
- Undiagnosed spinal stenosis, 2330
- Unicoronal synostosis
 - fronto-orbital distraction, 447, 448*f*

- natural history, 445
- Unilateral cleft lip adhesion
 - completion, 2633, 2633*f*
 - incision and dissection, 2631, 2632*f*
 - markings, 2631, 2631*f*
 - suturing, 2631–2633, 2632*f*
- Unilateral cleft lip, nasal deformity, 2715*t*
- Unilateral cleft lip repair
 - anatomy, 2606, 2607*f*
 - clefting degree, 2606
 - complications, 2615
 - definition, 2606
 - imaging, 2606
 - merits and demerits, 2607*b*
 - Millard/Mohler modifications
 - incisions, 2609
 - lateral lip dissection, 2609–2610, 2610*f*
 - lip closure, 2612–2613, 2613*f*
 - markings, 2607–2609, 2608*f*–2609*f*
 - medial lip dissection, 2609, 2610*f*
 - mucosa closure, 2610–2611, 2611*f*–2612*f*
 - nasal dissection, 2611–2612, 2612*f*
 - nasal refinement, 2613–2614, 2614*f*
 - outcomes, 2615
 - patient history and physical findings, 2606
 - postoperative care, 2615
 - surgical management, 2606–2607
 - approach, 2607
 - patient position, 2607
 - preoperative planning, 2607
- Unilateral complete cleft palate
 - two-flap palatoplasty
 - greater palatine vessels isolation, 2685–2686, 2686*f*

- markings, 2685, 2685*f*
- nasal closure, 2687
- nasal mucoperiosteum dissection, 2686–2687, 2687*f*
- oral closure, 2687–2688
- oral mucoperiosteal flaps elevation, 2685, 2685*f*
- velar musculature dissection and reconstruction, 2687
- Unilateral coronal synostosis (UCS)
 - anatomy, 434
 - bony fixation, 440, 440*f*–441*f*
 - completion, 440
 - definition, 434
 - exposure and bur hole placement, 438, 438*f*
 - patient history and physical findings, 435
 - supraorbital rim osteotomy and advancement, 438–439, 439*f*
- Unilateral craniofacial microsomia, 718
- Unilateral hyperplasia, mandible, 714
- Unilateral Karapandzic flap, 1059, 1059*f*
- Unilateral lambdoid synostosis, 456
- Unilateral nasal bone correction, 326–327
- Untreated compartment syndrome, 1765, 1765*f*
- Upper abdominal defects, 1589
- Upper arm lift (brachioplasty)
 - anatomy, 1645, 1645*f*
 - complications, 1648
 - definition, 1645
 - imaging, 1645
 - outcomes, 1648
 - pathogenesis, 1645
 - patient history and physical findings, 1645
 - postoperative care, 1648
 - surgical management
 - approach, 1646
 - positioning, 1646

- preoperative planning, 1645–1646
- Upper blepharoplasty
 - anatomy, 106, 171
 - complications, 108, 176, 177*f*
 - definition, 106, 169–170
 - differential diagnosis, 172
 - merits and demerits, 107*b*, 176*b*
 - nonoperative management, 172
 - outcomes, 107, 176
 - pathogenesis, 171–172
 - patient history and physical findings, 106, 172, 172*f*
 - postoperative care, 107, 176
 - surgical management, 106–107, 172
 - approach, 107
 - positioning, 107, 107*f*
 - preoperative planning, 106–107, 106*f*
 - techniques, 107*f*, 107*b*, 172–175, 172*f*, 173*f*
- Upper eyelid
 - anatomy of, 114, 114*f*, 2849*f*
 - fat grafting for periorbital rejuvenation, 162, 166
 - margin, position of, 3
 - ptosis, levator advancement technique, treatment, 123, 124*f*
- Upper eyelid reanimation with gold weight
 - anatomy, 1286, 1286*f*
 - anterior lamella, 1286
 - blood supply, 1287
 - complications, 1288
 - definition, 1286
 - imaging, 1287
 - lower eyelid retractors, 1287
 - merits and demerits, 1287*b*
 - outcomes, 1288
 - patient history and physical findings, 1287

- posterior lamella, 1286
- postoperative care, 1288
- surgical management
 - patient positioning, 1287
 - postseptal approach, 1288
 - preoperative planning, 1287
 - pretarsal approach, 1287, 1287*f*
- upper eyelid retractors, 1286
- Upper lateral cartilages (ULCs), 269, 291, 291*f*, 380, 2714
 - correction, 330, 330*f*
- Upper lid reconstruction, eyelids, 2778, 2778*f*–2779*f*
- Upper lip, 2606, 2607*f*, 2616
- Upper periorbital area, filler injection into
 - anatomy, 23
 - approach, 23
 - complications, 25
 - definition, 23
 - merits and demerits, 24*b*
 - outcomes, 25
 - patient history and physical findings, 23, 23*f*
 - positioning, 23
 - postoperative care, 25
 - preoperative planning, 23
 - techniques, 24, 24*f*
- Upper thigh lift
 - anatomy, 1649–1650, 1649*f*
 - complications, 1654
 - definition, 1649
 - pathogenesis, 1650
 - patient history and physical findings, 1650
 - postoperative care, 1654
 - surgical management
 - approach, 1650

- positioning, 1650, 1650*f*
- preoperative planning, 1650
- Urethra, preparation of, 1690*f*, 1691
- Urethral plate defect, bridging of, 3047
- Urethral plate elevation, 3066, 3066*f*
- Urinary tract, conjoined twins, 3095
- Urogenital sinus mobilization, 3066, 3066*f*
 - perineal flap creation, 3068, 3068*f*
 - reconstruction, 3066, 3066*f*
 - TUM and PUM, 3068, 3068*f*
 - use, 3068–3069, 3069*f*

V

- Vacuum-assisted closure (VAC) therapy, 2523, 2526–2527
- Vagina, 3062
- Vaginal agenesis, 3052
- Vaginal canal caliber, 3054–3055, 3054*f*, 3055*f*
- Vaginal pack, placement of, 1692, 1692*f*
- Vaginal reconstruction
 - anatomy, 1681, 3052, 3053*f*
 - complications, 1685, 3061
 - definition, 1681, 3052
 - gracilis flap for (*see* Perineal reconstruction)
 - imaging, 1682, 3053
 - merits and demerits, 3060*b*
 - natural history, 1681–1682, 3052
 - nonoperative management, 3053
 - outcomes, 1685, 3061
 - pathogenesis, 1681, 3052
 - patient history and physical findings, 1682, 3052–3053
 - posterior labial artery flap for (*see* Vaginal reconstruction; Vulvar reconstruction)

- postoperative care, 1684–1685, 3060
- surgical management, 3053–3054, 3054*f*
 - approach, 1682, 1682*f*
 - positioning, 1682
 - preoperative planning, 1682
- Vaginal vault, creation of, 1692, 1692*f*
- Vaginoplasty, 3053–3055, 3054*f*, 3055*f*
 - anterior sagittal transrectal approach, 3069–3070
 - high vaginal confluence, 3069
 - low vaginal confluence, 3069, 3069*f*
- Valsalva maneuver, 344
- Van der Woude syndrome, 2618
- Vancomycin, 2471
- Vascular anastomoses, 1694, 1695*f*
- Vascular anomalies, 2275
 - anatomy, 2759
 - circular excision and purse-string closure, 2761–2762, 2761*f*
 - complications, 2763
 - definition, 2759
 - differential diagnosis, 2759
 - imaging, 2759
 - lenticular excision and linear closure, 2760*b*
 - merits and demerits, 2763*b*
 - natural history, 2759
 - nonoperative management, 2759
 - outcomes, 2763
 - patient history and physical findings, 2759
 - postoperative care, 2763
 - suction-assisted lipectomy, 2762–2763, 2763*f*
 - surgical management, 2759–2760
 - approach, 2760
 - patient position, 2760
 - preoperative planning, 2760

- transverse mucosal resection and linear closure, 2762, 2762*f*
- Vascular clamps, 2166
- Vascular endothelial growth factor (VEGF), 504
- Vascular lesions
 - anatomy, 2798
 - complications, 2803
 - definition, 2798
 - imaging, 2799–2800
 - laser treatment, 2802, 2802*f*
 - merits and demerits, 2803*b*
 - natural history, 2798
 - nonoperative management, 2800
 - outcomes, 2803
 - pathogenesis, 2798
 - patient history and physical findings, 2798–2799, 2799*f*
 - postoperative care, 2803
 - surgical management, 2800–2802
 - approach, 2801–2802, 2802*b*, 2802*f*
 - patient position, 2800–2801
 - preoperative planning, 2800
- Vascular malformations, 78, 2456, 2798
- Vascular malformations (VMs)
 - definition and classification of, 2275
 - fast-flow, 2275
 - of hand, 2275–2279
 - approach, 2276
 - complications, 2279
 - differential diagnosis, 2276
 - digits and distal palm, 2277, 2277*f*–2278*f*
 - imaging, 2276, 2276*f*
 - merits and demerits, 2278*b*
 - natural history, 2275
 - nonoperative management, 2276

- outcomes, 2279
- palmar incision, 2277, 2277*f*–2278*f*
- pathogenesis, 2275
- patient history and physical findings, 2275–2276, 2275*f*
- postoperative care, 2279
- surgical management, 2276
- slow-flow, 2275
- Vascular pedicle, 2514
- Vascular perforators, 1557
- Vascular reconstruction of lower extremity, foot, and ankle
 - anatomy, 2400
 - complications, 2406
 - femoropopliteal bypass, 2402–2403, 2402*f*
 - above-knee popliteal exposure, 2403, 2403*f*
 - below-knee popliteal exposure, 2403, 2404*f*
 - femoral artery identification, 2402
 - longitudinal incision, 2402
 - imaging, 2400
 - merits and demerits, 2405*b*
 - outcomes, 2406
 - patient history and physical findings, 2400
 - postoperative care, 2406
 - surgical management, 2401
 - for tibial-peroneal arterial occlusive disease, 2404–2405
 - anterior tibial artery exposure, 2404
 - conduit, selection of, 2404
 - indications, 2404
 - pedal artery exposure, 2405
 - peroneal artery exposure, 2405, 2405*f*
 - posterior tibial artery exposure, 2404–2405
- Vascular supply
 - radial forearm free flap, 1074
 - scalp reconstruction with rotation flaps, 980

- Vascularized autograft, 2431
- Vascularized bone flaps, 928, 2510
 - advantage of, 2510
 - fibula, 2510
- Vascularized bone grafts (VBGs), 1880
- Vascularized bone reconstruction. *See* Scaphoid fracture nonunion
- Vascularized fibula flap, 2424, 2435
- Vascularized fibular graft, 2431
- Vascularized iliac crest flap, 1038
- Vascularized lymph node transfer (VLNT)
 - anatomy, 2557
 - complications, 2566
 - definition, 2557
 - differential diagnosis, 2559
 - donor sites, 1507, 1507*f*, 2560*t*
 - imaging, 2558–2559
 - indocyanine green appearance, 2561*b*
 - merits and demerits, 2565*b*
 - natural history, 2557–2558
 - nonoperative management, 2559
 - outcomes, 1509, 2566
 - pathogenesis, 2557
 - patient history and physical examination, 2558
 - postoperative care, 1509, 2565–2566
 - recipient sites, 1508, 1508*f*, 2564–2565, 2564*t*
 - surgical management
 - approach, 2560
 - patient positioning, 2560
 - preoperative planning, 2559–2560
- Vascularized medial femoral condyle corticoperiosteal flap, 1038
- Vascular/nerve supply, condyle fractures, 915
- Vaseline gauze packing, 2896
- VASERlipo

- fat emulsification and harvest, 1627–1628
- fat processing and injection, 1629
- markings, 1627
- power-assisted lipoplasty, 1627
- Vastus lateralis, 2392–2395, 2396*f*
- Vaughn-Jackson syndrome, 1935
- VBGs (vascularized bone grafts), 1880
- Veau classification, of cleft palate, 2668, 2668*f*
- Veau clefts, 2696
- Vector analysis, 158
- Vectra, 305
- VEGF (vascular endothelial growth factor), 504
- Vein repair, 2152
- Velar musculature, 2672
 - dissection and reconstruction, in two-flap palatoplasty, 2687
- Velopharyngeal dysfunction (VPD), 2697
- Velopharyngeal incompetence (VPI), 2658
- Velopharyngeal insufficiency (VPI)
 - anatomy, 2706
 - complications, 2713
 - definition, 2706
 - diagnosis, 2707
 - differential diagnosis, 2707
 - dynamic sphincter pharyngoplasty
 - dissection, 2709, 2710*f*
 - markings, 2709, 2710*f*
 - Furlow palatoplasty/double-opposing Z-plast
 - dissection, 2708, 2709*f*
 - markings, 2708, 2708*f*
 - imaging, 2707
 - merits and demerits, 2712*b*
 - natural history, 2706
 - nonoperative management, 2707

- outcomes, 2713
- pathogenesis, 2706
- patient history and physical findings, 2707
- posterior pharyngeal flap
 - dissection, 2710–2711, 2711*f*
 - markings, 2710, 2711*f*
- postoperative care, 2712–2713
- surgical management, 2707–2708
 - approach, 2707
 - patient position, 2708
 - preoperative planning, 2708
- Veloplasty, Z-plasty with
- Venae comitantes (VCs), 1171
- Venous anastomosis, 2526
- Venous congestion, 2485
- Venous drainage, 1515
 - of ear, 1129
 - RFFF, 1171
- Venous malformations (VM), 2798–2799
- Venous stasis, 2427
- Venous supply, SCAIF flap, 1249
- Ventral hernia
 - anatomy, 1563
 - complications, 1570–1571
 - definition, 1563
 - imaging, 1564
 - laparoscopic component separation, 1565, 1565*f*
 - merits and demerits, 1564*b*
 - minimally invasive component separation, 1566–1567, 1566*f*
 - open component separation, 1564–1565, 1564*f*
 - outcomes, 1568–1570, 1568*f*–1569*f*
 - pathogenesis, 1563
 - patient history and physical findings, 1563

- periumbilical perforator-sparing technique, 1565–1566
- posterior component separation, 1567, 1567*f*
- postoperative care, 1568
- surgical management
 - approach, 1564
 - positioning, 1564
 - preoperative planning, 1564
- Vermilion, 1055, 1055*f*, 2597–2598, 2598*f*, 2640
 - abnormalities of, 2648–2652
 - hypoplastic medial/lateral lip element, 2650–2651
 - lateral mucosa fullness, 2648, 2650*f*–2651*f*
 - notch in free edge, 2651–2652
 - red line malalignment, 2648
 - flap, 2731
- Vermilion-shifted commissuroplasty, with optional cutaneous Z-plasty
 - commissuroplasty and skin closure, 2732, 2733*f*
 - design, 2731, 2732*f*
 - dissection and orbicularis repair, 2731–2732, 2732*f*
 - markings, 2731, 2731*f*
- VERSAJET system, 2429, 2429*f*
- Vertical elliptical wedge excision, lip pits, 2654, 2655*f*
- Vertical mastopexy
 - incisions and closure, 1335–1336, 1335*f*
 - planning and markings, 1334–1335, 1334*f*–1335*f*
- Vertical maxillary excess (VME), 573
- Vertical rectus abdominis myocutaneous (VRAM) flap, 1215, 1528, 1657, 1657*f*–1658*f*, 1675, 1678, 1678*f*, 1685, 2519*f*–2520*f*
 - clinical anatomy, 2517*f*
 - double skin island, 1049, 1049*f*–1050*f*
 - lateral mandible defect, 1048
 - markings, 1049, 1049*f*
 - for perineal reconstruction (*see* Perineal reconstruction, vertical

- rectus abdominis myocutaneous flap for)
 - for perineal reconstruction, inset of, 1679, 1679*f*
- Vertical reduction genioplasty, 408, 408*f*
- Vertical rhytids, 12
- Vertical, superomedial pedicle reduction mammoplasty, 1342
- Vessels, subcutaneous lateral brow lifting, 82
- Vestibular web obliterating suture, 2614, 2614*f*
- Video fluoroscopy, 2697
- ViOptix tissue oximetry, 1555
- Virginal breast hypertrophy. *See* Juvenile breast hypertrophy
- VISI (volar intercalated segment instability) deformity, 1857, 1859
- Visible cords, 18, 18*f*
- VLNT. *See* Vascularized lymph node transfer (VLNT)
- VM (venous malformations), 2798–2799
- VME (vertical maxillary excess), 573
- Voiding cystourethrography (VCUG), 3022, 3063
- Volar carpal ligament, 1986, 1986*f*, 1989
- Volar forearm
 - curvilinear incision, 1761, 1763, 1763*f*
 - longitudinal incisions, 1764, 1764*f*
 - split-thickness skin graft, 1765, 1765*f*
- Volar intercalated segment instability (VISI) deformity, 1857, 1859
- Volar plate arthroplasty (VPA). *See* Proximal interphalangeal joint (PIPJ), of fingers
- Volar retinacular cysts, 2281–2282
- Volar thumb, 2105
- Volar wrist ganglion, 2280–2281, 2284, 2284*f*
- Volar wrist trauma with tendon, nerve, and arterial injuries
 - anatomy, 2061
 - complications, 2064
 - definition, 2061
 - imaging, 2061
 - injured structures repair, 2063, 2063*f*

- merits and demerits, 2062*b*, 2063*b*
- outcomes, 2064
- pathogenesis, 2061
- patient history and physical findings, 2061
- postoperative care, 2064
- proximal structures, tagging, 2063, 2063*f*
- surgical management
 - patient positioning, 2062
 - preoperative planning, 2062
- wound presentation, exposed injuries, 2062, 2062*f*
- Volkmann ischemic contracture, 1765, 1765*f*
- Vomer bone, 2659
- Vomer flap, 2658
- Von Langenbeck palatoplasty
 - anatomy, 2668, 2668*f*
 - complications, 2674
 - definition, 2668
 - differential diagnosis, 2669
 - elevation of oral mucoperiosteal flaps, 2670
 - greater palatine vessels isolation, 2671
 - markings, 2670, 2670*f*
 - merits and demerits, 2670*b*
 - muscle and intravelar veloplasty dissection, 2672
 - nasal mucosa closure, 2672, 2672*f*
 - nasal mucosa dissection, 2671
 - natural history, 2668–2669
 - nonoperative management, 2669
 - oral mucoperiosteal flaps elevation, 2670, 2670*f*
 - oral mucosa closure, 2673, 2673*f*
 - oral mucosa dissection, 2671
 - outcomes, 2673–2674
 - pathogenesis, 2668
 - patient history and physical findings, 2669

- postoperative care, 2673
- surgical management, 2669
 - approach, 2669
 - patient position, 2669
 - preoperative planning, 2669
- Vone marrow aspirate concentrate, 2360–2361, 2361*f*
- VRAM flap. *See* Vertical rectus abdominis myocutaneous (VRAM) flap
- Vulvar and vaginal reconstruction
 - anatomy, 1671
 - complications, 1674
 - definition, 1671
 - imaging, 1671
 - outcomes, 1674
 - pathogenesis, 1671
 - patient history and physical findings, 1671
 - postoperative care, 1674
 - surgical management
 - approach, 1672, 1672*f*
 - positioning, 1671–1672, 1672*f*
 - preoperative planning, 1671
- Vulvar reconstruction
 - anatomy, 3052, 3053*f*
 - complications, 3061
 - definition, 3052
 - imaging, 3053
 - merits and demerits, 3060*b*
 - natural history, 3052
 - nonoperative management, 3053
 - outcomes, 3061
 - pathogenesis, 3052
 - patient history and physical findings, 3052–3053
 - postoperative care, 3060

- surgical management, 3053–3054, 3054*f*
- V-Y advancement flap, 1702, 1703*f*, 2099, 2099*f*
 - antia-buch flaps, 1130, 1130*f*, 1131*f*
 - gluteal muscles of, bilateral, 2788, 2788*f*
 - for ischial pressure injury, 2787, 2787*f*
 - nasal reconstruction
 - anatomy, 1183, 1184*f*
 - classic V-Y Flap, 1183–1184, 1184*f*
 - complications, 1186
 - definition, 1183, 1183*f*
 - extended perforator V-Y flap, 1185, 1186*f*
 - merits and demerits, 1184*b*
 - outcomes, 1186
 - patient history and physical findings, 1183–1184, 1183*f*
 - postoperative care, 1186
 - standard perforator V-Y flap, 1185, 1185*f*
 - surgical management, 1184
 - reconstruction with, 2419
- V-Y perforator flap, 1183

W

- Wagner scale, 2407, 2407*f*
- WALANT (Wide-awake local anesthesia no tourniquet), 1754
 - definition, 1754
 - trigger finger release, 1758
- WALANT (wide-awake surgery), 2056
- Walt Disney eye, 1095
- Wartenberg sign, 1987, 1993, 2040
- Warwick-James elevator, 2676
- Watson scaphoid shift test, 1851, 1852*f*
- Wedge reconstruction
 - partial auriclectomy defects
 - anatomy, 1142, 1142*f*, 1165
 - complications, 1145, 1166
 - definition, 1142, 1165
 - full-thickness
 - imaging, 1142, 1165
 - keyhole-type cartilage excision, 1144, 1166, 1168*f*
 - merits and demerits, 1143*b*, 1166*b*
 - patient history and physical findings, 1142, 1165
 - postoperative care, 1145, 1166
 - surgical management, 1142–1143
 - variations, 1144, 1166, 1168*f*
 - wedge resection of helix, 1143, 1143*f*, 1166, 1167*f*
- Wedge skin excision, Stahl ear, 2821, 2823*f*–2824*f*
- White-eyed blowout fracture, 877
- Whitnall tubercle, 876, 877*f*
- Wide tip
 - open rhinoplasty with
 - anatomy, 294
 - complications, 296

- definition, 294
- imaging, 294
- merits and demerits, 296*b*
- outcomes, 296
- patient history and physical findings, 294
- postoperative care, 296
- surgical management, 294
- wide tip, correction of, 295, 295*f*
- Wide-awake local anesthesia no tourniquet (WALANT), 1754, 2056
 - definition, 1754
 - trigger finger release, 1758
- Wise pattern mastopexy, 1336–1337, 1336*f*, 1337*f*
- “Witch’s chin” deformity, 757, 757*f*
- World Health Organization groups, 2456, 2497
- Wound closure
 - constricted ear, 2830, 2830*f*
 - cryptotia, 2834
 - microtia, auricular reconstruction for, 2817–2818
 - prominent ears, 2839
 - thyroglossal duct cysts, 2909, 2909*f*
- Wound irrigation, 977
- Wound preparation, 977, 2384, 2384*f*
- W-plasty, 976, 1105, 2733
- Wrist
 - acute perilunate dislocations (*see* Perilunate dislocations)
 - anatomy, 1889, 1889*f*
 - definition, 1754
 - ganglion cysts
 - dorsal, 2281, 2282*f*, 2283, 2283*f*
 - volar, 2281, 2282*f*, 2284, 2284*f*
 - osteoarthritis
 - congenital conditions, 1957
 - distal radius fractures, 1957

- Kienbock/Preiser diseases, 1957
- STT joint arthritis, 1957
- surgical treatment of, 1958–1959
- total wrist fusion, 1971–1973, 1972*f*
- rheumatoid arthritis
 - caput ulna, 1933, 1933*f*–1934*f*
 - carpal tunnel syndrome, 1936
 - DRUJ instability, 1933
 - extensor tendon rupture, 1933–1935, 1934*f*, 1935*t*–1936*t*, 1935*t*
 - FPL rupture, 1942–1944, 1944*f*, 1945*f*
 - midcarpal extension, 1933
 - ulnar translocation of carpus, 1933
- slider-crank model of, 1899–1900
- Wrist arthritis
 - anatomy, 1905, 1905*f*
 - imaging, 1906
 - natural history, 1906
 - nonoperative management, 1906
 - pathogenesis, 1905–1906
 - patient history and physical findings, 1906
 - proximal row carpectomy (*see* Proximal row carpectomy (PRC))
 - radiologic staging systems of, 1906, 1907*b*
- Wrist arthroscopy
 - anatomy and, 1839, 1839*f*, 1840*t*, 1842*b*
 - complications, 1849
 - contraindications to, 1841
 - definition, 1839
 - diagnostic, 1842
 - dry, 1842
 - 4-5 portal in, 1844–1845, 1844*t*
 - imaging, 1839
 - indications for, 1839
 - merits and demerits, 1848*b*

- midcarpal radial portal in, 1846–1848, 1846*f*, 1848*t*
- midcarpal ulnar portal in, 1846–1848, 1846*f*, 1848*t*
- nonoperative management, 1839
- outcomes, 1849
- patient history and physical findings, 1839
- postoperative care, 1849
- scapholunate interosseous ligament injuries
- 6R portal in, 1845–1846, 1846*t*
- surgical management, 1839–1842
 - patient positioning, 1841, 1842*f*
 - preoperative planning, 1841, 1841*f*
- 3-4 portal in, 1843–1844, 1843*f*–1844*f*, 1844*t*
- treatment indications for, 1840
- wet, 1842
- Wrist extension procedures
 - anatomy, 2196, 2196*f*–2197*f*
 - complications, 2199
 - definition, 2196
 - imaging, 2197
 - merits and demerits, 2198*b*, 2199*b*
 - outcomes, 2199
 - patient history and physical findings, 2196–2197
 - postoperative care, 2199
 - pronator teres, 2026, 2026*f*–2027*f*
 - surgical management
 - approach, 2198
 - patient positioning, 2198
 - preoperative planning, 2198
- Wrist fusion, 2035
- Wrist/fingers reconstruction. *See also* Neonatal brachial plexus palsy (NBPP)
 - complications, 2968
 - FCU to ECRB tendon transfer, 2965–2966, 2965*f*

- finger flexion, free functioning gracilis transfer for, 2966, 2966*f*
- outcomes, 2968
- postoperative care, 2967–2968

X

- Xiphoid process, 1522
- X-rays
 - cubital tunnel syndrome, 1993
 - peroneal nerve injury, 2411
 - tibial nerve, 2452
- Xylocaine, 62

Y

- Y-V medial canthopexy, 2868, 2868*f*

Z

- Zancolli Lasso procedure, 2213–2214, 2214*f*
- ZF (zygomaticofrontal) suture, 185–187, 187*f*
- Zigzag Cairns approach, 1273, 1273*f*–1274*f*, 1276
- Zimmer-Hall drill, 81
- ZMC. *See* Zygomaticomaxillary complex (ZMC) fracture
- Zone III central slip repair, 2082
- Zone of injury, 2394, 2396*f*
- Zone V extensor tendon repair, 2083, 2083*f*
- Z-plasty, 976, 1105, 2582, 2582*f*. *See also* Furlow palatoplasty
 - cryptotia, 2833
 - cutaneous scar, 2733
 - double-opposing
 - dissection, 2708, 2709*f*
 - markings, 2708, 2708*f*
 - surgical management, 2707

- with intravelar veloplasty
- optional cutaneous, 2731–2732, 2731*f*, 2732*f*, 2733*f*
- oral and nasal layers
- thumb reconstruction, 2773–2774, 2773*f*–2774*f*
- Z-plasty approach, 653
- ZS (zygomaticosphenoid) suture, 876
- ZT. *See* Zygomaticotemporal (ZT) nerve
- Zygoma repair, 850, 850*f*
- Zygomatic and maxillary osteotomies, 549
- Zygomatic arch fractures
 - closed reduction and treatment
 - anatomy, 871, 871*f*
 - complications, 875
 - definition, 871
 - Gilles approach, 872–873
 - imaging, 872
 - Keen approach, 874, 874*f*
 - merits and demerits, 874*b*
 - nonoperative management, 872
 - outcomes, 875
 - patient history and physical findings, 871–872
 - percutaneous approach, 872
 - postoperative care, 875
 - surgical management, 872
 - osteotomy, 850, 1274
- Zygomatic branches, skin-only face and neck lifting, 196
- Zygomatic fractures, open correction of
 - alternative treatments, 881–882, 882*f*
 - anatomy, 876, 877*f*
 - complications, 883
 - definition, 876, 876*f*
 - imaging, 878
 - merits and demerits, 882*b*

- nonoperative management, 878
- outcomes, 883
- patient history and physical findings, 876–877, 877*f*
- postoperative care, 882–883
- surgical management, 878
- ZMC fracture, three-point fixation of, 879–881, 879*f*, 880*f*
- Zygomatic sphenoid (ZS) suture, 823
- Zygomaticofacial nerve, 392
 - anatomy, 966, 966*f*, 1084, 1085*f*
- Zygomaticofrontal (ZF) suture, 185–187, 187*f*, 876
- Zygomaticomaxillary buttress (ZMB), 876
- Zygomaticomaxillary complex (ZMC) fracture, 823, 826, 871, 871*f*, 876–877, 876*f*, 881
 - late malpositioning of
 - anatomy, 884, 884*f*
 - camouflage corrections, 887*b*
 - complications, 888
 - correction requiring osteotomies, 887, 887*f*
 - definition, 884
 - imaging, 884, 885*f*
 - merits and demerits, 888*b*
 - nonoperative management, 885
 - outcomes, 888
 - patient history and physical findings, 884
 - postoperative care, 888
 - reconstruction and fixation, 888
 - surgical management, 885–886, 885*f*, 886*f*
- open reduction internal fixation, pediatric midface fractures, 955–956
- three-point fixation of, 879–881, 879*f*, 880*f*
- Zygomaticosphenoid (ZS) suture, 876
- Zygomaticotemporal (ZT) nerve, 70
 - anatomy, 966, 966*f*, 1084, 1085*f*

- scalp reconstruction with rotation flaps, 980
- suture, 876
- Zygomaticus major muscle, anatomy, 1073, 1073*f*
- Zygomaticus minor muscle fibers, 32